Title
Biomass Fuels in the Developing Countries: An Overview

Authors
Meyers, S
Leach, G

Publication Date
1989-07-01

LBL-27222
UC-600

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Biomass Fuels in the Developing Countries: An Overview

S. Meyers and G. Leach

July 1989

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

LBL-27222

BIOMASS FUELS IN THE DEVELOPING COUNTRIES: AN OVERVIEW

Stephen Meyers*

Applied Science Division

Lawrence Berkeley Laboratory

1 Cyclotron Road

Berkeley, CA 94720

Gerald Leach**

International Institute for Environment and Development

London, England

July 1989

* Staff Scientist, International Energy Studies Group, Energy Analysis Program.

** Senior Fellow.

This work was supported by the Office of the Assistant Secretary for Environment, Safety, and Health of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

ABSTRACT

This report presents an overview of what is known about current patterns of biofuels supply and use in the developing countries. We illustrate the diversity of biofuels use, and discuss how use changes with urbanization and commercialization of biofuels. We present information on sources of biofuels, describe the basic technologies employed for using biofuels, and discuss the key factors involved in assessing change in biofuels use over time. We present biofuels consumption data from a number of surveys, and discuss the main factors that shape the level of use of different biofuels. We discuss the responses of rural people to the increasing fuelwood scarcity that is occurring in many parts of the developing world. We describe the transition from biofuels to modern fuels that occurs in cities, and discuss the factors that inhibit this transition. We present estimates of national biofuels consumption for 17 of the largest biofuels-using countries and for larger regions. We discuss the relationship between human use of biofuels and greenhouse gas emissions. Lastly, we present a discussion of policies designed to affect biofuels supply and demand, describing the experience with and prospects for increasing biofuels supply, improving end-use efficiency, and encouraging the transition away from biofuels.

TABLE OF CONTENTS

1. INTRODUCTION

Over two billion of the world's people depend on biomass fuels ("biofuels") such as wood, charcoal, crop residues, and animal dung for their daily energy needs. Annual consumption of biofuels in the developing world is uncertain. We estimate it to be around 26 EJ, which is equivalent to about one-third of total developing country modern fuels consumption. (1 EJ is approximately 1 quadrillion Btu.) In many developing countries, biofuels consumption dominates the national energy balance, though this is mainly due to the low efficiency with which biofuels are used.

Biofuels are primarily used by the poor. Throughout the developing world, people with sufficient income and access to modern fuels are switching away from biofuels for reasons of convenience, cleanliness, and status. For many people in rural and urban areas of developing countries, however, this is not a viable option. At the same time, woodfuel resources are dwindling in many places because of deforestation caused by the need for farming land, over-grazing, commercial logging, uncontrolled fires, and tree cutting for fuel. As wood resources diminish, the costs of obtaining woodfuels, whether in cash or time for gathering them, are imposing severe and increasing strains on already marginal household survival and production strategies.

This report presents an overview of what is known about current patterns of biofuels supply and use in the developing countries. This task is complicated by several factors. One is the considerable lack of detailed knowledge regarding supply and use of different biofuels, the extent to which these are shaped by various factors, and how supply and use patterns are changing. We discuss this problem briefly below. Another factor that makes analysis difficult is the substantial degree of diversity that exists in the nature of biofuels supply and use among and within countries. A third feature of biofuels consumption that makes complicates analysis is the variety of uses to which biofuels are put (such as domestic cooking, space heating, household income-earning activities, rural industrial use, and urban commercial use), and the difficulty of clearly dividing up consumption among uses. The combination of these factors means that one must be cautious in making general conclusions. We have attempted to be as conclusive as possible, while also highlighting the lack of definite knowledge. This report is, we believe, a reasonable statement of the current understanding of a phenomenon that is, in the final analysis, not very well understood.

Report Organization

Chapter 2 following this introduction presents an overview of biofuels use in the developing world. It illustrates the diversity of biofuels use, and briefly discusses how it changes with urbanization and commercialization of biofuels. It presents some information on sources of biofuels, describes the basic technologies employed for using biofuels, and discusses the key factors involved in assessing change in biofuels use over time.

Chapter 3 discusses household biofuels use in rural areas, where biofuels are the predominant energy source. It presents consumption data from a number of surveys, and discusses the main factors that shape the level of use of different biofuels. It also discusses the responses of rural people to the increasing fuelwood scarcity that is occurring in many parts of the developing world.

Chapter 4 discusses household biofuels use in urban areas, where biofuels are usually one of many available energy sources. It describes the transition from biofuels to modern fuels that typically occurs in cities, and discusses the factors that inhibit this transition.

Chapter 5 presents estimates of national biofuels consumption for 17 of the largest biofuels-using countries and for larger regions. It discusses the main sources of data, and the difficulties with these sources.

Chapter 6 discusses the relationship between human use of biofuels and greenhouse gas emissions. We include this due to the current high level of interest in the greenhouse effect that appears to be occuring largely as a result of human activities. We discuss particularly how the impact of biofuels use on CO_2 emissions varies according to the source of biofuels.

Chapter 7 concludes the report with a discussion of policies designed to affect biofuels supply and demand. We describe the experience with and prospects for increasing biofuels supply, improving end-use efficiency, and encouraging the transition away from biofuels. We highlight the importance of designing policies and programs that are sensitive to the broad context in which they are to be effective, that are based on local assessments and actions, and that seek to reach underlying causes rather than simply heal symptoms.

Uncertainty Regarding Biofuels Use

Before proceeding, it is advisable to briefly discuss the considerable lack of knowledge regarding supply and use of the various biofuels. This stems from the fact that biofuels production is, in contrast to modern fuels, highly decentralized. In rural areas, biofuels are typically collected directly by the users. In urban areas, biofuels are usually sold in well-organized markets, but there are numerous sellers and no centralized record-keeping of quantities sold as is the case for modern fuels.

Given this situation, biofuels consumption must be estimated based on surveys of households or other sectors. This is problematic, however, as sample sizes are often small or pertain to a specific region. As variation among specific sites is usually large, extrapolations from a few surveys to national averages is hazardous (though common). There are also difficulties with using survey results. Measurements of quantities consumed have differing degrees of reliability, and there are problems in conversion to common weight, volume, or energy units. Large surveys are most useful in terms of developing a broad understanding of patterns of biofuels use, but these often have the most difficulties with respect to reliability of measurement.

Perhaps most problematic is that there are few cases of comparable repeat surveys of the same location or region. This lack makes it difficult to draw definitive conclusions with respect to trends in biofuels use. There is also a lack of survey information on the sources of biofuels that inhibits understanding the relationship between biofuels use and the biomass resource base.

Despite these difficulties, the large number of surveys that have been made over the years, along with considerable information from observation and experience, do allow the careful analyst to make some important statements regarding biofuels use. While this is the case, it should not obscure the fact that much carefully focused "on-the-ground" research is needed in order to develop a better understanding of the ways in which biofuels use is evolving in the developing world.

2. OVERVIEW OF BIOFUELS USE

Biomass fuels are extensively used by rural and poor urban households in Asia, Africa, and Latin America. Although reliance on biofuels is gradually giving way to use of modern fuels like kerosene and LPG in many Third World cities, biofuels still provide the basic energy needs of the poor in much of Asia and Africa, and are also used (in combination with modern fuels) by more well-off households. In addition to household consumption, biofuels are also used in many areas by rural industries and by commercial enterprises in towns and cities.

There are broad general differences in patterns of use across the continents. In rural areas, use of crop residues and animal dung is more common in Asia, while wood tends to be more available in Africa and Latin America due to the historically lower population density. In urban areas, charcoal use is very important in Africa, fuelwood is used in large quantities in many Asian cities, while biofuels are comparatively less significant in Latin American cities (and also in Chinese cities, where coal is the predominant household fuel).

There is also considerable variation in the nature of biofuels use within these large regions, as well as within countries. The approximate levels of per capita rural biofuels consumption in broad regions of the developing world are given in Table 2-1. The consumption ranges are based on a study of nearly 350 household surveys and rough estimates for 88 countries done by the UN Food and Agriculture Organization (de Montalembert & Clement, 1983). Key features are the higher consumption for cold mountain areas, reflecting space heating needs, and for the warmer regions of sub-Saharan Africa and Latin America compared to north Africa, the Middle East, and Asia, reflecting more abundant biomass resources. The lower proportion of biomass in total household energy use in Latin America — 50-65% versus 80-95% in most of rural Asia and Africa — is a result of greater rural incomes, infrastructure development, and access to modern fuels. Elsewhere, biomass is typically 80-95% of total residential consumption, the remainder being mostly kerosene or occasionally electricity for lighting. The heavy dependence on crop residues and animal wastes in Asia reflects low forest and on-farm tree resources.

The nature of biofuels use varies from one location to another depending on the biofuel resource availability, modern fuel availability, and household income, to name three key factors. Each of these, of course, is shaped by a number of variables. Biofuel availability is determined by geographic and climatic factors, as well as by the historic human use of the resources. In many places, areas that were once forested are now largely denuded of trees (not necessarily due to fuelwood gathering). Increasing scarcity of wood in rural areas typically leads to greater use of lower quality wood, crop residues and animal dung. In urban areas, biofuels are typically not freely available in the immediate vicinity, and wood or charcoal are brought in, often from considerable distances. Availability of modern fuels is generally better the more urbanized the setting, but this also varies with country-specific factors (e.g., whether the country is an oil-producer or importer). Household income increases with the level of development, but differences in income distribution can result in varying patterns of biofuels use from one country to another.

Table 2-1
Rural Household Energy Use: Annual Regional Averages

Region	Per capita biomass consumption (m^3 wood equivalent)[a]	Per capita total energy (GJ)	Biomass share (%)
SUB-SAHARAN AFRICA			
Lowlands	1.0-1.5	10-14	95-98
Uplands (> 1500 m)	1.4-1.9	14-18	90-95
N.AFRICA & MIDDLE EAST			
Large consumers[b]	0.2-0.8	2-8	small
Small consumers[c]	0.05-0.1	0.5-1	small
Mountain areas[d]	up to 1.5	up to 15	
ASIA & FAR EAST			
Desert & sub-desert	0.3-0.5	3-5	small
Dry tropics	0.65-1.05	6-10	80-90
(Animal wastes: %)	(70-30)		
Moist tropics	0.85-1.3	8-12	80-90
(Animal wastes: %)	(65-30)		
Mountain areas	1.8-2.1	17-20	90-95
(Animal & crop wastes: %)	(30-10)		
LATIN AMERICA			
Hot areas	0.55-0.9	10-14	50-60
Temperate areas	0.7-1.2	12-17	55-65
Cold areas	0.95-1.6	18-23	50-65

Source: Montalembert & Clement (1983)
[a]Firewood plus primary wood to produce charcoal plus wood equivalent of crop residues and animal wastes.
[b]Tunisia, Iraq, Morocco, Algeria, Turkey.
[c]Lebanan, Egypt, Jordan, Syria, S & N. Yemen.
[d]N. Africa, Iraq, Turkey.

The level of per capita biofuels consumption and the mix of fuels in rural and urban areas are shaped by many interrelated factors that vary from place to place. These include:

- Settlement size and/or rural proximity to roads or large towns, which affects access to modern fuels and end-use equipment.
- Household income or, in rural societies, ownership of assets such as land or cattle.
- Household size, due to economies of scale for end-uses such as cooking and space heating.
- Fuel costs for biofuels and alternatives, in cash or in time for fuel gathering, and costs of energy equipment.
- The significance of end-uses other than cooking, especially space heating.
- End-use technologies, especially the thermal efficiency of cooking.
- Climatic factors, which affect space heating and drying needs.
- Culture and tradition, e.g., diet, cooking habits, and the use of fires as a social focus.

Unfortunately, a combination of poor or partial survey data makes it impossible to relate consumption to this list of variables in any rigorous way. Detailed energy surveys that consider most of these variables are invariably for small and almost certainly atypical samples. On the other hand, large nationally representative surveys usually include information only on household income and size, with a crude rural-urban split, and thus miss out on some of the most influential factors of demand.

The diversity in biofuels use within a single country can be considerable, as illustrated by an unusually comprehensive national survey done in Ethiopia (CESEN, 1986). Differences in biofuels use are to be expected between rural, small urban, and larger urban settlements, though Ethiopia is an example of a very poor country where fuelwood use is very high even in urban areas. What is striking is the large range of average per capita consumption of different biofuels among settlements of similar size (see Table 2-2).

Table 2-2

Range of Per Capita Biofuels Consumption in Ethiopian Settlements, 1985

(GJ per year)

	Fuelwood	Tree Residues	Crop Residues	Dung	Charcoal
Rural settlements	0.2-32.7	0-10.1	0-8.1	0-9.0	-
Mean	11.7	2.6	1.2	2.2	-
Small urban settlements	3.6-22.5	0-10.3	0-2.5	0-2.8	0-1.4
Mean	10.0	1.8	0.2	0.4	0.4
Medium-to-large urban settlements	2.2-14.3	0-2.6	0-6.2	0-3.2	0-4.1
Mean	7.0	0.6	0.2	0.2	1.0

Source: CESEN, The Rural/Urban Household Energy Survey, 1986
The national survey covered 38 rural settlements with population ranging from 228 to 3,163; 19 small urban settlements with population ranging from 555 to 3,932; and 24 medium-to-large urban settlements with population ranging from 5,266 to 265,000.

2.1. The Rural-Urban Distinction

It is helpful in considering biofuels consumption to distinguish between rural areas, where biofuels are the primary energy source for households and commercial enterprises, and urban areas, where non-biomass fuels are more readily available and biofuels tend to be mainly a "poor man's fuel." There is no clear line of demarcation between an urban and a rural situation, however. Instead, there is a gradation according to urban size and the associated state of infrastructure development for distributing modern fuels. Small towns that are considered "urban" for statistical purposes generally have patterns of energy use that have much in common with rural settlements. Supply of kerosene or LPG may be inconsistent, or the cost of modern fuels and equipment to use them may be too high for most residents. The nature of the biomass resource surrounding urban areas is also a factor.

