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REVIEW OF POTENTIAL FOR RENEWABLE ENERGY SOURCE IN JAMAICA

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Chapter 1

Introduction

1.1 Scope of Effort

The following report is prepared to meet three objectives. The first is to provide the basic input data on renewable energy sources for the National Energy Model being prepared for the Ministry of Mining and Energy by the Argonne National Laboratory. The second is to review the potential uses for renewable energy resources which have been proposed in the various reports and communications received by the Ministry or prepared by its staff. The third objective is to present financial and economic evaluations of certain resource and technology combinations so as to provide an insight into their potential usefulness.

The review of potential resources focuses on: (1) the availability of these resources; (2) the costs and conversion efficiencies of the technologies used with these resources; (3) the expected end-uses of these resource-technology combinations; (4) the extent to which these combinations will substitute for commercial fuels or meet new energy requirements; and (5) the period over which these combinations are expected to be introduced. The resources being considered include: solar insolation, wind, hydropower, fuelwood, energy crops, biomass residues, peat, ocean-thermal gradients, animal dung and urban wastes. The availability of the renewable resources are relatively well understood although there are significant gaps in the land use data and the statistics on agricultural production and livestock ownership.

The end-uses of the renewable energy resources are defined for purposes of this report as: electricity generation, irrigation pumping, transport shaft power, industrial process heat, industrial shaft power, on-farm shaft power, on-farm process heat, and residential process heat. The electricity generation category has been broken down into commercial (grid), industrial and residential (auto-generation). The level of demand for these end-uses are being examined in a series of energy demand surveys (agricultural, residential, industrial, commercial, transportation and tourism). However, the data from these surveys were not available at the time that this report was being prepared. Therefore, the demand markets have been loosely defined in terms of potential markets.

The technologies which are used to convert the renewable resources into fuels or energy which are appropriate for the selected end-uses are shown as entries into the technology matching chart in Figure 1.1. The rows refer to the renewable resources being considered. The columns refer to potential end-uses. The costs and conversion efficiencies of the technologies shown in Figure 1-1 were determined primarily from secondary sources. Although considerable discussion has taken place concerning the use of these technologies within Jamaica, only a few of these technologies have been considered in feasibility studies or firm bids by suppliers for use in Jamaica.

1.2 Macro-economics

This report does not provide detailed financial and economic evaluations of the various renewable resource-conversion-technology (R-T) combinations (other than for a few case studies). Nevertheless, some background on the macro-economic conditions in Jamaica is necessary in order to assess the potential of these combinations for meeting the future energy requirements of the country. The allocation of these R-T combinations in the future will be projected by the National Energy Model based on relative costs and potential markets.

FIGURE 1.1

Technology Matching Chart

Resource	Commercial Electricity	Residential Electricity	Industrial Electricity	Industrial Process Heat	Industrial Shaft Power	On Farm Agri. Process Heat	On Farm Agricultural Shaft Power	Transport Shaft Power	Residential Process Heat
Hydro	Turbine	Micro-hydro							
Wind	Turbine	Turbine					Turbine w/ generator		
Solar	Concentrating collectors, OTEC, Solar Pond	Photovoltaic		Concentrating Collectors Solar Pond		Flat-plate equipped driers			Flat-plate collectors
Urban Wastes	Direct combustion w/ steam turbine								
Agri. Field Residues						Direct combustion	Gasifier or direct combustion w/boiler	Small-scale gasifier, ethanol	Direct Combustion
Agri. Process Residues (Charcoal)				Direct combustion w/furnace	Direct combustion w/boiler	Direct combustion w/furnace	Direct combustion w/gasifier or steam engine	Small-scale gasifier	Direct Combustion
Fuelwood (Charcoal)	Direct combustion w/ steam turbine	Small-scale gasifier	Small-scale gasifier	Direct Combustion furnace	Direct combustion w/gasifier or steam engine	Direct combustion	Biogas digestor w/ I.C. engine-generator-set		
Manure		Biogas digestor w/ generator		Biogas digestor	Biogas digestor w/ I.C. engine	Biogas digestor w/ gas furnace			Biogas digestor w/ gas stove
Peat	Direct combustion w/ steam turbine								

The country has suffered a steady worsening of economic conditions over the last ten years. The Gross Domestic Product (GDP) declined at an average rate of two percent per annum. On a per capita basis, this rate of decline is closer to four percent per annum, despite a relatively low birth rate and considerable net migration. The most seriously affected sectors were construction, wholesale/retail and manufacturing. These declined by 10 percent, 5 percent and 4 percent per annum, respectively, as shown in Table 1.1. The mining sector declined by 3 percent per annum, primarily due to the reduction in the exports of bauxite. The agricultural sector was relatively unchanged because the decline in the sugar industry was compensated for by the introduction of new crops. The only significant growth was in the banking and service sectors and even there the growth rates were less than the rate of increase in population. While there were some signs of a recovery in 1981, this recovery appears to have stalled (see Table a.1).

The contribution to GDP of the different economic sectors has also changed over the last ten years as shown in Table 1.2. Both the agricultural and the mining sectors have fluctuated in importance over this period, but neither has contributed more than 8.25 percent to the GDP. The manufacturing sector has declined from 18 percent of GDP in 1973 to 16 percent in 1982. The wholesale/retail sector has declined from 21.5 to 16 percent of GDP over the same period, while government services rose from 11.25 to 19.5 and other services rose from 19 to 23 percent.

The general economic malaise, the movement away from manufacturing and trade to services, and the increase in the relative prices of fuels and energy have caused changes in the pattern of energy consumption. The expenditure for private consumption of fuels has increased at a more rapid rate than inflation

Table 1.1. Average Rate of Change in Major Sectors of GDP 1973-1982

Sector	Average Rate of Change Percent Per Year	R^2 for Constant Rate of Change
Agriculture	Negligible	-
Mining and quarrying	-3 %	(.28)
Manufacturing	-4 %	(.91)
Electricity and water	+1 %	(.71)
Construction and installation	-10 %	(.89)
Distributive trade (wholesale and retail)	-5 %	(.78)
Transport, storage and communications	Negligible	-
Financing and insurance services	1 %	(.47)
Real estate and business services	1 %	(.71)
Producers of government services	5 %	(.90)
Total gross domestic product	-2 %	(.85)

Source: National Income and Product 1982; simple exponential regression.

TABLE - 1.2

PERCENTAGE CONTRIBUTION OF GROSS DOMESTIC PRODUCT BY INDUSTRIAL SECTORS AT CONSTANT PRICES

INDUSTRIAL SECTOR	1973	1976	1979	1982
Agriculture, Forestry and Fishing	6.6	7.8	8.3	7.7
Mining and Quarrying	8.1	6.2	7.6	6.2
Manufacture	17.9	18.8	16.4	15.9
Electricity and Water	1.0	1.2	1.2	1.3
Construction and Installation	10.1	8.4	7.1	5.9
Distributive Trade (Wholesale and Retail)	21.5	16.8	15.1	16.0
Transport, Storage and Communication	5.5	6.8	6.6	6.9
Financing and Insurance Services	4.1	4.6	4.7	5.2
Real Estate and Business Services	9.3	10.6	11.1	12.3
Producers of Government Services	11.2	15.3	18.6	19.5
Miscellaneous Services	5.6	5.4	5.1	5.4
Household and Private Non-Profit Institutions	1.8	1.3	1.0	1.1
Less Imputed Service Charges	2.7	3.2	2.8	3.4

Source: National Product and Income 1982 (see Table a.2). Electricity consumption has increased during the decade, but with considerable fluctuations. The consumption of petroleum fuels has also fluctuated, but in a generally downward direction.

The experiences of the last decade make it somewhat difficult to predict what will occur over the next two decades. Projections of the economic growth through the year 1987 have been prepared by the National Planning Agency. Their projection of a growth rate in GDP of 4.7 percent per annum for the period 1983 to 1987 now appears optimistic. A series of three projections of the GDP by sector for the period 1981 to 2002 were prepared in support of this project. A summary of these is shown in Table 1.3. For the medium case, the GDP is expected to grow at an average rate of 2.6 percent for the first five years, then increase to a rate of 4.7 percent for the next five years and finally drop back to a rate of 2.6 percent for the final decade. The average rate for the period on a per capita basis is a relatively modest 1.7 percent per annum (a total increase of 40 percent over the two decades). The most rapid growth is forecast for the mining, manufacturing and construction sectors with average growth rates during the period of 7.9, 5.1, and 8.6 percent, respectively. The electricity and petroleum refining sectors are expected to grow by an average of less than 3 percent per annum during the same period.

Given these projections for a relatively slow economic growth and a slow rate of growth in population (estimated at between 1.4 and 2 percent per annum), it appears that the impact of renewable energy resources will be more in the area of fuel substitution than in meeting new demand.

1.3 Cost Inflation

Determination of the costs of using various resource-technology combinations for different end-uses was based on data available from two

Table 1.3. GDP Forecast by Sectors
in Constant Prices 1982-2002

Sector	Forecast	Actual 1982	1987	1992	1997	2002
Agriculture	High		225	274	340	424
	Medium	146	192	216	242	271
	Low		175	187	199	210
Mining	High		218	262	315	379
	Medium	117	175	238	323	439
	Low		163	216	285	378
Manufacturing	High		374	469	591	749
	Medium	303	350	410	480	563
	Low		297	313	330	349
Construction	High		178	252	355	500
	Medium	113	146	181	225	279
	Low		122	136	151	168
Wholesale/ Retail	High		359	426	505	600
	Medium	304	328	364	404	447
	Low		317	341	367	395
Electricity	High		29	33	37	42
	Medium	24	28	31	35	39
	Low		25	26	27	28
Other	High		1,135	1,315	1,535	1,805
	Medium		1,018	1,067	1,117	1,172
	Low		1,002	1,041	1,082	1,115
TOTALS	High		2,518	3,029	3,678	4,499
	Medium	1978	2,237	2,506	2,806	3,210
	Low		2,102	2,260	2,442	2,654

Source: Agro-Socio-Economic Research, Ltd., "An Economic Analysis in Connection with National Energy Plan," 1983.

sources; 1) various proposals for using these R-T combinations in Jamaica, 2) secondary sources on the use of these R-T combinations in countries other than Jamaica. In order to compare the different cost estimates, it was necessary to adjust them to base year (1981) prices. Because the prices were estimated in both Jamaican and foreign currencies, escalators were calculated to adjust price quotes for both, with the foreign currency escalator based on the U.S. dollar in the U.S. economy. For the Jamaican prices, only two indicators were available for making these adjustments; the consumer price index and the GDP deflator (see Table a.3). Since the latter contains a large labor component and no imports, it was used to adjust labor costs. The former was used to adjust the costs for equipment, facilities, and construction. For the foreign currency prices, two economic indicators were used. For equipment, facilities and construction costs the wholesale price index for industrial goods was used. For labor costs the index for average wages in manufacturing was used. The resulting inflators for labor and construction, facilities and equipment are shown in Table 1.4, together with inflation factors for the price of petroleum fuels.

TABLE - 1.4

Cost Escalation Factors

	Jamaican $			US$ (Foreign Currency)		
	Capital, Equipment, Construction [1]	Labour [2]	Fuels [3]	Capital, Equipment, Construction [4]	Labour [5]	Fuels [6]
1973	4.50	3.60		2.35	1.90	
1974	3.55	2.75		1.90	1.75	
1975	3.05	2.30	4.66	1.70	1.65	3.18
1976	2.75	2.05	4.88	1.60	1.50	3.18
1977	2.45	1.85	4.02	1.50	1.39	2.80
1978	1.85	1.45	2.68	1.40	1.28	2.77
1979	1.45	1.25	1.73	1.25	1.18	2.28
1980	1.15	1.07	1.20	1.09	1.10	1.32
1981	1.00	1.00	1.00	1.00	1.00	1.00
1982	.95	.93	.96	.98	1.04	1.16

1 based on CPI all items

2 based on GDP deflator

3 based on Bunker C prices f.o.b. ex Curacao

4 based on wholesale prices for industrial goods

5 based on average wages in manufacturing

6 based on medium fuel oil prices f.o.b. Singapore

Chapter 2

Hydropower

The potential for generating electricity in Jamaica through the use of falling water has been studied extensively. At present there are five hydro-electric facilities operating as part of the Jamaica Public Services (JPS) system. These facilities range in size from 2.5 to 4.75 megawatts of nominal capacity. They were constructed between 1945 and 1959. Their total output amounts to 15.2 megawatts. From the period 1976 to 1979, they operated at about 83 percent capacity. Since then they have reportedly been operating in excess of their nominal capacity of 133 Gigawatt-hours per year.* Currently, they provide about 10 percent of the total electricity generated by JPS.

During the last six years, a series of new hydro-electric projects have been identified by Swedish and Canadian consultants working in Jamaica. In the first phase of these studies, ten sites were identified. Five of these have been the subject of feasibility studies conducted by SWECO. These sites, Rams Horn, Constant Spring, Rio Bueno, Rio Cobre and Great River, range in size from 0.5 to 8 megawatts. They are expected to provide a total capacity of 11.2 megawatts and an annual output of 51.5 gigawatt hours. The largest of these projects, Great River, would provide about two-thirds of the total output. The planned construction of these units is tentatively scheduled for 1984. The other five sites were analyzed by two consultant firms, CEDSI and Motor Columbus. The former submitted prefeasibility studies on four sites, Laughland-Great River, Cave River, Morant Bay and Negro River, in 1981. The latter completed a feasibility study on a Y.S. River site in 1978. These five

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* Output as reported in Economic and Social Survey, Reference 63.

sites have a total capacity of 11 megawatts and an expected output of 51 gigawatt hours. The Laughlands project is expected to account for almost three-fifths of this output. As with the other schemes, the expected starting data for construction is 1984.

The various projects considered in the first phase are described in the data sheets in Tables b.1 to b.5. Because of the considerable capital investment for these ten schemes, about 60 million U.S. dollars, it is expected that they will be completed over a number of years with about 7.5 megawatts being brought on-line in each year from 1987 to 1989.

The second phase of site identification was undertaken by CEDSI and is currently nearing completion. An island-wide inventory was prepared and 51 sites were identified as possible hydro-electric sites. Based on data gathered during site visits, and on subsequent costs estimates, the original list was reduced to 23 sites at which electricity could be generated at a reasonable cost. From these 23 sites, ten were selected for feasibility studies. These ten are described in Table b.6. The other sites have various problems related to access, environment or size. The ten selected sites range in size from 0.5 megawatt to 5.5 megawatts. Their total capacity is 19.5 megawatts with an expected annual output of 103 gigawatt-hours.*

Assuming that the feasibility studies will require two years, the approval process another two years, and the construction and start-up an additional 2-3 years, these facilities will not come on-line until 1989. Since these facilities will require an estimated investment of 45 million U.S. dollars, it

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* This expected output is based on preliminary analysis. Better estimates will be provided in the feasibility studies.

is assumed that the construction will be phased and will follow the construction at the Phase I sites so that approximately 6.5 megawatts will be added each year from 1990 to 1992.

The remaining 13 sites from the second phase have an estimated capacity of 17 megawatts and an expected output of 98 gigawatts-hours/year. It is assumed that some of these sites will be considered in a third phase of analysis and about one-half of these sites will be developed by the mid-1990's. These would add an additional 8.5 megawatts by 1997, thus bringing the total hydro-electric power on the grid to 65.5 megawatts. The scheduled implementation is shown in Table 2.1.

The total cost for the 20 facilities to be constructed in Phases I and II is estimated to be $J186.3 based on the estimates presented in Table 2.2 (using a conversion factor in 1981 prices of J$1.78=US$1). If it is assumed that the local and foreign currency expenditures are divided evenly, then the cost would be US$52.3 million and $J93.2 million. The price per kilowatt of capacity is approximately $J4,450 or US$2,500. In the SWECO reports, the maintenance was assumed to be three percent of the capital costs. In the CEDSI report, 10 percent was used. For the current analysis, a median value of seven percent is assumed with two percent in foreign currency and five percent in local currency. The annual maintenance cost when all projects are completed would be $US2.1 million plus $J9.3 million. This is equivalent in 1981 prices to an annual cost per installed megawatt of US$50,000 plus $J223,000.

Table 2.1.

Projected Hydro-electric Capacity 1983-1997

Year	Megawatts	000's MWHR's*
1981-86	15.2	106.5
1987	22.6	141.0
1988	30.0	175.0
1989	37.4	209.0
1990	44.0	243
1991	50.5	277
1992	57.0	312
1993	57.0	312
1994	57.0	312
1995	60.0	329
1996	63.0	346
1997	65.5	356

* Assumes 80% availability for existing units.

Table 2.2.

Proposed Hydro-electric Facilities

Name	Capacity (MW)	Expected Energy Output 10^6 KW hr	1981 Capital Cost $$10^6$	Capital Cost per kwe 10^3J$	Earliest Date of Availability
<u>Phase I</u>					
1. Rams Horn	.48	3.1	J. 6.23	4.9	86
2. Constant Spring	.78	6.0	J. 6.23	4.9	86
3. Rio Bueno	1.10	5.9	J. 3.90	3.6	86
4. Rio Cobre	1.00	4.5	J. 7.72	7.7	86
5. Great River	7.80	32.0	J. 49.9	6.4	87
6. Laughlands Great River	6.50	27.8	U.S. 9.1	2.5	86
7. Cave River	.66	3.4	U.S. 1.5	3.6	86
8. Morant River	.22	13	U.S. .8	6.5	86
9. Negro River	1.00	6.1	U.S. 2.58	4.6	86
10. Y.S. River	2.60	12.4	U.S. 7.22	5.0	86
<u>Phase II</u>					
1. Wild Crane	1.04	6.14	U.S. 1.72	3.0	90+
2. Green River	1.42	7.84	U.S. 2.41	3.0	90+
3. Morgans River	.97	5.69	U.S. 1.91	3.5	90
4. Rio Grande Canal	3.54	18.30	U.S. 6.49	3.3	90
5. Yallahs River	2.56	15.03	U.S. 6.11	4.3	90
6. Swift Scheme 2	.56	3.04	U.S. 1.35	4.3	90
7. Swift Scheme 1	1.92	9.08	U.S. 4.20	4.0	90
8. Spanish Scheme 6	1.49	7.83	U.S. 3.81	4.6	90
9. One Eye River	.55	2.70	U.S. 1.48	4.8	90
10. Martha Brae River	5.59	27.42	U.S.15.94	5.1	90

+ 2 year feasibility, 2-3 year construction, 2 year decision-making.

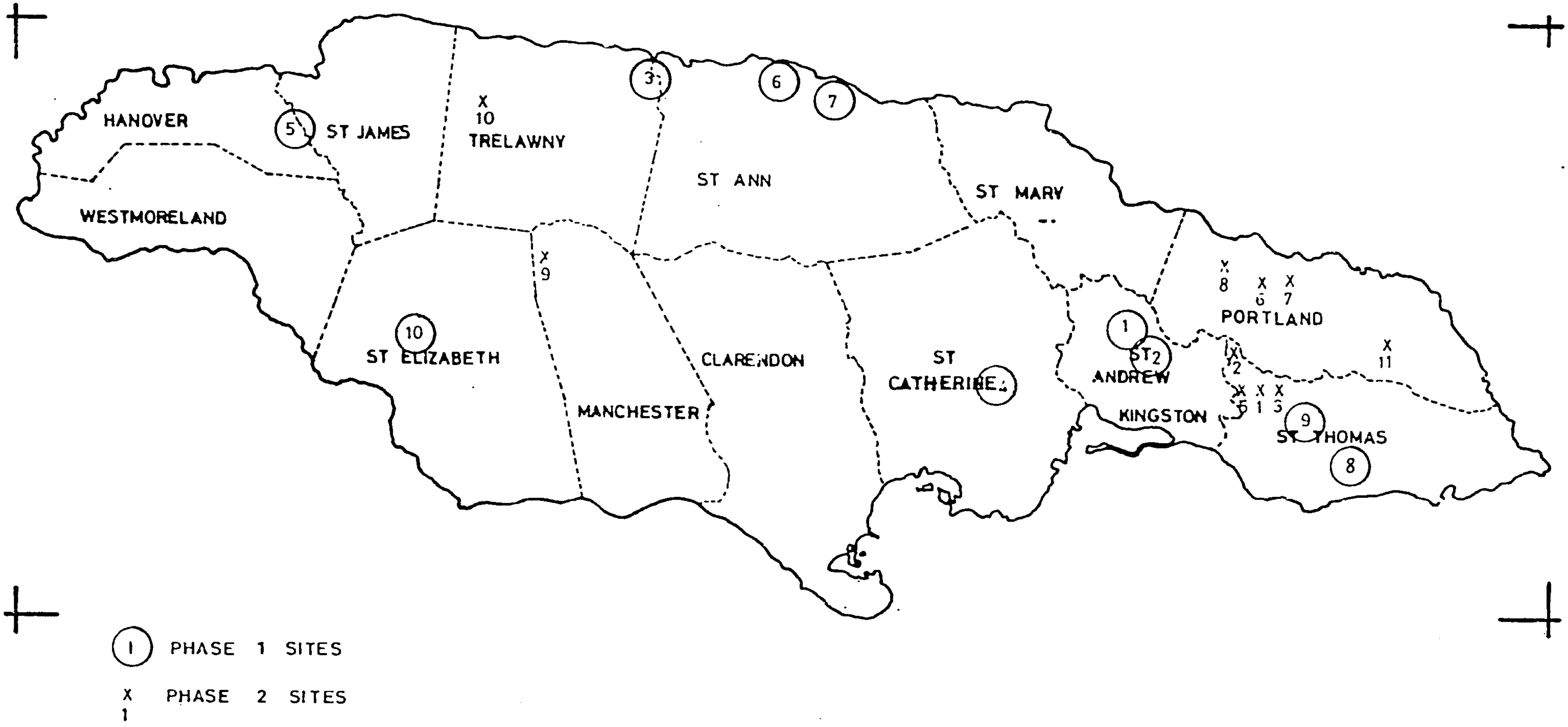
* Discounted by 8 percent to 1981 prices.

** 1.78J$ = 1 U.S. $.

Since all plants are expected to be hooked into the grid and operated as baseload facilities, the energy generated will be used to replace existing steam units or as substitutes for construction of new thermal plants. The location of these sites is shown in Figure 2.1.

FIGURE - 2.1

IDENTIFIED HYDRO ELECTRIC SITES



Chapter 3

Solar

This chapter examines five technologies which make use of solar radiation as a source of energy. These technologies are passive collectors for water heating, solar crop driers, photovoltaics, concentrating collectors for central power generation, and solar ponds. These technologies are very different in their applications. The most promising is passive collectors which are currently being installed on many institutions, businesses and homes in Jamaica. Crop driers are expected to have limited impacts because their applications are generally limited to specific designs for small-scale applications. Photovoltaics continue to be too expensive to be considered for widespread use and the nation of Jamaica is sufficiently compact that remote site applications are limited. The use of concentrating collectors and solar ponds for large scale electricity generation are experimental technologies with limited applications world-wide. The former is expensive and requires considerable electrical storage capacity. The solar ponds and concentrating collectors require considerable land areas in locations protected from high winds. The solar ponds have even more stringent requirements as to the geology of the area.

In the short-term, only the passive collectors are expected to be widely used. In the medium term, solar ponds may be constructed and crop driers used for specific high-value crops. In the long-term, photovoltaics may find some applications in small-scale irrigation.

Steve Marston of the MME staff provided considerable information regarding the current and potential uses of solar energy in Jamaica. He also provided costs estimates for local fabrication of many of these technologies.

3.1 Resource

The level of solar insolation in Jamaica is similar to that of other islands on the same latitude, e.g., Puerto Rico and Hawaii. The daily level of insolation is currently recorded at only one location, Norman Manley Airport.[1] Although close to Kingston, this site is not representative of the metropolitan area because it does not experience the same degree of cloudiness. Indeed, there is considerable variation in the availability of solar radiation throughout the island because the changes in topology cause variation in rainfall and cloudiness. These factors affect not only the available solar radiation, but also the mix of direct and diffuse radiation received at the different areas of the island.

In order to estimate the solar insolation in different areas of the island, the information on rainfall and extraterrestrial insolation were used in a formulation developed in Puerto Rico. This formula derives a "k-factor" based on the number of inches of rainfall. This parameter is multiplied by the extra-terrestrial radiation, which was computed directly for Jamaica.[2] The rainfall data used was the monthly data collected by the Meteorological Office.[3] This data is summarized in the form of rainfall contours for each month of the year based on the data from the previous decade.

With this information it was possible to divide the island into 8 zones as shown on the map in Figure 3.1. For each of these zones a monthly estimate of the solar insolation was calculated. The results are presented in Table 3.1.

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[1] There is now under review a program for an extensive monitoring of solar radiation throughout the island to include collection of data on direct and diffuse radiation; however, useful data from this effort will not be available for a few years.

[2] C. Cromer, Reference 22.

[3] Climatology Branch, Jamaican Met. Service, "The Climate of Jamaica," Reference 21.

FIGURE - 3.1

Regions of Jamaica Based on Annual Solar Insolation

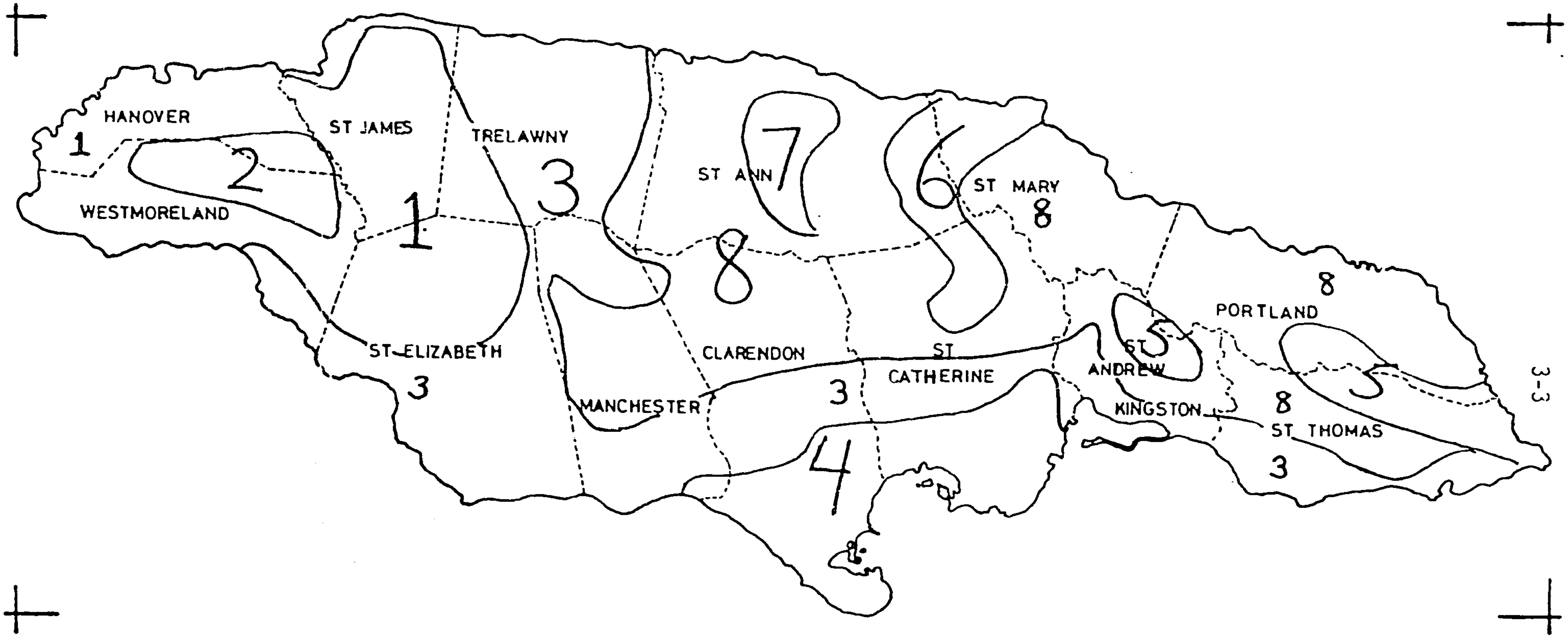

TABLE - 3.1

Estimated Monthly Insolation Levels

(000's Btu/ft^2/day)

Region Estimated

Month	1	2	3	4	5	6	7	8	9
Jan.	1.15	1.05	1.15	1.40	.75	.80	1.05	1.15	1.40
Feb.	1.60	1.30	1.60	1.60	1.15	1.15	1.25	1.50	1.65
March	1.60	1.45	1.60	1.70	1.10	1.45	1.30	1.60	1.80
April	1.50	1.35	1.50	1.80	1.35	1.45	1.50	1.50	1.95
May	1.15	.60	1.30	1.45	.75	1.15	1.30	.95	1.80
June	1.15	.60	1.45	1.55	.85	1.15	1.30	1.30	1.95
July	.75	.40	1.55	1.85	1.00	1.60	1.60	1.30	1.85
Aug.	.95	.40	1.60	1.90	.95	1.50	1.60	1.45	1.80
Sept.	.90	.35	1.20	1.45	.80	1.30	1.30	1.25	1.60
Oct.	.95	.65	.95	1.10	.45	.90	.80	.90	1.60
Nov.	1.05	.70	.85	1.30	.55	.85	.80	1.05	1.40
Dec.	1.10	1.00	1.10	1.35	.60	.95	.95	1.10	1.35
Ave.	1.15	.85	1.30	1.55	.80	1.10	1.25	1.25	1.70
Min.	.75	.35	.85	1.10	.45	.80	.80	.95	1.35
Max.	1.60	1.45	1.60	1.90	1.35	1.60	1.60	1.60	1.95

1. Westmoreland, Hanover, St. James, North St. Elizabeth
2. Upland Hanover and Westmoreland
3. Trelawny, St. Elizabeth, Manchester, parts Clarendon, St. Catherine St. Andrew and St. Thomas
4. Coastal Clarendon and St. Catherine
5. Upland Portland, St. Thomas and St. Andrew
6. Border St. Mary, St. Ann, St. Catherine
7. Upland St. Ann
8. North Central area from Clarendon and St. Ann to West coast
9. Norman Manley Meteorological Station data.

SOURCE: *Met. Office, K factor equation relating rainfall and cloud cover presented in Solar Water Heater Design notes.*

This data suffers from several problems. The first is that the rainfall contours may not be completely accurate because of the need to extrapolate contours from the measurements of a few rain gauges. The second is that the correlation between level of rainfall and cloudiness is generally not strong enough to make differentiations in the level of solar radiation between adjoining regions. The third is that it is difficult to estimate the direct and diffuse components of radiation from these estimates. Although formulas exist for making these extrapolations, they are necessarily less accurate.

Despite these problems, the estimates for the north coast of Clarendon and St. Catherine as shown in Table 3.1 are in general agreement with the measurements from Norman Manley airport which has a topology similar to these areas. The estimates in Table 3.1 indicate that regions other than the coastal lowlands receive from 25 percent to 50 percent less solar radiation during the year. The lowest levels of annual solar radiation occur in the upland areas where there is considerable rainfall throughout the year. (See Figures c.1 and c.2.)

The pattern of variation in solar radiation during the year is different for different regions of the island. In regions 1 and 2 (Figure 3.1) the periods of lowest radiation occur during the months of July through October. In the other regions the period of lowest radiation is estimated to occur during the months of October through January. While these monthly numbers must be used with care because of the uncertainties associated with the method of estimation, they do provide an indication of the considerable variation in solar insolation during the year. The use of solar insolation as a source of energy will be limited by monthly variations of ±25-30 percent and even greater daily fluctuations due to cloudiness.

Any system which is designed to make use of this resource must be equipped with a considerable storage capacity (e.g. solar ponds) or with a backup system (e.g. electric/solar water heaters). In the latter case, the solar technology will be financially viable only if its total cost is less than the marginal cost of fuel saved from lower utilization of the backup system.

3.2 Technologies

The technologies which are being considered for converting the energy from solar insolation to useful energy include: passive collectors for water heating and crop drying, photovoltaics for small-scale electricity generation, concentrating collectors for producing grid electricity, and solar ponds.

3.2.1 Collectors for Water Heating

A wide variety of collectors are used for heating water. The selection of an appropriate collector depends on the application for which it will be used and the quantity and temperature of water required. The most common application in Jamaica is for residential and institutional hot water. This is provided by locally-assembled, flat-plate collectors. The collectors have a conversion efficiency of between 50 and 80 percent, however, the overall efficiency of the hot water system will be much less. The efficiency for a thermosyphon system is estimated to be 30 percent whereas that for a forced water system is estimated to be 25 percent. The price in 1983 for the former ranges between J$60-80 per square foot while the price for the latter is about J$65 per square foot. A breakdown of costs for a typical system is shown in Table 3.2. It is expected that these costs will drop as local manufacturing experience increases and the markets expand. It is expected that they will be approximately 25 percent less by 1986 and 50 percent less by 1992. The annual maintenance costs are estimated to be about 2 percent of the total capital cost or about J$1.2-1.6 per square foot.

Estimates of the amount of energy captured and the cost per million BTU for the thermosyphon and forced-water systems are presented in Table 3.2 for different levels of solar insolation. These estimates assume that the systems have a life of 15 years, that they are amortized over their lives at a discount rate of 7 percent (in constant terms), and that 80 percent of the captured heat is used. These two systems are compared with the shallow pond system which utilizes polyethelene bags and is now being developed at Livermore Laboratories in the United States. The current price for this system is estimated to be $J30 per square foot, however, it is likely that its actual price, when available for distribution in Jamaica, will be closer to J$40 per square foot. These systems are expected to have a life of only 10 years.

For high levels of insolation the costs per million BTU for all three systems is estimated to be between J$55 and J$65 while for low levels of insolation the cost is estimated to rise to J$130-145.* While the numbers used in these estimates are limited in accuracy to ±25 percent, the implications are clear. Solar water heaters are competitive in applications where they are used in conjunction with an existing electric or LPG water heater systems but are not competitive when used in conjuction with industrial systems using diesel or bunker C.**

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* These costs include backup electric heaters in the storage tanks.

** These conclusions are similar to those arrived at by T. Lewis, S. Marston and D. Keith despite variation in assumptions as to system cost and efficiency.

Table 3.2.

Solar Water Heater Costs and Output

<u>Typical flat plate unit</u>

Two 4'x8' flat plate collectors	J$1200
60 gallon glass lined tank	J$1200
piping, controls, pumps	J$ 600-1500
installation	J$1000-1300
Total Cost	J$4000-5200
cost/sq. ft.	J$ 62-81

System	Solar Insolation (ave. BTU/ft^2/day)	System Efficiency	Useable* Energy (10^6 BTU/yr)	Cost per** 10^6 BTU (J$)
thermosyphon	1900	.30	10.6	54.8
	1500	.30	8.4	69.2
	1100	.30	6.2	93.8
	800	.30	4.5	129.2
forced water	1900	.25	8.8	61.2
	1500	.25	7.0	77.1
	1100	.25	5.1	105.9
	800	.25	3.7	145.9
polyethylene bag	1900	.20	7.2	58.4
	1500	.20	5.6	74.2
	1100	.20	4.1	101.4
	800	.20	2.9	143.3

* Assumes 80 percent utilization, 64 sq. ft. collector.

** 15 year life, 7 percent interest rate

Source: S. Marston, References 54 and 55, Consultant's estimates

With improvements in system efficiencies and reductions in system costs, it is expected that the solar water heaters will become more attractive relative to stand-alone electric and LPG water heaters, but not relative to oil-fired systems. This analysis has been done in 1983 prices, the 1981 prices for the same systems are shown in Table 3.3.

Other technologies can be used where higher temperature water is required. Potential uses include preheating water for use in open cycle boilers and preparing hot water for commercial and industrial applications. Typical costs and efficiencies are shown in Table 3.3 and Figure d.1. Despite the larger sizes of these units and the higher temperatures, the system costs per million BTU of useful energy are not expected to be significantly lower. Therefore, the same price constraint would apply to these applications. It is unlikely that solar water heaters will replace oil-fired boiler water heaters, but they may be used in conjunction with electric and LPG water heaters.

3.2.2 Photovoltaics

Photovoltaics are not currently in use in Jamaica except for experimental units. These devices remain among the most expensive technologies for converting solar radiation to useful energy. Early expectations for a drop in the price to less than US$1 (1980 $'s) per peak watt have generally been discarded for two reasons. First, the rate of investment in research and the cost reductions resulting from that research have greatly slowed down in the last few years. Second, the balance-of-system costs will not decrease significantly as a result of future research and these costs now account for more than half of the costs of the photovoltaic systems.

Table 3.3.

Solar Collector Designs

for Heating Water

Design	Final Water Temperature (°F)	Size (ft x ft)	1983 Costs (J$/ft^2)	1981 Costs (J$/ft^2)	Efficiency
flat plate	100-140	4 x 8	20[1]	19	50-80%[6]
-thermosyphon system	100-140	2--4 x 8	60-80[2]	55-73	30%[7]
-forced water system	100-140	2--4 x 8	65[2]	60	25%[7]
shallow pond[9]					
-polyethylene bags	100-140	2--8 x 25	40[3]	37	15-20%[8]
compound parabolic	140-300	8 x 4	70[4]	54	
evacuated tube	250-400	8 x 4	84[5]	77	
trough	400-600		120-150	110-138	

Notes:

1. Collector only, source: S. Marston.
2. System, source: S. Marston, future cost 30/ft^2.
3. Consultant's estimate.
4. $750 for 4' x 8' collector only; balance of system estimated $1500.
5. $900 for 4' x 8' collector only; balance of system estimated $1800.
6. Peak efficiency.
7. System efficiency.
8. Source: S. Marston.

The costs for photovoltaics and their conversion efficiencies vary. A typical cost for a module in 1983 is $5-11 per peak watt with an average efficiency of 10 percent.* The expectation is that the module cost can be reduced to about $2 per peak watt and the efficiencies increased to 12 percent by the end of the decade. However, these costs do not include the balance-of-system costs which are currently about US$10-20 per peak watt. Optimistic estimates project system costs in the US$2-5 (1980$'s) per peak watt range by 1990 but there is considerable disagreement as to whether or not the balance-of-system costs can be reduced to the required levels. For insolation levels averaging 1500 BTU per square foot per day and conversion efficiencies of 10 percent, 23 square feet of photovoltaic cells would be required to produce an average output of 1 kilowatt assuming a ratio of peak to average output of 2:1.

The cost per average kilowatt is about US$15,000 (in 1981$) for the collectors and another US$20-40,000 for the balance of the system, again assuming a ratio of 2:1 peak-to-average. In the future, the system cost is expected to drop to US$12-20,000 but this level is not expected to be realized until the end of the decade and would not be commercially available until the early 1990's.

Since Jamaica has grid electricity available throughout most of the island, it is unlikely that photovoltaics will have an important use in providing electricity. The exceptions are isolated uses such as cathodic protection for pipes and tanks and remote communication systems. Most of the

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* 8 percent if the output is converted from DC to AC.

remote locations are in the upper elevations towards the center of the island. These would not be appropriate for use of photovoltaics because of the high level of cloudiness and precipitation.

3.2.3 Crop Driers

The use of solar crop drying is common throughout the world, but is generally limited to patio-drying with direct radiation. The use of dryers incorporating solar collectors and drying chambers in which the pre-heated air is circulated through natural convection or forced air has been limited. Solar crop driers are generally designed for high-value crops which are produced in relatively small quantities such as coffee, cacao, bananas, coconut/copra, vegetables and herbs.

In Jamaica, coffee beans are dried while they are stored in bags. They are then transferred to the Coffee Board factories where the beans are husked and then dried again prior to hulling and roasting. The drying of the husked bean is done by burning diesel fuel. The drying is controlled to ensure a uniform moisture content. Proposals for dispersing the coffee drying activity to the plantations have been resisted by the Coffee Board because of the need to ensure a consistent moisture content prior to shipment.

Cacao is dried during the fermentation process. The drying heat is provided by patio-drying. For processing copra the coconut meat is dried at the factory by burning the husk and nut to generate the drying heat. Most bananas are sold or exported as fresh fruit, however, a small portion of rejects are dried and then used in the production of chips or other processed food. This drying is generally done with biomass residues. Vegetables and fruits are generally not dried but delivered directly to the markets for sale or export.

The potential use of solar crop driers appears to be limited given the current type of crops, their markets and the scale of processing. Most crop drying is done on a relatively large scale using agricultural or processing residues for fuel, therefore, it is unlikely that solar crop driers will be used except in isolated cases of on-farm drying of high value crops such as herbs. Because of the lack of well defined wet and dry seasons, crop drying may occur during periods of low solar insolation. It is therefore necessary to provide backup systems to provide drying heat when skies are overcast. In this situation, the benefits of solar crop drying are limited to the potential fuel savings.

The costs for crop driers and their conversion efficiencies are difficult to determine because most units are designed for specific applications. The efficiencies of solar crop drier collectors are assumed to be similar to those of flat plate collectors, i.e. 50 to 80 percent. However, the quantity of heat required depends on the required change in moisture content, the method of moving the air between the heater and the crop, and the temperature of the heated air. The cost of the solar crop driers would be less than for solar water heaters because of the simpler construction in the balance of the system, but the cost per million BTU would be higher because of the much lower level of utilization. For a crop drier utilized for three or four months in a year, the cost per unit energy would be 50 to 150 percent greater than for a water heating system.

