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RENEWABLE ENERGY TECHNOLOGY

EXECUTIVE SUMMARY

meta systems inc

Executive Summary

REVIEW OF POTENTIAL FOR RENEWABLE ENERGY SOURCES IN JAMAICA

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Introduction

This report was prepared in response to a request by the Ministry of Mining and Energy for assistance in collecting data on the renewable energy resources and technologies which might be used to meet the energy demands of Jamaica over the next two decades. These data were to be used as input to the National Energy Model.*

This model predicts the mix of resources and technologies which will be used to provide energy in the different sectors of the Jamaican economy. It allocates demand based on the relative costs of the delivered energy from each of these resource-technology combinations. The input for the model is summarized in the data sheets appended to this volume. The other two volumes of this report focuses on: (1) the availability of the renewable energy 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 potenti l end-uses for the renewable energy resources include: 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

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* Since providing data for the National Energy Model is the report's primary objective, the data to be used in the model has been included as an annex to this volume.

commercial (grid), industrial and residential (auto-generation). The technologies which are used to convert the renewable resources into fuels or energy appropriate for the selected end-uses are shown as entries into the technology matching chart in Figure 1.

No attempt was made to relate the resource-technology combinations to specific demands, since, at the time of the study, no demand data was available due to a delay in the survey activities. Potential markets were examined and the maximum market penetration was estimated, but the allocation of demand was left to the machinations of the model. The model will also analyze the financial or economic viability of these technologies, (some preliminary study evaluations were prepared by the MME staff and are included in this report).

This study was prepared over a three-month period. Because of the breadth of the study (11 resources and 16 technologies) relative to the time available, this report has been submitted in draft form. If a more detailed examination of any one of the technologies is undertaken, it should be preceded by a re-examination of the data presented in this study.* To assist in this effort, the sources of the data have been carefully documented.

Review of Technologies

The technologies considered in this study range from well-established equipment such as mini-hydro, flat-plate collectors, charcoal kilns, wood-fired boilers and biogas digesters to prototype technologies such as

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* The analyses presented in the case studies made use of some of this data, however, sensitivity analysis was used to explore the uncertainties associated with the estimated costs for capital, operations and maintenance.

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								

solar ponds, concentrating-collector power towers, energy cane and OTEC. A classification of the technologies considered in this study according to the extent of their development is presented in Table 1.

Some of these technologies have a relatively high capital cost such as mini-hydro, wind farms and thermal-electric plants for solar collectors, peat, urban wastes, Ocean Thermal Electric Conversion (OTEC), wood and bagasse. Others are land-intensive such as fuelwood plantations, energy cane, solar ponds and distilleries for ethanol-from-sugar. Five of these technologies have relatively stringent site reqirements for site selection; they are solar ponds, OTEC/solar ponds, wind farms, min-hydro, and peat-fired thermal-electric plants. The most critical input requirements for the various technologies are presented in Table 2. This table includes the availability of raw material inputs which are an important factor in almost all of the technologies that require biomass as an input fuel, especially for bagasse, large quantities of wood and agricultural field residues.

The time required for establishing these technologies depends on the period required for planning, design, construction (or erection), and startup. Typical time periods for these activities are estimated for each technology in Table 3. In addition, estimates are presented for the time required to obtain approval to implement projects using these technologies. Small-scale technologies or those to be introduced by the private sector would require very little time for project approval. In contrast, large, expensive projects to be undertaken by the government, would require a considerably longer period for approval including time for feasibility studies. This is true for OTEC, solar pond, power towers, and peat-fired thermal-electric plants. It would also be true for large ethanol distilleries, even though distilleries already exist in Jamaica for the production of industrial ethanol. For this technology, the

Table 1. Current Status of Renewable Technologies

Resource	Conversion Technology	Prototypes	Applications	Widely Used
Water	Mini-hydro			X
Solar	Collectors			X
	Photovoltaics		X	
	Crop driers		X	
	Solar ponds	X		
	Power tower	X		
Wood	Wood stoves			X
	Charcoal kiln			X
	Dendrothermal-electric		X	
	Wood boilers			X
	Gasifiers		X	
Sugar cane	Energy cane	X		
	Ethanol distillery		X	
	Thermal electric		X	
	Biogas digesters		X	
Agricultural wastes	Gasifiers		X	
	Charcoal kiln		X	
	Direct combustion			X
	Biogas digesters		X	
Animal wastes	Biogas digesters			X
Wind	Wind turbines		X	
	Wind mills			X
Peat	Thermal electric		X	
Urban wastes	Thermal electric		X	
OTEC	Thermal electric	X		
OTEC/Solar pond	Thermal electric	X		

Table 2. Major Requirements for Renewable Technologies

Resource	Conversion Technology	Capital Investment	Land	Skilled Labor	Special Sites	Substitutable Fuel	Raw Material
Water	Mini-hydro	X			X		
Solar	Collectors					X	
	Photovoltaics	X					
	Crop driers					X	
	Solar ponds		X		X		
	Power tower	X	X	X			
Wood	Wood stoves						X
	Charcoal kiln					X	
	Dendrothermal-electric	X	X				
	Wood boilers					X	X
	Gasifiers	X					X
Sugar cane	Energy cane		X				
	Ethanol		X				X
	Thermal electric	X					X
	Biogas digesters	X					
Agricultural wastes	Gasifier						X
	Charcoal kiln						X
	Direct combustion					X	X
	Biogas digesters	X					
Animal wastes	Bio digesters						X
Wind	Wind turbines	X			X		X
	Wind mills				X		X
Peat	Thermal electric	X					X
Urban wastes	Thermal electric	X					X
OTEC	Thermal electric	X		X	X		
OTEC/Solar pond	Thermal electric	X	X	X	X		

Table 3. Time Required for Introduction of Technologies

		Initial Facility			Follow-on Facilities		
Resource	Conversion Technology	Project Approval	Planning and Design	Construction and Startup	Assess-ment	Planning & Design	Construction and Startup
Water	Mini-hydro	2	2	2-3	-	1	2
Solar	Collectors	a	a	a	-	-	1
	Photovoltaics	2	-	1	2	-	1
	Crop driers	-	1	1	1	1	1
	Solar ponds	2	1.5	2.5	2	1	2
	Power tower	5	2	1	3	1	1
Wood	Wood stoves*	-	-	1	2	-	1
	Charcoal kiln*	1	1	1	2	-	1
	Dendrothermal-electric	2	1	8	1	1	6
	Wood boilers	2	.5	.5	1	.5	.5
	Gasifiers	2	-	1	1	-	1
Sugar cane	Energy cane	3	1	2	2	1	2
	Ethanol	a	a	a	5	1	2
	Thermal electric	2	1	2	1	1	2
	Biogas	1	1.5	1	1	-	1
Agricultural wastes	Gasifier	2	-	1	1	-	1
	Charcoal kiln	1	1	1	2	-	1
	Direct combustion	1	1	1	1	1	1
	Biogas	1	1	1	2	1	1
Animal wastes	Biogas	1	1	1	2	1	1
Wind	Wind turbines	2	1	1	2	1	1
	Wind mills	1	1	1	1	1	1
Peat	Thermal electric	3	2	2	2	1	2
Urban wastes	Thermal electric	5	1	1	-	-	-
OTEC	Thermal electric	3	2	2	2	2	2
OTEC/Solar pond	Thermal electric	3	2	2	2	2	2

a = Already available

* = Improved models

delay would involve an analysis of the economics of ethanol as a substitute for gasoline and an examination of the problems of operating a larger distillery. The resource-technology combinations that would require the most time for implementation are: (1) dendrothermal electric plants, which must be preceded by the establishment of a fuelwood plantation, (2) power towers, which have yet to be proven as an effective technology, and (3) OTEC/solar ponds, which require an extensive geological and hydrological analysis as part of the site selection process. A more detailed consideration of the potential of each resource-technology combination to provide energy for Jamaica is presented below.