The gradual change in reliance on biofuels with urban size is illustrated by a national survey of India in 1979 (Natarajan, 1985). In cities with population of 20,000-50,000, 38-39% of residential energy use was met by modern fuels. In those with 50,000-200,000, the proportion jumped to 56-58%, with an increase to 66% in cities of 200,000-500,000, and to 75% for even larger cities. A similar pattern is seen in survey results from Pakistan (see Table 2-3), with an even more striking decrease in the use of biofuels in cities with over 200 thousand people (which refers mainly to Karachi); here the extent of natural gas distribution is an important factor.

Table 2-3
Energy Consumption for Cooking and Heating by City Size
Pakistan (Sind Province), 1980
(percent)

City size	Biofuels	Kerosene	Nat. gas	LPG
Under 25 k	93.4	1.9	1.1	2.4
25-50 k	76.7	5.8	10.9	3.8
50-100 k	62.7	7.3	25.6	2.5
100-200 k	67.0	3.4	24.4	3.4
Over 200 k	25.4	33.3	36.9	2.4

Source: Government of Pakistan (1982)

While the distinction between rural and urban is a matter of degree, it is nonetheless important for a number of reasons. One is the shift in the sources of biofuels as one moves from "very rural" to "very urban" settings. Urban fuelwood and charcoal supplies are much more likely to be based on wood from felled trees rather than the branches, twigs, and roots that are predominant in the countryside. Although for most countries the total magnitude of biofuels use is much greater in the countryside than in the cities, the latter often have a disproportionately large effect on rural deforestation.

2.2. Commercialization of Biofuels

A distinction that is similar to the urban/rural one but perhaps more meaningful is that between commercial and non-commercial biofuels consumption. Non-commercial consumers gather woodfuel from their surroundings, while commercial consumers pay (in cash or by barter) for the fuel that they use. (Fuelwood gatherers may sometimes hire a donkey or truck to gather wood from a distant source.) In practice, many households gather or buy woodfuels at different times of the year, depending on their available time and cash.

Commercialization of fuelwood tends to cause increased pressure on forest resources and may exacerbate depletion of forests and degradation of forest quality. On the other hand, the existence of commercial markets for woodfuels is an important factor in the success of rural tree-growing efforts. People who pay for fuel are also more likely to be interested in measures to improve end-use efficiency.

Commercialization of biofuels changes the nature of wood exploitation; it becomes "more selective of tree species, whether for charcoal production or the urban consumer, and it is also more wasteful of the wood resource. It also diverts woodfuel from subsistence use as poor people in areas of short supply sell their wood to higher income groups in the towns" (Morgan, 1983). In Bangladesh, for example, villages near cities sell firewood for urban markets and shift to the use of crop residues and dung for their own needs (Islam, 1983).

The degree of woodfuel commercialization is uncertain but undoubtedly varies greatly among countries. In most countries, urban woodfuel consumption is predominantly commercial, though this becomes less the case as one moves from larger to smaller cities. In the rural areas, the degree and rate of commercialization varies greatly. In the poorer countries, few rural people other than teachers and government officials pay for fuelwood for household use. In Tanzania, for example, only a few percent of the rural population buy their wood (Nkonoki, 1983). With rising incomes, wealthier farmers or rural business people may buy their fuelwood rather than have their families expend time and effort collecting and preparing it. Thus, woodfuel commercialization does not necessarily indicate woodfuel scarcity; it may simply mean that some of the people in the area are becoming richer. In villages that have intense commercial activity, people may buy wood to carry out activities that have high energy requirements.

A national survey in India in 1978-79 found that 15% of rural firewood was purchased; as would be expected, the commercial share was much higher for firewood logs than for small branches and twigs (Natarajan, 1985). In Guatemala, a 1979 survey found that 29% of the rural population purchased woodfuels (Bogach, 1981), while in Nicaragua, a survey found that 40% of rural consumers bought some or all of their wood (van Buren, 1984). The above national averages obscure the fact that the degree of biofuels commercialization is often location-specific. In a survey of 23 villages in Bangladesh, for example, the percentage of biomass energy that was purchased ranged from 3% up to 37% (Islam, 1980).

2.3. Sources of Biofuels

The extent of commercialization of biofuels is difficult to assess because very few countries have adequate data to assemble a clear picture of the sources of biofuels. Even the most detailed village energy consumption surveys usually fail to collect information on supply sources: for example, whether firewood comes from common land or private on-farm trees, is gathered or purchased, or involves the felling of trees rather than the collection of twigs and brushwood. The lack of information can lead to serious misconceptions about issues such as the impact of fuelwood gathering on deforestation. One must be aware, further, that the relative importance of sources changes over time as the supply/demand balance shifts.

Examples of national portraits of the biofuel supply situation as of around 1980 come from India and Bangladesh. These are countries where crop residues and animal dung play equivalent or more important roles than firewood, and are thus atypical.

India. Results from a national survey in India for 1978-79 (see Table 2-4) indicate that firewood accounted for about half of total biofuels supply for households (on a weight basis; the figure would be somewhat higher on an energy basis). Animal dung accounted for 36%, and crop residues accounted for 16% of supply. Use in rural areas was 89% of total consumption. (We are not aware of the definition of "urban" in the survey.) As one would expect, the share of fuelwood in total biofuels consumption was much higher (72%) in urban than in rural areas (45%). Dung accounted for 23% of total biofuels consumption in urban areas, reflecting the high degree of poverty among the urban poor.

Table 2-4
Biofuels Supply for Households in India, 1978-79
(million tons per year)

	Firewood logs	Firewood twigs	Crop residues	Dung	Total
RURAL					
Total	20.11	58.75	29.53	66.76	175.15
Purchased	8.65	3.29	0.38	1.49	13.81
Collected	11.46	55.46	29.15	65.27	161.34
Collected from:					
Own land	5.24	19.06	17.56	51.63	93.49
Neighbor's land	0.29	3.04	11.59	-	14.92
Forest land	4.65	18.93	-	-	23.58
Roadsides, etc.	1.28	24.43	-	13.64	29.35
URBAN					
Total	11.50	4.20	1.09	4.95	21:74
Purchased	11.06	2.55	0.18	2.33	16.12
Collected					
Collected from:					
Own land	0.20	0.57	0.64	1.80	3.21
Neighbor's land	0.01	0.09	0.27	-	0.37
Forest land	0.18	0.56	-	-	0.74
Roadsides, etc.	0.05	0.43	-	0.82	1.30
TOTAL	31.6	62.9	30.6	71.7	196.8

Source: Natarajan (1985), presented in Leach (1987)

Of the total firewood supply, small branches and twigs accounted for two-thirds and logs one-third. The share of logs was about 25% in rural areas, but nearly 75% in urban areas, where most of the firewood is purchased rather than collected. Even in the rural areas, however, about 40% of the logs were purchased, which may reflect both the extent of scarcity of such wood and the existence of commercial woodfuel markets for rural businessmen, professionals, and others who would rather buy wood than collect it.

Of the total firewood logs supply of 32 million tons (MT), 12 MT were collected (nearly all in rural areas). About half of the collected firewood logs in rural areas came from the person's own land, while most of the rest came from forest land. Other data show that less than 15% of collected logs involved the felling of trees; the rest came from cutting large branches (which may have kept the tree at a small size and inhibited its growth or even contributed to its death). Of those who felled trees, around 25% said they 'always' or 'occasionally' replanted them, though this claim is somewhat suspect. Since 1978-79, there has been a transition away from firewood in urban areas (see Chapter 4), and total consumption of purchased logs may have declined.

In **Bangladesh**, firewood is less important than in India. A national survey in 1980-81 indicated that crop residues accounted for 66% of total biofuel supply (on an energy basis), dung for

16%, and woodfuel for only 17% (see Table 2-5). The survey included industrial and commercial use, which accounted for 24% of total consumption. Among households, rural areas accounted for 87% of total consumption, a similar figure to India. Nearly half of the household fuelwood demand was by urban households, so the share of logs in total fuelwood supply was nearly 75%. But of the firewood logs, only one-sixth came from public forests and can be assumed to have been felled directly for fuel. Most of the logs came from village trees, which are more likely to be managed for sustained harvest.

Table 2-5
Biofuels Supply in Bangladesh, 1980-81
(PJ per year)

	Firewood logs	Firewood twigs	Crop residues	Dung	Total
SOURCE:					
Cropped area	-	-	289	-	289
Village trees	42	23	-	-	66
Public forest	10	-	-	-	10
Fallow	5	-	4	-	7
Other	4	-	26	78	108
Total	61	23	318	78	480
(Households)	42	23	225	78	367
(Urban households)	31	-	17	-	48

Source: Islam (1986) and BEPP (1985), presented in Leach (1987)

Studies of the large Indian cities of Hyderabad and Bangalore that were done around 1980 confirmed that urban firewood supplies are based primarily on logs from felled trees rather than the twigs, branches, and roots from standing trees that are predominant in the countryside (Alam *et al.*, 1985). The main suppliers of firewood were private contractors obtaining supplies largely from private land-owners, not government Forest Departments. A major part of firewood supplies originated from considerable distances. In Bangalore, for example, one-half of total supplies came from between 120 and 300 km from the city, while in Hyderabad 55% of total supplies came from areas over 100 km from the city. (Of course, the same could be said for many basic commodities.) Most of the transport was by truck. While neither case study included direct observation of the state of the forest resource in supply areas, the researchers concluded that some degree of deforestation was most probable.

2.4. Cooking with Biofuels

The main end-use for biofuels in most parts of the developing world is domestic cooking. The technologies employed to use biofuels for cooking range from simple 3-stone fires, which are the most common technology in rural areas, to improved metal stoves whose design comes from laboratory testing. Of course, the stove is a part of a larger cooking 'system.' With a given technology, the amount of fuel required to perform a task can vary greatly according to the care taken with fire/stove management. Fire management can involve wind shielding (cooking indoors, or outdoors with wind screening), quenching the fire after use, and feeding the fire at the optimum rate to produce the required power output. The attention given to fire tending depends in part on the demands of other domestic tasks. Fuel use is also affected by the fit between the stove and cookpots, use of pot lids, and the use of aluminum versus less-efficient clay pots. The condition of the stove is also an important factor.

Average cooking efficiencies measured in laboratory tests and field measurements exhibit considerable variation, as shown in Table 2-6 (based on a variety of sources).[1] For wood stoves, field measurements show a range of 13-15% for '3-stone' open fires (this is based on a limited sample; the actual range is undoubtedly much larger), 8-14% for mud/clay stoves, 13-16% for brick stoves, and 20-30% for portable metal stoves. Field measurements for charcoal stoves show a range of 15-25% for clay/mud stoves and 20-35% for metal (lined) stoves. Measured efficiencies of kerosene stoves range widely from 20% to 55%, depending on the stove type, while the range for LPG stoves is 40-60%.

The efficiency in the field of traditional cooking technologies can vary greatly depending on fire or stove management. With careful management, the efficiency of such technologies can be higher than that of "improved" stoves, which, however, are somewhat less sensitive to the degree of management.

[1] Efficiency refers to the ratio of energy absorbed by the end-use task to the energy content of the fuel. This combines combustion and heat transfer efficiency. The wide range of efficiencies reported in the literature results in part from use of different test procedures or comparison of different types of stoves.

Table 2-6
Average Cooking Efficiencies for Household Stoves[a]
(percent)

Fuel/Stove Type	Laboratory[b]	Field[c]
Wood		
Open fire (clay pot)	-	5-10
Open fire (aluminum)	18-24	13-15[d]
Mud/clay	11-23	8-14
Brick	15-25	13-16
Portable metal stove	25-35	20-30
Charcoal		
Clay/mud	20-36	15-25
Metal (lined)	18-30	20-35
Kerosene		
Single wick	20-40	20-35
Multiple wick	28-32	25-45
Pressurized	25-65	25-55
LPG	38-65	40-60
Electricity		
Single element	55-80	55-75

Source: Leach & Gowen (1987)
(a) Assuming aluminum cooking pots unless otherwise indicated.
(b) Mostly from water boiling tests.
(c) Generally reflects cooking cycle tests.
(d) Based on a very limited range of field tests; actual range is certainly much larger.

The costs of stoves vary widely depending on the type, size, quality of materials and workmanship, and local factors. The cost of wood stoves can range from less than US$1.00 for a simple scrap metal type to as much as US$60 for a modern, heavy metal oven. Experience in a number of countries indicates that improved wood and charcoal stoves can be produced and sold for anywhere from US$1 to US$15. The relationship between the cost of various wood and charcoal stoves and kerosene and LPG stoves also varies considerably among countries.

Change in cooking devices may be motivated by economic and non-economic factors. Reduction in indoor smoke emissions, which appear to be a major cause of health problems in many places (Smith, 1987a), is an important example of the latter. Where traditional stoves cause large smoke exposures, most post-dessemination surveys have found that reduced exposure is cited by users as often as improved efficiency to be the largest benefit (Smith, 1987b). While improved efficiency and lower smoke exposure are in general compatible goals, there are tradeoffs between improved efficiency and reduced smoke emissions in many stove designs.

2.5. Change in Biofuels Consumption

Changes in the overall quantities consumed of different biofuels can be the result of a large number of often interrelated factors. On the demand side, important factors include: (1) population growth; (2) the extent and type of urbanization (i.e., focused on small or large cities); (3) the transition to modern fuels within urban areas, which is affected most by household income and fuel availability; (4) the cost of using particular biofuels, which involves money for fuel and equipment and/or time for fuel collection; and (5) change in biofuels usage habits or technology. The cost of using biofuels is shaped by the relative scarcity of particular biofuels, which tends to be reflected in market prices in urban areas or in difficulty of collection in rural areas, and, in some situations, by issues of access to resources.

