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BIOMASS CONVERSION TECHNOLOGIES

State of the Art

VOLUME I: GUIDE TO BIOMASS CONVERSION TECHNOLOGIES

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FOREWORD

The world energy crisis is affecting the developing countries in a variety of ways. National budgets in many countries poor in fossil fuels are being severely strained by the need to spend foreign exchange on expensive petroleum fuels. High kerosene prices are forcing the poor to substitute lower quality fuels for domestic cooking and to use less household lighting. Industries are seeing their profit margins and productivity squeezed by sudden increases in fuel prices as the competition for all fuels heightens. Remote regions and countries are losing their hard-won access to markets because of the high cost of transportation fuels.

The strain on national development budgets from these effects is sufficient stimulus for developing countries to reexamine their national energy policies. The aggregate real cost of oil imports to developing countries rose from $5 billion in 1970 to $29 billion in 1978 and to $58 billion in 1980. The World Bank estimates that these import costs will reach $107 billion by 1985 and $198 billion by 1990, assuming 10 percent inflation plus a real increase of 3 percent in the price of oil throughout the 1980's (World Bank, 1980).

These discouraging statistics have forced planners to recognize the inherent vulnerability of basing further development on imported fuels and to seek ways to curb the growth of this dependency. One of the possibilities is to develop energy from biomass, which is the subject matter for this series of seven volumes. The useful energy products from

biomass include alcohol, charcoal, biogas, fuelwood, producer gas, and vegetable oils. Indonesia, Brazil, and the Philippines have already launched ambitious bioenergy programs. These countries are already producing alcohol amounting to a significant fraction of their national liquid fuel needs. Other countries have programs to produce charcoal for use in households, small-scale industry, and for iron smelting. In the Philippines trees are grown to fuel thermal generation of electricity.

Biomass, among the renewable resources such as hydropower, geothermal, solar, and wind resources, is perhaps the most suitable to replace energy from fossil fuels. Conversion technologies are already well known for the production of gaseous, liquid, and solid biofuels capable of substituting for almost all uses of fossil fuels. In addition unlike hydropower, wind, and solar energy, which are limited to specific situations and locations, biomass can be produced most anywhere. The complicating factors in making bioenergy program decisions are the existence of so many possible energy crops and alternative production systems. For other renewable resources, such as a river that can be developed for hydroelectric power or a steam field within drill reach, standard (and universally accepted) engineering and economic analyses can be applied and relatively accurate predictions can be made concerning the roles these resources can be expected to play in the national energy budgets. It is a much more difficult task to make similar predictions with a proposed bioenergy system. There are no "off-the-shelf" bioenergy systems, and each must be tailored closely to local conditions.

This seven-volume series, Biomass Conversion Technologies, State of the Art, is a part of the Bioenergy Systems and Technology (BST) project carried out by the Office of Energy of the United States Agency for International Development (AID) Bureau for Science and Technology, in conjunction with the Forest Service and Office of Science and Education of the United States Department of Agriculture. The overall purposes of the project are to provide information and technical assistance to developing countries through USAID missions in evaluating the potential contribution of bioresources to national energy needs and help host countries plan specific bioenergy systems.

Among the many efforts of the BST project to date is a program to disseminate the increasing amount of information and data on bioenergy resources, conversion technologies and biomass-derived fuels. A first step is the publication of the Bioenergy Handbook, a document providing an introduction to biomass systems. It presents technical data and related information useful in assessing the potential of bioenergy projects. The handbook is addressed mostly to newcomers to the field of bioenergy and is designed to help them identify attractive and realistic bioenergy projects.

The present series of seven State-of-the-Art (SOA) volumes on biomass conversion technologies is a second step in the program of information dissemination. The purpose of this set of volumes is to provide enough background information necessary to initiate bioenergy projects. As such, the SOA volumes are more detailed and contain more technical data than the Bioenergy Handbook and should provide the background needed to conduct

feasibility studies of various bioenergy options. Other dissemination activities complementing the publication of the Bioenergy Handbook and of the Biomass Conversion Technologies, State of the Art volumes are planned for the future.

We hope that this series will facilitate the development of biomass for energy projects and prove valuable in reducing the impact of shortages and increasing costs of fossil fuels in developing countries.

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BIOMASS CONVERSION TECHNOLOGIES

State of the Art

INTRODUCTION

INTRODUCTION

Originally, the term biomass was used to describe the total quantity of all living matter: plants, animals, fungi, protists, and monerans (Falkehag, 1979). Recently, within the context of energy production from biological resources, the term biomass has been generally restricted to include biological matter generated through the process of photosynthesis. Within these boundaries, wood and agricultural materials are the major components of the biomass resource. These are used primarily as food, feed, fiber, structural materials and chemicals. In many cases, the by-products, or residues, rather than the products themselves, can be and are used for energy purposes.

Aquatic plants could become a significant resource if and when suitable methods are designed to recover and convert this material to useful energy. When appropriate, reference will be made to aquatic resources in the volumes. However, they will not be analyzed in depth for lack of sufficient experience and data to document their value as a source of energy.

Municipal solid and liquid wastes too are biomass resources that can be also converted to energy. The major objective of the treatment of wastes is usually their disposal in an environmentally acceptable fashion, not energy production. To achieve both acceptable disposal and energy production gives rise to some particular problems of systems design and optimization and of economic feasibility that are beyond the scope of the present series of volumes.

Five major conversion technologies are considered in these seven volumes: direct combustion, pyrolysis, gasification, anaerobic digestion and alcoholic fermentation. Some technologies, such as direct combustion, have been used since time immemorial, whereas other technologies, such as gasification, were developed more recently and reflect a trend toward more sophisticated utilization of biomass.

Conceptually, any biomass material can be converted to energy that can replace fossil fuels via any of the conversion technologies mentioned above. Some materials, however, are better suited as feedstocks for some conversion processes than others. Biomaterials of high moisture content are less attractive as feedstock for direct combustion than are, say, wood residues. The multiplicity of choices, or alternatives, for the conversion of biomass to energy are both attractive and puzzling features of biomass as an energy resource. Selecting the most appropriate bioenergy system for a given set of conditions will depend not only on the goal to be achieved, i.e., displace or replace petroleum fuels, but also on the context (land use, social, economic) within which the bioenergy system will operate. The task of selecting, designing, and implementing bioenergy projects is complex because each project is different from other projects, and there is no standard design as in the case, say, for a diesel generator.

The overall objectives of the series are to provide background information for the selection of appropriate biomass conversion pathways and to evaluate the merits of biomass as an alternative source of energy.

1. Biomass as an Energy Alternative

Table 1 summarizes some of the advantages and disadvantages of renewable energy sources. On balance, biomass appears as one of the most attractive sources because of its availability in many forms and because it can be converted to many energy forms and uses.

The majority of the people in developing countries (nearly half of the world's population) rely on biomass to meet most of their nonfood energy needs, particularly firewood, animal manure, and crop wastes. Total consumption is approximately 30×10^{18} joules of energy per year, worldwide, or nearly half the total energy consumed at end use in the developing countries (Taylor, 1979). Nevertheless, developing countries continue to allocate a disproportionately small fraction of their energy budgets to the improvement of biomass production, conversion, and end use, compared to the resources they expend on fossil fuel energy development and technology (Stout, 1979).

The global annual rate of net photosynthetic production of chemical energy stored in land plants has been estimated to be about $2{,}000 \times 10^{18}$ joules, or roughly eight times the worldwide primary energy consumption in 1975 (Stout, 1979). This comparison suggests that biomass energy could play a major role in meeting future energy demands as estimated by Weingart (1979) in Table 2. This table shows projected estimates of maximum possible installed capacities of renewable energy system technologies in the year 2030. These estimates represent what could possibly be achieved with substantial commitment to the development and installation of biomass conversion technologies. The global

TABLE 1.--ADVANTAGES AND DISADVANTAGES OF VARIOUS RENEWABLE ENERGY SOURCES

RESOURCE	ADVANTAGES	DISADVANTAGES
Biomass	Convertible in a variety of energy forms and fuels. Many conversion technologies are well known. Conversion can produce valuable by-products, such as cattle feed and fertilizer. In some forms the resource can be stored. Resource widely available.	Collection and handling costs can be high. Lower heat content per unit weight than coal or oil. Production and collection can create environmental problems. Competition with other uses: Food feed, fiber. Resource can be far from major end users.
Solar Energy	Can produce a variety of energy forms: heat, mechanical power, and electricity. Nonpolluting and safe.	Limited periods of sunlight. Variable solar intensity. Intermittent source: requires storage or back-up energy source. High cost of many systems. Some conversion methods still in development.
Wind	Can produce mechanical and electrical power. Technology available. Nonpolluting.	Variations in output according to duration and force of wind. Requires storage or back-up for reliable electricity supply. Limited number of sites with wind patterns suitable for large-scale utilization.
Ocean:		
Tidal	Nonpolluting. Technology in use. Produces electricity.	Limited number of suitable sites. Cyclic generation of electricity. Complex and costly installations. Potential environmental limitations.
Thermal	Non-polluting. Produces electricity.	Technology not available. High projected cost of electricity produced. Transmission to end users costly.
Waves	Nonpolluting. Produces electricity.	Intermittent power. Pilot units under test. Interferes with use of coastline. Variable wave patterns.

TABLE 1.--ADVANTAGES AND DISADVANTAGES OF VARIOUS RENEWABLE ENERGY SOURCES (Continued)

RESOURCE	ADVANTAGES	DISADVANTAGES
Hydropower	Produces electricity. Potential for small-scale distributed plants. May be combined with other water project purposes such as irrigation. Technology well known.	Requires suitable sites. Sites may be distant from users. High initial costs. Can create environmental problems. May require storage.
Geothermal	Can provide heat, mechanical and electrical power. Technology in use.	Generally limited to areas of tectonic activity. Environmental problems. Sites may be distant from users.

installed capacity in 1980 is only a very small fraction of that which is perceived to be achievable. At 100 percent load utilization, for example, the combined biomass-biogas capacity alone could generate the equivalent of about 5 terawatts (TW), which is more than the projected total energy consumption for developing countries in 2030. There is little doubt, therefore, that from a technical viewpoint, biomass resources for energy could significantly reduce the dependence on fossil fuels in many countries.

On the negative side, biomass related technologies are generally more expensive than their fossil fuel counterparts because they require costly

TABLE 2.--ESTIMATES OF MAXIMUM POSSIBLE INSTALLED CAPACITY OF RENEWABLE ENERGY SYSTEM TECHNOLOGIES IN 2030

Energy System	Global Installed Capacity by 2030
Ocean Thermal	10.0 TW*
Solar	6.0 TW
Biomass	3.0 TW
Wind	3.0 TW
Biogas	2.0 TW
Other Technologies	1.0 TW

Source: Weingart, 1979

*Terawatt = 10^{12} watts.

front-end handling equipment for feedstock preparation and storage space (Table 3). However, they tend to be less costly than hydro, geothermal, solar and wind systems. How well biomass systems compete depends to a large extent on the relative cost of the biomass feedstock versus that of fossil fuels or the other renewable energy options. For example, hydro and wind systems would be competitive in terms of capital investment where wind patterns are favorable and hydrologic resources are abundant.

TABLE 3.--CAPITALIZATION COSTS PER KW OF GENERATING CAPACITY

System	Cost ($1/kW)
Hydro[a]	1,296
Geothermal[a]	1,564
Fossil Fuel Thermal[a]	863
Solar-photovoltaics	10,000-20,000[b]
Wind:	
Less than 1kW	3,000-6,000
5-20 kW	1,000-2,000
Biomass:	
Thermal	1,000
Gasifier/Engine-Generator	700-1,200
Ethanol[c]	1,500

Source: Stout et al, 1979.

[a] Average costs in 97 developing countries

[b] Cost per peak kW, corresponds to about $50,000 to $100,000 per average kW installed capacity.

[c] Capital cost of an ethanol plant capable of driving a generator of 1 kW capacity

2. Bioenergy Systems

Bioenergy systems consist of four major components: the feedstock, the conversion technology, the end use or market for the bioenergy, and the system's socioeconomic feasibility. These components together determine the appropriate technology to use in different countries and different situations. Each situation is site specific, and what works in one country does not necessarily work in another. Which technology to use is also dependent on the existence of a distribution infrastructure, i.e., gas pipelines, electric transmission lines, or adequate transportation systems.

The success of a bioenergy project is measured not only in terms of its technical performance but also in terms of its economic and environmental and social impacts. Economic success has two facets. First, the project should be financially attractive from the perspective of a private investor; i.e., expected returns should be sufficiently high to attract the necessary investment capital. Second, the project should be economically attractive to the society as a whole, reflecting a broad government perspective. In the latter case, "shadow prices" are used intended to represent the "real" values of benefits and costs along with consideration of such elements as the creation of employment in rural areas, the development of a new industry to manufacture bioenergy systems, a reduction in petroleum imports, etc.--, or a combination of such elements. In addition, elements related to the implementation of bioenergy projects but difficult to quantify are assessed at least qualitatively in determining the economic attractiveness of the project.

Bioenergy projects may also have serious environmental repercussions. Increased harvesting of biomaterial or intensive production of energy crops can have negative long-term effects on the soil and watershed. Conversion processes that require large quantities of process water may deplete local water resources too fast. Other processes may generate burdensome quantities of by-products that cause disposal problems. End usage of some forms of bioenergy may create various health hazards particularly if the end use equipment is poorly maintained. The success of a bioenergy project will also depend on societal factors, such as availability of trained personnel or of training programs, integration of the bioenergy project in country or regional development plans, availability of support industries, manufacturing and/or spare parts, and others.

3. State-of-the-Art Volumes: Users and Objectives

Potential users of these volumes include U.S.A.I.D. mission personnel, host country agencies, field personnel such as Peace Corps Volunteers and extension agents, etc. Users may consult the volumes to obtain country resource overviews and to gain information for planning, program development, and project implementation purposes. The information provided ranges from essentially qualitative to fairly detailed technical data.

Since the nature of the information sought differs between individuals the SOA volumes are designed to allow users to approach their particular

problem areas in several different ways. One way is to obtain information on how to select the appropriate bioenergy pathway in view of the many possible systems available for any given situation. Another is to obtain a good technical and economic overview of the prospects of biomass as an alternative source of energy. Some readers may be more interested in end uses or how a petroleum-derived fuel used in a given sector can be replaced by bioenergy. Others may approach the problem from a resource point of view, or how a certain biomass resource can provide energy and who will benefit from this alternate source of energy. In these SOA volumes a systematic approach is developed that guides various users to the relevant data they need. The following are the objectives of the SOA Volumes:

- Provide a background of information concerning biomass resources, conversion technologies and end uses at a qualitative level relatively sufficient for general assessments of bioenergy
- Provide a methodology for the identification and selection of appropriate bioenergy pathways
- Provide the data needed to characterize bioenergy systems and assess their feasibility
- Discuss the environmental, social, and economic aspects of bioenergy systems

4. Organization, Content, and Utilization of the State-of-the-Art Volumes.

Volume 1 - Guide to Biomass Conversion Pathways--provides the user with the tools needed to identify, select and evaluate bioenergy systems. The volume provides a methodology for selection bioenergy systems, data on feedstock characteristics, data needed to estimate the energy requirements of various end uses and procedures for evaluating the investment feasibility of projects. Volume 1 also orients the reader to other volumes or sections of volumes needed to evaluate the systems selected.

Volume II - Country Statistical Data--describes the major biomass resources available in 66 countries. The volume also discusses energy consumption and consumption trends by countries and by categories of fuels.

Volumes III through VII are devoted to conversion technologies. The technologies are described, environmental and social aspects are discussed, design examples are given and economic case studies are described.

Volume III - Alcohol Fuels - describes the production of ethanol and methanol fuels from various feedstocks. The utilization of these fuels in various end use sectors is also considered.

Volme IV - Pyrolysis - discusses the production and utilization of charcoal, pyrolytic oil and gas and the use of char-oil mixtures in existing oil-fired boilers.

Volume V - Combustion - discusses cookstoves and industrial boilers. The problems of retrofitting existing boilers to biomass fuels are examined.

Volume VI - Biogas - discusses the anaerobic conversion of biomass to biogas and the use of this fuel in household and industrial applications.

Volume VII - Gasification - discusses the conversion of biomass to fuel gas and the utilization of this gas in small end use systems such as electric generators and in large industrial systems. The retrofitting of existing oil-fired boilers to biomass fuel gas is also examined.

The selection and evaluation of bioenergy systems will generally require inputs from several volumes. These may be used in a variety of sequences dictated by the characteristics of the bioenergy system under consideration. In all cases, Volume I should be consulted first because it will identify the systems of interest and for each system will refer the reader to the appropriate volumes in a logical sequence.

BIOMASS CONVERSION TECHNOLOGIES

State of the Art

VOLUME I: GUIDE TO BIOMASS CONVERSION TECHNOLOGIES

OVERVIEW OF VOLUME 1.

Volume I, Guide to Biomass Conversion Technologies, is designed to provide background data on biomass systems selection, biomass resources, sectorial energy uses and project evaluation to the users of the series. This volume therefore is a reference volume to be used in conjunction with others in the series dealing with individual or groups of technologies.

Chapter 1, Guide to the Selection of Bioenergy Systems, presents a methodology enabling various categories of users of the volumes to select in a systematic way biomass systems suiting their particular objectives. Specifically, the methodology enables a user to identify and, to a certain extent select, biomass technologies that will respond to various objectives and situations: convert specific biomass wastes to energy, provide a substitute fuel/energy for fossil fuels used in a given sector, etc.

Chapter 2, Biomass Resources, discusses the characteristics of biomass materials as they relate to conversion technologies and describes the major biomass resources: forests and wood wastes, agriculture and its wastes, animal wastes and aquatic plants. The problems of collection, transportation, and processing of the resources are also discussed. This chapter includes and regroups in one location material dispersed in several of the SOA volumes prepared by various authors (A. Kaupp and J. R. Goss, D. W. Pingrey et. al., E. S. Lipinsky et al., Acesita Florestal) in order to

facilitate the task of the reader in finding background data on biomass resources.

Chapter 3, Energy Consumption by User Sectors, provides data on energy consumption by the rural/household, industrial, agricultural, and transportation sectors. The purpose of this chapter is to provide the reader with estimates of the energy requirements of various potential users of bioenergy systems needed to design and evaluate candidate biomass conversion systems. This chapter draws on data presented in the state-of-the-art volume prepared by J. H. Arnold, Jr. (1980).

Chapter 4, Project Evaluation, discusses the elements of project feasibility studies and describes the methodology for the economic evaluation of biomass projects. Financial and economic analysis techniques, the latter based on shadow pricing, are reviewed and illustrated by an example. The chapter draws on data provided in the SOA volume prepared by Meta Systems, Inc.

CHAPTER 1

GUIDE TO THE SELECTION OF BIOENERGY SYSTEMS

1.1 Introduction

The objective of the series of State of the Art volumes is to provide the background and data needed to evaluate and design bioenergy projects. The present chapter proposes a methodology to select viable projects. Viability is meant here to include the following factors: availability of a resource to support the process, availability of a market for the bioenergy, and availability of a demonstrated technology. Other factors affecting project viability, such as economics and environmental and social impacts, are considered in volumes III to VII of this series of volumes.

Finally, the series of volumes and the methodology for selection of projects are organized to suit the backgrounds and needs of various potential users. These needs may range from simple planning-overview evaluations to fairly detailed project designs.

1.2 Approach to the Selection of Bioenergy Systems

The methodology for the selection of bioenergy systems described in Section 1.4 relies on three elements: Biomass Conversion Chart, Table of Associated Feedstocks and Technologies, and a Table of Bioenergy End Uses.

1.2.1 Biomass Conversion Chart

The Biomass Conversion Chart (Figure 1.1) identifies the bioenergy conversion technologies discussed in the series of volumes. The chart is made of a series or concentric circles. The central circle refers to the resources..forest (products and residues), agriculture (crops and residues), and animal wastes. The second set of circles (from the center) refers to individual or a combination of technologies. These circles and the subsequent one are divided in five sectors, one each for a technology a or group of technologies. The last circle (from the center) corresponds to energy end uses by sectors. As shown in Figure 1.1, individual volumes of the series of State of the Art volumes are associated with circles or sectors. This proposed organization of the technologies makes it possible to access the volumes in a systematic way through the master chart.

The use of the chart may be illustrated as follows. A user interested in the production of alcohol fuels will be referred to Volume III to find data concerning this technology (see Figure 1.1). The chart (Figure 1.1) shows that forest and agricultural products are potential feedstocks for the technology and that data concerning these resources can be found in Volumes I and II for the country of interest. The chart also shows that alcohol fuels can be substituted for a variety of fossil fuels used in the transportation, industrial, and utility sectors (outer circle within the alcohol fuels sector) and refers the reader to Volumes I and II for data

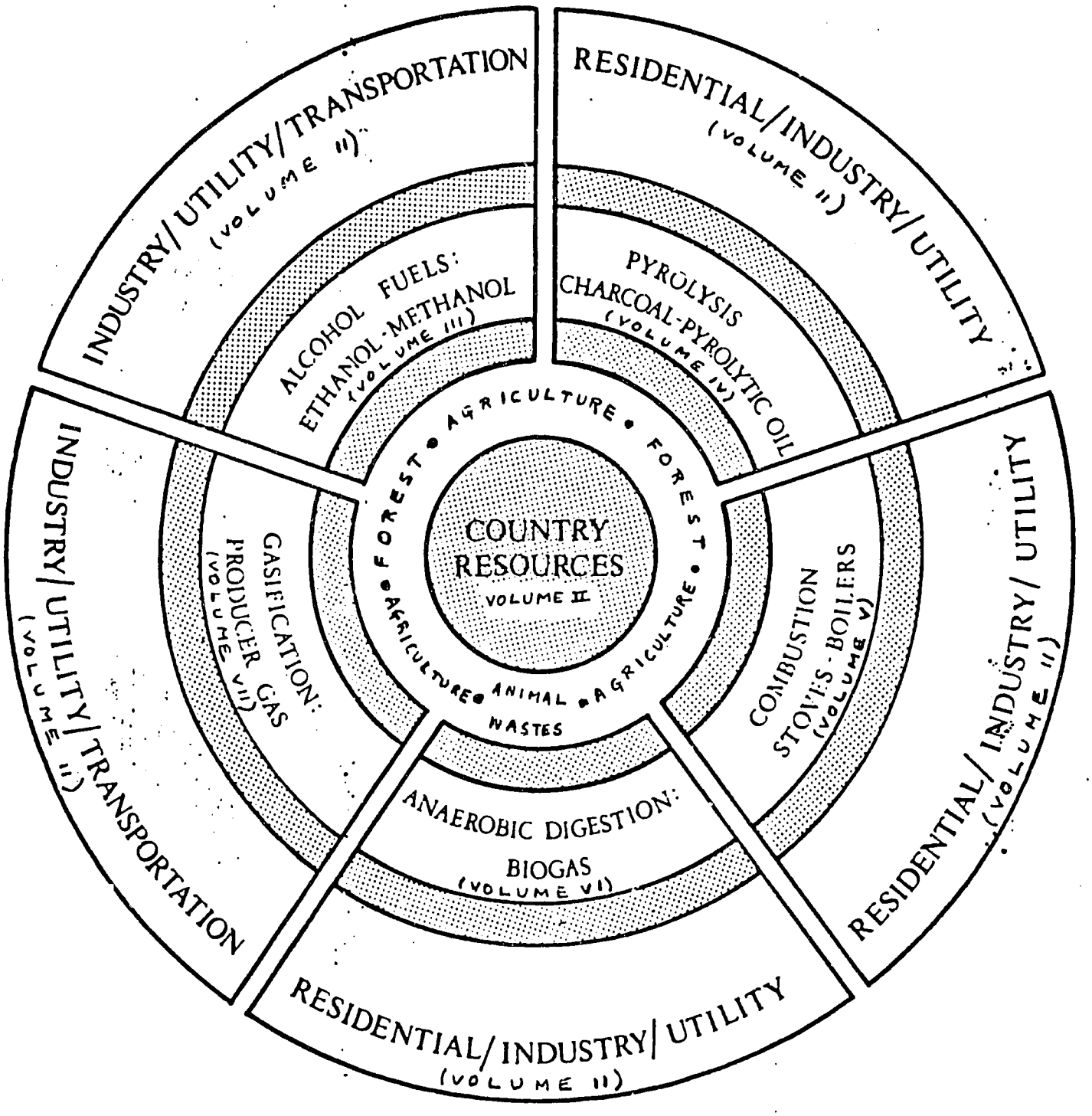

FIGURE 1.1 - BIOMASS CONVERSION CHART

concerning the consumption of fossil fuels to be replaced by alcohol fuels. Thus each of the five sectors of the chart defines biomass conversion paths in broad terms from the resource (central circle) to the end uses (outer circle) and refers the reader to the appropriate volumes needed to analyze a conversion path.

The chart defines conversion pathways in broad terms; i.e., it does not distinguish between various classes of agricultural materials nor does it address the viability of a given pathway. For example, the chart suggests that both forest and agricultural products can be used for ethanol production. However, if the user wants to further refine the choice between these two potential feedstocks, he will have to turn to the Table of Associated Feedstocks and Technologies described below.

1.2.2 Table of Associated Feedstocks and Conversion Technologies

Table 1.1 relates categories of feedstocks to the technologies most appropriate for their conversion, enabling the reader to refine the choice between several technologies suggested by the chart (Figure 1.1) on the basis of the type of resources available. The table also indicates the status of the various technologies: "available" refers to technologies currently commercial and other terms refer to technologies at various stages of development. Each technology is also characterized

TABLE 1.1.--ASSOCIATED FEEDSTOCKS AND CONVERSION TECHNOLOGIES

RESOURCES	CONVERSION PATHS	STATE OF TECHNOLOGY	SCALE OF PROJECT	BIOENERGY	VOLUMES
Forest and dry agricultural residues	--	--	--	--	I & II
	Hydrolysis-fermentation	R&D/ pilot	Large	Ethanol	III
	Gasification-methanol synthesis	Possible, none in operation	Large	Methanol	
	Pyrolysis	Demonstration	Variable	Char, pyrolytic oil	IV
	Combustion	Available	Variable	Heat, steam, electricity	V
	Gasification	Available	Variable	Producer gas	VII
Agricultural Resources					I & II
Sugar crops	Fermentation	Available	Variable	Ethanol	III
Starch crops	Fermentation	Available	Variable	Ethanol	
Animal Wastes and wet residues					I & II
	Anaerobic digestion	Available	Variable	Biogas	VI

by its scale: "large" refers to projects that can only be implemented on an industrial scale and "variable" indicates projects which can validly be scaled up or down (from a cooking stove to a power plant in the case of combustion, for instance). These two factors of the existence of a commercialized technology and of the existence of equipment of a size compatible with the end use identified are considered to be essential in selecting appropriate bioenergy pathways. The table also shows the bioenergy generated by the technologies and identifies the volumes in which the processes are described.

1.2.3 Table of Bioenergy End Uses

Table 1.2 characterizes the end use potential of each of the bioenergies identified in Table 1.1. It enables the user to further refine the choice between several technology options through consideration of the end-use applications of each bioenergy.

The second column in the table indicates the fossil fuels that can be replaced by each bioenergy. "Gas" refers to all forms of gaseous fuels: natural gas, LPG, etc; "All fuels" refers to the group of fossil fuels currently used in a given application (kerosene, LPG, etc., used for home cooking for instance); "Light fuels" refers to lighter distillate fractions typically used in gas turbines.

One of the important criteria in selecting a technology is its ability to substitute for fossil fuels in equipment designed for, and currently fired

TABLE 1.2.--BIOENERGY END-USES

Bioenergy	Substitute	Retrofit Potential	Volumes
Ethanol:			
Gasoline/ethanol mixtures	Gasoline	Excellent (up to 10 to 20% ethanol)	
pure ethanol (hydrated/dehydrated)	Gasoline	Good. Engine modifications required	III
	Diesel	Good. Engine modifications required.	
	Gas, Light fuels	Good after turbine modifications.	
Methanol	Gasoline	Demonstrated. Engine modifications required.	III
Char:			
Char alone	Charcoal	Good in some industrial processes. Requires processing or special stoves in residential applications.	IV
Char-oil mixtures	Fuel oil	Demonstrated in industrial boilers.	IV
Pyrolytic Oil:	Fuel oil	Demonstrated in industrial boilers; requires equipment modifications.	IV
Direct Combustion:			
Heat	All fuels	Cooking/heating stoves are less practical than fossil fuel-fired equipment and are often very inefficient.	V
Steam/Electricity	All fuels	Fossil fuel-fired industrial boilers are difficult to retrofit to use biomass solid fuels.	
Biogas	All fuels	Very good in household applications.	
	Gasoline	Very good. Minor modifications of engine required.	
	Diesel	Good. Dual configuration required (90% biogas, 10% diesel) for engine.	VI
	All fuels	Good in industrial boilers after modification of burners.	

TABLE 1.2.--BIOENERGY END-USES (Continued)

Bioenergy	Substitute	Retrofit Potential	Volumes
Producer Gas:			
	Gas, fuel oils	Good; some modifications to boilers needed; some derating may result.	
	Gasoline	Very good. Small modifications to engine required; some derating may result.	
	Diesel	Very good. Duel fuel system required (50 to 90% gas, 50 to 10% diesel); some derating may result.	VII
	Gas, Light oils	Good. Modifications to turbines and clean gas required.	
Medium-Heat Gas	Gas, Fuel oils	Demonstrated some modifications to boilers or turbines required.	VII

with fossil fuels, i.e., the potential for retrofitting existing equipment (column 3). Finally, the table indicates the volumes in which information relative to each bioenergy can be found.

1.3 Users of the Series of Volumes and Their Needs

The series of volumes is organized according to the background and needs of five classes of users:

- Users who search for information relative to any one of the components of a bioenergy project, i.e., information concerning the resources, the technologies or the end uses of bioenergy systems. These users may have little or no technical background, in which case they will be seeking for an overview and general information on the topic that interests them, or they may have some technical expertise and will be seeking more detailed data concerning their area of interest.

- Users who are familiar with a country's energy consumption and resource availability and want to identify a bioenergy system that can substitute for a particular fuel in a particular end use sector.

- Users who know the availability of a specific biomass resource in a country and who wish to identify a bioenergy system that could substitute for petroleum-derived energy. These users may or may not have a particular end use sector or a petroleum fuel in mind.

- Users who are aware of an end use sector and wish to identify a resource and a technology which could satisfy the needs of this sector.

- Users who are not familiar with a country's biomass resources or with its energy consumption pattern and wish to identify a bioenergy project for the country.

Table 1.3 summarizes the users' profiles and their needs for informaton (first column in the table).

1.4 Methodology for Identifying Sources of Data.

A methodology is described below to facilitate the task of users in locating the data they need. Each of the five categories of users described above is considered separately and appropriate examples are provided to illustrate the methodology. Table 1.3 summarizes the method of locating information for each category of users.

1.4.1 Need for Information on a Component of a Bioenergy System

A user with or without technical expertise requires source data relative to bioenergy system components. The user consults the Chart of Biomass Technologies (Figure 1.1), which will refer him to the appropriate volumes.

TABLE 1.3.--USER PROFILES AND METHODOLOGY FOR DATA IDENTIFICATION

USER PROFILE	BACKGROUND/ DATA AVAILABLE	SOURCE OF INFORMATION	INFORMATION PROVIDED
1. User needs information on components of bioenergy projects, i.e. resource, technology or end-use.	User with or without technical background.	Chart of Biomass Technologies (Figure 1.1)	Identification of the State of the Art volume in which the component of the bio-energy project is described in detail.
2. User knows energy consumption.	Energy consumption by fuel and sector.	Chart of Biomass Technologies (Figure 1.1).	Identification of a single technology and reference to the appropriate volume.
	Biomass resource available by types.	Chart of Biomass Technologies (Figure 1.1).	Identification of several optional technologies.
		Associated Feedstocks and Conversion Technologies (Table 1.1) and Bioenergy End-Uses (Table 1.2).	Selection of most appropriate technologies and reference to appropriate volumes.
3. User has identified a specific biomass resource and wants to identify a bioenergy project using the resource. The user may or may not know the country's energy consumption pattern.	Biomass resource and energy end uses.	Chart of Biomass Technologies (Figure 1.1).	Identification of several optional technologies.
		Tables 1.1 and 1.2.	Selection of most appropriate technologies for use of the resource to appropriate volumes.
	Biomass resource only.	Chart of Biomass Technologies (Figure 1.1).	Orients user to Volumes I and II for data concerning the country's energy consumption profile.
		Chart of Biomass Technologies (Figure 1.1).	Identification of one or several technologies linking the resource to the end uses identified below.
		Tables 1.1 and 1.2	Selection of most appropriate technologies for the case considered and reference to appropriate volumes.

TABLE 1.3.--USER PROFILES AND METHODOLOGY FOR DATA IDENTIFICATION (Concluded)

USER PROFILE	BACKGROUND/ DATA AVAILABLE	SOURCE OF INFORMATION	INFORMATION PROVIDED
4. User is aware of energy needs of an end-use sector and wants to identify bioenergy pathways capable of satisfying these needs.	End use sector identified.	Chart of Biomass Technologies.	Identification of several optional technologies and resources required.
	End use energy needs known.	Volumes I and II. Tables 1.1 and 1.2.	Availability and type of resource. Selection of technologies and reference to appropriate volumes.
5. User wants to identify potential bioenergy projects but does not know energy needs or biomass resources available.	End use sector identified. End use energy needs not known.	Chart of Biomass Technologies.	End-use needs from Volumes I and II. Same procedure as above.
		Chart of Biomass Technologies.	End-use needs or resources or both determined from volumes I and II. Once the needs and/or resources are known, the reader is brought back to cases discussed above.

Example 1. A user is interested in obtaining a listing of classes of biomass resources currently used for energy production and some general background information relative to these resources. Following the approach described in Table 1.3, he consults the Chart of Biomass Technologies, which refers him to Volume I where he will find the information needed.

Example 2. A user currently involved in the design of a biomass gasifier requires specific data concerning the biomass feedstock contemplated for use. The Chart (Figure 1.1) refers him to Volumes I and II.

1.4.2 Energy Consumption and Resource Availability Are Known

These users want to identify a bioenergy project that will provide a valid substitute for petroleum-derived energy. The user will first consult the Chart of Biomass Technologies (Figure 1.1) which will identify, one, or several, possible bioenergy systems. If only one system is identified, the chart refers the user to the appropriate volume of the series where the technology is described. If several options are suggested, the user will consult Table 1.1, which provides criteria for the selection of the most appropriate system(s). The volumes in which these systems are described are also indicated in the table.

Example 1. Animal wastes have been identified as a significant bioresource in a country where kerosene is currently extensively used as a cooking and lighting fuel in rural areas. What technologies could substitute for kerosene?

Following Table 1.3, the user refers to the chart, which indicates that anaerobic digestion of animal wastes can provide a substitute--biogas--for kerosene used in the residential sector. This technology is the only one suggested by the chart.

Example 2. Gasoline used in the transportation sector and fuel oil used in the industrial sector have been identified as the two major petroleum-derived fuels currently used in a country. Simultaneously, large amounts of forest residues have been shown to be potentially available in fairly small quantities in dispersed locations.

Following the methods suggested in Table 1.3, the user first consults the chart (Figure 1.1). The chart show that forest resources could substitute for transportation or industrial petroleum fuels through four technologies: alcohol fuels, pyrolysis, direct combustion, and gasification.

To narrow the choice between these technologies, the user then consults Table 1.1, Associated Feedstocks and Conversion Technologies. The alcohol fuel options--ethanol and methanol from forest resources--are not really demonstrated, although they are conceptually feasible. These options also are implemented as large-scale plants not compatible with the dispersed feedstock resource available in this case. The alcohol fuels options are therefore rejected.

Similarly, the pyrolysis option is demonstrated but not readily available for commercial use and is therefore rejected. The next two

technologies--combustion and gasification--are both available in variable sizes and are therefore equivalent as far as avilability and potential for a technology.

To further refine the choice between the two technologies, the user then refers to Table 1.2, Bioenergy End Uses. Direct combustion can substitute for fossil fuels used in industrial boilers but converting these boilers to solid biomass fuel may be difficult. Producer gas obtained through gasificaton of forest products can be substituted for various fuels in various applications with relative ease. Gasification is therefore the preferred choice and direct combustion is retained as a potential option.

The use of producer gas generated from a separated gasifier may have some limitations because of the lower energy value of the producer gas compared to fuel oil. This technology however appears as the most attractive for the case considered. The selection process therefore suggests that gasification be considered as a first candidate technology and direct combustion as an alternative. Table 3.1 refers the users to Volume VII and Volume V for a description of these technologies.

1.4.3 A Specific Biomass Resource Is Identified

A user is aware of the availability of a specific resource in a country and wishes to identify potential biomass technologies capable of using this resource. The user may or may not know the energy consumption profile of the country. If the user knows the energy consumption pattern of the

country, he is brought back to case 1.3.2 above: Resource and Energy Consumption are known. The user may have to consult both the chart and Tables 1.1 and 1.2 to identify a pathway matching the specific resource identified.

If the user does not know the energy consumption profile, the chart refers him to Volumes I and II from which he may obtain a picture of the energy needs of the country. The chart then shows possible pathways between the resources and the energy end uses identified. The chart, however, deals in general categories of resources--forest, agriculture, animal--which may result in some ambiguity concerning the choice of pathways.

The user then refers to Table 3.1, where resources (and pathways) are characterized in broad terms: dry/wet residues, sugar crops. Knowing the properties of the resource under investigation, the user can then select appropriate pathways.

Example 1. Numerous dispersed sugar mills produce residual molasses, which cannot be shipped to markets because of lack of adequate transportation. Simultaneously, the user has determined that gasoline is one of the major petroleum fuels imported by the country and that because of transportation problems gasoline is often scarce in remote areas where the mills are generally located.

In the classification of resources used in the chart, molasses are included in the category of agriculture. On that basis, all five technologies appear to be options for the conversion of molasses.

The user then consults Table 3.1 which suggests that "sugar crops" or "sugar residues" be converted to ethanol through fermentation. Ethanol is a good potential substitute for gasoline (see Figure 1.1 and Table 3.1) and the user is referred to Volume III, Alcohol Fuels for discussion of the technology.

Example 2. Olive pits are identified as residues currently discarded. The residues are produced in small-to-medium rural processing plants. The user has no knowledge of the energy consumption profile of the country.

The chart refers the user to Volumes I and II, where he finds some data on the country's energy use. From this and a minimum of data collected in the country, it appears that diesel or gasoline engines are the only sources of power in rural areas. Referring again to the chart, olive pits are included in the category "agriculture" in the resource circle. On this basis, all technologies could in principle be candidates for the conversion of the resource. The user then consults Table 1.1, which segregates the residues in various subcategories. Olive pits are dry agricultural residues and on the basis of the status and scale of application of the possible conversion technologies, combustion and gasification are attractive technologies. Table 1.2 then shows that producer gas (from

gasification) is best adapted for the conversion of gasoline and diesel engines to bioenergy. The user is referred to Volume VII.

1.4.4 A Specific Energy End Use Is Identified

A user has identified an end use sector and wishes to find bioenergy pathways which could satisfy the needs of the sector. The user must therefore identify one or several technologies capable of providing the end use needs and determine if the appropriate biomass feedstocks are available in the country.

The needs of the end use sector may or may not be known. If energy is already provided at the end use level, the user is aware of the needs to be matched by bioenergy systems. Such may be the case of an existing industry currently using fossil fuels. If energy is not currently provided at the end use level, the user must first determine the end use needs. Such may be the case when it is proposed to provide a remote village with electricity: the user will first have to estimate the projected demand on the basis of the population and level of services desired.

In the latter case, the chart refers the user to Volume I, where typical energy consumption data are provided. These enable the user to estimate the end use demand.

Once the end use is identified, the chart identifies various potential pathways (technology and associated feedstocks). Table 1.1 then helps the

user in reducing the number of options and in identifying more specifically the type of feedstock needed for each option. The user refers then to Volumes I and II to estimate which if any of these resources is available in the country, thereby focusing the selection of pathways to those technologies that can be supported by the country's resources.

The chart refers the user to Volume I to find the data needed to estimate the energy requirements of local processing industries. The needs are identified as electricity and process steam or hot water. The chart (Figure 1.1) suggests that all five technologies could provide these services from a variety of feedstocks. The availability and type of feedstocks must therefore be determined in order to select an appropriate technology. The chart refers the user to Volumes I and II to identify the resources available. These happen to be mostly wet agricultural residues. Table 1.1 shows that anerobic digestion is the preferred conversion technology and refers the user to Volume VI.

Example 1. The residential sector is identified as being in critical need of substitute fuel for cooking. Currently fuel wood is used and, as a result of population increases, wood consumption exceeds wood productivity. The situation has resulted in serious damage to the environment (erosion).

The chart suggests that agricultural residues could be used through pyrolysis (charcoal) or through direct combustion as replacement for fuel wood or that agricultural residues and animal wastes could be converted to biogas through anaerobic digestion.

Table 1.1 shows that pyrolysis and direct combustion require dry residues and anaerobic digestion requires wet residues. Volume II indicates that the major crops in the country are nuts, cotton, and rice. These crops provide dry residues at their points of processing and therefore the pyrolysis technology to produce charcoal is selected. The chart and Table 1.1 refer the user to Volume IV for a discussion of the technology.

Example 2. The agricultural sector of a country could provide significant amounts of foreign currency if the products could be processed and packed for shipping and export. It is proposed to examine the potential of bioenergy systems to provide the end use energy required for processing these food products. The chart refers the user to Volume I to find the data needed to estimate the energy requirements of local processing industries. The needs are identified as electricity and process steam or hot water. The chart (Figure 1.1) suggests that all five technologies could provide these services from a variety of feedstocks. The availability and type of feedstocks must therefore be determined in order to select an appropriate technology. The chart refers the user to Volumes I and II to identify the resources available. These happen to be mostly wet agricultural residues. Table 1.1 shows that anaerobic digestion is the preferred conversion technology and refers the user to Volume VI.

1.4.5 Energy Needs and Resources Are Not Known

The user wishes to determine if and what bioenergy systems could be attractive for a country for which neither the energy needs nor the

resources are known. This problem is the most general and can be addressed by identifying th resources or the energy needs for various sectors first. As indicated by the chart, Volumes I and II provide the information required to identify these elements. Once either, or both, these elements are determined, the user is brought back to one of the cases discussed previously (1.3.1 to 1.3.4).

CHAPTER 2 - BIOMASS RESOURCES

This chapter provides a broad overview of biomass resources in terms of their yields, properties, environmental requirements, energy potential, collectability, and processing requirements. Agriculture resources, forest resources, livestock resources, and aquatic plants are discussed in the chapter. The chapter also provides the general background of biomaterials needed to design and evaluate the bioconversion systems discussed in Volumes III to VII of the series of State of the Art volumes.

2.1 Characterization of Biomaterials

The ease and efficiency with which biomaterials can be converted to energy are largely determined by their physicochemical properties. There is no accepted, standardized method for the characterization of biomaterial with respect to its potential for conversion to energy for fuels. In the case of thermochemical conversion processes, the heating value, the ash content, and the moisture content are important parameters. In the case of biochemical conversion processes, the amount and chemical form of the carbohydrate constituents of the biomaterials are important parameters. These are discussed below.

2.1.1 Carbohydrates

Carbohydrates constitute a large group of closely related organic compounds composed of carbon, hydrogen, and oxygen. Together with proteins and fats

they are the major components of living matter where they maintain the functional activity of the cells and serve as structural and reserve materials. Cane and beet sugar, cotton fiber and honey are typical carbohydrates occurring in nature.

The photochemical assimilation of carbon dioxide from air followed by a series of complex enzymatic reactions results in the production of carbohydrates in green plants, as is illustrated below.

$$6\ CO_2 + 6\ H_2O \text{ ---------- } \text{Glucose} + 6\ O_2$$

In the process solar energy is stored in the plant in a form usable by the plant. Despite the fact that numerous compounds other than carbohydrates are synthesized by plants (such as lignin for example), carbohydrates account generally for 70 percent or more of the weight of plants on a dry basis.

The relatively simple carbohydrates are generally called sugars. More complex carbohydrates are formed through the combination of these simple sugar basic building blocks. In the basic units or monosaccharides, carbon atoms are joined together in a chain and are further combined with the elements of water resulting in the general formula of $C_n(H_2O)_n$. D glucose is the most common monosaccharide found for instance in honey and plant juices. Starch and cellulose are formed by the combination of D glucose basic units.

Disaccharides are formed by the combination of two monosaccharides. Maltose, a product of the reaction of amylase enzyme on starch, lactose or

milk sugar; and sucrose, the main sugar in the sap of plants such as cane and beet sugar, are typical disaccharides found in nature. Disaccharides can easily be hydrolized back to their original monosaccharides through acid or enzymatic hydrolysis.

Polysaccharides constitute a large group of compounds occurring widely in living matter. These compounds serve as reserve food or as protective and/or structural materials. Polysaccharides may contain one or several monosaccharide constituent units. Those containing one constituent unit are the most abundant and are represented by starch and cellulose in nature. These compounds may have linear structures as is the case in cellulose or may have branched and/or linear structures as is the case in gums and starches. The polysaccharides with linear structures provide a rigid structure to the plants whereas those with branched structures are generally water soluble and provide food reserves for the plants.

Starch--a branched chain polysaccharide--is found in large quantities in the storage organs of plants such as seeds, tuber, roots, and stem pith. Starch provides a reserve food supply for the plant during winter dormancy, germination, and early growth. Unlike cellulose (see below) starch can be dispersed in hot water. Starch can be hydrolyzed to D glucose by dilute acid or to maltose--a disaccharide--by amylase enzyme found in germinating cereal grains.

Cellulose--a straight chained polysaccharide--is the main constituent of cell walls and as such is the most abundant organic substance found in nature.

Cellulose is made of D glucose units joined end to end. Sources of cellulose in nature include cotton fiber, wood, straw, hemp, etc. Cellulose is characterized by its insolubility, chemical inertness and physical rigidity. Hemicelluloses are water-insoluble polysaccharides found in cell walls in association with cellulose. Unlike cellulose, hemicelluloses are soluble in dilute alkaline solutions.

The conversion of sugars to ethanol fuel through alcoholic fermentation is one of the bioconversion technologies currently being investigated. In the process, yeasts convert simple six-carbon sugars to ethanol fuel. The requirement of the availability of simple sugars such as glucose for ethanol production has led to the subdivision of biomaterials into three broad categories related to the chemical form in which carbohydrates are found in these materials. These three categories--sugar crops, starch crops, and lignocellulosic materials are further discussed below.

a. Sugar Crops. In sugar crops the 6-carbon sugars or fermentable sugars are found as monosaccharides or disaccharides. Minimal mechanical and chemical or biochemical treatment will release the 6-carbon sugars required for fermentation. Typical sugar crops include sugar cane, sugar beets, sweet sorghum, etc. These crops are also composed in part of lignocellulosic materials that provide structural strength in the stalks. Bagasse is an example of lignocellulosic materials associated with sugar cane.

The ease of recovery of fermentable sugars from sugar crops is counterbalanced by a significant disadvantage. The high moisture content of these easily

accessible sugars make them very susceptible to infestation by microorganisms resulting in crop spoilage during storage. Crop spoilage in turn will result in reduced alcohol production. Sugar loss during storage can be reduced or eliminated by pasteurization or concentration of the sugar solutions. Both treatments however are costly in terms of equipment and process energy. The conversion of sugar crops therefore will have to be a seasonal operation in most cases. Table 2.1 summarizes the main characteristics of sugar crops.

Table 2.2 shows typical composition of some sugar crops and of some residues and by-products containing sugars. The table provides an indication of which crops are the most attractive in terms of fermentable sugars content.

On a fresh-weight basis, sugarcane, sugarbeet and sweet sorghum are the most attractive crops. Of the residues considered, all except cheese whey have high sugar content and are prime candidates for alcohol production feedstocks. Whey is a very diluted material, which may require concentration to reach sugar concentrations compatible with economic alcohol production.

It must be recognized that the compositions shown in Table 2.2 are approximate and that actual values can range within wide limits around these typical values. Local conditions such as climate, soil, and nutrient availability can have a significant impact on the composition of the crop.

b. Starch Crops. In starch crops, the 6-carbon fermentable sugars are linked in long, branched chains. These chains must be broken down into individual or pairs of 6-carbon sugars (mono- or disaccharides) before yeast

TABLE 2.1.--SUMMARY OF FEEDSTOCK CHARACTERISTICS

Type of Feedstock	Processing Needed Prior to Fermentation	Principal Advantage	Principal Disadvantage
Sugar Crops			
(e.g., sugar beets, sweet sorghum, sugar cane, fodder beets, Jerusalem artichoke).	Milling to extract sugar.	o Preparation is minimal. o High yields of ethanol per acre. o Crop coproducts have value as fuel, livestock feed, or soil amendment.	o Storage may result in loss of sugar. o Cultivation practices vary widely, especially "nonconventional" crops.
Starch Crops			
Grains: corn, wheat, grain sorghum, barley. Tubers: culled potatoes, potatoes.	Milling, liquefaction, and saccharification.	o Storage techniques well developed. o Cultivation practices are widespread with grains. o Livestock coproduct is relatively high in protein.	o Preparation involves additional equipment labor, and energy costs. o DDG from aflatoxin-contaminated grain is not suitable as animal feed.
Cellulosic			
Crop Residues: corn stover, wheat straw. Forages: alfalfa, Sudan grass, forage, sorghum.	Milling and hydrolysis of the cellulosic linkages.	o Use involves no integration with the livestock feed market. o Availability is widespread.	o No commercially cost-effective process exists for hydrolysis of the cellulosic linkages.

Source: SERI, 1980.

TABLE 2.2.--TYPICAL COMPOSITIONS OF SUGAR CROPS AND SUGAR-CONTAINING RESIDUES
(Weight Percent)

Materials	Basis	Solubles		Insolubles	Water	Others	Total
		Sugars	Others				
Sugar cane stalks.	Wet	13.0	3.0	14.0	70.0	--	100.0
	Dry	43.3	10.0	46.7	--	--	100.0
Sugar beet roots.	Wet	15.0	2.0	5.0	78.0	--	100.0
	Dry	68.2	9.1	22.7	--	--	100.0
Sweet sorghum stalk.	Wet	4-15	1-6	12-20	67-80	--	100.0
	Dry	20-45	5-18	50-60	--	--	100.0
Sweet-stemmed grain sorghum.	Wet	2-6	1-5	20-30	65-75	--	100.0
	Dry	8-18	4-15	80-90	--	--	100.0
Cane molasses.	Wet	55	6	12	20	7	100.0
	Dry	58.7	7.5	15	--	8.8	100.0
Beet molasses.	Wet	51.0	12.5	11.5	20.0	5.0	100.0
	Dry	63.7	15.6	14.4	--	6.3	100.0
Corn molasses.	Wet	50.0	--	7	28.0	15.0	100.0
	Dry	69.5	--	9.7	--	20.8	100.0
Whey.	Wet	4.5	0.6	0.6	93.5	0.8	100.0
	Dry	69.2	9.2	12.4	--	9.2	100.0

Sources: Adapted from USDA, 1980; R.E. Nathan, 1978; E. Lipinsky et al., 1981; Van Nostrand Reinhold Co, 1974.

can use the sugars to produce alcohol. The starch crops therefore will require additional treatment--mechanical, chemical and/or biological--before fermentation can occur. Typical starch crops include grains, corn, wheat, rice, barley, milo, etc.; and tubers, potatoes, sweet potatoes, cassava, etc. These crops may also contain a significant lignocellulosic fraction, straw, stover, hulls, etc.