Hydropower

At present there are five hydro-electric facilities operating as part of the Jamaica Public Services (JPS) system. 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. They are expected to provide a total capacity of 22.1 megawatts and an annual output of 51.5 gigawatt hours. 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.

In the second phase of site identification ten more sites were identified as possible hydro-electric sites. Their total capacity is 19.5 megawatts with an expected annual output of 103 gigawatt-hours.* These facilities will

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

require an estimated investment of 45 million U.S. dollars. It 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.

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.

Solar

The level of solar insolation in Jamaica is similar to that of other islands on the same latitude, e.g., Puerto Rico and Hawaii. However, there is considerable variation in the availability of solar radiation throughout the island because the change in topology causes variation in rainfall and cloudiness.

Five technologies which make use of solar radiation as a source of energy were examined: 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. The units are 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 is only about 30 percent.

Crop driers are expected to have limited impact because their applications are generally limited to specific designs for small-scale applications. The use of solar crop drying is common in Jamaica, but is generally limited to

patio-drying with direct radiation. Since most large-scale crop drying is done using agricultural or processing residues for fuel, 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.

Photovoltaics continue to be too expensive to be considered for widespread use. Early expectations for a drop in the price to less than US$1 (1980 $'s) per peak watt have generally been discarded. The expectation now 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 US$10-20 per peak watt. High cost will restrict future applications to remote site applications, however most of the remote locations are in the upper elevations towards the center of the island and would not be appropriate because of the cloudiness and heavy precipitation.

The use of concentrating collectors and solar ponds for large-scale electricity generation are experimental technologies with limited applications world-wide. The major difficulty with establishing a power tower 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 limited availability of land and skilled labor. Both concentration collectors and solar ponds require considerable land areas in locations protected from high winds.

The selection of appropriate sites for solar ponds 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. A

5mW 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. Given the experimental nature of solar ponds and the difficulties discussed in the preliminary assessment by Dr. Tabor, 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.

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.

Biomass--Fuelwood

Some 44 percent of the island is covered with forests according to a 1970 FAO study but 45 percent of this is only scrub forest. Only seven percent of the island is covered in well-stocked natural forest and another one-half percent is covered with forest plantations, principally *Pinus caribaea* and *Hibiscus elatus*. All of the forest plantations and about 80 percent of the well-stocked forest are on government-owned land.

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 acquisition of large tracts of land is made more difficult by a rather cumbersome system of land registration. Two types of land that are considered as possible sites for planting trees are the dumping grounds of the bauxite mining companies and the peat bogs at Negril and Black River.

Three technologies that would require fuelwood plantations are dendrothermal electric-generation facilities, wood and charcoal boilers, and large-scale gasifiers. Another three technologies that could use fuelwood from existing forests as well as from plantations are wood cookstoves, charcoal kilns and small-scale gasifiers.

The wood-fired electricity plants would be located near to or within fuelwood plantations and would burn wood chips to produce steam. With a fuel consumption rate of 2.3 lbs. of air-dried wood per kilowatt hour, each megawatt of capacity would require about 1000 acres of fuelwood plantation.

Most of the requirements for heat or shaft power 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. Small to medium sized wood-fired boilers are generally available as package boilers at a cost of about US$50 per lb/hr of steam raising capacity.

Gasifiers fueled with wood or charcoal are attracting increasing interest throughout the world. In Jamaica large-scale gasifiers could be used with boilers. Another large-scale application is generating "clean" process heat for crop drying, ceramic firing and brick-making. Small-scale gasifiers could be used to fuel irrigation pumps and on-farm crop grinding equipment.

Fuelwood is used as a cooking fuel in about one-half 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. The cost of fuelwood will increase as supplies diminish and

this trend will encourage more efficient use of existing stoves as well as the purchase of more efficient stoves.

Charcoal is currently used as a cooking fuel in about one-third of Jamaican households and in a limited number of hotels, restaurants, and food shops (for barbecues, especially Jerk fish, chicken, and pork).

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. Still another household use is for heating water. Most of the water heated with wood or charcoal is used for drinking or for washing clothes. Charcoal is also used in a few industrial applications such as lead smelting for battery manufacture.

Two types of charcoal kilns are currently used in Jamaica. 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 generally in a configuration of two or more kilns and is moved only after many firings.

Of the wood-fueled technologies, those which appear likely to be used in the near-term are metal charcoal kilns, several of which are now in use around the island. If, in the medium term, fuelwood plantations can be established and regular supplies of fuelwood assured, then wood boilers will be attractive to industries currently using oil-fired boilers, assuming that the cost of the delivered fuelwood is less than the cost of the Bunker C replaced. Gasifiers would also be attractive for industries such as food processing and ceramics that require clean controllable process heat. Gasifiers and wood boilers may also be installed at sawmills where there are adequate residues and no alternative uses. For small-scale gasifiers, the primary use would be for

small-scale irrigation. 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 fuel distribution centers.

In the long term, it is expected that a dendrothermal generating facility will be established in conjunction with the fuelwood plantation. It is also likely that the increasing cost of collecting fuelwood will result in more efficient operation of existing cookstoves and the introduction of fuel-efficient stoves.

Biomass--Sugarcane

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. 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 then, their level of utilization has steadily declined as has their physical condition.

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 the dependency on fuel oil. The second involves burning 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 of sugar cane to produce ethanol. The fifth examines the use of the distillery wastes from rum-making to produce biogas.

The only two technologies that are expected to provide results in the short-term are fuel oil conservation and methane generation. There are plans to install air preheaters and superheaters on the boilers of some of the mills in order to improve their efficiency. 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 be upgraded to 300 psi and that multiple small boilers will be replaced with large boilers.

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.

In the medium term, it is possible that additional distilling capacity for industrial ethanol will be installed, but it is unlikely to exert a major impact on the use of petroleum fuels. Jamaica currently produces about 1.2 million proof gallons of hydrous ethanol for sale to industry at distilleries located in the Innswood and Monymusk mills. Since this production does not meet demand, additional quantities must be imported. A major problem with the distillation of fuel ethanol is that the costs of constructing and operating an ethanol plant and providing the cane are in excess of the market price of the ethanol which could be produced.

The logistics and timing of the current cane grinding activity make it unlikely that the sugar industry could generate electricity beyond that required for its own consumption. 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.

The growing of 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 labor shortages in the field. 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 have to be manually harvested and the fields could 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. The cost to produce the electricity generated would be relatively high for two reasons: (1) the cost of harvesting the cane accounts for about 40 to 45 percent of the total cost, and (2) the generating facility is used for only one-half of the year when the cane is available.

Biomass-Agricultural Wastes

Agricultural 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 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. 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. Charcoal used to be made 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 potential of corn cobs, coffee pulp or coffee hulls as feedstock for gasifiers is unlikely to be realized, 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.

Biomass-Animal Wastes

Anaerobic digesters are now available in a variety of configurations. Because of the costs of constructing a digester and the daily labor required for operation, these units have had limited success in residential applications. The most promising use is in those establishments which raise large numbers of cattle, pigs and chickens. These establishments produce enough dung to use larger digester and the marginal time required for handling the feedstock and the slurry is relatively small. 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.

These establishments would also have internal energy requirements which would consume the gas. 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 dairies, piggeries or chicken farms.

Wind

The two types of wind technologies 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.

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. Because of the intermittent nature of this type of generation, these units would require back-up capacity and could not be used for baseload demand. It is assumed that the first wind farm (if economically viable) would have about 7 megawatts nominal capacity and could be established by 1989.

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. Windmills are 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 water raised by windmills will be distributed through drip irrigation systems. The remainder will be distributed through unlined irrigation

canals. It is expected that at most 15-20 percent of the national irrigation needs could be met by windmills due to the distribution of farm sizes, the extent of electricity coverage, and the depths of the water table.