Change in the sources of biofuels depend on the co-evolution of the biomass resource base with biofuels demand. For urban centers, the mix of sources of woodfuels can change significantly in a relatively short period of time. The following model is a reasonable description of the evolution in many African cities. In stage one, population is low compared to tree resources, wood is plentiful, and prices remain low. At some point, tree clearance, principally for crop and grazing land, but also for timber and fuel, leads to significant deforestation around the city. Harvesting and/or transportation costs increase and retail prices rise. As the outreach distance for firewood increases, a charcoal trade may begin or expand rapidly. The switch to charcoal reduces unit transport costs and greatly expands the area from which resources can be drawn economically. But owing to the generally low conversion efficiency of wood to charcoal (which is only partly made up for by the higher end-use efficiency of charcoal stoves), it also intensifies pressures on wood resources, and may lead to intense tree "mining" for fuel rather than the use of "surplus" wood from farm clearance. Since suitable charcoal resources can be mined out quite suddenly, prices may rise very quickly. For example, in Dar es Salaam, Tanzania, charcoal prices rose by a factor of 2.7 in real terms between 1980 and 1983 (FAO, 1987). This is stage two, where rapid price increases are found alongside rapid deforestation. In stage three, woodfuel prices are high but are capped by the prices of alternative fuels and may be quite stable or even fall.

In rural areas, change in the consumption of different biofuels depends mainly on natural resource availability and social access to resources. As scarcity of the most-desired fuels increases, there is typically a downward progression from top quality firewood to lower quality firewood to twigs and bushes to crop residues or animal dung. At each stage, however, the magnitude of the available resource is much larger than in the previous stage. The response to fuelwood scarcity varies for different groups of consumers, as discussed further in Chapter 3.

The Impact of Urbanization

The problem of increasing fuelwood scarcity is a symptom of the larger problems facing the rural sector in many developing countries. These problems have contributed to the migration to urban areas that has occurred throughout the developing world to varying degree.

Migration of people from rural to urban areas is an important factor causing change in biofuels consumption. There are two distinct elements involved. One is the transition of urban migrants from use of local, mostly gathered biofuels to reliance on the marketed woodfuels that predominate in cities.[2] The other element is the transition from biofuels to modern fuels that takes place as urban households gain sufficient income to use the latter.

Both of these elements are shaped by the nature of the urbanization process in a particular region. The strength of both will likely be greater where most of the migration is to large cities than where much of the urban growth is occurring in smaller cities. The transition to modern fuels is typically weaker in smaller cities due to the lack of dependable supplies, and to some extent, the greater availability of low-cost woodfuels.

Is Biofuels Use Growing or Declining?

To our knowledge, it is not possible to state with much certainty whether overall biofuels consumption is growing or declining in most developing countries. This is due to the lack of consistent repeat surveys, and to complicating factors that make guessing from scattered or anecdotal evidence problematic.

There are two main factors to consider in assessing trends in overall biofuels consumption. One is the continued dependence of rural residents on biofuels and the growth in rural population. The other is the transition from biofuels to modern fuels that occurs to varying degree in urban areas, and the growth in urban population.

In most rural areas of the developing countries, there appears to have been little penetration of modern fuels for household uses other than lighting. If one assumes that average biofuels use per capita has held roughly steady, one could estimate growth in biofuels consumption from the growth in the rural population. A complicating factor in many rural areas, however, is the increasing scarcity of the usual biofuels and accompanying changes in consumption.[3] The wide range in average consumption per capita found by surveys is evidence that rural households do adjust their consumption in response to fuel scarcity. This may involve changes in the type of fuels used (shifting to less desirable wood species or crop residues), in cooking fire management, or, as a last resort, in cooking habits. In the extreme, the latter may mean fewer cooked meals. Thus, where there are conditions that might cause change in consumption patterns, it is inaccurate to assume constant per capita use. In areas where fuelwood supplies are relatively abundant, on the other hand, it is safer to assume that overall consumption is growing with population. We further discuss changes in rural biofuels use in Chapter 3.

[2] In most regions, few urban migrants arrive in the city with sufficient income to use modern fuels. In many cities, and especially where fuelwood prices are high, the poor rely heavily on whatever biomass they can gather.

[3] For many areas, there is even considerable uncertainty whether tree resources are in fact becoming scarcer. This is because of farm and village tree-growing, which is not captured in forest statistics (or by satellite cameras), but is known to be happening at quite rapid rates in many parts of Africa and South Asia.

In urban areas, the situation is more complicated and more varied among countries. It is also more dynamic and changable. Modern fuels are available and affordable to varying degrees. As household income grows, households tend to move away from biofuels use. Often, however, they retain the devices to use biofuels, and may do so for certain types of cooking. In many cases they are able to adjust their use of cooking fuels in response to changing prices.

Many urban households move up the fuel preference ladder away from biofuels. But new arrivals to the city are generally poor and rely on biofuels. Thus, the overall rate of change in biofuels consumption in a given city depends on the relative strength of the opposing forces of modern fuel substitution and rural-to-urban migration. Where the latter is particularly strong, and income growth is weak or even negative, there may be more people coming into the biofuels market than leaving it.[4] Furthermore, in some cases there may be a shift from modern fuels "back" to biofuels by established urban residents who are no longer able to afford modern fuels; this has occurred in some African cities where incomes have fallen steeply. In this situation the combination of "backward" movement of established residents into biofuels with entry by new urban residents can lead to rapid growth in demand for biofuels. Where charcoal is the primary urban biofuel, as is the case in most large African cities, the growing pressure on wood resources can and does create problems in rural areas. We further discuss change in urban biofuels use in Chapter 4.

2.6. Industrial and Commercial Use of Biofuels

In the following two chapters, we discuss household biofuels use in rural and urban areas. Before proceeding, it is important to note that rural industries such as tea, coffee, and tobacco drying and curing, brick and lime making, small-scale sugar refining, together with commercial enterprises such as bakeries, tea and coffee shops, hotels, metal workshops, laundries and such often consume substantial amounts of woodfuel. Most of this consumption is commercial, or is collected by paid laborers. In some cases, these consumers may switch from modern fuels back to woodfuels if the economics are favorable. The most prominent example of this is in the Brazilian steel industry, where charcoal is used on a massive scale. Where the wood demand is very high, it may be specially grown for industrial use; this is the case for much of the Brazilian steel industry that uses charcoal.

The proportion of national woodfuel consumption accounted for by industrial and commercial enterprises is very uncertain, but it no doubt varies widely. Estimates have placed the share at 18% in Guatemala in 1979, at 26% in Kenya in 1980, at 25% in Sri Lanka, and at 25-30% in some of the southern African countries (Foley, 1985).

Wood residues are also used for fuel by wood products industries in many countries. Similarly, agro-processing industries often make use of crop residues for steam raising. The most

[4] An additional complicating factor is that many new arrivals to Third World cities are single males in search of employment. They may eat much of their food from vendors and thus do little cooking.

common example of this is the use of bagasse by sugar cane processors. Other biomass materials that are used for energy purposes include rice husks, coconut husks and shells, and oil palm residues. Bagasse and other residues are typically burned with very low efficiency. Efforts to improve and expand utilization of crop residues by wood and agro-processing industries are underway in a number of countries.

3. HOUSEHOLD BIOFUELS USE IN RURAL AREAS

In remote rural areas, especially in poorer countries, modern fuels are virtually unobtainable in any substantial quantities. Biomass typically meets all energy needs, except for small amounts of lighting kerosene. In many parts of the world this is so even for the highest income groups, who presumably would use cleaner, more convenient and efficient modern fuels if they were available. For example, large nationally representative surveys in rural Brazil, India, Pakistan, and Sri Lanka found a 90-95% dependence on biomass, with a negligible reduction in this proportion even among higher-income households (Leach, 1988a). In parts of Latin America and in the Middle East and North Africa, on the other hand, penetration of modern fuels into rural areas is more substantial. This is especially the case for oil-producing countries, where kerosene and LPG prices are often very low, and supplies are more available.

Biomass fuels typically come from within walking distances of up to 5-7 km and are gathered as "free goods". Pack animals may be used to collect from further afield and fuels may be traded for cash or for barter as resources begin to run short (Howes, 1985). Fuelwood gatherers, who are usually women and children, must make trade-offs between fuel preferences, fuel economy, and time available for gathering. Their access to fuels is often governed by local rules on rights to use common land and client-patron relationships concerning the land of neighbors.

Firewood is obtained from many forms of woody biomass, including brushwood, fallen tree twigs and branches, and cut branches, but rarely from felled trees, except when woodland is being cleared for farming. Crop residues and animal wastes are generally thought to be poor substitutes for firewood because they have valued alternative uses, burn smokily, and require more time and attention for fire management. However, their use as fuels greatly expands available resources and provides an important safety net for small farmers and the landless, who have few trees of their own. These fuels are heavily used in the more densely populated parts of South Asia and China, in tree-scarce African countries such as Lesotho, and increasingly in the West African Sahelian zone.

Surveys of biofuels use in rural areas show large variation in per capita consumption (Table 3-1). Very high levels of consumption are often associated with colder locations where space heating needs are great. The effect of heating needs is illustrated by the range in consumption found in the Tanzanian villages. Per capita fuel use for 7 villages located below 1000 m altitude (therefore having lower space heating needs) was 7.0 GJ, whereas average use for 11 villages located above 1000 m was 11.1 GJ (Skutsch, 1984).

Table 3-1
Per Capita Residential Energy Use from Village Surveys

Location	Average (GJ)	Range (GJ)	Biomass share (%)
AVERAGE OF VILLAGES[a]			
Bangladesh, large survey	4.9	3.5-5.5	97-100
Chile, 8 villages	29.2	17.8-59.2	100
India, Tamil Nadu, 4 villages	7.6	5.8-8.8	97-99
India, Maharashtra, 4 villages	16.5	7.7-36.6	91-99
South Africa, 7 villages	8.2	5.2-14.5	100
Sri Lanka, 6 regions	8.4	7.5-11.2	89-93
Tanzania, 18 villages	10.9	4.4-26.1	100
AVERAGES OF GROUPS WITHIN A VILLAGE[b]			
Bangladesh: Sakoa	8.9	7.0-19.3	97-98
India: Pondicherry	11.0	10.2-11.2	91-97
Nepal: Pagma	9.0	4.0-37.8	100
PNG[c]: highland, January	5.8	2.5-9.2	100
May	5.4	2.4-16.1	100

Source: Leach & Gowen (1987); assembled from numerous sources
(a) Averages of all sampled households in each village.
(b) Averages of household subclasses in each village (e.g. groupings by household income or land-holding).
(c) Papua New Guinea.

If one looks at fuel consumption for cooking only, the degree of variation in per capita use among rural villages in different regions is much less than is the case for overall biofuels use (Table 3-2). Some of the lower values are attributable to partial use of modern fuels, or of wood stoves rather than open fires. (Some of the variation could also be due to differences in measurements.) The main variables that cause cooking energy use to differ from one location to another include the type of staple food (beans have high energy requirements, rice low) and the number of hot meals eaten.

Table 3-2
Fuel Consumption for Cooking in Rural Areas
(MJ per capita per day)

Location	Consumption	% Biomass
Fiji, 14 villages	11.6-16.9	100
Fiji, atolls	18.1	100
Indonesia, Lombok	12.3-15.3	84-96
Indonesia, Klaten	14.8-21.4	57-100
Indonesia, Luwu	17.0-24.4	99-100
Bangladesh, rural	13.7	95
Bangladesh, Sakoa	17.0-28.8	100
Bangladesh, 4 villages	22.2	100
S. Africa, Mondoro	15.1	100
India, Tamil Nadu	15.9-24.1	97-99
India, Karnataka	19.5-23.8	100
India, 2 villages	20.8-49.3	96-97
India, Pondicherry	27.1-29.3	91-97
Mexico, 2 villages	24.8	-

Source: Leach & Gowen (1987)

3.1. Factors Shaping Rural Biofuels Use

Not surprisingly, village surveys indicate that the volume of firewood use depends strongly on the abundance of local woody biomass resources. Looking at the survey results in Table 3-1, the extremely high consumption levels in Chile were for subsistence families living in a forest. Similarly, forest dwellers in the Ghodavari River district of India used nearly 25 GJ of fuelwood per person annually, while in the nearby delta with few trees, average use was 5 GJ. In one Indian village in Maharashtra, with a social forestry scheme designed to provide cheap fuel, annual per capita biomass use was 37 GJ. In a neighboring village without such a scheme, but with almost identical incomes, landholding, and cattle ownership, consumption was only 8 GJ.

While the local resource level obviously shapes the cost (in terms of time) of gathering biofuels, few surveys have measured biofuel resource availability at the same time as consumption. Where this has been done, consumption is generally found to be less where resources are scarcer or further away. For example, surveys in Karnataka State in India found that in a relatively tree-scarce district, per capita annual fuelwood use averaged 0.42 cu.m. where the distance from the forest was less than 5 km, but it averaged only 0.16 cu.m. where the distance was greater than 5 km (Reddy, 1987). In a relatively tree-abundant district, average use was much higher, but here too there was a significant variation according to the distance from the forest: from 2.09 cu.m. where the distance was less than 3 km down to 0.49 cu.m. where it was greater than 9 km.

