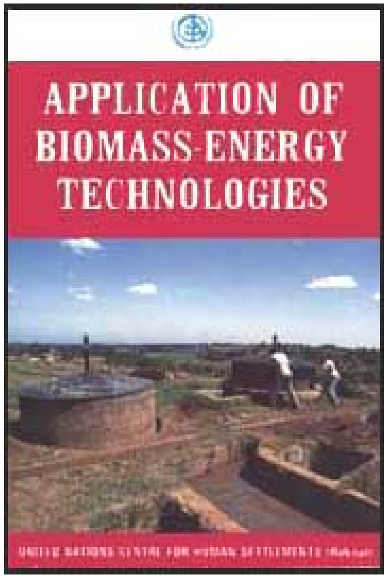

Application of biomass-energy technologies (1993) (Habitat)

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Foreword

The availability of energy and the security of its supply are of paramount importance to all human communities. Unfortunately, in most countries - both developed and developing current energy markets ignore the social and environmental costs and risks associated with fossil-fuel use. If externalities such as employment, import-substitution, energy security and environment are considered, then biomass systems compare very favourably with fossil-fuel systems.

Biomass currently accounts for about 14 per cent of the world's energy supply and is the most important source of energy for three quarters of the world's population living in developing countries. With increases in population and per capita demand, and depletion of fossil-fuel energy resources, the demand for biomass energy is expected to increase rapidly in developing countries. Even in developed countries, biomass is being increasingly used. For example, the United States of America now has 9000 MW of biomass power plants and Sweden, which derives 14 per cent of its energy from biomass has plans to increase it further as it phases down nuclear and fossil-fuel plants into the next century. With technologies available today, biomass can provide modem fuels such as electricity and liquid fuels, in addition to more traditional cooking fuels, and this energy can be produced and used in an environmentally sustainable manner, while emitting no net CO_2.

Yet. biomass energy continues to receive the lowest priority in energy planning in developing countries. Many factors contribute to this: the unreliability of production and consumption statistics; the uncertainty of production costs which are quite site-specific; its diverse sources and end-uses; and its interaction with land uses.

Integrating biomass energy in national energy planning and policy-making on an equal footing with other energy sources will not be easy and will require concerted action at national and sub-national levels. A reliable information base will have to be developed on the supply and utilization of biomass energy in the country; the policy environment must be made responsive to the needs of the biomass-energy sector, research, development and engineering efforts will have to be stepped up in required areas; and the commercialization of biomass technologies will have to be promoted through selective and well-targeted subsidies and fiscal and other forms of incentives.

These are some of the recommendations of an Expert Group Meeting recently organized by UNCHS (Habitat) to promote commercialization of biomass technologies in developing countries. The present publication brings together, in an edited form, the contributions of several eminent experts commissioned by the Centre on different biomass-energy technologies. The publication forms a part of the Centre's continuing efforts to promote wide dissemination and commercialization of renewable energy technologies - an area of expressed concern in chapter 7 of Agenda 21 on sustainable human settlements development. I am confident that the case studies presented in this report and the policy options suggested in the light of these experiences will prove useful to policy-makers, researchers and potential entrepreneurs.

UNCHS (Habitat) acknowledges the contributions of Professor D.O. Hall, Dr. B.K. Kaale, Dr. S. Karekezi and Dr. N.K. Ravindranath in the preparation of this publication.

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Introduction

Biomass is considered to be one of the key renewable energy resources of the future at both small- and large-scale levels (Johansson et al, 1992). It already supplies 14 per cent of the world's energy, and the many future projects being assessed, if implemented, could increase the role of biomass in the overall energy system. On average, biomass produces 38 per cent of the primary energy in developing countries (90 per cent in some countries), where it is the largest single energy source. Biomass energy is likely to remain an important global energy source in developing countries well into the next century. A number of developed countries also use biomass quite substantially, e.g., the United States of America which derives 4 per cent of its total energy from biomass (nearly as much as it derives from nuclear power), Sweden 14 per cent and Austria 10 per cent (Hall et al, 1992b).

Biomass is generally and wrongly regarded as a low-status fuel, and rarely finds its way into energy statistics. Nevertheless, biomass can lay claim to being considered as a renewable equivalent to fossil fuels. It offers considerable flexibility of fuel supply due to the range and diversity of fuels which can be produced (Jones, 1989). It can be converted into liquid and gaseous fuels and to electricity via gas turbines; it can also serve as a feedstock for direct combustion in modern devices, ranging from very-small-scale domestic boilers to multi-megawatt size power plants.

Biomass-energy systems can increase the energy available for economic development without contributing to the greenhouse effect since biomass is not a net emitter of CO_2 to the atmosphere when it is produced and used sustainably. It also has other benign environmental attributes such as lower sulphur and NO_X emissions and can help rehabilitate degraded lands. There is a growing recognition that the use of biomass energy in larger commercial systems based on sustainable, already accumulated resources and residues can help improve natural resource management (Hall and Rosillo-Calle, 1991).

A. The need for modernization

Despite its wide use, biomass is usually used so inefficiently that only a small percentage of useful energy is obtained. The overall energy efficiency in traditional use is only about 5-15 per cent, and biomass is often less convenient to use compared with fossil fuels. It can also be a health hazard in some circumstances, for example, cooking stoves can release particulates, CO, NO_X formaldehyde, and other organic compounds in poorly ventilated homes, often far exceeding recommended WHO levels (Smith, 1987b). Furthermore, the traditional uses of biomass energy, i.e., burning animal dung and crop residues, are often associated with the increasing scarcity of hand-gathered wood, nutrient depletion, and the problems of deforestation and desertification (UNCHS, 1990). In the early 1980s, almost 1.3 billion people met their fuelwood needs by depleting wood reserves (WRI, 1988), whilst the worldwide impact of burning dung is estimated to reduce grain production by 20 Mt annually due to loss of fertilising capacity (Myers, 1984).

There is an enormous biomass potential that can be tapped by improving the utilization of existing resources and by increasing plant productivity. Bioenergy can be modernized through the application of advanced technology to convert raw biomass into modem, easy-to-use energy carriers (such as electricity, liquid or gaseous fuels, or processed solid fuels). Therefore, much more useful energy could be extracted from biomass than at present. This could bring very significant social and economic benefits to both rural and urban areas. The present lack of access to convenient energy sources limits the quality of life of millions of people throughout the world, particularly in rural areas of developing countries. Since biomass is the single most important energy resource in these areas its use should be enhanced to provide for increasing energy needs (Smith, 1987a). Growing biomass is a rural, labour-intensive activity, and can, therefore, create jobs in rural areas and help stem rural-to-urban migration, whilst, at the same time, providing convenient energy carriers to help promote other rural industries.

Enhanced biomass availability on a sustainable basis requires support and development of new biomass systems in which production, conversion and utilization are performed efficiently in an environmentally sustainable manner. Efforts to modernize biomass energy should concentrate on those applications for which there are favourable prospects of rapid market development, e.g., biogas, the generation of electricity from residues and biomass plantations through the gasifier/dual-fuel engines route or using advanced gas turbines fired by gasified biomass, and the production of alcohol fuels from sugarcane (Williams, 1989).

B. Experience from case studies

Over the last 20 years there have been numerous proclamations of failure and success of biomass schemes and projects. Much of the criticism has been warranted and has certainly helped focus attention on such projects' shortcomings and often uncritical acceptance. The designation "successful" to a project must be seen as relative to past failures and it does not imply that all components of a project are acceptable for any specific programme. Ideally, a successful biomass programme should show sustainability, replicability and flexibility, multiple benefits, and should also be economic when all costs and benefits, particularly the externalities, are considered.

The socio-economic and technological implications of the use of biomass technologies have been considered in this publication through several case studies. In most cases, the relevant authors have had long-term direct experience of evaluation at the local, national and international levels. Only such case studies have been selected for this publication where economic data are available in disaggregated form or the projects had been operating for a reasonable period, extending over at least several years. Particular attention has been paid to the modern attributes of biomass and to the opportunities for upgrading biomass production and use, highlighting the under-utilized biomass energy potential.

I. Woodfuel production technologies

A. Introduction

Woodfuel accounts for about 10 per cent of the total energy used in the world. It provides about 20 per cent of all energy used in Asia and Latin America, and about

50 per cent of total energy used in Africa (Arnold, 1991, Murray and De Montalembert, 1992). However, it is the major source of energy , in particular for domestic purposes, in poor developing countries: in 22 countries, woodfuel accounted for 2549 per cent, in 17 countries, 50-74 per cent, and in 26 countries, 75-100 per cent of their respective national energy consumption (UNCHS, 1984).

More than half of the total wood harvested in the world is used as woodfuel (Eckholm, 1976). For specific countries, for example, the United Republic of Tanzania, the contribution can be as high as 97 per cent (Mnzava 1990).

Although woodfuel is the major source of energy for most rural and low-income people in the developing world, the potential supply of woodfuel is dwindling rapidly, leading to scarcity of energy and environmental degradation (UNCHS, 1990). It is estimated that, for more than a third of the world population, the real energy crisis is the daily scramble to obtain woodfuel to meet domestic use (Eckholm, 1975).

Current studies on woodfuel supply in developing countries have concluded that woodfuel scarcities are real and will continue to exist, unless appropriate approaches to resource management are undertaken (Arnold, 1991, SADCC Energy Sector 1992b). The increase of woodfuel production through efficient techniques, can, therefore, be considered as one of the major pre-requisites for attaining sustainable development in developing countries.

The following paragraphs describe the main points of case studies on woodfuel technologies which were conducted in eight Southern African countries, namely, Botswana, Lesotho, Malawi, Mozambique, Swaziland, the United Republic of Tanzania, Zambia and Zimbabwe.

B. Botswana

Botswana has a land area of 582,000 sq km. The most distinctive characteristic of the land is its aridity, with unreliable rains. The population of Botswana in 1991 was estimated to be around 1,370,000 with an average annual growth rate of 3.3 per cent. Over 90 per cent of the population depend on natural woodlands for fuelwood and poles. In the eastern part of the country, where most of the population is concentrated, woodfuel supplies are being rapidly depleted, with some areas experiencing acute woodfuel scarcity.

The main woodfuel production technologies used in Botswana include: establishment of woodlots by the Government and NGOs, individual tree planting, and management of the existing natural forest.

1. Establishment of woodlots

Establishment of community woodlots was introduced in 1970 and implemented mainly by the Forestry Unit, with financial support from the United States Agency for International Development (USAID). The main objective was to produce woodfuel and poles. The woodlots were supposed to be run by village development committees. However, there was little participation by villagers, and hence the method failed. Some of the reasons attributed to the failure of the community woodlots are: undefined distribution of the endproducts from the woodlots; lack of proper extension services to support the establishment of the woodlots; lack of experience by the local people on growing exotic species; and lack of short-term benefits to villagers commensurate with their efforts (Walker, 1990).

2. Individual tree growing

The Government and NGOs are encouraging individual tree growing through agroforestry. By the end of 1991, there were 12 government and seven NGO nurseries, which raised, in total, 300,000 seedlings for sale to individuals. Government nurseries supply mainly exotic species like eucalyptus species, while NGO nurseries tend to supply more indigenous species and fruit trees. The number of planted trees nationwide is low due to drought and the unavailability of seedlings. This has made many people in Botswana conclude that management of natural woodlands, rather than planting of trees, is the only realistic option for supplying people with woodfuel and other forest products.

3. Management of natural woodlands

Walker (1990) reported that, in the past, local chiefs were very successful in managing natural woodlands in Botswana Conservation was encouraged through the deliberate use of existing taboos and beliefs. For example, the widespread belief that heifers belonging to persons responsible for cutting indigenous species, would only produce male calves was used to ensure such species were not cut.

After independence, the powers of chiefs in many areas were delegated to government officers who had little interest in managing the natural woodlands, thus leading to uncontrolled clearing of natural woodlands.

4. Role of NGOs in woodfuel production

NGOs have been more active in promoting and implementing tree-growing activities than the Government due to an acute shortage of official forestry staff.

An NGO, the Forestry Association of Botswana (FAB), has been leading in conducting forestry research on suitable woodfuel species, establishment of tree nurseries in rural areas, management of natural woodlands and creation of mass-awareness on the need to sustain tree-growing and environmental protection at the local level. FAB has also been involved in formulating the National Conservation Strategy of Botswana In addition, it has lobbied hard to influence national forestry policies and create awareness to the urgent need to strengthen the Forestry Unit in the Ministry of Agriculture.

C. Lesotho

Lesotho is a land locked country in the middle of the Republic of South Africa It has a total surface area of 30,350 square kilometres. The population of Lesotho in 1992 was estimated to be 1.9 million people with an average annual growth rate of 2.6 per cent (SADCC Energy Sector, 1992b)

Lesotho is largely a tree-less country, with no natural forest land other than shrub land. By mid- 1992, the total area planted with trees, through individual, school, and government woodlots was estimated to be around 20,000 ha, or 0.66 per cent of the country land area of which, only 9 per cent is suitable for permanent arable agriculture. About 80 per cent of the land is used as rangelands.

No individual or organization can own land in Lesotho, but people can acquire the right to use a piece of land for a specific purpose and for a specific time under customary law. The free grazing on agricultural fields after crop harvest make tree-growing by individual farmers almost impossible (Hall and Green, 1989).

Biomass fuels account for 88 per cent of the total energy consumed in Lesotho (in the rural areas, the proportion approaches 95 per cent), coal, paraffin, LPG and electricity accounting for the remaining 12 per cent. The main biomass fuels used and their contribution to the total national energy balance are: woodfuel, 62 per cent (mainly from shrubs), animal dung, 20 per cent and crop residues 6 per cent (MWEML, 1991).

The main woodfuel production technologies used in Lesotho are the establishment of woodlots and individual planting.

1. The Lesotho Woodlot Project (LOOP)

After the failures of a village tree-planting scheme of the 1940s, intensive establishment of woodlots for woodfuel and poles production was started again in 1973, when the Lesotho Woodlot Project was commenced by a private company, Anglo de Beers Forest Services Lesotho Ltd. The Overseas Development Administration (ODA) joined the LWP as a donor in 1974. The same year, the World Food Programme (WFP) provided additional support to the LWP through "food for work" (Green, 1990).

By the end of 1991, an area of about 10,250 ha of woodlots had been established in over 350 sites, as Government Forest Reserves. Some of the woodlots have now reached maturity. However, the Forestry Division is having problems selling wood from the mature woodlots due to the inaccessibility of the woodlots by trucks and lack of proper plans on how to sell the woodfuel. Furthermore, funds for re-establishing harvested woodlots are not available from local sources.

2. Individual tree-planting

The Lesotho Energy Master Plan of 1988 indicated that the country was experiencing acute energy scarcity for the household sector. To provide energy to the household sector, the Plan recommended that at least an equivalent of 7500 ha of woodlots be planted annually. To achieve this target, individual tree-planting on a participatory basis was emphasized. However, as stated earlier, due to uncontrolled grazing on crop land after harvesting, it has been difficult for individuals to grow trees on farmland successfully.

D. Malawi

Malawi, located in Southern Africa, has a total surface area of 119,140 square kilometres of which 20 per cent is water. According to the 1987 population census, the population of Malawi was 8.0 million people, with an average growth rate of 3.2 per cent

The country is divided into three administrative regions, the Southern Region, the Central Region and the Northern Region. Rapid population growth has created severe land pressure in the Southern and Central Regions, where deforestation caused by expansion of agriculture land and the supply of poles and woodfuel is reported to be high.

Woodfuel for about 93 per cent of the total energy used in the country. Due to the high share of woodfuel in the energy balance of Malawi, efforts have been initiated to sustain woodfuel production.

The main woodfuel technologies used include establishment of rural woodfuel projects, of large-scale plantations, government and individual tree nurseries, demonstration woodlots combined with research, individual tree-planting programmes, conservation of natural forests and provision of bonus for surviving planes.

1. The Rural Fuelwood Project

The first government project to address the problem of woodfuel scarcity in Malawi, the Rural Fuelwood Project, was started in 1976. It was funded by the Government of Malawi with additional funds from a British Government grant. The main objective of the project was to establish plantations for woodfuel and poles production.

To facilitate selection of appropriate tree species, the country was divided into eight silvicultural zones. Successfully growing species in each zone were surveyed, documented and disseminated to extension workers. Research on suitable woodfuel species continued as a routine forestry activity.

In addition, another project, the Rural Fuelwood and Poles Research Project was also started. The long-term objective of the project was to provide the basic silvicultural information in order to promote rural afforestation for the sustained production of woodfuel and poles and to provide shade, fodder and soil improvement. It was financed by the Government of Malawi and the International Development Research Centre (IDRC) of Canada, which provided a grant of $Can500,000.

A total of 93 experimental plots were established at 73 sites in seven silvicultural zones. Of these, 48 sites were on communal lands used for grazing or denuded hill slopes, 20 on individual farmer's land and the remaining five in government forest reserves, as a safety measure against losses on the other sites.

Communal lands for establishing the trial plots were obtained through negotiations with chics and village headmen. Land in individual farms was obtained through negotiation with farmers, involving both wife and husband.

Paid labour was used for establishing and protecting the trial plots with some assistance from the community and individuals. The end-products of the trees belonged to those who had provided land, but they were not allowed to cut the trees without prior approval of forestry officers.

The project gave the following positive results:

- Support and land for tree-growing were obtained from the community and individual farmers because they had been consulted.
- It provided on-farm demonstration to farmers on the methods to grow trees and establish woodlots.
- It provided income to rural people, through employment by the project.
- It provided woodfuel, poles and local environmental protection.
- It provided some knowledge and experience of suitable exotic tree species for the areas covered by the trials.

2. The Malawi Wood Energy Project

The first large-scale woodfuel project in Malawi was the Wood Energy Project. which was started in 1979 with a World Bank loan of $US 10 million, and expanded in December 1986 with another World Bank loan of $US16.7 million. The main objective of the Project was to establish and develop a sustainable wood production programme to meet the current and future demands for woodfuel and construction poles, while conserving and ameliorating the natural forests and the environment. It aimed at increasing woodfuel production through government and private initiatives, enhance the economic utilization of woodfuels through the promotion of energy-efficient technologies, and improving natural ecosystems by offering efficient protection and management of the indigenous forests.

In the first phase, a total of 88 central-government nurseries were established by the end of 1988 which provided seedlings for establishing large-scale woodfuel plantations as well as for selling to farmers at a subsidized price.

By that time, a total of 15,000 ha of woodfuel plantations had been established by the Forestry Department using paid labour. The plantations were established close to urban centres, mainly in Lilongwe and Blantyre cities, with the main objective of providing woodfuel at affordable prices to urban low-income groups.

However, the first phase of the project proved to be a failure as, inspire of heavy subsidies, few farmers could afford the purchase of seedlings. Secondly, most of the farmers who planted trees indicated that their main objective was to produce poles for sale and for house construction and not for woodfuel. As long as free woodfuel was available from customary land forests, people did not feel compelled to plant trees except for sale.

The government woodfuel plantations under the monoculture production system proved to be very expensive, technically and financially.

Yields were low for most plantations: a mean annual increment of 4.6 m^3 per ha per annum was obtained against a planned increment of 10 m^3/ha/annum at a rotation of seven years. The plantations supplied less than 1 per cent of the wood consumed hence their contributions were insignificant.

These observations tend to suggest that large-scale plantations run by governments, might not be the best option for woodfuel production. On the other hand, tree-planting by the private sector, NGOs and the people themselves in participatory efforts appeared to be the most cost-effective way of growing woodfuel. However, the method required a catalytic support from the Government, through extension services and formulation of policies and laws which would promote and protect the interest of individual tree growers.

Wood from indigenous forests was regarded as a free commodity. To put a value to the wood, a pricing policy of woodfuel from indigenous forests was introduced, mainly to cover the cost of re-establishment of the trees (Nkaonja, 1990).

Lessons reamed from the first phase of the project and those collected by a special unit on social aspects related to woodfuel production were utilized in the implementation of phase two of the project started in 1987. The main differences between the two phases were:

- Less emphasis was placed in the second phase on large-scale government plantations and the main emphasis was directed towards tree-growing by the private sector on a participatory and sustainable system. The role of the Government and other funding agencies was limited to catalytic support.

- Small-scale farmers were encouraged to grow trees based on agroforestry practices.

- Large-scale tobacco farmers were encouraged to establish woodlots or woodfuel plantations to provide wood for tobacco curing.

- To intensify provision of extension services, the Malawi Forestry College and the Forestry Research Institute were strengthened, mainly through worker development. The key role of women in forestry development was emphasized. To enhance this key role, female student dormitories were constructed at the Malawi Forestry College to facilitate enrolment of female students.

- The private sector and individual farmers were encouraged to establish small-scale tree nurseries. Efforts were also made by the Government to decentralize its nurseries in order to locate them closer to the people. The 88 nurseries started under phase one were maintained and 60 new ones were added. Seedlings continued to be sold to farmers at a subsidized price and a wider range of species was raised in order to meet farmers' needs.

- To encourage and intensify proper protection and management of trees planted on farms and school compounds, a bonus system of about $US0.03 per surviving tree after two years was introduced. To qualify for the bonus, a farmer had to plant more that 100 trees. The bonus system had the main impacts of providing intermediate financial returns to the farmers whilst awaiting the financial benefits from the full rotation of the tree crops and reduced government costs of growing woodfuel through large-scale plantations, as the private-sector production costs were considerably lower.

- To enhance effective control and management of natural forests, chiefs requested the Government to reserve their communal natural forests. Once they had been reserved, the local people were not allowed to collect woodfuel from the forests without a permit. This decision enabled the area under Forest Department control to increase from 980,00 ha to 3.7 million ha.

3. The Blantyre City Woodfuel Plantation

The first phase of the Blantyre City Woodfuel Plantation Project was started in 1986 and was completed in 1991. It was funded by Norway with a grant of $US6,540,000. The main objective of the project was to manage an area of 65,000 ha of natural forest for the sustainable supply of woodfuel and poles. To fulfil the objective, woodfuel plantations were established in areas with low biomass potential, while management of existing natural woodlands was intensified (SADCC Forestry Sector, 1988; Chiyenda et al, 1989). By the end of 1991, a total of 6350 ha of woodfuel plantation was already established, mainly with eucalyptus species. However, the average productivity per hectare is reported to have been lower than predicted. In addition, the Forestry Division had no comprehensive plan on how to harvest and manage the plantation on a sustainable basis (SADCC Energy Sector, 1992a). NORAD, therefore, provided further financial and technical assistance to work out a system of harvesting and sustaining the project, based on local resources. Establishment of the plantations provided employment to over 4000 workers of whom 20 per cent were women.

4. Individual tree-planting programmes

The National Tree Planting Day Programme. The Programme was started in 1976 with the main objective of intensifying individual tree-growing. It is commemorated annually on 21 December, which is a public holiday for tree-planting. The average annual number of trees planted by this Programme is about 25 million (SADCC Energy Sector, 1992a).

The Carlsberg Brewery Company Tree Planting Programme. The company sponsors two tree seedlings for each bottle top of Carlsberg beer collected by tree growers. Through this system, the company supported the planting of 4 million trees in 1988 and 7 million trees in 1989. Although current figures are not available, the company's contributions to tree-growing is reported to be expanding progressively every year (Nkaonja, 1990).

E. Mozambique

Mozambique has a land area of 799,380 km² and is located in Southern Africa The population of Mozambique in 1990 was estimated to be around 15.7 million with an average annual growth rate of 2.6 per cent (Pereira, 1990).

Woodfuel accounts for more than 80 per cent of the total energy consumed in Mozambique and for about 95 per cent of the total energy used for domestic purposes.

Due to low population density, there is enough woodfuel resources to meet local demand from existing natural forests and woodlands. The annual demand of woodfuel is estimated at 16 million m³ while the annual potential supply is above 35 million m³. However, most of the forests are not accessible to the people due to civil war, which is, consequently, creating localized woodfuel scarcities, particularly around the cities. To enhance the supply of woodfuel to the majority of the low-income people, the Government has established large-scale urban woodfuel plantations in Maputo, Beira and Nampula.

1. Establishment of large-scale urban woodfuel plantations

Between the financial years 1978/79 and 1987/88 a total of 7892 ha of woodfuel plantations were established in Maputo (3696 ha), Beira (3231 ha) and Nampula (965 ha). The total costs of establishing the plantations were 1007 million meticais as the local component provided by the Government of Mozambique and $US4974 million, provided by NORAD as a grant.

The main objective of the plantations was to produce woodfuel and poles. The annual total planting target for the three towns were 1500 ha Hence, between the periods 1978/79 and 1987/88 a total of 15,000 ha should have been planted, but, in fact, only 7892 ha were planted due to shortage of a skilled and experienced workforce.

2. Individual tree-planting

In 1982, the Government, with the support of the mass media, launched a campaign of planting at least I million trees annually by individuals, for woodfuel, shade and fruits. In 1986, a campaign was launched in Maputo with its suburbs to plant ornamental trees around houses and along streets.

In 1985, the pert-urban dwellers of the main towns of Mozambique were encouraged to plant trees on agroforestry principles to intensify their subsistence farming. Nurseries were established to provide seedlings for individual tree-planting. In addition, farmers are planting trees so as to increase the value of their land.

3. NGOs' support in individual tree-planting

The Canadian University Service Overseas (CUSO) is assisting farmers in individual treeplanting in Chokwe. They are conducting extension services, helping in raising multipurpose tree species and encouraging farmers to conserve indigenous trees on farmland. Their budget for the period 1987 to 1992 was estimated to be $US1.9 million. Treeplanting is also taking place in Umbeluzi with NGO support.

F. Swaziland

Swaziland, covering an area of 17,364 square kilometres, is land-locked between the Republic of South Africa and Mozambique. The census of 1986 estimated the population of Swaziland to be 676,000 with an average annual growth rate of 3.2 per cent.

There are two distinct systems of land tenure in Swaziland: the Swazi National Land (SNL), which is communally-owned and occupies 57 per cent of the total land area, and the Individual Tenure Farms (ITF) which can be bought and sold freely by Swazi citizens.

Woodfuel accounts for about 50 per cent of the total energy used in Swaziland. At the national level, 64 per cent of households use woodfuel exclusively for cooking and heating. However, for the rural areas, the proportion of households depending entirely on woodfuel for cooking and heating is over 91 per cent. Main sources of woodfuel for households are indigenous forests and trees on agriculture land, in particular black wattle which flourishes well in both the SNL and the ITF. It is estimated that black wattle covers about 7500 ha, of which 5000 ha are on the SNL with an average productivity of 6 m^3/ha/year as compared to a productivity of 18 m^3/ha/year on the ITF due to intensive management in the latter.

Swaziland also has more than 102,000 ha of intensively-managed industrial plantations for the production of woodpulp and saw-timber which also produce an estimated 150,000 tons of wood- waste annually. A proportion of this waste is used for the generation of electricity and the rest is either collected for household woodfuel by those who have access to the plantation, or burned or left to rot in the forest.

Localized woodfuel scarcities in the SNL, mainly due to population pressure, are being experienced and it is reported to be expanding rapidly (Magumba, 1990). For this reason, the Government of Swaziland has initiated tree-growing and environmental protection programmes.

The main woodfuel technologies employed in Swaziland include raising of seedlings in centralized government nurseries, establishment of community woodlots and encouragement of individual tree-growing.

1. Establishment of nurseries

Centralized government nurseries have been established by the Forestry Department for raising seedlings, primarily for the community and individual woodlots on the SNL. The woodlots are expected to produce woodfuel and poles as well as contribute to soil conservation. Seedlings are issued free of charge and technical expertise is provided by extension workers on the establishment and management of tree crops.

Community woodlots are established under the supervision of local chiefs and their society, through participatory efforts. The chief nominates a special village committee to select sites for woodlots and mobilize people for the establishment, protection and tending of the woodlots. Eucalyptus trees are generally grown for a rotation period of five to eight years under a coppicing system. Mahlangatsha village has managed to establish a 155 ha eucalyptus woodlot, which is currently generating income to the village through sale of poles and woodfuel.

In spite of the encouraging success of the Mahlangatsha village project, Magumba (1990) reported that establishment of community woodlots is experiencing the following problems:

- Most people are not enthusiastic about community woodlot projects and they would prefer individual tree-planting.

- Individual farmers sometimes take trees for planting (as they are issued free) but do not plant them, due to pressure on farming, leaving the trees to dry up in their backyards.

  Villagers believe that trees are self-regenerating entities which do not require weeding or fertilization. In some areas, they expect establishment of woodlots to be the Government's responsibility, using paid labour as for demonstration plots.

- Protection of woodlots from grazing animals by fencing is the greatest problem with community woodlots. Where fencing is not done by the Government a local NGO or donor agency, then the chance of trees surviving in community woodlots is almost zero.

Learning from models of best practices and intensification of extension services are, however, expected to enhance the successful establishment of woodlots with individual tree-planting being emphasized.

2. NGO and donor support

Magumba (1990) reported that the Council of Swaziland Churches was the first NGO in Swaziland to support tree-growing efforts. Its support, which started in 1989, includes introduction of tree-growing and establishment of tree nurseries in schools, provision of funds for establishing tree nurseries in rural areas and fencing materials for community woodlots.

The main donors supporting woodfuel production and environmental protection in Swaziland are: the Food and Agriculture Organization of the United Nations (FAO) which provided funds for conducting an inventory of indigenous forests and on how to improve their management which was conducted in 1986, and the German Association for Technical Cooperation (GTZ) which is supporting household woodfuel-consumption surveys and inventories of existing potential of black wattle for producing woodfuel.

According to Magumba (1990) and the SADCC Energy Sector (1992a), the main constraints in woodfuel production in Swaziland are:

- Critical shortage of a trained workforce.

- Lack of an integrated land-use plan for the SNL which would have effectively combined forestry, livestock and agriculture, and ensured sustainable land management and economic growth.

- Lack of knowledge of suitable woodfuel species with multi-purpose uses.

- Low priority accorded to forestry and tree-growing in rural areas within the total development system of the country.

- Lack of comprehensive multi-sectorial policies and strategies for enhancing coordination between sectors, NGOs and donors dealing with land-use planning, agriculture, forestry, livestock and environmental protection.

G. United Republic of Tanzania

The United Republic of Tanzania is located in East Africa and, based on a 1988 census, its population was estimated to be around 25.3 million in 1992 with an annual growth rate of 2.8 per cent.

Woodfuel is the principal source of energy, quantitatively accounting for 91 per cent of the total energy consumed. The dependency on woodfuel is expected to continue for the foreseeable future but the supply of woodfuel potential is dwindling in all regions.

Since the welfare of the people of Tanzania depends, to a large extent, on the sustainable management of its land resources, the Government has accorded high priority to the production of woodfuel and to environmental protection (MWEMT, 1991).

The main woodfuel-production technologies used include establishment of communal woodlots, combination of land reclamation with woodfuel production, central and individual nurseries, use of cuttings and self-germinating seedlings, individual tree-planting based on agroforestry, intensification of women involvement in the programmes, adoption of a multisectorial approach and monitoring of past efforts in order to learn from models of best practices.

1. Establishment of communal village woodlots

Considerations of woodfuel as a major source of energy and the need to sustain its production started in 1967, when the Government adopted a policy with a major emphasis on rural development. In 1968, regional tree-planting efforts were started in all regions with seedlings being raised in government nurseries and issued free to villages for establishing communal woodlots for woodfuel production. Exotic species were planted, based on the availability of seeds and ease of raising seedlings.

Village governments set aside land for establishing communal woodlot and provided free labour for land preparation and planting the trees. However, after planting, most village governments did not tend or protect the woodlots from grazing animals which led to mass failures (Mnzava, 1983).

Research on arid zone afforestation to find suitable tree species for woodfuel was initiated in 1970 with SIDA financial and technical assistance. Trial plots, which consist mainly of exotic species, are now the main sources of seeds to farmers.

2. Combination of land reclamation with woodfuel production

In 1973, the first large-scale National Soil Conservation Project (Hifadhi Ardhi Dodoma HADO) was started, with the objectives of reclaiming eroded land and producing woodfuel. It was jointly funded by the government of the United Republic of Tanzania and SIDA.

The main activities of the project in the initial phase were soil conservation, establishment of woodlots and encouragement of people to plant trees on farmland for environmental conservation and for woodfuel.

Achievements attained in the initial 10 years of project implementation were:

Establishment of woodlots. A total of 2624 ha of woodlots were established as demonstration areas to villagers on growing trees and on Land conservation.

Individual tree-planting. A total of 3.4 million seedlings were distributed to individual farmers for planting on their farms.

Conservation of natural woodlands. After 10 years, the project area of 114,000 ha was satisfactorily covered with shrubs, small trees and grass. Due to this success it was decided to allow villagers to collect fodder and dead wood from the area for fuelwood.

The success of HADO encouraged other regions to initiate similar land-reclamation programmes. In addition, a second phase of HADO, based on a multi-sectorial management team, has been initiated with the main objective of integrating forestry, agriculture, livestock and environmental protection as a sound Land-use system for the project area.

3. Monitoring of tree-growing efforts and learning from models of best practices

In 1981 a small community forestry unit was established by the Forestry Division to monitor and disseminate models of best tree-growing practices in the United Republic of Tanzania and in other African countries. The main impacts of the unit to woodfuel production include:

- On-going systematic monitoring and follow-up of tree-growing efforts in the regions which were initiated in 1981. Data on seedlings distribution, field survival rates and technologies used for growing trees are collected, analysed and lessons learned communicated back to tree-growers to facilitate sharing of field experiences.

- A national mass awareness campaign on tree-growing and environmental protection is being conducted in order to cover grass root problems adequately.

- Sociological studies on farmers' needs for tree-growing and analysis of traditional methods for growing trees were conducted in 1982/83 with FAO assistance (FAO, 1984; Mnzava, 1983; Mascarenhas et al, 1983).

- The first Tanzania Five Year National Village Afforestation Plan 1982/83 to 1986/87 was compiled in 1983 (Kaale, 1983) which emphasised the need to give high priority to individual and school tree-growing. It also emphasized the need to intensify management of natural forests and adoption of a multi-sectorial approach in implementing woodfuel production programmes.

4. The Shinyanga region soil conservation project (HASHI)

The project was stated in 1986 with the Government and NGOs providing catalytic support in terms of finance and technical assistance. The bulk of the project activities are undertaken by village governments and individuals on a self-reliance basis. Between 1987 and 1989 the HASHI project distributed 2.1 million seedlings from forest nurseries to 113 villages for individual planting on farm lands (Mnzava, 1990).

5. Establishment of nurseries

Tree seedlings are raised in a few government nurseries, located close to water reservoirs and distributed to individual farmers and schools. Self-germinating trees and shrubs on farmland are protected by farmers and are assisted to grow through weeding and mulching. Through this system, millions of self-germinated trees are now available on farmlands.

Individual farmers are also planting trees for shade by using wildings obtained from pioneer species which were planted in some villages a few years ago through a World Bank-funded project. The existing trees also provide seeds for direct sowing on farm land.

Cuttings are widely planted as shade trees and as fence for animal kraals; however' et the end they are used for woodfuel.

6. Intensifying women's role in tree-planting

To intensify tree-planting by women, the project associates women in its village treeplanting. The project facilitates Women Organisation branches in their mobility for implementing development programmes like child health care, clean water and treeplanting. Through this catalytic support, women's organizations in Shinyanga have become effective extension agents and more importantly, they understand the role of trees in their society and how to promote treegrowing, by utilizing local knowledge.

7. Management of natural woodlands

The main actions taken include exclusion of livestock, restricted tree-cutting and eradication of wild fires to encourage natural regeneration. By the end of 1989, village governments had set aside 26,285 ha of natural forests for conservation. Customary laws and beliefs are used for protecting the forests (Mnzava, 1990).

8. Woodlots

Woodlots have been established on a few strategic areas by the Forest Department for demonstration purposes and for testing the performance of new tree species. Between 1987 and 1989 a total of 410 ha of woodlots were established. Government institutions, such as prisons and schools, have also established woodlots for meeting their own woodfuel demand.

9. Tree-planting by individual farmers

Provided with appropriate opportunities, individual tree-planting has proved to be an important contributor to woodfuel supply and environmental protection in the Babati district. Instead of concentrating trees in one area, as with plantations or woodlots, individual planting has facilitated to scatter trees over a large area, consequently enhancing supply of woodfuel close to consumers and improving the macro climate. Due to people's participation, costs of establishment and protection are very low as compared to woodlots or plantations. Women and children play a major part in tending and protecting trees, during farming and grazing.

10. Individual tree -planting in Bashnet village

Bashnet village is one of the few villages in the semi-arid zone of Tanzania which has managed to grow trees and meet its demand for woodfuel and poles from individually planted trees.

Successes were achieved with the initial planters, and the number of villagers growing black wattle increased slowly. By 1960, it had picked up involving the whole village community. Currently each household has a black wattle plot, sufficient to supply its needs of fuelwood and building materials.

H. Zambia

Zambia, located in Southern Africa, has an areas of 750,614 sq km, with flat topography, except for isolated hills and hill ranges. In 1990, its population was estimated to be about 8,120,000 with an average annual growth rate of 3.7 per cent. About 44 per cent of the population live in urban areas. More than 95 per cent of Zambian households depend on woodfuel as their major source of domestic energy (Akapelwa, 1990).

It is estimated that 55 per cent of Zambia's land is covered with forests and woodlands. The supply of woodfuel is therefore high, but scarcities are experienced in areas with high population densities, in particular around cities with Lusaka being the worst affected area (Chidumayo, 1989). Efforts have, therefore, been initiated to increase the supply of woodfuel in deficit areas.

The main woodfuel-production technologies used are: establishment of woodfuel plantations, intensive research on suitable species for woodfuel, individual tree-planting based on agroforestry, establishment of woodlots by commercial farmers and management of natural forests. NGOs and donor agencies are both active in supporting on-going initiatives.

1. Woodfuel plantations

In 1976, establishment of 6000 ha of rural plantations for production of poles and woodfuel was started in the Copperbelt Province and a few other places, with a loan of $US5 million from the World Bank. Species planted were mainly eucalyptus (Akapelwa, 1990).

In 1978, an attempt to start a large-scale woodfuel plantation for Lusaka with a target of 7500 ha had failed due to lack of donor assistance. Nonetheless, through local resources, a total of 100 ha was established by the end of 1991 (SADCC Energy Sector, 1992a).

2. Research on suitable woodfuel species

Intensive research on suitable woodfuel species was started in 1984 with a grant from the International Development Research Centre (IDRC) of Canada A total of 13 different eucalyptus species, 38 acacia species, and various Leucaena leucocephala species were tried at four sites. This has provided useful information on suitable tree species for woodfuel and poles production (Akapelwa, 1990).

3. Individual tree-planting

Individual tree-planting on agroforestry principles is encouraged, with financial and technical assistance from the International Committee for Research in Agroforestry (ICRAF). On-going activities include: identification of tree species suitable for agroforestry, development of suitable agroforestry techniques and transferring these techniques to farmers.

4. National Tree Planting Day programme

A large number of trees are planted by individuals during the National Tree Planting Day (15 December) and during the national tree-planting month which is between 15 December and 15 January. For example, between 1985/86 and 1988/89, a total of 2.8 million trees was planted although the target was to plant 20 million trees annually. The shortfall is attributed to a shortage of seedlings from government nurseries.

NGOs and donor agencies are contributing effectively to tree-growing efforts in Zambia. The Children's Christian Fund, based in Lusaka, has been actively engaged in individual tree-planting at Katuba and in the pert-urban of Lusaka. For example, in 1989, the Fund managed to plant about 10,000 trees. Other donors supporting tree-growing programmes include SIDA, IDRC, the Commonwealth Development Corporation (CDC) and DANIDA.

5. Establishment of woodlots

Commercial farmers in Zambia, especially tobacco and coffee farmers, have formed a "Commercial Farmers Bureau" for tree-growing. Tobacco farmers in Choma and Kalomo districts have established woodlots of eucalyptus species, for curing Virginia tobacco, of sizes ranging between 10 and 30 ha Coffee farmers have planted trees as wind breaks.

6. Management of natural woodlands

Management of natural woodlands is practiced by the Forestry Department in gazetted forest reserves, through early burning at the start or mid of the dry season (April - July). Early burning results in a patchy burn and lower fuel loads, which prevent the occurrence of extensive and destructive heat, consequently promoting biomass regeneration (Akapelwa, 1990). Outside the forest reserves, there is little management by the public. Chidumayo (1989) and Akapelwa (1990) strongly urge that more emphasis be given to the management of existing natural forests and woodlands which is a pre-requisite for sustaining woodfuel supply and environmental protection in Zambia.

I. Zimbabwe

Zimbabwe, situated in Southern Africa, has a total area of 391,000 square kilometres and its population in 1991 was estimated by Moyo et al (1991) to be around 10 million, with an average annual growth rate of 3.0 per cent. About 22 per cent of the population live in urban areas.

