BIBLIOGRAPHIC DATA SHEET

1. CONTROL NUMBER: PN-AAK-843

2. SUBJECT CLASSIFICATION (695): DA00-0000-G-23(

3. TITLE AND SUBTITLE (240)
Biomass for energy in Morocco; report to Office of Energy, Agency for International Development

4. PERSONAL AUTHORS (100)

5. CORPORATE AUTHORS (101)
USDA

6. DOCUMENT DATE (110): 1980

7. NUMBER OF PAGES (120): 120p.

8. ARC NUMBER (170)

9. REFERENCE ORGANIZATION (180): USDA

10. SUPPLEMENTARY NOTES (500)

11. ABSTRACT (950)

Morocco
energy

12. DESCRIPTORS (920)
energy needs
biomass
analysis
wood

13. PROJECT NUMBER (150)
—

14. CONTRACT NO.(140)
PASA AG/DSB-5709-6-79

15. CONTRACT TYPE (140)
—

16. TYPE OF DOCUMENT (160)
—

AID 590-7 (10-79)

PN-AAK-843

BIOMASS FOR ENERGY IN MOROCCO

REPORT
TO

OFFICE OF ENERGY
AGENCY FOR INTERNATIONAL DEVELOPMENT

BY

AID/USDA BIOENERGY TEAM
PASA NO. AG/DSB-5709-6-79

AUGUST 1980

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EXECUTIVE SUMMARY

The energy situation in Morocco is of grave concern to its Government. The needs for energy are growing while the balance-of-payments accounts is getting worse because of mounting fossil fuel imports.

Fossil fuels supply slightly less than 90% of Morocco's primary energy needs. Domestic coal production provides almost 30% of the primary energy and imported petroleum close to 60%. Domestic production of petroleum and natural gas accounts for only about 1.5% of the primary energy supply. Renewable energy sources, fuel wood and hydroelectric power account for slightly more than 10% of the primary energy supply.

Approximately one third of the primary energy supply is devoted to the production of electric power in thermal plants. About 12% of the petroleum consumption and 88% of the coal consumption in Morocco are for electric power production. The sources of electric power are as follows:

Thermal Power Plants	
Coal	32%
Petroleum	32%
Hydroelectric Plants	36%

Almost one-half of the petroleum consumed in Morocco, an amount equivalent to about 28% of the primary energy supply, is used for transportation purposes (gasoline, diesel fuel, aviation fuel). Another 30% of the petroleum consumed is fuel oil used in non-electric utility applications.

Approximately 9% of the petroleum consumed (5% of total primary energy supply) and 100% of the wood consumed (9% of the primary energy supply) are used for residential or commercial lighting, heating and cooking. (See also Figure IV-1, p. 38, and Table VI-1, p. 39).

In response to a request from the Government of Morocco, USAID has initiated a Renewable Energy Development Project which includes the establishment of a Renewable Energy Center in Marrakech. During a few weeks in July 1980, a team sent out by the Office of Energy, AID, visited Morocco in order to: (1) advise on biomass needs in facility design of the proposed Renewable Energy Center in Marrakech, and (2) assess the potential of forestry and agriculture biomass for energy production.

With respect to the production of biomass for energy, the team found that:

1. Animal waste was the only form of agriculture biomass to offer moderate near term potential for energy conversion. The maximum production of methane rich fuel gas from anaerobic digestion of all cattle manure would be equivalent to 10 percent of the quantity of oil now imported. If all manure from all herds with 10 or more head were digested, the quantity of methane would be equivalent to 4-5 percent of the oil imports.

2. Municipal solid waste from the larger cities in Morocco presents an opportunity for conversion to energy. For example, the city of Marrakech,

could produce some 9500 Nm^3 of biogas per day from anaerobic digestion. It is assumed that the other large cities will offer similar opportunities in pronortion to their populations.

3. The greatest opportunity for energy from biomass lay in the use of woody material either purposely grown in plantations of fast growing species under special regimes, or as residue from harvesting and processing forest products.

The Forest Service in Morocco has a tradition of planting trees, resulting in several hundred thousand hectares of plantations. The most promising group of species for fast growth of biomass were the eucalypts, with an average growth, the team was told, of $8m^3$/ha/yr. A preliminary economic appraisal of planting eucalyptus for biomass gave encouraging results, using present conditions. There are strong indications, however, that a combination of genetic tree improvement and special growing methods could at least double the growth of these plantations.

The problem with woody biomass lies in the identification of sites to establish plantations. These sites will probably be on land marginal for agriculture, either state-owned or collectively owned and with rainfall between 350 and 500 mm per year. Higher rainfall would make the site too good for biomass production and lower than 350 mm precipitation would lower the

production of biomass per hectare below the level of economic feasibility. If a planting program is contemplated, it should include the provision for compensating the people of the "communes" until the first harvest of wood has been sold. Also, a strong extension effort should be made.

An essential element for the success of a biomass for energy program is the effective cooperation and coordination between the Departments of Energy and Mines, Interior, and Agriculture. The team proposes a technical assistance project to increase the present area in plantations by 300,000 hectares in 10 years. This figure represents the team's best judgment but can be increased at will. The biomass from 300,000 hectares would fuel for example, at least 6 power plants of 25 megawatt capacity and make a significant contribution to the energy balance in Morocco by reducing the import of petroleum by nearly 10 percent.

The project proposal includes a component to help streamline the whole sequence of steps from seed collection to plantation tending in order to lower costs and increase the efficiency of labor. In addition, the optimum combinations of growth factors must be worked out for a range in planting site quality.

The project will require 3 resident specialists and some half dozen short term consultants, various pieces of equipment and academic training of 3 persons.

With respect to the conversion of biomass for energy, the team identified a number of tested conversion technologies which showed promise for implementation or adaptation in the next 10 years under Moroccan conditions:

High Potential

-Stationary internal combustion engines retrofitted with airblown gasifiers (irrigation pumping, electric power production).

-Portable metal kilns for charcoal making.

Moderate to High Potential

-Stoves for heating and cooking.

-Retrofitting existing oil-fired industrial boilers with airblown gasifiers.

-Retrofitting vehicles with gasifiers.

-Missouri Kilns for charcoal making.

-Densification of agricultural residues, sawdust, charcoal dust, etc.

Moderate Potential

-Methane fermentation of animal wastes and low lignin content vegetable or plant wastes.

(For other technologies of moderate and low potential see Tables IV-2 and 3).

Conventional ethanol fermentation processes using sugars or starches as feedstocks do not appear to have much near-term potential. Starch crops are not produced in quantities to supply both human food and energy needs. Utilization of lignocellulosic materials as feedstocks for ethanol has no near-term potential in Morocco because no suitable hydrolysis processes are now available for commercial use.

The following list indicates feasible development projects for biomass conversion in Morocco, covering a range of scale, complexity and cost. Local conditions will have to govern the choice of project to implement.

POTENTIAL BIOMASS CONVERSION PROJECTS (Table 4)

Combustion:

-Woodburning Stoves

Moderate/high near-term potential

Cost of $2000

Requires 3 dry metric tons/year (dmt/yr) wood

1 hectare tree plantation.

-Mass burning of biomass and wastes to produce steam; in shop fabricated boilers with grates or shop fabricated furnace with waste heat boiler.

Moderate near-term potential

Cost $300,000

Requires 2800 dmt/yr wood

875 hectares tree plantation

Field erected fluidized bed burners with waste heat boilers, producing steam, using olive pits, nut shells, waste wood

Moderate near-term potential

Cost $1,000,000

Requires about 9100 dmt/yr biomass from processing plant waste with high moisture content

-Biomass derived char/fuel oil slurry in an oil fired boiler

Moderate near-term potential

Cost $1,000,000 to 2,000,000

Requires about 16,000 dmt/yr wood

5,000 hectares tree plantation

Gasification

-Air-blown gasifiers to produce fuel gas for diesel electric generators in rural areas

High near-term potential

Cost $600,000 to $900,000 (250 Kw engine)

Requires 875 dmt/yr wood

274 hectares tree plantation

-Air-blown gasifiers on vehicles or trailers

Moderate/high near-term potential

Cost $5,000 - $10,000 (300 hp engine)

Requires 164 dmt/yr wood

51 hectares tree plantation

-Air-blown gasifiers to fuel existing oil fired industrial boilers

Moderate/high near-term potential

Cost $250,000

Requires 4030 dmt/yr wood

125 hectares tree plantation

Anaerobic Digestion

-Digester to produce methane rich fuel gas from shredded municipal solid waste

Moderate/high near-term potential

Cost about $1,500,000

Requires 9000 dmt/yr solid waste from Marrakech or same size city

-Digester to produce methane rich fuel gas from large farm or feedlot

Moderate near-term potential

Cost varies from $25,000 to $100,000

Requires 80 dmt/yr manure from 100 cattle

-Digester to produce methane rich fuel gas from small family run farms

Moderate near-term potential

Cost highly variable, up to $2000

Requires 8 dmt/yr manure from 10 cattle

Pyrolysis

-Portable metal kilns for charcoal production

High near-term potential

Cost less than $2000

Requires 288 dmt/yr wood

90 hectares tree plantation

-Missouri Kiln for charcoal production

Moderate/high near-term potential

Cost $10,000 to $15,000

Requires 1248 dmt/yr wood

390 hectares tree plantation

Densification

Densification equipment to produce fuel pellets or briquettes from agricultural residues, sawdust, charcoal dust, or crops like alfa

Moderate near-term potential

Cost up to $2,000,000

Requires $12,500 dmt/yr residue

For the Renewable Energy Center in Marrakech the team recommended 600-800 ft^2 of space to be allocated each for a thermochemical and mechanical processes laboratory and a chemical and biochemical processes laboratory, and provided an equipment list for each. In addition there should be 1000 ft^2 for a pilot plant and equipment testing area, and a 20 hectare remote site for large scale tests and some small demonstration plantings.

A training plan was developed for a lead engineer in each of the two laboratories to receive 1 year of academic training and 3-6 months of field training in the U.S. A chemist and a biochemist each should receive 6 to 12 months of academic training in the U.S.

The team emphasized that biomass production and conversion cannot be considered independently and must be integrated with any renewable energy plan.

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INTRODUCTION

1.1 Background

Morocco has become increasingly sensitive to its growing energy needs and the worsening of its balance-of-payments accounts caused by increasing fossil fuel imports. These concerns have been expressed to the donor community and USAID has responded by coordinating the development of a project paper on Renewable Energy Development including the establishment of a Renewable Energy Center in Marrakech. The purpose of this report is to indicate how a biomass for energy component could be added to the activities to be carried out by the Center. Background materials for this report are given in the list of references. This report is a further development of those background materials but with a sharper focus on the potentials of biomass for energy production and conversion technologies in Morocco. A statistical profile of Morocco and its resource base is given in Appendix A.

1.2 Objectives

The study team visited Morocco from July 12 to August 2, 1980. Jones stayed one week, Christophersen 2 and Hoekstra 3 weeks. Appendix B lists the contacts made during the visit. The objectives were as laid out in the cable traffic as follows:

A. Advise GOM and Mission on biomass needs in facility design of proposed Renewable Energy Center in Marrakech in coordination with C. T. Main. Team will deal with the range of biomass conversion technologies feasible in Morocco. Report will include staffing proposals, skill requirements, training needs, space needs for personnel and laboratory requirements, outside space for pilot plant tests, and equipment needs. Biomass projects will also be indicated for consideration by GOM and Mission.

B. Assess the potential of forestry and agriculture biomass for energy production. Consider integration of biomass production with appropriate technologies for energy conversion.

1.3 Problems

How can biomass alleviate the growing reliance on fossil fuel imports? Is there enough biomass produced to make a significant impact on energy use in Morocco? How is biomass converted to energy and what can be done in terms of improving old or introducing new conversion technologies. These are the basic problems with which this report is concerned.

Approximately 60% of the total primary energy demand in Morocco is met by oil of which 99% is imported, largely from Russia and the OPEC countries. Another 30% of the total primary demand is being met by coal and the remaining 10-11% by renewable resources, wood and hydro-electric power. Fossil fuel imports now account for more than 14% of total imports, up from 6.5% in 1973.

Cash outflows from energy imports also exceed cash inflows from phosphate exports which account for more than 50% of total exports. Morocco is the biggest phosphate exporter in the world (World Bank, 1978).

Table 1 shows the growth rates in energy production in Morocco. During the 1974-76 period, and in subsequent periods, production has declined while consumption has increased; hence, the necessity to increase imports and the renewed emphasis on and interest in alternative energy sources.

TABLE I-1 - ENERGY PRODUCTION GROWTH RATES, MOROCCO

Energy Production % 1974-76	.2
Energy Consumption % 1974-76	2.7
Per Cap. energy consumption 1960 (kg of coal equivalent)	148.
Per Cap. energy consumption 1976, (kg of coal equivalent)	273.

Source: World Development Indicators, World Bank, June 1979.

Although Morocco has discovered deposits of shale the economic feasibility of its development is not yet certain. Other alternatives, such as hydro, solar, wind and biomass are being considered in conjunction with the Renewable Energy Center project.

Natural gas reserves are projected to last for another 32 years and coal for another 50 years at current rates of consumption. The rate of consumption, however, is expected to increase by 10% per year, which will deplete the reserves much faster.

Morocco's forest resource base (see Appendix A) has the most promising biomass for energy potential. The biggest problem, however, is to keep the land continually in production. This is not happening because of excess harvesting in natural forests, grazing and general population pressures, and failure to reforest plantations that have been clearcut.

In the natural forests, harvesting takes place at a rate 5 times the annual growth. The result is a gradual decrease in standing forest capital and effective deforestation estimated at close to a total of 30,000 hectares per year overall.

The situation with respect to plantations for wood production for all purposes also is cause for concern:

REFORESTATION IN HA

	1976	1978
Eucalyptus	4,659	1,236
Other broadleaf	4,203	618
Conifers	10,677	2,278
	19,412 1/	4,132

1/ Only one half of this total survived.

Source: Royaume du Maroc, Rapport Annuel, 1978.

With some 200,000 hectares in eucalyptus plantations which are harvested after 30 years, at least 7,000 hectares must be planted each year in order to maintain the present plantation area.

The amount of fuelwood needed to meet projected requirements by the year 2000 for 83 developing countries, including Morocco, is addressed in the World Bank Renewable Energy Task Force Study (1980). In Morocco current fuelwood consumption is approximately 3 million m^3 annually which is projected to grow, in accordance with the projected population growth, to 6 million m^3 by the year 2000. In order to meet this projected increase, reforestation for fuelwood must increase by at least a factor of 2, according to the World Bank 1979 estimates.

II BIOMASS PRODUCTION PROBLEMS AND POTENTIALS

2.1 Introduction

Biomass conversion to energy must be preceded by the production of biomass. This is a truism but should be pointed out nevertheless because conversion and production of biomass fall into sharply distinct disciplines where the practitioner of one has little knowledge of the other.

The team looked into the potential for agriculture biomass and for forest biomass with the help of officials of the Department of Agriculture and USAID. It appears that the agricultural biomass potential offers some promise with respect to animal waste but is negligible in all other areas as is discussed in 2.8.