The distance that fuelwood gatherers can cover depends on the amount of time available, and the value given to that time compared with other household activities.[1] The latter include

[1] The opportunity cost of firewood collection may be very high. In a Mexican village, the average collection rate was found to be 6.2 kg/hour, while the local market price of wood was 3 pesos/kg (Evans, 1984).

those related to cooking (fuel preparation, food preparation and cooking, fire tending), as well as other household and productive activities. Fuel collection times found in surveys show an extremely large range. One cannot correlate fuel consumption with time to collect fuels, however. Where there is fuel scarcity, and therefore long collection times, one might expect low consumption, but long collection times may also be a result of high fuel consumption. Detailed surveys in Malawi found that people scavenging close to home often spent longer than people who walked a long way to collect from an abundant resource (French, 1981). This may be preferred, however, because small amounts of fuel can be gathered rapidly (women caring for children may not be able to leave home for long periods). Strong preferences for particular tree species may also override time considerations.

The fuel collection rate (kg per hour), which combines distance to fuel sources, collection time, and density of the fuel stock, is a good indicator of fuel scarcity. Not surprisingly, surveys show very wide variation in this indicator. For the locations shown in Table 3-3, the range is from 1.7 kg/hour in a South Asian village to more than 70 kg/hour in a Chilean village located close to forest resources. Obviously, the collection rate for a given village may change over time, which may in turn cause changes in consumption (see discussion below).

Table 3-3
Collection Rates for Firewood
(kg/hour)

Location	Average	Range
Chile, 8 villages	27	13 - 71
India, Tamil Nadu, 4 villages	3.9	1.8 - 5.4
India, Karnataka, 6 villages	2.8	1.7 - 3.8
Indonesia, 3 villages	-	10 - 20
Mexico, 2 villages	-	6.2 - 9.2
South Africa, 3 villages	5.5	3.8 - 6.7
Tanzania, 18 villages	12	4.3 - 44
Yemen, 8 villages	3.6	-

Source: Leach & Gowen (1987); assembled from numerous sources

The effective scarcity of fuelwood is sometimes shaped not only by the local biomass resources, but also by social constraints over access to wood or crop residue sources. In South Asia, larger farmers have greater diversity and security of fuel supplies. Small farmers and the landless typically face fuel scarcities because they have to depend on others or on limited and unproductive common lands. In Africa, settlements are much more dispersed and there are few

The "value" of wood collecting was thus MN$18.6/hour. The minimum wage at the time was 27.5 pesos/hour. If jobs were available, it would thus be more cost-efective to earn cash as a laborer in order to buy wood than to collect it. Of course, the fuel collection may be done by household members who for various reasons may not be available for wage labor.

landless, so access constraints are less important.

While lower-income households may have greater difficulty in securing fuel, on a per capita basis there is often little change in consumption with household income or landholding. For example, a large survey in India found that per capita annual fuel use (mostly biomass) ranged from 4.3 GJ in the low-income group to 5.6 GJ in the high-income group (Natarajan, 1985). The lack of change indicates that there are substantial economies of scale associated with fuel use for cooking and space heating. (Wealthier rural households have more people in most developing countries.) The additional energy required to cook for six persons rather than four is small compared with the fixed "overheads" for keeping the fire going, etc. For space heating, energy use depends on the dwelling area, which in general does not increase proportionally with household size. The importance of this effect is well-illustrated by survey results from Pangma village in Nepal (Table 3-4). Average biofuels use per capita steadily declines with household size until a large size is reached; per capita use for two-person households is 3-4 times that of households with five or more persons.

Table 3-4
Per Capita Biofuels Consumption and Household Size
Pangma village, Nepal

	Persons in household								
	1	2	3	4	5	6	8	10	12
GJ per year	21	15	13	11	8.1	8.0	7.7	6.6	7.7

Source: Bajracharya (1981)

Cultural factors often have an important effect on rural biofuels consumption. In well-wooded parts of Africa, the use of a household or village communal fire as a meeting/talking focus is common. Fires may be kept going all day to provide visitors with tea or a hot snack. The frequency of feasts and rituals, which may use large amounts of fuel, is also important. Non-domestic activities such as beer-brewing, pottery, fish-smoking, etc. can also use significant amounts of woodfuel.

3.2. Responses to Fuelwood Scarcity in Rural Areas

When wood is readily available, it tends to be used in large quantities and little effort is made to economize in use. Wood can become more scarce for a variety of reasons. Expansion of farming into forest lands or less dense woodlands is perhaps the most common cause, though increasing population, the impact of external woodfuel demand (i.e., for commercial markets), fires, and overgrazing that prevents the regeneration of tree cover can all result in wood becoming scarce.

While very little information is available on how people actually adjust to increasing wood scarcity, the considerable anecdotal evidence indicates that the first reaction of people is usually to try to maintain their previous level of consumption (Foley, 1985). Typically, people will search longer for the quantity and quality of wood to which they have been accustomed. As the resources become scarcer still, the quantities of fuel collected become smaller and lower quality but more accessible wood is used. This greatly expands the resource base and may postpone the need for any further adaptations.

As wood becomes yet more difficult to obtain, there tends to be more careful use, as noted by several authors (Evans, 1984; Evans *et al.*, 1980; Skar *et al.*, 1982). This normally occurs when the time required to collect wood has become an unacceptable burden. People may light smaller fires, quench and re-use the embers of a fire that they formerly would have let burn away, and position and shelter fires more carefully. Less essential end-uses, such as water heating for bathing or washing clothes and dishes, may be reduced. This level of adaptation may coincide with the first signs of interest in fuel-saving stoves. Indeed, indigenous types of stoves are often found in areas where wood has traditionally been scarce, as in much of India and China.

With increasing fuelwood scarcity, people also begin to make greater use of the other burnable biomass available to them. This shift to crop residues and dung, which are rarely used as fuel where dry wood is abundant, opens up a wide range of new fuel supplies. In Indonesia, for example, it has been estimated that the amount of fuel available when people start relying on general biomass resources is four times as great as when stemwood only is used (Weatherly, 1980). Though inconvenient, use of crop residues and dung is often seen as an easier response than tree-planting. In some areas, most crop residues are fed to animals, whereas in others, they are heavily used for fuel. In China, for example, it is estimated that two-thirds of total crop residues are burned for fuel (Lu *et al.*, 1987). Although the lack of crop residue recycling is recognized as a problem, use of residues for fuel is essential on the long-deforested and densely populated plains and lowlands of the eastern third of China. The lack of fuel has been one factor prompting the use of biogas in rural China, though improvement of hygiene (through recycling of human and other wastes) has also been an important factor.[2]

The above general description overlooks the reality that different groups of rural consumers face and are able to respond to fuelwood scarcity in a varying way. As wood from common land becomes more scarce, those with adequate land holdings of their own may be able to obtain most of their fuel requirements from live hedges, trimmings of fruit and shade trees, and other sources. People who have a cash income can often choose between continuing to search for wood or purchasing it.

---

[2] Mass construction of biogas digesters (mostly single-family units of relatively simple design) took place in China in the 1970s. The nation-wide total surpassed 7 million units by 1979, but many of these have failed for various reasons. Of the remaining digesters, only about half can be used normally, and most of these are not fully utilized (Smil, 1988). Promotion of biogas is now focused on areas where livestock and poultry operations are rather concentrated.

People who have little land or income are obviously in the worst position, and have to obtain their fuel by scavenging from common lands, roadsides, and farming areas where they may have traditional rights of access. In South Asia, many people in this position rely heavily on animal dung that they collect from fields and roads. As biomass supplies of all kinds are depleted, traditional rights of access to fuel sources are often closed off to the poor. Where access has been restricted, or the biomass productivity is low relative to the numbers of landless, the amount of fuel may be insufficient to meet the need. Reductions in living standards and diet are found in conditions of acute scarcity. The burden tends to bear most heavily on women and children as income-earning tasks, hygiene, child feeding and care, or visits to health and education services may be reduced or eliminated in order to make time for fuel gathering (Cecelski, 1984).

There is a great need for better information about the actual situation in rural areas of the developing world with respect to fuel scarcity and people's responses to it. It is clear that the severity of the "fuelwood crisis" varies from place to place, as does the capacity of people to adjust by modifying resource use patterns. The success of interventions in the rural sector requires a solid understanding of the actual situation in specific locations.

4. HOUSEHOLD BIOFUELS USE IN URBAN AREAS

Biofuels are commonly used for cooking by lower-income households in most cities of the developing world. The extent of reliance on biofuels is quite variable, however, ranging from very high in smaller African cities to very low in the capitals of newly-industrialized Asia. While rigorous study across cities is lacking, the evidence suggests that the pattern of biofuels use in urban areas is determined mainly by the overall level of income and income distribution, and the extent of modern fuels supply to and within cities. Relative prices of woodfuels and modern fuels appear to play a lesser role, but can help to speed substitution away from biofuels or precipitate a 'backward' shift into them.

While the quality of modern fuel supply is difficult to measure, the effect of fuel access is suggested in the survey data showing that the extent of biofuels use declines as city size increases, as discussed in Chapter 2. (Larger cities often have higher income levels as well as better fuel distribution, so part of the effect may be do to income.) The growth of large cities, which is a common feature of many developing countries, is thus an important element in the transition away from biofuels. Large cities are the gateways to 'modern' aspirations and patterns of living and working and are thus the growth centers for modern fuel consumption. Combined with their political and economic dominance and favored position regarding infrastructure investments, they are best served by modern fuel supply and distribution systems. History and geography also play their part, of course. Outside the large cities, the availability of modern fuels is shaped by the location of fossil fuel and hydropower resources, policies on rural and small town development, the extent of road networks, and the costs of road transport.

In contrast to rural areas, in urban areas fuelwood use declines sharply as household income increases and people are able to afford modern fuels. This is less the case for charcoal, which is a common fuel in African cities, but is less used elsewhere. Multiple fuel use for cooking is common, offering both convenience and greater fuel security.

The destitute in cities typically use any free burnable scraps of wood, leaves, and paper, or even tires, on open fires. The mass of low-income households both gather and purchase biomass fuels, often with an income gradation from firewood to charcoal, which is easier to carry and store and less smoky than firewood, and from open fires to enclosed stoves. Kerosene may be used for quick cooking tasks such as boiling water for drinks. As income increases, kerosene use tends to increase and then decline as it is replaced by bottled gas or, usually for wealthier households, by electricity.[1] In many parts of Africa and some areas in Latin America, however, charcoal is preferred to kerosene and even displaces gas and electricity. (Charcoal is also used for ironing clothes.) In some places, wood may continue to be used for cooking tasks for which modern fuel stoves perform poorly, such as making tortillas (Masera, et al., 1989).

[1] In a few countries where residential electricity is inexpensive, use of electricity for cooking may be fairly common, as in Costa Rica (Sazama, 1986). In most cities, however, use of electricity for cooking is found mainly among the wealthier households.

The fuel progression described above is illustrated in Table 4-1 by results from a national survey of urban areas in Kenya in 1980. The poorest households relied heavily on firewood, but wood use gave way quickly to charcoal and kerosene as income increased. LPG and electricity did not become significant until a relatively high income level was reached. Charcoal use remained high among all income groups, reflecting its popularity for certain types of cooking.

Table 4-1
Residential Energy Use by Household Income
Urban Kenya, 1980
(GJ per household)

Income ('000 Ksh.)[a]	Firewood	Charcoal	Kerosene	LPG	Electricity[b]	Total
0-3.1	20.0	8.9	2.7	0	0	31.6
3.1-9.1	8.5	19.1	5.7	0	0	33.3
9.1-18.2	6.1	23.8	6.1	0.6	0.5	37.1
18.2-54.6	2.3	22.2	5.2	3.4	3.1	36.2
Above 54.6	0.7	13.4	1.7	6.1	19.9	41.8

Source: O'Keefe, *et al.* (1984)
(a) 1 Ksh. = 0.13 US$ (1980)
(b) Consumption for all uses, not just cooking.

As one would expect, surveys show large differences among cities in the prevalence of biofuels use. An indication of these differences can be seen in the survey results shown in Table 4-2. In relatively wealthy Kuala Lumpur (Malaysia), LPG and even electricity use was not uncommon in 1980 even in the lowest income group. There was little use of firewood, but charcoal use was fairly common across income groups. In Hyderabad (India), where incomes are much lower, firewood use was (and is) much more common, but there is little use of charcoal.

Table 4-2
Fuels Used for Residential Cooking
(percent of households using fuel)

Income group	Firewood	Charcoal	Kerosene	LPG	Electricity
Kuala Lumpur, 1980					
Low	4	15	75	25	19
Medium	7	23	57	52	35
High	0	17	19	87	50
Hyderabad, 1982					
Low	41	neg.	70	19	-
Medium	24	neg.	65	54	-
High	13	neg.	57	71	-

Source: Sathaye & Meyers (1985); based on other sources

The income level at which various modern fuels come into use depends on the local prices of fuels and equipment, as well as the supply of modern fuels. Within the same region, biofuel use may decline at a lower income level in large cities, where modern fuel and stove supply may be good, than in a smaller city where supplies are often inconsistent. This is illustrated by survey results from the Philippines (Table 4-3), which show much greater use of firewood among the urban poor in the outer provinces than in the capital city, Manila. Note especially how use of LPG, which is more difficult to transport to provincial urban areas, is much less among the provincial urban households than in Metro Manila.

Table 4-3
Main Cooking Fuel of the Urban Poor in the Philippines, 1979
(percent of households in region)

Fuel	Metro Manila	Luzon	Visayas	Mindanao
Wood	9	48	75	73
Charcoal	1	7	9	3
Kerosene	35	24	11	18
LPG	45	16	4	5
Electricity	11	3	0	1

Source: Government of Philippines (1982)

Among households that rely heavily on fuelwood, per capita use in urban areas is usually lower than in rural areas (see, for example, the Ethiopian data in Table 2-2). Reasons for this include partial use of kerosene for cooking, greater use of prepared foods (e.g., bread), and the fact that urban residents eat out more often (from street stalls as well as cafes and restaurants). Differences in dwelling characteristics contribute to more common use of ovens and portable metal stoves in urban than in rural areas. The latter especially usually have higher efficiency than the open fires that are more common in rural areas. There may also be greater use of aluminum pots in urban areas, which yields as much as double the efficiency of using clay pots. It appears that the commercial nature of urban fuelwood supply also prompts people to economize on wood use, though this probably varies according to the local price of fuelwood.