Makoni (1990) reported that woodfuel accounts for 85 per cent of household energy consumption and for about 40 per cent of all energy consumed in Zimbabwe. However, the supply of woodfuel is dwindling rapidly in particular in the communal land, consequently creating localized woodfuel scarcities.

Land use in Zimbabwe is divided into three main sectors, namely, communal land, commercial farms and urban areas. Production of woodfuel takes place in the first two sectors.

Communal lands constitute 42 per cent of the total land and is used by more than 60 per cent of the total population. Communal lands are located in semi-arid to arid areas with poor soils such as in the provinces of Masvingo, Matebeleland North, Matebeleland South and Midlands. As the land is communally owned, individual farmers can cultivate but not sell the land. Communal free- grazing is also practiced, which has contributed to serious overstocking. Scarcity of woodfuel in Zimbabwe is mainly confined to the communal lands, due to population pressure and poor soil fertility. Also, it is estimated that between 70,000 and 100,000 ha of woodlands are cleared for agricultural expansion annually (Moyo et al 1991).

Commercial farms constitute 43 per cent of the total land area They are located in the best fertile lands and their average size is about 2500 ha per farm. They are normally self-sufficient in energy supply including woodfuel.

The Government of Zimbabwe, like those of many other developing countries, has initiated tree-growing programmes for woodfuel and environmental protection.

1. The Zimbabwe Rural Afforestation Project

The initial main government effort in tree-growing for woodfuel and environmental protection in Zimbabwe was the Rural Afforestation Project, Phase one. It was implemented between 1983 and 1989 with a total budget of $Zim 17.4 million (about $US7.31 million) from the World Bank and executed by the Forestry Commission. The project had the following major components:

- Establishment of centralized nurseries for seedling production;
- Establishment of demonstration and trial woodlots;
- Establishment of woodlots in the communal lands;
- Establishment of block plantations in urban and rural areas.

Nurseries were successfully established and seedlings produced according to targets. However, costs were very high, when compared with those of NGOs and school nurseries.

Demonstration trial woodlots of 5 ha in size, were established close to most nurseries. The objective was to demonstrate to farmers the rotational practices of the species tried. However, farmers were not prepared to establish such woodlots or to practice fixed rotations.

Establishment of woodlots in communal land through participatory efforts was not successful either. Farmers were required to establish small woodlots of 750 trees (0.5 ha) each but most of them were keen to plant only a few trees on farmland and not to establish woodlots, partly due to land scarcity.

Establishment of block plantations also proved to be very expensive and as a result the target of establishing a total of 1400 ha was not attained.

Some of the basic weaknesses of the initial planning of the project were:

- It was based mainly on paid labour with little people's participation; Local knowledge on tree-growing and possible interventions for meeting rural and urban woodfuel needs were not considered in detail;
- The multiple use of tree products and people's needs were ignored, the project concentrating only on woodfuel;
- Central nurseries were expensive due to the need to construct supportive infrastructure, and the cost of distributing seedlings over long distances;
- Growing of indigenous species was ignored in favour of exotic species;

The whole project suffered from a rigid conception that was not sufficiently based on actual socio-economic situation of the target population.

According to Makoni (1990), the main constraints experienced in implementing the phase one were:

- Lack of an experienced workforce for implementing woodfuel programmes.
- Inadequate extension services to farmers;
- Land shortage for establishing woodlots in the communal lands;
- Grazing problems on woodlots and planted trees on farm lands;
- Lack of a knowledge of suitable tree species for the different ecological zones of the country.

Nevertheless, the experience gained from the project provided a better opportunity for implementing future projects more successfully.

Phase two of the project was initiated by encouraging the following: individual treeplanting on agroforestry principles; establishment of small local nurseries in villages or schools or by individual farmers; establishment of pilot schemes in forest and grazing management; consideration of local knowledge on tree growing, farmers' needs and growing of multi-purpose trees including indigenous species; and adoption of a multisectorial approach in planning and implementing the project.

2. Catalytic assistance from NGOs

NGOs in Zimbabwe have been active and instrumental in the development of afforestation activities in the rural areas. They provide materials for establishing individual nurseries and individual tree-growing on agroforestry principles, conduct courses, workshops and seminars on tree-growing, establish woodlots and provide management of natural woodlands. They also conduct research on indigenous species for woodfuel and identification of indigenous technical knowledge on tree growing and management of forests.

1. Analysis of the case studies 1. Introduction

The case studies show the existence of several common features and constraints related to woodfuel production. Several of these features are also common to the other biomassenergy technologies described in this report and are examined at the end of the report. Here, only features relevant to woodfuel-production technologies are examined.

2. Supply-side constraints

(a) Understanding the woodfuel problem

Lack of knowledge of the supply potential of woodfuel and the rate of its depletion is a major constraint. Without reliable data on the supply potential, it is difficult to understand the dynamics of the woodfuel-production process.

(b) Lack of knowledge of means to sustain woodfuel supply

Efforts to sustain woodfuel supply started in the mid-1970s. This task was given to foresters, but they had little experience on how to sustain tree crops in farmland and rangelands. The means for sustaining woodfuel supply are, therefore, only being developed through trial and error.

(c) Lack of knowledge of suitable specks

To meet the farmers' needs for growing trees, a wide range of species for the different ecological zones has to be tested and proven appropriate, before they are given to farmers to grow them on a wide scale. Unfortunately, knowledge on appropriate species is lacking, particularly for indigenous species, as past research efforts concentrated only on exotic species. Furthermore, research results of the few species studied are not yet widely disseminated which thus inhibits sharing of experiences and learning from models of best practices.

(d) Land-tenure problems

In many countries, land tenure is based on undefined traditional laws and rules. Management of woodlands under communal land tenure thus tends to be problematic, in particular where such efforts are not initiated by the local people themselves.

(e) Termites and drought attacks

In the arid and semi-arid ecological zones, drought and termites attacks on planted trees are a problem, particularly with exotic species. Termite- and drought-resistant species are, therefore, urgently needed.

(f) Shortage of seeds

Seeds of species appropriate for woodfuel and agroforestry are in short supply. In addition, many of the desired species have low seed viability and require special storage facilities. Seed collection and distribution centres for woodfuel species are not yet established, except for a few NGOs which are assisting in seed collection and distribution.

(g) Lack of knowledge on traditional methods of growing indigenous trees species

The main reason why foresters concentrate on exotic species is their lack of knowledge on how to grow most of the indigenous species. This is leading to a loss of genetic resources, and a risk of losing the planted trees in the event of a disease or insect epidermic.

(h) Lack of emphasis on management of natural forests

Tree growing in arid and semi-arid climatic zones is difficult. For these areas, effective management of the indigenous natural forests is a pre-requisite for sustaining woodfuel supply. This is lacking in most countries.

(i) Lack of harvesting and marketing plans for urban woodfuel plantations

In most cases, only establishment plans have been developed for urban woodfuel plantations. Harvesting and marketing plans are not yet developed. As a result, foresters experience problems in selling woodfuel from the few maturing urban plantations.

3. Demand-side constraints

The demand-side constraints refer to those factors which prevent people obtaining wood from supply sources. These are, mainly, inaccessibility, privatization, unaffordability and low security.

(a) Inaccessibility

Natural forests and large-scale timber plantations, which could contribute to woodfuel production, are located far from many users' reach, in particular beyond their walking distance. Inaccessibility, therefore, limits the contribution of these potential woodfuel supply sources to the community.

(b) Privatization

Granting of land-tenure rights to individuals, in particular large-scale farmers, privatize large areas which were formerly the main sources of wood to surrounding villagers and landless people. In many cases, collection of woodfuel from private farms is prohibited and protected by law. It is therefore, not an uncommon phenomenon, to find under-utilized woodfuel resources in private farms, while the majority of the surrounding population experiences woodfuel scarcity.

K. Conclusions

The following can be concluded from the case studies.

Woodfuel is the main source of energy, but its supply potential is dwindling rapidly, locking people into a vicious circle of energy scarcity, poverty, soil deterioration and environmental degradation.

Efforts have been initiated in all the countries to increase woodfuel production using technologies appropriate to local conditions. The most successful and sustained technologies which also used local initiatives are: tree nurseries run by individuals, school and NGOs; tree planting by individuals on agroforestry; woodlots established by commercial farmers and government institutions; and management of communal natural forests through traditional laws and beliefs.

Production technologies which were not very successful were communal woodlots, which were unsuccessful due to villagers' unwillingness to have to tend and protect them from grazing animals, and large-scale woodfuel plantations, which proved to be too expensive to establish.

The contributions of donors and NGOs in woodfuel production have been significant. However, use of wrong production technologies has often minimized their impact: sharing of field experiences from different models of best practices of woodfuel production could enhance the success of future projects.

Finally, sustainability of woodfuel production, which is a pre-requisite for enhancing overall sustainable development, relies upon active people's participation, where production of woodfuel is part and parcel of their daily development efforts, just as for food crops. NGOs, Government and donors' catalytic support are however, instrumental for enhancing people's efforts. Arnold (1991) stated that, the desired condition is that of active participation of the local people, with external involvement being of a supportive rather than management nature.

II. Improved charcoal production

A. Introduction

Charcoal is an important household fuel and to a lesser extent, industrial fuel in many developing countries. It is mainly used in the urban areas where its ease of storage, high energy content (30 MJ/kg as compared with 15 MJ/kg few woodfuel), lower levels of smoke emissions, and, resistance to insect attacks make it more attractive than woodfuel. In the United Republic of Tanzania, charcoal accounts for an estimated 90 per cent (round wood equivalent basis) of biofuels consumed in urban centres (World Bank, 1988).

The production of charcoal spans a wide range of technologies from simple and rudimentary earth kilos to complex, large-capacity charcoal retorts. The various production techniques produce charcoal of varying quality. Improved charcoal production technologies are largely aimed at attaining increases in the net volume of charcoal produced as well as at enhancing the quality characteristics of charcoal. Typical characteristics of good-quality charcoal are shown in table 1.

Table 1. Typical characteristics of good-quality charcoal

Characteristics

Ash content	5 per cent
Fixed carbon content	75 per cent
Volatiles content	20 per cent
Bulk density	250-300 kg/m³
Physical characteristics	Moderately friable

Efforts to improve charcoal production are largely aimed at optimizing the above characteristics at the lowest possible investment and labour cost while maintaining a high production volume and weight ratios with respect to the wood feedstock.

The production and distribution of charcoal consist of seven major stages:

1. Preparation of wood

2. Drying - reduction of moisture content

3. Pre-carbonization - reduction of volatiles content

4. Carbonization - further reduction of volatiles content

5. End of carbonization - increasing the carbon content

6. Cooling and stabilization of charcoal

7. Storing, packing, transport, distribution and sale

The first stage consists of collection and preparation of wood, the principal raw material. For small-scale and informal charcoal makers, charcoal production is an off-peak activity that is carried out intermittently to bring in extra cash. Consequently, for them, preparation of the wood for charcoal production consists of simply stacking odd branches and sticks either cleared from farms or collected from nearby woodlands. Little time is invested in the preparation of the wood. The stacking may, however, assist in drying the wood which reduces moisture content thus facilitating the carbonization process.

More sophisticated charcoal production systems entail additional wood preparation, such as debarking the wood to reduce the ash content of the charcoal produced. It is estimated that wood which is not debarked produces charcoal with an ash content of almost 30 per cent. Debarking reduces the ash content to between I and 5 per cent which improves the combustion characteristics of the charcoal.

The second stage of charcoal production is carried out at temperatures ranging from 110 to 220 degrees Celsius. This stage consists mainly of reducing the water content by first removing the water stored in the wood pores then the water found in the cell walls of wood and finally chemically-bound water.

The third stage takes place at higher temperatures of about 170 to 300 degrees and is often called the pre-carbonization stage. In this stage pyroligneous liquids in the form of methanol and acetic acids are expelled and a small amount of carbon monoxide and carbon dioxide is emitted (Fernandes, 1991).

The fourth stage occurs at 200 to 300 degrees where a substantial proportion of the light tars and pyroligneous acids are produced. The end of this stage produces charcoal which is in essence the carbonized residue of wood (Fernandes, 1991).

The fifth stage takes place at temperatures between 300 degrees and a maximum of about 500 degrees. This stage drives off the remaining volatiles and increases the carbon content of the charcoal.

The sixth stage involves cooling of charcoal for at least 24 hours to enhance its stability and reduce the possibility of spontaneous combustion.

The final seventh stage consists of removal of charcoal from the kiln, packing, transporting, bulk and retail sale to customers. The final stage is a vital component that affects the quality of the finally-delivered charcoal. Because of the fragility of charcoal, excessive handling and transporting over long distances can increase the amount of fines to about 40 per cent thus greatly reducing the value of the charcoal. Distribution in bags helps to limit the amount of fines produced in addition to providing a convenient measurable quantity for both retail and bulk sales.

Past efforts to improve charcoal production have largely focused on enhancing the efficiency of the combustion stages two to five through the design of new charcoal kilns. The improved charcoal kilns can be broadly classified into five categories, namely:

1. Earth kilns

2. Metal kilns

3. Brick kilns

4. Cement or masonry kilns

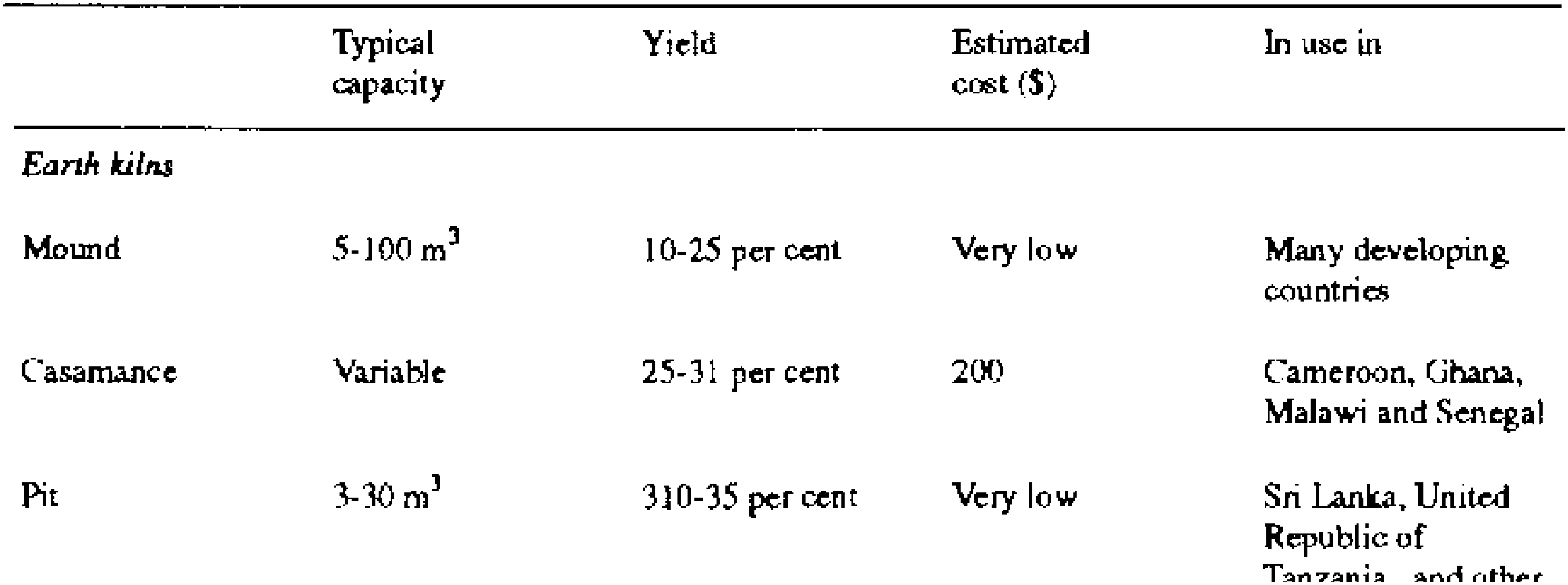
5. Retort kilns

The above categories are differentiated mainly by the technical sophistication and investment costs of the different kilns. The categories range from the rudimentary and low-cost earth kiln which is widely used in many developing countries to high-cost retort kilns, which in addition to charcoal, produces other valuable by-products. The main characteristics of the each of the five categories of kilns are given in table 2.

Suitable designs are available for the itinerant small-scale charcoal producers and large-scale industrialists who require the charcoal for steel production as in the case of Brazil where, in 1987, an estimated 7 million tons of charcoal were used to produce 35 per cent of local pig iron (Abracave, n.d., and Fernandes, 1991). Investment costs vary with the sophistication of the technology used but even simple designs such as the brick kilns and oil-drum kilns can be upgraded to large-scale complex charcoal production through the simultaneous installation and operation of a battery of kilns.

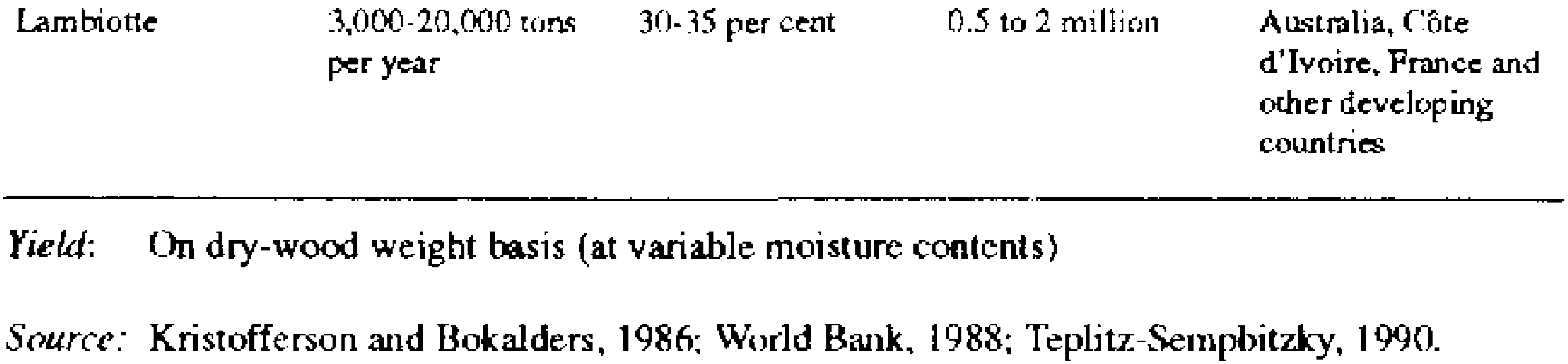
Retort kilns common in the developed world before and during the Second World War were used to produce a wide range of charcoal by-products that included acetic acid, methanol and tar. One of the largest retorts was operating in Pemery, France, in 1947 and had a capacity of 20,000 tons per year of charcoal. With the advent of the petro-chemical industry that was able to produce at much lower cost many of the chemicals previously produced by retorts, many of the large-scale retort operations have now been discontinued. The last known large-scale installation, closed in the late 1970s, was in Wundowie, Australia and had a capacity of 35 tons of charcoal per day (Fernandes, 1991).

In addition to cost, there are some general characteristics that differentiate the above five categories of charcoal production. The more complex designs are less labour intensive and include semi-automated operations. In addition, by-products in the high-cost designs are often as important, and sometimes more important than, the charcoal produced. The low-cost simpler designs are mostly found in developing countries where labour is abundant while the high-cost designs are mainly found in developed countries.



	Typical capacity	Yield	Estimated cost ($)	In use in
Earth kilns				
Mound	5-100 m^3	10-25 per cent	Very low	Many developing countries
Casamance	Variable	25-31 per cent	200	Cameroon, Ghana, Malawi and Senegal
Pit	3-30 m^3	310-35 per cent	Very low	Sri Lanka, United Republic of Tanzania, and other

				developing countries
Metal kilns				
Mark V	300-400 kg	20-25 per cent	2000 to 5000	Uganda
Oil drum	12-15 kg	23-28 per cent	Low	Kenya, the Philippines
Brick kilns				
Beehive and half-orange	9-45 m^3	25-35 per cent	150 to 1500	Argentina, Brazil and Malawi
Cement or masonry kilns				
Katugo	70 m^3	25-30 per cent	8000	Uganda
Missouri	350 m^3	25-33 per cent	15000	United States of America and other developed countries
Retort kilns				
Cornell	1-3 tons	22-33 per cent	40000	Norway and other developed countries (smaller prototypes tried in Ghana and Zambia)



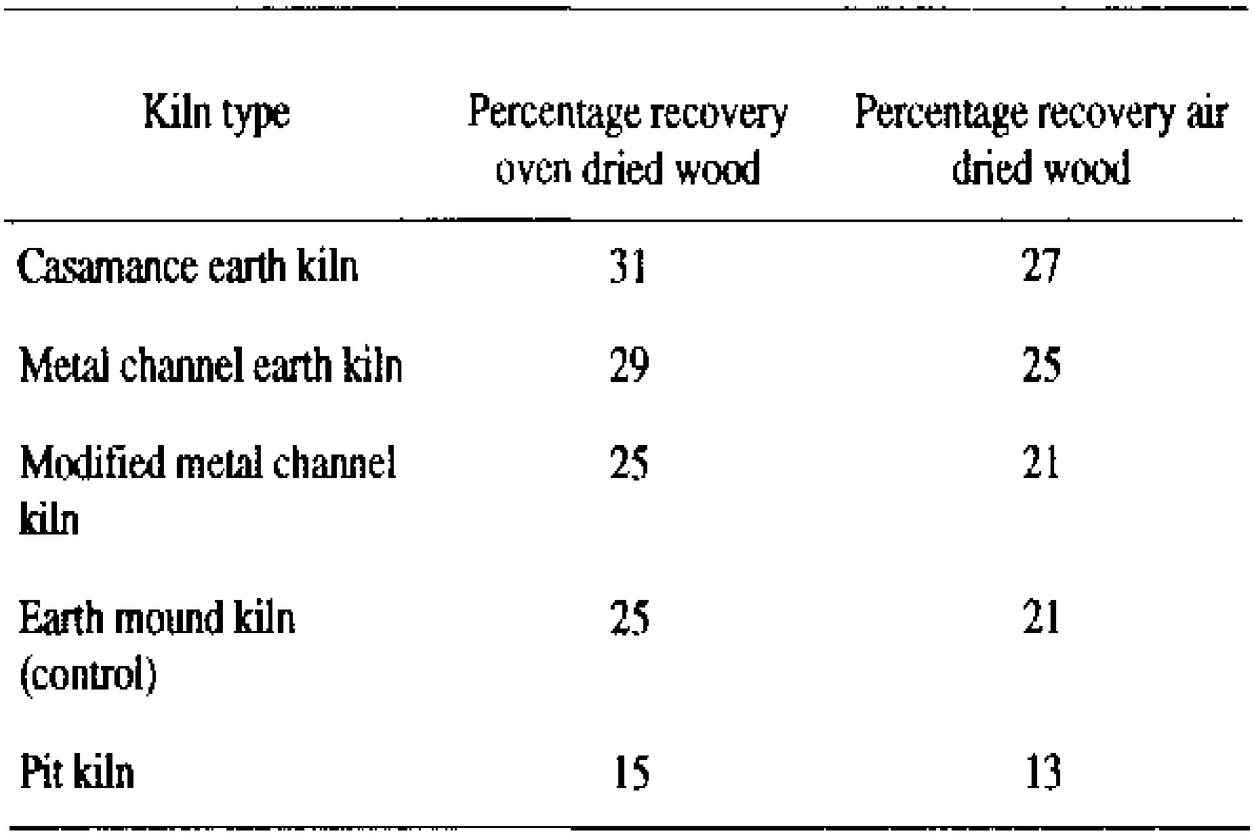
Lambiotte	3,000-20,000 tons per year	30-35 per cent	0.5 to 2 million	Australia, Côte d'Ivoire, France and other developing countries

Yield: On dry-wood weight basis (at variable moisture contents)

Source: Kristofferson and Bokalders, 1986; World Bank, 1988; Teplitz-Sempbitzky, 1990.

Table 2. Main characteristics of various categories of charcoal kilns

While most of the low-cost improved charcoal kilns have demonstrated high efficiencies under test conditions, none of the developed designs have attained substantive dissemination, largely because of the nature of charcoal production in many developing countries and the surprisingly high efficiency of traditional kilns under field conditions. Initially thought to be a grossly inefficient technology, a 1984/85 study in Sudan indicated that the efficiency of the traditional earth kiln is comparable with improved brick and metal portable kilns (Tebicke, 1991). A comparative study of five different kiln types showed that with the exception of the pit kiln, traditional kilns can attain similar levels of performance to improved metal kilns (World Bank, 1988) as shown in table 3.



Kiln type	Percentage recovery oven dried wood	Percentage recovery air dried wood
Casamance earth kiln	31	27
Metal channel earth kiln	29	25
Modified metal channel kiln	25	21
Earth mound kiln (control)	25	21
Pit kiln	15	13

Table 3. Conversion efficiencies of earth and pit kilns

This is also confirmed in the previous table on charcoal production technology which shows that there is no clear demarcation between the various designs in terms of yield. The critical factors appear to be operational and supervisional skill and moisture content of the utilized wood (Teplitz-Sempbitzky, 1990). The presence of a chimney that ensures optimum draught conditions also appears to be important.

The quality of charcoal, however, differs significantly since the more complex systems allow more elaborate control of combustion characteristics. The quality of charcoal is not as important in developing countries where it is largely used as a household fuel. Charcoal quality is, however, a crucial issue when it is used for industrial purposes such as the manufacture of steel or for tobacco drying and cement manufacture.

A large proportion of charcoal production in developing countries is carried out as a semi-illegal part-time activity since the wood used is often illegally procured. Consequently, few charcoal makers are willing to make the investment required by improved charcoal kilns are they willing to construct in-situ kilns since they would be vulnerable to punitive official measures such as imposition of tax and seizure. Consequently, dissemination of improved charcoal techniques to the informal sector has proved to be a difficult undertaking. Improved charcoal production technologies have proved more successful in areas where production is undertaken on a commercialized basis as in the case of Malawi, as shown in the case study below.

B. The Malawi Charcoal Project

The Malawi Charcoal Project started in 1986 as part of a World Bank-financed credit for restructuring the wood-industries sector. In 1989, the project was continued as a component of the Phase 2 of the Malawi Wood Energy Project discussed in chapter II. The project was under the auspices of the Forestry Department and technical assistance was provided by a German consulting firm, Interdisziplinaere Project Consult. The principal objectives of the Malawi Charcoal Project were to:

- Develop and improve the utilization of waste and surplus production in forestry plantations for charcoal production;
- Commercialize and privatize on-going charcoal production activities within forest plantations;
- Undertake wide-scale dissemination of improved charcoal production and utilization technologies.

One of the first activities undertaken by the project was the selection of an appropriate charcoal production system. After careful review of a wide range of options, the project adopted a half-orange kiln design which is widely used in Argentina and Brazil.

With a diameter of 3.5 m and an effective capacity of about 13.3 m^3, the half-orange kilns were mainly made of fired bricks and clay soil plus a steel bar for the door frame. The total cost of the kiln in 1988 was $US150. The performance of these kilos yield an estimated efficiency by weight of 31.2 per cent with a feedstock of average moisture content of 20 per cent. With mainly pine and cypress logs of an average diameter of 20 cm and a density of about 250 kg per square metre, the typical production cycle lasted about 70 hours with cooling accounting for 30 hours.

The softwood charcoal produced by the kilns was found to be satisfactory with a fixed carbon content of 85 per cent and an ash content of 3 per cent.

The most important factors that determined the quality of the charcoal were found to be moisture content of the feedstock and the skill level of operators. The quality of output was satisfactory when the kilns were worked by operators who had, at least, between three to six months of training and practical experience.

After detailed assessment of the various investment options, the project selected a production system consisting of the following:

14 half-orange kilos

4 ox-carts

7 pairs of oxen

1 charcoal store water tanks and tools

In 1988, the total investment cost of the above model production centre was Malawi kwacha (MK) 25,000 (1 $US = MK 2.5 in 1989). The total charcoal output of the centre was 1000 tons per year with a feedstock of about 13,300 m^3. The centre's site was selected to allow access to a catchment area of about 1000 hectares using ox-carts for transporting wood to the charcoal kilns. Labour costs were based on a piece-rate system to provide an incentive to increase production. About 10 work-days were needed to process I metric ton of charcoal which worked out to a total of MK 35 per ton of charcoal inclusive of the cost of feedstock extraction and transport. The total production cost of charcoal at Viphya amounted to MK 90 per ton (about $US36 per ton) which is comparable with costs in other African countries. (A World Bank mission estimated that in 1987, the production cost of a ton of charcoal in the United Republic of Tanzania was about $US30 (World Bank, 1988).)

One of the key strategic concerns of the promoters of the project was to determine the optimum pricing policy for the Viphya charcoal. Three options were considered: (a) to set the charcoal price on the basis of prevailing fuelwood stumpage rates; (b) to price the charcoal on the basis of replacement costs of the feedstock used; or (c) to base the price on prevailing prices of traditional hardwood charcoal. The first and second options were considered unrealistic because the production circumstances of plantation fuelwood were significantly different and replacement costs were not relevant since the Viphya charcoal was made from wood waste. Consequently, the price of traditional hardwood charcoal provided the benchmark for determining the price of the Viphya charcoal.

A uniform stumpage fee for Viphya thinning was used to avoid the administrative complexities associated with a discriminatory stumpage fee that would differentiate the charcoal by the profit margin realized at the point of sale. The collection of the stumpage fee was on the basis of capacity to encourage optimum utilization of existing installations. The other options, namely, collecting the stumpage fee on the basis of per unit of output; sales commission; unit of input; and profit were found to be too cumbersome and complicated to administer.

At MK 285 per ton, the landed cost of Viphya charcoal was competitive with that of traditional hardwood charcoal (MK 265-290 per ton) and the locally available coal (MK290 per ton). The distinctive feature of the cost structure is the importance of the cost of transport which accounts for about 70 per cent of the total landed cost. (The cost structure of charcoal in Dar-es-Salaam showed similar characteristics with the transportation accounting for close to 60 per cent of total landed cost (World Bank, 1988).)

This has important implications for energy policy since it is often assumed that traditional fuels provide an independent source of energy but clearly in the case of charcoal, access and pricing of petroleum fuels - imported in most parts of the region - are crucial determining factors.

C. Charcoal markets

The project initially targeted potential industrial markets because a review of existing industrial fuel consumption had shown a substantial use of coal and diesel oil: 25 large-scale users of fuel consuming 39,900 tons of coal and 473 tons of diesel oil per year (IPC, 1988). Coal could be substituted by charcoal and combustion trials were undertaken at Portland Cement Limited, the country's sole manufacturer of cement. Findings of the tests indicated that a blend of 83 per cent coal and 17 per cent charcoal could be realized without incurring any significant operational problems. With the planned expansion of the cement factory, use of charcoal was expected to reach 10,000 tons per year but, to date, the expansion of the factory has not taken place.

Other industries that used coal were interested in converting their boilers to charcoal and steam boilers alone could use about 13,000 tons of charcoal per year. This potentially large market did not materialize as quickly as expected because of the necessity of costly modifications to existing installations required for optimum use of charcoal. The estimated cost of modifications ranged from $US3000 to $5000 and many of the industrial consumers were not willing to incur the added cost.

The tobacco agricultural which, in 1986, accounted for over half of Malawi's export earnings, appeared to be an attractive marketing outlet for the Viphya charcoal. The total fuelwood consumption for curing of tobacco was estimated to be about 300,000 tons in 1986. About 40 per cent of the required fuelwood was derived from existing plantations, and the tobacco farming community was finding it increasingly difficult to procure the balance of its fuelwood requirements.

The project therefore, undertook several field tests to assess the suitability of softwood charcoal from the Viphya forest plantation. Field tests were undertaken in the 1988/89 curing season and involved the processing of 275 barn loads. The average specific fuel consumption was 2.91 kg of charcoal per kg of processed tobacco. The field tests also demonstrated that the implementation of several modifications and improvements could reduce specific fuel consumption by 60 per cent. Most of the improvements were aimed at ensuring more stable combustion conditions and more effective control of secondary air.

The field tests revealed several interesting findings. First, the introduction of a fan realized smaller savings than was originally expected. Secondly, the field test showed that the use of charcoal improved the quality of the final tobacco produced. This is largely due to the fact that control and monitoring of charcoal combustion is easier than controlling wood combustion which is a less homogeneous fuel. Poor control of wood fires leads to frequent temperatures fluctuations which adversely affects the quality of cured tobacco. The field tests showed that the use of charcoal could increase returns from the sale of cured tobacco by 20 per cent. The improvement in quality proved to be the most attractive characteristic of charcoal use for tobacco curing and concerned this agricultural subsector to be one of the most attractive market outlets for Viphya charcoal.

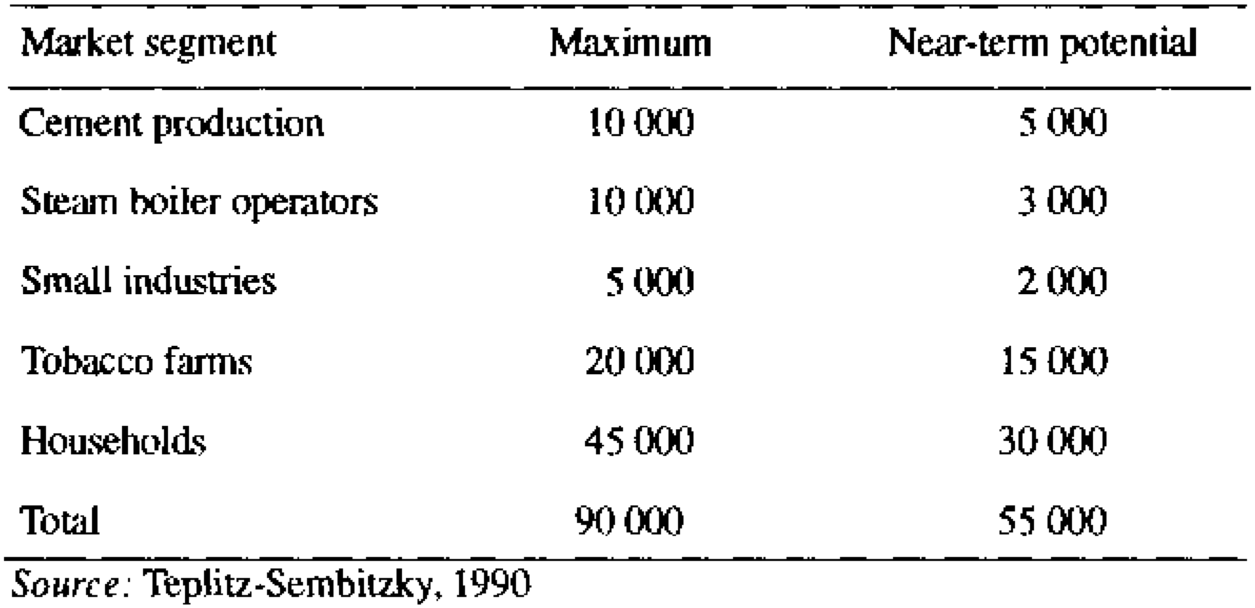
The other important market that was assessed by the Malawi Charcoal Project was the household sector. In the five major towns of Malawi, annual charcoal consumption was estimated to be 50,000 tons in 1989. Prices of hardwood charcoal had been rising partly as a result of increased population and the Forestry Department campaign to stop illegal charcoal production in 1987. As shown earlier, the average price of softwood charcoal from Viphya was competitive with that of traditional hardwood charcoal.

To reach the household market, the Project first eschewed the traditional charcoal marketing channels and established a new distribution channel. With the assistance of SEDOM, a local small enterprise development agency, the project selected 20 small-scale entrepreneurs for a trial marketing campaign. After a few months, this approach was found to be unsuccessful because the entrepreneurs charged high prices in attempt to realize very high profit margins.

Used to the generous subsidies from SEDOM, many of the selected business people not paying the project for the ordered supplies of charcoal although the credit period had been limited to 30 days.

The poor performance of the small-scale entrepreneurs was compounded by the scepticism of the public used to purchasing charcoal by volume. The lower bulk density of softwood charcoal led to complaints on the part of customers that more fuel was needed to cook. Complaints persisted even when project personnel stressed that the softwood charcoal was sold by weight rather than volume.

Nevertheless the Project was convinced that the market was there. The total potential market for softwood charcoal from industrial, tobacco farming and household sectors is shown in table 4.



Market segment	Maximum	Near-term potential
Cement production	10 000	5 000
Steam boiler operators	10 000	3 000
Small industries	5 000	2 000
Tobacco farms	20 000	15 000
Households	45 000	30 000
Total	90 000	55 000

Source: Teplitz-Sembitzky, 1990

Table 4. Potential markets for softwood charcoal (1990-1995) (tons per Year)

As a result of the lessons learned in the initial market test, the Project changed its marketing strategy and adopted a dual approach. The first was to target traditional charcoal distributors who would use the traditional marketing channels to distribute the softwood charcoal from Viphya so as to reach the low-income segment of the population. The second approach was to distribute charcoal in supermarkets and petrol stations in attractive packages aimed at reaching medium- and high-income groups. This strategy appeared to show more encouraging results.

D. Constraints

The key constraints that the Malawi Charcoal Project faced were: (a) the failure to establish an independent charcoal marketing system that worked in parallel with the traditional channels for distribution of hardwood charcoal; and (b) an under-estimation of the difficulties inherent in engineering fuel-switching particularly in the household sector.

To overcome these constraints, the Project developed innovative strategies and mechanisms which could assist future attempts to undertake large-scale charcoal production activities in the region. These innovative strategies are discussed in the following section.

E. Policy environment and role of the Government

Devising an enabling environment for the marketing of softwood charcoal proved particularly difficult because of the limited understanding of the biomass-energy sector in Malawi and, in particular, the very limited appreciation of the operations of the traditional hardwood charcoal sub-sector. For example, the Government attempt to ban illegal charcoal production was based on the premise that the ban could be effectively policed and administered. Initial results showed some signs of success but by the end of 1988, it was estimated that confiscated charcoal accounted for less than I per cent of the country's production of illegal hardwood charcoal.

In addition, the expected biomass energy crisis which had been based on overly simplistic modelling of woodfuel consumption trends in the country led policy-makers to believe that this would lead to increased scarcity which, in turn, would substantially increase prices thus setting the stage for the introduction of alternatives. In the event, prices of charcoal were largely determined by the fluctuations in the cost of transport, and, also, the expected scarcity of biofuels did not occur. The above policy gap was compounded by the non-existence of a national policy on solid fuels which could have set preferences and priorities for this important sub-sector.

The Project overcame the above constraints by undertaking a detailed assessment of the charcoal production-to-final-sale chain and paid special attention to variation in prices. This provided information to the Project that allowed the setting of an optimum pricing of softwood charcoal and the determining of the most appropriate production and marketing system. Effective use was made of shadow-pricing mechanisms using the price of hardwood charcoal as a reference. The adoption of a dual marketing approach that targeted both low-income and high-income households was particularly effective and provides a model marketing strategy that could be emulated in other countries of the region.

One of the shortfalls of the Malawi Charcoal Project was its location in a Government agency - the Forest Department - which had many other ongoing programmes (Wood Energy Project and Blantyre City Fuelwood Project) and was overburdened. This limited the effectiveness of the Project and had an adverse impact on attempts to involve the private sector, the subject of the next section.

F. Role of entrepreneurs and informal-sector artisans

By mid-1989, the Project had successfully contracted out 3000 tons of capacity per year to the private sector but a balance of 6500 tons per year was still with the Government. Although this was an encouraging development, the Project could have realized a higher level of success if the involvement of the private sector had been considered right from the initiation of the project.

Involvement of local entrepreneurs increases the chances of long-term sustainability and makes use of the limited pool of local capital. The Project underestimated the complexity and difficulty of involving local enterprises and left it until late in the Project. Early involvement of the private sector would have served to raise early interest and provided a convenient avenue for informing the local sector of the potential and opportunities that the production and marketing of softwood charcoal provided. Early involvement of local entrepreneurs and informal-sector artisans would have averted the Project's ill-fated attempt to set up an independent charcoal marketing channel that involved SEDOM entrepreneurs many of whom are retired civil servants long-accustomed to Government subsidies.

The Project has, however, demonstrated the viability of undertaking productive conversion of the substantial wood waste generated by wood industries and could be replicated in many developing countries having similar wood waste.

G. Local research initiatives and indigenous technical skills

Involvement of local research organizations was not significant as demonstrated by the fact that the testing of local charcoal was carried out by a German Frankfurt-based company, Degussa AG. This is likely to impair the development of local capacity which could adversely affect continuity.