A distinct advantage of starch crops is the relative ease with which they can be stored with minimal loss of the fermentable portion. Ease of storage is related to the fact that a conversion step is needed before fermentation. Many microorganisms, including yeasts, can utilize individual or small groups of sugar units but not the long chains found in the crops. Some microorganisms present in the environment produce enzymes needed to breakdown the chains, but unless certain environmental conditions are just right-moisture, temperature, acidity, the rate of conversion during storage is very low. When crops are dried to about 12 percent moisture (the percentage below which micro-organisms are not active) the deterioration of starch and other valuable components such as fats and proteins is minimal. Grains are routinely dried before storage and therefore little risk of loss is expected from these feedstocks. Tubers can usually be stored several months before losses occur. Starch crops therefore are more suitable for year-long conversion plant operation than sugar crops. Table 2.1 summarizes the main characteristics of starch crops. Table 2.3 shows typical compositions of some starch crops.

TABLE 2.3.--TYPICAL COMPOSITIONS OF STARCH CROPS
(Weight Percent)

Materials	Basis	Starch	Protein	Sugars	Fiber	Fats/Oils	Others	Water	Total
Corn	Wet	61.2	8.7	7.0	2.6	8.7	1.7	15.0	100.0
	Dry	72.0	10.2	8.2	3.0	4.5	0.1	--	100.0
Grain sorghum (milo)	Wet	63.2	11.3	3.5	2.4	3.0	6.6	10.0	100.0
	Dry	70.2	12.5	3.9	2.7	3.4	7.3	--	100.0
Wheat	Wet	57.4	12.9	9.5	2.6	1.7	5.9	10.0	100.0
	Dry	63.8	14.8	10.6	2.9	1.9	6.5	--	100.0
Rye	Wet	58.5	12.1	13.6	2.3	1.6	1.9	10.0	100.0
	Dry	65.0	13.4	15.1	2.6	1.8	2.1	--	100.0
Oats	Wet	40.5	12.2	8.6	11.3	4.6	12.8	10.0	100.0
	Dry	45.0	13.5	9.5	18.5	8.1	14.4	--	100.0
Rice	Wet	73.8	8.3	2.6	2.4	1.3	1.6	10.0	100.0
	Dry	82.0	9.2	2.9	2.7	1.4	1.8	--	100.0
Millet	Wet	46.8	12.2	6.4	8.1	4.0	12.5	10.0	100.0
	Dry	52.0	18.5	7.1	9.0	4.4	14.0	--	100.0
Potatoes	Wet	15.7	2.0	--	0.5	0.1	3.7	78.0	100.0
	Dry	71.4	9.1	--	2.3	0.4	16.8	--	100.0
Sweet potatoes	Wet	22.0	2.0	1.5	--	--	9.5	65.0	100.0
	Dry	62.9	5.7	4.3	--	--	27.1	--	100.0
Cassava	Wet	30.0	1.8	1.1	1.0	0.2	0.9	65.0	100.0
	Dry	86.0	5.0	3.0	3.0	0.5	2.5	--	100.0

Source: Adapted from USDA, 1980, D. F. Miller, 1958, T. J. Doering, 1979.

In the table, "sugars" refers to fermentable sugars while high molecular weight sugars are included in the "others" column. Proteins, fats and oils, and fibers may be removed from the feedstock before fermentation or may be found in the residue of the fermentation process; in both cases, these components have a high potential market value (food, feed, feed additives), which should be taken into account in the economic feasibility analysis of the alcohol production process. The table also suggests that because of the similarity of chemical composition of the major crops considered, only minor changes in the process operating conditions will be required when similar crops are substituted for one another as feedstocks.

c. Lignocellulosic Materials. In lignocellulosic materials, the 6-carbon, fermentable sugars are linked in long chains involving strong chemical bonding. Releasing the fermentable sugars requires extensive pretreatment. Typical cellulosic materials include crop residues, mill residues, forest residues, etc. Preprocessing of the cellulosic materials to release the six-carbon sugars may require mechanical, chemical, and biological treatments. No commercial preprocessing process has been demonstrated so far, and cellulosic feedstocks can only be considered as a long-term prospect for bioconversion to fuel. Cellulosic materials are the least sensitive of the classes of crops considered subject to degradation during storage. Table 2.1 summarizes the characteristics of lignocellulosic materials. Table 2.4 shows typical compositions of cellulosic materials.

Most of the residues listed in the table have a significant protein content and therefore conversion of these materials to energy could compete with their

TABLE 2.4.--TYPICAL COMPOSITIONS OF LIGNOCELLULOSIC MATERIALS
(Weight Percent)

Materials	Basis	Cellu-lose	Hemicel-lulose	Lignin	Ash	Protein	Others	Water	Total
Hybrid poplar	Wet	22.0	16.0	11.0	0.4	--	0.6	50.0	100.0
	Dry	44.0	32.0	21.0	0.7	--	2.3	--	100.0
Sweetgum	Wet	22.3	15.6	12.6	0.3	--	1.3	48.0	100.0
	Dry	42.8	30.0	24.2	0.4	--	2.6	--	100.0
Eucalyptus	Wet	23.2	14.5	13.1	0.2	--	3.0	46.0	100.0
	Dry	43.0	26.9	24.2	0.4	--	5.5	--	100.0
Average hardwood	Wet	21.8	14.5	10.5	0.2	--	3.0	50.0	100.0
	Dry	43.5	29.0	21.0	0.5	--	6.0	--	100.0
Average softwood	Wet	21.2	12.3	14.0	0.5	--	2.0	50.0	100.0
	Dry	42.5	24.5	28.0	1.0	--	4.0	--	100.0
Corn stover	Wet	25.2	21.0	11.2	4.2	4.9	3.5	30.0	100.0
	Dry	36.0	30.0	16.0	6.0	7.0	5.0	--	100.0
Wheat straw	Wet	29.6	17.8	9.8	5.7	2.6	4.5	30.0	100.0
	Dry	42.3	25.4	14.0	8.1	3.8	6.4	--	100.0
Rice straw	Wet							7.5	100.0
	Dry	37.9	25.4	14.2	16.8	4.2	1.5	--	100.0
Sugar cane bagasse	Wet	18.5	13.6	9.2	1.0	--	7.7	50.0	100.0
	Dry	37.0	27.2	18.3	2.0	--	15.5	--	100.0
Average field crop residue	Wet	27.0	19.4	10.6	7.3	3.6	2.1	30	100.0
	Dry	38.5	27.7	15.1	10.4	5.2	3.1	--	100.0
Green forage	Wet	9.1	7.4	1.9	2.4	4.6	4.6	70	100.0
	Dry	30.4	24.7	6.2	8.0	15.4	15.3	--	100.0
Dry roughage	Wet	20.2	22.0	9.3	7.9	18.4	13.2	12	100.0
	Dry	23.0	25.0	10.6	9.0	17.5	14.9	--	100.0

Source: Adapted from D. F. Miller, 1958; R. A. Nathan, 1978; USDA, 1979; R. L. Browning, 1975.

use as animal feed. Bagasse contains sugars and is also used as feed supplement. The values quoted in the table should be considered as indicative: significant deviations from these numbers are found in practice because of variations in local growing conditions.

2.1.2 Thermochemical Conversion Characteristics

Carbonaceous materials for thermochemical conversion processes are generally characterized by several chemical and physical parameters. Common parameters used are proximate analysis, ultimate analysis, moisture content, heating value, and ash content.

a. Proximate Analysis. The proximate analysis characterizes the material in terms of its moisture, volatile matter, ash, and by difference "fixed" carbon content. The proximate analysis gives the percentage of material burned in the gaseous state (volatile matter) and in the solid state (fixed carbon) as well as an indication of the amount of ash residue.

Table 2.5 show proximate analysis data for selected fossil fuels and biomass materials. It is apparent that, generally speaking, biomaterials contain about twice as much volatile matter as fossil fuels, about half as much (or less) fixed carbon, and generally, less ash.

TABLE 2.5.--PROXIMATE ANALYSIS DATA FOR SELECTED SOLID FUELS AND BIOMASS MATERIALS
(Dry Basis, Weight Percent)

	Volatile Matter	Fixed Carbon	Ash
Coals			
Pittsburgh seam coal	33.99	55.3	10.3
Wyoming Ekol coal	44.4	51.4	4.2
Lignite	43.0	46.6	10.4
Oven Dry Woods			
Western hemlock	84.3	15.0	0.2
Douglas fir	86.2	13.7	0.1
White fir	84.4	15.1	0.5
Ponderosa pine	87.0	12.3	0.2
Redwood	83.5	16.1	0.4
Cedar	77.0	21.0	2.0
Oven Dry Barks			
Western hemlock	74.3	24.0	1.7
Douglas fir	70.6	27.2	2.2
White fir	73.4	24.0	2.6
Ponderosa pine	73.4	25.9	0.7
Redwood	71.3	27.9	0.8
Cedar	86.7	13.1	0.2
Mill Wood Waste Samples			
Redwood shavings	76.2	23.5	0.3
Alabama oak chips	74.2	21.9	3.3
Pyrolysis Chars			
Redwood (790°F to 1020°F)	30.0	67.7	2.3
Redwood (800°F to 1725°F)	23.9	72.0	4.1
Oak (820°F to 1185°F)	25.8	59.3	14.9
Oak (1050°F)	27.1	53.6	17.3
Crop residues	63-80	17-36	1-20
Lignite	40	50	10
Charcoal	3-30	65-96	2-5
Peat	70	28.4	1.6

Source: Adapted from The Aerospace Corporation, 1980 and A. Kaupp and J. R. Goss, 1981.

b. Ultimate Analysis. The ultimate analysis involves elemental analyses for carbon, hydrogen, nitrogen, sulfur, and by difference, oxygen. The ultimate analysis is used to calculate the chemical balance of the combustion reactions as well as the quantity of combustion air and excess air required. Additionally, the ultimate analysis enables identification and quantification of the potential pollutants resulting from the thermoconversion of fuels. A sample of ultimate analysis data for various fossil fuels and selected biomaterials is shown in Table 2.6. Biomass materials have carbon contents lower than coal. The oxygen content of biomaterials is higher than that of coals, but the nitrogen, sulfur, and ash content of biomaterials is generally lower than that of coals. An exception to this statement are rice residues, which have a high content of silica (their high ash content is comparable to that of some coals). Heating values of materials are also quoted in Table 2.6 and are discussed in Section d below. Figure 2.1 shows the ultimate analysis (C-H-O; ash free) of various biomass fuels tested at the University of California, Davis; these fuels show very similar C-H-O fractions.

c. Moisture Content. One of the serious problems with the thermoconversion of biomaterials is the wide variability in moisture content as shown in Tables 2.2 to 2.4. Moisture content may vary from dry materials, such as fines and trims in furniture factories, to green wood and bark containing nearly equal amounts of dry fiber and water.

TABLE 2.6.--ULTIMATE ANALYSIS DATA FOR SELECTED SOLID FUELS AND BIOMASS MATERIALS
(Dry Basis, Weight Percent)

Material	C	H	N	S	O	Ash	Higher Heating Value (Btu/lb)
Pittsburgh seam coal	75.5	5.0	1.2	3.1	4.9	10.3	13,650
West Kentucky No. 11 coal	74.4	5.1	1.5	3.8	7.9	7.3	13,460
Utah coal	77.9	6.0	1.5	0.6	9.9	4.1	14,170
Wyoming Ekol coal	71.5	5.3	1.2	0.9	16.9	4.2	12,710
Lignite	64.0	4.2	0.9	1.3	19.2	10.4	10,712
Charcoal	80.3	3.1	0.2	0.0	11.3	3.4	13,370
Douglas fir	52.3	6.3	0.1	0.0	40.5	0.8	9,050
Douglas fir bark	56.2	5.9	0.0	0.0	36.7	1.2	9,500
Pine bark	52.3	5.8	0.2	0.0	38.8	2.9	8,780
Western hemlock	50.4	5.8	0.1	0.1	41.4	2.2	8,620
Redwood	53.5	5.9	0.1	0.0	40.3	0.2	9,040
Beech	51.6	6.3	0.0	0.0	41.5	0.6	8,760
Hickory	49.7	6.5	0.0	0.0	43.1	0.7	8,670
Maple	50.6	6.0	0.3	0.00	41.7	1.4	8,580
Poplar	51.6	6.3	0.0	0.0	41.5	0.6	8,920
Rice hulls	38.5	5.7	0.5	0.0	39.8	15.5	6,610
Rice straw	39.2	5.1	0.6	0.1	35.8	10.2	6,540
Sawdust pellets	47.2	6.5	0.0	0.0	45.4	1.0	8,814
Paper	43.4	5.8	0.3	0.2	44.3	6.0	7,572
Redwood wastewood	53.4	8.0	0.1	39.9	0.1	0.6	9,163
Alabama oak woodwaste	49.5	5.7	0.2	0.0	41.3	3.3	8,266
Animal waste	42.7	5.5	2.4	0.3	31.3	17.8	7,380
Municipal solid waste	47.6	6.0	1.2	0.3	32.9	12.0	8,548

Source: The Aerospace Corporation, 1980.

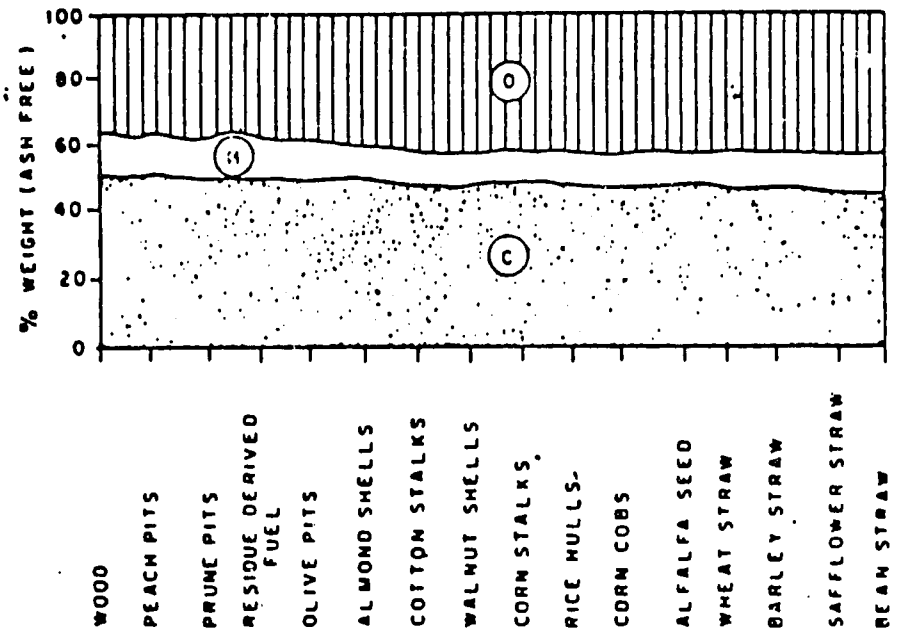

FIGURE 2.1.--ULTIMATE ANALYSIS OF BIOMASS FUELS TESTED AT THE UNIVERSITY OF CALIFORNIA, DAVIS

Source: A. Kaupp and J. R. Goss, 1981.

Moisture in biomass can be fundamentally subdivided into three categories:

1. Inherent moisture is the moisture a fuel can hold when it is in equilibrium with ambient atmosphere at 96-97 percent relative humidity. Inherent moisture is held in capillary openings in the biomass.

2. Surface moisture is the moisture on the surface and is in excess of inherent moisture.

3. Decomposition moisture is the moisture formed from organic compounds of the fuel as they are decomposed by heating. Generally temperatures in the range of 200°C to 225°C are required, which is well above the temperatures required for expelling surface and inherent moisture.

The moisture content of fuels cited in the literature usually refers to inherent moisture plus surface moisture.

Two systems are used to evaluate the water content of biomaterials: the "wet" and "dry" bases. In calculating combustion performance, the wet basis is commonly used. The percentile moisture content on a wet basis (MC wet) is given by:

$$(\text{MC wet}) = \frac{(\text{wet weight} - \text{oven-dry weight})}{\text{wet weight}} \times 100\ (\%) \qquad (2.1)$$

Many data relating to biomaterials however are quoted on a dry basis. The moisture content on a dry basis (MC dry) is given by

$$(\text{MC dry}) = \frac{(\text{wet weight} - \text{oven-dry weight})}{\text{ovendry-weight}} \times 100\ (\%) \qquad (2.2)$$

Thus green wood having 50 percent moisture on a wet basis, has 100 percent moisture on a dry basis. Oven dry wood has zero percent moisture both on a wet and a dry basis.

To convert moisture content on a dry basis to moisture content on a wet basis, the following expression is used:

$$(\text{MC wet}) = \frac{(\text{MC dry}) \times 100}{100 + (\text{MC dry})}\ (\%) \qquad (2.3)$$

A conversion chart is shown in Figure 2.2.

Moisture contents of various fossil and biomass fuels are shown in Table 2.7.

d. Energy Content. The energy content of biomass (heat of combustion) is usually determined by use of a bomb calorimeter, which measures the energy change for combustion to gaseous carbon dioxide and liquid water. This gives the "high" or "gross" heating value of the biomass (HHV), including energy

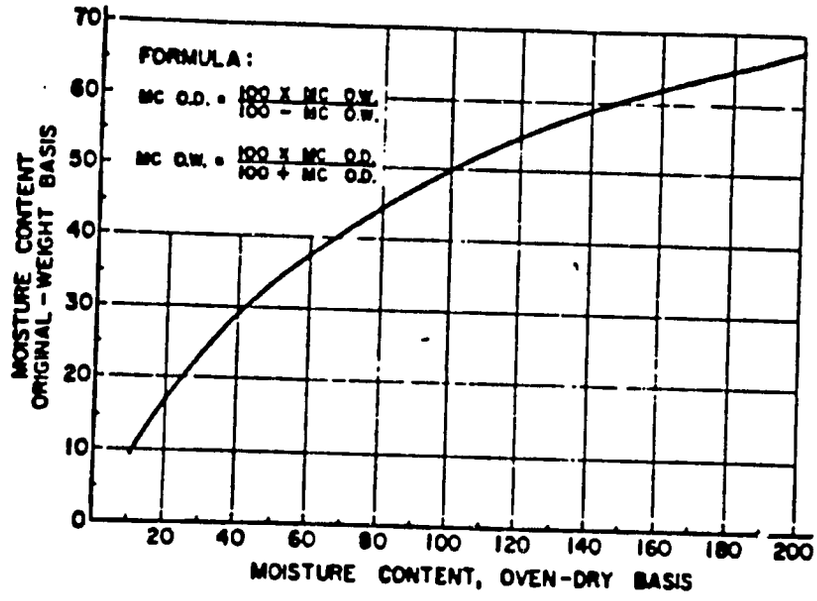

FIGURE 2.2.--MOISTURE CONTENT COMPARISON

TABLE 2.7.--MOISTURE CONTENT AND HEATING VALUES OF FOSSIL AND BIOMASS FUELS

Fuel	Moisture Content (% wet weight)	Average Higher Heating Value (MJ/kg dry basis)
Coal, air dried		
Lignite	45	19.7
Subbituminous C	30	22.1
Subbituminous B	25	25.6
Subbituminous A	17	30.2
High Volatile C bituminous	17	30.2
High Volatile B bituminous	10	32.6
High Volatile A bituminous	4	33.7
Medium Volatile bituminous	5	34.8
Low Volatile bituminous	4	36
Semi Anthracite	3	34.9
Anthracite	3	33.7
Meta Anthracite	5	31.4
Bituminous Coal Char	--	28.1
Peat (Finland), average	40-70	22.5
Milled Peat, 40%-50% moisture, dry basis	--	7.5-12*
Sod Peat 30%-40% moisture, dry basis	--	11-14*
Peat briquettes 10%-15% moisture, dry basis	--	17-18.5*
Peat pellets 10%-20% moisture, dry basis	--	16.8-18.9*
30%-40% moisture, dry basis	--	12.6-14.7*
Gasoline	--	43.6
Diesel Oil	--	43.6
Wood average		
Pine bark	--	20
Pine, freshly felled	40-60	21
Fir, freshly felled	40	19.9
Fir, seasoned	37	11.4
Fir, kiln dried	15-20	14.9
Beech, freshly felled	8	17.8
Birch, freshly felled	40	19
Oak, freshly felled	31	19
Wood Charcoal - mixed forest wood	35	18.3
Kenya native burned		
Yarura wood British Guiana	--	31.3
English mixed hard wood, stationary retort	--	30.1
Japanese hard wood	--	32.2
Japanese palm nut	--	31.9
Wood charcoal, average	--	32
	2-10	29

*Wet basis, net heating value.

TABLE 2.7.--MOISTURE CONTENT AND HEATING VALUES OF FOSSIL AND BIOMASS FUELS (Concluded)

Fuel	Moisture Content (% wet weight)	Average Higher Heating Value (MJ/kg dry basis)
Alfalfa seed straw, air dried	8	18.4
Almond shell, air dried	7	19.4
Barley straw	8-20	17.3
Bean straw	8-20	16.8
Beef cattle manure	--	14.6
Coffee hulls	70	28.8
Corn cobs	8-20	18.9
Corn stalks	8-20	18.3
Cotton gin trash	20	16.4
Cotton stalks	25-45	15.8
Flax straw, collected off ground	--	20
Furfural residue	50	20
Olive pits, air dried	10	21.4
Peanut husks, air driedc	--	19.7
Peach pits, air dried	11	23
Prune pits, air dried	8	23.3
Rice hulls	--	15
Sunflower hulls, oil type	--	20
Sunflower stalks, grown in greenhouse	--	21
Screened composted sewage sludge, 22% inorganic	--	9.9
Sewage sludge and wood chips, composted, 14% inorganic	--	15.2
Safflower straw cubes	9	19.5
Walnut shell (cracked)	7-10	21.1
Walnut shell (6 mm pellet)	7-10	20.4
Walnut hull	25-45	--
Wheat straw with 50% corn stalks	8-20	16.9
Wheat straw, collected behind a combine	--	18.9

Source: A. Kaupp and J. R. Goss, 1981.

recovered from the condensation of the water; but the 2.45 kJ/g (1,050 Btu/lb) required to vaporize water is not recovered in combustion processes. Therefore, in combustion calculations the "low" or "net" heating value (LHV) is used. The low heating value can be derived from the high heating value by:

$$(LHV) = (HHV) - 0.2122H \tag{2.4}$$

where H is the percentage of hydrogen by weight and all figures are in kJ/g. This relation can easily be converted to English units by using the conversion factors given in the Appendix. Heating values (higher heating values) of various fossil and biomass fuels are given in Table 2.7.

e. Energy Content versus Moisture Content.

Most biomaterials contain significant quantities of moisture that greatly reduce the energy release in combustion processes for two reasons: (1) the combustible fraction of the biomaterial is only 1-(MC wet), where (MC wet) is the fractional water content on a wet basis and (2) the fraction (MC wet) of water must be evaporated. The heating value of wet biomass having a moisture content of (MC wet) is given by:

$$(LHV)\ wet = [1 - (MC\ wet)](LHV)\ dry - 2.45\ (MC\ wet) \tag{2.5}$$

where all figures are in kJ/g. The second term on the right hand side of equation (2.5) accounts for the heat lost in vaporizing the water present in

the material. Figure 2.3 shows the dependence of the energy content on moisture content for a material having a heat value of about 21,000 kJ/g (about 9,000 Btu/lb) when dry.

The "as-fired" heat value of fuels can be estimated from the equations given above and data available in this volume. This is illustrated for the case of rice straw as follows:

High heating value (dry) from Table 2.6: 6,540 Btu/lb.

Higher heating value in SI metric units: 6,540 Btu/lb x 2.32 10^3 = 15.17 kJ/g (conversion factor from Appendix A)

Low heating value (dry): (LHV) = 15.17 - 0.2122 (5.1) = 14.09 kJ/g (from equation (2.4) and hydrogen content in Table 2.6)

Moisture content of rice straw: 7.5% (wet basis) (from Table 2.4)

Low heating value of as-fired rice straw:

(LHV) = (1 - 0.075) (14.09) - 2.45 (0.075) = 12.85 kJ/g (from equation (2.5) and above data).

Table 2.8 shows heating values of various fuels on an as-fired basis. It is apparent that some air-dry biomaterials such as coconut shells, poplar, pine, and oak bark have heating values comparable to that of low quality coal (assumed 12,290 Btu/lb dry and 30 percent moisture) on an as-fired basis. The same biomaterials as well as rice straw and hulls have a higher heating value than lignite on an as-fired basis.

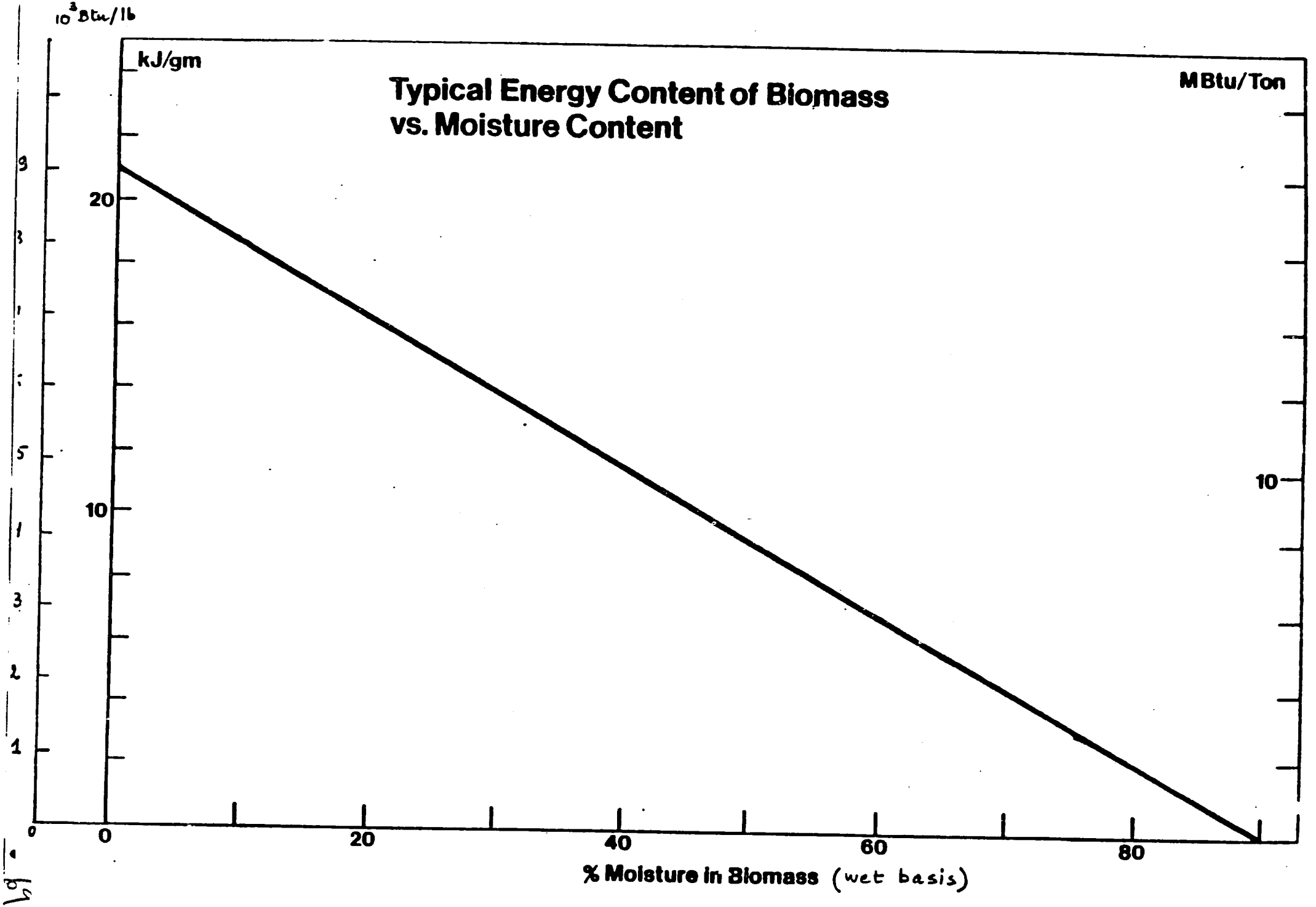

FIGURE 2.3.--SENSITIVITY OF ENERGY CONTENT TO MOISTURE CONTENT

TABLE 2.8.--HEATING VALUES OF MISCELLANEOUS FUELS

FUELS	Heating Value (dry) M) kJ/g	Heating Value (dry) M) Btu/lb	Moisture Content (wet) %	Heating Value (as-fired or wet) kJ/g	Heating Value (as-fired or wet) Btu/lb
Coal	28.6	12,290	15-30	19.3-23.9	8,300-10,280
Lignite	24.0	10,300	45-50	10.8-12.1	4,640-5,200
Bagasse	19.6	8,430	50	8.6	3,690
Coconut shells	20.6	8,860	10	18.3	7,870
Rice straw	14.1	6,060	7.5	12.9	5,550
Rice hulls	14.1	6,060	10	12.5	5,360
Poplar (green)	19.4	8,340	50	8.5	3,660
Poplar (air dry)	19.4	8,340	15	16.1	6,920
Pine (green)	21.2	9,120	50	9.50	4,080
Pine (air dry)	21.2	9,120	15	17.1	7,590
Oak Bark (air dry)	20.5	8,820	15	17.1	7,330
Charcoal	31.8	13,680	10	28.3	12,170

(1) Low heating value

Date generated from Table 2.6 and T. Reed B. Bryant, (1978).

f. Ash Content. The mineral content in the fuel that remains in oxidized form after conversion (combustion, gasification, etc) is usually called ash. The ash content of the fuel and the composition of the ash can have a major impact on the operation of bioconversion systems: high ash content in the fuel lowers the amount of energy available per unit volume of the conversion system. Table 2.9 shows the ash content of various fuels. It is apparent that a conversion unit fueled with cotton gin trash would have to dispose of about 20 times as much ash as a wood residue-fired unit.

If the temperature in the conversion system rises above its melting point, the ash will melt and the molten material will flow together and form clinkers clinging to internal surfaces, grates, etc. This can eventually obstruct the flow of fuel in the system. Table 2.10 shows the mineral oxide composition of various fuels. The individual melting points of these oxides are generally high. However, the ash minerals form eutectic mixtures which will start melting at the lowest possible temperature, dependent on the fraction of the individual minerals. As shown in Table 2.10, the bulk of the minerals in biomass lies within the SiO-K_2O-Na_2O-CaO system for most fuels. The most troublesome components of the ash are SiO_2 and the alkalies Na_2O and K_2O. Although silicon oxides have a high melting point, it has been shown that large amounts of SiO_2 can evaporate at 1,550^{o} C despite the fact that the boiling point of SiO_2 is higher than 2,230^{o} C. The SiO vapor can react with oxygen from water for example and extremely fine, highly abrasive

TABLE 2.9.--ASH CONTENT OF MISCELLANEOUS FUELS

Fuel	% Weight Ash, Dry Basis	Fuel	% Weight Ash, Dry Basis
Alfalfa seed straw cubed	6.0	Municipal solid waste	3.0
Almond shell	4.8	Olive pits	3.2
Barley straw mix	10.3	Peach pits	0.9
Bean straw	10.2	Peanut husks	1.5
Charcoal	2-5	Peat (average)	1.6
Coffee hulls	1.3	Douglas fir wood blocks	0.2
Coal	5-17	Prune pits	0.5
Corn cobs	1.5	Refuse-derived fuel	10.4
Corn stalks	6.4	Rice hulls	16-23
Cotton gin trash	17.6	Safflower straw	6.0
Cubed cotton stalks	17.2	1/4" pelleted walnut shell mix	5.8
Pelleted rice hulls	14.9	Walnut shell (cracked)	1.1
Furfural residue	12	Wheat straw and corn stalks	7.4
Hogged wood manufacturing residue	0.3	Whole log wood chips	0.1

Source: A. Kaupp and J. R. Goss, 1981.

TABLE 2.10.--MINERAL OXIDES IN COAL AND BIOMASS ASH

Coal	% SiO_2	% Al_2O_3	% FE_2O_3	% TiO_2	% CaO	% MgO	% Na_2O	% K_2O	% SO_3	% CL
Antracite	48-68	25-44	2-10	1.0-2	0.2-4	0.2-1	--	--	0.1-1	--
Bituminous	7-68	4-39	2-44	0.5-4	0.7-36	0.1-4	0.2-3	0.2-4	0.1-32	--
Subbituminous	17-58	4-35	3-19	0.6-2	2.2-52	0.5-8	--	--	3.0-16	--
Lignite	6-40	4-26	1-34	0.0-08	12.4-52	2.8-14	0.2-28	0.1-1.3	8.3-32	--
Biomass										
Wheat straw	56.8	--	0.5	--	5.8	2.0	6.0	14.8	7.6	5.0
Corn stover	18.6	--	1.5	--	13.5	2.9	13.3	26.4	8.8	0.9
Rice straw	78.64	1.38	0.14	0.1	2.2	3.03	1.79	9.93	0.34	--
Residue-derived fuel	31	27	4	6.0	6	1	7	6	--	--
Rice hulls	90-97	--	0.4	--	0.2-1.5	0.1-2	0-1.75	0.6-1.6	0.1-1.13	0.15-0.4
Wood	0.09-?	1-75	0.5-3.3	--	10-60	1.4-17	under 10	1.5-41	--	--

This list indicates the wide range of possible ash compositions for various coial and biomass fuels. Knowing the ash composition is especially important for high ash fuels, since any clinker foirmation will quickly obstruct the gas and fuel flow and stop operaion. High ash fuels combined wth low ash melting point are the most difficult to gasify, due to the poor gas uality one obtains at fire zone temperatures below 1,000°C.

Source: A. Kaupp and J. R. Goss, 1981.

glassy particles of SiO_2 can be entrained with the flue gas creating potentially serious problems in various parts of the conversion system. Reactions can also occur between silicon sulfides and oxygen.

A realistic picture of the slagging potential of biomass fuels can only be obtained through actual trials. Tests for slagging conducted at the University of California at Davis with a small gasifier resulted in the classification of fuels shown in Table 2.11.

The mineral content of the fuel has a catalytic effect on reactions in converters, which can modify the composition and reactivity of gases in the system. The composition of the ashes is also an important factor to take into account when ashes are disposed of: recycling of ashes to the land may contribute to maintaining a required level of some minerals but may also result in leaching and pollution of underground water or of waterways.

g. Bulk Density. The volume occupied by a fuel depends not only on the specific gravity of the single fuel particles and their moisture content but also on the grading and whether the fuel is piled loosely or compacted. Bulk density has an impact on the storage capacity of a conversion system, on the cost of transportation of the fuel, and the residence time and fuel bed density in conversion systems. Table 2.12 shows the bulk density of various fuels.

TABLE 2.11.--SLAGGING BEHAVIOR OF CROP RESIDUES AND WOOD

Slagging Fuels	% Ash	Degree of Slagging	Nonslagging Fuels	% Ash
Barley straw mix	10.3	Severe	Cubed alfalfa seed straw	6.0
Bean straw	10.2	Severe	Almond shell	4.8
Corn stalks	6.4	Moderate	Corn cobs	1.5
Cottin gin trash	17.6	Severe	Olive pits	3.2
Cubed cotton stalks	17.2	Severe	Peach pits	0.9
RDF pellets	10.4	Severe	Prune pits	0.5
Pelleted rice hulls	14.9	Severe	Walnut shell (cracked)	1.1
Safflower straw	6.0	Minor	Douglas fir wood blocks	0.2
1/4" pelleted walnut shell mix	5.8	Moderate	Municipal tree prunings	3.0
Wheat straw and corn stalks	7.4	Severe	Hogged wood manufac-facturing residue	0.3
			Whole log wood chips	0.1

Source: A. Kaupp and J. R. Goss, 1981.

TABLE 2.12.--BULK DENSITY OF VARIOUS FUELS

Fuel	Grading	Bulk Density kg/m^3
Sawdust	loose	177
Sawdust	briquets 100 mm long 75 mm diameter	555
Peat	dust	350-440
	briquets 45x65x60 mm	550-620
	hand cut	180-400
Charcoal (10% moisture)	beech	210-230
	birch	180-200
	softwood blocks	150-170
	softwood slabs	130-150
	mixed 60% hard/40% soft	170-190
Wood	sizes as in Table 16	
	hardwood	330
	softwood	250
	mixed 50/50	290
Straw	loose	80
	bales	320
Alfalfa seed straw	cube 30x30x50 mm, 7% moisture	298
Barley straw	cube 30x30x50 mm, 7% moisture	300
Bean straw	cube 30x30x50 mm, 7% moisture	440
Corn cobs	11% moisture	304
Corn stalks	cube 30x30x50mm	391
Cotton gin trash	23% moisture	343
Peach pits	11% moisture	474
Olive pits	10% moisture	567
Prune pits	8% moisture	514
Rice hulls	cube 30x30x50 mm	679
Safflower straw	cube 30x30x50 mm	203
Walnut shells	cracked	336
	8 mm pellets	599
Wood, blocks	17% moisture	256
chips	10% moisture	167
Coal	anthracite	830-900
	bituminous	770-930
Coke	hard	380-530
	soft	360-470
Brown coal	air dry lumps	650-780

Source: A. Kaupp and J. R. Goss, 1981.

2.1.3 Biomass Conversion Paths

Based on the characteristics of the biomaterials reviewed in the preceding sections, the most effective conversion paths for various classes of biomaterials are shown in Figure 2.4.

The drier lignocellulosic materials (wood, wood residues, dry agricultural residues) are better feedstocks for thermoconversion processes: combustion, gasification and pyrolysis. The products of the conversion processes may include heat, steam, electricity, producer gas, charcoal, and pyrolytic oils. Sugar and starch crops or crop residues are better feedstocks for ethanol fermentation; the product of conversion is ethanol fuel. Wet feedstocks containing lignocellulosic materials such as animal manures can easily be converted to biogas through anaerobic digestion. Lignocellulosic materials can be converted to sugars through hydrolysis and then converted to ethanol through fermentation. This process has been demonstrated but has not been commercialized as yet, as is indicated by a dashed line in Figure 2.4.

2.2 Agricultural Resources.

This section describes some characteristics, environmental requirements, and fuel values of crops and crop residues of interest for fuel/energy production.

2.2.1 Agricultural Crops.

Table 2.13 summarizes the environmental requirements of various agricultural crops. Climate is broadly characterized as temperate or tropical; when

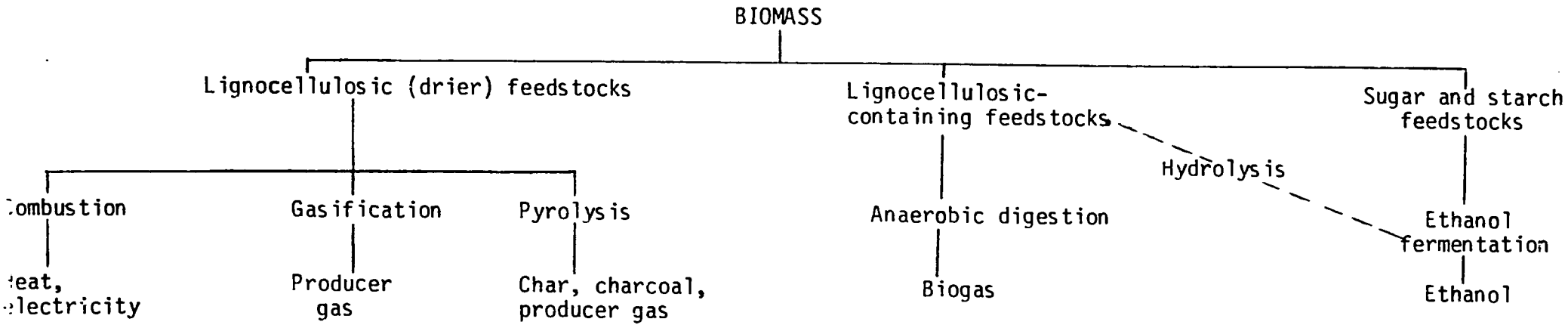

FIGURE 2.4.--BIOMASS CONVERSION PATHS

TABLE 2.13.--ENVIRONMENTAL REQUIREMENTS OF SELECTED AGRICULTURAL CROPS

Crop	Climate	Soil	Temperature C	Rainfall mm	Elevation m	Growing season days	Comments
Wheat	Temperate (30-60N) (25-40S)	Most types	3-22	250-1800	0-3000	80-95 (spring) 180-333(winter)	
Rice	Temp./Tropical (53N-35S)	Low lands River beds	20-38	Flooded conditions preferred.		90-250	Fertile soil desired.
Barley	Temperate	Many types	20-30	Soil moisture dry weather needed.		60-90 (spring) 150-180 (winter)	Some growth in tropics.
Corn	Temp./Tropical	Many types	19	400-600		90-300	High requirements in N,P,K.
Grain sorghum	Temp./Tropical	Many types	16-32	400-600		100-140	
Potatoes	Temp./Tropical	Many types	15-20	50% soil moisture preferred.		90-130	
Cassava	Tropical	Many types	Warm	Low/Intemediate	Low/High	Year round	
Soybeans	Temp./Tropical	Many types	15-35	600-800	Low/High	70-150	Nitrogen fixing.
Peanuts	Temp./Tropical	Many types Light preferred	Warm	Uniform moisture		120-150	Nitrogen fixing.
Cotton	Tropical/Subtrop.	Fertile	20	500		120-150	Sensitive to pests.
Sugar cane	Tropical/Subtrop. Temperate	Many types Alluvial better	21-40	1150		240-720	High bioconversion efficiency.
Sugar beet	Temperate	Heavy	16-28	500		180-300	Sensitive to disease.
Sweet sorghum	Tropical	Many types	18-40	450		100-180	

available, ranges of latitudes between which the crops are known to grow are given. The column describing soils is meant to indicate the adaptability of the crop to various soils rather than list the types of soils in which the crop is known to grow. The temperature, rainfall, and elevation data quoted indicate, when available, the range of values of these parameters within which the crops grow satisfactorily.

Table 2.14 gives world average, high, and low yields for several agricultural crops most commonly grown in developing countries. Yields vary substantially, ranging fom 400 kilograms per hectare for sweet potatoes in Mauritania as an example, to 80,000 kilograms per hectare in Israel. The latter represents production under highly intensive greenhouse management. Statistical data on crop productivity by country are given in Volume II.

A short description of some of the crops follows.

Wheat (*Triticum aestivum*). Wheat as it is known now evolved from wild grasses probably in the Near East area through natural hybridization. Over 34,000 varieties are recorded in the USDA World Wheat Collection; these are used for variety improvements. Many varieties with specific properties--tall, short, stress tolerant, disease resistant, etc.--are available for commercial use. As seen in Table 2.13, wheat is quite adaptable to many environmental conditions and is therefore grown in many parts of the world.

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Table 2.14.--Agricultural Yields

Crops	Scientific Name	Yields/kg/ha Low Yield	Low Country	World Avg.	High Yield	High Country
Wheat	Triticum aestivum	360	Jordan	1,782	7,000	UAE
Rice	Oryza sativa	500	F. Guyana	2,615	7,000	Gabon
Barley	Hordeum vulgare	107	Jordan	1,761	36,667	UAE
Corn	Zea mays	100	Cape Verde	3,271	12,833	UAE
Sorghum	Sorgum sp	260	Botswana	1,322	5,326	Spain
Millet	Panicum Miliaceum	200	Botswana	670	3,740	Egypt
Potatoes	Solanum Tuberosum	2,000	Swaziland	15,503	37,772	Netherlands
Sw. Potatoes	Ipomoea batatas	400	Mauritania	8,355	80,000	Israel
Cassava	Manihot esculenta	2,474	Antiqua	8,748	30,769	Cook Island
Soybeans	Glycine max	150	Tanzania	1,660	2,524	Egypt
Peanuts	Arachis hypogaea	400	Mozambique	1,016	3,783	Malaysia
Castor Beans	Ricinus communis	200	Burundi	652	3,000	Cape Verde
Rape Seed	Brassica spp	400	Ethiopia	856	3,000	Belgium
Sesame Seed	Sesamum indicum	40	Bulgaria	300	1,000	Iran
Linseed	Linum usitatissimum	50	Greece	503	2,800	New Zeland
Seed Cotton	Cossypium	73	Grenada	1,251	3,306	Guatemala
Coconuts	Cocos nucifera	1,000	Polynesia	NA	8,000	Philippines
Sugar cane	Saccharum officinarum	2,941	Yemen Ar	56,041	126,415	Peru
Green Coffee	Coffea arabica	120	Sao Tome	521	1,736	Sri Lanka
Tea	Camellia Sinensis	300	Korea Rep.	861	2,586	Bolivia
Tobacco	Nicotiana tabacum	20	Fiji	1,248	3,721	Samoa

Source: FAO, 1980.

Rice (Oryza sativa). Rice is often considered a tropical crop, although it grows within a wide range of latitudes. The major varieties of Oryza saliva used commercially are: japonica in temperate zones, indica in tropical climates and javanica in Indonesia and The Philippines. Highest yields are obtained under flooded conditions therefore, soils that conserve water are preferred. Some rice is grown in uplands without irrigation.

Barley (Hordeum vulgare). Barley is the oldest cereal grain and is distributed more widely than any other cereal grain. Many varieties adapted to specific geographical areas are grown around the world. Barley is generally a cool climate crop and is less tolerant to hot humid climates than other cereals. Some barley is grown in the drier and higher altitudes of the tropics.

Corn (Zea mays). Originally a tropical crop, corn is now grown throughout the world. Summer temperatures and rainfall distribution patterns are important parameters which influence yields. Many hybrids are available which display increased resistance to diseases and increased yields under different climatic conditions. Corn is a demanding crop in terms of nitrogen, phosphorus, and potassium, and some other mineral elements; only fertile soils will provide high yields without fertilization.

Sorghum (Sorghum bicolor). Grain sorghum is a tropical grass generally found from the tropics to latitudes as high as 45 N. Deep, well-drained soils, well supplied with nutrients and moisture, are needed to obtain high

yields. Sorghum is considered as more heat and drought resistant than other cereal crops. The crop therefore is useful in areas where other cereal crops cannot produce reliable yields. Sorghum requires relatively large amounts of N, P, and K.

Potatoes (Solanum tuberosum). Potatoes originated in South America and were brought to Europe in the fifteenth and sixteenth centuries. Potatoes are now commercially grown in every continent of the world. Potatoes are a cool climate crop which grows well in a wide variety of soils where adequate soil moisture is available. Appropriate fertilizer supplies, particularly potassium, are required for high starch content in the crop.

Cassava (Manihot esculenta). Cassava is a tropical crop which originated in South America and is now grown in many parts of the world particularly in Africa. Cassava is one of the most important starch crops in the world and has displaced several other starch crops as a source of edible starch. Cassava is a semiwoody shrub or small tree. Only the tuberous roots are used for food and the stem material is often available as an inexpensive residue available for other uses. Cassava tolerates many soil types and climatic conditions and is not particularly sensitive to seasons of the year. Year-round production therefore is often possible, making the crop particularly attractive. High soil fertility results in very high production yields. Cassava can be grown by planting woody stems, which generally root easily. It is resistant to many diseases and insects, although these can become problems in large plantations where conditions favoring the propagation of epidemics may exist.

Soybeans (Glycine max). The soybean probably originated from China and spread to most regions of the world. It is a temperate climate crop, which can be grown in a variety of soil types. The plant is a nitrogen-fixing legume. Soybeans or soybean by-products provide a variety of products: food, feed, oils, fertilizers, chemicals, etc.

Peanuts (Arachis hypogaea). Peanuts probably originated in Brazil, from where it was brought to Africa and many other parts of the world. The peanut plant is a nitrogen-fixing legume adapted to a variety of soils in different temperature zones in the northern and southern hemispheres. All parts of the plant are used: the kernel for food and feed; the hulls for fuel, mulch, feed, and industrial feedstock, the leaves and stems for feed and soil-conditioning soil nutrients; and the roots for nitrogen enrichment of the soil. Peanut shells accumulated at processing plants have little value as feed and are often used as fuel for boilers. The shells can also be used as litter, roughage for animals, filler for boards, etc.

Cotton (Gossypium hirsutum). Originally cotton plants were tropical shrubs that subsequently spread to the subtropics. Cotton is the major textile fiber of tropical countries. Cotton grows best in fertile soils with adequate moisture in areas with long (200 days or more) frost-free periods. Cotton is grown under irrigated and dry land conditions. Typically about 15 percent of the crop is lost to insect damage in an average year. The use of insect-resistant varieties, insecticides and appropriate cultural practices are essential to control pest problems.

Sugar Cane (Saccharum officianarum L.)[1/]. The basic structure of the sugar cane is closely related to that of other members of the family Gramineae, of which it is a giant member. The major structure of this perennial grass is the stem (culm or stalk), which is the principal organ of sucrose storage. The stem is solid, 2.5 - 6 meters in height, usually erect and unbranched except for tillers (secondary stems) at the base. The stem is composed of a series of joints, 5 to 25 centimeters long and 1.5 to 6 centimeters in diameter consisting of a node and internode. The length, diameter, shape, and color of the joints varies with the cultivar but can also be influenced by climatic and other factors, particularly light and nitrogen status.

The leaves are two-ranked as in other grasses, alternating on opposite sides. The number of mature green leaves *during* the "grand growth" period is about 10. As new leaves emerge, the older lower leaves dry and die and may drop off or be retained.

The root system is fibrous and composed of two components. The sugar cane plant is generally propagated by cuttings, therefore the first component of the system is a group of thin, highly branched roots that develop from the cuttings. The secondary roots, which develop from the secondary shoots as the plant matures, are thicker than the primary roots and penetrate the soil to a depth of 2 meters or more. However, the roots most active in uptake of water and nutrients function in the upper 50 centimeters of the soil.

[1/] Adapted from Lipinski et al., 1981.

The flower of the sugarcane plant is a loose terminal panicle 25 to 50 centimeters long and silky in appearance. The extent of flowering varies greatly with cultivars and climate (photoperiod). For example, most sugar cane produced in the world is harvested prior to flowering.

In the United States, the proportion of total millable stalk to the total wet biomass varies greatly, ranging from 50 percent in 12-month-old Hawaiian sugar cane to approximately 70 percent in 9-month-old Louisiana cane.

Sugar cane has long been recognized as the earth's most efficient bioconverter on a large scale. The efficiency of sugar cane is due to:

(1) High rates of photosynthesis
(2) A large, effective leaf area
(3) A long growing season.

The world's average yield of sugar cane is 56.6 ton/ha/yr (1977-1978), and assuming an average 72.5 percent moisture content, the average yield of dry matter (half sugar, half fiber) is 15.5 tons/ha/yr. A number of sugar cane regions (Malawi, Zimbawbe, Swaziland, Iran, Hawaii, Colombia, and Peru) obtain yields averaging 100 tons/ha/yr or more. However, these high yields are only 36 percent of the theoretical maximum yield of sugar cane; thus, there is considerable room for yield improvement.

In small plot tests, utilizing narrow row spacings of 0.5 and 0.6meters, respectively, yields of 190 and 160 tons/ha/yr were obtained in Australia

and the United States. Increased yields can be realized in many areas by applying approved cropping practices. In addition, yields may be improved through plant breeding. The sucrose and fiber content of commercial sugar cane cultivars range from 10 to 16 percent. Since these cultivars were developed through selection for low fiber, a change in selection pressure for high fiber and high total sugars would likely result in genotypes with a higher energy content per ton and per unit area.

Sugar Beet (Beta vulgaris L.)[1/]. The sugar beet is a herbaceous dicotyledon, a member of the family chenopodiaceae, characterized by small, greenish, bracteolate flowers. The major structure of this biennial shrub is the fleshy root (the principal organ of sucrose storage). At maturity, the beet is composed of three major segments: the crown, the neck, and the root. The crown is composed of the leaves and the leaf bases. Located just below it is the neck, which is the broadest part of the beet. The cone-shaped root is found below the neck region.