The forestry sector offers the only real opportunity for growing biomass for energy but this potential is clouded by steady deterioration of the forests in Morocco. We quote from Adams and Christophersen (1980 Review of Forestry needs in Morocco and recommendations for USAID involvement):

> "the problems are rooted in silvicultural, economic, management/ administrative, and other limitations. The potential increase in biological productivity from changing of silvicultural management is substantial, but is held back for lack of adequate budgets, qualified

manpower, and necessary resource information. Economic productivity of the forests is also deferred for lack of any economic analysis of the resources and their utilization."

Some details of the deforestation problems have already been discussed in 1.3.

It is difficult to separate general forestry concerns from those of woody biomass production. In a forest or plantation managed for multiple use, a portion of the harvest (some 25 percent) can be used as biomass for energy. This requires a rotation long enough for the individual stands to reach the size of poles, mine timber, pulpwood, or sawlogs. These products have a much higher value per cubic meter than biomass for energy or fuelwood. Plantations grown strictly for biomass can be grown at a much closer spacing than multiple use plantations, can be harvested at much shorter intervals, and will produce more cubic meters per hectare but the value of the product will be lower than the other products from a multiple use forests. For the purposes of this report, we discuss production of biomass only in terms of plantations--an economic analysis of biomass production in eucalyptus plantations is also given. It should be emphasized, however, that managing such plantations for multiple products may give greater economic returns.

2.2 Woody Biomass

There are a number of characteristics of woody biomass that should be considered if this feedstock is to be used for energy:

- It has to be grown over a relatively large area.

- It requires a relatively long time to produce, i.e. from growing seedlings in the nursery, to plantation establishment and harvesting. This sequence of events may take 4 to 15 years or longer depending on site productivity and species. It should be emphasized that a large scale effort of this kind requires professional skills and a competent organization.

-Production and harvesting of woody biomass can be done on a year round basis.

-Woody biomass is bulky and heavy and offers transportation problems. Drying the wood on the harvest site will reduce weight. Extreme reduction in weight is achieved by converting to charcoal.

-Wood may be burned in large pieces or it may be chipped, ground or made into charcoal depending on the requirements of the conversion process.

For the purposes of this report we shall recognize 3 levels of woody biomass consumption:

-Low. This is the household consumption level where wood or charcoal is used to cook food, heat the home, and for other household uses. Consumption per household probably ranges from a few cubic meters of wood to 15 or 20 per year. This is a dispersed use and can be met by dispersed production in small plantings, except where located close to population centers.

-Medium. This level of consumption corresponds to that of cottage industries, bakeries, bathhouses etc. Level of consumption would be on the order of 20 to 500 cubic meters per year per user. Production of wood must be fairly well under control in order to assure timely and dependable supply.

-High. This is the level of consumption associated with medium and large industry and utilities, which requires a large and steady supply of wood on a daily basis. Amounts involved would range from 500 to several thousand cubic meters of wood and more per industrial unit. This requires large plantations grown under precise control and located fairly close to the plant.

2.3 Land Available for Afforestation

If woody biomass is to play a role in the energy supply of Morocco much land will have to be planted with trees for that specific purpose. In

Dr. Wayne Murphey's report appended to "Morocco Energy Study", November/December 1978, submitted by the team headed by Mr. Alan B. Jacobs, Director, Office of Energy, AID/Washington, mention is made that "There are four million hectares of class four land. Such land is poor agricultural soil, but is deemed sufficient for growing trees". Class IV land is a U.S. Soil Conservation classification with the following partial definition: "Class IV land is fairly good land that is best maintained in perennial vegetation but can be cultivated occasionally or in a limited way if handled with great care." The team was not able to find where the estimate of 4 million hectares of Class IV land comes from.

In discussions with officials of the Directorate of Economics and Planning, Department of Agriculture, we learned that in Morocco there are 4,750,000 hectares of natural forests, 2,650,000 hectares of alfa,*/ and 20,900,000 hectares of forest range (see also Appendix A). They were of the opinion that the 4 million hectares of Class IV land might be found in the latter category.

In interviews with the Forest Service, it was pointed out that on State lands a change in land use from open range to fast-growing plantations would conflict with traditional grazing rights of local villagers who depend on sheep, goats, and/or cattle for their livelihood. Perhaps the

*/ Other official statistics put the area in alfa as high as 3,200,000 hectares.

solution would lie in increasing the carrying capacity of the range as the FAO-UNDP is doing with some measure of success. Thus some of the range could be converted to productive forests.

In an interview with officials of the Department of Interior a note of cautious optimism was sounded. In the opinion of the officials present there is a good chance that the "Communes" or local collectives will agree to change a portion of their range to fast growing plantations, if certain conditions are met: (1) the income from plantations exceeds the income from grazing by a considerable margin, and (2) provision is made, either in kind or in coin, for the feeding of the animals that are deprived by the change in land use. When asked, the following locations were suggested: South Chaouia in central west Morocco and the area of Guercif in the northeast.

2.4 Growth and Yield of Biomass Plantations

The growth of wood per hectare per year covers a wide range of values - from a fraction of a cubic meter in near-desert conditions to $45m^3$ on fertile bottom land with ample and well distributed rainfall in the north of Morocco (Zabielsky, 1977). However, we shall narrow this range from 5 to about $25m^3/ha/yr$ because higher production would be possible only on land better used for other purposes and lower production clearly would be uneconomical. These constraints would focus woody biomass potential on land marginal or less for agriculture but with at least 300-400 mm annual precipitation.

Few published growth and yield figures are available for the tree species growing in Morocco, either in natural forests or in plantations.

The best figures were obtained from Mr. C. Knockaert, a Belgian forester who has worked with the Forest Research Station for the past 8 years in the framework of bilateral aid. Mr. Knockaert, was kind enough to show us around the eucalyptus forests of Mamora.

From an article published in Annales de la Recherche Forestiere au Maroc (see References) by Mr. Knockaert, the following growth and yield figures for Eucalyptus camaldulensis are available:

Plot	Spacing	Age (years)	Mean Annual Growth/m3/ha/yr	Coppice	Total Volume (m3/ha)
Eupl 2	3x3m	52.5	10.7	None	565
Eupl 1/52	"	35	8.8	15 years	307
Eupl 1/50	"	33.9	8.4	"	283.8

These stands are growing on a site consisting of 40-80 cm sand of low fertility over-lying a clay layer and receiving 500 mm precipitation.

In a spacing experiment with Eucalyptus camaldulensis on a poor site with 120 cm sand over clay and 400 mm precipitation Mr. Knoeckart found the following growth figures after 8 years:

Spacing in m	Growth (m3/ha/yr)
0.5 x 0.5	11.13
0.75 x 0.75	11.34
1.00 x 1.00	9.45
1.50 x 1.50	6.15
1.50 x 3.00	5.65
3.00 x 3.00	4.09

On these sites the rainfall in the winter recharges the sand and clay layer underneath to field capacity and furnishes moisture to the tree root systems during the long dry summer.

We also saw Eucalyptus grandis growing at 15 m^3/ha/year on a good site with more rainfall although we did not receive precise data.

From Mr. Mandouri, soil scientist at the Forest Research Station, we received information about provenance testing and a fertilizer experiment with eucalyptus in Mamora Forest in the 500 mm rainfall zone. It seems that the Lake Albacutya (Australia) provenance shows a growth of 14 m^3/ha/year growth. Also, an experiment adding a complete fertilizer showed that in the first few years growth was increased by 25%, even when

the Lake Albacutya provenance was used. While these preliminary results are highly encouraging, the tests should be observed much longer and should be repeated at other locations before results can be considered dependable.

In general we were told at the Forest Service that a good average growth figure for eucalyptus would be $8m^3$/ha/year. Growth of the natural forests is estimated at less than $1m^3$/ha/year.

2.5 Potential of Woody Biomass

The team concluded that woody biomass has the potential to make a significant contribution to the energy budget in Morocco. In order to bring this potential to reality, however, a number of requirements must be met.

Any biomass for energy program in Morocco will not have a chance to succeed unless there is close cooperation between the Departments of Energy and Mines, Interior, and Agriculture. In fact, we reiterate here, in the strongest terms, the recommendation made by the Jacobs team in the 1978 report "Morocco Energy Study" for establishment of an Energy Council where all interested parties, including the above named Departments, will be represented.

The Department of Energy and Mines must determine the appropriate conversion technologies that will be developed and applied and further must provide projections as to the quantities of biomass needed in terms of time and location. It is understood that the Renewable Energy Center will play a lead role in this effort.

The Department of Interior's support is absolutely essential to promote establishment of biomass plantations of appropriate tree species on "commune" land.

The Department of Agriculture must function in two areas. Its Forest Service must provide the technical expertise for plantation establishment from seed collection to harvest. In addition, the Forest Service must carry out a program of tree improvement to increase yields per hectare, and achieve greater efficiency in all aspects of afforestation in order to lower costs. The Department of Agriculture's Extention Service will need to launch a strong effort among the people in the communes to gain their understanding of the benefits of biomass plantations and their active support of a planting program.

The three Departments in concert or perhaps as an Energy Council should approach bilateral or multilateral aid donors or lending agencies, about a program to compensate herders for the loss of grazing land until such a time that regular and adequate revenue from the established plantations becomes available.

The Government of Morocco needs some assistance in launching a program of woody biomass production and a project to that effect is detailed below.

2.6 Program to Produce Woody Biomass

In order to capitalize on the large potential in Morocco to grow woody biomass, a strong program is needed that will require cooperation and support among government institutions dealing with: the production of biomass, the land on which it is produced and the conversion of biomass to energy.

A program to grow woody biomass is, in fact, only a facet of a larger problem having to do with the deteriorating condition of all forests in Morocco. In this report attention will be focused on a program of growing biomass for energy in plantations of fast growing tree species.

The program we envision will have a two thrusts:

-an action program using presently available technology. It will consist of identifying areas for planting, both on State and collective land, growing the seedlings and establishing and tending the plantations.

-a development program streamlining the whole sequence of steps from seed collection to plantation tending in order to lower costs and increase

the efficiency of labor. In addition, for each quality of planting site the optimum combination of species, provenance, spacing, silvicultural treatment, and time of harvest should be worked out.

2.6.1 Action Program

Identifying planting sites on State land is obviously within the purview of the Direction des Eaux et Forets. There should be no problem identifying those hectares of planted production forests which were cleared but not reforested. An additional 7000 hectares must also be planted merely to maintain the area of planted production forest. Finally areas should be identified, preferably at a reasonable distance from population or industrial centers, that will be available for new plantations. It is realized that some conflict with grazing rights can be foreseen; however, there should be a considerable area where biomass plantations make a higher contribution to the "commune" or the nation than the present land use.

Identifying planting sites on collective land will be more complicated. Here the efforts of the Ministere de l'Interior will be needed to help select probable regions (see above) and to liaise with the collectives; the efforts of the extension arm of the Ministere de l'Agriculture will be needed to win the support and understanding of the people involved; the efforts of la Direction des Eaux et Forets will be needed to do the actual planting, tending and supervise the harvesting.

It is difficult to predict just how many acres will have to be planted as this is determined by many as yet unknown factors. The following is an estimate based on reasonable compromise between probable demand for woody biomass and an appraisal of the capabilities of the Forest Service to plant, given sufficient appropriations and personnel.

The proposed goal is establishment of 300,000 hectares of new biomass plantations in 10 years. Eaux et Forets has already demonstrated that it can plant 20,000 hectares (in 1976) and a significant increase will be a question of organization, appropriations and planning, using established technology.

The following schedule of planting should be used in planning:

Year	Hectares Planted
1	10,000
2	15,000
3	20,000
4	25,000
5	30,000
6	35,000
7	40,000
8	40,000
9	40,000
10	45,000
Total	300,000

For an estimate of what 300,000 hectares of plantations can contribute, see sections 4.4, 4.5, and Table IV-4.

2.6.2 Development Program

Concurrent with the Action Program it is proposed that a development program be undertaken with the Forest Service Experiment Station.

While present technology and capabilities of Forest Service will offer no problems carrying out a planting program of 20,000 hectares, a significant increase beyond that number will become a severe strain. For that reason and for economic considerations, it will be necessary to modify seed handling, nursery production and plantation establishment in order to raise the output per man/day as well as lower the costs of the operation.

Preliminary results from some tests on the use of certain provenances of *Eucalyptus camaldulensis*, application of fertilizer and effect of closer spacings on biomass production, show greater yields per hectare even on poor sites. This work should be diligently pursued. Of importance over a slightly longer term would be work in economic analysis, tree improvement, testing of direct seeding, use of soil improving species such as *Acacia mollissima* and natural regeneration.

2.7 Technical Assistance Project

If USAID were to consider a technical assistance project to help the GOM implement both the action and the development program, the following recommendations apply.

2.7.1 Technical Assistance for an Action Program

1 Resident Forestry Advisor. 5 years.

A forester experienced in running a large reforestation program with sound knowledge of nursery practices, and ability to plan, administer and motivate.

2.7.2 Technical Assistance for a Development Program

1 Resident Forest Research Advisor. 5 years.

An experienced forest researcher with a good background in reforestation research including a good knowledge of nursery research.

1 Resident Forest Research Advisor. 5 years.

An experienced researcher with a good background in tree improvement and a good knowledge of the silviculture of eucalyptus and species that tolerate semi-arid conditions.

2.7.3 Short-term Consultants in

Plant physiology
Nursery techniques

Biomass production
Forest and resource economics
Pathology
Entomology
Genetics 15 person months total

2.7.4 Equipment and Supplies

Seed handling equipment

1 Dybvig Seed Cleaner with variable speed motor Malcolm R. Dybvig 4007 Elmwood Avenue, Tillamook, Oregon 97141	$775
1 Crippen Model PS-S324 Tree Seed Scalper from R. W. McPherson 8 Assoc. P. O. Box 5011 Monroe, LA 71203	$4400
1 Crippen Model PS-C424 Tree Seed Cleaner Sizer	$6900
1 Oliver Model 30 Gravity Separator with motor Oliver Mfg. Co. P.O. Box 512 Rocky Ford, CO 81067	$2700
1 Burrows Model 400/245 Moisture Meter Burrows Equipment Co. 1316 North Sherman Avenue Evanston, Illinois	$ 230
1 Burrows Seed Blower with Large Seed Tube Set Burrows Equipment Co. 1316 Sherman Avenue Evanston, IL 60204	$ 850
200 Fiber Drums - Weatherpak, 24 gal. #WM2405-5X Continental Forest Industries Fibre Drum Division 1902 Leland, Suite 3 Marietta, GA 30067	$1382
2 Upright 10-12 cu. ft. capacity Refrigerators.	$1200

Germination Testing Equipment

1 Stultz Sr. Duplex Model 48 Cabinet Germinator	$8900
Purity analysis equipment	$ 90

Sample divider	$ 178
Low-power microscope	$ 500
Oven and scales for moisture measurement	$1100
Miscellaneous equipment:	$5000

Container Nursery Equipment

Specific equipment to be chosen by nursery consultant during visit to Morocco	$50,000

2.7.5 Host Country Participant Training

1 year of graduate study in forest nursery operations
Recommended: Oregon State University
University of Georgia
University of Florida

1 year of graduate study in seed technology with emphasis on germination testing and processing

Recommended: Mississippi State University
Oregon State University

1 year of graduate study in tree improvement with emphasis on species introduction, provenance testing and selective breeding.