The Project contributed to the development of local technical skills particularly with respect to production of softwood charcoal. As explained earlier, the skill of operators is one of the two most important determinants of charcoal production efficiency (the other being the water content of the feedstock). By 1989, the Project had trained over 100 skilled charcoal makers who are expected to form the core of a future softwood charcoal industry in Malawi.

H. Role of non-governmental organizations

There are few non-governmental organizations (NGOs) in Malawi and Government policy is not very supportive of NGO activity in the country. Consequently, local NGOs were not involved in the project. This led to limited general awareness of the Project among the population of Malawi and has constrained the dissemination of the lessons learned by the Project to a wider public.

I. Role of end-users

End-users were involved in a number of field trials but there appears to have been no attempt to involve consumer groups or reach various citizen groups. As a result, the Project was not able to predict and-users' response to softwood charcoal, with adverse consequences on its early marketing efforts.

J. External financial support and local credit and banking institutions

The Project was part of a World-Bank financed programme, and external financial support provided the initial funds for undertaking scheduled activities. There appears to have been limited efforts to involve local credit and banking institutions in the activities of the Project which may account for the almost total absence of local entrepreneurs in the initial phases of the Project.

III. Fuel-efficient cookstoves

A. The KCJ Project

One of the most successful urban stove projects in the world is the Kenya Ceramic Jiko (KCJ) initiative. Over 500,000 stoves of this new improved design have been produced and disseminated in Kenya since the mid-198Os (Davidson and Karekezi, 1991). Known as the Kenya Ceramic Jiko, KCJ for short, the improved stove is made of ceramic and metal components and is produced and marketed through the local informal sector. One of the key characteristics of this project was its ability to utilize the existing cookstove production and distribution system to produce and market the KCJ. Thus, the improved stove is fabricated and distributed by the same people who manufacture and sell the traditional stove design.

Another important feature of the Kenya stove project is that the KCJ design is not a radical departure from the traditional stove. The KCJ is, in essence, an incremental development from the traditional all-metal stove. It uses materials that are locally available and can be produced locally. In addition, the KCJ is well adapted to the cooking patterns of a large majority of Kenya's urban households. The KCJ design was not selected or identified at the onset of the stove programme but was arrived at through a series of iterative and dynamic research and development steps that involve a large number of individuals including existing artisans producing stoves; interested NGOs; government ministries; and research agencies.

In many respects, the KCJ project provides an ideal case study of how an improved stove project should be initiated and implemented. To obtain a comprehensive understanding of the KCJ initiative, an appreciation Kenya's household sector, the subject of the next section, is vital.

B. Traditional cookstoves

The vast majority of Kenya's population use three-stone hearths for cooking. Wood is the principal rural fuel, while charcoal is dominant in the urban household sub-sector. The most popular urban stove is the charcoal-burning traditional metal stove, TMS for short.

As with most East African countries, Kenya's urban population depends on charcoal as its primary source of household energy. Charcoal has several advantages over wood. It is easy to transport and to store and is also a commercial commodity, thus attracting efficient distributors. As far as the user is concerned, charcoal has the major advantage of being nearly smokeless. In addition, the metal stoves were quickly accepted by the more affluent members of several communities and this acceptance led to the general popularity in the urban areas.

The metal stoves were easy to fabricate and there was plenty of scrap metal for this purpose. Many more people learned to make the charcoal than could be used in the stoves. The success of the traditional metal charcoal stoves (see figure 1) can therefore be attributed to three main reasons. They were a new innovation; they generated an income for those involved in making them or producing fuel for them, and they used a more convenient and superior fuel (ITDG, 1986-1988).

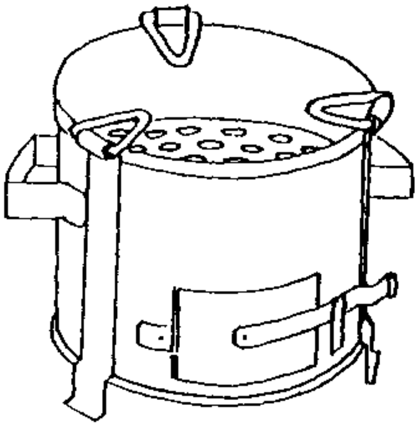


Figure 1. Traditional metal stove.

The Kenya traditional metal stove (TMS) is very similar to the traditional charcoal-burning metal sigiri of Uganda or the all-metal mbaula of Malawi and Zambia. It is made from scrap sheet metal obtained from discarded oil and bitumen drums or in some cases abandoned car body shells. The TMS has a cylindrical shape, three pot rests, three feet, two handles, a grate and an adjustable, hinged door. The TMS come in different sizes depending on the function they are expected to perform. Thus, while the average-sized TMS have a diameter of 27 cm and a height of 20 cm; larger TMSs are quite common. The 27 cm diameter TMS has a door measuring 5 cm high and 9 cm wide. The fire box and the ash box have depths of 8 cm and 7.5 cm, respectively.

About 19 per cent of the TMS's grate area is perforated. The TMS heat transfer efficiency been measured to be in the region of 15 to 20 per cent. Estimates of the lifespan of the TMS range from 6 to 12 months depending on the frequency of use and the gauge of scrap metal used in manufacture. TMS grates do not generally last for longer than six weeks.

There are several reasons for the low efficiency and short life span of the TMS. Direct contact between the TMS fire-box walls and glowing hot charcoal which may attain a temperature of 900 degrees Celsius quickly leads to rapid degradation of the stove. Sheet metal is a very poor heat insulator. As a result, TMSs lose a large amount of energy to the surrounding atmosphere, indicated by high wall temperatures. From a safety viewpoint, the high temperatures of the TMS walls are a hazard to the unwary and playful child.

In addition, the TMS does not have a good finish and is thus not very attractive.

TMSs are made by informal-sector artisans who establish their temporary manufacturing stalls near areas of high population concentration. These artisans can be found in most towns and market places of the country. The largest stove production and marketing centre in Kenya is found at Shauri Moyo, which is located about 3 km from the centre of the city of Nairobi.

In addition to TMSs, the artisans make a variety of household products that include pots, buckets and suitcases. These items are made from scrap metal. Competition for access to scrap metal has increased prices significantly. Scrap metal is no longer perceived to be waste; it is now a valuable and expensive raw material. Depending on its condition, a single, discarded, standard 210-litre drum costs between KSh 60 and 80 (ITDG, 1986-88). In spite of the high cost of raw materials, entry into the cookstove-making industry does not require high levels of investment. According to artisans in Shauri Moyo, KSh 1500 to 2000 ($US75.00 to 100.00) is sufficient to start a cookstove-making enterprise.

TMS production tools and methods are almost identical to those of sigiri makers of Uganda or mbaula makers of Malawi. Production tools include: hammers, pliers, tinsnips, cold chisels, a centre punch, measuring tape, a piece of rail, file, dividers and a marker.

The production of TMS involves four basic operations:

1. Obtaining and preparing scrap sheet metal
2. Marking out and cutting
3. Forming and folding
4. Assembly of TMS components.

Most of the artisans sell the TMSs directly to consumers; although some hardware shops on the outskirts of the city keep a stock for sale.

C. Development of the KCJ - the institutions

Improved stove initiatives started in earnest in Kenya after the United Nations Conference on New and Renewable Sources of Energy held in Nairobi in August, 1981. After the Conference, a number of multilateral and local agencies started improved stove projects. The most important agencies which got involved in improved stoves then, were:

- The Ministry of Energy and Regional Development (MOERD)
- Kenyatta University Appropriate Technology Centre (KU-ATC)
- Kenya Energy and Environment Organisation (KENGO)
- Intermediate Technology Development Group (ITDG)
- CARE-Kenya
- Artisans of Shauri Moyo

- Maendeleo Ya Wanawake

The Ministry of Energy and Regional Development (MOERD) which has since changed its name to the Ministry of Energy was, in many respects, the single most important institution in the initiation of improved stove activities. Under the auspices of the MOERD, a USAID-funded project, the Kenya Renewable Energy Development Project (KREDP) embarked on an improved stove research and development project in 1982. It was under this project that the famous improved metal-ceramic jiko (the Swahili term for cookstove), known as the Kenya Ceramic Jiko (see figure 2) was developed (UNCHS, 1991).

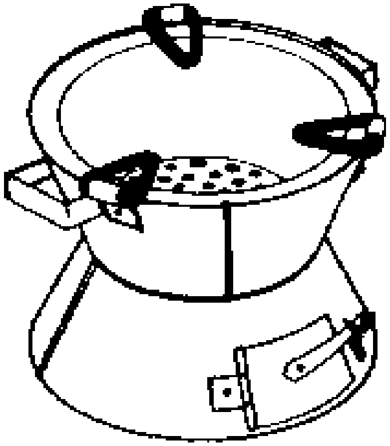


Figure 2. Kenya ceramic jiko

The KCJ industry is now a relatively mature cottage industry. As expected, the level of specialization in the manufacture of the KCJ has increased and so has the level of mechanization. There is now a discernible division of labour. For example, in Shauri Moyo, there are artisans who specialize in procurement and retailing of discarded drums, while others specialize in the cleaning, marking out and flattening of metal drums. Other artisans specialize in the manufacture of discrete components of the KCJ cladding. In addition, there are artisans whose sole occupation is to purchase clay liners and metal cladding and to assemble and retail to customers.

Mechanization has enhanced liner production to 3200 units a month (Jones et al, 1988). Semi-mechanized producers (Sunrise Clayworks, Jiko Bora, Jerri/Miaki and Rural Enterprises) are now producing an estimated 10,600 liners per month. Thus the total current production rate in Nairobi alone is in the region of 13,800 stoves a month. This yields an annual total of over 165,000 stoves.

D. Constraints

From the above, it might appear that the KCJ is a success story and that its funkier development is assured for years to come. However, data that have recently become available have raised doubt as to the future of the KCJ. A 1987 household survey carried out by a KENGO team and financed by the Foundation for Woodstove Dissemination (FOOD) found that the KCJ is largely confined to the middle-class neighbourhoods of Nairobi, while its penetration in the lower income areas (Kibera) was a lot lower than anticipated (Joseph, et al, 1990). The overall penetration rate for Nairobi was in the region of 13 per cent, which indicates that the dissemination of the KCJ is far from complete. Unfortunately, such information has become available when most donor agencies have declared the KCJ a success and ceased to support any more research and development in the technology.

Another development that has continued to be a source of concern is quality control. As the attention of NGOs and Government on the KCJ is waning, stove producers are increasingly producing sub-standard stoves. This is resulting in considerable consumer anxiety. In pursuit of higher profits or under the duress of fierce competition, a number of stove producers have decreased the amount of vermiculite and cement used in the KCJ, thus adversely affecting its charcoal-saving potential and life span.

One of the constraints that is open cited as being a key factor in the limited dissemination of fuelwood technologies, such as the KCJ, is the absence of reliable baseline data. The KCJ programme was fortunate in that it was implemented during the time of an extensive wood energy study executed by the Beijer Institute. While the data and information developed by the Beijer Institute were not comprehensive, it was one of the more detailed wood energy studies carried out in sub-Saharan Africa. Almost all literature on the KCJ makes reference to the Beijer Institute study.

Perhaps the most important role that the Beijer Institute study played was to provide the rationale and the justification for improved stove activities. It provided the intellectual underpinnings for justifying the involvement of the Government, donor agencies and the NGO community in the promotion of energy-efficient cookstoves. The study provided data that showed that the rate of depletion of wood-energy resources was higher than that of replacement. Thus, any intervention, such as improved cookstoves, that could slow the rate of consumption of wood-energy resources would slow or even reverse the mining of the country's wood-energy resources. In this sense, the Beijer institute study provided the rationale for major donor and government investment in improved stove activities.

Inspite of the above constraints and limitations, the KCJ stove design has now been successfully replicated in Malawi, Rwanda, Senegal, Sudan, Uganda and the United Republic of Tanzania In Tanzania, it is now estimated that the national stove project financed by the World Bank has disseminated over 50,000 KCJ-type stoves in the years 1989-1990 (Otiti, 1991). By the mid-1990s, the KCJ is expected to be the stove design of choice in most urban centres of sub-Saharan Africa.

The constraints that faced the dissemination of the KCJ were overcome through the concerted activities of a large number of institutions and actors. The role of the main actors and importance of key issues are discussed in the following section.

E. Policy environment and role of the Government

The KCJ programme was largely distinguished by limited detailed guidance on the part of the Government and concerned policy-makers. The absence of coherent national energy policy guidelines in the early stages of the development of the KCJ seems to have been, paradoxically, a blessing. The energy policy and planning vacuum in which the KCJ operated provided the space for innovative research and initiatives that were instrumental in the success of the KCJ.

It is believed that if there had been a strong policy direction in the early stages of the KCJ development, it could have stunted research and stifled the energies of NGOs and the informal sector, both of which were instrumental in the success of the KCJ.

One interesting example of government policy guidance in the early stages of the stove programme was its insistence that all production activities of the KCJ should take place within the informal and or small-scale industrial sector. While that was a valid guideline with respect to the manufacture of metal cladding, the production of ceramic liners is a much more difficult undertaking that requires a higher level of technical know-how and quality control. As a result, the KCJ has continued to be plagued by poor quality liners. However, most of the small-scale producers have been eliminated from the industry due to competition and lack of transport to distribute their liners. Only medium- to large-scale producers have survived the competition, and the level of mechanization has grown dramatically over the last two years. This seems to suggest that policy guidance was not very successful or advisable.

Now that the KCJ has achieve a measure of success, there appears to be a need for policy support to replicate the KCJ success in other parts of Kenya and to assist in quality control. The KCJ has only penetrated the Nairobi stove market. The Mombasa and Kisumu markets (the second and third largest towns in Kenya) have not felt the impact of the KCJ yet. Policy guidance that would provide finance and donor support would greatly facilitate the expansion of the KCJ to other urban areas of Kenya.

As mentioned earlier, quality control, particularly with respect to clay liners is a major source of concern. Government involvement in developing quality standards and encouraging adoption of trademarks would be of great assistance.

F. Role of private entrepreneurs and informal-sector artisans

Production and marketing of the KCJ have been undertaken primarily by the private sector consisting of medium- and small-scale entrepreneurs and informal-sector artisans. The active participation of private entrepreneurs appears to be the single most important factor in the sustainability of the KCJ programme.

By making major efforts to involve local entrepreneurs, the KCJ project did not attempt to install a new production and marketing system. It basically used the same network that produces and markets the traditional jiko. This strategy was effectively an incremental approach that proved particularly cost-effective, since the existing producers and entrepreneurs shouldered the cost of placing the KCJ onto the market.

Active participation of private entrepreneurs was further stimulated by the decision of KREDP not to provide subsidies. The initial result of this step was highly-priced KCJs. The first KCJs were outrageously expensive but competition soon lowered prices from a peak of $US 15.00 to a current price of $US3.00 per stove. The initial high prices ensured high profits which in turn attracted more producers. The ensuing competition soon brought down the prices to more realistic and affordable levels. One local entrepreneur, Richard Kimani of Jerri International, invested his own capital in the production of ceramic liners for the KCJ, then an unknown product. Once he took this important decision, he worked very hard to recover his investment and unwittingly ensured the survival of the KCJ programme. This experience was repeated in different variations by numerous private-sector participants and informal sector entrepreneurs and gave birth to a highly competitive and dynamic stove industry in the country.

Recent evidence, however, seems to indicate that while the role of the private sector is important, it requires additional institutional support to assist in continued R & D and in assisting quality control.

G. Local research initiatives and indigenous technical skills

The insistence of the KREDP on simple and familiar technology in the development of the KCJ was a very important decision. It ensured long-term sustainability. The only new technology involved in the KCJ is the production of the ceramic liner. Local ceramic technology had to be upgraded to be able to meet the requirements of the KCJ.

The simplicity of the KCJ design ruled out problems of maintenance since local producers of the KCJ could easily repair or replace any broken parts. Since the KCJ was, in effect, an improvement on the traditional jiko, the existing technical and maintenance system for the traditional metal stove could be used to service maintenance and technical back-up needs.

The experience of the KCJ in Kenya is testimony to the central importance of ensuring local participation and ensuring that any external expertise is largely deployed for the development of local human resources and capability. In this respect, one of the more important events was the appointment of a local consultant as the lead project manager for the KREDP stove project at the Ministry of Energy.

The rapid development of the ATC of Kenyatta University into an important stove-testing centre and the establishment of KENGO as an effective NGO dedicated to the dissemination of the KCJ were equally important developments. Thereafter, external technical support which was provided by a variety of agencies (Approvecho, ITDG and EDI) was fully utilized, since there was a strong local team of experts and institutions in place.

The regional programmes and networks that were involved in various stages of the KCJ development and dissemination played an important role in encouraging the adoption of the KCJ design in other countries of Eastern Africa

The more notable institutions and programmes. the Regional Wood Energy Programme for Africa (RWEPA); the Foundation for Woodstove Dissemination (FWD); and, the African Energy Policy Research Network (AFREPREN).

H. Role of non-governmental organizations

Local and international NGOs involved in the stove sector have become an important channel for the dissemination of information and the provision of free technical support. The development of local NGOs is an important element of stove dissemination in Kenya and has been a central component of efforts to engineer wide-scale use of energy-efficient stoves in the country and in the region.

While the role of local NGOs is generally welcomed by the stove industry, there have been instances when local NGOs contemplated initiating the production of the improved stoves. This has, in fact, become reality in the case of institutional stoves where an NGO, Bellerive Foundation, is actively involved in production and marketing of stoves for rural schools and hospitals. Because of its tax-free status, access to external finance and technical support, the activities of the Foundation have hampered the growth of an indigenous institutional stove industry. Bellerive Foundation is now reviewing its strategy and is seriously considering limiting its activities to training and information dissemination.

The above fate has not befallen the household stove industry largely because of the rather unattractive profit margins and loud and insistent complaints from the highly aggressive local community of stove producers and distributors.

I. Role of the end-users

Although there is no organized consumer organization that is actively interested in stove activities, end-users have been involved largely through participation in surveys, field testing and public awareness. Word-of-mouth appears to be one of the most effective dissemination channels. End-users have also been particularly effective in ensuring some minimum level of quality and price control by limiting their purchases to good-quality stoves that are not excessively priced.

J. External financial support and local credit and banking institutions

As explained earlier, the KCJ project received a modest amount of external financial support which was largely used to provide technical support and to finance training and information- dissemination activities. The seed funding provided by external donors was instrumental in initiating the KCJ programme. Perhaps the single most important characteristic of the availed external support was that a significant amount was directed towards local organizations and local experts thus ensuring some continuity and long-term sustainability.

Involvement of local banking institutions was mainly through the private and personal initiatives of the various stove entrepreneurs. No concerted effort was made to involve local credit and banking organizations. This is often cited as one of the most crucial drawbacks of the KCJ programme that slowed the country-wide dissemination of the technology.

K. Conclusions

The two case studies on improved charcoal production and energy-efficient cookstoves respectively, provide contrasting examples of interventions in the biomass sector of the developing world. The improved charcoal production is located in Malawi, a country where NGO activities are limited while, the improved cookstoves are in Kenya, a country where NGO activities flourish. This difference has important implications with respect to the kind of institutional and policy interventions that could be undertaken. It may in part explain why there was limited involvement of NGOs in the Malawi Charcoal Project, while NGOs played a prominent and visible role in the development and dissemination of improved cookstoves in Kenya.

Both case studies indicate limited involvement of the Government in detailed selection of technologies and development of strategies. As illustrated by the KCJ stove project, this gave free rein to local innovative talent which resulted in the successful dissemination of the KCJ. But there appears to be a strong case for the Government to take the lead role in ensuring quality control once the industry is sufficiently mature since local entrepreneurs, particularly those in the informal sector, see little need to establish self-regulating mechanisms. Both case studies appear to stress the need for substantial generic policy support from the Government in the form of endorsement of the need for wood energy development in the national development agenda.

The case studies showed a contrasting level of local involvement which has important implications for continuity. In the case of the Malawi Charcoal Project, the predominance of the foreign consulting company that managed the project with limited local involvement could, possibly, adversely affect the long-term sustainability of the project. In the case of the Kenya Ceramic Jiko project, local research institutions, NGOs and local consultants took the lead which may account not only for the continued development of the improved cookstove but also the dissemination of the concept to other countries of the sub-region.

The case studies address different technologies that have some inherent differences but also share some common characteristics. Charcoal production is an intermediate transformation process that converts biomass into a more useable form of energy. Improved cookstoves are end-use technologies. Nevertheless, the two technologies share the characteristic of involving the informal sector. In addition, both technologies are deployed in an energy sub-sector that is beset by serious data uncertainties that complicate attempts to develop and implement appropriate interventions.

Although the technologies promoted by the two case-study projects differ significantly, there is some commonality in the approach that was utilized. In both cases, mature and proved technologies from other developing countries were used. In the case of the Malawi Charcoal Project, the half-orange kiln technology that is widely used in Argentina and Brazil was used while in the KCJ project, the Thai Ceramic Stove from Thailand provided the starting point for the final design of the KC] stove. This appears to confirm the need to eschew basic technology research and to focus on incremental improvements of existing and proved technologies. In essence, it appears that the technical research agenda should be focused on modifications and adaptation rather than development of completely new devices or technologies.

The involvement of the private sector (both small-scale entrepreneurs and informal sector artisans) differs markedly between the two projects. In the Malawi Charcoal Stove Project, involvement of entrepreneurs and informal-sector artisans was effected in the later stage of the project, while the KCJ project involved the private sector from the beginning. The success of the KCJ appears to stress the need to give priority attention to private-sector involvement for two reasons. First, unless indefinite external financial support and Government subsidies can be assured, the local private sector provides the only source of continued inflow of investment. Therefore, for long-term sustainability to be realized, private-sector participation is crucial. The second reason for early attention to the issue of private-sector participation is that it is a painstaking and lengthy process that requires time and substantial effort on the part of project managers. Hence, the sooner they are involved in the project the better are the chances of its success.

Both case studies show that the involvement of the end-users was limited to participation in field tests. It could be argued that since both technologies are in the commercial sector, the direct involvement of the end-user is less crucial since he or she can implicitly participate through purchase or non-purchase of the end-product. The KCJ stove project, however, demonstrates that end-users are an important source of innovations and modifications. Involvement of end-users was, in both case studies, hampered by the absence of large and well-organized consumer organizations. This is now less of an impediment in Kenya due to the presence of the Kenya Consumer Organization.

Both case studies also show that there was limited involvement of the crucial local banking and credit sector which may have significantly slowed the dissemination of the promoted technologies. As shown in the case of solar technologies promoted in many developing countries and the dissemination of micro-hydro technologies in Nepal, the involvement of local credit agencies is vital to ensuring continuity when external support ceases. More importantly, using local credit institutions provides access to the considerable local know-how and expertise found in most local credit institutions. Many such institutions already have nationwide networks in place which could eliminate the need to incur the high cost associated with the establishment of national outreach programmes.

IV. Conversion of biomass into ethanol

A. Introduction

Alcohols can be used as a liquid fuel in internal combustion engines either on their own or blended with petroleum. Therefore, they have the potential to change and/or enhance the supply and use of fuel (especially for transport) in many parts of the world. There are many widely-available raw materials from which alcohol can be made, using already improved and demonstrated existing technologies. Alcohols have favourable combustion characteristics, namely clean burning and high octane-rated performance. Internal combustion engines optimized for operation on alcohol fuels are 20 per cent more energy-efficient than when operated on gasoline (Johansson et al, 1992), and an engine designed specifically to run on ethanol can be 30 per cent more efficient (EPA, 1990). Furthermore, there are numerous environmental advantages, particularly with regard to lead, CO_2, SO_2, particulates, hydrocarbons and CO emissions.

Global interest in ethanol fuels has increased considerably over the last decade despite the fall in oil prices after 1981. In developing countries interest in alcohol fuels has been mainly due to low sugar prices in the international market, and also for strategic reasons. In the industrialized countries, a major reason is increasing environmental concern, and also the possibility of solving some wider socio-economic problems, such as agricultural land use and food surpluses. As the value of bioethanol is increasingly being recognized, more and more policies to support development and implementation of ethanol as a fuel are being introduced. A number of countries have pioneered both large-scale and small-scale ethanol fuel programmes. In the United States, the current fuel ethanol production capacity is over 4.6 billion litres and there are plans to increase this capacity by more than 2.3 billion litres. Worldwide, fermentation capacity for fuel ethanol has increased eightfold since 1977 to about 20 billion litres per year in 1989 (Rosillo-Calle, 1990).

Latin America, dominated by Brazil, is the world's largest production region of bioethanol. Countries such as Brazil and Argentina already produce large amounts, and there are many other countries such as Bolivia, Costa Rica, Honduras and Paraguay, among others, which are seriously considering the bioethanol option (Rosillo-Calle, 1990). Alcohol fuels have also been aggressively pursued in a number of African countries currently producing sugar - Kenya, Malawi, South Africa and Zimbabwe. Others with great potential include Mauritius, Swaziland and Zambia. Some countries have modernized sugar industry and have low production costs. Many of these countries are landlocked which means that it is not feasible to sell molasses as a by-product on the world market, while oil imports are also very expensive and subject to disruption. The major objectives of these programmes are: diversification of the sugarcane industry, displacement of energy imports and better resource use, and, indirectly, better environmental management. These conditions, combined with relatively low total demand for liquid transport fuels, make ethanol fuel attractive (Hall and Rosillo-Calle, 1991).

The production of ethanol by fermentation involves four major steps: (a) the growth, harvest and delivery of raw material to an alcohol plant; (b) the pre-treatment or conversion of the raw material to a substrate suitable for fermentation to ethanol; (c) fermentation of the substrate to alcohol, and purification by distillation; and (d) treatment of the fermentation residue to reduce pollution and to recover by-products. Fermentation technology and efficiency has improved rapidly in the past decade and is undergoing a series of technical innovations aimed at using new alternative materials and reducing costs (Yasubisa, 1989). Technological advances will have, however, less of an impact overall on market growth than the availability and costs of feedstock and the cost-competing liquid fuel options.

The many and varied raw materials for bioethanol production can be conveniently classified into three types: (a) sugar from sugarcane, sugar beet and fruit, which may be converted to ethanol directly; (b) starches from grain and root crops, which must first be hydrolysed to fermentable sugars by the action of enzymes; and (c) cellulose from wood, agricultural wastes etc., which must be converted to sugars using either acid or enzymatic hydrolysis. These new systems are, however, at the demonstration stage and are still considered uneconomic. Of major interest are sugarcane, maize, wood, cassava and sorghum and to a lesser extent grains and Jerusalem artichoke. Ethanol is also produced from lactose from waste whey; for example in Ireland to produce potable alcohol and also in New Zealand to produce fuel ethanol. A problem still to be overcome is seasonability of crops, which means that quite often an alternative energy source must be found to keep a plant operating all-year round.

Sugarcane is the world's largest source of fermentation ethanol. It is one of the most photosynthetic efficient plants - about 2.5 per cent photosynthetic efficiency on an annual basis under optimum agricultural conditions. A further advantage is that bagasse, a byproduct of sugarcane production, can be used as a convenient on-site electricity source. The tops and leaves of the cane plant can also be used for electricity production. An efficient ethanol distillery using sugarcane by-products can therefore be energy self-sufficient and also generate a surplus of electricity, in addition to CO: for industrial use, animal feeds and a range of chemical-based products. The production of ethanol by enzymatic or acid hydrolysis of bagasse could allow off-season production of ethanol with very little new equipment

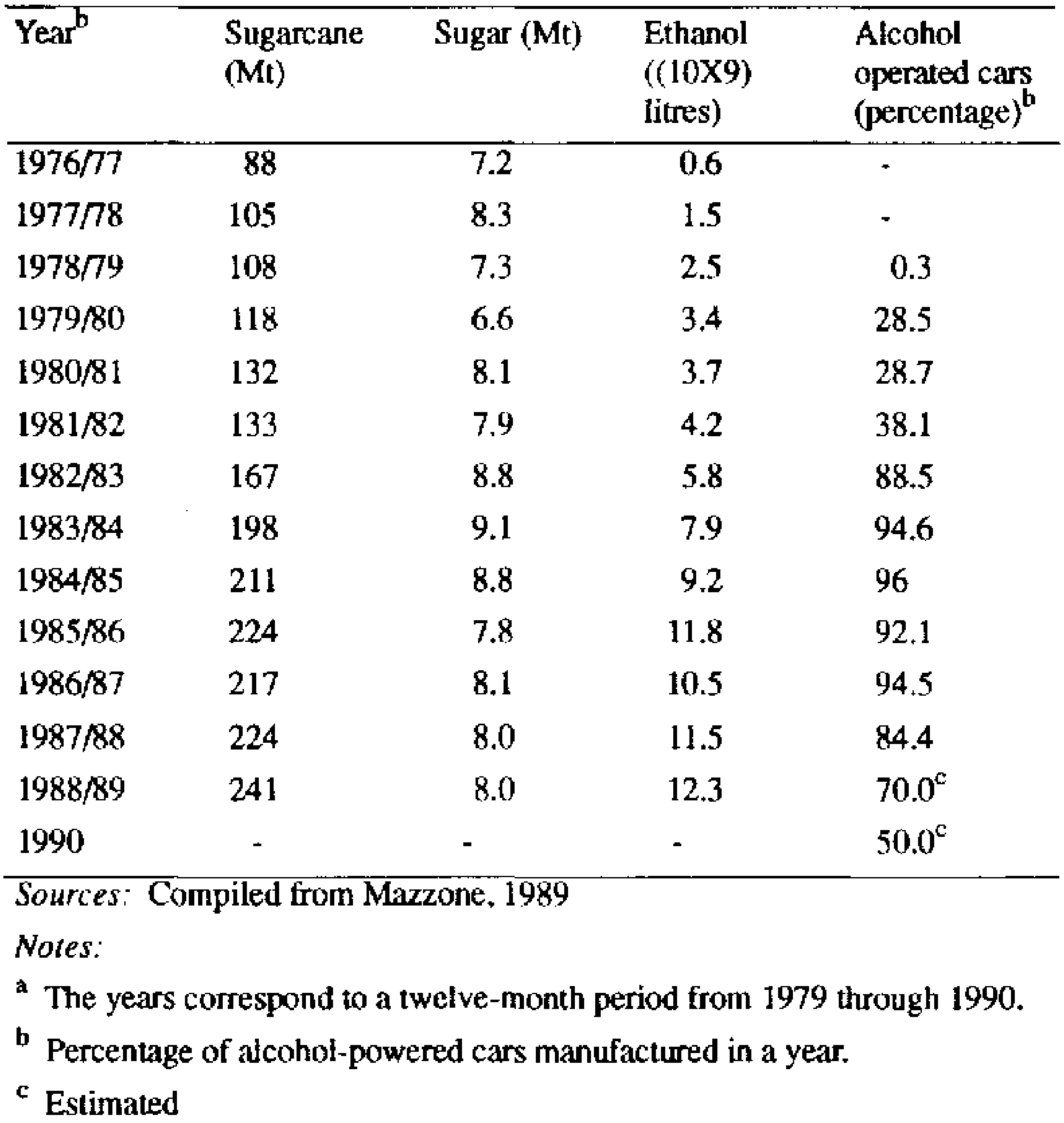
Methanol which can be obtained from biomass and coal, but which is currently produced from natural gas, has only been used as fuel for fleet demonstration and racing purposes and, thus, will not be considered here. In addition, there is a growing consensus that methanol does not have all the environmental benefits that are commonly sought for oxygenates and which can be fulfilled by ethanol (NAS, 1983).

B. Brazil

Brazil first used ethanol as a transport fuel in 1903, and now has the world's largest bioethanol programme. Since the creation of the National Alcohol Programme (ProAlcool) in 1975, Brazil has produced over 90 billion litres of ethanol from sugarcane. The installed capacity in 1988 was over 16 billion litres distributed over 661 projects (Anon, 1989). In 1989, over 12 billion litres of ethanol replaced about 200,000 barrels of imported oil a day and almost 5 million automobiles now run on pure bioethanol and a further 9 million run on a 20 to 22 per cent blend of alcohol and gasoline (Hall et al, 1992a) (the production of cars powered by pure gasoline was stopped in 1979). From 1976 to 1987 the total investment in ProAlcool reached $6,970,000 million and the total savings equivalent in imported gasoline was $12,480,000 million (Anon, 1989; Lima, 1989).

Table 5 shows sugarcane, sugar, and alcohol production as well as sales of alcohol-powered cars in Brazil from 1976/77 to 1990. Sugarcane production has increased from about 88 million tons in the 1976/77 harvest to 241 Mt in 1988/89, while alcohol production has increased from about 660 million litres to 12.3 billion litres during the same period (Mazzone, 1989). The planted area of sugarcane increased from 1,540,000 ha in 1972 to 2,820,000 ha in 1982 and 4.31 million ha in 1987 (IBGE, 1989). In the 1983/84 harvest, 47 per cent of the total amount of sugarcane crushed was used for ethanol production, and in 1987/88 the proportion reached 61 per cent (Rosillo-Calle et al,1991). In 1978, only 0.3 per cent of vehicles sold in the domestic market ran on ethanol but by 1985 this figure has reached 96 per cent. However, by 1990 this was down to an estimated 50 per cent due to difficulties in alcohol supply and retail prices (Mazzone, 1989).

Apart from ProAlcool's main objective of reducing oil imports, other broad objectives of the programme were to protect the sugarcane plantation industry, to increase the utilization of domestic renewable-energy resources, to develop the alcohol capital goods sector and process technology for the production and utilization of industrial alcohols, and to achieve greater socio-economic and regional equality through the expansion of cultivable lands for alcohol production and the generation of employment. Although ProAlcool was planned centrally, alcohol is produced entirely by the private sector in a decentralized manner.



Year[b]	Sugarcane (Mt)	Sugar (Mt)	Ethanol ((10X9) litres)	Alcohol operated cars (percentage)[b]
1976/77	88	7.2	0.6	-
1977/78	105	8.3	1.5	-
1978/79	108	7.3	2.5	0.3
1979/80	118	6.6	3.4	28.5
1980/81	132	8.1	3.7	28.7
1981/82	133	7.9	4.2	38.1
1982/83	167	8.8	5.8	88.5
1983/84	198	9.1	7.9	94.6
1984/85	211	8.8	9.2	96
1985/86	224	7.8	11.8	92.1
1986/87	217	8.1	10.5	94.5
1987/88	224	8.0	11.5	84.4
1988/89	241	8.0	12.3	70.0[c]
1990	-	-	-	50.0[c]

Sources: Compiled from Mazzone, 1989

Notes:

[a] The years correspond to a twelve-month period from 1979 through 1990.

[b] Percentage of alcohol-powered cars manufactured in a year.

[c] Estimated

Table 5. Sugarcane, sugar, and alcohol

Achievement of these objectives involved an intricate and politically difficult combination of technology and economic policy in the agricultural and industrial sectors. The Government established several support mechanisms: agreeing that the State-owned oil company, Petrobras, would purchase a guaranteed amount of ethanol; providing financial incentives such as low interest rates and $US2.0 billion in loans to ethanol producers; establishing a price policy to ensure an effective remuneration to alcohol producers; encouraging consumers by selling ethanol at 59 per cent of the price of gasoline (the price of ethanol is now 75 per cent of the price of gasoline, and hence there is almost no subsidy in ethanol (Goldemberg et al, 1992)); public investment in agricultural research; and incentives for alcohol production and utilization technology, and for private innovation and investment. In the Centre-South region of Brazil, it is no longer considered necessary to provide economic incentives to producers and end-users. The combination of these factors, together with the introduction of new equipment, increases in productivity and the number of new plantations, has given a continued boost to alcohol production.

1. Improved sugarcane yields

Between 1977 and 1985, sugarcane yields per hectare increased by 16 per cent and yield of alcohol per ton of cane increased by 23 per cent (Goldemberg et al, 1992) with alcohol productivity increasing from 2660 litres/ha to 3800 litres/ha (Mazzone, 1989). Cane productivity stood at 62.6 tons/ha in 1988 (Carpentieri, 1991). New varieties of sugarcane have been developed in order to gain greater productivity on poor soils, in consideration of the need to expand sugarcane growth without interfering with traditional food production. Intercropping and rotation cropping technologies developed by Brazilian sugar research laboratories have also made it possible for sugar plantations to increase food production. The Brazilian Government has undertaken a major effort to promote the improvement of cane-production technology, e.g., through the establishment of cane prices based on sucrose content rather than on weight, efficient management of sugarcane plantations and pest control, among other devices.

2. Industrial development

The ProAlcool programme has accelerated the pace of technological development and reduced costs within agriculture and other industries. Brazil has developed a modem and efficient agribusiness capable of competing with any of its counterparts abroad. The alcohol industry is now among Brazil's largest industrial sectors, and Brazilian firms export alcohol technology to many countries. Brazilian distillery manufacturers have been so successful in producing efficient hardware that the distilleries were frequently found to perform at up to 30 per cent above their rated capacity. In a number of distilleries, small additional investments have increased production still further to 50 per cent above nominal capacity (Weiss, 1990).

Another industry which has expanded greatly due to the creation of ProAlcool is the ethanol chemistry sector. Installed capacity for ethanol utilization in the chemical industry rose from 60,105 tons in 1976 to 336,980 tons in 1984. From 1975 to 1985 the ethanol-based chemical sector consumed a total of nearly 2.2 billion litres of ethanol, i.e., about 3.5 per cent of the annual alcohol production (Rosillo-Calle, 1986). Ethanol-based chemical plants are more suitable for many developing countries than petrochemical plants because they are smaller in scale, require less investment, can be set up in agricultural areas, and use raw materials which can be produced locally.

3. Social development

Until recently the Government's main objectives had been economic growth, with relatively little emphasis on social development. However, rural job creation has been credited as a major benefit of ProAlcool because alcohol production in Brazil is highly labour-intensive. Some 700,000 direct jobs with perhaps three to four times this number of indirect jobs have been created, although it is unclear how many of these jobs are new ones. The investment to generate one job in the ethanol industry varies between $12,000 and $22,000, about 20 times less than in the chemical industry for example (Goldemberg et al, 1992).

4. Environmental impacts

Environmental pollution by the ProAlcool programme has been a cause of serious concern, particularly in the early days. The environmental impact of alcohol production can be considerable because large amounts of stillage are produced and often escape into waterways. For each litre of ethanol produced the distilleries produce 10 to 14 litres of effluent with high biochemical oxygen demand (BOD) stillage. In the later stages of the programme serious efforts were made to overcome these environmental problems, and today a number of alternative technological solutions are available or are being developed, e.g., decreasing effluent volume using the Biostil process and turning stillage into fertilizer, animal feed, biogas etc. These have sharply reduced the level of pollution and in Sao Paulo. The use of stillage as a fertilizer in sugarcane fields has increased productivity by 20-30 per cent (Rosillo-Calle, 1986). Tougher environmental regulations have also reduced pollution considerably.

5. Economics

Despite many studies carried out on nearly all aspects of the programme, there is still considerable disagreement with regard to the economics of ethanol production in Brazil. This is because the production cost of ethanol and its economic value to the consumer and to the country depend on many tangible and intangible factors making the costs very site-specific and variable even from day to day. For example, production costs depend on the location, design and management of the installation, and on whether the facility is an autonomous distillery in a cane plantation dedicated to alcohol production, or a distillery annexed to a plantation primarily engaged in production of sugar for export. The economic value of ethanol produced, on the other hand, depends primarily on the world prices of crude oil and sugar, and also on whether the ethanol is used in anhydrous form for blending with gasoline, or used in hydrous forte in 100 per cent alcohol-powered cars.

The costs of ethanol were declining at an annual rate of 4 per cent between 1979 and 1988 due to major efforts to improve the productivity and economics of sugarcane agriculture and ethanol production (Goldemberg et al, 1992). The costs of ethanol production could be further reduced if sugarcane residues, mainly bagasse, were to be fully utilized as has been shown by Ogden et al, (1990). With sale credits from the residues, it would be possible to produce hydrous ethanol at a net cost of less than $0.15/litre, making it competitive with gasoline even at the low early-1990 oil prices. Using the biomass gasifier/intercooled steam-injected gas turbine (BIG/STIG) systems for electricity generation from bagasse, they calculated that simultaneously with producing cost-competitive ethanol, the electricity cost would be less than $0.0451kWh. If the milling season is shortened to 133 days to make greater use of the barbojo (tops and leaves) the economics become even more favourable. Such developments could have significant implications for the overall economics of ethanol production.