3.2.4 Solar Ponds

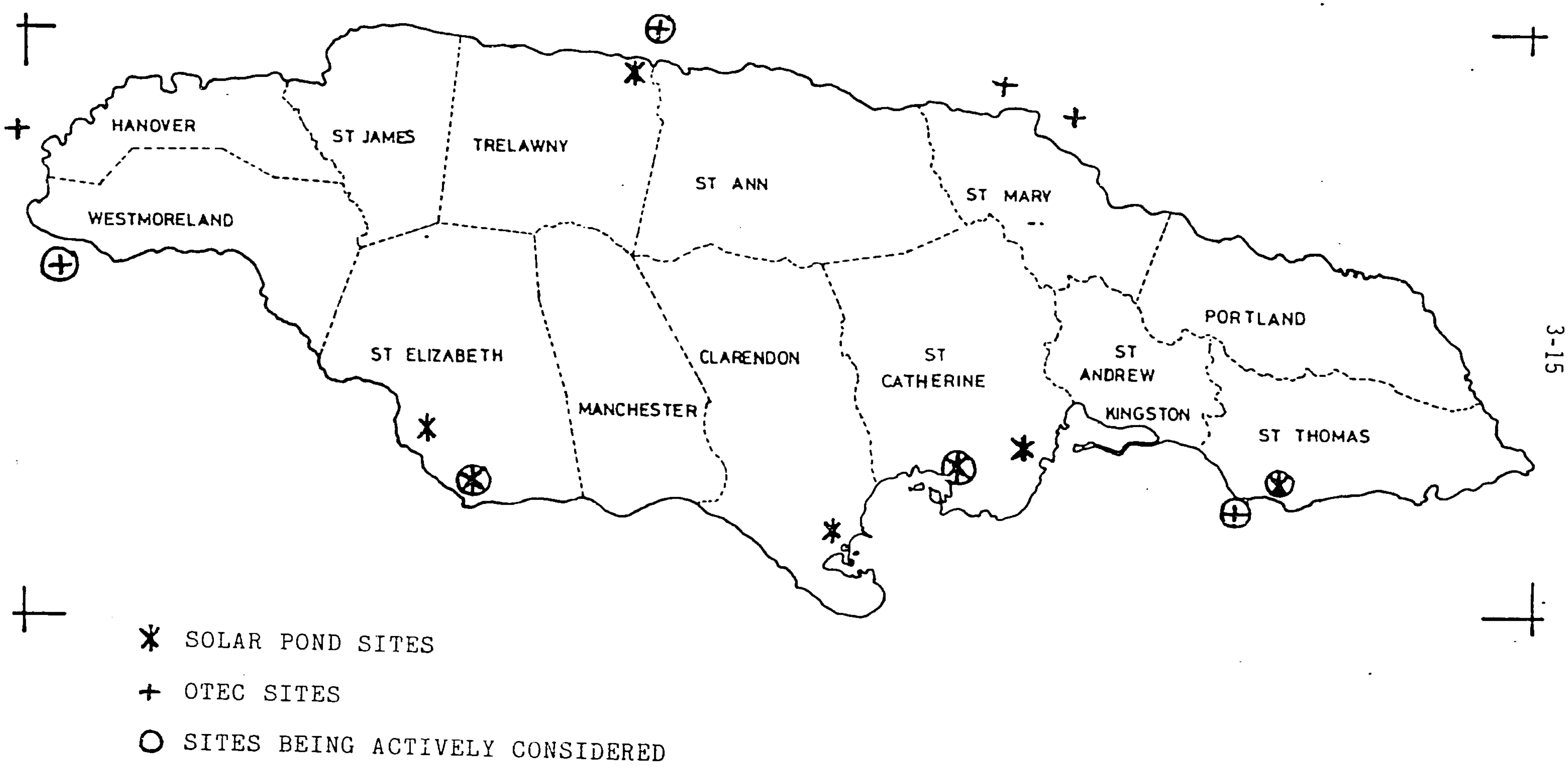
The potential for using a non-convecting solar pond for the production of process heat or electricity in Jamaica was first examined by H. Tabor as part of an IDB consultancy in 1982. As part of this effort, he visited seven potential sites. The selection of an appropriate site is a fairly complex undertaking since it requires knowledge of the wind regime, the permeability of the ground, and the location of underground water, including aquifers. The selected sites must have sufficient land area (30-50 acres per megawatt) and be located close to a source of water, preferably sea water, to make up for evaporation losses. Also, the sites must be free of stresses or strains in the earth which might cause differential thermal expansions resulting in earth movement. Of the seven sites visited, three were selected for further examination to collect the information indicated above. These sites are the Salt Island Lagoon in the Hellshire Development area, the Grand Pedro Pond in St. Elizabeth and the smaller of the Yallah Ponds in St. Thomas. (See the map in Figure 3.2.)

Without knowledge of these sites it is difficult to estimate the cost of constructing a solar pond. Also, data on these ponds are limited because at present, there are very few in the world. Israel has the most experience with solar ponds, having constructed several over the last two decades. Two of the most recent ones are used for electricity generation. The first is a 150KW facility that has been in operation since 1979, the other is a 5MW facility that is currently under construction.

Any discussion of costs for generating electricity through the use of a solar pond must be considered speculative. In a 1980 paper, Reference 80, Dr. Tabor estimated the costs for a solar pond power station located in a sunny climate as: US\$13/m^2 for a lined pond, US\$8 for an unlined pond, and US\$1500/kw for a generating facility. In his report for Jamaica, Reference 78, he estimated the cost for a lined pond as US\$9/m^2 and for a generating facility as US\$1320/KW. He also included a cost of \$10.80/m^2 for salt.

FIGURE - 3.2

Sites for Solar Ponds and OTEC



He further estimated that the efficiency of the pond as a collector would be 18 percent and that the efficiency of the electricity generation would be 8 percent with 25 percent of the electricity being used by the plant itself. A summary of the conversion factors and costs are shown in Table 3.4 based on Tabor's 1980 and 1982 numbers. The input solar insolation is assumed to average 1700 BTU/ft^2/day as was observed near Manley Airport. It is expected that the seasonal output will vary by a factor of 2:1 for maximum versus minimum. The costs are presented for two separate scenarios: in the first, the facility is used to provide a base load and in the second, the facility is used to provide the peak load during 8 hours of the day. The second case requires a larger pond and therefore a higher capital cost, but would replace the more expensive generating capacity, i.e., gas turbines. Cost calculations are made for a 5MW facility. This facility would require 166 acres to serve peak loads and 505 acres to serve a base load. The capital costs for a baseload system would be about J$10,800 per kw_e while those for a peak system would be about J$7,800 per kw_e. The annual operating and maintenance cost per megawatt-hour sent out would be J$26.4 for the baseload system and J$60.5 for the peak system.

The three sites under consideration -- Salt Island, Grand Pedro and Yallahs Pond -- have sizes of 200, 85, and 190 acres. They could be used for 6, 2 1/2, 6 MW peak load facilities respectively or for 2, 1, and 2 MW base load facilities. Given the experimental nature of solar ponds and the ambivalence reflected in Dr. Tabor's report, it would appear that if solar ponds are a feasible source of electricity they will not be introduced into Jamaica for at least 10 years. This assumes that a feasibility study to select a site and to determine the costs and benefits of such a project would require two years, that construction would require about 2 1/2 years from

Table 3.4.

Solar Pond Costs and Technical Parameters

Annual Solar Radiation*	1700 BTU/ft^2 (74 mm BTU/acre) (21.7 MWHR/acre/day)
Lower Boundary Temperature	87°C
Upper Boundary Temperature	28°C
Temperature drop across heat exhanger	15°C
Carnot Efficiency (T 44°C)	12.5%
Pond Solar Conversion	18%
Turbine Efficiency	65%
Overall Efficiency	1.46%
Internal Energy Requirements	25%
Net Efficiency	1.1%
Plant Availability*	85%
Utilization of Generating Capacity*	90%
Annual Energy Sendout	66.6 MWHR/acre
Busbar Generating Capacity:	
Eight hour peak	30 kw/acre
Twenty-four hour base load	9.9 kw/acre
Pond costs:	
--lined**	US$52,500/acre
--unlined**	US$32,400/acre
--salt	US$43,700/acre
Generating facility**	US$1500/kw
Annual maintenance (1.5%)	US$22.5/kw
(1.5%)	J$40.1/kw
Water	--0--
Labor	J$485,000

5 MW$_e$ Plant Costs (Mn$)**

	Peak	Baseload
Capital Cost		
-- pond	J 22.6-28.6	J 68.4-86.5
--generation facility	US 7.5	US 7.5
Annual Cost		
-- maintenance	US .113	US .113
	J .200	J .200
-- labor***	J .169	J .485
Sent out (GWHR)	11.2 GWHR	33.5 GWHR
Delivered****	9.4 GWHR	28.1 GWHR

Source: H. Tabor's, "Report on Mission to Jamaica",

* Consultant's estimate.

** Tabors, Review Article: Solar Ponds, Reference 80.

*** J$1.78 = US$1.

**** Assume 16 percent distribution losses.

signing the contract through start up, that the preliminary and final designs and tendering would require another 1 1/2 years, and that the process would not begin until the large Israeli plant had been operating for at least three years.

3.2.5 Solar Central Receiver Generating Facilities

The "power tower" is perhaps the most speculative of the proposed solar conversion technologies. Only a few units have been constructed world-wide and only one large plant is operating to produce commercial electricity, the 10MW large facility in Barstow, California. Therefore, all estimates of conversion efficiencies, capital costs, and operating costs are highly speculative. The only proposal for use of a "power tower" for electricity generation in Jamaica is contained in a proposal by CEDSI to perform a feasibility study of a 5MW Central Receiver Power System that would use heliostats for collectors and molten salts for heat transfer. The major difficulty with establishing such a facility in Jamaica is the problem of cloudiness which would necessitate a considerable storage capacity. Other difficulties are associated with environmental problems, such as the high level of humidity, occassional hurricane force winds and salt in the air, and resource problems, such as the availability of land and labor.

The central receiver can be used in four configurations: first, as a stand-alone power generation system, second, as a fuel-saver which does not replace existing grid capacity but instead saves fuel by supplying electricity to the system on an as-available basis, third, as a repowering unit which can be used to provide steam to existing steam-based generating facilities, and fourth, as a part of a new hybrid generating facility. Presently, CEDS is considering the third option, but there may be a difficulty in locating a site of sufficient size near an existing facility.

It is unlikely that this technology will be useful as a source of power in Jamaica for three reasons. First, it is unlikely that the technology will be technically proven and commercially available before the early 1990's. Second, the technology will have significant requirements for skilled labor to operate and maintain the large number of tracking heliostats. Third, the costs are not likely to become competitive for some time. Although costs and conversion factors can only be estimated, current estimates range from $1500 to $7000 per effective kilowatt of capacity. The costs shown in Table 3.5 are not conservative but they are high relative to other technologies. The operating and maintenance costs are estimated to be J$ 158 per megawatt-hour.

Table 3.5.

Solar Power Tower Costs and Technical Parameters

Average Solar Radiation	1700 BTU/ft^2/day 1/ 5.4 kwhr/m^2/day
Average power available	.48 kw/m^2 2/
Conversion efficiencies	
collector	.65
generating system	.32
internal electricity use	5% 3/
net efficiency	20%
plant utilization	85% 3/
Average Output at Busbar	.08 kwhr/hr/m^2
Unit Capital Costs (US$)	
collector	145-250/m^2 (770-1330 per kw$_e$) 4/
receiver and converter	500/kw$_e$
4 hour storage	240/kw$_e$
Subtotal	1510-2070 kw$_e$
For 5 MW$_e$ Station	
land area	28 acres 5/
capital cost US$mn	7.55-10.35 6/
labor costs 000's J$/year	370
maintenance US$ 000's	189-259
J$ 000's	336-461
Busbar output (GWHR)	7.4
Delivered output (GWHR)	6.2 10/

Sources: Argonne 1983 Reference 4, Caputo 198 Reference 16.

Note:

1. Typical of Hellshire/Norman Manley airport area.
2. Assume 90 percent of insolation falls during 10 hour period (ignoring cloudiness).
3. Consultant's estimate.
4. 5.3 m^2 of heliostat per kilowatt of effective capacity (.5/(.48 x .65 x .32 x .95) assuming 2:1 peak-to-average).
5. Assume area required is four times the area of the heliostats
6. Excludes land costs.
7. Two unskilled, six semiskilled, and four skilled per shift with two shifts to cover 7 12-hour days of operation.
8. 2 1/2 percent of capital cost for imported parts and consultancy and 2 1/2 percent for local parts and labor.
9. 365 x 10 x .85 x .09 x 5000 x 5.3 Kwhr.
10. 16 percent losses in distribution.

Chapter 4

Biomass--Fuelwood

This chapter discusses the potential for establishing fuelwood plantations in Jamaica. Three technologies are considered that would make use of the fuelwood from these plantations; these are dendrothermal electric generation facilities, wood and charcoal boilers, and large-scale gasifiers. Another three technologies are discussed that would make use of fuelwood from existing forests as well as from these plantations: these are wood cookstoves, charcoal kilns and small-scale gasifiers.

The information on the potential of fuelwood plantations was obtained primarily through discussions with Messrs. Budhlall and Kelley of FIDCO and with two FAO consultants Messrs. Thompson and Stamphers. However, the extrapolation of their information to the presentation in this chapter was done by the author and does not necessarily reflect their opinions.

Of the technologies examined, those which have appeared likely to be used in the near-term are the charcoal kilns, several of which are now in use around the island. In the medium-term it is expected that improved kilns will be introduced and that a fuelwood plantation will be established. It is also expected that gasifiers will be introduced to make use of sawmill wastes and that small-scale gasifiers will be introduced for irrigation pumping. In the long term, it is expected that a dendrothermal generating facility will be established in conjunction with a fuelwood plantation. It is also likely that the increasing cost of collecting fuelwood will result in more fuel efficient operation of existing cookstoves and the introduction of new fuel efficient stoves.

4.1 Resources

Much of Jamaica is classified as wooded areas. A survey by the FAO in 1970 based on an aerial photographic survey indicated that some 44 percent of the island was forested, 20 percent of which was scrub forest. A breakdown of the types of land use is shown in Table 4.1. This breakdown indicates that 7 percent of the island is covered in well-stocked natural forest and another 1/2 percent is covered with forest plantations, principally Pinus caribaea and Hibiscus elatus. All of the forest plantations and about 4/5 of the well-stocked forest are on government-owned land. Two-thirds of the well-stocked forests are located in three tracts, John Crow Mountain, Bull Head Mountain, and Mount Hairy.[*] The size of these government lands by Parish is shown in Table 4.2. About 45 percent of the reserves are located in the hills and mountains of Portland, St. Thomas and St. Andrew. Another 20 percent are located in the rugged terrain of Trelawny. In fact most of the wooded areas are located in the hilly or mountainous regions of the country as can be seen by comparing the maps in Figures 4.1 and 4.2. The relative isolation afforded by the topography has protected these forest lands from being cleared for agriculture and from being cut for timber and fuelwood.

A more recent survey of land use that used the same photographic survey data as well as some more recent survey work[**], produced the results shown in Table 4.3. The total wooded area is 1.33 million acres or 49 percent of the total area of Jamaica. Most of this land (95 percent) is covered with deciduous trees. The proportion of wooded land in each parish ranges from 28 percent to 70 percent. The highest percentages are in Westmoreland, Trelawny,

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[*] Lilieth Nelson, Reference 68.

[**] Cries, Reference 81.

Table 4.1.

Forest Areas of Jamaica

	Acreage	Percent of Total Land Area
<u>All Forest Areas</u>	655,000	24.1%
--Well stocked natural forest	191,500	7.0
--"ruinate" (temporarily unstocked)	453,000	16.7
--forest plantations	10,200	.4
--other wooded land	540,600	19.9
	1,195,600	44.0
<u>Government Forest Areas Only</u>		
--forest plantation	10,200	.4
--well-stocked natural forests	150,000	5.5
--"ruinate"	45,000	1.7
--other wooded areas	60,000	2.2
	265,000	9.8

Source: FAO Wood/fuel Energy Study 1970, Reference 39

TABLE - 4.2

AREAS OF FOREST LAND - FOREST RESERVES BY PARISHES : 1976

PARISH	000s ACRES	
St. Andrew	14.7	
St. Thomas	32.5	
Portland	74.4	
St. Mary	3.7	
St. Ann	10.9	
Trelawny	55.8	
St. James	5.9	
Hanover	1.1	
Westmoreland	1.1	
St. Elizabeth	18.8	
Manchester	26.6	
Clarendon	19.5	(Including Portland Ridge 15.1)
St. Catherine	23.9	(Including Hellshire 19.5)
TOTAL	264.9	

Source: Statistical Yearbook of Jamaica 1981.

FIGURE - 4.1

Location of Forested Areas in Jamaica

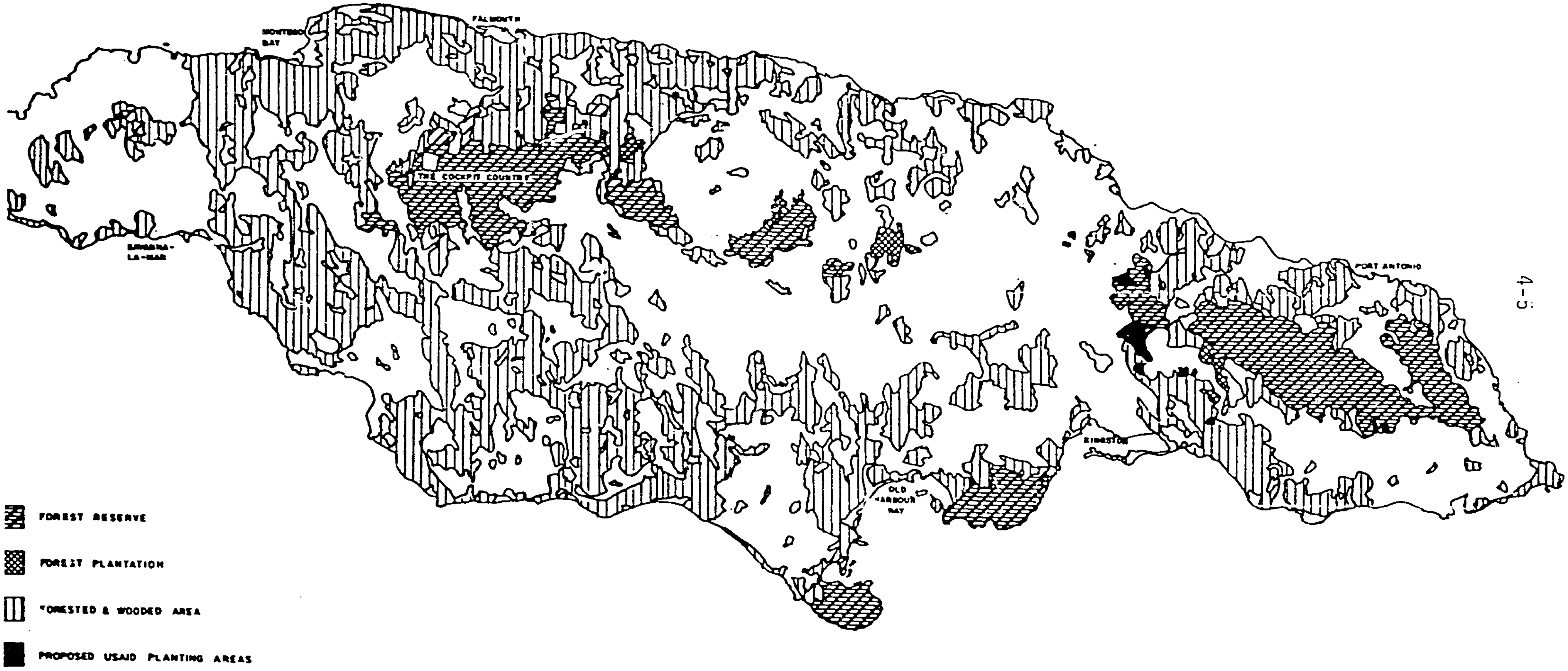

FIGURE - 4.2

TOPOGRAPHY OF JAMAICA

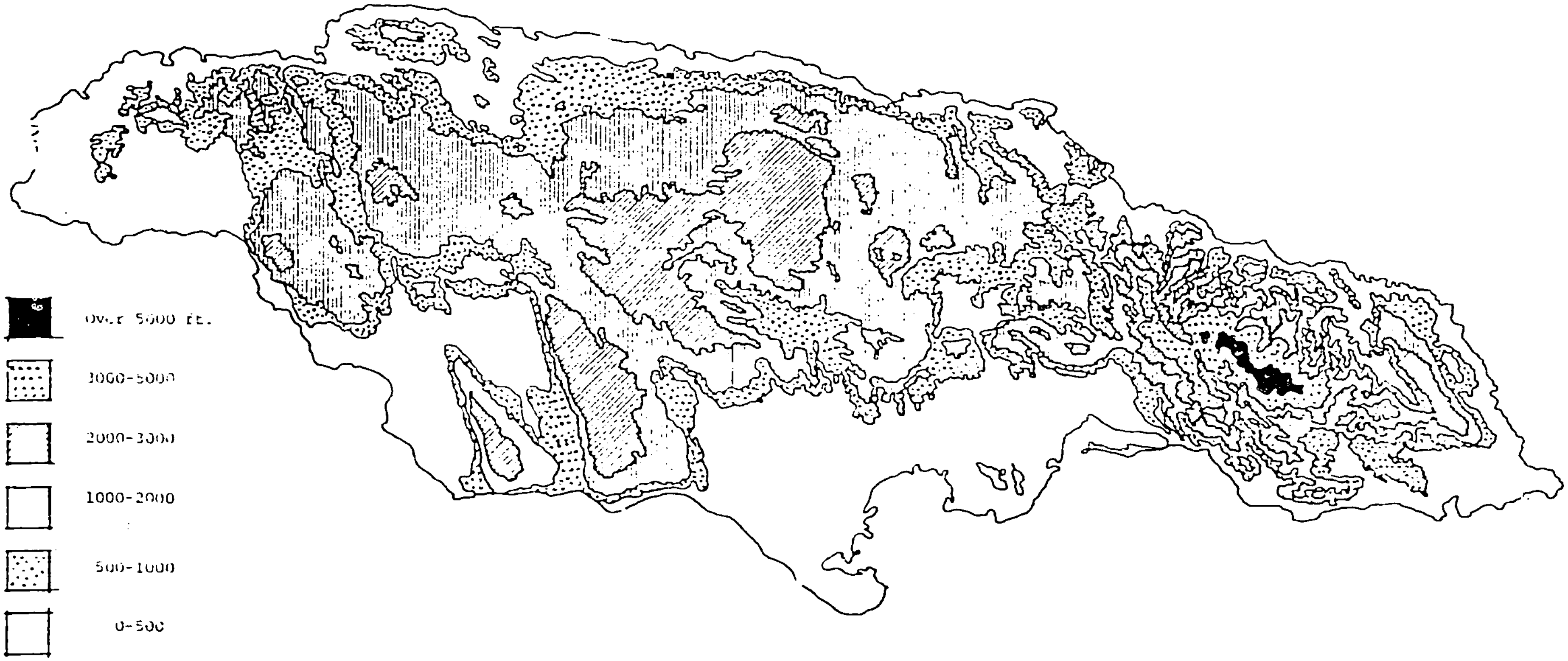

TABLE - 4.3

Land Use for Pastures and Woodlands

Parishes/Land Use	(000's hectares) A	B	C	D	E	(% of land) A	B	C	D	E
Westmoreland	8.82	.16	-	33.79	.43	10.9	.2	-	41.9	.5
Portland	4.92	2.65	.54	56.73	.09	6.0	3.3	.7	69.7	.1
St. Thomas	5.60	4.93	-	38.98	.05	7.5	6.6	-	52.5	.1
St. Andrew	4.22	4.06	2.21	19.49	.20	9.3	9.0	4.9	43.1	.5
St. Mary	6.09	2.07	-	25.43	.08	10.0	3.4	-	41.7	.1
St. Ann	25.83	.42	.01	56.19	.82	21.3	.3	-	46.4	.7
St. Catherine	10.06	1.04	.29	55.91	2.58	8.4	.9	.2	49.4	2.2
Clarendon	21.32	3.51	.53	40.11	2.24	17.8	3.0	.4	33.5	1.9
Manchester	14.01	.76	.03	29.47	5.43	16.9	.9	-	35.5	6.6
St. Elizabeth	8.98	.85	-	34.34	9.69	7.4	.7	-	28.3	8.0
Trelawny	2.92	.58	.06	58.27	.15	3.3	.7	.1	66.6	.2
Hanover	5.41	1.12	-	20.52	.69	12.6	2.6	-	47.7	1.6
St. James	5.88	.06	.12	32.90	.44	9.9	.1	.2	55.3	.8

A	B	C	D	E
Unimproved Pasture	Unimproved Pasture Limited by Slope	Coniferious	Deciduous	Brush

Source: Resource Assessment in Jamaica (CRIES)

St. James, and St. Thomas, all with over half the land classified as wooded area. The lowest percentages are in the parishes of St. Elizabeth, Clarendon and Manchester, where the agricultural activity is the greatest.

The productivity of the wooded areas is difficult to determine since the density of trees and the species vary. For the forest areas the FAO estimated an average sustainable yield of 130-160 ft^3/year (2.5-3.2 tons air-dried biomass) for pine and eucalyptus and 58-84 ft^3/year (1.2-1.7 tons air-dried biomass) for other species.

The potential for growing and harvesting fuelwood is determined by the availability of land suitable for growing timber. According to an evaluation of the soils, topology, climate and land use of Jamaica performed as part of the CRIES study, Reference 80, the land areas most suited for growing timber are located in the middle and western sections of the island and include most of the land in the parishes of St. Ann and Manchester and more than half of the land in the parishes of St. Catherine, Clarendon, St. Elizabeth, St. James and Trelawny, as shown in Figure 4.3. Most of these areas are at the lower elevations. They are currently used for pastureland or agriculture or are unused wooded area as shown in Table 4.4.

Perhaps the major problem with establishing plantations for growing timber or fuelwood is the land tenure system of Jamaica. Land which is not controlled by the large agricultural estates is divided into relatively small private holdings. The records of ownership of these parcels is not well established and there is considerable legal difficulty in acquiring large tracts of land.

FIDCO is currently establishing timber plantations in the Blue Mountain area. Their program, which is supported by loans from the IBRD and CDC as

Placeholder for figure 4.3.1.

FIGURE - 4.3(cont.)

Legend/Crop Potential	High	Medium-High	High-Low	Medium	Medium-Low	Low
BLACK	Sugar Cane	Banana Improved pasture	Cocoa Vegetable	Timber Coffee	Tobacco	Natural forest
YELLOW	Sugar Cane Improved pasture		Vegetable Cocoa			Tobacco, Coffee, timber, natural forest banana
DOTTED BLACK	Timber	Coffee Natural Forest	Cocoa		Improved pasture	Sugar Cane, banana, vegetable, tobacco
MAGENTA	Improved pasture Coffee			Sugar cane, cocoa, timber		Banana, vegetable, tobacco, natural forest
DARK BLUE		Timber, natural forest		Sugar cane, improved pasture	Vegetable, coffee	Banana, Tobacco, Cocoa
WHITE	Sugar cane Improved pasture	Coffee		Timber	Vegetable Coffee	Banana, Tobacco, natural forest
GREEN			Improved pasture, Coffee Timber		Sugar Cane, Tobacco, Cocoa, Natural forest	Banana Vegetable
RED		Improved pasture Coffee		Timber	Vegetable Cocoa	Sugar cane, banana, tobacco, natural forest

Table 4.4. Existing Land Use in Areas Suitable for Growing Timber

(Percent of Area)

	CURRENT LAND USE					
				Agricultural		
Parish	Deciduous	Unimproved Pasture	Improved Pasture	Sugar	Other	Other
St. Anns	46.4	21.6	14.2	1.2	9.7	6.9
Manchester	35.5	17.8	22.6	.3	9.7	14.1
St. Catherine	49.4	9.3	7.7	14.9	7.0	11.
Clarendon	33.5	20.8	5.2	18.2	10.6	11.7
St. Elizabeth	28.3	8.1	22.7	5.3	18.1	17.5
St. James	55.3	10.0	8.5	4.6	10.8	10.8
Trelawny	66.6	4.0	9.5	8.2	7.3	4.4

well as the JNIC, is to produce 14 million board-feet, about 28 percent of the current domestic demand. FIDCO is planting Carribean pine with a 20 year economic rotation period. Assuming that 70,000 m^3 of sawlogs must be delivered to the FIDCO mill in order to produce 14 million board feet (along with 30,000 m^3 of chips, sawdust, and other waste), then the total area planted would have to be 15-20,000 acres. The operating plan for FIDCO is to plant 1000 acres per year, but because of difficulties in obtaining contiguous parcels of sufficient size, they have been unable to meet this schedule. Most of the areas they are planting are mountainous. This will make the cost of extraction and replanting quite high. The Forest Dept. has leased 24,000 acres to FIDCO for 99 years, but much of this land has poor access and steep slopes.

In order to understand the costs of establishing and maintaining a fuelwood plantation in Jamaica, the actual costs for FIDCO to clear areas to be converted to plantations were compared with planning estimates prepared by the FAO for their study of a fuelwood plantation in Jamaica, Reference 39. These costs are summarized in Table 4.5.[1] Using this data, an estimate was prepared of the costs for establishing eucalyptus plantation with an 8 year rotation. They will vary considerably depending on the terrain.[2] The costs shown in Table 4.6 represent a median, neither flatland nor mountainous. They do not include the cost of the land. For the flatlands the costs of harvesting would be less but the costs of land acquisition would be higher. The opposite is true for land with steep slopes.

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[1] for comparison Brazilian costs for a seven year rotation Eucalyptus forest are shown in table d.1.

[2] An analysis of Brazilian Fuelwood Plantation Costs indicated an 80 percent higher cost for land preparation and planting on steep slopes relative to flat land and a 150 percent higher cost for maintenance.

TABLE - 4.5

FIDCO AND FAO FUELWOOD PLANTATION COSTS

FAO (1975) for FUELWOOD ITEM	1975 COST	MULTIPLIER	1981 COST
Road	J$110/acre	3.05	$335/acre
Road maintenance			$33.5/acre/year
Felling	J$1.20/ton	3.33	$4/ton
Extraction to road with tractor	J$3.60/ton	3.05	J$11/ton
(With cable)	(4.50)		(J$13.70)
Replanting	J$280/acre	2.70	J$755/acre
Transport	J$.1/ton-mile	3.85	J$.39/ton-mile

FIDCO (1982/3) FOR TIMBER

	1981 costs (J$/acre)
Site Preparation	76 - 171
Planting	152
Weeding	
Year 1 (3x)	76
2 (2x)	48
3 (1x)	29
Road construction	J$885/acre
Harvest	J$70/ton (includes J$30/ton transport)
Hauling	J$.3/ton-mile

Source discussions with
FIDCO management,
FAO 1975 ref

4-14 TABLE - 4.6

ESTIMATED YEARLY FUELWOOD PLANTATION COSTS

Species Eucalyptus, rotation 8 years, density at 95 tons/acre cutting. (50% moisture).

Costs per 1000 acres (develop/harvest = 125 acres/year).

YEAR	TASK	$J/1000 acres
1	Road construction	110,600
	Site preparation	21,400
	Planting	25,000
	Weeding	12,500
	Subtotal	169,500
2	Road construction	110,600
	Road maintenance	11,100
	Site preparation	21,400
	Planting	25,000
	Weeding 1	12,500
	2	8,000
	Subtotal	188,600
3	Road construction	110,600
	Road Maintenance	22,200
	Site preparation	21,400
	Planting	25,500
	Weeding 1	12,500
	2	8,000
	3	4,800
	Subtotal	204,500
4	Road construction	110,600
	Road maintenance	33,300
	Site preparation	21,400
	Planting	25,000
	Weeding	25,300
	Subtotal	215,600

TABLE - 4.6 cont.

- 2 -

YEAR	TASK	J$/1000 acre
5	Subtotal	226,700
6	Subtotal	237,800
7	Subtotal	248,900
8	Subtotal	260,000
9	Harvesting	296,900
	Hauling *	59,400
	Road maintenance	88,800
	Site preparation	21,400
	Planting	25,000
	Weeding	25,300
	Total	516,800

* 10 miles round trip, J$.5/ton mile.

TABLE - 4.6 cont.

FUELWOOD PLANTATION COST SUMMARY

YEARS	FIXED COSTS J$/ACRE	VARIABLE COSTS J$/TON Greenwood 50%MC
1	169.5	
2	188.6	
3	204.5	
4	215.6	
5	226.7	
6	237.8	
7	248.9	
8	260.0	
9 on	160.5	20

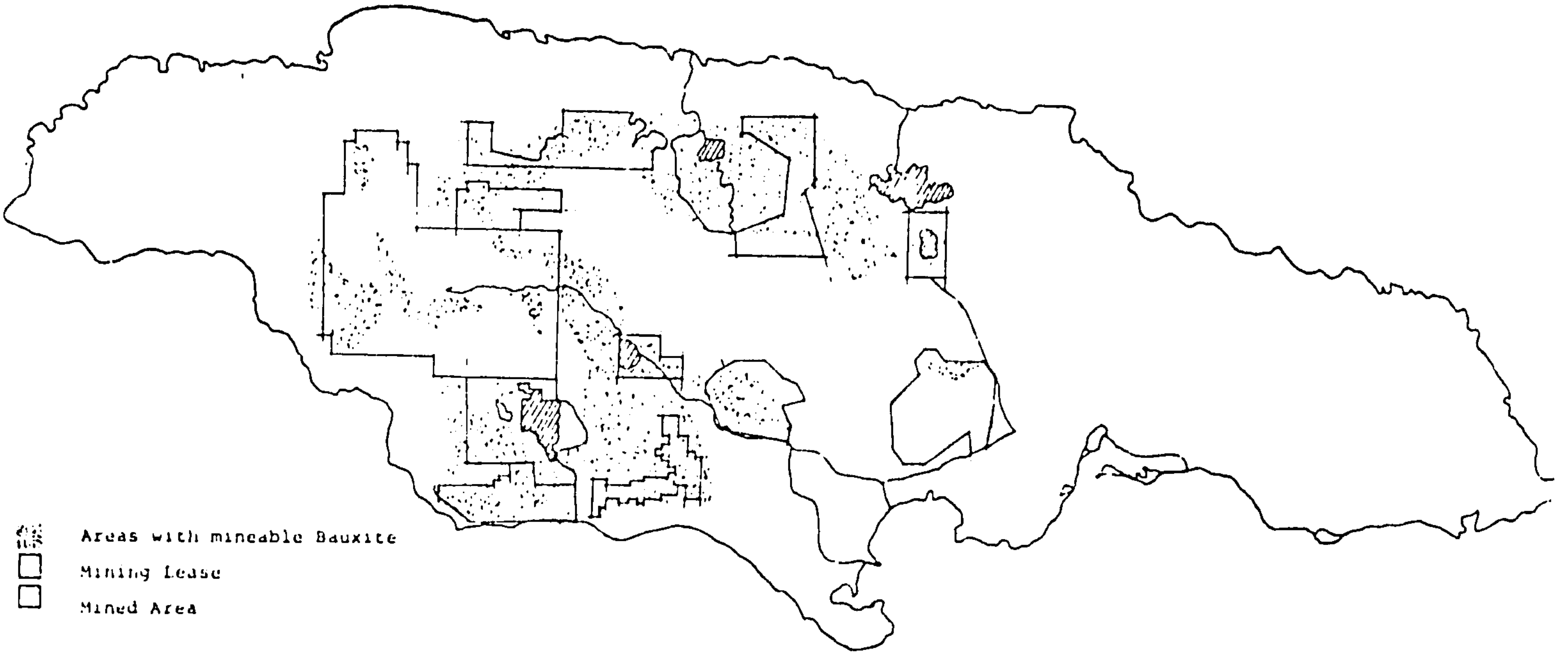
Currently the Forestry Department is conducting species trials in order to identify species suitable for establishing fuelwood plantations. It is expected that next year a few 40 acre test plots will be established. No plan has been made for establishing a plantation. The primary constraint is the non-availability of large parcels of land.

Two types of land that are considered as possible site areas for planting trees are the dumping grounds of the bauxite mining companies (Figure 4.4) and the peat bogs at Negril and Black River (Figure 9.1). For the bauxite lands, the species Caliendra has shown some promise. It has a high yield and can be coppiced with a machete every two years to yield about 10 tons of oven-dry stemwood per acre. The two difficulties with using the bauxite lands are; 1) that they are controlled by the Aluminum companies, and 2) that experiments have already been conducted on growing agricultural crops which indicate a potentially higher return. For the peat bogs, no species has yet been identified as suitable. Seven species are now being grown on test plots in the bogs but only one is reported to be doing well. Eucalyptus would not be satisfactory because of its tendency to dry out the land thereby causing salt intrusion. Even if a species can be identified that grows well in the bog soils, considerable study would be required to determine how to establish raised areas for planting the trees and how to transport labor and equipment into and fuelwood out of the bogs.

If sufficient land is identified and suitable species selected, then it should be possible to establish a fuelwood plantation by the early or mid 1990's, assuming the following: 3 years species selection and planning, 1 year initial land clearing and planting, 7 years growing and 1 year harvesting.

Figure 4.4

Map of Bauxite Mining Lands



The potential uses for fuelwood include domestic cooking, conversion to charcoal for industrial and domestic fuel, production of electricity in dendrothermal plants, direct combustion for industrial process heat including steam raising, and combustion in a gasifier to generate producer gas. These options are discussed below.

4.2 Conversion Technologies

4.2.1 Wood Cooking

Fuelwood is used as a cooking fuel in about 1/2 of the households in Jamaica. No data has been collected on the type of stoves used or the efficiencies of various indigenous stove designs. It is thought that most of the stoves are of simple construction, predominantly the three rock configuration. These stoves have an average efficiency in the range of 6-12 percent depending on the operating environment, the skill of the operator and the type of cooking. More efficient wood stoves have been the subject of considerable research over the years. Although various compendiums of stove designs have been prepared,* the number of new designs which have been successfully introduced and adopted by a significant percentage of the population is limited. Although some new designs can increase efficiency to the range of 12-20 percent, they tend to be more difficult to construct and operate and more expensive than traditional designs. Given the conservative nature of cooking activities, it is not surprising that new stove designs are relatively slow to be accepted. However, the rapid diffusion of aluminum cooking utensils among the rural population of developing countries, indicates that marketing channels are available if the product is clearly advantageous. In Jamaica, the "modern" method of cooking is with electricity or LPG, but it

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* Vita/ITOG, Reference 84.

is probable that fuelwood will continue to be the least costly cooking fuel in the rural areas for the foreseeable future. The cost of fuelwood will increase as supplies diminish and as the distance between the user and the supply increases over time. This trend will encourage more efficient use of existing stoves as well as the purchase of more efficient stoves. These more efficient units will probably cost on the order of J$10-J$50, will provide an average conversion efficiency of about 16 percent and have an average life of 5-10 years.

4.2.2 Charcoal Kilns

Two types of kilns are currently used in Jamaica. One is a locally fabricated metal kiln based on a design prepared by the Tropical Products Institute. The kiln has four chimneys and four input ports. It is built up from metal rings which are three meters in diameter and when stacked are about two meters high. The other type of kiln is an earth mound kiln. Many of these are constructed by piling branches into a conical shape and covering them with earth. Others are simple earth pit kilns. At present no brick beehive kilns are used in Jamaica.

A comparison of the costs and conversion efficiencies of the metal, earth mound and beehive kilns is shown in Table 4.7. The conversion efficiencies (computed in terms of the calorific value of the output charcoal divided by the calorific value of the input fuelwood) averages 33 percent for the earth mound kilns, 45 percent for the metal kilns and 53 percent for the beehive kilns. These three designs are generally used for different activities.

The earth mound kiln is used for small-scale production activities in which the charcoal is prepared at the source of the wood and the kiln is completely mobile. The metal kiln is also used at the source of the wood. It

Table 4.7.

Charcoal Kiln Parameters

kiln type	Mound	Metal 1	Metal 2	Metal 3	Brick Beehive
data source	1	1	2	3	4
size	variable	7 m^3	7 m^3	7 m^3	5 m diameter
input charge					
--volume	2-4 cords	2 cords	4.5 ^{3}m	6 m^3	37 steres
--weight (000's lbs.)	5-10	5	3.15-4.14	5.2	30-33
output					
--bags	18-50	18-25	25	20	19-21
--weight (1,000 lbs.)	9-2.5	1.26-1.75	1.25	1.2	10-11.5
weight conversion ratio[6]	18-.25	.25-.35	.28-.40	.23	.33-.35
energy conversion ratio[7]	.28-.39	.39-.55	.44-.63	.36	.52-.55
wood species	hardwoods	hardwoods	coconut	hardwood	eucalyptus
labor man-hours					
--load	4-8	4-14	12	20	40-45
--unload	4-8	4-14	9-12		
firing time (days)	1-4	1-2	1	1 1/2	4
cooling time (days)			2	1 1/4	4
total production time (days)	2-7	2-3	4	3 1/2	8 1/2
capital cost J$ (000's)	---	3.0	3.0	3.0	7.5[8]
variable costs (J$/firing)[2]					
labor	10-21	10-35	70-80	75	100-112[4]
bags	18-50	18-25	25	30	200
wood delivery	20	10-25	--		48-314[3]
fuel (chain saw)	--	10	--	10	
Subttotal J$/ton charcoal	73-107	60-108	152-174	190	70-100
income					
--per bag	10-15	12	10	12	12[5]
--per firing	216-600	216-300	250	240	2400-2760
--per ton	400-600	480	400	400	480

Notes for Table 4.7.

Charcoal Kiln Parameters

Notes: 1) 1 cord = 3 1/2 m^3 stacked,
1 stere = 1 m^3 stacked = .5 m^3 wood = 350 kg.

2) $J1.78 = US$1 for beehive kiln.

3) Lower number wood from native forest,
higher number wood for Eucalyptus plantation.

4) Assume J$20 per 8 man-hr.

5) Estimates.

6) Oven-dry weights for wood in and charcoal out.

7) Assume oven-dry wood 7600 BTU/lb and oven-dry charcoal 11,900 BTU/lb.

8) Kiln alone J$2,350.

Sources: 1. L. Nelson Reference 68.

2. Personal communications J. Stamphers.

3. A.R. Paddon Reference 71, consultant's estimates.

4. Florestal Acesita, SA, Reference 40.

is portable but less so than the earth mound kilns. It is generally used in a configuration of two or more kilns and is moved only after many firings. The metal kiln has a capital cost which the earth mound kiln does not. The beehive kiln is not necessarily located near the source of wood. It is a permanent unit and must therefore be located in the centroid of an area which will provide fuelwood for the expected life of the facility. The beehive kiln has a higher capital cost, but a lower cost per unit capacity than the metal kiln.

The capacity of the kilns is quite different. The beehive is the largest, with an area of about 40 cubic meters. The metal kiln has a capacity of about six cubic meters or less for the size currently used in Jamaica, but there is a larger design which has a capacity of about 16 cubic meters. The capacity of the earth mound kiln can be varied according to the size required. Generally it is built with a capacity in the same range as the metal kilns.

The firing time for a kiln varies with its size, therefore, the longest firing times are for the beehive kilns and the larger earth mound kilns. The annual output of the three types of kilns depends on their production cycle and their level of utilization. If two days is allowed between production cycles and the kilns are used throughout the year, then the average annual capacities would be:

Earth mound kiln	40-50 tons/year
TPI small metal kiln	38-60 tons/year
Beehive kiln	175-200 tons/year

For these production levels the capital costs for the three kiln designs would be 0, J$50-$75, and J$12-$14 per ton of annual capacity. For purposes of the national energy model a utilization level of 70 percent is assumed thus reducing average annual outputs to 32, 35 and 130 tons per year and the capital costs to J$0, J$86, and J$18 per ton of capacity.

The system capital costs and the variable operating costs are much more difficult to estimate because they depend on a number of factors. The estimates for variable costs presented in Table 4.7 range from J$70 to J$200 per ton of charcoal,* however, the bases for these estimates differ because of the assumptions made about:

a. the costs for delivering the wood to the kiln

b. the number of kilns operated in parallel

c. the level of mechanization in the collection of the wood and the preparation of the kiln for firing

d. the costs of labor including the generally uncounted cost of the owner of the kiln.