Peat

Jamaica has a number of peat bogs located along its shores. The potential of the largest morasses, those at Black River and Negril, has been studied for use in a thermal-electric facility. At the same time, the swamps are being considered for agricultural development and for the establishment of fuelwood plantations. The difficulty with using the peat is its high moisture content and low heat value. 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 the peat and the environmental impacts of mining the peat. The patio drying area required for a 40mW plant would be 1-1.5 square miles and the covered storage area would occupy an additional 15-25 acres.

It is unclear how the issues of drying and environmental impact can be resolved. If a decision is made to use the peat for electricity generation, then it is likely that a 40mW plant will be established at Negril because of its better fuel properties and less immediate environmental impacts.

Urban Waste Resources

A study by Delgor 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. The solid waste currently collected would be sufficient for a plant of 6-8mW. The expected collection of solid waste by 1990 would be sufficient for an 8-11mW plant and that for 2000 would be enough

for a 14-19mW plant. At the current time the cost for the generation facility is too high, however, in the future a larger plant might prove financially viable. The generation facilities have one major operational problem, the removal of the moisture in the fuel. During the rainy months, the moisture content would rise to 65 percent, while the solid wastes cannot be burned at moisture levels above 35 percent.

OTEC

The waters off of Jamaica have sufficient depth and temperature gradients to be used in the OTEC conversion process. 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.

At present there is no existing facility in the 10 to 40mW range so it is difficult to estimate the cost. The combination of OTEC and a solar pond would considerably improve the efficiency and thus reduce the size of the pumps and heat exchangers. However, construction of this pond would add US$1,950/$kW_e$ (including the cost of salt) to the cost of the facility. The annual costs for operation and maintenance of the different configurations were estimated to be J$.10 per kilowatt-hour send out for the OTEC plant and J$.09 for the OTEC/Solar Pond facility.

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

Further Work

The two volumes in this report include most of the readily accessible data on the potential for renewable energy technologies in Jamaica. However, this study effort involved only two man-months in Jamaica and one man-month for analysis and report preparation. The data presented in this report is clearly preliminary. Additional financial and economic analyses are required to evaluate different projects that would involve government financing or legislative support. As part of these evaluations sensitivity tests should be made by varying the capital and operational costs by the values shown in item 14.b on the data sheets at the end of this volume.

This study has provided insights into those areas which require further data collection. Clearly the existing site-specific solar and wind data are not adequate for evaluating the feasibility of wind turbines, concentrating collectors or crop driers. For both of these resources, the data on the availability over time must be augmented. The same is true for biomass fuels, especially agricultural residues and wood. The data on existing wood resources used in the FAO survey and the CRIES study is 13 years old and leaves considerable doubt as to what was the existing inventory, since so much of the wooded area was included in the "ruminate" category. While a thorough photogammetric survey is too expensive, it should be possible through sampling and sattelite-image analysis to produce a reasonable estimate of the current quantity and location of Jamaica's forest lands. Any additional analysis of the availability of agricultural residues should be based on the work of L. Nelson and Malcolm and Associates. From their work, it is possible to identify those residues that are readily available in concentrated form and have suitable fuel characteristics. The peat areas and the OTEC sites are

currently being studied so that better information on their potential will be available in the future.

Better information on the technologies is difficult to obtain. Most of the data in this report is largely from secondary sources. Most of the projects using these technologies are not at a stage where calls for tenders can be used to obtain more reasonable costs and technical data. The quality of most of the proposals submitted to the Jamaican government concerning the use of renewable energy technologies is relatively poor. Most do not include costs and have very little technical data. Those which do have technical data are not always correct in their assessment of the availability or quality of the renewable resources or the achievable conversion efficiencies of the technologies. A rather careful engineering and operational analysis is required before any of these proposals receives consideration by anyone at the ministerial level.

Annex 1

Model Data

The data to be used in the model is summarized in the following pages. A data sheet has been prepared for each resource-technology combination. The relationship between each combination and the model links is shown on the data sheet in Item 2. The capital costs have been specified in terms of local and foreign currency per unit capacity in Item 5. These costs are computed in terms of the appropriate unit capacity for that technology (e.g., horsepower for motors and engines) and in terms of the expected annual output in million Btu. This latter figure takes into account load factors, downtime of the technology, and intermittent availability of the resource. Information on special assumptions used for calculating these costs are presented in Item 14a. In general, these calculations were made directly from the cost data presented in the main volume of the study. The reliability of these cost estimates is indicated in Item 14b.

Most of the variable costs were included in the calculation of the fixed annual costs, Item 6. The exceptions are the costs for collecting or harvesting the resource, which are presented in Item 8. All costs were computed in 1981 U.S. and Jamaican dollars with an exchange rate of 1:1.78. For some of the technologies there is expected to be a reduction in cost with improvements in technology. These reductions have been included in the revised prices presented in Item 13 for the years 1987, 1992, 1997 and 2002.

The maximum market penetration is specified for 1987, 1992, 1997 and 2002 in Item 12, the potential markets which were identified in Item 11. Information on the constraints to the development of these resource technology combinations is presented separately for technical problems in Item 14c and for resource problems in Item 14d.

1. Resource-Technology-End Use: Water-Hydro Electric-Grid Electricity

2. Model Link: Hydro-mini hydro-grid electricity

3. Conversion coefficient: 1.0

4. Annual Output: 5 mW hr sendout per kilowatt

		per kilowatt	per million Btu/yr
UNITS (Capacity)		per kilowatt	per million Btu/yr
5. Unit capital Cost	US$	1,590	93.2
	J$	1,770	103.8
6. Unit annual costs:			
6a. O&M	US $	50	
	J $	223	
6b. Labor	J$	98	
7. Subtotal	US$	50	2.9
	J$	321	18.8
UNITS			
8. Unit variable costs	US$		
	J$		

9. Life of Equipment (years): 50 years

10. First year of implementation: 1987

11. Potential markets: JPS grid

12. Potential market penetration: current 15.2 Mw; 106.5 Mw/hr.

1987	141 Mwhr	1992	312 Mwhr
1997	356 Mwhr	2002	356 Mwhr

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: 6 skilled and 4 semi-skilled workers per installation, 24 hour operation

14b. Sensitivity of cost estimates: ± 15% phase I, ± 30% Phase II

14c. Major Technical Problems: Finish feasibility studies

14d. Major resource problems: Low water seasons

1. Resource-Technology-End Use: Solar-solar-collector water heating

2. Model Link: Solar, Solar/distillate backup--household and tourism water heating

3. Conversion coefficient: .3

4. Annual Output: _____

   UNITS (Capacity): Per Million Btu/yr

5. Unit capital Cost US$: _____
   J$: 548

6. Unit annual costs:
   6a. O&M US $: _____
   J $: _____
   6b. Labor J$: 11

7. Subtotal US$: _____
   J$: 11

   UNITS: _____

8. Unit variable costs US$: _____
   J$: _____

9. Life of Equipment (years): 15

10. First year of implementation: 1983

11. Potential markets: Supplement household & hotel distillate units

12. Potential market penetration

1987	10%	1992	30%
1997		2002	80% existing distillate heater demand
1997	50%		

13. Possible cost reductions:

1987	J$ 410	1992	J$ 275
1997	J$ 275	2002	J$ 275

14. Notes:

14a. Assumptions: Thermosyphon household unit J$4,800 with yield 8.4 mn BTU for median insolation; excludes cost of existing distillate system