The leaves are simple with a large blade and petiole. Flowers of the sugar beet are perfect and incomplete. The fruit is an aggregate that yields a seedball with two or more viable seeds. Because the entire fruit is used in planting operations, efforts have been made to develop a monogerm seed. Both mechanically and through breeding, a monogerm seed is currently available, which allows the planting of a more uniform stand.

[1/] Adapted from Lipinski et al., 1981.

The sugar beet, unlike the other sugar crops, has been selected for temperate environments and may show limited potential for production in many of the developing countries. Yields in the current sugar beet-producing countries average 30 tons/ha/yr of millable root. The highest national yield is that of Austria at 63.2 tons/ha/yr (1977-1978).

A serious problem that arises when considering the sugar beet as a feedstock for alcohol is its susceptibility to pests and diseases. Currently, more research is concerned with enhancing pest and disease resistance than improving yields. Crop rotation frequently is employed to reduce sugar beet pest populations. This method decreases the quantity and reliability of feedstock supply for the ethanol facility.

Sweet Sorghum and Sweet-Stemmed Grain Sorghum (Sorghum bicolor L. Monech)[1/]. Like sugar cane, the sorghums are members of the grass family and are often grown in cultivation as a single-stemmed type, but also show great variation in tillering capacity, as determined by both cultivar and plant population. The stem of the plant varies in height from 0.5 to 4 meters and, like sugar cane, can accumulate and store sugar. The stem diameter ranges from 0.5 to 3 centimeters, the general size tapering from the base to the seed head.

The number of leaves varies from ten to thirty, according to the cultivar and appear to alternate in two ranks. Leaves of the sorghum plant have long blades ranging from 30 to 135 centimeters with a width of 1.5 to 13 centimeters.

1/ Adapted from Lipinski et al., 1981.

The roots of sorghum are divided into a temporary and a permanent system. A single radicle is produced by the seedling, followed by adventitious fibrous roots from the lowest nodes of the stem. The entire system may penetrate to a depth of 1 meter with a spread of 1.5 meters, depending on soil conditions and cultural practices.

The sorghum inflorescence, or "head", is a somewhat compact or loose panicle. A well-developed panicle may contain as many as 1,000 to 2,000 seeds. As an indication of the variation in seed size, sorghum cultivars range from 44,000 to 60,000 seeds per kilogram.

The proportion of total wet stalk to total wet biomass is highly dependent on the type of sorghum (whether sweet or sweet-stemmed grain) and the cultural practices employed, particularly the plant population and the row spacing. A general range for this value is 60-80 percent, the sweet sorghums being at the higher end of the range and the sweet-stemmed grain sorghums at the lower. Grain yields will range from 500 kg ha^{-1} with the sweet sorghum to approximately 6,000 kg ha^{-1} with sweet-stemmed grain sorghum.

The sorghum plant, whether sweet or sweet-stemmed grain, has a number of distinctive physiological and agronomic characteristics which increase its potential as a viable multiuse crop over a wide geographic range. First, sorghum exhibits the C_4 (Hatch-Slack) photosynthetic pathway and is therefore quite efficient in assimilating carbon dioxide. Also, sorghum lacks the process of photorespiration and is highly productive, achieving maximum short-term crop growth rates of approximately 51 g m^{-2} ground day^{-1}.

Second, sorghum utilizes water efficiently. The root system is fibrous and extensive. Ponnaiya demonstrated the existence of heary silica deposits in the endodermis of the root, forming a complete silica cylinder in the mature roots. This mechanical strength is of great importance in preventing collapse of the system during drought stress. A waxy cuticle covers the above-ground structure to retard drying. Unlike corn, sorghum has the ability to remain dormant during a drought period and then to become active rapidly following moisture reintroduction. The water requirement to produce 1 kilogram of sorghum dry matter ranges from 250 to 350 kilograms, whereas the requirement for wheat and soybean is approximately 500 to 700, respectively,

Current commercial yields of sweet sorghum range from 33 to 44 tons of millable stalks/ha/crop season. These yields are achieved with the use of older, early maturing cultivars and row spacings of 1 meter. Also, no hybrids of sweet sorghum have been developed for commercial use; therefore, if an analogy can be drawn between sweet sorghum and corn improvement, sweet sorghum is at the same stage of development as corn was in the 1930's.

Experimental yields of sweet sorghum have reached 120 tons/ha for a 6-month crop in the Texas Rio Grande Valley. Development of sweet-stemmed grain sorghum has occurred within only the past few years but results have been very encouraging. These sweet-stemmed grain sorghum yields have reached 40 to 60 tons of millable stalks/ha (equivalent to 0.8 to 1.2 tons of fermentable sugars) in addition to 2 to 6 tons of starch/ha. It is quite apparent that, if sweet sorghum and sweet-stemmed grain sorghum received

the same amount of funding and research interest as corn, sugar cane, or sugar beets, they could well become useful crops in developing country agricultural systems.

2.2.2 Energy Crops

The crops described in Section 2.2.1 can in principle all be grown for fuel/energy feedstock. These crops however have a high value as food or feed. Except for situations where land suitable for growing these crops is plentiful, and therefore a surplus of crops over the food and feed requirements of the country can be generated, it is doubtful that these crops will become a significant source of feedstock for fuel production.

The potential of a number of grasses as cellulosic energy feedstocks has been investigated, Benton et al. (1978). Grasses are well suited for use on poorer soils that have a high erosion potential since the soil remains covered permanently where a perennial grass is grown. Some grass species also display high productivities, comparable to sugar cane when soil and climate conditions are adequate, and have the potential for higher yields in energy farms than short-rotation tree plantations. Grasses require a much shorter period between initial planting and first harvest than trees do, thereby reducing the initial capital outlay. Grass farms can also easily be reverted to crop production if need be. These advantages are partially offset by the higher bulk density and more complex handling characteristics of grasses as compared to coal or charcoal.

Some of the grasses considered for energy feedstock are briefly described below.

Kenaf (hibiscus cannabinis). Kenaf is widely cultivated in Africa as a source of fiber. The leaves and flowers are used as vegetables. It is a fast-growing annual crop growing from the Tropics to the Midwest of the United States. A crop is produced in 90 to 120 days. In temperate climates, it should be seeded after the danger of frost is over. Kenaf is relatively immune to disease and insects. Yields of the order of 17 to 18 metric tons per hectare (mt/ha) have been reported under favorable conditions.

Giant Reed (arundo donax). A native of the Mediterranean area, it has been introduced in most subtropical and warm temperature areas of the world. The plant is fast growing and survives periods of extreme drought after its first year of growth. Abundant soil moisture favors growth. It is a perrenial crop, which can be started by root cuttings. Some weed control may be required during establishment. Annual yields of 7.2 mt/ha and of 18 mt/ha (oven dry) have been reported for wild stands in India and the United States respectively . Annual yields of 29 mt/ha have been reported in Italy for cultivated crops.

Napier Grass. Annual yields of 27 mt/ha have been reported for a hybrid (Sordan 7A) grown in Puerto Rico.

2.2.3 Residues

Agricultural residues are parts of a crop plant left in the field after harvest and materials accumulated at processing plants. For the majority of crops given in Table 2.13 it is the residues that are possibly available for energy utilization. It should be kept in mind, however, that residues have competing uses. In many countries they are often burned in the field to prevent diseases, they may be plowed back as soil amendments, used as livestock feed or as animal bedding, as roofing materials or as mattress stuffers. Because of these many alternative uses it would be highly speculative to estimate the residue volumes available for energy purposes in individual countries. The straw and chaff factors (Table 2.15) only give an indication of the total potential available, of which only a fraction will be diverted for energy purposes. The size of this fraction is an economic problem depending on the relative values of the residues between competing uses, and perhaps more importantly, on the problems of collecting and transporting biomass to a central place for conversion to energy.

Agricultural residues can be estimated as follows:

crop residues = crop yield x residue factor

where: crop yield = weight of crop at harvest moisture content,

residue factor = amount of residue produced per unit of crop material harvested or processed,
crop residue = weight of material at harvest or disposal moisture content.

The residue factors shown in Table 2.15 for various agricultural crops may vary substantially from country to country because of the harvesting methods used, varieties of crops grown, etc. Table 2.16 show residue factors and moisture contents for some crop residues. Moisture contents and heating values of other residues can be found in Table 2.7.

An example of the use of the residue factors and other tables from this volume is given below.

Example. Estimate the heating value of barley straw recovered on a hectare of land producing barley at the average world rate, assuming that all the straw can be recovered.

Average world yield: 1,761 kg/ha/year (Table 2.14)

Residue produced: 1,761 x 1.5 = 2,642 kg/ha/year (residue factor from Table 2.15)

Moisture content of barley straw: 14 percent (midrange value from Table 2.7)

Average higher heating value: 17.3 MJ/kg (dry basis-Table 2.7)

Hydrogen content: 8 percent approximately (from Figure 2.1)

Lower heating value, dry: 15.6 MJ/kg (equation 2.4)

Lower heating value, as-fired :(14 percent moisture): 13.07 MJ/kg (equation 2.5)

Heating value per hectare-year, as-fired: 13.07 x 2,462 =

34,531 MJ/ha/year

32.8 MBtu/ha/year

13.7 MBtu/acre/year.

Table 2.15.--RESIDUE FACTORS OF VARIOUS CROPS

Crops	Residues	
	Straw	Chaff
Wheat	1.5	.25
Rice	1.5	.25 (husks)
Barley	1.5	.25
Corn	1.5	.60
Sorghum	1.0	.25
Millet	1.5	.25
Potatoes	.20	.15
Sweet potatoes	.30	.15
Cassava	.50	.25
Soybeans	2.5	1.0 (Pods)
Peanuts	2.0	.4 (Pods)
Castor beans	4.0	.25 (Pods)
Rape seed	1.0	.20 (Pods)
Sesame seed	1.0	.20 (Pods)
Linseed	2.5	.20 (Pods)
Seed cotton	2.0	.30 (Lint)
Coconuts	10.0	.60 (Husks)
Sugar cane	.20	.10

TABLE 2.16.--RESIDUE FACTORS AND MOISTURE CONTENT OF VARIOUS CROPS

Crops	Residue Factor	Moisture Content (% Wet)
Dry beans and peas	1.58	60
Sugar beets	0.52	80
Vegetables	0.85	83
Vegetable packing residues:		
Asparagus	0.19	90
Carrots	0.08	90
Cauliflower	0.76	92
Celery	0.14	94
Sweet corn	0.06	82
Safflower	0.83	8
Seed grass	4.44	20
Oats	1.40	10
Rye	2.50	28
Sunflower	6.07	15
Collected trash and hulls:		
Almond and other hulls and trash	1.10	10
Cotton gin trash	0.51	8
Sugar beet pulp	0.07	7

Source: Adapted from R. K. Ernest et al., 1979.

2.2.4 Environmental Considerations.

Not all the residues produced are available for energy production. It is difficult to harvest more than 60 or 70 percent of the residues of some crops because of collection difficulties. Also, part or all of the residues may be needed for protection of the soil from serious water or wind erosion and for the maintenance of soil organic matter.

The amounts needed for soil conservation depend on the soil slope, the existing soil organic level, soil texture, and climate. The organic level of the soil is helped by crop residues, which is important for maintaining long term soil productivity. Removal of the residues also removes the plant nutrients they contain, and in many cases these nutrients would have to be replaced by applying additional fertilizer.

Crop residues on the surface of the soil reduce water erosion by intercepting the raindrop impact and reducing the velocity of the run-off water. In addition, because the organic matter tends to keep the soil aggregated in granules, less soil is moved by the water. The residues and organic matter of the soil also affect the rate of water infiltration: if the water can be absorbed by the soil, it will not run over the surface and cause erosion. The steeper and the longer the slopes, the greater the need for plant residues to protect the soil from water erosion.

Residues reduce wind erosion by reducing wind speed near the surface of the soil, preventing the direct force of the wind from moving the soil

particles. The wider the unobstructed field width, the greater the need for surface residue protection.

The effect of residues on soil erosion by water can be estimated with the Universal Soil Loss Equation:

$$A = RKLSCP$$

where A is the estimated soil loss, R is a rainfall factor, K is a soil erosive factor, L is the slope length factor, S is the slope gradient factor, C is the cropping management factor and P is the erosion control practice factor. (Wischmeier and Smith, 1965). The factor C accounts for crop rotation and crop types (row crops, grains, hay, etc) while the factor P accounts for conservation practices such as contour plowing, etc. The values of the factors used in the equation are obtained from soil erosion studies and may not be available in some countries.

The effect of residues on the amount of soil lost by wind erosion can be estimated through the Wind Erosion Equation:

$$E = f(I,K,C,L,V)$$

where E is the estimated soil loss, I is an erosive factor, K is a roughness factor, C is the climatic factor, I is the field length and V is the equivalent quantity of vegetative cover. Depending on soil properties, depths, topography and prior erosion, Wischmeier and Smith (1965) estimate soil losses ranging from 2 to 11 metric tons per hectare per year as tolerable.

2.3. Forest Resources

This section describes some characteristics, environmental requirements, and fuel values of wood crops and wood residues usable as feedstocks for fuel/energy production.

2.3.1 Wood Crops

Many tree species have the potential of providing fuelwood for industrial and residential uses. Desirable characteristics for firewood-producing species include high heating value and high specific gravity, potential uses other than fuel (food, feed, etc), adaptability to climate extremes (low rainfall, high temperatures, long periods of drought, etc.), adaptability to a variety of soils including poor and eroded soils, ability to coppice or to grow rapidly from roots and stumps, ability to fix atmospheric nitrogen, and high yields.

The characteristics of a number of species identified by the National Academy of Sciences (1980) as potential firewood crops are summarized in Table 2.17 (Species for Humid Tropics), Table 2.18 (Species for Tropical Highlands) and Table 2.19 (Species for Arid and Semiarid Regions). Further details concerning these species can be found in the original document (National Academy of Sciences, 1980). More specific data concerning yields of species grown in plantations can be found (for some species) in Volume II, Country Statistical Data. The environmental requirements described in the tables (altitude range, rainfall, etc.) are generally those recorded for species in their native habitat.

TABLE 2.17.--DESCRIPTION OF FUELWOOD SPECIES (HUMID TROPICS)

NAME	Acacia auriculiformis	Caliandra calothyrsus	Casuarina Equisetifolia	Derris indica
Common name	--	Calliandra	Cassaurina, she-oak, horsetail oak, Australian pine, ironwood, agoho, ru,. . .	Pongam, ponga, oil tree, kona, kanji, pari-pari Indian beech.
Native area	Papua New Guinea, northern Australia.	Central America	North Australia, Pacific, Indonesia India, Sri Lanka.	Indian subcontinent.
Fuelwood use	Good - Plantations in Indonesia and India.	Good - Plantations in Indonesia.	"Best firewood in the world."	Good, used in India.
Heating value-kJ/kg	20,000 - 20,500	18,800 - 19,850	20,700	19,200
Specific gravity	0.6 - 0.75	0.51 - 0.78	0.8 - 1.2	--
Other uses	Wood, pulp, shade, tannin.	Erosion control, soil improvement fodder, firebreak,. . .	Timber, erosion, windbreak, tannin, dye, pulp, good charcoal.	Wood, fiber, oil (lighting), fodder.
Temperature -°C	26-30	Unknown	10-33	0-50
Altitude - m	0-600	150-1,500	0-1,500	0-1,200
Rainfall-mm	1,500-1,800	More than 1,000	700-2,000	500-2,500
Drought (months)	6	Several	6-8	--
Soil	Variable, including poor soil.	Variable, including poor soil.	Variable but not heavy.	Sandy, rocky, most others.
Coppice	--	Yes	No	Yes
Yield-m^3/ha	--	--	60-250	Fast growing.
age-rotation	10-12	1	7-10	
spacing	--	1x1 - 2x2	2x2	
m^3/ha/year	17-20	5-20	--	
country	Malaysia.	Indonesia	Malaysia	
m^3/ha	--	--		
age-rotation	15	1 (coppice)		
spacing	--	--	--	--
m^3/ha/year	5	35-65	--	--
country	West Bengal.	Indonesia		
	Legume. Seedlings sensitive to weed competition.	Shrub-legume Suppresses competition rapidly.	Not legume but fixes atmospheric nitrogen. Aggressive plants, can displace native vegetation. Other casuarina species should be tested.	Legume Competes with weeds.

TABLE 2.17.--DESCRIPTION OF FUELWOOD SPECIES (HUMID TROPICS) (Continued)

NAME	Gliricidia sepium	Gmelina arborea	Guazuma ulmifolia	Leucaena leucocephala
Common name	Madre de cacao, mata-raton, kakauati, Mexican litac.	Gmelina, yemane, gumhar, gamar.	Guacina, majagua de torro, West Indian elm, bastard cedar.	Leucaena, ipil-ipil, lamtora, guaje, uaxin, leadtree.
Native area	Central America.	India, Bangladesh, Sri Lanka, SE Asia, Southern China.	Tropical America, Caribbean.	Southern Mexico
Fuelwood use	Good.	Used in Malawi, Sierra Leone, Nigeria.	Good.	Excellent; used in Philippines extensively.
Heating value	20,500	20,060	--	17,600-19,200
Specific gravity	--	0.42-0.64	0.55-0.58	--
Other uses	Timber, fence, shade, fodder honey.	Wood, pulp, honey good charcoal.	Wood, forage, shade, food, charcoal production.	Forage, wood, soil improvement, reforestation, excellent charcoal.
Temperature -°C	22-30	Up to 52, injured by frost.	Tropical.	Tropics, subtropics killed by frost.
Altitude - m	0-1,600	0-1,000	0-1,200	0-500
Rainfall-mm	1,500-2,300	750-4,500	700-1,500	600-1,700
Drought (months)	--	7	4-7	--
Soil	Dry or moist.	Wide range including humid lowlands.	Wide range.	Wide variety.
Coppice	Yes.	Yes.	--	Difficult.
Yield-m^3/ha		--		--
age-rotation	--	5-8	--	--
spacing		2x2		--
m^3/ha/year		20-35		30-40
country		Malaya		Philippines
m^3/ha				
age-rotation	--	--	--	--
spacing				
m^3/ha/year				
country				
	Legume. Fast growing. Good for cultivation in populated areas.	Weeding needed first yea.r Compatible with agricultural crop.	--	Legume. Weed control needed.

TABLE 2.17.--DESCRIPTION OF FUELWOOD SPECIES (HUMID TROPICS) (Continued)

NAME	Mangroves	Mimosa scabrella	Muntingia calabura	Sesbania bispinosa
Common name	--	Bracatinga, bracaatinga, abaracaatinga.	Jamaica cherry, Japanese cherry, capulin, chitato, majaguillo, calabura.	Dhaincha, prickly sesban.
Native area	Tropics and Subtropics.	Southern Brazil.	Southern Mexico to Bolivia, Brazil.	Indian subcontinent.
Fuelwood use	Excellent. Used extensively in Philippines, Thailand, Puerto Rico	Used for railroad fuel in Brazil.	Good.	Used in Pakistan, Vietnam, Cameroon.
Heating value	16,700-18,000	--	--	--
Specific gravity	0.7-1.0	--	--	0.3
Other uses	Wood, coastal protection, food, extractives, pulp. Excellent charcoal.	Pulp, green manure.	Shade, fruit, fiber, wood.	Gum, pulp, fiber, forage, green manure.
Temperature -°C	Tropics - subtropics.	Subtropics mostly.	Humid tropical.	Tropics, subtropics, temperate (Italy).
Altitude - m	0	0-2,400	0-1,300	0-1,200
Rainfall-mm	Over 1,000	--	1,000-2,000	550-1,100
Drought (months)	--	--	--	--
Soil	Coastal and estuarine areas.	Many varieties.	Many varieties, prefers sand.	Adapted to difficult soils.
Coppice	--	--	--	Yes.
Yield-m^3/ha age-rotation spacing m^3/ha/year country	-- --	Fast growing coppice rotations can be as short as 3 years.	--	Two crops per year possible in tropics.
m^3/ha age-rotation spacing m^3/ha/year country	--	--	--	--
	No competition from weeds. Plantations established in Thailand, Malaysia, Bangladesh, Puerto Rico.	Legume. Trial plantations in Zaire, Senegal, Ethiopia, Central America.	Planted in Southeast Asia, Pacific and Caribbeans. No competition from weeds.	Legume. No competition from weeds. Shrub. Can be grown in rice fields. Planted in Africa, Southeast Asia, China, Caribbeans.

TABLE 2.17.--DESCRIPTION OF FUELWOOD SPECIES (HUMID TROPICS) (Concluded)

NAME	Sesbania grandiflora	Syzygium cumini	Terminalia catappa	Trema species
Common name	Abati, bacule, katurai, West Indian pea tree, turi, gallito, chogache.	Jambolan, Java plum, jaman, jabu Jamun, Indian blackberry	Indian almond, tropical almond, sea almond, badan.	--
Native area	Asian countries.	India, Burma, Sri Lanka, Philippines	Malaya	Native species from India, Africa, Central America, SE Asia.
Fuelwood use	Medium. Used in Southeast Asia. Plantations in Indonesia.	Excellent	Good.	Widely used. Medium quality.
Heating value	--	20,600	--	18,800
Specific gravity	0.42	0.77	0.59	--
Other uses	Food, forage, green manure, reforestation, tannin, gum, pulp.	Wood, food, hedges, tannin, honey.	Wood, fruit, tannin, dune fixation. shade, silk.	Afforestation, shade pulp, wood, fodder.
Temperature -°C	Tropical; frost sensitive.	Tropical; warm subtropical.	Humid tropics	Tropics, subtropics.
Altitude - m	0-800	0-1,800	0-300	0-2,000
Rainfall-mm	Over 1,000	1,500-10,000	Over 1,000	Humid to dry depending on species.
Drought (months)	A few months	--	--	--
Soil	Wide range including poor.	Sand and many other types.	Variable	Many types including denuded, fallow and poor.
Coppice	Yes.	Yes.	--	Yes.
Yield-m^3/ha	--		38-61	
age-rotation	--		10	
spacing	--	--	--	Fast growing.
m^3/ha/year	20-25		--	
country	Indonesia		--	
m^3/ha	3			
age-rotation	2	--	--	--
spacing	Along edges of fields.			
m^3/ha/year	--			
country	Java			
	Legume. Grows in Caribbean, Mexico, Central and South America, Mauritius. Can be densily planted (3,000 stems/ha).	Found in Caribbean, Central America and Australia. Competes well with weeds.	Found in Philippines, Indonesia Ghana, South Pacific, tropical America Competes very well with weeds	Often called charcoal tree. Competes very well with other species.

TABLE 2.18.--DESCRIPTION OF FUELWOOD SPECIES (TROPICAL HIGHLANDS)

NAME	Acacia mearnsii	Ailanthus altissima	Alnus acuminata	Alnus nepalensis
Common name	Black or tan wattle.	Ailanthus, Tree of heaven, China sumac.	Alder, aliso, ramram, lambran, jaul.	Indian alder, nepalese alder, maibau.
Native area	Australia	China	Central/South America	Burma, Himalayas, China
Fuelwood use	Excellent.	Good.	Good.	Burns quickly.
Heating value	14,630-16,720	--	--	--
Specific gravity	0.7-0.85	--	0.5-0.6	0.32-0.37
Other uses	Green manure, tannin, good charcoal, erosion control.	Charcoal, lumber, erosion, soil improvement.	Wood, watershed protection, soil improvement.	Wood.
Temperature -°C	Cool, somewhat frost tolerant.	Temperate-Subtrop., stands frosts.	4-27	Cool, moist, tropical highlands.
Altitude - m	0-1,100	0-2,000	1,200-3,200	1,000-3,000
Rainfall-mm	500-700	350-600	1,000-3,000	Over 500
Drought (months)	--	8	--	--
Soil	Varied including poor.	Variety including poor.	Many, prefers good agricultural land.	Many, soil moisture important.
Coppice	Poor.	Yes.	Yes.	--
Yield-m^3/ha	--		--	
age-rotation	7-10		20	
spacing	--	--	--	Very fast growing.
m^3/ha/year	10-25		10-15	
country	Indonesia		--	
m^3/ha	--	--	--	--
age-rotation				
spacing				
m^3/ha/year				
country				
	Legume. Good for small woodlots, line planting, etc. Cultivated in New Zealand, Central, South and East Africa, India, Sri Lanka, Central America, Indonesia.	Cultivated in Europe, Morocco Iran, North America. Competes well with weeds. Grows in city environment.	Nitrogen fixing. Cultivated in Costa Rica, Colombia, Bolivia, Peru, Chile, New Zealand. Does not compete well with weeds.	Probably nitrogen fixing. Planted in India, Hawaii, Burma. Competes well with weeds.

TABLE 2.18.--DESCRIPTION OF FUELWOOD SPECIES (TROPICAL HIGHLANDS) (Continued)

NAME	Alnus rubra	Eucalyptus globulus	Eucalyptus grandis	Grevillea robusta
Common name	Red alder	Southern blue gum, Tasmanian blue gum, fever tree.	Flooded gum, rose gum.	Silk oak, silver oak, roble de seda.
Native area	North America	Tasmania	Australia	Australia
Fuelwood use	Good.	Good.	Excellent.	Used in Sri Lanka.
Heating value	29,230	20,060	--	--
Specific gravity	0.39	0.8-1.0	0.40-0.55	0.57
Other uses	Good charcoal, wood, pulp, land reclamation.	Good charcoal, wood, pulp oil, honey, reclaimation.	Timber.	Wood, honey, shade.
Temperature -°C	-20 - 45	Temperate, sensitive to cold.	-3 -40	Mean of about 20.
Altitude - m	0-750	0-3,000	0-2,700	0-2,300
Rainfall-mm	600-3,000	800-1,500	1,000-1,800	700-1,500
Drought (months)	--	Sensitive.	--	6-8
Soil	Many, prefers moist sites.	Well drained.	Moist, well drained.	Many.
Coppice	Yes.	Yes.	Yes.	Poor.
Yield-m^3/ha	--	--	--	217
age-rotation	20-30	5-15	--	14
spacing	--	--	--	--
m^3/ha/year	10-11 (stem)	10-30	17-45	--
country	North America	Europe, Peru	Uganda	Tanzania
m^3/ha	--	--	--	--
age-rotation	short rotation.	--	6 (coppice)	--
spacing	--	--	--	--
m^3/ha/year	17-21	--	30-46	--
country	North America	--	Kenya	--
	Nitrogen fixing. Planted in Europe and New Zealand. Competes very well with weeds.	Plantations in Spain, Portugal, Italy, France, Africa, Ethiopia, Peru, Ecuador, Colombia, Uruguay India. Does not compete well with weeds.	Cultivated in South America, East/South Africa, Brazil. Sensitive to weeds. Sensitive to frost.	Cultivated in India, Sri Lanka, Kenya, Mauritius, Zambia, Malawi, Zimbabwe Tanzania, Uganda, South Africa, Jamaica. Competes well with weeds.

TABLE 2.18.--DESCRIPTION OF FUELWOOD SPECIES (TROPICAL HIGHLANDS) (Concluded)

NAME	Inga vera
Common name	Guaba, guama, poix doux a paille, pan chock.
Native area	Caribbean
Fuelwood use	Excellentn
Heating value	--
Specific gravity	0.57
Other uses	Charcoal, wood, shade, honey, food.
Temperature -°C	Humid tropics.
Altitude - m	Lowlands
Rainfall-mm	Moist to dry.
Drought (months)	Some tolerance.
Soil	Many types.
Coppice	Yes.
Yield-m^3/ha age-rotation spacing m^3/ha/year country	Fast growing.
m^3/ha age-rotation spacing m^3/ha/year country	--
	Legume. Planted in Caribbean, Central and north South America.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMI ARID REGIONS)

NAME	Acacia brachystachya	Acacia cambagei	Acacia cyclops	Acacia nilotica
Common name	Umbrella nulga, turpentine nulga	Gidgee, gidya, stinking wattle.	Rooikrans	Egyptian thorn, red-heat, kudupod, babul, sunt.
Native area	Australia	Australia	Australia	Pakistan, India, Africa
Fuelwood use	Excellent.	Excellent.	Very good.	Used in India.
Heating value	--	--	--	20,060-20,690
Specific gravity	--	1.3	--	0.67-0.68
Other uses	Wood, fodder.	Wood	Fodder.	Charcoal, wood, tannin, gum.
Temperature -°C	4-58	34 (summer)	5-31	Frost sensitive when young.
Altitude - m	0-600	75-500	0-300	0-500
Rainfall-mm	200-300	125-500	200-800	Arid but stands flooding.
Drought (months)	--	5	--	--
Soil	Many types.	Wide variety.	Sand, Limestone.	Variety including poor.
Coppice	--	--	--	Poor.
Yield-m^3/ha			Relatively slow growth.	Fast growing.
age-rotation	--	--		20-30
spacing				--
m^3/ha/year				--
country				India, Pakistan, Sudan
m^3/ha				
age-rotation	--	--	--	--
spacing				
m^3/ha/year				
country				
	Legume, shrub.	Legume. Trial plantings in India, North Africa, Persian gulf.	Legume, shrub. Planted in South Africa.	Legume. Planted in India, Pakistan, Sudan Zambia, Botswana. Requires weeding when young.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Continued)

NAME	Acacia saligna	Acacia senegal	Acacia seyal	Acacia tortilis
Common name	Golden wreath wattle, orange wattle.	Gum acacia, hashab gum arabic tree.	Talk, skittim wood.	Umbrella thorn, Israeli babool, sayal, seyal.
Native area	Australia	Southern Sahara, Sahel	Sahel	Excellent.
Fuelwood use	Medium.	Excellent.	Excellent.	Excellent.
Heating value	--	13,800	--	18,390
Specific gravity	--	--	--	--
Other uses	Sand dune fixation, fodder, gum.	Charcoal, wood, gum fodder, seeds, erosion control.	Wood, forage, gum.	Charcoal, wood, fodder, sand stabilization.
Temperature -°C	4-36	-4 - 48	Hot.	0-50
Altitude - m	0-300	100-1,700	0-2,100	Lowlands
Rainfall-mm	250-600	200-450	350 and over.	100-1,100
Drought (months)	Very resistant.	8-11	Very tolerant.	Resistant.
Soil	Mostly sandy coastal, many others.	Mostly sand.	Most soils including rocky.	Alkaline, shallow.
Coppice	Yes.	Yes.	--	Yes.
Yield-m^3/ha	--	--		54 ton/ha
age-rotation	5-10	--	Rather slow growing.	12
spacing	--	--		3x3
m^3/ha/year	1.5-10	0.5-1.0		--
country	--	--		India
m^3/ha				
age-rotation				
spacing	--	--	--	--
m^3/ha/year				
country				
	Legume, shrub. Planted in Uruguay, Mexico, Iran, Iraq, Jordan, Syria, North Africa. Sensitive to frost. Competes very well with weeds.	Legume. Planted in Sudan, Senegal, India, Pakistan, Nigeria, Upper Volta. Very robust, weeding needed for 2 years.	Legume, shrub. Found in Egypt, eastern and southern Africa.	Legume. Introduced in India for fuelwood plantations.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Continued)

NAME	Adhatoda vasica	Albizia lebbek	Anogeissus latifolia	Azadirachta indica
Common name	Vasaka, adhatoda, adusa, etc.	Lebbek, karana, East Indian walnut siris-tree, acacia amarilla	Axle wood tree, bakli, dhausa, dhau	Neem, nim
Native area	India	India, Bangladesh, Burma, Pakistan	India, Sri Lanka	India, Pakistan, Sri Lanka, Malaya, Indonesia Thailand, Burma
Fuelwood use	Good.	Good.	Good.	Good.
Heating value	--	21,740 (dry)	20,480	High.
Specific gravity	--	0.55-0.60	0.9	0.56-0.85
Other uses	Charcoal, drugs, dye, herbicide, green manure, insecticide.	Wood, fodder, erosion control.	Excellent charcoal, wood, gum, tannin, dye, fodder, silk, pulp.	Wood, oil, soil improvement, chemicals, insect repellent.
Temperature -°C	Tropical/subtropical, sensitive to frost.	Tolerates light frost.	Tropical/subtropical.	0-44
Altitude - m	0-1,300	0-1,600	0-1,300	50-1,500
Rainfall-mm	500-1,650	500-2,000	600	450-1,150
Drought (months)	--	Tolerates light drought.	--	Tolerates long dry season.
Soil	Many types.	Most types prefers moist soils.	Dry sandy, rocky.	Most soils.
Coppice	Yes.	Yes.	--	Yes.
age-rotation	--	10-15	--	8
spacing		--	--	2.4 x 2.4
m^3/ha/year		5		13.5-17.1
country		India		Ghana
m^3/ha	--	--	--	--
age-rotation				8
spacing				--
m^3/ha/year				2.4-21.1
country				Nigeria
	Shrub. Grows in Sri Lanka, Malaysia, Burma.	Fixed nitrogen. Cultivated in North Africa West Indies, South America, Southeast Asia, Nepal. Must be weeded during 2 first years.	--	Cultivated in India and Africa, Sudan, Sahel Sierra Leone, Malawi Zimbabwe, Tanzania, Zanzibar, Guinea, Nigeria, Ghana. Needs weeding.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Continued)

NAME	Cajanus cajan	Cassia siamea	Colophospermum mopane	Emblica officinalis
Common name	Pigeon pea, congo pea, red gram	Yellow cassia, minjri, cassia, nuong, Bombay blackwood	Mopane, balsam tree, turpentine tree Rhodesian ironwood, mapani	Emblic, India gooseberry aonla, Malacca tree, amba.
Native area	Northeastern Africa	Southeast Asia	Central/Southern Africa	Tropical Asia.
Fuelwood use	Used in India and Malawi.	Excellent.	Excellent.	Excellent.
Heating value	--	--	--	21,740
Specific gravity	--	0.6-0.8	1.0	0.7-0.8
Other uses	Food, forage, erosion control.	Wood, revegetation.	Wood, fodder.	Excellent charcoal, wood, food, fodder, green manure.
Temperature -°C	18-35, killed by frost.	Tropical.	0-36	0-46
Altitude - m	0-3,000	Lowland.	0-900	0-1,800
Rainfall-mm	600-1,000	1,000 or more.	200-450	Humid climates.
Drought (months)	Tolerant.	4-5	--	--
Soil	Wide range.	Dry, relatively rich.	Variety of soils.	Varied including poor.
Coppice	--	Yes.	Yes.	Yes.
Yield-m^3/ha	30,000 plants/ha	--		
age-rotation	2 tons/ha/year	5-10	Not fast growing.	Fast growing.
spacing		--		
m^3/ha/year		15		
country		--		
m^3/ha	--	--	--	--
age-rotation				
spacing				
m^3/ha/year				
country				
	Legume, shrub. Cultivated in India, West Indies Tropics. Weeding needed for about 8 weeks.	Legume. Planted in Ghana, Nigeria, Zambia, Tanzania, Uganda, Central America.	Legume. Grown in Mozambique, Zimbabwe, Zambia, Botswana, Angola, Namibia, India.	Competes well with weeds.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Continued)

NAME	Eucalyptus camaldulensis	Eucalyptus citriodora	Eucalyptus gomphocephala	Eucalyptus microtheca
Common name	Red river gum, red gum, river gum	Spotted gum, lemon scented gum	Tuart	Flooded box, coolibah
Native area	Australia	Australia	Australia	Australia
Fuelwood use	Excellent.	Very good.	Good.	Very good.
Heating value	20,060	--	--	--
Specific gravity	0.6	0.75-1.1	--	--
Other uses	Wood, honey, pulp, excellent charcoal.	Wood, perfume, honey good charcoal.	Wood, soil stabilization.	Charcoal, wood, erosion control.
Temperature -°C	Over 3.	Light Frost-35	-4-Temperate	5-38
Altitude - m	0-1,200	0-2,000	0-2,000	80-700
Rainfall-mm	400-1,250	600,900	300-1,000	200-1,000
Drought (months)	Tolerates long dry seasons.	5-7	6	7
Soil	Wide variety.	Generally poor.	Sandy.	Heavy.
Coppice	Yes.	Yes.	Yes.	Yes.
Yield-m^3/ha	--	--	--	--
age-rotation	7-10	8	7-10	6-8
spacing	--	--	--	--
m^3/ha/year	20-30	15	21-44 (irrigated)	--
country	Argentina, Israel, Turkey	Tanzania	Morocco	--
m^3/ha	--	--	--	
age-rotation			--	
spacing			--	
m^3/ha/year			--	--
country			6-7 (difficult sites)	
			--	
	Plantations in Morocco, Spain, Pakistan, Uruguay, Argentina, Kenya, Nigeria, Tanzania, Upper Volta, Senegal.	Cultivated in Portugal, Africa Brazil, India. °Competes well with weeds.	Cultivated in Morocco, Lybia, Tunisia, Ethiopia, Uruguay. Cultivation needed for 1-2 years.	Grown in Sudan, Iran, Iraq, Pakistan, Tanzania Nigeria, Egypt. Weeding needed.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Continued)

NAME	Eucalyptus occidentalis	Eucalyptus aphyllum	Eucalyptus persicum	Eucalyptus aculeata
Common name	Swamp yate, flat-topped yate.	Black saksaul, odzhar	White saksaul, ak-sazak	Jerusalem thorn, palo de rayo, horse bean tree, sessaben, retama
Native area	Australia	Central Asia	Sinai, Arabia, Iran, Afganistan, Central Asia	U.S. to Argentina
Fuelwood use	Good.	Good.	Excellent.	Good.
Heating value	--	--	--	--
Specific gravity	--	1.02	--	0.6
Other uses	Wood.	Charcoal, desert stabilization, forage.	Charcoal, forage, sand fixation.	Charcoal, erosion control, fodder.
Temperature -°C	0-38	-35-50	--	Light frost - 36
Altitude - m	50-300	Low	--	0-1,300
Rainfall-mm	300-760	100 and over	100 and over	200-1,000
Drought (months)	Tolerant.	Tolerant.	Resistant.	9
Soil	Clays, salty soils.	Desert soils.	Sands.	Poor, sandy alluvial, desert grasslands.
Coppice	--	Yes.	--	Yes.
Yield-m^3/ha		--	1-6	Fast growth.
age-rotation		5	--	
spacing	--	--	--	
m^3/ha/year	20-30	1.4	--	
country		Iran	Turkestan	
m^3/ha				
age-rotation				
spacing	--	--	--	--
m^3/ha/year				
country				
	Planted in Iran, Morocco, Algeria Sri Lanka, California, Hawaii, Israel.	Also found in deserts of Middle East, Asia Minor, North Africa. Competes well with weeds.	--	Legume. Cultivated in India, Jamaica, Uganda, South Africa.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Continued)

NAME	Pinus halepensis	Pithecellobium dulce	Prosopis alba	Prosopis chilensis
Common name	Aleppo pine, pino carrasco, sanaoubar halabi	Manila tamarind, quamachil, blackbead, Madras thorn,. . .	Algarrobo blanco, ibope tacu	Algarroba, algarrobo de Chile, mesquite
Native area	Mediterranean	Central America	Argentina, Paraguay, Bolivia	Peru, Chile, Argentina
Fuelwood use	Good.	Medium.	Good.	Good.
Heating value	--	21,740-23,400	--	--
Specific gravity	--	--	--	0.80-0.92
Other uses	Timber, resin, soil conservation.	Wood, food, forage, seed, tanning, honey, gum.	Timber, fodder, food,. . .	Feed, wood.
Temperature -°C	-18 and above.	Subtropical/tropical.	Mild frost and up.	Sensitive to frost - 27.
Altitude - m	0-2,000	0-1,800	0-1,000	0-2,900
Rainfall-mm	250-800	450-600	100-500	200-400
Drought (months)	7-8	Resistant.	Very resistant.	8-11
Soil	Shallow, poor, eroded soils.	Most soils including sands.	Sands even with some salt.	--
Coppice	--	Yes.	--	--
Yield-m^3/ha	--		--	--
age-rotation	--		10	1
spacing	--	--	2x2	1.6x1.6
m^3/ha/year	3-5		7	13.4-15.4
country	Jordan, Israel		Argentina	California (irrigated)
m^3/ha	--			
age-rotation	--			
spacing	8-12	--	--	--
m^3/ha/year	plantations			
country				
	Planted in Argentina, Chile. Uruguay, Mexico, South Africa. Weeding needed for 2 years.	Legume. Planted in Philippines Indonesia, Sudan, Tanzania, Jamaica, Coastal Africa. Competes well with weeds.	Legume. Competes well with weeds.	Legume. Grown in Africa (sub-desert area), India.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Continued)

NAME	Prosopis cineraria	Prosopis juliflora	Prosopis pallida	Prosopis tamarugo
Common name	Jand, khejri, ghaf, jandi	Mesquite, algarroba	Algarrabo, huaraugo, kiawe	Tamarugo
Native area	--	Central and northern South America	Pacific coast of Peru, Colombia and Ecuador	Northern Chile salt desert.
Fuelwood use	Excellent.	Excellent.	Good.	Good.
Heating value	20,900 (charcoal)	--	High.	--
Specific gravity	--	0.7	--	--
Other uses	Fodder, afforestation, timber, fertilizer, charcoal.	Excellent charcoal.	Charcoal, fodder, food, afforestation.	Wood, Forage.
Temperature -°C	-6 - 50	Warm - arid zones.	-2 and over.	-12-36
Altitude - m	Low.	0-1,500	0-300	1,000-1,500
Rainfall-mm	75-850	150-750	250-1,250	10
Drought (months)	Resistant.	Resistant.	--	Long periods.
Soil	Alluvial, coarse sand.	Variety including sandy and rocky.	Many types.	Salty soils.
Coppice	Yes.	Yes.	--	Yes.
Yield-m^3/ha	7-70			
age-rotation	--	15		
spacing	--	--	--	
m^3/ha/year	--	7.1-9.5		Relatively slow.
country	--	--		
m^3/ha	--	--		
age-rotation	--	10		
spacing	--	--	--	--
m^3/ha/year	2.9	7.1-8.6		
country	--			
	Legume. Occurs in India, Pakistan, Afganistan, Iran, Arabia. Some weeding needed the first year.	Legume. Planted in Africa and Asia (particularly India). Competes well with weeds.	Legume. Tolerates salt water. Tree or shrub. Cultivated in India, Australia, Puerto Rico and Hawaii.	Legume. Competes well with weeds.

TABLE 2.19.--DESCRIPTION OF FUELWOOD SPECIES (ARID AND SEMIARID REGIONS) (Concluded)

NAME	Tamarix aphylla	Zizyphus mauritania	Zizyphus spina-christi
Common name	Tamarisk, athel tree, salt cedar, eshel	Indian jujube, Indian plum, Chinese date, ber, beri, etc.	Christ thorn, kurna, nabbag
Native area	Species originate from Sahara, China, Mediterranean.	South Asia	Africa (Sahara, Sahel)
Fuelwood use	Good.	Excellent.	Good.
Heating value	--	20,480	--
Specific gravity	--	0.93	--
Other uses	Charcoal, wood, afforestation, windbreaks.	Good charcoal, wood, fruit, tannin, silk, fodder, shellac.	Wood, fodder, erosion control.
Temperature -°C	-10-50	Tropical, frost resistant.	High.
Altitude - m	--	0-600	0-1,500
Rainfall-mm	100-500	300--500	100
Drought (months)	Tolerant.	Tolerant.	Tolerant
Soil	Many, including sand and salty soils.	Wide variety.	Dry, desert areas; prefers alluvial soils.
Coppice	Yes.	Yes.	Yes.
Yield-m^3/ha age-rotation spacing m^3/ha/year country	--	Fast growth.	--
m^3/ha age-rotation spacing m^3/ha/year country	--	--	--
	Found in Iran, Pakistan, India, Afganistan, Middle East, Somalia, Kenya, Ethiopia, Australia, Mexico, Israel. Competition must be controlled during establishment.	Found in Asia, Australia, West Indies, Tropical America, Africa (Senegal, Gambia, Ghana, Nigeria, Sudan).	--

2.3.2 Firewood Plantations

Firewood plantations are man-made forests established for the purpose of producing wood fuel or feedstock for the manufacture of charcoal. These plantations may range from single rows of trees along roads or field boundaries, to individual or collective woodlots, to large (several thousand hectares) plantations devoted to the production of fuel for industrial applications. Many countries have established firewood plantations as is reported in Volume II: Country Statistical Data. Brazil for instance, has a long history of firewood production in plantations: since 1900, firewood plantations have provided fuel for the railways and charcoal for the pig iron industry. At present, about four million hectares have been reforested as man-made forests generating wood feedstock for a variety of users (Florestal Acesita, 1982). Through appropriate management and selection of species, these plantations are capable of reaching much higher yields per hectare than natural, unmanaged forests. The establishment and management of the plantations, which may include the production of seedlings, weed control and fertilization, however, increases the cost of production of the wood feedstock.

Firewood plantations are generally densely planted forests harvested on short rotation cycles and relying on coppicing for regeneration; two or three harvests at 5-to-10 year intervals can often by obtained from a single planting.

The following sections describe typical features of firewood plantations. The description draws much on the Brazilian experience (Florestal Aciesta, 1982) but many of the aspects discussed will apply in other situations.

Plantation Establishment. The establishment of a plantation includes a series of steps: selection of an area, selection of species, production of seedlings, selection of a planting pattern and of a rotation, site preparation, fertilization if needed, forest protection and management.

The selection of an area for the establishment of plantations will be influenced by factors such as availability and suitability (climate, temperature, soil, precipitation, etc.) of the land, proximity of an end user for the firewood, availability of labor, accessibility and ecological constraints.

Desirable characteristics of candidate species for firewood plantations include rapid juvenile growth, adaptability to various site conditions, easiness to establish and regenerate and resistance to insects and diseases. Another factor influencing the selection of species is the proposed utilization of the biomaterial produced. For charcoal production for instance, the density of the wood is an important characteristic which is influenced by age, growth rate and other factors. Experiments conducted in Brazil with Eucalyptus spp. indicate that climatic factors are most important in selecting species appropriate for a given site. Many species have been tried under plantation conditions (see Tables 2.17 to 2.19 and the data presented in Volume II). Among the species tested, eucalyptus

species are attractive in many areas of the world; country reports gathered by the Food and Agriculture Organization of the United Nations (FAO, 1979) indicate that eucalypts have been tried in ninety-two countries of the world.

It has been recognized that the availability of planting stock of good quality is a prerequisite for the establishment of highly productive plantations (Florestal Acesita, 1982; J.F. Henry, 1979). Nursery management required to produce high quality seedlings may include seed collection, irrigation, control of diseases and weeds, fertilization, and thinning and selection of the best seedlings. Seedlings may also be produced from cuttings rather than from seeds.

Spacing has a direct influence on the rotation age. For a given spacing the optimum rotation age is the age at which, or close to which, the mean annual increment culminates; longer rotations will result in decreasing yields. In denser spacings, competition for light and nutrients will set in sooner than in larger spacings thereby reducing the growth rate. In denser spacings, harvesting should therefore occur before competition sets in, in order to derive the maximum yield per growth cycle from a given area of land. The selection of spacing and rotation will depend also on the ultimate projected use of the biomaterial generated. For instance, younger, smaller trees appear to produce charcoal of better quality than older, larger trees. The interrelation between spacing and rotation age is illustrated in Table 2.20, which presents results recorded in E. Grandis experimental plantations in Brazil. The data show that for the densest

TABLE 2.20.--RELATIONSHIP BETWEEN PRODUCTIVITY AND SPACING IN EUCALYPTUS PLANTATIONS

Spacing (m)	Trees Per Hectare	Age Months 9 Productivity[1]	9 Mean Increment[2]	12 Productivity[1]	12 Mean Increment[2]	15 Productivity[1]	15 Mean Increment[2]	18 Productivity[1]	18 Mean Increment[2]
0.5x0.5	23,800[a]	20.06	2.23	33.89	2.82	65.21	4.35	71.53	3.97
1.0x1.0	10,000	6.22	0.69	14.67	1.22	37.08	2.47	52.90	2.94
1.0x1.0	6,800[a]	4.22	0.47	10.08	0.84	26.44	1.76	38.82	2.16
1.5x1.0	6,667	2.25	0.25	8.35	0.70	24.15	1.61	41.14	2.29
1.5x1.5	8,888[b]	3.39	0.38	11.07	0.92	26.65	1.78	46.32	2.57
3.0x1.5	4,444[b]	0.99	0.11	4.46	0.37	15.92	1.06	28.02	1.56

1. Productivity: cubic meter per hectare

2. Mean Increment: cubic meter per hectare per month

a. Bands of 3m wide provided every 2 rows to manage the plantation

b. Two seedlings per planted site.

Source: adapted from Florestal Acesita, 1982.

plantings (0.5 x 0.5 m) the mean monthly increment peaks sometimes between the fifteenth and eighteenth month. This suggests that very short rotations of the order of 18 months might be appropriate in this case. At the 1.0 x 1.0 m spacings, the mean increment still increases at age 18 months although the rate of increase is slower than it was in the previous periods (up to 15 months). This suggests that longer rotations may be appropriate in this case. It must be stressed that achieving yields of the order quoted in the table will often require fertilization; i.e., the management cost of the plantation will be increased. To select the most attractive combination of spacing and rotation, data such as those shown in Table 2.20 will have to be generated through experimental plantings. Such experimental plantings are being conducted in many countries (see Volume II). When production data in plantations is not available or not well documented, sample data will have to be collected to derive yield curves (cubic meter/hectare versus age) for sites of various productivity potential. A relative measure of the productivity potential is given by site index curves (plots of height of a sample of trees versus age). Using experimentally recorded height versus diameter relationship one can then build yield curves (cubic meter/hectare versus age) for sites of various indexes or various productivity potential. An example of this procedure is given in E. L. Medema et al, 1981, for Sri Lanka. Currently spacings of 2.0 x 2.0 m, 3.0 x 2.0 m and 3.0 x 1.5 m are used in Brazil; the latter two spacings rely on fertilizers to achieve the yields desired.

These spacings are generally combined with three cuttings at 7-year intervals for a total plantation cycle duration of 20 years. Tests similar

to those described in Table 2.20 have shown that shorter rotations of 3 to 4 years correspond to an optimum area per plant of about 2 square meters, or the equivalent of about 5,000 trees per hectare. Such dense plantings make the mechanical upkeeping of the plantations more difficult and spacing alternatives including wider (3 m) strips interspaced between two rows of trees 1 meter apart have been tested (see Table 2.20). This arrangement also facilitates the removal of the crop at harvest time.

Soil preparation before planting is an important component in insuring the success of plantations. The preparation process may include (as needed) land clearing by mechanical means and plowing and disking. Many experiments have shown that a positive interaction exists between tree growth and the extent of soil preparation (Florestal Acesita, 1982; J.F. Henry, 1979).

Fertilization has been shown to be beneficial in many cases. Nitrogen-Phosphorus-Potassium (NPK) fertilizers are generally used in plantations. For each individual situation experiments will have to be conducted to determine the optimum economic level of fertilizer required, the relative proportions of the N, P, and K components of the fertilizer applied and the schedule of application. Experiments in Brazil have shown that fertilized areas were 50 to 70 percent more productive than unfertilized areas.

Forest protection includes a variety of activities ranging from control of diseases and insects, control of competing vegetation to fire protection. Chemicals are often used to protect against diseases and insects, and control of parasitic vegetation is often achieved through mechanical cultivation between the rows of trees. Cultivation may have to be performed several times per year in the first and second year of growth until the seedlings are well established and have developed enough of a canopy to shade out most of the competing vegetation.

Management of the plantations may also include improvement of the plantations during the regrowth period after a cutting. Activities may include the replacement of poor quality stock, replacement of dead trees, and pruning of the sprouts growing from the roots after cutting.

The productivity of plantations will depend on a number of factors such as climate, soil, management, etc. Typical values recorded in Brazil range from 25 to 35 steres per hectare per year for traditional plantations to 40 to 60 steres per hectare per year for plantations including improved seedlings, fertilization, and denser spacings in various combinations.