The cost of the fuelwood input must be computed differently if it is obtained; a) from existing forests without replanting, b) as a byproduct of forestry or sawmill activities or c) from fuelwood plantations organized to provide wood for charcoal making.

In order to compute costs for the National Energy Model, three scenarios were used. The first makes use of the earth mound kiln and the natural forests to provide cooking fuel directly to the household. The second makes use of logging and sawmill residues to produce charcoal in metal kilns for sale in the market or direct to hotels and commercial establishments. The third scenario makes use of a fuelwood plantation and a battery of beehive kilns to produce industrial charcoal for large scale users such as the cement

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* Not included in these estimates are the costs for transport of the charcoal to the market or consumer.

Table 4.8.

Comparison of Kiln Operation Scenarios

	Scenario One	Scenario Two	Scenario Three
1. Source of Wood	natural forest	logging, sawmilling	fuelwood plantation
2. Type of Kiln	earth mound	metal	beehive
3. Kiln Life	0	5 years	15 years
4. Annual production per kiln (tons charcoal)	32	35	130
Monthly consumption per kiln (tons wood)	150	120	380
5. Distance (miles)			
to source	0	0	2
to market	10	15	25
6. Transport Cost (J$ per ton charcoal)			
wood	0	0	1.4
charcoal	7	10.5	17.5
7. Capital Costs (J$/ton-year)			
kiln	0	86	18
balance of system[1]	11.3	11.3	39.5
8. Product per firing (tons)	.63	.63	5.0
9. Variable cost J$ per ton	208[2]	327[3]	112[4]
10. Annual Maintenance Costs[5] (J$/ton-year/year)	1.63	4.88	3.50

Notes:
1. Two chain saws, two shovels, wheelbarrow, two sieve chutes for scenarios one and two.
2. J$16 for chainsaw fuel, J$40 for bags, J$75 for labor, including that of the owner.
3. J$16 for chainsaw fuel, J$40 for bags, J$150 for labor, including that of the owner, per firing.
4. J$50 for chainsaw fuel, J$320 for bags, J$190 for labor, including that of the owner, per firing.
5. 5 percent for kilns, 15 percent for chain saws, ten percent for other equipment.

industry, smelters, industrial gasifiers, etc. These scenarios are summarized in Table 4.8. The cost of transport has been calculated based on the costs presented in Table d.2.

4.2.3 Dendrothermal Plants

The demand for electricity is steadily increasing and many of the existing generating units are due for retirement in the next ten years.* A possible source of future generating capacity is the use of wood-fired, steam-generating plants. These plants would be located near to or within fuelwood plantations and would burn wood chips to produce steam.

The conversion efficiencies of wood-fired boilers is about 80 percent, when computed using the low heat value of the wood. The overall conversion efficiency of the turbines and generator is about 30 percent so that the system efficiency is 24 percent. This implies a fuel consumption rate of 2.3 lbs. of air-dried wood per kilowatt hour (assuming that air-dried wood has a moisture content of 20 percent and a low heat value of 6150 BTU/lb.). For fuelwood plantations with an output of 95 tons greenwood (50 percent moisture content) every 8 years, 100 acres would supply enough fuel for 640 megawatt-hours per year. For a generating plant serving the base load with a .9 load factor and an 80 percent availability, each megawatt of capacity would require 1000 acres of fuelwood.

The capital and operating costs for several different size plants are shown in Table 4.9. The cost per kilowatt of capacity decreases with an increase in plant size, from $1925 per kilowatt for a 3 megawatt facility to $1385 per kilowatt for a 50 megawatt facility. These costs are derived from

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* This subject is discussed in Chapter 10.

Table 4.9. Dendrothermal Generating Plant

Capacity	3MW	10MW	50MW	1.3MW
Hours operation[1]	7,000	7,000	7,000	5,250
Load Factor[2]	.9	.9	.9	.9
Annual Generation (000's MW HR)	18.9	63	315	6.14
Annual send out[3] (000's MW HR)	17.7	59.0	295.0	5.74
Annual Delivered[4] (000's MW HR)	14.9	49.6	248.0	4.82
Boiler Efficiency[5]	.8	.8	.8	.8
Generation Efficiency[6]	.3	.3	.3	.176[19]
Rate of fuel consumption (lbs air-dried wood/kw hr)	2.31	2.31	2.31	3.37
Consumption of air-dried wood[7] 000's tons/yr.	21.9	72.8	364.0	9.1[20]
Consumption of green wood 000's tons/yr[8]	35.0	116.5	582.5	N/A
Plantation Size[9] (000's acres)	3.0	10.0	50.0	N/A
Capital Cost (mn$US)[21]	4.62[10]	13.36[2]	55.40[11]	1.435[19]
(mn$J)[13]	2.08	5.95	24.65	.639
Unit Capital Cost ($ US/kwe)	1,925	1,670	1,385	1,380
Maintenance Costs[12]				
(000's $ US)	115.5	334.0	1,385.0	35.9
(000's $ J)[13]	205.6	594.5	2,465.3	63.9
Labour Costs (000's J$/year)				
Unskilled[14]	129.6	259.2	388.0	129.6
Semiskilled[15]	453.6	453.6	635.0	226.8
Skilled[16]	182.4	182.4	182.4	182.4
Transport Costs[17] (000's J $)	122.4	655.2	4893	N/A
Plant Life (years)	25	25	25	20

N/A = Not Applicable

Notes for Table 4.9.

Dendrothermal Generating Plant

Notes:

1. JPS average plant availability.
2. Consultant's estimate.
3. Assume 6.5 percent internal consumption. (including chipper 12 kw hr/ton green wood).
4. Assume 16 percent loss in transmission and unmetered use.
5. Based on Low Heat Value of Fuel at 20 percent Moisture.
6. Delgor Reference 24.
7. Assume 20 percent moisture content, 6150 Btu/lb low heat value.
8. Assume 50 percent moisture content at the forest.
9. 95 tons/acre greenwood if clear cut every 8 years.
10. ESI/EDI Reference 32.
11. FAO fuelwood study, Reference 39.
12. 2 percent of capital costs for imported spares and consultancy 2 percent of capital costs for local spares and labour.
13. J$ 1.78 = US$ 1.0.
14. Annual cost J$ 10,800/man year.
15. Annual cost J$ 15,000/man year.
16. Annual cost J$ 24,000/man year.
17. J$ .7/ton mile average distance 5 miles for 3 MW, 8 miles for 10 MW, and 12 miles for 50 MW.
18. For operation of sawmill wastes, 2 shifts per day.
19. SETIMEG proposal to FIDCO.
20. Sawmill wastes at FIDCO facility, 7200 BTU/lb., Reference.
21. 80 percent US$, 20 percent J$.

sources outside of Jamaica. The only proposals for a dendrothermal facility in Jamaica are contained in a paper prepared by the Scientific Research Council and a proposal submitted to FIDCO by the French concern SETIMEG for a 1.3 megawatt facility to be installed at the sawmill in Spanishtown. The details of the former are summarized in Tables d.3 and d.4. The latter proposal contains a relatively low cost, $1380 per kilowatt, however, the technology is relatively simple and the system conversion efficiency would be only 14 percent.

The possibility of using 3 and 10 megawatt plants for electricity generation are analyzed in a paper by Ms. Wright and Mr. Illori presented in the case studies in the appendices. Their findings indicate that these plants may be financially viable but are not economically viable as discussed in Chapter 11. The 3, 10 and 50 megawatt plants would require 4.7, 15.5 and 78 square miles of fuelwood plantation, respectively. The difficulties in obtaining large tracts of land for fuelwood planting have already been mentioned. Even if the current problems regarding land records and land tenure were resolved, and if the government were to institute a program for more efficient use of land, the fact remains that most agricultural activities provide a greater return than fuelwood plantations.*

4.2.4 Wood Fired Boilers

Industrial process heat requirements can be classified according to whether or not steam is raised as a means of energy transfer. A similar classification of industrial shaft power requirements can be made. At present

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* Assuming that the dendro-thermal plant would replace a Bunker "C" steam plant with a heat rate of 14,000 BTU/kw-hr, the value of the fuel replaced per acre of plantation would be about J$825 per year (using the 1981 price of Bunker "C" of J$1.58 per imperial gallon).

most of the requirements that involve steam raising make use of oil-fired boilers, with the notable exception of bagasse-fired boilers in the sugar mills. In the future, some of these steam requirements could be met by using boilers fired with wood chips or sawmill residues. These boilers have conversion efficiencies ranging from 75 percent to 82 percent. The costs for various size boilers are presented in Table 4.10 and their performance characteristics are compared with oil-fired package boilers. There are no apparent economies-of-scale in boiler costs; in fact, the larger units are more expensive per unit capacity than the smaller units. Smaller boilers are generally available as package boilers at a cost of about US$50 per lbs/hr. of steam raising capacity. The larger boilers are field-erected units with costs of about $90 per lbs./hr. The costs in Table 4.10 do not include the costs for material handling, including chipping the wood and transferring the fuel from the trucks into the furnace. The cost for these activities is estimated to be between US$5 and US$10 per ton.

The rate of fuel consumption for wood-fired boilers is between .2 and .22 lbs per 1000 BTU. One acre of fuelwood plantation would provide sufficient fuel for 65-71 million BTU per year. A package boiler with a capacity of 10,000 lbs. of steam per hour, operating 24 hours a day at 80 percent of load with an availability of 80 percent, would require 1050-1150 acres of fuelwood. For a single shift operation the demand would be reduced to about 300 acres of fuelwood.

The difficulty of obtaining sufficient land to grow fuelwood presents a constraint on the use of larger boilers. Smaller units requiring 50 to 100 acres of fuelwood could be more easily established. Units of this size would be sufficient to provide 500-1000 horsepower-hours (assuming a compound steam

Table 4.10.

Fuelwood and Charcoal Boilers

Type Boiler Fuel	Package Wood					Field Erected Wood			Package Oil
Output									
- psi	300[1]	300[1]	900	900	300[1]	900	900	900	300[1]
- °F	400[1]	400[1]	800	800	400[1]	800	800	800	400[1]
- 000's lbs steam/hr	1.1	11.0	10	20	26.4	120	200	500	26.4
- mn BTU/hr	1.32	13.2	14.5	29.0	31.7	174	290	725	31.7
Efficiency (%)	75[2]	75[2]	80	80	82	80	80	80	90
Consumption									
- Short tons/hr	.14	1.43	1.47	2.95	3.14	17.6	29.4	73.6	1.00
- lbs/mn BTU	217	217	203	203	198	203	203	203	
Capital Cost[3]									
(mn US$)	.061	.227	.747	1.12	1.39	10.6	14.1	45.5	.736
(US $/lb.-hr)	55.2	20.6	74.7	56.2	52.5	88.3	70.5	91.0	27.9
Maintenance Costs[4]									
000's US$/yr	1.2	4.5	14.9	22.5	27.7	212	282	910	14.7
000's J$/yr	2.2	8.1	26.6	40.0	49.3	377	502	1,620	26.2
Unit Maintenance Costs									
(US$/lb.-hr	1.10	.41	1.49	1.12	1.05	1.77	1.41	1.82	.56
Labor[1],[3],[5]									
Skilled	–	–	–	–	–	–	–	–	
Semi-skilled	1	1	1	1	1	2	2	2	1
Unskilled	1	2	2	2	2	4	4	4	
Labor Costs[6]									
Skilled	–	–	–	–	–	–	–	–	
Semi-skilled	15.0	15.0	15.0	15.0	15.0	30.0	30.0	30.0	15.0
Unskilled	10.8	21.6	21.6	21.6	21.6	43.2	43.2	43.2	–
Subtotal	25.8	36.6	36.6	36.6	36.6	73.2	73.2	73.2	
Annual Output[5],[7]									
10^9 BTU	2.20	22.0	24.1	48.3	52.7	290	483	1,206	52.7
10^6 lb. steam	1.83	18.3	16.6	33.3	43.9	200	333	832	43.9
Source	a	a	b	b	c	b	b	b	c

Notes for Table 4.10.

Fuelwood and Charcoal Boilers

Notes

1. Consultant's estimate.
2. Wood 6150 BTU/lb.
3. Boiler only, not material handling equipment.
4. 4 percent of capital cost, 1/2 US$, 1/2 J$, $1.78=US$1.
5. One shift operation.
6. Unskilled $10,800 man-year, semiskilled $15,000/man-year.
7. 80% utilization.

Sources

[a] Meta, Reference 57.

[b] OTA, Reference 87.

[c] Flores Asecita, Reference 40.

engine is used), or 12.5 - 25 million BTU of steam per day for 260 days per year.

4.2.5 Wood and Charcoal Gasifiers

Gasifiers fueled with wood or charcoal are attracting increasing interest throughout the world. In Jamaica large-scale gasifiers could be used in industrial applications for raising steam or generating process heat. Small-scale gasifiers could be used to provide on-farm shaft power. Most of the applications considered for Jamaica are for fixed gasifiers. There is also the option for using gasifiers to provide mobile shaft power such as on tractors or jitneys. These applications are common in the Phillipines, but it is unlikely that they will be used in significant quantities in Jamaica.

The large-scale applications include retrofitting boilers and installing new gasifier equipped gas boilers. Although these gasifier-equipped boilers consume more fuel than wood-burning boilers, they are easier to control and, therefore, are preferable in applications where the rate of steam generation must be adjusted to specific levels. Another large-scale application is generating "clean" process heat for crop drying, ceramic firing and brick-making.

The small-scale applications include powering small irrigation pumps and on-farm crop grinding equipment. Shaft power can be obtained by fitting gasifiers to gasoline and diesel engines. In the case of the gasoline engine the capacity must be derated by 40 percent because of the low energy density of the producer gas. For the diesel engines the derating is less but the engines require a fuel mixture with at least 10 percent diesel in order to ensure combustion.

The price of a gasifier varies with size, source, and application. The small-scale gasifiers, 20 hp or less, are relatively simple since they are manually loaded and do not require sophisticated, complex controls. The larger scale units are more difficult to operate and require fuel-handling equipment as well as controls to ensure proper matching of the supply of gas and the demands of the end use. For units from 1 to 20 horsepower the price averages about US$50-75 per horse-power. It is possible to construct these units locally but quality work is required for their fabrication. For engines in the range of 100-500 horse-power, the cost for a gasifier is about US$40-60 but this cost does not include fuel-handling equipment. For large boilers with outputs ranging from 1 to 10 million BTU per hour, the cost of the gasifier is US$10-20,000 per million BTU/hr of capacity. The unit cost for the gasifier decreases as the size increases. For small-scale gasifier and generator sets, 10 to 50 kilowatt capacity, the costs range from US$1900 per kilowatt for the smaller units to US$1080 per kilowatt for the larger units. A summary of some typical costs for gasifiers alone and gasifiers connected to boilers and generating sets are shown in Table 4.11.

An analysis of the costs and technical parameter for a typical medium size gasifier, 1.27 million BTU per hour, and a typical large gasifier, 12.7 million BTU per hour, is shown in Table 4.12. The conversion efficiencies for wood gasifiers are estimated to be 80 percent. When the wood gasifiers are attached to gas boilers the system efficiency is only to 72 percent. For charcoal gasifiers these efficiencies are higher, 89 percent for the gasifier and 80 percent for the boiler and gasifier. The charcoal gasifiers are simpler to operate and more units are designed for charcoal than for wood. However, the loss of heat content in the conversion from wood to charcoal is much greater than the marginal savings in heat content due to the higher

Table 4.11.

Gasifier Prices
(US$)

Configuration	Fuel	Size	Country	Capital Cost	Unit Cost[1]	
					Quoted	Standard
gasifier for boilers	wood chips	1.6mn BTU/hr	US	30,000		19
"	"	4.2mn BTU/hr	"	50,000		12
"	"	8.4mn BTU/hr	"	82,000		10
gasifier and generator sets	wood, charcoal	15-500 kw$_e$	Brazil		100-200/kw$_e$	10-20
	wood	12 kw$_e$	Germany	22,660	1,888/kw$_e$	553
	"	16 kw$_e$	""	26,438	1,652/kw$_e$	484
	"	50 kw$_e$	""	54,013	1,080/kw$_e$	317
		25 kw$_e$	Costa Rica		500/kw$_e$	147
gasifier for engine	charcoal	5 hp	Various		40-75/HP	16-30
gasifiers for engines	charcoal	10-16 HP	Phillipines		34-207/HP	13-81
gasifier for engine	"	156 HP	""	10,000		25
gasifier for engine	"	389 HP	""	18,000		18
gasifier for tractor	"	65 HP	""	2,500		15

[1] Per 1,000 BTU/hr of capacity.

Source: Meta 1982 Reference 56.

Table 4.12.

Typical Gasifier Costs and Technical Parameters

Fuel Size	Typical Gasifier Costs and Technical Parameters				
	Gasifier Only		Gasifier and Boiler		Gasifier Engine
	Wood and Charcoal		Wood and Charcoal		Wood and Charcoal
	Medium	Large	Medium	Large	Small
Output					
- mn BTU/hr	1.27	12.7	1.27	12.7	-
- 000's lb. steam/hr	-	-	1.05	10.5	-
- HP	-	-	-	-	5
Efficiency					
- wood	80%	80%	72%	72%	25 %
- charcoal	89%	89%	80%	80%	25 %
Consumption (short ton/hr)1/					
- Wood	.126	1.26	.14	1.40	8.3 lbs./hr
- Charcoal	.064	.64	.07	.71	4.5 lbs./hr
Capital Cost2/					
- 000's US$	22.7	124	56.4	210.5	875
US$/000's BTU/hr	17.9	9.8	44.4	16.6	-
US$/HP	-	-	-	-	175
Maintenance Cost3/					
000's US$	.45	2.48	1.13	4.21	17.50
000's JR	.80	4.41	2.01	7.49	-
US$/000's BTU/hr	.36	.20	.89	.33	-
J$/000's BTU/hr	.64	.36	1.58	.59	
Labor4/ 5/					
Skilled		1	1	1	-
Semi-skilled	1	2	1	3	.2
Labor Cost (000's J$/yr)5/					
Skilled	19	19	19	19	-
Semi-skilled	0	30	15	45	3
Subtotal	19	49	34	64	3
Annual Output6/					
- 10^9 BTU	2.2	22.2	2.2	22.2	-
10^6 lb. steam	-	-	1.84	18.4	-
- 10^3 HP-hr	-	-	-	-	8.3

Notes for Table 4.12.
Typical Gasifier Costs and Technical Parameters

Notes

1. Assume wood 6150 BTU/lb. low heat, charcoal 11,200 BTU/lb.
2. Excludes fuel handling equipment.
3. 2 percent of capital cost in US$ and 2 percent in J$, J$1.78=US$1.
4. Single shift, consultant estimate.
5. Semi-skilled: 15,000/man-year; skilled: 19,000/man-year.
6. 80 percent utilization, single shift, six hours per day.

Source: Meta Reference 56.
Consultants estimates.

efficiencies of the charcoal gasifiers. The medium size wood gasifier consumes 255 lbs. of wood per hour (assuming 6150 BTU/lb. low heat value) at full load while a similar charcoal gasifier would consume 135 pounds per hour (assuming a heat value of 11,200 BTU/lb.). The larger gasifiers consume about 10 times these amounts. Since both charcoal and wood gasifiers are relatively simple to operate the labor requirements are limited to a semi-skilled operator for the smaller unit and to one skilled operator and two semi-skilled helpers for the larger units.

The costs and technical parameters for a small-scale gasifier and engine are also shown in Table 4.12. The small-scale gasifier is less expensive to operate but has an estimated efficiency of only 75 percent. When connected to an engine the system efficiency drops to 20-25 percent. Fuel consumption therefore averages 1.6 to 2 lbs. of fuelwood per horsepower-hour.

4.3. Markets

4.3.1 Fuelwood Cooking Fuel

At present there is very little information about the use of fuelwood for cooking in Jamaica. The household survey conducted for MME in 1979 and the one currently in preparation, do not collect data on actual fuelwood consumption but merely attempt to determine what proportion of the households use fuelwood. A summary of the results from the first survey are shown in Table 4.13. These results do not distinguish between households which use a single fuel and those which use a mixture of fuels. The data on quantity of wood consumed were not included in the first survey and were recorded in non-weight terms* in the second survey. The parishes with the highest

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* Without standardization of measurements it is somewhat meaningless to record fuel consumption. The only common unit is weight.

TABLE - 4.13

Household Choice of Cooking Fuels

(% household using)

PARISH	ELECTRICITY	LPG	KEROSENE	CHARCOAL	FUELWOOD	TOTAL
Kingston	1	47	66	42	12	168
St. Andrew	4	61	54	31	16	166
St. James	54	43	40	37	49	223
St. Catherine	1	31	56	33	40	161
St. Ann	49	30	57	24	74	234
Hanover	-	30	35	24	75	164
Trelawny	-	22	45	22	70	159
Portland	37	20	53	37	75	222
Clarendon	1	24	37	43	69	174
Manchester	35	27	40	17	64	183
Westmoreland	-	23	35	14	80	152
St. Thomas	-	28	41	43	76	188
St. Mary	-	23	40	24	86	173
St. Elizabeth	-	13	42	5	95	155

- less than ½%

Source: Household Energy Survey 1979-1980 percentage of households using fuelwood for cooking are St. Elizabeth, St. Mary and Westmoreland. The parish with the lowest percentage is St. Andrew. The lowest percentage is associated with the high level of urbanization in St. Andrew, the higher percentages do not appear to be related to the distribution of population or the availability of fuelwood. If the data from St. Andrew is excluded, then between 40 and 95 percent of the respondents from each parish use fuelwood for some part of their cooking. Island-wide about 54 percent of the households use fuel wood for some part of their cooking. The data in Table 4.13 reveal that many of the households which use fuelwood also use charcoal, especially in St. Mary, St. Thomas, Clarendon, and Portland. Fuelwood is collected by the household or purchased from higglers in the market. It is burned in three-rock or other simple wood stoves. No information is currently available on the cooking activity, the types of utensils used and the resulting level of fuel consumption. Data from other countries indicate that households which cook exclusively with fuelwood use between 1 1/6 and 1 2/3 lb. of air-dried wood per capita per day. If it is assumed that 54 percent of the households obtain half their cooking heat from fuelwood then the level of consumption would be between 270 and 390 thousand tons per year. If it is further assumed that the fuelwood has a 20 percent moisture content at the time it is used, but a 50 percent moisture content at the time it is removed from the forest, then the total amount of greenwood consumed for cooking is between 430 and 620 thousand tons. If the wood is obtained from both undisturbed forests and from disturbed forests/scrub land in a ratio of 1:2, then the equivalent area cut would be 2.4-3.5 thousand acres of the former and 18-26 thousand acres of the latter*. This is a

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* Assuming 60 tons/acre from mixed forests and 16 tons/acre from disturbed forests.

conservative estimate since marginal sources of wood are not included in the calculation. These areas represent 1 to 2 percent of the natural forests and 2-3 percent of the ruinate, and "other" wooded lands. However, they represent a much larger percentage of those areas which are easily accessible to the rural population.

4.3.2 Charcoal Production and Markets

Charcoal is currently used as a cooking fuel in 29 percent of the Jamaican households and in a limited number of hotels, restaurants, and food shops (for barbecues, especially Jerk fish, chicken, and pork). Charcoal is also used in a few industrial applications such as lead smelting for battery manufacture. It is also a potential fuel for use in cement manufacturing which is expected to consume 112,000 tons of coal in 1984 and 168,000 tons in 1987.*

Charcoal is currently produced by small-scale producers using either metal "TPI" kilns rented from the Forestry Department or "ground" kilns (either earth mound or pit kilns). A survey conducted by L. Nelson, Reference 68, in 1982 of some 30 charcoal producers revealed that they collect the wood from a distance of one mile or less and use mostly wood which has been cut by someone else as part of forest clearing activities. The kilns are generally fired for 1 to 2 days, either once or twice a week. About 2/3 of the respondents used single kilns while the remainder used 2 or 3 kilns. Most of the charcoal makers have helpers who include not only friends and relatives but also hired labor. The latter were mentioned by nearly 2/3 of the respondents. Most of charcoal is sold directly to the households, although 1/3 of the respondents indicated that they had also sold some charcoal to hotels and other commercial establishments.

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* Source: MME National Energy Plan 1982.

Another review of the charcoal making activities was performed by a member of the Tropical Products Institute in the spring of 1979.* This survey concerned the use of the "TPI" metal kilns which had been fabricated in Jamaica for the Forestry Department and which were leased to various charcoal producers. A summary of the findings is shown in Table d.5. Although 30 kilns had been fabricated only 9 were found to be in active use at five sites with a weekly output averaging about 146 bags (about 3 1/2 tons) per week. Another seven sites had the remaining 21 kilns but these were not being used. Most of the activities surveyed suffered from lack of equipment, especially chain saws, lack of adequate training and incentives for workers, and lack of raw materials.

Most of the facilities had been organized to use the wood from forest or estate clearing activities to make charcoal. One example is a large facility, now shut down, located at Serge Island. It contained 16 kilns of which 9 did not work properly because of poor fabrication. This facility was set up to process Carribean Pine from a clear-felling operation in the Blue Mountains. It was closed because of lack of transport and technical supervision. Another example is a facility located at Cambridge Backland that operated three kilns to process felling wastes produced as part of Forestry Department harvesting activities. When the Forestry Department ceased activity, the charcoal producers cut down their own trees for charcoal.

A charcoal-making activity using metal kilns was visited by the author in the summer of 1983. It is a downstream activity of a sawmill, in the parish of St. Ann, which is milling wood obtained from coconut trees killed by the "lethal yellow" disease. The kilns are located at the sawmill and plans are

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* A.R. Paddon 1979 Reference 71.

underway to expand production as the volume of wood milled increases and a market for the "low density" charcoal is established.

No information has been collected on the weight of charcoal consumed for cooking. It is mostly burned in pit barbecues or cast-iron coal pot stoves. Data from other countries and estimates by the FAO indicate a level of charcoal consumption of between .3 and .6 lb. per capita per day. It is assumed that the higher figure is for families which use only charcoal. If the average household that burns charcoal obtains only half its fuel from charcoal, then the annual national demand would be about 31.5 thousand tons. With an average yield of .3 lbs. charcoal from 1 lb. of fuelwood, this implies a demand for 105,000 tons of fuelwood per year. Since most of the feedstock is obtained directly from the forests and only slightly dried, the demand for greenwood would be only about 25 percent greater. This implies that about 2250 acres must be cleared each year to produce charcoal for household cooking. If an eucalyptus plantation were used to meet this demand and the wood was converted to charcoal in kilns then about 12 thousand acres would be required assuming that the harvested wood has a moisture content of 50 percent and the wood used in the kiln has a moisture content of 35 percent.

Another use for charcoal in the household is for ironing which is done either with a flat iron heated on a charcoal stove or with a charcoal iron. About 23 percent of the households in Jamaica use charcoal for ironing. The distribution of demand by parish is shown in Table 4.14.

Still another use for wood and charcoal in the household is for heating water. About 9 percent of the households surveyed indicated that they used charcoal for water heating while another 26 percent indicated that they used fuelwood for the same purpose. Most of the water heated with wood or charcoal

TABLE - 4. 14

Household Choice of Ironing Fuels

(% household using)

PARISH	ELECTRICITY	FLAT IRON LPG OR KEROSENE STOVE	CHARCOAL IRON OR FLAT IRON CHARCOAL STOVE	FLAT IRON FIREWOOD STOVE
Kingston	55	8	15	3
St. Andrew	71	8	10	3
St. James	39	9	23	11
St. Catherine	35	14	23	11
St. Ann	33	37	22	45
Hanover	26	13	28	22
Trelawny	25	16	28	37
Portland	21	12	43	22
Clarendon	21	5	39	30
Manchester	23	18	19	38
Westmoreland	26	6	16	32
St. Thomas	13	13	55	38
St. Mary	15	12	22	32
St. Elizabeth	8	26	13	78

Source: Household Energy Survey 1979-1980

a'

is used for drinking or for washing clothes. The distribution of this demand by parish is shown in Table 4.15.

The demand for charcoal as a cooking fuel appears to be income elastic as indicated by the data in Table d.6. This same table indicates that the demand for charcoal for ironing is more income elastic, that is, it decreases more rapidly with an increase in income. Since the income elasticity for electric and gas water heaters is positive, the income elasticity for charcoal as a fuel for water heating is thought to be negative.*

The long term trends in the demand for fuelwood and charcoal can only be guessed at, in lieu of better data. The assumptions used in the market analysis are shown in Table 4.16.

4.3.3 Market for Dendrothermal Plants

It is assumed that the dendrothermal plants, in order to be financially attractive, must be 3 megawatts or larger. Because of the amount of land required to grow the fuel, this plant would probably not exceed 10 megawatts. It would be operated by JPS or the Aluminum companies, perhaps in co-operation with FIDCO or the Forestry Department. The electricity generated would be fed into the grid to meet the baseload demand. The market for this generation capacity is discussed in Chapter 10.

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* This is not necessarily true since the demand for both could increase with income.

TABLE - 4.15

Water Heating Fuels

(% households using)

PARISH	ELECTRICITY	LPG	KEROSENE	CHARCOAL AND FIREWOOD
Kingston	4	17	28	27
St. Andrew	7	20	21	13
St. James	2	3	2	6
St. Catherine	1	6	6	17
St. Ann	2	28	42	82
Hanover	1	3	7	8
Trelawny	1	15	23	58
Portland	2	6	40	30
Clarendon	1	10	9	59
Manchester	5	7	14	53
Westmoreland	-	7	7	43
St. Thomas	-	8	13	57
St. Mary	-	3	2	43
St. Elizabeth	-	5	24	90

- less than ½%

Source: Household Energy Survey 1979-1980

Table 4.16.

Assumed Trends in the Demands for Fuelwood and Charcoal

User	End Use	Fuelwood	Charcoal
Residential	Cooking	will grow together with rural population	will grow together with urban population
	Ironing	will decrease as a proportion of population	will decrease as a proportion of population
	Water Heating	will decrease as a proportion of population	will decrease as a proportion of population
Industrial	Process Heat	will increase in importance as a fuel and as a source of charcoal	will increase in importance as a substitute for oil and coal
	Producer Gas	limited use except for package boilers	increase in importance for boilers and process heat applications
Commercial	Cooking	no increase	grow in proportion to population

4.3.4 Market for Boilers and Gasifiers

It is difficult to determine the market for wood-fueled boilers and for wood and charcoal gasifiers since there are no data available on the extent of the demand for industrial process heat and no breakdown of demand by those applications which use steam and those which do not. The same can be said for the demand for industrial shaft power and on-farm shaft power. At this point it is only possible to list the potential applications as has been done in Table 4.17.

If fuelwood plantations can be established in Jamaica and regular supplies of fuelwood assured, then wood boilers will be attractive to industries currently using oil-fired boilers provided that the cost of the delivered fuelwood is less than the cost of the bunker C replaced. In 1981 prices, this amounts would mean less than US$58 per ton of wood at 20 percent moisture content. For existing facilities, consideration will be given to retrofitting boilers with gasifiers provided that the net savings in fuel provides a discounted payback period for the gasifier of five years or less. The gasifiers could also be attractive for industries requiring clean controllable process heat, such as food processing and ceramics. Retrofitting of diesel and gasoline engines for stationary shaft power greater than 20 horsepower is not likely to occur given the proximity of the rural areas to the grid and to major urban centers. Gasifiers and wood boilers may also be installed at sawmills where there are adequate residues and no alternative use (e.g. particle board, charcoal). A map of some potential sawmills is shown in Figure d.1.

Table 4.17.

Potential Markets for Wood and Charcoal Furnaces, Gasifiers and Boilers

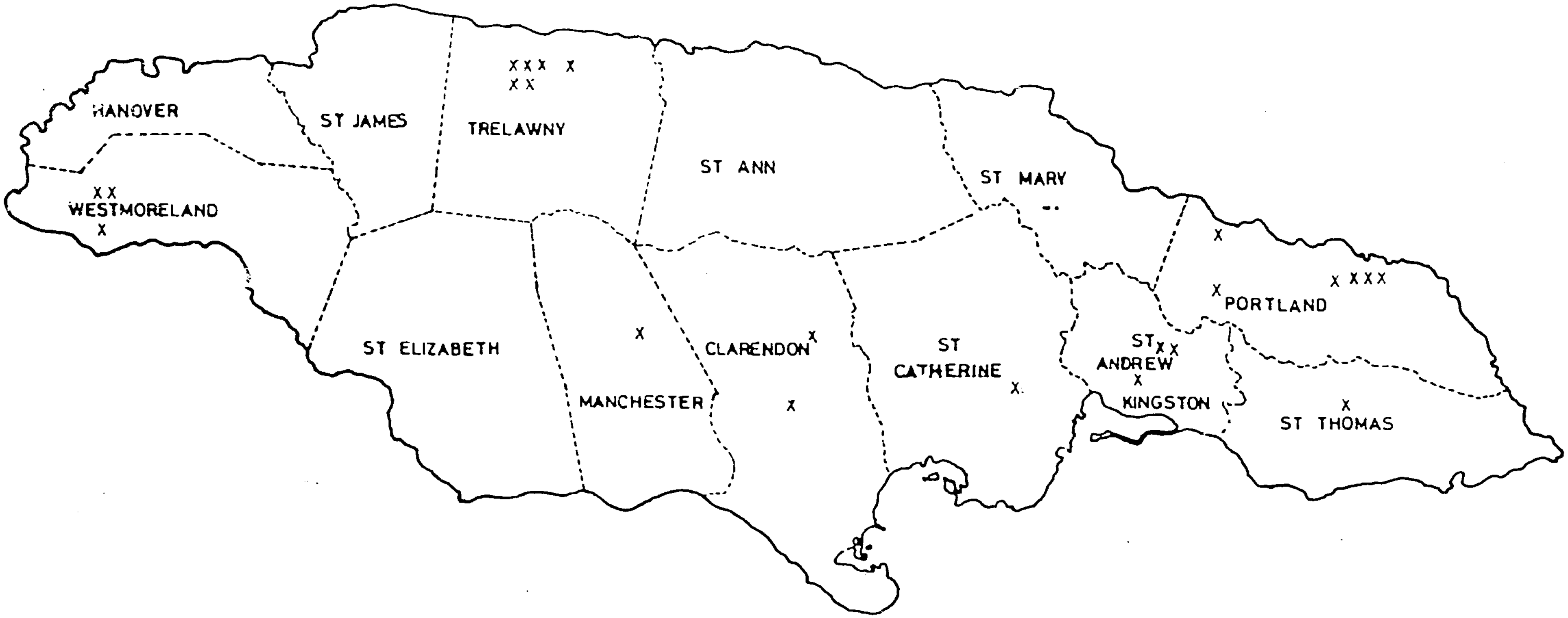
Economic Activity	Wood Boiler	Wood Gasifier	Charcoal Gasifier	Charcoal and Wood Furnaces
<u>Large Scale</u>				
poultry	x	x		
beverages*	x			
ceramics		x	x	x
sawmill		x		
food processing	x	x		
metal working				x
textiles	x			
pharmaceuticals	x			
sugar, rum, molasses				x
flour mills	x			
canning	x			
footwear	x			
tobacco	x	x	x	x
metal fabrication				x
fertilizers	x			
crop drying		x		x
<u>Small Scale</u>				
irrigation		x		
small crop grinders		x		
tractors		x		
on-farm trucks		x		

* Non-alcoholic.

For small-scale gasifiers, the primary use would be for small-scale irrigation. This demand is discussed in Chapter 10. Other demands are not expected to be significant until much later in the planning period.

FIGURE - 4.4

SAWMILLS SURVEYED BY L. NELSON



Chapter 5

Biomass--Sugarcane

This chapter discusses the potential role of the sugar industry in the conservation and production of energy. The conservation of energy involves improvements in the milling equipment so as to reduce the dependence on petroleum-based fuels. The production of energy involves the use of bagasse for electricity generation, cane juice for the production of ethanol, cane lands for production of biomass and distillery wastes for the production of methane.

The data presented in this chapter is based largely on estimates and secondary sources. The author is grateful to Mr. Richardson of the MME for tracking down what little data were available on the current operation of the sugar industry and for his analysis of the energy requirements and potential technical modifications which might be made to the mills.

The conservation effort is currently underway and the construction of a pilot methane production unit is expected to be approved soon. These are the only two technologies that are expected to provide results in the short-term. In the medium term, it is possible that additional ethanol distilling capacity will be installed, but it is unlikely to exert a major impact on the use of petroleum fuels unless there is another dramatic shift in relative prices of fuels. Such a shift would also be necessary to encourage the growing of energy cane. The energy cane has the same attraction as other technologies which are only partly understood, it appears as a panacea. However, there are serious difficulties in grafting a biomass production activity onto a declining industry which is suffering from overstaffing in the mills and shortages of field labor. The logistics and timing of the cane grinding activity make it unlikely that the existing industry could generate electricity beyond that required for its own consumption.

5.1 Resource

The growing of sugar cane is one of the oldest agricultural activities in Jamaica, dating back to early colonial times. It is also the major agricultural activity on the island involving between 110 and 120,000 acres (about 4.5 percent of the total land area) of which only 20 percent is on estates. Sugar cane is planted once every six years. The cane is coppiced during the intervening years. The maximum yield obtained in Jamaica is 40 to 50 tons per acre per year in the parish of Westmoreland. The overall yield is about 23.5 tons per acre although the estates obtain an average of 26 tons.

The sugar industry has been in a state of rapid decline for the last 15 years. During this period the annual production of cane decreased by about 60 percent. Between 1972 and 1982, the rate of decline in production averaged about 6.5 percent per year, as shown in Table 5.1. Since the yields have not changed significantly during this period, this means that land harvested has also declined. It is not known what percentage of the approximately 165,000 acres that have gone out of production in the last 15 years is currently used for agriculture or pastureland, but much of this land is unused and overgrown.

The quantity of sugar cane required to produce a ton of sugar has increased during this period as shown in Table 5.2. This is due in part to the practice, introduced over the last decade, of burning the fields prior to harvest. It is also due to the quality of cane received at the mills.

TABLE - 5.1

Sugar Production Statistics

Year	Sugar Cane Produced (MM tons)[1]	Sugar Produced (000's tons)[2]	Sugar Exported (000's tons)[1]	Domestic Sugar (000's tons)[2]	Molasses Produced (tons)[2]	Molasses Exported (tons)[1]	Rum Produced (000's liters)[2]	Rum Exported (000's liters)[1]
1972	4.07	373	276	97	144	60	14.6	7.2
1973	3.58	326	261	66	129	39	17.2	6.7
1974	3.79	367	270	97	121	39	18.6	14.0
1975	3.52	355	254	101	120	N/A	18.4	11.4
1976	3.57	363	230	133	118	43	14.3	10.1
1977	3.18	291	213	78	116	31	14.8	9.9
1978	3.22	287	196	91	131	52	13.3	8.5
1979	2.93	279	185	94	108	24	14.9	11.1
1980	2.74	228	130	98	101	7	16.9	12.4
1981	2.41	195	123	72	90	0	18.6	10.9
1982	2.48	194			99	5	15.1	6.1

1. Source = Social and Economic Statistics 1971-1982

2. Source = Statistical Review - Various Years

TABLE - 5.2

Sugar Industry Production Ratioes

	Tons Cane/Acre	Tons Cane/Ton Sugar
1973	26.8	10.5
1974	26.4	10.0
1975	24.5	9.8
1976	25.6	9.9
1977	24.8	10.9
1978	27.6 (32.7)	11.7
1979	26.2 (30.1)	11.0
1980	24.0 (30.0)	11.0
1981	21.5 (27.6)	12.0
1982	23.4 (26.1)	12.5

Estate Yields in Parenthesis

Source: NPA, Economic and Social Survey, 1981

The increased use of equipment for loading cane in the field has increased the quantity of dirt in the cane that is delivered to the mill. In a well run mill, such as Worthy Park, the owners have the option of rejecting dirty cane so the production of one ton of sugar requires only about nine tons of cane. However, at government mills which must accept all cane, such as Bernard Lodge, one ton of sugar requires 12-13 tons of cane.

5.1.2 Sugar Industry

The sugar mills have also gone into a state of decline during this period. Although the quantity of cane milled has declined, the number of mills has remained relatively constant. The mills were operating close to capacity in 1967-1968. Since that time their level of utilization has steadily declined as has their physical condition. Normally, the mills operate during the half of the year in which the cane is harvested. While the period of milling has remained the same, the actual number of days operated has been greatly reduced. Large work forces and relatively high prices for cane (fixed by the government at $55/ton in 1983 for cane sold to mills) have reduced the profitability of the sugar industry to the point where an IBRD loan had to be obtained for renewing the equipment in the government mills.*

Some of the hardest hit of the mills are those owned by the government. While the private sector has attempted to operate their mills at reasonable levels, some of the government mills are all but closed. The severity of the situation in the government mills is indicated by the data in Table 5.3. There are now plans to close down some of these mills to reduce the excess capacity as well as the level of government subsidy to the industry.

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* Approximately $450 million announced in July 1983.

Table 5.3. Sugar Production in Government Mills
(000's tons 96° Sugar)

	1980	1981	1982
Frome	522.8	516.2	235.4
Monymusk	565.0	461.2	118.6
Bernard Lodge	315.5	321.0	72.8
Ducken Field	157.7	151.3	5.7
Grays Inn	124.5	80.4	--
Long Pond	177.0	118.1	9.2

Source: SIRI.

The principal products of the sugar industry are sugar, molasses and rum. Currently the sugar industry exports its production to the EEC countries and to the United States under quota systems. The current quota price of 17.5 cents per pound is considerably higher than the world price of 12 cents per pound. Despite this implicit subsidy to the sugar industry, Jamaica is unable to fill its quota, which is 68,000 tons to U.S. and 125,000 tons to EEC. Rum continues to be the most profitable product of the sugar industry. Despite this fact, the production and export of rum has not improved significantly since the mid-1970's (see Table 5.1). Molasses is used as a base for rum and as an input to livestock feed and food products. The domestic production of molasses has dropped by nearly one-third since the mid-1970's with the result that the export of molasses has been sharply curtailed. A resource flow diagram of the product of the sugar industry is shown in Figure 5.1 for the years 1981 and 1982.