14b. Sensitivity of cost estimates: ± 25%

14c. Major Technical Problems: Better collector covers and physical supports

14d. Major resource problems: Cloudy seasons or locations

1. Resource-Technology-End Use Solar-Solar collector-water heating

2. Model Link Solar--Solar/Electric Backup-household and tourism water heating

3. Conversion coefficient .3

4. Annual Output

UNITS (Capacity) per million Btu/yr

5. Unit capital Cost US$
J$ 548

6. Unit annual costs:
6a. O&M US $
J $ 11
6b. Labor J$

7. Subtotal US$
J$ 11

UNITS

8. Unit variable costs US$
J$

9. Life of Equipment (years) 15

10. First year of implementation 1983

11. Potential markets replace existing electric household and institutional systems

12. Potential market penetration

1987	20%	1992	40%
1997	60%	2002	80% of existing electric water heaters

13. Possible cost reductions:

1987	J$ 410	1992	J$ 275
1997	J$ 275	2002	J$ 275

14. Notes:
14a. Assumptions Same as with distillate back-up

14b. Sensitivity of cost estimates ± 25%

14c. Major Technical Problems Same as for solar/distillate

14d. Major resource problems

1. Resource-Technology-End Use Solar-Solar c[illegible]ector-water heating

2. Model Link Solar-Solar/LPG Backup-Household and Tourism water heating

3. Conversion coefficient .3

4. Annual Output 548

UNITS (Capacity) per million Btu/yr

5. Unit capital Cost US$ _____
J$ _____

6. Unit annual costs:
6a. O&M US $ _____
J $ 11
6b. Labor J$ _____

7. Subtotal US$ _____
J$ 11

UNITS _____

8. Unit variable costs US$ _____
J$ _____

9. Life of Equipment (years) 15

10. First year of implementation 1983

11. Potential markets Supplements household and hotel LPG units

12. Potential market penetration

1987	10%	1992	30%
1997	50%	2002	80% of LPG units

13. Possible cost reductions:

1987	J$410	1992	J$275
1997	J$275	2002	J$275

14. Notes:
14a. Assumptions Same as solar/distillate backup, excludes cost of existing LPG system

14b. Sensitivity of cost estimates ± 25%

14c. Major Technical Problems Better collector covers and supports

14d. Major resource problems Cloudy season

1. Resource-Technology-End Use: Solar-Photovoltaic pump-Irrigation

2. Model Link: Solar-Photovoltaic-Agric water pumping

3. Conversion coefficient: .1 x .6 = .06

4. Annual Output: 2.8 mn Btu/hp

	UNITS (Capacity)	per installed hp	per million Btu/yr
5.	Unit capital Cost US$	11,400	4,071
	J$	26,700	9,535
6.	Unit annual costs:		
	6a. O&M US $	570	
	J $	1,335	
	6b. Labor J$		
7.	Subtotal US$	570	203.6
	J$	1,335	476.8
	UNITS		
8.	Unit variable costs US$		
	J$		

9. Life of Equipment (years): 10

10. First year of implementation: 1985

11. Potential markets: Small area pumping; less than 50 ft depth

12. Potential market penetration

1987	.28 bn Btu	1992	2.8 bn Btu
1997	14 bn Btu	2002	20 bn Btu

13. Possible cost reductions:

1987	US$7650/J$21,000	1992	US$4,750/J$16,500
1997	US$3150/J$12,000	2002	US$3,150/J$12,000

14. Notes:

14a. Assumptions: Assume 1.5 peak watts per horsepower of pumping energy; 3,650 hours X .3

14b. Sensitivity of cost estimates: + 35%

14c. Major Technical Problems: Maintenance of cells and pumps

14d. Major resource problems: Seasonal availability of insolation

1. Resource-Technology-End Use: Solar-photovoltaics-electricity

2. Model Link: Solar-photovoltaics-electrical needs (household and agric.)

3. Conversion coefficient: .1

4. Annual Output: 3.7 mn Btu/kW

UNITS (Capacity)		per kilowatt	per million Btu/yr
5. Unit capital Cost	US$	7,500	1,995
	J$	17,800	4,734
6. Unit annual costs:			
6a. O&M	US $	375	
	J $	890	
6b. Labor	J$		
7. Subtotal	US$	375	99.7
	J$	890	236.7
UNITS			
8. Unit variable costs	US$		
	J$		

9. Life of Equipment (years): 20

10. First year of implementation: 1987

11. Potential markets: Rural households and farms away from grid

12. Potential market penetration

1987	.2 bn Btu	1992	.6 bn Btu
1997	1.2 bn Btu	2002	2 bn Btu

13. Possible cost reductions:

1987	US$5000/J$14000	1992	US$3000/J$11000
1997	US$2000/J$8000	2002	US$2000/J$8000

14. Notes:

14a. Assumptions: All balance of system costs in local currency; 50% renewal after 10 years

14b. Sensitivity of cost estimates: ± 50%

14c. Major Technical Problems: Reducing balance of system costs

14d. Major resource problems: land

1. Resource-Technology-End Use: Solar-photovoltaic-electricity

2. Model Link: Solar-photovoltaics--electric allocation

3. Conversion coefficient: .1

4. Annual Output: 3.7 mn Btu Kw

	UNITS (Capacity)	per kilowatt	per million Btu/yr
5.	Unit capital Cost US$	7,500	1,995
	J$	17,800	4,734
6.	Unit annual costs:		
	6a. O&M US $	375	
	J $	890	
	6b. Labor J$		
7.	Subtotal US$	375	99.7
	J$	890	236.7
	UNITS		
8.	Unit variable costs US$		
	J$		

9. Life of Equipment (years): 20

10. First year of implementation: 1990

11. Potential markets: Grid electricity

12. Potential market penetration

1987		1992	.4 bn Btu
1997	1.8 bn Btu	2002	3.6 bn Btu

13. Possible cost reductions:

1987	US$5000/J$14000	1992	US$3000/J$11000
1997	US$2000/J$8000	2002	US$2000/J$8000

14. Notes:

14a. Assumptions: All balance of system costs in local currency, 50% renewal after 10 years

14b. Sensitivity of cost estimates: ± 50%

14c. Major Technical Problems: Reducing balance of system costs

14d. Major resource problems: Land

1. Resource-Technology-End Use: Solar-power tower-grid electricity

2. Model Link: Solar-Thermal electric-electric allocation

3. Conversion coefficient: .2

4. Annual Output: 1.25 MWHR/kW

	UNITS (Capacity)	per kilowatt	per million Btu/yr
5.	Unit capital Cost US$	2,176	510.2
	J$	968	227.0
6.	Unit annual costs:		
	6a. O&M US $	62	
	J $	110	
	6b. Labor J$	74	
7.	Subtotal US$	62	14.5
	J$	184	43.1
	UNITS		
8.	Unit variable cos. J US$		
	J$		

9. Life of Equipment (years): 20

10. First year of implementation: 1990

11. Potential markets: JPS grid; steam for existing thermal electric plant

12. Potential market penetration

1987		1992	21 bn Btu
1997	42 bn Btu	2002	42 bn Btu

13. Possible cost reductions:

1987		1992	US$ 1,510
1997	US$ 1,510	2002	US$ 1,510

14. Notes:

14a. Assumptions: includes $650/kW cost of thermal plant based on 5MW facility

14b. Sensitivity of cost estimates: + 100%; -50%

14c. Major Technical Problems: Maintenance of concentrating collectors and tracking units

14d. Major resource problems: Land

1. Resource-Technology-End Use: Solar-Solar pond/thermal electric-electricity

2. Model Link: Solar-Solar pond-electricity allocation

3. Conversion coefficient: .18

4. Annual Output: 5.6 Mwhr sendout/kW

		per kilowatt	per million Btu/yr
UNITS (Capacity)		per kilowatt	per million Btu/yr
5. Unit capital Cost	US$	1,500	78.5
	J$	15,300	800
6. Unit annual costs:			
6a. O&M	US $	22.5	
	J $	40.1	
6b. Labor	J$	97	
7. Subtotal	US$	22.5	1.2
	J$	137.1	7.2
UNITS			
8. Unit variable costs	US$		
	J$		