4.1. The Modern Fuels Transition

The transition from biofuels to fossil fuels and electricity that occurred long ago in the industrialized countries is well underway in cities of many developing countries.[2] Although the level of knowledge about the phenomenon is poor, it is clear that the rate at which it is occurring, and the extent to which it has already taken place, varies considerably among countries, as well as among urban areas within a given country.

In his study of the impact of modern fuel substitution on woodfuel demand, Foley (1985) aptly observes, "The substitution of woodfuel by conventional fuels is driven both by the push of scarcity and the pull of convenience, efficiency, and modernity." The "push factor" of scarcity varies from place to place, but the "pull" forces are more or less a constant. Foley writes: "The dirt, smoke, and general inconvenience of woodfuels have led to their use being heavily reduced, or abandoned, virtually everywhere living standards have risen substantially.[3] Conventional fuels, in comparison, are clean and simple to use; their adoption is widely regarded as an indication of the modernity and higher social status of their users in the community." The use of modern fuels can bring about significant improvements in living conditions (especially less indoor and ambient air pollution), as well as making cooking quicker and generally more convenient. Compared to woodfuels, kerosene and LPG require less space for storage, and are much easier to bring to the home. (Electricity scores highest in this regard, but in most places its expense limits its use for cooking to the higher-income groups.) Further, in many places, kerosene is actually cheaper on a useful heat basis than wood or charcoal.

The main obstacles to the adoption of modern fuels are the cost of buying kerosene or gas stoves and keeping them supplied with fuel, and the problem of erratic or unreliable supplies. The relative importance of these barriers varies among regions. Related to the cost of using modern fuels is the fact that their use usually requires payment of a large (for the urban poor) amount of cash at one time, whereas firewood and coal can be purchased in small quantities.

---

[2] For further discussion of the modern fuels transition, see Leach (1988b).

[3] The substantial growth in use of wood for heating that occurred in the U.S. and in Sweden after the rise in energy prices of the 1970s and early 1980s indicates, however, that even in the wealthy countries, people may return to use of wood (though in modern, relatively clean devices) if there are compelling economic advantages.

The importance of unreliable supply of modern fuels has tended to be underemphasized. Security of supply is a major consideration for consumers with basic needs such as cooking. With kerosene, typically the first fuel on the transition ladder, there is firm evidence that difficulties in obtaining supplies are often a major barrier for the poor. For example, a 1985 survey in Lucknow, India found that few poor families cooked with kerosene even though they realized that it would cost only 40% as much as cooking with firewood (Sharma & Bhatia, 1987). With average daily incomes of around US$1, the cost of a kerosene stove ($1-4) was not seen as a major deterrent. Kerosene shortages and long lines at the local stores were given as the main reason for not using the fuel. While such constraints are less strong in some places, they are common in many cities in Africa, where the stoves as well as fuels are often hard to find. There is often little incentive for retailers in poor urban areas to stock and insure regular deliveries of kerosene for cooking, as opposed to small amounts for lighting.

With LPG, high investment costs for the cooking stove and cylinder deposit tend to be a major deterrent for lower-income families. For example, in Colombo, Sri Lanka, the entry cost for LPG in 1983 was close to $80, which represented at least one month's average income for the poorest 70% of households (Leach, 1987). In Kenya in 1986, a standard charcoal stove cost 20-50 shillings (sh) and an improved model 60-100 sh; kerosene stoves, which are mostly imported, cost about 450 sh (US$30) (FAO, 1987). However, switching to LPG cost at least 3100 sh: 1440 sh for the deposit on a cylinder and 1650 sh for a 2-ring LPG stove. Erratic supply is also a problem for LPG, as available supplies are often routed to higher income districts where demand is larger and more dependable.

Although cost and supply problems are the most important barriers to use of modern fuels, difficulties with modern fuel stoves are also a factor. The power output of kerosene stoves is often much lower than for a wood or charcoal fire, so cooking takes longer. The heavy stews that form the staple diet in many places are difficult to cook on the generally flimsy appliances in which modern fuels are burned. These drawbacks can be important: in Eastern Niger, for example, it is much cheaper to cook with kerosene than with wood, but kerosene is hardly used (Floor, 1987). A related factor is that certain types of cooking that are popular in some countries, especially grilling, cannot be performed easily with modern fuels.

In part because of convenience and cooking preferences, and in part for reasons of security, many urban households use biofuels and modern fuels. How much of each is used depends on complex adjustments between preferences and cooking habits on the one hand, and access, availability, and price factors on the other. Although rather little is known in detail about this process, it can obviously be very rapid and flexible. High prices or shortages of modern fuels compared to biofuels can easily lead to 'backward' switching from modern fuels to biofuels, since in most cases households retain the equipment to use biofuels. This occurred, for example, in Sri Lanka after the kerosene price rose far above the firewood price (Leach, 1987), and also in the Philippines, among other places. The reverse condition, where modern fuels are cheaper than biofuels (they are rarely more readily available), is likely to have a much lesser impact because only a minority of consumers typically owns modern fuel-using devices.

The Role of Prices

While the above observations about the urban fuel transition are a reasonable guide, it remains the case that little is known about the relative importance of the different factors that bring about the transition, and how and why they differ from place to place. The evidence indicates, however, that the transition to modern fuels is driven mostly by rising income and the urbanization process itself, rather than by relative fuel prices. An analysis by Barnes (1986) of consumption, income, and price data for nineteen countries appears to confirm this point. The transition is also driven by improvements in fuel distribution through increasing consumer demand in the poorer city areas.

Though rigorous analysis is lacking, it is apparent that fuel switching is affected to some extent by the prices of modern fuels and biomass fuels. While governments usually control modern fuel prices, they have little or any control over woodfuel markets. Woodfuel prices vary enormously among cities, as indicated in Table 4-4. The reasons for the variation include the costs of producing and/or harvesting the wood, the cost of transport and fuel preparation, the level of wholesale and retail profit, the quantities purchased (small bundles normally cost more per kg), fuelwood quality, locale within the city, and the cost of competing fuels.[4] The cost of production may be very small when wood comes from land cleared for agriculture, or is taken from public forests, whether illegally or with a permit.

[4] There is some evidence that in several countries woodfuel prices have risen in line with jumps in the price of kerosene, the main competitor to woodfuels.

Table 4-4
Retail Fuelwood Prices in Various Developing Countries

	Year	US$ per ton
AFRICA		
Ethiopia	1983	80-90
Gambia	1982	140
Gambia (Banjul)	1982	53
Kenya	1981	10
Liberia	1984	50-130
Madagascar	1985	20-25
Malawi (Blantyre)	1981	37
Morocco	1983	20-60
Niger	1982	60
Sudan (Khartoum)	1982	72
ASIA		
Bangladesh (Dacca)	1982	38
Burma (Rangoon)	1982	60
India (Bombay)	1982	87
Nepal	1981	20-60
Pakistan (Karachi)	1982	20-40
Sri Lanka (Colombo)	1982	61
Thailand	1984	17
LATIN AMERICA		
Guatemala (G.C.)	1982	34
Peru	1983	20-60

Source: Leach & Gowen (1987); compiled from various sources

Changes over time in woodfuel prices in a given location are less well documented, but they have been known to vary greatly. For the countries studied by Barnes, price changes (corrected for inflation) varied from a rise of 14.9% per year for firewood in the Ivory Coast to a decline of 7.3% per year for charcoal in Zambia. In terms of switching between biofuels and modern fuels, it is the change in relative prices that is most significant. Data from a number of countries show that the ratio of kerosene to firewood price (per unit of estimated delivered energy) in 1982-83 varied from 0.3 in parts of Nigeria (a major oil-producer) to 10 in Cameroon (Anderson & Fishwick, 1984). Change in relative prices may favor modern fuels or woodfuels, depending on the situation. This is influenced by many factors, including change in the subsidies on kerosene or LPG. Here too the trends have varied among countries.

Is the Transition to Modern Fuels Happening?

One can infer from surveys of cities with different average income levels that the transition from biofuels to modern fuels is taking place in those urban areas where incomes are growing and modern fuel supplies are adequate. Statistical documentation of changes over time in urban biofuels use is scarce, however. A notable exception comes from large urban household surveys conducted in India in 1979 and 1984 (Natarajan, 1986). (The surveys were conducted by the same organization, so comparisons are probably fairly reliable.) Firewood prices rose relative to kerosene during this period, while prices of LPG and domestic electricity fell in real terms. More importantly, incomes rose and were more evenly distributed, so that the numbers of middle-income families increased sharply. As a consequence of these factors, the share of cooking and space heating energy demand (expressed in terms of approximate useful energy) met by firewood fell in only five years from 42% to 27%, while the shares for kerosene and LPG nearly doubled from 19% to 36% and 7% to 12% respectively (Table 4-5). As expected, the largest percentage reductions in firewood use were for the middle-income groups. The percentage of all households falling into this category (annual income between 3 and 18 thousand Rs. 1978-79) rose from 66% in 1979 to nearly 80% in 1984.

Table 4-5
Fuel Shares for Cooking and Space Heating[a]
Indian Urban Households
(percent within group)

		Income group[b]					
Fuel type	Year	L	LM	M	HM	H	All
Firewood	1979	60.0	40.9	25.1	17.4	12.1	42.4
	1984	53.5	30.8	17.9	9.9	9.6	27.4
Kerosene	1979	13.2	21.3	21.5	22.0	18.9	18.7
	1984	23.8	36.9	40.2	38.2	32.8	35.7
LPG	1979	0.8	4.6	14.2	26.9	32.9	6.6
	1984	1.2	4.6	15.7	27.9	39.3	11.5
Soft coke	1979	12.8	20.2	23.6	16.7	17.3	18.4
	1984	6.4	18.0	17.9	15.2	8.3	15.3
Other[c]	1979	13.3	13.1	15.6	17.0	18.8	13.9
	1984	15.2	9.7	8.3	8.8	10.1	10.1
% of HH	1979	31.5	42.8	20.7	2.6	2.4	100
	1984	17.6	33.5	35.1	9.4	1.4	100

Source: Natarajan (1986)
(a) Shares are on an approximate useful heat output basis for average fuel/device combinations.
(b) Annual income is in thousand Rs. 1978-79: L = Low (<3); LM = Low-middle (3-6); M = Middle (6-12); HM = High-middle (12-18); H = High (>18)
(c) Other includes crop residues, animal dung, and electricity.

The Indian example shows that the transition away from biofuels can occur very rapidly if the conditions are right. Government policy can have a important effect on the transition away from biofuels, as discussed in Chapter 7, but it is growth in income that appears to exert the strongest influence.

5. ESTIMATES OF NATIONAL BIOFUELS CONSUMPTION

The lack of supply-side statistics on biofuels and the problems with demand-side surveys make it difficult to place a high degree of confidence in estimates of biofuels consumption at the national level (see discussion in Chapter 1). Despite this, the available estimates do give an indication of the approximate magnitude of biofuels consumption, and of the countries that account for the largest amounts of biofuels use. As a careful review of the sources of national estimates was beyond the scope of this study, and would be inconclusive in any case, the estimates presented in this chapter should be taken as rough approximations of actual biofuels consumption.

5.1. Sources for National Estimates

The main international source for estimates of national fuelwood consumption (including wood for charcoal production) is the Food and Agriculture Organization of the United Nations (FAO). The FAO publishes an annual *Yearbook of Forest Products* which gives estimates of fuelwood 'production' (equal to consumption) for most of the world's countries. The values in the *Yearbook of Forest Products* are based on estimates of per capita fuelwood and charcoal consumption that derive from national surveys in so far as these are available. Many of these are based on very small samples or have partial coverage within the country.

An internal FAO study conducted in 1980 (Wardle & Pontecorvi, 1981) gathered numerous estimates of per capita woodfuels use through questionnaire enquiry to countries and by search of available reports and studies. It was found that for many countries there was a wide range of estimates and for only very few were comprehensive and statistically reliable survey data available. Estimates of industrial and commercial woodfuels consumption were available for only a very few countries. The various estimates were treated as random observations and weighted according to the population with which they were associated to calculate a weighted average consumption for each country. In the absence of any apparent time trend in the estimates, all available observations were pooled irrespective of the year to which they related. To derive estimates of total national consumption for each issue of the *Yearbook of Forest Products*, the estimates of per capita fuelwood and charcoal consumption from the 1980 study, or revised estimates based on later information, are multiplied by the total national population for a given year.[1] To estimate primary wood consumption for charcoal production, the FAO assumes a constant value of 6 cu.m. per ton of charcoal produced. The actual conversion factor varies among countries, but is often much higher than 6 cu.m. per ton.

The problems inherent in the FAO's method are several. The estimates that were pooled to calculate a national weighted average consumption were of varying and uncertain quality. For

[1] The statistics on fuelwood and charcoal given in the annual *Energy Statistics Yearbook* of the United Nations are mostly taken from the FAO. In a few cases, the UN uses data from country sources instead of the FAO estimates.

some countries, several of the surveys were conducted many years prior to 1980, but these were pooled with later surveys. The FAO endeavors to revise consumption estimates as new information becomes available. In those countries where more recent information has not become available, using the 1980 per capita estimates for later years is problematic because of possible change in the rural/urban population mix and in the consumption levels in rural and urban areas.

The FAO does not estimate national consumption for energy of crop residues and animal dung. For the countries that have high levels of use of these fuels (South Asia and China), estimates are available from official sources or national surveys.