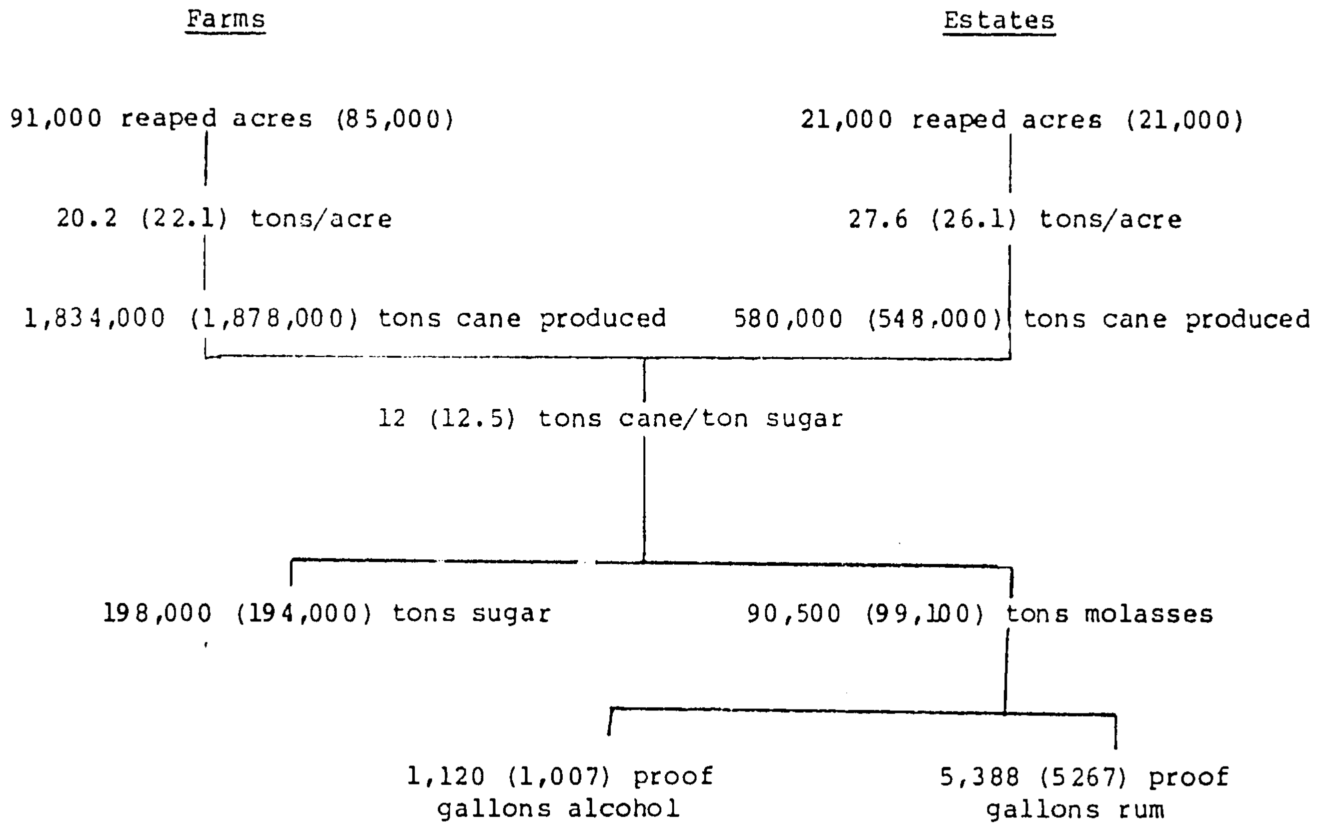
The long-term prospects for the sugar industry are not good, not only because of the decline of the industry within Jamaica, but also because of the change in the worldwide market. In the United States, a rapidly increasing percentage of the sugar requirements are being met with fructose, primarily from corn, rather than sucrose. In the EEC, the increasing surplus of beet sugar is reducing the demand for cane sugar. Although the price of sugar recovered from the slump in the late 1970's, it peaked in 1980 and has steadily declined since then (see Table e.1).

5.1.3 Energy and Sugar Cane

The sugar industry is the subject of five proposals for improving energy production and consumption. The first concerns improvements of the boilers at the mill to reduce their dependency on fuel oil. The second involves burning

Figure 5.1.

Resource Flow Diagram for Sugar Industry in 1980 and 1981



Notes: 1982 values in parentheses.

Source: Economic and Social Survey 1982, adjustments by consultant.

excess bagasse to generate electricity. The third suggests the growing of high-fiber energy cane on cane land not currently in production. The fourth considers the use sugar cane to produce ethanol. The fifth examines the use of the distillery wastes from rum-making to produce biogas.

The proposed improvement of the sugar mill boilers is meant to reduce the relatively high level of oil consumption at the mills. The mills normally consume a certain quantity of fuel oil in starting up their boilers and in maintaining the mill during the out-of-cane season. The use of fuel oil at the mills began increasing in the early 1970's, when bagasse was diverted to the manufacture of particle board. Recently, the problems with irregular supplies of cane and the increasingly intermittent nature of the mills' activities have increased the demand for boiler fuel, especially for bunker C. The increasing cost of oil has caused the mills to adopt measures to reduce oil consumption including the use of wood wastes for boiler fuel. These measures appear to have been successful in certain mills, e.g., Bernard Lodge, but not in others, e.g., Monymusk, as shown in Table 5.4. Overall, the industry has continued to consume about five million gallons of bunker C per year as shown in Table 5.5.

Currently, there are plans to install air preheaters and superheaters on the boilers of some of the mills in order to improve their efficiency. These units were delivered to Jamaica several years ago as part of an IBRD-financed project, however, they were never installed. Other near term plans call for installation of a partial suspension boiler at Frome and a new, water-wall boiler at Monymusk. It is also planned that all mill boilers will eventually be upgraded to 300 psi and that where multiple small boilers are used they

TABLE - 5.4

Oil Consumption in Sugar Industry 1979-1982

(Gallons oil/ton sugar for Government-owned Mills)

Sugar Mills	1979	1980	1981	1982
Frome	1.64	1.81	.82	.92
Monymusk	1.86	1.44	1.74	4.33
Bernard Lodge	6.96	3.02	2.91	.66
Duckenfield	4.51	3.80	4.60	4.07
Gray's Inn	3.48	2.92	3.83	-
Holland	3.27	.69	1.38	1.66
Long Pond	4.58	2.72	3.37	1.84
TOTAL	3.27	2.18	2.00	1.64

Table 5.5.

Fuel Oil Consumption in Sugar Mills 1980-1982

(000's Imperial Gallons Oil Used)

	1980	1981	1982
Frome[b/]	947	422	554
Monymusk[b/]	1,026	1,256	2,452
Bernard Lodge[b/]	954	906	78
New Yarmouth[e/]	102	358	124
Innswood[b/,g/]	--	--	--
Duckenfield[b/]	600	660	366
Long Pond[b/]	492	378	363
Worthy Park[d/]	19	15	43
Appleton[e/]	339	310	343
Hampden[f/]	200	139	78
Holland[b/,c/]	39	101	-
Gray's Inn[b/]	364	325	593
Total	5,072	4,868	4,996

a/ Total Annual Consumption.
b/ National Sugar Company Ltd. Plant.
c/ Non Operational - dismantled.
d/ Worthy Park Ltd.
e/ Wray Nephew.
f/ Hampden Ltd.
g/ Burns no oil, does not generate electricity.

Source: National Sugar Co. Ltd.

will be replaced with large boilers. The potential for improved efficiency of the mills or for fuel substitution is excellent, but the funds for capital investment are severely limited. The technical considerations of this proposal are dealt with in the next section.

The possibility of burning excess bagasse to produce electricity was contained in a proposal submitted by one concern. This proposal contains a number of unlikely assumptions including:

a. the sugar mill can operate on 35 percent of the bagasse produced from grinding the cane;

b. The bagasse boiler can achieve an efficiency of 87 percent;

c. the turbine/generator can achieve efficiencies of 93 percent.

Even in a well-run mill, the quantity of excess bagasse would be limited to 30 percent. The proposed efficiencies are well in excess of those normally achieved as was pointed out in an analysis by Mr. Keith. Using excess bagasse for electricity generation is generally not a good idea because bagasse is produced only during the grinding period which lasts about one-half the year and there are considerable difficulties involved in storing bagasse. Further consideration is given to this proposal in the next section.

The growing of high fiber "energy cane" was proposed by the Scientific Research Council of Jamaica.* Currently, the SRC is trying to obtain permission to import energy cane from the U.S. in order to run it through an existing mill. This high fiber cane yields 80 to 120 tons per acre of above-ground biomass. It would produce about three times as much molasses as existing varieties per acre and this molasses could be used to increase rum

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* The specifics of this proposal were not available at the time this report was prepared. The information presented is based on a discussion with Dr. Binger of the SRC.

production. The cane would also produce about the same quantity of sugar per acre. The fiber from the cane would be used as a boiler fuel. Some of the problems involved in introducing this high fiber cane are:

1. about 40 percent of the biomass is contained in the leaves and therefore it would not be possible to burn the field prior to the harvest without a considerable loss of fuel value;
2. the cane would have to be manually harvested since equipment is not available for harvesting the dense cane;
3. 250 to 400 percent more grinding capacity would be required per acre planted, however, the existing mills are now operating at about one-half of capacity;
4. the current floor price for cane of $55 per ton would make this an uneconomical fuel. The financial viability of this proposal will be extremely sensitive to the cost of delivered cane.

The problems of creating an energy production activity from a declining agricultural activity are considerable. This proposal is discussed further in the next section.

The production of ethanol from sugar cane has been the subject of considerable discussion in most countries. Brazil has taken the lead in developing this technology. Its decision to proceed with large-scale distillation of ethanol from sugar cane was based on the availability of large amounts of uncultivated land suitable for growing cane and on national policies which gave great weight to reduced dependence on foreign oil. Neither of these conditions pertains in Jamaica. Jamaica currently produces about 1.2 million proof gallons of hydrous ethanol for sale to industry at distilleries located at the Innswood and Monymusk mills. Since this production does not meet demand, additional quantities must be imported.

A consultant's study of the possibility of large-scale ethanol production concluded that the project was not feasible. A major problem is that the cost of the cane delivered to the mill would be higher than the value of the ethanol produced. Another problem is that the return on the production of sugar and rum is higher than on the production of ethanol. A detailed study of the possibility for retrofitting an existing mill, Bernard Lodge, for ethanol production was prepared by Messrs. Richardson and Lucas. Their findings are presented in the appendix, "Case Studies". They concluded that neither the existing mill nor the retrofitted mill would be financially viable given the 1981 prices. If the sugar were sold at the quota price then a sugar mill would lose less money than an ethanol plant, but if the sugar were sold at the world price, which at that time was only 7¢ per lb., then an ethanol plant would lose less money. The costs and conversion efficiencies for a newly built ethanol plant are presented in the following section.

The proposal for introducing a large biogas digester to convert the dunda, distillery wastes from rum, into methane was initiated by Bacardi which has such a facility in operation at their distillery in Puerto Rico. This proposal is now being considered for funding by USAID. A summary of the financial and technical characteristics of this proposal is presented in the next section.

5.2 Conversion Costs and Efficiencies

5.2.1 Mill and Distillery Efficiencies

The sugar mills now use the bagasse as a boiler fuel, exclusively. Because of the variability of supply, the reduced efficiency of the boilers, and the need for steam during the out-of-cane season, the mills consume in addition to the bagasse, approximately two imperial gallons of fuel oil for

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every ton of cane ground. The material flow for a typical plant is shown in Figure 5.2a. These mills require between 1,100 lbs. of steam per ton of cane crushed for an efficient mill and 1,500 lbs. of steam for an inefficient mill. The latter is more common. If we assume a low heat value for bagasse of 3,250 BTU/lb.,* and for fuel oil of 166,000 BTU per imperial gallon, and if we assume a a boiler efficiency of 75 percent for bagasse and 85 percent for oil then the heat rate per ton of cane processed is 1,520 lb. of low pressure steam (1,150 BTU/lb.). The bunker C provides about 16 percent of the required steam which is used primarily in starting up the boilers prior to cane grinding and in running the generators during the out-of-cane season. In the 1960's when the boilers were in good condition, the mills burned no oil and produced 10 to 15 percent excess cane which was incinerated.

If the mills are retrofitted with air preheaters and steam superheaters, the expected material flow would be as shown in Figure 5.2b. The consumption of bunker C would be eliminated, but all of the bagasse would continue to be used as a fuel. The out-of-cane fuel requirement would be met with the excess bagasse produced during the grinding. The estimated price for the retrofit of Bernard Lodge is J$.5 million excluding the cost of the preheaters and equipment.

A modern mill has a material flow as shown in Figure 5.3. Assuming a boiler efficiency of 75 percent producing 300 psi steam (1,200 BTU/lb.), the steam rate is about 1,100 lbs. per ton of cane, as shown in Figure 5.4. The excess bagasse would be used for maintaining the mill during the out-of-cane season and also to provide the energy for a distillery, if one were attached to the mill.

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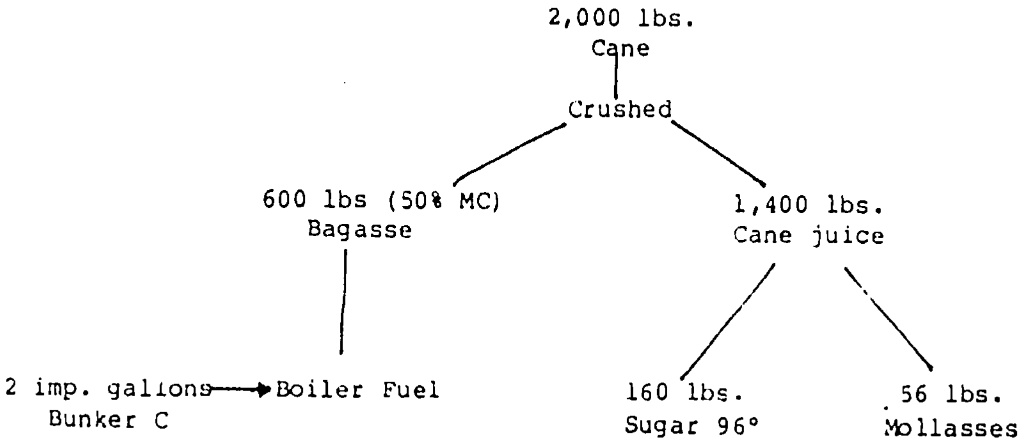
* Based on 50 percent moisture content.

Figure 5.2.

Sugar Mill Material Flows

a. Present Mill



b. Well Run Retrofitted Sugar Mill

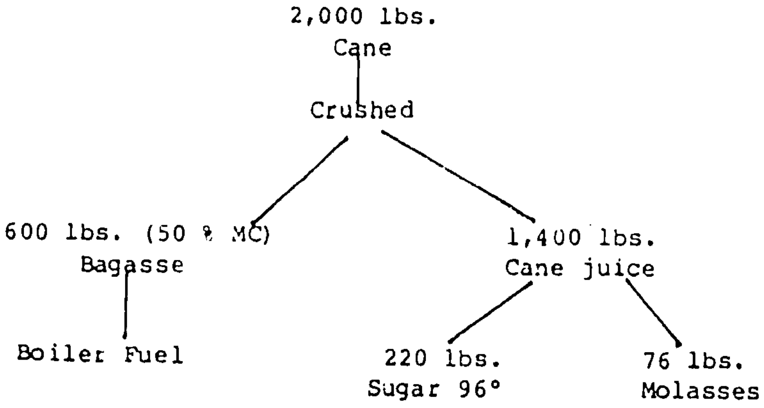


Figure 5.3.

Sugar Mill Material Flows

c. Material Flow for a modern Sugar Mill and Rum Refinery

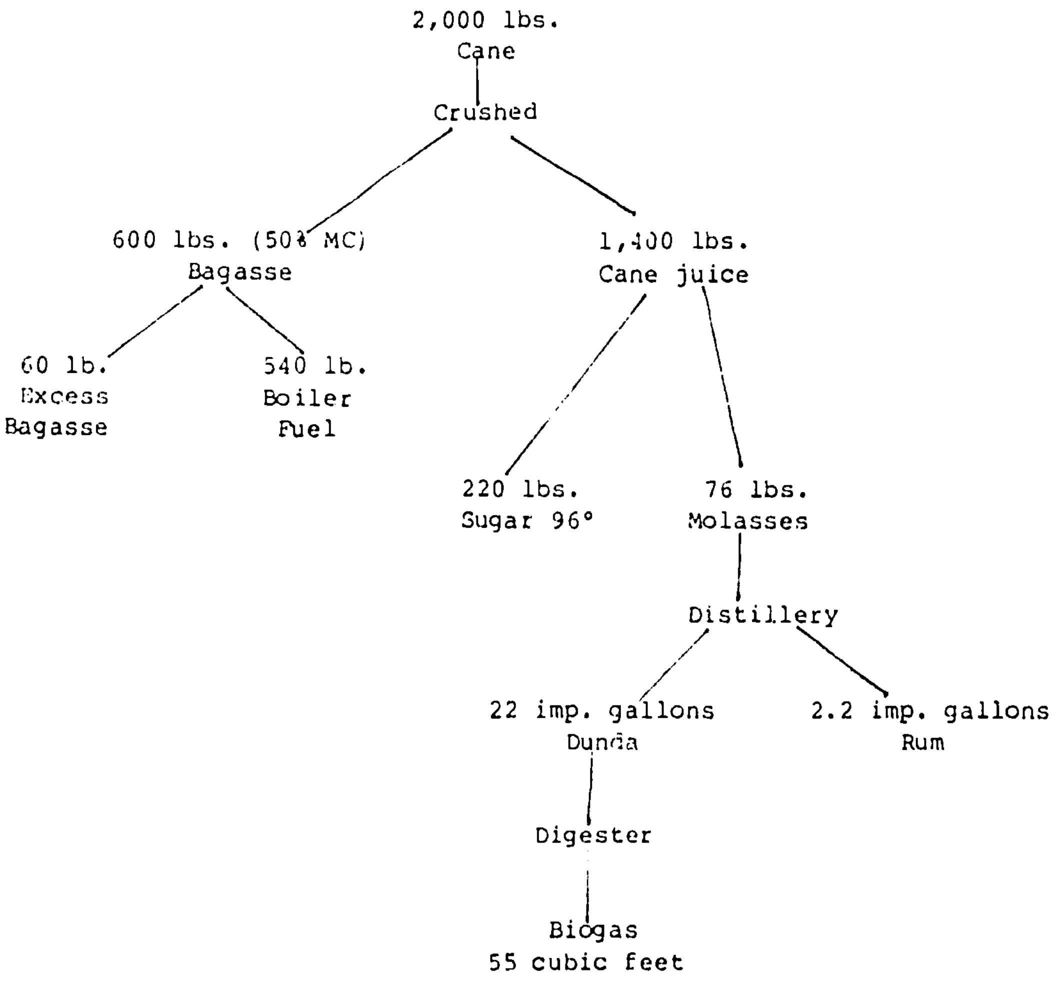
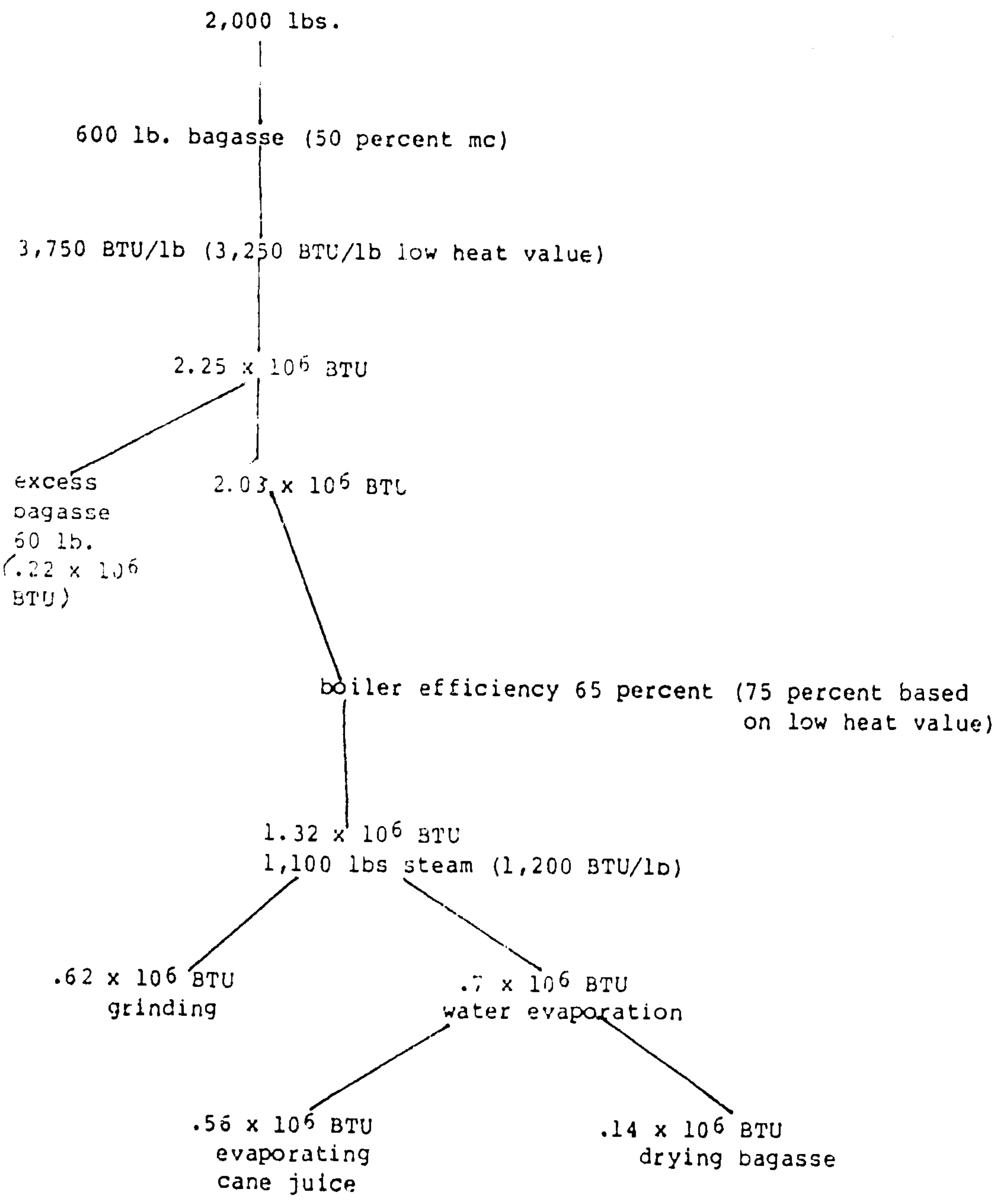


Figure 5.4.

Modern Mill-Energy Flow



Source: FAO fuelwood study, modified by consultant's estimates.

Note: Bagasse bone-dry heat content 7,500 BTU/lb.

A national plan for rationalization of the sugar mills is currently under consideration but had not been made public at the time this report was prepared. The components of this plan are thought to include:

a. a large IBRD loan for renewing the government mills, including the installation of new boilers;

b. upgrading the steam systems in all mills to 300 psi;

c. closing some of the less efficient mills; and

d. retrofitting air preheaters and superheaters on mills for which this equipment was procured, (i.e., Monymusk, Duckenfield, Bernard Lodge, Long Pond).

In the short run, proposals have been made for improving the manual controls for the bagasse boilers, adding automatic bagasse feeding systems to the furnaces, and adding equipment to the oil burners to improve their efficiency.

It is anticipated that by 1987 the consumption of bunker C at the mills will have been consideraoly reduced and that the purchase of electricity from JPS at the Holland and Innswood factories will have been discontinued in favor of auto-generation.

5.2.2 Electricity Generation

Although the French proposal was unrealistic, it did identify the potential for using bagasse to generate electricity for commercial use. It is possible that the mills could generate electricity for sale to JPS during the in-cane season. Assuming a 15 percent surplus of bagasse, a boiler efficiency of 80 percent, and a generating efficiency of 27 percent, a mill grinding 100,000 tons of cane could generate 835 Megawatt hours (allowing 10 percent for internal uses) for sale to JPS. If the in-cane season lasts six months, this would amount to an average output of .2 Megawatts. At current grinding levels, the mills, if upgraded, could generate 4 1/2 Megawatts. The problems with this scheme are numerous:

1. The condition of the sugar industry is not good and its future is unclear;
2. The availability of generating capacity during only one-half the year has limited benefits for JPS;
3. The current problems of irregular cane supply and intermittent operation would have to be eliminated; and
4. The cost of installing and operating generating capacity for only six months of the year would be expensive.

The logistics are too problematic to include this potential source of electricity until the 1990's and by then it is uncertain what the condition of the industry will be. A summary of the probable costs for a generating facility at a large mill handling 400,000 tons per year is shown below.

Table 5.6. Costs for Electricity Generation from Bagasse

Input	400,000 tons cane
Bagasse	120,000 tons
Excess	18,000 tons
Conversion efficiency	.215
Output	3,320 MWHR
Average output	.85 MW*
Capital for 1.0 MW steam generating capacity	U.S. $ 2.0 million
Annual maintenance	U.S. $ 40,000
	J $ 71,200
Annual labor	J $ 76,000**

5.2.3 Ethanol Plants

It is generally agreed that the costs of constructing and operating an ethanol plant and providing the cane are in excess of the market price for the

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* Plant availability 95 percent, six months per year, load factor .95.

** Assume operation by existing mill personnel except for technical supervision.

ethanol which could be produced. The cane currently has a price at the mill of J$55 per ton. This cane will yield approximately 15 imperial gallons of ethanol. If this is mixed with gasoline at a 1:9 ratio so that no changes have to be made to the automobiles using the fuel, then the ethanol can be sold at the refinery for about J$4.50 per imperial gallon in current prices (about $J3.50 in 1981 prices). The cost of refining and transport must be less than J$.83 per imperial gallon if the ethanol plant is to be financially viable. With the transport costs between the refinery and a distillery in Spanish town estimated to be about J$.15 per imperial gallon at current tariffs, the cost of refining must be less than US$.68 per imperial gallon or J$8-10 per ton of cane processed.

The capital and operating costs of a sugar mill and an ethanol distillery are about the same since both require labor and equipment to crush the cane and evaporate the juice. Currently the yield from a ton of cane is 165 lbs. of sugar which can be sold, C.I.F., to the EEC or the USA for about J$82. Assuming that 15 percent of this is for transportation, the income per ton of cane processed into sugar is about $70; the income per ton of cane processed into ethanol is about $65.

The costs for some typical ethanol plants for capacities ranging from 4.4 thousand imperial gallons per day to 53 thousand imperial gallons per day are shown in Table 5.7. These plants are stand-alone units. Their costs are based on Brazilian estimates as presented in the IBRD publication "Alcohol Production from Biomass in Developing Countries". The prices have been updated to 1981. The labor costs for these plants are relatively high since the manning levels are assumed to be comparable with Jamaican sugar mills which are operating at productivity levels of one man per 1,000 tons of cane

Table 5.7.

Ethanol Plant Costs

Capacity (litres/day)	20,000	120,000	240,000
Annual input			
000's tons/year 7/	40	239	478
Annual output mn litres	2.8	16.7	33.4
Capital Costs (000's) 1/			
Engineering (US$)	175	519	883
Process Equipment (US$)	1,306	5,430	9,350
Utilities (J$)	568	2,387	4,181
Civil Works, Land (J$)	649	1,802	3,004
Erection (US$)	100	295	370
(J$)	176	516	655
Contingency 2/ (US$)	252	981	1,649
(J$)	183	631	1,075
Subtotal (US$)	1,833	7,325	12,252
Subtotal (J$)	1,576	5,336	8,915
Total (US$) (mn US$) 3/	2.72	10.23	17.26
Unit costs (US$/1,000 lit/day)	136	85	72
Labor 4/			
Skilled	33	60	75
Semi-skilled	33	60	75
Unskilled	22	40	50
Labor Cost 5/ (000's J$/yr)			
Skilled	627	1,140	1,425
Semi-skilled	495	900	1,125
Unskilled	238	432	540
Subtotal (mn J$/yr)	1.36	2.47	3.09
Maintenance 6/			
(000's US$/yr)	41	153	259
(000's J$/yr)	73	273	461

Source: IBRD Reference 45.

Notes:
1/ 1979 prices escalated by following factors:
1.3 engineering, 1.375 equipment, 1.45 utilities, 1.35 civil works, 1.25 erection.
2/ 15 percent of cost.
3/ J$ 1.78 = US$1.
4/ Largest facility based on estimate of Bernard Lodge. Work force for others scaled down assuming labor varies as the capacity raised to the 1/3 power.
5/ Assume full year employment for half years work skilled J$ 19,000/man year, semi-skilled $15,000, unskilled J$ 10,800.
6/ 1 1/2 of capital cost in US$ and 1 1/2 percent in J$; J$ 1.78 = US$1.
7/ 6 months per year, 85 percent plant availability 90 percent load factor, 24 hours per day operation.

ground. Economies-of-scale are assumed so that the labor cost drops from J$2.20 to J$.42 per imperial gallon as the size of the plant increases from 4.4 to 53 thousand gallons per day.

The material flow for the ethanol plants is shown in Figure 5.5a. Since these facilities have a processing sequence similar to sugar mills, it is possible to retrofit existing mills to produce ethanol rather than sugar. The retrofit involves diverting the cane juice from the evaporation vats for raw sugar to the evaporation columns for producing ethanol. The material flow for a retrofitted ethanol plant is shown in Figure 5.5b. The costs for these retrofitted plants was estimated by using the costs for a molasses-based distillery. The costs were estimated to be 65 percent of the costs for a completely new ethanol plant. These costs are explained in more detail in Richardson and Lucas's case study.

5.2.4 Energy Cane

The projected yield from energy cane is about 80-120 tons per acre. Of this, 20-30 tons is in the form of leaves and other non-cane biomass. The cane would be manually harvested and the fields would not be burned prior to cutting. The cane would be transported to a sugar mill and ground to produce sugar. The leaves and the bagasse would be burned to generate steam for grinding and for electricity generation. A proposed material flow for the processing of this high fiber cane is shown in Figure 5.6. This flow assumes that the cane would produce the same amount of sugar per acre but 200 percent more molasses. The costs for growing and harvesting this crop have not yet been determined,[1] although a study is currently underway by Swedish consultants.

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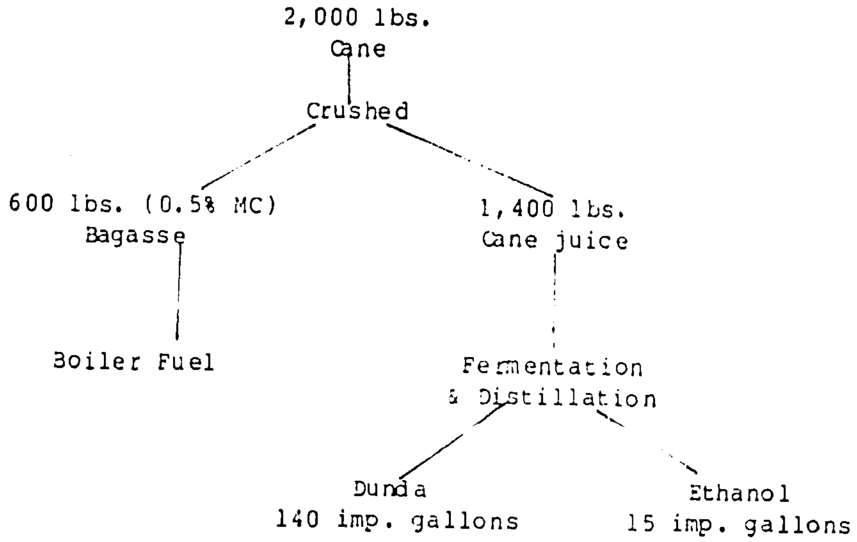
[1] A preliminary economic evaluation was made by Dr. Binger of the SRC, however, it is currently being revised. The numbers used in this section are crude estimates and should be revised when actual planning figures are available.

Figure 5.5.

Material Flows for Modern Ethanol Plants

a. Retrofit Ethanol Plant



b. Stand-Alone Ethanol Plant

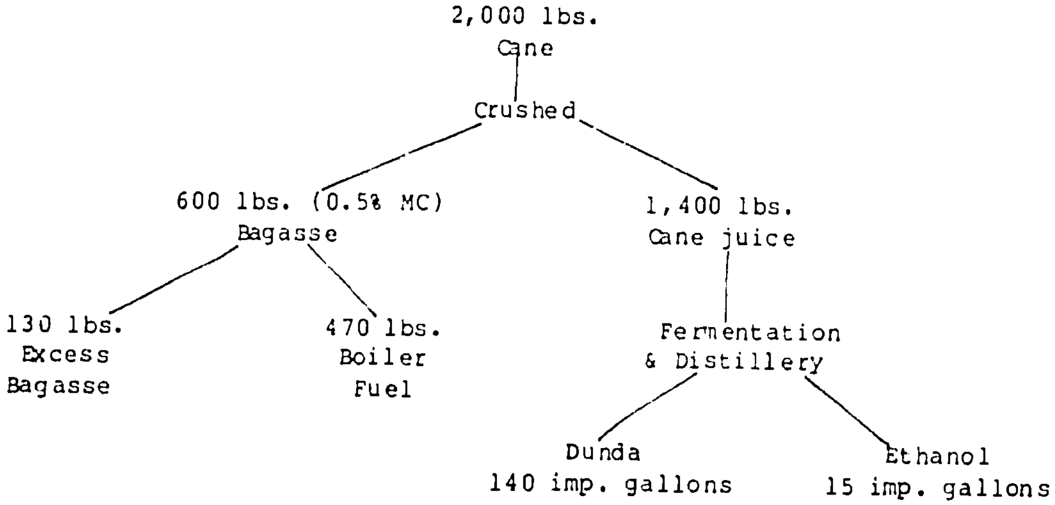
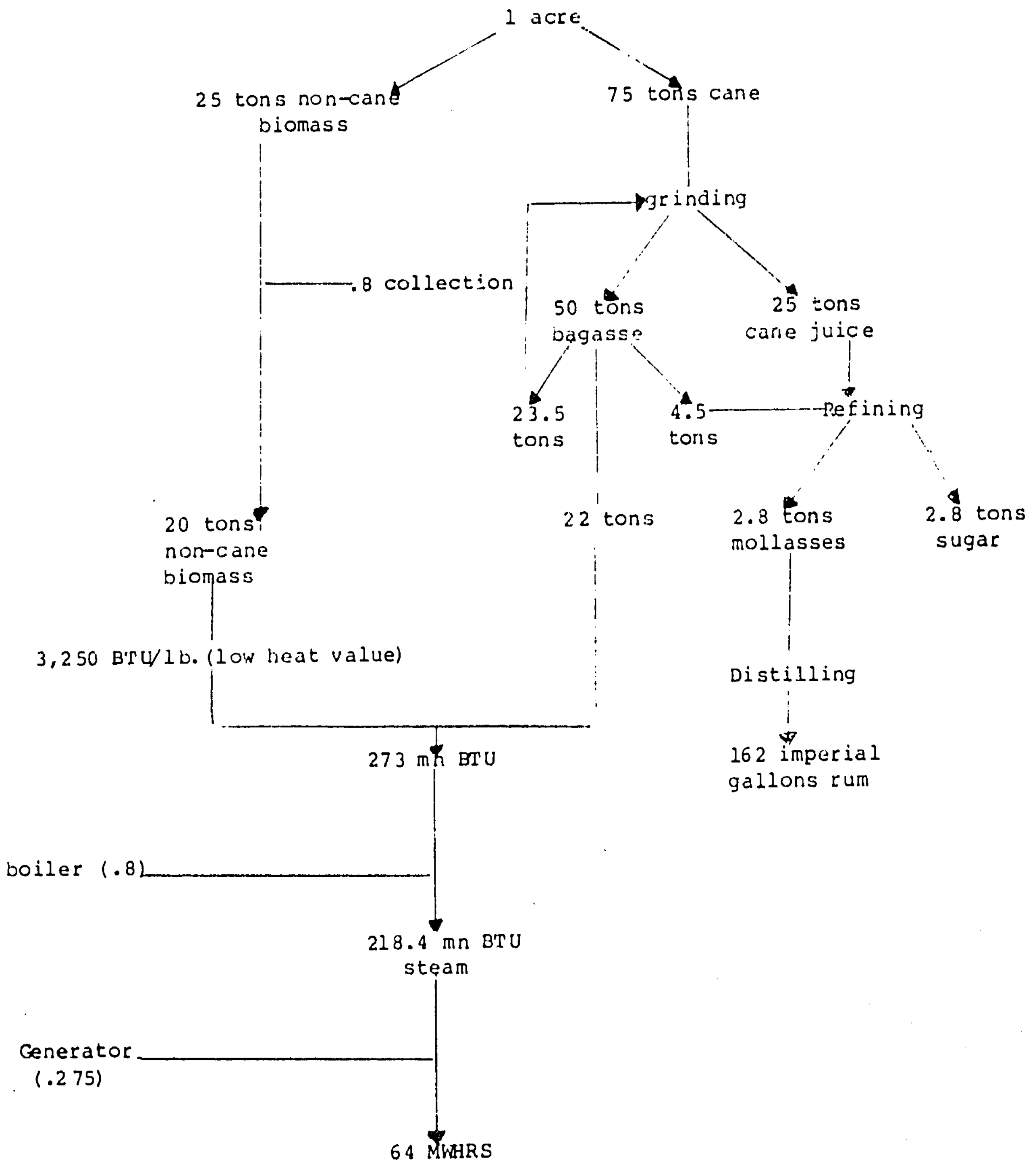


Figure 5.6.

Material and Energy Flow for High Fiber Cane



The high energy cane would produce considerably more fuel per acre planted than a fuelwood plantation. Assuming that approximately 40-60 tons of bagasse are produced per acre and 15-25 tons of non-cane biomass are collected, each with a 50 percent moisture content, then this amounts to about 360-560 million BTU of fuel per acre per year (using the low heat value for bagasse). This compares with a yield of only about 90 million BTU per acre per year for proposed fuelwood plantations. If it is assumed that the energy for grinding is the same for high fiber cane as for regular cane, then about 47 percent of the bagasse would be used for grinding. Another 4-5 tons would be used for making the sugar, molasses and rum. No energy is assumed to be required for preparation of the non-cane biomass. If the bagasse were converted to electricity using a steam plant with an overall efficiency of 20-22 percent, then the total output would be 12.3 to 21.7 megawatt hours per acre of energy cane.

The requirements for producing this electricity would include:

1. an increase in grinding capacity or the utilization of the excess mill grinding capacity (approximately 18 million tons of excess capacity assuming that one-half of the unused capacity from the late 1960's is no longer available);
2. An increase in labor for harvesting an acre greater than the increase in yield because the cane will not be burned prior to harvest;
3. No increase in mill labor since the mills are heavily overstaffed, but additional labor for operating the electricity generation plant to be employed for the full year;
4. Electricity generation for the six months of cane harvesting;
5. An installed capacity of electricity generation of 4 to 7 kilowatts per acre assuming a baseload operation with .9 load factor and .83 plant availability; and
6. No change in the transport cost per ton of cane delivered to the mill;

A summary of the basic costs for a 2,000 acre operation is presented in Table 5.8. The harvesting labor costs were determined by assuming that the current floor price for cane of J$55 per ton is allocated 30 percent to land rent (or return to owner), 10 percent for materials, 10 percent for transport, and 50 percent for labor, assuming manual harvesting. The resulting labor cost of J$27.5 /ton was increased to J$30/ton to allow for more difficult harvesting. The cost to produce the electricity generated would be relatively high for two reasons: first, the cost of harvesting the cane which accounts for about 40 to 45 percent of the total cost, and second, the cost of the generating facility which is used for only one-half of the year since it is difficult to store large quantities of bagasse. It might be possible to extend the period of harvest to eight months which would reduce the size of the generation facility and the additional grinding facility. This would reduce the overall cost of the electricity by about 10-15 percent.

The analysis presented so far remains highly speculative since no attempt has been made to grow or process energy cane in Jamaica, much less use it for the generation of electricity. The emphasis on manual harvesting has led to relatively high costs. It is unclear whether the Jamaicans would willingly return to manual harvesting, especially for a denser cane, or whether mechanical harvesting would be required.

5.2.5 Biogas

A project is currently underway to construct a pilot 3,000 liter capacity biogas plant using the Bacardi Corporation design. This plant would process the wastes, dunda, from one of the rum distilleries. The principal function of the anaerobic digester is to reduce the BOD count of the wastes prior to discharge. As a by-product, the digester produces biogas which contains

Table 5.8.

Costs for Energy cane Grinding Mill and Electricity Generation Mill

Inputs	
2,000 acres	
100,000 tons bagasse	
40,000 tons non-cane biomass	
910 x 10^9 BTU	
Outputs 1/	
Generated	34 x 10^6 kwhr
Send out	30.5 x 10^6 kwhr
Delivered	25.7 x 10^6 kwhr
Generation Plant (10 MW)	
Capital Cost 2/	
(mn US $)	13.36
(mn J$)	5.95
Maintenance Cost 3/	
(000's US$)	334
(000's J$)	595
Labor 000's J$ 4/	895
Additional Grinding Facility	
Capital Cost 5/	
(mn US$)	1.30
(mn J$)	.96
Maintenance Cost 6/	
(000's US$)	36.8
(000's J$)	65.5
Labor	--
Additional Cane Harvesting	
Labor (mn $J)	4.20
Transport (mn $J)	.77

Notes: 1/ Send out excludes 10 percent for internal use, delivered excludes 16 percent losses.

2/ $1,670/kw comparable to dendrothermal plant.

3/ 2 percent of capital cost in US$ and 2 percent in J$, 1.78 = 1.

4/ Same labor as 10 MW dendrothermal.

5/ Derived from cost estimate of cost for 60,000 lit/day ethanol plant, assume 35 percent of cost for grinding.

6/ 1/2 the estimated maintenance costs of a 60,000 lit/day ethanol plant.

52-66 percent methane. The digester has a retention time of approximately 10 days so that the pilot plant will be able to process about 300 liters per day of dunda. The gas yield is estimated to be 2.5 cubic feet of biogas (1.7 cubic feet of methane) per imperial gallon of waste processed. The estimated gas production for the six rum distilleries is shown in Table 5.9. The total potential is nearly 1 million cubic feet per day.

The costs for these digesters were estimated based upon the projected costs for the pilot plant. It was assumed that the cost of a facility would increase in proportion to the size of the facility raised to the 2/3 power. The results for a 10,000 and a 100,000 imperial gallons per day plant are shown in Table 5.10. The costs are assumed to be predominately in local currency based on the proposal by the Bacardi Corporation. If the larger units require a higher percentage of foreign investment, then it is likely that the costs will increase to allow for transport and foreign production. The labor costs have been held constant for both plants. It is assumed that two skilled and eight semi-skilled workers are required for continous operation of both digesters. The labor costs contribute significantly to the economies-of-scale of operating the larger unit. The estimated cost of the biogas for the 100,000 imperial gallon/day unit is about J$.03-.05 per cubic foot or J$.06-09 per thousand BTU of heat content. If the labor costs were eliminated by using refinery personnel exclusively, then the cost would be reduced by about 30 percent. For the 10,000 imperial gallon/day plant the cost per cubic foot of gas would be about 5 times as large.