9. Life of Equipment (years): 30

10. First year of implementation: 1992

11. Potential markets: JPS grid

12. Potential market penetration

1987		1992	38 bn Btu
1997	134 bn Btu	2002	230 bn Btu

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: baseload system of 5MW

14b. Sensitivity of cost estimates: ± 25%

14c. Major Technical Problems: Location of site, loss of salt and seepage of pond water

14d. Major resource problems: Salt, land

1. Resource-Technology-End Use: Fuelwood Plantation-dendrothermal plant-grid electricity

2. Model Link: industrial wood-dendrothermal-industrial elec allocation
also wood alloc.-dendrothermal-electric allocation
also industrial wood-dendrothermal-bauxite electricity

3. Conversion coefficient: .24

4. Annual Output: 5.9 sendout mwhrs/kW

	UNITS (Capacity)	per Kilowatt	per million Btu/yr
5.	Unit capital Cost US$	1,440	71.5
	J$	640	31.8
6.	Unit annual costs:		
	6a. O&M US $	36	
	J $	64	
	6b. Labor J$	166	
7.	Subtotal US$	36	1.8
	J$	130	6.5
	UNITS	per ton greenwood	per million BTU/yr
8.	Unit variable costs US$		
	J$	37.7	21.8

9. Life of Equipment (years): 25

10. First year of implementation: 1995

11. Potential markets: JPS grid

12. Potential market penetration

1987		1992	
1997	100 bn BTU	2002	200 bn BTU

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on 5 mw plant, variable cost includes harvest and transport costs

14b. Sensitivity of cost estimates ± 50% harvesting ± 20% electricity generation

14c. Major Technical Problems: Chipping

14d. Major resource problems: Large contiguous land areas

1. Resource-Technology-End Use: Wood-metal Kiln-Charcoal

2. Model Link: Wood Alloc-charcoal prod-household charcoal

3. Conversion coefficient: .47

4. Annual Output: 35 ton/yr/kiln

UNITS (Capacity)	per ton/yr	per million Btu/yr
5. Unit capital Cost US$		
J$	97.3	4.2
6. Unit annual costs:		
6a. O&M US $		
J $	4.9	
6b. Labor J$	238	
7. Subtotal US$		
J$	243.9	10.6
UNITS		
8. Unit variable costs US$		
J$	89	3.9

9. Life of Equipment (years): 5

10. First year of implementation: 1984

11. Potential markets: Household cooking and ironing

12. Potential market penetration

1987	5%	1992	25%
1997	30%	2002	50%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Feedstock from logging operation or sawmill; no feedstock cost, transport assumed 0

14b. Sensitivity of cost estimates: ± 25%

14c. Major Technical Problems: Local fabrication of metal kilns

14d. Major resource problems: Forest clearing operations

1. Resource-Technology-End Use Wood-Beehive charcoal kiln-charcoal

2. Model Link Wood Alloc.-charcoal production-industrial or commercial charcoal

3. Conversion coefficient .52

4. Annual Output 130 tons/kiln/yr

UNITS (Capacity)	per tons charcoal/yr	per million Btu/yr
5. Unit capital Cost US$		
J$	57.5	2.50
6. Unit annual costs:		
6a. O&M US $		
J $	3.5	
6b. Labor J$	38	
7. Subtotal US$		
J$	41.5	1.80
UNITS	per ton charcoal	per million Btu
8. Unit variable costs US$		
J$	74+222=296	12.90

9. Life of Equipment (years) 15

10. First year of implementation 1986

11. Potential markets Commercial and industrial charcoal

12. Potential market penetration

1987	15%	1992	50%
1997	80%	2002	80%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions Beehive kilns, large-scale production, continuous firings, fuelwood plantation, 23 mn Btu/ton, use initial clearings as feedstock, variable cost includes harvesting, transport, and bags

14b. Sensitivity of cost estimates ± 30%

14c. Major Technical Problems Continuous kiln firing

14d. Major resource problems Reliable source of wood, land for plantation

1. Resource-Technology-End Use: Charcoal-improved charcoal stove-cooking

2. Model Link: household charcoal-charcoal stove-cooking

3. Conversion coefficient: .22

4. Annual Output: 1.6 mn Btu/family/yr

UNITS (Capacity)	per improved stove	per million Btu/yr
5. Unit capital Cost US$		
J$	30	18.8
6. Unit annual costs:		
6a. O&M US $		
J $		
6b. Labor J$		
7. Subtotal US$		
J$		
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 5

10. First year of implementation: 1986

11. Potential markets: Household cooking

12. Potential market penetration (for existing and approved stoves)

1987	15%	1992	25%
1997	40%	2002	50%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Assume family of 5, 1.75 kg charcoal/day (2.5 with current models); 11,200 Btu/lb charcoal cost of charcoal not included

14b. Sensitivity of cost estimates ± 35%

14c. Major Technical Problems: The design and industrial production of improved stove

14d. Major resource problems:

1. Resource-Technology-End Use: Wood-improved wood stove-cooking

2. Model Link: Household wood-wood stove-cooking

3. Conversion coefficient: .16

4. Annual Output: 1.6 mn Btu/family/yr

		per unit	per million Btu/yr
UNITS (Capacity)		per unit	per million Btu/yr
5. Unit capital Cost	US$		
	J$	25	15.6
6. Unit annual costs:			
6a. O&M	US $		
	J $		
6b. Labor	J$		
7. Subtotal	US$		
	J$		
UNITS			
8. Unit variable costs	US$		
	J$		

9. Life of Equipment (years): 5

10. First year of implementation: 1987

11. Potential markets: Household cooking

12. Potential market penetration (for existing or improved wood stoves)

1987	27%	1992	35%
1997	35%	2002	35%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Average family 5 persons, 5 lb. air-dried fuelwood per day (7.6 with less efficient stove), 5,500 Btu/lb air-dried wood, cost of wood not included

14b. Sensitivity of cost estimates ± 30%

14c. Major Technical Problems: design of appropriate stove & dissemination

14d. Major resource problems:

1. Resource-Technology-End Use Charcoal-Stove/Iron-Ironing

2. Model Link Household charcoal-charcoal stove-ironing

3. Conversion coefficient .12

4. Annual Output .17 mn Btu/yr

UNITS (Capacity)	per iron	per million Btu/yr
5. Unit capital Cost US$		
J$	10	59
6. Unit annual costs:		
6a. O&M US $		
J $		
6b. Labor J$		
7. Subtotal US$		
J$		
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years) 3

10. First year of implementation 1983

11. Potential markets

12. Potential market penetration

1987	23%	1992	25%
1997	30%	2002	35%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions Existing iron uses 2.4 lb. per week; cost for charcoal not included

14b. Sensitivity of cost estimates ± 50%

14c. Major Technical Problems

14d. Major resource problems

1. Resource-Technology-End Use: Wood-Woodstove Iron-Ironing

2. Model Link: Household wood-wood stove iron-ironing

3. Conversion coefficient: .08

4. Annual Output: .17 mn Btu

UNITS (Capacity)	per iron	per million Btu/yr
5. Unit capital Cost US$		
J$	10	59
6. Unit annual costs:		
6a. O&M US $		
J $		
6b. Labor J$		
7. Subtotal US$		
J$		
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 3

10. First year of implementation: 1983

11. Potential markets: Household ironing

12. Potential market penetration

1987	60%	1992	60%
1997	60%	2002	60%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: No information, assume 7.5 lbs/family/week 5500 Btu/lb cost of wood not included

14b. Sensitivity of cost estimates: ± 50%

14c. Major Technical Problems:

14d. Major resource problems:

1. Resource-Technology-End Use: Wood-boiler-steam

2. Model Link: Industrial wood-boiler-indirect industrial heat

3. Conversion coefficient: .80

4. Annual Output: 2410 mnBtu/yr per 1000 lbs/yr steam

UNITS (Capacity)	per 1000 lbs/hr	per million Btu/yr
5. Unit capital Cost US$	55,000	22.8
J$		
6. Unit annual costs:		
6a. O&M US $	1,100	
J $	2,000	
6b. Labor J$	25,800	
7. Subtotal US$	1,100	.5
J$	27,800	11.5
UNITS	per 1,000/lbs steam	per mn Btu
8. Unit variable costs US$		
J$	8.4	7.0