Several economic analyses exist for Brazilian alcohol production. Zabel (1990) estimated that the average cost of ethanol was $0.20 litre in Sao Paulo State and that this could be reduced by 17 per cent by the year 2000 to $0.16 litre. Reddy and Goldemberg (1990) calculated that the cost of ethanol produced in Sao Paulo was about $0.185 per litre; and that at this price, ethanol could compete successfully with imported oil. Goldemberg et al (1992) estimate that an overall cost reduction of about 23 per cent could be achieved in a few years just by using existing technology. Borges and Campos (1990) calculated that ProAlcool is economically feasible with both basic and high petroleum prices but in the low-petroleum-price scenario their analysis indicates that it would be more economical to use gasoline instead of ethanol.

The total gains per annum of ProAlcool were estimated to be equivalent to $7.2 billion and $2.5 billion in the high and basic petroleum price scenarios, while in the low-petroleum-price scenario there would be an estimated loss of about $700 million.

In 1989, ProAlcool received severe economic criticism, with many voices calling for its reduction or even total dismantling (Seroa-da-Motta, 1989). The main reason was the sharp drop in oil prices and the steady growth in Brazil's domestic petroleum production, e.g., about 212 million barrels in 1988 at an estimated cost of $20 per barrel versus an "estimated cost" of alcohol of $45 per barrel according to Young (1989). With the current relatively low oil prices (about $19-20 per barrel, May, 1993) and increased domestic oil production, the economics of alcohol production are unfavourable on a microeconomic basis.

The situation was exacerbated due to a shortage of alcohol fuel. In 1988, the Government was forced to import 200 M litres of alcohol to fill the fuel-ethanol shortage which continued in 1989 and 1990, resulting in a drastic reduction in sales of alcohol cars. Although a drought in the north-east was blamed for the shortfall, part of the crisis stemmed from bureaucratic and technocratic shortcomings. For example, fuel consumption was greatly stimulated when prices were frozen by the Summer Plan (a Federal economic anti-inflation programme launched in January 1989) and by the stagnation of alcohol prices, both of which discouraged the distillers from producing more alcohol. Government policies of maintaining low alcohol prices relative to the cost of gasoline were not accompanied by sufficient incentives to expand the production of alcohol. while depressing the price to hold down inflation destabilized the industry further. This led to the Government raising prices in 1991. Further, in 1989, sugar prices surged in the international market making it more profitable to sell sugar than to produce alcohol. Meanwhile, farmers had been shifting from cane to other more profitable export commodities so sugar production was down. This illustrates the vulnerability of the programme to short-term market fluctuations (Hall et al, 1992a; Goldemberg et al. 1992).

Many of the problems with ProAlcool are blamed by the industry on two institutions: the Institute of Sugar and Alcohol (IAA), which in June 1989 finally lost its 56-year monopoly over the country's sugar industry; and Petrobras, the State oil monopoly. The first was blamed for creating a price production stalemate by not correctly evaluating price levels for sugarcane and alcohol, and the second, for its long-standing opposition to the alcohol programme, e.g., payment delay tactics to distillers which, in an economy with very high inflation rates, results in large financial losses to the alcohol producers (Mazzone, 1989). Petrobras' opposition to ProAlcool stemmed from the fear of losing its monopoly of liquid-fuel supply and also because the company made.

Large investments in fluid catalytic crackers (large refining installations that convert residual fuel oil into lighter distillates, especially gasoline) which increased the proportion of gasoline obtained from oil and resulted in Large surpluses of gasoline.

6. Future implications

The recent economic problems have decreased the overriding importance of ethanol as a liquid-fuel substitute although supply interruptions and energy security are still of great concern to Brazil. Some policy changes were contemplated including a reduction in the alcohol content in gasoline from 22 per cent to 18 per cent, a decrease in the retail differential between gasoline and alcohol from 40 per cent to 25 per cent. and a proposed reduction in the manufacture of alcohol-powered cars to between 30 to 50 per cent of all new vehicles. These last two measures posed the greatest long-term threat to the future of ProAlcool. It is likely that the trend to lower use of ethanol-fuelled cars will continue, considering present low oil prices and the Government's attempt to reduce subsidies for ethanol production.

Brazil's alcohol programme crisis has many international as well as domestic implications. Abandoning ProAlcool, or even down-playing it, could mean a great increase in Brazil's capacity to produce sugar which could have serious implications for the world sugar trade. It was ProAlcool in part, that pushed international sugar prices upward in the 1980s after a decade of slump. A new export policy would flood the international sugar market, which would have serious economic consequences for the cane-growing developing countries which are already calculated to be losing $7 billion in sugar export earnings annually as a result of trade barriers in industrialized countries (Durning and Brough, 1991).

However, ProAlcool is an outstanding technical success that has achieved many of its aims, its physical targets were achieved on time and its costs were below initial estimates. It has enabled the sugar and alcohol industries to develop their own technological expertise along with greatly increased capacity (Rosillo-Calle, 1990). It has increased energy independence, made significant foreign-exchange savings, provided the basis for technological developments in both production and end-use, and created jobs. Overall, Brazil's success with implementing large-scale ethanol production and utilization has been due to a combination of factors which include: government support and clear policy for ethanol production; economic and financial incentives; direct involvement of the private sector; technological capability of the ethanol production sector; long historical experience with production and use of ethanol; cooperation between Government, sugarcane producers and the automobile industry; an adequate labour force; a plentiful, low-priced sugarcane crop with a suitable climate and abundant agricultural land; and a well established and developed sugarcane industry which resulted in low investment costs in seeing up new distilleries. In the specific case of ethanol-fuelled vehicles, the following factors were influential: government incentives (e.g., lower taxes and cheaper credit); security of supply and nationalistic motivation; and consistent price policy which favoured the alcohol-powered car (Hall et al, 1991a; Goldemberg et al, 1992).

The Brazilian experience with ProAlcool shows the inherent difficulty of long-term energy planning. As Weiss (1990) points out "on the positive side, Brazilian energy planners enjoy a substantial buffer against any possible future energy shortage, an advantage the rest of the world may some day come to envy. But as things now stand, the

ProAlcool Program appears today to be an expensive and impossible-to-cancel insurance policy against an unlikely contingency".

C. Zimbabwe

Zimbabwe is an example of a relatively small country which has begun to tackle its energy import problem while fostering its own agro-industrial base. An independent and secure source of liquid fuel was seen as a sensible strategy because of Zimbabwe's geographical position, its politically vulnerable situation and foreign-exchange limitations, and for other economic considerations.

The consumption of liquid fuel in Zimbabwe is relatively modest (but crucial to the running of a modern economy), with diesel now accounting for 55 per cent and gasoline 32 per cent (the remainder being kerosene) of the country's total liquid fuel consumption. Zimbabwe's current annual consumption of motor gasoline is about 1,850,000 barrels. Zimbabwe has no oil resources and all petroleum products must be imported, accounting for nearly $120 million per annum on average in recent years (Steinglass et al, 1988) which amounted to 18 per cent of the country's foreign-exchange earnings in 1984. Because of its landlocked position Zimbabwe had to import petroleum fuels by means of a pipeline from Mozambique, or by road and rail through South Africa. Both means of import are subject to disruption.

Zimbabwe pioneered the production in Africa of fuel ethanol for blending with gasoline in 1980. Initially a 15-per cent alcohol/gasoline mix was used, but due to increased consumption, the blend is now about 12 per cent alcohol. This is the only fuel available in Zimbabwe for vehicles powered by spark-ignition engines (Scurlock et al, 1991). Annually, production of 40 million litres has been possible since 1983, although this has recently been severely constrained by the drought. Plans for a 35 million litres per year expansion have been finalized, but the expansion depends on the availability of water. Production costs in 1988 were approximately $0.75 per gallon (Steinglass et al, 1988) which at least break even with landed gasoline imports when compared with local molasses prices of approximately $25/ton.

Zimbabwe's sugar industry consists of two private sugar companies, Hippo Valley Estates Ltd and Triangle Ltd. both located in the south-east low-yield of the country. Together they operate two of the world's most efficient irrigated sugarcane estates and factories. Until recent droughts, each grew and processed approximately 2 million tons of cane per year. Zimbabwe was exporting some 240,000 tons of sugar in 1986 which constituted the country's ninth largest foreign-exchange earner.

Any estimates of cost must consider the volatility of the international sugar and oil prices, supply problems and transport difficulties. Alcohol production in Zimbabwe reduces the amount of sugar available for export, and so reduces foreign-exchange earnings. The sugar commodity market is notoriously prone to price fluctuations. In 1973 a ton of sugar could buy 76.6 barrels of oil but, only 2.8 and 9.5 barrels in 1984 and 1990, respectively. However, about half of Triangle's annual sugar production of 200,000 tons goes to the relatively unlucrative home market, and most of the rest is exported to the European Community under special trade agreements at around $450 per ton. Any remaining sugar has to be sold on the world market. Zimbabwe's sugar has to be transported through South Africa for export, which reduces the price obtained by around $100 per tonne. Scurlock et al (1991) discuss these economic factors in some detail.

At November 1989 sugar and oil prices, ethanol costs fractionally more than imported gasoline, but when the strategic advantage gained from greater liquid-fuel self-sufficiency is taken into consideration, the balance is firmly in favour of home alcohol production. In August 1990 the price of gasoline was increased by about 50 per cent due to the Gulf War and world sugar prices dropped by 40 per cent between 1989 and 1991. Now oil prices have fallen again and sugar prices have risen due to failing crops in the drought. This demonstrates the vulnerability of ethanol production to political factors and commodity prices.

Serious consideration is being given to the possibility of expanding both sugar and ethanol production. The area of land which would be needed to grow cane to provide enough alcohol to replace all imported gasoline and meet domestic sugar needs (but with none for export) is about 52,000 ha. This is less than double the total area now planted with sugar cane, and represents only 0.2 per cent of available agricultural land in Zimbabwe. An alcohol programme that would power all Zimbabwe's cars with pure alcohol would not, therefore, necessarily compete for land with food crops. However, water for irrigation is the key problem.

An integrated long-term plan has been drawn up allowing a flexible approach to changing variables. The expansion plan involves five phases, the first of which started with the opening of the Mushwe Dam in 1991 that would allow an extra 3000 ha of cane to be planted; the capacity of the ethanol plant could be extended to 50 million litres/year provided there is no appreciable increase in the demand for sugar. The second phase is also dependent upon the construction of the Tokwe-Mukorsi Dam (currently at the planning stage) which will substantially increase the water supply and allow for a significant increase in the sugar-growing area and eventually in ethanol production.

1. The Triangle Plant

The ethanol plant at Triangle is an example of a biomass-to-energy system which has successfully for almost a decade. In November 1978, Triangle Ltd., a company involved in producing sugar and cotton, received permission to build a distillery at Triangle in southeast Zimbabwe. Triangle farms 13,000 ha of irrigated sugarcane plantations, yielding, on average, 115 tons of cane (fresh weight) per ha The production of alcohol began in March 1980. The plant was designed to produce 120,000 litres ethanol per day, with, on average, I ton of sugarcane giving 125 kg of sugar and 7.5 litres of alcohol.

With a realistic 96 per cent time efficiency, and operating the distillery for 24 hours per day 50 weeks of the year, production can reach 40 million litres per year. After nine years of operating experience, the expected output was regularly achieved, or even exceeded as in 1986, when the plant produced 41.6 million litres of alcohol. However, the need to supply the increasing demand for domestic sugar can limit the output of ethanol when the cane harvest is low. Also, drought in 1987 reduced the output of ethanol to 37.4 million litres, and similar production levels were forecast for subsequent years for the same reason. In 1992, the droughts were severe and cane productivity fell to only 2 t/ha resulting in the loss of 3000 jobs in the agricultural sector (Nature Special, 1992). Since the cane will have to be replanted, and it takes a year to grow, there will not be a significant crop in 1993 either.

The plant was financed mainly by local capital (one strict government condition was that foreign capital had to be recouped within six months by savings in foreign exchange) and home-based technology was required rather than sophisticated equipment from abroad, whenever possible. All decisions concerning the construction of the plant were made locally. The plant was locally planned with local control over its running. There was considerable cooperation between the various parties involved with very few external constraints and the industry was able to select low-cost technology closely tailored to the industry's needs. By using this approach, Zimbabwe was able to build the plant at a capital cost of $6.4 million (at 1980 prices) - the lowest capital cost per litre for any ethanol plant in the world.

After considering a number of options, it was decided to build a standard batch-type fermentation plant. This process requires that tanks are emptied and sterilized after each fermentation, but the plant can be operated by existing staff at the sugar mill. The design was produced by foreign consultants, but the construction was carried out in Zimbabwe by a local project team. Instead of importing distillery components, the locally-available fabrication structure was exploited. The consultants provided technical assistance where necessary, but a remarkable 60 per cent of the plant was fabricated and constructed in Zimbabwe. Only specialist items such as plate heat exchangers, an air blower and instrumentation were imported. To ensure high standards, local welders were given spectral training. Few problems have been experienced so far; only the fermentation tanks have shown abnormal corrosion.

The sugar mill is capable of producing cane juice and molasses of varying purities and concentrations to suit the needs of both the sugar factory and the distillery. The ethanol plant was also designed to operate on a variety of feedstocks using different grades of molasses, cane juice, or even raw sugar itself. This flexibility means that the plant is fully integrated with the rest of the sugar production process and can respond rapidly to changes. Thus the fermentable sugar content, for example, of molasses entering the plant can be adjusted at the expense of sugar production, depending on relative market prices, in order to maximize the return on total investment in both sugar and ethanol production. Triangle also buys in cane from 150 local growers (small farmers and private companies) and molasses to supplement its own supplies.

The mill is powered from "free" sugarcane bagasse during the seven-month cane-crushing season, and coal for the remaining five months. The Triangle ethanol plant enjoys an advantage over the typical annex molasses-to-ethanol plants built in other locations, which can operate only during the harvest season. During the off-season at Triangle, it is more economical to generate electricity from coal-fired boilers than to purchase electricity from the grid to operate irrigation pumps. The ethanol plant thus serves as a condenser for the electrical turbines, thereby operating on what would otherwise be waste steam. This enables the plant to have an energy output:input ratio of 1.94 (Scurlock et al, 1992). This system permits year-round ethanol production (330 days average), reducing investment, operating costs and seasonal inventory accumulation costs. These factors also make it economically feasible to operate on purchased molasses during the off-season (Steinglass et al, 1988).

Triangle has overcome the stillage disposal problem by diluting the waste up to 200-fold with irrigation water. After cooling in ponds, the water-plus-stillage is applied as fertilizer to around 7500 ha, about half of the sugarcane plantation. Although returning stillage to the land increases crop yields by 7 per cent, care has to be taken not to damage the soil's nutrient balance. Therefore, stillage disposal at Triangle has become a carefully monitored recycling of nutrients. The stillage-rich irrigation water at present provides all the necessary phosphates, and an excess of potassium. The total value of potassium as fertilizer in Triangle's stillage is estimated at $1.1 million each year. Alternative methods of making use of stillage and wastes are also being investigated. One practical method of disposal, for example, is to use the liquid "wastes" to generate more energy by concentrating and then burning for heat and power generation. Alternatively, stillage could be anaerobically digested to make biogas.

Scurlock et al (1991) has recently completed an analysis of the plant. Unfortunately there is no detailed breakdown of costs due to security reasons. Over the first three years of operation, the ethanol production cost was around $0.35 to 0.40 per litre, compared with a "landed" cost of gasoline in Harare of $0.50 per litre. Ethanol therefore cost I I to 27 per cent more than gasoline in terms of energy content only, but this was paid for entirely in domestic currency once the initial foreign-exchange investment had been recouped. The entire production of ethanol has been sold to the State-controlled National Oil Corporation of Zimbabwe. Gasoline and ethanol prices, as well as profit margins for gasoline wholesalers and retailers, are fixed by the Government.

Zimbabwe has proved that a relatively small country can diversify its agro-industry, to become less dependent on the perturbations of the external oil and commodities markets. The country has now gained considerable experience in the building of fermentation and biotechnological industries. Zimbabwe has pioneered the production of fuel ethanol in Africa, and provided valuable experience for other countries wishing to diversify their sugar industry to include fuel production. It sets an example of technological initiative to increase biomass-energy use and achieve some degree of energy independence. From the outset Zimbabwe has maintained both local and national involvement in decision-making at all levels. It offers an example of good use of relatively simple technology and local infrastructure and political commitment. The very survival of this project till now demonstrates that it has fulfilled the important criterion of involvement with local security, industry and agriculture. Indeed, local motivation seems to underpin every aspect of biomass energy at Triangle (Scurlock et al, 1991).

D. Malawi

Malawi is entirely dependent upon an agricultural economy for its export earnings. A major reason for embarking on the production of fuel ethanol has been the continuous deterioration of the regional transport system and the uneasy security situation with regard to Mozambique, both of which have caused frequent petrol shortages. Malawi commenced its bioethanol programme in 19X2 utilizing ethanol from a distillery located at Dwangwa sugar mill with a capacity to produce 10 million litres/yr. The Ethco (Ethanol Company Ltd) produces ethanol from molasses and raw sugar efficiently and profitably. Ethco has also provided the driving force for the exploration of wider applications of ethanol as neat fuel, diesel fuel substitute and illumination fuel for paraffin lamps. It has sought to expand the options for feedstock with work on cassava and wood chips.

Ethco currently produces ethanol to supply a national blend of 15 per cent (v/v) ethanol which could be increased to 20 per cent. A production of 20 million litres/yr could be achieved with minimal capital investment by operating the present fermentation/distillation plant all year round. A further option under consideration is the construction of a second plant near the Sucoma estate whose by-product molasses are of little or no opportunity value. The potential exists to double ethanol production immediately and, in the longer term, to produce sufficient to displace the country's entire gasoline imports. The annual demand is approximately 60 million litres of gasoline and 80 million litres of diesel oil (Moncrieff and Walker, 1988). If extended applications of neat ethanol, being tested in a small fleet of government Land Rovers (approximately 1500) indicate that only a modest substitution of diesel fuels in transport and agriculture can be achieved, even then, Malawi could displace as much as 10 to 20 million litres of imported petroleum with ethanol in the medium term.

In terms of feedstock for new ethanol production in Malawi, a report (Steinglass et al, 1988) estimates that surplus molasses and the sugar sold at world market prices would be the cheapest feedstocks and would yield approximately twice the current amount of ethanol produced. Beyond this level alternative feedstocks would have to be considered if the ethanol market expands sufficiently.

E. Kenya

In the 1970s, the combination of high oil prices, the large fluctuations of world molasses prices and sharp a rise in transport costs enabled the creation of the economic and political conditions to set up a bioethanol programme in

Kenya. This programme was plagued with difficulties from the start. Initially, the idea was to set up two ethanol plants using sugarcane molasses - the Madhvani and the Muhoroni plants. The Madhvani plant was never completed due to a number of techno-economic and political reasons. The plant was too costly and sophisticated and took little advantage of the local conditions. Due to lack of access to information and untied finance, the choice of technology in the international market was severely constrained and the resulting technology chosen was very sophisticated and capital intensive. Unlike the KCJ woodstove programme, government involvement in the joint project had a negative impact and distorted the economics, which was further complicated by the absence of a clear and cohesive long term government policy on ethanol production (Rosillo-Calle et al 1991).

The second smaller plant integrated into an existing sugar refinery was, however, successfully constructed (the Muhoroni plant inland from Kisumu). The Muhoroni plant was completed in 1983. It is an integrated sugar-ethanol plant which also produces 4 tons of baker's yeast per day. At the current capacity of 60,000 litres day, it produces all of Kenya's ethanol using sugarcane molasses. This is blended at 10 per cent with gasoline. At present the plant operates at 75 per cent of its capacity.

F. Thailand

Thailand produced about 20 million tons of cassava in 1988. A typical Thai tapioca starch factory discharges approximately 15-23 m^3 wastewater per ton of starch. The COD (chemical oxygen demand) of the wastewater is high and is in the range of 15,000 to 45,000 mg/l which can be a serious pollution problem. In the early 1980s there was a strong interest in producing ethanol from cassava and in 1983, a pilot plant was set up with a capacity of 1500 litres of ethanol per day to study the feasibility of ethanol from tapioca starch. The plant yield was in the range of 185-200 litres ethanol per ton of fresh cassava, and the production cost of ethanol (99.5 per cent v/v) was estimated to be about $0.48/litre (at 1987 prices), including factory operation and depreciation costs (Thomas, 1990).

However, in spite of the technical success of the project, it seems unlikely that fuel ethanol will be produced from cassava, at least in the near future, with the prevailing oil prices. Instead biogas from wastewater treatment looks more promising and efforts are being made to this end. Laboratory and pilot plant studies have shown that it is technically and economically possible to produce biogas from the wastewater in a fixed-bed reactor. The pay-back period of the anaerobic digester system is estimated to be less than three years for a factory producing 70-80 tons of starch per day (Tanticharoen, 1990). The biogas produced from wastewater is estimated to be able to save $11,860 per month (at 1988 prices) in factory fuel costs.

V. Biogas

A. Introduction

Biogas is produced by the anaerobic fermentation of organic material. Biogas production can be considered as being one of the most mature biomass technologies in terms of the numbers of installations and years of use in countries such as China and India It has the potential for multiple uses, e.g., cooking, lighting, electricity generation, running pumpsets and other agricultural machinery, and use in internal-combustion engines for motive power (Bhatia, 1990). Biogas technology is currently receiving increasing attention due to a combination of factors. Anaerobic digestion can make a significant contribution to the disposal of domestic, industrial and agricultural wastes which, if untreated, could cause severe public-health and water-pollution problems. The remaining sludge can then be used as a fertilizer (providing there is no polluting contamination). It therefore contributes to control of environmental hazards and recycling of nutrients whilst alleviating dependence on imported fuels (Gunnerson and Stuckey, 1986). When manure is used in digesters, the sludge actually performs better as a fertilizer since less nitrogen is lost during anaerobic digestion, the nitrogen is available in a more useful form, weed seeds are destroyed, and the sludge does not smell and does not attract flies or mosquitoes. Furthermore, it yields more useful energy than when burnt for cooking as is the common practice in many rural regions.

Biogas production systems are relatively simple and can operate at small and large scales in urban or very remote rural communities. Almost all current biogas programmes. however, are based on family-sized plants which lose significant economies of scale, are suited more for cooking than electricity generation, and often do not produce enough output just to supply this need. Community biogas plants are more economical and can provide enough electricity for pumping water lighting etc. However, there are social difficulties of organization and equity in the contribution of feedstock and the distribution of costs and benefits.

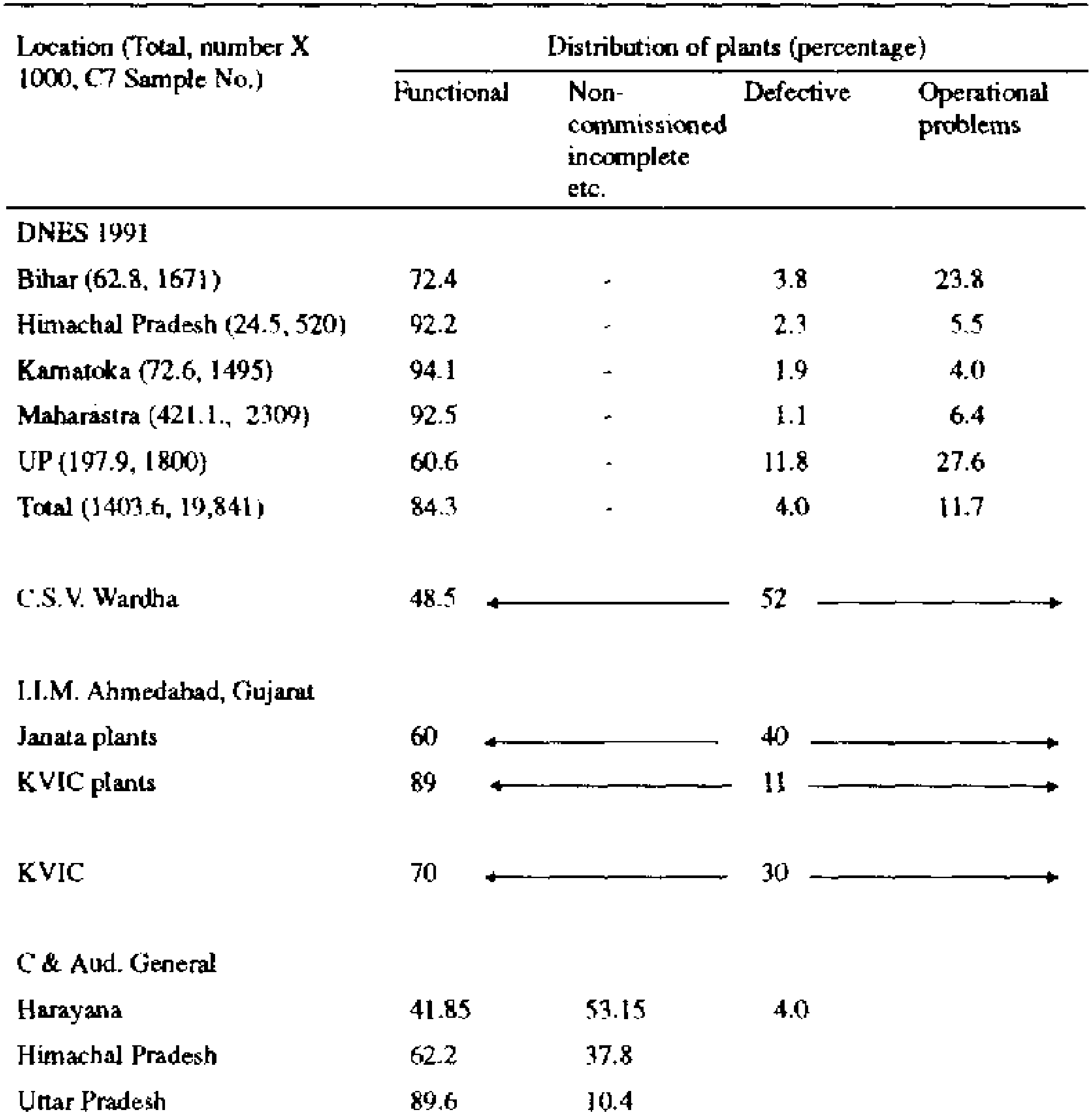
The basic designs of biogas plants - fixed-dome (Chinese), floating-drum (Indian), and bag (membrane) - have been used in a number of countries for many years. The designs reflect modest optimization for reduced capital costs and increased volumetric gas yields. Biogas can be used in internal-combustion engines using either the gas alone in an adapted petrol engine, or using a mixture of biogas and diesel in an adapted diesel engine. The main advantage of a diesel/biogas engine is the flexibility in its operation since it can operate as a dual-fuel engine using biogas and/or diesel. Usually, dual-fuel engines are so designed that when biogas is available the engine will utilize it, and when it is exhausted, the engine automatically switches over to diesel without any interruption. Diesel engines are reliable, simple to maintain, have a longer working life and higher thermal efficiency than petrol engines and are also more extensively used in rural areas.

Biogas technology has made some important advances in recent years, e.g., in China, Denmark and the United States. However, the technology of anaerobic digestion has not yet fully realized its promised potential for energy production. In industrialized countries biogas programmes have been hindered by operational difficulties, lack of basic understanding, and innovation. In some developing countries, development of biogas programmes has lacked urgency because of readily available and inexpensive traditional fuels such as fuelwood and residues. Lack of local skills, together with high costs, tend to be a significant deterrent to optimization and widespread acceptance of biogas technology (Hall and Rosillo-Calle, 1991).

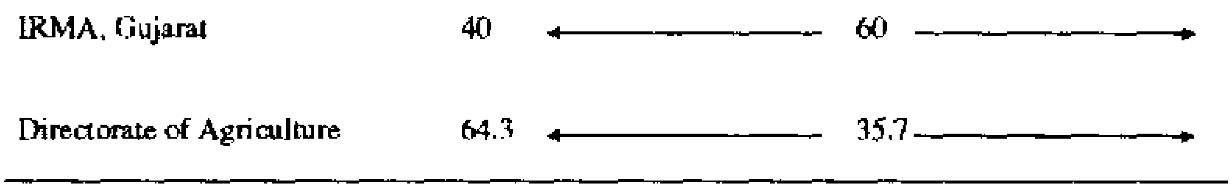
B. India

In India, the history of biogas technology goes back to 1937, when experiments with anaerobic digestion were carried out using municipal sewage sludge. Experiments were then extended to cattle dung in 1939, and in 1946, a batch-type reactor was developed. In 1950, the floating-cover digester was designed, which was subsequently improved and propagated by the Khadi and Village Industries Commission (KVIC). This model is, thus, known as the "KVIC" or Indian type, extensively used in India and elsewhere the world.

The "multi-model multi-agency" approach adopted by the Department of Non-conventional Energy Sources (DNES), which has become a full-fledged Ministry (MNES) has greatly stepped up the propagation of family biogas plants (FBPs) in the country. In this approach, several NGOs have been recognized and encouraged as disseminators of FBPs, in addition to the traditional disseminators, such as KVIC and Rural Development Departments (RDDs) (Khandelwal, 1990; Moulik, 1990). With a planned crash programme beginning in 1984 and subsequently involving many NGOs (Moulik, 1990), annual targets exceeding 150,000 biogas plants in the country have been consistently recorded (Khandelwal, 1990). In response to several field-level problems, and low dung availability etc., the DNES has been funding and monitoring several R&D attempts to improve efficiency of existing plants as well as to bring out alternative designs and fermentation concepts for alternate feedstocks. The number of biogas plants built in India is extremely low (3-9 per cent of the potential, as discussed below) and the percentage of satisfactorily functioning plants is equally low.

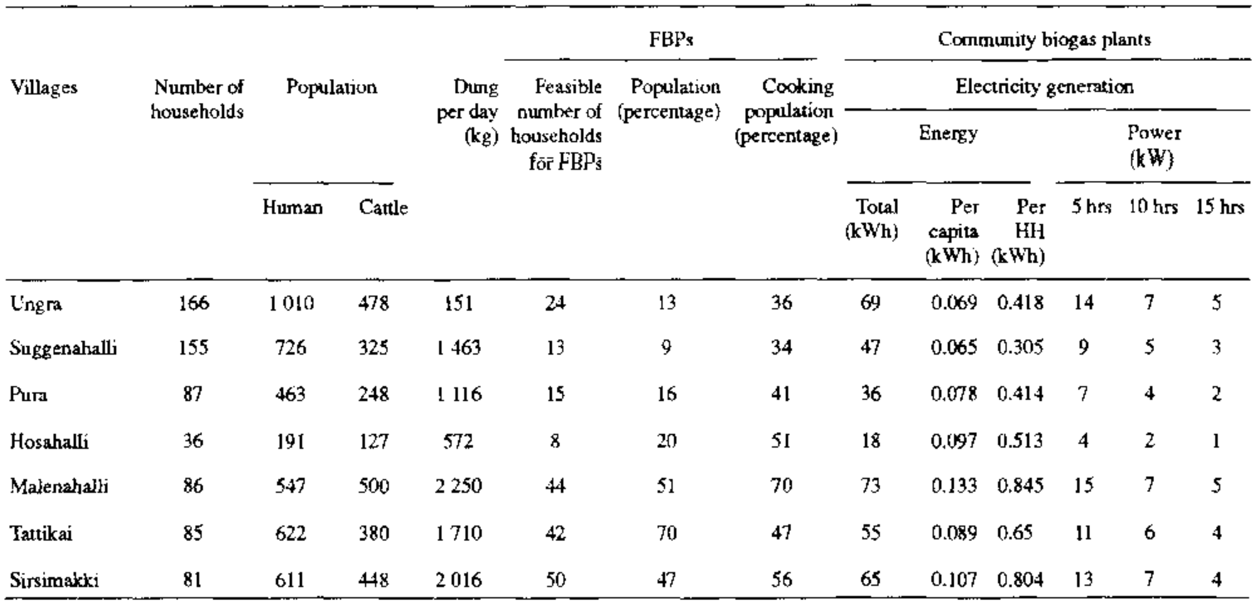


Location (Total, number X 1000, C7 Sample No.)	Distribution of plants (percentage)			
	Functional	Non-commissioned incomplete etc.	Defective	Operational problems
DNES 1991				
Bihar (62.8, 1671)	72.4	-	3.8	23.8
Himachal Pradesh (24.5, 520)	92.2	-	2.3	5.5
Karnatoka (72.6, 1495)	94.1	-	1.9	4.0
Maharastra (421.1., 2309)	92.5	-	1.1	6.4
UP (197.9, 1800)	60.6	-	11.8	27.6
Total (1403.6, 19,841)	84.3	-	4.0	11.7
C.S.V. Wardha	48.5	← 52 →		
I.I.M. Ahmedabad, Gujarat				
Janata plants	60	← 40 →		
KVIC plants	89	← 11 →		
KVIC	70	← 30 →		
C & Aud. General				
Harayana	41.85	53.15	4.0	
Himachal Pradesh	62.2	37.8		
Uttar Pradesh	89.6	10.4		



IRMA, Gujarat	40	60
Directorate of Agriculture	64.3	35.7

Table 6. Performance evaluation of biogas application in India



Villages	Number of households	Population		Dung per day (kg)	FBPs			Community biogas plants					
					Feasible number of households for FBPs	Population (percentage)	Cooking population (percentage)	Electricity generation					
								Energy			Power (kW)		
		Human	Cattle					Total (kWh)	Per capita (kWh)	Per HH (kWh)	5 hrs	10 hrs	15 hrs
Ungra	166	1 010	478	151	24	13	36	69	0.069	0.418	14	7	5
Suggenahalli	155	726	325	1 463	13	9	34	47	0.065	0.305	9	5	3
Pura	87	463	248	1 116	15	16	41	36	0.078	0.414	7	4	2
Hosahalli	36	191	127	572	8	20	51	18	0.097	0.513	4	2	1
Malenahalli	86	547	500	2 250	44	51	70	73	0.133	0.845	15	7	5
Tattikai	85	622	380	1 710	42	70	47	55	0.089	0.65	11	6	4
Sirsimakki	81	611	448	2 016	50	47	56	65	0.107	0.804	13	7	4

Table 7. Biogas for cooking and power-generation

Currently with nearly 1.5 million biogas plants in the country, monitoring the spread and efficiency is being carried out at many levels involving the state governments, the DNES's own monitoring offices and by independent agencies commissioned by the DNES. In addition, several independent surveys carried out by various research, educational, developmental and financial institutions also exist in the form of published articles, reports and surveys. However, there are wide variations among them, possibly because of differences in criteria used. An excerpt of these surveys, presented in table 6, shows that, barring two locations, most biogas plants had a performance rating above 60 per cent. The national-level performance reported by DNES shows a good performance of 84 per cent. However, more details are needed to evaluate these data.

The biogas potential has been estimated differently and varies according to the feasibility criteria adopted. Consequently the estimated potential family biogas plants varies from a low value of 15 million (Khandelwal, 1990), to a medium value of 23 million (Moulik and Mehta,1991) and a high of 40 million (DNES, 1992). The maximum potential for utilizing biogas for cooking/power generation has been estimated in table 7. The bovine population in different states varies significantly along with average dung yield (TEDDY, 1991). As a result, in the states of Haryana, Himachal Pradesh and Rajasthan, 44 to 55 per cent of the rural population could meet their daily cooking needs through this energy technology. In most other states, 24-33 per cent of the rural cooking-energy needs can be met through biogas, thus reflecting its large potential in the country. It is also evident that in most states basic rural energy services (characterized by constant year round demand), such as domestic lighting, water supply and flour milling, among others, can be met through biogas systems. It is, however, acknowledged that it might not be possible to realize this high potential.

The target set for the year 2000 is 12 million units with an estimated budget of $7 billion (Dec. 1988 $). There are indications, however, that in the coming decade the subsidy policy of the Government for the biogas programme will be reduced significantly - from 40 per cent of the total investment in the 1985-1990 plan to 25 per cent in 1990-1995 and to 10 per cent in 1995-2000 (Sinha and Kandpal, 1990). Since electricity is heavily subsidized and the electricity tariff is only one fifth of the real cost of providing electricity in rural areas, the farmer will usually opt for an electric motor instead of a diesel engine or a dual-fuel (biogas/diesel) engine. It is worth noting that "presently the main motivation of farmers for adapting a dual-fuel engine (usually meaning better-off farmers who could afford $15 to $20 for converting the existing diesel engine to a duel-fuel engine) is to provide a back-up power source for their irrigation systems to guard against inadequate electricity supplies and diesel shortages" (Bhatia, 1990, p. 582).

1. Family biogas-plants (FBPs)

The family biogas plant (FBP) implementation programme in the country is mostly carried out by state-level rural development bodies which rarely transcend the state boundaries in this matter. Presented below are case studies in four different states of the country, representing different agroclimatic situations, designs of biogas plants adopted, promotional techniques etc. These case studies have been chosen based on availability of a reasonably holistic analysis of the techno-economic parameters. The four states chosen are Maharashtra, Bihar, Himachal Pradesh and Karnataka. The techno-economic and management aspects are discussed later.

The approach and methodologies pertaining to diffusion of FBPs are generally uniform throughout the country. The approach of the programme is broadly promotional and therefore incorporates a significant subsidy component, financed through the apex governmental body, the Department of Non-conventional Energy Sources (DNES) and implemented through the state-level Rural Development Departments (RDD). A promotional approach becomes necessary in the existing mixed economy and dual society, because over 50 per cent of rural households neither have the purchasing power nor are capable of articulating demands for a conventional market economy (Krishnaswamy and Reddy, 1988, unpublished studies). This necessitates alternative technology-transfer mechanisms. A flow chart representing this action programme is presented in figure 3. The entire programme is a target-oriented programme, where targets fixed by the RDD to zilla parishats (ZP, the nodal agency) is further distributed among blocks (taluts) where the block development officer (BDO) is the responsible official. The promotion of the biogas plants begins at the village level wherein the gram sevaks motivate potential beneficiaries and receive applications for onward transmission to the BDO. The BDO is responsible for their scrutiny for the satisfaction of the feasibility criteria and size selection, sanctioning of subsidy and assistance in obtaining required bank loans. The extent of subsidy provided depends upon the backwardness (socially) and the geographic location (DNES, 1992). Following the sanctioning the NGOs, entrepreneurs and skilled masons are enlisted to supervise and construct these plants on a turnkey basis.

Normally the beneficiaries are free to choose from six different designs and models approved by the DNES for the purpose of taking advantage of the subsidy. Both types of plants, namely the Indian floating-drum type (KVIC) and the Chinese fixed-dome types, and their variants are promoted by the programme (Khandelwal, 1990). All these biogas plants have been designed mainly for use with cattle dung as substrate, though other slurrifiable animal dung can also be utilized. The main technical features of these two types of plants are listed in table 8 which shows that while fixed dome plants are cheaper they are found to have low reliability in the field owing to several technological and diffusional constraints discussed later. Currently there is greater thrust in the promotion of the latest fixed-dome design (Deenabandu, improved "Shanghai" design).