Recommended: North Carolina State University
University of California at Berkeley
University of Texas
University of Idaho

6 months of non-academic training in reforestation. Participant will study reforestation programs on the ground moving from region to region with the planting season, starting in the fall with a gap in mid-winter, then picking up again in the spring. During the middle of winter observe planning, equipment, nurseries, organization, etc.

2.8 Agricultural Biomass

Discussions were held with officials of the Department of Agriculture to obtain their estimates of volumes produced in various categories to see

if possibilities exist for the production of energy. Precise figures were not obtained but these will be available from the proper official at the Department.

Agricultural Residues

-Straw is used and offers no opportunity for energy production.

-Cotton waste from the 15,000 ha planted is not enough to consider for energy conversion.

-Animal waste might offer some opportunities for energy conversion. There are 3.6 million goats in Morocco most of which are grazed on the open range and thus of no interest for energy. However, about half the cattle are grazed close to the farmstead and some 850,000 cows are stall fed.

Alfa grows on some 3 million hectares in eastern Morocco. Annually some 200,000 green tons of alfa are harvested. We heard conflicting reports on utilization of alfa: (a) 120,000 tons remain unused each year and (b) that every ton of harvested alfa is being used. This should be further investigated.

Bagasse from sugar mills is used to produce energy for those mills and the excess (25-35 percent) is briquetted and sold.

Sugar Crops. Morocco currently imports substantial quantities of sugar crops (sucrose) because sugarcane and sugarbeet production cannot satisfy the demand for sugar.

Sugarbeet production was 1,445,318 tons and 2,297,920 tons in 1977 and 1978 respectively. Energy use for processing is quite high; 52 kg. of fuel oil are used to process one ton of beets. About 20,000 metric tons of fuel oil were used by this industry in 1978 or 3 to 4 percent of the imported oil.

Starch Crops. Grain production is not sufficient to supply both food and energy needs.

2.9 Municipal Solid Waste

Municipal solid waste in the larger cities in Morocco is produced and collected in amounts sufficient to consider processing for energy.

III. PRELIMINARY ECONOMIC APPRAISAL

3.1 Introduction

Whether an investment in biomass production is worthwhile depends on the economic returns. If returns are positive; i.e., discounted benefits exceed discounted costs, the effort is said to be economically feasible. The following is a preliminary economic appraisal of biomass production from eucalyptus based on rather limited information. The analysis therefore, should be interpreted only as indicative of economic feasibility. Furthermore, it addresses only the "bankability" of biomass production and thus ignores shadow prices where they may be appropriate and also the variety of associated social benefits and costs, such as erosion control and general watershed management values, and displaced grazing costs. A social benefit/cost analysis is beyond the scope of this report.

3.2 Method of Analysis

The unit of analysis is one hectare. Three assumed land productivity classes are represented by differences in yields of 5.65, 8, and $10m^3/ha/yr$, or low, medium and high. The former is an empirical measure based on yet unpublished growth and yield studies carried out by Mr. C. Knockaert, (see 2.4). The latter two yield figures are assumed.

Without reporting the analytical details, the optimal economic spacing was found to be 1.5x3m based on Mr. Knockaert's stand density experiments, although the yields from the denser spacings were substantially higher. The 1.5x3m spacing density is assumed in the analysis presented below.

A net present value (NPV) criterion is employed to analyze the economic attractiveness of investments in biomass production under the three different yield assumptions.*/ IN NPV analysis projected net cash flows (benefits minus costs) are discounted to the present by an appropriate rate of discount.**/ A positive NPV suggests economic feasibility,

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*/ Had more detailed growth and yield information been available the more appropriate analytical framework would be the Faustmann (1849) mathematical method of compounding and discounting cash flows in analyzing forest investments.

**/ The mathematical formulation for the NPV in dirhams per hectare is expressed as:

$$NPV = \sum_{t=o}^{k} \frac{Rt-Ct}{(1+i)^t}$$

Where:

R_t = revenues received at time t in dirhams per hectare
C_t = costs incurred at time t in dirhams per hectare
t = time in years
k = length of the site occupancy in years
i = discount rate

particularly if the discount rate chosen equals or exceeds the opportunity cost of capital. The latter is defined as the highest rate of return obtainable from alternative investments.

The magnitudes of the NPV's depend primarily on the selected discount rate. The lower the discount rate the higher the NPV and the project appears more attractive. It is very important to note that the choice of a particular discount rate can make or break a project on economic grounds. Therefore, careful study of the interest rates prevailing in the urban as well as rural capital markets should be undertaken prior to selecting a discount rate. It should also be noted that the discount rates applicable to the rural poor will probably be significantly higher than the rates applicable to the government for similar types of activities. This is to reflect the aversion to risk typical of the rural poor who, by nature of their subsistence level of living, are reluctant to change from their usual ways to something of a more risky nature. For them, the promise of more distant future returns from investing in biomass production must be substantially higher than the immediate cash flow returns from their present employment.

A second decision concerning the discount rate is whether to use a real or a nominal rate. A real discount rate reflects the economic "attractiveness" of the project uncluttered by the influence of inflation. A nominal rate includes inflation. If the latter is used, then cost and benefit estimates must also be inflated for the project's duration. Since, however,

inflation rates are highly uncertain and variable between years, analyses based on nominal data are likely to be erroneous. For this reason, a range of real discount rates of 5, 7, and 9% are used in this analysis, or the equivalent of 17, 19, and 21% in nominal terms assuming 12% annual inflation.

A base case is constructed in the necessary detail around the $8m^3$/ha/yr assumption and the 7% real rate of discount which is assumed to be representative of the opportunity cost of capital in Morocco. The $8m^3$/ha/yr assumption represents land of medium quality capable of supporting some marginal agriculture but better suited for tree planting. Only the results will be reported for the 5.65 and $10m^3$/ha/yr assumptions.

3.3 Assumptions

1. Spacing density: 1.5x3m, number of seedlings required: 2222/ha.
2. Harvest schedules:

	m3/ha/yr		
Year:	low:	Medium:	High
11	5.65	8.0	10
23	5.65	8.0	10 Coppice
35	5.09	7.2	9 Coppice
47	4.52	6.4	8 Coppice

The final two coppice crops are 10 and 20 percent lower than the initial volume respectively.

3. Costs/ha 1980 (from Department of Reforestation)

-Site preparation	200 Dh
-Plowing	500 Dh
-Layout of plantation	75 Dh
-Fertilization at plant time	300 Dh
-Seedlings, 2222 @ .30 DH	667 Dh
-Transportation	634 Dh
-Weeding	
-Years 0, 11, 23, 35	400 Dh
-Years 1, 12, 24, 36	300 Dh
-Guard (every year)	30 Dh
-Other misc. costs (every year)	60 Dh

4. Stumpage value: 70 Dh/m3. For the sake of analytical simplicity, this assumption ignores other, probably more valuable uses of the biomass. At a 1.5x3m spacing the stems would be of the more valuable polewood size at rotation age.

5. Prices and costs held constant during period of analysis.

6. Real discount rates: 5%, 7%, 9%

3.4 Results

Table III-1 shows the behavior of the cash flows over the entire 47 year period for the $8m^3$/ha/yr yield alternative. The NPV at the 7% real rate of discount of 198 Dh/ha indicates that the plantation is economically sound given the assumptions. That is, if the 7% real rate of discount equals or exceeds the opportunity cost of capital then the investment is attractive since it returns more than that which can be expected from

TABLE III-1 PRELIMINARY ECONOMIC APPRAISAL
EUCALYPTUS PLANTATION YIELD $8m^3$/HA/YR 1.5x3M SPACING

COSTS	0	1	2-10	11	12	13-22	23	24	25-34	35	36	37-46	47
Site preparation	200												
Plowing	500												
Plantation Layout	75												
Fertilization	300												
Seedlings (a) 30 DH	667												
Transportation	634												
Weeding	400	300		400	300		400	300		400	300		
Guard	30	30	30	30	30	30	30	30	30	30	30	30	30
Other misc.	60	60	60	60	60	60	60	60	60	60	60	60	60
Total Costs	3,166	390	90	490	390	90	490	390	90	490	390	90	90
Revenues				6,720			6,720			6,048			5,376
Net Cash Flows	-3,166	-390	-90	6,230	-390	-90	6,230	-390	-90	5,558	-390	-90	5,286

NPV at 7% real rate of discount: +198 Dh/ha

alternative investments. If the 9% is the more appropriate discount rate, however, the NPV decreases to a negative 899 Dh per hectare, or an unacceptable investment (Table III-2). A 5% real rate of discount, of course, makes the investment most attractive.

TABLE III-2 NPV's UNDER ALTERNATIVE YIELD ASSUMPTIONS AND DISCOUNT RATES

Yield Assumptions	NPV in Dh		
	5%	7%	9%
$8m^3$/ha/yr	+1685	+ 198	- 899
$10m^3$/ha/yr	+3529	+1549	+ 81
$5.65m^3$/ha/yr	- 782	-1253	-2050

The land capable of producing $10m^3$/ha/yr under the 1.5x3m spacing generates positive NPV's for all three rates of discount. This land, however, is assumed to be fairly productive also for agricultural purposes and would thus be less available to produce woody biomass. The poor land, low rainfall areas, producing only 5.65 m^3/ha/yr generates negative NPV's for all three discount rates, as would be expected.

3.5 Sensitivity Analysis

Sensitivity analysis is the response of the NPV estimates to changes in the assumptions. Since economic inflows and outflows are all to occur in the future, circumstances may conspire to produce results different from the

analyst's best predictions. The purpose of the sensitivity analysis therefore, is to take these uncertainties and risk into account. In effect, it answers the questions: what if revenues and/or costs were to change during the course of the project; and how would such changes affect the NPV's? The resulting matrix (Table III-3) shows how NPV changes as costs and revenues are increased or decreased by increments of 10%. The zero column shows the NPV's obtained in the analysis of the base case, using the original assumptions.

TABLE III-3 SENSITIVITY ANALYSIS, CHANGES IN NET PRESENT VALUE
DISCOUNT RATE: 7%

	-30%	-20%	-10%	0%	+10%	+20%	+30%
				8m3/ha/yr			
Costs	+1762	+1242	+720	+198	-323	-844	-1360
Revenues	-1423	-883	-306	+198	+738	+1279	+1819
				10m3/ha/yr			
Costs	+3113	+2593	+2070	+1549	+1028	+506	-10
Revenues	-478	+198	+874	+1549	+2225	+2758	+3576
				5.65m3/ha/yr			
Costs	+174	-346	-868	-1253	-1910	-2432	-2947
Revenues	-2534	-2153	-1767	-1253	-991	-626	-245

The base case alternative ($8m^3$/ha/yr and 7% discount rate) becomes increasingly attractive as costs are decreased, or revenues are increased by increments of 10%. Cost increases or revenue decreases would immediately generate negative NPV's. The greatest potential for change in Morocco is

probably on the cost side, particularly in nursery management. It is not unrealistic to expect that nursery/seedling costs could be reduced by as much as 20 to 30% with changes in nursery management techniques. The potential for nursery improvements is documented by Adams and Christophersen (1980) and elsewhere, and is not discussed further in this report.

The $10m^3$/ha/yr alternative can stand nearly a 30% increase in costs, all other factors held constant, before the investment becomes infeasible. Revenues can be allowed to decrease by as much as 20% before NPV turns negative. For the low productivity land, $5.65m^3$/ha/yr, costs must decrease by a minimum of 30%, all other factors held constant, before the investment becomes feasible. Revenues must increase by more than 30% to ensure feasibility.

It should be noted again that this analysis only reflects the "bankability" of the project. There are indeed numerous other legitimate economic values of a non-quantifiable nature that should be weighed in the decision making process, particularly concerning the low productivity lands. It may be possible that the utilization of even the low productivity lands for biomass production is feasible from a national economic point of view (as opposed to from the investor's point of view) when appropriate shadow prices and other factors are taken into account.

IV. CONVERSION TECHNOLOGIES FOR PRODUCING FUELS AND ENERGY FROM BIOMASS

4.1 Introduction:

The selection of specific conversion processes that are suitable for Morocco has been based on consideration of the following factors:

-Current energy production and consumption patterns in Morocco and the goal to reduce imports of petroleum and refined products;

-Status of development of technologies (in Morocco and worldwide) for biomass conversion to energy;

-Current and projected biomass availability for energy;

-Other potential energy resources (renewable and nonrenewable) in Morocco; and

-The desire of the Moroccan government to improve the living conditions in the rural areas through rural electrification programs and other energy related programs.

In addition to the selection of specific biomass conversion processes for use in Morocco, this section also includes a discussion of environmental

considerations associated with the conversion processes, descriptions of laboratory and pilot plant space and equipment needs, personnel skills and training requirements, plus a list of projects to be considered by the Moroccan government for near-term implementation.

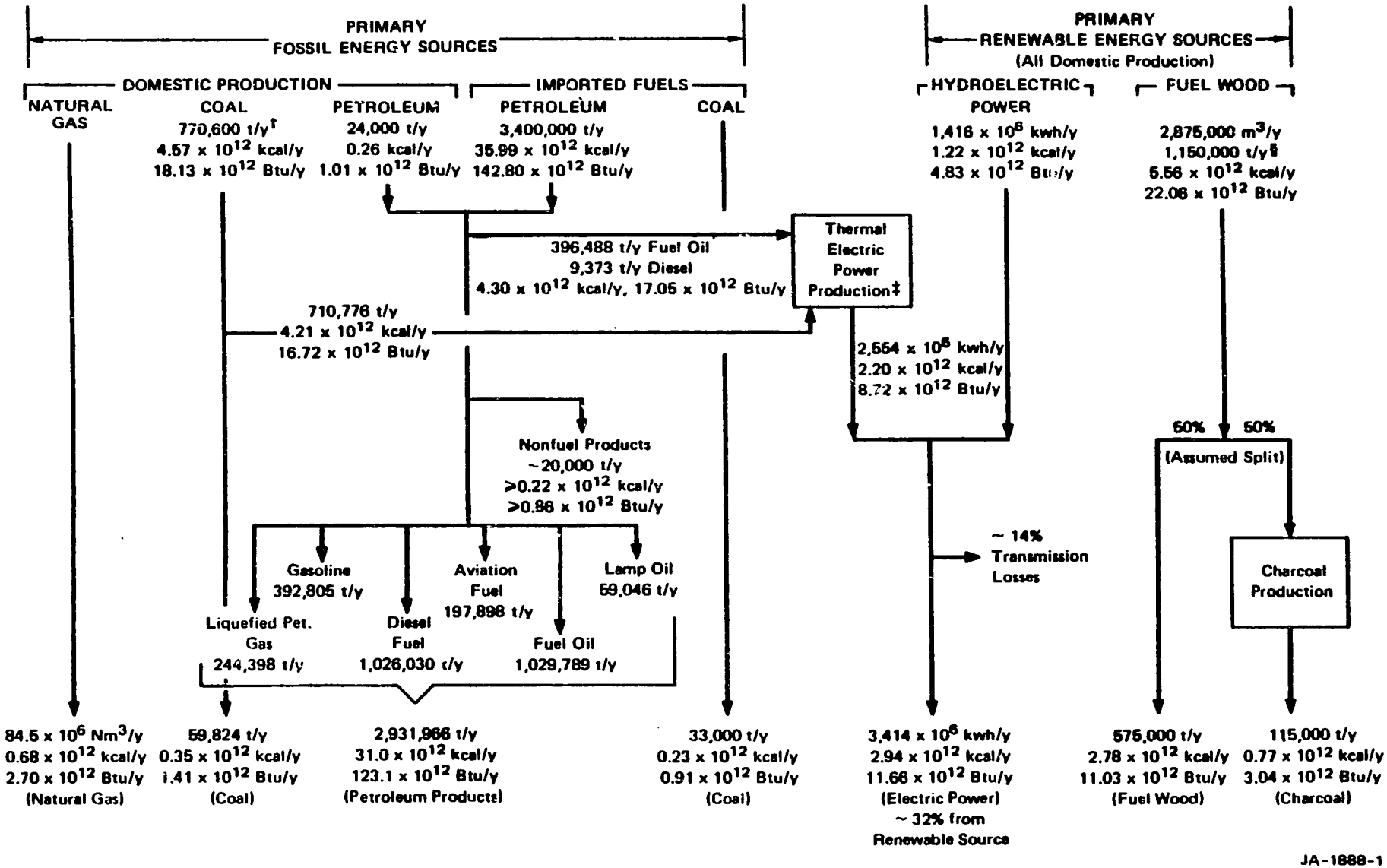
4.2 Current Energy Sources for Morocco:

Primary energy sources for Morocco are summarized in Figure IV-1 and major fuel for energy products are shown. The data presented in Figure IV-1 are tabulated in Table IV-1 in terms of domestic and imported sources of fossil and renewable primary energy sources.