Plantation Economics. The costs of establishing and managing a plantation vary significantly from case to case because of site-specific or country-specific conditions (type of land, cost of land, labor cost, subsidies, etc.). The following discusses costs associated with the establishment of a plantation in Brazil. Although the actual costs quoted

may vary widely from country to country, the man-hour and machine-hour requirements will probably be similar in other comparable situations.

Table 2.21 summarizes the features of the plantation used for the cost analysis. The plantation includes seven 1,000 hectares sections planted and cut at one year interval to provide a yearly supply of about 200,000 steres or about 100,000 metric tons of wood at about 25 percent moisture.

Table 2.22 summarizes the stand establishment costs by categories: planting, seedling production (nursery), and site clearing are by far the most expensive components of the cost. Irrigation refers to additional water applied to seedlings when natural rainfall is not sufficient; the water is brought by truck and applied from tractor-drawn carts. Planting is performed by hand in furrows opened during site preparation. Fertilizer is applied manually during planting. Replanting to replace dead or damaged seedlings is performed within 2 months after planting. Seedlings are produced in nurseries including irrigation sprinklers and fertilization. The period between seeds to plantable seedlings is about 100 days.

Table 2.23 shows the direct cost of maintenance of a plantation during the first year in flat areas. Maintenance includes mechanized harrowing of weeds between rows of trees, manual weeding between trees along rows and application of chemicals for pest control (referred to as "others" in the table).

TABLE 2.21.--FEATURES OF A TYPICAL PLANTATION

Items:

Topography: flat

Vegetation cover: brushwood

Species: Eucalyptus spp.

Spacing: 3 m x 1.5 m; 2,223 trees/hectares

Rotations: 3; first rotation: 7 years
second rotation: 6 years
third rotation: 6 years

Yields: First cutting: 34 steres/hectare/year = 17 metric tons/hectare/year[1]

second cutting: 30 steres/hectare/year = 15 metric tons/hectare/year

third cutting: 30 steres/hectare/year = 15 metric tons/hectare/year

Area: seven 1,000 hectare units planted and harvested at 1-year interval

Cuttings: 1,000 hectares/year or 238,000 or 180,000 steres per 1,000 hectare for first and second and third cuttings respectively.

Source: Adapted from Florestal Acesita, 1982.

[1] Assumes 500 kg at 25% moisture per stere.

TABLE 2.22.--DIRECT COSTS FOR A STAND ESTABLISHMENT

Operations	Items	Units	Quantity Of Unit Per Ha	Cost per HA US$/HA[1]
Building of roads and tracks	Bulldozer	hour	0.52	8.62
	Moto-scraper	hour	0.31	6.33
	Loader	hour	0.36	3.12
	Dump Truck	hour	0.36	2.00
	Subtotal	--	--	20.07
Site clearing	Bulldozer	hour	3.00	49.74
	Chain-saw	hour	4.00	12.08
	Truck	hour	4.70	26.23
	Labor	man-hour	38.00	36.10
	Subtotal	--	--	125.15
Termite control	Spray Equipment	hour	2.00	4.08
	Chemicals	--	--	2.69
	Labor	man-hour	6.00	5.70
	Subtotal	--	--	12.47
Site preparation:				
plowing	Tractor/Plow	hour	2.50	24.75
harrowing	Tractor/Plow	hour	1.50	14.52
furrow	Tractor/Plow	hour	1.80	16.63
	Subtotal	--	--	55.90
Nursery	Seeds	kg	0.67	73.63
	Labor	man-hour	39.98	37.98
	Others	--	--	19.39
	Subtotal	--	--	131.00
Planting	Truck	hour	1.50	8.37
	Tractor/Cart	hour	4.50	43.52
	Fertilizer	metric/ton	0.23	101.09
	Labor	man-hour	30.00	28.50
	Subtotal	--	--	181.48
Irrigation	Water truck	hour	0.50	2.79
	Tractor/cart	hour	1.50	14.67
	Labor	man-hour	8.00	7.60
	Subtotal	--	--	25.06
Replanting	Truck	hour	0.70	3.91
	Tractor/Cart	hour	0.70	6.85
	Labor	man-hour	4.00	3.80
	Subtotal	--	--	14.56
Total				565.69

Source: Adapted from Florestal Acesita, 1982.

[1] Cost per effective hectare planted.

TABLE 2.23.--DIRECT COST FOR FIRST-YEAR MAINTENANCE OF PLANTATIONS

Operations	Items	Units	Quantity Of Unit Per Ha	Cost per HA US$/HA
Weed control:				
mechanical	Tractor/harrow	hours	1.80	13.39
manual	Labor	man/hours	15.20	14.44
Others	Spraying, etc	--	--	2.34
Total	--	--	--	30.17

Source: Adapted from Florestal Acesita, 1982.

TABLE 2.24.--COMPOSITION OF TOTAL COSTS OF ESTABLISHMENT AND MAINTENANCE OF 1,000 HECTARES OF EFFECTIVE PLANTATION

	Cost per Hectare			
Item	Establishment	Maintenance First Year	Maintenance Following Year	Regeneration
Direct costs	565.69	30.17	13.49	34.54
Indirect costs	85.82	4.92	2.39	5.15
Overhead	39.07	2.11	9.53	2.38
Total	690.28	37.20	25.41	42.07

Source: Adapted from Florestal Acesita, 1982.

Table 2.24 summarizes the total costs associated with the establishment, maintenance and regeneration of a plantation. Indirect costs include such items as depreciation, rent, taxes, etc., while overhead costs include office expenses, technical services, etc. The composition and relative value of these compoents of total costs will vary from situation to situation and are given here as an illustration of a real life case. On steep sites, the establishment costs may be double those quoted in Tables 2.22 and 2.24.

Table 2.25 reports establishment costs of plantations (mostly Eucalyptus spp.) for various countries in the world. The data show the wide range of costs recorded. These variations are related to the type of site on which the plantation is established, the level of usage and cost of labor, the use of fertilizers, the quality of seedlings, etc.

2.3.3 Wood Residues

Wood residues include logging residues, i.e., the material abandoned on the forest floor when trees are felled, tops, branches, dead trees, etc., and mill residues, i.e., residues generated during the processing of rough wood into finished or semifinished products, slabs, bark, sawdust, etc..

Depending on the logging practices used, as much as 80 percent of the original biomass may be left on the forest floor. In Volume II: Country Statistical Data, the noncommercial portion of a whole tree (tops, branches, . . .) is

TABLE 2.25.--COMPARISON OF ESTABLISHMENT COSTS OF PLANTATIONS
(In Dollars per Hectare)

Country	Trees Per Hectare	Site Preparation	Nursery	Planting	Maintenance	Total
Argentina	1100-2500	--	--	--	--	500-600
Bolivia	625	--	--	--	--	250
Brazil	1400-2600	--	--	--	--	300-600
Chad	1,100	--	--	--	--	540
Colombia-warm	1,700	33	30	19	178	260
cool	2,500	--	61	48	224	333
Ethiopia	2,500	14-41	40	27-36	14-39	95-156
Guyana	2,200	200	119	30	133	482
Lesotho	2,200	12	47	58	39-73	156-190
Madagascar	1700-2500	34	43	102	49	254
Malawi-manual	1300-2200	17-32	7	49-95	18	91-152
-mechanical	1300-2200	26-86	7	56-125	18	107-235
Mozambique	1,600	103	21	63	51	238
Nepal	1,700	106	25	39	98	268
Nigeria	1,100	61	15	43	33	152
Peru	2,500	--	107-142	--	--	365-107
Sri Lanka	1,100	13	22	22	80	137
Tanzania	1,700	28-56	8	17	42-84	95-165
Uganda	1,700	7	22	6	148	183
Upper Volta	625	112	71	169	42	407
Zambia	750	277	21	58	52	408
Quebec-Canada	1100-2000	--	--	--	--	920-1170
USA	2200-4000	1300-2100	--	130-280	--	

Source: Adapted from: J.F. Henry, 1981, (USA-hardwoods); A. Musnier, 1976 (Canada-poplars); FAO, 1979 (Other Countries, Eucalytus spp).

assumed to be 40 percent (by volume) of the commercial volume of wood. For consistency, the same volume fraction is used here.

The amounts of residues generated at the mills vary considerably because of differences in mill equipment, size and species of roundwood logs, extent defects in logs and specifications for the finshed products. Table 2.26 show typical recovery factors for lumber, plywood, and veneer manufacture in the United States. The by-products may or may not be recovered for use as raw materal in the manufacture of other wood products (particle boards, for example).

Table 2.27 show ranges of values of residues generated in the manufacture of plywood, lumber, and miscellaneous products in the United States. The conversion of quantities of products from English units (board feet, square feet, 3/8th inch basis) to metric units may be difficult because of the different standards used in characterizing the finished products. The most accurate method of comparison may be in terms of volume of finished products as suggested in Table 2.26

An example of the use of the above residue tables and of other tables included in the volume is given below.

Example. What is the heating value of the sawdust generated annually by a sawmill producing 5 cubic meter of lumber per day, 200 days per year.

Annual production of lumber: 200 x 5 = 1,000 cubic meters

assumed to be 40 percent (by volume) of the commercial volume of wood. For consistency, the same volume fraction is used here.

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Table 2.27 show ranges of values of residues generated in the manufacture of plywood, lumber, and miscellaneous products in the United States. The conversion of quantities of products from English units (board feet, square feet, 3/8th inch basis) to metric units may be difficult because of the different standards used in characterizing the finished products. The most accurate method of comparison may be in terms of volume of finished products as suggested in Table 2.26

An example of the use of the above residue tables and of other tables included in the volume is given below.

Example. What is the heating value of the sawdust generated annually by a sawmill producing 5 cubic meter of lumber per day, 200 days per year.

Annual production of lumber: 200 x 5 = 1,000 cubic meters

TABLE 2.26.--TYPICAL RECOVERY FACTORS FOR SAWMILLS AND VENEER MILLS IN THE UNITED STATES

Product	Units	Volume Required (ft^3)	Products Recovered (%)	By-Products (%)	Shavings, Sawdust, etc. (%)
Lumber:					
-softwood	1,000 board feet	158	45	28	28
-hardwood	1,000 board feet	161	47	23	30
Plywood:					
-softwood	1,000 feet square 3/8 inches	73	50	48	2
Veneer:					
-hardwood	1,000 feet square, 3/8 inches	71	50	48	2

Source: Adapted from Risbrudt and Ellis, 1981.

1,000 board feet = 304.8 m x 25.4 mm x 304.8 mm
= 83.33 cubic feet = 2.36 cubic meter of finished product.

1,000 feet square, 3/8 inch = 92.9 meter square x 9.53 mm
= 31.25 cubic feet = 0.885 cubic meter

TABLE 2.27.--RESIDUES PRODUCED IN VARIOUS WOOD MANUFACTURING OPERATIONS

Items	Residues (metric tons dry)
Plywood manufacture (softwood)[1]	
Log trim	0.042 - 0.044
Cores	0.045 - 0.080
Veneer clippings and trims	0.227 - 0.245
Dry trim and layup loss	0.088
Sander dust	0.019 - 0.020
Total residue	0.413 - 0.469
Bark	0.120
All residues	0.533 - 0.589
Plywood produced	0.420 - 0.444
Original log	0.953 - 1.033
Lumber production (softwood)[2]	
Slabs, edgings, sawmill trims	0.409 - 0.590
Planer trim	0.032 - 0.045
Sawdust	0.173 - 0.269
Planer shavings	0.140 - 0.204
Total residues	0.863 - 0.991
Bark	0.204 - 0.392
Lumber produced	0.707 - 0.793
Original log	1.796 - 1.881
Miscellaneous (pilings, shingles, posts, etc)[3]	
Coarse residues	7,075
Fine residues	2,594
Bark	3,774
Orchard prunings[4]	2.18

Sources: Adapted from Risbrudt and Ellis, 1981 and from R. K. Ernest et al. (1979).

1 Per 1,000 square feet, 3/8 in., see Table 2.26 for conversion.
2 Per 1,000 board feet, see Table 2.26 for conversion.
3 Per 1,000 cubic feet = 28.3 cubic meters.
4 Per hectare.

Equivalent in board feet: 1,000/2.36 = 423.7 thousand board feet (from conversion values at bottom of Table 2.26)

Amount of sawdust: 423.7 x 0.221 = 93.64 dry metric tons (mid-range value of residues produced from Table 2.27)

The procedure for calculating the heating value is the same as is described in Section 2.2.3 for crop residues using moisture content and higher heating values provided in Table 2.7.

2.3.4 Environmental Considerations

The removal of residues from the forest floor can lead to the same environmental problems as those discussed in conjunction with the removal of crop residues (see Section 2.2.4).

Using the equations discussed in Section 2.2.4, C. W. Vail and J. F. Henry (1975) compared erosion and wind losses associated with the production of agricultural crop and with the production of wood fuel from short rotation forests; for comparable soil and relief conditions, the management of short rotation forests results in much smaller soil losses than that of agricultural crops. Similar conclusions based on measurements made in Cameroon are quoted by Perera (1979).

2.4 Livestock Resources

Animal wastes are an important bioresource, which can be converted to solid or gaseous fuels.

The amount of manure recoverable from animals depends on the size of trhe animals, their feeding regime, their degree of confinement and the method of collection of the wastes.

Table 2.28 shows estimates of daily production (wet basis) for normalized animal weights of 500 kg. The table also shows the approximate compositions of the manures on a wet basis. The data in the table are estimates that can vary significantly because of some of the factors mentioned above. Table 2.29 shows annual estimates of manure production on a dry basis for some animals not mentioned in Table 2.28. Table 2.29 does not give animal sizes and therefore even more significant variations could be observed when comparing the data in the table with real situations.

2.5 Aquatic Resources

Although aquatic biomass is not included as a main topic in the series of volumes, a summary description of some characteristics of this resource is given below in view of its potential as a biofuel feedstock in the future.

Freshwater aquatic resources include microalgae, submerged plants, floating plants, and emergent plants. These resources have been and still are used as food, fiber, fertilizer and feed (National Academy of Sciences, 1976). Of these categories of aquatic resources, floating and emergent plants are probably the most extensively used because they are easier to collect than the other classes of resources. Although still used for various useful purposes, in many countries aquatic plants are mostly considered as

TABLE 2.28.--MANURE PRODUCTION AND COMPOSITION

Animal	Daily Production[1]		Composition (Percent Wet Weight)			
	Wet Weight (kg)	Volume (m^3)	Volatile Solids	Moisture and Others[2]	Nitrogen	Phosphorus
Dairy cattle	38.5	0.038	7.98	91.54	C.38	0.10
Beef cattle	41.7	0.038	9.33	89.77	0.70	0.20
Horses	28.0	0.025	14.30	84.71	0.86	0.13
Swine	28.4	0.028	7.02	91.68	0.83	0.47
Sheep	20.0	0.020	21.50	77.20	1.00	0.30
Poultry	31.3	0.028	16.80	80.80	1.20	1.20

Source: National Academy of Sciences, 1977.

1 Daily production per 500 kg live animal

2 Mostly moisture and ash.

TABLE 2.29.--ESTIMATED ANNUAL MANURE PRODUCTION (DRY MATTER)

Livestock	Annual Production Kg/Year
Horses	1,800
Cattle	1,700
Camels	600
Pigs	200
Buffalo	1,800
Sheep	200
Goats	200
Asses/Mules	1,100
Chickens	10
Turkeys	25
Ducks	15

Source:

damaging weeds blocking navigation channels, interfering with hydroelectric projects or interfering with irrigation projects or fishing activities. The eradication or control of these weeds and their subsequent use as feedstock for energy conversion could therefore result in a double benefit.

Table 2.30 lists some of the aquatic plants which have received considerable attention as potential feedstocks for biofuel production or other applications such as fertilizer (Azolla).

Azolla is widely distributed in temperate and tropical freshwaters. It can fix atomospheric nitrogen and has been used for green compost in rice production in areas of Southeast Asia.

Water hyacinth (Eichornia crassipes) is a perennial herbaceous plant widespread in tropical warm regions. It is believed to be one of the most productive plants on earth. It has been grown on sewage ponds and lagoons. Water hyacinth is used for animal feed.

Duckweeds (Lemnaceae) is fairly tolerant of cool climates and as a result distributed around the world. In cool temperate climates, the productivity is restricted to the summer months. Species have been cultivated in ponds; fertilizers may be required to acheive maximum productivity.

Salt marsh plants (Spartina) are usually found in maritime marshes in temperate regions. Two of the most common plants, Spartina and Distichlis,

TABLE 2.30.--AQUATIC PLANTS OF INTEREST IN BIOMASS PRODUCTION AND CONVERSION

Plants	Genes	Examples of Habitats
Floating Plants		
Azolla	Azolla	Rice paddies
Duck weeds	Lemna	Ponds
Water Hyacinths	Eichornia	Warm Climates
Emergent Plants		
Salt marsh plants	Spartina	Brackish or maritime marsh
Reeds	Phragmites	Freshwater marshes
Rushes	Typha	Freshwater marshes

belong to the grass family (Graminaceae). Spartina has been used for grazing sheep, cattle, pigs and horses or has been cut for hay.

Reeds (Phragmites) are members of the grass family and are found in temperate regions. They are perennial grasses found mostly in freshwater marshes and along river and lakes.

Cattails (Typha) are found in a variety of climates and can grow to heights of about 3 meters. Productivity appears to be closely related to nutrient levels in the environment.

Table 2.31 shows ranges and mean proximate analyses for floating and emergent plants. A large amount of variability exists; variability results probably more from growth conditions than plant species in each class. Emergent plants often have a high content of lignocellulose, making them suitable for fiber but reducing their biodegradability.

Aquatic plants are characterized by high productivities, as is shown in Table 2.32. Their high water content make harvesting, handling and utilization difficult. The resource, however, deserves further investigation.

2.6 Biomass Collection and Handling

Biomass collection and handling includes all operations needed to bring the biomass feedstock from its point of production--field, forest--to its point

TABLE 2.31.--RANGE AND MEAN PROXIMATE ANALYSES OF FLOATING AND EMERGENT AQUATIC PLANTS

Constituant	Floating Plants Mean	Floating Plants Range	Emergent Plants[1] Mean	Emergent Plants[1] Range
Crude Fiber	10.5[a] 21.2[b]	7.3-13.5	23.5	9.2-41
Fat	4.8	1.1-6.7	2.6	1.0-4.1
N	4.0	1.5-7.04	1.7	0.9-2.3
P	0.63	0.1-1.8	0.18	0.09-0.32
K	2.5	0.2-6.2	2.1	0.5-5.0
Ash	14.1	1.6-22.0	8.56	0.9-20.6
Water	94.2	92.2-96	79.6	69.2-89.0

Source: Adapted from Office of Technology Assessment, 1980.

a All except water hyacinths.

b Water hyacinths.

c Shoots only.

TABLE 2.32.--PRODUCTIVITIES OF AQUATIC PLANTS

Plant	Country	Productivity kg/HA/day	Comments
Azolla	India	34	Natural Habitat
		120-200	Fertilized
	China	69	In rice fields
	Philippines	16-31	
Water Hyacinth	Florida	210	Average
		50-240	Fertilized
Duck Weeds	Thailand	39	Unfertilized
	Burma, Laos	38	Unfertilized
Salt Marsh Plants	Georgia	12-25	
Reeds	England	42	Average seasonal
	Czechoslovakia	120-174	Average seasonal
	Poland	151	Average seasonal
Rushes	Southern U.S.	58-126	Average seasonal
	Czechoslovakia	154-300	Average seasonal

Source: Adapted from M. A. Murry and J. R. Benemann, 1981.

of utilization. The operations--harvesting, loading, transport, etc., may be performed manually, semimechanically or mechanically. The choice of the operations procedure will depend on many factors such as terrain, availability of equipment, availability of labor, size, and seasonality of the operation, tradition, and others. Significant variations in the rates at which the various biomass collection and handling operations are performed can be expected from country to country. Table 2.33 reports data recorded in Brazil in charcoal production operations. Despite the expected fluctuations in productivities, these data can probably be used as an approximation of productivities when no other data are available.

Small trees can be felled and cut to logs, using axes or chainsaws as indicated in the table. Depending on the distances involved and terrain, the transportation of the logs can be accomplished by mules or oxen over short distances on flat or steep terrain, trucks or tractors with carts on flat terrain or roads, loaders mostly on flat terrain, or by winches (diesel powered or fitted to a wheeled tractor) on steep terrains.

A. Musnier (1976) quotes productivities for felling and delimbing by chainsaw ranging from about 4 m^3 per hour for 12-year-old stands (about 1,000 trees per hectare) to 12 to 16 m^3/hour for 25-year-old stands (about 200 trees per hectare); the trees in the 12-year-old stands have volumes of 0.17 to 0.22 m^3 and the trees in the 25-year-old stands have volumes of 1.6 to 2.1 m^3 per tree. A tractor operated winch is reported to move from 5.6 to 15.4 m^3 per hour depending on the size of the trees.

TABLE 2.33.--TYPICAL WOOD COLLECTION AND HANDLING PRODUCTIVITIES

Operation	Item	Daily Productivity (steres)
Felling, delimbing, cutting in logs	Labor - ax	7 (average)
	Labor-chain saw	25
Transport	Mules/ox-cart	7-20
	Trucks, tractor/cart	50-80
	Loaders	230
	Winch	35-60

Source: Adapted from Florestal Acesita, 1982.

TABLE 2.34.--TYPICAL BIOMASS TRANSPORTATION COSTS

Distance (km)	Cost (US $/Metric Ton) U.S.	Brazil
16	0.075	
40	0.069	
80	0.069	
200	--	0.06
400	--	0.05
600	--	0.046
800	--	0.045

Sources: Adapted from Florestal Acesita, 1982 and K. Howlett and A. Gamache (1977).

Long-distance transportation of biomass feedstocks or biomass-derived fuels can be done by road, rail or waterways. Transport by rail over long distances is cheaper than transport by truck but is limited to areas accessible through the railroad network. Most biomass feedstocks moved from collection areas to conversion plants have moisture contents ranging from 15 to 50 percent and have lower bulk densities (see section 2.1.2 g) than fossil fuels. Many biomass feedstocks such as grains, wood chips, crop residues will fill a conventional tractor trailer truck without reaching highway weight limits. Transportation costs will thus generally be higher for biomass feedstocks than for fossil fuels thereby putting biomass at a disadvantage in terms of transportation costs. Table 2.34 shows typical biomass transportation costs reported for the United States and Brazil.

The transportation costs of biomass may impose limitations on the size of a biomass-fired conversion plant: as the size of the plant and thus the amount of fuel used yearly increases the area over which biomass is collected and the collection cost increase. The area needed to provide the biomass fuel also increases as the availability of biomass per unit area of land decreases. If Q (tons) is the quantity of biofuel needed yearly to fire a boiler,

$$Q = \pi \quad pr^2$$

where p is the average availability of biofuel collectible per square kilometer (metric tons per square kilometer per year) and r is the radius of the circle drawn around the power plant from which the fuel is collected. Table 2.35 illustrates the impact of biomass availability on

the radius of collection required to supply a power plant with 1,000 metric tons per day of green wood, i.e., 365,000 tons of wood per year (this would be enough to support a 50 to 60 megawatt electric power plant). The table shows that transportation costs can be a major factor when the availability of biomaterial is low. The table points to a few facts:

-Large biomass users may drain the biomass resources of a large area when biomass is only available at a low level on a sustained basis.

-The data in the table supposes that all the resource is available to the large user; other users would therefore be penalized, or the collection area should be expanded to make up for the biomass needed by competing users.

-Even if the biomass collection costs are small or nil, when collection areas become large, transportation costs should be carefully compared to the corresponding costs of fossil fuels before deciding on the use of biomass fuel.

TABLE 2.35.--AREA OF COLLECTION AND TRANSPORTATION OF BIOMASS

Availability (ton/hectare/year)	0.01	0.05	0.1	1.0	10
(ton/square km/year)	1	5	10	100	1000
Average travel distance =0.94 r(km*)	320	143	102	32	10
Cost (million dollars/year)	5.85	3.13	2.59	0.82	0.30

Basis: 1,000 metric tons/day, 50% moisture
365,000 metric tons/year

*Assumes real travel distance is $\sqrt{2}$ times linear distance (OTA, 1980).

2.7 Biomass Processing

Fuels with high mass energy density (energy content per unit mass) and high volume energy density (energy content per unit volume) are preferable to fuels with low values because they are easier to store, ship and burn. Biomass feedstocks are generally materials with high moisture content, low specific gravity, low bulk density, and variable particle sizes. They are thus generally less attractive than fossil fuels. Table 2.36 compares energy densities of various fuels and it is clearly apparent that raw biomass fuels are less favorable than fossil fuels on a mass and volume energy density basis.

Densification processes were developed to upgrade raw biomass fuels into efficient fuels having uniform physical and thermal characteristics and high bulk density.

Simple densification processes are used in rural areas of developing countries: one approach consists of tying dispersed materials such as twigs, straw, hay, and dry leaves into bundles. This reduces the admittance of air to the fuel particles, slows down combustion, and improves fuel utilization. Hand presses built locally can be used to facilitate bundling. Dispersed materials such as sawdust, coffee bean husks, or charcoal dust are difficult to burn directly in domestic stoves or small commercial stoves. One of the methods of processing these fuels is to compress them into briquettes. Briquetting can be formed with or without a binder. The latter is more convenient but requires fairly

TABLE 2.36.--ENERGY DENSITIES OF VARIOUS FUELS BY MASS AND VOLUME*

Fuel	Water Content (%)	Density g/cm^3 (lb/ft^3)**	Heat of Combustion (low) by Mass kJ/g (MBtu/ton)**	Heat of Combustion (low) by Volume kJ/cm^3 (Btu/ft^3)**
Biomass	50	1.0 (62.4)	9.2 (8.0)	9.2 (250.0)
	10	0.6 (37.5)	18.6 (16.0)	11.2 (300.0)
Densified Biomass	10	1.0 (62.4)	18.6 (16.0)	20.9 (499.0)
	10	1.25 (78.1)	18.6 (16.0)	26.1 (625.0)
Charcoal	-0-	0.25 (15.6)	31.8 (24.0)	8.0 (374.0)
Coal-Bituminous	-	1.3 (81.1)	28.0 (24.1)	36.4 (977.0)
Methanol	-0-	0.79 (49.3)	20.1 (17.3)	15.9 (426.0)
Gasoline	-0-	0.70 (43.7)	44.3 (38.1)	30.9 (832.0)

*Values shown are representative of a range for each fuel.

**"Density" as used in this column, refers to the compactness of individual pieces of biomass. Bulk density is less than the density of individual biomass pieces. (See Section 2.1.2.g).

Source: Adapted from T. Reed and B. Bryant, 1978.

sophisticated and costly equipment, which does not lend itself to practical usage at a small scale in rural areas.

In rural areas, briquetting will tend to use waste materials. Briquettes made with hand-operated presses are held together by a binder, such as waste oil, resins, manures, sludge, etc. When organic binders are not available, noncombustible binders such as clay or mud may be used. The heating value of the briquettes will be reduced but materials that otherwise would not be usable became valuable fuels.

Presses for rural use range from hand-operated presses to fairly automated units. Simple hand presses used to produce spherical briquettes made of soaked paper develop pressures of 5 to 15 kilos per square centimeter and can be built by local metal shops. It has been estimated that the manufacture of such presses requires from 3 to 4 man hours and from 1 to 2 kilos of iron. More sophisticated lever presses may develop from 3 to 40 kilos per square centimeter and produce square or cylindrical briquettes (J. Janczak, 1981).

Commercial presses for wood and agricultural residues develop much higher pressures, ranging from 1,000 to 1,200 kilos per square centimeter. At these pressures, the temperature of the material being compressed is very high and the combination of high pressure and temperature destroys the elasticity of the biomaterial. Under these conditions, it is possible to form briquettes without binder. These commercial presses are further discussed below.

2.7.1 Biomass Densification Processes

Five forms of biomass densification are now practiced commercially; other processes are well on the way to commercialization. Pelleting (used, for example, in feed manufacture) employs a hard steel die which is perforated with a dense array of holes 0.3 to 1.3 centimeters (1/8 to 1/2 inches) in diameter. The die rotates against inner pressure rollers, forcing a biomass feedstock into dies with pressures of 7.0 kilograms per square millimeter (10,000 psi). As a pellet is extruded through the die, it is broken off at a specified length. Cubing is a modification of pelleting which produces larger cylinders or cubes, 2.5 to 5.0 centimeters (1-2 inches) across. Straw and paper feedstocks are generally used. Briquetting compacts a feedstock between rollers with cavities, producing forms like charcoal briquettes. Extrusion uses a screw to force a feedstock under high pressure into a die thereby forming large cylinders 2.5 to 10 centimeters (1-4) inches) in diameter. Binding agents such as pitch or paraffin are often added to increase structural strength and heat content. Extruded logs are widely available in U.S. supermarkets; they have a specific gravity of 1.0. Another process, rolling-compressing, is based on the natural tendency of forage crops to wrap tight around rotating shafts. Finished rolls are cylindrical with diameters ranging from 5 to 7 inches, lengths between 3 and 8 inches, and densities from 20 to 50 pounds per cubic foot. Presently commercial, this process has been employed to increase the efficiency of haying operations and to produce high-quality cattle feed.

Although these densification techniques are widely practiced, little explanation of the mechanism by which biomass attains high density or

"selfbonding" is available. The following explanation is based on observation of processes and on densification patents and literature. Cellulose is stable at temperatures up to 250°C, but the lignin, a "waterproof glue" holding the cellulose together, begins to soften at 100°C, permitting the molding of wood shapes in steam boxes. Water plays an important role in densification; if the feedstock is either too dry or too wet, the pressures required for densification increase dramatically. For that reason, a moisture content of 10 percent to 25 percent is optimal. The feedstock is heated to 50°C to 100°C, both to soften the lignin and to obtain the desired moisture content. Mechanical densification follows with the product fuel emerging at 150°C. The dies also reach this temperature at steady-state, but temperature can be controlled by water cooling. The mechanical work of densification requires 32 to 80 joules per gram. With a heat capacity of about 1.7 joules per gram per degree celsius, this would raise the temperature of the pellet by 20°C to 50°C, which is enough to cause both local boiling areas that are not fully compacted and the excretion of waxes and volatiles. The resulting fluids act as a glue to hold the pellets together after cooling. The hot pellets are fragile and must be carefully handled until cooled (T. Reed and B. Bryant, 1978).

A typical biomass compacting plant involves four or five steps. The first step is separation--stones and sand must be removed from forest or agricultural wastes. The remaining biomass portion is then pulverized with hammer mills or ball mills to a size that is somewhat smaller than the minimum dimension of the pellets to be formed. This fraction is then dried in a rotary kiln or convection dryer. Finally, dried biomass is fed into the

compactor, which then delivers pellets for storage or use. In some cases, binders may be added to the dried biomass prior to compacting.

The energy required for densification depends on the moisture content of the feedstock, the size and type of material used, the size of the final product, the equipment used, etc. Table 2.37 show the approximate production rate and energy requirements for various feedstocks treated in a typical densification system. The energy required by the densification process is small, 1 to 3 percent of the energy contained in the feedstock. Raw biomass, however, is often too wet and too large for densification, and more energy must be expanded for drying and reducing the size of the raw material. The energy thecretically required to remove the moisture from raw biomass could amount to 16 percent of the energy content of the feedstock. However, energy balances of various commercial systems (T. Reed and B. Bryant, 1978, and J. J. Fritz et al., 1979) indicate that only 7 percent of the energy required in the original feedstock are required. This apparent discrepancy in the energy balance is resolved when it is kept in mind that the fuel used in the process, about two-thirds of the energy used for drying, is recovered in the densified product's increased heat of combustion and that other sources of heat for drying such as waste heat of combustion are recycled for use in the process.

2.7.2 Properties of Densified Biomass Fuels

Densified biomass fuels generally have a moisture content of 5 to 10 percent and a bulk density of 0.5 to 0.8 grams per cubic centimeter. Densified fuels are available in two basic forms: fuel logs and stoker fuel.

TABLE 2.37.--ENERGY REQUIRED FOR PELLETING (300 HORSEPOWER PELLET MILL)

Feedstock	Production Rate metric tons/hr (tons/hr)	Electrical Energy Used kWh/metric ton (kWh/ton)	Fraction of Product Energy Consumed (%)
Sawdust	6.1 (6.7)	36.8 (33.5)	2.3
Aspen wood	8.2 (9.0)	27.2 (24.8)	1.7
Douglas Fir bark	4.5 (5.0)	49.2 (44.7)	3.1

Notes:

(1) 11.6 KJ (11,000 Btu) Thermal/kWh

(2) The figures in this table are only representative; values are highly dependent on feed size, moisture content, etc.

Source: Adapted from Reed and Bryant, 1978.

Fuel logs are usually extruded in the form of a cylinder 6 to 10 centimeters in diameter and 30 to 60 centimeters in length. The logs have densities of the order of 0.83 to 1.28 gram per cubic centimeter (52 to 80 pounds per cubic foot) and heating values of the order of 11,600 to 18,000 kilojoules per gram (5,000 to 8,000 Btu per pound).

Stoker fuel is extruded into pellets or cubes. The pellets are usually 0.6 to 2.5 centimeters, in diameter and 2.5 to 5.0 centimeters in length. The cubes are usually 2.5 to 5.0 centimeters square and 5 to 7.5 centimeters long. This fuel is generally used for industrial boiler applications but can also be used in stoves and in gasification processes. The bulk density of the pellets or briquettes ranges from 0.48 to 0.80 grams per cubic centimeter (30 to 50 pounds per cubic foot). Heating values range from 14,600 to 34,800 kilojoules per gram depending on the composition of the briquettes which may include such materials as biomass residues, paper, and plastics.

Depending on the degree of compacting and the material used, densified biomass may have a water-repellent skin. Exposure to water during storage should, however, be avoided, particularly if the fuel contains significant amounts of paper. Densified fuels have a low moisture content and, therefore, biodegrade slowly; they can thus be stored for long periods of time if kept dry during storage.

Table 2.38 presents some typical characteristics of various densified biofuels used in rural areas of developing countries; these fuels are generally

TABLE 2.38.--CHARACTERISTICS OF SOME DENSIFIED BIOMASS FUELS

Composition	Moisture	Ash	Net Heat Value	Comment
	. . . .Percent. . . .		kJ/kg	
Dry Beech Wood	8.0	0.3	17,656	Type of wood rarely available in poor rural areas.
Green birch wood	42.9	0.25	12,076	Type of wood commonly found in poor rural areas of developing countries.
Waste paper balls (made from soaked newspaper)	6.9	2.9	15,989	Made by hand; burn better if wood ash is added.
Briquettes made of 30-45% charcoal dust 30-45% chopped twigs 15-20% manure	2.4	32.2	18,425	Comparable to medium-quality hard coal; high ash content probably from sand.
Briquettes made of 25% charcoal dust 25% straw 30% chopped twigs 20% manure	7.2	13.7	12,996	Lower percentage of charcoal dust reduces heat output.
Briquettes made of 50% straw 50% cow manure	5.4	9.5	15,044	Feasible everywhere but, has high manure content--and manure is better used for fertilizer.
Briquettes made of 40% straw 40% sawdust 20% manure	9.2	14.0	13,652	Needs careful drying because of sawdust.
Briquettes made from charcoal dust with clay as binder	--	73.0	4,076	High mineral content lowers heat value and creates much ash.

Source: Adapted from J. Janczak, 1981.

prepared with manually operated equipment as was described in the early part of this section.

2.7.3 Cost of Densification Equipment

The cost of small hand presses manufactured by local labor in rural areas is difficult to estimate because of wide variations in the cost of labor and of raw materials (iron, etc). Some indications of the labor and materials needed to manufacture a simple hand-operated system have been given above.

Most log manufacturing units have capacities ranging from 5 to 25 tons of product per day. Installed costs of equipment are estimated to be of the order of $8,000 to $10,000 per ton per day of capacity. The extrusion machines used to manufacture the logs are either screw (tapered or nontapered) extruders or piston extruders.

Current manufacturing units for stoker fuel have capacities ranging from 120 to 300 tons per day capacity. Plant installed costs range from 3,000 to 5,000 per ton per day capacity (J. J. Fritz et al., 1979).

CHAPTER 3. ENERGY CONSUMPTION BY USER SECTOR

3.1 Introduction

This chapter describes typical energy requirements of households, industry, agriculture, and transportation. The data may be used to determine the energy requirements to be matched by biomass-derived fuels when analyzing the feasibility of biomass for energy projects. Because of specific country conditions such as tradition, type of fuels used, process design, labor productivity, and others, the actual energy requirements for any given case may vary widely from country to country. Whenever possible, actual data should be gathered; if these are not available, the data presented in this section can be used as a starting point for the evaluation process.

Most of the data presented for industrial energy consumption are averages for developed countries (the United States specifically). In many cases, it is expected that the corresponding energy consumption per unit of product will be higher in developing countries because of the lesser degree of sophistication of the processes used and the nonavailability of the most advanced type of equipment. In these instances, the data of energy consumption per unit of product presented in the tables can be used as a guide setting a goal for improving the energy efficiency of processes used in developing countries.

3.2 Rural Household/Residential Sector

At the household and village level, energy requirements are a highly integrated system involving all village resources. Agricultural residues and fuelwood are used for cooking and heating and to fuel small-scale industries such as tea and tobacco drying, brick and tile manufacturing, bakeries and others. The traditional fuels are generally gathered as free goods for the household's use in rural areas, or sold in cash markets to rural industrial and urban users.

The potential for energy from fuel wood, charcoal, and agricultural residues in rural areas cannot be analyzed in isolation or apart from other land use demands, or from other alternative uses of the products. Trees supply a multitude of products, not only fuel wood. Stems and biomass may be used for construction as well as for energy or pulp. Given a range of markets for the products (construction poles, pulp, fuel wood, etc.) resource owners will sell in whichever market brings the highest return. There is also the opportunity cost of land to consider. It is entirely possible that allocating an area to fuel wood production is economically suboptimal to some other use, whatever that use may be. Given the productivity of a certain piece of land, the landowner would hardly plant trees if his income would be twice as high from rice production.

The potential supply of traditional fuels as alternatives to fossil fuel energy must be put in perspective with other renewable energy sources and land

use demands. The total energy picture is highly interrelated and sources of supply will develop in harmony with the relative economic attractiveness of each source. For example, if an area is particularly productive for agricultural cash crops, a major traditional energy source there is likely to be agricultural residues i.e., straw, rice husks, bagasse, etc.

The major activities requiring fuel wood in the household sector are cooking and space heating, although little information has been collected on the cooking activity itself. The work of Reddy in India, Meta Systems in Bangladesh, Ernst in Upper Volta, Weatherly and Arnold in Indonesia, and Bialy in Sri Lanka indicate that cooking requires on the order of 0.4 to 0.7 tons of air-dried wood per capita per year. Most of this variation can be explained by the fuel supply availability and the use of alternative fuels such as kerosene.

A recent survey conducted by the Instituto Nacional de Energia in Ecuador concluded that the average energy needed for cooking in that country is 977 kilocalories per person per day or 4,084 kilojoules per person per day. The survey estimates that this corresponds to about 2 kilograms of air-dried fuel wood per person per day, or 0.73 metric tons per capita per year (G. Beinhart and J. F. Henry, 1981). This estimate falls within the range of fuel consumption quoted for cooking in Table 3.1. An interesting aspect of the Ecuadoran study is that, based on traditional cooking patterns, the per capita estimated fuel wood consumption suggests that the average efficiency of the cooking process (useful heat to consumed heat) is about 16 percent. Such low

TABLE 3.1.--FUELWOOD AND OTHER TRADITIONAL FUEL USE SURVEYS

Country	Type of Use	Fuel	Consumption	Wood Equiv. (TPY)	Source
Group I					
Bangladesh	rural cooking	A		.4	1
Bolivia	rural general	W	2t	2	3
Brazil	general	A,C,W		.8t	5
China	general	A		.23	6
	general	W		.11	6
	rural general	A,W		1.5	3
Gambia	general	W	.9 - 1.1t	.9 - 1.1	7
India	rural	W	.6t	.6	10
Indonesia	rural cooking	W,A		.5	11
Kenya	cooking/heating	W	.7t	.7	13
	general	W	1 - 1.5m^3	.7 - 1.1	15
Mexico	rural general	A,W		.9	3
Nepal	rural general	W	.73t	.73	15
	general	W	1m^3, .43t	.43 - .73	16
Nigeria	rural	A,W		1.0	3
Peru	rural general	W	1.2	1.2	20
Sri Lanka	rural cooking	W	.43	.43	30
Sudan	general	W	1.2	1.2	21
	rural	W,C		3.2	22
Tanzania	general	W	1.5 - 1.7t	1.5	23
	general	W,C		1.4	24
	rural general	A,W		1.5	3
Thailand	general	W	1.4m^3, 1.1t	1 - 1.1t	25
	urban	W	.5	.5	26
Upper Volta	general	W	.5	.5	28
	rural cooking	A,W		.6 - .8	29

TPY: tons per capita, per year
A - agricultural residues; C - charcoal, W - wood; D - dung

TABLE 3.1.--FUELWOOD AND OTHER TRADITIONAL FUEL USE SURVEYS (Continued)

Country	Type of Use	Fuel	Consumption	Wood Equiv. (TPY)	Source
Group II					
Benin	general	W	2.1 - 2.6t	2.1 - 2.6	2
Botswana	water heating	W	.53 - .7t	.53 - .7t	4
India	general	A,W		.8	8
	domestic	A,W,D		.6	9
Iran	village	W	1.2t	1.2	12
Kenya	general	W	1.1t	1.1	14
Nigeria	general	W	.27t	.27	17
	urban	W,C		.55	18
Papua New Guinea	rural general	W	.4t	.4	19
Tunisia	rural general	W	1.2	1.2	27

TPY: tons per capita, per year
A - agricultural residues; C - charcoal, W - wood; D - dung

TABLE 3.1.--Sources (Concluded)

The sources of these data are as follows:

1. B.E.S. (1977)
2. Digernes (1979)
3. M & P (1975); Malchajani and Poole (1979)
4. Thipe S. Makobi (1979)
5. Muthoo (1978)
6. Smil (1978)
7. Floor (1977); Arnold & Jongma (1978)
8. Argal (1978)
9. Gosh (1979)
10. Reddy (1979)
11. Weatherly and Arnold (1979)
12. Nyoike (1979)
13. Openshaw (1979)
14. Arnold & Jongma (1978); Mungala (1979); Digernes (1979); Spurgeon (1979); Murguand & Githing (1979); Muchiri (1978)
15. Hughart (1979)
16. Eari (1975)
17. McComb & Jackson
18. Ag (1979)
19. PNG - Ministry of Minerals & Energy (1978)
20. Hughart (1979)
21. Arnold & Jongma (1978)
22. Digernes (1979)
23. Openshaw (1976, 1979); Arnold & Jongma (1978)
24. Tanzania National Science Resources Council
25. Openshaw (1976); Arnold & Jongma (1978)
26. Openshaw (1972)
27. Hanza (1978)
28. Floor (1977)
29. Ernst (1978)
30. Bialy (1979)

The numbers in Group II are based on data reported by D. O. Hall in a paper presented to the Technical Panel on Business Energy of the U.N. Conference on New and Renewable Sources of Energy, 2/80.

efficiencies, suggest that significant improvements could be achieved in rural combustion technology which could reduce drastically the demand for fuel wood in the rural sector. The topic of rural stoves is addressed in Volume V of the series of State of the Art volumes.

Total domestic requirements for biomass fuels varies more as shown in Table 3.1, from 0.4 to 1.5 tons of air dried wood per capita per year. Mountaineous countries, such as Peru, Bolivia, and Iran, are among those with high consumption numbers, whereas warmer climate countries with no heating requirements consume less per capita on the average. Wood is still the dominant fuel compared to agricultural residues and dung in most of these countries. As wood becomes increasingly scarce, however, the use of agricultural residues and dung are expected to increase.

3.3 Industrial Sector

A number of urban, rural and agricultural industries currently using commercial fuels could switch to wood and charcoal if the relative prices of the former continue to increase. Principal candidate industries are those which already use firewood and charcoal to produce some of the process heat and shaft power--iron and steel making, lime and cement, bricks and ceramic firing, crop drying and refining, glass blowing and others.

The fuel requirements for these industries, if they were to be switched to firewood, are difficult to determine accurately without information on

relative biomass-to-energy conversion efficiencies in the countries being studied. The estimates of potential fuelwood consumption in industries for selected countries that are given in Table 3.2 below are therefore only approximate. The table indicates that the potential consumption is considerable, amounting to 1.4, 5.0, 14.7 and 52.5 million tons (see subtotal) of air-dried wood in Bangledesh, Thailand, Egypt, and Brazil, respectively.

Few countries are likely to be able to dedicate sufficient amounts of biomass fuels to have a significant impact on the industrial consumption of fossil fuels. Biomass fuels are more likely to contribute to the energy needs of rural, often relatively small-scale industries.

Rural industries can have a very positive impact on the economic development of rural areas by increasing employment, providing services and goods to the rural population and the agricultural sector, reducing the dependence on externally produced goods and other benefits. Rural industries on the other hand operate within a specific set of constraints: shortage of capital, shortage of trained labor, limited access to wide markets, etc. These constraints will have to be recognized and dealt with when attempts are made to expand rural industries. These socioeconomic issues are reviewed in the report on Rural Industries prepared by J. H. Arnold, Jr. (1980). The purpose of the present review is to provide data on energy consumption of typical industries that may help planners or promoters of bioenergy related projects in conducting feasibility studies of the projects investigated.

Table 3.3 shows the average process heat requirements per unit of product manufactured (kilojoules per metric ton) for various industrial processes as

TABLE 3.2.--ESTIMATED WOOD FUEL REQUIREMENTS FOR SAMPLE URBAN INDUSTRIES

1. Rate of Consumption

Product	Tons of Fuelwood per Ton Product
Steel	3.25[a]
Cement	.55
Cotton spinning	4.0[b]
weaving	3.8
Jute	1.2
Sugar	2.0
Tobacco	1.3

2. Production in Selected Industries (000's tons)

Product	Brazil 1978	Egypt 1976	Thailand 1977	Bangladesh 1977/1978
Steel ignots	12,128	457[c]	300	120
Cement	23,084	3,362	5,063	339
Cotton cloth	na	122	666[d,e]	84
Cotton yarn	70[d]	193	67[f]	49
Jute	na	na	na	546
Sugar	na	576	1,604	175
Tobacco	na	7,381	na	na

3. Total Demand (000's tons of air-dried wood)

Product	Brazil	Egypt	Thailand	Bangladesh
Steel ingots	39,416	1,485	975	390
Cement	12,696	1,849	2,785	186
Cotton spinning	280	772	268	196
weaving	127[g]	463	1,012	g
Jute	--	--	--	655
Tobacco	na	10,180	na	na
Subtotal[h]	52,519	14,749	5,040	1,427
Sugar	na	1,152	3,208	350
Total	52,519	15,901	8,248	1,777

a. Conversion 40% efficiency wood to charcoal, pig iron produced locally.
b. Overall conversion efficiency 15%.
c. Crude steel
d. 1976
e. mn yds.
f. 1975
g. 2500 yds = 1 ton
h. Assume bagasse used in sugar refining

Source: 1977 U.N. Yearbook of Industrial Statistics, various issues of quarterly Economic Reviews for Egypt, Brazil, Thailand and Bangladesh by Economist Intelligence Unit.

TABLE 3.3.--ENERGY REQUIREMENTS OF VARIOUS INDUSTRIES IN THE UNITED STATES

Industry	Process	Energy Thousand kJ/metric ton product	Temperature C
Iron ore	Production of iron pellets for blast furnaces.	633-844	1300-1370
Copper ore	Concentration of extracted ore.	730	1200
Bitumous coal and lignite	Drying of coal/lignite to improve heating value and decrease transportation costs.	Coal: 451 Lignite: 878	480
Potash	Production of potassium compounds (expressed as K_2O equivalent) from potassium-containing deposits.	300	150
Phosphate rock	Conversion of phosphorus ore (phosphate rock) to phosphorus compounds used as fertilizer.	Calcination: 698 Drying: 430	870 150
Sulfur	Extraction of native sulfur by injected steam.	8000	165
Meat packing and processed meat	Slaughter and cutting of animals. Packing of cuts and processing into lard, smoked meats, and sausage.	Slaughter: - steer: - hog: Smoking/cooking: - drying/cooking: 460-520 - canning: 1,050 Lard:	 93 93 66-83 32-82 71-116 100
Poultry processing	Slaughter and dressing of the carcasses (chilling not included in the energy requirements).	930	60
Natural and processed cheese	Production of natural and processed cheese (cooked and pasteurized) cheese. Dry whey is a by-product used for human and animal consumption	Natural cheese: 1,590 Processed cheese: 216 Dried whey: 11,750	38-77 74 49-93
Condensed and evaporated milk	Production of evaporated milk products and milk powder including canning, sterilizaton and packaging.	Evaporated products 2,200 Dry milk products: 12,000	70-120 70-205
Fluid milk	Processing and pasteurization of milk.	56	77
Canned specialties	Production of pre-cooked canned products such as baby food, dry bean products, soups, macaroni, etc.	Canned dry bean product 1,680	80-120

TABLE 3.3.--ENERGY REQUIREMENTS OF VARIOUS INDUSTRIES IN THE UNITED STATES (Continued)

Industry	Process	Energy Thousand kJ/metric ton product	Temperature, C
Canned fruits and vegetables	Production of canned fruits, vegetables, juices, jams, preserves, sauces.	Corn: 1,630 Tomatoes: 1,120-5,210 Peas, beans: 1,630 Peaches: 1,120 Citrus drinks: 168	70-120
Dehydrated fruits, vegetables and	Dehydration of fruits, vegetables, and soup mixes.	Prunes: 13,900 Apples: 51,000 Raisins: 25,500 Carrots: 55,700 Onions: 81,200 Potatoes: -flakes: 23,200 -granules: 23,200	85-135 70-180
Frozen fruits and vegetables	Production of forzen foods (energy requirements for freezing not included).	Vegetables: 460-700 Fruits: 460 Single strength juices: 140 Concentrated juices: 2,090 Prepared foods: 1,000	40-90
Wet corn milling	Separation of the corn kernal into its various components: starch, corn oil, gluten, fiber and refining of the constituents to dried starch, syrups and sugar from starch.	Milling: 1,725 Starch drying: 2,000 Syrup processing 1,900 Sugar processing 2,600	45-50 60-70 55-10 120-180
Prepared animal feeds	Production of complete feeds (grain, protein meals, supplement, feed material), concentrates from meals and oilseed cakes and specialized feed materials from crushed mineral mixtures and dried forage.	Pelletized dried feeds: 170 Pelletized dried alfalfa: field dried: 4,073 fresh: 12,000	82-88 870
Bakery products	Production of bread, cakes, and othe yeast-raised goods.	Rising: 0 - 139 Baking: 810-1,000	36 215-232
Cane sugar refining	Production of granulated sugar and by-products such as brown sugar, syrups and molasses from sugar (energy needs per MT of raw sugar processed).	5,560	55-132
Beet sugar	Production of granulated sugar and by-products such as molasses, beet pulp and fertilizers from beets (energy needs per MT of beets processed).	2,100-4,440	60-650

TABLE 3.3.--ENERGY REQUIREMENTS OF VARIOUS INDUSTRIES IN THE UNITED STATES (Continued)

Industry	Process	Energy Thousand kJ/metric ton product	Temperature C
Soybean oil mills	Production of oil and animal feed from soybean (energy needs per MT of soybean treated).	940	54-77
Animal and marine fats and oils	Processing of inedible residues from slaughter houses--fats and meats and bones--to chemical feedstock (soap), lubricants, feed supplements or fertilizers (energy per MT of residues treated).	Fats: 13,000 Meats: 10,000	36-177
Shortening and coking oils	Production of shortening, partially hydrogenated oil. Cooking/salad oil and oil for margarine manufacture from raw vegetable oils (soybean, cottonseed, palm oil). Process energy is only one-third of total energy requirements.	Shortening, partially hydrogenated margarine oils: 640 Salad/cooking oils: 535	71-204
Malt beverages	Production of beer, ale, malt liquor. Energy estimates assume that all products are packed in returnable containers. Residue grains are dried for animal feed. Energy requirements no not include cooling and are expressed per hectolitre of product	Cooking: 12.2 Mash: 3.5 Brewing: 23 Grain drying: 140 Bottling: 68	82-100 76 100 537 60-71
Distilled, blended and rectified	Production of grain neutral spirits, whisky, gin, rum, etc., and residual distillers grain. Enrgy requirements are per liter at 50% ethanol.	Whisky: 16 Spirits: 17 Gin/Vodka: 20 Distillers grain: 5	63-182 121-143
Bottled and canned soft drinks	Production of soft drinks, carbonated or not in bulk or in consumer packaging. Energy requirements per hectoliter of product.	Returnable bottles: 15 Cans: 11 Bulk: 6	66-77 24-29
Cigarettes	Manufacture of cigarettes from tobacco received in bulk. Energy per Metric Ton of tobacco processed. Most energy is required for drying/humidifying stored tobacco.	18,600	121-204
Tobacco stemming and redrying	Production of an intermediate for cigarette, cigar and smoking/chewing tobacco industries.	9,250	--
Textiles	Manufacture of fabrics from natural--cotton, wool, silk--and man-made fibers--rayon, acetate, nylon, polyester, acrylic, etc.--. Estimates of energy consumption vary widely on basis of fiber used, process, nature of finished products. Energy requirements are approximate and include only steps mentioned in table: no quotes available for other steps of the process.	Wet processing: 45 Finishing: - wool: 108 - cotton: 24 - synthetics: 32	 43-77 43-177

TABLE 3.3.--ENERGY REQUIREMENTS OF VARIOUS INDUSTRIES IN THE UNITED STATES (Concluded)

Industry	Process	Energy Thousand kJ/metric ton product	Temperature C
Saw mills	Production of rough-cut and dressed lumber. Process heat is required in drying. Mechanical power not included in estimates. Quotes per Metric Ton of product assuming 4.53 cubic meter per 1,000 board feet and 700 kg per cubic meter.	330-1,164	149
Plywood and veneer	Production of plywood and veneer from hardwoods and softwoods. Mechanical energy not included in energy estimates. Quotes per assuming 0.295 cubic meter per 1,000 feet square (1/8") and 750 kg per cubic meter for plywood.	Veneer: 12,655 Plywood: 11,900	99
Pulp mills	Production of pulp from logs for the manufacture of paper products. Brak and black liquor residues are often used as fuels.		
Papermills	Manufacture of paper from wood pulp and other fibrous materials including recycled materials.		
Paperboard mills	Manufacture of paperboard from wood pulp, waste paper and other fibers. The product is used for folding cartons, milk cartons, containers, etc.		
Building paper	Manufacture of building paper and building board from wood pulp and other fibrous materials.		
Corrugated and	Manufacture of corrugated or solid boxes by lamination of two or more layers of paperboard.	Fluting and gluing: 454-1,700 per thousand square meter.	149-177 177

they are currently pursued in the United States. These energy requirements include only process heat and not shaft power when needed. Typical temperatures at which the process heat is required are also indicated in the table. The actual energy requirements per unit of product will depend on a number of factors such as quality of the finished product, degree of automation of the production line, recycling of waste heat, etc. The data in the table therefore are only indicative of an order of magnitude of the energy requirements of various industries, but they can provide a starting point for energy flow analyses when no other data are available. When using the data in Table 3.3, care should be taken to be sure that the process described in the table corresponds to the project analyzed; for example, sugar refining in the table does not include sugar extraction from the cane and therefore the energy expended is lower than that quoted in Table 3.2.