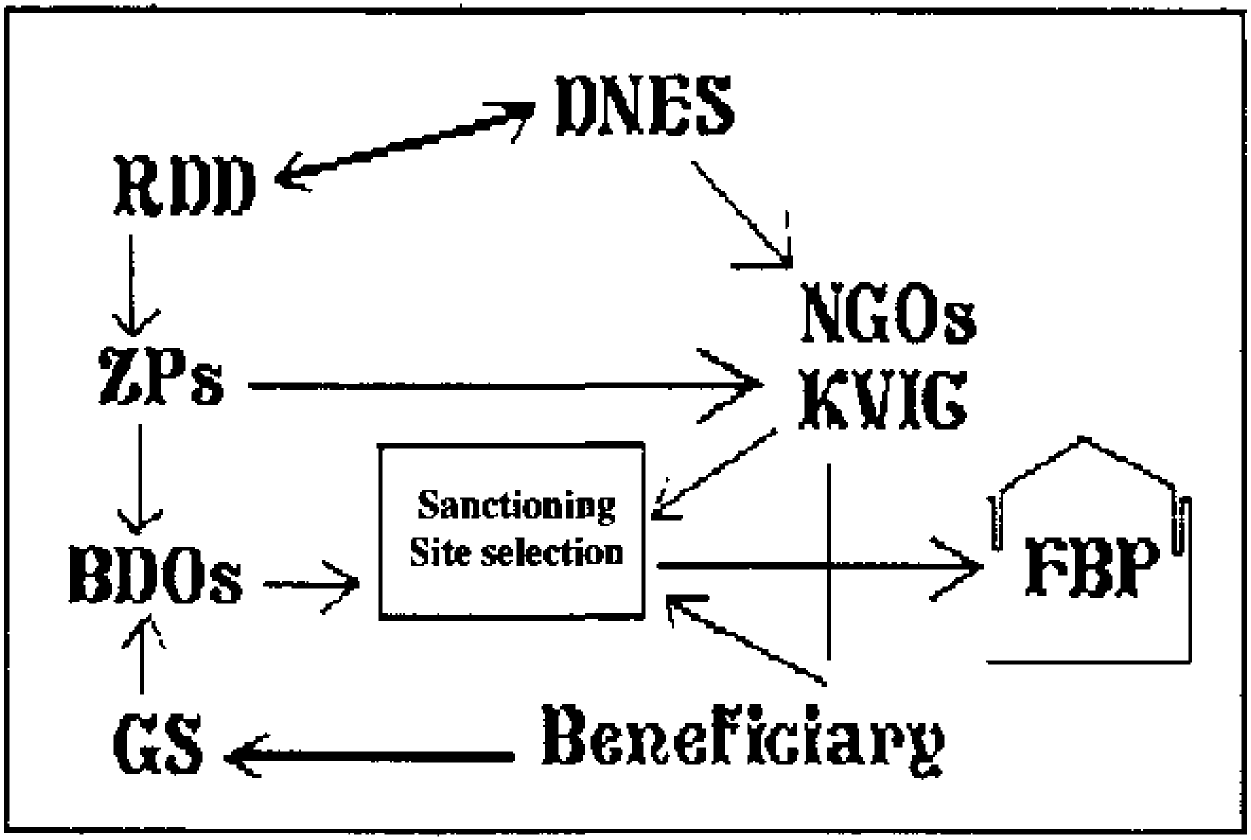
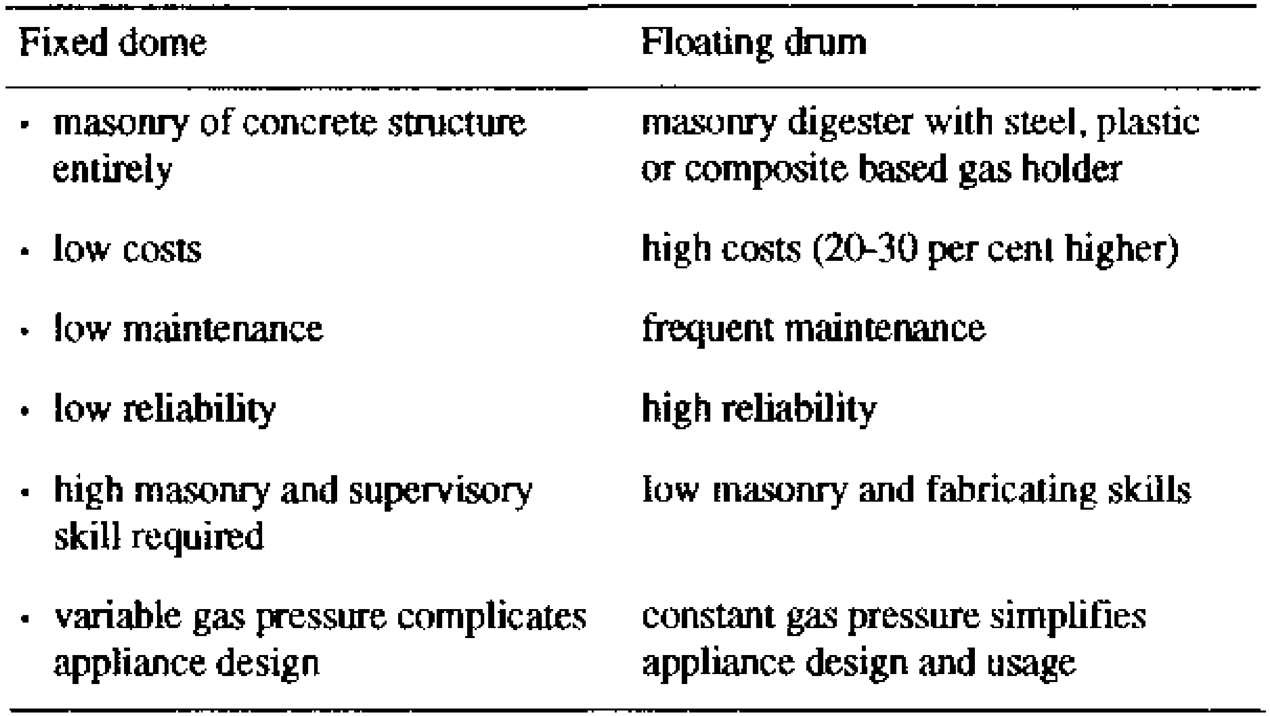


Figure 3. FBP diffusion pattern



Fixed dome	Floating drum
• masonry of concrete structure entirely	masonry digester with steel, plastic or composite based gas holder
• low costs	high costs (20-30 per cent higher)
• low maintenance	frequent maintenance
• low reliability	high reliability
• high masonry and supervisory skill required	low masonry and fabricating skills
• variable gas pressure complicates appliance design	constant gas pressure simplifies appliance design and usage

Table 8. Main technical feature of fixed-dome and floating dome and floating-drum biogas plants

Greater attention is currently being focused on fixed-dome plants since they are cheaper and are being diffused through several voluntary agencies which offer a two year warranty and a follow-up programme (Veena Joshi et al, 1992). During the construction of biogas plants the following steps are involved (in close coordination with the BDO and supervisor):

- Selection of appropriate sites;
- Excavation for the digester (mostly by the beneficiary);
- Procurement of materials required (cement, sand, bricks, burner etc.);
- Construction and installation;
- Commissioning, use and maintenance of the biogas plants.

All these steps play an important role and impart several constraints on the diffusion as discussed later.

The management of the technology at the national level is effected through the governmental machinery and a few NGOs. Its implication, effectiveness and alterations needed are discussed later. At the FBP user's level however, the management is restricted to operation and maintenance of the devices and plants as well as storage and deployment of manure after they are installed. The routine operation and maintenance involve the following:

- Daily feeding and slurry removal;
- Cleaning and upkeep of plant, pipelines and devices;
- Frequent painting of the gas holder (mild steel, (MS) floating-drum design);
- Minor repairs to plants.

All major repairs require the services of a skilled mason or biogas supervisor.

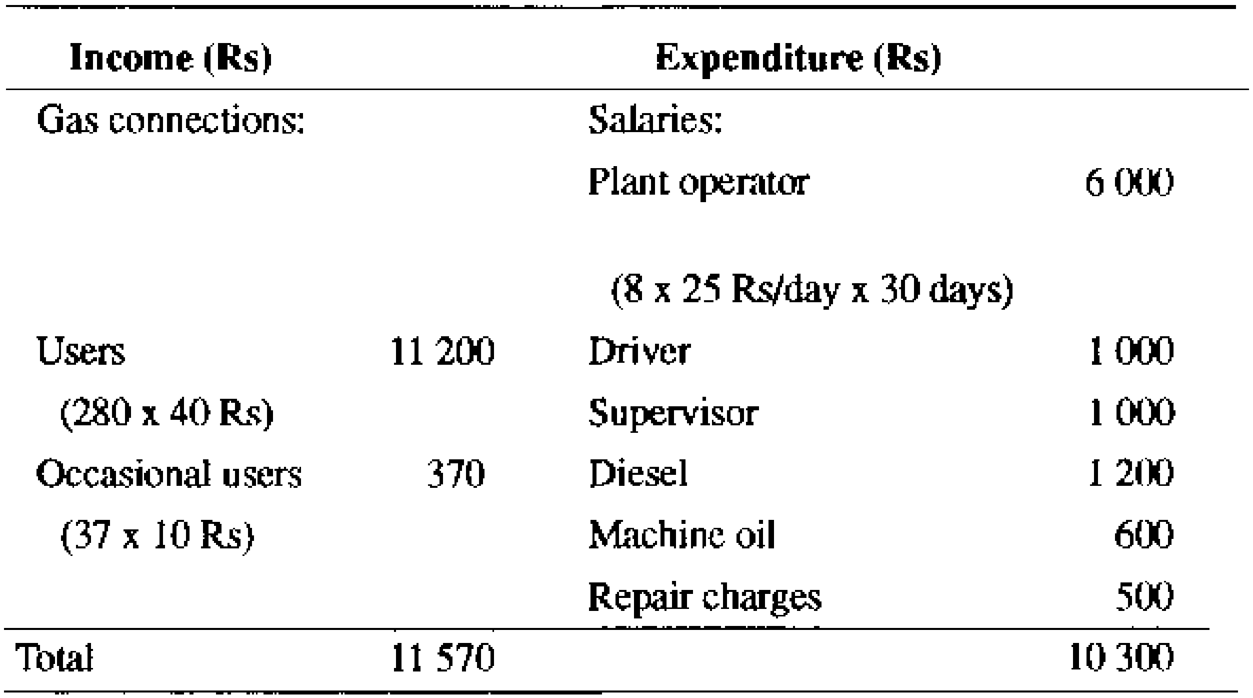
2. Results

(a) Maharashtra

The state of Maharashtra accounts for the Largest number of biogas plants constructed (421,000, DNES (1992)). The state is centrally located in the country and is less subject to gross temperature fluctuations leading to less fluctuating gas yields. Maharashtra also was one of the largest promoters of the biogas programme accounting for nearly half the annual rate of biogas plants being built in the country and amounting to approximately 1000 plants per district annually. While both designs of plants coexist in the state, the Deenabandhu model has received greater attention in the recent past (Dyal Chand, 1988, 1989). The very rapid dissemination rate of biogas plants has been characterized by an approach to target fulfillment and laxity in adhering to the feasibility criteria established for sanctioning, namely, bovine holding and family size). This is the possible reason for non-commissioning of over 50 per cent of the biogas plants built during the study years. It is also reported that about 30 per cent of the plants are underfed leaving only 4 per cent of them optimally functioning (see tables 6 and 8). The adoption pattern indicated that the probability to "commission" and successfully operate biogas plants increased with the land- and bovine-holding size. Therefore the large-sized plants had greater chances of being commissioned due to the fact that they were sanctioned to households having larger bovine-holdings as well as possible access to resources. Conversely, the smaller plants led to poor adoption because they were being aimed at the lower economic groups who did not have enough cattle, a crucial feasibility criterion which had been overlooked.

(b) Bihar

In Bihar, the majority of the biogas plants have been constructed in the plains. The prevailing agro-climatic conditions of Bihar suggest that there would be seasonal fluctuations in gas yields and efficiency caused by the extreme climate. Moulik and Mehta (1991) report a high degree of functional plants (89 per cent) sampled in 21 districts of Bihar. The major failure pattern among the non-functional plants is presented in table 9. While both types of plants exist, the dissemination programme is dominated by the fixeddome plants. Irrespective of the design, nearly 39 per cent of the failures could be attributed to lack of adequate training in operation and maintenance. About 53 per cent of defective plants were structural failures due to inadequate knowledge and training in FBP construction. Seasonal variations in plant performance were gauged by measuring the time for which gas was used for cooking and lighting purposes. While lighting use seemed to be constant irrespective of the season, marked shortages in gas for cooking were felt in winter. The authors conclude that the construction of biogas plants in the state has been stalled by the lack of adequately trained masons necessitating additional follow-up programmes to reduce failures.



Income (Rs)		Expenditure (Rs)	
Gas connections:		Salaries:	
		Plant operator	6 000
		(8 x 25 Rs/day x 30 days)	
Users	11 200	Driver	1 000
(280 x 40 Rs)		Supervisor	1 000
Occasional users	370	Diesel	1 200
(37 x 10 Rs)		Machine oil	600
		Repair charges	500
Total	11 570		10 300

Table 9. Cash-flow statement (August, 1989), Methan Community Biogas Plant

(c) Himachal Pradesh (HP)

Kalia and Kanwar (1991) studied the performance of FBPs during 1987- 1988 from a sample survey (5 per cent, 553 plants of the 10,093 installed) in six districts of HP. They reported a high functionality rate of 82 per cent as well as low gas yields in winter (see tables 6 and 8). Of the 553 plants,11.5 per cent were found to suffer from different modes of failure. All plants installed in the state were of the fixed-dome "Janata" model type. Though plant sizes ranged from 2 to $6m^3$, over 65 per cent them were of 3-m capacity. Background information collected indicated that the literacy rate among the biogas users in the sample was high (76 per cent). About 18 per cent of the biogas plants were constructed for households belonging to backward sections. Most beneficiaries had income levels well above the state's average. The cost of plants in this state seems to be strongly influenced by accessibility to construction materials and, on an average, were 1245 per cent higher than costs recommended by the DNES. Owing to low winter temperatures, the gas production levels fall to 50 per cent of the rated capacity. The $2m^3$ size plants seem to be the least affected by the low temperatures. From these results the authors suggest that the 2-m^3 size is the optimum and most efficient..

(d) Karnataka

Karnataka has many distinct agro-climatic zones and offers a good location for studying the application of biogas plants in contrasting situations. As a part of this study a sample survey of 50 biogas plants in the Western Ghat region (Sirs), Uttara Kannada district) and of another 50 plants installed in a semi-arid region (Kunigal, Tumkur district) were carried out. While 6-m^3 and 8-m floating-drum plants were popular in Sirsi, both fixed-dome and floating-drum plants have been installed in Kunigal. Biogas plants constructed in Sirsi were generally over-sized and cost about 20-30 per cent more than recommended prices. The plant users had a high level of income, high literacy and exhibited a high degree of motivation. These were probably the reasons for the absence of the non-functional FBP in the sample. Most plants were well maintained and repaired within 2-3 months of the occurrence of faults. There was little relation between the land-holding size, income levels, adult bovines, family size, time required between awareness and installation etc. In order to overcome the maintenance problems of the MS gas holders, most plant owners were switching to FRP gas holders at the time of major gas holder breakdown.

In Kunigal, the fixed-dome biogas plants designed and installed locally have exhibited a high degree of failure (70 per cent). The major cause of failure was identified as gas leakage through the dome. However, all floating-drum plants installed were functioning well in the sample.

3. Community biogas plants (CBPs)

In contrast to the FBP programmes mentioned earlier, the community biogas plants (CBPs) and institutional biogas plants (IBPs) are diffused through a separate programme due to the amount of funding and expertise required. From 1972 to date, about 494 large-scale biogas plants (Venkata Ramana, 1992) have been constructed among which 254 are claimed to be CBPs (although many do not exist today). There is little information available on 224 of the CBPs and only partial information on 34 of them. As in the case of FBPs, 40 per cent or more of these plants have, possibly been, closed down and about 10 per cent not commissioned due to having been built without proper feasibility studies. Another 6 per cent are being run for demonstration purpose and are virtually institutional biogas plants (IBPs). Among the rest, 34 per cent have severe problems of inadequate dung supply. Most CBPs are in Punjab (16) and Gujarat (4) (Venkata Ramana, 1992; Singh, 1988). In all these plants gas has been supplied for cooking except for the case of Pura village, where gas is now being converted into electrical power after having passed through the cooking-gas supply phase. Four CBPs are reported to be working satisfactorily at present, three of which are in the Gujarat state characterized by a very high cattle to human ratio and existence of successful milk cooperatives. The success of the Pura plant in a semi-arid tract of the country may however be attributed to: (a) the gas being converted to electricity where felt needs like water supply and reliable domestic illumination are strong binding forces; and (b) continuous monitoring and involvement of research scientists (of ASTRA).

From the literature available it appears that there has been a learning phase between 1972 and 1987 wherein most biogas plants constructed have been abandoned for one or several reasons. All success reports about CBPs are after this period. It has been analysed that there are three categories of CBPs and, consequently, three case studies representing each of them have been outlined below.

> (a) Successful CBPs operating continuously and located in areas where dung availability is high, such as in Gujarat and Punjab. Nevertheless, in spite of high dung availability, the cooking needs of only 50 per cent of families are being met.
>
> (b) "Problematic/sick" CBPs where problems are related to inadequate dung input: 70 per cent of the CBPs fall into this category. There is, however, very few data available for plants in this category. The case study of Pura, phase I, is therefore cited in which the authors were involved and the gas produced was supplied for cooking during that period. It is, therefore, considered suitable for this category of CBPs.
>
> (c) CBPs used for energy services other than cooking (Pure, phase II).

(a) Community biogas plant at Methan Village, Gujarat (Venkata Ramana, 1992)

(i) Approach

With the confidence developed by the successful on-going milk cooperative, a community biogas plant system was planned for the cooking-gas supply. The entire capital cost was borne by DNES and the installation work was executed through a private fusion of consultants on a sum-key basis. The dung required for the initial charging of the plants (600 tons) was contributed by the villagers and was paid for by the contracting firm.

All the members of the village contribute dung to the system daily, and in turn, get the digested slurry back on a pro-rata basis. The gas users are charged at a flat rate of Rs. 40/month. There are some 40 migratory families who use the gas only for a few months. When their connections are not in use, they are charged only Rs.10/month.

The daily operation of the plant has been entrusted to a contractor who supplies a minimum of eight labourers to feed the plant, remove the slurry and clean the plant.

(ii) Technologies

Biogas plants: There are eight biogas plants with a tote] gas capacity of 630 m^3/day. Six of them are of 85 m^3/day capacity, and the remaining two are of 60 m^3/day. All of them are of the conventional Indian (KVIC) design. The plants are spread over three sites in the village to ensure a uniform pressure in the gas distribution system. Each of the sites measure 50m X 50m approximately. The biogas plants are fitted with mechanical stirrers for mixing the inlet dung slurry.

Piping Underground piping of a total length of 40km has been installed for the gas distribution from the plants to the individual households Fourteen water traps have been built at various points of the piping to remove the condensed water.

Number of biogas stoves: Initially in 306 households, currently in 326 households.

(iii) Capital cost Rs. 1,919,000 (1987).

(iv) Results

Since its commissioning in April 1987, the system has run more or less continuously without any major problem. A supervisor and a driver remove the dung from households to the plant daily on a trolley, attached to a tractor. Complete cooking-fuel requirements of 326 out of the 600 families, i.e., 54 per cent, are being met with biogas. The drudgery of collecting firewood by the women belonging to these 326 families and their exposure to smoke has been avoided and hence there has been an improvement in health and quality of life. Furthermore, nearly 13 tons of fresh cattle dung is being transformed to an excellent fertilizer everyday. In addition, 10 of the villagers namely, one supervisor, one driver and eight plant operators, have been employed in their own village. It has been proved that the villagers, by forming a cooperative society, can manage the decentralized energy systems in the village environment successfully.

(v) Management

A registered society, The Silver Jubilee Biogas Producers and Distributors Cooperative Society (SJCS), was established with all the biogas beneficiaries as members. A sum of Rs. 100 per household was charged as share price towards membership of the SJCS. In addition, a sum of Rs. 301 was collected as a connection fee from each beneficiary, with an assurance that the money would be utilized within the village. These sums of money formed the capital base for the Society.

The Society maintains such documents as resolutions of the meetings, cash bills and pass books, share capital register, ledgers and stock registers, accounts etc.

(b) Pura Community Biogas Plant (First Phase) (KSCST, 1983, 1984)

(i) Location

Pura village, in Kunigal Block, Tumkur district, Karnataka State.

(ii) Approach

The energy consumption and requirement patterns of some six villages in the block were studied. After analysing the data, Pura village was selected for installing the biogas plant. Several discussions about the proposed community biogas system were held with the village community so as to ensure its support for the system.

The main approach adopted was: (a) priority was given for cooking needs because cooking alone accounts for 91 per cent of the energy consumed in Pura; (b) to supply gas to all the households to enable the whole community to benefit; (c) to supply gas free of cost because firewood, their cooking fuel, was gathered at zero cost; (d) all households owning bovines should contribute dung to the plant to ensure maximum community participation; (e) dung supply would not be paid as the gas would be supplied free of cost; and (f) digested sludge should be returned to all the dung suppliers on a pro-rata basis. Finally, a "public utility" approach, e.g., having salaried employees, was adopted like in an urban setting unlike the traditional expectation of "voluntary labour" in rural areas.

The complete cost of the system was borne by the sponsors, the Karnataka State Council and Technology (KSCST), and the gas supply system started operating on I June 1982. Intensive training had earlier been imparted to the plant operators and the village women were trained in cooking with biogas. Regular joint discussions of all involved in the scheme, namely the project team, village leaders and beneficiaries, were maintained, with a frequency of at least once a month, about the status of the project. Accounts of dung and sludge were maintained to build the confidence among the beneficiaries/participants.

(iii) Technologies

Biogas plants: The biogas digesters were of the Indian floating-drum type (Rajabapaiah et al, 1992). However, the detailed dimensions were based on the cost-minimization theory developed earlier and on realistic residence times that had been observed under similar conditions and low-cost construction techniques were utilized. The salient features of the modified design are: (a) the volumetric ratio (gas produced/unit volume of the digester) is high, i.e., 0.5 compared to 0.2-0.3 in conventional fixed-dome and floating-drum plants; (b) the plants have a better performance rating compared with the original KVIC plants, producing 14 per cent more biogas at the ambient temperature in spite of the 40 per cent reduction in the digester volume; (c) the plants are shallower and wider compared with the conventional ones, thereby accelerating the rate of gas release from the production zone to the gas holder; hence, the modified plants are easier to construct wherever the ground water table is high, and (d) the plants are 40 per cent cheaper than conventional plants.

The Pura plants are capable of digesting a maximum of 1.25 tons of cattle dung/day and delivering a maximum of 42.5 m biogas/day as well as 1.2 tons/day of sludge. In order to increase the reliability of the system, it was decided to construct two plants (each with half the rated gas production capacity) with a common inlet tank, instead of a single plant.

Sand-bed filters: These filters enable: (a) transporting digested sludge from the biogas plant back to the homes and compost pits; (b) the use of the filtrate which contains some anaerobic micro- organisms, to mix with the input dung thereby marginally enhancing gas production; and (c) a reduction in the water requirement for charging biogas plants (Chanakya and Deshpande, 1993).

The 11 filters constructed at the village can, together, handle as much as 1.7 m^3/day of slurry. Each filter of 4 m^2 area (4m x 1m), consists of three layers; 5 cm of gravel at the bottom, 3 cm of sand in the middle, and a wire mesh on top. The digested slurry effluent is poured to a height of 10 cm above the wire mesh. The maximum recovery of water from the filter is about 70 per cent. The filtered and dried sludge was returned to the dung suppliers at the rate of 600 gms for each kg of dung delivered to the biogas plant.

Piping: A network of underground PVC rigid piping consisting of different diameters, ranging form 65 mm to 15 mm, and totalling 1500 m in length, was installed to connect the households to the plants.

Burners: Low-cost biogas burners made out of discarded tins, costing Rs.15 each and one tenth of the cost of biogas stoves then available in the market, were developed, fabricated and installed in all the households.

(iv) Results

At best, the gas could be supplied for only about I hour/day, leaving most of the households cooking unfinished even for the morning meal. It became clear that dung alone was not sufficient to meet the complete cooking energy requirements and other feedstocks had to be explored. However, on the organizational side, the project provided the following insights: (a) the merits of the slurry filtration and of the non-monetization of dung and filtered sludge rather than buying dung and selling sludge; (b) the advantage in running the system with trained and salaried employees just as in any urban public utility which does not depend on voluntary labour; (c) the importance of training the households in the safe and efficient use of gas; (d) the crucial role of periodic maintenance of the system; and, above all, (e) the complete participation of the community.

After two-and-a-half years of trouble-free operation, the villagers did not want to lose the system despite the disappointments as regard the amount of gas, and they requested the project team to utilize the established infrastructure and divert the gas to noncooking purposes such as electricity generation. This is detailed in section VI. B.

C. China

For over 50 years the Chinese have struggled to develop and diffuse biogas technology. At present, China has about 5 million family biogas plants in working order. Although over 7 million have been constructed in the past, many of them were poorly built with inadequate mixtures of earth, sand and lime, This was mainly because during the 1950s and 1970s "quality" was sacrificed at the altar of "quantity" which has left a lasting impression in farmers' minds of digesters never producing much gas. Today, about 25 million Chinese people use biogas mainly for cooking and lighting. A further 10,000 largeand medium-size biogas digesters are working in food factories, wineries, livestock farms etc. Biogas produced in large enterprises is transferred to centralized biogas supply stations, biogas motive power stations (422 with an installed capacity of 5849 HP) or biogas electric power stations (822 with a total of 7836 kW).

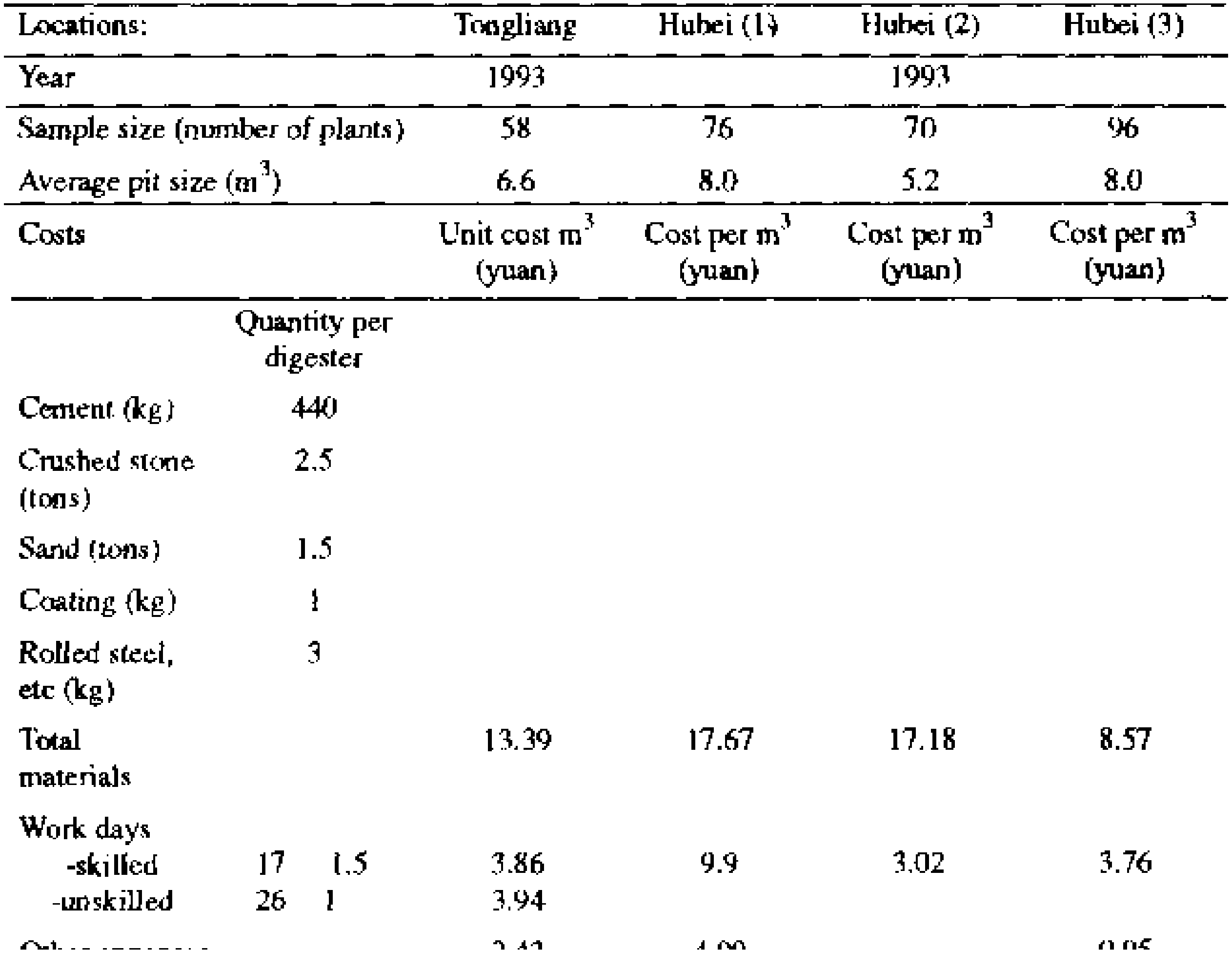
The Bureau of Environment Protection and Energy (1991) estimates that about 54 per cent of the energy requirements (equivalent to about 282 Mtcoe) of the 900 million rural population comes from over 560 Mt of biomass, mainly in the form of straw and firewood although this is probably a conservative estimate. Continued reliance on traditional patterns of biomass supply and use to meet rural household fuel needs may result not only in greater disparity between supply and demand, but also in greater disruption of local agricultural and ecological systems. Improved efficiency of biomass production and use thus has become imperative (World Bank, 1985). Additionally, energy shortages may be one of the fundamental motives for the continued development of biogas. The use of human excrement in digesters rather than spreading it on the field (as is usual in China) can destroy more than 90 per cent of the intestinal parasites and other pathogens thus making the nutrient recycling process far more hygienic. This is because the Chinese digestion plants have a long retention time of about six months (Rajabapaiah et al, 1992). In addition to animal and human dung, about 2 Mt straw is digested each year (Daxiong et al, 1990; Zong 1989).

Daxiong et al (1990) carried out an economic analysis of 58 biogas plants in Tongliang, Sichuan, and compared this with data produced by other researchers in 242 biogas plants in Hubei. Their analysis shows a high rate of return on investment in biogas and short payback periods of between one and four years (see table 10). Capital costs vary from 15 to 40 yuan per m^3 of digester capacity, and the annual gas output varies from about 30 to 40 m^3 per yr for each m^3 of digester. The annual value of this biogas in terms of savings in coal, kerosene, burned biomass, labour and fertilizer varies from about 7 to 16 yuan If operating costs are included, the internal rate of return (IRR) varies from 59 per cent to 114 per cent.

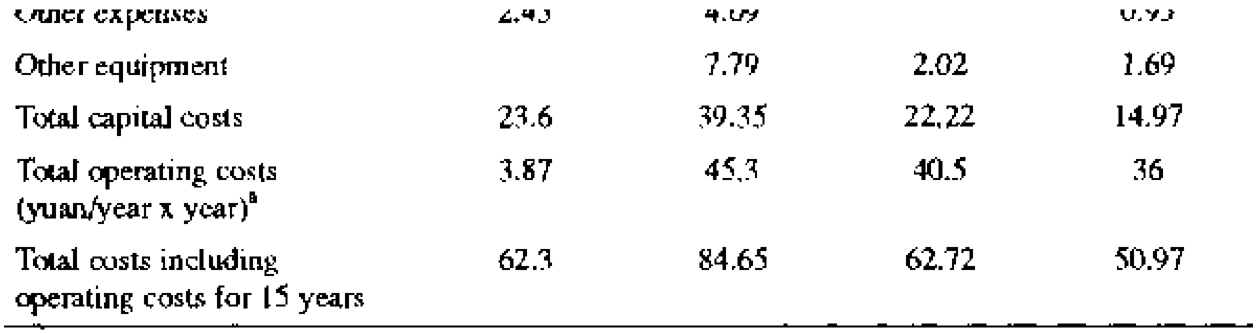
Biogas plants in China have been subsidized and/or received low-interest loans. Since 1980, the State has allocated more than 10 million yuan every year for the development of biogas, which represents 200 yuan for each plant constructed every year. This money is spent in improving biogas equipment, promotion, standardization, servicing, training, research on new technology etc. Standardized production techniques and equipment have significantly improved the reliability and quality of biogas supply; there are 116 biogas research centres in China today (Daxiong et al, 1990; Anon., 1991).

The more recent opening-up of the economy to financial incentives is beginning to have a major effect on the biogas programme. Until 1983, when a peasant built a digester the State and local government provided two thirds of the money and also guaranteed the supply of building materials. Since 1983, there has been a move towards financial selfreliance which has resulted in a reduction in subsidies from two thirds to one third which, in turn, has led to a decrease in the construction of biodigesters. Although the rate of return remains high, the increase in the initial capital outlay is a disincentive to users. For example, Sichuan province which before 1983 built an average of 250,000 biodigesters annually, constructed only 81,000 in 1983 (Daxiong et al, 1990).

Socio-economic changes in China are also affecting biogas production. For example, rural migration to the more-economically-developed areas has resulted in peasants not having sufficient organic matter to fill their biogas digesters (since they produce fewer pigs); also, since biogas production is labour-intensive, there are not enough people (particularly young people) to take care of the biodigesters. Additionally, due to improving living standards, a growing number of peasants prefer to buy privately-sold coal than to use biogas, because it saves time which can be spent on more lucrative work (Daxiong et al, 1990).



Locations:			Tongliang	Hubei (1)	Hubei (2)	Hubei (3)
Year			1993		1993	
Sample size (number of plants)			58	76	70	96
Average pit size (m^3)			6.6	8.0	5.2	8.0
Costs			Unit cost m^3 (yuan)	Cost per m^3 (yuan)	Cost per m^3 (yuan)	Cost per m^3 (yuan)
	Quantity per digester					
Cement (kg)	440					
Crushed stone (tons)	2.5					
Sand (tons)	1.5					
Coating (kg)	1					
Rolled steel, etc (kg)	3					
Total materials			13.39	17.67	17.18	8.57
Work days						
-skilled	17	1.5	3.86	9.9	3.02	3.76
-unskilled	26	1	3.94			



Other expenses	2.43	4.09		0.93
Other equipment		7.79	2.02	1.69
Total capital costs	23.6	39.35	22.22	14.97
Total operating costs (yuan/year x year)[a]	3.87	45.3	40.5	36
Total costs including operating costs for 15 years	62.3	84.65	62.72	50.97

Table 10. Economic analysis of biogas plants in Tongliang

Notes: a Life = 15 years

The costs of construction of biogas plants are difficult to compare between countries and over time due to the importance of controlled prices in China. The capital costs in Tongliang and Hubei vary from 15 to 40 yuan per 1 m^3 of digester capacity, and the annual gas output vanes from about 30 to 45 m^3 yr from each m^3 of digester.

The value of this gas in terms of savings in coal, kerosene, burned biomass, labour and fertilizer varies from about 7 to 16 yuan /m^3 digester capacity. This represents a paybach period of between about I and 5 years. If the daily operating costs are included, the internal rate of return vanes from about 59 to 14.2 per cent.

In the 1975-1978 period, each biogas plant cost about 80 yuan as compared with 156 yuan for a 6.6 m^3 plant in 1983, although this involved twice as much labour (80 work days/plant in 1988) and the output from each digester averaged only 151 m^3 compared with nearly 300 m in the current plants. Source: Daxiong et a. 1990.

This changing situation seems to indicate that production and management of biogas will become more centralized and industrialized in both rural and urban areas and will be used as part of an integrated production system. In this way, advanced technology could be used to increase production and financial returns and thus will have greater appeal to peasants. As living standards improve so will the demand for energy. Since commercial energy production in China cannot keep pace with the expected rise in consumption, adequate energy supplies in rural areas cannot be guaranteed. Hence, biogas appears to be a very viable energy source.

VI. Conversion of biomass into electricity

A. Gasification

Usually, electricity from biomass is produced via the condensing steam turbine, in which the biomass is burned in a boiler to produce steam' which is expanded through a turbine driving a generator. The technology is well-established, robust and can accept a wide variety of feedstocks. However, it has a relatively high unit-capital cost and low operating efficiency with little prospect of improving either significantly in the future. A promising alternative is the gas turbine fuelled by gas produced from biomass by means of thermochemical decomposition in an atmosphere that has a restricted supply of air (Larson and Svenningson, 1991). Gas turbines have lower unit-capital costs, can be considerably more efficient and have good prospects for improvements of both parameters.

The basic principles of gasification have been under study and development since the early nineteenth century, and during the Second World War nearly a million biomass gasifier-powered vehicles were used in Europe. Interest in biomass gasification was revived during the "energy crisis" of the 1970s and slumped again with the subsequent decline of oil prices in the 1980s. The World Bank (1989) estimated that only 1000 - 3000 gasifiers have been installed globally, mostly small charcoal gasifiers in South America.

Biomass gasification systems generally have four principal components:

(a) Fuel preparation, handling and feed system;

(b) Gasification reactor vessel;

(c) Gas cleaning, cooling and mixing system;

(d) Energy conversion system (e.g., internal-combustion engine with generator or pump set, or gas burner coupled to a boiler and kiln).

When gas is used in an internal-combustion engine for electricity production (power gasifiers), it usually requires elaborate gas cleaning, cooling and mixing systems with strict quality and reactor design criteria making the technology quite complicated. Therefore, "Power gasifiers worldwide have had a historical record of sensitivity to changes in fuel characteristics, technical hitches, manpower capabilities and environmental conditions" (Sanday and Lloyd, 1991, p. 14).

Gasifiers used simply for heat generation do not have such complex requirements and are, therefore, easier to design and operate, less costly and more energy-efficient.. All types of gasifiers require feedstocks with low moisture and volatile contents. Therefore, goodquality charcoal is generally best, although it requires a separate production facility and gives a lower overall efficiency.

In the simplest, open-cycle gas turbine the hot exhaust of the turbine, is discharged directly to the atmosphere. Alternatively, it can be used to produce steam in a heatrecovery steam generator. The steam can then be used for heating in a cogeneration system; for injecting back into the gas turbine, thus improving power output and generating efficiency known as a steam-injected gas turbine (STIG) cycle; or for expanding through a steam turbine to boost power output and efficiency - a gas turbine/steam turbine combined cycle (GTCC) (Williams & Larson, 1992). While natural gas is the preferred fuel, limited future supplies have stimulated the expenditure of millions of dollars in research and development efforts on the thermo-chemical gasification of coal as a gas-turbine feedstock. Much of the work on coal-gasifier/gas-turbine systems is directly relevant to biomass integrated gasifier/gas turbines (BlG/GTs). Biomass is easier to gasify than coal and has a very low sulphur content. Also, BIG/GT technologies for cogeneration or stand-alone power applications have the promise of being able to produce electricity at a lower cost in many instances than most alternatives, including large centralized, coal-fired, steam-electric power plants with flue gas desulphurization, nuclear power plants, and hydroelectric power plants.

It appears that the BIG/GT technology could be available for commercial power generating applications before the turn of the century. According to Williams and Larson (1992), efficiencies of 40 per cent or more will be demonstrated in the mid-1990s, and by 2025 these could reach 57 per cent using fuel-cell technologies being developed for coal. Gasifiers using wood and charcoal (the only fuel adequately proved so far) are again becoming commercially available, and research is being carried out on ways of gasifying other biomass fuels (such as residues) in some parts of the world (Foley and Barnard, 1983). Problems to overcome include the sensitivity of power gasifiers to changes in fuel characteristics, technical problems and environmental conditions. Capital costs can still sometimes be limiting, but can be reduced considerably if systems are manufactured locally or use local materials. For example, a ferrocement gasifier developed at the Asian institute of Technology in Bangkok had a capital cost reduced by a factor of ten (Mendis, undated). For developing countries, the sugarcane industries that produce sugar and fuel ethanol are promising targets for near-term applications of BIG/GT technologies (Ogden et al, 1990).

Gasification has been the focus of attention in India because of its potential for largescale commercialization. Biomass gasification technology could meet a variety of energy needs, particularly in the agricultural and rural sectors. A detailed micro- and macroanalysis by Jain (1989) showed that the overall potential in terms of installed capacity could be as large as 10,000 to 20,000 MW by the year 2000, consisting of small-scale decentralized installations for irrigation pumping and village electrification, as well as captive industrial power generation and gridfed power from energy plantations. This results from a combination of favourable parameters in India which includes political commitment, prevailing power shortages and high costs, potential for specific applications such as irrigation pumping and rural electrification, and the existence of an infrastructure and technological base. Nonetheless, considerable efforts are still needed for large- scale commercialization.

B. Pura village, India

In India, there has recently been increasing interest in large community-sized digesters, of which around 25 are now in operation nationwide. An example of one of the few successful community biogas plants can be found in Pura village, some 100 miles west of Bangalore. The Centre for Application of Science and Technology to Rural Areas (ASTRA) at the Indian Institute of Science at Bangalore helped to build the community plant. As explained earlier, despite careful planning and execution, the plant was initially subject to many problems. However, ASTRA learnt a lot from this first effort and used the experience and recommendations of the villagers to redesign the plant to meet different requirements (Ready et al, 1990).

As of April 1991, the population of Pura village was 463. Before the biogas system was installed, only 45 per cent of the homes were electrified from the grid (Rajabapaiah et al, 1992), and this often did not provide enough electricity to power their lights.

Although the team from ASTRA had assumed that gas for cooking would be a priority, the villagers of Pura actually put clean drinking water first. It had been calculated that the digester could supply enough gas to power a generator to supply electricity which could then be used to pump water to a reservoir. However, the villagers, understandably, wanted assurance that other people would supply dung before they handed over their own. At the same time, ASTRA wanted the assurance that people would supply dung before it set up the water pump. There seemed no way out of this impasse, and the biogas project stopped in 1984. Meanwhile, other developmental project work by the ASTRA team within the village continued, and it was eventually able to overcome many of the problems and revive the project.