Fossil fuels supply slightly less than 90% of Morocco's primary energy needs. Domestic coal production provides almost 30% of the primary energy and imported petroleum close to 60%. Domestic production of petroleum and natural gas accounts for only about 1.5% of the primary energy supply. Renewable energy sources, fuel wood and hydroelectric power account for slightly more than 10% of the primary energy supply.

Approximately one third of the primary energy supply is devoted to the production of electric power in thermal plants. About 12% of the petroleum consumption and 88% of the coal consumption in Morocco are for electric power production. The sources of electric power are as follows:

Thermal Power Plants	
Coal	32%
Petroleum	32%
Hydroelectric Plants	36%



*Adapted from data presented in Activite Du Secteur Energetique — 1978, Ministere De L'Energie Et Des Mines and FAO reports on fuel wood use in Morocco.

†Tonnage figures for all fuels reported in metric tons.

‡Average thermal efficiency calculated to be ~26% based on higher heating value of input fossil fuel. Electric power output expressed in actual energy equivalent, not as fossil fuel equivalent to generate power.

§Dry tonnage basis used. Charcoal yield assumed to be 20 wt% on a dry basis.

FIGURE IV-1 ESTIMATES OF PRIMARY ENERGY SOURCES FOR MOROCCO (1978)*

TABLE IV-1
Approximate Values for Primary
Energy Sources for Morocco
(1978 Data)

	10^{12} kcal/yr
Fossil Fuels	
Domestic Sources	
Coal	18.13 (29.1%)
Petroleum	0.24 (0.4%)
Natural Gas	0.68 (1.1%)
Subtotal	19.05
Imported Sources	
Coal	0.24 (2.0%)
Petroleum	36.00 (58.0%)
Subtotal	36.23
Renewable Energy	
Domestic Sources	
Hydro Electric Power	1.22 (2.0%)*
Fuel Wood	5.56 (9.0%)
Subtotal	6.78
TOTAL	62.06 (100%)

*Energy value of hydroelectric power calculated based on 1kwh = 3413 Btu = 860 kcal, not on the basis of the fossil fuel equivalent required to generate the power in a thermal power plant.

Almost one half of the petroleum consumed in Morocco, an amount equivalent to about 28% of the primary energy supply, is used for transportation purposes (gasoline, diesel fuel, aviation fuel). Another 30% of the petroleum consumed is fuel oil used in non-electric utility applications.

Approximately 9% of the petroleum consumed (5% of total primary energy supply) and 100% of the wood consumed (9% of the primary energy supply) are used for residential or commercial lighting, heating and cooking. In the case of wood, it has been assumed that about 50% of harvested fuel wood is converted to charcoal with a 20 wt % yield (dry basis) of charcoal from wood.

4.3 Conversion Technologies Applicable in Morocco

The many types of conversion processes now used or under development for biomass conversion to energy have been classified into two categories as (1) thermochemical and mechanical processes or (2) chemical and biochemical processes. These are displayed in Figure IV-2. The thermochemical processes operate at high temperatures and typically use biomass feedstocks with low to moderate moisture content (10-50 wt % H_2O). Biochemical processes utilize microorganisms (bacteria, yeast, fungi), to convert biomass and typically operate at relatively low temperatures (20° to 60^oC) with the biomass dissolved or dispersed in water. The important chemical characteristics of biomass and brief descriptions of thermochemical and mechanical technologies, and chemical and biochemical conversion technologies are given in Appendix C.

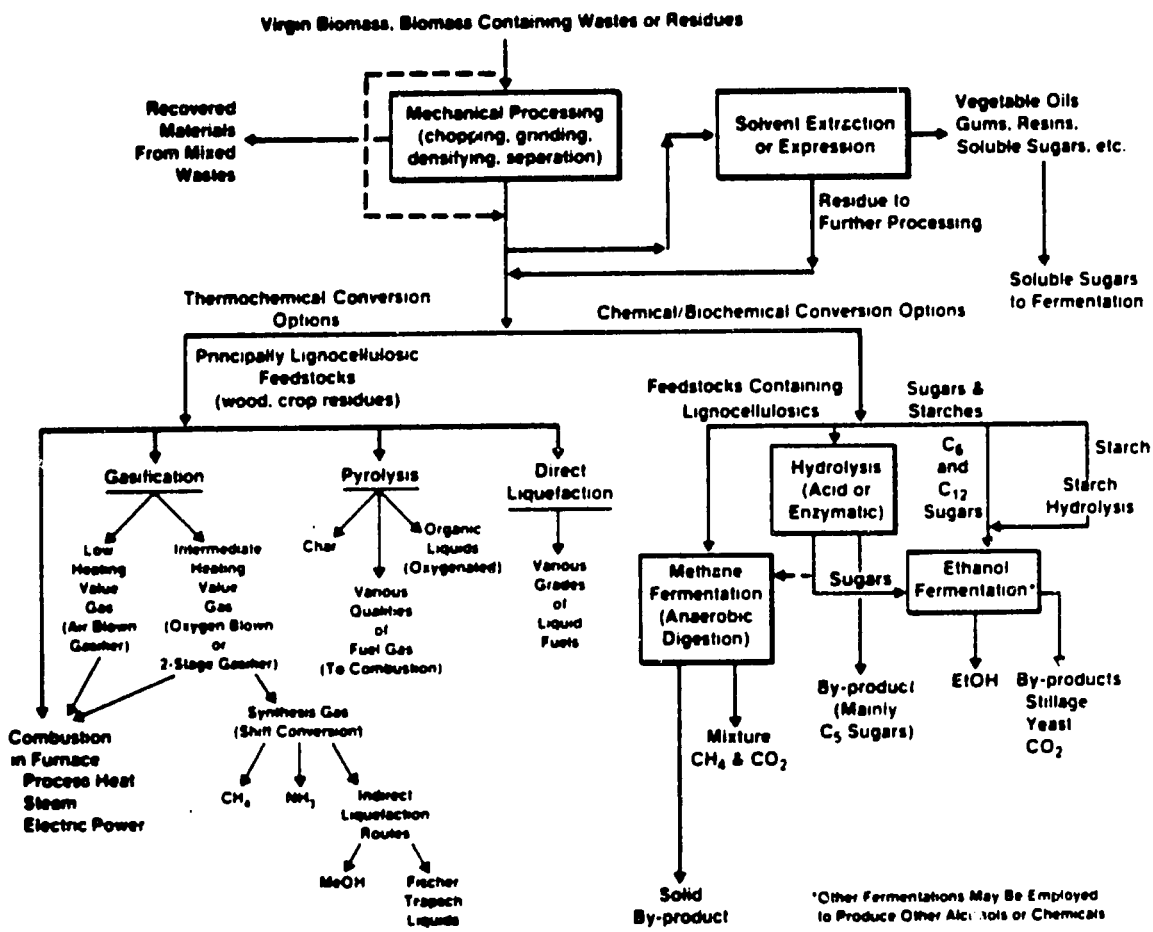


FIGURE IV-2 Conversion Technologies for Production of Fuels and Energy from Biomass

4.3.1 Status of Thermochemical and Mechanical Processes:

The worldwide status of processes and the status or extent of current use of the processes in Morocco are briefly described in Table IV-2. Based on consideration of the status of technology and likely feedstock availability, processes are ranked as having low, moderate or high potential for near-term* application in Morocco. As is the case in many other regions of the world, combustion options are likely to be very attractive. Production of a low heating value fuel gas or improved char production process may also be attractive. Direct production of liquid fuels from biomass by thermochemical means has no near-term potential in Morocco. Indirect liquefaction routes for biomass conversion, such as methanol production, also have no near-term potential because of a lack of sufficient feedstock and the developmental nature of processes for producing synthesis gas from biomass.

Production of densified fuel pellets from agricultural residues or alfa may be technologically possible. Fuel pellets could be burned in stoker fired boilers or gasified to provide fuel for engines (stationary and mobile).

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* Near-term is defined to be within the next 10 years.

Table IV-2 STATUS OF THERMAL AND MECHANICAL PROCESS TECHNOLOGY FOR BIOMASS CONVERSION AND POTENTIAL FOR NEAR-TERM USE IN MOROCCO

Conversion Technology	Scale of Application	Types of Applications Worldwide	Status of Development and Use Worldwide	Status of Technology in Morocco	Potential for Near-Term Use in Morocco
Combustion	Small	Controlled air supply metal stoves for space heating, water heating, and cooking	Extensive use in Scandinavia and North America	No installations identified by AID team	Moderate to high
	Medium	Shop-fabricated boilers with grates for burning biomass	Industrial use in Europe North America	No installations identified by AID team	Moderate
	Medium	Shop-fabricated furnaces equipped with heat recovery boilers for mass-burning	Industrial and municipal use in Europe and North American	No installations identified by AID team	Moderate
	Large to very large	Field-erected biomass-fired or multifuel-fired boilers	Extensive use in Europe, Asia, and North America for the production of steam at pulp and paper mills, sugarcane mills, municipal waste plants, and wood-fired power plants	No installations identified by AID team	Low (inadequate feedstock)
	Medium to large	Field-erected fluidized burners for burning olive pits, wood wastes, or nut shells	Numerous industrial installations in North America	No installations identified by AID team	Moderate
	Medium	Shop-fabricated cyclonic burners for sawdust	Numerous industrial installations in North American	No installations identified by AID team	Low (inadequate feedstock)
	Medium to very large	Existing oil-fired boilers retrofitted to burn mixture of biomass derived char and residual fuel oil	Commercial scale testing of coal/oil mixtures underway in the U.S. and Japan	No installations identified by AID team	Moderate (for medium scale application)

Table IV-2 (Continued)

Conversion Technology	Scale of Application	Types of Applications Worldwide	Status of Development and Use Worldwide	Status of Technology in Morocco	Potential for Near-Term Use in Morocco
Gasification	Small to medium	Existing oil-fired industrial boilers retrofitted with air-blown gasifiers that produce low-heating value fuel gas	Installations in the Philippines, Nicaragua, and the United States	No installations identified by AID team	Moderate to high
	Small to medium	Vehicles retrofitted with air-blown gasifiers that produce low-heating value fuel gas	Extensive use (>500,000 units) of such gasifiers in Europe during World War II	No installation identified by AID team	Moderate to high (rural areas)
	Small to medium	Stationary internal combustion engines retrofitted with air-blown gasifiers (irrigation pumping, electric power production)	Demonstration projects underway in US, Canada, and Philippines	No installations identified by AID team	High (rural electrification)
	Large to very large	Two-stage air-blown gasifiers for synthesis gas production or intermediate heating value gas (production of methanol, methane, ammonia)	Previous commercial installations in Asia. Development activities in the U.S., Canada, and Brazil	No installation identified by AID team	Low
	Large to very large	Oxygen-blown gasifiers for synthesis gas production or intermediate heating value gas	Development activities in the U.S. and Canada	No installations identified by AID team	Low
	Large to very large	Advanced gasification processes employing catalysts	Development activities in the U.S. and Canada	--	None

Table IV-2 (Continued)

Conversion Technology	Scale of Application	Types of Applications Worldwide	Status of Development and Use Worldwide	Status of Technology in Morocco	Potential for Near-Term Use in Morocco
Pyrolysis (for char production)					
Bath feed operations	Small to medium	Masonry block kilns and beehive ovens for charcoal production	Extensive use of such kilns in various developing countries	No installations identified by the AID team	Not recommended at this time
	Medium	Missouri kilns for charcoal production	Extensive use in the U.S.	No installations identified by the AID team	Moderate to high
	Small	Portable metal kilns	Previous use in developing countries such as Uganda and Thailand.	No installations identified by the AID team	High
Continuous feed operations	Large	Vertical Lambiotte retorts or Herreschoff furnace (multiple hearth)	Extensive use in Europe, Australia, and the U.S.	No installations identified by the AID team	Low
	Medium to large	Directly and indirectly fired rotary kilns	Prototype and demonstration projects underway in the U.S., Europe, and Japan	No installations identified by the AID team	Low
	Medium to large	Directly fired vertical shaft furnaces for multiple product production	Prototype tests completed in the U.S., no commercial plants in operation	No installations identified by the AID team	Low

Table IV-2 (Continued)

Conversion Technology	Scale of Application	Types of Applications Worldwide	Status of Development and Use Worldwide	Status of Technology in Morocco	Potential for Near-Term Use in Morocco
Liquefaction (Direct)	Medium to Large	Equipment for the recovery of tar and chemicals from pyrolysis of wood Yields of chemicals from hardwood on a dry weight of wood basis are: Acetic acid 4-5.6 wt% Methanol 1-2 wt% Acetone 0.5 wt%	Prior to development of petrochemicals industry, pyrolysis of wood was a major source of methanol and acetic acid. Industrial recovery of chemicals from pyrolysis of hardwoods has been practiced since 1850. Yields of methanol and acetic acid are lower from softwoods, however. Chemical recovery not considered economic in most developed countries.	No installations identified by AID team	Probably low
(Direct)	Large to very large	Catalytic liquefaction processes	Research and development activities underway in the U.S. and Canada	--	None
(Indirect)	Large to very large	Methanol synthesis processes	Methanol is produced in many large facilities from synthesis gas derived from natural gas. Some coal to methanol projects are planned in the U.S. Process development activities for production of methanol from biomass are underway in the U.S., Canada, and Brazil (see gasification).	--	None
(Indirect)	Large to very large	Production of Fischer Tropsch liquids from synthesis gas	Fischer Tropsch liquids are produced from coal and refined into products at plants in South Africa. Development of a modified Fisher Tropsch synthesis using a synthesis gas produced from biomass is underway in the U.S.	--	None
(Indirect)	Large to very large	Production of polymer gasoline from olefins	Research work on production of olefins from biomass is underway in the U.S.	--	None

Table IV-2 (Continued)

Conversion Technology	Scale of Application	Types of Applications Worldwide	Status of Development and Use Worldwide	Status of Technology in Morocco	Potential for Near-Term Use in Morocco
Mechanical Processing/ Physical Separations					
Densification	Small to large	Densification of agricultural residues, saw dust, charcoal dust or crops like alfa	Agricultural residues are pelletized or cubed in a number of countries, charcoal dust is briquetted in several countries	Excess bagasse is pelletized for fuel purposes	Moderate (if biomass available)
Expression/ Extraction	Medium to large	Expression/extraction of sugar from sugarcane and sugar beets	Processes have been available and in use for many years for sugarcane and sugar beet processing.	Sugar production from sugarcane and sugar beets is an established industry in Morocco.	None (production from sugar currently satisfies only 50% of food demand for sugar)
	Medium to large	Vegetable and seed oil expression/extraction	Processes have been available and in use for many years for the production of corn oil, soybean oil, cottonseed oil, sunflower seed oil, olive oil, etc.	Production of olive oil is a major industry in Morocco	None (value is too great for fuel use)
	Medium to large	Expression/extraction of oils from plants not currently produced in large tonnages as agricultural crops (Euphorbia lathyris for example)	Research on plant production is in progress in the U.S., Mexico and other countries. Work has been in progress for 40 years or more on guayule production as a source of rubber	No research program known to be in progress	None

4.3.2 Status of Biochemical and Chemical Processes:

The worldwide status of processes and the extent of process use in Morocco are described in Table IV-3. Anaerobic digestion processes appear to have some near-term potential in Morocco.