Despite differences in equipment and in some cases in fuels used, the energy requirements per unit of product manufactured quoted in Table 3.3 for the United States are not too different from those quoted by J. H. Arnold, Jr. (1980) for various rural industries. For instance, Table 3.3 reports from 3,850 to 4,000 thousand kilojoules per ton of brick produced whereas Arnold (1980) reports 3,500 to 4,700 thousand kilojoules, with an exceptional case of 9,000 kilojoules, for continuous-firing processes. Bread baking is reported to consume from about 1,000 to 1,300 thousand kilojoules per metric ton of product in Table 3.3 compared to 1,200 to 3,000 thousand kilojoules for rural industries. This does suggest that when no other data are available, the data of Table 3.3 can be used as a rough estimate, keeping in mind that in many

cases rural industries will require more energy per unit of product because of the lesser sophistication of the equipment used.

The shaft power required for rural industries depends on the size and capacity of the industries, degree of mechanization desired, and type of industry considered. A review of specific industries by J. H. Arnold (1980) suggests that most needs of rural industries such as brickmaking, textile spinning and weaving, furniture making, metal work, sawmills, pottery, etc., can generally be satisfied with shaft power ranging from a few horsepower to about one hundred horsepower. This power can be provided by electricity from the grid when rural electrification is sufficiently developed or by fixed diesel or gasoline-powered engines. The latter offer opportunities for substitution of the fossil fuels by biomass or by biomass-derived fuels.

3.4 Agricultural Sector

Most of the energy needs of the agricultural sector are required in the form of shaft power. This mechanical power is used to provide a number of functions such as planting, cultivating, irrigation pumping, harvesting milling, etc. Some energy is needed in the form of process heat for such functions as crop drying and processing, etc.

The specific needs in shaft power are extremely variable and are influenced by such local factors as type of work to be delivered, terrain over which the activities take place, degree of mechanization searched for and affordable,

etc. It is, therefore, virtually impossible to characterize agricultural activities in terms of typical energy requirements by activity.

Much of the shaft power needed will be provided by diesel or gasoline-powered engines. Table 3.4 shows typical consumption of such engines for various horse power ranges. Using local data for the productivity of engines performing various functions (number of hours and engine rating needed to perform a certain task), one can then estimate the fuel requirements to perform a certain function on the basis of the data of Table 3.4.

Some of the process heat requirements of some agriculture-related industries such as dairy farms and food processing, have been described in Table 3.3.

Several biomass options are available to substitute for fossil fuels in delivering shaft power, i.e., small-scale gasification and alcohol fuels. These are discussed in Volumes VII and VIII respectively.

TABLE 3.4.--AVERAGE FUEL CONSUMPTION OF TRACTORS

Rated Power Horsepower	Fuel Consumption (liter per hour) Gasoline	Diesel
30	5.9	4.6
40	10.9	7.3
55	14.6	9.1
75	18.2	12.7
100	--	16.8

Source: Adapted from Musnier, 1976.

3.5 Transportation Sector

The fuel requirements for the transportation sector depend on a multiplicity of factors such as equipment characteristics, terrain, loads, speed, and degree of maintenance etc. It is, therefore, impossible to give typical values for fuel consumption. Data will have to be collected locally in order to assess the energy needs of the sector prior to evaluating the potential of biomass-derived fuels in replacing fossil fuels used in the transportation sector. In the case of heavy-duty equipment such as trucks, the data of Table 3.4 can probably be used as a first approximation.

CHAPTER 4. PROJECT EVALUATION

4.1 Introduction

This chapter discusses the elements involved in evaluating biomass for energy projects. The components of feasibility studies are first briefly reviewed. Among these components financial and economic studies are of prime importance: no project will be initiated if it does not offer attractive economic and financial prospects. The remainder of the chapter therefore is devoted to the discussion of the techniques used to conduct financial and economic analyses.

4.2 Evaluation and Implementation of Bioenergy Projects

Initiating and then implementing a bioenergy project involves various steps of increasing complexity. A range of planning studies are first required to define and formulate the project. These studies are then followed by detailed design studies, construction, testing, and finally, operation of the project.

Planning studies are generally divided in three categories: prefeasibility, feasibility and detailed planning studies. Prefeasibility studies, also referred to as reconnaissance studies, provide an overview of a proposed project, identify potential problem areas and assess qualitatively if the proposed project has enough merit to warrant a more detailed feasibility study. The objective of the feasibility study is to reach a go-no-go decision concerning the project. As such, the feasibility study should be complete,

detailed, and should answer all questions concerning the viability of the project. In most cases, the feasibility study is a major document used to promote the project to financing institutions, government agencies, potential users, and individuals involved in the project's realization. The feasibility study, therefore, must be encompassing and thorough.

Detailed planning studies are special studies addressing specific aspects of the project and answering specific questions or problems. The prefeasibility and feasibility studies for simple and small bioenergy projects may in some cases be handled by one person having a wide enough background in bioenergy systems and benefiting from the support of consultants. Larger projects will require multidisciplinary teams.

Some of the major elements to be considered in project feasibility and assessment studies are shown in Table 4.1. The list is not exhaustive and should only be considered as an indication of all the aspects of bioenergy projects that must be taken into account and evaluated before launching such projects. An important feature of bioenergy projects is that these projects cannot be dissassociated from the social, environmental, and economic context within which they occur. Implementing bioenergy projects requires that a careful balance between technical, social, economic, and environmental factors be realized.

As was pointed out in the introduction, the economic analysis of projects is a key element in the decision-making process of selecting and implementing bioenergy projects. The remainder of the chapter is devoted to a description of the techniques involved in conducting economic analyses of projects.

TABLE 4.1.--ELEMENTS OF AN ASSESSMENT OR FEASIBILITY STUDY

1. End-Use Market
   - Energy requirements (type of energy/fuel, quantities, projections,. .)
   - Utilization pattern
   - Distribution system
   - By-products of bioenergy
   - Competing energy sources (type, cost,. . .)

2. Resources
   - Biomass feedstock (nature, characteristics, production schedules, cost,)
   - Land
   - Water
   - Others
   - Present resources utilization

3. Conversion Technologies
   - Selection of technology(s)
   - State of development
   - Availability and cost of equipment
   - Maintenance and repair requirements
   - Labor requirements

4. Environmental Factors
   - Land and water impacts
   - Air pollution
   - Health hazards
   - Safety hazards

5. Social Factors
   - Regulatory aspects
   - Employment (regional, national,. . .)
   - Training and skills
   - Relation to development plans

6. Financing
   - Options
   - Financial analysis
   - Comparison between bioenergy alternatives and competing sources of energy
   - Risk and sensitivity

7. Economic Analysis
   - Cost/benefits to region/nation
   - Comparison of alternatives
   - Sensitivity to external factors

8. Recommendations
   - Selection of a technology plan for implementation

4.3 Economic Evaluation of Biomass Systems

Investments in nonconventional energy alternatives are analyzed in the same fashion as investments in fossil fuel-based energy systems. Flows of benefits and costs are the "raw materials" used in the economic analysis of any project where investments are made, whether they are in fossil fuel or biomass energy systems. Only the assumptions and the data inputs differ. The analysis of the biomass energy alternatives, however, is perhaps a bit more complex for the following reasons:

1. Biomass energy conversion technologies have rarely been proven in the field on a massive scale because oil has been abundant and cheap. Investments in alternative energy systems have therefore not been necessary and there are today few off-the-shelf conversion units available for ready implementation in developing countries. Those that are operational have short, if any historical track records on which to anchor the credibility of the economic evaluations.

2. The biomass feedstock is not of uniform quality. Biomass varies in energy content, residual content (ash), and performance characteristics, and equipment must be designed and operated accordingly. Economic analyses must therefore be site specific and results from one experience are not easily applicable to another.

3. Feedstock availability is often ignored in project appraisal. The problems that should be addressed include not only the technical and economic

efficiency of the biomass conversion technologies, but also the feedstock supplies. The apraisal must include the availability of land to produce the feedstock, and the costs of growing, harvesting, and transporting the feedstock to a central place.

4. Economic benefits and costs cannot be valued at market prices when markets do not exist. For example, fuel wood is often a "free good" in the rural areas, since people gather enough from the natural forest to meet their daily needs. As a result the value of charcoal made from the wood will be distorted since the wood has no market value. Similarly, the value of biogas produced will be distorted if the value of the cow dung input, also a "free good," cannot be correctly estimated. While it can be argued that the value of the biogas should be based on the value of the labor input for fuel wood or dung collection, the estimate is likely to be very subjective since the value of time in most developing countries is most difficult, if not impossible, to determine objectively.

These and other technical and socioeconomic caveats that tend to complicate the economic evaluation of alternative bioenergy systems should always be kept in mind. The analytical results are not cast in stone and should always be interpreted with caution, realizing that the validity of the results, no matter how refined and theoretically sound the approach, always hinges on the assumptions employed, and more importantly, on the reliability of the data inputs. In many developing countries economic data are often nonexistent or highly unreliable, which means that the analyst must apply a good measure of judgement and "rules-of-thumb" in his project appraisal.

What this section will hopefully impart is an understanding of the basic "how-to's" in economic evaluation of projects without describing in detail the many approaches and variants thereof that make it possible for the analyst to be more elaborate and complex. Analysts who develop and work with intricate and complex investment models still utilize the same basic analytical techniques. The model refinements simply mean that the numbers used in the analytical "spreadsheets" are probably more reliable. And this, in turn, is limited by the availability of data. If the data are not available, or are not reliable, the analyst forfeits analytical sophistication and settles for less reliable results.

4.3.1 Economic Evaluation Analyses

The economic evaluation of a project involves three sets of analyses: a financial analysis, an economic analysis, and a sensitivity analysis, which may apply to either or both of the two previous analyses (Bussery and Chartois, 1975).

The objective of the financial analysis is to determine if the funds invested in the project can be recovered at a rate that makes the investment an attractive financial proposition for a prospective investor. This analysis is conducted from the point of view of the investor who must decide if the project considered is more or at least as attractive as some other opportunities of investing his money. The analysis will be performed for the entire projected life of the project and will take into account projected changes in market demand, maintenance and repair costs, etc.

The objective of the economic analysis, also sometimes called social cost-benefit analysis, is to evaluate whether the project considered is attractive from the point of view of the national economy as a whole. Projects may be technically feasible, commercially viable, and financially attractive but may not be beneficial to the national economy. Indeed, in countries in which financial, material, and qualified labor resources are scarce, the implementation of a new project may have a negative impact on certain sectors of the existing economy and therefore be unattractive to the national economy as a whole. The problem in conducting economic analyses is to be able to assign realistic values to the components of the project which reflect their real value to the national economy rather than values distorted by various factors such as price controls, minimum salaries, rates of exchange, etc.

The financial and economic analyses are based on estimates and projections of costs and benefits over the lifetime of the project. Significant variations in the values of the costs and benefits could occur during the life of the project. It is therefore essential to test what the impact of variations of the most critical elements of the analyses would mean in terms of the financial and/or economic viability of the project. The purpose of the sensitivity analyses is to evaluate the risks associated with unpredictible variations in some of the key assumptions made in deriving the financial and economic analyses of a project.

4.3.2 Methodologies

Economic analysis of projects is basically a process of assembling relevant economic information and transforming it into a meaningful economic "picture"

of the project period. The analytical results, or economic "picture" may be presented in the forms of Net Present Value (NPV), Benefit/Cost ratio (B/C), or Internal Rate of Return (IRR). These project evaluation methods are briefly described below.

4.3.2.1 Some Factors Common to Net Present Value, Benefit/Cost Ratio and Internal Rate of Return

Since project benefits and costs are generated in the future, decision-makers need to know what they are worth in present terms before deciding to go ahead with an investment. If the estimated present values generated by a project exceed the return one can reasonably expect from investing in alternative projects, the project is said to be economically feasible.

The mechanics of determining economic feasibility consist of four steps:

1. Determine the magnitudes of benefits and costs.
2. Estimate appropriate price and cost increases over the project period.
3. Determine the timing of benefits and costs during the project.
4. Choose a discount rate.

Benefits are the volume of output multiplied by its market price. Costs include capitalization costs, or the initial investment, and operating and maintenance costs.

The rates at which benefits and costs appreciate during the project time frame must also be estimated. A problem is whether to express appreciation rates

(if any) in real or nominal terms. The majority of economic analyses fail to make this distinction explicitly. If expressed in real terms, prices and costs are uncluttered by the influence of inflation. A nominal rate includes inflation. Nominal rates should be avoided since inflation rates are highly unpredictable and variable between years.

The third step--timing of events--is very important in project evaluation, since events occurring early have a much greater impact on present values than later events. For example, the present value of $1,000 one year from today is $909 at 10 percent interest, and only $386 ten years from today.[1/]

The fourth step--the choice of a discount rate, is a major problem in project evaluation. There exists no correct rate because interested parties will always disagree with the rate chosen. A low discount rate will yield higher present values, which encourage project funding, but a high discount rate discourages project funding vis-a-vis alternative projects that compete for financing. Often, the choice of a discount rate falls in the political realm over which project analysts have little or no control, or the rate chosen is arbitrary. Twelve percent seems to be a popular choice and almost all projects are analyzed with a discount rate lying somewhere between 10 and 15 percent. Nevertheless, a rate must be chosen, and disagreement over precisely what is a satisfactory estimate of the discount rate will probably continue to be the rule rather than the exception.

1/ The mathematical formulations are:

$$PV = \frac{1000}{(1 + .10)} = \$909$$

$$PV = \frac{1000}{(1 + .10)^{10}} = \$386$$

Economic theory suggests that the discount rate should be equal to, or at least approximate to the market rate of interest or rates charged for local loans. In the urban areas of many developing countries this may be in the neighborhood of 12 percent to 15 percent for loans made to businesses and local institutions. In rural areas, however, where credit is generally unsubsidized and loans are made to the local farmers, the interest rates charged may be as high as 30 percent or more, in real terms (French 1979). Hence, the appropriate discount rate applied to the rural farmers for new investments must be well above the rates applicable to the government or business and institutions for similar types of activities. This is usually not recognized in analyses of pojects in developing countries where rates between 10 percent and 15 percent tend to be applied across the board.

4.3.2.2 Net Present Value (NPV)

In NPV analysis the net cash flow (benefits minus costs) is discounted to the present by means of a prespecified discount rate. Discounting is simply a process of converting a stream of net cash flows anticipated over the life of the project into a single number representing the present value of the project as a whole. A positive NPV indicates economic feasibility if the discount rate chosen equals or exceeds the prevailing market rate of interest (often referred to as the opportunity cost of capital), or the rate of return one can expect from alternative investments.

To briefly illustrate, Table 4.2 shows a hypothetical, simple cash flow distribution for a 5-year project. The investment of $700 made today (year 0) generates streams of benefits and costs during the project period amounting to a net cash flow of $300 annually. At a discount rate of 15 percent the NPV of the net cash flow for years 1 through 5 is $1,006 which is $306 more than the original investment of $700[2/]. Since the NPV of $306 is greater than 0 the project is feasible as well as desirable in relation to alternative investments.

2/ A mathematical formulation for the NPV approach is:

$$NPV = \sum_{t=o}^{K} \frac{B_t - C_t}{(1 + i)^t}$$

where B = Benefits each year
C = Cost each year
K = Number of years in project
i = Discount rate
t = Time in years

TABLE 4.2.--HYPOTHETICAL INVESTMENT ANALYSIS EXAMPLE

Cost and Benefits	Years 0	1	2	3	4	5
Capitalization Costs	700					
Operating Costs		100	100	100	100	100
Maintenance Costs		50	50	50	50	50
Total Costs (Cash Outflow)	700	150	150	150	150	150
Benefits (Cash Inflow)		450	450	450	450	450
Net Cash Flow	-700	300	300	300	300	300

NPV = $306

4.3.2.3 Benefit/Cost Analysis (B/C)

In B/C analysis, benefits and costs are discounted separately and then joined in a ratio which shows how much the project returns for every dollar expended.[3/] If the ratio is greater than 1 the project is feasible, again assuming that the discount rate used equals or exceeds the prevailing market rate of interest. The B/C ratio is useful in ranking projects where the higher the ratio the more economically attractive is the project.

3/ A mathematical formulation for the B/C approach is:

$$B/C = \frac{\sum_{t=o}^{K} \frac{B_t}{(1+i)^t}}{\sum_{t=o}^{K} \frac{C_t}{(1+i)^t}}$$

See footnote 2 for definitions of symbols.

The B/C ratio for the cash flows given in Table 4.1 is 1.25 or for every dollar expended the project will earn back $1.25.

4.3.2.4 Internal Rate of Return (IRR)

Three of the four basic steps discussed above apply to the IRR analysis. The fourth step--specification of a discount rate does not. The IRR itself is the discount rate which is required to make the present value of the net cash flow equal to zero. This rate must be determined through a process of trial and error by inserting different values of i in the formula (see footnote 2) until the NPV equals zero. Since NPV for the net cash flow given in Table 4.2 is a positive $306 at i = 15 percent, the IRR must obviously be higher in order to force NPV equal to 0. At i =35 percent, NPV= -$34, or less than zero which means that the IRR must lie somewhere between 15 percent and 35 percent. In this case NPV equals 0 at i = 32 percent, or the IRR on investment is 32 percent. This represents the average earning power of the money used in the project over the project life.

Many favor the IRR approach because it does avoid the necessity of having to specify a rate of discount. Both the NPV and B/C approaches rely on a prespecified rate of discount, the magnitude of which is usually subject to considerable disagreement, as previously discussed. Depending on decision makers' biases, projects can be made to appear attractive or unattractive by manipulating the discount rate.

The IRR itself, however, has little meaning unless measured against a standard of comparison. In this example, the standard is the opportunity cost of capital or 15 percent used for the NPV and B/C examples. Thus, in comparison with the likely returns obtainable from alternative investments this project is attractive.

4.3.3 Economic and Financial Analyses

The distinction between two types of analyses performed, economic and financial, needs to be brought into focus at this time.[4/] The analyses are similar in methodology and utilize the same data base, but differ in results and emphasis.

Economic analysis, also referred to as social benefit-cost analysis, measures the economic attractiveness of a project to society as a whole, regardless of who receives the benefits or pays the costs; i.e., it is neutral to income distribution and capital ownership. In contrast, financial analysis represents the point of view of the private investor who must take income distribution and capital ownership into account. The methodology of comparing costs and benefits is the same for both economic and financial analysis (see Section 4.3.2). How costs or benefits are defined is different, largely because of the use of shadow pricing in economic analysis.

4/ The discussions are drawn from: J. Price Gittinger, Economic Analysis of Agricultural Projects, the John Hopkins University Press, Baltimore, 1972.

4.3.3.1 Shadow Pricing

Shadow pricing is a legitimate replacement of market prices when the latter either do not exist or do not adequately reflect underlying economic conditions in the country. While shadow prices should ideally be determined from comprehensive mathematical modeling of the country, such models are rarely available in developing countries. The alternative is to use "rule-of-thumb" shadow prices in areas that deviate the most from perfectly competitive conditions. For example, many countries arbitrarily fix exchange rates at artifically high levels so that the buying power of their currency in world trade is overstated. One result is that imported goods appear cheaper than they would be in the absence of the pegged exchange rate and import controls become necessary to avoid massive balance-of-payment deficits. Therefore, the cost of the imported goods should be increased by means of a shadow price to reflect what the actual costs would be if the exchange rate were not pegged.

Shadow pricing is also appropriate when there is chronic unemployment during the slack season. For the economic analysis of the project, labor can be shadow priced at near zero even though the workers are actually paid full wages. In this case, the government subsidizes the project, since the society as a whole is considered to be better off with a project that employs people who would otherwise be unemployed. The shadow wage rate for labor can range from zero to full market wages depending on the extent to which labor is otherwise occupied.

4.3.3.2 The Analytical Process

While financial analysis is straightforward and generally a simple undertaking, economic analysis can be very complex. The financial analysis is only the beginning of the overall analytical process which is described below:

1. Financial Viability - Calculate NPV, B/C, or IRR using market prices and market interest rate. The analysis includes tax liabilities and interest on capital borrowed (debt servicing) as costs and project subsidies as benefits. The hypothetical investment analysis given in Table 4.2 is an example of financial analysis.

2. Economic Viability - a. Taxes, subsidies, and debt servicing costs are removed from analytical consideration as these are transfer payments within the economy. Taxes are "benefits" to the total economy and are transferred to society as a whole. Conversely, subsidies are "costs" incurred by society for the operation of the project. Debt servicing on borrowed capital is not a cash flow item, since it is part of the total return to capital available to society as a whole.

b. Account for market distortions in the economy such as price and quantity controls, minimum wage regulations, labor cost fluctuations, pegged foreign exchange rates and trade regulations, by applying shadow prices in lieu of market prices to reflect the real values of inputs and outputs. Because of these market distortions a straightforward financial analysis would not adequately reflect the true economic return from a project to society.

c. If desired, incorporate income distribution, regional development, employment, and savings and investments goals in the economic analysis. For example, projects that meet basic needs such as food and energy may be adjusted upward in value by a weighting scheme in relation to other projects competing for funding. Other projects may be adjusted to ensure a more favorable income distribution for poor people. Yet others may promote regional development in favor of national economic development goals.

d. Use of a shadow discount rate. The discount rate is often a very sensitive parameter in the economic evaluation of projects. In financial analysis the discount rate should equal or at least approximate the opportunity cost of capital measured by the expected returns from alternative investments. This rate, however, may be as high as 30 percent in real terms, or more in rural areas where credit is not subsidized, and 12-15 percent in the urban areas for loans made to businesses and institutions. The shadow (social) rate of discount, on the other hand, reflects the weight society puts on future consumption. If the project is likely to satisfy a number of national objectives its chances for funding are encouraged by the choice of a discount rate considerably below the prevailing market interest.

In summary, financial and economic analyses of projects meet different needs. Financial analysis is done from the perspective of potential investors who want to know whether the project is "bankable"; i.e., does the project appear to offer a return greater than the return one can reasonably expect from alternative investments. Economic analysis, on the other hand, is carried out

from the perspective of the nation as a whole, where taxes, subsidies, and debt servicing costs need not be considered, since they are merely transfer payments within the economy. Further refinement of the analytical inputs by shadow pricing is legitimate when foreign exchange rates are pegged, prices and costs are fixed, and labor availability is seasonal. Economic analysis can also be made to reflect societal preferences by applying weighting schemes or manipulating discount rates to favor certain kinds of projects over others.

Referring to the financial analysis shown in Table 4.2 a corresponding analysis was performed assuming the following shadow price:

1. Capitalization costs are increased by a factor of 1.25 to offset the impact of a pegged foreign exchange rate on imported goods.
2. Operating costs are reduced by one-half to reflect that labor with only limited employment alternatives is available.
3. Discount rate is 6 percent to reflect a government preference that this project be undertaken. The economic analysis cash flow is given in Table 4.3.

The NPV for the economic analysis, given these shadow values, is $599, or substantially higher than the financial analysis NPV of $381.

TABLE 4.3.--HYPOTHETICAL ECONOMIC ANALYSIS EXAMPLE

Costs and Benefits	Years 0	1	2	3	4	5
Capitalization Costs	875					
Operating Costs		50	50	50	50	50
Maintenance Costs		50	50	50	50	50
Total Costs (Cash Outflow)	875	100	100	100	100	100
Benefits (Cash outflow)		450	450	450	450	450
Net cash flow	-875	350	350	350	350	350

NPV @ 8 percent = $599

Basis: financial analysis of Table 4.2, using shadow pricing of 1.25 the original capital cost, one-half the operating costs and a discount rate of 6%.

4.3.4 Sensitivity Analysis

It is important to note that financial and economic analyses of projects cannot possibly cover everything. There are literally an infinite number of alternatives or combinations of project alternatives one can analyze. For example, a project considering four operating capacities of a gasification unit using wood as feedstock, four possible levels of technical sophistication of the unit, three soil productivity alternatives for feedstock production along with three different levels of management intensity and three levels of stocking density, yields a total of 432 permutations (4x4x3x3x3x=432). Several other possibilities could easily be added that would contribute to an exponential growth of alternatives. The analyses must be held to a reasonable number of alternatives making use of a base case judged to be representative of the conditions pertinent to the problems being studied. Thus, a base case should be constructed in the necessary detail and analyzed in detail, emphasizing that the results given are strictly a function of the assumptions. If the assumptions are changed so are the results.

Sensitivity analysis is the response of an estimate to input changes, or changes in the base case assumptions. In effect, it answers the question: to what extent would NPV (or B/C or IRR) change if benefits and/or costs do not behave as anticipated in the base case, or if a different discount rate were applied because of a change in the opportunity cost of capital?

The magnitude of the change in result, per se, is not the critical factor. One knows, a priori from mathematics of capital theory that changes in base case

assumptions concerning benefits and costs have a linear impact on NPV's; whereas changes in discount rate assumptions have a geometric impact (Medema and Moore, 1980; Christophersen et al., 1978; Mills et al., 1976; Sweitzer, 1970). What is critical in the sensitivity analysis is whether a change in the assumption results in a change in the preferred course of action. If so, the sensitivity analysis has identified an assumption that should be closely evaluated by the decision maker.

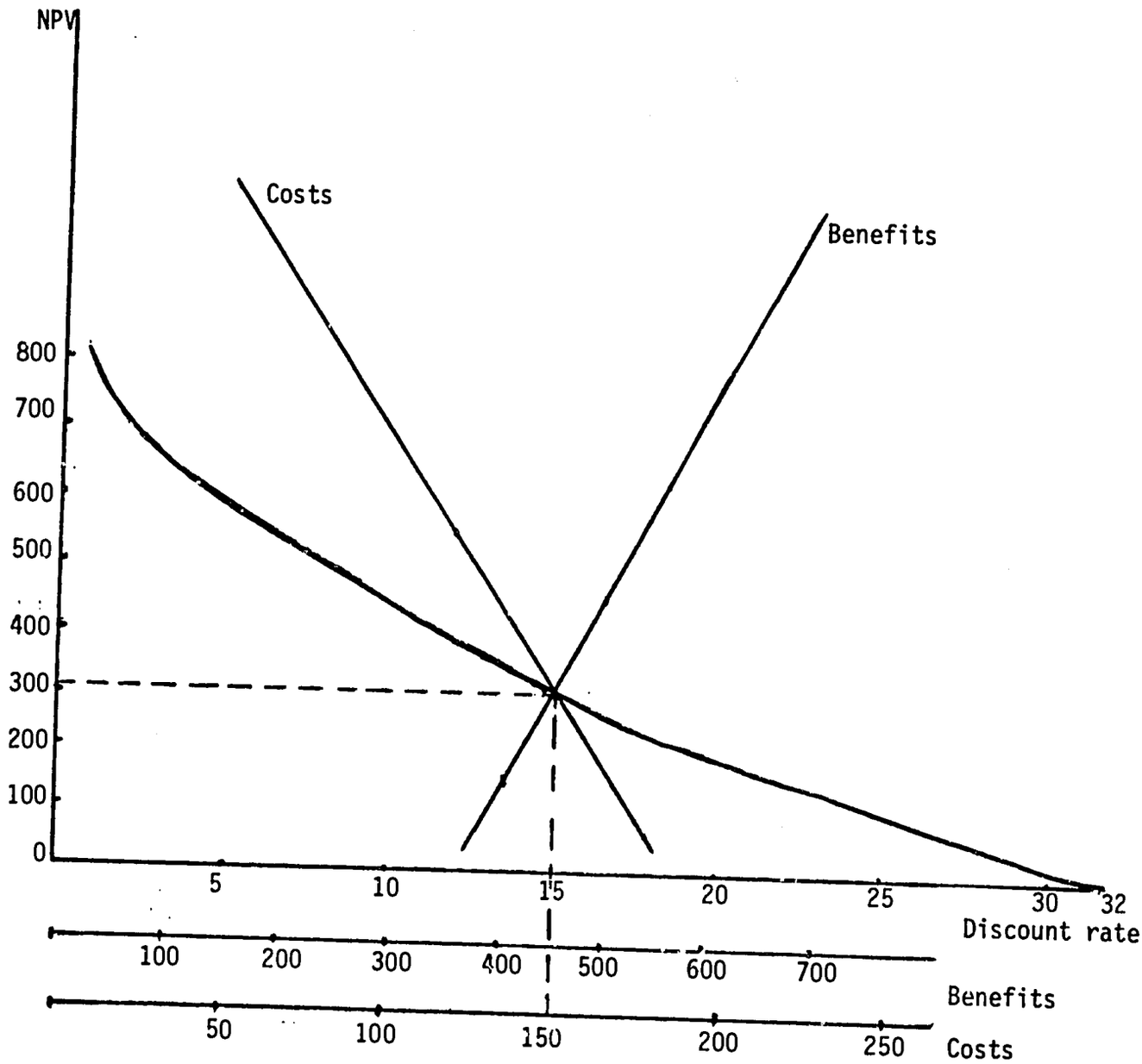
One way to portray the sensitivity of the analytical parameters is shown in Table 4.4. Based on the simple cash flows in Table 4.2 (Financial Analysis example), the Table 4.4 matrix shows how NPV changes as costs and benefits are increased or decreased by increments of 10 percent. The base case column shows the NPV's obtained using the original base case assumptions.

TABLE 4.4.--SENSITIVITY ANALYSIS, CHANGES IN NET PRESENT VALUE, FINANCIAL ANALYSIS
(Discount Rate: 15%, Base Case)

	-30%	-20%	-10%	Base Case	+10%	+20%	+30%
Cost	669	548	427	306	185	65	-56
Benefits	-144	6	156	306	456	607	757

The NPV's becomes increasingly attractive in a linear fashion as costs are decreased, or benefits are increased by increments of 10 percent. Cost increases or benefit decreases lower NPV's. It would take a 30 percent reduction in benefits to generate a negative NPV. The sensitivity of the NPV to costs, benefits and also the discount rate is shown graphically in Figure 4.1.

FIGURE 4.1.--SENSITIVITY ANALYSIS



The horizontal axes are calibrated so that the three curves on the graph coincide at the base case assumptions. By means of extrapolation or interpolation this graph can be used to trace the changes in NPV as a result of literally an infinite number of assumptions.

It is important that the results of an economic analysis of a project must always be interpreted with caution because no one can accurately predict the future behavior of economic parameters. For this reason the sensitivity analysis can be a powerful tool where optimistic and pessimistic scenarios can be used to bracket the base case assumptions. The optimistic scenario establishes a ceiling above which prices and costs are not expected to rise during the project period, and the pessimistic scenario establishes a conservative floor below which prices and costs are not expected to decline. If the pessimistic case is also economically feasible given the assumptions, one can be reasonably assume that the project is on safe economic grounds.

4.4 Case Study: Family-Sized Biogas Plant

The previous discussion on economic evaluation methodologies sets the stage for a case study of a family-sized biogas plant in India[5/]. The NPV criterion is employed to analyze the economic attractiveness of the required investments. Both financial and economic analyses will be presented

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[1/] This case study is drawn from: Bhatia, R. "Economic Appraisal of Biogas Units in India: Framework for Social Benefit Cost Analysis," Economic and Political Weekly, August 1977.

for a base case. Detailed sensitivity analyses are also carried out for the economic analysis to trace the impact on NPV's as base case assumptions are changed.

The biogas unit in India is assumed in this case study to be the smallest one available and has capacity to produce 70 cubic feet of gas per day, or enough to meet the daily cooking and lighting requirements for five people. This size unit requires dung input from four to five large animals.

4.4.1 Assumptions

The assumptions for the base case are as follows:

a. Costs The capitalization and operating costs are given in Table 4.5 for both the financial and economic analyses. The values are different because of the shadow prices used in the economic analysis. Skilled labor is assumed to be employable all the time and is valued at $71.40 for the installation of the digester well for both the financial and economic analyses. Unskilled labor is valued at one-half the rate of skilled labor for the financial analysis, and at zero for the economic analysis to reflect nonavailability of alternative employment.

The steel gas holder and required appliances are imported and subject to a pegged foreign exchange rate. A factor of 1.25 is added to the economic analysis cost side to neutralize the impact of the pegged rate and thus reflect the true economic costs of the project. The raw material input, dung,

TABLE 4.5.--CAPITALIZATION AND OPERATING COSTS, BIOGAS PLANT (IN US DOLLARS)

Costs and Benefits	Financial Analysis	Economic Analysis
Capitalization Costs		
1. Digester well:		
Skilled labor	$71.40	$71.40
Unskilled labor	35.70	0
Cement steel and other material	35.70 (x 1.25)=	44.60
2. Gas holder (steel)	116.60 (x 1.25)=	145.80
Applicances, misc.	32.00 (x 1.25)=	40.00
Operating Costs		
1. Dung	0	0
2. Labor for dung collection and operating the plant	9.00/yr	9.00/yr

is assumed to be a free good as the four to five animals are likely to be owned by the family installing the biogas unit. There also is no opportunity cost in terms of fertilizer value foregone since the slurry, once digested, still retains its fertilizer value. Labor for dung collection and maintenance of the unit is assumed at $9 per year for both financial and economic analyses.

b. Benefits The benefits of the biogas unit are given in Table 4.6 for both the financial and economic analyses. The unit produces a total of 70 cubic feet of biogas per day of which 20 cubic feet are assumed to be used for lighting purposes. This is sufficient for one lamp for four hours, or two lamps for two hours. The biogas used for lighting is valued at imported kerosene prices since electricity is not available.

The 20 cubic feet of biogas is equivalent to 0.37 liters of kerosene based on a conversion factor of 1 liter kerosene = 54.05 cubic feet gas. If the subsidized market price of kerosene to the final consumers is $0.25 per liter, the financial analysis benefit value is $33 per year, or 0.37 liters x 360 days x $0.25 = $33. The shadow price for kerosene is $0.40 per liter. On this basis the economic analysis benefit is $53 per year, or 0.37 liters x 360 days x $0.40 = $53. Thus, if biogas is available for lighting, society will not have to incur $53 per year in terms of equivalent quantities of kerosene.

The remaining 50 cubic feet of gas meets the daily cooking requirements for five people. It can substitute for fuel wood, which may or may not have a market price, or for other energy sources such as soft coke, which is plentiful in India and does have a market price. For this case study it is

TABLE 4.6.--BENEFITS FROM THE BIOGAS PLANT
(In US Dollars)

Costs and Benefits	Financial Analysis	Economic Analysis
Benefits		
Lighting		
Gas used at 20 ft^3/day and valued at equivalent kerosene prices	$ 33	$ 53
Cooking		
Gas used at 50 ft^3/day and valued at equivalent soft coke prices	31	20
Additional Fertilizer		
Additional N content of .6% in 13.36 tons of biogas slurry valued at area prices	35	55
Total	$99	$118

assumed that the biogas serves as a substitute for soft coke, having a market price of $25 per ton and a shadow price of $8 per ton. The latter assumes that two-thirds of the coke costs represent unskilled labor valued at zero wage rate.

The 50 cubic feet of gas produced per day is equivalent to 1.25 tons of coke annually. This quantity multiplied by $25 per ton yields an annual financial benefit of $31, and an economic benefit of $10 with the $8 per ton shadow price.

The final benefit-fertilizer, is based on the assumption that the digested slurry improves in nitrogen content by .6 percent and thus is more valuable. The assumed annual benefit for the financial analysis is $35, and $55 for the economic analysis based on $0.20 per kilogram market price and $0.30 shadow price for urea. 6/.

c. Discount Rate. Since the analysis concerns a family sized biogas unit the family itself is likely to bear the financial burden. Assuming

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6/ Urea has approximately 45% nitrogen content. If the digested slurry (13.36 tons/year) is higher in nitrogen concentration by 0.6 percent compared with cow dung the annual benefit attributable to the slurry is:

$$\frac{13360 \times .006\% \times \$.20}{.45} = \$35$$

unsubsidized credit, the finanical real discount rate applied is 30 percent. For the economic analysis representing a government-financed project, a shadow discount rate of 12 percent in real terms is applied.

d. Financing. One hundred percent equity financing is assumed for the financial analysis base case. A separate example will be presented showing 80 percent financing where the cost of borrowing is 20 percent in 3 years.

e. Project Duration. The project is analyzed over a 10-year period beginning in year 0 (the present) and ending in year 9. The biogas unit is assumed to have zero salvage value at the end of the project.

f. Changes in Prices and Costs. Prices and costs are held constant during the project period.

4.4.2 Results

Table 4.7 shows the timing and magnitude of the cash flows for the financial analysis base case. Year zero, the present, contains all of the capitalization costs plus one-half of the annual operating costs and benefits incurred in subsequent years. This assumes that the biogas unit is quickly installed and generates benefits in the first year. At a 30 percent discount rate, the NPV is $31, a feasible investment since the NPV is greater than zero.

TABLE 4.7.--FINANCIAL ANALYSIS OF FAMILY-SIZED BIOGAS PLANT, 100% EQUITY
(In US Dollars)

Costs and Benefits	Years 0	1	2	3	4	5	6	7	8	9
Costs										
Capitalization costs	291.4									
Operating costs	4.5	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Total cash outflow	295.9	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Benefits										
Lighting	16.5	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0
Cooking	15.5	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
Fertilizer	17.5	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Total cash inflow	49.5	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0
Net cash flow	-246.4	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0

NPV @ 30 percent = $31.3

Table 4.8 shows the financial analysis when 80 percent of the capitalization costs are borrowed at 20 percent and the remaining 20 percent of the capitalization costs are equity financed. The debt servicing of $106 annually contributes to the negative net cash flows in years 1, 2, and 3. This is offset, however, by a substantially smaller negative net cash flow in year 0, since the benefits are increased by the amount borrowed--$236.70. At a 30 percent discount rate the NPV is $69, or more than double the return in the 100% equity financing case. At a 12 percent discount rate, however, the NPV is $215 or lower than the 10 percent equity financing case, resulting from the proportionately higher impact of the debt servicing of 20 percent that the borrower must pay early in the project.

The economic analysis of the base case is presented in Table 4.9. At a 12 percent (shadow) discount rate and shadow pricing of costs and benefits, the NPV is an attractive $369.

4.4.3 Sensitivity Analysis

A sensitivity analysis showing how the economic analysis NPV changes as costs and benefits are increased or decreased by increments of 10 percent is given in Table 4.10. The base case column shows the NPV of $368 using the original assumptions. The NPV remains positive even in the face of a 40 percent reduction in benefits (total cash inflow), represented approximately by the elimination of the entire fertilizer benefit. On the cost side, a 40 percent increase reduces the NPV to $225.80.

TABLE 4.8.--FINANCIAL ANALYSIS OF FAMILY-SIZED BIOGAS PLANT, 20% EQUITY
(In US Dollars)

Costs and Benefits	Years 0	1	2	3	4	5	6	7	8	9
Costs										
Capitalization costs	291.4									
Operating costs	4.5	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Debt servicing (20%) (int. & principal)		106.0	106.0	106.0	106.0	106.0	106.0	106.0	106.0	106.0
Total cash outflow	295.9	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0
Benefits										
Lighting	16.5	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0
Cooking	15.5	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
Fertilizer	17.5	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Borrowed	236.7	0	0	0	0	0	0	0	0	0
Total cash inflow	286.2	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0
Net cash flow	- 9.7	-16	-16	-16	-90.0	90.0	90.0	90.0	90.0	90.0

NPV @ 30 percent = $69.4
NPV @ 12 percent = $215.26

TABLE 4.9.--ECONOMIC ANALYSIS OF FAMILY SIZED BIOGAS PLANT: BASE CASE, (In US Dollars)

Costs and Benefits	Years 0	1	2	3	4	5	6	7	8	9
Costs										
Capitalization costs	301.8									
Operating costs	6.5	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Total cash outflow	306.3	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Benefits										
Lighting	26.5	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0
Cooking	5.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Fertilizer	27.5	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0
Total cash inflow	59.0	118.0	118.0	118.0	118.0	118.0	118.0	118.0	118.0	118.0
Net cash flow	-247.3	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0	109.0

NPV @ 12 percent = $368.6.

TABLE 4.10.--SENSITIVITY ANALYSIS - ECONOMIC ANALYSIS, CHANGES IN NET PRESENT VALUE (NPV), DISCOUNT RATE: 8 PERCENT

Costs and Benefits	Net Present Value -40%	-30%	-20%	-10%	Base Case	+10%	+20%	+30%	+40%
Costs	$511.40	$475.70	$440.00	$404.30	$368.60	$332.90	$297.20	$261.50	$225.80
Benefits	78.20	150.8	223.40	296.00	386.60	441.20	513.80	864.40	659.00

Figure 4.2 shows the sensitivity of the NPV to changes in costs, benefits and the discount rate. At a 1 percent rate the NPV reaches a high of $686; and, at 42 percent, it reaches zero. Forty-two percent is also the IRR of the project. Again, the horizontal axes are calibrated so that the curves coincide at the base case assumptions.

As a final note it is important to emphasize that the economic analysis presented can include only quantifiable primary benefits and costs. In addition to these there are secondary effects that warrant recognition in a qualitative fashion such as the convenience of a clean fuel, reduction of the uncertainity of energy supplies, a renewable source of energy, and the employment of local people.

4.5 Setting the Stage

The economic evaluations given in this chapter are straightforward and represent a format for the evaluations to be given in Volumes III through VII. These investment analyses, it should be noted, are not site specific and lend themselves to flexible interpretation. It is not so much the magnitude of the results that is important but rather whether the results portray reasonable expectations of returns. Site specificity, for readers who may have detailed information available, can be approximated through the use of the sensitivity analyses.

The analyses presented in the subsequent volumes are based on a set of standardized assumptions concerning capitalization and operating costs, benefits, and discount rates. The assumptions common to all of the investment analyses are summarized in Table 4.11.

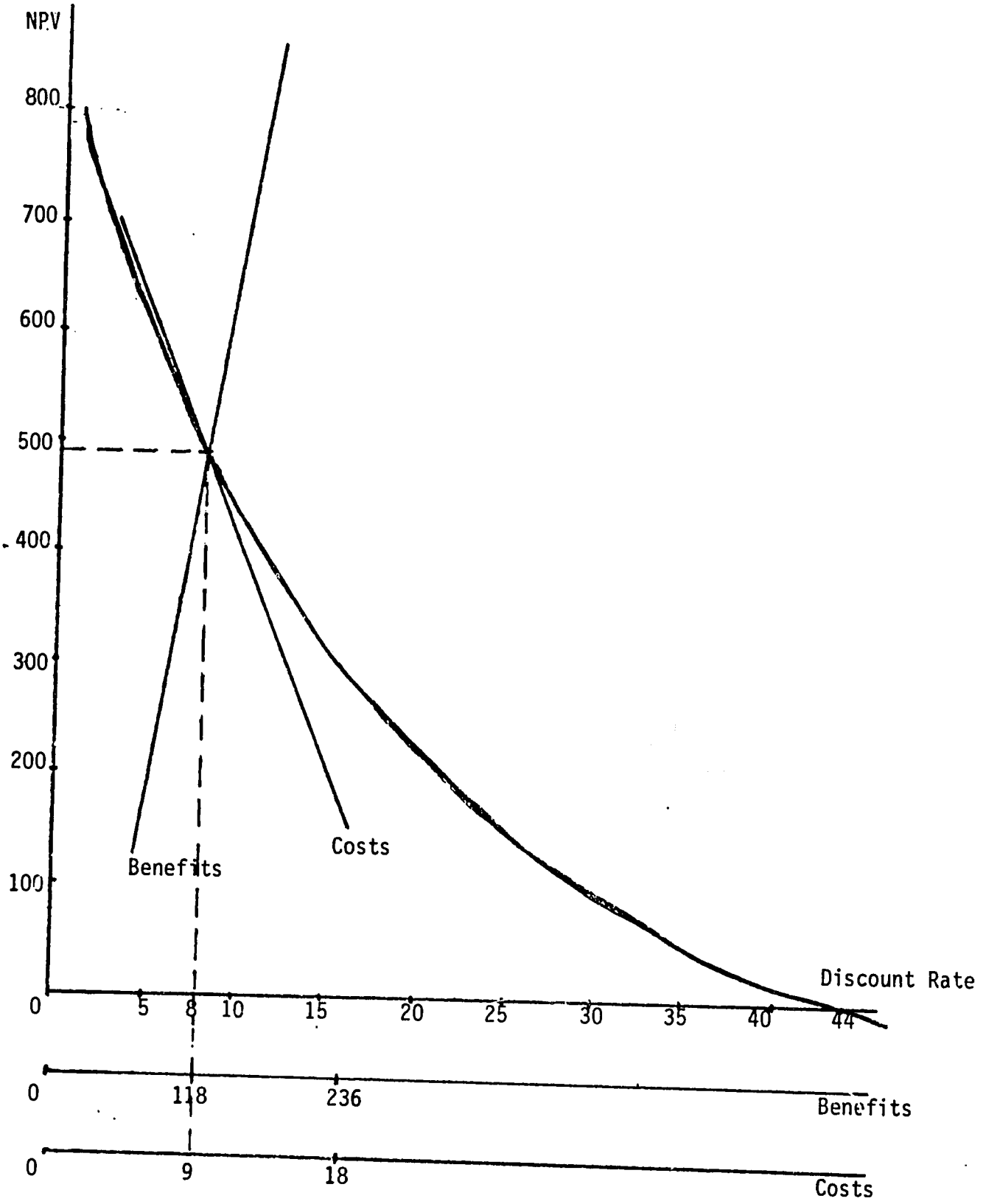

FIGURE 4.2.--SENSITIVITY ANALYSIS
ECONOMIC ANALYSIS
BASE CASE

Capitalization costs include necessary hardware and the erection of the unit on the site. It is assumed that the hardware must be imported and that the capitalization costs be inflated by a factor of 1.25 to reflect a pegged foreign exchange rate for the economic analysis. Skilled labor is valued at market prices for both the financial and economic analyses. Unskilled labor, on the other hand, is valued at half the market price for the economic analysis to reflect limited alternative employment possibilities. Benefits, or the bioenergy output produced, are valued by a factor of 1.5 times the market price to account for the desirability of substituting for fossil fuel imports. The discount rate is expressed in real terms--15 percent for the financial analyses, representing the opportunity cost of capital, and 8 percent for the economic analysis. The time period of for all the investment analyses is 10 years unless otherwise specified. Finally, costs and prices are held constant during the project period.