5.3 Market Penetration

The improvements in sugar mill boilers and the reduction in oil consumption are expected to occur over the next five years, together with a

Table 5.9.

Potential Biogas Generation From Distillery Wastes

Distillery	Wastes (imp. gallons)		Biogas (cubic ft)		Energy (BTU)*	
	Daily 000's	Yearly mn	Daily 000's	Yearly mn	Daily 10^6	Yearly 10^9
Innswood	39.6	14.5	99	36	50	18
Long Pond	44.0	16.1	110	40	55	20
Monymusk	110.1	40.2	275	101	139	51
Appleton	110.1	40.2	275	101	139	51
Hampden	33.0	12.0	83	30	42	15
New Yarmouth	44.0	16.1	110	40	50	20

* Low (net) energy value, assume 56 percent methane.

Source: Bacardi Corp. Reference 11.

Table 5.10.

Projected Costs for Dunda Biogas Digester

Capacity	3,000 Litres	10,000 imp. Gallons	100,000 imp. Gallons
Capital Costs			
(J$ 000's)	74.10	454.0	2,108.0
(US$ 000's)	2.78	17.0	78.9
Maintenance Costs 1/			
(J$ 000's)	2.24	13.6	63.2
Labor 2/			
(J$ 000's)	-	62	62
Input per day	300 litres	1,000 imp. Gallons	10,000 imp. Gallons
Daily gas output			
- (cubic feet)	165	2,500	25,000
- (mn BTU fuel)	.083	1.26	12.6
Annual gas output			
(000's cu ft)	59.4	900	9,000
(mn BTU fuel)	30	454	4,540

* Adjusted from Bacardi memo from early 1983 to mid-1981 prices then escalated by $(\text{volume})^{2/3}$.

1/ 3 percent.

2/ One skilled, 4 semi-skilled, plus distillery staff.

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rationalization of the industry which will result in the closing of some of the less efficient mills. By 1992 it is expected that the consumption of fuel oil in the mills will have been reduced to 10 percent of the current level and that this oil will be used for maintaining the mills in the out-of-cane season. The use of the excess bagasse for electricity generation is not expected to occur because of the logistic problems previously mentioned.

The use of cane for producing ethanol will not be considered over the next five years, assuming that the relative price of oil does not increase significantly. If the downturn in the relative price of sugar continues and the real price of oil increases, then ethanol plants may be established to provide for mixing with gasoline. The maximum production level is expected to be that required to provide a 10 percent mixture by 1992 and a 20 percent mixture by 1997. Following this period, consideration may be given to conversion of automobile engines to run on ethanol if the relative fuel prices are favorable. In this case, the maximum market penetration by the year 2002 would be a volume equal to 25 percent of the gasoline consumption.

The use of "energy cane" for electricity generation will be introduced gradually if it proves to be financially viable. The costs for growing and harvesting energy cane will not be understood before 1986. After this time, if the economics are favorable and there are no preferable uses for cane land, it is expected that in 1992 as much as 20 percent of the cane land would be used for growing energy cane. By 1997 this percentage may have increased to 40 percent and by 2002 to 50 percent. This option would occur in place of the ethanol option.

The use of dunda for biogas is expected to be introduced rapidly if the economics prove favorable. The results of the test plant are expected to be available by 1986. By 1992, it is expected that 50 percent of the wastes will be processed by anaerobic digesters if the economics are favorable and that this percent will increase to 90 percent by 1997.

Chapter 6

Biomass-Agricultural Wastes

This chapter discusses the potential use of agricultural residues as fuels. The residues are categorized as *field* residues which are left behind after harvesting and *process* residues which are generated at the location of the crop processing. The technologies which can be used to convert these wastes into useable fuels include: biogas digesters, small-scale gasifiers, ethanol distilleries and charcoal kilns. In addition, these residues can be burned directly to provide process heat or to raise steam.

The data on the availability of residues were obtained from two studies. The first, written by Lilieth Nelson, Reference 68, made use of a considerable amount of survey data collected under her supervision. The second, written by Malcolm Assoc., Reference 51, integrated data collected from interviews with the commodity boards and the Agricultural Ministry in Jamaica with data from secondary sources. The data on the potential of agricultural residues for fuels were obtained from laboratory measurements made in Thailand, Reference 73, and California, Reference 47, as well as secondary data.

The potential uses of field residues are limited because of the dispersed nature of these resources. The only possible application is as a feedstock for small-scale gasifiers used to power irrigation pumps in fields where the residues are located. Many of the potential uses of process residues have already been explored by the crop processing industries. Bagasse is used as a boiler fuel, cocoa wastes are used as a mulch, citrus wastes are used as animal feed, banana rejects are used for processed foods, coffee wastes are used as a fertilizer. It is expected that biogas digesters will become important for converting some of the process residues to methane to be used within the processing industries. Neither charcoal kilns nor gasifiers will be used in significant numbers to convert residues to fuels in the near or medium term because of the difficulties in using these types of residues as feedstocks. Ethanol distillation would not prove to be economic for the small-scale operations that would use agricultural residues as feedstocks.

6.1 Resources

The primary uses of land in Jamaica are for forests, pastureland and sugar cane, however, a considerable amount of land is used for other crops. According to the 1970's land use data, about 25,000 acres are planted in bananas and about 39,000 acres in coconuts, about 105,000 acres are used for mixed intensive agriculture and about 65,000 acres for mixed extensive agriculture. Smaller areas are planted in orchards (4,000 acres) and tobacco (1,700 acres). In addition, coconuts and bananas are grown on about 57,000 acres of forested area. The area planted by crop type and by parish is shown in Table 6.1 based on data from the CRIES report (Reference 31), which in turn was based on aerial data from the previous decade. The parishes that are most intensively cultivated are those in which sugar cane is predominant, Westmoreland, Clarendon and St. Catherine. The parish with the greatest percentage of land used for mixed agriculture, 18 percent, is St. Elizabeth. Manchester, St. Mary, St. Ann, St. James and Trelawny all use between 6 and 9 percent of their land for mixed agriculture (see Table 6.1). Those with the largest percentage of land planted in bananas and coconuts are St. Thomas and St. Mary. The latter has 16 percent in these crop and the former has 13 percent.

TABLE 6.1

Area Planted by Crop Type
(in hectares)

Crop Type / Parishes	1	2	3	4	5	6	7	8	9	10
Portland	8.1	12.2	26.7	1.2	.12	.16	51.4	1.2	2.8	4.4
St. Thomas	39.0	21.0	38.5	2.1	.33	0	51.8	1.6	20.2	2.2
St. Andrew	.49	0	9.35	0	0	.16	14.8	0	4.5	0
St. Mary	45.3	17.9	32.8	1.7	6.0	0	45.4	.63	35.3	1.6
St. Ann	13.9	4.3	19.0	1.0	.7	0	17.6	0	54.5	20.8
St. Catherine	177.2	14.1	2.9	.8	5.6	.12	15.0	.4	32.0	13.5
Clarendon	217.7	20.3	6.3	2.9	1.8	5.0	8.4	.24	47.0	34.4
Manchester	2.3	5.1	1.6	0	.2	0	.8	0	43.5	28.8
St. Elizabeth	63.7	2.9	3.8	.4	0	0	2.1	0	151.1	59.0
Trelawny	71.5	.12	3.4	.08	.32	1.2	0	0	17.7	41.9
Hanover	46.1	.5	1.3	0	.04	0	7.3	1.3	3.3	9.5
St. James	27.1	2.5	8.7	0	.3	0	6.5	.2	4.3	41.5
Westmoreland	180.1	.6	2.7	0	.4	0	1.6	0	5.1	6.0
	892.39	101.52	157.6	10.18	15.31	6.64	222.7	5.57	421.3	263.6

1. Sugar Cane
2. Bananas
3. Coconuts
4. Mixed Bananas/Coconuts
5. Orchards
6. Tobacco
7. Mixed Coconuts/Forest
8. Mixed Bananas/Forest
9. Intensive Mixed
10. Extensive Mixed

Source: 19[illegible] Land Classification as presented in Jamaica Research Assessment 1982

6.1.1 Current Levels of Crop Production

The principal export crops other than sugar are bananas, cocoa, coffee, spices and citrus. A summary of the level of production and areas cultivated is presented in Table 6.2. The total production of bananas for export has declined significantly over the last decade. However, the acreage planted in bananas has not declined proportionally with the result that more bananas are being sold on the local market or are being left unharvested. It is not clear from the data in Table 6.2 whether the decline in land planted in bananas has occurred in the cultivated areas or the forested areas.

The amount of coffee sent to the packing plants has fluctuated considerably over the last decade probably in response to changes in weather. The published data on the areas reaped and the resulting yields, as presented in Table 6.2, do not appear to be accurate. The lowland coffee are thought to yield between 1 and 3 tons per year per acre whereas highland coffee yields are only about 10 percent as much.

The production of cocoa declined during the 1970's but appears to be improving in the 1980's. The area planted appears to have increased, while yields have declined. In 1979 it was estimated that some 33,000 acres of cocoa were harvested. A similar trend of decline and recovery can be seen in the production of citrus. In this case, the yields did not change significantly but the amount of land reaped appears to have declined. At present, somewhere between 15 and 25 thousand acres are planted in citrus. The area planted in condiments is much smaller, about 5 thousand acres, but both the quantity and the yields have been steadily increasing.

The principal non-export crops are tubers, vegetables, and legumes. Statistics on their production over the last 13 years are shown in Table 6.3.

TABLE - 6.2 cont.

Year	Cocoa			Condiments			Citrus		
	000's Acres Reaped [3]	Tons Produced	Yield/Acre	000's Acres Reaped	Tons Produced	Yield/Acre	000's Acres Reaped [3]	Tons Produced [2]	Yield/Acre
			Tons/Acre					000 Boxes	Boxes/acre
1971	27.0	2,104	.08	2.4	3.4	1.4	25.0	1,124	45.0
1972		2,333		2.7	3.7	1.4		1,102	
1973		2,071		2.5	3.7	1.5		1,062	
1974		1,593		3.0	5.0	1.6		1,077	
1975		1,771		3.4	5.9	1.7		1,028	
1976		1,573		3.9	7.7	2		946	
1977		1,614		4.5	9.9	2.2		666	
1978		1,300		6.3	15.7	2.5		866	
1979	33.0	1,793	.08	4.5	9.	2.1	15.0	703	[illegible]
1980		1,368		4.6	N/A	-		1,112	
1981		1,814		N/A	N/A	-		808	

TABLE - 6.2

Export Crop Statistics 1971 - 1981

	Sugar Cane			Banana			Coffee		
Year	000's Acres Reaped	Tons Produced	Yield/Acre	000's Acres Reaped [3]	Tons Produced [1]	Yield/Acre	000's Acres Reaped [3]	Tons Produced [2]	Yield/Acre
		000 Tons			000 Tons			Tons	
1971	146.0	4,214	28.9	84.0	125	1.5	15.0	9,120	.61
1972	150.9	4,068	26.9		127			6,527	
1973	133.9	3,584	26.8		108			9,394	
1974	143.6	3,785	26.4		74			7,230	
1975	139.6	3,524	25.2		68			11,621	
1976	128.0	3,571	27.9		77			7,015	
1977	128.0	3,177	24.8		80			9,516	
1978	118.0	3,215	27.2		75			5,460	
1979	112.0	2,931	26.2	63.9	69	1.1	7.0	13,756	2.0
1980	114.0	2,736	24.0		33			7,625	
1981	112.0	2,414	21.5		19			8,601	

notes:
1. Exports
2. Deliveries to packaging and processing plants.
   1 box of coffee weigh approx. 61 lbs & yield 11.1 lbs of clean coffee
3. 1970 Land use area planted

Sources: • Economic and Social Survey Jamaica - 1974-1981
Statistical Yearbooks - 1971-1981
Jamaica Resource Assessment
Data Bank and Evaluation Division - Ministry of Agriculture

Units: Short tons and acres

TABLE - 6.3

Domestic Crop Statistics 1971-1982

	Yams, Potatoes and other Tubers '			Bitter and Sweet Cassava			Vegetables			Legumes		
Year	Acreage Reaped	Tons (short) Produced	Yield/acre	Acreage Reaped	Tons (short) Produced	Yield/acre	Acreage Reaped	Tons Produced	Yield/acre	Acreage Reaped	Tons Produced	Yield/acre
71	42,665	201,242	4.72	5,094	19,199	3.77	19,511	68,110	3.49	21,786	7,046	0.32
72	46,545.25	213,079	4.58	5,921	23,424	3.96	19,541.6	67,212	3.43	25,067	8,294	0.33
73	43,269.25	196,678	4.55	4,608.5	16,528	3.59	18,270	63,338	3.46	19,377.5	5,965	0.30
74	44,585	214,220	4.80	4,410	16,270	3.69	18,825	66,110	3.51	18,792	6,790	0.36
75	47,190	215,240	4.56	5,390	20,550	3.81	19,800	69,570	3.51	20,350	6,920	0.34
76	42,269	191,420	4.53	5,665	23,070	4.07	22,385	85,225	3.8	18,183	5,770	0.31
77	45,287	229,218	5.06	7,525	36,989	4.92	24,226	94,665	3.9	22,329	8,104	0.36
78	57,333	298,902	5.21	8,172	39,517	4.84	24,822	116,320	4.68	35,014	13,138	0.38
79	N/A	N/A	N/A	6.215	31,521	5.07	20,651	92,831	4.54	31,301	11,778	0.38
80	N/A	N/A	N/A	4,912*	43,176*	8.79*	20,338	46,736	2.29	26,485	N.A	-
81	42,206	229,747	5.44	4,836	24,118	4.99	24,425	126,463	4.9-	25,202	11,066	0.44
82	35,599	188,748	5.30	4,053	18,692	4.61	22,079	107,326	4.9-	22,083	9,780	0.44

Unit - Short tons (2,000 lbs) *Numbers not consistent

Source: Economic and Social Survey

In 1982, 190 thousand tons of yams, potatoes and other tubers were harvested from about 36,000 acres. The best harvest, almost 300 thousand tons, occurred in 1978. Although the yields had improved during the previous decade, the area planted in these crops fluctuated and then declined after 1978. The trend for cassava has been similar with yields increasing to 5 tons per acre harvested. The acreage planted in cassava peaked at 8,000 acres in 1978 but has since dropped to about half this level. This is probably in response to the farmgate price received for the cassava. The production of legumes increased over the last decade as yields improved. The peak production occurred in 1978 when 13 thousand tons were harvested from 35 thousand acres. Production has since declined to about 10 thousand tons on 22 thousand acres. Vegetables have shown the most consistent trend with both yields and areas reaped showing increases over the last decade despite a serious setback in 1979. At present, about 110 thousand tons of vegetables are harvested from 22 thousand acres.

6.1.2 Future Crop Production

The decline in the production of many of the export crops over the last decade creates some uncertainty as to the future composition of Jamaican agriculture. The importance of agricultural to the national economy is considerable not only as a source of domestic production but also as an earner of foreign exchange. The income from agricultural exports currently accounts for about 13 percent of the total export earnings of the country and about 2/3 of the earnings from exports other than bauxite and alumina (see Table 6-2.).

The production of crops for domestic consumption has shown a mixed performance over the last decade with an initial period of growth, followed by a period of significant decline and finally by a recovery. This production has failed to keep pace with population growth. As a result, the country imports a considerable amount of food, especially cereal and cereal preparations. Food imports accounted for between 1/6 and 1/5 of the nation's import bill over the last decade (see Table f-3). The value of the imports has been increasing by about 21 percent per year (see Table f-4). The cost of these imports in 1981 dollars has fluctuated about the J$400 million level for the last few years despite a decline in the real prices of food imports. This amount is nearly double the amount earned from agricultural exports.

Despite the dilemma of declining agricultural exports and increasing agricultural imports, the government is only now seeking to develop a comprehensive plan for agricultural development. Some piecemeal plans have already been devised for specific crops. These include the rapid expansion of the cultivation of coffee in the Blue Mountains (see Table f.5) to service the export markets, especially Japan. Despite the profitability of growing coffee, the projected increase in production of 30 percent a year seems optimistic given the difficulties of working in this terrain and the lack of experienced coffee farmers. In the sugar industry, a process of rationalization is expected to occur with mills being closed and presumably cane lands being converted to other uses. The production of coconuts has been severly reduced by the "lethal yellow" disease which is slowly destroying most of the coconut palms in Jamaica. At present, about a half million trees are being planted each year, mostly in dwarf varieties, however, it is unlikely that this crop will recover to former levels of production. Other plans have been generated by the individual commodity boards and some forecasts have been prepared by the National Planning Agency but as yet no government policy has been prepared.

The preparation of a program for agricultural development is the goal of a government effort called Agro-21. This program has two goals, food self-sufficiency and export promotion. The program will use as its base the sectoral forecasts prepared by the NPA for coffee, rice, banana, sorghum and livestock among others. It seeks to develop the highest value uses of the land while emphasizing employment. The program will focus on large-scale agriculture but will take into account the needs of the small-holder through development of peripheral farms. It proposes to develop about a quarter million acres of which 1/4 will be forests and 1/5 will be improved pasture. Part of this quarter million acres is located in the Morasses in Black River and near Negril.

The Agro-21 project has only recently begun and no firm plans have been established. Some of the major difficulties to be faced are: a) the problem of land acquisition due to question of land titles, land tenure and absentee owners; b) the current dispersal of authority and data among the various marketing boards as well as the Ministry of Agriculture; c) the problem of high unemployment which inhibits any change in labor-intensive agricultural practices; d) the high cost of agricultural production in Jamaica relative to neighboring countries; and e) the high post-harvest losses due to poor harvesting techniques and multiple handling of the product because of the lack of organization in the purchase and transport of agricultural products.

6.1.3 Farm Size and Ownership

The agriculture of Jamaica has traditionally been based on estate agriculture, but in the last several years the number of small holdings has increased as shown in Table 6.4. Currently about 93 percent of the farms have 10 acres or less. These account for about 26 percent of the total acreage

Table 6.4.

Percentage Distribution of Farms and Acreage by Size of Farm

Years	0 to Under 5 Acres	5 Acres to Under 25 Acres	25 Acres to Under 100 Acres	100 Acres to Under 500 Acres	500 Acres and Over
			Percentage of Farms		
1968/69	78.5	19.3	1.6	.4	.2
1978/79	81.9	16.2	1.3	.5	.2
			Percentage of Acres		
1968/69	14.8	22.1	8.3	9.9	44.9
1978/79	16.0	19.3	8.1	12.3	44.3

cultivated. The large farms, those over 500 acres, account for only .2 percent of the farms but about 44 percent of the total acreage. The predominance of large farms is especially significant for farms growing crops for export where about half the acreage is controlled by farms larger than 500 acres, and for farms raising livestock and poultry, where about two thirds of the acreage is controlled by large farms. In contrast, the growing of domestic crops is done primarily on small farms, 10 acres or less, which account for about 58 percent of this acreage. The large farms account for less than 9 percent of this acreage. The growing of mixed crops is balanced between large and small farms with 48 percent of the acreage on farms greater than 200 acres and 46 percent on farms with 50 acres or less. A summary of the distribution of farm sizes by crop type is shown in Table 6.5; more details are given in Table f.6.

Most of the farms under 200 acres are owned by individuals. Some farms between 50 and 200 acres are owned by partnerships. The ownership of farms larger than 200 acres is a mix including single owners, partnerships, corporations, co-operatives and governments (see Table f.7).

6.1.4 Field Residues

The field residues from sugar cane include the top leaves, the ground fibers and the ratoon. These three account for 10-15 percent, 15 percent, and 5 percent of the plant weight with the remainder accounted for by cane. Currently, the top leaves and ground fibers are burned prior to harvest even though the former can be used as livestock feed and the latter can be turned under to provide soil nutrients. The ground fibers have a heat value of 7,500 BTU/lb when oven-dried.

Table 6.5.

Distribution of Farm Size by Crop Type

Farm Size (acres)	Greater than 500	200-500	50-200	20-50	Less than 10
<u>Percentage of Acreage</u>					
Total	44.3	7.5	9.0	13.0	26.1
Export crops	50.0	6.5	7.3	12.6	23.6
Domestic crops	8.9	3.6	7.7	21.8	58.0
Mixed crops	44.7	3.6	6.1	13.9	31.6
Livestock and poultry	64.4	11.6	12.2	7.7	3.8
<u>Percentage of Farms</u>					
Total	.2	.2	.7	5.9	93.0
Export crops	.2	.2	.9	7.6	91.2
Domestic crop				10.4	95.5
Mixed crops				5.7	94.2
Livestock and poultry	1.5	1.5	6.2	18.5	72.3

The main plant stem of the banana tree accounts for about 63 percent of the total plant weight. It has a high moisture content, about 80 percent on a wet basis. It is not cut down until the plant becomes unproductive. Field residues include unharvested bananas which can be considerable. At present, about 5 percent of the bananas are left on the vine. Since the boxing plant rejection rate is about 22 percent, it is possible that a higher percentage of bananas will be left on the vine in the future to minimize the cost of transporting potential rejects to the boxing plants (currently estimated at J$1.40 per ton/mile).

Coffee is grown in two areas; the lowlands where it is harvested between August and December and the Blue Mountains where it is harvested between October and March. The coffee bushes are coppiced every 8 to 10 years but other than that, there are no field residues.

The major citrus crops are oranges and grapefruits. The only field residues are the trees which are cut down when they are old.

Cocoa has two harvest seasons, September-February and March-June. The cocoa is harvested by removing the beans from the pods in the field. These pods account for about 75 percent of the weight of the harvested plant. Only about 1/4 of the pods are turned under for soil nutrients. The rest are discarded.

The primary residues from the coconut trees are the palm leaves. The majority of the coconuts grown on large farms are removed to a central location for husking. About 50 percent of the coconuts are harvested unofficially and are sold or eaten as "jelly" coconuts.

Cassava is harvested by removing the plant from the ground and then separating the root from the stem. About 1/3 of the stem is used for replanting and the remainder is discarded. The dry stem has a weight equal to about 35 percent the weight of the root and has an energy content when bone dry of 8,000 BTU/lb.

The primary field residue from corn is the stalk which is generally turned under for soil nutrients. This stalk weighs about 68 percent of the weight of the unhusked corn and has a heat value, when bone-dry, of 6,500 BTU/lb.

The field residues from vegetables include the stem and leaves. The quantity varies with the type of vegetable. The average quantity of field residue is about the same as the quantity of vegetable harvested. The residue, when fresh cut, has a moisture content of about 70 percent on a wet basis but this reduces to about 17 percent after it has been left in the field for a few weeks. The heat energy value of these residues when oven dried ranges from 6,000-7,500 BTU/lb.

6.1.5 Process Residues

Among the major process residues for bananas are the stems and plant rejects. The stems account for about 56 percent of the weight of the harvested plant. These stems are generally discarded at the boxing plants. For bananas the emphasis in export markets on "unmarked bananas" has led to a boxing plant reject ratio averaging about 22 percent as shown in Table f.8. These rejects are either sold in the market, made into specialty products such as banana chips, or used as livestock feed.

The process residues for coffee include the husk and the skin. The husk is removed in the milling process and accounts for about 55 percent of the weight of the unprocessed bean. The hull is removed after the processed bean is dried and accounts for about 15 percent of the weight of the dried bean. Both the husk and hull are used as a fertilizer or mulch. The former must be fermented to reduce acidity, but is has an NPK value of about 1.4-.3-3.7. About 70 percent of these husks are used to fertilize coffee farms.

The process wastes from citrus are generated at the processing plants for juices, canned fruit, oils and jellies. About half of the citrus harvested is processed at these plants. The residues are mostly skins and pulp which account for about 35 percent of the weight of the fruit and have a moisture content of about 70 percent. The pulp can be used as an animal feed but must first be dried which requires about 100 imperial gallons of fuel oil per ton of feed.

The fermenting of the cocoa beans produces a placenta in small quantities, but otherwise there are no significant process residues.

The processing of coconut occurs in stages. The removal of the husk generally occurs at a central location. The husk averages about 1.2 lbs. per nut and has a calorific value of approximately 3,700 BTU/lb (6,900 BTU/lb. oven-dried). The husk is used as a mulch in nurseries or by soya manufacturers. If the coconut is used to make copra, then it is transported to the copra factory where the husk and shell are removed. The shell averages about .2 lbs per nut and has a heat value of 7,400 BTU/lb (7,600 BTU/lb. bone-dry). Both the husk and nut are used as fuels for drying the copra. The shells make good charcoal, especially, activated charcoal. At present, there are no shell charcoaling activities.* The copra industry has been declining steadily. In the early 1970's about 20,000

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* Activated charcoaling requires expensive imported technologies.

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tons were produced but by 1977 only 3,400 tons were produced. For 1981 the figure was below 1,000 tons, but in 1982 there was a slight resurgance to 1,400 tons. However, between 90 and 95 percent of the coconuts harvested legally are sold as green or dry coconuts. Currently, many of the island's coconut trees are suffering from the "lethal yellow" disease and are being cut down and replaced mostly with Malayan dwarf varieties.

The process residues from cassava vary depending on the processing. If the roots are cut into chips or pelletized for animal feed, then there are no residues. If the root is processed into flour then two mill residues are produced. The first are the skins and associated dirt from the roots. The second are the residuals from the centrifuging process. The former has no use while the latter can be used as a binder in charcoal-making.

A summary of available information on crop production and estimates of the field and process residues is presented in Table f.9. Estimates of the total quantities for different process residues are shown in Table 6.6.

6.2 Conversion Technologies, Costs and Efficiencies

The technologies which can be used to produce energy from agricultural wastes include: anaerobic digesters, ethanol distillation, pyrolization for charcoal, gasification, and direct combustion. A number of factors determine the suitability of the different agricultural wastes for these technologies.

For biogas digesters the critical factors are the C/N ratio, the acidity, and the lignin content. The biogas slurry should have a C/N ratio of less than 30. Since most agricultural residues have a higher ratio, it is necessary to mix these residues with manure or with other residues to lower the C/N ratio. The pH of the slurry must be kept close to 7.0, thus the

Table 6.6.

Estimates of the Volume of Process Residues

Crop	Residue	1979-1981 Average Crop Production 000's Short Tons	Residue Factor	Residue Production 000's Short Tons	Moisture Content %
Sugar cane	Bagasse	2,700	.3	810.0	50
Banana	Harvested stems	46	1.25	57.5	80
	rejects		.28	12.8	
Coffee	Husk	10	.55	5.5	
	Hull		.06	.6	
Citrus	Skins, pulp	37.7	.35	13.2	70
Coconut	Husk	250 mn	1.2 lb.	300.0	55
	Nut		.2 lb.	50.0	3-5
Plantain	Harvested stems	29.4	1.25	36.8	80

Notes:

No residues: cocoa, cassava (no fuel value).

No information: corn, legumes, yams and potatoes.

addition of acidic residues must be balanced with the addition of lime or other basic materials. The lignin content of residues is not only non-biodegradable but also limits the breakdown of cellulose.

For gasifiers, the moisture content, particle size, fuel density, and ash content affect the suitability of fuels. The higher the moisture content, the lower the heat content per pound of fuel and the lower the gas yield. A high moisture content also increases the moisture content of the gas produced. The size of the particles is also important. If they are too large, they will cause bridging within the combustion chamber and slag formation. If they are too small, they can cause excessive pressure drop across the gas producer. A desirable size for residues is on the order of a 1 to 3 centimeter cube. The density of the fuel and the surface-to-volume ratio affect the design of the gasifier and the fuel feeding system. The ash content is also important. If it is too high, it will cause slagging. This is a significant problem for bean stems, cereal straw and corn stalks.

Ethanol distillation is affected by the chemical composition of the residues. Crops which have a high sugar content are the most easily converted to ethanol. Crops which are mostly starch, such as grains, corn and potatoes, require additional processing. Cellulosic materials are the least desirable feedstocks for ethanol. This group includes wood and agricultural residues.

Various feedstocks can be used to produce charcoal, but the important quantities are the density, moisture content, heat content, and the surface-to-area ratio of the material. Most agricultural residues have a high surface-to-area ratio and low density. These tend to produce fines which are difficult to briquette. The moisture content and heat content determine the yield of charcoal. The only commonly pyrolized residues are coconut husks and shells. Experiments with pyrolysis of rice husks and cocoa wastes have had limited success. The factors which affect the use of residues for direct combustion are the same as those which affect their use for charcoal making or gasification.

One factor that affects the proposed uses of all residues is their collectability. Field residues which are not collected as part of the harvesting or land preparation process are generally too costly to collect for use as a fuel. Process residues from large-scale agricultural processing facilities generally have the greatest potential for use as a source of energy. In many cases, these residues are used in the processing activity, e.g., bagasse for sugar mills and ethanol distilleries, coffee skins for coffee drying. Process residues from small-scale mills are limited in their use by the volume generated.

The characteristics of several of the different agricultural residues available in Jamaica are shown in Table 6.7. A matching of these residues with potential technologies is presented in Table 6.8. The coconut husks and shells can be converted to charcoal or producer gas. Other potential gasifier fuels include corn cobs, dried coffee pulp and coffee skins. Charcoal can be made from corn cobs or bagasse. The only residues which can be used for ethanol production are citrus pulp, banana rejects, wet coffee pulp, and unused cassava roots. Most of the residues can be used in the production of biogas provided they are mixed with manure to ensure a low C/N ratio. Some exceptions are coconut husks and shells, sugar cane leaves, bagasse, corn stalks, and cassava stems. Nearly all of the residues can be used as a fuel in direct combustion processes with the exception of those having a high moisture content such as banana rejects, wet coffee pulp, and citrus skins.

Table 6.7.

Fuel Characteristics of Agricultural Wastes

Type of Biomass	Air-Dried Moisture Content	Density	Oven-Dry Heat Content 020	Ash Content	Volatile Solids	C/N Ratio
	(% wet basis)	(lbs/ft3)	BTU/lb	%	%	
Coffee pulp	70	--	12.4	1.3	--	--
Citrus pulp	--	40 *	--	--	--	--
Bean stem	8-20	27.4 *	6.4-7.2	--	--	32
Corn stalk	8-20	24.4 *	7.9	6.4-7.5	92	53-57
Corn cob	8-20	18.9	8.1	1.5	50	96
Cereal straw	8-20	5.0	8.1	3.5-6.0	79	51-87
Rice hulls	--	42.3	6.2-6.5	16-23		
Coconut shell	3-7	--	7.6	4	--	--
Cassava stem	--	--	8.0	--	--	--
Tobacco stalk	--	--	6.8	--	--	--
Coconut husk	30-55	--	6.9	--	--	--
Grasses	8-20	--	7.1-7.6	--	--	--
Vegetable residues	8-25	--	6-7.5	--	63-80	--

-- No information.

* Densified.

Sources: Kaup, Gross Reference 47.
Van Buren Reference 83.
Olympic Assoc. Reference 70.
Pukting, Arnold Reference 73.

Table 6.8.

Agricultural Residues and Conversion Technology Matrix

	Biogas	Gasifiers	Charcoal	Ethanol	Direct Combustion
Coconut husk		x	x		x
Coconut shell		x	x		x
Banana rejects	x			x	
Banana stems	x				x
Sugar cane leaves					x
Sugar cane bagasse			x		x
Corn cobs	x	x	x		x
Corn stalks					x
Coffee pulp	x	x			x
Coffee skins		x			x
Cocoa pods	x				x
Citrus pulp	x			x	
Citrus skins	x				
Citrus reject				x	
Potato vines	x				x
Cassava stems					x
Vegetable wastes	x				x
Cassava roots				x	x
Bean stems	x				x

Source: Preliminary categorization by consultant.

The fuel yields for different resource-technology combinations are shown in Table 6.9. The highest yields of ethanol are obtained from corn, cassava and molasses, between 36 and 74 liters per ton. The yields of biogas from agricultural residues range between 4 and 10 cubic feet per pound. For those residues found in Jamaica, the range is expected to be between 4 and 8 cubic feet per pound. Charcoal weight conversion ratios are expected to range between .13 and .38. For gasifiers, the yield is specified in terms of horsepower-hours, since it is expected that this technology will be used for producing shaft power. The production of 1 horsepower hour is estimated to require between 2 and 3 pounds of air-dried residues.

The costs for the different conversion technologies are similar to their costs when used with other forms of biomass as shown in Table 6.10. The only exceptions are ethanol distilleries which are more costly because of the small size of the production units. Also, these distilleries have large variable costs associated with the yeasts and enzymes required to convert the residues to sugars for distillation. This technology is clearly too costly for further consideration.

6.3 Market Penetration

The only potential use of field residues during the planning period is expected to be as fuel for small gasifiers used with pump-motor sets for irrigation. This resource-technology combination could provide 1 percent of the pumping capacity by 1988 but probably not more than 5 percent of the capacity by the end of the planning period.

The major use of process residues will be in industrial-scale biogas digesters attached to large processing activities. Citrus, banana and coffee packing plants are the most likely establishments to use these digesters.

Table 6.9.

Fuel Yields for Agricultural Residues

	Ethanol [1] (Imp. Gallons/ Short Ton)		Biogas [2] (Cubic Ft/lb)
Sugar cane	14	corn cob	7.5
Molasses	58	Cereal straw	5.5
Cassava	36	Potato vines	4.3
Corn	74	Grasses	10.1
Banana	18	Rice hulls	9.3
Wet coffee pulp	2.5		
Citrus wastes	6.6-7.8		
Cocoa pods	.45		

	Charcoal [3] (lbs./short ton)		Producer Gas [4] (hp-hr/short ton)
Coconut husks	350-520	Biomass	650-950[5]
Coconut shells	520-770		
Corn cobs	500-750		

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[1] IBRD Reference 45, Malcolm, Reference 51.

[2] Olympic Assoc., Reference 70; NA's Reference 67.

[3] Charcoal 11,200 BTU/lb., energy conversion efficiency .40-.60.

[4] Efficiencies: gasifier 75-80 percent engine 28-32 percent.

[5] 10-30 percent mc.

Table 6.10. Costs for Agricultural Residue Conversion Technologies

Source	Technology	Capacity	Unit Capital Cost	Total Capital Cost	Output	Annual Maintenance	Labor	Variable Cost
	Biogas	ft^{3}	J$/ft^{3}	J$000's	000ft^{3}	J$/yr	J$/yr 1/	
1		1060	5.1	5.43	130	650	10,000	--
2		1060	15.2	16.1	130	2090	10,000	
	Charcoal	ft^{3}	J$/ft^{3}	J$000's	tons/yr	J$/yr	J$/yr	J$/ton
3		210	14.2	3.0	18-27	150	--	100-150
	Gasifier	hp	US$/hp 2/	J$	hp-hr/yr 3/	J$/yr 4/	J$/yr 5/	
4		5	75	375	6,500	66.8	1,625	--
5		50	60	3000	65,000	534.0	1,625	--
	Ethanol	US$/imp.gal-yr	US$	imp.-gal/yr	J$/yr 6/	$/yr 7/		J$/imp-gal 8/
6			17.59	387,000	22,000	10,000	86,000	2.32
6			7.52	496,000	66,000	13,200	86,000	2.32
7			3.12	562,000	180,000	15,000	172,000	2.32

Footnotes:

1/ 1 hour/day; J$5/hr
2/ gasifier only
3/ 1,300 hrs. operation/year
4/ 10% maintenance, J$1.78 = US$1
5/ engine operator, $5/hr.. 15 min. per hour
6/ 1.5% of capital cost
7/ 1 - unskilled, 2 - semi-skilled, 2 - skilled per shift
8/ yeast, enzyme, denaturant, water, but not fuel and electricity

Sources:

1 plastic bag, Appendix-Case Studies.
2 chinese design, Appendix-Case Studies.
3 assume feedstock density 30 lb/ft^{3}, 50 firings/year, .4-.6 energy efficiency, metal kiln
4 Meta, Reference 56.
5 Kaupp, Goss, Reference 47.
6 Malcolm, Reference 51, single shift.
7 Meta, Reference 56.
8 Meta, Reference 56, with 50 percent surcharge, double shift.

Charcoal making used to occur at the larger copra factories, however, the decline in the production of copra has eliminated this activity. It seems unlikely that the coconut processing industry will recover to the point where coconut husk and shell charcoal will be produced. The use of these residues for fueling gasifiers is even less likely. The potential use of corn cobs, coffee pulp or coffee hulls for gasifier feedstock is also unlikely, since there is no large corn processing industry and the coffee residues have alternative uses. The coffee pulp is a potential biogas digester fuel while the hulls can be burned directly to provide process heat for drying the beans. At present, the coffee beans are dried in rotary or vertical driers using diesel fuel. The cost of the diesel fuel is sufficiently large to justify conversion to a hull-burning system as has been done in other coffee producing countries, e.g., Costa Rica.

Since there is no information available on the consumption of energy for the different agricultural processing industries, it is not possible to estimate the potential for fuel substitution in these industries. Instead it is estimated that the maximum possible utilization of the residues will be as follows:

Residue	Technology	End-Use	Maximum Percent of Residue Used			
			1988	1992	1997	2002
banana rejects	biogas	cooking heat	2%	5%	10%	15%
banana stems	biogas	shaft power	3%	10%	25%	50%
coffee pulp	biogas	drying heat	-	10%	25%	50%
citrus pulp	biogas	drying heat	-	10%	20%	35%
coffee skins	direct combustion	drying heat	10%	30%	100%	100%

Chapter 7

Biomass-Animal Wastes

This chapter describes the use of animal wastes to produce methane. The conversion technology, anaerobic digester, is now available in a variety of configurations. Because of the costs of constructing the digester and the daily labor required for operation, these units have had limited success in residential applications. In this chapter the focus is on the use of digesters in those establishments which raise large numbers of cattle, pigs and chickens. These establishments produce enough dung to use larger units and the marginal time required for operation and for handling the feedstock and the slurry is relatively small since much of this work is already done. These establishments would also have internal energy requirements which would consume the gas.

The data in this chapter is drawn primarily from secondary sources, since the OLADE digester program has produced poor results at relatively high costs. It was collected and analyzed by Don Peterson of Meta Systems. The interpretation of his results was entirely the responsibility of the author.

7.1 Resource

Jamaica has a relatively large livestock industry which includes cattle ranches, dairy farms, pig farms, and poultry breeders. The census data on poultry and pig farms are shown in Table 7.1. Of the 1,226 poultry farms, 376 were listed as having more than 500 chickens. Most of these farms are located in the parishes of St. Catherine and Clarendon. About 70 percent of the farms raise broilers exclusively. Another 17 percent raise broilers and layers and

TABLE - 7.1

Pattern of Animal Ownership

POULTRY

Flock Size	No. of Farms	% of Farms Specified
50 - 99	243	25
100 - 499	351	36
500 - 999	80	8
1000 - 2499	73	8
2500 - 4999	37	4
≥ 5000	186	19
Unspecified	256	
TOTAL	1226	

PIGS

Herd Size	Quality Pigs	Non-Quality Pigs	Sub Total	Sows	Preweaners
1 - 4	1858	6107	7801	5240	567
5 - 9	991	1249	2143	241	1253
10 - 19	779	605	1301	99	553
20 +	654	178	761	66	238
TOTAL	4282	8136	12006	5646	2611

Souce: M of Agriculture 1960, 1970 ref.

the remainder raise layers exclusively. The broilers are kept for an average of 8 weeks and weigh about 3.7 lbs. at the time they are slaughtered.

The pig farmers are distinguished by those keeping quality pigs and those keeping non-quality pigs. About 1/3 of the 4,282 quality pig farmers have herds of 10 or more pigs whereas only about 10 percent of the 8,136 non-quality pig farmers have herds of this size. Of the 5,646 pig farms which have sows only about 3 percent have 10 or more. Most of the pigs are sold to butchers or packing houses. The quality pigs sold to packing houses average about 160 lbs. at the time of the sale while the non-quality pigs sold to butchers averaged just over 140 lbs.

No census data is available on cattle farms. A 1978 census of dairy cattle indicated a population of 35,000, but the current inventory is thought to be significantly lower. There are about 40 large independent dairy farms having between 100 and 700 head. There are another 80 to 100 farms with about 25 head.* An average of 62,000 head of cattle were slaughtered per year from 1980 to 1982 and an estimated 40 million quarts of milk were produced. The dairy cattle population is estimated to be 30-40,000 based on the dairy farm data. From the rate of slaughter, it is estimated that the total cattle population, dairy and non-dairy, is between 180 and 230 thousand head. It is assumed that most of these animals are on large farms.

The level of production of dung from poultry, pigs and cattle was estimated based on the liveweight of the animals. For pigs the average liveweight was assumed to be 65 lbs, slightly less than half the weight at the

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* This information was obtained in conversation with officials at the Jamaica Livestock Association.

time of slaughter. For poultry, the average weight was assumed to be 2.5 lbs., about 2/3 the weight at time of sale. For the cattle, an estimate of 500 lbs. was used for fully grown animals. Estimates of the amount of dung produced per day on a dry weight basis are shown in Table 7.2.

7.2 Conversion Efficiencies and Costs

The expected yield of biogas from the three types of animal dung depends on several factors relating to the operation of the digester as well as to the type of feed the animal receives or the type of pasture on which it grazes. An example of the range of estimates for biogas production from pig dung are shown in Table 9.1. The range of biogas yield from dung is shown in Table 7.2. The dung produced by a herd of ten cattle is capable of producing between 220 and 370 cubic feet of biogas per day in a digester. Similarly, the dung from a herd of 20 pigs is capable of producing 82-156 cubic feet of biogas per day and that from a flock of 100 chickens is capable of producing 18-30 cubic feet of gas per day. It is assumed that these yields will not vary significantly for different types of digesters.

The cost of a digester depends on its size which is determined from the amount of gas to be produced. The digester has to be large enough to hold the slurry as well as the gas produced in one day. The volume of slurry is determined by the retention time and the ratio of water-to-solids. For a typical retention time of 30-50 days* and a 7-9 percent concentration of solids, the following calculations would apply:

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* The longer the retention time the greater the yield of gas.

Table 7.2. Estimation of Dung and Biogas Production by Type of Animal

Dung Production

	Average Weight lbs.	Dung/Day (dry weight lbs. per 100 lb. Liveweight)	Gas Yield ft^3/lb	ft^3/Day/ Animal	000's ft^3/Year Animal
Cattle	500	1.1-1.5	4-5	22-37	8.0-13.5
Pigs	65	.9-1.2	7-10	4.1-7.8	1.5-2.8
Poultry	2.5	1.0-1.3	7-9	.18-.30	.08-.11

Gas Production (ft^3/day)

Number of Animals	20	50	100	500
Cattle	600	1,500	3,000	14,800
Pigs	120	300	600	3,000
Poultry	4.8	12	24	120

Sources: Meta Systems Inc, Reference 56.
Van Buren, Reference 83.
Pukting & Arnold, Reference 73.
NAS, Reference 67.