Conventional ehtanol fermentation processes using sugars or starches as feedstocks do not appear to have much near-term potential. Morocco currently imports 50% of its sugar (sucrose) needs and it appears unlikely that sugar production could be increased to meet food needs as well as fuel needs. Of the molasses that is produced, about 20% is used for fermentation feedstocks (products unknown by AID staff) and 50% is exported. Utilization of the 50% that is exported would allow production of about 12 million liters of fuel grade ethanol per year (10,000 metric tons/year or well below 0.5% of the tonnage of imported petroleum).

Starch crops are not produced in quantities to supply both human food and energy needs.

Utilization of lignocellulosic materials as feedstocks for ethanol has no near-term potential in Morocco, because no suitable hydrolysis processes are now available for commercial use.

Table IV-3 STATUS OF CHEMICAL AND BIOCHEMICAL PROCESSES FOR BIOMASS CONVERSION AND POTENTIAL FOR NEAR-TERM USE IN MOROCCO

Conversion Technology	Scale of Application	Types of Applications Worldwide	Status of Development and Use Worldwide	Status of Technology in Morocco	Potential for Near-Term Use in Morocco
Ethanol Fermentation					
Sugars in molasses	Medium	Fermentation of molasses to produce ethanol	Production of alcoholic beverages (rum) or concentrated ethanol from molasses has been practiced for many years in several areas of the world	No installations identified by AID team Beer and wine production require comparable technology	Low (insufficient feedstock)
Sugar crops	Medium to large	Fermentation of sugar juice from sugar beet and sugarcane processing	Technology is available for fermentation of juice from sugar plants and is being used in Brazil	No installations identified by AID team	None
Starch crops	Medium to large	Enzymatic hydrolysis of starches to sugars and fermentation of sugars	Technology is available and in use in many countries	Beer and wine production require comparable technology	None
Lignocellulosic Materials	Large	Acid hydrolysis of wood or agricultural field residues (straw) to sugars and fermentation of six carbon sugars	Technology has been available in Germany, Switzerland, Japan and the U.S. for 40+ years. Existing processes are not considered economical in free market economies. Russians have built some wood hydrolysis plants. Newer processes are being developed in several countries such as the U.S. and Canada	--	None
Lignocellulosic materials	Large	Enzymatic hydrolysis of wood or agricultural field residues (straw) to sugar and fermentation of six carbon sugars	Technology is under development in the U.S., Japan, and several European countries	--	None

Table IV-3 (Concluded)

Conversion Technology	Scale -- Application	Types of Applications Worldwide	Status of Development and Use Worldwide	Status of Technology In Morocco	Potential for Near-Term Use in Morocco
Methane Fermentation (Anaerobic Digestion)	Small (farm with ~ 10 head of cattle)	Production of methane rich fuel gas from human wastes, animal wastes, and low lignin content vegetable or fruit wastes	Thousands of digesters are in operation in developing countries such as India, Korea, and Taiwan.	No installations identified by AID team	Moderate
	Medium (large farm or feedlot ~100 head of cattle)	Production of methane rich fuel gas from human wastes, animal wastes and low lignin content vegetable or fruit wastes	Numerous digestion plants are in operation in India, the Philippines, and the U.S. for production of fuel gas from manure generated by animals in confinement	No installations identified by AID team	Moderate
	Large	Production of methane rich fuel gas from shredded municipal solid waste with high percentage of ferrous metal and plastics removed.	A demonstration project is now in progress in the U.S. Research and development projects are underway in Europe and Brazil.	No installations identified by AID team	Moderate to high (possible installation at existing compost plant)

4.4 Dispersed Use of Biomass vs. Large Scale Projects:

One of the stated goals of the Moroccan renewable energy program is to improve the standard of living in rural villages through rural electrification and other energy related projects. Near-term rural electrification projects may be implemented with dispersed renewable energy installations such as:

-small wind powered generators

-small hydro electric projects

-biomass gasifiers prodiving a fuel gas to small diesel engine/generator sets.

Rural electrification could also be accomplished by installation of relatively large power generating facilities such as a thermal electric (steam cycle) plant burning biomass as a fuel. The electric power would then need to be transmitted by a distribution network.

The relative costs of installing a large number of small plants at the villages vs. the larger central plant and a distribution network will depend on numerous site specific factors for each region such as distance between villages, size of the villages, load cycling, terrain over which the distribution network must be constructed, and local availability of

personnel to maintain and operate the system. It seems reasonable to assume, however, that in at least some cases the smaller village or farm scale generating system may be the best option.

Another goal of the Moroccan government is to decrease the importation of petroleum and refined products. This goal may be accomplished by use of both large scale as well as dispersed use of biomass. At the community level, for example, vehicles (tractors, short-haul trucks and buses) could be retrofitted with vehicle mounted (or trailer mounted) wood or charcoal gasifiers. During World War II, over 800,000 biomass gasifiers were used worldwide for buses, trucks, automobiles, boats and even motorcycles. The fuel wood for the gasifiers could be harvested in the local area, converted to charcoal at the local level, if required, and then sold to the vehicle operators. The gasifiers could probably be fabricated in Morocco using the European designs (from Sweden, for example).

Medium and large scale projects have the potential to have a significant impact on fuel oil use, but will require large tonnages of wood or charcoal delivered to a single site.

For example, if a biomass derived char/oil slurry (50 wt % char) is burned, an industrial boiler that produces 20,000-25,000 kg/hr of saturated steam would require 1 metric ton/hr of charcoal. If the boiler operates 24 hours/day, 330 days/year, the facility would require in excess of 7,900

metric tons/year of char. (Current charcoal production in Morocco is estimated to be in excess of 100,000 metric tons/year. See Figure IV-2.) At a 25% yield (dry basis) of char from wood, 32,000 dry metric tons/year of wood must be pyrolyzed. The use of the char would replace the use of 4,500 metric tons of fuel oil or over 31,000 barrels/year of fuel oil. It is important to note that for this case where charcoal is used, it takes about 1 dry metric ton of wood production to replace a barrel of oil (or 7 dry metric tons wood/metric ton of petroleum). This is equivalent to 3.2 kcal of wood/kcal of fuel oil.

$$\frac{(7 \text{ metric ton wood})\ (4850 \text{ kcal/kg})\ (1000 \text{ kg/ton})}{(1 \text{ metric ton fuel oil})\ (10534 \text{ kcal/kg})\ (1000 \text{ kg/ton})} = \frac{3.2 \text{ kcal wood}}{\text{kcal fuel oil}}$$

The point to remember is that the production and use of the equivalent of 1 kcal of biomass will not necessarily save the equivalent of 1 kcal of petroleum.

As an example of a very large project, we will estimate the amount of wood required to generate sufficient electric power to replace all existing oil fired power plants. Approximately 12% of current oil consumption is used to produce 1277 million kwh/year of electric power. At a projected fuel consumption rate of 0.95 dry metric tons of wood/1000 kwh,*/ approximately 1.2

*/ Based on data from S. M. Kohan and P. M. Barkhordar, Mission analysis for the Federal Fuels from Biomass Program, Volume IV: Thermochemical Conversion of Biomass to Fuels and Chemicals, SRI International /Report submitted to the U.S. Department of Energy (January 1979) (NTIS: SAN - 0115-TS).

million dry metric tons/year of wood would be required. This is an equivalent to the current fuel wood production in Morocco (see Figure IV-1).

Assuming 70 to 80% utilization of generating capacity, it would be necessary to install 200 MW of wood fired generating capacity. If it is assumed that eight 25 MW power plants would be installed, each plant would require 150,000 dry metric tons/year of wood (411 metric tons/day) or 375,000 m^3/year. At an average wood yield of $8m^3$/hectare, each wood fired power plant would require harvesting wood from about 47,000 hectares of forested land. The eight plants would require a total of 376,000 hectares of forested land to supply wood.

It appears that there is no immediate potential for very large biomass energy projects because of feedstock limitations. A vigorous tree planting program would be required to produce the required wood supplied in 10-15 years (see section 2.6.1). There is potential, however, for a number of medium scale projects as well as dispersed use of biomass. Site specific factors related to biomass supply, costs for other fuels or energy sources, and investment costs to retrofit existing petroleum fueled systems or to install new biomass fueled systems must be considered for each case.

4.5 Investment Requirements for Very Large Projects:

Although there is no near-term potential for very large biomass energy projects in Morocco, it is appropriate to provide some order-of-magnitude type estimates of investment requirements for such projects. These estimates can be used by government planners to estimate the capital requirements for a major longterm biomass energy program. Such estimates will be required to compare the economics of biomass energy with alternatives such as oil shale processing.

The following estimates of feedstock requirements and investment costs are based on process and cost data developed by SRI International for the U.S. Department of Energy and published in the following reports:

S. M. Kohan and P. M. Barkhordar, "Mission Analysis for the Federal Fuels from Biomass Program, Volume IV: Thermochemical Conversion of Biomass to Fuels and Chemicals," (January 1979). Available from NTIS, Report No. SAN-0115-T3.

J. L. Jones and W. S. Fong, "Mission Analysis for the Federal Fuels from Biomass Program, Volume IV: Biochemical Conversion of Biomass to Fuels and Chemicals," (December 1978). Available from NTIS, Report No. TID-29093.

J. L. Jones et al, Interim results of an Analysis of biochemnical conversion processes reported in SRI Technical Status Report No. 19 on Preparation of a Solar Cost Data Bank for DOE/Biomass Energy Systems Branch. DOE Contract No. EY-76-C-03-0115/PA 141.

Costs have been updated to a mid-1980 basis by use of the Chemical Engineering plant cost index. It has been assumed that investment costs for power plants, or alcohol production facilities will be 10% higher in North Africa compared with the U.S. Gulf Coast based on data from the following reference:

A. V. Bridgewater, "International Construction Cost Location Factors," Chemical Engineering, (November 5, 1979) pp 119 to 121.

For the example of wood fired power plants discussed in the previous section, it is likely that the total investment cost (in 1980 U.S. dollars) for the eight 25 MW plants would be in excess of $350 million. This estimate is only for the power plants. Costs for any new distribution lines to transmit the power and the biomass production (nurseries, planting, and harvesting) must also be considered.

Considering the current status of direct liquefaction processes for biomass, that a biomass program in Morocco would probably be based on wood, and the

chemical composition of wood, it is likely that methanol would initially be the biomass-derived liquid fuel of choice to replace petroleum. A replacement of 10% by volume of the petroleum (6850 barrels/day or 287,700 liters/day) with methanol will be considered here as the basis for cost calculations. (In this discussion, we will not address the differences in heating value per unit volume and the performance characteristics of methanol/gasoline or methanol/diesel fuel blends in internal combustion engines.) Using an expected methanol yield figure of 725 liters methanol/dry metric ton of wood (4.55 barrels/dry metric ton), the wood requirement to produce the methanol can be readily calculated:

$$\frac{6850 \text{ bbl/day}}{4.55 \text{ bbl/dry metric ton}} = \begin{array}{l} 1505 \text{ dry metric tons/day} \\ (549{,}325 \text{ dry metric tons/yr}) \end{array}$$

At an average wood yield of $8m^3$/hectare, almost 172,000 hectares of forested land would be required to provide the wood.

The estimated total investment cost for 3 methanol plants, each capable of converting 550 dry metric tons/day of wood (330 operating days/year), would be in excess of $250 million (1980 U.S. dollars).

Another liquid fuel option would be to produce ethanol from wood. Using as a basis an acid hydrolysis process now under development at Purdue University, it is estimated that the ethanol yield would be 300 liters/dry

metric ton of wood (1.89 bbl/dry metric ton). The wood requirements to produce 6850 barrels/day (or 1.1 million liters/day of ethanol) would be as follows:

$$\frac{6850 \text{ bbl/day}}{1.89 \text{ bbl/dry metric ton}} \qquad \begin{array}{c} 3624 \text{ dry metric tons/day} \\ (1.3 \text{ million dry metric tons/year}) \end{array}$$

At an average wood yield of $8m^3$/hectare, approximately 400,000 hectares of forested land would be required to provide the wood for ethanol production facilities.

The estimated total investment costs for 4 ethanol plants, each capable of converting 1000 dry metric ton/day of wood (330 operating days/year) would be in excess of $500 million (1980 U.S. dollars).