TABLE 4.11.--SUMMARY OF ASSUMPTIONS COMMON TO INVESTMENT ANALYSES IN VOLUMES III AND VII

Assumptions	Financial Analysis	Economic Analysis
Capitalization costs	Market price of unit(s)	Market price x 1.25
Operating costs		
Skilled labor	Market price	Market price
Unskilled labor	Market price	Market price x 0.5
Benefits	Market price	Market price x 0.5
Discount rate	15 percent	8 percent
Project duration	10 years	10 years
Changes in prices and costs over time	None	None

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CONVERSION FACTORS

Multiply	By	To Obtain
Acres	443560	Square feet
	0.004047	Square kilometers
	4047	Square meters
	0.0015625	Square miles
	4840	Square yards
Acre-feet	43560	Cubic feet
	1233.5	Cubic meters
	1613.3	Cubic yards
Angstroms	1×10^{-8}	Centimeters
	3.937×10^{-9}	Inches
	0.0001	Microns
Atmospheres	76	Centimeters of Hg ($0^{o}C$)
Atmospheres H_2O	1033.3	Centimeters of ($4^{o}C$)
	33.8995	Feet of H_2O ($39.2^{o}F$)
($32^{o}F$)	29.92	Inches of Hg
	14.696	Pounds-force/square inch
Barrels (petroleum U.S.)	5.6146	Cubic Feet
	35	Gallons (Imperial)
	42	Gallons (U.S.)
	158.98	Litres
British thermal Units	251.99	Calories, grams
	777.649	Foot-pounds
	0.00039275	Horsepower-hours
	1054.35	Joules
	0.000292875	Kilowatt-hours
	1054.35	Watt-seconds
British thermal units/hour	4.2	Calories/minute
	777.65	Foot-pounds/hour
	0.0003927	Horsepower
	0.000292875	Kilowatts
	0.292875	Watts (or joules/second
British thermal units/pound	7.25×10^{-4}	Calories/gram

Multiply	By	To Obtain
British thermal units/square foot	0.261246	Calories/square centimetre for langleys)
	0.292875	Watt-hours/square foot
British thermal units/ square foot/hour	3.15×10^{-7}	Kilowatts/square metre
	4.51×10^{-3}	Calories/square centimetre minute (or langleys/minute)
	3.15×10^{-8}	Watts/square centimetre
Calories	0.003968	British thermal units
	3.08596	Foot-pounds
	1.55857×10^{-6}	Horsepower-hours
	4.184	Joules (or watt-seconds)
Calories	1.1622×10^{-6}	Kilowatt-hours
Calories (food unit)	1000	Calories
Calories/minute	0.003968	British thermal units/ minute
	0.06973	Watts
Calories/square centimetre	3.68669	British thermal units/ square foot
	1.0797	Watt-hours/square foot
Calories/square centimetre/minute	796320	British thermal units/ square foot/hour
	251.04	Watts/square centimetre
Candle power (spherical	12.566	Lumens
Centimeters	0.032808	Feet
	0.3937	Inches
	0.01	Metres
	10,000	Microns
Centimeters of Hg ($0^{o}C$)	0.0131579	Atmospheres
	0.44605	Feet of H_2O ($4^{o}C$)
	0.19337	Pounds/Square inch
Centimeters of H_2O ($4^{o}C$)	0.0009678	Atmospheres
	0.01422	Pounds/square inch

Multiply	By	To Obtain
Centimeters/second	0.32808	Feet/second
	0.022369	Miles/Hour
Cords	8	Cord-feet
	128 (or 4 x 4 x 8)	Cubic feet
Cubic centimeters	3.5314667	Cubic feet
	0.06102	Cubic inches
	1×10^{-6}	Cubic meters
	0.001	Litres
	0.0338	Ounces (U.S. fluid)
Cubic feet	0.02831685	Cubic meters
	7.4805	Gallons (U.S. liquid)
	28.31685	Litres
	29.992	Quarts (U.S. liquid)
Cubic feet of H_2O (60°F)	62.366	Pounds of H_2O
Cubic feet/minute	471.947	Cubic centimeters/ second
Cubic inches	16.387	Cubic centimeters
Cubic inches	0.0005787	Cubic feet
	0.004329	Gallons (U.S. liquid)
	0.5541	Ounces (U.S. Fluid)
Cubic meters	1×10^{6}	Cubic centimeters
	35.314667	Cubic feet
	264.172	Gallons (U.S liquid)
	1000	Litres
Cubic yards	27	Cubic feet
	0.76445	Cubic meters
	201.97	Gallons (U.S Liquid)
Cubits	18	Inches
Fathoms	6	Feet
	1.8288	Metres
Feet	30.48	Centimeters
	12	Inches
	0.00018939	Miles (statute)
Feet of H_2O (4°C)	0.029499	Atmosphere
	2.2419	Centimeters of Hg (0°C)
	0.433515	Pounds/square inch

Multiply	By	To Obtain
Feet/minute	0.508	Centimeters/second
Feet/minute	0.508	Centimeters/second
	0.018288	Kilometers/hour
	0.0113636	Miles/Hour
Foot-candles	1	Lumens/square foot
Foot pounds	0.001285	British thermal units
	0.324048	Calories
	5.0505×10^{-7}	Horsepower-hours
	3.76616×10^{-7}	Kilowatt-hours
Furlong	220	Yards
Gallons (U.S., dry)	1.163647	Gallons (U.S. Liquid)
Gallons (U.S., liquid)	3785.4	Cubic centimeters)
	0.13368	Cubic feet
	231	Cubic inches
	0.0037854	Cubic meters
	3.7854	Litres
	8	Pints (U.S., liquid)
	4	Quarts (U.S., liquid)
Gallons/minute	2.228×10^{-3}	Cubic feet/second
	0.06308	Litres/second
Grams	0.035274	Ounces (avoirdupois)
	0.002205	Pounds (avoirdupois)
Grams/centimeters	9.3011×10^{-8}	British thermal units
Grams/square metre	3.98	Short tons/acre
	8.92	Pounds/acre
Horsepower	42.4356	British thermal units/ minute
	550	Foot-pounds/second
	745.7	Watts
Horsepower-hours	2546.14	British thermal units
	641616	Calories
	1.98×10^{6}	Foot-pounds
	0.7457	Kilowatt-hours
Inches	2.54	Centimeters
	0.83333	Feet

Multiply	By	To Obtain
Inches of Hg (32°F)	0.03342	Atmospheres
	1.133	Feet of H_2O
	0.4912	Pounds/square inch
Inches of H_2O (4°C)	0.002458	Atmospheres
	0.07355	Inches of Hg (32°F)
	0.03613	Pounds/square inch
Joules	0.0009485	British thermal units
	0.73756	Foot-pounds
	0.0002778	Watt-hours
	1	Watt-seconds
Kilocalories/gram	1378.54	British thermal units/ pounds
Kilograms	2.2046	Pounds (avoirdupois)
Kilograms/hectare	0.893	Pounds/acre
	0.0004465	Short tons/acre
Kilometers	1000	Metres
	0.62137	Miles (Statute)
Kilometers/hour	54.68	Feet/minute
Kilowatts	3414.43	British thermal units/ hour
	737.56	Foot-pounds/second
	1.34102	Horsepower
Kilowatt-hours	3414.43	British thermal units
	1.34102	Horsepower-hours
Knots	51.44	Centimeters/second
	1	Miles (nautical)/hour
	1.15078	Miles (statute)/hour
Langleys	1	Calories/square centimeters
Litres	1000	Cubic centimeters
	0.0353	Cubic feet
	0.2642	Gallons (U.S. liquid)
	1.0567	Quarts (U.S. liquid)
Pounds/acre	0.0005	Short tons/acre
Liters/minute	0.0353	Cubic feet/minute
	0.2642	Gallons (U.S. liquid/) minute

Multiply	By	To Obtain
Lumens	0.079577	Candle power (spherical)
Lumens (at 5 550 A)	0.0014706	Watts
Metres	3.2808	Feet
	39.37	Inches
	1.0936	Yards
Meters/second	2.24	Miles/hour
Microns	10000	Angstoms
	0.0001	Centimeters
Miles (statute)	5280	Feet
	1.6093	Kilometers
	1760	Yards
Miles/hour	44.704	Centimeters/second
	88	Feet/minute
	1.6093	Kilometers/hour
	0.447	Metres/second
Milliliters	1	Cubic centimeters
Millimeters	0.1	Centimeters
Ounces (avoirdupois)	0.0625	Pounds (avoirdupois)
Ounces (U.S. liquid)	29.57	Cubic centimeters
	1.8047	Cubic inches
	0.0625 (1/16)	Pint (U.S. Liquid)
Pints (U.S. Liquid)	473.18	Cubic centimeters
	28.875	Cubic inches
	0.5	Quarts (U.S. liquid)
Pounds (avoirdupois)	0.45359	Kilograms
	16	Ounces (avoirdupois)
Pounds of Water	0.01602	Cubic feet of water
	0.1198	Gallons (U.S. Liquid)
Pounds/acre	0.0005	Short tons/acre
Pounds/square inch	0.06805	Atmospheres
	5.1715	Centimeters of Hg (0^oC)
	27.6807	Inches of H_2O (39.2^oF)

Multiply	By	To Obtain
Quarts (U.S. liquid)	0.25	Gallons (U.S. liquid)
	0.9463	Litres
	32	Ounces (U.S. liquid)
	2	Pints (U.S. liquid)
Radians	57.30	degrees
Square centimeters	0.0010764	Square feet
	0.1550	Square inches
Square feet	2.2957×10^{-5}	Acres
	0.09290	Square meters
Square inches	6.4516	Square centimeters
	0.006944	Square feet
Square kilometers	247.1	Acres
	1.0764×10^{7}	Square feet
	0.3861	Square miles
Square meters	10.7639	Square feet
	1.196	Square yards
Square miles	640	Acres
	2.788×10^{7}	Square feet
	2.590	Square kilometers
Square yards	9 (or 3 x 3)	Square feet
	0.83613	Square meters
Tons (long)	1016	Kilograms
	2240	Pounds (avoirdupois)
Tons (metric)	1000	Kilograms
	2204.6	Pounds (avoirdupois)
Tons (metric)/hectare	0.446	Short tons/acre
Tons (short)	907.2	Kilograms
	2000	Pounds (avoirdupois)
Watts	3.4144	British thermal units/hour
	0.056591	British thermal units/minute
	14.34	Calories/minute
	0.001341	Horsepower
	1	joules/second

Multiply	By	To Obtain
Watts/square centimetre	3172	British thermal units/ square foot/hour
Watt-hours	3.4144	British thermal units
	860.4	Calories
	0.001341	Horsepower-hours
Yards	3	Feet
	0.9144	meters

Approximate equivalents:

1 stere: 0.72 cubic meters; 25.4 cubic feet (solid wood).
1 cord: 2.55 cubic meters; 90 cubic feet (solid wood).

GLOSSARY OF TERMS

Anthracite - A hard type of coal that gives much heat but little flame or smoke.

Bole - The main tree trunk

Canopy - The layer of tree crowns in a forest

Clearcut - A harvesting and regeneration technique in which in one operation all trees are removed from anarea regardless of size. Most used with species that require full sunlight to reproduce and grow well.

Coppice - The ability to regenerate by shoots or root suckers, or a forest so established.

Cultivar - A variety of a plant species in cultivation.

Density or Specific Gravity: Where given, these are based on air-dry samples, as to both weight and volume, and (wherever possible) for plantation-grown specimens.

Diameter - All tree trunk diameters were measured at breast height (1.37m).

Direct Seeding or Broadcast Seeding - Scattering seed over the area on which a forest stand is to be raised.

Ecotype - A group of plants within a species genetically adapted to a particular habitat.

Firewood - Although the terms "firewood" and "fuelwood" are generally used interchangeably, "firewood" connotes small scale use such as for home cooking, whereas "fuelwood" implies large-scale industrial use.

Innoculation - The deliverate introduction of organisms, usually microorganisms, into a new environment. Used here especially for the introduction of beneficial rhizobia bacteria into soils to improve growth of leguminous plants.

Insolation - Solar radiation, as received by the earth.

Laterite - A red, residual soil containing large amounts of aluminum and ferric hydroxides, found especially in well-drained tropical rain forests.

Lignotuber - Woody tuberous root that resprouts when the main stem (trunk) is damaged (found notably in some eucalypts).

Naturalize - To adapt a plant to a new environment; acclimate.

Nitrogen fixing - The conversion of elemental nitrogen (N_2) from the atmosphere to organic forms utilizable in biological processes.

Nodulation - The quality of having small knots or lumps on the roots, especially ones containing nitrogen-fixing bacteria.

Provenance - The original geographic source of seed, seedlings, or cuttings.

Provenance Trial - A planting of populations of different provenances of the same species, usually to identify those most suitable for silvicultural use in the test region.

Pulse Crop - Leguminous crop with edible seeds such as peas, beans, and peanuts.

Ratoon - A shoot growing from the root of a plant that has been cut down, used expecially for sugarcane.

Root Sucker - A shoot arising from below the ground level either from a root or a rhizome.

Saw Timber - Trees of size and quality for producing sawn wood.

Shade Intolerance - The characteristic of some species to regenerate naturally only in open sunlight.

Silvics - The study of the life history and general characteristics of trees and forests.

Silviculture - The theory and practice of controlling the establishment, composition and growth of forests.

Ton - The symbol "t" is used for metric ton (2,200 lb avoirdupois).

Yield - Figures quoted for each of the species in this report are merely rough estimates. Yields and densities vary greatly with age of the tree and the locale (the wood of Eucalyptus grandis, for example, has a specific gravity of 0.82 in natural Australian stands and 0.55 in plantations in South Africa). Some of the species do not produce usable construction timber and have not previously attracted the attention of foresters, so that the figures quoted (if any) may be based on a single sampling.

Anaerobic - In the absence of air (i.e. oxygen).

Biogas - The gaseous product obtained by the anaerobic fermentation of organic materials. Since methane is the chief constituent of biogas, the term is often loosely used as synomymous with methane.

Cellulose - Biological polymer composed of sugar molecules; the basic building material of plant fiber.

Cellulolytic - Having the property of hydrolyzing (i.e., making water-soluble) cellulose.

C/N Ratio - The ratio by weight, of carbon to nitrogen.

Detention time - the average time that a meterial remains in the system, generally calculated by dividing the total weight of material in the system by the weight removed per unit time (hour, day, week, etc.)

Digestion - The process by which complex organic molecules are broken down into simpler molecules; in this case the anaerobic process (fermentation) by which bacteria accomplish this decomposition.

Enzyme - Biological catalyst (a protein) that facilitates the breakdown of complex organic molecules into simpler molecules.

Fermentation - The biological process by which organic material is broken down into simpler constituents by microorganisms, usually yeasts; see Digestion.

Lipids - Fatty material.

Methane - The simplest hydrocarbon, consisting of one carbon atom and four hydrogen atoms (CH_4); a flammable, odorless gas.

TKN - Total Kjedahl nitrogen; the amount of nitrogen obtained by the Kjeldahl method of digesting organic material with sulfuric acid.

Total Solids - The weight of the solid matter remaining after a sample is dried to constant weight at 103+1°C.

Volatile Acids. The low molecular weight fatty acids.

Volatile solids. The portion of solids volatilized at 550+50°C; the difference between the total solids content and the ash remaining after ignition at 550+50°C.

BIOMASS CONVERSION TECHNOLOGIES

State of the Art

VOLUME II: COUNTRY STATISTICAL DATA

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OVERVIEW OF THE VOLUME

This volume presents statistical profiles of agricultural and forest biomass production, fossil fuel energy consumption, and demographic statistics for sixty-six developing countries, the majority of which are recipients of U.S. aid. The information from various sources is standardized in tabular format. The following geographical breakdown was used:

1. Africa
   - -Sahel countries
   - -Other West Africa
   - -East Africa

2. Asia and Pacific

3. Latin America and Caribbean

The Near East countries (including North Africa) were excluded because they have little potential for energy from biomass and several of the countries are net energy exporters.

The purpose of this volume is to give the reader a general background on resource availability in individual countries. The information is intended to be used in conjunction with the other volumes. For example, the straw and chaff residue factors given in Volume I, can be used in conjunction with the agricultural production tables in this volume to obtain estimates of the

biomass for energy potential from agriculture in individual countries. Similarly, the table on livestock manure production in Volume I, can be used in conjunction with the livestock statistics given in this volume to obtain approximate estimates of the biogas potential in individual countries.

The statistical information provided for each of the sixty-six countries include demographic, land area and climate, agricultural production, forest production, livestock, and fossil fuel consumption data. The items included in the country data tables are briefly reviewed below.

Demographic data. The tables include population for 1979 expressed in thousands of people, population growth rates expressed in annual percentage growth for the 1970-78 period, food consumption per capita expressed in calories for 1979, the percentage of daily food requirement reached in the country, and the gross national product (GNP) per capita for 1977.

The population growth rate is an important parameter when estimating the food and energy requirements of a country. In developing countries where fuelwood is the major cooking/heating fuel, population growth has greatly contributed to deforestation and this should be taken into account when plans for biomass production and usage are made.

The percentage of daily food requirement achieved in a country is an indication of the potential surplus or deficiency of food crops. A

potential surplus, suggested by a percentage of daily food requirement larger than 100 percent could possibly be used as feedstock for energy production.

Per capita income reported in the tables is a measure of relative standards of living. It is also an indication of the potential for implementation of bioenergy systems. For example, low income rural families would probably not be able to invest in biogas family digesters unless subsidies or other financing mechanisms are available.

Land Area and Climatic Summary. The tables report land area of the country divided into areas of arable, irrigated, and forest land, as well as mean annual temperature and precipitation. The forest land category is generally the largest, since it includes both shrub land and open (deforested) land. These are often classified as permanent pasture in other statistical sources. Forest land may also overlap in the arable land category because of the high incidence of shifting agriculture (SHAG) in most developing countries. SHAG areas are generally forested areas that are temporarily converted to agriculture for two to three years and then fallowed for a period until soil productivity is restored. They are classified as arable or forested land in different statistical sources. In the tables, therefore, it is possible that the sum of all land areas (arable, forest, and irrigated) could exceed the reported total land area.

Climate is characterized by mean annual temperature and mean annual precipitation. These parameters, however, only give a general indication

of the country's climate. There are wide climatic variations within countries that must be taken into account when regional biomass assessments are made.

Agricultural Production. The tables list the areas planted and yields of the major agricultural crops by individual countries. Yields are expressed in weights of food products, including their moisture content at harvest. Grain weights exclude straw, chaff, and husk. Root crop and sugarcane production are expressed in fresh weights. Coconut production is expressed in terms of weight of the whole nut excluding only the outer fibrous husk. Production of nuts relates to nuts in the shell or in the husk. Production of coffee refers to green beans and production of tea relates to made tea. Production of tobacco refers to farm sales weight (about 10 percent moisture). The production data quoted in the tables can be used in conjunction with the residue factors given in Volume I to estimate the amounts of residues available for each crop.

Forest Production. Forest production is described in a set of five tables: forest area, forest biomass potential, roundwood production and utilization, and mean annual increments of plantations.

Forest areas are divided into closed forests, open forests, shrub land, and fallow land. Closed forests have canopies in which individual tree crowns are nearing general contact with one another. Plantations are cultivated

forests planted in order to produce industrial wood or fuelwood. Shrub land is an area where trees are no larger than 10 centimeters diameter-breast-height (dbh - diameter 1.37 meters above ground level). Fallow land is recently cutover open or closed forest land.

The tables describing the forest biomass potential distinguish between the types of forest lands discussed above and between broad-leaf and coniferous trees, and productive and unproductive areas. Unproductive areas include national parks, reserves, marginal land, steep, inacessible slopes, etc. Productive areas include everything else except the shrub land category. Volumes given in cubic meters include the tree bole over bark for trees larger than 10 centimeters dbh excluding the volume of the crown, small trees, and shrubs. Whole tree volumes include the tree bole over bark larger than 10 centimeters dbh plus the volume of crown and biomass considered to be 40 percent of gross bole volume (FAO, 1981). Shrubs and small trees in closed and open forests are biomass material in addition to trees larger than 10 centimeters dbh.

The tables also include total, average, and annual average biomass potential. The total is the amount of forest biomass that would be available if all forest lands were harvested at one time. The average potential is the ratio of the total potential divided by the total forest area (cubic meters per hectare); this number is probably a rough measure of the potential of the land in terms of forest production and it indicates average density. This is an important parameter because the time, effort, and energy required to collect a given amount of wood is inversely

proportional to the density of the forest. Average potentials can be obtained for the various types of forests--closed, shrub land, etc.--using the appropriate data from the tables.

The last column of the forest biomass potential tables estimates the annual average potential for fuelwood production in cubic meters per hectare per year (m^3/ha/year). This potential reflects the amount of biomass material usable for energy--tops, branches, crown, small trees, shrubs--excluding the boles of trees larger than 10 centimeters dbh. To derive the annual average fuelwood potential, the productivity for fuelwood material (m^3/ha/year) for various classes of land, as estimated by the University of Idaho (1982), was first multiplied by the area (ha) of the classes of land on which this productivity is recorded (closed forest, open forest, etc.). The total annual potential--the sum of the annual potentials for all classes of land--was then divided by the total forest area: this is the number quoted by country in the last column of the table (average yearly fuelwood potential). This number represents the amount of fuelwood which can be harvested yearly on a sustained basis without depleting the forest resource. A comparison of the number in the last column (average yearly fuelwood potential) with the next to the last column (average potential) gives an estimate of the fraction of the forest resource which can be harvested annually without risk of deforestation.

As an example, the data of Table 1.5 Forest Biomass Potential By Country, Africa: Sahel, suggests that in Chad about 0.45 m^3/ha out of the biomass

potential of 21.9 m^3/ha could be harvested yearly without depletion of the forest resorce. This suggests that fuelwood could be harvested on a 49-year rotation without depleting the resource. Exceeding this rate of harvest will ultimately result in deforestation. The country-by-country data provided in the University of Idaho report (1982) can be used to estimate the average annual fuelwood production potential for various types of forest land (closed forest, open forest, shrub land, etc).

Trends and projections of forest resource utilization are important in planning biomass for energy projects. The tables describing roundwood production and utilization also provide data on total roundwood production in 1979 divided into industrial roundwood, fuelwood, and charcoal. Future production is projected by linear trends of the form:

$Y = a + bx$ where

Y = production

a = Y axis intercept

b = slope of the trend line

x = time (year)

The trends are based on data from 1968 to 1979. Closeness of the fit is indicated by the correlation coefficients (cc) column in the Tables. A high correlation coefficient (cc close to ± 1) indicates that the data points are well clustered around the derived trend line and that the projections are reasonable estimates. Low correlation coefficients reduce the credibility of the projections.

The tables devoted to plantation productivities report mean annual increments (MAI) or ranges of MAI for various plantation species by countries. The wide ranges of MAI's sometimes quoted may be a result of differences in soils and/or climate, differences in record keeping, etc. Used with caution the MAI data can provide estimates of the biomass potential of plantations designed for industrial or fuelwood production.

Expanding demand for fuelwood has resulted in over utilization of the forest resource and is a major cause for deforestation in many countries. To obtain an estimate of the potential impact of fuelwood demand on forest resources, a sixth table was prepared for each of the regions considered. The table compares the current and projected fuelwood utilization to the fuelwood production that can be tolerated on a sustained basis without depleting the forest resource. The fuelwood utilization for 1979 and for 1990 (projected) is obtained from the table describing roundwood production and utilization. The tolerated fuelwood utilization is obtained by multiplying the annual average potential for fuelwood production (m^3/ha/year in the Table of Forest Biomass Potential) by the total forest area (ha in the Table of Forest Area). If the present and/or projected fuelwood utilization rate exceeds the annual potential, deforestation is occurring. The table provides an overall indication of potential over utilization of forests resources on a country-by-country basis.

It must, however, be recognized that even in countries showing an average fuelwood consumption below the average fuelwood potential, deforestation

can occur locally or regionally: large forest resources may be too remote from population centers to contribute to the fuelwood supply and as a result forests close to population centers may be completely over exploited. The table therefore provides a global view of the impact of fuelwood demand on forests but more regionally specific assessments will have to be made when analyzing specific biomass for energy projects. The table also shows only the amounts of fuelwood utilized that have been recorded: significant amounts of unrecorded cuttings probably occur that could make the situation worse than the table suggests.

Further details concerning the forest resources by countries can be found in the University of Idaho report (1982). A table of conversion factors is provided in Appendix 1.

Livestock Statistics. Livestock numbers are given for all domestic animals irrespective of their age and place or the purpose of their breeding. Cattle therefore, includes milk cows, steers, etc. Before estimating the biomass potential of livestock, it will be necessary to determine the extent to which animals are confined.

Fossil Fuel Consumption. Consumption data of gasoline, diesel oil, kerosene, residual fuel oil, and liquefied petroleum gas (LPG) are given for the year 1979. Linear trends for data covering the 1970-1979 period are also given.

The statistical data presented in this volume should be used with caution. The data provide an overall picture of the biomass resources of a country, whereas significant regional/local fluctuations that can occur are not accounted for in this volume. For example, the forest resources of a country may appear statistically substantial, although in fact, they may be too distant or inaccessible to be of real value as potential fossil fuel substitutes. The global overview derived from this volume will eventually have to be refined through regional and site evaluations before a biomass for energy project can be adequately designed.

CHAPTER 1. AFRICA

The African continent is divided into three geographical subregions -- Sahel, Other West Africa, and East Africa. Statistical profiles for each region and by country are given below.

1.1 Sahel

The countries included in this subregion are: Cape Verde, Chad, Gambia, Mali, Mauritania, Niger, Senegal, and Upper Volta. The Sahelian countries, bordering the great Sahara desert in the north, are poorly endowed with resources and are among the poorest of the poor nations in the world. These countries generally have little arable land and low precipitation, and their potential for biomass producton and utilization for energy is small.

1.1.1 Demographic Summary

Demographic summaries for the eight Sahelian countries are given in Table 1.1. Population ranges from a low of 319,000 in the island country of Cape Verde, to more than 6.7 million people in the landlocked country of Upper Volta. The highest population growth rate is found in Niger, 3.3 percent per year. All Sahelian countries are deficient in terms of calorie food consumption per capita. Mali is meeting only 75 percent of the requirements, while Gambia has almost reached the sufficiency level at 98 percent of the daily requirement. Gross national product per capita is

TABLE 1.1.—DEMOGRAPHIC SUMMARY, AFRICA: SAHEL

Country	Population (x 1,000) 1979)	% Growth 1970-78	Food Consumption per Capita (Calories) 1979	% of Requirements	$ GNP per Capita 1977
Cape Verde	319	—	--	--	--
Chad	4,417	2.2	1,762	89	130
Gambia	587	3.1	2,318	98	210
Mali	6,465	2.5	2,117	75	120
Mauritania	1,588	2.7	1,976	87	270
Niger	5,150	3.3	2,139	83	190
Senegal	5,518	2.6	2,261	91	380
Upper Volta	6,728	1.6	1,875	78	140

Note: — Not available.

Source: World Bank, 1980.

also lowest in Mali at $120 per capita per year. Senegal has the highest per capita income among the Sahelian countries, $380 per year.

1.1.2 Land Area and Climate

The largest country in the Sahel is Chad with 128 million hectares, followed by Niger and Mali (Table 1.2). Gambia has the largest proportion of arable land relative to total area (23 percent) as well as the highest annual precipitation (1,090 millimeters). Mauritania has the smallest proportion of arable land relative to total land area, less than 1 percent, and also the lowest annual rainfall. The forest land category ranges from 69 percent of the total land area in the Gambia to about 2 percent in Niger. Only Gambia has more than 1 percent of total land area in irrigated agriculture. Mean annual temperatures are fairly uniform throughout the Sahelian countries with the exception of the much cooler Cape Verde islands.

1.1.3 Agricultural Production

Crops with relatively high energy potential and yields by country are given in Table 1.3. Millet is by far the biggest crop among the Sahelian countries with a total of 7.3 million hectares under cultivation, followed by sorghum and peanuts.

1.1.4 Forest Production

Forest areas by type and country are presented in Table 1.4. Open forest and shrub land occupy the largest fraction of the total forest land in all

TABLE 1.2.—LAND AREA CLIMATIC SUMMARY (1979), AFRICA: SAHEL
(In Thousands of Hectares)

Country	Total	Arable	% of Total	Irrig.	% of Total	Forest	% of Total	Mean Annual Temp. (°C)	Mean Annual Precip. (mm)
Cape Verde	403	40	10	2	<1	--	--	17.8	400
Chad	128,400	1,950	2	2	<1	24,053	19	28.2	810
Gambia	1,130	265	23	27	2	776	69	26.8	1,090
Mali	124,000	2,050	2	95	<1	2,000	16	28.3	690
Mauritania	103,070	195	<1	8	<1	--	--	26.9	240
Niger	126,700	3,112	3	34	<1	3,000	<2	28.0	470
Senegal	19,672	2,404	12	127	<1	1,750	9	26.7	780
Upper Volta	27,420	5,633	21	3	<1	4,500	16	28.0	910

Note: -- Not available.

Sources: USDA, Economic Botany Laboratory, 1981.
Wernstedt, 1972.
University of Idaho, 1982.

TABLE 1.3.--AGRICULTURAL PRODUCTION BY COUNTRY (1979), AFRICA: SAHEL

Crop	Cape Verde Hectares Planted (x 1,000)	Cape Verde Yield (kg/ha)	Chad Hectares Planted (x 1,000)	Chad Yield (kg/ha)	Gambia Hectares Planted (x 1,000)	Gambia Yield (kg/ha)	Mali Hectares Planted (x 1,000)	Mali Yield (kg/ha)	Mauritania Hectares Planted (x 1,000)	Mauritania Yield (kg/ha)	Niger Hectares Planted (x 1,000)	Niger Yield (kg/ha)	Senegal Hectares Planted (x 1,000)	Senegal Yield (kg/ha)	Upper Volta Hectares Planted (x 1,000)	Upper Volta Yield (kg/ha)	Total Hectares Planted (x 1,000)
Wheat	—	--	2	4,000	--	--	2	1,333	--	5,000	2	1,056	--	--	--	--	6
Rice paddy	--	—	40	750	25	1,400	160	1,107	2	2,000	25	960	80	1,625	40	1,000	372
Barley	—	—	--	--	--	--	--	--	--	667	--	--	--	--	--	--	--
Corn	10	100	10	1,500	9	1,176	90	667	9	556	7	1,143	50	1,000	120	667	305
Sorghum	—	—	—	--	--	--	--	--	--	--	810	427	--	--	1,000	600	1,810
Millet	—	—	1,140	509	35	714	1,400	531	110	318	2,800	445	900	556	900	444	7,285
Potatoes	—	13,333	3	4,960	—	--	--	--	--	13,333	—	--	1	5,833	—	—	[illegible]
Sw. potatoes	—	20,000	6	5,700	—	—	3	12,467	5	400	4	7,500	3	2,321	15	2,800	36
Cassava	—	30,000	40	3,614	2	3,182	5	8,000	--	—	25	8,400	32	4,722	6	6,774	110
Soybeans	—	—	--	--	--	--	--	--	--	—	--	--	--	--	--	--	--
Peanuts	—	—	40	2,125	100	1,500	200	893	5	700	—	--	950	1,053	170	441	1,465
Castor beans	—	3,000	--	--	—	--	--	--	--	—	—	--	--	--	--	—	--
Rape seed	—	—	--	—	--	—	--	--	--	--	—	--	--	--	--	--	--
Sesame seed	—	—	28	400	--	—	--	--	--	--	--	—	--	—	40	178	68
Linseed	—	—	--	—	—	—	--	--	--	—	—	--	--	—	—	--	--
Seed cotton	—	—	243	473	2	703	109	1,239	--	--	9	444	40	1,250	72	836	475
Coconuts	—	—	--	--	—	--	--	--	--	--	--	--	--	--	--	--	--
Sugar cane	1	16,000	3	86,000	--	--	2	66,727	--	--	4	38,750	6	50,000	4	105,000	20
Gr. coffee	—	400	—	--	—	--	--	--	--	--	--	--	--	--	--	--	--
Tea	—	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tobacco	--	--	--	1,545	—	--	1	800	--	--	1	477		1,522	2	526	4

Note: -- Not available.

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 1.4.—FOREST AREA, BY COUNTRY, AFRICA: SAHEL
(In Thousands of Hectares)

Country	Closed Forest		Open Forest	Shrub Land	Fallow Land		Total
	Natural	Plantations			Closed	Open	
Cape Verde	—	—	—	—	—	—	—
Chad	500	3	13,000	9,750	—	800	24,053
Gambia	65	1	150	360	—	200	776
Mali	—	2	8,800	6,000	—	2,500	17,302
Mauritania	—	—	—	—	—	—	—
Niger	—	6	2,900	6,000	—	3,000	11,906
Senegal	220	15	10,825	1,365	—	1,750	14,175
Upper Volta	—	12	7,200	3,000	—	4,500	14,712

Note: — Not available.
Source: University of Idaho, 1982.

countries. Table 1.5 presents the total forest biomass potential by country and types of forest lands. It is apparent that in almost all Sahelian countries the major forest resources are found in open forest as trees and shrubs and small trees. The average forest biomass potential is low, ranging from about 10 to about 25 m^3/ha (a factor of 10 lower than in many areas of the world). Table 1.6 shows the allocation of the total roundwood production between fuelwood/charcoal production and industrial roundwood by countries for the year 1979 and linear production trends.

The high correlation coefficients in all the cases indicate that the data points for the period considered are well clustered around the trend line and therefore that the predicted annual increases in roundwood production (and consumption) are reasonable estimates.

In all Sahelian countries at least 80 percent of the recorded roundwood production is used for fuelwood or charcoal. In all countries, the annual rate of increase of fuelwood production (expressed in percent as b/a) is comparable or slightly higher than the percentage rate of population growth (See Table 1.1).

Plantations are not widely established in Sahelian countries as shown in Table 1.4. A few have been established, however, and some growth data and mean annual increment measurements have been reported for several species. These are given in Table 1.7.

TABLE 1.5.—FOREST BIOMASS POTENTIAL BY COUNTRY, AFRICA: SAHEL
(In Millions of Cubic Meters)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Closed Forests						Open Forests					Fallow Land				
	Broad Leaf		Coniferous													
Country	Pro-ductive	Unpro-ductive	Pro ductive	Unpro-ductive	Whole Trees	Shrub a Small Trees	Pro-ductive	Unpro-ductive	Whole Tree	Shrub a Small Trees	Shrub Land	Closed	Open	Total Biomass Poten-tial	Average Potential (m3/ha)	Average Yearly Fuel wood Potential (m^3/ha/yr)
Cape Verde	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chad	60.0	—	—	—	84.0	7.5	7.5	105	252.0	130.0	48.8	—	4.0	526.3	21.9	0.45
Gambia	0.3	4.8	—	—	7.1	1.0	—	1.5	2.1	1.5	1.8	—	1.0	14.5	18.7	.49
Mali	—	—	—	—	—	—	28.5	78.5	149.8	88.0	30.0	—	12.5	280.3	16.2	.32
Mauritania	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Niger	—	—	—	—	—	—	4.5	26	42.7	29.0	30.0	—	15.0	116.7	9.8	.19
Senegal	1.7	8.3	—	—	14.0	3.3	61.0	90.3	211.8	108.3	6.8	—	8.8	353.0	24.9	.52
Upper Volta	—	—	—	—	—	—	34.0	63.5	136.9	72.0	15.0	—	22.5	246.4	16.7	.30

Note: — Not available.
Source: University of Idaho, 1982

1. Closed forest has canopy in which individual tree crowns are nearing general contact with one another.
2. Biomass volume include the tree bole over bark for trees <10cm dbh; volume of crowns, small trees, and shrubs not included.
3. Includes national parks, reserves, marginal land, steep, inaccessible slopes, etc.
4. "Whole tree" includes the tree bole over bark <10cm dbh plus volume of crown and biomass, considered to be 40 percent of gross bole volume (FAO, 1981).
5. Shrubs and small trees on closed and open forest land in addition to trees <10cm dbh.
6. Biomass volumes on shrub land not containing trees <10 cm dbh.
7. Fallow land is recently cutover open or closed forest land.
8. Sum of columns 5, 6, 9, 10, 11, and 13.

TABLE 1.6.—PRODUCTION AND UTILIZATION OF ROUNDWOOD 1979, AFRICA: SAHEL
(In Thousands of Cubic Meters)

Country	Total	a 1/	b 2/	cc 3/	Industrial	a	b	cc	Fuel wood Charcoal	a	b	cc
Cape Verde	—	—	—	—	—	—	—	—	—	—	—	—
Chad	7,490	5,726	142.5	0.998	440	343.0	7.85	.994	7,050	5,383	134.70	0.998
Gambia	857	593	22.2	.999	10	10.0	—	1	847	583	22.20	.999
Mali	28,619	20,891	621.3	.998	262	208.0	4.20	.949	28,357	20,684	617.10	.998
Mauritania	615	481.8	10.8	.997	43	34.4	.66	.977	572	446	10.20	.998
Niger	2,861	2,011	68.8	.998	205	139.0	5.50	.998	2,656	1,872	63.30	.998
Senegal	2,774	1,917	71.7	.999	470	310.0	13.20	.989	2,304	1,607	58.50	.999
Upper Volta	4,779	3,625	93.8	.999	450	417.0	3.60	.779	4,329	3,208	90.20	.997

Note: — Not available.

Source: FAO, 1979.

1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

TABLE 1.7.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY, AFRICA: SAHEL
(In Cubic Meteors per Hectare per Year)

Country	Species 1	2	3	4	5
Cape Verde	10-15	4	1.	—	—
Chad	—	—	—	—	—
Gambia	—	—	—	6.5-20	—
Mali	—	6	—	7.0- 9.5	5
Mauritania	—	—	—	—	—
Niger	—	—	—	—	—
Senegal	—	—	—	—	—
Upper Volta	—	—	—	—	—

1. Pinus radiata - Pine
2. Eucalyptus spp. - Eucalyptus
3. Prosopis juliflora - Mesquite, algarroba
4. Gmelina arborea - Gmelina, yemane
5. Azadirachta indica - Neem, Nim.

Note: — Not available

Source: University of Idaho, 1982.

Table 1.8 compares the current and projected fuelwood utilization to tolerable production: in all countries except Senegal, the sustainable production of fuelwood is or will soon be exceeded by fuelwood demanmd resulting in the already recorded problems of systematic deforestation.

1.1.5 Livestock Summary

Livestock statistics by country are given in Table 1.9. In terms of pure numbers, chickens are by far the most numerous in the Sahelian countries followed by goats and sheep. There is little energy potential from goats and sheep, however, since they are generally not confined. Cattle, on the other hand, being almost as plentiful as either sheep or goats, may have a greater potential for energy since manure production is much higher and confinement, or semiconfinement, is more common.

1.1.6 Fossil Fuel Consumption

Consumption of gasoline, diesel oil, kerosene, residual fuel oil, and liquefied petroleum gases by individual countries is given in Table 1.10. In addition to the consumption figures given for the year 1979, linear trends are also given. Since all of the b-coefficients in Table 1.9 are positive, consumption of all petroleum-derived fuels in all eight countries is expected to increase over time.

TABLE 1.8.--COMPARISON OF PRESENT AND PROJECTED FUELWOOD UTILIZATION WITH TOLERATED FUELWOOD UTILIZATION, AFRICA: SAHEL
(In Thousand Cubic Meters)

Country	Fuelwood Utilization[1]		Tolerated Fuelwood Utilization[2]
	1979	1990	
Cape Verde	--	--	--
Chad	7,050	11,579	10,824
Gambia	847	1,094	380
Mali	28,357	35,077	5,537
Mauritania	572	681	--
Niger	2,656	3,328	2,262
Senegal	2,304	2,953	7,371
Upper Volta	4,329	5,283	4,414

1. Derived from Table 1.6

2. Derived from Tables 1.4 and 1.5

TABLE 1.9.—LIVESTOCK SUMMARY (1979), AFRICA: SAHEL

Country	Horses	Cattle	Camels	Pigs	Buffalo	Sheep	Goats	Asses/Mules	Chickens	Turkeys	Ducks
Cape Verde	61	12	0	20	0	2	22	78	62	0	0
Chad	154	4,070	410	6	0	2,278	2,278	271	2,940	0	0
Gambia	0	280	0	9	0	95	92	4	260	0	0
Mali	180	4,459	208	31	0	6,067	5,757	489	10,884	0	0
Mauritania	23	1,600	720	0	0	5,200	3,250	220	3,000	0	0
Niger	230	2,995	330	29	0	2,500	6,400	440	7,600	0	0
Senegal	271	2,806	4	182	0	1,884	1,000	202	7,306	0	0
Upper Volta	90	2,700	5	170	0	1,850	2,700	180	13,100	0	0
Total	1,009	18,922	1,677	447	0	19,876	21,499	1,884	45,152	0	0

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 1.10.—PETROLEUM-DERIVED FUEL CONSUMPTION BY PRODUCT 1979, AFRICA: SAHEL
(In Thousands of Metric Tons)

Country	Gasoline				Diesel Oil (Distillates)				Kerosene				Residual Fuel Oil (Bunker Oil)				Liquefied Petroleum Gases (LPG)			
	Total Consumption	a[1]	b[2]	cc[3]	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc
Cape Verde	—	—	—	—	20	1.6	1.9	0.98	—	—	—	—	3	-0.27	0.3	0.95	—	—	—	—
Chad	23	12.1	1.1	0.90	33	18.4	1.6	.89	—	—	—	—	—	—	—	—	—	—	—	—
Gambia	20	5.5	1.4	.93	23	1.7	2.0	.91	4	0.7	0.3	0.90	—	—	—	—	—	—	—	—
Mali	48	24.0	2.4	.96	50	21.6	3.2	.96	10	9.1	0.2	0.48	—	—	—	—	—	—	—	—
Mauritania	30	6.1	2.3	.97	118	77.3	3.7	.86	—	—	—	—	34	31.7	0.5	0.16	—	—	—	—
Niger	29	11.9	1.6	.96	90	24.2	6.4	.98	—	—	—	—	—	—	—	—	—	—	—	—
Senegal	117	75.4	3.9	.80	270	33.3	23.6	.89	18	9.1	6.0	0.81	550	64.2	54.5	0.93	5	2.1	0.3	0.81
Upper Volta	38	13.3	2.2	.96	51	13.2	3.3	.95	11	7.5	.3	0.73	—	—	—	—	—	—	—	—

Note: — Not available.
Source: 1979 Yearbook of World Energy Statistics, United Nations, 1980.

1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

1.2 Other West Africa

The other West African Countries considered in this volume include Benin, Cameroon, Ghana, Liberia, Nigeria, Sierra Leone, Togo, and Zaire. These countries, south of the Sahel, are significantly better off in terms of resources and income per capita. The differences are attributable largely to a higher annual rainfall in the sub-Sahelian coastal countries. The average annual rainfall in the Sahelian countries is 825 millimeters whereas the Other West African region it is 1,932 millimeters, or more than double.

1.2.1 Demographic Summary

Demographic summaries for the nine countries in West Africa other than the Sahel, are given in Table 1.11. Population ranges from a low of 1.4 million in Ghana to more than 27.5 million people in Zaire. The highest population growth rate is found in Liberia, 3.4 percent per year. Only Sierra Leone is sufficient in daily calorie consumption requirements. The other eight countries, however, are only barely deficient. Gross national product per capita is highest in oil-rich Nigeria, $510. The lowest GNP is found in Guinea and Sierra Leone $200 per capita per year for each country.

1.2.2 Land Area and Climate

The largest country in this West African Region (other than the Sahel) is Zaire by a wide margin with nearly 235 million hectares, followed by

TABLE 1.11.—DEMOGRAPHIC SUMMARY, AFRICA: OTHER WEST AFRICA

Country	Population (x 1,000) 1979	% Growth 1970-78	Food Consumption per Capita (Calories) 1979	% of Requirements	$ GNP per Capita 1977
Benin	3,424	2.9	2,249	97	210
Cameroon	1,850	2.2	2,428	96	420
Ghana	1,440	3.0	1,963	99	370
Guinea	2,320	3.0	1,943	90	200
Liberia	2,760	3.4	2,404	84	410
Nigeria	1,850	2.6	2,308	89	510
Sierra Leone	3,381	2.5	2,150	100	200
Togo	2,618	2.6	2,069	94	280
Zaire	27,519	2.7	2,304	92	210

Source: World Bank, 1980

Nigeria and Cameroon (Table 1.12). Nigeria has the largest proportion of arable land relative to total area (26 percent). Liberia and Zaire have the smallest proportion in this category (3 percent). The forest land category ranges from 95 percent of the total area in Benin and Togo to less than 1 percent in Liberia. Irrigated agriculture occupies less than 1 percent of the total land area in all of the countries. Mean annual temperatures are fairly uniform ranging from 24.3^{o}C in Cameroon to 26.9^{o}C in Benin. Mean annual precipitation ranges from 1,170 millimeters in Benin to 3,190 millimeters in Sierra Leone.

1.2.3 Agricultural Production

Crops with relatively high energy potential and yields by country are given in Table 1.13. Sorghum production occupies the largest total land area (6.4 million hectares) followed closely by millet (5.9 million hectares).

1.2.4 Forest Production

Forest areas by countries and types of forest land are presented in Table 1.14. With the exception of Cameroon and Zaire, open forests and shrub land constitute the major part of the total forest land. Closed forests are dominant in Cameroon and Zaire.

Table 1.15 presents the total forest biomass potential by country and types of forest lands. In contrast to the Sahelian countries the major part of

TABLE 1.12.—LAND AREA CLIMATIC SUMMARY (1979), AFRICA: OTHER WEST AFRICA
(In Thousands of Hectares)

Country	Total	Arable	% of Total	Irrig.	% of Total	Forest	% of Total	Mean Annual Temp. (°C)	Mean Annual Precip. (mm)
Benin	11,262	575	5	6	<1	10,718	95	26.9	1,170
Cameroon	47,544	7,390	16	12	<1	41,239	86	24.3	1,850
Ghana	23,854	2,720	11	22	<1	18,248	76	26.4	1,440
Guinea	24,586	4,170	17	8	<1	20,553	83	25.2	2,320
Liberia	11,137	371	3	2	<1	40	<1	25.6	2,760
Nigeria	92,337	23,990	26	20	<1	64,363	70	26.5	1,850
Sierra Leone	7,174	566	8	5	<1	6339	88	26.2	3,190
Togo	5,678	1,420	25	7	<1	5410	95	25.8	1,270
Zaire	234,541	6,200	3	4	<1	207,436	88	24.7	1,540

Sources: USDA, Economic Botany Laboratory, 1981.
Wernstedt, 1972.
University of Idaho 1982.

TABLE 1.13.--AGRICULTURAL PRODUCTION BY COUNTRY (1979), AFRICA: OTHER WEST AFRICA

Crop	Benin Hectares Planted (x 1,000)	Benin Yield (kg/ha)	Cameroon Hectares Planted (x 1,000)	Cameroon Yield (kg/ha)	Ghana Hectares Planted (x 1,000)	Ghana Yield (kg/ha)	Guinea Hectares Planted (x 1,000)	Guinea Yield (kg/ha)	Liberia Hectares Planted (x 1,000)	Liberia Yield (kg/ha)	Nigeria Hectares Planted (x 1,000)	Nigeria Yield (kg/ha)	Sierra Leone Hectares Planted (x 1,000)	Sierra Leone Yield (kg/ha)	Togo Hectares Planted (x 1,000)	Togo Yield (kg/ha)	Zaire Hectares Planted (x 1,000)	Zaire Yield (kg/ha)	Total Hectares Planted (x 1,000)
Wheat	0	0	2	500	0	0	0	0	0	0	14	1,500	0	0	0	0	5	1,000	21
Rice Paddy	9	2,000	20	1,000	80	688	400	975	200	1,300	528	1,894	400	1,200	20	1,250	280	821	1,937
Barley	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	600	1
Corn	350	657	535	897	340	1,118	420	762	0	0	1,665	901	13	1,077	115	1,348	600	583	4,038
Sorghum	100	700	0	0	240	833	8	563	0	0	6,000	631	7	1,571	0	0	30	667	6,385
Millet	13	538	440	886	240	542	0	0	0	0	5,000	620	9	1,000	200	600	30	667	5,932
Potatoes	184	7,632	19	3,053	0	0	0	0	0	0	3	14,000	0	0	0	0	6	4,921	212
Sweet potatoes	12	4,167	47	3,664	0	0	10	7,300	2	10,000	18	12,778	5	2,037	2	3,000	63	4,762	159
Cassava	110	7,000	198	4,362	250	7,600	90	6,111	60	3,000	1,150	10,000	0	0	23	20,000	1,800	6,667	3,681
Soybeans	0	0	0	0	0	0	0	0	5	362	195	385	[illegible]	0	0	0	10	667	210
Peanuts	80	875	0	0	110	818	32	969	5	622	600	1,035	18	1,111	20	1,000	460	674	1,325
Castor beans	1	600	0	0	0	0	0	0	0	0	0	0	0	0	1	500	0	0	2
Rape seed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sesame seed	2	250	21	760	0	0	2	100	0	0	235	311	2	500	7	222	8	462	277
Linseed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seed cotton	0	0	62	1,000	5	800	0	0	0	0	567	194	0	0	15	593	185	286	834
Coconuts	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0
Sugar cane	0	0	21	34,951	9	21,111	2	82,353	0	0	16	51,282	0	0	0	0	14	51,471	62
Gr. Coffee	1	400	314	356	7	157	8	300	25	380	6	750	18	739	20	300	235	370	634
Tea	0	0	1	2,000	0	0	0	0	0	0	0	0	0	0	0	0	10	520	11
Tobacco	2	900	6	500	3	582	2	829	0	0	30	370	0	1,250	4	500	14	478	61

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 1.14.—FOREST AREA, BY COUNTRY, AFRICA: OTHER WEST AFRICA
(In Thousands of Hectares)

Country	Closed Forest		Open Forest	Shrub Land	Fallow Land		Total
	Natural	Plantations			Closed	Open	
Benin	47	19	3,820	3,075	7	3,750	10,718
Cameroon	17,920	19	7,700	9,500	4,900	1,200	41,239
Ghana	1,718	75	6,975	300	6,500	2,680	18,248
Guinea	2,050	3	8,600	7,000	1,600	1,300	20,553
Liberia	2,000	6	40	100	5,500	40	7,686
Nigeria	5,950	163	8,800	36,800	7,750	4,900	64,363
Sierra Leone	740	6	1,315	3	3,860	415	6,339
Togo	304	11	1,380	2,265	250	1,200	5,410
Zaire	105,750	66	71,840	11,380	7,800	10,600	207,436

Source: University of Idaho, 1982.

TABLE 1.15.--FOREST BIOMASS POTENTIAL BY COUNTRY (Million m^3) - AFRICA: SAHEL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Closed Forests						Open Forests					Fallow Land				
	Broad Leaves		Coniferous													
Country	Pro-ductive	Unpro-ductive	Pro ductive	Unpro-ductive	Whole Trees	Shrub a Small Trees	Pro-ductive	Unpro-ductive	Whole Tree	Shrub a Small Trees	Shrub Land	Closed	Open	Total Biomass Poten-tial	Average Potential (M3/Ha)	Average Yearly Fuelwood Potential (m^3/ha/yr)
Benin	6.1	—	—	—	8.5	0.7	21	28	68.6	38.2	15.4	0.1	18.8	150.3	14.0	0.28
Cameroon	4,645	98	—	—	6,640.2	268.8	81	50	183.4	47.5	49.0	77.0	49.0	6.0	176.3	1.89
Ghana	198.0	60.0		—	361.2	25.8	47	54	141.4	69.8	1.5	65.0	13.4	678.1	37.2	0.61
Guinea	257.0	54.0	—	—	435.4	30.8	57	58	161.0	86.0	35.0	16.0	6.5	770.7	37.5	0.72
Liberia	220.0	84.0	—	—	425.6	30.0	—	0.4	0.6	0.4	0.5	55.0	0.2	512.3	66.7	1.05
Nigeria	492.0	358.0	—	—	1190.0	89.3	28.0	74.5	143.5	88.0	184.0	77.5	24.0	1,786.8	27.9	0.52
Sierra Leone	35.0	47.0	—	—	114.8	4.2	4.2	11.1	22.4	13.2	—	38.6	21.0	202.2	31.9	0.58
Togo	38.2	3.2	—	—	51.4	4.6	3.0	12.3	21.4	13.8	11.3	2.5	6.0	111.0	0.42	0.42
Zaire	20,014.0	3,319.0	—	—	32,666.2	1,586.3	126.8	2,249.5	718.4	56.5	78.0	53.0	37,407.9	180.3	2.36	2.36

Note: -- Not available.
Source: University of Idaho, 1982

1. Closed forest has canopy in which individual tree crowns are nearing general contact with one another.
2. Biomass volume include the tree bole over bark for trees <10cm dbh; volume of crowns, small trees and shrubs not included.
3. Includes national parks, reserves, marginal land, steep, inaccessible slopes, etc.
4. "Whole tree" includes the tree bole over bark <10cm dbh plus volume of crown and biomass, considered to be 40 percent of gross bole volume (FAO, 1981).
5. Shrubs and small trees on closed and open forest land in addition to trees <10cm dbh.
6. Biomass volumes on shrub land not containing trees <10 cm dbh.
7. Fallow land is recently cutover open or closed forest land.
8. Sum of columns 5, 6, 9, 10, 11, and 13.

the potential resource is found in closed forests even though these may not be the largest fraction of the forest land. Of the countries considered, Zaire has by far the largest forest biomass potential. Average forest potential are generally higher than in the Sahel, particularly in Cameroon and Zaire where broad-leaved closed forests dominate the forest land area.