Loading Rate (lbs. dry weight/day)	Retention Time (days)	Total Slurry (cubic feet)	Daily Gas Production (cubic feet)		Total Digester Capacity (100 cubic feet)	
			cattle	pig	cattle	pig
10	50	100-125	45	85	1.6	21
50	40	400-500	220	425	7.2	9.3
100	30	600-750	430	850	11.8	16.0

At present there are 9 biogas digesters which have been tested in Jamaica. They range in size from 70 to 300 cubic feet as shown in Table g.2. The results from these tests are somewhat unclear as is the interest of the individuals who tested them. Since the cost of fabricating these units was considerably above that for other countries, digester costs were obtained from secondary sources. In Thailand, with much lower labor and material costs, the Indian-design digesters cost about US$1.45-2.85 per cubic foot. In Costa Rica, the cost is closer to US$5.70 per cubic foot. Assuming slightly higher labor and material costs in Jamaica, it is assumed that the digester cost would be J$12.60 to J$17.65/per cubic foot. This cost is assumed to apply to the Chinese and Indian designs but not to the more elaborate designs fabricated by OLADE. An alternative digester technology is the plastic bag described in Appendix g. These units are expected to cost about J$5 per cubic foot.

The maintenance costs for the digester systems are expected to run about 5 percent of the capital costs per year. The bags are expected to last about 8 years so that the replacement costs for the bags would increase the average cost of maintenance to about 12 percent. The metal tops on the Indian designs are expected to last about 6 years while the Chinese designs are expected to require major renewals at the end of five years so that their maintenance costs will average closer to 13 percent per year.

A summary of the costs for the two types of digesters is presented in Table 7.3. The labor costs for loading and unloading the digesters are not included under the assumption that the amount of material handling involved does not increase as a result of the introduction of the digester. If the cost of operation is included then an additional cost of about J$1,000/year would be incurred. For a more complete analysis of the digester economics refer to the case studies in the appendices.

7.3 Markets

The use of animal wastes for the production of biogas is a well established technology, but the potential for successful applications are somewhat limited. Large but unsucessful programs for the introduction of household digesters have been undertaken in several countries including India, Thailand, and China.* Because of the small land area of Jamaica and the extensive network of roads and electrical-distribution, most of the population has access to electricity and petroleum-based fuels for use in household cooking and lighting. It is considered unlikely that the biogas will have a significant impact in the residential sector, therefore this chapter has focused on the livestock sector as potential users of biogas digesters.

The biogas digesters would serve as a source of fuel for process heat (about 620 BTU per cubic foot), electricity generation (28 cubic feet per kilowatt-hour) or shaft power (16-18 cubic feet per horsepower-hour) for

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* The definition of success is relative, here the concern is not so much with how many units have been installed, but rather on how many units continue to be operated after five years.

Table 7.3.

Estimated Biogas Digester Costs

	Indian or Chinese Design			Plastic Bag*		
Size-(m^3)	15	30	50	15	30	50
- (ft^3)	530	1,060	1,760	530	1,060	1,760
Output Capacity						
100 ft^3/day	1.6-2.6	3.2-5.2	5.3-8.8	1.6-2.6	3.2-5.2	5.3-8.8
10^3 ft^3/ year**	50-80	100-160	160-270	50-80	100-160	160-270
Construction Costs J$ 1,000's						
Total	9.3	16.1	22.3	3.56	5.43	8.97
Material	--	--	--	2.66	4.15	7.24
Labor	--	--	--	.90	1.28	1.73
Unit Cost J$/$ft^3$	17.5	15.2	12.7	6.7	5.1	5.1
Maintenance ($J/year)	1,210	2,090	2,900	430	650	1,080
Period Between Renewals (years)	5-6	5-6	5-6	8	8	8
System Life	15	15	15	15	15	15

* Source: Case Study, Donald Peterson.

** Assume 85 percent availability.

dairies, piggeries or chicken farms. Since no data is available on the quantity of fuels used by these establishments as a function of the size of the herd or flock, it is assumed that they will use all of the dung available up to a limit of the input required for a 75 cubic meter digester (approximately 160 lbs. of dry matter dung per day). The availability of dung depends on the type of animal and the type of operation. For quality pigs which are kept penned and chickens which are kept in a coop, the availability of dung is assumed to be 90 percent of that produced. For dairy farms, where the cows are allowed to graze during the day, and for farms with non-quality pigs, it is assumed that the availability is only 50 percent of that produced. For cattle which graze continually the availability is assumed to be negligible.

Since the capital costs for a biogas digester are considerable it is assumed that only the larger establishments will use them. Specifically, pig herds of 10 or more, cattle herds of 10 or more and chicken flocks of 100 or more. If the biogas is a less expensive fuel than petroleum fuel in the production of process heat and shaft power or than electricity in producing shaft power, then it is assumed that 1 percent of these establishments will use digesters by 1988, 15 percent by 1992, 29 percent by 1997 and 50 percent by 2002. The annual production of biogas would then be as shown in Table 7.4.

Table 7.4. Estimated Biogas Generation from Animal Dung 1988-2002

	Dairy Cattle	Pigs	Chickens	
Number of farms with large herds or flocks	130	2,216	727	
Estimated number of animals (000's)	18.3	53.0	2,300	
Annual collectable dung production (lbs./animal)	1,190	195	9	
Estimated annual dung production (10^6 lbs.)	21.8	10.3	20.7	
Potential biogas production (10^6 cubic ft)	98	88	166	
Years	1988	1992	1997	2002
Maximum expected gas productioh (10^6 cubic ft/yr)	3.5	53	102	176

Chapter 8

Wind

This chapter examines the use of windpower in Jamaica. The two types of technologies which are considered are wind turbines for the generation of electricity and windmills for pumping water. The former would be configured in the form of multiple-unit wind farms, while the latter would be used in small-scale irrigation. It is possible that a number of sites could be identified for establishing wind farms, but there is a question of the value of intermittent and unpredictable power to JPS. It is unlikely that such a generation facility would be financially viable, since it would require 100 percent backup. The windmills have a better chance of being used in the future, especially for irrigating small fields that are located away from the grid.

The data in this chapter was compiled with the aid of Donald Peterson of Meta Systems Inc. Dr. Vaughn Nelson provided valuable technical guidance during the latter stages of the analysis. The presentation and the results are the responsibility of the author.

8.1 Resources

The information on the availability of wind power in Jamaica is somewhat spotty. The Meteorological office has collected data for wind roses from selected sites in Jamaica for several decades, but continuous measurements of wind speed were not reported until 1979 and then only in a few sites. The data gathered since then suffers from discontinuities due to maintenance problems with the recorders and anemometers. Data is currently now being collected in at least 10 sites: Passley Gardens, Discovery Bay, Yallahs, Hellshire, Munro, Flagaman, Manley International Airport, Sangster

International Airport, Crawford and Bodles (see Figure 8.1). A much more extensive program of wind monitoring has been proposed at 15 additional sites as shown in Figure h.1.

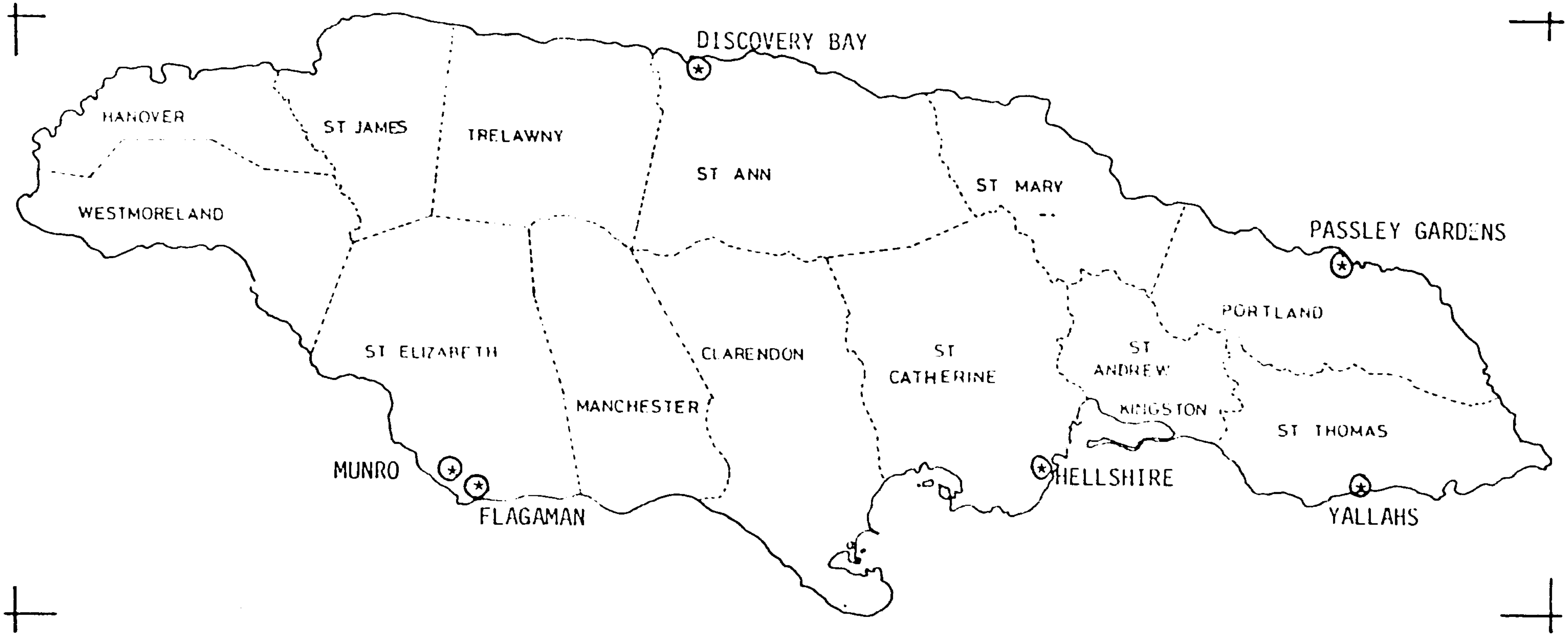
Sufficient data were available from the first five sites to determine the frequency distribution of wind speeds for different months. Sample monthly wind frequency distribution curves for Hellshire, Discovery Bay, and Passley Gardens are shown in Figures h.2 to h.5. For Hellshire, relatively strong winds were recorded in the months of January and July, the months of April and September had intermediate winds, and periods of low wind occurred in February and October. The Hellshire frequency distribution curves display a double peak with a high probability of occurrence of winds in the range of 6-10 miles per hour and a lower probability of occurrence for winds in the range of 16-28 miles per hour. Since most of the wind machines have a minimum requirement of 10 miles per hour, this first peak does not represent a source of useful power.

For Discovery Bay and Passley Gardens the average wind speeds are lower. Both have double peak distributions with the higher speed peak occurring between 10 and 15 miles per hour. The highest average wind speeds were recorded for Munro. The wind speeds at Yallah were between those of Discovery Bay and Passley Gardens.

The diurnal wind pattern was examined by averaging the hourly wind speeds over a month. The results are shown in Figures h.6 to h.7 for the Hellshire, and Figures h.8 and h.9 for Munro. In four of the first five months of the year, Hellshire had an afternoon wind which picked up at about 11 a.m. and continued until 6-9 p.m. In March, this pattern was inverted with a wind that began in the early morning, about 3 a.m, and continued until 8 a.m. The

FIGURE - 8.1

Sites of Wind Measurements



pattern changed in July, August and December, to an all day wind which started at about 8 a.m. and continued until 5-6 p.m., but in November the pattern was similar to that in the beginning of the year. At the Munro station the diurnal pattern for six of the nine recorded months was one of relatively constant wind throughout the day. Of the other three months, May and October had short afternoon peaks between 3 p.m. and 7 p.m. and February had a calm period between 12 noon and 5 p.m. In the other months the winds were relatively constant through the day.

The trends observed above were recorded during one or at most two years in the period 1979-1983. Since the calibration of the equipment was not carefully maintained, it is not possible to extrapolate these observations to other areas of the island or to other years. However, this data does provide a basis for evaluating the potential of wind machines for providing shaft power.

Three uses of wind machines are being considered for Jamaica. These are: a wind farm to generate electricity for the grid, water pumping for irrigation, and remote site applications for autogeneration of electricity. The latter application was examined by Dr. Chen of UWI, References 18 and 19, and rejected because of the high cost. His finding concurs with experience elsewhere with the caveat that such units may be viable in situations where the excess electricity produced can be sold to JPS for use on the grid. However, this option is in conflict with the assumption of remote applications as well as with the JPS's inability to benefit from such small, dispersed sources of power. As a result, only the wind farm and irrigation applications will be examined.

8.2 Technology, Costs and Conversion Factors

In order to determine the two potential applications for wind power, two types of wind machines were analyzed. The first are wind turbines with outputs ranging from 25 kw to 2.5 megawatts. The second are wind mills which would be used for vertical pumping up to depths of 20 meters and for horizontal pumping.*

8.2.1 Wind Turbines

The capital costs for wind turbines generally display economies of scale for sizes approaching 1/2 megawatt. Above this size it is unclear whether the increased costs for materials and maintenance and for the more expensive electrical controls will result in a higher unit cost. The costs for some intermediate size wind turbines currently available are shown in Table 8.1. The costs for a large scale 2.5 MW unit presently under development was estimated by ANL to be about US$1050/kw in 1981 prices. However, this unit is not expected to be available for about 4 years and this cost estimate appears optimistic.

The power curves for three of these units are presented in Table 8.2. Also shown is an approximation of the power curve for a 2.5 MW unit. The expected outputs from these four units were computed based on the wind frequency curves in Figures h.2-h.5. These were calculated assuming that the wind frequency data was for a height of 15 meters and that at higher elevations the velocities would increase according to the "1/7th Law", i.e.,

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* Pumping at depths in excess of 20 meters creates problems of load matching due to differences in the velocity versus torque curves for the pumps and windmills. At depths below 20 meters it is possible to use a wind turbine to power an electric pump but this would involve additional costs.

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TABLE - 8.1

Capital costs for various Wind Turbines

Brand	KW	Rotor Dia	Power Curve Available	Cost/KW Rated*
Carter	25 KW	32'	✓	$1,300 - $1,400/KW
Carter	200 KW	65'	✓	$1,125 - $1.250/KW
Wind Worker	10 KW	33'	✓	3,000/KW
Enertech 1900	1.8 KW	13'	✓	2,778 - 3,333/KW without towers not installed
Enertech 21/5	4 KW	21'	✓	3,250 - 3,750/KW
Enertech 44	25 KW 40 KW	44'		2,000/KW 1,500/KW
Windmaster 72'	100 KW 150 KW	150'		1,800/KW 1,333/KW

Table 8.2.

Wind Turbine Power Curves

Velocity Range (MPH)	Carter 200 kW (kW)	PM 25 kW (kW)	Wind Worker (kW)	Mod-2 2.5 MW (MW)
7-9	0	.5	.5	0
10-12	5	3.3	1.6	0
13-15	16.3	6.2	3.3	0
16-18	33.8	10.0	6.7	.56
19-21	58	16.2	8.4	.91
22-27	106.8	24.8	8.4	1.68
28-33	170.8	31.4	8.4	2.50
Greater than 33	188.5	30.7	8.4	2.50
Cutoff Velocity	50	50	45	45.0

in proportion to the height raised to the .143 power. The expected annual outputs for the different units and locations, assuming a 90 percent availability, is shown in Table 8.3.

For Hellshire, the utilization of capacity would be about 22 1/2 percent, for the 10 kW unit, 22 percent for the 25 kW unit, 12 1/2 percent for 200 kW unit and 14 percent for the 2.5 MW unit. The utilization would be higher in Munro (16 percent for the 200 kW unit and 31 1/4 percent for the 10 kW unit) and much lower for Passley Gardens (.8 percent for the 200 kW unit and 3.3 percent for the 10 kW unit). The smaller units have a higher level of utilization because they are designed for the light winds found at most of the sites. The expected outputs and costs for the four turbine sizes are shown in Table 8.4. Despite the lower utilization of capacity for the larger units, their lower unit cost makes them less expensive per unit of electricity generated. However, the low cost of the 2.5 MW unit is somewhat suspect since it is based on an extrapolated price and a theoretical power curve which assumes 100 percent output above 28 mph. Since the specification of a unit's power curve has a significant effect on its financial viability, it is difficult to draw any conclusions about the 2.5 MW unit. The Carter 200 kW unit has a power curve which makes it more expensive as a source of electricity than the 25 kW unit from Enertech.

8.2.2 Windmills

The units considered for water pumping applications are multi-vane windmills. Data for a number of these units are summarized in Table 8.5. From this data, the general characteristics were obtained for a unit with a five meter diameter rotor and is attached to a piston pump. The specification for this typical unit is shown in Table 8.6.

Table 8.3.

Estimated Energy Generated (MWHR) for Five Sites

Location	Month	Year	200 kW Model 1	10 kW Model 2	25 kW Model 3	2.5 MW Model 2
Passley Gardens	6	79	1.7	.38		
	7	79	1.6	.33		
	10	79	2.0	.40		
Discovery Bay	4	79	31.5	2.7		
	5	79	34.3	2.8		
	7	79	21.3	2.2		
Yallahs	3	79	22.9	2.4		
	5	79	7.4	1.3		
	6	79	7.1	2.8		
	7	79	11.4	1.6		
	9/10	79	2.2	.42		
Hellshire	1	82	44.0	2.2	9.0	534
	2/3	82	35.0	3.4	7.3	402
	4/5	82	9.8	1.1	3.0	119
	7/8	82	48.2	4.0	9.2	672
	9	81	35.3	3.3	7.1	410
	10/11	81	12.2	1.9	2.8	355
	11/12	81,82	12.5	1.3	3.0	226
Munro	2	81,83	47.8	4.0		
	2/3	81,82	66.1	4.6		
	4	81	9.7	1.4		
	5	81,82	30.2	3.5		
	6	81	11.6	1.7		
	7	81	37.6	3.6		
	8	81	39.0	4.3		
	9	81	51.1	4.7		
	11	80,81	17.2	2.3		
	12/1	81,82	36.9	3.9		

Notes:

Rotor axis height	10kW 15 meters.
	25kW 15 meters.
	200kW 30 meters.
	2.5MW 50 meters.

Table 8.4.

Annual Electricity Generation for Wind Turbines

Location/Unit	10 kw	25 kw	200 kw	2.5 MW
Passley Gardens	2.9		13.9	
Discovery Bay	20.3		229	
Yallahs	13.4		80.4	
Hellshire	19.8	45.9	217.7	3020
Munro	27.3		278.4	

Capacity	10kW	25 kW	200 kW	2.5 MW
Annual Output (Hellshire)				
Sendout Mwhr	19.8	45.9	217.7	3,020
Delivered Mwhr [1]	16.6	38.6	182.9	2,537
Unit Cost US/kW	3,000	1,600	1,200	1,050
Capital Cost (000 US$)	30	40	240	2,625
Installation (000 US$)	7.5	10	60	656
O & M (US$) [2]	500	666	4,000	43,750
(J$) [3]	1,780	2,374	14,240	155,750
Unit Capital Cost (J$/kWhr)	4.02	2.31	2.92	2.30
Unit Variable Cost (J$/kWhr)	.161	.100	.116	.092

Notes:

[1] Distribution losses 16 percent.

[2] One-third operation and maintenance cost in US$ for parts and 2/3 in J$ for parts and labor overall cost is 4 percent of capital cost.

[3] US$1=J$1.78.

Table 8.5.

Multi-Vane Windmill Costs

Unit	Rotor Diameter	Blades	Efficiency	Output at 10 m Head	Installed Cost (US$)
1	4.9	18	13.6 %	6.2	2,538
2	3.7	18	8.3 %	6.6	750
3	4.2	18	2.8 %	1.7	1,800
4	2.3	20		1.1	1,084
5	7.6	18		3.6	1,016
6	4.9	6		5.2	1,530
7	4.9	12	13 %	5.2	1,200

Source: Meta Systems Inc, Reference 56.

Table 8.6.

Typical Multi-Vane Windmill Characteristics

Rotor diameter-5 m
Axis height-10 m
Efficiency .163
Output at 10 m head-5.5 m^3/hr
Blades-12
Maximum head-20 m
Cost US$-1,750
Annual maintenance - US$ 29
- J$ 104

Life-20 years
Pump-piston
Pump efficiency-.8

Power curve (overall efficiency .13)

	Output		Imperial Gallon/Minute		
Mph	kW	hp	15 ft.	30 ft.	50 ft.
7-9	.04	.06	13	6.5	4
10-12	.11	.14	32	16	10
13-15	.22	.30	69	35	21
16-18	.40	.53	121	61	36
19-21	.64	.87	198	99	59
22-27	1.19	1.59	365	183	110

Greater than 27 cutoff.

The costs presented in Table 3.6 exclude the cost for water storage and distribution. There are three basic systems for water distribution: sprinklers, which are common in Jamaica, gravity flow open channels, and drip irrigation. The second uses the least energy but requires gently sloping fields. The third uses the least water but requires a large amount of piping. Because of the intermittent nature of the winds, it is necessary to provide buffer storage into which the water can be pumped, for release at a later time. The cost for this storage is assumed to be similar to the cost for establishing solar ponds, about J$5.5 per cubic meter ($J.16 per cubic foot).

Table 8.6 includes a power curve which was estimated using the following equation.

$$P = B \times E \times p \times V^3 \times 10 \times A$$

where:

P = Power output in kW.

B = Betz constant = .593

E = System efficiency = .13

p = Density of air = 1.18 kg

V = Velocity of wind in meters/second

A = area of rotor = $19.6 m^2$

This power curve was used to estimate the pumping capability of windmills in different sites. The total quantity of water pumped, assuming a 90 percent availability of the windmill and pump, is shown in Table 8.7 for each of the sites and for four depths, 5, 15, 30 and 50 feet. In the low wind areas, such as Passley Gardens, the windmill would provide 2.6 acre-inches per year for a 15 foot pumping depth. For high wind areas such as Munro, the same windmill

Table 8.7.

Windmill Pumping Output

Parish	Annual* kW-hr	Pumping Output per Year							
		000's imperial gallons				Acre-inches			
		5 ft	15 ft	30 ft	50 ft	5 ft	15 ft	30 ft	50 ft
Passley Gardens	200	185	62	30.7	18.4	7.8	2.6	1.3	.8
Yallahs	900	929	276	138	82.9	35.1	11.7	5.9	3.5
Hellshire	1,320	1,216	405	203	122	51.6	17.2	8.6	5.2
Munro	1,830	1,686	562	281	169	71.4	23.8	11.9	7.2
Discovery Bay	1,350	1,244	415	207	124	52.8	17.6	8.8	5.3

* Assume 90 percent availability.

would pump about 1 acre-foot per year for a pumping depth of 30 feet. In order to approximate the national demand, it is assumed that the wind regime is generally similar to something between Yallahs and Passley Gardens with an annual pumping capacity of .8 acre-feet at a pumping depth of 15 feet. The demand for irrigation is discussed in Chapter 10.

8.3 Market Potential for Wind Machines

The potential for wind farms as a source of grid electricity is limited by the number of available sites with a good wind regime. With the exception of relatively inaccessible locations on the mountains, it is unlikely that more than a half dozen suitable sites will be found. The electricity generated by a wind farm is determined by the number of wind turbines and their capacity. If it is assumed that a wind farm consists of 36 turbines, then the 25 KW units would have a capacity of .9 megawatts and provide an average output of about .2 megawatts from an area of 18 1/2 acres. A wind farm with 200 KW turbines would have a capacity of 7.2 megawatts and an average output of .9 megawatts from an area of 74 acres. For a wind farm with twelve 2.5 MW turbines, the capacity would be 30 megawatts, the average output would be 4.2 megawatts and the space required would be 154 acres.

It is unlikely that the first wind farm will not be established before 1988 because of the time required to collect reliable data on wind regimes. It is also assumed that the first wind farm (if it is economically viable) would use 200 kW units (although with units other than the Carter 200 KW). By 1992, a second wind farm might be established with turbines of one half to one megawatt capacity. If additional sites are located and the economics remain favorable, it is possible that two more farms could be added by 1997 and another two by 2002.

Because of the intermittent nature of this type of generation, these units would not replace any capacity but rather they would require back up capacity. Because their supply cannot be guaranteed, this source of power cannot be used for baseload demand. When the wind farm is supplying electricity to the grid, it will have one of two effects; either it will substitute for peak capacity units which can be taken off the line or it will cause the baseload units to run at a lower load factor and thus less efficiently. In the latter case, the savings resulting from the wind farm will be slightly less than the amount of fuel normally consumed in baseload units. Given these circumstances, it is unlikely that wind farms will prove to be financially viable. However, if they are, the maximum amount of electricity which would be obtained from these farms is estimated to be as follows:

	1988	1992	1997	2002
Average output (MW)	.9	5.6	15	25
Peak output (MW)	7.2	43	115	192
Electricity generated annually (GWHR)	7.9	49	131	219

The market potential for windmills is more difficult to define because it is dependent on the type of agriculture, the cropping patterns and the location of growing areas for different crops.

At present, the sugar industry is in a steady state of decline with some indication that vegetable and other cash crops will replace the cane no longer being produced. The government does not have any specific plans for developing the agricultural sector. There are some loosely connected ideas associated with development of the coffee production and some schemes being generated as part of AGRO-21, but none of these seem very firm. The introduction of irrigation in Jamaica has been very slow. Although there are no current statistics, it is estimated that about 70,000 acres are currently under irrigation with most of this acreage located on sugar estates. There appears to be no central government activity in promoting irrigation. The responsibility for public irrigation is left to the local governments which maintain some large pumps. If irrigation is increased, it is likely that electrical pumps will be used for large centralized systems.

Windmills will be useful only for small holdings in areas away from the grid. The windmills will be used in situations where water is available within 20 meters of the surface or where water is being lifted out of rivers. If a system can be developed for maintaining pressure in the pipes, it is likely that a significant proportion of the irrigation water raised by windmills will be distributed through drip irrigation systems. The remainder will be distributed through unlined irrigation canals. It is expected that no more than 15-20 percent of the national irrigation needs will be met by windmills (if they prove to be economically viable) due to the distribution of farm sizes and the extent of electricity coverage.

Chapter 9

Electricity Generation Using Peat, Urban Waste and OTEC

This chapter discusses three sources of energy which could be used in intermediate-sized generating facilities. The first resource is the peat located in the wetlands at Black River and Negril. This is not a renewable resource and depending on the rate of extraction would provide fuel for 40-80 years of electricity generation. The second resource is urban waste which is currently collected in Kingston and disposed of as landfill. This waste could be incinerated and the heat produced used to raise steam in a thermal plant. Although the urban waste is not a renewable resource, it would be continuously available in increasing quantities for the forseeable future. The third resource is the stored heat of the ocean. OTEC makes use of the ocean's temperature gradient as a function of depth of water to generate electricity. This resource can be considered renewable because of the vastness of the ocean's thermal mass provided that the facility is properly designed so that the temperature gradient is maintained.

9.1 Peat Resource

Jamaica has a number of peat bogs located along its shores as shown in Figure 9.1. The potential of the largest morasses, those at Black River and Negril, has been the subject of considerable study as shown in Table 9.1. The initial studies were performed to determine if the peat could be harvested and burned efficiently in thermal generating plants. A preliminary cost estimate for harvesting the peat was prepared and is summarized in Table 9.2. The fixed annual cost of extraction is estimated to be J$22.2 per ton of peat at 50 percent m.c. (in 1981 prices). The initial capital cost would be US$18.8 million and J$4.2 million. The difficulty with using the peat is its high

FIGURE - 9.1

Sites of Available Peat

Table 9.1.

Studies Related to Peat Deposits at Black River and Negril

Project History

1. 1977 Prefeasibility Study - Preliminary Report
   Ewbank Engineering Consl., Ltd.

2. 1979 Prefeasibility Study - Report on the Production and Utilisation of Peat at Negril and Black River Morasses
   Ewbank Engineering Consl., Ltd.

3. 1981 Report on land costs for drying peat by APEC

4. 1981 Environmental Feasibility Study of the Jamaica Peat Resources Utilization Project for NRCD by Traverse Group

5. 1982 The Peat Resources of Jamaica and Their Potential for Fuel Supply - Robinson from PCJ

6. 1983 Study of environmental and economic feasibility of using Peat Resources - Lund University - Sweden

7. 1983 Analysis of Fuel Characteristics of Peat by Finish Consultants

Table 9.2.

Harvesting Costs for Peat
1981 Prices[1]

Initial Costs[1]	1976 000's (Irish Pounds)	1981 000's (US$)	1981 000's (J$)
900 acres land[2]	196		1,225
Extraction equipment	6,463	17,010	
Railroad equipment	684	1,800	
Structures	484		2,997
Subtotal	7,827	18,810	4,222
Annual Costs			
Labor	1,642		7,968
Maintenance	213		500
Fuel[3]	388		2,636
Subtotal	2,243		11,104

Notes:
[1] For harvesting .5 million tons at 50 percent moisture content.
[2] Excludes costs of land for drying.
[3] Assume J$2.90/imperial gallon of truck diesel and J$.255/kwhr.

Source: Ewbank, Reference 37.

moisture content and low heat value. The in-situ moisture content is about 88 percent. This must be reduced to 50 or less in order to be burned in a boiler. The time required for drying is between 10 and 50 days in the period from November to April. During the period from May to October it is not possible to dry the peat because of the rains and the low wind. Therefore, a drying area must be prepared which includes covered storage for a half year's supply of peat. For the six month drying period about 5 rotations can be achieved so that at any time 20 percent of the annual consumption will be kept in the patio area. The patio drying area has an active capacity of 71 tons of peat per acre.

The heat content of the peat is relatively low, about 7,200 BTU/lb on an oven-dry basis at Negril and 6,400 BTU/lb. at Black River. The former has an ash content of 16 percent and a sulfur content of 1.6 percent and the latter has an ash content of 21.5 percent and a sulfur content of 1.8 percent. At 50 percent moisture content, the low heat value of the peat would be 3,100 BTU/lb. for Negril and 2,700 BTU/lb. for Black River. Assuming a boiler efficiency of .8 based on the low heat value and a turbine/generator efficiency of .3, a megawatt-hour of generated electricity would require 2.29 short tons of Negril peat at 50 percent moisture content or 2.63 tons of Black River peat. The peat was successfully burned in an Irish peat-fueled generating station, however, it required a maximum draft and manual ash removal in order to maintain the burning. The Negril peat can be briquetted but the Black River peat cannot.

The current peat reserves in the two morasses were surveyed by Dr. Robinson, formerly of UWI, Reference 75. The reserves at Negril cover an area of 5,840 acres of which about 96 percent has an average seam thickness of 18 1/2 feet with a maximum thickness of 52 feet. The total reserve is estimated to be 12.8

million tons, dry matter. About 89 percent of this reserve is easily accessible, i.e., seams of more than 10 feet. At Black River, the reserves cover about 10,729 acres with an average seam depth of 12 1/4 feet and a maximum seam depth of 40 feet. The total reserves are estimated to be 16.1 million tons dry matter, of which about 74 percent is easily accessible.

9.2 Peat-Fired Generation Plant

For a 40 MW generating station, the annual output would be about 250 GWHR. This would require between 575 and 675 thousand tons of peat at 50 percent moisture. The combined reserves of Negril and Black River would be sufficient to fuel such a facility for 70 to 80 years assuming that only the easily accessible peat is mined. For an 80 MW facility, the useful life would be 35-40 years for these two reserves.

Although the estimated cost of the peat would be considerably less than petroleum fuels per kilowatt hour of generated electricity, the cost for the generating plant would be considerably higher. An estimate of the capital costs for a 40 MW and an 80 MW plant were prepared and a summary of the costs is shown in Table 9.3. The initial capital cost for the 80 MW plant is estimated to be US$103 million plus J$46 million. The annual cost for operations and maintenance is estimated to be US$2 million and J$5 million. The fixed annual cost per megawatt-hour sendout, exclusive of capital costs, would be J$19 (using the 1.78:1 exchange rate). For a 40 MW plant, the capital and maintenance costs are halved, but the labor costs are unchanged. As a result the fixed annual costs would increase to J$22.5.

The preliminary cost estimates indicate that a peat-fired thermal plant would be less expensive to construct and operate than an oil-fired plant, but the financial viability is jeopardized by two factors, the problems of drying

Table 9.3.

Thermal Station Costs Urban Waste
Coal and Peat

Fuel	Coal			Peat		Urban Waste		
Fuel capacity (MW)	70	70	100	80	40	6	12	18
Hours operation[1]	8760[14]	8760	8760	7000	7000	7000	7000	7000
Load factor[2]	.65[14]	.65	.65	.9	.9	.9	.9	.9
Annual generation (000's MW hr/yr)	399	399	569	504	252	37.8	75.6	113.4
Annual sendout[3] (000's MW hr/yr)	371	371	529	449	225	32.1	64.3	96.4
Annual delivered (000's MW hr/yr)[4]	311	311	445	377	189	27.0	54.0	81.0
Boiler efficiency[5]	.9	.9	.9	.8	.8	.8	.8	.8
Generation efficiency[6]	.3	.3	.3	.3	.3	.24	.26	.28
Rate of consumption[7] of fuel (lb/KW hr)	1.0	1.0	1.0	4.9	4.9	5.3	4.9	4.6
Consumption of fuel (000's tons/yr)	200	200	28.6	1,235	617	100	185	258
Capital cost[8]								
(Mn $ US)	66.64	86.80	117.6	103.42	51.71	21.12	39.17	58.03
(Mn $J)	29.65	38.63	52.33	46.02	23.01	9.40	17.43	25.82
Unit costs (US $/Kwe)	1190[14]	1550[15]	1470[15]	1616[15]	1616[15]	4400[13]	4080[13]	4030[13]
Maintenance costs[9]								
(000's US$)	1000	1300	1765	1994	997	320[13]	618[13]	923[13]
(000's J$)[10]	1780	2320	3140	3548	1774	1047[13]	1985[13]	2947[13]
Labor requirements[11]								
Unskilled	12	12	15	21	21	8[13]	8[13]	8[13]
Semi-skilled	51	51	52	55	55	24[13]	24[13]	24[13]
Skilled	15	15	15	15	15	5	5	5
Labor costs[12] (000's J$)								
Unskilled	129	129	162	227	227	86	86	86
Semi-skilled	771	771	786	832	832	363	363	363
Skilled	342	342	342	342	342	114	114	114
Total	1242	1242	1290	1431	1431	563	563	563
Plant life (years)	30	30	30	30	30	30	30	30

Notes for Table 9.3.

Thermal Station Costs Urban Waste Coal and Peat

1. 80 percent plant availability.
2. Baseload .9 load factor, for coal ESI, ref. 34.
3. Internal consumption 7 percent for coal, 11 percent for peat, 15 percent urban waste.
4. 16 percent line less.
5. Leased on low heat value of fuel.
6. Steam turbine, Delgor ref. 24.
7. Coal 12,600 BTU/lb. peat 2,900 BTU/lb., urban waste 3,350 BTU/lb.
8. 80 percent foreign 20 percent local.
9. 2.5 percent capital cost for coal, 3 percent for peat.
10. Half foreign currency for parts and for labor consultancy, half local.
11. Based on JPS staffing plus unskilled labor for fuel handling.
12. J$900/month unskilled J$1,260/month semi-skilled; J$1,900/month skilled.
13. Delgor ref. 24.
14. ESI ref. 34.
15. ESI ref. 33.

the peat and the environmental impacts of mining the peat. The patio drying area required for a 40 MW plant would be 1-1.5 square miles and the covered storage area would occupy an additional 15-25 acres. For an 80 MW plant the storage requirements would be doubled. A study by the consultants APEC pointed out the problems of finding a site with sufficient land area. Proposals have been made for building up part of the bogs as a drying area, but no costs have been computed for establishing such a site or for the labor and transport required for the drying.*

The environmental impacts of mining the peat could be significant because the bogs are actually wetlands. The Black River Morass is a peat-filled swamp transected by the sediment-free Broad and Gayle Rivers and bounded by the sediment-laden Black and Y.S. Rivers. The swamp provides a breeding area for fish and shrimp. The fishing industry is one of the major economic activities of the area around Black River. The conversion of this swamp to a lake through the digging of peat to depths of 10 feet (7 feet below sea level) or more,** would significantly change the ecosystem of the Morass and would have significant impact on the fishing industry in the area. At Negril, the Morass is a coastal swamp developed as infill behind a barrier beach. The Morass is drained by the Negril River in the south and the Orange River in the north. The beach area is being developed as a sattelite tourist area. The principal attraction of the area is the white sand beaches and the reef located about a kilometer off shore. The principal environmental impact of converting this

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* No consideration was given to using the waste heat from the thermal plant to dry the peat, however, this would probably be an important component of any drying scheme.

** The author observed that the area in the Negril morass that had been mined for testing the peat was inundated.

swamp to a lake is that the flow of water through the area will be enhanced and may threaten the coral reef; since the reef protects the beach, any damage to it would be detrimental to the tourist industry.

It is unclear as to how the issues of drying and environmental impact will be resolved. Currently, there is a study underway by members of the Lund University in Sweden to determine the potential environmental and economic impacts of mining the peat for electricity generation. At the same time, the swamps are being considered for agricultural development and for the establishment of fuelwood plantations. If a decision is made to use the peat for electricity generation, then it is likely that a 40 MW plant will be established at Negril because of its better fuel properties and less immediate environmental impacts. If this plant proves financially viable and without major negative environmental impacts, then it is likely that a second plant will be constructed at Black River.

9.3 Urban Waste Resources

It is estimated that the residents of Kingston produce on average, 1.8 lbs. of solid waste per capita per day. This would imply that about 700 tons is produced each day in the metropolitan area. Only about 300 tons of this amount is collected due to a lack of sanitation equipment. The per capita generation of solid wastes is expected to increase for the next two decades so that by 1990 between 810 and 860 tons will be produced each day and by the year 2000, 1,000-1,150 tons. Assuming that the rate of collection increases to 50 percent by 1990, and to 70 percent by 2000, then the amount of solid waste collected will be about 420 tons per day in 1990 and about 750 tons per day in 2000.

An analysis of the solid waste revealed that it had a moisture content which varied between 10 percent and 65 percent, but tended to be above 35 percent, especially during the rainy months. Ten to twenty percent of the solid matter is inorganics and therefore cannot be burned. The high heat value of the organic material at 0 percent moisture content was measured as 7,400 BTU/lb. When the inorganics are included and the low heat value computed, the heat value for the solid waste at 35 percent moisture content would be 3,000-3,700 BTU/lb.

9.4 Urban Waste Generating Plant

A study by Delgor, Reference 24, concerning the use of urban waste as a source of fuel for electricity generation examined facilities with capacities ranging from 300 to 900 tons per day. These plants would use two to three incinerators, a steam generator and turbine/generator set. The boiler efficiency was estimated to be .8, based on the low heat value, and the efficiency of the turbine and generator system was estimated to be between .24 and .28 with an overall efficiency of .19-.22. The plant would require 2.1-3 short tons (at 35 percent moisture content) per megawatt hour. For a plant with an 80 percent availability and a .9 load factor, each MW of capacity would require an average of 36-52 tons per day. Thus, the solid waste currently collected would be sufficient for a plant of 6-8 MW. The expected collection of solid waste by 1990 would be sufficient for an 8-11 MW plant and that for 2000 would be enough for a 14-19 MW plant.

The costs for a 6, 12 and 18 MW plant were estimated and are presented in Table 9.3. The capital costs for the plant are based on quotes obtained from manufacturers. The costs for a 300 ton per day plant with a 6 MW capacity include initial capital costs of US$21 million plus J$9.4 million and fixed annual costs of US$320 thousand plus J$1.6 million, excluding the collection cost for the solid waste. The annual fixed cost would amount to only J$6.8 cents per kilowatt hour sendout, however, the capital charges are sufficiently large that the consultants determined that the project would not be feasible. Neither the 12 MW nor the 18 MW plant presented in Table 9.3 show significant economies of scale to justify their consideration for construction in 1990 or 2000 unless there is another major shift in the relative price of petroleum products. In this case, a 6 MW plant could be operated in 1986, a 12 MW facility could be operated in 1995 and an 18 MW plant could be operated starting in 2002.

One of the major operational problems that would occur in an urban waste thermal plant is removing the moisture content of the fuel. During the rainy months, the moisture content would rise to 65 percent; the solid wastes cannot be burned at moisture levels above 35 percent. Another problem is the variation in the supply of urban wastes which would require that a few days of storage be maintained. Both these problems would increase the material handling costs for the urban waste plant.

9.5 <u>Ocean Thermal Energy Conversion</u>

The waters off of Jamaica have sufficient depth and temperature gradients to be used in the OTEC conversion process. The gradient of 40°F (22°C) has been observed over a depth of 3,300 feet (1,000 meters) within 1-3 miles (2-5 kilometers) of the shore. Three sites have been identified in the waters off of Cow's Bay Point, Homer's Cove in Westmoreland and Rio Bueno in St. Ann (see Figure 3.2). Biofouling experiments are now being conducted to determine the potential buildup of micro-organisms that might occur in the heat exchangers of an OTEC plant.

While the concept of obtaining energy from the temperature gradient in the ocean waters is not new, the applications of this technology have been limited. Two experimental units have been constructed, one in 1979 and the other in 1981. The former was a barge-mounted system which produced a net output of 15 kW; the latter was a shore-based unit with a net output of 120 kW.

Although several reports have been submitted regarding the potential use of OTEC in Jamaica, only two serious proposals have been made. The first was put together by a Brazilian group which proposed to construct a 1 MW shore-based facility at Cow's Point that would use a nearby solar pond to enhance the temperature gradient. This proposal has been temporarily shelved due to lack of financing and the withdrawal of one of the consortium's partners. The other proposal was made by Ocean Thermal Energy Corporation. This proposal concerns the construction of a 12 megawatt facility composed of a first-phase, closed-cycle 2 MW plant and a second-phase open-cycle 10 MW plant. Both units would be shore-based. They would be built, financed, insured and operated by the corporation. An agreement would be signed with the Jamaican government which would guarantee purchase of the output up to 12 megawatts at US$.056 per kWhr (and pegged to the official OPEC price for a barrel of crude) and 1.1 million gallons of drinking water per day at US$6.8 per thousand gallons. The agreement anticipates a 50 week per year operation at an output of 11 MW or greater. There is a rather loose provision for compensation to JPS if the unit is down for a period greater than 2 weeks. JPS is currently reviewing this proposal to determine the effects on system reliability and foreign exchange expenditures. The net present value of this 25 year agreement was estimated to be US$102 million based on the following assumptions:

1. a discount rate in real terms of 4 percent;
2. the prices of electricity and water computed in constant prices did not change;
3. the annual output of the unit averaged 50 weeks at 11.5 MW and 1.05 million gallons of water per day;
4. an annual payment in foreign currency over the life of the agreement of $7.94 million based on #2 and #3;
5. a two year period before implementation of the agreement during which the price does not change but inflation averages 10 percent;
6. no balloon payment at the end of the agreement, (this payment would add about $1 million to the net present value).