4.6 Near-Term Projects for Morocco:

In sections 4.3.1 and 4.3.2, the near-term (next 10 years) potential for use of a variety of conversion technologies was disucssed. The near-term potential for large scale projects was stated to be low because of a lack of sufficient quantities of biomass. In this section, the small and medium scale projects with near-term potential will be further analyzed (see Table IV-4). Very preliminary order-of-magnitude type investment cost

Table IV-4

POSSIBLE NEAR-TERM PROJECTS TO CONSIDER FOR BIOMASS CONVERSION IN MOROCCO

Scale of Application	Conversion Technology	Type of Application	Potential for Near-Term Use in Morocco	Development Needs	Applications Testing and Training	Estimated Installed Cost of Equipment for Testing and Demonstration Project	Capacity and Operating Assumptions	Feedstock Requirements	Total Annual Feedstock Requirement	Source of Feedstock
Small	Combustion	Use of metal stoves for space heating, water heating and cooking	Moderate to high	Little required	Yes	≤$2,000	Woodburning stoves	--	≤ 3 dry metric tons/yr (≤ 7.5 m^3/year)	≤ 1 hectare of forested land
Medium	Gasification	Use of air-blown gasifiers to produce fuel gas for diesel electric generators in rural areas (or to drive irrigation pumps)	High	None required	Yes	$600,000 to $900,000	250 KW; 90% of fuel demand from wood; 50% capacity utilization	1.0 kg wood/kWh (≤20% moisture)	875 dry metric tons/yr (2188 m^3/year)	274 hectares of forested land
Small	Gasification	Use of air-blown gasifiers mounted on vehicles or trailers to provide a fuel gas for vehicles	Moderate to high	None required	Yes	$5,000 to 10,000	300 HP engine at 40% load; 90+% of fuel demand from wood; 2000 hr/yr of operation	0.95 kg wood/HP-hr (≤ 20 wt% H_2O)	164 dry metric tons/yr (410 m^3/year)	51 hectares of forested land
Medium	Gasification	Use of air-blown gasifiers to produce fuel gas for existing oil-fired industrial boilers	Moderate to high	None required	Yes	>$250,000	4500 kg/hr of steam; 56% overall thermal efficiency; 46% capacity utilization	1.0 dry metric ton/hr of wood	4030 dry metric tons/yr (10,000 m^3/year)	1250 hectares of forested land
Small	Pyrolysis	Use of portable metal for charcoal production	High	None required	Yes	<$2000	6 metric tons/month of charcoal product	4 dry tons wood/ton of charcoal	288 dry metric tons/yr (720 m^3/year)	90 hectares of forested land
Medium	Pyrolysis	Use of improved stationary kilns such as the "Missouri" kiln for charcoal production	Moderate to high	None required	Yes	$10,000 to $15,000	26 metric tons/month of charcoal product	4 dry tons wood/ton of charcoal	1248 dry metric tons/yr (3120 m^3/year)	390 hectares of forested land
Medium	Densification	Use of densification equipment to produce fuel pellets or briquettes from agricultural residues, saw dust, charcoal dust, or crops like alfa	Moderate	Some required	Yes	>$2,000,000	50 dry metric tons/d; 250 operating days/yr	--	12,500 dry metric tons/year	Alfa or sawdust and bark
Small	Anaerobic digestion	Use of digesters to produce a methane rich fuel gas on small family run farms using human, animal and vegetable (low lignin content) wastes	Moderate	None required	Yes	Highly variable depends on design ≥$2000	10 head of cattle supply manure; 6 m^3 of biogas/day; gas contains 55 vol% methane	--	8 dry metric tons of manure/year	10 cattle

Table IV-4 (Concluded)

Scale of Application	Conversion Technology	Type of Application	Potential for Near-Term Use in Morocco	Development Needs	Applications Testing and Training	Estimated Installed Cost of Equipment for Testing and Demonstration Project	Capacity and Operating Assumptions	Feedstock Requirements	Total Annual Feedstock Requirement	Source of Feedstock
Small	Anaerobic digestion	Use of digesters to produce a methane rich fuel gas on a large farm or feedlot using human, animal and vegetable (low lignin content) wastes	Moderate	Some required	Yes	Highly variable, depends on design $25,000 to $100,000	100 head of cattle supply manure; 60 Nm^3 of biogas/day; Gas contains 55 vol% methane	--	80 dry metric tons of manure/year	100 cattle
Medium	Combustion	Use of shop fabricated boilers with grates for burning biomass to produce steam or use of shop fabricated furnace equipped with waste heat boiler for mass burning of biomass and wastes to produce steam	Moderate	Some required	Yes	>$300,000	4500 kg/hr of steam; 70% thermal efficiency; ~ 46% capacity utilization	0.7 dry metric tons/hr of biomass	2800 dry metric tons/yr (7000 m^3 of wood)	875 hectares of forested land
Medium	Combustion	Use of field erected fluidized bed burners equipped with waste heat boilers for burning olive pits, nut shells and wood wastes to produce steam or	Moderate	Some required	Yes	$1,000,000	11,000 kg/hr of steam; 55% thermal efficiency; ~ 46% capacity utilization	2.25 dry metric tons/hr of biomass	~ 9100 dry metric tons of biomass	Processing plant waste with high moisture content (~ 55 wt% H_2O)
Medium	Combustion	Use of a biomass derived char/fuel oil slurry in an oil-fired boiler	Moderate	Extensive	Yes	$1,000,000 to $2,000,000	23,000 kg/hr of steam; Fuel oil/char slurry with 50 wt% char; 80% thermal efficiency; 46% capacity utilization	1.0 dry metric ton/hr of char (assume 4 dry metric ton wood required to produce one dry metric ton of char)	~ 16,000 dry metric tons of wood/yr (40,000 m^3/yr)	5,000 hectares of forested land
Medium	Anaerobic digestion	Use of digesters to produce a methane rich fuel gas from shredded municipal solid waste prior to composting	Moderate to high	Some required	Yes	≥$1,500,000	~100 metric tons of municipal solid waste/day (~ 35 dry metric tons/day); 9500 Nm^3 of biogas/day; Gas contains 55 vol% methane	--	~ 9000 dry metric tons/year of solid waste for digestion	City of Marrakech

estimates have been made in mid-1980 U.S. dollars for these projects. Based on data from A.V. Bridgewater mentioned above, it has been assumed that investments for medium scale projects in Morocco will be 10% greater than for comparable facilities in the U.S. These estimates should be revised when more accurate information becomes available. The economic feasibility must be determined once a specific site is selected and information is available on benefits and costs of biomass energy versus fossil fuels.

4.6.1 Combustion Projects:

Small Scale Combustion Project

The international donor community is paying increasing attention to the great potential for improving cooking stoves in developing countries. Much effort and study have been expended on this issue which should culminate in several significant and workable solutions. The Renewable Energy Center would be an excellent facility for testing the applicability of these existing cooking stove designs and developments, as well as developing new designs. Small metal stoves with dampers to control the intake of air for combustion also have potential for near-term use in urban Morocco. These can be purchased and installed for less than $1000--larger stoves or furnaces for less than $2000.

Medium Scale Combustion Projects

Shop-Fabricated Units

The use of shop-fabricated boilers with grates or shop-fabricated burners equipped with heat recovery boilers can be used to generate steam from wood wastes, warehouse wastes (dry packaging and crates), or wood chips. The thermal efficiency of the units could range from a high to over 70% to a low of 50% depending on the characteristics of the biomass fuel. The following assumptions have been made concerning operation:

70% thermal efficiency

2 shifts/day, 5 days/week

1 metric ton/hr of biomass burned (30 wt% H_2O)

4500 kg/hr of steam produced

The installed cost of the system is estimated to be $300,000

Field-Erected Units

The installation of a field erected fluidized bed burner with a waste heat boiler may be possible at a food processing operation to burn high moisture residues (50-60% H_2O). The following assumptions have been made concerning operation:

55% thermal efficiency

2 shifts/day, 5 days/week

5 metric ton/hr of biomass burned (55 wt% H_2O)

11,000 kg/hr of steam produced.

The installed cost of the system is estimated to be $1,000,000.

Biomass Char/Oil Slurry

The use of char/oil slurry fuel was mentioned in Section 4.4. The following assumptions have been made concerning operation:

80% thermal efficiency

2 shifts/day, 5 days/week

Slurry with a 50 wt% char content (1 metric ton char/hr)

23,000 kg/hr of steam produced

The installed cost of the char storage and handling, char/oil slurry preparation, and fuel pumping and burner system modifications would cost an estimated $1,000,000. Air pollution control equipment could add another $800,000 to the cost.

4.6.2 Gasification Projects:

Gasifier/Diesel-Electric Generator

A wood gasifier (fixed-bed design) can be installed to produce a fuel gas that will satisfy 90% of the fuel requirements of a diesel engine used to generate electric power. The following assumptions have been made concerning operation:

Power output: 250 kw

Fuel required/kWh

1.0 kg wood chips (20 wt% H_2O)

2.025 liter diesel fuel

The purchased cost of the major items of equipment (gasifier engine, generator) is estimated to be $300,000. The total installed cost of the power generating system is estimated to be between $600,000 and $900,000.

Gasifier/Industrial Boiler

A wood gasifier (fixed-bed design) can be installed to produce a fuel gas that will satisfy all of the fuel requirements of an oil-fired boiler. The following assumptions have been made concerning operation:

56% overall thermal efficiency for gasifier/boiler combination

2 shifts/day, 5 days week

4500 kg/hr of steam produced

The installed cost of the gasification system is estimated to be $250,000.

Vehicle Mounted Gasifiers

Short haul trucks and buses with diesel engines are considered as initial candidates for retrofitting. The following assumptions have been made concerning operation:

300 HP engine at 40% load

biomass fuel required/HP-hr = 0.95 kg wood (20 wt% H_2O)

8 hrs/day of operation, 250 days/year

The cost of retrofit a large vehicle is estimated to range between $5,000 and $10,000 for the initial units.

4.6.3 Pyrolysis Projects

Pyrolysis is used to convert wood to a more desirable solid fuel. The conversion of wood to charcoal is currently practiced in various parts of Morocco. The process used entails the use of crude earthen kilns. Yield of charcoal per unit of biomass could be greatly improved, from the current 13% to 25%, by the following two techniques:

Portable Kiln

The portable kiln will be made of steel and fashioned after those used in Thailand and Uganda. The production capacity will be assumed to be 6 metric tons/month of charcoal.

The estimated cost for one of these kilns is $2000 based on information from a UN report.

"Missouri" Type Kiln

The kiln will have the capacity to produce 26 metric tons/month of charcoal. The installed cost for one of these kilns is $10,000 to $15,000 based on information from a UN report.

4.6.4 Densification Projects

Fuel pellets for use in gasifiers or furnaces could possibly be produced from alfa or sawmill residues such as bark and sawdust. The facility will be assumed to have a capacity to produce 50 dry tons/day of fuel pellets. Based on previous SRI cost estimates for densification facilities, it is likely that the plant will cost in excess of $2 million.

Another project that should be considered is charcoal briquetting to use fines or dust. No data were available on the quantity of material available.

4.6.5 Anerobic Digestion Projects

Small Scale Digestion Projects

Although there are many more goats and sheep than there are cattle in Morocco, only the cattle are fed in semi-confined areas where manure can be

easily collected (see Table IV-5). Also, because manure production depends on the diet and the body weight of the animal, cattle produce far more manure/head than do sheep or goats. The maximum production of methane rich fuel gas from anaerobic digestion of all cattle manure would be equivalent to 10 % of the quantity of oil now imported. If all manure from herds with 10 head were digested, the quantity of methane would be equivalent to 4-5% of the oil imports.

TABLE IV-5 NUMBER OF LIVESTOCK IN MOROCCO

	# of Head
Cattle	3,620,300
Sheep	14,200,000
Goats	5,500,000

Source: L'Elevage Au Maroc, Ministere de L'Agriculture et de la Reforme Agraire, Direction de L'Elevage (Feb. 1977)

TABLE IV-6 DATA ON SIZE AND NUMBER OF CATTLE HERDS

Size of Herd (Number of Head)	Number of Ranchers	No. of Animals
1	102,700 (11.1%)	102,700 (8%)
2 to 5	660,800 (71.7%)	1,969,300 (54.4%)
6 to 10	124,700 (13.5%)	897,100 (24.8%)
11 to 20	27,200 (3.0%)	376,900 (10.4%)
21 to 50	4,800 (0.5%)	139,300 (3.8%)
51 to 100	1,500 (0.2%)	106,700 (2.9%)
>100	200	28,300 (0.8%)
	921,900 (100%)	3,620,300 (100%)

NOTE: 50% of all cattle are grazed close to residence, 800,000 to 900,000 cows are stall-fed.

Source: L'Elevage au Maroc, Ministere de L'Agriculture et de la Reforme Agraire, Direction de L'Elevage (Feb 1977).

The smallest size of digestion system that will be considered in this analysis is one that is supplied by manure from 10 head of cattle. This size system should supply sufficient gas for the cooking needs of 10 people. As indicated by the data in Table IV-6, there are a significant number of farms with 10 or more head of cattle.

The next size system will handle the manure from 100 head of cattle. Because of the likelihood that such a larger system cannot be built entirely from locally available construction materials and will require the purchase of specially fabricated equipment, the cost of the larger system will be much higher per unit of capacity. Mechanical equipment may also be required for manure handling. There are few sites in Morocco where more than 100 head of cattle are fed (see Table IV-6).

The cost estimates for these two size systems are shown on Table IV-4.

Medium Scale Digestion Project

Anaerobic digestion of shredded and separated municipal solid waste is being tested in the U.S. at a demonstration facility located at Pompano Beach, Florida. Many of the problems encountered to date in the U.S. have been concerned with the preparation of the waste prior to digestion.

Because of the high moisture content of municipal solid waste in Morocco, incineration is not possible without burning a supplemental fuel. In

addition, several composting plants already exist and could provide a material suitable for anaerobic digestion. After shredding and removal of ferrous metals, the waste could be sent to an anaerobic digester instead of to the composting operation. (See Appendix D for information on composting plant, solid waste and sewage composition.) After anaerobic digestion, the undigested solids and supernatant liquor could be used for fertilizing agricultural land.

It might be economical to heat the anaerobic digester with hot water supplied by a solar collector. This possibility should be evaluated.

The cost of a digestion facility installed at the existing composting plant in Marrakech would exceed $1.5 million.

4.7 Environmental Considerations:

Based on the previous experience with the biomass conversion technologies listed as candidates for near-term use in Morocco, no insurmountable environmental problems are envisioned. In selecting projects and sites, certain factors should be kept in mind. Some of these are listed below.

Thermochemical Processes

-Particulate emissions from combustion or gasification of wood will be higher than those from oil-fired systems. Control equipment may add a substantial cost to the projects.

-SO_x emissions from biomass systems will probably be well below those from systems burning residual oil or coal. Biomass projects might be installed where ambient SO_x levels are a problem.

-Emissions from vehicles equipped with gasifiers may be a problem and use may be restricted to nonurban areas.

-Emissions from charcoal kilns can be a hazard to both workers and surrounding populations. The location of kilns should be carefully studied.

Biochemical Processes (Anaerobic Digestion)

-Certain simple safeguards should be taken to minimize workers exposure to wastes and prevent contamination of wells from improper location of buried digesters. (See "Methane Generation from Human, Animal and Agricultural Wastes, National Academy of Sciences, Washington, D.C. (1977)).

-Proper effluent management systems should be designed so as to prevent surface water contamination and wastage of the fertilizer value of the liquid and solid effluents from digesters.

Environmental impacts from biomass energy systems are not restricted to the conversion processes. Production, harvesting, transportation and storage will also result in some adverse environmental effects. These impacts should also be considered when evaluating specific projects.

Preliminary evaluations of possible environmental problems with biomass conversion have been completed in the U.S. and may be used as a guide for analysis in Morocco. Several of these studies are listed below:

"Environmental Readiness Document, Biomass Energy Systems," U.S. Department of Energy (September 1979) DOE/ERD-0021.