We include in this section estimates of annual bagasse consumption by sugar mills.[2] These are published in the United Nations (UN) *Energy Statistics Yearbook.* The methodology employed by the UN assumes use of 3.26 tons of fuel bagasse at 50% humidity per ton of sugar cane produced. In most cases sugar production data are extracted from the *Sugar Yearbook* of the International Sugar Organization (London). We have not included consumption of wood wastes by wood processing industries or crop residues by agro-processing industries, as data on this usage is not readily available.

5.2. Biofuels Consumption Estimates

Table 5-1 presents estimates of total consumption in 1986 of the major biofuels for broad regions and for the largest consuming countries within the regions. We have converted the estimated quantities consumed from the original units to a common energy unit (Petajoules)[3] based on the conversion factors described in the table notes. Since the conversion of biofuels to energy depends on the moisture content of the biomass, which varies from place to place and is typically somewhat uncertain, the selection of any single conversion factor is a possible source of error. For wood and charcoal, we use the same conversion factors for all countries, though in actuality the appropriate values differ somewhat among countries.

The main source for fuelwood and charcoal consumption is the FAO *1986 Yearbook of Forest Products,* though in cases where we had access to other sources that we judged to be more accurate, we made use of these (as described in the table notes). The estimates of crop residue and animal dung energy consumption are from various country sources. The estimates of bagasse consumption are from the UN *1986 Energy Statistics Yearbook,* except in the case of Brazil, where the source is the national energy balance. For Brazil, we include under bagasse the sugar cane that is converted to ethanol.

[2] Bagasse, a residue of sugar cane processing, is different from the other biofuels in Table 5-1 in that it is part of an agro-industrial system and there are not competing uses for it. There are other crop residues (rice husks, palm oil residues, etc.) that are used by agro-industries in developing countries, but statistics on this consumption are difficult to obtain.

[3] 1 Petajoule = 10^{15} Joules; 1000 Petajoules is approximately 1 quadrillion Btu ('quad'), or 24 million tons of oil equivalent.

Table 5-1
Estimated National Biofuels Consumption, 1986
Asia, Africa, Latin America
(Petajoules)

	Fuelwood[1] Direct use	Wood for Charcoal[2]	Residues[3]	Dung[4]	Bagasse[5]	Total
Asia	**10764**	**520**	**4413**	**1125**	**528**	**17350**
China†	4930*	neg.	3600*	100**	120	8750
India	2365	160	430**	860**	190	4005
Indonesia	1420	15	X	0	54	1489
Thailand†	125*	250*	49*	0	53	477
Bangladesh	54	neg.	300**	78**	18	450
Pakistan	220	neg.	34*	87*	29	370
Philippines	330	neg.	X	0	32	362
Vietnam	245	neg.	X	?	5	250
Others	1055	60	X	neg.	27	1142
Africa	**3820**	**918**	**X**	**X**	**185**	**4923**
Nigeria	915	115	X	0	1	1031
Ethiopia	395	15	X	X	5	415
Kenya	220	175	X	neg.	5	400
Sudan	130**	220**	X	?	14	364
Zaire	270**	80**	?	0	2	352
Tanzania†	270**	33**	X	neg.	3	306
Others	1620	280	X	X	155	2055
Latin America/Carib	**2000**	**739**	**X**	**X**	**1187**	**3926**
Brazil†	1070*	565*	X	0	725*	2360
Colombia	130	44	X	0	32	206
Mexico	140	15	X	0	105	260
Others	660	115	X	neg.	325	1100
Total	**16564**	**2142**	**4413**	**1125**	**1900**	**26144**

Sources: Fuelwood and charcoal -- FAO 1986 Yearbook of Forest Products, except as noted; Bagasse -- UN 1986 Energy Statistics Yearbook (Table 13).
* indicates source is a government estimate derived from surveys (see notes below).
** indicates other source (see notes below)
"X" indicates the fuel is used, but the quantity is very uncertain (though probably small in relation to other fuels)
† denotes that industrial and commercial consumption is included. Inclusion in other cases is uncertain.

(1) Converted at 11 GJ/cu.m. of solid-volume wood, assuming a demsity of 1.4 cu.m./ton and an average 20% moisture content (wet basis).
(2) Assumes 8 cu.m. of wood per ton of charcoal produced, except where source is government data; converted at 11 GJ/cu.m.
(3) Conversion factors vary among fuels and countries.
(4) Converted at 12 GJ per ton.
(5) Assumes use of 3.26 tons of fuel bagasse at 50% humidity per ton of cane sugar produced; converted at 7.75 GJ/ton.

Notes to Table

Government sources

China -- Fuelwood value is based on new estimate from Ministry of Forestry, given in Yang (1987); residues use is from Ministry of Agriculture, given in Qiao (1988); dung use is estimate by Smil (1988).

Pakistan -- *Energy Year Book 1985*. Values are for 1983-84. Residues include cotton sticks and sawdust only; consumption of other crop residues n.a.

Thailand -- *Thailand Energy Situation 1987*. Residues include use by industry (rice hulls).

Brazil -- *Balanco Energetico Nacional 1987*. Includes residential, industrial, agricultural, and commercial use of wood, and charcoal production for industry. For wood conversion to energy, we use 15.5 GJ/ton, not value used in the energy balance. For wood used for charcoal, we adopt conversion factor used in the energy balance (10.57 GJ/ton). Total given under "Bagasse" refers to sugar cane used for alcohol fuel production (which includes bagasse that is utilized); non-energy use of bagasse is subtracted. We adopt the Brazilian conversion to energy.

Other sources

Bangladesh -- From Leach (1986) for residues and dung; data refer to 1980-81.

India -- From Leach (1986) for residues and dung; data refer to 1978-79.

Zaire -- Based on 1983 World Bank study, results given in Byer (1987); FAO estimated zero use of charcoal, which is inaccurate.

Tanzania -- Estimated by authors based on various surveys.

Sudan -- Estimated by authors based on divergent estimates from FAO and World Bank 1980 survey.

The most significant replacement of an FAO estimate, which also illustrates the high degree of uncertainty surrounding estimates of fuelwood consumption, concerns China. Until recently, the accepted official estimate of annual fuelwood consumption was 180 million tons. (This number is still seen in some Chinese papers on energy use.) Large numbers of surveys done in recent years under the direction of the Ministry of Forestry have resulted in substantial upward revision of the estimated amount of fuelwood consumption to 320 million tons (Yang, 1987). (This includes an estimated 50 million tons used by rural industries.) The new estimate is equivalent to approximately 450 million cu.m. The value given for China in the FAO *1986 Yearbook of Forest Products* is only 174 million cu.m. The difference between the FAO estimate and the revised Chinese estimate, around 270 million cu.m., is nearly as great as the total estimated fuelwood consumption in all of Latin America!

Results. The statistics in Table 5-1 indicate that Asia (including the 'Middle East') accounts for about two-thirds of total LDC biofuels consumption. Africa accounts for about 19%, and Latin America/Caribbean (hereafter referred to as "Latin America") accounts for about 15%. If bagasse is excluded, the Latin American share falls to 11%. China is by far the largest biofuels consumer, followed by India, Brazil, and Indonesia.

The estimated total LDC 1986 biofuels consumption, around 26,000 PJ (~25 'quads'), is equivalent to 36% of total LDC 'modern energy' consumption, which in 1986 was around 73,000 PJ. Adding these two together, we can estimate that biofuels accounted for about 25% of total LDC energy consumption.

Direct use of fuelwood accounts for an estimated 63% of total LDC biofuels consumption. Wood used in charcoal production accounts for another 8%, crop residues account for 17%, animal dung accounts for 4%, and bagasse accounts for 7%. The magnitude of crop residues use for fuel is likely higher than shown in Table 5-1, since we did not have estimates of consumption for many countries where residues are known to be used (though in relatively small quantities).

The shares of the different biofuels vary among the regions and countries. The regional fuel shares are summarized in Table 5-2 below. Crop residues are most significant in Asia, while wood for charcoal is minor. Direct use of fuelwood dominates total biofuels use in Africa. In Latin America, bagasse (including sugar cane for ethanol) accounts for around 30% of total biofuels consumption.

Table 5-2

Estimated Fuel Shares in Total Biofuels Consumption, 1986

(percent)

	Fuelwood Direct use	Wood for Charcoal	Residues	Dung	Bagasse	Total
Asia	62	3	25	6	3	100
Africa	78	19	neg.	neg.	4	100
Latin America	51	19	neg.	neg.	30	100
Total	63	8	17	4	7	100

For most of the countries shown in Table 5-1, direct use of wood dominates total biofuels consumption, but wood for charcoal is significant in Thailand, Sudan, Kenya, and Brazil. In Brazil, most of the charcoal production is for steel manufacturing, and much of the wood derives from trees grown specifically for this purpose. Crop residues are important in China, India, and Bangladesh, and animal dung is significant in India, Bangladesh, and Pakistan. Sugar cane for ethanol production and industrial use accounts for about 30% of total biofuels use in Brazil, and bagasse use is also significant in Mexico.

5.3. Change in National Biofuels Consumption

To our knowledge, it is not possible to state with statistical certainty whether overall biofuels consumption is growing in any developing country. One can make inferences based on population growth, but in most cases this is problematic due to lack of comparable surveys over time and uncertainty with respect to complicating factors, as discussed in Chapter 2. The time trends that can be derived from the FAO's *Yearbook of Forest Products* (which are subsequently published in the UN *Energy Statistics Yearbook)* assume constant per capita consumption, which may be incorrect for many countries where the woodfuel situation is undergoing significant change. In the absence of longitudinal surveys, discussion with people with continuous experience in rural areas or in urban areas where woodfuels are important may be the best guide to the type of changes that are taking place in a particular country.

6. BIOFUELS USE AND GREENHOUSE GAS EMISSIONS

The implications of human use of biofuels with respect to greenhouse gas emissions depend on the type of biofuel used, the manner in which the fuel is harvested (for woodfuels), and the design and utilization of the end-use technology. Accordingly, the impact on greenhouse gas emissions of improved efficiency of biofuels use and transition into non-biomass fuels also depends on these factors. In the case of improved stoves, the impact depends on the type of modification, since different designs have varying effects on emissions.

6.1. Greenhouse Gas Emissions and Stove Efficiency

Three types of greenhouse gases are produced from biofuel combustion: carbon dioxide (CO_2), nitrous oxide (N_2O), and various products of incomplete combustion (e.g. organic and inorganic aerosols, carbon monoxide, and methane). A rough estimate is that typical release of nitrous oxide and methane in biomass combustion is equivalent to approximately 10 percent of CO_2 emissions.[1] The greenhouse impact of these gases is much greater than CO_2, however: about 200 times more in the case of N_2O, and about 20 times more for methane (Ramanthan *et al.*, 1985).

In general, the less fuel used for a given cooking task, the less of each type of emissions will be released. Fuel utilization in cookstoves, however, is a function of two internal efficiencies: combustion and heat transfer. Design and operation changes that reduce overall fuel utilization sometimes increase one internal efficiency at the expense of another. In particular, heat-transfer efficiency is often increased at the expense of combustion efficiency. Reduction in combustion efficiency has a small effect on CO_2 emissions but causes a large increase in release of incomplete combustion products (Smith, 1989). Changes in stove design that improve efficiency by increasing combustion temperature lead to higher emissions of N_2O. Thus, the net impact on greenhouse warming of changes in stove design that result in lower fuel use depends on the design, as well as on how the improved stove is used in practice. While it is possible that design changes can increase greenhouse gas emissions per unit of fuel burned, the reduction in fuel use may still lead to lower emissions per meal cooked.

6.2. The Importance of Biofuels Sources

The impact on greenhouse warming of biofuels use also depends on the type of fuel and the nature of harvesting. As shown in Table 6-1 below, use of biofuels results in additional CO_2 release when the source of the fuel is trees felled specifically for fuel (either for direct use or for charcoal production), or branches and twigs cut from living trees on a non-sustainable basis. When the source is crop residues, animal dung, trees felled for agricultural land clearing, or wood residues from forestry operations, if the material were not burned as fuel it would oxidixe

[1] Mark Modera, Lawrence Berkeley Laboratory, personal communication.

naturally on the ground and release CO_2. Burning for fuel releases CO_2 and other gases more rapidly, of course, and may prevent some carbon from being incorportated into the soil. Burning also releases nitrous oxide, which would not occur if the material were to decompose aerobically.

When the source of wood is branches and twigs cut from living trees on a sustainable production basis, whether from farm and homestead trees, plantations, woodlots, or natural forests and woodlands, there are no or few net CO_2 emissions, though in some cases if the wood were not harvested and burned as fuel the trees would grow and absorb carbon. The degree to which uptake of CO_2 is prevented by harvesting depends on the point in the tree's life at which harvesting takes place.[2] Over its natural life, a tree sequesters carbon according to an S-shaped curve. If a tree is allowed to remain at its mature size in harvesting, the tree mass lost is minimal. In many areas, however, trees are cut down to small size; they may still be alive, but the loss of sequestered carbon is substantial, and harvesting may be such that the tree does not reach but a small portion of its carbon-sequestering potential.

Table 6-1

CO_2 Implications of Biofuels Consumption

Biofuel type/source	Added CO_2?
NON-WOOD	
Crop residues	NO
Animal dung	NO
WOOD	
Fallen branches and twigs	NO
Branches & twigs cut from living trees:	
On sustainable production basis	NO*
On non-sustainable basis	YES
Residues from forestry operations	NO
Felled trees for agricultural land clearing	NO
Felled trees specifically for fuel	YES

* Depends on manner of harvesting.