Table 1.16 shows the distribution of the total roundwood production between fuelwood/charcoal production and industrial roundwood production by countries for the year 1979. The table shows that fuelwood production accounts for at least 75 percent and in some cases up to over 95 percent of the roundwood production. Linear production trends are also shown in the table. The high correlation coefficients indicate that the trend lines are representative of expected production. In some cases, very high correlation coefficients may result from the fact that some of the data points in the original reference (FAO, 1981) are themselves linear extrapolations between real data points. The trends in fuelwood production generally follow the trends in population growth (see Table 1.12).

Table 1.17 present statistical productivity data for plantations by country and species as reported by the University of Idaho (1982).

Table 1.18 compares the present and projected fuelwood production with the tolerable fuelwood utilization. Of the countries considered, Benin, Nigeria, and Sierra Leone appear to have an immediate problem and Ghana and Liberia could run into a problem of over exploitation in the not-too-distant future.

TABLE 1.16.—PRODUCTION AND UTILIZATION OF ROUNDWOOD 1979, AFRICA: OTHER WEST AFRICA
(In Thousands of Cubic Meters)

Country	Total	a[1]	b[2]	cc[3]	Industrial	a	b	cc	Fuel wood/ Charcoal	a	b	cc
Benin	3,662	2,576	85.7	0.996	196	139	4.5	0.970	3,446	2,443	82.3	0.995
Cameroon	9,782	6,854	237.0	.994	2,155	867	103.0	.975	7,627	5,797	135.0	.999
Ghana	9,359	6,315	247.0	.959	2,519	1,614	75.7	.740	6,840	4,701	172.0	.996
Guinea	3,454	2,575	71.5	.998	522	402	10.6	.983	2,932	2,174	61.0.0	.996
Liberia	4,814	2,756	169.0	.994	869	164	59.0	.951	3,945	2,611	108.0	.997
Nigeria	93,492	65,782	2,245.0	.997	4,337	2,600	151.0	.920	89,155	63,181	2,094.0	.998
Sierra Leone	7,350	5,351	160.0	.997	182	120	3.9	.723	7,168	5,231	157.0	.998
Togo	660	444	18.0	.999	145	87	5.2	.978	515	353	13.3	.995
Zaire	10,009	7,618	191.0	.995	2,207	2,011	14.4	.550	7,802	5,607	177.0	.997

Source: FAO, 1979.

1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

TABLE 1.17.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY, AFRICA: SAHEL
(M^3/ha/Year)

Country	Species 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Benin	—	—	—	—	—	—	—	—	10-20	—	—	—	—	—	—	10-15	—	10-15
Cameroon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ghana	7.5-8.7	15	20	20	9	—	—	—	—	—	—	—	—	—	—	—	—	—
Guinea	—	—	—	—	—	13.7-25.5	10.8-29	12	14.1	—	—	—	—	—	—	—	—	—
Liberia	—	—	13-20	—	—	25.0-35.0	—	—	—	—	—	—	—	—	—	—	—	—
Nigeria	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sierra Leone	—	—	—	—	—	3.5	—	—	—	—	—	4.5-8	—	—	—	—	—	—
Togo	—	15	—	—	—	—	—	—	—	—	—	—	—	—	—	15	—	—
Zaire	—	12-20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—

1. Azadirachta indica - Neem, Nim.
2. Eucalyptus spp. - Eucalyptus
3. Pinus caribaea - Pine
4. Pinus oocarpa - Pine
5. Terminalia ivorensis - Indian almond
6. Gmelina arborea - Gmelina, yemane
7. Pinus kesiya - Pine
8. Pinus patula - Pine
9. Tectona grandis -
10. Nauclea diderrichii -
11. Eucalyptus camaldulensis - Red river gum, red gum, river gum.
12. Terminalia spp. - Tropical almond.
13. Cordia alliodora -
14. Heritiera utilis -
15. Entandrophragma spp. -
16. Cassia siamea - Yellow cassia.
17. Terminalia Superba - Indian almond
18. Casuarina equisetifolia -

Note: — Although plantations of the species mentioned are reported, no growth data is available.

Source: University of Idaho, 1982.

TABLE 1.18.--COMPARISON OF PRESENT AND PROJECTED FUELWOOD UTILIZATION WITH TOLERATED FUELWOOD UTILIZATION AFRICA: OTHER WEST AFRICA
(In Thousands of Cubic Meters)

Country	Fuelwood Utilization[1]		Tolerated Fuelwood Utilization[2]
	1979	1990	
Benin	3,466	4,336	3,001
Cameroon	7,627	9,082	77,942
Ghana	6,840	8,657	11,131
Guinea	2,932	3,577	14,578
Liberia	3,945	5,095	8,070
Nigeria	89,155	111,343	33,469
Sierra Leone	7,168	8,842	3,677
Togo	515	965	2,272
Zaire	7,082	9,678	489,549

1. Derived from Table 1.16

2. Derived from Tables 1.14 and 1.15

1.2.5 Livestock Summary

Livestock statistics by country are given in Table 1.19. In terms of pure numbers chickens are by far the most numerous, followed by goats. There is little energy potential from goats, however, since they are generally not confined. Cattle, the third most plentiful livestock category, may have a greater potential for energy since manure production is much higher and confinement, or semiconfinement, is more common.

1.2.6 Fossil Fuel Consumption

Consumption of gasoline, diesel oil, kerosene, residual fuel oil, and liquefied petroleum gases by individual countries and linear consumption trends are given in Table 1.20.

Where the b-coefficients are negative (negative slope), such as the cases of diesel oil consumption in Benin, kerosene consumption in Liberia and Togo, and others, the consumption of those energy products is declining over time.

1.3 East Africa

The East Africa countries included in this volume are: Botswana, Burundi, Djibouti, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Rwanda, Somalia, Sudan, Swaziland, Tanzania, Uganda and Zambia. Of the three regions in Africa treated in this volume, East Africa is better off

TABLE 1.19.—LIVESTOCK SUMMARY (1979), AFRICA: OTHER WEST AFRICA

Country	Horses	Cattle	Camels	Pigs	Buffalo	Sheep	Goats	Asses/Mules	Chickens	Turkeys	Ducks
Benin	6	800	0	470	0	930	950	1	3,500	0	0
Cameroon	61	3,027	0	806	0	2,211	1,720	78	10,352	0	0
Ghana	4	280	0	9	0	0	92	25	11,500	0	0
Guinea	1	1,700	0	37	0	430	395	3	5,500	0	0
Liberia	0	38	0	100	0	190	190	0	2,200	0	212
Nigeria	250	12,000	17	1,100	0	8,000	24,500	700	2,200	0	212
Sierra Leone	0	270	0	35	0	60	175	0	3,600	0	62
Togo	3	250	0	275	0	835	748	1	2,900	0	0
Zaire	1	1,144	0	753	0	779	2,783	0	12,411	0	0
Total	325	19,509	17	3,585	0	13,435	31,553	808	54,163	0	698

Source: USDA, Economic Botany Laboratory, 1981.

Table 1.20.—PETROLEUM-DERIVED FUEL CONSUMPTION BY PRODUCT 1979, AFRICA: OTHER WEST AFRICA
(In Thousands of Metric Tons)

Country	Gasoline				Diesel Oil (Distillates)				Kerosene				Residual Fuel Oil (Bunker Oil)				Liquefied Petroleum Gases (LPG)			
	Total Consumption	a 1/	b 2/	cc 3/	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc
Benin	42	17.8	2.2	0.91	49	7.8	-2.0	-0.51	28	13.9	1.4	0.87	10	1.4	1.4	0.92	—	—	—	—
Cameroon	146	72.7	6.5	0.83	210	59.3	14.8	0.94	54	-2.0	5.6	0.93	55	13.3	3.2	0.77	4	1.2	0.3	8.70
Ghana	229	169.0	7.5	0.81	320	186.0	13.8	0.92	110	74.5	3.9	0.95	170	155.0	1.7	0.11	10	1.8	0.8	0.73
Guinea	45	33.5	1.0	0.81	44	40.0	.3	0.75	18	13.1	0.5	0.91	172	161.0	0.9	0.66	—	—	—	—
Liberia	68	50.4	1.9	0.95	143	145.0	3.3	0.23	7	11.9	-0.7	-0.68	234	198.0	9.4	0.32	—	—	—	—
Nigeria	1,070	385.0	86.2	0.83	960	405.0	57.9	0.90	415	265.0	18.5	0.69	560	654.0	-9.8	-0.20	22	17.3	0.3	.30
Sierra Leone	40	38.3	0.5	0.49	26	21.8	0.4	0.29	24	14.5	1.2	0.93	100	105.0	0.04	0.01	—	—	—	—
Togo	45	11.9	3.3	0.98	57	28.5	2.4	0.75	5	13.3	-0.9	-0.66	42	23.7	1.7	0.70	—	—	—	—
Zaire	175	127.0	5.4	0.77	370	250.0	13.1	0.80	90	69.7	2.3	0.55	95	42.4	6.0	0.90	1	1.7	-0.05	-0.28

Source: 1979 Yearbook of World Energy Statistics, United Nations.
1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

than the Sahel and worse off than the countries in Other West Africa in terms of resource endowments and income per capita. The region is characterized by a wide variety of climates and topography resulting in drastically different potentials for biomass production.

1.3.1 Demographic Summary

The demographic summaries for the sixteen countries in the East Africa region are given in Table 1.21. Population ranges from a low of 116,000 people in Djibouti to more than 31 million people in Ethopia. The highest population growth rate is found in Uganda, 3.7 percent per year. Madagascar and Malawi are the only two countries exceeding the minimum daily calorie consumption requirements. The remaining fourteen countries are deficient. Gross national product per capita is highest in Botswana, $540, followed, by Swaziland and then Zambia. Ethiopia has the lowest GNP per capita of $110 per year.

1.3.2 Land Area and Climate

The largest country in the East African region is Sudan, with 250 million hectares, followed by Ethiopia, less than half as large, and by Tanzania (Table 1.22). Burundi has the largest proportion of arable land relative to total area (46 percent). Djibouti has the smallest proportion in this category (less than 1 percent). The forest land category ranges from as high as 97 percent in Somalia to 3 percent of the total land area in Burundi. Irrigated agriculture occupies less than 1 percent of the total

TABLE 1.21.—DEMOGRAPHIC SUMMARY (1979), AFRICA: EAST AFRICA

Country	Population (x 1,000) 1979	% Growth 1970-73	Food Consumption per Capita (Calories) 1979	% of Requirement	$ GNP per Capita 1977
Botswana	798	1.9	2,186	70	540
Burundi	4,383	2.2	2,254	99	130
Djibouti	116	—	—	—	—
Ethiopia	31,773	2.5	1,754	92	110
Kenya	15,780	3.4	2,095	98	290
Lesotho	1,309	2.4	2,245	95	250
Madagascar	8,511	2.5	2,486	108	230
Malawi	5,963	2.9	2,237	103	150
Mozambique	10,199	2.5	1,906	94	—
Rwanda	4,649	2.9	2,264	93	160
Somalia	3,542	2.3	2,221	80	120
Sudan	17,865	2.7	2,282	72	330
Swaziland	540	2.2	2,357	90	530
Tanzania	17,382	3.7	2,603	88	210
Uganda	12,796	3.0	2,110	91	—
Zambia	5,465	3.1	2,002	84	460

Note: — Not available.

Source: World Bank, 1980.

TABLE 1.22.—LAND AREA CLIMATIC SUMMARY (1979), AFRICA: EAST AFRICA
(In Thousands of Hectares)

Country	Total	Arable	% of Total	Irrig.	% of Total	Forest	% of Total	Mean Annual Temp. (°C)	Mean Annual Precip. (mm)
Botswana	60,037	1,360	2	--	0	52,560	88	19.9	470
Burundi	2,783	1,277	46	5	<1	84	3	19.1	1,180
Djibouti	2,200	1	<1	--	0	106	5	28.3	180
Ethiopia	122,190	13,730	11	55	<1	62,525	51	20.1	920
Kenya	58,265	2,270	4	44	<1	40,646	70	21.2	880
Lesotho	3,035	310	10	--	0	--	--	14.2	730
Madagascar	58,704	2,929	5	450	<1	20,966	36	23.0	1,550
Malawi	11,848	2,298	19	10	<1	4,731	40	21.9	1,070
Mozambique	78,303	3,080	4	68	<1	57,660	74	24.0	1,020
Rwanda	2,634	960	36	1	<1	414	16	18.9	1,170
Somalia	63,766	1,066	2	165	<1	62,111	97	26.9	360
Sudan	250,581	7,515	3	1,550	<1	146,438	58	27.3	560
Swaziland	1,736	154	9	28	2	--	--	19.8	940
Tanzania	94,509	5,140	5	60	<1	60,038	64	22.9	1,120
Uganda	23,604	5,610	24	4	<1	7,715	33	22.3	1,200
Zambia	75,261	5,058	7	5	<1	40,348	54	21.0	1,020

Note: -- Not available.
Sources: USDA, Economic Botany Laboratory, 1981.
Wernstedt, 1972.
University of Idaho, 1982.

land area in all of the countries except Swaziland where roughly 2 percent is irrigated. Mean annual temperatures ranges from a high of 28.3°C in Djibouti to 14.2°C in Lesotho. Mean annual precipitation ranges from 1,550 millimeters in Madagascar to 180 millimeters in Djibouti.

1.3.3 Agricultural Production

Crops with relatively high energy potential and yields by country are given in Table 1.23. Corn occupies the largest total land area (7.4 million hectares) followed by sorghum (5.3 million hectares). Millet, cassava, and peanuts occupy approximately the same land area (about 2.2 million hectares) and rank third in terms of the area occupied by each crop.

1.3.4 Forest Production

Table 1.24 shows the forest area by country and type of forest land for the East African countries considered. With the exception of Madagascar and Burundi, the largest forest area consists of open forest and shrub land.

Table 1.25 shows the total forest biomass potential by country and type of forest land. With the exception of Burundi, Madagascar, and Rwanda, most of the resource is found in open forest and shrub land. With the exception of Madagascar and Rwanda, the average forest potential is relatively low,

TABLE 1.23.—AGRICULTURAL PRODUCTION BY COUNTRY (1979), AFRICA: EAST AFRICA

Crop	Botswana Hectares Planted (x 1,000)	Botswana Yield (kg/ha)	Burundi Hectares Planted (x 1,000)	Burundi Yield (kg/ha)	Djibouti Hectares Planted (x 1,000)	Djibouti Yield (kg/ha)	Ethiopia Hectares Planted (x 1,000)	Ethiopia Yield (kg/ha)	Kenya Hectares Planted (x 1,000)	Kenya Yield (kg/ha)	Lesotho Hectares Planted (x 1,000)	Lesotho Yield (kg/ha)	Madagascar Hectares Planted (x 1,000)	Madagascar Yield (kg/ha)	Malawi Hectares Planted (x 1,000)	Malawi Yield (kg/ha)
Wheat	—	3,000	8	625	—	—	511	878	117	923	38	798	—	1,667	—	2,500
Rice Paddy	—	—	4	2,429	—	—	—	—	7	6,143	—	—	1,216	1,914	52	962
Barley	—	—	—	—	—	—	891	822	80	938	1	308	—	—	—	—
Corn	30	267	125	1,120	—	—	1,001	1,066	1,400	1,286	120	1,076	100	1,000	1,000	1,200
Sorghum	50	260	110	1,000	—	—	726	936	210	886	59	1,447	—	441	15	5,333
Millet	5	200	36	833	—	—	249	767	81	1,358	—	—	—	—	—	—
Potatoes	1	5,385	26	9,054	—	—	38	6,184	48	7,500	—	—	21	6,431	30	3,667
Sweet potatoes	—	—	99	9,506	—	—	—	—	38	8,947	—	—	63	5,378	—	—
Cassava	—	—	78	12,108	—	—	—	—	80	7,875	—	—	200	6,739	—	—
Soybeans	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Peanuts	8	933	20	1,350	—	—	47	603	14	589	—	—	35	860	250	680
Castor beans	—	—	—	—	—	—	11	1,009	9	250	—	—	5	260	—	—
Rape seed	—	—	—	—	—	—	50	400	—	—	—	—	—	—	—	—
Sesame seed	—	—	—	—	—	—	80	574	19	411	—	—	—	—	—	—
Linseed	—	—	—	—	—	—	36	373	—	1,000	—	—	—	—	—	—
Seed cotton	1	2,727	9	533	—	—	165	455	120	278	—	—	22	1,500	34	1,131
Coconuts	—	—	—	—	—	—	—	—	80	—	—	—	—	—	—	—
Sugar cane	—	—	—	—	—	—	13	105,197	34	106,823	—	—	35	37,143	11	100,000
Gr. Coffee	—	—	35	693	—	—	692	280	105	762	—	—	180	333	2	667
Tea	—	—	3	577	—	—	—	—	83	1,196	—	—	—	—	18	1,863
Tobacco	—	—	2	762	—	—	5	609	2	900	—	—	6	833	79	681

Note: — Not available.

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 1.23.—AGRICULTURAL PRODUCTION BY COUNTRY (1979), AFRICA: EAST AFRICA (Concluded)

Crop	Mozambique Hectares Planted (x 1,000)	Mozambique Yield (kg/ha)	Rwanda Hectares Planted (x 1,000)	Rwanda Yield (kg/ha)	Somalia Hectares Planted (x 1,000)	Somalia Yield (kg/ha)	Sudan Hectares Planted (x 1,000)	Sudan Yield (kg/ha)	Swaziland Hectares Planted (x 1,000)	Swaziland Yield (kg/ha)	Tanzania Hectares Planted (x 1,000)	Tanzania Yield (kg/ha)	Uganda Hectares Planted (x 1,000)	Uganda Yield (kg/ha)	Zambia Hectares Planted (x 1,000)	Zambia Yield (kg/ha)	Total Hectares Planted (x1,000)
Wheat	5	600	4	833	4	343	248	1,073	—	3,250	50	1,300	10	1,500	2	3,333	997
Rice Paddy	65	538	2	2,677	2	3,000	8	2,597	2	2,632	167	1,198	18	722	4	1,125	1,457
Barley	—	—	—	—	—	—	—	—	—	—	2	1,000	—	—	—	—	974
Corn	600	583	67	1,075	160	500	85	588	50	1,100	1,300	692	550	909	900	667	7,488
Sorghum	250	720	140	1,071	300	333	2,700	730	2	870	350	686	350	1,143	70	429	5,332
Millet	20	250	6	545	—	—	1,200	308	—	—	220	727	550	818	100	500	2,467
Potatoes	6	6,333	30	7,073	—	10,000	1	19,231	3	2,000	22	3,864	45	7,348	—	8,667	271
Sweet potatoes	9	4,706	106	7,913	—	—	2	24,118	2	5,882	53	6,226	140	4,912	3	7,143	515
Cassava	450	5,556	44	10,363	3	11,071	37	2,973	—	—	895	4,804	375	3,333	55	3,182	2,217
Soybeans	—	—	6	821	—	—	—	—	—	—	4	150	5	660	2	1,500	17
Peanuts	200	400	18	915	10	980	980	1,122	—	—	119	587	260	873	138	533	2,099
Castor Beans	—	—	—	—	—	—	10	1,000	—	—	4	561	2	208	—	—	41
Rape Seed	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	50
Sesame Seed	7	429	—	—	71	355	960	219	—	—	25	240	128	352	—	—	1,289
Linseed	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	36
Seed Cotton	121	372	—	—	12	275	365	989	18	1,000	405	449	486	74	22	689	1,780
Coconuts	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	80
Sugarcane	50	42,000	1	48,871	7	42,857	26	66,341	21	10,667	42	34,929	31	18,667	10	82,000	281
Gr. Coffee	1	714	32	679	—	—	—	—	—	—	100	490	170	706	—	—	1,317
Tea	11	1,455	6	1,186	—	—	—	—	—	—	18	994	6	1,000	—	—	145
Tobacco	3	962	2	1,000	—	395	—	—	1	789	26	831	3	1,000	5	971	37

Note: — Not Available.
Source: USDA, Economic Botany Laboratory, 1981.

TABLE 1.24.—FOREST AREA, BY COUNTRY (1,000 HA), AFRICA: EAST AFRICA
(In Thousands of Hectares)

Country	Closed Forest		Open Forest	Shrub Land	Fallow Land		Total
	Natural	Plantations			Closed	Open	
Botswana	—	—	32,560	20,000	—	—	52,560
Burundi	26	20	14	—	14	10	84
Djibouti	6	—	100	—	—	—	106
Ethiopia	4,350	75	22,800	25,000	300	10,000	62,525
Kenya	1,105	181	1,255	37,500	55	550	40,646
Lesotho	—	—	—	—	—	—	—
Madagascar	10,300	266	2,900	4,000	3,500	—	20,966
Malawi	186	80	4,085	380	—	—	4,731
Mozambique	935	25	14,500	29,000	500	12,700	57,660
Rwanda	120	29	110	90	25	40	414
Somalia	1,540	11	7,510	53,000	—	50	62,111
Sudan	650	188	47,000	87,000	600	11,000	146,438
Swaziland	—	98	—	—	—	—	—
Tanzania	1,440	98	40,600	13,800	100	4,000	60,038
Uganda	717	48	5,250	100	—	1,600	7,715
Zambia	3,010	38	26,500	3,200	900	6,700	40,348

Note: — Not available.
Source: University of Idaho, 1982.

TABLE 1.25.—FOREST BIOMASS POTENTIAL BY COUNTRY, AFRICA: EAST AFRICA
(In Millions of Cubic Meters)

Country	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Closed Forests 1,2/						Open Forests					Fallow Land 7/				
	Broad Leaf		Coniferous													
	Productive	Unproductive 3/	Productive	Unproductive	Whole Trees 4/	Shrub a Small Trees 5/	Productive	Unproductive	Whole Tree	Shrub a Small Trees	Shrub Land 6/	Closed	Open	Total Biomass Potential 8/	Average Potential (m3/ha)	Average Yearly Fuelwood Potential (m3/ha/yr)
Botswana	—	—	—	—	—	—	4.0	323.6	458.6	325.6	100.0	—	—	884.2	16.8	0.36
Burundi	0.8	0.7	—	—	2.1	0.4	—	0.14	0.2	0.1	—	0.1	0.1	3.0	35.7	0.60
Djibouti	0.2	—	—	—	0.3	0.1	0.5	—	0.7	1.0	—	—	—	2.1	19.8	—
Ethiopia	82.0	286.0	54.0	60.0	674.8	62.3	140.0	200.0	476.0	228.0	125.0	3.0	50.0	1,619.1	25.9	0.41
Kenya	52.0	27.0	8.8	7.0	132.7	16.6	11.0	6.9	25.4	12.6	187.5	0.6	2.8	378.2	9.3	0.20
Lesotho	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Madagascar	740.0	330.0	—	—	1,498.0	154.5	6.0	26.0	44.8	29.0	20.0	35.0	—	1,781.3	85.0	2.06
Malawi	5.0	15.0	—	—	28.0	2.8	27.0	36.3	88.6	40.9	19.0	—	—	179.3	37.9	0.51
Mozambique	24.0	14.5	—	—	53.9	14.0	117.0	111.2	319.5	145.0	145.0	5.0	63.5	745.9	12.9	0.28
Rwanda	6.7	3.6	—	—	14.5	1.8	0.9	0.8	2.4	1.1	0.5	0.3	0.2	20.8	50.2	0.80
Somalia	5.0	72.0	3.0	0.9	113.3	23.1	0.5	75.0	105.7	75.1	265.0	—	0.3	582.5	9.4	0.21
Sudan	37.8	24.0	0.2	0.3	87.2	9.8	930.0	160.0	1,526.0	470.0	435.0	6.0	55.0	2,589.0	17.7	0.35
Swaziland	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tanzania	94.0	43.0	—	—	191.8	21.6	200.0	306.0	708.4	406.0	69.0	1.0	20.0	1,417.8	23.6	0.54
Uganda	86.0	7.0	—	—	130.2	11.5	26	39.5	91.7	52.5	0.5	—	8.0	294.4	38.2	0.73
Zambia					421.4	45.2			494.2	265.0	16.0	9.0	33.5	1,284.3	31.8	0.69

Note: — Not available.
Source: University of Idaho, 1982.

1. Closed forest has canopy in which individual tree crowns are nearing general contact with one another.
2. Biomass volume include the tree bole over bark for trees <10cm dbh; volume of crowns, small trees and shrubs not included.
3. Includes national parks, reserves, marginal land, steep, inaccessible slopes, etc.
4. "Whole tree" includes the tree bole over bark <10cm dbh plus volume of crown and biomass, considered to be 40 percent of gross bole volume (FAO, 1981).
5. Shrubs and small trees on closed and open forest land in addition to trees <10cm dbh.
6. Biomass volumes on shrub land not containing trees <10 cm dbh.
7. Fallow land is recently cutover open or closed forest land.
8. Sum of columns 5, 6, 9, 10, 11, and 13.

comparable to that of some Sahelian countries and some West African Countries.

Table 1.26 shows the production of roundwood, industrial roundwood, and fuelwood and charcoal by country for the year 1979. Also included in the table are the constants a and b that characterize the linear variation of production of those materials over the 1968-1979 period. In Botswana, Burundi, Ethiopia, Lesotho, Mozambique, Sudan, and Tanzania, the annual percentage rate of growth of fuelwood production follows closely that of growth of population, as can be expected if no significant switch to fossil fuel occurs (see Table 1.21). In the other countries (with the exception of Djibouti) fuelwood production increases at a higher rate than population and consumption of kerosene also increases (Table 1.30). Table 1.27 shows the productivity (mean annual increments) of plantations by country and by species as gathered by the University of Idaho (1982).

Table 1.28 compares the tolerable fuelwood utilization to the current and projected utilization: many of the countries considered have reached, or will reach in the near future, a critical situation of over exploitation of the forest resources. A few countries such as Botswana, Madagascar, Somalia, and Zambia appear to have ample forest resources for fuelwood production.

TABLE 1.26.—PRODUCTION AND UTILIZATION OF ROUNDWOOD 1979, AFRICA: EAST AFRICA
(In Thousands of Cubic Meters)

Country	Total	a 1/	b 2/	cc 3/	Industrial	a	b	cc	Fuel wood/ Charcoal	a	b	cc
Botswana	780	633.6	13.3	.980	52	39.9	1.0	.958	729	586.3	13.0	.991
Burundi	735	561.0	13.3	.986	37	27.9	0.7	.926	698	533.0	12.6	.988
Djibouti	—	—	—	—	—	—	—	—	—	—	—	—
Ethiopia	23,821	17,624	508.1	.999	1,436	1,056	32.0	.992	22,385	16,568	476.1	.999
Kenya	26,351	16,257	816.2	.997	1,141	541.9	51.7	.953	25,210	15,715	764.4	.998
Lesotho	286	214.3	5.9	.998	—	—	—	—	286	214.3	5.9	.998
Madagascar	5,976	4,755	98.0	.839	807	1,257	-63.8	-.570	5,169	3,498	161.8	.995
Malawi	9,721	6,664	261.8	.989	302	209.3	8.8	.909	9,419	6,455	253.0	.989
Mozambique	11,083	8,426	216.7	.998	953	809.7	10.9	.849	10,130	7,616	205.8	.999
Rwanda	4,793	3,343	117.0	.998	60	58.2	0.2	.731	4,733	3,285	116.8	.998
Somalia	706	505.5	16.5	.997	63	42.5	1.9	.923	643	463.0	14.6	.997
Sudan	33,432	24,094	758.0	.999	1,491	1,075	37.6	.983	31,941	23,019	720.4	.998
Swaziland	2,588	956.8	154.9	.990	2,061	585.0	142.4	.952	527	371.8	12.4	.997
Tanzania	33,015	23,878.7	782.7	.998	160	1,209	-40.8	-.567	32,855	22,669	823.5	.998
Uganda	5,616	3,966	133.6	.998	1,388	1,060	26.1	.972	4,228	2,906	107.3	.999
Zambia	5,297	3,647	131.7	.992	459	348.3	7.9	.574	4,838	3,299	123.7	.998

Note: — Not available.
Source: FAO, 1979.

1. a = Regression intercept.
2. b = Slope of regression line.
3. c = Correlation coefficient.

TABLE 1.27.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY: EAST AFRICA
(In Cubic Meters per Hectare per Year)

Country	Species																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Botswana	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Burundi	—	—	10–15	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Djibouti	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ethiopia	—	—	—	20	—	—	—	—	—	—	—	—	—	—	—	—	—
Kenya	10.7–27	—	—	—	12.2–32	5–27	—	—	—	—	—	—	—	—	—	—	—
Lesotho	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Madagscar	—	—	20	—	—	5–16	13	—	—	—	—	—	—	—	—	—	—
Malawi	7.1–9.5	—	17.5	—	—	15	—	—	4.8–9	—	—	—	—	—	—	—	—
Mozambique	—	—	—	—	—	15	—	—	—	20–22	—	—	—	—	—	—	—
Rwanda	22	—	—	—	—	15	—	—	—	17	23	17	—	—	—	—	—
Somalia	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sudan	20	—	—	—	—	—	—	—	—	—	—	—	10–25	7–10	9.6	3–5	—
Swaziland	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tanzania	23–30	—	—	—	—	19.7–30	—	18.1	—	—	—	—	—	—	—	—	5.4–28.4
Uganda	11.2–32.1	7.6–35	12.9–52	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Zambia	—	—	—	—	—	—	20.7–20.9	—	—	—	17.6–30	—	—	—	—	—	—

1. Cupressus lusitanica
2. Pinus spp. - Pine
3. Eucalyptus spp. - Eucalyptus
4. Eucalyptus globulus - Southern blue gum, fever tree
5. Pinus radiata - Pine
6. Pinus patula - Pine
7. Pinus kesiya - Pine
8. Pinus elliottii - Pine
9. Widdringtonia whytei -
10. Eucalyptus saligna - Flooded gum, rose gum
11. Eucalyptus grandis - Flooded gum, rose gum
12. Eucalyptus gigantea -
13. Acacia nilotica - Egyptian thorn
14. Eucalyptus microtheca - Flooded box, coolibah
15. Eucalyptus camaldulensis - Red river gum, red gum, river gum
16. Tectona grandis - Teak
17. Pinus caribaea - Pine

Note: — Not available.
Source: University of Idaho, 1982.

TABLE 1.28.--COMPARISON OF PRESENT AND PROJECTED FUELWOOD UTILIZATION WITH TOLERATED FUELWOOD UTILIZATION, AFRICA: EAST AFRICA
(In Thousands of Cubic Meters)

Country	Fuelwood Utilization[1]		Tolerated Fuelwood Utilization[2]
	1979	1990	
Botswana	729	885	18,922
Burundi	698	823	50
Djibouti	--	--	--
Ethiopia	22,385	27,518	25,635
Kenya	25,210	33,296	8,129
Lesotho	286	350	--
Madagascar	5,169	7,219	43,190
Malawi	9,419	12,274	1,231
Mozambique	10,130	12,349	16,145
Rwanda	4,733	5,971	331
Somalia	643	799	13,043
Sudan	31,941	39,588	51,253
Swaziland	527	657	--
Tanzania	32,855	41,610	32,421
Uganda	4,228	5,374	5,632
Zambia	4,838	6,144	27,840

1. Derived from Table 1.26

2. Derived from Tables 1.24 and 1.25

1.3.5 Livestock Summary

Livestock statistics by country are given in Table 1.29. In terms of pure numbers, chickens are by far the most numerous, followed by cattle, goats and sheep. There is little energy potential from goats and sheep since they are generally not confined. Cattle, however, may have a greater potential for energy since manure production is much higher and confinement, or semiconfinement, is more common.

1.3.6 Fossil Fuel Consumption

Consumption and trends in consumption of gasoline, diesel oil, kerosene, residual fuel oil and liquefied petroleum gases by individual countries are given in Table 1.30. Where the b-coefficients are negative, such as the cases of gasoline consumption in Ethiopia, Mozambique, Tanzania, and Uganda, the consumption is declining over time.

TABLE 1.29.—LIVESTOCK SUMMARY (1979), AFRICA: EAST AFRICA

Country	Horses	Cattle	Camels	Pigs	Buffalo	Sheep	Goats	Asses/Mules	Chickens	Turkeys	Ducks
Botswana	9	3,300	0	22	0	450	1,200	42	620	0	0
Burundi	0	3,300	0	51	0	336	585	1,041	0	0	45
Djibouti	0	32	25	0	0	310	520	5	0	0	0
Ethiopia	1,530	25,900	966	18	0	22,234	17,120	5,331	52,926	0	0
Kenya	2	10,470	550	65	0	4,000	4,500	0	17,500	0	0
Lesotho	110	550	0	80	0	1,300	730	159	1,150	0	0
Madagascar	2	8,744	0	580	0	658	1,583	1	14,082	1,162	2,352
Malawi	0	790	0	174	0	140	860	0	8,000	0	0
Mozambique	0	1,380	0	110	0	105	330	20	17,500	0	565
Rwanda	0	640	0	83	0	257	786	0	872	0	0
Somalia	1	3,800	5,400	9	0	10,000	16,000	46	2,800	0	0
Sudan	20	17,300	2,500	8	0	17,200	12,200	681	26,000	0	0
Swaziland	2	650	0	22	0	33	265	13	600	0	0
Tanzania	0	15,300	0	25	0	3,000	4,700	160	20,700	0	2,450
Uganda	0	5,367	0	225	0	1,068	2,144	16	13,100	0	0
Zambia	0	1,800	0	180	0	51	300	1	14,000	0	0
Total	1,676	99,323	9,441	1,652	0	61,142	63,823	6,475	190,891	1,162	5,412

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 1.30.—PETROLEUM-DERIVED FUEL CONSUMPTION BY PRODUCT 1979, AFRICA: EAST AFRICA
(In Thousands of Metric Tons)

Country	Gasoline				Diesel Oil (Distillates)				Kerosene				Residual Fuel Oil (Bunker Oil)				Liquefied Petroleum Gases (LPG)			
	Total Consumption	a[1]	b[2]	cc[3]	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc
Botswana	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Burundi	15	7.2	0.7	0.89	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Djibouti	10	7.5	0.2	0.76	15	14.7	-0.20	-0.19	12	9.0	0.3	0.82	25	3.4	23.0	0.99	—	—	—	—
Ethiopia	70	86.9	-1.5	-0.57	95	19.4	-10.50	-0.71	—	—	—	—	97	149.0	-5.2	-0.77	2	3.1	-0.02	-0.11
Kenya	310	149.0	16.7	0.98	385	230.0	15.20	0.78	30	14.6	0.9	0.43	590	259.0	33.2	0.95	20	5.3	1.5	0.97
Lesotho	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Madagascar	99	77.4	2.0	0.70	146	130.0	1.2	0.22	49	27.9	1.9	0.78	149	-6.7	16.1	0.83	8	7.5	0.02	0.04
Malawi	50	22.4	2.6	0.90	85	36.9	4.3	0.96	10	13.7	-0.4	-0.69	4	5.3	-0.2	-0.56	—	—	—	—
Mozambique	58	97.7	-3.9	-0.70	65	112.0	-5.4	-0.72	53	29.3	2.3	0.70	250	148.0	13.3	0.85	8	9.5	-0.24	-0.60
Rwanda	24	2.9	1.9	0.95	15	4.9	1.0	0.90	—	—	—	—	—	—	—	—	—	—	—	—
Somalia	45	9.5	4.1	0.69	130	13.1	13.6	0.90	13	5.3	0.7	0.68	—	—	—	—	—	—	—	—
Sudan	211	176.0	4.2	0.80	625	602.0	7.9	0.45	98	118.0	-1.7	-0.65	550	548.0	5.8	0.19	7	2.9	0.60	0.81
Swaziland	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tanzania	79	134.0	-4.4	-0.64	190	205.0	6.1	0.32	35	57.7	-1.8	-4.50	140	217.0	-7.6	-0.59	6	4.4	0.20	0.86
Uganda	78	123.0	-3.9	-0.83	55	104.0	-5.0	-0.97	36	39.0	0.6	0.27	32	111.0	-7.8	-0.96	—	—	—	—
Zambia	185	135	5.5	0.95	310	269.0	5.6	.44	20	0.9	2.0	0.94	120	-14.7	15.5	0.92	10	-0.60	1.20	0.94

Note: — Not available.
Source: 1979 Yearbook of World Energy Statistics, United Nations, 1980.

1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

CHAPTER 2: ASIA AND PACIFIC

The Asia and Pacific region consists of ten countries: Bangladesh, Burma, India, Indonesia, Korea, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand. Wide variations in climate, precipitation and topography occur between and within these countries which are reflected in variable potential for biomass production. Statistical profiles for each country are given below.

2.1 Demographic Summary

Demographic summaries for the 10 countries in the Asia and Pacific region are given in Table 2.1. Population ranges from a low of nearly 14 million people in Nepal to more then 678 million people in India. Burma, Korea, and Thailand are the only three countries exceeding the minimum daily calorie consumption requirements. The remaining seven countries are deficient. Gross national product per capita is highest in Korea, $980, followed by the Philippines and Thailand. The GNP per capita of Bangladesh is the lowest, $80 per year.

2.2 Land Area and Climate

The largest country in the Asia and Pacific region is India with nearly 329 million hectares (Table 2.2). Bangladesh has the largest proportion of arable land relative to total area

TABLE 2.1.—DEMOGRAPHIC SUMMARY, ASIA AND PACIFIC

Country	Population (x 1,000) 1979	% Growth 1970-78	Food Consumption per Capita (Calories) 1979	% of Requirement	$ GNP per Capita 1977
Bangladesh	89,062	2.8	1,891	89	80
Burma	34,434	2.2	2,199	101	140
India	678,255	2.0	2,021	92	160
Indonesia	148,470	1.8	2,117	91	320
Korea	37,313	2.0	2,785	114	980
Nepal	13,938	2.3	2,002	94	110
Pakistan	79,620	2.9	2,281	94	200
Philippines	49,493	2.7	2,189	86	460
Sri Lanka	14,608	1.7	2,055	94	160
Thailand	46,437	2.8	1,929	103	430

Source: World Bank, 1980.

TABLE 2.2.—LAND AREA CLIMATIC SUMMARY (1979), ASIA AND PACIFIC
(In Thousands of Hectares)

Country	Total	Arable	% of Total	Irrig.	% of Total	Forest	% of Total	Mean Annual Temp. (°C)	Mean Annual Precip. (mm)
Bangladesh	14,400	9,127	63	1,450	10	1,330	9	25.6	2,190
Burma	67,655	10,006	15	981	1	52,727	78	25.1	2,810
India	328,759	168,500	51	35,500	11	73,482	22	25.1	1,250
Indonesia	190,435	16,368	9	5,304	3	160,915	84	23.4	2,400
Korea	9,848	2,222	23	1,122	11	—	—	12.3	1,170
Nepal	14,080	2,319	16	210	1	2,461	17	19.5	1,680
Pakistan	80,394	19,990	25	14,000	17	3,822	5	23.0	330
Philippines	30,000	8,100	27	1,113	4	13,330	44	26.7	2,570
Sri Lanka	6,651	2,145	33	536	8	2,857	43	25.4	2,400
Thailand	51,400	17,500	34	2,600	5	17,282	34	27.1	1,610

Note: — Not available.
Sources: USDA, Economic Botany Laboratory, 1981.
Wernstedt, 1972.
University of Idaho, 1982.

(63 percent). Indonesia has the smallest proportion in this category (9 percent). The forest land category ranges from as high as 84 percent in Indonesia to 5 percent of the total land area in Pakistan. Irrigated agriculture occupies as much as 17 percent of Pakistan total land area and only 1 percent of the total land area in Nepal. Mean annual temperatures range from a high of 27.1^{o}C in Thailand to 12.3^{o}C in Korea. Mean annual precipitation ranges from 2,810 millimeters in Burma to 330 millimeters in Pakistan.

2.3 Agricultural Production

Crops with relatively high energy potential and yields by country are given in Table 2.3. Rice occupies the largest total land area (79.5 million hectares) followed by wheat, millet, sorghum, and corn.

2.4 Forest Production

Table 2.4 shows the forest area by country and type of forest land. In all countries reported, closed natural forest occupies the largest part of the total forest area. The relative area of open forest, shrub land, and fallow land with respect to the total forest area varies from country to country. The area of plantations reported for India and Indonesia is much larger than the largest areas of plantations reported for Africa (i.e. Madagascar and Sudan).

Table 2.5 shows the total forest biomass potential for the countries considered by types of forest land. In all reported cases, the potential

TABLE 2.3.—AGRICULTURAL PRODUCTION BY COUNTRY (1979), ASIA AND PACIFIC

Crop	Bangladesh Hectares Planted (x 1,000)	Bangladesh Yield (kg/ha)	Burma Hectares Planted (x 1,000)	Burma Yield (kg/ha)	India Hectares Planted (x 1,000)	India Yield (kg/ha)	Indonesia Hectares Planted (x 1,000)	Indonesia Yield (kg/ha)	Korea Hectares Planted (x 1,000)	Korea Yield (kg/ha)	Nepal Hectares Planted (x 1,000)	Nepal Yield (kg/ha)	Pakistan Hectares Planted (x 1,000)	Pakistan Yield (kg/ha)	Philippines Hectares Planted (x 1,000)	Philippines Yield (kg/ha)	Sri Lanka Area Planted (x 1,000)	Sri Lanka Yield (kg/ha)	Thailand Area Planted (x 1,000)	Thailand Yield (kg/ha)	Total Area Planted (x 1,000)
Wheat	265	1,865	83	496	22,220	1,574	--	—	13	3,206	356	1,166	6,696	1,485	—	—	—	—	—	—	29,633
Rice paddy	10,000	1,936	5,013	1,995	38,500	1,792	8,850	2,977	1,228	6,556	1,265	1,852	1,975	2,508	3,500	2,000	899	2,009	8,300	1,884	79,530
Barley	20	665	—	—	1,836	1,155	—	—	473	3,186	26	885	177	730	—	—	—	—	—	—	2,532
Corn	2	773	80	975	5,500	909	2,600	1,231	--	—	450	1,778	656	1,290	3,276	1,007	25	800	1,466	2,251	14,055
Sorghum	1	714	—	—	15,500	645	—	—	5	800	—	—	477	587	—	—	2	1,150	220	1,091	16,205
Millet	—	727	183	306	17,500	486	—	—	3	1,200	120	1,167	629	493	—	—	35	600	—	—	18,470
Potatoes	97	9,401	11	4,851	790	12,812	35	7,143	32	11,125	55	5,455	30	10,667	3	6,349	3	10,000	1	11,404	1,057
Sweet potatoes	—	—	4	4,103	225	6,875	309	7,605	70	19,814	--	—	18	8,901	228	4,556	21	6,190	36	9,669	911
Cassava	—	—	3	9,146	361	16,748	1,398	9,371	—	—	—	—	—	--	182	9,802	75	7,867	1	12,500	2,019
Soybeans	—	—	23	680	330	909	710	810	260	988	—	—	—	—	9	772	1	1,000	160	783	1,493
Peanuts	25	1,120	523	735	7,200	806	517	1,430	11	1,455	—	—	40	1,425	49	761	9	500	135	962	8,509
Castor beans	—	650	—	—	446	528	7	288	1	340	—	—	20	750	7	1,538	—	—	42	1,071	523
Rape seed	213	645	1	1,000	3,557	528	—	—	17	1,612	—	—	420	578	—	—	—	—	—	—	4,208
Sesame seed	57	561	958	215	2,400	208	16	375	68	393	—	—	34	397	—	—	30	567	30	732	3,593
Linseed	15	497	—	—	2,025	254	—	—	—	—	—	—	13	530	-	—	—	—	—	—	2,053
Seed cotton	11	685	165	310	7,500	488	4	568	5	1,000	—	—	1,891	1,032	5	567	3	2,939	92	1,063	9,676
Coconuts	—	—	—	--	—	—	—	—	--	--	—	--	—	—	—	—	—	—	—	—	—
Sugar cane	155	44,061	50	36,346	3,119	50,160	165	97,927	—	—	20	16,850	738	37,639	483	42,411	7	50,000	480	41,667	5,217
Gr. Coffee	—	—	3	440	190	553	456	586	—	--	—	—	—	--	123	695	7	1,736	—	—	779
Tea	40	969	—	—	360	1,528	83	1,120	1	300	—	--	—	—	—	—	243	864	—	—	727
Tobacco	50	878	61	837	411	1,098	169	471	56	2,210	8	750	53	1,361	74	775	11	714	159	449	1,072

Note: -- Not available.

Source: USDA, Economic Botany Laboratory 1981.

TABLE 2.4.--FOREST AREA, BY COUNTRY ASIA AND PACIFIC
(In Thousands of Hectares)

Country	Closed Forest		Open Forest	Shrub Land	Fallow Land		Total
	Natural	Plantations			Closed	Open	
Bangladesh	927	82	—	—	315	—	1,330
Burma	31,941	86	—	2,600	18,100	—	52,727
India	51,841	1,400	5,393	5,378	9,470	—	73,482
Indonesia	113,895	2,760	3,000	23,900	13,460	3,900	160,915
Korea	—	—	—	—	—	—	—
Nepal	1,941	—	180	230	110	—	2,461
Pakistan	2,185	237	295	1,105	—	—	3,822
Philippines	9,510	300	—	—	3,520	—	13,330
Sri Lanka	1,659	130	—	215	853	—	2,857
Thailand	9,235	307	6,440	500	800	—	17,282

Source: University of Idaho, 1982.
Note: -- Not available.

TABLE 2.5.—FOREST BIOMASS POTENTIAL BY COUNTRY, ASIA AND PACIFIC
(In Millions of Cubic Meters)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Closed Forests						Open Forests					Fallow Land				
	Broad Leaves		Coniferous													
Country	Pro-ductive	Unpro-ductive	Pro ductive	Unpro-ductive	Whole Trees	Shrub & Small Trees	Pro-ductive	Unpro-ductive	Whole Tree	Shrub & Small Trees	Shrub Land	Closed	Open	Total Biomass Poten-tial	Average Potential (M3/ha)	Average Yearly Fuel wood Potential (m^3/ha/yr)
Bangladesh	68.5	2.6	—	—	99.5	13.9	—	—	—	—	—	3.2	—	116.6	87.7	2.09
Burma	3,794	727	16.4	—	6352.9	479.1	—	—	—	—	13.0	181.0	—	7,026.0	133.3	1.49
India	2,558	309	470.5	111.0	4869.9	777.6	—	53.9	75.5	—	26.9	94.7	—	5,844.6	79.5	2.04
Indonesia	13,810	7,026	12.8	9.6	29,201.7	1708.4	—	30.0	42.0	30	119.5	134.6	19.5	31,255.7	94.1	2.85
Korea	33.3	—	41.1	—	—	—	—	—	—	—	—	—	—	—	—	—
Nepal	73.6	22.3	21.6	6.9	174.3	29.1	—	1.8	2.5	1.8	1.2	—	1.1	210.0	25.3	1.95
Pakistan	30.9	34.9	139.0	34.0	334.4	32.8	7	1.0	11.2	3.0	5.6	—	—	387.0	101.3	1.37
Philippines	1,525	211.0	18.0	—	2455.6	142.7	—	—	—	—	—	35.2	—	2633.5	197.6	2.83
Sri Lanka	75.6	8.7	—	—	118.0	24.9	—	—	—	—	1.1	8.5	—	152.5	53.4	2.04
Thailand	315	340	10	1	933.8	138.5	92	32	173.6	64.4	2.5	8.0	—	1320.8	76.4	3.43

Note: — Not available.
Source: University of Idaho, 1982.

1. Closed forest has canopy in which individual tree crowns are nearing general contact with one another.
2. Biomass volume include the tree bole over bark for trees <10cm dbh; volume of crowns, small trees and shrubs not included.
3. Includes national parks, reserves, marginal land, steep, inaccessible slopes, etc.
4. "Whole tree" includes the tree bole over bark <10cm dbh plus volume of crown and biomass, considered to be 40 percent of gross bole volume (FAO, 1981).
5. Shrubs and small trees on closed and open forest land in addition to trees <10cm dbh.
6. Biomass volumes on shrub land not containing trees <10 cm dbh.
7. Fallow land is recently cutover open or closed forest land.
8. Sum of columns 5, 6, 9, 10, 11, and 13.

of closed forests largely exceeds that of all other types of forest land reported. Indonesia, Burma, and India have the highest total forest biomass potential of the countries considered. On a per hectare of total forest area basis, the Philippines and Burma have the highest average potential (from about 198 m^3/ha to 133 m^3/ha); Sri Lanka has the lowest potential (about 53 m^3/ha).

Table 2.6 shows the total production of roundwood, the production of industrial roundwood, and of fuelwood and charcoal by country for the year 1979 as well as the trends in the production of these wood products for the 1968-1979 period. Fuelwood/charcoal production accounts for the largest fraction of the total roundwood production. Industrial roundwood production decreased at a rate of about 2 percent per year over the period in Bangladesh, Burma, and the Philippines and at a rate of one-third of 1 percent in Nepal; correspondingly, the rate of fuelwood production in those countries is higher than the rate of increase in population.

Table 2.7 shows the mean annual increments of plantation species by countries as reported by the University of Idaho (1982).

Table 2.8 compares the current and projected fuelwood utilization to the tolerable fuelwood production. On the basis of country-wide estimates Bangladesh, India, Nepal, Pakistan, and Sri Lanka exceed their fuelwood production potential, and the Philippines could soon reach excessive utilization of forest resources.

TABLE 2.6.—PRODUCTION AND UTILIZATION OF ROUNDWOOD 1979, ASIA AND PACIFIC
(In Thousands of Cubic Meters)

Country	Total	a [1]	b [2]	cc [3]	Industrial	a	b	cc	Fuelwood Charcoal	a	b	cc
Bangladesh	10,345	7,977	185.2	.972	881	1,111	-19.9	-.421	9,464	6,866	205.1	.994
Burma	25,303	19,611	448.6	.993	2,257	2,669	-44.9	-.762	23,046	16,942	493.5	.992
India	215,952	155,588	4,954	.999	14,536	8,178	524.5	.990	201,416	147,410	4,430	.999
Indonesia	159,247	103,361	4,799	.981	29,809	7,520	2,025	.901	129,438	95,841	2,775	.999
Korea	67,443	52,889	1,232	.993	2,720	1,621	128.9	.738	64,723	51,268	1,103	.997
Nepal	13,311	10,266	246.0	.994	560	578.2	-1.85	-.344	12,751	9,687	247.3	.995
Pakistan	18,315	12,509	468.5	.998	525	420.3	9.15	.644	17,790	12,133	449.1	.998
Philippines	34,614	29,933	391.8	.849	9,325	13,081	-292.2	-.782	25,289	16,852	684.0	.998
Sri Lanka	7,951	6,086	119.8	.997	596	440.8	9.05	.772	6,995	5,645	110.8	.999
Thailand	37,421	27,055	855.6	.995	5,205	4,629	54.0	.482	32,216	22,426	801.7	.999

Source: FAO 1979

1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

TABLE 2.7.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY, ASIA AND PACIFIC
(M^3/ha/Year)

Country	Species																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Bangladesh	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Burma	18	6-10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
India	—	—	6.3-7.4	10-20	2.8-5.3	21-24.8	3.6-7.8	1.3-5.6	8.6	8.5-10	4.1-11.3	3.3-12	—	—	—	—	—	—
Indonesia	—	—	—	—	—	—	—	—	—	—	—	5-23	28	29-42	9-24	16-24	19-37	18-46

1. Eucalyptus grandis
2. Eucalyptus camaldulensis
3. Anthocephalus indicus
4. Ailanthus grandis
5. Acacia auriculiformis
6. Cryptomeria japonica
7. Dalbergia sissoo
8. Eucalyptus teriticornis
9. Gmelina arborea
10. Michelia champaka
11. Shorea robusta
12. Tectona grandis
13. Mechelia velutina
14. Agathis lorantifolia
15. Altingia excelsa
16. Anthocephalus chinensis
17. Dalbergia latifolia
18. Pinus merkusii

Note: -- Not available.
Source: University of Idaho, 1982.