9. Life of Equipment (years): 20

10. First year of implementation: 1988

11. Potential markets: Industrial process heat and shaft power

12. Potential market penetration

1987		1992	5%
1997	10%	2002	15%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on 1,000 lbs/hr package boiler, cost of fuelwood from plantation included, single shift operation

14b. Sensitivity of cost estimates: ± 30%

14c. Major Technical Problems: Supply of fuelwood and chipping

14d. Major resource problems: Land

1. Resource-Technology-End Use Charcoal-gasifier/boiler-steam

2. Model Link Industrial charcoal-gasifier/residential boiler-direct heat

3. Conversion coefficient .8

4. Annual Output 2,200 mn Btu/yr per 1000 lbs steam/hr

UNITS (Capacity)	per 1,000/lbs/hr	per million Btu/yr
5. Unit capital Cost US$	5,500	25.0
J$		
6. Unit annual costs:		
6a. O&M US $	1,080	
J $	1,910	
6b. Labor J$	32,380	
7. Subtotal US$	1,080	.5
J$	34,290	15.6
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years) 20

10. First year of implementation 1988

11. Potential markets Industrial steam

12. Potential market penetration

1987		1992	5%
1997	10%	2002	25%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions Includes cost of residential boiler, excludes cost of charcoal, based on 1000 lb/hr

14b. Sensitivity of cost estimates ± 30%

14c. Major Technical Problems Fuel preparation

14d. Major resource problems Charcoal

1. Resource-Technology-End Use: Wood-wood gasifier/boiler-steam

2. Model Link: Industrial wood-gasifier/residual boiler-direct heat

3. Conversion coefficient: .72

4. Annual Output: 2200 mn Btu/yr/1000 lbs/steam/hr

		per 1000 lbs/steam/hr	per million Btu/yr
UNITS (Capacity)		per 1000 lbs/steam/hr	per million Btu/yr
5. Unit capital Cost	US$	55,000	25
	J$		
6. Unit annual costs:			
6a. O&M	US $	1,080	
	J $	1,910	
6b. Labor	J$	32,380	
7. Subtotal	US$	1,080	.5
	J$	34,390	15.6
UNITS			
8. Unit variable costs	US$		
	J$		

9. Life of Equipment (years): 20

10. First year of implementation: 1988

11. Potential markets: Industrial steam

12. Potential market penetration

1987		1992	5%
1997	10%	2002	25%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Includes gasifier and boiler costs and conversion efficiency, excludes cost of fuel from plantation, based on 1,000 lbs/hr steam units

14b. Sensitivity of cost estimates: ± 25%

14c. Major Technical Problems: Fuel handling

14d. Major resource problems: Land

1. Resource-Technology-End Use: Wood-mound kiln-charcoal

2. Model Link: Wood alloc-charcoal production-household charcoal

3. Conversion coefficient: .35

4. Annual Output: 32 ton/kiln/yr; 717 mn Btu charcoal/yr

UNITS (Capacity)	per ton charcoal/yr	per million Btu/yr
5. Unit capital Cost US$		
J$	11.3	.5
6. Unit annual costs:		
6a. O&M US $		
J $	1.6	
6b. Labor J$	119	
7. Subtotal US$		
J$	120.6	5.2
UNITS	per gon charcoal	
8. Unit variable costs US$		
J$	89	3.9

9. Life of Equipment (years): 1

10. First year of implementation: 1983

11. Potential markets: Household cooking and ironing

12. Potential market penetration

1987	95%	1992	95%
1997	95%	2002	95%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Wood feedstock from forest

14b. Sensitivity of cost estimates: ± 25%

14c. Major Technical Problems:

14d. Major resource problems: Availability of natural forests

1. Resource-Technology-End Use: Wood-furnace-process heat

2. Model Link: Industrial wood-wood furnace-direct heat any fuel

3. Conversion coefficient: .7

4. Annual Output: _____

UNITS (Capacity): _____ per million Btu/yr

5. Unit capital Cost US$: _____ 7.6
J$: _____ .2

6. Unit annual costs:
6a. O&M US $: _____
J $: _____
6b. Labor J$: _____

7. Subtotal US$: _____ .16
J$: _____ 3.8

UNITS: _____ _____

8. Unit variable costs US$: _____ _____
J$: _____ 2.3

9. Life of Equipment (years): 20

10. First year of implementation: 1984

11. Potential markets: Industrial process heat

12. Potential market penetration
1987 _____ 1992 _____
1997 _____ 2002 _____

13. Possible cost reductions:
1987 _____ 1992 _____
1997 _____ 2002 _____

14. Notes:
14a. Assumptions: Assume 1/3 cost of a boiler, wood cost not included

14b. Sensitivity of cost estimates: ± 60%

14c. Major Technical Problems: Design of combustion chamber

14d. Major resource problems: Fuelwood/land

1. Resource-Technology-End Use: Wood-small gasifier/gasoline pump-irrigation

2. Model Link: Wood alloc-gasifier/gasoline pump-agric water pumping

3. Conversion coefficient: .13 (.17x.75)

4. Annual Output: 3.4 mn Btu/hP

UNITS (Capacity)	per hP	per million Btu/yr
5. Unit capital Cost US$	200	58.8
J$		
6. Unit annual costs:		
6a. O&M US $	3.5	
J $	6.3	
6b. Labor J$		
7. Subtotal US$	3.5	1.0
J$	6.3	1.9
UNITS	per hr operation	per million Btu
8. Unit variable costs US$		
J$	.9	140

9. Life of Equipment (years): 5

10. First year of implementation: 1985

11. Potential markets: Irrigation of farm land

12. Potential market penetration

1987		1992	
1997		2002	

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Estimated for 2-1/2 hp unit, variable cost is unskilled operating labor at 10 min/hr of operation

14b. Sensitivity of cost estimates ± 35%

14c. Major Technical Problems: Operating of engine, cleaning of gas

14d. Major resource problems: Wood (5/8 ton of wood per million Btu)

1. Resource-Technology-End Use: Sugar cane-distillery-ethanol

2. Model Link: Sugar syrup-ethanol feed alloc-ethanol feed prod.

3. Conversion coefficient: 15.5 imperial gal/ton cane

4. Annual Output: 12.5 mn Btu/yr per imp gal/day

	UNITS (Capacity)	per 1000 imp gal/yr	per million Btu/yr
5.	Unit capital Cost US$	1975	21.9
	J$	1440	16.0
6.	Unit annual costs:		
	6a. O&M US $	41.2	
	J $	73.6	
	6b. Labor J$	670	
7.	Subtotal US$	41.2	.5
	J$	743.6	8.3
	UNITS	per 1000 imp gallons	per million BTU
8.	Unit variable costs US$		
	J$	3550	39.4

9. Life of Equipment (years): 25

10. First year of implementation: 1991

11. Potential markets: Blending with gasoline up to 10% of total

12. Potential market penetration

1987		1992	10%
1997	20%	2002	20%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on a 3.7 mn imp gal/yr plant; sugar cane $55/ton

14b. Sensitivity of cost estimates: ± 25%

14c. Major Technical Problems:

14d. Major resource problems: Sugar cane

1. Resource-Technology-End Use Bagasse-Thermal electric facility-electricity

2. Model Link Bagasse-Thermal electric-industrial electricity

3. Conversion coefficient .215

4. Annual Output 3.3 Mwhr sendout per kW capacity

	UNITS (Capacity)	Per kW	per million Btu/yr
5.	Unit capital Cost US$	1600	142.1
	J$	712	63.2
6.	Unit annual costs:		
	6a. O&M US $	40	
	J $	71.2	
	6b. Labor J$	76	
7.	Subtotal US$	40	3.5
	J$	147.2	13.1
	UNITS		
8.	Unit variable costs US$		
	J$		