One can estimate total CO_2 emissions from combustion of biofuels in developing countries using the values in Table 5-1. Dry wood averages about 50% carbon by weight. Assuming a density of 1.4 cu.m. per ton of wood in actual use, and a 20% moisture content (wet basis), we get 0.29 tons of carbon per cu.m. of wood. This amounts to emissions 0.026 tons per GJ. If as an approximation we apply the same emission factor to crop residues and dung, total carbon emissions from 1986 biofuels use in developing countries can be estimated at around 680 million tons. To place this in context, total carbon emissions from forest clearing are highly uncertain, but are estimated (based on 1980 data) to range between 600 and 2600 million tons per year (Houghton,

[2] We acknowledge the comments of Ashok Gadgil of Lawrence Berkeley Laboratory in elaborating this point.

et al., 1985).

Much of the 680 million tons of carbon would be released into the atmosphere (though at a slower rate) in the absence of human use for fuel. As discussed above, knowing about the sources of woodfuels is important for estimating the net CO_2 input to the atmosphere from human biofuels use, as well as the impact of improved end-use efficiency and substitution by non-biomass fuels. Comprehensive information about the origin of woodfuels is generally lacking, however. A wide spectrum of wood harvesting practices can be found in the developing countries, ranging from resource-preserving silviculture to high degrees of over-exploitation. Using a number of assumptions about woodfuel demand and production potential in various regions, the net annual atmospheric input from biomass energy use in the mid-1980s has been estimated to be 100-300 million tons of carbon (Kohlmaier *et al.*, 1986). This amounts to 2-6% of the annual input of carbon from world fossil fuel combustion.

Summary. Use of biofuels results in net additions of CO_2 mainly when the source of the fuel is: (1) Trees felled specifically for fuel (either for direct use or for charcoal production), or (2) Branches and twigs cut from living trees on a non-sustainable basis. Harvesting from living trees, even on a "sustainable" basis, also reduces the capacity of trees to sequester carbon if they are not maintained at a mature size. The importance of different sources compared to others varies from one area to the next. In general, however, one can say that the felling of trees specifically for fuel is mainly associated with urban fuelwood and charcoal demand, particularly that of larger cities. Cutting of branches from living trees on a non-sustainable basis is a phenomenon whose extent is difficult to assess, though it is likely to be more common in areas where fuelwood supplies are most scarce.

6.3. Policies Affecting Biofuels: Greenhouse Gas Implications

We discuss policies affecting biofuels in the next chapter. It is clear from the above discussion that the impact of improvements in biofuels use and production (here referring to charcoal) efficiency on greenhouse gas emissions depends on the source of the biofuel and the nature of changes in stove design. Generally, improvements in end-use efficiency will have the largest impact on CO_2 emissions when they occur in urban areas, for which wood "mining" as opposed to sustainable harvesting is often a major source of woodfuels. This is fortuitous, since purchase of improved stoves has been and is likely to be far greater in urban than in rural areas.

The net impact on greenhouse gas emissions of the urban transition from biofuels to modern fuels depends on supply and demand-side factors. As these vary among urban centers and among households, it is difficult to draw general conclusions. On the supply side, the source of the biofuel and the manner of harvesting (wood "mining" vs. sustained yield management) are important. For many urban areas, much of the wood and charcoal used probably comes from felled trees, some of which are felled for fuel purposes rather than land clearance. Data to quantify the sources of urban woodfuels are generally lacking, but the degree of reliance on wood "mining" undoubtedly varies considerably among cities and over time for a given city. In many cases where kerosene or LPG partially replace charcoal, however, the change would result in much lower CO_2 emissions.

On the demand side, the key factors for a given household are its level of woodfuel use prior to acquiring modern fuel equipment, the degree to which the modern fuel displaces the woodfuel (since in many and perhaps most cases the household retains its wood or charcoal stove and continues to use it for some types of cooking), the efficiency of the new stove, and changes in cooking habits as a result of having the new stove. Very little information is available to shed light on these factors, but in most cases the improvement in stove efficiency associated with the transition to modern fuels will bring about a substantial reduction in energy consumption.

Efforts to increase biofuel supply through tree planting, whether specifically or indirectly for fuel, are obviously all to the good in terms of greenhouse gas impacts. The growing trees sequester carbon from the atmosphere, and the fuelwood harvested from them may displace wood that might come from tree-felling or damaging harvesting from living trees.

7. POLICIES AFFECTING BIOFUELS

The problems associated with the current use of biofuels in much of the developing world concern the welfare of those who rely on biofuels for their basic needs, the impact of biofuels harvesting on natural ecosystems, and the availability of the more desirable biofuels over the long term. In many places woodfuel resources are dwindling because of deforestation caused by the need for farming land, over-grazing, commercial logging, uncontrolled fires, and tree cutting for fuel. As wood resources diminish, for millions of people the costs of obtaining woodfuels, whether in cash or time for gathering them, are imposing severe and increasing strains on already marginal household survival and production strategies. These impacts are greatest for the poor and for women. In many rural areas, women have to spend considerable time to gather biofuels, thus taking time away from other domestic tasks. Cooking with biofuels is also often unhealthy due to smoke emissions, and inconvenient as well. Increasing scarcity of higher-quality wood is bringing greater use of crop residues, which are usually even more inconvenient to use and may have valued alternative uses.

The impact of biofuels harvesting on natural ecosystems varies greatly, but there are many areas where rural use and harvesting for urban markets contribute to degradation of forests and open woodlands. While fuelwood cutting is only one of the causes of deforestation (and not the major one in most places), the long-term availability of the traditional biofuels is threatened by the general deforestation that is occurring in many areas.

As a result of the perception of problems associated with biofuels use, aid and lending agencies and governments have over the past decade and more implemented policies and programs intended to affect biofuel supply and demand. In many places, indigenous non-governmental institutions and private voluntary organizations have also had considerable involvement in biofuels programs.

There are three general technical solutions to the biofuels problem that policies and programs have addressed with varying degrees of effort and success. The first is to increase supply of biofuels. The second is to reduce demand among biofuels users by improving end-use efficiency. And the third is to encourage fuel substitution away from biofuels. This seems straightforward enough, but in fact part of the reason why so many interventions have been unsuccessful is because of a too-narrow focus on woodfuels and the symptoms of their scarcity. Energy-focused approaches have all too often ignored the much broader and deeper strains in the environmental, social, economic, and political fabric, of which woodfuel scarcity is only one manifestation. Further, top-down and over-specialized approaches often failed to notice that in many places people were already responding to woodfuel problems in ways that are imaginative and less costly than most project interventions. It is now increasingly recognized that successful remedies for woodfuel problems must be firmly rooted in a broad context, though this is easier said than done. Before considering these approaches, it is thus important to briefly discuss the context in which policies and programs intended to affect biofuels supply and demand operate.

The Rural Context

The rural economy is based almost entirely on the production and use of biomass of all kinds. Where biomass fuels are scarce — typically in dry regions, or on good land with high population densities — people usually face many other scarcities or have many other concerns in their attempts to secure decent livelihoods. Adequate fuel is only one such concern. Whether or not people feel they have a significant energy problem depends on their prioritization of the costs entailed in fuel provision compared to those of other problems, and to the costs of doing something about it, such as buying or making an improved stove, or planting and maintaining trees for fuel.

On the supply side, firewood is only one useful product or service of woody biomass management, along with wood for construction and tools, animal leaf fodder, shade, fruit and nuts, windbreaks, and soil conservation. Decisions on the uses, planting, and management of woody biomass are made within complex and holistic perspectives of the entire land use and biomass economy. They are based on such fundamental issues as the distribution of landholding, security of tenure, changes in control and access to common lands, access to agricultural production inputs, credit and markets, as well as soil and climatic conditions that govern the productive potential of land.

These observations do much to explain the repeated failures of rural woodfuel interventions such as stove programs and energy woodlots. Based on energy-focused assessments by outside experts, they have all too often tried to provide solutions to problems that local people did not know they had or gave a low priority, and did nothing to tackle the fundamental causes. They also underlie the current focus on indirect approaches to the woodfuel problem, especially the encouragement and enhancement of many forms of farm and agro-forestry for multipurpose products and services, with woodfuel provision as one product.

The Urban Context

Most urban consumers of woodfuels purchase them in well-organized markets. Supply of wood or charcoal may come from considerable distance, and originate from government forest lands, from agricultural land clearance, from open forest, and in some places, from farm tree crops. A key feature of the supply system is that urban consumers generally pay little or nothing for the production and replacement of the woodfuels that they consume, thereby often imposing substantial costs on rural people and the natural resource base. Since the mass of poor urban consumers cannot tolerate substantial (or any) increases in woodfuel prices, there are strong (and mounting) pressures on woodfuel traders to take wood from any unguarded or 'open access' sources they can find or, if they must pay, to get it on the cheap.

On the demand side, people with sufficient income typically move away from reliance on biofuels to use of modern fuels where supplies of the latter are adequate. What is uncertain in this process is the relative importance of economic reasons (reducing costs) and non-economic factors such as fuel preference and fuel availability. If the non-economic reasons dominate, people may be more interested in substitution away from biofuels than in more efficient devices. For example, low-income charcoal users might be more receptive to improvements in kerosene distribution or efficient, low-cost kerosene stoves than in fuel-saving charcoal stoves. On the other hand, if costs are the dominant consideration, measures to support woodfuels saving may be more successful than the encouragement of fuel switching, although this will obviously depend to some extent on relative fuel prices. In a given city motives are likely to be mixed and to vary from one social group to another.

7.1. Increasing Supply of Biofuels

Efforts to increase wood supply through peri-urban plantations and village woodlots have been a major focus of governments and donor agencies. In general, the success of these efforts has been minimal, and over the past two decades there has been a major shift in attitudes to forestry and rural tree growing by the donor community and governments. Although the shift is by no means complete, there is now a broad concensus that small-scale tree production for multiple purposes is perhaps the single most important option for easing rural woodfuel problems and in helping generally to sustain rural livelihoods. (See Leach & Mearns, 1988, and Munslow, 1988, for very informative discussions of opportunities and difficulties with this approach in Africa.)

Techniques for integrating trees into farming systems, which generally fall under the heading "agro-forestry", aim to use the productive and protective features of woody plants to increase, sustain, and diversify total output from the land. Many studies and trials of various agro-forestry combinations have shown that they can provide large benefits in terms of extra wood, fodder for livestock, and increased yield of crops.[1] Where there are well-developed markets for wood products, whether locally or in nearby urban areas, tree growing may well be a viable and attractive means of earning cash. It is well suited to farmers who are short of capital or labor, since tree growing for saleable output tends to be cheaper to start and is less labor intensive than cash cropping.

While agro-forestry is a promising option for increasing rural and urban woodfuel supply, and there are many success stories, it also faces a number of constraints. Resource-poor farmers are of necessity risk-averse, and tend to value short-term benefits. They may not be willing to invest scarce labor in trees that will take many years to yield income. Some agro-forestry options involve short-term costs which are perceived as prohibitive in relation to the stated long-term benefits. Lack of secure tenure over land and trees, or clear rights to their use, can also be a barrier to development of rural tree growing.

The nature of the involvement of external agencies is a crucial factor in overcoming the often formidable constraints to expanding agro-forestry. An examination of a large number of initiatives designed to assist tree growing by farmers in Africa concluded that success is more likely if projects incorporate and build on indigenous technical knowledge (Leach & Mearns,

[1] To the extent that trees can help intensify crop or livestock production, they reduce the need to clear woodlands and other tree resources to make new farming land, thus reducing deforestation.

1988). Placing greater control in the hands of local communities was also a key to success in many cases. Another critical lesson is the need for external agencies to be flexible and responsive to local needs, and to learn from and work with local communities.

The interaction between farmers and urban markets is also important in developing agroforestry. People who have land often may have sufficient fuel for their needs or need little help in planting a few trees to provide more fuel. If they are to be induced to grow more fuel than they need themselves, there must be a market in which to sell woodfuels and other wood products which provides a greater return on investment than alternative uses of their land and labor. In many locations, these market factors are dominated by the demands of urban areas, which can extend far into the hinterland. Urban demands for woodfuels are often one of the principal causes of rural woodfuel depletion, but also provide the major opportunity for increasing rural fuel production.

7.2. Improving Biofuels End-Use Efficiency

Programs to design and disseminate more fuel-efficient cooking stoves have been a major feature of woodfuel strategies in developing countries, but in general results have been disappointing (Manibog, 1984). To a large extent this is due to the emphasis of the first generation of stove programs on heavy-mass mud stoves for rural areas. The lifetime of these stoves has often been short, or they have not been well-adapted to user requirements. Where fuelwood could still be freely gathered, there was often low incentive for households to invest in new stoves (except where subsidies were offered). Low demand for stoves has in turn made it difficult for producers to maintain a steady income.

There has been some controversy as to whether the improved stoves that have been disseminated actually save fuel in practice (Foley & Moss, 1983). An important lesson of recent reviews of stove performance is that whereas traditional cooking fires and stoves can be very fuel-efficient if they are operated carefully (and very inefficient if not), improved stoves tend to have consistently high efficiencies however they are operated. Recent tests on twelve designs of improved charcoal stoves, for example, found that at high power outputs fuel efficiencies of 40-45% (roughly double that of traditional stoves) were obtained almost regardless of what utensils were used or how the stoves were used (World Bank, 1986). Substantial fuel savings have also been reported for improved rural woodstoves in Indonesia, Guatemala, and to a lesser extent, in North India (Joseph, 1987).

While there have been some successes in rural areas as a result of strong, well-run programs, the prospects for improved stoves are much more promising in urban areas where commercial markets already exist for woodfuels and stoves. In rural and urban areas, benefits other than fuel saving have proven very important to adoption and continued use of improved stoves. In the programs reviewed by Joseph, smoke removal was cited as an important factor by a high percentage of people who purchased stoves. Shorter cooking time is also an attractive feature for women. To enhance stove acceptance, stove producers must be able to adapt designs to meet consumers' demands for multiple benefits.