It appears from the proposal that a concessionary rate is being given so that the corporation and its suppliers will have a chance to demonstrate their technology. In order to provide OTEC generating capacity at an equivalent cost, it would be necessary to provide a 12 MW plant at a capital cost of about US$5,000-5,500/$kW_e$. The major risk is that if the system does not prove reliable then the JPS will have to provide backup and therefore the only savings would be in reduced fuel consumption of the backup unit.

9.6 OTEC Plant Characteristics

The efficiencies of the OTEC plants are limited by the relatively small temperature gradient. The carnot cycle efficiency for a temperature gradient from 75°F to about 40°F is only 7 1/2 percent. Half of this temperature differential is lost across the evaporators and the condensers. The turbine/generator has an efficiency of about 65 percent so that the overall system efficiency is only about 2 1/2 percent. The quantity of the electricity generated which is required for internal use is considerable. In the pilot plants about 75 percent of the power generated was used internally with 45 percent being used for the pumps. Therefore, it is estimated that the system conversion efficiency computed at the busbar will be only about 1.5 percent for the larger capacity units.

The problem of estimating the capital cost of an OTEC facility is due to the lack of a demonstrated facility in the 10 to 40 MW range and the lack of a specific site. Recent estimates for a 40 MW unit have ranged from \$6,500 to \$7,250 per kw_e in 1981 prices.* For 10 MW units, the cost is expected to increase to US\$7,600/kw_e or more; for still smaller units it is expected to increase to US\$ 8,000/Kwe or more. Estimates for the costs of constructing and operating various sizes of OTEC plants are presented in Table 9.4. Also included in this table are the estimated costs for an OTEC plant combined with a solar pond. This configuration increases the system conversion efficiency from 2 1/2 percent to about 11 1/2 percent and thereby reduces the costs for pumps, pipes and heat exchangers. The costs for a 5 MW OTEC Solar Pond facility to be built in Hawaii was estimated to be only US\$5,000/kw_e but it required about 160 acres of solar pond. In Jamaica, this pond would add US\$1,950/kw_e (including the cost of salt) to the cost of the facility. The annual operating and maintenance costs for the different configurations in Table 9.4 were estimated to be J\$.10 per kilowatt-hour send out for the 10 MW OTEC plant, J\$.09 for the 40 MW OTEC plant, J\$.09 for the 5 MW OTEC/Solar Pond and J\$.07 for the 40 MW OTEC/Solar Pond.

If an OTEC plant appears financially viable, it is expected that the government might install a 40 MW unit after 1990, if the technology has been proven for large scale generation. If the first plant is successful, then a second with 60 MW might be constructed by the year 2000. The current proposal

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* The lower estimate is from the Alfa Laval proposal, Reference 6 and the higher estimate is from Gibbs and Cox, Reference 42.

Table 9.4.

OTEC Plant Cost Estimates

Configuration Capacity	OTEC		OTEC/Solar Pond	
	10 MW_e	40 MW_e	5 MW_e	40 MW_e
Availability	7,500	7,500	7,500	7,500
Load factor	.9	.9	.9	.9
Annual Generation [5]	122.5	490	61.5	490
Annual sendout (GWHR) [5]	67.5	270	33.8	270
Annual delivered (GWHR) [6]	56.7	226	28.4	226
System efficiency [5]	2.4%	2.4%	11.5%	11.5%
Capital cost (US$ mn)	76	280	30	220
Unit cost (US$/$KW_e$)	7,600[1]	7,000[1]	6,000[2]	5,500[3]
Maintenance US$ mn[4]	1.79	6.58	.71	5.17
J$ mn	3.18	11.71	1.26	9.20
Labor				
Skilled	8	10	8	10
Semi-skilled	20	30	20	30
Unskilled			8	8
Labor costs (000'sJ$)				
Skilled	182	228	182	228
Semi-skilled	302	454	302	454
Unskilled			86	86
Subtotal	484	682	570	768

Notes:

[1] Alfa Laval AB, Reference 6; Gibbs & Cox, Reference 42.

[2] \$1,950/kw_e for the pond and the rest for the plant (approximately 50 percent of \$8,000/kw_e).

[3] \$1,950/kw_e for the pond and 50 percent of \$7,000/kw_e for the plant.

[4] 4.7 percent based on Gibbs and Cox with half in foreign currency at 1.78:1.

[5] Assumes effective capacity is at the busbar after 40-50 percent of generated electricity is taken off for plant operation.

[6] Assumes 16 percent distribution losses.

for establishing a 12 MW facility, which would be operating by 1986, is under review by JPS. Since the proposed foreign exchange costs for the water and electricity combined are less than the fuel costs for the less efficient thermal plants, this proposal would appear to provide a good source of capacity.

Chapter 10

Demands for Electricity and Irrigation

Two of the potential major uses of renewable energy are for generation of electricity and small-scale irrigation. In this chapter electricity generation is examined from the point of view of the existing supply of generating capacity and the demand for electricity consumption in the major economic sectors. The data in this analysis is drawn primarily from a report prepared by Messrs. Fagin and Miller of JPS.

The demand for small-scale irrigation pumping is examined by first estimating the potential demand for irrigation. At present very little irrigation is used in Jamaican agriculture; the principal exception being estate agriculture, especially sugar cane. The data used to estimate potential demand was obtained from a UNDP/FAO study conducted in 1974. This study examined the irrigation requirements for different crops in the various basins on the island. The method for calculating pumping requirements from this data was suggested by Winston Boyne of the MME and was undertaken by Jim Fells of the Peace Corps.

The observations presented in this chapter do not necessarily reflect the opinions of Messrs. Fagin, Miller, Boyne or Fells, but, without their assistance, no analysis could have been performed.

10.1. The Electricity Generating System

The electricity generation capacity of Jamaica can be divided between the public system operated by the JPS and the private system operated by the larger users such as the bauxite/alumina industry. In addition, there is some small-scale auto-generation capacity on the island, but there is no data available on these systems and they are thought to represent a relatively small part of the island's total generating capacity. The JPS system currently accounts for 68 percent of the island's nominal generating capacity and produces about 61 percent of the total electricity generated in Jamaica as shown in Table 10.1. The distribution system of JPS covers most of the island as can be seen in Figure j.1. It includes 492 miles of primary distribution (138-69 KV), 1653 miles of secondary distribution (33-12 KV), and 33129 miles of tertiary distribution (4-6.9 KV). There is an on-going rural electrification program but it has had limited success because the areas which remain without electricity are relatively remote and therefore costly to connect.

The JPS system consists of a mixture of oil-fired steam plants, gas turbines and mini-hydro facilities. The system is relatively old. The age of the steam plants averages 16 years, and the age of the gas turbines averages 11 years. The mini-hydro facilities were all built in the late 1940's or the 1950's. Although the nominal capacity of this system is 416 Megawatts (net CMR, see Table j.1), the available capacity is considerably less. The availability of the steam units averages about 77.5 percent, as shown in Table 10.2. The availability of the other units is thought to be higher but probably not greater than 85 percent. As a result the average available capacity is about 330 megawatts, and the probability that 1/3 or more of the nominal steam capacity is unavailable is 25 percent. In evaluating new plants it was assumed that these plants would be available 80-85 percent, or 7000-7500 hours per year.

The system capacity is divided into 69 and 138 KV distribution systems with about 60 percent on the former and 40 percent on the latter. As a result of the age of the equipment, including the distribution system, there is a relatively low system reliability and frequent power outages or low voltage

Table 10.1.

National Electricity Generating Capacity in 1981

	Capacity		Output	
	MW	Percent	GWHR	Percent
Public (JPS)	454	68	1261	61
Private (Large Units)	212	32	828	39
Bauxite/Alumina	168	25	782	37
Cement	14	2	23	1
Sugar	30	5	23	1

Source: MME annual report

TABLE - 10.2

JAMAICA PUBLIC SERVICE CO. LTD.

AVAILABILITY FIGURES

STATION	UNIT NO.	TYPICAL AVAILABILITY*
Hunts Bay 'A'	1	0.802
Hunts Bay 'A'	2	0.902
Hunts Bay 'A'	3	0.848
Hunts Bay 'A'	4	0.807
Hunts Bay 'A'	5	0.814
Hunts Bay 'B'	6	0.889
Hunts Bay GT	1	0.620
Hunts Bay GT	2	0.804
Hunts Bay GT	4	0.734
Hunts Bay GT	5	0.870
Old Harbour	1	0.872
Old Harbour	2	0.750
Old Harbour	3	0.709
Old Harbour	4	0.421

*Based on Data for the years 1977 to 1980

Availability figures for the following units not available

STATION	UNIT
Bogue Diesels	1-9
Bogue GT	3
Roaring River Hydro	1
Rio Bueno Hydro	1
Lower White River Hydro	1
Upper White River Hydro	1
Maggotty Hydro	1

Source: JPS Annual Report

conditions despite the fact that the peak demand is only about 220 megawatts. (See Table j-2.)

The generating units are relatively inefficient, especially the steam plants. The gross heat rates for the steam plants averaged about 15,200 BTU/kwhr, about 22 percent gross efficiency in 1980. The more efficient units had efficiencies on the order of 33 percent while the least efficient units had efficiencies of only 13 percent. (See Table j-3.) The gas turbines have an efficiency of about 20 percent as shown in Table 10.3. The average heat rate and efficiency for the system changes from year to year, as can be seen from the data in Table 10.4, depending on the availability of equipment, major renewals, and the acquisition of new equipment. The construction of a 65 megawatt unit thermal plant in 1975 resulted in a considerable reduction in the heat rate for the Hunts Bay facility in particular and the total system in general. However, the heat rate increased in the years after 1976 until 1980 when this unit was unavailable for much of the year and the heat rate increased to 14,500 BTU/kwhr (23.5 percent gross efficiency).

The low system reliability and the low fuel efficiency are further aggravated by significant losses in the system. About 10 percent of the losses occur in the distribution system, but another 13 percent result from unauthorized use (see Table 10.5). Attempts are being made to reduce the losses. In the evaluation of new generating units it has been assumed that the total loss is only about 15 percent.

TABLE - 10.3

EFFICIENCY OF GENERATING UNITS 1980

STATION	UNITS	GROSS HEAT RATE		GROSS EFFICIENCY %
		BTU/KWH	KJ/KWH	
HUNTS BAY A	1-5	18940	19980	18.0
GAS TURBINES	1-5	16630	17540	20.5
OLD HARBOUR	1	16150	17040	21.1
OLD HARBOUR	2-3*	13850	14612	24.6
DIESELS	1-12	11380	12010	30.0
HUNTS BAY B	6	10478	11054	32.6

* The more efficient unit No. 4 at the Old Harbour was out of service in 1980.

Source: MilGann, ref

TABLE - 10.4

JPSCo. HEAT RATE BY STATION, 1972-1980

(BTU/Kwh)

YEAR	STEAM		GAS TURBINES		DIESEL	TOTAL SYSTEM
	HUNTS BAY	OLD HARBOUR	HUNTS BAY	BOGUE		
1972	19677	12969	18596	-	11577	N/A
1973	19187	13377	19055	16862	11419	15181
1974	19801	12952	15553	16146	11571	14377
1975	19891	12453	15365	16390	11104	13970
1976	14756	13520	14877	14415	10981	13894
1977	13879	13281	14889	15216	11708	14101
1978	13318	12821	15255	31693	11208	13134
1979	14048	14244	16014	15926	12033	14341
1980	14991	15719	17328	16346	11477	14502

Source: MilGarm, ref.

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TABLE - 10.5

JAMAICA PUBLIC SERVICE CO. LTD.

POWER AND ENERGY LOSSES - 1980

NET GENERATION: 1274484 MWH

LOSSES AND UNACCOUNTED ENERGY: 245769 MWH (19%)

CATEGORY	MW LOSS AT PEAK	ENERGY LOSS (MWH)	PERCENT OF GENERATION	ESTIMATED COST OF LOSSES (J$)
TRANSMISSION	3.5	20542	1.9	2,793712
SUBSTATION TRANSFORMERS	2.3	10628.2	1	1,445530.4
DISTRIBUTION LINES	12.0	60584.4	5.7	8,239478.4
TRANSFORMER	3.5	15943	1.5	2,168283
SUBTOTAL	21.3	107697.6	10.1	14,647003.8
UNACCOUNTED	30.6	138174.9	13.0	18,791789
TOTAL	51.9	245873.2	23.1	$33.4 M

Source: MilGann, ref

10.2. Electricity Demand

The demand for electricity is divided into four billing categories by JPS: residential, large industrial and commercial, small industrial and commercial, and "other".

The residential demand accounts for 31 percent of the total demand while the small commercial and industrial users account for another 43 percent. The large commercial and industrial users and the "other" users each account for 13 percent of the demand.

The number of residential hookups has increased since 1973 by about 7 percent per year but the average consumption per hookup has been declining steadily due to the deteriorating economic situation and the lower average demand of new hookups (see Figure 10.1). The large commercial and industrial hookups increased from 15 to 24 during the period 1973 to 1978 but has declined to 22 since then. The average consumption per hookup has also decreased as the economic condition worsened although a slight increase was recorded between 1981 and 1982. The small commercial and industrial hookups increased during the last ten years, but the average consumption per hookup declined from 1975 to 1981. The number of "other" users increased up until 1979 and then leveled off. The average consupmtion per "other" hookup fluctuated during this period. The total number of hookups and average consumption for each class of users during the last 10 years are shown in Table 10.6.

The annual load factor for the system is 29 percent based on all available units. If only the available units are considered then the annual load factor is closer to 38 percent. The peak demand increased during the period 1970 to 1976 but declined thereafter as can be seen in Table 10.7. The demand for

FIGURE 10.1

Residential Electricity Consumption

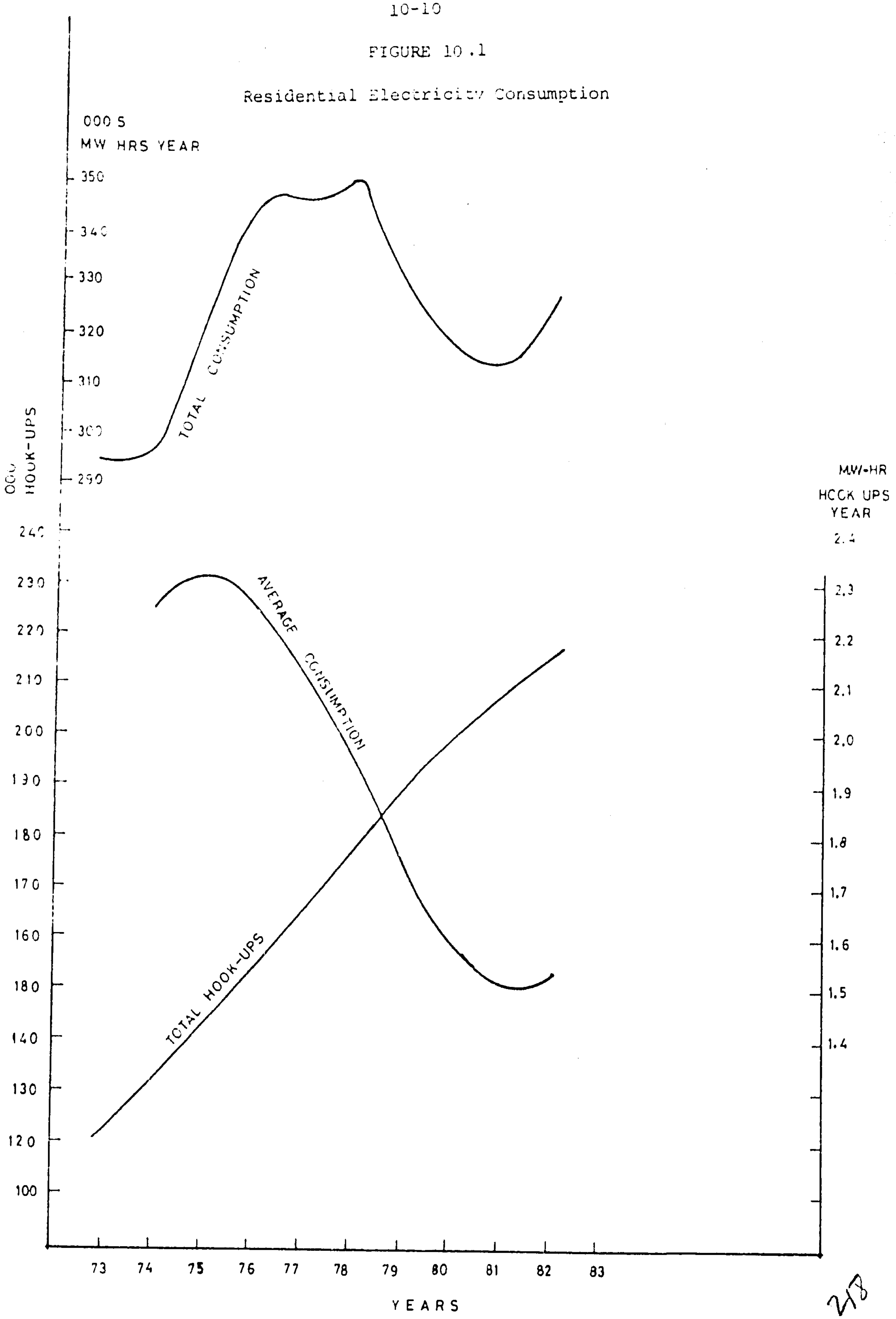


TABLE - 10.6

AVERAGE NUMER OF CONSUMERS

1973-1981

CATEGORY	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982*
RESIDENTIAL	122,515	131,964	142,075	153,272	163,834	177,745	189,858	199,468	208,390	216,403
COMMERCIAL AND INDUSTRIAL										
. SMALL	20,875	21,441	21,999	22,636	23,316	23,615	23,861	23,765	23,876	24,207
LARGE	15	15	19	21	21	24	24	23	23	22
OTHERS	1,788	1,847	1,983	2,014	2,094	2,168	2,223	2,229	2,229	2,221
TOTAL	145,193	155,267	166,075	177,943	189,265	203,588	215,966	225,485	234,518	242,853

*PRELIMINARY

ELECTRICITY CONSUMPTION 1973 - 1981

AVE MWHR PER USER PER YEAR

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982*
RESIDENTIAL	2.40	2.26	2.31	2.26	2.12	1.97	1.74	1.59	1.51	1.52
INDUSTRIAL AND COMMERCIAL										
- SMALL	20.62	20.23	21.15	21.36	20.82	20.25	18.75	18.30	18.07	19.29
- LARGE(000's)	9.46	9.43	7.90	7.47	7.10	6.49	5.87	5.80	5.47	6.30
OTHER	57.95	63.22	65.74	66.73	73.87	69.64	63.76	61.32	65.03	65.14

Source: Economic and Social Survey; various issues

Notes: growth in residential consumers 7% per annum with $R^2=99$

reduction in average annual residential consumption 6% per annum with $R^2=93$

TABLE - 10.7

JPSCo. SYSTEM PEAK LOAD DEMAND 1970-81

YEAR	PEAK (MW)
1970	156.7
1971	173.4
1972	204
1973	214.3
1974	221.3
1975	228.7
1976	239.1
1977	238.1
1978	234.7
1979	228.3
1980	223.5
1981	223.6

Source: MilGann, ref

electricity is relatively flat over time. Both the annual and diurnal peaks are small. The daily distribution of demand reveals a rather broad peak which lasts from 10 a.m. to 9 p.m. with a slight dip during the period 5 p.m. to 8 p.m. (see Figure 10.2). The period of lowest demand occurs between midnight and 7 a.m. when the level of consumption is about 2/3 that of the peak period. The yearly variation in demand in 1982 had slight increases in demand due to higher air conditioning loads in the hotter months, but the fluctuation between the lowest and the highest months was only ±7 percent. (See Figure 10.3.)

In the evaluation of alternative sources of electricity generation, it was assumed that the dendro-thermal, mini-hydro, OTEC, peat, and urban waste facilities would all serve the baseload demand. This baseload is currently served by the steam plants. It accounts for about 85 percent of the average demand.

The JPS prepared a series of forecasts for each category of user based on regression models (see Table j.4). These forecasts are presented in graphical forms in Figures 10.4 for the total demand and in Figures 10.5 and 10.6 for each category of demand. The cyclical growth pattern for small commercial and industrial and "other" demands is due to the use of lagged variables in preparing these forecasts. The projections were made several years ago and have not taken into account the last few years of slow growth. The discrepancy between the most recent consumption figures and the forecast is significant only for residential demand as shown in Table j.5.

The anticipated increase in total demand of 3 1/2 percent per annum from 1982 to 1991 is not unreasonable given the trend in recent years. It implies an increase in demand equivalent to about 10 1/2 megawatts per year, if

FIGURE - 10.2

HOURLY AVERAGE LOAD DISTRIBUTION — OCTOBER 1982

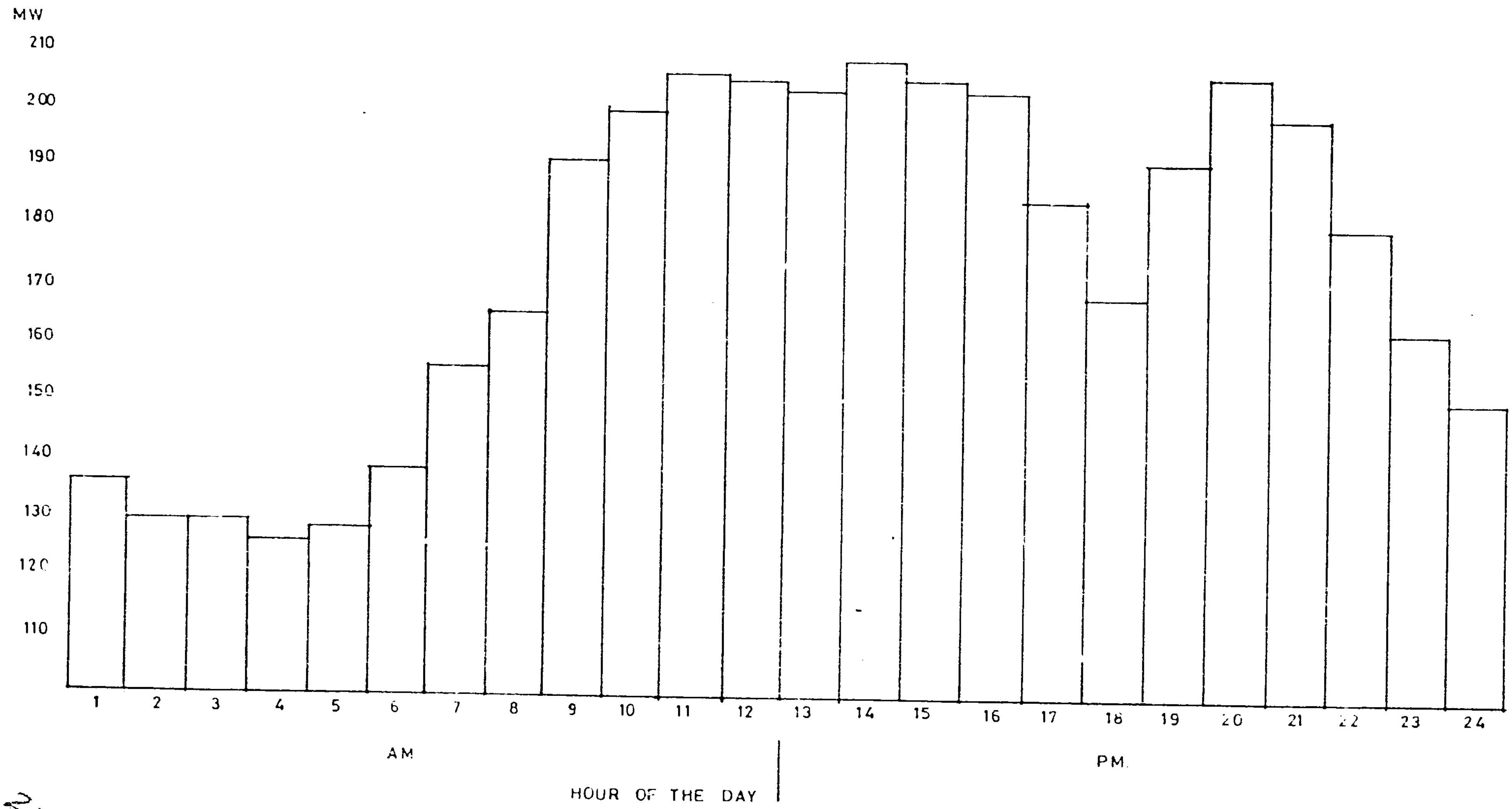
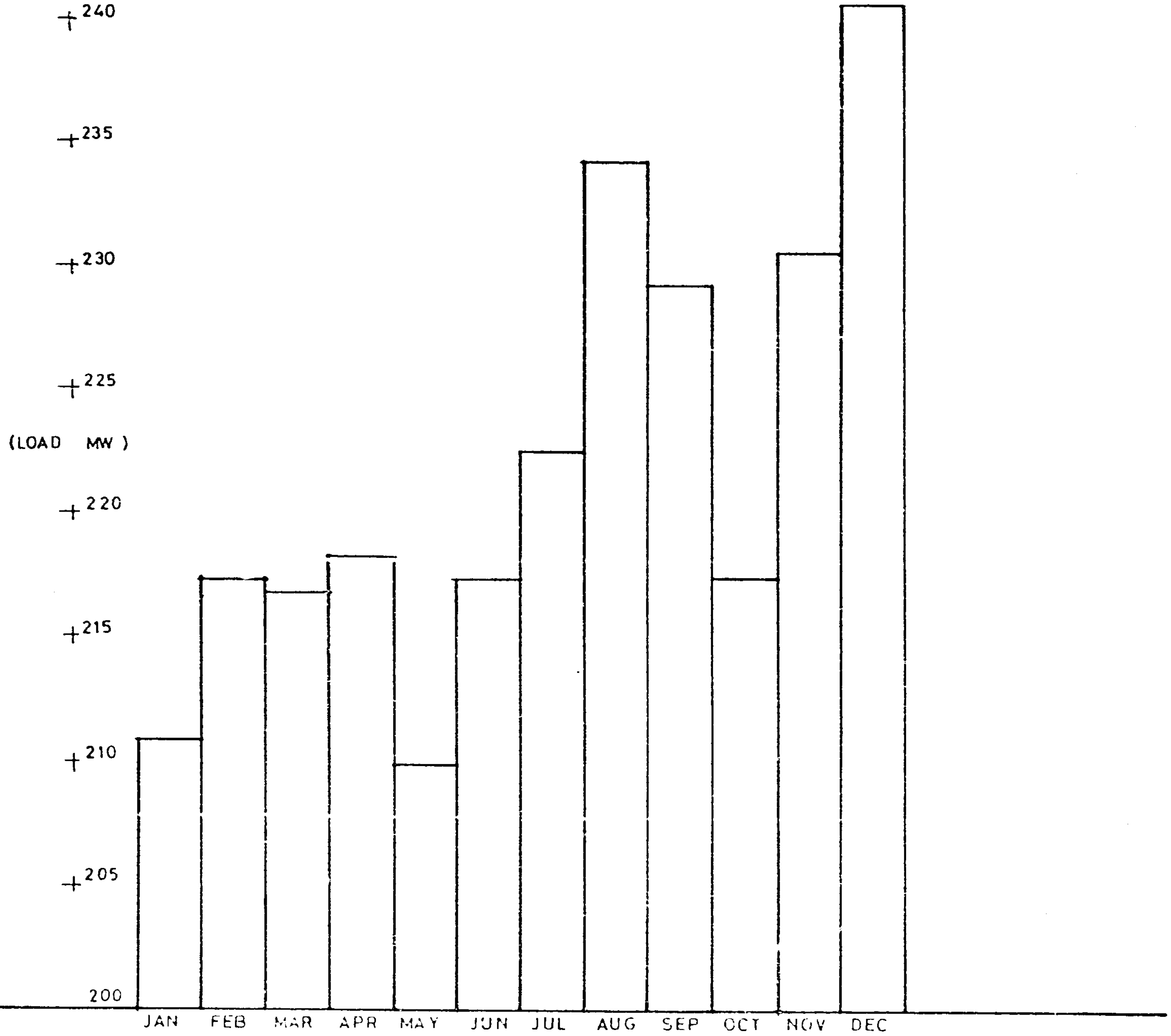


FIGURE - 10.3

ELECTRICITY DEMAND MONTHLY PEAK 1982



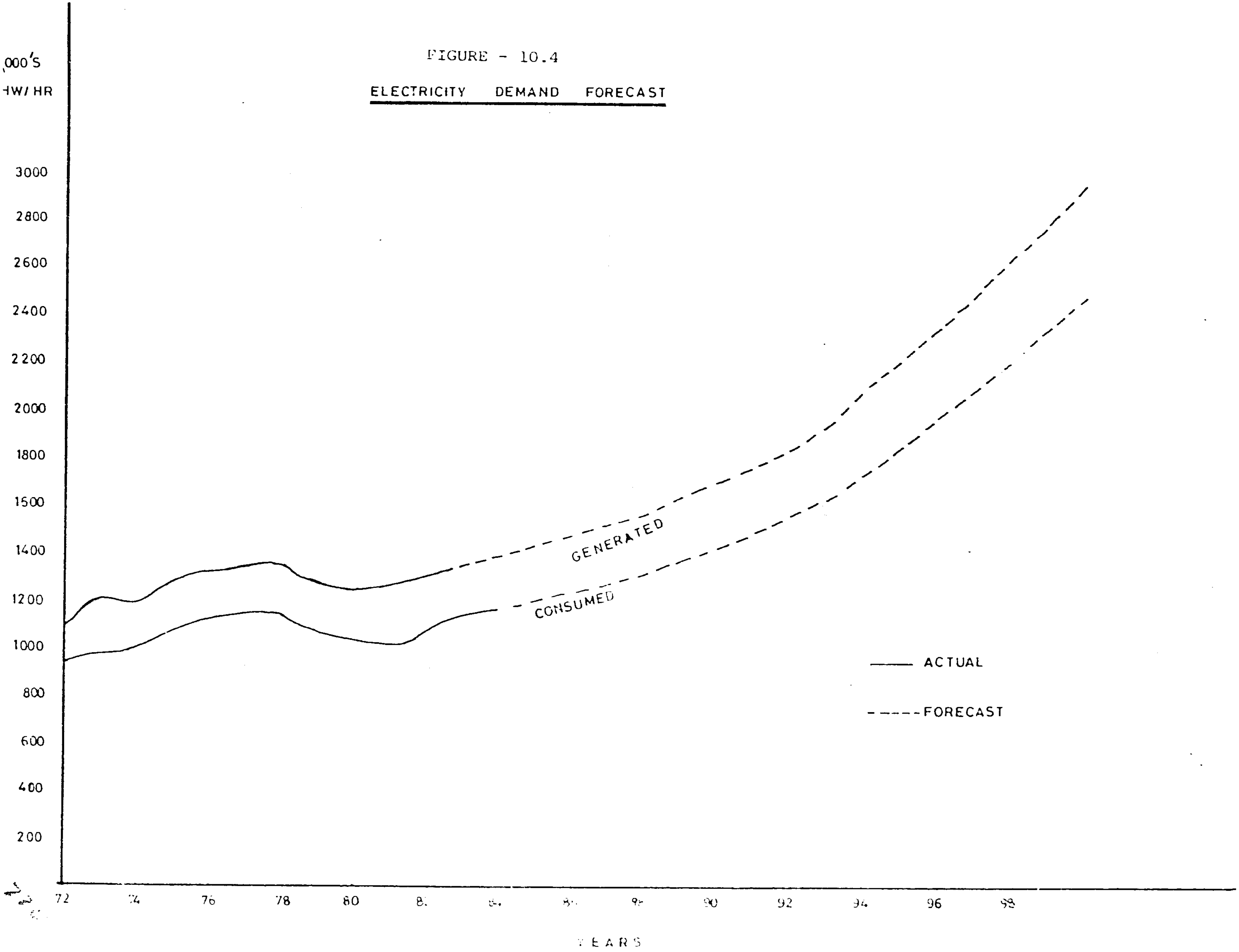
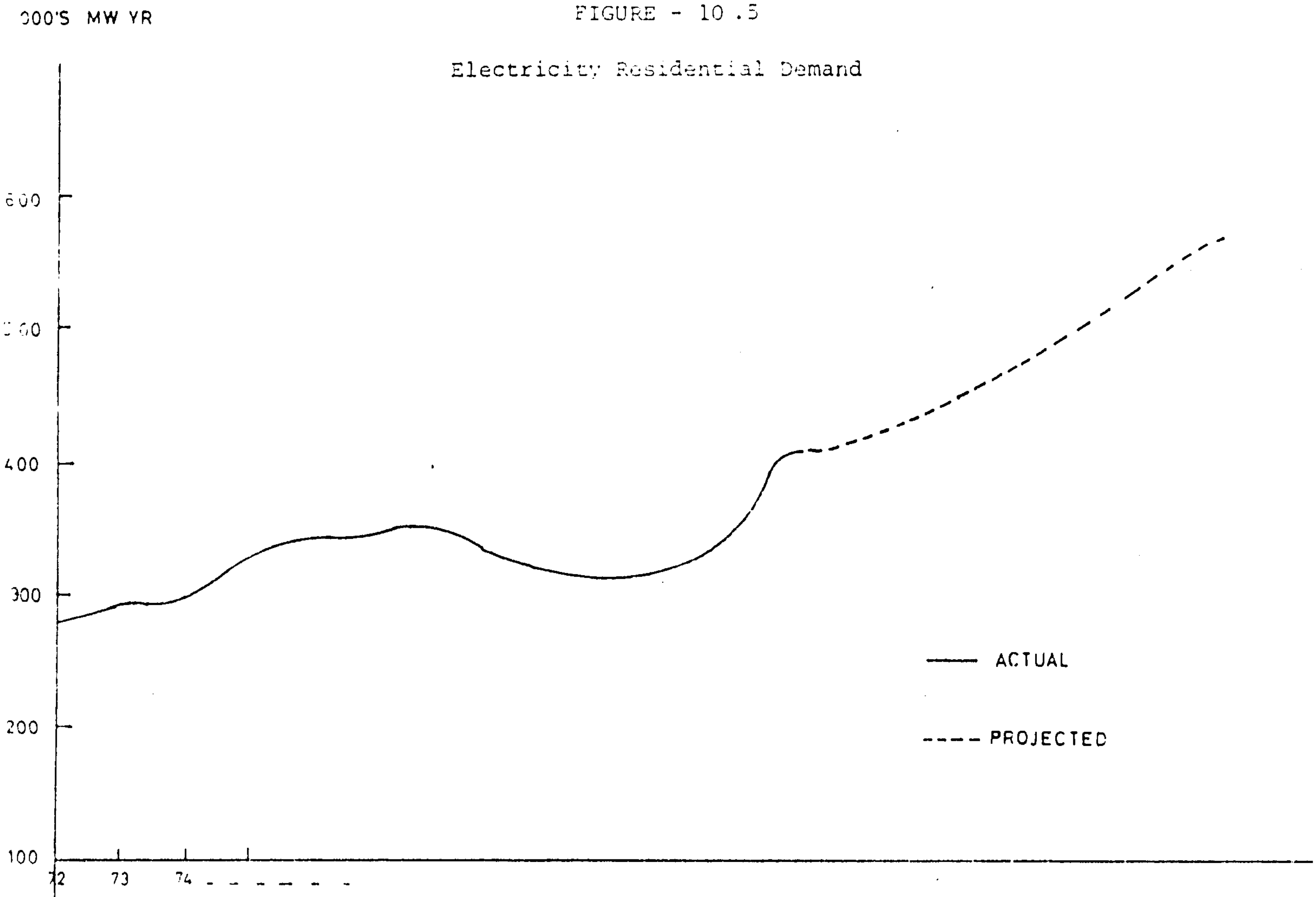


FIGURE - 10.4

ELECTRICITY DEMAND FORECAST

FIGURE - 10 .5

Electricity Residential Demand



ELECTRICITY LARGE COMMERCIAL DEMAND

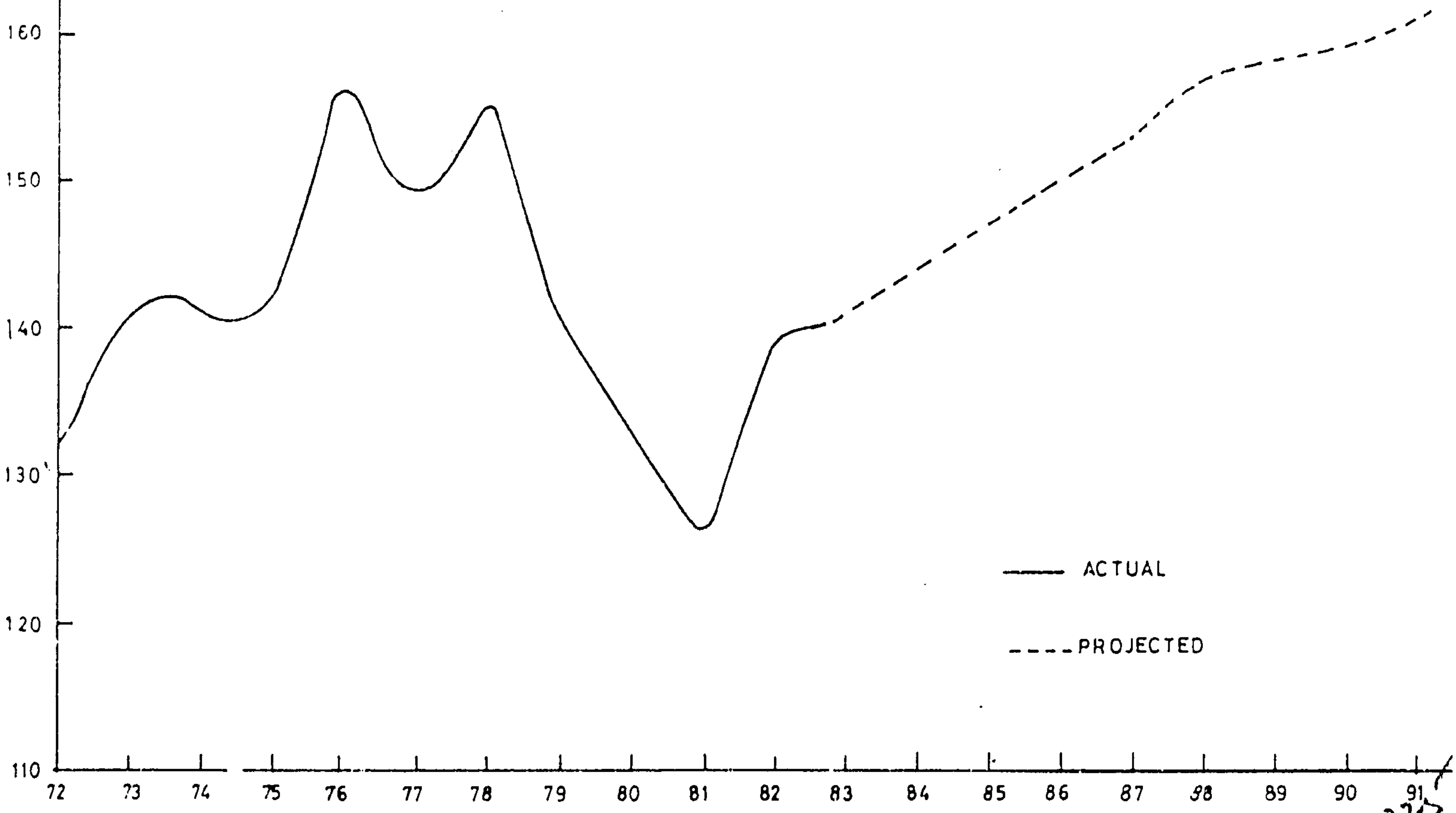
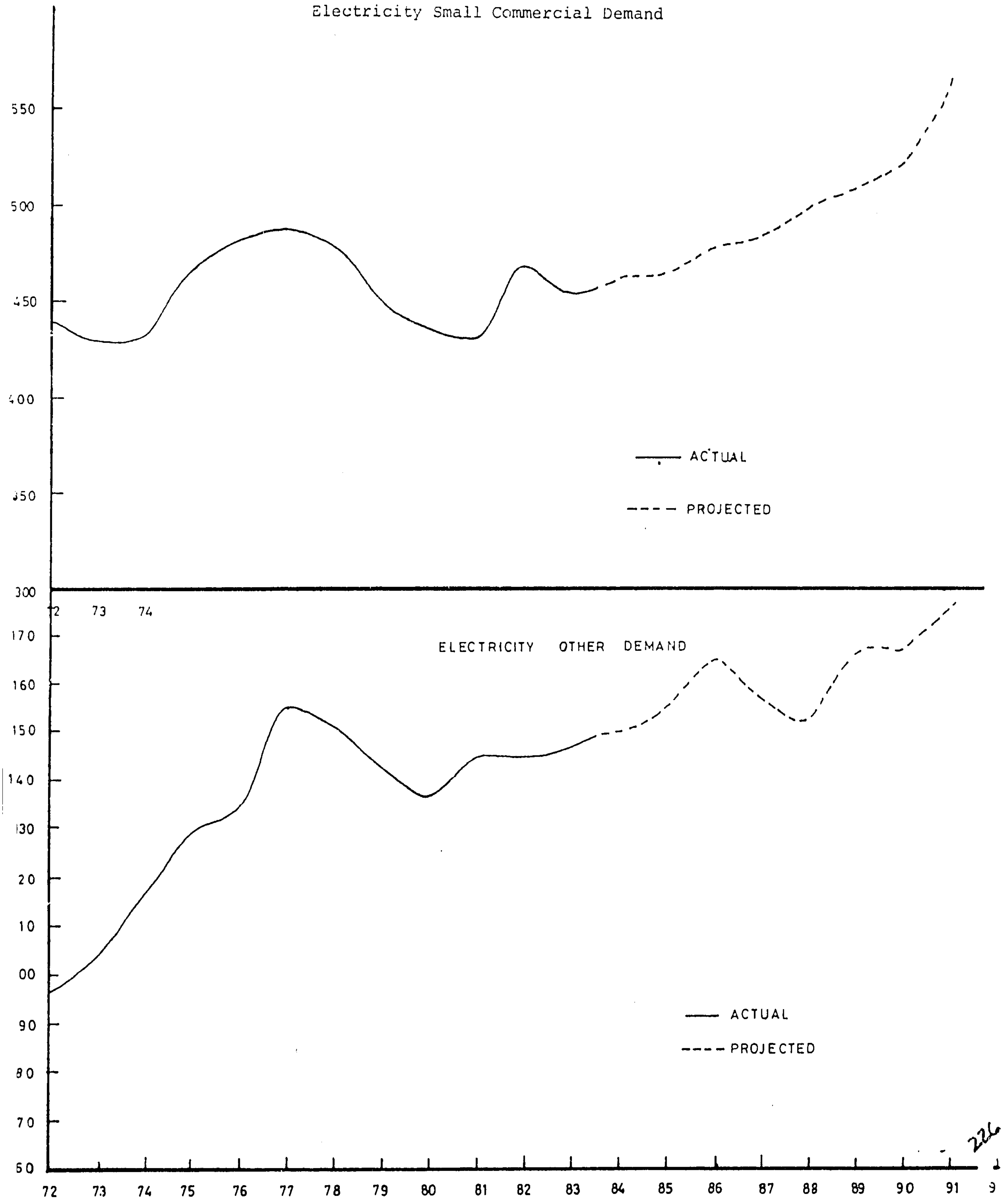


FIGURE - 10.6


Electricity Small Commercial Demand

ELECTRICITY OTHER DEMAND

operated at .90 load factor with an 80 percent availability. These forecasts provide a reasonable projection based upon the assumption of an increasing GDP. If an economic recovery is delayed, as it now appears it will be, then these projections need to be shifted further into the future.