9. Life of Equipment (years) 20

10. First year of implementation 1989

11. Potential markets Sugar mill electricity requirements

12. Potential market penetration

1987		1992	
1997		2002	

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions Based on 1 Mw facility of installed at large (+400,000tpy) mill

14b. Sensitivity of cost estimates ± 20%

14c. Major Technical Problems Renewing mill to provide sufficient excess

14d. Major resource problems

1. Resource-Technology-End Use: Sugar cane-combustion-grinding

2. Model Link: Industrial bagasse-bagasse boiler-indirect heat

3. Conversion coefficient: .75

4. Annual Output: 3850 mn BTU per 1000 lbs/hr steam

	UNITS (Capacity)	per 1000 lbs/hr	per million Btu/yr
5.	Unit capital Cost US$	60,000	15.6
	J$		
6.	Unit annual costs:		
	6a. O&M US $	1,210	
	J $	2,200	
	6b. Labor J$	25,800	
7.	Subtotal US$	1,210	.3
	J$	28,000	7.3
	UNITS		
8.	Unit variable costs US$		
	J$		

9. Life of Equipment (years): 20

10. First year of implementation: 1984

11. Potential markets: Sugar mills

12. Potential market penetration (existing and renewed boilers

1987	80%	1992	90%
1997	95%	2002	95%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: For retrofitted mill, bagasse 3250 Btu/lb, boiler prices assumed 10% higher than for wood; 1.3 mn Btu steam (about 1,100 lbs) per ton of cane, 6 mo. 3-shift operation

14b. Sensitivity of cost estimates

14c. Major Technical Problems

14d. Major resource problems

1. Resource-Technology-End Use: Energy cane-thermal electric-electricity

2. Model Link: Industrial bagasse-thermal electric plant, elec. alloc.

3. Conversion coefficient: .22

4. Annual Output: 3.1 Mwhr sendout/kW

UNITS (Capacity)	per kW	per million Btu/yr
5. Unit capital Cost US$	1,466	138.6
J$	691	65.3
6. Unit annual costs:		
6a. O&M US $	37.1	
J $	66.1	
6b. Labor J$	89.5	
7. Subtotal US$	37.1	3.5
J$	155.6	14.7
UNITS	per mn Btu biomass	per million Btu
8. Unit variable costs US$		
J$	8.5	38.5

9. Life of Equipment (years): 20

10. First year of implementation: 1990

11. Potential markets: JPS grid electricity

12. Potential market penetration

1987		1992	10MW
1997	20MW	2002	20MW

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on 10 MW facility, $55/ton biomass harvesting cost

14b. Sensitivity of cost estimates: ± 25%

14c. Major Technical Problems: Manual or mechanical harvesting of all biomass

14d. Major resource problems: Land

1. Resource-Technology-End Use: Distillery wastes-biogas digester-methane

2. Model Link: Agricultural wastes-biogas digester-agricultural biogas

3. Conversion coefficient: No information

4. Annual Output: 454 mn BTU/1000 imp gallons dunda/day

UNITS (Capacity)	per 1,000 imperial gallon capacity	per million Btu/yr
5. Unit capital Cost US$	1,700	3.7
J$	45,400	1,000.0
6. Unit annual costs:		
6a. O&M US $		
J $	1,360	
6b. Labor J$	15,800	
7. Subtotal US$		
J$	17,160	41.8
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 20

10. First year of implementation: 1986

11. Potential markets: Distillery wastes

12. Potential market penetration

1987	1%	1992	50%
1997	90%	2002	

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Only 1 skilled labor, based on 10,000 imperial gallon units

14b. Sensitivity of cost estimates: ± 35%

14c. Major Technical Problems: Fabrication of digester

14d. Major resource problems:

1. Resource-Technology-End Use Agric process wastes-gasifier/engine-water pumping

2. Model Link Agric waste allocation-gasifier/engine-agric water pumping

3. Conversion coefficient .13

4. Annual Output 1.7 mn BTU/hp

UNITS (Capacity)	per horsepower	per million Btu/yr
5. Unit capital Cost US$	200	34.5
J$		
6. Unit annual costs:		
6a. O&M US $	3.5	
J $	6.3	
6b. Labor J$	--	
7. Subtotal US$	3.5	.6
J$	6.3	1.1
UNITS	per hour operation	per million BTU
8. Unit variable costs US$		
J$	.19	248

9. Life of Equipment (years) 5

10. First year of implementation 1985

11. Potential markets Agricultural irrigation

12. Potential market penetration

1987		1992	
1997		2002	

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions Estimated for 5 hp unit, variable cost of 15 minutes labor per hour of operation, residue available 6 months in the year, labor J$ 7.5 per hour

14b. Sensitivity of cost estimates ± 40%

14c. Major Technical Problems Combustion of biomass without slagging bridging, etc.

14d. Major resource problems Availability of residues

1. Resource-Technology-End Use: Agric process residues-biogas digester-agric bio

2. Model Link: Agric waste allocation-agric biogas production-industrial biogas

3. Conversion coefficient: _____

4. Annual Output: 130 ft^3 per yr per cubic foot capacity

UNITS (Capacity)	per 100 cubic ft capacity	per million Btu/yr
5. Unit capital Cost US$		
J$	1,520	216.5
6. Unit annual costs:		
6a. O&M US $		
J $	209	
6b. Labor J$	1,000	
7. Subtotal US$		
J$	1,209	172.2
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 12

10. First year of implementation: 1986

11. Potential markets: Boxing plants for bananas, processing plants for citrus, coffee, beans

12. Potential market penetration

1987	--	1992	140 mn BTU/yr
1997	350 mn BTU/yr	2002	700 mn BTU/yr

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on 1,060 ft^3 ($30m^3$), chinese design labor for 1 hr/day at J$5/hr

14b. Sensitivity of cost estimates: ± 40%

14c. Major Technical Problems: Material handling

14d. Major resource problems: Feedstock

1. Resource-Technology-End Use: Agric process wastes-charcoal kiln-charcoal

2. Model Link: Agric waste allocation-charcoal production-charcoal

3. Conversion coefficient: .55

4. Annual Output: 536 mn BTU charcoal/kiln

UNITS (Capacity)	per kilowatt	per million Btu/yr
5. Unit capital Cost US$		
J$	3,000	5.6
6. Unit annual costs:		
6a. O&M US $	--	
J $	150	
6b. Labor J$	--	
7. Subtotal US$	--	
J$	150	.3
UNITS	per ton charcoal	
8. Unit variable costs US$		
J$	149	6.7

9. Life of Equipment (years): 5

10. First year of implementation: 1986

11. Potential markets: Commercial charcoal

12. Potential market penetration

1987	1.5 bn BTU/yr	1992	15 bn BTU/yr
1997	30 bn BTU/yr	2002	50 bn BTU/yr

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Assume $6m^3$ metal kiln, unit costs include binder J$15/ton, biomass 3,250 BTU/lb., charcoal 11,200 BTU/lb. excludes cost of collecting biomass

14b. Sensitivity of cost estimates: ± 50 percent

14c. Major Technical Problems: binding and briquetting

14d. Major resource problems: Feedstock

1. Resource-Technology-End Use: Manure-biogas digester-biogas

2. Model Link: Animal wastes-agric biogas production-agric biogas

3. Conversion coefficient: .3

4. Annual Output: .07 mn BTU/ft ^{3} digester (130 cubic feet biogas)

UNITS (Capacity)	per 100 ft ^{3} of digester	per million Btu/yr
5. Unit capital Cost US$		
J$	510	72.9
6. Unit annual costs:		
6a. O&M US $		
J $	65	
6b. Labor J$		
7. Subtotal US$		
J$	65	9.3
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 8