S. T. Di Novo, et al., "Preliminary Environmental Assessment of Biomass Conversion to Synthetic Fuels," report prepared by Battelle Columbus Laboratories for the U.S. Environmental Protection Agency (October 1978) EPA-600/7-78-204 (available from NTIS).

B. J. Gikis, et al., "Preliminary Environmental Assessment of Energy Conversion Processes for Agricultural and Forest Product Residues," report prepared by SRI International for the U.S. Environmental Protection Agency (March 1978) EPA-600/7-78-047 (available from NTIS).

4.8 Proposed Renewable Energy Center in Marrakech

4.8.1 Suggested Scope of Activities Concerned with Process Development, Testing and Evaluation.

Considering the specific types and level of development of the technologies listed in section 4.6 for potential near-term use in Morocco, the scope of activities of the center may include:

o Commercialization Support

- Analysis of project economics
- Performance testing of available equipment and systems for use in Morocco (commercial scale equipment)
- Preparation of installation an operating manuals to use in training courses
- Selection and monitoring of demonstration projects
- Presentation of training lectures

o Process Development or Modification

- Analysis of feedstock and product characteristics
- Modification of available equipment or processes to satisfy unique feedstock conditions or specific local needs

- Laboratory testing and pilot plant testing of equipment or processes.

4.8.2 Facility Needs and Staffing

Two laboratories and a pilot plant area should be provided as follows:

Thermochemical and Mechanical Processes Laboratory (TMPL)

Location: Ground Level

Laboratory space: 600-800 ft^2

Access to loading dock

Benches along one wall for equipment such as:

- Calorimeters (measurement of heating values)
- Drying ovens (determination of moisture content)
- Muffle furnaces (volatile matter and ash determination)
- Screens (particle size analysis)
- Gas analysis equipment
- Scales (several)
- Bench-scale charcoal furnaces
- Walk-in hood for ventilation of certain equipment
- Floor drains

Staff: Lead engineer (probably mechanical or chemical engineer with combustion background)

1 chemist

1 engineering technician

Chemical and Biochemical Processes Laboratory (CBPL)

(Principally anaerobic digestion work*)

Location: Ground Level

Laboratory space: 600-800 ft^2

Access to loading dock

Benches for chemical analysis such as:

Chemical oxygen demand for aqueous wastes

Biochemical oxygen demand of aqueous wastes (requires incubator)

Suspended solids content

Kjeldahl nitrogen

Ammonia nitrogen

Total solids

Organic acids

Alkalinity

*To possibly expand to include work on hydrolysis and ethanol fermentation in the future.

Benches for equipment such as:

- Wet test gas meters
- Drying ovens
- Muffle furnaces
- Scales
- Gas analysis equipment

Floor space for

- 15 liter fermenters
- Gas reservoirs

Floor drains

Staff: Lead engineer (chemical sanitary or agricultural engineer with training in anaerobic digestion)

1 biochemist or micro-biologist

1 technician

<u>Pilot Plant and Equipment Testing Area</u>

Location: Ground level

Floor space: 1000 ft^2

Access to loading dock

High ceiling and entry door - 20 ft.

Floor drains

Floor space along one wall for size reduction equipment scale (capacity up to 500 kg), work bench

Staff: Initially to be staffed by TMPL and CBPL staff

Satellite Site for Large Scale Pilot Plant Testing

About 14 km outside of Marrakech not far from the industrial park, is a 20 ha site, owned by the State and available for purchase by the Energy Center. We recommend that the site be bought for the Center for the following reasons:

- It will afford space for two small *Eucalyptus camaldulensis* plantations, one irrigated and one not irrigated, for demonstration purposes. They will provide visitors to the Center a look at the most promising biomass feedstock for energy in Morocco.

-Space will be available for large scale pilot plant testing of stoves, charcoal kilns, combustion processes, pyrolysis, and gasification which could not be undertaken at the Center proper.

-Space will also be available for pilot plant tests in fields other than biomass conversion.

4.8.3 Staff Training:

The training requirements for four professionals are described in Table IV-7. The training is intended to provide the individuals with sufficient background to direct projects concerned with combustion, pyrolysis (charcoal production), thermal gasification, mechanical processing, and anaerobic digestion.

If work on acid or enzymatic hydrolysis wood and ethanol fermentation is to be undertaken in the future, a chemical engineer should do graduate study in the U.S. at a university such as the Massachusetts Institute of Technology, Cornell University, the University of Pennsylvania, Purdue University, or the University of California at Berkeley.

4.9 List of References not Cited:

Charcoal Production and Testing

D. E. Earl, "A Report on Charcoal," Food and Agricultural Organization of the United Nations, Rome (1974).

C. Moscowitz, "Source Assessment--Charcoal Manufacturing State-of-the-Art," EPA 600/2-78-0047 (December 1978) (available from NTIS).

Table IV-7

STAFF TRAINING REQUIREMENTS

Position	Laboratory	Academic Training	Field Training
Lead Engineer	Thermochemical & Mechanical Processes Laboratory	1 year of graduate training in the U.S. Some Possible Schools • Mechanical Engineering Dept. Oregon State University • Mechanical Engineering Dept. Auburn University • Mechanical Engineering Dept. Georgia Institute of Technology • Chemical Engineering Dept. University of W. Virginia • Forest Products Laboratory University of California, Berkeley	3 to 6 months Possible Sites • University experimental station • U.S. Forest Services Laboratories • Research institutes
Lead Engineer	Chemical and Biochemical Processes Laboratory	1 year of graduate training in the U.S. (emphasis on anaerobic digestion) Some Possible Schools • Environmental Engineering Dept. Stanford University • School of Civil Engineering University of Illinois • Agricultural Engineering Dept. Cornell University	3 to 6 months Possible Sites • USDA Research Center Clay City, Nebraska • University experimental stations • Research institutes such as Institute of Gas Technology Chicago, Illinois

Table IV-7

STAFF TRAINING REQUIREMENTS (concluded)

Position	Laboratory	Academic Training	Field Training
Chemist	Thermochemical & Mechanical Processes Laboratory	6 months to 1 year of training with forestry or chemistry departments at many U.S. universities* (emphasis on analysis of wood and fuels characterization)	None required
Biochemist or Microbiologist	Chemical and Biochemical Processes Laboratory	6 months to 1 year of training with chemistry departments or environmental engineering departments at many U.S. universities* (emphasis on standard wet chemical analysis used in sanitary engineering)	None required

*Attendance at the same university where appropriate lead engineer is in attendance may be desirable.

Gasification - Stationary Applications

"A Survey of Biomass Gasification, Volume III--Current Technology and Research," Solar Energy Research Institute, Golden, Colorado (April 1980) SERI/TR-33-329 (available from NTIS)

Gasification - Vehicle Mounted Gasifiers

"Generator Gas--The Swedish Experience from 1935-1945," (1950), report translated from Swedish to English by the Solar Energy Research Institute, Golden, Colorado (January 1979) SERI/SP-33-140 (available from NTIS).

N. A. Skov and M. L. Papworth, "The Pegasus Unit," Pegasus Publishers, Inc., Olympia, Washington (1974).

Vegetable Oil Use in Diesel Engines

J. M. Cruz, et al., "Biomass-Based Fuels for Diesel Engines," Paper No. 80-027 presented at the American Society of Agricultural Engineers (March 1980).

Anaerobic Digestion

D. K. Walter, "Methane Production from Municipal Wastes in a 100-Ton-Per-Day Plant," paper presented at the IGT Symposium Energy from Biomass and Wastes III, Lake Buena Vista, Florida (January 1980).

Combustion of Char/Oil Mixtures

A. K. Chatterjee, "State-of-the-Art Review on Direct Combustion Systems with Biomass Char-Oil Mixtures," report prepared by SRI International for the U.S. Department of Agriculture (June 1980).

Books and Conferences Proceedings

"3rd Annual Biomass Energy Systems Conference Proceedings," Solar Energy Research Institute, Golden, Colorado (October 1979). SERI/TP-33-285 (available from NTIS).

Thermal Conversion of Solid Wastes and Biomass, edited by J. L. Jones, et al., ACS Symposium Series, American Chemical Society, Washington, D.C. (to be published August 1980).

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   1980 Review of forestry needs in Morocco and recommendations for USAID Involvement.

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   1978 Morocco Energy Study.

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   1979a Renewable Energy and Moroccan Development, Report 608-0159.

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   1979b Project paper - Morocco: Renewable Energy Development.

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6. International Agricultural Development Service.
   1978a Agricultural Development Indicators, A Statistical Handbook.

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9. Knockaert, C.
   1977b Production d' Eucalyptus camaldulensis traite en differents regimes dans le Sud du Rharb. Annales de la Recherche Forestiere au Maroc, Tome 17, pp-123.

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    1971 L'economie des boisements d'eucalyptus du Rharb, Faculte de Droit et Sciences Economiques Universite de Montpellier.

11. Royaume du Maroc
    1978a, Le Maroc en chiffres, secretariat d'Etat aupres du Premiere Ministre.

12. Royaume du Maroc
    1978b Activite du Secteur Energetique, Ministere de l'Energie et des Mines, Direction de l'Energie.

13. Royaume du Maroc
1978c Rapport Annuel d'Activite' de la Direction des Eaux et Forest et de la Conservation de Sols, Ministere de l'Agriculture et de la Reforme Agraire.

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1979 Donnees Essentielles sur le Secteur Agricole, Division des Affaires Economiques, Ministere de l'Agriculture et de la Reforme Agraire.

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1978 Commodity Trade and Price Trends
Commodities and Export Projection Division.

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1980 Developing Countries Fuelwood Supply and demand Analysis.
Renewable Energy Task Force Study.

17. Zabielsky, S.
1977 Les possibilites de culture du peuplier au Maroc. Annales de la Recherche Forestiere au Maroc, Tome 18, pp 2-123.

APPENDIX A

STATISTICAL PROFILE OF MOROCCO

This Appendix offers a brief summary of background statistics and other information about Morocco, relevant to the tasks outlined in the report. The statistics are useful in setting the stage for the biomass conversion proejcts recommended in Section IV. These project recommendations are intended to reflect that which is judged realistically attainable given current conditions in Morocco.

Basic Indicators

Basic indicators for Morocco, such as population, GNP, inflation rate, literacy rate, life expectancy, and others are given in Table A-1. Morocco had a population base of 19.4 million in 1979 growing at an approximate rate of 3.2% annually. The northern areas, where agriculture and forestry are dominant have been suffering from population and growing pressures for some time.

The percentage of the population living in the cities increased significantly between 1960 and 1975, from 29% to 37%. This may be a reflection of the decreasing productivity of the resource base due to overuse. The index of food production per capita in 1977 of 78 compared

with the base of 100 in 1971 also shows the results of population pressure and general depletion of the natural resource base. So does the low growth in agricultural production of .6% per year relative to the large increases in population.

Table A-1 - BASIC INDICATORS, MOROCCO

Population 1979 (millions)	19.4
Annual pop. growth rate (%)	3.2
Pop. projected to year 2000	35.6
Urban pop. as % to total (%)	
1960	29
1975	37
Life expectancy at birth, 1977	55
Adult literacy 1975 (%)	28
Index of food prod/cap 1975-77 (1969-71=100)	78
Annual growth, agric. prod. 1970-77 (%)	.6
Annual growth, industry 1970-77 (%)	7.8
Annual growth, manufacturing 1970-77 (%)	5.7
Annual growth, services 1970-77 (%)	5.5
GNP/cap 1977 (US$)	550
GNP/cap % growth 1960-77	2.2
Annual inflation rate (%) 1970-77	2.2
Annual inflation rate (%) 1960-70	8.9

Sources:

World Development Indicators,
World Bank, June 1979
World Food System Data Sheet
World Resources Inventory Division of the World Game

Today, according to the International Agriculture Development Service Report (1978), more than 10% of Morocco's population are calorie deficient. It also reports that food production would have to double every 14 years in order to meet projected consumption requirements. Major cereal crops are wheat and maize which occupy approximately 4.6 million hectares. Yields average 1 ton per hectare (1978).

While food production is low relative to present and projected consumption requirements, and the natural resource base is being depleted, annual growth rates in the industry, manufacturing and services sectors of 7.8%, 5.7% and 5.5% respectively are more optimistic trends. They indicate a general strengthening of the overall economy. The distribution of income, however, is largely concentrated in the urban areas.

Life expectancy at birth, 55 years, is high relative to most other developing countries while the adult literacy rate at 28% is low. Gross National Product per capita is also fairly high placing Morocco among the middle income countries of the world. The average annual rate of inflation has increased from 2.2% in 1960-70 period to nearly 9% during the 1970-77 period. Table A-2 shows the extent to which the balance of payments and debt service ratios have changed in Morocco between 1960 and 1977. Public debt has increased from $101 million in 1970 to more than 1.7 billion in 1977. Interest payments alone in 1977 exceeded the total external public debt in 1970. The debt service of 1.8% and 2.4% of GNP for 1970 and 1977 respectively puts Morocco right on the average for the middle income countries of the world.

Table A-3 shows the growth of merchandise trade and the terms of trade for Morocco between the 1960-70 and 1970-77 periods. Imports greatly exceed exports and the margin between them is widening. Energy imports in 1976 accounted for nearly one-fourth of total export earnings.

TABLE A-2 - BALANCE OF PAYMENTS AND DEBT SERVICE RATIOS, MOROCCO

Current account balance before interest payments on external public debt (US $ Millions)	
1970	101
1977	1743
Interest payments on external public debt	
1970	23
1977	129
Debt service as % of GNP	
1970	1.8
1977	2.4

Source: World Development Indicators, World Bank, June 1979.

TABLE A-3 - GROWTH OF MERCHANDISE TRADE, MOROCCO (Million US $)

Merchandise Exports 1977	1300
Merchandise Imports 1977	3194
% Annual avg. growth rates exports (%)	
1960-70	2.5
1970-77	2.1
% Annual avg. growth rates imports (%)	
1960-70	3.3
1970-77	11.9
Terms of Trade, 1970 = 100	
1960	103
1977	90
Energy imports as % of export earnings	
1960	9
1976	23

Source: World Development Indicators, World Bank, June 1979

Biomass Resource Base, Production and Consumption

Temperature and rainfall by major population centers for 1978 are given in Table A-4. The northern areas generally have abundant rainfall relative to the southern areas. The potential for biomass production is therefore largely in the north with isolated pockets of productive land further south.

Relevant statistics on forest land, production, imports, and value of imports are given in Tables A-5, 6, and 7. Morocco has an estimated 8.4 million ha of forest land divided into the species shown Table A-5. The dominant uses and rough indications of the relative economic values of the species, as perceived by the Moroccans, are also given in Table A-5. Species with the greatest energy potential include eucalyptus (*Eucalyptus spp.*), green oak (*Quercus ilex*) and thuya (*Tetraclinis articulata*). There are severe problems of deforestation, however, as was pointed out by Adams and Christophersen (1980).

Roundwood production and imports, by product, have increased slightly between 1970 and 1978 (Table A-6). The value of imports (Table A-7), on the other hand, has increased subvstantially over the same time period, contributing to an already severe foreign exchange problem.