It was possible to set up the biogas plant in the first place because the villagers had nothing to lose by participating in the project. Women already collected the dung for use as fertilizer, the project merely "borrowed" this dung and returned an equivalent quantity of better-quality slurry. However, to make it successful required the establishment of community involvement in the organization and running of the scheme. According to Rajabapaiah et al, (1992),

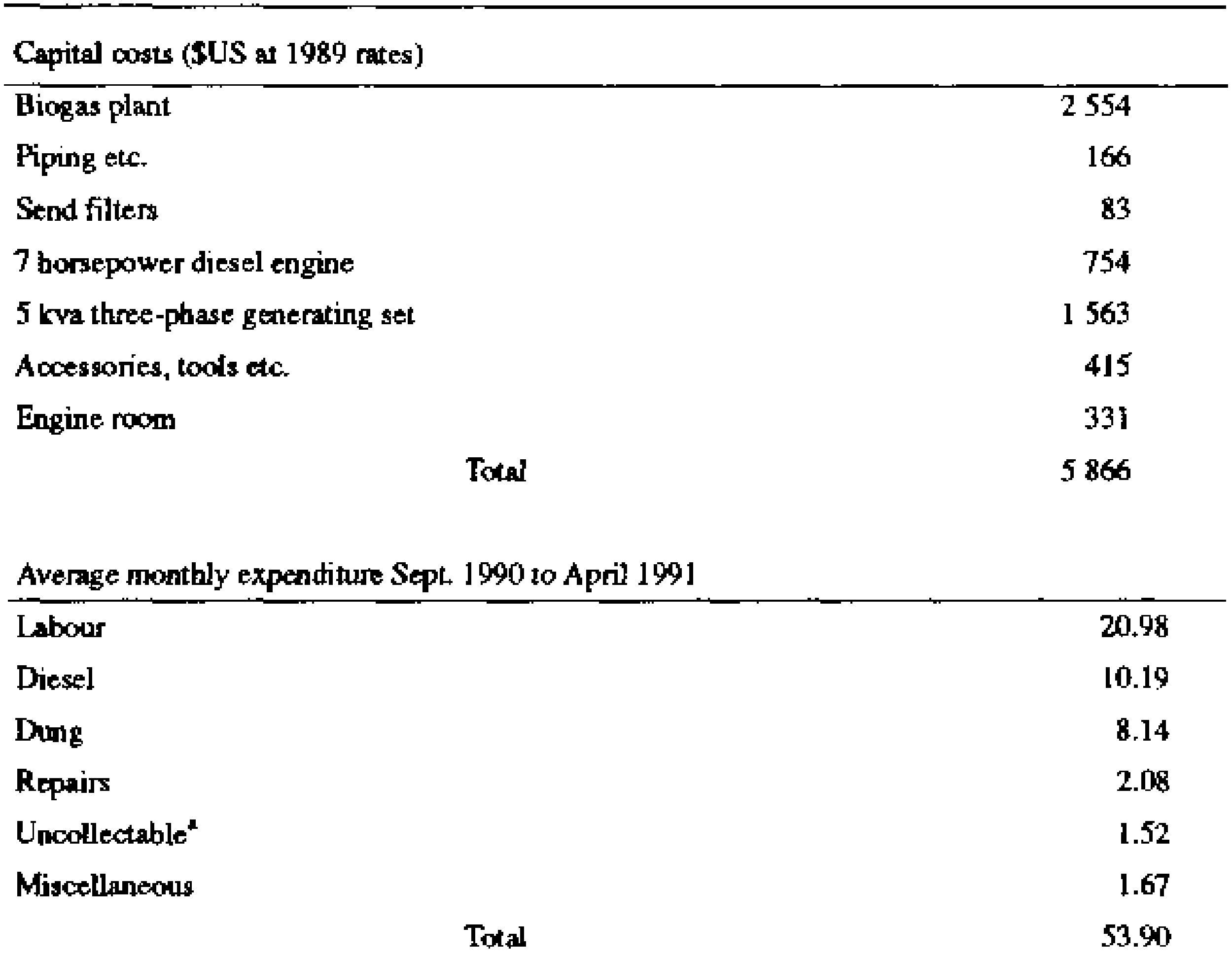
> "The crucial administrative step in Pura was establishing a scheme for dung collection and sludge return based on a delivery fee (of Rs. 0.02 or 0.1586 US cents per kilogram), which goes primarily to the women. This ensures the involvement of women who are the principal beneficiaries of the water supply and the electric lights."

Once villagers experienced the benefits of the gas - clean drinking water from taps, a reliable source of electricity, improved fertilizer etc. - they were willing to take responsibility for the running of the digester, and ensuring that the benefits were distributed fairly. A village development society (grama vikasa sabha) was established involving the traditional community leaders. Pura had not had a village committee since before colonial days. They achieved an outstanding 93-per cent collection of dues from 1988 to 1991. Equity is maintained by keeping records of the weight of dung delivered and compost received for each family. These records are displayed publicly for all to see. The system appears to work well (Hall and Rosillo-Calle, 1991; Rajabapaiah et al, 1992).

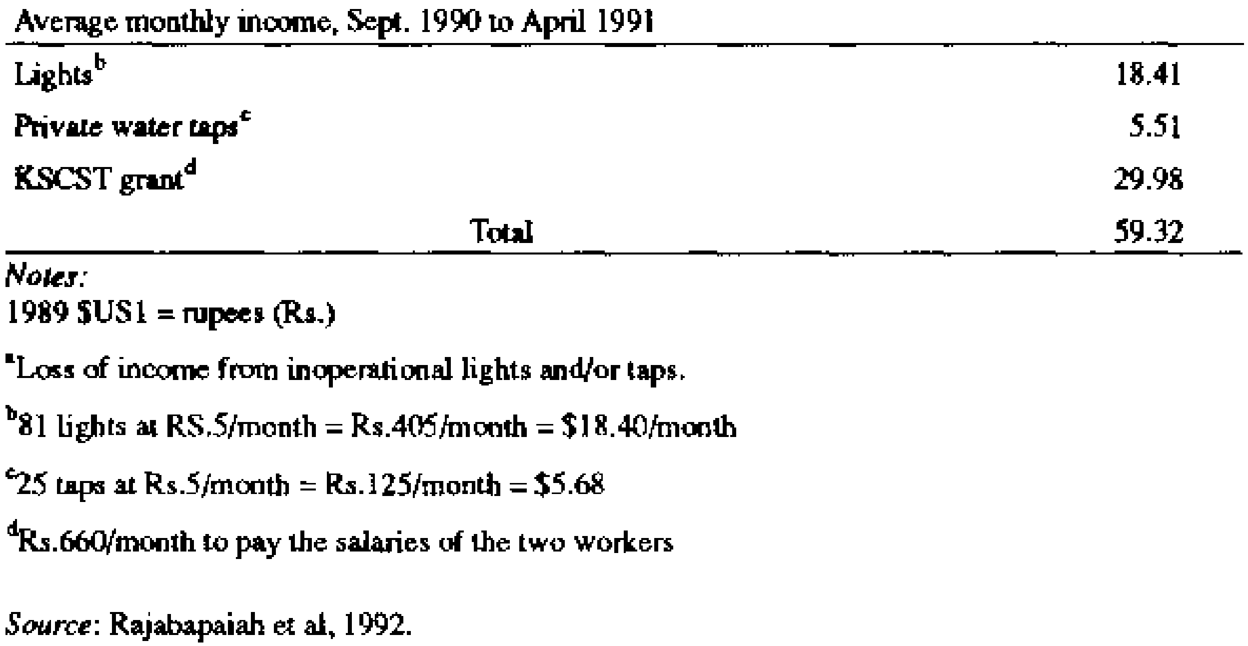
The biogas system still consists of two plants with a common inlet tank connected to a dualfuel engine. Between September 1987 and April 1991, the engine ran for about 4521 hours, and an 80 per cent diesel replacement rate was achieved. The project is now managed by the villagers and employs two village youths to operate the biogas plant and the electricity and water distribution systems, while maintaining plant records and accounts. Their salaries are provided by the project sponsor, the Karnataka State Council for Science and Technology (Rajabapaiah et al, 1992).

In September 1987, the water-supply system began operating consisting of a 3 HP pump lifting water from a 50 m depth to an overhead tank from which it is distributed by gravity to nine public taps, the location of which was decided by the villagers. This saved the villagers travelling 1.6 km for water collection and caused an increase in per capita consumption of water, although the villagers have restricted access to the water supply to keep the consumption to a reasonable level. By September 1990, 29 private taps had been installed in households for which the owners pay a tariff. Excess electricity is used to power domestic lights (currently 10^3 X 20 W fluorescent tubes), for which the recipients also pay (Rajabapaiah et al, 1992).

The economics of production are highlighted in table 11. From September 1990 to April 1991, the revenues from lighting and private water taps covered 93 per cent of the expenditures apart from the workers' salaries. The biogas system is operated for about 4.2 hrs/day with a dung input of 291 kg/day and a unit cost of energy over $US0.25/kWh. However, the system is capable of handling 1250 kg dung/day (the amount of dung actually produced in the village) and operating for 18 hrs/day which would reduce the unit cost considerably. The income from lights and private water taps currently covers only about half of the recurring expenses, but as demand for electricity and supply of dung increases, and costs fall, this will become more economic. When the hours of operation reach 6 hrs/day, at current tariff charges, the system will cover all of its operating expenses and the surplus can be used to return the capital investment. At 15.1 hrs/day, the unit cost of electricity is lower than that from a central power station. Extra gas can be used, for example, for cooking or to provide power for local industries, thereby increasing living standards even further. There are plans under consideration for a dairy development scheme, selling milk and providing more dung.



Capital costs ($US at 1989 rates)	
Biogas plant	2 554
Piping etc.	166
Send filters	83
7 horsepower diesel engine	754
5 kva three-phase generating set	1 563
Accessories, tools etc.	415
Engine room	331
Total	5 866
Average monthly expenditure Sept. 1990 to April 1991	
Labour	20.98
Diesel	10.19
Dung	8.14
Repairs	2.08
Uncollectable*	1.52
Miscellaneous	1.67
Total	53.90



Average monthly income, Sept. 1990 to April 1991	
Lights[b]	18.41
Private water taps[c]	5.51
KSCST grant[d]	29.98
Total	59.32

Notes:
1989 $US1 = rupees (Rs.)

[a] Loss of income from inoperational lights and/or taps.

[b] 81 lights at RS.5/month = Rs.405/month = $18.40/month

[c] 25 taps at Rs.5/month = Rs.125/month = $5.68

[d] Rs.660/month to pay the salaries of the two workers

Source: Rajabapaiah et al, 1992.

Table 11. Economic analysis of a biogas electricity system, Pura village, India

> Rajabapaiah et al, (1992) believe that
>
> "The Pura biogas plant is held together and sustained by the convergence of individual and collective interests and that Non-cooperation with the community biogas plant results in a heavy individual price (access to water and light being cut off by the village), which is too great a personal loss to compensate for the minor advantages of non-cooperation to collective interests."

Residents now realise that biogas has raised their standard of living by making their lives more comfortable at a relatively low cost, so they will ensure that the system is maintained; this is a good illustration of the meaning of sustainable development. One resident is quoted as saying "The grid provides government power, but biogas provides people power, which is far more reliable".

People in Pura village are now thinking of building a wood gasifies to provide producer gas as a supplement to its supply of biogas. Their gasifier would be similar to the successful project in the nearby village of Hosahalli the next case study - which provides electricity for lighting and water pumping. They are establishing an energy forest to grow the feedstock and ASTRA is confident that the villagers will follow it through, having seen a nearby success of a gasification system and the benefits of electrification.

C. Hosahalli village, India

The ASTRA group in Bangalore (Ravindranath et al, 1990; Ravindranath and Mukunda, 1990) had carried out studies, at the micro-level, of biogas and producer-gas-driven electricity generating sets in the village of Hosahalli in Karnataka State. They believe that

> "The field experiments at Hosahalli village have demonstrated so far the technical feasibility of a decentralized electricity generation system based on wood gasifier biogas technology for meeting various energy needs of remote rural settlements" (Ravindranath et al, 1990 p. 1975).

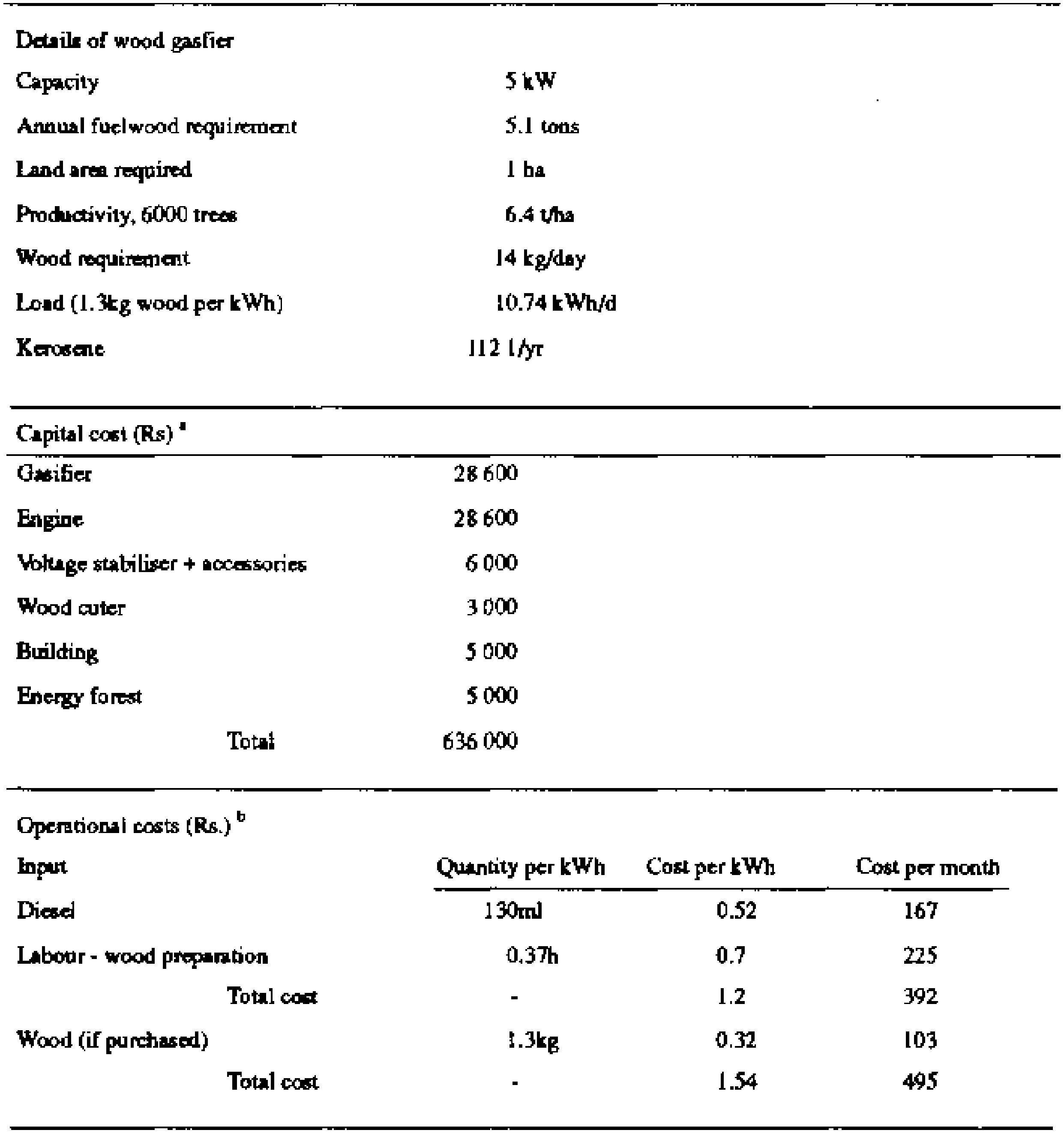
The wood gasifies provides gas to drive a 7 HP dual-fuel engine (80 per cent woodgas and 20 per cent diesel) and a 5 kVA 3-phase generator. The life of the engine has been taken to be 20,000 hours, after which the engine has to be replaced. The cost of the system is based on an operating time of 15 hours/day. Table 12 shows the operational and capital costs of a 3.7 kW wood system for generating electricity. The operational cost considering diesel and labour is Rs. 1.22 per kWh if wood is free, and Rs 1.54 if wood is to be purchased. The capital cost amounts to Rs. 63,600; in contrast, the capital cost of an equivalent engine running on diesel is estimated to be around Rs. 39,600.

According to Ravindranath and Mukunda (1990), at the current level of operation for lighting only for 4 hours/day, the wood-gasification system would be economic only if electricity is priced at Rs 3.5 per kWh. However, if the gasification system operates beyond 5 hours/day, the unit cost of energy becomes cheaper than the diesel system. The economic viability could be improved further by: (a) matching of the gasifier-diesel engine capacity (5 kW) since currently a 3.7 kW generator is connected; and (b) by diversifying the use of the gasifier system for meeting other energy needs such as pumping water which would lead to increased capacity utilization. At present, a subsidy is still required at this stage of development, but there is a strong possibility that the system will become economically viable in the near future. It should be noted that the centralized electricitygeneration and distribution systems are also subsidized in the district. For comparison, the present subsidized price of grid-based electricity is Rs. 0.65/kWh.

An important aspect of this project is that the villagers are prepared to pay over twice as much for their electricity (Rs. 1.3/kWh) because: (a) the supply is reliable; (b) it provides ancillary benefits (clean drinking water, flour mill etc.); (c) quality of supply; and (d) of emergence of self-reliance (the formation of a village management committee) (Ravindranath, in press).

D. Mauritius

Mauritius is dominated by the production of sugar, which represents around 88 per cent of the cultivable area Sugarcane accounts for nearly 20 per cent of the country's gross domestic product (GDP) and over 40 per cent of its export earnings. The economy is thus quite sensitive to fluctuations in domestic sugar production and world sugar markets. Almost 60 per cent of total energy



Details of wood gasfier	
Capacity	5 kW
Annual fuelwood requirement	5.1 tons
Land area required	1 ha
Productivity, 6000 trees	6.4 t/ha
Wood requirement	14 kg/day
Load (1.3kg wood per kWh)	10.74 kWh/d
Kerosene	112 l/yr

Capital cost (Rs) [a]	
Gasifier	28 600
Engine	28 600
Voltage stabiliser + accessories	6 000
Wood cuter	3 000
Building	5 000
Energy forest	5 000
Total	636 000

Operational costs (Rs.) [b]

Input	Quantity per kWh	Cost per kWh	Cost per month
Diesel	130ml	0.52	167
Labour - wood preparation	0.37h	0.7	225
Total cost	-	1.2	392
Wood (if purchased)	1.3kg	0.32	103
Total cost	-	1.54	495

Table 12. Costs of a 3.7 kW woodgasifier system for generating electricity, Hosahalli village, India

Notes: $1 -17.2 Rupees (Rs.) (January 1990).

The economic analysis of the wood gas-based electricity system was carried out using a discounted cash flow (DCF) technique, namely, net present value (NPV) method as follows:

NPV - Present value of life cycle benefits Present value of total life cycle costs. Total lifecycle benefits were calculated from the sale of electricity. The unit cost of sale of energy (Rs/kWh) was computed by setting NPV-O and solving for the cost of energy. The unit cost of energy was calculated taking a discount rate of 12 per cent, for the wood and gasbased system and then compared with a diesel-based system of similar capacity.

2 Life of gasifier 50,000 hours; annual maintenance cost 5 per cent, and operational level 20 hours/day.

Cost per month is calculated considering the current energy consumption of 10.74 kWh per day. Labour is priced at Rs. I 5 for 8 hours, and wood is freely available from the energy forest Its market price is Rs.0.25/kg of twigs.

Source: Revindranath et al, 1990; Ravindranath And Makunda, 1990 requirements in Mauritius (excluding wood fuels primarily used for cooking) are met by bagasse-fired generation of power and steam in the sugarcane industry. Bagasse is playing an increasing role in power supply and currently provides around 10 per cent of Mauritius' electricity requirements. Woody biomass supplied approximately 63 per cent ($3.5x10^6$ GJ) of all the energy required for household cooking in the country in 1988. There is a potential for producing $10.2x10^6$ GJ, using the by-products of the sugar industry and to a lesser extent solar energy.

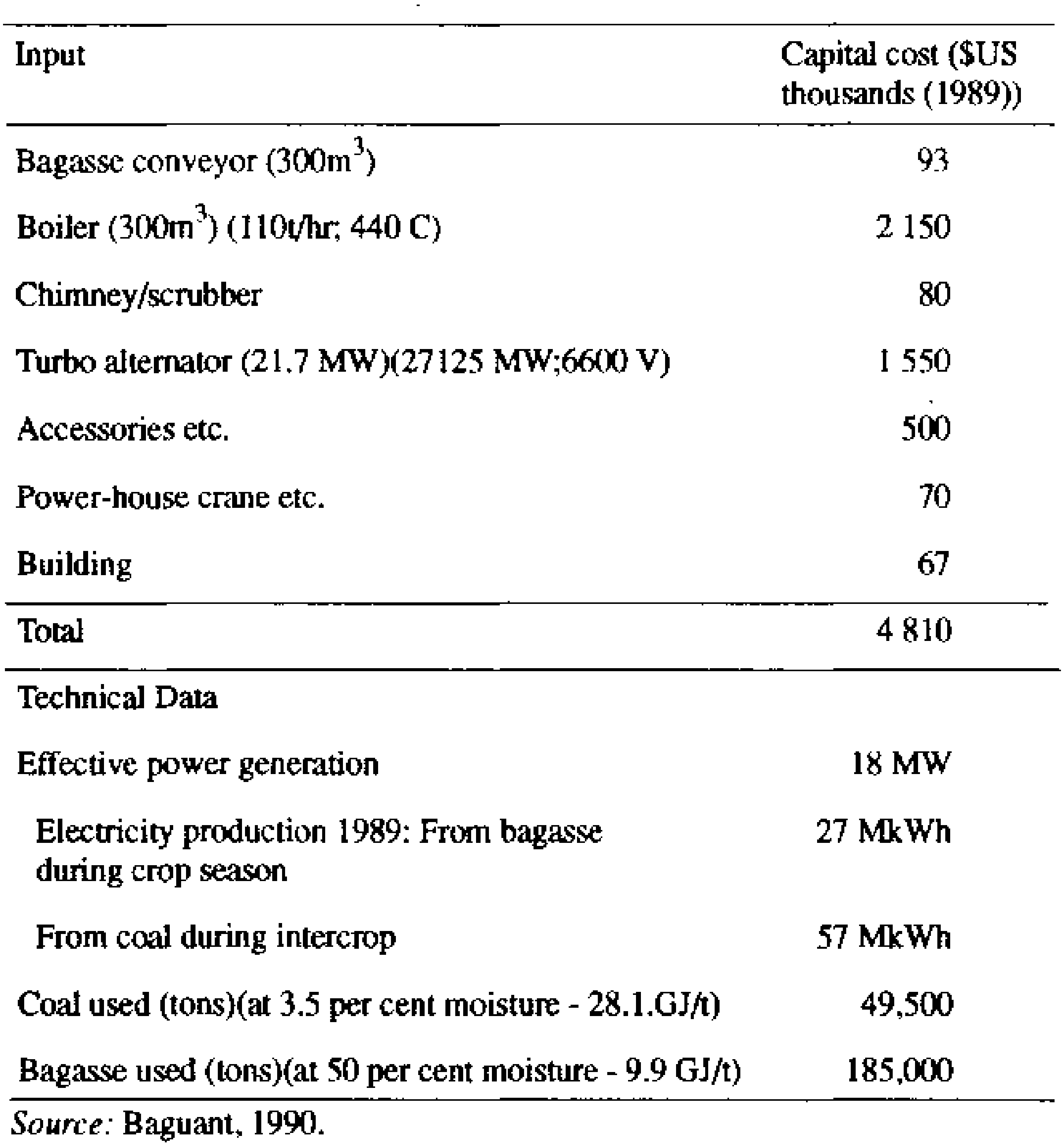
According to Baguant (1990) the Flacq United Estate Limited (FUEL) is the largest sugar estate in Mauritius with an annual average production of 700,000 tons of fresh cane, and 79,000 tons of sugar. FUEL was among the first sugar estates to produce excess steam for production of electricity for sale to the national grid in the mid-1950s. In 1982, the FUEL sugar estate installed a dual-fuel, bagasse and coal furnace to produce electricity all year-around and substantially increase its output. Bagasse is used at the rate of about 3540 t/hour and coal at about 14 l/hour. A boiler with capacity of 110 t steam/in, 42 bars pressure, 440°C and a condensing turbine coupled with a generator of 21.7 MW led to an average production of $75x10^6$ kWh of excess electricity ($30x10^6$ kWh produced solely from bagasse during the crop season and $45X10^6$ kWh from coal). This represents about 12-15 per cent of the total electricity requirements of Mauritius.

In 1989, the electricity output by FUEL increased to $94X10^6$ kWh ($26x10^6$ from bagasse and 68X106 from coal) representing about 16 per cent of the country's total requirements and resulting in over 80 per cent of the electricity being sold to the grid. Unfortunately detailed economic costs of production are not yet available fdor the updated plant following negotiation with the electricity boards, but some available information is set out in table 13.

E. The Philippines

In August 1980, the Government of the Philippines raised the price of fuels, doubling the price of diesel within two years. This adversely affected the farmers who pumped water for irrigation and caused severe economic difficulties. The Government's response was to look for alternative energy sources and gasifiers were chosen due to the extensive R and D experience of the University of Philippines in this field (Foley and Barnard, 1983).

Attempts to introduce gasifiers on a large scale began in 1981 when the Government, with assistance from USAID, embarked on an ambitious programme which initially planned to retrofit 1150 diesel-pump-powered irrigation systems converting them to gas/diesel fuel operations with charcoal-fed gasifiers. This involved 495 irrigator's service associations (ISA) with a total membership of over 26,000 farmers and covered over 46 000 ha The Government's main agency in promoting the use of the gasifiers was the Farm Systems Development Corporation (FSDC). Bernardo and Kilayko (1990) carried out an analysis of the gasifier programme. The results were very disappointing, with just 1 per cent (three out of 248 plants) still being used in1987; and over 80 per cent in need of repair. The gasifier programme thus failed to achieve its objectives in reducing farmers' dependence on diesel fuel and in improving their financial position. The causes of this unsatisfactory outcome are claimed to arise more from institutional and management problems than from any inherent weakness in the technology itself.



Input	Capital cost ($US thousands (1989))
Bagasse conveyor ($300m^3$)	93
Boiler ($300m^3$) (110t/hr; 440 C)	2 150
Chimney/scrubber	80
Turbo alternator (21.7 MW)(27125 MW;6600 V)	1 550
Accessories etc.	500
Power-house crane etc.	70
Building	67
Total	4 810
Technical Data	
Effective power generation	18 MW
Electricity production 1989: From bagasse during crop season	27 MkWh
From coal during intercrop	57 MkWh
Coal used (tons)(at 3.5 per cent moisture - 28.1.GJ/t)	49,500
Bagasse used (tons)(at 50 per cent moisture - 9.9 GJ/t)	185,000

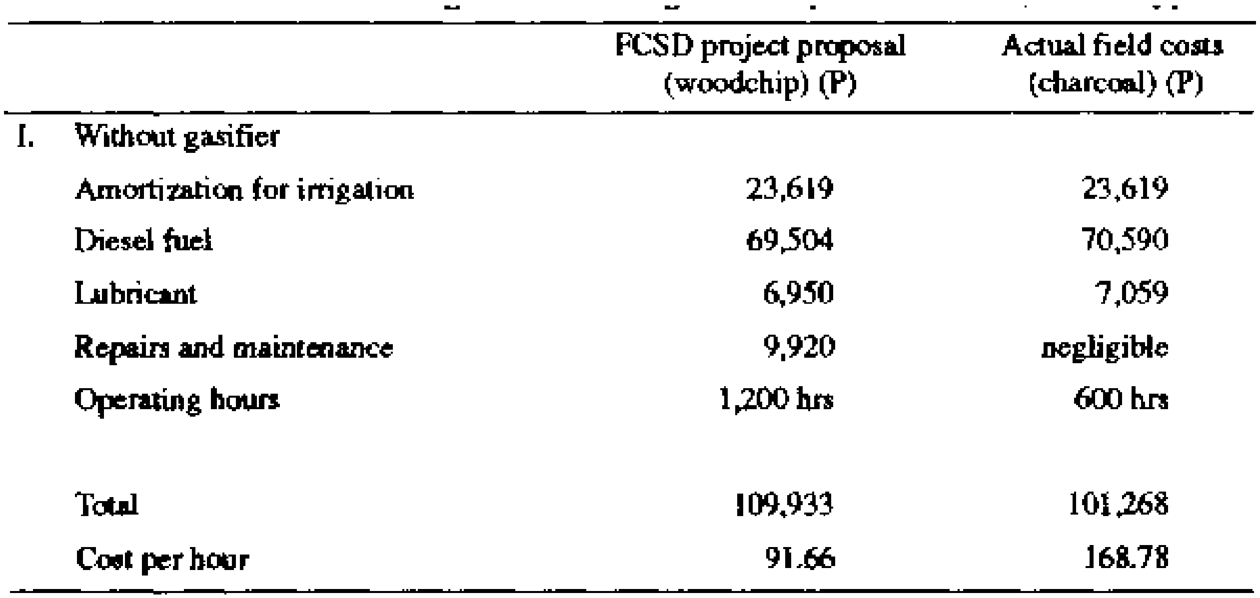
Source: Baguant, 1990.

Table 13. Capital costs of FUEL'S dual-uel thermal power plant, Mauritius

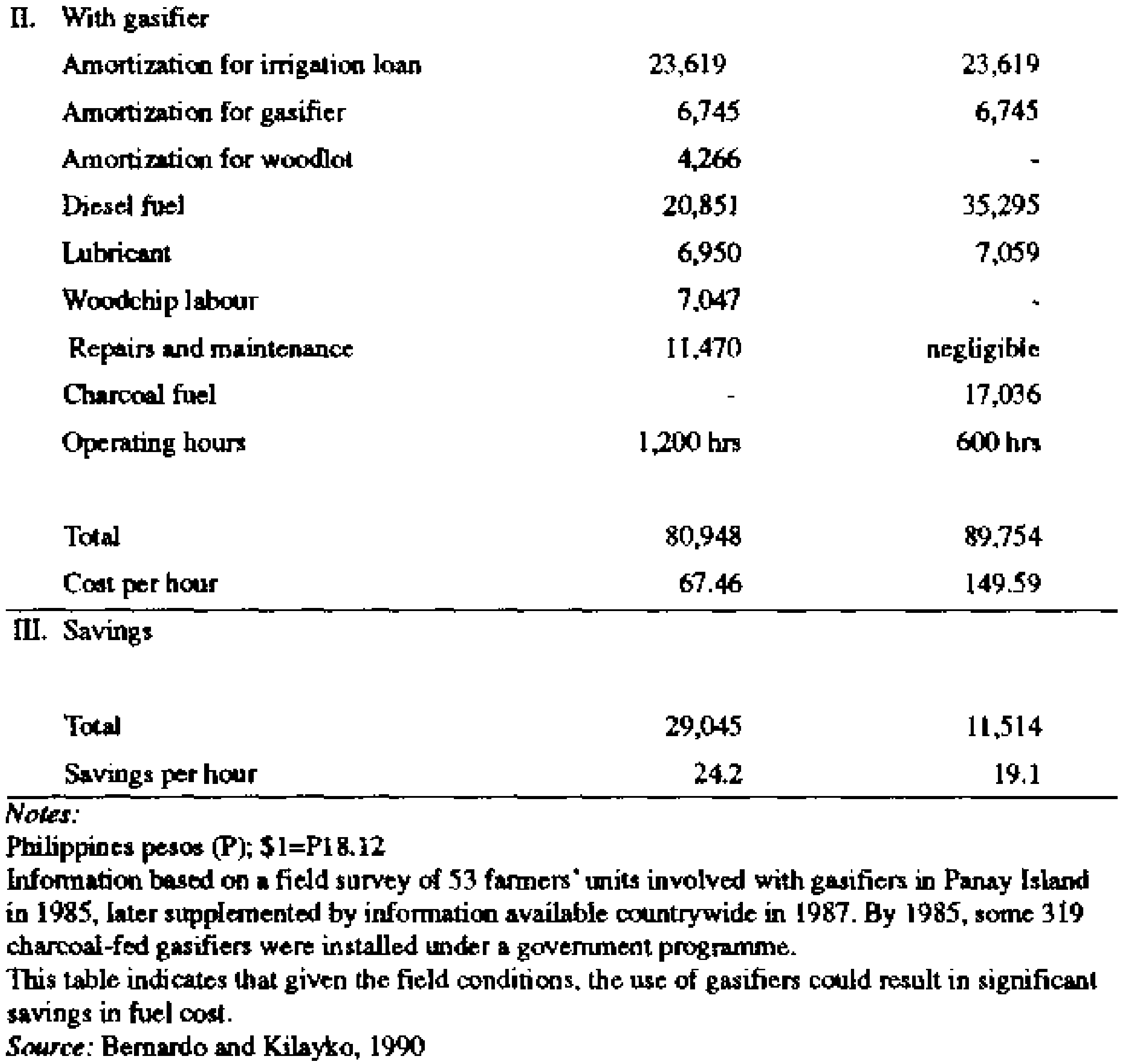
According to Bernardo and Kilayko (1990), success required a "fit" between the technology, the users and the implementing agency. Many farmers did not view their irrigation systems as a means of improving their productivity and profitability, but largely as a type of insurance against inadequate rainfall. Therefore, they saw lime value in gasifier-powered pumps. The gasification programme was imposed from above with little understanding of the users' needs. The method of financing also failed to provide clear economic signals to the farmers, and failed to acknowledge the financial realities of the farmers' lives. Many farmers did not know how much the gasifier was costing them, and they frequently did not realize that its costs were covered by a loan rather than a grant. As projects failed, this clearly affected their ability to meet loan repayments.

The half-hearted support of the FSDC area officers and their more general financial difficulties created serious problems in implementation, and the FSDC were generally unable to enforce minimum requirements of its projects with many consequent failures. Additionally, the failure of the ISAs to observe proper maintenance practices ultimately resulted in engine failures, and even permanent damage to engines. Poor maintenance reduced the life expectancy of the gasifier which, in turn, raised the annual capital cost charge significantly. An additional problem was that inflation had a very negative effect on farmer's living standards forcing them to cut down on production inputs, one of which was irrigation - not a priority for many farmers despite FSDC's objectives.

As indicated in table 14, the use of gasifiers could have resulted in significant savings in fuel costs; however, this was not so. Solely on the basis of the cost of fuel, running a 50 HP diesel motor on 50 per cent diesel and 50 per cent charcoal produced only minor savings in 1982 and 1985, and losses in 1983 and 1984. This was partly because charcoal prices increased by 600 per cent from 1977 to 1985 and charcoal was, on occasion, more scarce and expensive than diesel due to increasing household and industrial demand. The greatest savings occurred in 1987 when charcoal prices fell faster than those of diesel. Charcoal gasifiers thus did not completely displace the use of diesel oil. The farmers found it inconvenient to procure two types of fuel without obtaining sufficient benefits for their extra efforts. The implementing agency was inadequately funded and was subject to unrealistic installation targets imposed by the political system. This case highlights the considerable difficulties in setting up and running an infrastructure necessary to carry out repairs and supply spare parts to support new technologies. It illustrates the even more difficult problem of ensuring an adequate supply of raw material (charcoal) at acceptable prices (Bernardo and Kilayko, 1990).



		FCSD project proposal (woodchip) (P)	Actual field costs (charcoal) (P)
I.	Without gasifier		
	Amortization for irrigation	23,619	23,619
	Diesel fuel	69,504	70,590
	Lubricant	6,950	7,059
	Repairs and maintenance	9,920	negligible
	Operating hours	1,200 hrs	600 hrs
	Total	109,933	101,268
	Cost per hour	91.66	168.78



II. With gasifier		
Amortization for irrigation loan	23,619	23,619
Amortization for gasifier	6,745	6,745
Amortization for woodlot	4,266	-
Diesel fuel	20,851	35,295
Lubricant	6,950	7,059
Woodchip labour	7,047	-
Repairs and maintenance	11,470	negligible
Charcoal fuel	-	17,036
Operating hours	1,200 hrs	600 hrs
Total	80,948	89,754
Cost per hour	67.46	149.59
III. Savings		
Total	29,045	11,514
Savings per hour	24.2	19.1

Notes:
Philippines pesos (P); $1=P18.12
Information based on a field survey of 53 farmers' units involved with gasifiers in Panay Island in 1985, later supplemented by information available countrywide in 1987. By 1985, some 319 charcoal-fed gasifiers were installed under a government programme.
This table indicates that given the field conditions, the use of gasifiers could result in significant savings in fuel cost.
Source: Bernardo and Kilayko, 1990

Table 14. Estimated costs of gasification using wood chips and charcoal, the Phillipines

F. The South Pacific

The island States of the South Pacific are generally dependent on imported fossil fuels. Due to the high oil prices in the early 1980s and plentiful indigenous biomass resources (on the larger islands), there was considerable interest in installing biomass gasification units for electricity production and crop drying. Available resources include residues from over 600,000 ha of copra plantations and almost 44.5 million ha of forested areas (Sanday and Lloyd, 1991). The main impetus for the introduction of power gasifiers into the South Pacific region was the European Community-funded Lome II Pacific Region Energy Programme (PREP) in 1983/X4. This proposed, and budgeted for, 17 gasified projects, but finally, only two were installed, both considerably reduced in scale, capacity and cost relative to the original proposals. Other gasifies units were also installed privately in the region. Sanday and Lloyd (1991) of the Energy Studies Unit (ESU) at the University of the South Pacific carried out a survey and monitoring programme of all power and heat gasifiers. They found that of the 16 power gasifiers installed altogether, only one was known to be still operating satisfactorily, the rest having ceased operation. Similarly, for the "Waterwide" heat gasifiers installed in Papua New Guinea, only 20 out of 80 were still in use in January 1990, and most of the other documented heat gasifiers in this region were also expected to have shut down.

The operational problems were thought mainly to be due to flaws in original designs resulting in shortened plant lifetime. The systems installed experienced severe operational and design problems that should have been solved prior to installation in remote sites. To Sanday and Lloyd (1991, p. 17) it seemed

> "that the Pacific Islands have been used as experimental stations for technologies that have not been proven in industrial countries". (Furthermore,) "gasifiers have often quickly deteriorated resulting from mismanagement of operational and maintenance procedures, and the persisting hostile operational environment."

Most of the manufacturers were external to the region, some based as far away as Europe. Therefore, there was a lack of spare parts and skilled technicians to carry out maintenance and repair wore This situation was exacerbated by the fact that five of the six manufacturers who supplied systems to the region in the last decade went out of business. There was also a lack of infrastructure support within the region as personnel trained in gasifier technology were extremely scarce, so ordinary mechanics and technicians were often called on to carry out repair work with limited success. Since the gasifier locations were scattered amongst different islands it was difficult and costly to locate maintenance services and they could not be promptly available. Information on the technology was limited and usually in the form of papers for academics and other technical personnel rather than being designed for potential end-users.

The availability of biomass feedstocks may have been over-estimated originally, and the quality these feedstocks and their erratic supplies resulted in intermittent gasifier operation with some systems being periodically shut down. The shortages due to lack of fuelwood supplies were "compounded by domestic cooking receiving priority, difficulties associated with land availability and ownership, and soil salinity problems when replanting programmes were used" (Sanday and Lloyd, 1991, p. x). Also, lacking were schemes to collect scattered fuel and the failure to implement tree replanting programmes. Furthermore, the "Waterwide" heat gasifiers experienced problems with smoke contamination affecting the quality of dried agricultural products and causing heavy financial losses; this was mainly due to improper use.

Repetitive breakdowns and lack of maintenance support meant gasifier operators usually preferred to choose diesel systems which had been proved to be relatively successful and user-friendly in such situations. Furthermore, initial capital costs of gasifiers were high and unable to compete with equivalent diesel sets at current diesel fuel prices. All the problems experienced appear to have discouraged further developments towards implementation of gasifier technology in the region. Most success was found with small wood and husk-fuelled gasifiers installed in Papua New Guinea for agro-drying applications. The single power gasifier that was still operational, a BECK unit in Vanuatu, connected with a school, was successful due to "the availability of wood fuels, the commitment of the operators and the school management and the fortune to have a very gifted and enthusiastic support staff as one of the teachers at the school."