Along with sensitivity to the diverse needs of stove users, succesful dissemination of improved stoves requires attention to the needs of stove producers. Income from stove-making must be attractive relative to alternative activities, and credit to buy equipment and materials and assistance with marketing and planning may be necessary. Training and technical support may also be important to ensure quality control.

Substantial woodfuel savings are also possible for industrial and commercial users. Fuelwood savings achieved at low cost in tobacco curing in Malawi and Uganda, for example, were 75% and 65%, respectively (Floor, 1988). Regionally, agro-industries are often major consumers of available wood resources, and reductions in their consumption can have substantial effects on fuelwood supply for both rural and urban households.

7.3. Encouraging Substitution Away from Biofuels

Apart from the wide range of policies that promote urban income growth among the poor, governments can encourage the transition away from biofuels in several ways. The most frequently used lever is to control the prices of the main alternatives to woodfuels, kerosene and LPG. This approach has turned out to be less effective than one might suppose, however, because price controls do little to address the main constraints to fuel switching, which are usually poor access to modern fuels and their unreliable supply, and high equipment costs for modern fuels (see discussion in Chapter 4). Subsidies on kerosene and LPG usually most benefit middle-class consumers who may already have switched away from woodfuels. Subsidies can also have unintended results. In Senegal in the mid 1970s, for example, concern over deforestation led the government to heavily subsidize butane to encourage substitution away from charcoal. The controlled price of butane became roughly one-fifth the price of charcoal on a useful heat basis. What happened was that charcoal use rose slightly but consumption of butane almost quadrupled as kerosene users rather than charcoal users switched into butane (World Bank, 1983).

Although pricing may have a role to play, there is now a growing consensus that fuel switching has to be encouraged by a more direct attack on the main barriers that prevent the urban poor from achieving their aspirations for modern fuels. Access to fuels and the reliability of supplies can be enhanced by (1) improving facilities for transporting kerosene and LPG within cities (especially to poorer districts) and to smaller, outlying towns; (2) improving storage facilities to smooth out supply bottlenecks; (3) improving the supply of LPG cylinders; and by (4) providing support to retailers or encouraging the expansion of retail outlets.

There are several options for reducing the costs of modern fuel devices and improving product quality. These include: (1) encouraging local design, manufacture, and dissemination of appropriate, efficient, and hopefully low-cost kerosene and LPG cookstoves;[2] (2) subsidies on

[2] Modern fuel devices are often imported, resulting in high consumer prices and foreign exchange costs, and may not satisfy consumer needs. If local manufacture could be built up sufficiently, economies of scale in production and marketing could result in substantial unit cost reductions.

kerosene and LPG stoves targetted to poorer families; (3) loan or stamp schemes to enable poorer families to spread the often prohibitively high first cost of kerosene and LPG equipment; and (4) experimenting with production and sale of LPG in smaller and cheaper than usual cylinders.

Policies to encourage switching to petroleum fuels raise the question of the associated impact on foreign exchange (through increased oil imports or reduced exports). A study of replacing all urban woodfuels with kerosene for a number of African countries estimated that the increase in total oil demand would range greatly from less than 15% in middle-income countries to 25-50% for most of the lower-income countries (Byer, 1987). These findings suggest that the heavy costs in foreign exchange may render replacement of woodfuels with oil an unattractive option for most poorer countries.

The need to rely primarily on a woodfuel economy need not be seen as "anti-development", however. If the woodfuel economy and its broader socio-economic context are handled with vision and determination, there are enormous opportunities for enhancing woodfuel supplies, while providing multiple benefits within the country for employment, income generation, and a more productive and sustainable environment.

7.4. Conclusion

The experience teaches that if policies and programs affecting biofuels are to create lasting successes, they must be sensitive to the broad context in which they are to be effective, and seek to reach underlying causes rather than simply heal the symptoms. An important element is the need for local assessments and actions. The natural, cultural, and economic settings in the developing world are extremely diverse, and problems and opportunities to solve them are therefore specific to place. It is also crucial to develop indirect approaches to woodfuel issues and greater participation by local people at every stage to help them to prioritize and solve their own problems. Success normally depends on starting and stengthening processes rather than simply delivering technical packages. The above elements highlight the need for decentralized and multi-disciplinary approaches. New institutional linkages, joint policies and data gathering, and other kinds of alliances between government agencies, extension services, and non-governmental organizations are all needed if woodfuel issues are to be addressed in a more holistic and relevant way. Lastly, there is also a need for economic, legal, and political initiatives at the macro-level to improve the broad contexts for local change.

8. REFERENCES

Alam, M., Dunkerley, J., Reddy, A.K. (1985). "Fuelwood use in the cities of the developing world: two case studies from India", *Natural Resources Forum*, Vol. 9, No. 3.

Anderson, D., Fishwick, R. (1984). Fuelwood Consumption and Deforestation in African Countries. World Bank, Washington, D.C.

Bajracharya, D. (1981). Implications of Fuel and Food Needs for Deforestation: an Energy Study in a Hill Village Panchayat of Eastern Nepal. PhD dissertation, Sussex University, England.

BEPP (1984). Bangladesh Energy Planning Project.

Barnes, D.F. (1986). Understanding Fuelwood Prices in Developing Nations. World Bank, Washington, D.C. (draft).

Bogach, S. (1981). A Fuelwood Policy for Guatemala. United Nations Development Programe Report.

Bowonder, B., Prasad, S.S.R., Unni, N.V.M. (1986). "Deforestation around urban centres in India", *Energy Environment Monitor*, Vol. 2, No. 2.

Byer, T. (1987). Review of Household Energy Issues in Africa. World Bank, Washington, D.C. (Unpublished).

Cecilski, E. (1984). The Rural Energy Crisis, Women's Work and Family Welfare: Perspectives and Approaches to Action. Working Paper, International Labour Office, Geneva.

CESEN (1986). The Rural/Urban Household Energy Survey (Ethiopia).

Evans, M.I. (1984). Firewood Versus Alternatives: Domestic Fuel in Mexico. Commonwealth Forestry Institute, University of Oxford.

Evans, I., Gern, E., Jacobs, L. (1980). Improved Cookstoves for Rural Senegal. VITA, Arlington, Virginia.

FAO (1987). Wood Based Energy and Substitution Among Fuels in Africa. Forestry Department, U.N. Food and Agriculture Organization, Rome (unpublished).

Floor, W. (1988). "Why Bother About Household Energy?", in *Proceedings of the ESMAP Eastern and Southern Africa Household Energy Planning Seminar* (Harare, Zimbabwe, Feb. 1988), World Bank, Washington, D.C.

Floor, W. (1987). Household Energy in West Africa: Issues and Options. World Bank, Washington, D.C. (unpublished).

Foley, G. (1985). Exploring the Impact of Conventional Fuel Substitution on Woodfuel Demand, Earthscan Working Paper, London.

Foley, G., Moss, P. (1983). Improved Cooking Stoves in Developing Countries. Earthscan Working Paper, London.

French, D. (1981). Malawi Rural Energy Survey. Energy Unit, Ministry of Agriculture, Lilongwe, Malawi.

Government of Pakistan (1982). Housing Census of Pakistan 1980: Summary Results.

Government of Philippines (1982). Energy Sectoral Survey Series: 1979 Urban Household Energy Demand. Ministry of Energy, Manila.

Houghton, R.A., Schlesinger, W.H., Brown, S., Richards, J.F. (1985). "Carbon dioxide exchange between the atmosphere and terrestrial ecosystems", in *Atmospheric Carbon Dioxide and the Global Carbon Cycle,* U.S. Department of Energy, Washington, D.C.

Islam, I. (1986). Some Observations on Assessment of Biomass Fuel Resources. Paper to Technical Workshop of Biomass Resource Assessment Project, Commonwealth Secretariat (London, April 1986).

Islam, N.M. (1983). The Impact of Fuel Taxes in Thailand (draft). Faculty of Economics, Cambridge, England.

Islam, M.N. (1980). Village Resources Survey for the Assessment of Alternative Energy Technology. International Development Research Centre, Ottawa.

Joseph, S. (1987). "An Appraisal of the Impact of Improved Wood Stove Programmes: Synthesis of Experience", in *Stoves for People: Proceedings of International Workshop* (Guatemala, Oct. 1987), Foundation for Woodstove Dissemination, Utrecht, Netherlands.

Kohlmaier, G.H., Broehl, H., Fricke, R. (1986). The Biogenic Fuels: Fuelwood, Charcoal, Crop Residues and Animal Dung as a Net Source of Atmospheric Carbon Dioxide. Unpublished manuscript, Institut fuer Physikalische und Theoretische Chemie, J.W. Goethe Universitaet, Frankfurt.

Leach, G. (1988a). "Residential energy in the Third World", *Annual Review of Energy* 13:47-65.

Leach, G. (1988b). "Interfuel Substitution", in *Proceedings of the ESMAP Eastern and Southern Africa Household Energy Planning Seminar* (Harare, Zimbabwe, Feb. 1988), World Bank, Washington, D.C.

Leach, G. (1987). *Household Energy in South Asia.* London and New York: Elsevier Applied Science Publishers.

Leach, G., Mearns, R. (1988). *Beyond the Woodfuel Crisis: People, Land, and Trees in Africa.* London: Earthscan Publications.

Leach, G., Gowen, M. (1987). *Household Energy Handbook.* World Bank, Washington, D.C.

Lu, Y.Z. *et al.* (1987). The Study of China's Energy Utilization and Policies for Comparison with India: Annual Report of 1987. Institute for Techno-Economics and Energy System Analysis, Tsinghua University, Beijing.

Manibog, F. (1984). "Improved Cooking Stoves in Developing Countries: Problems and Opportunities." *Annual Review of Energy* 9: 199-277.

Masera, O.R., *et al.* (1989). *Energy Use Patterns and Social Differences: A Mexican Village Case Study.* International Development Research Centre, Ottawa, Canada.

de Montalembert, M.R., Clement, J. (1983). *Fuelwood Supplies in the Developing Countries.* Food and Agriculture Organization of the United Nations, Rome.

Morgan, W.B. (1983). Urban Demand: Studying the Commercial Organization of Woodfuel Supplies. Chapter in Woodfuel Survey, FAO, Rome.

Munslow, B. (1988). *The Fuelwood Trap: A Study of the SADCC Region.* London: Earthscan Publications.

Natarajan, I. (1986). Personal communication.

Natarajan, I. (1985). Domestic Fuel Survey with Special Reference to Kerosene. National Council of Applied Economic Research, New Delhi.

Nilsson, P. (1983). Support to Village Afforestation, Tanzania: Survey of Woodfuel Supply Needs. Institute of Resource Assessment, Dar es Salaam.

Nkonoki, S.R. (1983). The Energy Crisis of the Poor in Tanzania. Institute of Development Studies, Dar es Salaam.

O'Keefe, P., Raskin, P., Bernow, S. (1984). *Energy and Development in Kenya.* Stockholm: Beijer Institute.

Qiao, M. (1988). "Energy utilization in rural China", in *Proceedings of the Chinese-American Symposium on Energy Markets and the Future of Energy Demand* (Nanjing, June 1988), Lawrence Berkeley Laboratory, Nov. 1988.

Ramanathan, V. *et al.* (1987). "Climate-chemical interactions and effects of changing atmospheric trace gases", *Reviews of Geophysics* 25:1441-1482.

Reddy, A.K.N. (1987). On the Loss and Degradation of Tropical Forests. Indian Institute of Science, Bangalore.

Sathaye, J., Meyers, S. (1985). "Energy use in cities of the developing countries", *Annual Review of Energy* 10:109-133.

Sazama, G. (1986). Comparison of Urban Residential Energy Consumption Patterns in Costa Rica and India. University of Connecticut (unpublished).

Sharma, R.K., Bhatia, R.K. (1987). "Energy needs and the low-income groups in India", in *Energy Pricing Policies in Developing Countries*. International Labour Office, Geneva.

Skar, S.L., Samanez, N.A., Cotarma, S.G. (1982). Fuel Availability, Nutrition and Women's Work in Highland Peru. World Employment Research Program, Research Working Paper.

Skutsch, M. (1984). Why People Don't Plant Trees: The Socioeconomic Impacts of Existing Woodfuel Programs -- Village Case Studies, Tanzania. Resources for the Future, Washington, D.C.

Smil, V. (1988). *Energy in China's Modernization*. M.E. Sharpe, Inc., Armonk, New York.

Smith, K.R. (1989). Village Stoves and Climate Change: How Close the Connection? (draft), East-West Center, Honolulu, Hawaii.

Smith, K.R. (1987a). *Biofuels, Air Pollution, and Health: A Global Review*. Plenum: New York.

Smith, K.R. (1987b). The Dialectics of Improved Stoves. Presented at the 2nd International Workshop on Stove Dessemination (Antigua, Guatemala, Oct. 1987).

van Buren, A. (1984). Wood Fuel Commerce in Nicaragua. International Institute for Environment and Development, London.

Wardle, P.A., Pontecorvi, F. (1981). Special Enquiry on Fuelwood and Charcoal. Forestry Department, U.N. Food and Agriculture Organization, Rome (unpublished).

Weatherly, W.P. (1980). Environmental Assessment of the Rural Electrification I Project in Indonesia. U.S. Agency for International Development, Washington, D.C.

World Bank (1986). Test Results on Charcoal Stoves from Developing Countries. World Bank, Washington, D.C.

World Bank (1983). Senegal: Issues and Options in the Energy Sector. World Bank, Washington, D.C.

Yang, Y. (1987). Consumption of Fuelwood and Development of Forest Energy (translated). Presented at 3rd National Rural Energy Study Meeting, Beijing, Dec. 1987.