TABLE A-4 - TEMPERATURE AND RAINFALL BY MAJOR POPULATION CENTERS, 1978

	Temperature (Celcius) (Average)	Rainfall mm
Agadir	18.5	233.6
Al Hoceima	18.0	159.7
Casablanca	17.2	425.2
Essaouira	17.0	208.4
Fes	17.0	475.2
Ifrane	11.0	931.8
Beni Mellal	18.2	377.5
Kenitra	17.6	580.9
Laayoune	20.3	75.8
Larache	17.1	711.8
Marrakech	19.7	314.8
Meknes	17.2	534.7
Midelt	14.2	124.3
Ouarzazate	19.3	112.3
Oujda	16.4	211.6
Rabat	17.2	648.8
Safi	18.0	281.7
Tanger	17.9	793.8
Taza	17.4	704.6
Tetouan	17.8	642.5

Source: Service da la Meteorologie Nationale.

TABLE A-5 - FOREST LAND IN MOROCCO BY RELATIVE VALUE AND DOMINANT USE

Species	Hectares	Relative Economic Value*	Dominant Use
Alfa	3,200,000	4	Fine paper, browse
Cork oak	425,000	3	Cork manufacture, charcoal
Green oak	1,430,000	4	Charcoal
Other oaks	25,000	4	Charcoal
Argan	740,000	3	Oil, charcoal, browse
Acacia saharien	75,000	4	Fuelwood, soil protection
Cedrus	140,000	1	Furniture, lumber
Pines	80,000	2	Furniture, lumber
Junipers	240,000	4	Fuelwood
Thuya	950,000	4	Fuelwood
Cupressus	6,000	3	Lumber
Abies pinsapo	3,000	-	In reserve
Pistachiers, tizra oleastre phylaria	740,000	-	Other
Reforested:			
Pines	162,000	2	Furniture, lumber
Eucalyptus	230,000	2	Fuelwood, Polewood
Total	8,446,000		

*No. 1 is most valuable

Source: Adams, David L., and Kjell A. Christophersen, Review of forestry needs in Morocco - Recommendations for USAID Involvement, January 30, 1980

TABLE A-6 - FORESTRY STATISTICS IN MOROCCO
PRODUCTION AND IMPORTS (1000 CUM)

Production and Imports	1970		1971		1972		1973		1974		1975		1976		1977	
	C*	NC*	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
Fuelwood Production	470	1860	480	1920	500	1980	500	1980	510	2038	525	2100	541	2165	558	2231
Fuelwood Import	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sawlogs/Veneer Prod.	70	2	70	2	68	1	68	1	130	1	105	--	73	--	85	--
Sawlogs/Veneer Import	--	158	--	150	--	158	--	158	--	193	--	82	10	109	6	181
Pitprops Production	--	16	--	17	--	17	--	17	--	24	--	25	--	17	--	20
Pitprops Import	--	49	--	72	--	30	--	30	--	79	--	91	--	76	--	69
Pulpwood Production	--	160	--	165	--	169	--	169	--	230	--	184	--	223	--	200
Pulpwood Import	--	5	--	14	--	5	--	--	--	--	--	--	--	--	--	--
Other Ind. Rndwd Prod.	15	140	15	145	15	150	15	150	17	150	18	80	19	80	20	138
Other Ind. Rndwd Imp.	--	3	--	3	--	7	--	7	--	7	--	13	--	5	--	8
Total Roundwood Available.	555	2393	565	2488	583	2517	583	2512	657	2722	648	2575	643	2675	669	2847

*C - Coniferous
NC - Nonconiferous

Source: Yearbook of Forest Products. FAO 1977.

TABLE A-7 - FORESTRY STATISTICS IN MOROCCO -
VALUE OF IMPORTS ($1000)

Imports Of:	1970	1971	1972	1973	1974	1975	1976	1977
Sawlogs/Veneer (C)*	--	--	--	--	--	--	910	496
Sawlogs/Veneer (NC)*	5504	6186	7505	7505	15568	7804	10898	15466
Pit Props	1622	2610	931	931	4707	7849	5407	4685
Pulpwood	41	64	42	--	--	--	--	--
Other Ind. Roundwood	170	154	399	399	529	1454	343	859
Total Value of Roundwood Imports	7337	9014	8877	8835	20804	17107	17558	21506

*C - Coniferous
NC - Nonconiferous

Source: Yearbook of Forest Products, FAO 1977.

APPENDIX B

LIST OF CONTACTS

USAID Mission

Harold Flemming, Director

Eric Griffel, Deputy Director

Mark Ward, Program Officer

Marion Ford, Agricultural Officer

Andres Acedo, Procurement Officer

Tom Eghmy, Economist

Jack Sleeper, Asst. Agriculture Officer

Hanafi, Agriculture Office

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Frank Piason, Agricultural Attache

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Mr. Sdiqi, Deputy Minister

Mr. Hounead Houdaigui, Directorate of Energy

Mrs. Assad

Mr. Abdelhaq Fakihani, Director, Energy Center

Mr. M'Zabi, Deputy Director Energy Center

Mr. Bennani

Department of Agriculture, Forest Service

Mr. Zaki, Director

Mr. Karmouni

Mr. Ahizoune

Mr. Hissem

Forest Research Station

Mr. Tamri, Director

Mr. C. Knockaert, Belgian Bilateral Assistance

Mr. Mandouri, Soil Scientist

Animal Husbandry

Mr. Bensouda, Deputy Director

Economics and Planning

Mr. Saissi, Director

Department of Commerce

Mr. Megzari, Director, Agro-Industry

Department of Interior

Mr. Zaher, Director of Local Collectives

APPENDIX C

CHARACTERISTICS OF BIOMASS; THERMOCHEMICAL AND MECHANICAL PROCESS DESCRIPTIONS; CHEMICAL AND BIOCHEMICAL PROCESS DESCRIPTIONS

Important chemical characteristics of biomass:

By the process of photosynthesis, plants combine carbon dioxide and water to form mainly carbohydrates. Charbohydrates contain 50 wt % of chemically bound oxygen as compared with solid fossil fuel (hydrocarbons) such as coal, oil or natural gas which contain practically no chemically bound oxygen. Depending on the variety of the plant, however, numerous other types of substances may be formed such as proteins, fats, lignin, etc.

Plants that produce large quantities of carbohydrates in the form of starch (grains and tubers) or disaccharides (sucrose in sugarcane, sugar beets, sweet sorghum) are valuable sources of food for man, or in some cases, for other mammals grown for food by man. Woody plants and parts of certain starch or sugar producing plants (stems or straw), however, contain carbohydrates in forms (cellulose or hemicellulose) that are not readily digestible by man. These woody plants and plant stems also contain lignin which sheaths the carbohydrates and inhibits biochemical breakdown of the carbohydrates. These latter forms of biomass are often referred to as lignocellulosic materials.

Starch and sugar crops are currently widely used as feedstocks for biochemical processes such as ethyl alcohol fermentations. Starches and disaccharides are readily hydrolyzed to simple six carbon sugars (monosaccharides, $C_6H_{12}O_6$) and then fermented to ethanol.

Lignocellulosic materials are typically used as feedstocks for thermal processes such as combustion or for pyrolysis to produce charcoal. Even though lignocellulosic materials may contain as much as 30 wt % lignin (dry basis) and 5 to 6 wt % of other noncarbohydrate materials, carbohydrates typically make up 65 to 75 wt % of the material. Therefore, a lignocellulosic material is composed of roughly 34 to 38 wt % oxygen and to produce a synthetic liquid or gaseous fuel with chemical characteristics and physical properties comparable to those of hydrocarbon fuels is difficult.

Thermochemical and Mechanical Process Descriptions:

In order to avoid any confusion in terminology, the different types of processes are briefly described below:

Combustion is an exothermic process in which a carbonaceous material (liquid or solid) is reacted with substoichiometric quantities of oxygen and/or steam to produce a fuel gas containing relatively high concentrations of carbon monoxide (CO) and hydrogen (H_2).

Pyrolysis is also known as destructive distillation. The classical definition of a pyrolysis process stipulates that a carbonaceous material be indirectly heated (through the vessel wall) in the absence of oxygen to temperatures sufficiently high to decompose the material and to leave a carbon residue referred to as char or charcoal. Another widely used definition of a pyrolysis process states that the process produces multiple products (noncondensible fuel gas, condensible water-soluble compounds, tars and char). In many cases only the char is recovered. Using the latter definition, processes that utilize direct heat transfer with heat generated within the reactor by partial combustion of the material are also classified as pyrolysis processes.

Liquefaction processes may be divided into three groups. (1) Pyrolysis processes can directly produce a liquid product which contains a high percentage of oxygenated compounds including organic acids, alcohols and phenols. These liquids are corrosive and may contain significant quantities of carcinogenic compounds. (2) A second group of direct liquefaction processes includes those processes that entail the use of hydrogen, carbon monoxide and catalysts to hydrogenate and/or deoxygenate the feedstock. (3) The last group of processes are those that are commonly referred to as indirect liquefaction processes. A synthesis gas is produced that contains mostly CO and H_2. The synthesis gas can then be used to produce methyl alcohol (methanol or wood alcohol) ($CO + 2H_2$ - catalyst CH_3OH) or

hydrocarbon fuels using the Fischer Tropsch process developed in Germany and now used in South Africa. Methanol can be used as a fuel or converted to gasoline using the mobile methanol to gasoline process. It is also possible to produce olefins that can then be polymerized to produce a polymer gasoline.

In many cases it is necessary to mechanically process a biomass feedstock prior to conversion as well as following conversion. Some of the commonly used processes include:

Densification (prior to hauling) - baling
Size reduction - cutting, chopping, milling or grinding
Densification (prior to or after conversion)
- cubing
- pelletizing — binders may be required
- briquetting

Mechanical pressing may also be used to express juice or oils. Expression may be followed by or done in conjunction with extraction or leaching.

Chemical and Biochemical Process Descriptions:

The two major categories of processes to be described here are those that produce a methane-rich fuel gas from biomass and those that produce ethanol from biomass. In the case of the ethanol fermentation, it will be necessary to include a hydrolysis process if non-sugar feedstocks are to be used.

In methane fermentation, also commonly known as anaerobic digestion, water soluble and insoluble organic materials are converted by bacteria to a gas containing two primary constituents, methane (CH_4) and CO_2. The process was first applied in a controlled system for conversion of organic materials to energy near the end of the 19th Century. The technology has been widely used in large scale applications for stabilization of highly putrescible sewage sludges. The process has also been widely used on foams for animal manure digestion.

The relative quantities of CH_4 and CO_2 in the product gas depend on several factors, of which the most important is the composition of the organic feedstock. Feedstocks contianing high percentages of proteins and fats (like sewage sludges) will produce a product gas with a high CH_4 content, 65-70 vol %. Carbohydrate feedstocks, such as starch containing wastes, will produce a product gas with a lower methane content, typically 50-55 vol %.

The amount of gas production is also influenced by the chemical characteristics of the feedstock. Biomass with a high lignin content is generally not degraded rapidly or extensively in an anaerobic digester. The complex carbohydrates (cellulose and hemicellulose) in lignocellulosic solids must first be hydrolyzed by bacterial extracellular enzymes so as to allow passage into the cells. The lignin sheathing of polymer strands makes

it difficult for hydrolysis to proceed. Other factors such as cellulose crystallinity are also important but will not be discussed here. As a first approximation for the extent of degradation of low lignin content materials 15 wt %; one may assume that none of the lignin will be degraded and a quantity of cellulose equal to at least the quantity of lignin present will also not be degraded. For lignocellulosic materials with very high lignin content (20-30 wt %) like wood, very little, if any, degradation will occur without extensive mechanical and chemical or thermal pretreatment to disrupt the lignin sheathing and cellulose crystallinity.

Anaerobic digesters are often operated as continuous flow processes, unlike ethanol fermentation which are usually operated as batch processes.

In an ethanol fermentation, six-carbon sugars (hexoses) are converted to ethanol by yeast under anaerobic conditions. Yeast can also ferment 12 carbon sugars such as sucrose to ethanol, but not 5 carbon sugars (pentoses). Man has produced ethanol by fermenting naturally occuring sugars and starches for thousands of years, and the process is currently used all over the world to produce alcoholic beverages, ethanol for solvent use and ethanol for fuel use. A great deal of research and development effort is now being devoted to the following areas with the goal of reducing costs for ethanol:

-Acid and enzymatic hydrolysis of lignocellulosic materials.

-Fermentations that will produce liquid fuels from pentoses which are by-products of hydrolysis (hemicellulose contains pentosans).

-Continuous ethanol fermentations.

-Improved ethanol recovery.

APPENDIX D

SUMMARY OF INFORMATION COLLECTED ON JULY 19, 1980, VISIT TO COMPOSTING FACILITY IN MARRAKECH AND OFFICE OF CITY ENGINEER

o Facility was constructed in 1967 using Swiss equipment supplied by Buhler.

o Maintenance of the Facility has been a problem because of the unavailability of spare parts in Morocco.

o Facility is reported to have a capacity to process about 200 metric tons/day of municipal waste.

o City of Marrakech generates 200 t/day of solid waste/day (5 days/week), but hand sorting of waste at transfer stations reportedly results in a reduction in the quantity of waste for processing to 110-115 metric tons/day.

o Much of plastic and textile material is removed from the waste at the transfer stations.

o As is the case in most developing countries, the municipal waste has a very high moisture content (66 wt%). The waste characteristics reported for Casablanca are believed by the City Engineer to be comparable to those for wastes from Marrakech. These characteristics are summarized in Table D-1.

City of Marrakech does not now have a sewage treatment plant. Sewage treatment is being considered. Sewage characteristics are summarized in Table D-2.

Table D-1

TYPICAL COMPOSITION OF MUNICIPAL SOLID WASTE
FROM CASABLANCA

Component	Wt% (wet basis)	Wt% (dry basis)
Organics (assumed to be food scraps)	23.0	65.7
Paper and cardboard	6.5	20.5
Plastic	0.5	1.5
Rags	1.0	3.0
Glass	0.2	0.5
Gravel and sand	2.3	8.0
Misc. or unaccounted for	0.5	-
Water	66.0	-
	100.0	100.0

Report states that 10 liters of fuel oil required per metric ton of waste for combustion.

Table D-2

AVERAGE DRY-WEATHER FLOW AND TYPICAL COMPOSITION OF SEWAGE FROM MARRAKECH
(Data reported in 1976)

Component	(Concentration (mg/ℓ)
BOD	350 to 1200
Suspended solids	300 to 450
Chlorides	200 to 500
Sulfate	30 to 50
Sodium	100 to 400
Total residue (assumed to be total solids)	1000 to 2000

Average flow = 600 liters/sec.
(13.7 million gallons/day)

Quantity suspended solids

$$\left(\frac{0.375\ \text{gm}}{\ell}\right)\left(\frac{600\ \text{liters}}{\text{sec}}\right)\left(\frac{86{,}400\ \text{sec}}{\text{d}}\right)\left(\frac{1\ \text{metric ton}}{100{,}000\ \text{gm}}\right) = \frac{19.4\ \text{metric tons}}{\text{day}}$$