10. First year of implementation: 1988

11. Potential markets: on-farm process heat and shaft power

12. Potential market penetration

1987	2 bn BTU	1992	28.6 bn BTU
1997	55 bn BTU	2002	95 bn BTU

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Plastic bag digester 30 m^3

14b. Sensitivity of cost estimates: ± 35%

14c. Major Technical Problems: Fabrication of bag

14d. Major resource problems: Feedstock

1. Resource-Technology-End Use Biogas-generating set-electricity

2. Model Link Agric biogas-on-site gas generator-agric. electricity

3. Conversion coefficient _____

4. Annual Output 2.2 Mwhr sendout/kW

UNITS (Capacity)	per kW	per million Btu/yr
5. Unit capital Cost US$	1000	133.2
J$		
6. Unit annual costs:		
6a. O&M US $	20	
J $	35.6	
6b. Labor J$	55	
7. Subtotal US$	20	2.7
J$	90.6	12.1
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years) 10

10. First year of implementation 1987

11. Potential markets On-farm electricity

12. Potential market penetration

1987		1992	2 bn Btu
1997	10 bn Btu	2002	40 bn Btu

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions Based on 25-50 kW unit, labor 1 hr/day at $5/hr 12 hrs/day, excludes cost of biogas

14b. Sensitivity of cost estimates ± 50%

14c. Major Technical Problems _____

14d. Major resource problems Supply of biogas

1. Resource-Technology-End Use: Peat-thermal electric-grid electricity

2. Model Link: Peat alloc-peat steam turbine-elec allocaton

3. Conversion coefficient: .24

4. Annual Output: 5.6 mwhr/kW

UNITS (Capacity)	per kW	per million Btu/yr
5. Unit capital Cost US$	1,857	97.2
J$	702	36.7
6. Unit annual costs:		
6a. O&M US $	24.9	
J $	44.4	
6b. Labor J$	35.8	
7. Subtotal US$	24.9	1.3
J$	80.2	4.2
UNITS	per ton @50% MC	per million But/yr
8. Unit variable costs US$		
J$	22.2	14.9

9. Life of Equipment (years): 30

10. First year of implementation: 1991

11. Potential markets: JPS grid

12. Potential market penetration

1987		1992	850 bn Btu
1997	1700 bn Btu	2002	1700 bn Btu

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on 40MW unit, estimated increase estimated harvest cost for 1/2 mn ton/yr by 20%

14b. Sensitivity of cost estimates: ± 50%

14c. Major Technical Problems: Drying peat

14d. Major resource problems: peat-filled wetlands

1. Resource-Technology-End Use: Solar-OTEC/thermal electric-electricity

2. Model Link: OTEC-electricity allocation

3. Conversion coefficient: .024

4. Annual Output: 6.75 MWHR per kilowatt

UNITS (Capacity)	per kilowatt	per million Btu/yr
5. Unit capital Cost US$	7,000	303.9
J$		
6. Unit annual costs:		
6a. O&M US $	164.5	
J $	292.8	
6b. Labor J$	17.1	
7. Subtotal US$	164.5	7.14
J$	309.9	13.5
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 30

10. First year of implementation: 1991

11. Potential markets: JPS grid

12. Potential market penetration

1987		1992	920 bn BTU
1997	920 bn BTU	2002	2,300 bn BTU

13. Possible cost reductions:

1987		1992	US$ 6,000
1997	US$ 5,000	2002	US $4,500

14. Notes:

14a. Assumptions: Based on 40 MW unit

14b. Sensitivity of cost estimates: ± 40%

14c. Major Technical Problems: biofouling, pump maintenance

14d. Major resource problems: ocean site with proper currents and depths

1. Resource-Technology-End Use: Solar-OTEC/Solar Pond Thermal Electric-electricit

2. Model Link: Solar Pond/OTEC-Electricity Allocation

3. Conversion coefficient: .115

4. Annual Output: 6.75 MWHR per kilowatt

UNITS (Capacity)	per kilowatt	per million Btu/yr
5. Unit capital Cost US$	5,500	238.8
J$		
6. Unit annual costs:		
6a. O&M US $	129.3	
J $	230.0	
6b. Labor J$	19.2	
7. Subtotal US$	129.3	5.6
J$	249.2	10.8
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 30

10. First year of implementation: 1991

11. Potential markets: JPS grid

12. Potential market penetration

1987		1992	10MW (230 bn BTU)
1997	460 bn BTU	2002	1,380 bn BTU

13. Possible cost reductions:

1987		1992	5,000
1997	4,500	2002	4,250

14. Notes:

14a. Assumptions: Assumed 40 MW plant

14b. Sensitivity of cost estimates: ± 40%

14c. Major Technical Problems: pump maintenance, pond maintenance

14d. Major resource problems: proximity of OTEC and solar pond sites

1. Resource-Technology-End Use: Urban Waste-Thermal Electric-Electricity

2. Model Link: Urban Waste-Steam Turbine - Electricity Allocation

3. Conversion coefficient: .21

4. Annual Output: 5.36 MWHR per kilowatt

UNITS (Capacity)	per kilowatt	per million Btu/yr
5. Unit capital Cost US$	3,264	178.5
J$	1,453	79.5
6. Unit annual costs:		
6a. O&M US $	51.5	
J $	165.4	
6b. Labor J$	46.9	
7. Subtotal US$	51.5	2.8
J$	212.3	11.6
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 30

10. First year of implementation: 1992

11. Potential markets:

12. Potential market penetration

1987		1992	12 MW 220 bn BTU
1997	220 bn BTU	2002	330 bn BTU

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on 12 MW plant, excludes cost of collect of waste or drying.

14b. Sensitivity of cost estimates: ±20%

14c. Major Technical Problems: Drying wastes, removing slag

14d. Major resource problems: Supply of feedstock

1. Resource-Technology-End Use: Wind-wind turbine-electricity

2. Model Link: wind-wind farm-electricity allocation

3. Conversion coefficient: --

4. Annual Output: 1.84 MWHR send out per kilowatt

UNITS (Capacity)	per kilowatt	per million Btu/yr
5. Unit capital Cost US$	1,200	191.1
J$	534	85
6. Unit annual costs:		
6a. O&M US $	20	
J $	71.2	
6b. Labor J$		
7. Subtotal US$	20	3.2
J$	71.2	11.34
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 15

10. First year of implementation: 1988

11. Potential markets: JPS grid

12. Potential market penetration

1987	27 bn BTU	1992	167 bn BTU
1997	447 bn BTU	2002	747 bn BTU

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Based on 200 kw units at Hellshire assuming 21 percent utilization.

14b. Sensitivity of cost estimates: ± 35%

14c. Major Technical Problems: Matching power curves to wind regime

14d. Major resource problems: Site with sufficient wind

1. Resource-Technology-End Use: Wind-windmills-irrigation

2. Model Link: wind-wind pump-water pumping

3. Conversion coefficient: (.163 x .8) = .13

4. Annual Output: .4 acre-ft per unit (30 ft depth) = 2.5 mn BTU/yr

UNITS (Capacity)	per unit	per million Btu/yr
5. Unit capital Cost US$	1,750	700
J$		
6. Unit annual costs:		
6a. O&M US $	29	
J $	104	
6b. Labor J$		
7. Subtotal US$	29	11.6
J$	104	41.6
UNITS		
8. Unit variable costs US$		
J$		

9. Life of Equipment (years): 20

10. First year of implementation: 1986

11. Potential markets: Small farm irrigation

12. Potential market penetration

1987	1%	1992	5%
1997	10%	2002	20%

13. Possible cost reductions:

1987		1992	
1997		2002	

14. Notes:

14a. Assumptions: Hypothetical 5m diameter rotor; excludes cost of holding pond (about J$ 200)

14b. Sensitivity of cost estimates: ± 50%

14c. Major Technical Problems: Maintenance of pumps

14d. Major resource problems: wind