G. Indonesia

Rice husks are one of the most widely available agricultural residues in Indonesia, but they have few uses. They are a significant potential energy source if reliable conversion technologies can be developed. In Indonesia in 1986, milled rice production was over 26 Mt and 6.5 Mt of rice husks were subsequently produced - husks are estimated at 20 per cent of unmilled paddy weight. Use of 25 per cent of these husks (about 1.8 Mt) and a similar amount of available straw would yield about 3.6 Mt of energy feedstock which could produce an estimated 155 or 300 MW electricity depending of the amount of capital invested in the facility (USAID, 1988). Research and development work in gasifier technology has expanded considerably in Indonesia, and has been supported by the Government In 1987, the Government mandated that 10 gasifiers, manufactured in Indonesia, should be placed in field operation to help demonstrate their technical and economic viability.

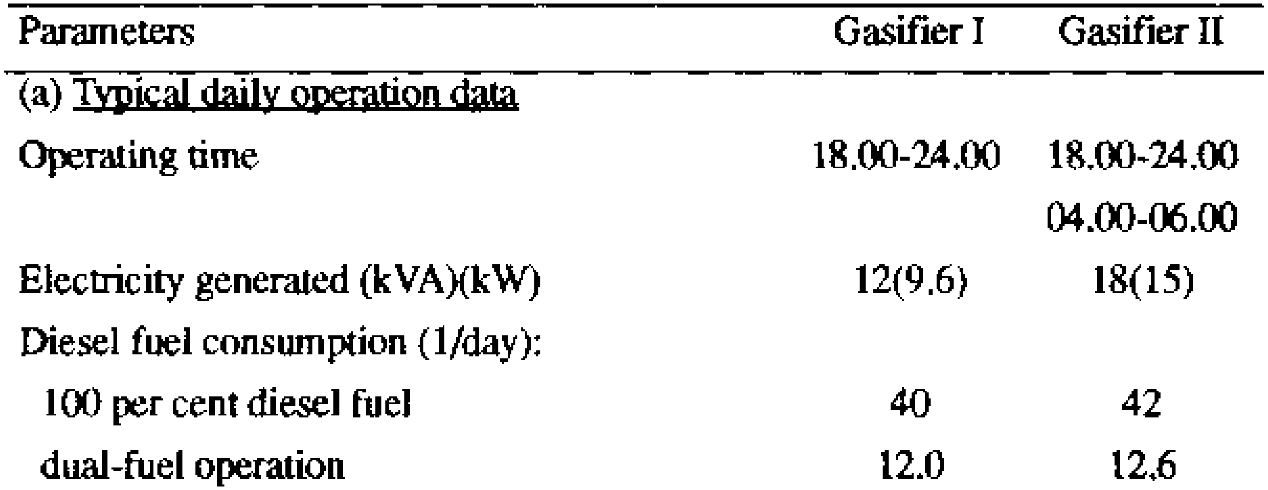
This case study is based on a system designed by Manurung and Beenackers (1990). Their continuous, small-scale down-draft rice-husk gasification system appears to have overcome many of the previous problems related to the gasification of rice husks. Based on laboratory experience the first unit (10 kWh) was installed in a village, 100 km east of Bandung, West Java, in 1986. This was followed up by two scaled-up versions each with a capacity of 35-40 kWh. One powers a 1000 kg/hr rice mill and the other provides 10 kWh of electricity for 320 rural consumers.

Typical performance of these field units (called Gasifier I and II) are illustrated in table 15. Diesel fuel replacement up to 70 per cent was achieved; the rice husk to electricity conversion is about 2.4 and 2.0 kg/kWh for Gasifier I and II, respectively. The economic analysis shown in part C of the table is based on Gasifier II only, and demonstrates the pay-back period (PBP) and the net present value (NPV) of the investment. In addition, the economics of the gasification unit are compared with those of a conventional diesel-engine generating set of the same capacity. The costs are based on 1989 economic data and on the present actual performance of Gasifier II for that year.

Under present conditions, according to Manurung and Beenackers (1990), the operating costs of the dual-fuel plant were lower than the plant revenues, resulting in a positive income, with a pay-back period of 7 years compared with 8 years for the full diesel plant. Since the diesel costs for a full diesel plant are 66 per cent of its operating costs, and only 22 per cent for a dual-fuel plant, the economics are particularly sensitive to the price of diesel, and also to load capacity, total annual operating hours and the level of diesel substitution. If applied to rural electricity production, economic feasibility appears to be good with capacities of 30 to 50 kWh and upward, under Javan conditions of 1989.

H. Mali

Chinese-built rice-husk gasifies power plants (160 kWh) were installed in the early 1970s, according to Mahin (1989), at two rice mills at Dogofiri and N'Debougou. These have operated successfully since then with more than 55,000 hours operating experience, although economic analyses of these plants are not easily available. In 1986, with the assistance of GTZ (German Agency for Technical Cooperation), an additional Chinese-built gasifier was installed nearby at the rice mill in Molodo which processes about 20,000 t/yr of rice. The plant produces about 1 kWh for each 2.5 kg of rice husks used in the gasifier. It generates up to 160 kW of power. The total annual operating costs were DM146,877 (or DM0.261kWh) which is 54 per cent of that of a diesel- engine plant. The GTZ study (Mahin, 1989) indicates the difference in capital cost between the diesel and the gasifies plant. Investment costs of the gasifier power plant could be recovered in less than four years. Table 16 provides a summary of cost of the rice husk-fulled gasifier power plant at Molodo.



Parameters	Gasifier I	Gasifier II
(a) Typical daily operation data		
Operating time	18.00-24.00	18.00-24.00 04.00-06.00
Electricity generated (kVA)(kW)	12(9.6)	18(15)
Diesel fuel consumption (1/day):		
100 per cent diesel fuel	40	42
dual-fuel operation	12.0	12.6

Lubricant oil consumption	8l/60hr	8l/20hr
Rice husk consumption (kg/hr)	23.3	30.0
Temperature of outlet gas (K)	673	603
Temperature or gas entering the engine (K)	303	308
Lower heating value of gas (kJ/m^3)	not measured	4,300
Filter cleaning	once in 2 weeks	once in 2 weeks
Tar in gas at gasifier outlet (g/m^3)	1.7	3.8
Tar in gas after dry filter (g/m^3)	0.37	1.00
(b) <u>Parameters relevant to economic analysis</u>		
Diesel oil replacement (percentage)	70	70
Rice husk to electricity energy conversion factor (kg/kWh)	2.4	2.0
Lubricating oil cost (Rp/dm^3)	900	2,500
Rice husk price (Rp/kg)	7.5	7.5
Electricity delivered price (Rp/10 W/month)	2,000	1,000
Transmitted electrical power (kW)	4.5	5.0
Diesel oil price (on site) (Rp/dm^3)	250	250
Operator salary (Rp/month)	30,000	25,000

Table 15. Gasification of rice husks, Indonesia

Parameters	Gasifier I	Gasifier II
(c) <u>Economics of generating electricity using dual-fuel and full diesel</u>		
	Dual-fuel	Full-diesel

	Rupiahs	Percentage	Rupiahs	Percentage
Investment:				
Gasifier	5 000 000	27		0
Diesel engine	13 000 000	70	13 000 000	96
Building	500 000	3	500 000	4
Installation	200 000	1		0
Total	8 700 000	100	13 500 000	100
Operating costs:				
Labour	306 000	7	180 000	4
Maintenance	639 840	14	336 960	7
Rice husk	583 200	13		0
Diesel oil	1 010 880	22	3 369 600	66
Sub-total	2 539 920		3 886 560	
Depreciation	1 962 500	44	1 187 500	23
Total expense	4 502 420	100	5 074 060	100
Production cost (Rp/kWh consum.)	347		392	
Production cost (Rp/kWh gen)	116		131	
Sales income (Rp)	5 404 320		5 404 320	
Cash flow (Rp)	2 864 400		1 517 760	

Table 15. (continued)

Parameters	Gasifier I	Gasifier II
Economic variables:		
Gasfier lifetime (years)	8	8
Engine lifetime (years)	12	12
Building lifetime (years)	8	8
Daily operating hours (hr/day)	8	8
Annual operating hours (hours)	2 592	2 592
Load level (kW)	15	15
Diesel consumption (1/hr)	2	5
Husk consumption (kg/hr)	30	33
Registered load (kW)	5	5
Electricity consumed (kWh/yr)	12 960	12 960
Electricity generated (kWh/yr)	38 880	38 880
Diesel price (Rp/l)	250	250
Husk price (Rp/kg)	8	-
Operator wage (Rp/hr)	63	63
Labour wage (Rp/hr)	44	44
Load factor	1	1
Electricity price (Rp/kWh)	417	417
Interest (percentage)	12	12

Notes: $US1=Rp 1750

Capital cost for a gasifier of 15 HP is $US 3000; the price of higher capacities is calculated by:

Capital cost (x HP) = Capital costs (15HP) * (x/15) (10x0.3)
Interest rate is 12 per cent per annum
Gasifier economic life is 7 years
Engine derating due to oil replacement is proportional to the percentage of oil replacement
Mechanical power to run a rice meal is 27 kW per ton of rice milled per hour
250 kg husk is produced per ton of rice, of which only 25 per cent is needed to power the mill
Source: Manrung and Beenackrs, 1990.

Table 15. (continued)

I. Brazil - potential

Although this paper is involved in the analysis of established bioenergy projects, it is also of value to examine the potential for electricity production in the north-east region of Brazil, as assessed by Carpentieri et al, (1992), since this has implications for other developing countries. The north-east region has a low population density, an economy heavily dependent on agriculture, and an energy consumption about half the national average. Over 90 per cent of all electricity produced in Brazil, and virtually all that is produced in the north-east is hydroelectric. To meet projected growth rates for electricity consumption in the north-east up to 2015 would require a capital investment in new power plants (all hydroelectric) in excess of £40 billion. It is planned to develop essentially all remaining hydroelectric potential in the Northeast by 2005, and costs will rise as less favourable sites are developed. However, the hydroelectric potential will inevitably be exhausted and alternative electricity sources must be found. One option under consideration is importing electricity from new hydroelectric projects to be located in the Amazon river basin. But this would be expensive, environmentally controversial and would involve little direct long-term investment or job creation in the north-east.

In 1982, the Division of Alternative Energy Sources of the Hydroelectric Company of Sao Francisco (CHESF), responsible for production and transmission of bulk energy in the north-east, initiated studies on alternative advanced technologies for converting biomass into electricity. There are three potential biomass resources in the north-east that could be utilized for electricity production: sugarcane residues, plantations. and the residues of other agricultural products. Of these, the first two show most promise for large-scale use as plantations are well established. In fact, both plantation industries in Brazil are recognized as world leaders.

In this region practically all woodfuel comes from natural forests with devastating environmental effects. Efforts to establish plantation have been quite successful in Brazil as a whole with over 40 per cent of all charcoal now being derived from this source (Abracave, 1992), and plantations are estimated to cover 4 to 6 million ha (mostly used by steel and paper and pulp producers). Large investments have been made in plantation technology and techniques resulting in a great improvement over the last 15 to 20 years. CHESF carried out a biogeoclimatic assessment to evaluate the potential for wood-plantation energy, considering only land area judged to be sub-optimal for agriculture (CHESF, 1990). It estimated that 50 million ha (a third of the land area of the north-east) was available for plantations with productivities ranging from 6 to 44 m^3/ha/yr of wood, and that the total plantation production potential is about 1340 million m^3/yr of wood which could produce 12.6 EJ/yr. This compares with a total energy use in the north-east of about I. I EJ. Cost estimates range from 7.3 c/kWh for condensing steam turbine technology (CST) down to 4.3 c/kWh for gas turbine/steam turbine combined cycle technology (GTCC). Over 86 per cent of the wood production would be at an average cost less than $1.35/GJ (Carpentieri et al, 1992).

Details of rice mill at Molodo		
Mill capacity	20,000 t paddy	
Operating season (24 hrs, 5500 h/yr)	230 days/yr	
Energy requirements - electric motor	110 kW/h	
- auxiliary equipment	12kW/h	
Cost of diesel power (DM)		
Capital cost		370 000
Annual costs		43 030
		198 000
		10 000
		7 000
		15 000
		570 000kWh
Total annual operating costs		273 030
Unit cost		0.48/kWh
Details of the gasifier power plant:		
Rice-husk consumption	250-350 kg/h	
Lubricating oil	0.41 l/hr	
Diesel oil engine (every 600 hrs)		
Maximum energy generation (1 kWh for 2.5 kg of rice husks)	200 l	
	160 kW	
Cost of the gasifier power plant		
Capital costs:		
Purchase price of gasifier		490 000
Transport and insurance		40 000
Assembly and installation		60 000
Building and structure		150 000
36 kWh standby diesel generator		40 000
Total costs of installation		780 000
Annual costs:		
Annual capital cost (amortization period 13 years at 11.73 per cent)		85 877
Lubricating oil		19 000
Standby generator		5 000

Standby generator		3 000
Repairs and maintenance		12 000
Labour		25 000
	Total annual operating costs	146 877
	Unit cost	0.26/kWh

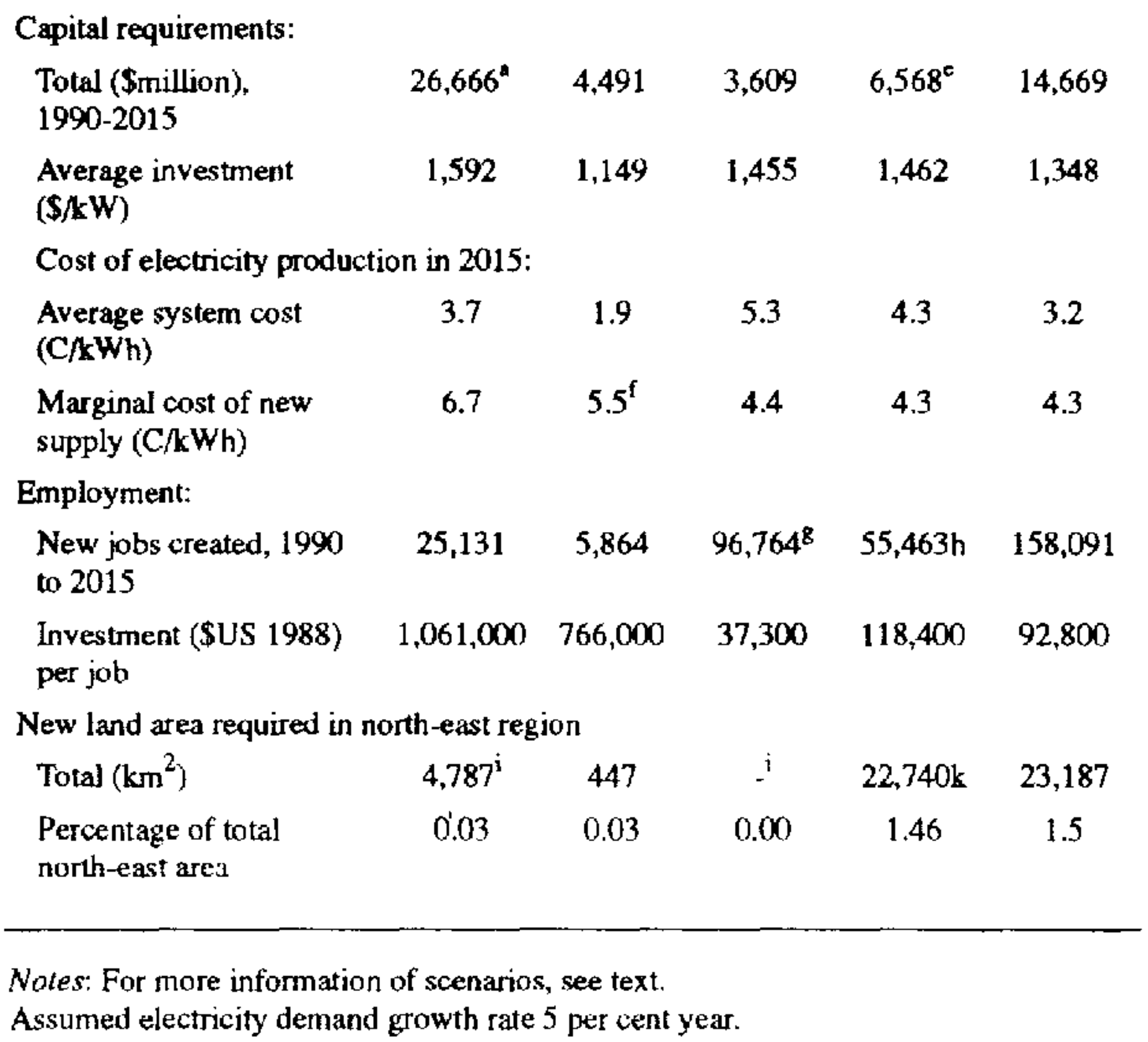
Note: $US1=DM 1.70
Source: Based on Mahin, 1989.

Table 16. Economic analysis of a rice-husk-fueled gasifier

Sugarcane, on the other hand, is already widely grown in Brazil and some sugarcane processing facilities are already selling small quantities of electricity produced from bagasse to utilities. The present biomass energy production potential in the north-east from the area of cane planted in 1989 is estimated to be 174 PJ/yr. Looking at a future scenario, the average cost of producing the electricity with STIG technology is around 4.04.4 c/kWh. This would be competitive with marginal costs of anticipated new hydroelectric supply. If tops and leaves are also used, the bioenergy available could be increased by up to 75 per cent, and off-season jobs baling and transporting the barbojo would be created (Carpentieri et al, 1992).

Carpentieri et al, (1992) constructed two alternative scenarios for the production of electricity in the Northeast to the year 2015, these are summarized in table 17. The "Hydro" scenario is based on CHESF plans for continued expansion of the hydroelectric system; while the "Biomass" scenario is "intended to be a plausible scenario of how biomass could be incorporated into the utility system." Both proposals include the initial installation of 4100 MW of hydroelectric power at a single site, Xingo 1. The Biomass scenario then assumes sugarcane CEST systems (including barbojo) begin to make a contribution in 1987 such that half of the total potential is installed by 2000 at 320 MW/yr. From 200O, STIG systems come on line at the rate of 280 MW/yr until 2010 when the full electricity-generating potential of sugarcane is realized. Plantation activity is assumed to begin in 1994 with stand-alone power stations first coming on line in 2000 based on GTCC technology with an installed capacity of 250 MW, and annual additions will increase up to 1000 MW of new supply in 2015 (this is supplied by only 4 per cent of CHESF's assumed potential fuelwood in the north-east).

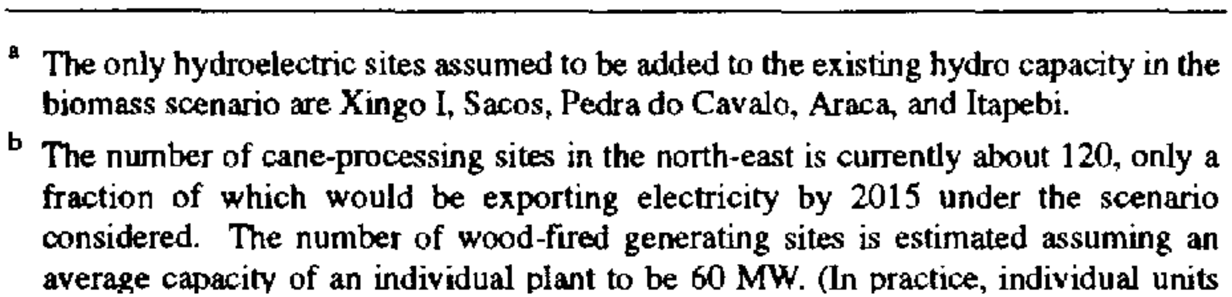
	Hydro scenario	Biomass scenario			
		Hydro	Cane	Wood	Total
Generating capacity:					
Added MW, 1990-2015	16,745	3,909	2,480	4,494	10,883
Total MW in 2015	23,957	11,112[a]	2,480	4,494	18,806
Number of generating units	27	14	50[b]	75[b]	140
Electricity generation (GWh):					
Total in 2015	103,555	52,875	17,214	33,465	103,555
Added, 1990-2015	72,975	22,295	17,214	33,465	72,975
Total (percentage of estimated potential) c	0.21	0.1	0.42	0.024	0.052



Capital requirements:					
Total ($million), 1990-2015	26,666[a]	4,491	3,609	6,568[c]	14,669
Average investment ($/kW)	1,592	1,149	1,455	1,462	1,348
Cost of electricity production in 2015:					
Average system cost (C/kWh)	3.7	1.9	5.3	4.3	3.2
Marginal cost of new supply (C/kWh)	6.7	5.5[f]	4.4	4.3	4.3
Employment:					
New jobs created, 1990 to 2015	25,131	5,864	96,764[g]	55,463h	158,091
Investment ($US 1988) per job	1,061,000	766,000	37,300	118,400	92,800
New land area required in north-east region					
Total (km^2)	4,787[i]	447	-[j]	22,740k	23,187
Percentage of total north-east area	0.03	0.03	0.00	1.46	1.5

Notes: For more information of scenarios, see text.
Assumed electricity demand growth rate 5 per cent year.

Table 17. Comparison of alternative electric system scenarios in north-east



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[a] The only hydroelectric sites assumed to be added to the existing hydro capacity in the biomass scenario are Xingo I, Sacos, Pedra do Cavalo, Araca, and Itapebi.

[b] The number of cane-processing sites in the north-east is currently about 120, only a fraction of which would be exporting electricity by 2015 under the scenario considered. The number of wood-fired generating sites is estimated assuming an average capacity of an individual plant to be 60 MW. (In practice, individual units

might be clustered into modules of 4 or 5 units each).

[c] The total ultimate hydro GWh potential is estimated based on a total MW capacity potential of 113,300 MW, which includes the potential in both the north-east and north regions. The total ultimate wood and cane potentials are taken to be 1400 TWh and 41 TWh respectively.

[d] Includes an additional amount of $300 per kW for transmission from plants in the north to the north-east

[e] The total investment includes plantation-establishment costs totalling $611 million incurred during the years 2010 to 2015. Because of the 6-year period before the first harvest, the plantation investments during these years do not lead to any electricity production until the period 2016 to 2021. The assumed plantation-establishment cost is $213/kW. This assumes an average yield of 33 m^3/yr per planted hectare, conversion to electricity at 40 per cent efficiency, an unplanted (natural-vegetation) equal to 43 per cent of the planted area, and a capital investment of $689/hectare.

[f] Estimated average cost of power from building and of operating the 7 hydropower plants in north-east region that are not included in the biomass scenario.

[g] The number of currently seasonal jobs that would be converted to full-time jobs.

[h] Includes 13,099 jobs associated with establishing and maintaining plantations during the period 2010 to 2015. These plantations would not be harvested until after 2010. See note[e] above.

[i] Land area flooded by new hydro facilities in the north-east region only. The area that would be flooded in the north region is an additional 7700 km^2

[j] Zero additional area is required for electricity from sugarcane, since the total planted area is assumed to remain at today's level.

[k] Only 70 per cent of this area would be active plantation. The balance would be left in "natural" from. The total includes 8870 km^2 of plantation area that would be established between 2010 and 2015, but which would not be harvested until the period 2016 to 2021. See note[e] above.

Source: Carpentieri et al, 1992.

Table 17. (continued)

Total new land required by the Biomass scenario would represent only 1.6 per cent of the total land area of the north-east. Since the biomass facilities are smaller and greater in quantity they offer more security and can follow demand more closely. The Hydro scenario would contribute 25 GW between 1990 and 2015 compared with 15 GW in the Biomass scenario. Average unit investment costs would be 25 per cent higher for the HYDRO case, the total required capital investment would be twice as much, average electricity production costs will be higher, and marginal production costs will be substantially higher. This scenario assumes "a reasonable commitment from government, utilities, industry and relevant R&D organizations, and the support of the population in general." (Carpentieri et al, 1992).

The energy potentially available from other agricultural residues in the north-east is estimated to be about 145 PJ/yr, which is equivalent to about 10 per cent of primary energy consumption in this region. Since these sources are widely dispersed and lack any infrastructure for energy use, they are of more importance for use locally, in a decentralized manner (Carpentieri et al, 1992). The Brazilian Government is promising to introduce a new policy across Brazil that will mandate the State-controlled electricity utilities to enter into long-term contracts to buy cogenerated power. This will encourage further the growth of biomass electricity production from residues.

VII. Perceived problems, solutions and policy options

Biomass energy is often considered problematic because it has many facets and interacts with so many different areas such as land use, forestry, agriculture, animals, and societal factors. The provision and use of biomass energy is a complex issue and is only one part of the problems associated with sustainability of all types of vegetation, which, in turn, is an integral part of ensuring stable socio-economic development. Biomass projects set up to enhance energy availability are also very difficult to quantify because of the many "intangibles" involved. There are no short cuts to trying to obtain a detailed understanding of the successes and failures of projects except by prolonged and repeated local visits and discussions over an extended period by all interested parties. This also requires interaction with diverse groups associated with a project. Generalizations are difficult and can only be derived from individual case studies which have been carefully analysed over long time periods. Nevertheless, answers to the following questions can be very important for replicability. Can generalizations be drawn from such analyses? Can the data be trusted to reflect current knowledge? How replicable, how sustainable and how flexible are the examples, both nationally and internationally?

A. Environmental impacts

Biomass has numerous environmental advantages, both globally and locally, but no energy source is entirely without some environmental impact. The environmental impacts of widespread biomass use are among the most important uncertainties concerning this resource. The positive and negative impacts, unfortunately, do not receive a balanced and systematic analysis where new developments are considered.

As mentioned previously, biomass fuels make no net contribution to atmospheric CO_2 if produced and used sustainably to allow regrowth. Therefore, if they could displace fossil fuels, they could reduce atmospheric carbon emissions. Many biomass systems produce no sulphur oxides and low levels of particulates when operated efficiently. Reforestation and revegetation, in general, also have the potential for improving soil conditions, reducing erosion and, ultimately, decertification. Another environmentally positive factor is the use of residues as an efficient way of dealing with potentially polluting wastes and obtaining recycled nutrients.

On the negative side, bioenergy could cause serious environmental damage if feedstocks are not properly managed and conversion technologies are inadequately controlled. Biomass conversion and end-use impacts are, in principle, similar to those of fossil fuel burning (i.e., air pollution and ash disposal problems), but some unique hazards depend on the biomass source (OECD, 1988). However, it is important to note that a large proportion of the potentially available biomass may be obtained with few adverse effects on the environment, and their impacts tend to be small-scale and localized compared with the larger, more widely distributed impacts of use of fossil fuels. Therefore, the impacts of the use of biomass are "more controllable, more reversible and, consequently, more benign" (Pasztor and Kristoferson, 1990, p. 28).

1. Biomass plantations

A major uncertainty about the development of biomass for large-scale energy production is whether high productivities can be achieved sustainably over wide areas without damaging the environment or without impinging on agricultural land requirements. An expansion of intensive agricultural production of the kind needed for biomass energy plantations could result in serious soil erosion, increased use of agrochemicals, monocultures etc., and the subsequent impact on land and water quality and resultant ecosystem changes. Most of these problems are not widely different from present concerns with agriculture and forestry. However, as shown in the successful examples of woodfuel technologies in chapter I, with good management, the production of biomass can be accomplished in a sustainable manner.

The case studies in chapter I have shown that plantations could be established on degraded or deforested lands; short-rotation tree crops (and various perennial grasses) would be an improvement on annual row-crop agriculture on both productive and poor lands. Generally, achieving sustainable production may require polycultural strategies which would help maintain biological diversity. Interconnecting corridors of natural vegetation help to ensure that flora and fauna do not become genetically isolated and thereby susceptible to weakening by inbreeding. This can also minimize pesticide use (primarily due to the birds that reside in the natural vegetation) and fertilizer use (due to the mix of species) whilst maintaining a diverse landscape mosaic. The use of clonal strategies could facilitate the incorporation of desirable characteristics such as pest- or drought-resistance. Energy cropping could be carried out under nutrient optimized conditions and good land management could avoid nutrient wastage and leaching; additionally nutrient status could be maintained by recycling nutrients and choosing suitable mixed species such as nitrogen-fixing Albizia (Beyea et al, 1992; Hall et al, 1990). As shown by the Banshet village example in the Tanzanian case study, biomass production can be increased without irrigation by selecting species better adapted to water limitations and by management techniques.

Similarly, eucalyptus plantations examined in this report have almost invariably been shown to have been failures, though not necessarily for their environmental impacts. Biomass plantations, especially eucalyptus plantations, have received adverse criticism in countries such as India and Thailand (Lohmann, 1990; Saxena, 1992). Eucalyptus has been blamed for causing soil erosion, water competition, loss of biological diversity, being the cause of deforestation etc. There is a complex history behind the Indian and Thai experience which should not condemn eucalyptus. Most of these plantations are not grown for fuelwood but for other industrial uses such as pulp and for construction. There were also problems of land use, planning and markets. There have however been notable successes with eucalyptus in Ethiopia and Brazil and even in some parts of India (Conroy, 1992). Since the returns from woodfuel-plantation investments are long-term, there is some in-built economic incentive to ensure that such sustainable practices are pursued, as appears to be the case of the Zambia experience on the establishment of woodlots (see chapter I) and for many companies operating plantations in Brazil (Betters et al, 1991). It is a typical practice in Brazilian plantations to leave 20-30 per cent of the area in a natural or otherwise undisturbed state to enhance productivity and environmental benefits (Carpentieri et al, 1992).

2. Bioethanol

(a) Production

Many of the impacts of ethanol production depend more on such factors as the design and operation of plants and on legislation than any other inevitable problems with the production process. This contrasts favourably with many other polluting industries. Emissions from the conversion of biomass to biofuels involve mostly non-fossil CO_2 residues from upgraded or spent catalysts, phenolic compounds, ash, and organic acids during conversion. CO_2 emissions associated with the use of ethanol as a fuel, while definitely less than gasoline, are still present. The processing needed, first to grow the plants and then to extract ethanol accounts for these CO_2 emissions. However, most of the biomass to ethanol conversion wastes can be converted to by-products or recycled as energy for the conversion process, so that clean up costs are low (Pasztor and Kristoferson, 1990; USDOE, 1989; 1990).

Stillage is the most important waste stream. It is a liquid waste with low solids content, having a high biological oxygen demand (BOD) and a high chemical oxygen demand (COD), and contains organic residues, inorganic solids and other pollutants. Stillage and other wastes from ethanol plants can cause serious damage to aquatic ecosystems if they are mishandled; the high BOD and COD levels in the stillage could result in oxygen depletion in any waters receiving the waste. However, control technologies are available for reducing the impacts from these waste streams including biological treatment methods (biological filters, anaerobic digestion, stillage recycling, etc). In the United States, stillage is a source of DDG (distillers dried grains), which is a valuable cattle feed. In Brazil and Zimbabwe stillage is increasingly being used as a substitute for chemical fertilizers in sugarcane fields: through the use of stillage in Sao Paulo (Brazil), productivity increased by 20-30 per cent (Rosillo-Calle and Hall, 1986).

(b) End use

The effects of alcohol-gasoline blends on automobile emissions depend on how the engine is tuned, whether or not it has a carburetor with feedback control and whether the engine is running on pure alcohol or on a blend of alcohol and petroleum. Experimental data from the Office of Technology Assessment (1980) indicate (a) a substantial reduction in reactive hydrocarbon and NO_X exhaust emissions when using 100 per cent methanol, and to a lesser extent when using ethanol; (b) an increase in aldehyde emissions with neat alcohol and blends; (c) a substantial reduction in particulate emissions if neat alcohol fuels are used; and (d) a substantial reduction in polynuclear aromatic compounds with neat alcohols and blends. Most literature also indicates that CO emissions are reduced, and that NO_X emissions may or may not be reduced, depending on the vehicle under test. Furthermore, alcohol blended with petroleum enables the elimination of tetraethyl lead in gasoline. The blend resulted in an 80-per cent drop of lead concentration in the air in Sao Paulo between 1978 and 1983 (Goldemberg et al, 1992). In Argentina, results with 15 per cent (v/v) addition of ethanol to gasoline blend show a 50-per cent reduction of CO emissions, 35-per cent reduction of lead emissions, and a 34-per cent decrease of hydrocarbon emissions (Gotelli, 1988).

With regard to health and safety, the use of alcohol fuels does not suggest that they are inherently unsafe to use. However, many toxic substances may be produced and handled during biomass commercial operations, and accidental releases of these materials could pose a significant health hazard in the vicinity of conversion facilities. Fermentation plant workers may be affected by prolonged or accidental exposure to the toxic and corrosive chemicals employed (OECD, 1988). Nonetheless, the toxic effects of ethanol (and methanol) are considered to be less hazardous than those of gasoline and gasoline components. Bioethanol is completely biodegradable and any toxic effects may be eliminated in hours, whereas the ill effect of fuel oils can last for several years.

B. Food or fuel?

A major criticism often levelled against biomass energy, particularly against schemes for large-scale bioethanol fuel production, is that it could divert agricultural production away from food crops, especially in developing countries. The basic argument is that energy-crop programmes compete with food crops in a number of ways (agricultural, rural investment, infrastructure, water, fertilizers, skilled labour etc.) and thus cause food shortages and price increases. However, this so-called "food versus fuel" controversy appears to have been exaggerated in many cases. The subject is far more complex than has generally been presented since agricultural and export policy and the politics of food availability are factors of far greater importance. The argument should be analysed against the background of the world's (or an individual country's or region's) real food situation of food supply and demand (ever-increasing food surpluses in most industrialized and a number of developing countries), the use of food as animal feed, the under-utilized agricultural production potential, the increased potential for agricultural productivity, and the advantages and disadvantages of producing biofuels (Rosillo-Calle and Hall, 1987).

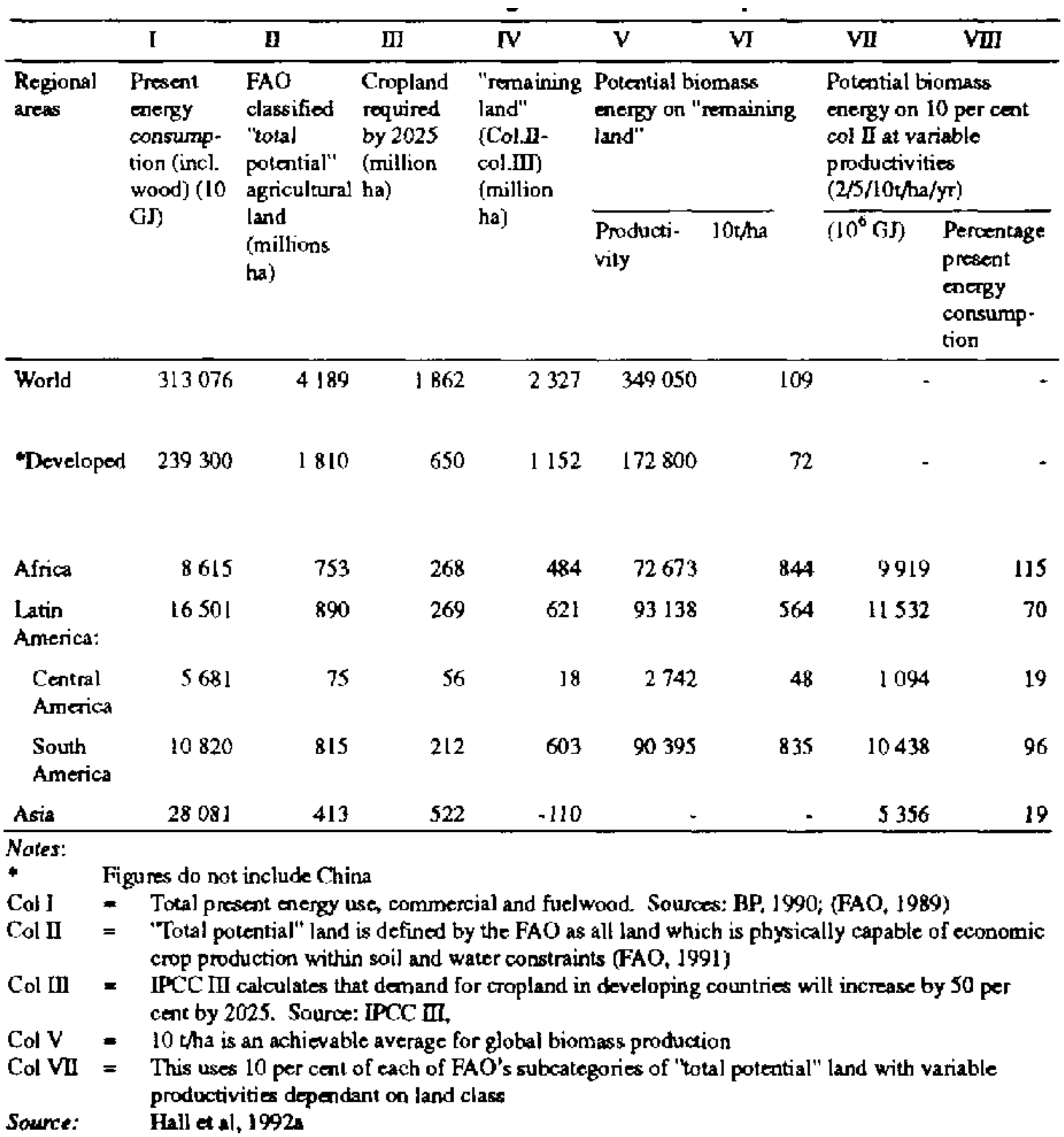
The food shortages and price increases that Brazil suffered a few years ago, were blamed on the ProAlcool programme. However, a closer examination does not support the view that bioethanol production has adversely affected food production since Brazil is one of the world's largest exporters of agricultural commodities and agricultural production has kept ahead of population growth: in 1976 the production of cereals was 416 kg per capita, and in 1987,418 kg per capita. Of the 55 million he of land area devoted to primary food crops, only 4.1 million ha (7.5 per cent) was used for sugarcane, which represents only 0.6 per cent of the total area registered for economic use (or 0.3 per cent of Brazil's total area). Of this, only 1.7 million ha was used for ethanol production, so competition between food and energy crops is not significant (Goldemberg et al, 1992). Furthermore, crop rotation in sugarcane areas has led to an increase in certain food crops, while some byproducts such as hydrolyzed bagasse and dry yeast are used as animal feed. Goldemberg et al, (1992, p. 856) believe that "In fact, the potential for producing food in conjunction with sugarcane appears to be larger than expected and should be explored further,". Food shortages and price increases in Brazil have resulted from a combination of policies which were biased towards commodity export crops and large acreage increases of such crops, hyper-inflation, currency devaluations, price control of domestic foodstuffs etc. Within this reality, any negative effects that bioethanol production might have had should be considered as part of the overall problem, not the problem (Rosillo-Calle and Hall, 1986; Goldemberg et al, 1992).

It is important to appreciate that developing countries are facing both food and fuel problems. Adoption of agricultural practices should, therefore take into account this reality and evolve efficient methods of utilizing available land and other resources to meet both food and fuel needs (besides other products), e.g., from agroforestry systems. Ellis clearly comes out in the various case studies on woodfuel technologies examined in chapter I. In India, according to Anithkumar (1990), trials with so-called "Big-energy Eco Farming" (BEEF) indicate that to provide food and fuel for a family of five requires an area of about 0.2 ha of arable land, integrated with two milking cows and a heifer. This is because the BEEF concept is based on mixed multiple-cropping and employs whole plant materials either as a quality food or as a feedstock to produce industrial motive power and fibre without mechanization. In this context, it is also important to study Agarwal and Narain's (1990) concept of "green villages" where the importance of environmentally integrated villagemanaged ecosystems provide the multiple products required from the land. Land can best be used for sustainable development by considering what mixture of land use and cropping patterns would meet the multiple objectives of food, fuel, fodder, societal needs etc.

C. Land availability

Chapter I discussed how biomass differs fundamentally from other forms of energy since it requires land to grow on and is therefore subject to the range of independent factors which govern how, and by whom, that land should be used. This point is also forcefully brought out by Newman and Halls (1990). There are basically two main approaches to deciding on land use for biomass energy. The "technocratic" approach starts from a need for energy, then identifies a biological source, the site to grow it, and then considers the possible environmental impacts. This has generally been the case in an the examples shown in chapter 1, especially in the first phases. As the case studies have shown, this generally had ignored many of the local and more remote side-effects of biomass energy plantations and also ignored the expertise of the local farmers who know the local conditions. This has resulted in many biomass project failures in the past. The "multi-uses" approach asks how land can best be used for sustainable development, and considers what mixture of land use and cropping patterns will make optimum use of a particular plot of land to meet multiple objectives of food, fuel, fodder, societal needs etc. This requires a full understanding of the complexity of land use.