TABLE 2.7.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY, ASIA AND PACIFIC (Continued)
(M^3/ha/Year)

Country	Species														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Indonesia	16-46	40-50	20-25	20	—	—	—	—	—	—	—	—	—	—	—
Korea	—	—	—	—	6.1	12.5	6.0	6.4	6.7	2.7	8.5	15.0	20.0	—	—
Nepal	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pakistan	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Philippines	25-30	—	—	—	—	—	—	—	—	—	—	—	—	18-20	10

1. Swietenia macrophylla-
2. Albizia falcaturia-
3. Sesbania grandiflora-
4. Eucalyptus spp.-
5. Pinus densiflora - unmanaged
6. Pinus densiflora - managed
7. Pinus koralensis - unmanaged
8. Pinus rigida - unmanaged
9. Larix leptolepis - unmanaged
10. Quercus spp. - unmanaged
11. Pinus rigida - managed
12. Larix leptolyis - managed
13. Robinia pseudoacacia-
14. Eucalyptus deglupta-
15. Pinus Caribaea-

Note: — Not available.
Source: University of Idaho, 1982.

TABLE 2.7.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY ASIA AND PACIFIC (Concluded)
(M^3/ha/Year)

Country	Species																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sri Lanka	8.6	4.8	4.8	10.2	10.2	14.3	14.3-28.5	11.9-14.9	11.9-18.6	—								
Thailand	—	—	—	—	—	—	—	—	—	10-12								

1. Tectona grandis
2. Swietenia macrophylla
3. Cedrela tooma
4. Alstonia macrophylla
5. Melia composita
6. Albizia mohiccana
7. Eucalyptus grandis
8. Pinus caribaea var. hondurensis
9. Pinus patula
10. Pinus kesiya

Note: — Not available.
Source: University of Idaho, 1982.

TABLE 2.8.--COMPARISON OF PRESENT AND PROJECTED FUELWOOD UTILIZATION WITH TOLERATED FUELWOOD UTILIZATION, ASIA AND PACIFIC
(In Thousands of Cubic Meters)

Country	Fuelwood Utilization[1]		Tolerated Fuelwood Utilization[2]
	1979	1990	
Bangladesh	9,464	11,583	2,780
Burma	23,046	28,293	78,563
India	201,416	249,300	149,903
Indonesia	129,438	159,666	1,307,032
Korea	64,723	76,637	--
Nepal	12,751	15,375	4,799
Pakistan	17,790	22,462	5,236
Philippines	25,289	32,584	37,724
Sri Lanka	6,995	8,193	5,828
Thailand	32,216	40,865	59,277

1. Derived from Table 2.6

2. Derived from Tables 2.4 and 2.5

2.5 Livestock Summary

Livestock statistics by country are given in Table 2.9. In terms of pure numbers chickens are by far the most numerous, followed by goats, cattle and sheep. There is little energy potential from goats and sheep since they are generally not confined. Cattle, however, may have a greater potential for energy since manure production is much higher and confinement, or semiconfinement, is more common.

2.6 Fossil Fuel Consumption

Consumption of gasoline, diesel oil, kerosene, residual fuel oil, and liquefied petroleum gases by individual countries is given in Table 2.10. In addition to the consumption figures, given for the year 1979, linear trends are also reported. Where the b-coefficients are negative, such as gasoline consumption in India, Nepal, Philippines, and Sri Lanka, the consumption is declining over time.

TABLE 2.9.—LIVESTOCK SUMMARY (1979), ASIA AND PACIFIC

Country	Horses	Cattle	Camels	Pigs	Buffalo	Sheep	Goats	Asses/Mules	Chickens	Turkeys	Ducks
Bangladesh	43	31,741	0	0	1,529	1,061	11,000	0	70,158	0	19,788
Burma	110	7,560	0	2,200	1,750	215	575	9	17,100	3	3,600
India	760	0	0	9,300	0	41,000	71,000	1,125	145,000	0	0
Indonesia	615	6,453	0	2,925	2,312	3,611	8,051	0	99,179	0	14,581
Korea	5	1,651	0	1,719	0	8	224	0	40,753	8	560
Nepal		6,850	0	350	4,150	2,360	2,480	0	21,500	0	0
Pakistan	480	14,992	830	96	11,306	24,185	27,804	2,437	48,872	0	1,079
Philippines	325	1,910	0	7,300	3,018	30	1,430	0	60,000	200	5,477
Sri Lanka	2	1,623	0	49	844	24	461	0	5,882	9	16
Thailand	167	4,850	0	5,386	5,500	58	31	0	65,324	0	9,013
Total	2,507	109,371	830	29,925	30,409	72,552	123,056	3,571	573,768	220	54,114

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 2.10.—PETROLEUM-DERIVED FUEL CONSUMPTION BY PRODUCT 1979, ASIA AND PACIFIC
(In Thousands of Metric Tons)

Country	Gasoline				Diesel Oil (Distillates)				Kerosene				Residual Fuel Oil (Bunker Oil)				Liquefied Petroleum Gases (LPG)			
	Total Consumption	a[1]	b[2]	cc[3]	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc
Bangladesh	62	36.8	3.6	0.78	319	129	26.0	0.86	375	216.0	21.2	0.91	421	220.0	28.1	0.93	—	—	—	—
Burma	241	149.0	8.3	0.89	364	260	6.7	0.52	70	341.0	-26.5	-0.96	235	97.3	8.8	0.43	2	6.5	-.44	-0.68
India	1,570	1,496.0	-8.0	-0.17	10,127	4,331	564	0.99	4,144	3,126.0	57.3	0.42	6,893	4,429.0	210.0	0.90	426	136.0	29.7	0.99
Indonesia	2,188	957.0	132.0	0.99	3,807	846	275	0.98	4,799	1,831.0	325.0	0.98	5,743	2,902.0	337.0	0.91	34	-2.5	4.6	0.94
Korea	1,026	572.0	27.3	0.50	5,239	880	398	0.98	1,148	172.0	69.3	0.82	15,164	4,359.0	967.0	0.98	275	-.67	22.8	0.94
Nepal	20	22.1	-0.4	-0.42	—	—	—	—	25	24.3	-0.14	-0.12	35	32.9	.01	0.01	—	—	—	—
Pakistan	485	319.0	11.5	0.36	1,490	1,219	21.0	0.61	576	667.0	-11.7	-0.36	830	1,054.0	-21.0	-0.47	25	-5.2	3.1	0.95
Philippines	1,790	1,853.0	-9.9	-0.42	2,500	1,270	108.0	0.96	460	406.0	2.6	0.35	4,625	2,439.0	229.0	0.99	200	101.0	11.0	0.94
Sri Lanka	112	138.0	-3.6	-0.58	330	252	8.6	0.70	230	294.0	-8.6	-0.70	255	277.0	-4.4	-0.56	6	7.7	-.5	-0.50
Thailand	1,755	595.0	121.0	0.99	3,420	1,841	157.0	0.96	246	129.0	12.2	0.84	3,810	1,267.0	255.0	0.98	160	21.7	13.8	0.99

Note: — Not available.
Source: 1979 Yearbook of World Energy Statistics, United Nations, 1980.

1. a = Regression Intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

CHAPTER 3: LATIN AMERICA AND CARIBBEAN

The Latin America and Caribbean region consists of twenty-three countries: Costa Rica, the Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, and Panama in Central America, and Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Surinam, Uruguay, and Venezuela in South America. These countries range over a wide variety of climatic and topographic zones and as a result have widely different potentials for biomass production and utilization. Statistical profiles for each country are given below.

3.1 Demographic Summary

Demographic summaries for the twenty-three countries in the Latin America and Caribbean region are given in Table 3.1. Population ranges from a low of 69,000 people in French Guiana to nearly 123 million people in Brazil. The highest population growth rate is found in Venezuela, 3.4 percent per year. The majority of the countries exceed the minimum daily calorie consumption requirements. Gross national product per capita is highest in oil-rich Venezuela, $2,630, followed by Argentina and Surinam. Haiti has the lowest GNP per capita of $230 per year.

3.2 Land Area and Climate

The largest country in the Latin America and Caribbean region is Brazil with more than 851 million hectares, followed by Argentina and Mexico (Table 3.2). El Salvador and Haiti have the largest proportions of arable

TABLE 3.1.—DEMOGRAPHIC SUMMARY, LATIN AMERICA AND CARIBBEAN

Country	Population (x 1,000) 1979	Growth 1970-78	Food Consumption per Capita (Calories) 1979	of Requirement	$ GNP per Capita 1977
Argentina	26,723	1.3	3,347	129	1,870
Bolivia	5,430	2.7	2,137	76	480
Brazil	122,879	2.9	2,562	104	1,410
Chile	10,919	1.7	2,656	113	1,250
Colombia	26,253	2.3	2,310	92	760
Costa Rica	2,162	2.5	2,550	110	1,390
Dominican Republic	5,800	3.0	2,094	88	840
Ecuador	7,779	3.3	2,104	91	820
El Salvador	4,663	2.9	2,051	79	590
French Guiana	69	—	2,545	—	--
Guatemala	7,048	2.9	2,156	92	830
Guyana	865	2.0	2,502	104	520
Haiti	5,677	1.7	2,100	87	230
Honduras	3,565	3.4	2,015	99	420
Jamaica	2,162	1.7	2,660	103	1,060
Mexico	67,676	3.3	2,654	105	1,160
Nicaragua	2,649	3.3	2,446	106	870
Panama	1,899	2.7	2,654	105	1,160
Paraguay	2,979	2.9	2,824	121	750
Peru	17,291	2.8	2,274	99	720
Surinam	381	0.2	2,181	103	1,870
Uruguay	2,905	0.2	3,036	114	1,450
Venezuela	14,437	3.4	2,543	—	2,630

Note: — Not available.
Source: World Bank, 1980.

TABLE 3.2.—LAND AREA CLIMATIC SUMMARY (1979), LATIN AMERICA AND CARIBBEAN
(In Thousands of Hectares)

	Total	Arable	of Total	Irrig.	of Total	Forest	of Total	Mean Annual Temp. (°C)	Mean Annual Precip. (mm)
Argentina	276,689	35,100	13	1,540	<1	39,850	14	15.6	670
Bolivia	109,858	3,327	3	125	<1	78,835	72	17.6	880
Brazil	851,197	40,720	5	1,050	<1	680,155	80	22.0	1,530
Chile	75,695	5,828	8	1,320	2	5,380	7	12.8	990
Colombia	113,891	5,600	5	295	<1	66,195	58	20.7	1,960
Costa Rica	5,070	490	10	26	<1	2,041	40	22.4	2,820
Dominican Republic	4,873	1,230	25	140	3	956	20	25.2	1,400
Ecuador	28,356	2,615	9	520	2	18,243	64	19.3	1,040
El Salvador	2,104	680	32	50	2	456	22	24.1	1,880
French Guiana	9,100	4	<1	—	—	9,052	99	26.1	2,880
Guatemala	10,889	1,800	17	64	<1	6,423	59	23.1	2,840
Guyana	21,497	379	2	122	<1	18,819	88	26.6	2,460
Haiti	2,775	885	32	70	3	144	5	26.3	1,430
Honduras	11,209	1,757	16	80	<1	5,900	53	21.8	1,700
Jamaica	1,099	265	24	32	3	466	42	24.0	1,800
Mexico	197,255	23,220	12	5,000	3	134,030	68	20.8	900
Nicargua	13,000	1,511	12	76	<1	6,077	47	24.4	1,840
Panama	7,708	566	7	26	<1	4,293	56	26.8	2,650
Paraguay	40,675	1,155	3	55	<1	35,983	88	23.3	1,340
Peru	128,522	3,430	3	1,180	<1	79,424	62	18.4	670
Surinam	16,327	47	<1	32	<1	15,992	98	29.2	2,160
Uruguay	17,622	1,910	11	64	<1	766	4	17.8	1,160
Venezuela	91,205	5,357	6	3,600	4	48,061	53	24.5	1,110

Sources: USDA, Economic Botany Laboratory, 1981.
Wernstedt, 1972.
University of Idaho, 1982.

land relative to total area (32 percent). French Guiana and Surinam has the smallest proportion in this category (less than 1 percent). The forest land category ranges from as high as 99 percent in French Guiana to only 4 percent of the total land area in Uruguay. Irrigated agriculture occupies 4 percent of the total land area in Venezuela and less in the other countries. Mean annual temperatures range from a high of 29.2^{o}C in Surinam to 15.6^{o}C in Argentina. Mean annual precipitation ranges from 2,880 mm in French Guiana to 670 mm in Argentina and Peru.

3.3 Agricultural Production

Crops with relatively high energy potential and yields by country are given in Table 3.3. Corn occupies the largest total land area (25.7 million hectares) followed by wheat and soybeans. Coffee, sugar cane, and cotton (all potential export crops) are the next most important crops in terms of land area occupied for their production.

3.4 Forest Production

Table 3.4 shows the forest area by country and type of forest. The relative importance of closed versus open forests varies between countries. Closed forests are dominant except for Argentina, Paraguay, Mexico, and Jamaica. Open forests and shrub land account for a large fraction of total forest land in Bolivia, Brazil, Guatemala, and Honduras. Shrub land occupies over half the forest area of Mexico. Areas devoted to plantations are extensive particularly in Brazil, Chile, Argentina, Mexico, Uruguay, Peru, and Venezuela.

TABLE 3.3.—AGRICULTURAL PRODUCTION BY COUNTRY (1979), LATIN AMERICA AND CARIBBEAN

Crop	Argentina Hectares Planted (x 1000)	Argentina Yield (kg/ha)	Bolivia Hectares Planted (x 1000)	Bolivia Yield (kg/ha)	Brazil Hectares Planted (x 1000)	Brazil Yield (kg/ha)	Chile Hectares Planted (x 1000)	Chile Yield (kg/ha)	Colombia Hectares Planted (x 1000)	Colombia Yield (kg/ha)	Costa Rica Hectares Planted (x 1,000)	Costa Rica Yield (kg/ha)	Dom. Republic Hectares Planted (x 1,000)	Dom. Republic Yield (kg/ha)	Ecuador Hectares Planted (x 1,000)	Ecuador Yield (kg/ha)
Wheat	4,564	1,709	87	646	3,831	763	560	1,776	27	1,427	—	—	—	—	—	—
Rice paddy	102	3,184	72	1,420	5,439	1,395	47	3,849	422	4,222	85	2,518	109	2,235	107	2,825
Barley	270	1,220	95	650	85	1,161	60	1,875	—	—	—	—	—	—	38	680
Corn	2,800	3,107	255	1,298	11,314	1,442	130	3,752	615	1,416	50	1,729	10	1,500	195	1,112
Sorghum	2,044	3,033	—	—	81	1,761	—	—	—	—	30	2,248	5	2,000	2	2,000
Millet	238	1,303	—	—	—	—	—	—	215	2,202	—	—	—	—	—	—
Potatoes	133	14,971	130	6,154	203	10,596	81	9,520	151	13,698	2	12,000	2	12,500	45	12,105
Sweet potatoes	34	9,448	5	6,040	136	11,155	1	7,000	—	—	—	—	8	10,000	1	4,000
Cassava	21	8,714	25	12,000	2,105	11,844	—	—	236	8,755	2	6,364	16	10,000	24	7,083
Soybeans	1,600	2,313	23	1,565	7,321	1,360	2	1,022	69	1,997	—	—	—	—	23	1,210
Peanuts	393	1,709	14	1,321	286	1,612	—	—	3	1,154	—	—	50	1,257	12	823
Castor beans	—	667	—	—	400	925	—	—	—	—	—	—	—	—	9	778
Rape seed	3	667	—	—	—	—	54	1,199	—	—	—	—	—	—	—	—
Sesame seed	—	—	—	—	5	556	—	—	25	550	—	523	1	467	1	500
Linseed	1,029	730	—	—	10	660	1	800	—	—	—	—	—	—	—	—
Seed cotton	667	699	32	1,358	2,467	678		—	219	1,416	12	916	3	968	25	1,298
Coconuts	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	-
Sugar cane	339	41,612	81	39,419	2,519	54,906	—	—	282	85,816	34	76,491	178	64,141	100	70,000
Gr. Coffee	—	—	32	938	2,227	581	—	—	1,170	651	83	1,163	136	301	250	409
Tea	41	728	1	2,586	6	1,500	—	—	36	1,915	—	—	—	—	1	1,071
Tobacco	76	901	2	1,143	318	1,330	3	2,341	—	—	2	1,212	32	1,494	2	1,489

Note: — Not available.
Source: USDA, Economic Botany Laboratory, 1981.

TABLE 3.3.—AGRICULTURAL PRODUCTION BY COUNTRY (1979), LATIN AMERICA AND CARIBBEAN (Continued)

Crop	El Salvador Hectares Planted (x 1,000)	El Salvador Yield (kg/ha)	Fr. Guiana Hectares Planted (x 1,000)	Fr. Guiana Yield (kg/ha)	Guatemala Hectares Planted (x 1,000)	Guatemala Yield (kg/ha)	Guyana Hectares Planted (x 1,000)	Guyana Yield (kg/ha)	Haiti Hectares Planted (x 1,000)	Haiti Yield (kg/ha)	Honduras Hectares Planted (x 1,000)	Honduras Yield (kg/ha)	Jamaica Hectares Planted (x 1,000)	Jamaica Yield (kg/ha)	Mexico Hectares Planted (x 1,000)	Mexico Yield (kg/ha)
Wheat	—	—	—	—	59	1,017	—	—	—	—	1	1,000	—	—	628	3,618
Rice paddy	15	3,800	—	500	13	2,952	88	2,773	42	2,262	19	1,491	3	2,205	151	3,238
Barley	—	—	—	—	—	1,515	—	—	—	—	—	—	—	—	326	1,549
Corn	277	1,886		4,000	650	1,308	2	1,158	250	1,040	350	1,051	13	1,154	7,148	1,295
Sorghum	144	1,233	—	—	47	1,468	—	—	—	166	1,084	54	667	—	1,456	2,680
Millet	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Potatoes	—	18,000	—	—	17	3,758	—	—	1	14,844	1	5,412	1	10,556	56	12,982
Sweet potatoes	—	—	—	6,250	—	—	—	—	20	4,801	—	3,548	3	7,786	9	10,795
Cassava	1	10,500	1	10,000	3	2,700			58	4,513	3	2,667	4	8,417	6	15,088
Soybeans	—	—	—	—	—	—	—	417	—	—	—	—	—	—	386	1,816
Peanuts	1	1,417	—	—	—	2,057	1	714	6	484	—	1,250	1	1,154	58	1,534
Castor beans	—	—	—	—	—	—	—	—	3	520	—	—	—	—	8	750
Rape seed	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	1,000
Sesame seed	8	800	—	—	16	968	—	—	—	556	2	938	—	—	250	600
Linseed	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	1,000
Seed cotton	102	1,983	—	—	121	3,306	—	—	6	500	13	1,819	—	—	381	2,323
Coconuts	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sugar cane	40	81,013	—	37,500	74	67,797	57	68,457	75	38,667	75	34,667	49	61,777	502	70,548
Gr. Coffee	180	1,000	—	—	248	680	2	720	35	1,131	130	577	5	336	345	661
Tea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tobacco	2	1,200	—	—	6	1,451	—	1,056	—	945	6	1,225	1	1,559	48	1,667

Note: — Not available.

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 3.3.—AGRICULTURAL PRODUCTION BY COUNTRY (1979), LATIN AMERICA AND CARIBBEAN (Concluded)

Crop	Nicaragua Hectares Planted (x 1,000)	Nicaragua Yield (kg/ha)	Panama Hectares Planted (x 1,000)	Panama Yield (kg/ha)	Paraguay Hectares Planted (x 1,000)	Paraguay Yield (kg/ha)	Peru Hectares Planted (x 1,000)	Peru Yield (kg/ha)	Surinam Hectares Planted (x 1,000)	Surinam Yield (kg/ha)	Uruaguay Hectares Planted (x 1,000)	Uruaguay Yield (kg/ha)	Venezuela Hectares Planted (x 1,000)	Venezuela Yield (kg/ha)	Total Hectares Planted (x 1,000)
Wheat	—	—	—	—	52	1,114	95	1,000	—	—	316	1,204	2	313	10,222
Rice paddy	20	150	110	1,818	30	1,890	122	4,463	52	4,231	68	3,646	218	2,995	7,821
Barley	—	—	—	—	—	—	185	946	—	—	52	1,058	—	—	1,111
Corn	180	931	68	956	377	1,553	360	1,667	—	2,083	94	758	519	1,634	25,657
Sorghum	55	1,058	—	—	7	1,234	19	3,158	—	—	39	1,390	215	1,996	4,364
Millet	—	—	—	—	—	—	—	—	—	—	—	—	—	—	453
Potatoes	—	4,250	1	11,000	1	8,828	255	6,667	—	—	21	6,416	17	13,366	1,118
Sweet potatoes	—	—	—	—	15	8,267	16	10,369	—	5,000	15	5,667	1	3,573	264
Cassava	7	4,046	5	8,511	120	12,450	38	10,958	—	6,667	—	—	38	9,117	2,715
Soybeans	—	—	—	—	360	1,524	3	2,000	—	1,000	51	787	—	—	9,838
Peanuts	5	1,696	—	—	24	980	5	1,404	—	1,172	2	804	22	1,209	883
Castor beans	—	—	—	—	10	1,000	—	2,000	—	—	—	—	—	—	430
Rape seed	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
Sesame seed	8	675	—	500	—	—	—	938	—	—	—	—	100	400	416
Linseed	—	—	—	—	—	—	—	636	—	—	61	515	—	—	1,108
Seed cotton	173	1,708	—	—	360	639	146	1,781	—	—	1	476	41	1,181	4,769
Coconuts	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
Sugarcane	41	60,976	44	59,408	48	35,417	53	126,415	2	85,000	10	37,682	63	69,841	4,587
Gr. Coffee	85	621	24	238	16	450	130	554	—	—	—	—	253	247	5,351
Tea	—	—	—	—	—	—	4	750	—	—	—	—	—	—	89
Tobacco	2	1,671	1	1,373	16	1,226	3	1,123	—	—	1	1,679	14	1,075	535

Note: -- Not available.
Source: USDA, Economic Botany Laboratory, 1981.

TABLE 3.4.—FOREST AREA, BY COUNTRY, LATIN AMERICA AND CARIBBEAN
(In Thousands of Hectares)

Country	Closed Forest		Open Forest	Shrub Land	Fallow Land		Total
	Natural	Plantations			Closed	Open	
Argentina	7,000	600	32,250	—	—	—	39,850.0
Bolivia	44,010	25	24,700	9,000	1,100	—	78,835.0
Brazil	357,480	3,855	211,200	61,200	46,420	—	680,155.0
Chile	4,640	740	—	—	—	—	5,380.0
Columbia	46,400	95	5,700	5,500	8,500	—	66,195.0
Costa Rica	1,638	2.8	160	120	120	—	2,040.8
Dominican Republic	629	5.7	—	54	267	—	955.7
Ecuador	14,250	43.0	550	1,050	2,350	—	18,243.0
El Salvador	163	—	—	293	—	—	456.0
French Guiana	8,900	—	70	7	75	—	9,052.0
Guatemala	4,442	15.5	100	1,505	360	—	6,442.5
Guyana	18,475	4.0	25	115	200	—	18,819.0
Haiti	48	—	—	53	43	—	144.0
Honduras	3,797	3.0	200	1,200	680	—	5,900.0
Jamaica	67	12.8	—	227	159	—	465.8
Mexico	46,250	180.0	2,100	59,500	26,000	—	134,030.0
Nicaragua	5,866	1.0	—	210	—	—	6,077.0
Panama	4,165	3.5	—	—	124	—	4,292.5
Paraguay	4,070	3.0	28,640	—	3,270	—	35,983.0
Peru	69,680	124.4	1,120	3,150	5,350	—	79,424.4
Surinam	14,830	2.0	690	200	270	—	15,992.0
Uruguay	610.5	155.0	—	—	—	—	765.5
Venezuela	31,870	121.0	3,300	2,120	10,650	—	48,061.0

Note: — Not available.
Source: University of Idaho, 1982.

Table 3.5 shows the forest biomass potential by country and forest types. In the majority of developing countries elsewhere, open forests or shrub land are dominant fractions of the total forest area. In Latin America, however, the major fraction of the total forest resource is in closed forests. Average forest potentials (m^3/ha) in countries vary widely in the countries considered, ranging from almost 400 m^3/ha to less than 30 m^3/ha in countries such as Haiti and Jamaica.

Table 3.6 shows the allocation of total roundwood production to industrial roundwood and fuelwood and charcoal. Total roundwood production tends to decline in Guyana and Jamaica. Industrial roundwood production tends to decline in Guatemala, Guyana, Jamaica and Panama. Fuelwood production tends to increase in all countries except Bolivia and Chile.

Table 3.7 shows mean annual increments in plantations by countries and species as reported by the University of Idaho (1982). Wide ranges of productivities are reported reflecting the variety of climatic and soil conditions found in the countries considered. The data must therefore be used with caution in order not to overstate the potential of plantations.

Table 3.8 compares the current and projected fuelwood utilization to the tolerable fuelwood utilization. On the basis of these country-wide estimates, El Salvador and Guatemala have reached a critical point in terms of forest utilization. The data must however be used with caution as is illustrated by the case of Ecuador. Table 3.8 indicates that Ecuador

TABLE 3.5.—FOREST BIOMASS POTENTIAL BY COUNTRY, LATIN AMERICA AND CARIBBEAN
(In Thousands of Cubic Meters)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Closed Forests						Open Forests					Fallow Land				
	Broad Leaves		Coniferous													
Country	Productive	Unproductive	Productive	Unproductive	Whole Trees	Shrub a Small Trees	Productive	Unproductive	Whole Tree	Shrub a Small Trees	Shrub Land	Closed	Open	Total Biomass Potential	Average Potential (M3/Ha)	Average Yearly Fuelwood Potential (m^3/ha/yr)
Argentina	—	—	—	—	1,400.0	105.0	—	—	905.4	322.5	—	—	—	2,732.9	68.6	—
Bolivia	3063.0	733.0	—	—	5,314.4	660.2	85	86.2	239.7	247.0	45.0	711.0	—	6,517.3	82.7	1.89
Brazil	46,990.0	4,605.0	98.0	92.0	72,499.0	5,362.2	5,860	940.5	3,660.7	1,570.0	306.0	464.2	271.0	84,133.1	123.7	2.35
Chile	—	—	—	—	1,240.0	69.6	—	—	—	—	—	—	—	1,309.6	243.4	—
Columbia	5,046.0	445.0	—	—	7,687.4	696.0	—	57.0	79.8	57.0	27.5	85.0	—	8,632.7	130.4	2.86
Costa Rica	154.0	27.0	—	—	253.4	24.6	—	1.6	2.2	1.6	0.6	1.2	—	283.6	139.0	2.06
Dominican Rep.	19.9	1.9	4.9	0.1	36.2	9.4	—	—	—	—	0.3	2.7	—	48.6	50.9	2.10
Ecuador	1,349.0	224.0	0.3	0.7	2,203.6	213.8	—	5.5	7.7	5.5	5.3	23.5	—	2,459.4	134.8	2.37
El Salvador	0.3	2.9	1.6	1.2	8.4	2.1	—	—	—	—	1.5	0.2	—	12.2	26.8	0.92
French Guiana	2,200.0	260.0	—	—	3,444.0	133.5	—	0.7	1.0	0.7	—	0.8	—	3,580.0	395.5	3.94
Guatemala	310.0	104.0	25.0	1.4	616.6	66.6	—	1.0	1.4	1.0	7.5	3.6	—	696.7	108.5	2.01
Guyana	2,289.0	501.0	—	—	3,906.0	277.1	—	0.3	0.4	0.3	0.6	2.0	—	4,186.4	222.4	3.44
Haiti	0.8	0.7	0.5	0.02	2.8	0.7	—	—	—	—	0.3	0.4	—	4.2	29.2	0.81
Honduras	214.0	—	66.7	12.0	409.8	57.0	—	2.0	2.8	2.0	6.1	6.8	—	484.5	82.1	1.65
Jamaica	5.4	0.9	—	—	8.9	1.0	—	—	—	—	1.1	1.6	—	12.6	27.1	0.49
Mexico	1,065.0	640.0	967.0	517.0	4,464.6	693.4	—	21.0	29.4	21.0	297.5	260.0	—	5,765.9	43.0	0.85
Nicaragua	502.0	30.0	17.0	—	768.6	67.4	—	—	—	—	1.1	13.7	—	850.8	140.0	2.18
Panama	489.0	78.0	—	—	791.8	62.5	—	—	—	—	—	1.2	—	855.5	199.3	3.88
Paraguay	194.0	36.0	—	—	322.0	61.1	220	175.9	554.3	286.4	—	32.7	—	1,256.5	34.9	1.01
Peru	8,125.0	3,215.0	12.0	9.0	15,905.4	1,045.2	—	11.2	15.7	11.2	15.8	53.5	—	17,046.8	214.6	2.64
Surinam	2,611.0	234.0	—	—	3,983.0	222.5	—	6.9	9.7	6.9	1.0	2.7	—	4,225.8	264.2	3.27
Uruguay	—	—	—	—	36.3	9.2	—	—	—	—	—	—	—	45.5	59.4	—
Venezuela	2,726.0	1,013.0	—	—	5,234.6	478.1	—	33.0	46.2	33.0	10.6	100.7	—	5,903.2	122.8	1.70

Note: — Not available.
Source: University of Idaho, 1982.

1. Closed forest has canopy in which individual tree crowns are nearing general contact with one another.
2. Biomass volume include the tree bole over bark for trees <10cm dbh; volume of crowns, small trees, and shrubs not included.
3. Includes national parks, reserves, marginal land, steep, inaccessible slopes, etc.
4. "Whole tree" includes the tree bole over bark <10cm dbh plus volume of crown and biomass, considered to be 40 percent of gross bole volume (FAO, 1981).
5. Shrubs and small trees on closed and open forest land in addition to trees <10cm dbh.
6. Biomass volumes on shrub land not containing trees <10 cm dbh.
7. Fallow land is recently cutover open or closed forest land.
8. Sum of columns 5, 6, 9, 10, 11, and 13.

TABLE 3.6.—PRODUCTION AND UTILIZATION OF ROUNDWOOD 1979, LATIN AMERICA AND CARIBBEAN
(In Thousands of Cubic Meters)

Country	Total	a[1]	b[2]	cc[3]	Industrial	a	b	cc	Fuelwood Charcoal	a	b	cc
Argentina	10,224	8,664.0	155.3	0.924	3,644	3,065.0	73.9	.752	6,580	5,599.0	81.4	0.999
Bolivia	4,550	4,199.0	4.3	.078	490	177.9	16.8	.734	4,060	4,021.0	-12.5	-0.227
Brazil	212,727	134,681.0	6,168.0	.989	42,790	15,940.0	2,020.0	.935	169,937	118,742.0	4,148.0	0.999
Chile	11,560	7,361.0	253.3	.876	8,342	3,565.0	291.0	.884	3,218	3,796.0	-37.6	-0.900
Colombia	42,022	31,999.0	811.0	.996	3,209	3,027.0	8.3	.118	38,813	28,972.0	803.0	0.999
Costa Rica	3,553	2,048.0	135.2	.991	1,495	537.3	89.8	.979	2.058	1,511.0	45.3	0.999
Dominican Rep.	188	131.7	5.2	.875	14	9.2	0.93	.306	174	122.0	4.3	0.999
Ecuador	6,213	4,470.0	154.2	.978	1,720	1,372.0	41.1	.739	4,493	3,098.0	113.0	0.998
El Salvador	3,073	2,142.0	75.2	.999	91	77.2	0.35	.332	2,982	2,065.0	74.9	0.999
French Guiana	110	59.2	1.2	.176	94	43.2	1.2	.176	16	16.0	0	1.000
Guatemala	11,091	8,170.0	246.6	.977	190	591.0	-18.7	-.644	10,901	7,578.0	265.0	0.976
Guyana	155	266.3	-8.3	-.765	145	259.0	-8.5	-.772	10	7.4	0.20	0.907
Haiti	4,914	3,787.0	91.8	.999	239	238.0	0.10	.173	4,675	3,549.0	91.7	0.999
Honduras	5,308	4,697.0	37.4	.419	1,119	867.0	27.8	.512	4,109	3,830.0	9.6	0.217
Jamaica	59	69.3	-1.2	-.853	46	64.1	-1.6	-.963	13	5.3	0.4	0.648
Mexico	11,694	9,296.0	218.4	.795	6,029	4,699.0	152.0	.662	5,665	4,597.0	66.2	0.925
Nicaragua	3,104	1,863.0	112.5	.983	880	356.0	53.8	.916	2,224	1,507.0	58.8	0.996
Panama	1,677	1,274.0	36.3	.972	44	124.0	-3.1	-.303	1,633	1,150.0	39.4	0.999
Paraguay	4,428	3,033.0	120.2	.896	1,035	690.0	34.5	.832	3,393	2,343.0	85.7	0.831
Peru	4,346	2,973.0	133.2	.926	1,480	942.0	65.1	.762	2,866	2,031.0	68.1	0.999
Surinam	405	177.8.0	11.7	.694	387	177.0	10.4	.617	18	1.2	1.4	0.719
Uruguay	2,117	1,184.0	75.2	.932	345	95.2	22.2	.962	1,772	1,088.0	53.0	0.910
Venezuela	8,872	6,261.0	214.8	.999	636	492.0	15.6	.806	8,236	5,770.0	199.0	0.997

Source: FAO, 1979.

1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

TABLE 3.7.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY, LATIN AMERICA AND CARIBBEAN
(M^3/ha/Year)

Country	Species 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Argentina	10-20	5-15	10-30	—	—	—	—	—	—	—	—	—	—	—				
Bolivia	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
Brazil	—	5-14.9	8-34	17.9	3.3	38	9.9-17.1	10.6-20.7	—	—	—	—	—	—				
Chile	—	—	—	—	—	—	—	—	8.25	—	—	—	—	—				
Colombia	—	—	—	—	—	—	—	—	20	14	25	16	20	—				
Equador	—	—	—	—	—	—	—	—	9-37	—	12-26	—	—	24-29				
French Guiana	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
Guyana	—	—	—	3.8-13.5	—	—	—	—	—	—	—	—	—	—				

1. Eucalyptus spp.-
2. Araucaria angustifolia-
3. Pinus elliotii-
4. Pinus caribaea-
5. Eucalyptus citriodora-
6. Gemlina arborea-
7. Cryptomeria japonica-
8. Cunninghamia lanceolata-
9. Pinus radiata-
10. Tectona grandis-
11. Eucalyptus globulus-
12. Cupressus lusitanica-
13. Pinus patula-
14. Cordia alliodora-

TABLE 3.7.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY LATIN AMERICAN AND CARIBBEAN (Continued)
(M^3/ha/Year)

Country	Species																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Costa Rica	30	30	28	—	—	—	—	—	—	—	—							
Domin. Rep.	—	—	—	10-20	—	—	—	—	—	—	—							
El Salvador	—	—	17	—	9	—	—	—	—	—	—							
Guatemala	—	—	—	—	—	6.3	—	—	—	—	—							
Haiti	—	—	—	—	—	—	—	—	—	—	—							
Honduras	—	—	—	—	—	—	10-20	—	—	—	—							
Jamaica	—	—	—	11-17	—	—	—	8	11	9	—							
Mexico	—	—	—	—	—	5-20	—	—	—	—	10-30							
Nicaragua	—	—	—	—	—	—	—	—	—	—	—							
Panama	—	—	—	10-20	—	—	—	—	—	—	—							

1. Gmelina arborea-
2. Alnus jorullensis-
3. Cupressus lusitanica-
4. Pinus caribaea-
5. Tectona grandis-
6. Pinus spp.-
7. Pinus oocarpa-
8. Hibiscus elata-
9. Pinus patula-
10. Eucalyptus saligna-
11. Eucalyptus spp.-

TABLE 3.7.—MEAN ANNUAL INCREMENTS OF PLANTATION SPECIES BY COUNTRY, LATIN AMERICA AND CARIBBEAN (Concluded)
(m^3/ha/Year)

Country	Species																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Paraguay	17	13-20.3	15.7	10.8	15.4-19.7	2.3-22	3.4-24.4	2.7-17.5	—	—	—	—						
Peru	—	—	—	—	—	—	—	—	10	—	—	—						
Surinam	—	—	—	—	—	—	—	—	—	3.3-15.7	—	—						
Uruguay	—	—	—	—	—	—	—	—	—	—	10-20	5-25						
Venezuela	—	—	—	—	—	—	—	—	—	10	20	—						

1. Cedrela spp.
2. Eucalyptus citriodora-
3. Eucalyptus saligna-
4. Eucalyptus tereticornis-
5. Paulownia tomentosa-
6. Pinus elliottii-
7. Pinus Taeda-
8. Araucaria angustifolia-
9. Eucalyptus globulus-
10. Pinus caribaea-
11. Eucalyptus spp.-
12. Pinus spp.-

TABLE 3.8.--COMPARISON OF PRESENT AND PROJECTED FUELWOOD UTILIZATION WITH TOLERATED FUELWOOD UTILIZATION, LATIN AMERICA AND CARIBBEAN
(In Thousands of Cubic Meters)

Country	Fuelwood Utilization[1]		Tolerated Fuelwood Utilization[2]
	1979	1990	
Argentina	6,580	7,471	--
Bolivia	4,060	3,734	142,691
Brazil	169,937	214,146	1,598,364
Chile	3,218	2,931	--
Colombia	38,813	47,441	189,318
Costa Rica	2,058	2,553	4,204
Dominican Republic	174	221	2,007
Ecuador	4,493	5,697	43,236
El Salvador	2,982	3,788	420
French Guiana	16	16	35,665
Guatemala	10,901	13,673	12,909
Guyana	10	12	64,737
Haiti	4,675	5,658	117
Honduras	4,109	4,051	9,735
Jamaica	13	15	228
Mexico	5,665	6,120	113,926
Nicaragua	2,224	2,859	13,248
Panama	1,633	2,056	16,655
Paraguay	3,393	4,314	36,343
Peru	2,866	3,597	209,680
Surinam	18	33	52,294
Uruguay	1,772	2,407	--
Venezuela	8,236	10,347	81,704

1. Derived from Table 2.6
2. Derived from Tables 2.4 and 2.5

possesses sufficient forest resources to accomodate the current and projected demand for fuelwood. Much of this resource, however, is located east of the Andes in the Amazon Basin, and it is generally inaccessible or too expensive for the large rural population living in the Inter Andes plateau. In this latter area, severe deforestation and concurrent erosion problems are observed (author). As indicated before, regional evaluations will be required in many cases when assessing area specific projects.

3.5 Livestock Summary

Livestock statistics by country are given in Table 3.9. In terms of pure numbers chickens are by far the most numerous, followed by cattle and pigs. There may be a substantial energy potential from the cattle since manure production is generally higher than for the other livestock categories and confinement, or semiconfinement, is more common.

3.6 Fossil Fuel Consumption

Consumption of gasoline, diesel oil, kerosene, residual fuel oil, and liquefied petroleum gases and their trends are given in Table 3.10 by individual countries. Where the b-coefficients are negative, such as the case of gasoline consumption in Chile, the consumption is declining over time.

TABLE 3.9.--LIVESTOCK SUMMARY (1979), LATIN AMERICA AND CARIBBEAN

Country	Horses	Cattle	Camels	Pigs	Buffalo	Sheep	Goats	Asses/Mules	Chickens	Turkeys	Ducks
Argentina	300	60,174	0	3,650	0	35,400	3,000	255	32,000	1,000	1,000
Bolivia	393	3,990	0	1,412	0	8,700	3,000	885	844	107	255
Brazil	6,000	90	0	36,000	310	18,000	7,400	3,450	320,000	2,400	5,000
Chile	450	3,607	0	1,028	0	5,952	600	41	22,000	0	0
Colombia	1,644	26,137	0	1,916	0	2,357	639	1,152	32,800	0	0
Costa Rica	112	2,071	0	226	0	2	1	7	5,600	0	0
Dominican Republic	203	2,150	0	700	0	53	370	216	8,000	279	82
Ecuador	295	2,532	0	3,427	0	2,278	245	284	0	0	0
El Salvador	89	1,368	0	560	0	12	14	23	6,000	0	0
French Guiana		3	0	6	0	0	0	0	152	0	3
Guatemala	100	1,575	0	42	0	3	18	51	13,821	0	0
Guyana	2	280	0	132	0	113	68	1	12,000	0	0
Haiti	408	1,000	0	0	0	0	0	337	0	0	0
Honduras	149	1,800	0	530	0	3	15	88	4,770	0	0
Jamaica	4	290	0	250	0	6	370	270	4,100	0	0
Mexico	6,447	29,920	0	12,578	0	7,850	8,103	6,410	150,000	1,300	2,700
Nicaragua	280	2,846	0	725	0	2	7	51	4,620	0	0
Panama	165	1,423	0	205	0	0	6	5	4,900	37	124
Paraguay	334	5,203	0	1,273	0	423	126	41	12,471	43	303
Peru	648	4,187	0	2,200	0	14,473	2,000	702	36,000	0	0
Surinam	0	27	0	19	0	5	5	0	1,038	0	50
Uraguay	525	10,007	0	400	0	18,690	12	5	7,575	94	157
Venezuela	474	9,963	0	2,099	0	314	1,354	530	34,000	0	0
Total	19,022	170,643	0	69,378	310	114,636	27,353	14,804	712,691	5,260	9,674

Source: USDA, Economic Botany Laboratory, 1981.

TABLE 3.10.—PETROLEUM-DERIVED FUEL CONSUMPTION BY PRODUCT 1979, LATIN AMERICA AND CARIBBEAN
(In Thousands of Metric Tons)

Country	Gasoline				Diesel Oil (Distillates)				Kerosene				Residual Fuel Oil (Bunker Oil)				Liquefied Petroleum Gases (LPG)			
	Total Consumption	a[1]	b[2]	cc[3]	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc	Total Consumption	a	b	cc
Argentina	4,954	4,155.0	43.1	.36	7,549	5,142.0	191.0	0.90	742	858.0	-12.2	-.66	8,181	8,729.0	-86.9	-.57	1,055	1,004.0	2.3	.11
Bolivia	574	133.0	39.4	.96	225	50.9	19.7	.96	115	110.0	3.2	.61	230	125.0	11.1	.97	44	-3.3	5.1	.98
Brazil	9,616	7,666.0	304.0	.76	15,102	3,452.0	1,173.0	.98	695	615.0	12.9	.34	17,216	7,125.0	1,044.0	.98	2,483	1,179.0	128.0	.99
Chile	1,030	1,300.0	-36.7	-.67	975	615.0	33.4	.89	345	464.0	-13.3	-.57	1,670	1,880.0	-34.4	-.56	485	314.0	17.2	.94
Colombia	3,075	1,686.0	146.0	.98	1,045	789.0	26.6	.80	415	434.0	-2.3	-.39	1,015	1,044.0	9.7	.25	280	223.0	6.1	.84
Costa Rica	152	74.5	8.0	.96	430	119.0	30.3	.96	38	35.9	-0.4	-.23	165	109.0	4.1	.53	17	6.3	1.0	.90
Dom. Rep.	307	212.0	12.8	.88	407	236.0	18.8	.93	27	16.8	0.42	.41	913	686.0	43.7	.58	67	23.6	4.0	.97
Ecuador	1,101	208.0	81.2	.97	691	180.0	46.2	.96	357	49.7	40.4	.93	796	161.0	51.7	.85	65	-8.0	6.7	.98
El Salvador	150	77.9	7.3	.98	234	95.6	14.6	.97	52	31.5	1.7	.68	220	171.0	8.0	.62	23	5.1	1.6	.95
Fr. Guiana	28	4.4	2.4	.90	70	-0.2	7.0	.88	0	0	0	0	0	0	0	0	0	0	0	0
Guatemala	290	152.0	14.4	.93	280	159.0	13.8	.91	54	54.9	-0.42	-.30	358	264.0	10.4	.83	27	22.5	0.72	.51
Guyana	38	39.3	0.16	.12	134	92.1	7.4	.61	22	26.7	-1.0	-.35	430	316.0	9.3	.66	7	4.5	0.20	.74
Haiti	34	25.5	0.4	.23	75	46.0	2.2	.73	0	0	0	0	35	28.8	0.42	.42	0	0	0	0
Honduras	100	83.1	2.3	.65	205	170.0	6.4	.58	42	26.8	1.5	.87	67	77.9	0.80	.09	11	3.4	0.80	.94
Jamaica	287	288.0	-1.6	-.12	255	297.0	-1.1	-.07	71	4.1	7.1	.91	1,230	1,312.0	22.4	.20	46	21.8	2.8	.88
Mexico	10,230	5,932.0	411.0	.96	11,950	3,274.0	758.0	.97	1,895	1,539.0	21.8	.57	13,610	4,732.0	871.0	.96	3,620	2,034.0	160.0	.99
Nicaragua	159	102.0	7.1	.84	205	146.0	5.6	.76	17	31.9	-1.6	-.80	275	107.0	20.3	.89	16	6.8	0.9	.97
Panama	210	178.0	5.6	.64	350	106.0	26.6	.95	15	40.8	-2.9	-.89	320	280.0	6.9	.61	39	19.3	2.2	.95
Paraguay	110	75.1	2.7	.46	155	11.6	16.0	.93	19	16.1	.12	.12	65	39.3	3.7	.69	4	3.6	.11	.16
Peru	1,150	1,308.0	0.13	.01	1,315	794.0	54.0	.96	715	502.0	21.1	.97	2,035	1,545.0	42.4	.86	130	32.9	12.5	.88
Surinam	40	21.4	1.7	.93	175	67.5	11.6	.96	0	0	0	0	330	425.0	-10.2	-.56	0	0	0	0
Uruguay	255	24.3	-.35	-.05	530	341.0	19.2	.96	180	195.0	-2.2	-.44	905	801.0	9.5	.44	45	31.2	1.1	.85
Venezuela	6,310	2,293.0	396.0	.99	5,030	2,298.0	248.0	.80	550	500.0	10.1	.25	0	0	0	0	750	666.0	9.1	.30

Source: 1979 Yearbook of World Energy Statistics, United Nations, 1980.

1. a = Regression intercept.
2. b = Slope of regression line.
3. cc = Correlation coefficient.

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APPENDIX I

TABLE OF CONVERSION FACTORS

UNITS OF LENGTH

1 mile	= 1760 yards	= 5280 feet
1 kilometer	= 1000 meters	= 0.6214 mile
1 mile	= 1.607 kilometers	
1 foot	= 0.3048 meter	= 30.5 centimeters
1 meter	= 3.2808 feet	= 39.37 inches
1 inch	= 2.54 centimeters	
1 centimeter	= 0.3937 inch	

UNITS OF AREA

1 square mile	= 640 acres	= 2.5899 square kilometers
1 square kilometer	= 1,000,000 square meters	= 0.3861 square mile
1 acre	= 43,560 square feet	
1 square foot	= 144 square inches	= 0.0929 square meter
1 square inch	= 6,452 square centimeters	
1 square meter	= 10.764 square feet	
1 square centimeter	= 0.155 square inch	

UNITS OF VOLUME

1.0 cubic foot	= 1728 cubic inches	= 7.48 US gallons
1.0 British imperial gallon	= 1.2 US gallons	
1.0 cubic meter	= 35.314 cubic feet	= 264.2 US gallons
1.0 liter	= 1000 cubic centimeters	= 0.2642 US gallons

UNITS OF WEIGHT

1.0 metric ton	= 1000 kilograms (kg)	= 2204.6 pounds (lb)
1.0 kilogram (kg)	= 1000 grams (g)	= 2.2046 pounds (lb)
1.0 short ton	= 2000 pounds (lb)	

UNITS OF PRESSURE

1.0 pound per square inch (psi)	= 144 pound per square foot
1.0 pound per square inch (psi)	= 27.7 inches of water*
1.0 pound per square inch (psi)	= 2.31 feet of water*
1.0 pound per square inch (psi)	= 2.042 inches of mercury*
1.0 atmosphere	= 14.7 pounds per square inch (psi)
1.0 atmosphere	= 33.95 feet of water*
1.0 foot of water = 0.433 psi	= 62.355 pounds per square foot
1.0 kilogram per square centimeter	= 14.223 pounds per square inch
1.0 pound per square inch	= 0.0703 kilogram per square centimeter

*At 62 degrees Fahrenheit (16.6 degrees Celsius)

UNITS OF POWER

1.0 horsepower (English)	= 746 watt = 0.746 kilowatt (kw)
1.0 horsepower (English)	= 550 foot pounds per second
1.0 horsepower (English)	= 33,000 foot pounds per minute
1.0 kilowatt (kw) = 1000 watt	= 1.34 horsepower (hp) English
1.0 horsepower (hp) (English)	= 1.0139 metric horsepower (cheval-vapeur)
1.0 metric horsepower	= 75 meter X kilogram/second
1.0 metric horsepower	= 0.736 kilowatt = 736 watt

MISCELLANEOUS

1 metric ton gasoline	= 1,430 liters
	= 377.5 (Gallons (US)

APPENDIX II

GLOSSARY OF TERMS

Arable Land: land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen garden (including under grass) and land temporary fallow or lying idle.

Irrigated areas: areas purposedly provided with water, including land flooded by river water for crop production or pasture improvement, whether the area is irrigated several times or only once during the year.

Closed forests: forest with canopy where individual tree crowns are nearing general contact with one another.

Shrub Land: area with trees no larger than 10 cm diameter-breast-height (dbh).

Diameter Breast Height (dbh): Diameter 1.37 m above ground level.

Fallow land: Recently cutover open or closed forest land.

Unproductive Land: includes national park, reserves, marginal land, steep, inacessible slopes, etc.

Productive areas: includes all forest land except the shrub land and unproductive areas.

Volumes: include tree bole over bark for trees larger than 10 cm dbh excluding the volume of the crown, small trees and shrubs.

Whole tree volume: includes the tree bole over bark larger than 10 cm dbh plus the volume of the crown and biomass considered to be 40 percent of gross bole volume.

Shrubs and small trees: in closed and open forests are biomass material in addition to trees larger than 10 cm dbh.

Coniferous: All woods derived from trees classified botanically as "Gymnospermae" - e.g. fir (abies, parana pine (Araucaria), deodar (Cedrus), ginkgo (Ginkgo), larch (Larix), spruce (Picea), pine, chir, kail (Pinus), etc. These are generally referred to as softwoods.

Nonconiferous (broadleaf): All woods derived from trees classified botanically as "Angiospermae"--e.g. maple (Acer), alder (Alnus), ebony (Diospyros), beech (Fagus), Lignum vitae (Guiaicum), poplar (Populus), oak (Quercus), sal (Shorea), teak (Tectona), casuarina (Casuarina), etc. These are generally referred to as broadleaved or hardwoods.

Roundwood: Wood in the rough. Wood in its natural state as felled, or otherwide harvested, with or without bark, round, split, roughly squared or

other forms (e.g. roots, stumps, burls, etc.). It may also be impregnated (e.g. telegraph poles) or roughly shaped or pointed. It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period - calendar year or forest year. Commodities included are sawlogs and veneer logs, pitprops, pulpwood, other industrial roundwood, and fuelwood. The statistics include recorded volumes, as well as estimated unrecorded volumes as indicated in the notes. Figures are given in solid volume of roundwood (or roundwood equivalent) without bark.

Fuelwood: Wood in the rough (from trunks, and branches of trees) to be used as fuel for purposes such as cooking, heating, or power production. Wood for charcoal, pit kilns and portable ovens is included. The figures for trade in charcoal are given in weight.

Industrial Roundwood: The commodities included are saw logs or veneer logs, pitprops, pulpwood, other industrial roundwood, and in the case of trade, chips or particles and wood residues.