10.3. Generating Costs

The difficulties faced by the JPS in meeting current demands and improving the reliability of its system are due in large part to a financial crunch. Although the charges for electricity have increased rapidly in the last ten years, the costs for supplying the electricity have increased more rapidly. The average revenue per kilowatt hour for all users increased from 2.8 cents in 1973 to 27.3 cents in 1982. The average revenue in 1982 for residential users was 15 percent higher and that for large scale commercial demand users was 19 percent lower (see Table j.6). During the same period the operating costs increased from 2.2 cents per kilowatt hour to an estimated 27.8 cents per kilowatt hour (see Table 10.8). The primary increase has been in the cost of fuel which accounted for about 25 percent of the operating cost in 1973 and rose to about 65 percent in 1983. This operating cost does not include the costs for interest, repayment of principal or dividends on bonds, but does include a provision for depreciation which in 1980 accounted for 1/6 of the operating costs. The costs of labor for plant operation are not reported in the JPS annual reports. In order to estimate costs for operating new plants, the 1981 salary scale for JPS employees (Table j.7) was used together with typical JPS plant staffing levels (Table j.8). In 1983 there were about .9 operating personnel per installed megawatt of capacity and they were receiving an average salary of about J$13,000 per year. This implies a cost for operating labor of about 1/2 cent per kilowatt hour, exclusive of benefits.

TABLE - 10.8

JPS FINANCIAL STATISTICS

($ J million)

YEAR	REVENUES					OPERATING COSTS*	
	Residential J$ mn	Small Commercial & Industrial	Large Commercial & Industrial	Other	Total	Total	Fuel
1972	7.3	9.6	1.9	2.2	20.93	16.14	4.2
1973	9.5	12.2	2.5	2.7	26.91	22.78	7.3
1974	16.0	20.9	5.5	5.2	47.52	43.76	23.1
1975	21.8	27.3	6.4	7.2	62.71	52.90	28.1
1976	30.3	35.7	8.6	9.7	84.38	60.05	28.6
1977	35.7	41.5	9.7	12.7	99.57	85.97	35.9
1978	47.3	53.9	13.8	17.2	132.14	111.47	50.0
1979	61.6	69.4	17.9	22.9	171.78	160.65	87.3
1980	75.7	87.6	22.3	29.2	214.[illegible]	220.17	125.7
1981	91.3	105.6	26.2	36.5	259.6		166.7
1982	103.1	121.6	30.5	39.6	294.8		193.4

* includes depreciation
excludes interest, debt repayment, dividends, construction

Source: JPS Annual Reports

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For many of the renewable energy technologies this figure would be higher because of the higher material-handling costs.

The capital costs for replacement units were computed in 1981 prices to provide a basis for comparison with the proposed plants that use renewable sources of energy. Three types of plants were analyzed: a 70 MW oil-fired steam plant, a 20 MW diesel generator and a 20 MW gas turbine. The costs are presented in Table 10.9. The first two are assumed to be used for baseload generation and to have an availability of 85 percent. The third is assumed to meet peak demand and to be used 40 percent of the time. These are the types of units which would be constructed by JPS to provide additional capacity. It is also these units which would be needed to provide backup capacity for intermittent sources such as wind farms and solar power towers.

10.4. Future Supply Requirements

The future demand for new electricity generating plants will result from the increasing demand for electricity as discussed in section 10.2 and from the retirement of existing capacity. The retirement schedule presented in Table j.9 indicates that 58.5 megawatts of capacity are scheduled for retirement before 1990 and another 92.5 megawatts are scheduled to be retired by 1995. An agreement has been signed by JPS for the purchase of a power barge which is being built by the Japanese for delivery before 1985. This barge would have a capacity of 40 MW and would cost about J$1200 per installed kilowatt. No other investments are currently underway. A detailed plan of future investment in generating capacity has been prepared by Messrs. Miller and Fagin but this forecast was not available at the time the report was prepared.

Table 10.9.

Replacement Costs for JPS Facilities

Fuel Process	Oil-Steam Turbine	Diesel-Generation	Gas Turbine
Capacity (MW)	70	20	20
Hours of operation 1/	7,500 / yr	7,500 / yr	3,500
Load factor	.9	.9	.9
Annual generation (000's MWHR)	472.5	135.0	70
Sendout 2/	448.9	128.2	66.5
Loss 3/	377.0	107.7	55.9
Heat rate (000's BTU/kwhr)	11,508	8,335	13,532
System efficiency	.295	.41	.25
Fuel consumption (imp gallons/MWHR)	69	52	95
Plant life (years)	30	25	20
Unit costs (US$/$kW_e$)	1,020	1,291	450
Capital Costs			
000's US$	64,260	21,940	8,100
000's J$	12,709	6,906	1,602
Maintenance Costs			
000's US$	546 4/	254 5/	144 5/
000's J$	972	452	255
Labor Costs			
Skilled	182.4	182.4	182.4
Semi-skilled	453.6	302.4	302.4
Subtotal	636.0	484.8	484.8

Source: Miller, Fagin personal communication.

Notes:

1/ 85 percent availability.

2/ 5 percent internal consumption.

3/ 16 percent distribution loss.

4/ Fixed US$ 2.1/kw variable US$ 2.0/kwhr, 50 percent J$.

5/ Fixed US$ 2.45/kw variable US$ 3.4/kwhr 50 percent J$.

If it is assumed that the demand will increase at the equivalent of 10 megawatts of effective capacity per year, that the retirement schedule is as shown in Table 9.9, and that the current capacity is just adequate to meet the present demand, then by 1990 75 megawatts would be required to meet new demand and another 59 megawatts of capacity would have to be replaced. Since the replaced equipment has a relatively low output, it should be possible to substitute this capacity with 30-40 megawatts of new capacity. The total requirements for new generating capacity, 100-115 MW, are well in excess of those proposed for the various generating facilities that would use renewable resources. Also the size of most units using renewable resources would be acceptable to the JPS, which currently plans to limit the size of any new plants to 70 megawatts. Larger units would create too high a risk of system breakdown in situations where these facilities unexpectedly drop out of the grid.

10.5. Demand for Irrigation

The island of Jamaica contains some 33 catchment areas as shown in Figure 10.7. The UNDP/FAO prepared a study of the irrigation potential in some of the major catchment areas that include areas suitable for intensive agriculture. In all, eight areas were studied, including the Rio Cobre and Rio Minho basins, Dry Harbour, the basin at Negril, Bull Savannah, the Pedro Plains and two sections of the Martha Brae River valley. The boundaries of these areas are shown in Figure 10.8. The existing well depths in these areas indicate that the Rio Cobre basin, the Negril basin, the Pedro Plains and Bull Savannah have relatively shallow wells, 50 feet or less, while the Rio Minho and Martha Brae River basins and Dry Harbour have relatively deep wells, 50 feet or more. A distribution of well depths by area is presented in Table 10.10. This data is based on periodic measurements made by the Division of

FIGURE - 10.7

CATCHMENT AREAS

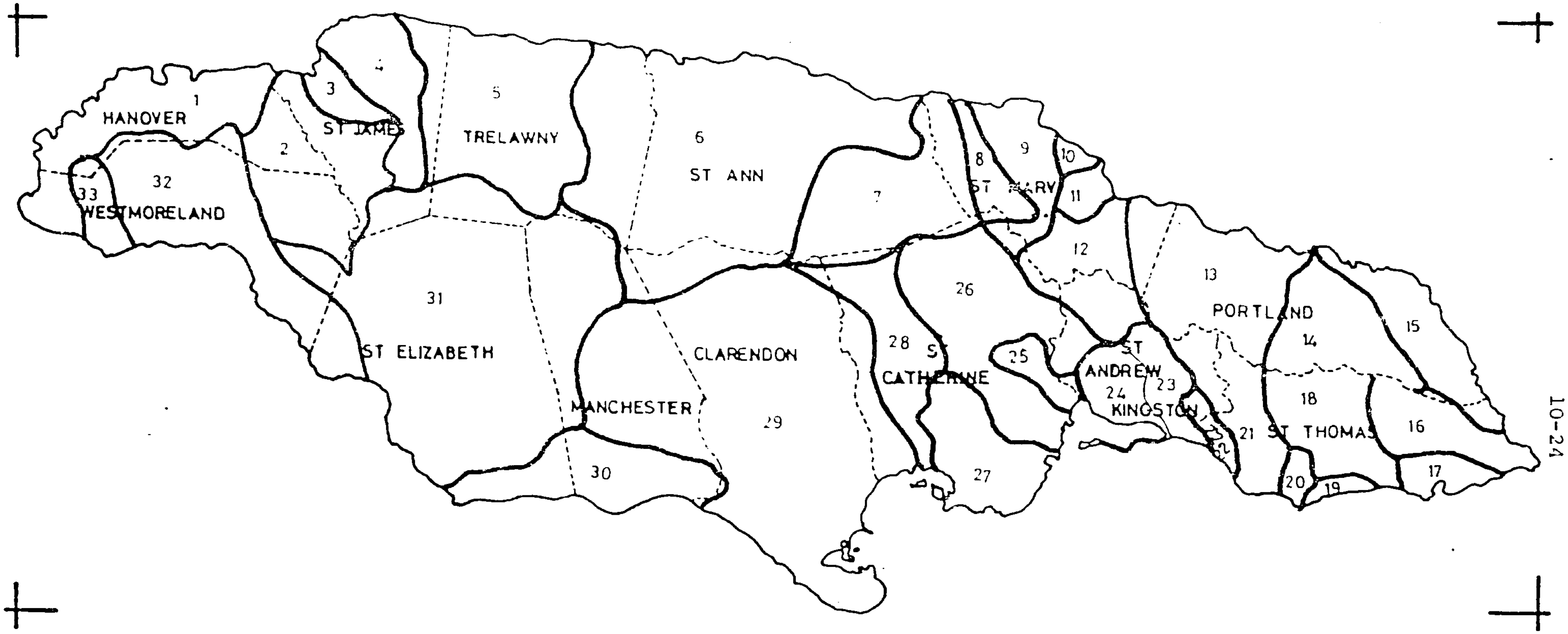
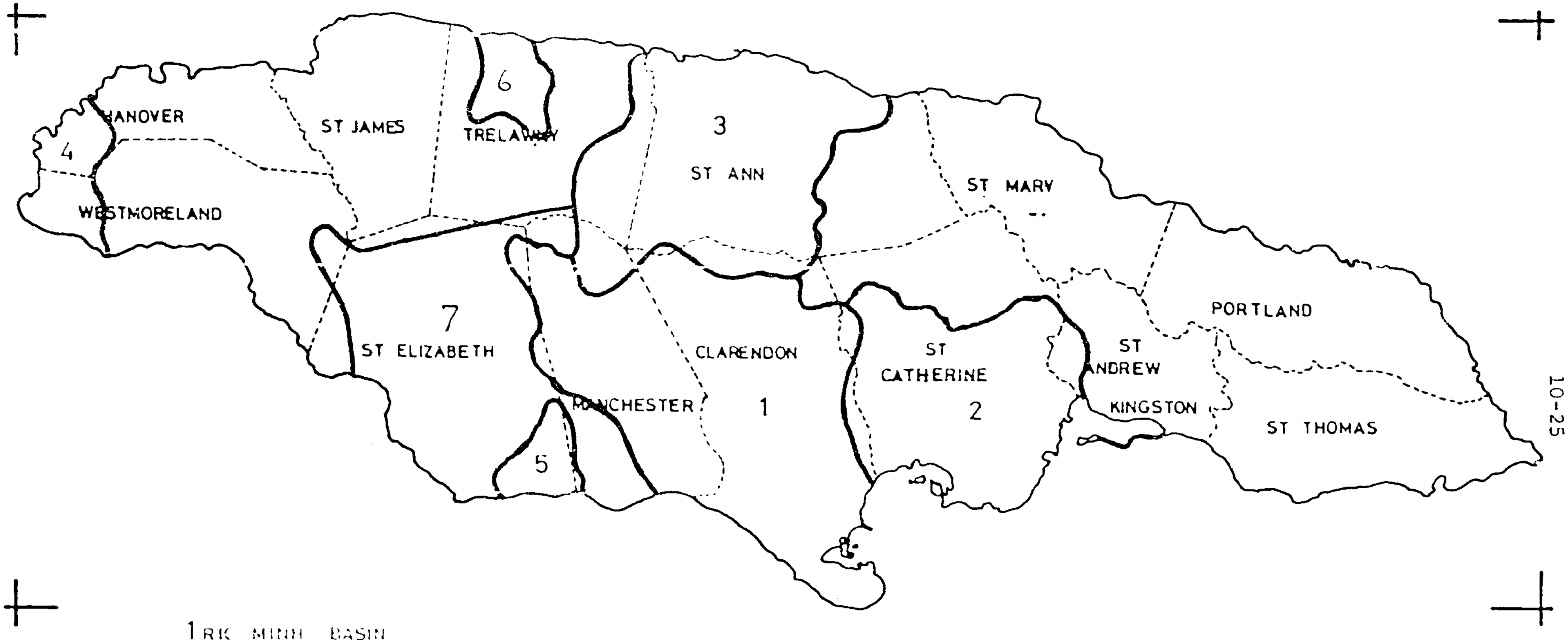


FIGURE - 10.8

UNDP/FAO IRRIGATION PLANNING AREAS



1 RIO MINHO BASIN
2 RIO COBRE BASIN
3 DRY HARBOUR
4 NEGRIL BASIN
5 BULL SAVANNAH
6 MARTHA BRAE
7 PEDRO PLAINS

Table 10.10.
Frequency Distribution of Depth to Water for Existing Wells*

		DEPTHS (ft.)		
Parish	0-20**	21-50	51-100	greater than 100
Clarendon	52 16%	106 33%	98 30%	68 21%
S. St. Catherine	130 45%	59 20%	63 22%	38 13%
St. Elizabeth	85 37%	55 24%	35 15%	55 24%
Martha Brae River Basin	4 6%	20 31%	19 30%	21 33%
Hanover and Westmoreland	47 62%	19 25%	3 4%	7 9%
St. Ann	3 9%	1 3%	4 12%	26 76%
<u>TOTALS</u>	321	260	222	215

Note: Number of wells, upper left, percent of wells in lower right.

* Includes wells for which there have been water level measurements taken.

** Includes artesian wells.

Source: P. Lamm, Water Resources Div. MME

Water Resources. The overall availability of groundwater is indicated by the classification scheme used in Figure 10.9.

The existing irrigation systems are relatively large units operated by the estates or the Parish Councils. Most of the units operated by the Parish Councils are located in the parishes of Westmoreland, St. Elizabeth, and St. Ann. The size of the pumps are reported as being between 10 and 200 horsepower, powered by electric motors or diesel engines. Details of these irrigation facilities are presented in Table 10.11. The estimates of the volume of water pumped averaged out to about 7 million imperial gallons per year or 325 acre-inches per facility.

In this study, the focus is on smaller irrigation systems that use renewable resources such as biomass fed gasifiers and windmills. The pumping requirements for the seven UNDP/FAO study areas were calculated by first estimating the net irrigation requirements for each area and each major crop and then computing the pumping requirements associated with providing this net irrigation requirement. These pumping requirements were converted to power and energy requirements per acre for different pumping heads.

The net irrigation requirements were determined using the Blaney Criddle method. In this method the net irrigation requirement is defined as:

$$(1) \qquad I_N = I_C - R_e$$

where I_N is the net irrigation requirement in inches
I_C is the gross irrigation requirement in inches
and R_e is the effective rainfall in inches.

The value for the net irrigation is computed for each month by first computing the gross irrigation requirement as shown in equation (2);

FIGURE - 10.9

Ground Water Availability

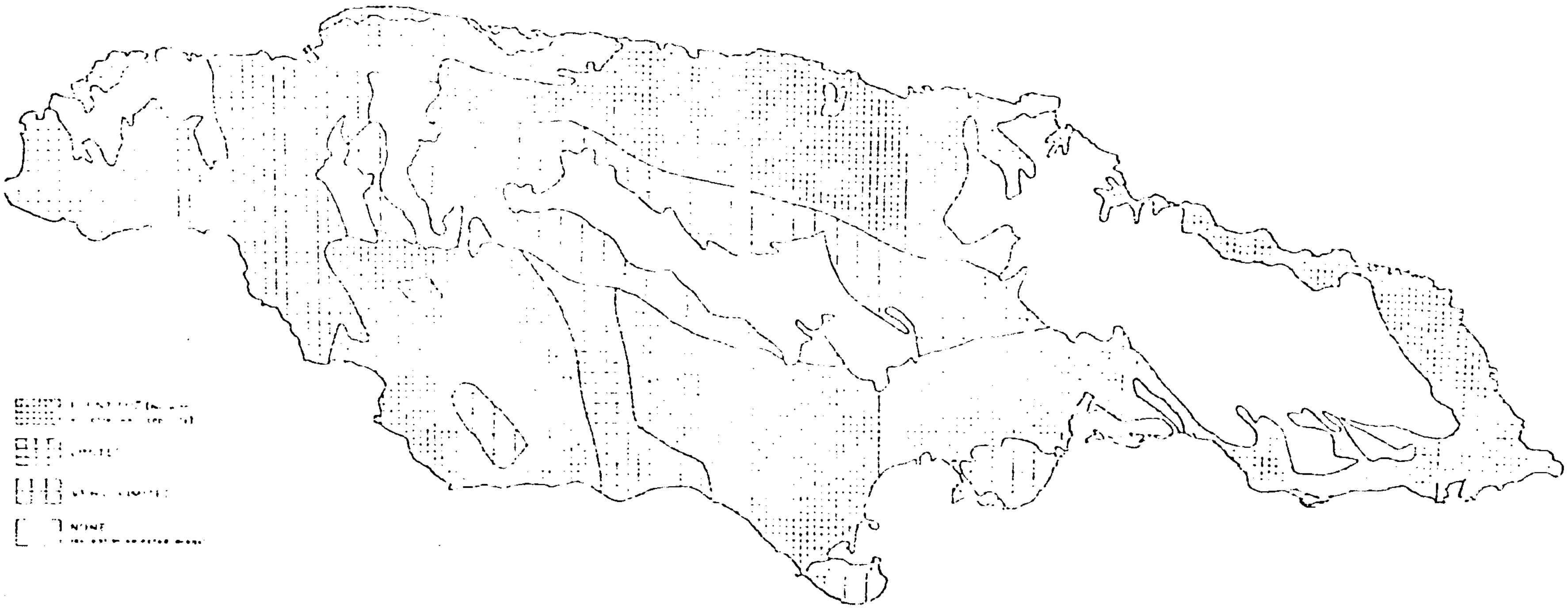


Table 10-11.

Existing Parish Council Irrigation Pumps

Parish	Pumping Facilities	Type of Pumps			
		Gravity	Diesel	Electric	Unspecified
Westmoreland	18	2	8	7	1
St. Elizabeth	9		3	5	
St. Ann	7			7	
Not Specified	6			6	

Parish	10 hp	10, 50	50, 100	100	Average Horsepower	Average Estimated Water Pumped per Facility (imp gal.)
Westmoreland	na	na	na	na	na	7.2 million
St. Elizabeth	-	3	3	3	83	11.5 million
St. Ann	-	3	1	3	98	6.1 million
Not Specified	-	1	2	3	120	8.8 million

(2) $I_C = f K_C K_T$

where f is the water consumption factor in inches

K_C is the crop cover coefficient

and K_T is the climatic coefficient.

The water consumption factor, f, is a function of the percentage of annual daylight hours occuring during the month, p, and the mean temperature, T, as shown in equation (3):

(3) $f = p\,T / 100$

The percentage of annual daylight hours for each month is assumed to be constant throughout the island as shown below. The mean temperature was determined from meteorological data for each region.

Month	Percentage of Annual Daylight Hours	Month	Percentage of Annual Daylight Hours
Jan.	7.9	July	9.2
Feb.	7.2	Aug.	8.8
March	8.4	Sept.	8.3
April	8.5	Oct.	8.2
May	9.1	Nov.	7.7
June	9.0	Dec.	7.9

The climatic coefficient, K_T, is determined from the regression equation:

(4) $K_T = .0173T - .314$

The crop cover coefficient, K_C, is determined from the leaf area of the plant, which in turn affects the evapotranspiration rate of the plant. This factor changes as the plant grows. For precise analysis, separate factors can be used for each month, but for the purposes of this analysis an average value has been used for each type of crop as shown below:

Crop	K_c
Banana	.83
Citrus	.60
Maize	.80
Pasture	.75
Sugar Cane	.90
Vegetables	.65
Rice	1.10

The effective rainfall, R_e, was obtained from the rainfall statistics collected over several decades by the Meteorological Department. Values for each region and each month are shown in Table 10.12. The results of the computation of net irrigation requirements are presented in Tables k.1, k.3, k.5, k.7, k.9, k.11, k.13, and k.15 for Rio Minho, Rio Cobre, Dry Harbour, Negril Basin, Bull Savanna, Pedro Plains and two sections of Martha Brae River basin, respectively.

The pumping requirements were determined by taking the daily pumping period and the average daily evapotranspiration rate and determining the flow rate required to meet this demand. The resulting relationship is shown in equation (5):

$$(5)\quad Q = (450E_t)/(e_1 t_1)$$

where E_t is the average daily evapotranspiration rate (inches/day)

Q is the pumping rate (gallons/minute/acre)

e_1 is the efficiency of the distribution system

and t_1 is the average daily pumping period (hours/day)

Sample values for the evapotranspiration rate, E_t, are shown in Table 10.13. The efficiency of the distribution system depends on the type of system. For a furrow system, the value of e_1 is between .55 and .65, for a sprinkler system, e_1 is between .6 and .75, and for drip irrigation systems e_1 is between .8 and .9. The average period of application was assumed to

Table 10.12.

Effective Rainfall at Eight Sites
(inches)

Month	Rio Minho	Rio Cobre	Dry Harbor	Negril Basin	Bull Savana	Pedro Plains	Martha Brae Valleys
Jan	1.0	3.2	1.4	1.0	1.5	2.4	2.3
Feb	.7	2.5	1.6	1.0	1.3	1.6	1.3
Mar	.7	2.0	2.2	1.3	1.6	1.4	1.7
April	1.2	2.5	3.3	2.2	2.5	1.0	2.3
May	2.7	4.1	5.0	3.5	3.2	4.4	5.8
June	2.7	2.8	4.6	2.9	2.5	3.2	4.5
July	.7	1.6	4.5	1.7	1.6	1.8	2.9
August	2.8	2.2	4.8	2.9	2.7	2.9	3.8
Sept	2.3	2.6	4.4	3.7	3.4	3.7	4.6
Oct	6.3	4.1	4.5	4.3	4.0	4.5	5.1
Nov	2.2	4.1	2.5	2.6	3.5	3.6	3.7
Dec	.7	4.1	1.8	1.5	1.6	3.9	3.5

Table 10.13

Daily and Yearly Exapotranspiration Rates

Crop	Et.* Ins./yr.	Et. Ins./day
	Clarendon	
Sugar cane	78.10	0.21
Pasture	81.60	0.22
Citrus	36.0	0.10
Bananas	63.6	0.17
Tobacco	40.8	0.11
	St. Catherine	
Sugar cane	65.17	0.18
Pasture	59.47	0.16
Rice (2 crops/yr)	56.20	0.15
Tobacco (Sept-Jan)	15.68	0.10
Vegetables (3 crops/yr)	55.0	0.15
	St. Elizabeth	
Corn (3 mths.)	19.2	0.21
Ground nuts (3 mths.)	18.3	0.20
Tobacco (4 mths.)	19.2	0.16
Rice (8 mths.)	69.5	0.27
Pasture	64.3	0.18
Vegetables	60.7	0.17

E.T. = Evapotranspiration Rate (a measure of the consumptive use of water).

Source: W. Boyne ref.

be 6 hours per day. The pumping flow rates in gallons per minute are shown for different crops in Tables k.2, k.4, k.6, k.8, k.10, k.12, k.14, and k.16 for the eight areas of study.

The power and energy requirements are determined by first calculating the number of hours required to provide the required net irrigation, I_N, given a flow rate Q. This calculation is shown in Equation 6.

$$(6) \qquad t_2 = (452\ I_N)/(e_1\ Q)$$

The constant 452 is used to convert the irrigation requirement in inches and the flow rate in gallons per minute into hours of pumping. The power requirements, P, are determined by multiplying the flow rate, Q, by the effective head, h, which includes a draw-down factor and distribution losses, and then dividing by the pump efficiency, e_2, as shown in equation (7)

$$(7) \qquad P = (Q\ h)/(3960\ e_2)$$

The constant 3960 is used to convert the results into horsepower. The efficiency of the pump depends on the type of pumping mechanism. For an electric motor and pump, e_2 is about .6. For an internal combustion engine and pump, the value of e_2 is .17. For a windmill, the efficiency of the pump only is assumed to be between .6 and .7. The draw-down factor and the distributional losses are assumed to add 20 feet to the value of the effective head.

The pressure requirements for horizontal pumping have not been included. For situations in which the pumps are used for horizontal pumping, the equivalent head, h, depends on the type of distribution. For sprinklers it is 100 feet, for furrow systems 30-50 feet and for drip irrigation 20 feet.* The

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* Based on private communication with Dr. Vaughn Nelson.

energy required for annual pumping is determined by simply multiplying the power requirement, P_1 by the annual period of operation, t_2, to obtain the answer in horsepower hours.

The power and energy requirements for irrigation pumping in different regions and for different crops are shown in Table 10.14. On average, the horsepower requirements are 1/4 horsepower per acre for the depths up to 20 meters assuming open trough irrigation. If drip irrigation is used then the power requirements average 1/3 horsepower per acre. When the depth increases to the range of 20-50 feet, the power requirements increase to an average of 4/9 horsepower per acre for trough irrigation and 1/2 horsepower per acre for drip irrigation. In the water depths ranging from 50 to 100 feet, the trough irrigation requires an average of 3/4 horsepower per acre whereas the drip irrigation requires 4/5 horsepower per acre. The higher values for the drip irrigation are due to the additional effective head required for horizontal pumping versus the trough system which is assumed to use gravity flow. The increase is not as great as it could be, since the efficiency of distribution with the system is higher. The average energy requirements during a year and the range for different crops and regions is computed in kilowatt hours as follows:

	Trough Irrigation		Drip Irrigation	
Depth	Average	Range	Avearage	Range
0-20	190	40-350	260	60-560
20-50	350	60-560	400	80-770
50-100	610	130-1010	610	130-1010

The monthly energy requirement will fluctuate with the net irrigation requirements over the year.

Table 10.14.

Typical Power and Energy Requirements by Region, Crop, Type of Irrigation and Depth

Type of Irrigation		Open Channel (e_1=7)						Drip e_1 = (.85)					
Depth		10		35		75		10		35		75	
Area	Crop	P	E	P	E	P	E	P	E	P	E	P	E
Rio Minho	sugarcane	.30	3.2	.59	5.8	.96	10.1	.42	4.4	.63	6.6	.96	10.1
	pasture	.32	2.4	.58	.4.3	1.01	7.5	.44	3.2	.66	4.8	1.01	7.4
	tobacco maize	.17	2.7	.30	5.0	.52	8.6	.23	3.7	.34	5.6	.52	8.6
	vegetable	.24	2.0	.44	3.6	.76	6.3	.33	2.7	.49	4.1	.76	6.3
Rio Cobre	sugarcane	.26	3.7	.48	6.9	.83	1.18	.36	5.1	.54	7.7	.83	1.18
	pasture	.24	2.6	.43	4.8	.74	8.3	.32	3.6	.48	5.1	.74	8.3
	tobacco	.15	1.2	.27	2.2	.47	3.8	.20	1.6	.30	2.5	.47	3.8
	vegetable	.22	2.1	.40	3.9	.69	6.7	.30	2.9	.45	4.4	.68	6.7
Dry Harbour	sugarcane	.30	2.5	.56	4.6	.96	7.9	.42	3.4	.63	5.1	.96	7.9
	pasture	.32	1.8	.59	3.3	1.02	5.7	.44	2.5	.67	3.7	1.02	5.7
	tobacco, maize	.16	2.0	.30	3.7	.51	6.4	.22	2.2	.33	4.8	.51	6.4
	vegetable	.25	1.2	.46	2.2	.79	3.8	.34	1.6	.51	2.5	.79	3.8
Bull Savannah	pasture	.26	2.4	.48	4.3	.83	7.5	.36	3.2	.54	4.9	.83	7.4
	maize, tobacco	.23	.9	.43	1.7	.75	2.9	.32	1.3	.48	1.9	.74	2.9
	vegetable	.25	1.8	.46	3.4	.79	5.8	.34	2.5	.51	3.8	.79	5.8
Negril	sugarcane	.30	2.0	.56	3.8	.96	6.6	.42	2.9	.63	4.3	.96	6.6
	pasture	.29	1.3	.53	2.4	.92	4.1	.40	1.8	.60	2.7	.92	4.1
	vegetable	.25	.8	.46	1.4	.79	2.5	.34	1.1	.51	1.6	.79	2.5
Pedro Plains	pasture	.26	3.7	.48	6.9	.83	11.8	.36	5.1	.54	7.7	.83	11.8
	tobacco, maize	.24	1.2	.43	2.1	.75	3.7	.32	1.6	.48	2.4	.74	3.6
	vegetable	.25	2.4	.46	4.4	.79	7.6	.34	3.3	.51	4.9	.79	7.6
Martha Brae	sugarcane	.30	1.1	.55	2.0	.96	3.5	.42	1.5	.63	2.3	.96	3.5
	pasture	.24	.4	.43	.7	.75	1.3	.32	.6	.48	.8	.74	1.3
	vegetable	.29	.6	.53	1.2	.92	2.0	.40	.9	.60	1.3	.92	2.0

Notes:

P in horsepower per acre.

E in 00's kw hours per acre per year.

Pump efficiency .65 for depths heads tor effective heads with gravity system open channel and horizontal pumping crip system. The following values were used:

System	Depth (ft)	10	25	75
Drip		50	75	115
Open Channel		30	55	95

The motivation beyond the rather laborious calculation is to determine the potential of using small irrigation pumps powered by windmills or gasifiers rather than electricity or petroleum based fuels. The windmill described in Chapter 8 would be suitable for irrigating an acre provided that the distribution of the wind during the year corresponded to the pumping requirements during the year. The options would include units irrigating from 1 to 10 acres. The important consideration for gasifiers would be the availability of residues at the time the irrigation is required. The field residues would only be available for a few months following the harvest. If a second crop were planted, then the gasifier could use the residues as fuel during the early stages of growth. However, for the full season it would be necessary to find a more continuous supply of fuel.

Assuming a rate of fuel consumption of 1.7 lbs. of air-dried wood per horsepower hour or about 2.3 lbs. per kilowatt hour, then the total quantity of fuelwood required per acre for a gasifier powered pump would be in the range of 140 to 1,300 lbs. for wells of less than 20 feet in depth. About double this quantity would be required for wells with depths in the range of 50-100 feet. Since residues have a lower heat value, the annual requirement per acre would be on the order 200-1800 lbs. per acre for the shallow wells and double this for the deeper wells.

Pumping technologies using wind or gasifiers would find their principal use in farms of 25 acres or less which currently account for about 35 percent of the total acreage. It is assumed that the use of these technologies will be restricted by local conditions including wind regimes, crop calendars, water table depths, cropping patterns and topology. They will also be restricted to current practices which rely vheavily on rain-fed agriculture or irrigation from rivers. Therefore, the initial uses will be relatively slow in growing, so that by 1988 at most 2 percent of the small farms or .7 percent of the total farm acreage would use either of these technologies. By 1992 this percentage might have doubled and by 1997 doubled again. However, it is not expected to account for more than 10 percent of the small farm lands or 3 1/2 percent of the total planted acreage during the next twenty years.

Chapter 11

Case Studies--Project Evaluation

This chapter concerns four case studies prepared by personnel from the Ministry of Mining and Energy and by project consultants. They were produced as assignments for a seminar on project evaluation. These four reports examine the economic and financial viability of establishing wind farms, dendro-thermal plants, ethanol distilleries and biogas digesters in Jamaica. These reports are preliminary efforts and some of the problems with their analyses are discussed below. However, they do point out those factors which are critical to the success or failure of these technologies. A summary of the implications of these studies is presented below. Copies of each report are included in the Appendices.

11.1. Problems of the Analyses

These evaluations were to be prepared in 1981 prices since the data being prepared for the National Energy Model was to be in 1981 prices. However, the biogas digester analysis was prepared in 1983 prices, the dendro-thermal plant analysis in 1981 prices, and the other two reports in a mix of 1981 and 1983 prices. The significant devaluation during 1983 and the threat of rapid inflation as a result of the devaluation have made it difficult to equate foreign and local cost. The financial conversion rate that was used for 1981 was 1.78:1 whereas the economic conversion rate (the shadow exchange rate) was 2.8:1. Thus the foreign exchange costs are underestimated in the financial analysis, but not in the economic analysis. This also affects the calculation of savings due to reduction in the consumption of petroleum fuels. For the biogas digester calculated in 1983 prices, the financial rate was set at 2.8:1 and the economic rate at 3:1. The local costs have not yet adjusted to the considerable inflationary impact of this devaluation so these are underestimated relative to foreign costs.

Since no experience or firm bids were available for estimating the cost of these technologies installed in Jamaica, it was necessary to estimate costs from secondary sources. In most cases these cost estimates are similar to those used in the previous chapters, but they are not identical since they were prepared at different times and for different purposes.

The analyses are in various stages of completeness due to the limited time available for their preparation and review. The most detailed evaluation was prepared for the biogas digesters since this report was also being prepared for use in a project. The least detailed report is for wind farms since the least preparation time was available.

The worth of these evaluations is that they provide a basis for further analysis. The basic assumptions have been set out, the financial and economic parameters have been defined (see Tables 11.1 to 11.3), and the economic base cases have been identified. The principal costs and benefits have been estimated and their relative importance to the project examined through the preparation of spread sheets. Revisions of these estimates or sensitivity analyses on major parameters can be carried out with relative ease using these same sheets. The use of sensitivity analysis is very important given the uncertainties associated with the costs for most of these projects, especially the labor and capital costs.

11.2. Implications of the Analyses

The analysis of the wind farm revealed several key factors. First, the capital and maintenance costs for the turbines are the dominant costs. The

TABLE - 11.1
Evaluation Planning Costs 1981

Fuels	Financial[1]	Economic[3]
	$ Jam./Imperial Gallon	$Jam.Imperial Gallon
Premium	4.65	2.70
Regular	4.55	2.60
Truck diesel	2.90	2.55
Kerosene	2.50	2.65
Bunker C	1.58	1.24

Labor[2]	Financial J$/Month	+ 20% Benefits	Economic
Supervisory-plant	2,000	2,400	2,400
-floor	1.400	1,680	1,680
Engineer	1,650	1,980	1,980
Skilled Labor	1,200	1,440	1,440
Semi-skilled labor	1,050	1,260	1,260
Unskilled urban labor	750	900	630
Unskilled rural labor	500	600	420

estimate

1. June 1981 Final selling price in Jamaica
2. 1980/81 JPS tariff
3. ex-Curacao refinery prices plus 15¢ /gal. ocean transport + 45¢ /gal. land distribution costs per kerosene, gasoline, diesel (0¢ for bunker C).
4. Consultant's estimate.

TABLE - 11.2

ECONOMIC EVALUATION FACTORS

1981 BASE YEAR

	Financial	Econimic
Foreign exchange	J$ 1.78 = US$1	J$ 2.8 = US$1
Discount rate	4%	11%
Electricity cost	25.5 ¢J/Kwhr	30 ¢ J/Kwhr
Cost of land	J$ 1000/acre	J$ 1000/acre

TABLE - 11.3

Cost Escalation Factors

	Jamaican $			US$ (F
	Capital, Equipment, Construction[1]	Labour[2]	Fuels[3]	Capital, Equipment, Construction[4]
1973	4.50	3.60		2.35
1974	3.55	2.75		1.90
1975	3.05	2.30	2.38	1.70
1976	2.75	2.05	2.49	1.60
1977	2.45	1.85	2.05	1.50
1978	1.85	1.45	2.16	1.40
1979	1.45	1.25	1.72	1.25
1980	1.15	1.07	1.20	1.09
1981	1.00	1.00	1.00	1.00
1982	.95	.93	.96	.98

1 based on CPI all items

2 based on GDP deflator

3 based on Bunker C prices f.o.b. ex Curacao

4 based on wholesale prices for industrial goods

5 based on average wages in manufacturing

6 based on medium fuel oil prices f.o.b. Singapo

costs for land and for the interface with the grid are relatively small. Second, the wind regime does not appear to be favorable for the larger turbines because of their higher starting speeds. The analysis was conducted for the Hellshire area where the wind speeds are reasonable but not strong. Also, no allowance was made in the analysis for the greater wind speeds at higher elevations in accordance with the "1/7 law" or for differences in the air density. Third, the smaller turbine, a 25 kW unit, was able to generate about 24 percent of its capacity during the year, whereas the 200 kW Carter unit was able to achieve only 11 percent of its capacity. Fourth, the monthly output varied by a factor of 5 from the minimum to the maximum for the 200 kW unit and by a factor of more than 3 for the 25 kW unit.

The conclusion of this analysis is that a wind farm using the larger turbines would be neither financially nor economically viable, but that a wind farm with the smaller units might be financially viable at the 4 percent discount rate though not economically viable at the 11 percent discount rate.

The analysis of the biogas digesters revealed that on farms with large quantities of livestock the generation of biogas as a substitute for certain petroleum-based fuels is both economically and financially viable. However, the selection of substitutable fuels depends on the assumptions about capital and labor costs and about the cost of petroleum fuels. Specifically, in the financial analysis, biogas cannot compete with kerosene at its subsidized price, but is always preferable to gasoline at its controlled price. In the economic analysis the border prices are about the same for gasoline, diesel and kerosene, so biogas can compete with kerosene. The costs for using biogas digesters are less for the plastic bag digesters than for the chinese (Brazilian) designs which use cement and fiberglass. This analysis is sensitive to the cost of labor. If the biogas digester is installed in such a way as to require no additional labor for material handling, then the biogas costs less in economic and financial terms than LPG, kerosene, diesel and gasoline. However, if labor must be hired for loading and unloading the digester, then the biogas costs more than petroleum fuels cost except for the most expensive, LPG and gasoline.

The results of the analysis are also sensitive to the capital costs per unit capacity which in the case of the plastic bags can vary by a factor of 50 percent depending on size. In the case of the chinese design, the capital cost can vary by a factor of 4 depending on the efficiency of construction.

The analysis of biogas digesters was limited to comparing the costs per delivered BTU for biogas and petroleum products. The differences in conversion efficiencies for various fuel-technology-end-use combinations have not been considered. It would be necessary to perform separate analyses for each end-use. If the biogas were to be used in a new application, it would be necessary to compare the system costs for the fuel and conversion technology. In shaft power applications the cost of the biogas digester would have to be added to the cost of a gas engine and then compared with gasoline and diesel engines. If existing end-use devices were to be used then allowances would have to be made for the costs of modifications and for possible capacity derating.

The evaluation of the ethanol distillery provided some useful insights into the sugar industry. The distillery was to be grafted to an existing mill by utilizing the existing boilers and cane crushers as well as the labor force from the mill. The analysis indicates that the high costs of labor and cane make it financially unviable to make either sugar or ethanol. This result may need to be revised since the analysis used the current fixed price for cane and the 1981 price for sugar converted at the 1.78:1 exchange rate. With the new exchange rate of 2.8:1 and the current f.o.b. price for sugar to the EEC of about US$280/ton of raw sugar, the income from the sugar would cover the cost of the cane, estimated to be between $500 and $600 per ton of raw sugar produced and the cost for mill labor, estimated to be J$125-150 per ton of raw sugar. However, the residual left for maintenance of the mill or for financing improvements to the out-dated equipment would be minimal.

Ethanol is less profitable than sugar since one ton of cane will produce about J$70 of ethanol and between $70 and $87 of raw sugar, in current prices. The two activities require about the same labor and quantity of bagasse for fuel. Since Jamaica is currently exporting less than it can sell under the EEC and USA quotas, it is able to maintain an inflated price for its sugar. However, if the sugar production were to increase to the levels of the 1960's or the subsidized EEC/USA price were to drop significantly, then the production of ethanol would be more profitable, i.e. generate a smaller loss, than milling sugar at the margin.

The analysis of the dendrothermal plants indicated that both the 3 and 10 Megawatt plants were financially viable but not economically viable. The internal rate of return in financial terms was 10 percent for both sizes. The reason that the plants were not economically viable is due to the higher discount rate used in economic analysis, and also to the assumptions used for the base case. First, it was assumed that if the dendrothermal plant were not built then an existing unit which would otherwise have been retired would be maintained for another 25 years. It is likely that such a unit would have to be replaced or renewed during this period at considerable capital cost.

Second, it was assumed that the labor from the older unit to be replaced could not be completely transferred to the dendro-thermal plant and that some of this work force would be absorbed into the existing multiple generator facility, even though its capacity was being reduced. Third and perhaps most important, there is a considerable cost for establishing a fuelwood plantation, over eight years, before any return is realized. It is possible that the wood cleared to establish the plantation could be used to fuel the dendro-thermal plant after the first few years of the project or that this wood could provide other benefits during the first eight years of the project.

The economic analysis points out that the savings in petroleum fuel are not enough to justify the establishment and operation of a fuelwood plantation and dendrothermal plant. It also points out that the maintenance costs for an old thermal plant are similar to those for a new dendrothermal plant because of the higher costs of material handling equipment in the latter.