FAO recently released data categorizing land use in 91 developing countries by rainfall class and techno-economic potential for agriculture (Bruinsma, 1991). Analysis of this data (see table 18) (Hall et al, 1992b) shows that, after accounting for food production (a 50per cent increase in agricultural land in developing countries by the year 2025), sufficient land would be available for biomass energy production which could even exceed developing countries' energy requirements, except possibly in the case of Asia. Table 18 shows that developing countries have an estimated 955 million ha of land potentially available for biomass production which, if it yields 10 t/ha/yr, could theoretically provide nearly three times their energy requirements. Hence, developing countries could provide 50 per cent of their total energy needs (Africa and Latin America could be completely energy self-sufficient) using only 10 per cent of their potential productive agricultural land (as defined by FAO). A similar estimate for industrialized countries shows that they could produce 72 per cent of their present energy use from biomass on available land (Hall et al, 1992).



	I	II	III	IV	V	VI	VII	VIII
Regional areas	Present energy consumption (incl. wood) (10 GJ)	FAO classified "total potential" agricultural land (millions ha)	Cropland required by 2025 (million ha)	"remaining land" (Col.II-col.III) (million ha)	Potential biomass energy on "remaining land"		Potential biomass energy on 10 per cent col II at variable productivities (2/5/10t/ha/yr)	
					Productivity	10t/ha	(10^6 GJ)	Percentage present energy consumption
World	313 076	4 189	1 862	2 327	349 050	109	-	-
*Developed	239 300	1 810	650	1 152	172 800	72	-	-
Africa	8 615	753	268	484	72 673	844	9 919	115
Latin America:	16 501	890	269	621	93 138	564	11 532	70
Central America	5 681	75	56	18	2 742	48	1 094	19
South America	10 820	815	212	603	90 395	835	10 438	96
Asia	28 081	413	522	-110	-	-	5 356	19

Notes:

* Figures do not include China

Col I = Total present energy use, commercial and fuelwood. Sources: BP, 1990; (FAO, 1989)

Col II = "Total potential" land is defined by the FAO as all land which is physically capable of economic crop production within soil and water constraints (FAO, 1991)

Col III = IPCC III calculates that demand for cropland in developing countries will increase by 50 per cent by 2025. Source: IPCC III,

Col V = 10 t/ha is an achievable average for global biomass production

Col VII = This uses 10 per cent of each of FAO's subcategories of "total potential" land with variable productivities dependant on land class

Source: Hall et al, 1992a

Table 18. Potential land for agriculture and biomass production

However, some of the FAO-defined potential land would come at the expense of natural ecosystems which has to be avoided. Nevertheless, much land already too degraded to produce agricultural crops could be suitable for some energy crops. Much of this land has already been targeted for reforestation. According to Grainger

(1988), 758 million ha of land in the tropics has a theoretical potential for forest replenishment (and biomass production). Houghton (1990) estimated that 500 million ha of land in Africa, Asia and Latin America could be available for reforestation and an additional 365 million ha of land in the fallow cycle of shifting cultivation might also be targeted for this purpose. In the developed world, large areas of surplus agricultural land in North America and Europe (possibly as much as 150 million ha in the next century) are potentially significant biomass producing areas (Hall et al, 1992).

D. Raw-material supply

The biomass resource endowment in developing countries varies enormously. There are few, if any, reliable and comprehensive data of biomass resources on a country or worldwide basis. There is also the added uncertainty of natural disasters, such as the recent drought in Africa, which might adversely affect the resource.

1. Energy crops

Table 18 gave some indication of the potential contribution to regional energy from biomass grown on "available" land as discussed in section 8.3. It is also interesting to note that, globally, if plantations were established on a total amount of land equivalent to 10 per cent of the area now under forests/ woodlands, cropland, and permanent pasture, the annual biomass energy production would be larger than present global consumption of all commercial fuels (oil, gas, coal, hydro and nuclear energy) (Hall et al, 1992b).

Biomass productivities must be improved since they are generally low, being much less than 5 t/ha/yr for woody species without good management (see chapter 1). The case studies and Kulp (1990) show that increased productivity is the key to both providing competitive costs and meeting the large feedstock demands biofuel conversion facilities will have. Advances have included the identification of fast-growing species, breeding successes, intercropping and multiple species opportunities, new physiological knowledge of plant growth processes, and manipulation of plants through biotechnology applications, which could raise productivities 5 to 10 times over natural growth rates in trees and microalgae.

It is now possible with good management, research, and planting of selected species and clones on appropriate soils to obtain 10 to 15 t/ha/yr in temperate areas and 15 to 25 t/ha/yr in tropical countries. Record yields of 40 t/ha/yr (dry weight) have been obtained with eucalyptus in Brazil and Ethiopia. High yields are also feasible with herbaceous (nonwoody) crops where the agroecological conditions are suitable. For example, in Brazil, the average yield of sugarcane has risen from 47 to 65 t/ha (harvested weight) over the last 15 years while over 100t/ha/yr are common in a number of areas such as Hawaii, South Africa, and Queensland in Australia. Given appropriate R and D efforts it should be possible with various types of biomass production to emulate the three-fold increase in grain yields which have been achieved over the past 45 years although this would require the same high levels of inputs and infrastructure development. However, in trials in Hawaii, yields of 25 t/ha/yr have been achieved without N-fertilizers when eucalyptus is interplanted with N-fnxing Albizia trees (De Bell et al, 1989).

Experience has shown that biomass energy plantations are unlikely to be established on a large scale in many developing countries, especially in poor rural areas, so long as biofuels (particularly wood) can be obtained at zero or near zero cost.

2 . Existing forests

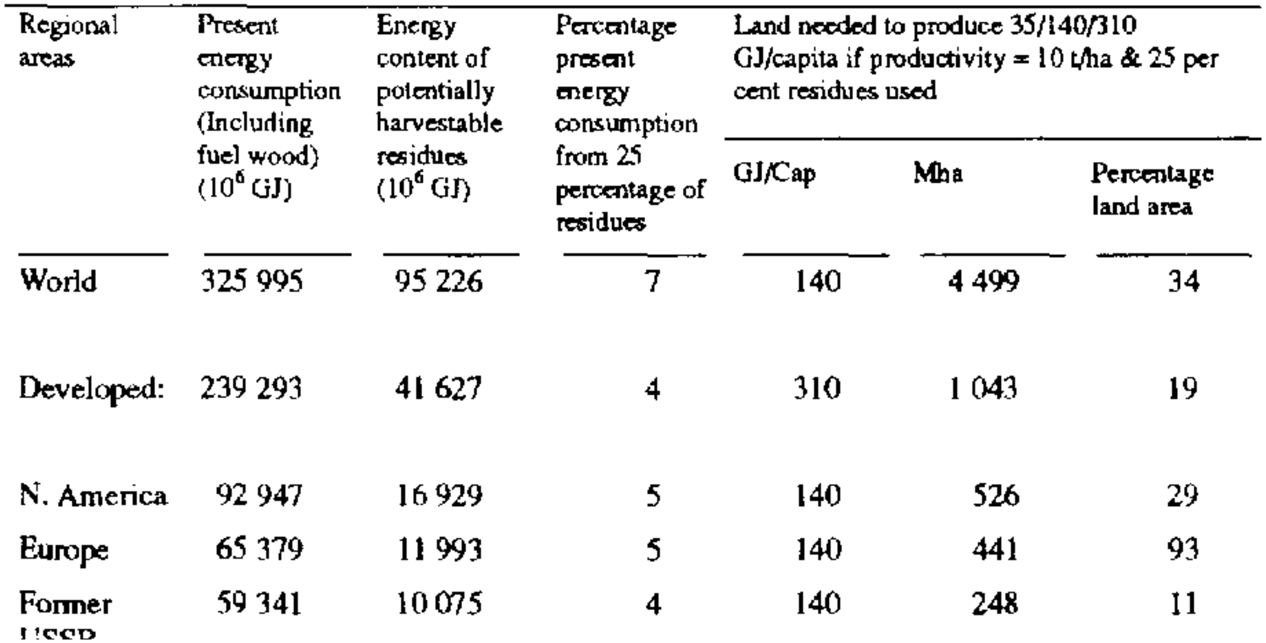
As shown in chapter I, wood can be, and is, removed sustainably from existing forests and plantations worldwide by using methods such as coppicing. It is difficult to estimate the mean annual increment (MAI) (growth) of the world's forests. One rough estimate (Openshaw, 1990) is 12.5x1O9m^3/yr with an energy content of 182 EJ equivalent to 1.3 times the total world coal consumption in 1988. The estimated global average annual wood harvests in the period 1985- 1987 were 3.4x 10^9m^3 /yr (equivalent to 40 EJ/yr), so some of the unused increment could, conceivably, be recovered for energy purposes while maintaining or possibly even enhancing the productivity of forests (Hall et al, 1992b).

3. Residues

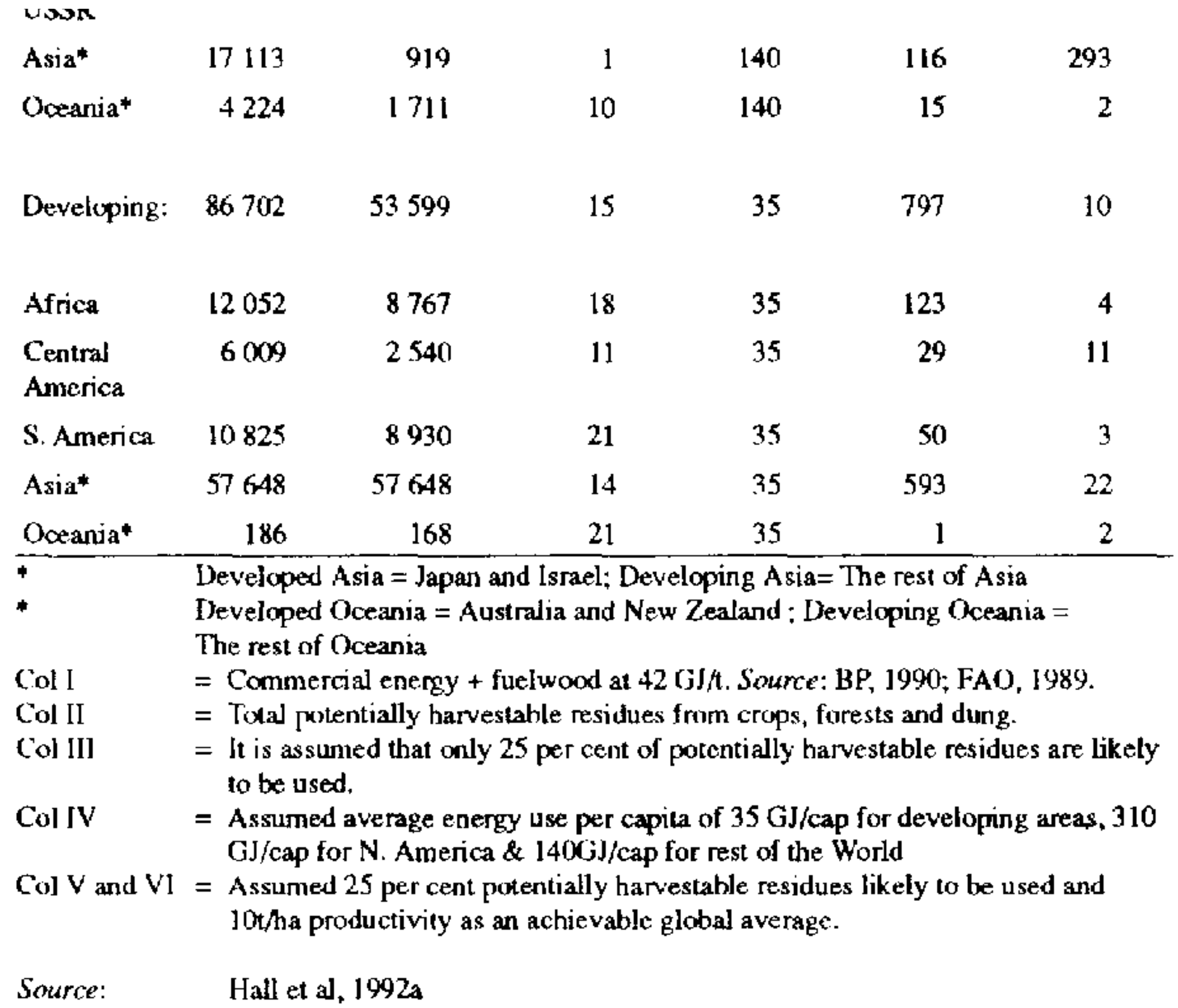
Agricultural residues have an enormous potential for energy production. In favourable circumstances, biomass power generation could be significant given the vast quantities of existing forestry and agricultural residues - over 2 billion t/yr worldwide. This potential is currently under-utilized in many areas of the world. In wood-scarce areas, such as Bangladesh, China, the northern plains of India, and Pakistan, as much as 90 per cent of household energy in many villages comes from agricultural residues. It has been estimated that about 800 million people worldwide rely on agricultural residues and dung for cooking, although reliable figures are difficult to obtain (Leach and Gowen, 1987; Barnard and Kristoferson, 1985). Contrary to the general belief, the use of animal manure as an energy source is not confined to developing countries alone, e.g., in California a commercial plant generates about 17.5 MW of electricity from cattle manure, and a number of plants are operating in the EEC (Rader et al, 1989; Constant et al, 1989).

The energy theoretically available from recoverable residues is about 54 El in developing countries and 42 EJ in industrialized regions (see table 19; Hall et al, 1992b). The amount of potentially recoverable residues in table 18 includes the three main sources: forestry, crops and dung. The calculations assume only 25 per cent of the potentially harvestable residues are likely to be used. Developing countries could theoretically derive 15 per cent of present energy consumption from this source and industrialized countries could derive 4 per cent. This is feasible given incentives and efficient conversion, but must encompass environmental sustainability. The table also shows the percentage of land needed, in addition to harvestable residues, to provide all of a region's energy from biomass. It shows that many regions could theoretically achieve energy self-sufficiency by using a relatively small percentage of their total land area, e.g., 2 per cent for Oceania, 3 per cent for South America and 4 per cent for Africa (Hall et al, 1992).

Sugarcane residues (bagasse, and tops plus leaves) - are particularly important and offer an enormous potential for generation of electricity (Ogden et al, 1990; Williams and Larson, 1990). Generally, residues are still used very inefficiently for electricity production, in many cases deliberately to prevent their accumulation, but also because of lack of technical and financial capabilities in developing countries. In many sugarcane-producing countries where cane has been grown for a century or more with increasing yields and good soil maintenance (or even improvement), there are unfortunate commercial pressures to shift away from cane to crops such as cotton which are extremely soil-erosion prone and not nearly as well suited to tropical weather



Regional areas	Present energy consumption (Including fuel wood) (10^6 GJ)	Energy content of potentially harvestable residues (10^6 GJ)	Percentage present energy consumption from 25 percentage of residues	Land needed to produce 35/140/310 GJ/capita if productivity = 10 t/ha & 25 per cent residues used		
				GJ/Cap	Mha	Percentage land area
World	325 995	95 226	7	140	4 499	34
Developed:	239 293	41 627	4	310	1 043	19
N. America	92 947	16 929	5	140	526	29
Europe	65 379	11 993	5	140	441	93
Former USSR	59 341	10 075	4	140	248	11



USSR						
Asia*	17 113	919	1	140	116	293
Oceania*	4 224	1 711	10	140	15	2
Developing:	86 702	53 599	15	35	797	10
Africa	12 052	8 767	18	35	123	4
Central America	6 009	2 540	11	35	29	11
S. America	10 825	8 930	21	35	50	3
Asia*	57 648	57 648	14	35	593	22
Oceania*	186	168	21	35	1	2

* Developed Asia = Japan and Israel; Developing Asia= The rest of Asia

* Developed Oceania = Australia and New Zealand ; Developing Oceania = The rest of Oceania

Col I = Commercial energy + fuelwood at 42 GJ/t. *Source*: BP, 1990; FAO, 1989.

Col II = Total potentially harvestable residues from crops, forests and dung.

Col III = It is assumed that only 25 per cent of potentially harvestable residues are likely to be used.

Col IV = Assumed average energy use per capita of 35 GJ/cap for developing areas, 310 GJ/cap for N. America & 140GJ/cap for rest of the World

Col V and VI = Assumed 25 per cent potentially harvestable residues likely to be used and 10t/ha productivity as an achievable global average.

Source: Hall et al, 1992a

Table 19. Potential energy production from harvestable residues conditions. It is thus important to improve the economic viability of the more environmentally-acceptable cane.

Depending on the choice of the gas turbine technology and the extent to which barbojo cane tops and leaves can be used for off-season generation, Williams (1989) points out that the amount of electricity that can be produced from cane residues could be up to 44 times the on-site needs of the sugar factory or alcohol distillery. He calculates that for each litre of alcohol produced a BIG/STIG unit would be able to produce more than 11 kWh of electricity in excess of the distillery's needs (about 820 kWh/t). Another estimate of bagasse in condensing-extraction steam turbines (CEST) puts the surplus electricity energy values at 20-65 kWh per ton of cane, and this surplus could be doubled by using barbojo for generation during the off-season. The cost of the generated electricity is estimated to be about $US0.05/kWh (Centro de Tecnologia Copersuca, 1991). Revenues from the sale of electricity co-produced with sugar could be comparable with sugar revenues, or alternatively, revenues from the sale of electricity co-produced with ethanol could be much greater than the alcohol revenues. In the latter instance, electricity would become the primary product of sugarcane, and alcohol the by-product (Williams, 1989).

In India alone, electricity production from sugarcane residues by the year 2030 could be up to 550 TWh/year (the total electricity production from all sources in 1987 was less than 220 TWh (Ogden et al, 1990). Globally, it has been estimated that about 50,000 MW could be supported by currently produced residues. The theoretical potential of residues in the 80 sugarcane-producing developing countries could be up to 2800 TWh/yr, which is about 70 per cent more than the total electricity production of these countries from all sources in 1987 (Williams and Larson, 1992). Studies of the sugarcane industry by Ogden et al, (1990), and of the pulp industry by Larson and Svenningsson (1991) indicate a combined power grid-export capability in excess of 500 TWh/yr. Assuming that a third of the global residue resources could economically and sustainably be recovered by new energy technology, 10 per cent of the current global electricity demand (10,000 TWh/yr) could be generated.

Obviously these are theoretical calculations which gloss over the many country- and sitespecific problems to achieving such goals. They do however emphasize the potential which many countries have to provide a substantial proportion of their energy from biomass grown on a sustainable basis.

E. R&D and technology transfer

The tools of science and technology, particularly biotechnology, offer great opportunities for modernizing bioenergy production and end use.

However, as shown by, e.g., the KCJ case study, translating basic research discoveries into commercial applications and social benefits requires a complex set of interactions involving many types of people and institutions, which unfortunately many developing countries lack (NRC, 1987). A great deal of local and foreign investment in renewable energy development in many countries, as shown by the Malawi Charcoal Project case study, has been concentrated in the public sector without sufficient attention to the application of research and development results in the market place. Thus much of the research has created little commercial interest which is important if the bioenergy industry is to become successful.

Almost total neglect has left plant biomass R & D in a very poor condition compared with agricultural and even forestry research. The government funding for renewable energy R. D & D in the IEA Member countries in 1989 was only $489 million compared with about $3.5 billion for nuclear fission (OECD, 1987; OECD 1990; Flavin and Lenssen, 1990). In the United States, R & D expenditure on biomass fell from about $70 million in 1981 to an estimated $9 million in 1990 (at 1990 prices) (Racer et al, 1989). Despite some increased research on biomass over the past decade (compared with other renewable energies), this has not yet resulted in the actual introduction of much new technology for the conversion of biomass into energy; furthermore, the R & D effort still lags far behind the practical requirements. Thus R. D & D will have to be extensively supported to increase productivity and efficiencies of use in all areas in parallel with training and the build-up of infrastructure on a long-term basis.

The major technological challenges faced by biomass fuels include: (a) to reliably produce and deliver large quantities of biomass to conversion facilities (e.g.,1000-2000 t/day of biomass daily from within a range of 80 km) at a cost of between $1.50 and $2.00/GJ; (b) large increases in bioproductivity and conversion efficiency using less energy and capital (e.g., to produce 270 litres of gasoline-equivalent per tons of dry matter, i.e., twice the current levels, at a total cost of about $0.26 to $0.32/1); and (c) to increase efficiency in harvesting, handling, and storage of biomass (Hall and Rosillo-Calle, 1991).

Technology transfer has been widely advocated in the past as the best way for developing countries to obtain access to new technologies (Hoffman and McNelis, 1986). It should be regarded as an important component in speeding up the process of modernization of bioenergy. As shown by the case studies on ethanol distillation plants, biogas, charcoal production, improved stoves and gasifiers, the technologies are often universally available so that technology transfer to optimize production and conversion can be quite easy given the appropriate institutional structure and financial incentives - especially in comparison with fossil fuels. Indeed a number of developing countries could adapt and improve the technologies for these so-called modem biofuels. However, technology transfer is a complex process and must be adapted to the prevailing socioeconomic conditions if it is to succeed. This point has been clearly proved by the KCJ case study, where a Thai technology was modified and widely disseminated in Nairobi, Kenya, because of the strong involvement of various sectors, government, NGOs, the informal sector and local entrepreneurs.

Technological constraints have often limited propagation of the biomass-energy technologies since their cost and performance deficiencies fare poorly in comparison with more commercial alternatives. The USDOE (1990, p. 15) have identified the following technical constraints: "resource access, conversion efficiency, lifetime and reliability, market compatibility and manufacturability. They also usually involve limits to scientific knowledge, unsolved engineering problems, unavailability of required materials or production techniques, maintenance difficulties etc. (USDOE, 1990). Lack of contacts and cooperation between scientists in the developing world and entrepreneurs, sometimes exaggerated claims by scientists and enthusiasts alike which did not stand up to scrutiny and resulted in loss of credibility etc., have often been major obstacles to more rapid introduction of alternative energy technologies. Testing unproven technologies in remote rural areas often leads to failure of the project which then creates prejudices against the technology (as shown in the South Pacific study).

The most important obstacles to technology transfer, however, are the lack of trained personnel, lack of understanding of local circumstances, and the absence of an extensive basic scientific and technical support structures - with the interdisciplinary and multidisciplinary collaboration which is required for modernizing bioenergy. This is clearly demonstrated in chapter I. Training and extension services are vital for the success of technology transfer. Also, information on the technology must be available in a form suitable to the end-user, and the technology must be seen to be reliable. The training of human resources is therefore paramount and should be oriented toward supporting locallybased applications engineering and development. Most of the renewable energy technologies have been developed in the industrialized countries and many of those are too expensive for widespread use in developing countries (Hoffman and NcNelis, 1986) unless they are adapted to local manufacture and maintenance as with over 500 sugarcane alcohol fermentation and distillation plants manufactured in Brazil since the late 1970s. R & D must take into account local, environmental and socioeconomic conditions in order to really produce "bioenergy technologies for development".

Technically simple projects do not always receive the greatest priority in many developing countries. Often, it is scientists with extensive credentials, and who follow developed countries models, who tend to influence planners and dominate funding, while often accomplishing little that is applicable to the needs of the great majority of the people. As shown in this report, technology should not only be readily transferable, but also flexible. Indigenous technology may well prove a fertile startingpoint for many innovative activities. Many technological innovations in the rural sector owe much to the creativity, ingenuity and skill, not necessarily of research scientists, but of local farmers, artisans and entrepreneurs.

The Chinese Government, for example, has been supportive of technology transfer. Official policy has been to push research institutes into pursuing practical engineering problems, e.g., biogas technology is supported by a large and long-standing R & D programme. There are over 100 scientific research institutes in China carrying out biogas-related research, and more than 50 experimental stations have been created to develop new techniques, standardize procedures and train technicians in biogas technologies. The actual involvement of the industry and local entrepreneurs in biogas dissemination is difficult to gauge because of the given, but changing socioeconomic pattern in China. However, in general, the result has been several major improvements in renewable energy systems, construction materials etc.

India also has developed institutional mechanisms for strengthening the technology-transfer system of biomass energy technologies. Some of these mechanisms include the setting up of state agencies to support entrepreneurs, market support, sponsoring R. D & D projects, the creation of biomass-related programmes such as the National Biogas and Improved Chullah Programmes, and the establishment of biomass research centres. Saxena and Vasudevan (1991) conclude that although these efforts have met with some success, most biomassenergy technologies have not yet reached a stage where market forces alone can make the adoption of these technologies possible. A successful instrument in transferring such biomass technologies appears to have been the creation of an artisan network in rural areas to train youths in the operation and maintenance of these technologies.

F. Social factors

Many biomass energy projects ignore the importance of social factors. For instance, bioenergy may not be a priority to poor rural communities who have much more pressing requirements and are unable to take a longer-term view toward generally rehabilitating their biomass resources. As shown in chapter II - Improved Charcoal

Production - they are reluctant to adopt technologies that may appear risky and do not meet their short-term needs. Outside (non-local) "energy experts" mainly focus on only one aspect of biomass use to the exclusion of all its other products and services. Therefore, locals are seldom consulted when bioenergy projects are being implemented and will not change their practices unless they can afford to do so with minimal risks. This has happened frequently in the past and lead to many failed biomass energy projects and programmes (as shown in several of the case studies examined in this report).

Village plantations, for example, rely on growing trees on a small scale to feed the gasifier. Unfortunately, such tree-planting schemes have generally been a failure, with a few notable exceptions such as eucalyptus plantations in Ethiopia. Fuelwood plantations have run into many problems: as shown by several of the woodfuel production technologies case studies, they rarely produce fuelwood itself as the wood is more valuable for other purposes such as timber and pulp. Women, the collectors and users of fuelwood, rarely benefit from plantations because such projects tend to plant trees on land owned by the more well-off men. Plantations can often reduce the quantity of fuelwood available to local people, as foresters tend to restrict access to planted areas and thus the wood is no longer a freely collected resource, and has to be paid for (Soussan et al, 1990). Similarly, the large-scale commercial utilization of biomass residues could threaten poorer members of society as they may end up having to pay for cooking fuels that they used to collect free. The provision of modernized bioenergy has to be developed in such a way that the usual free availability of both wood and residues to rural people remains unchanged.

All the case studies have shown that local involvement and control is a prerequisite for success so that the ideals of multiple benefits, flexibility and sustainability can be achieved to catalyse development. The lessons reamed show that, generally, technologies and programmes which have won the widest acceptance have been those which are more readily integrated into the existing social and economic situations and which do not require radical change. The failure of the gasifies projects in the Philippines and the South Pacific were largely due to a lack of understanding of local circumstances such as the priorities and financial realities of farmers. In China, rural-urban migration began to undermine bioenergy projects due to the lack of organic matter and people. As shown in the biogas case studies of India, biogas subsidies are often available to those who do not have enough cattle to warrant a biogas plant and some of the biogas plants installed by landless or marginal farmers are idle for lack of cow dung. On the positive side, as shown in the Pura village project, the project team of ASTRA was also involved in social and development issues. The problems encountered during the initial phase of the project were only overcome by listening to what the villagers said they needed, adapting the project so the benefit was seen to be fair to all, and instituting a village committee to organize and administer the production of biogas, and the equitable distribution of the benefits. Similarly, the Triangle project in Zimbabwe also placed great emphasis on local planning, control, manufacture of machinery etc., which contributed much to the successful running of the project.

G. Economics

The main contentious problems of bioenergy provision relate to economics. The application of economic principles to biomass energy is difficult given its many socioeconomic ramifications and the diversity of types, production and use techniques in the overall energy production cycle. There is no such thing as "fixed" biomass production costs since the economics are quite site-specific. They depend on many varying factors, including agricultural costs, the type of raw material utilized, the location of the manufacturing plant, the design, type and degree of modernization of equipment, the relative labour costs represented, the scale of production, the total investment, market and institutional barriers, and continuously fluctuating international and local markets for petroleum, sugar, charcoal etc. Additionally, biomass is seldom grown only for energy but is a derived byproduct of other forestry and agronomic practices and is, therefore, dependent on these management (or non-management) practices. The provision of biomass energy on an economic basis undoubtedly needs local entrepreneurs to make judgements and decisions.

The economics of biomass fall into various categories. Kleinhanss and Kogl (1989) divide it in three main sections:

(a) Biomass production: Biomass energy feedstocks for commercial use could be divided into two major categories: (a) those that have minimal or zero resource costs, e.g., on-site waste products; and (b) those that have a higher market value, e.g., plantation-based wood and highvalue agricultural crops. As Gowen (1989, p. 462) stated: "The dominant economic characteristic of most financially competitive bioenergy systems is that they almost always depend on feedstocks that are free (or nearly) as valued by the private market." If biomass energy can be obtained 'free', incentives to improve efficiency of production and use and to replace non-commercial by commercial sources will be limited. French (1984, p. 161) summarizes the problem well: "As long as there is 'free' indigenous wood, people will neither plant trees nor turn to alternative sources of energy". When using feedstock with a market value, seasonal variations in price have to be considered, as well as other market fluctuations that are less predictable. An advantage of purchasing indigenous biomass fuels is that all expenditure is retained within the local economy.

(b) Biomass processing: Important economic considerations include the capital cost of the plant, conversion procedure, the number of process stages, seasonal utilization of the conversion plants, the size of the conversion plants, transport costs and use of the main products and by-products.

(c) Biomass use: The value of biomass can be derived from the benefit gained in the overall use system. The individual benefit of a specific product can, however, be very different and can be strongly influenced by socioeconomic factors, culture etc. The value of biomass also depends on the available quantity of the resource because the marginal benefit generally decreases with increasing use.

To obtain the maximum benefit from biomass energy requires simultaneous optimization of biomass production and use, taking into account progress in bioproductivity and conversion technologies. Renewable energy sources are currently not utilized to their full competitive potential and are introduced into the market considerably later than the optimum time of market introduction based on their overall cost situation (including social costs) (Hohmeyer, 1988). The future cost of biomass energy will depend on many varying factors such as the extent of technological advances in biomass-energy conversion and in feedstock productivity. These developments in turn will partly be determined by the general energy situation, especially the price and availability of commercial fuels. It will also depend on how developing countries address the overall energy problem, particularly with regard to bioenergy incentives and R&D investments compared with other energy sources (Holdren, 1990). The progress made in all areas of biomass-energy use has been much greater per unit of expenditure than has been achieved in the pursuit of nuclear fusion for example. Indeed, some believe that if half as much had been spent on the development of solar energy as spent on all forms of nuclear energy, the world would already have achieved a large, renewable source of energy.

1. Subsidies

A major criticism levied against renewable energy in general and biomass energy in particular is the need for large subsidies. However, it is forgotten that subsidies to promote energy and agricultural development are at the core of nearly all economic systems, and energy from renewable resources generally receives far less subsidies than do conventional sources. For example, the 24 countries of the OECD provide agricultural subsidies totalling about $299 billion per year (OECD, 1991), while United States Federal energy subsidies to all forms of energy are estimated at $100-300 billion per year. There are many other types of subsidies and hidden costs, for example, the

United States Department of Defense spent at least $ 15 billion to safeguard oil supplies in the Persian Gulf. Chinese consumer subsidies for oil, electricity and coal amount to $ 19.4 billion per year, which is 7 per cent of China's GNP; and in Egypt petroleum subsidies totalled $4 billion in 1985, equal to 13 per cent of the GNP (Kosmo, 1987).

In the Pacific and Asia, "small-scale biofuel systems may receive substantial aid only for initial capital costs" also "it is common ... for biomass system users to agree to charges that pay back the full system costs, whereas most industrial users of centralized fossil-fuelbased systems receive subsidized tariffs". This makes the electricity produced from biomass more expensive than that produced from kerosene or diesel-based electricity (Gowen, 1989, p.465). In India, where the electricity tariff is only one fifth of the real cost of providing electricity in rural areas, it could be argued that the high subsidies given to the electricity and diesel sectors are two of the main barriers to alternative energy technologies in India today (Bhatia, 1990).

Subsidies conceal real commercial energy costs. This badly allocates scarce capital and disrupts fair competition between energy sources. Heavy subsidies to conventional energy sources retard commercialization of renewable energy technologies even further. As Kosmo (1987, p.37) points out:

> "Low energy prices are often justified by governments in developing countries on the grounds that they favourably affect the poorest strata of the population, who spend larger portions of their income on energy. This is not necessarily the case since the poor people (either rural or urban) use little commercial energy and rely disproportionately on biomass, and therefore commercial energy subsidies actually do little to better their standard of living."

The amount and impact of subsidies with biomass systems varies widely from country to country and with different biofuels and it is difficult to compare energy costs on a level basis given the inherent internal and external costs of fossil fuels. Many successful commercial biofuel systems have not relied upon subsidies - the Zimbabwe alcohol project is an excellent example of a commercial development with rapid payback (although it may well need financial support after the recent devastating drought).

2. Internalizing the externalities

One of the principal barriers to the commercialization of renewable energy technologies is that current energy markets mostly ignore the social and environmental costs and risks associated with fossil-fuel use. In effect, relatively harmful energy sources, e.g., highsulphur coal and oil, are given an unfair market advantage over relatively benign sources such as biomass, solar and wind (Weinberg and Williams, 1990). Since competing conventional energy technologies are able to pass on to society a substantial part of their costs (such as environmental degradation and health-care expenditures) renewable energy sources, which produce very few or no external and may even cause positive external effects (such as job creation, rural regeneration and foreign-exchange earnings), are systematically put at a disadvantage. Internalizing all these costs therefore must become a priority if a "level playing field" is to be created.

While it is extremely difficult to quantify the external costs of such pollution, and some simply cannot be quantified, several studies show them to be substantial (Brower, 1990). For example, a German study (Hohmeyer, 1988) concluded that the external costs (excluding global warming) of electricity generated from fossil-fuel plants are in the range of 2.4-5.5 c/kWh, while those from nuclear power plants are 6.1-3.1 c/kWh. Had external economic effects been included in the market allocation process, renewable energy technologies would be in a far better ("the level playing field") position to compete with fossil fuels, and there might already have been a substantial shift to the penetration of renewable energy in the market.

Biomass energy systems should also be perceived as providing substantial foreign-exchange savings if they replace imported petroleum products, although the issue is not always clearcut since it depends on import substitution and export earnings. In countries like Brazil, with a long historical experience of bioethanol production and use, there are substantial savings in oil imports and also foreign-exchange earnings from alcohol-related technology exports. Zimbabwe similarly saves foreign exchange on petroleum imports while developing a technical infrastructure which leads to import substitution. One needs, however, to consider the net benefit to a country if local resources which were used for domestic energy production could have earned more foreign exchange through exports; it can be a complex calculation, especially if it incorporates (as it should) factors such as employment, energy security and so on.

3. Bioethanol cost

Cost estimates for producing bioethanol vary considerably and are not without controversy. These vary from $26 to $60 per barrel of oil-equivalent from sugarcane in Brazil, and $60 from maize in the United States, to $65 from grain in the EC (Rosillo-Calle et al, 1991). Prices drop rapidly with improvements in biomass production and conversion. In Brazil, the cost of production declined 4 per cent annually between 1979 and 1988, and analyses indicate that the prospects for reducing production costs by another 23 per cent over the next several years are good (Goldemberg et al, 1992). Free-market microeconomics of bioethanol are still unfavourable relative to heavily subsidized oil-derived fuels. The cost of bioethanol in the absence of direct or indirect subsidies still remains a serious obstacle to its widespread use. In the United States, highly variable maize and byproduct prices and the wide variations in final ethanol costs among existing plants over time have caused doubts as to the future direction of this industry (Dinneen, 1990). In the short term, some kind of economic and financial incentives would be needed in many cases to allow bioethanol projects to succeed. There are, however, a number of other factors that, if pursued further, could significantly reduce production costs.

The use of by-products can have a major impact on ethanol production, depending on the choice of feedstock. Higher-value by-products include other fermentation products, fermented animal feed or developed food products, energy, and fertilizers. Ethanol can therefore be produced as one of a number of co-products among which the raw materials and capital costs are shared. Thus environmentally-related problems can be eliminated while maximum advantage can be taken of the feedstock. In Brazil, a multi-product industry is emerging based on "sugarcane-alcohol-bagasse" products, that is having a major impact on ethanol costs. By using biomass-integrated gasifier/gas-turbine cogeneration systems to produce electricity from residues, alcohol could be competitive with gasoline at 1991 oil prices and the excess electricity would be competitive with that from new hydroelectric power plants (Goldemberg et al, 1992).

Johansson et al (1992) predict that as production of petroleum declines in the next decade, biofuels will be competitive against those manufactured from coal and natural gas. Biofuels will be cheaper than fuels from coal, but unable to compete with methanol manufactured from natural gas at today's prices.

4. Biogas production

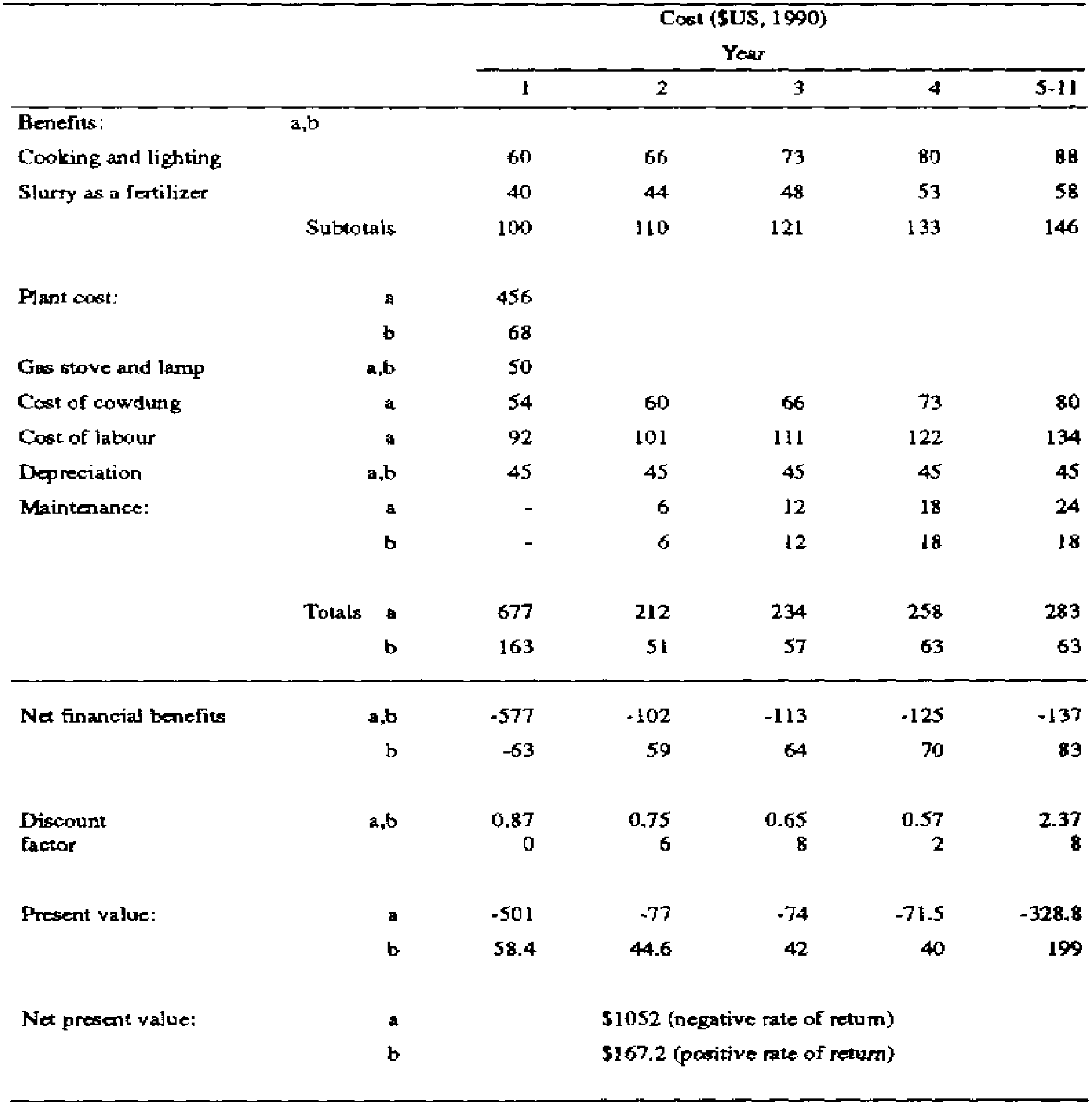
In assessing the economic viability of biogas programmes one should distinguish four major areas of applications: individual household units, community plants, large-scale commercial animal- rearing operations, and industrial plants. In each of these cases, the financial feasibility of the facility depends largely on whether outputs in the form of gas and slurry can substitute for costly fuels, fertilizers or feeds which were previously purchased, while at the same time abating pollution. According to Gunnerson and Stucky (1986), the economics of biogas technology rest on the following factors: (a) the useful energy content of different fuels, e.g., dung, fuelwood, kerosene and biogas; (b) the effficiencies with which these fuels are currently being used, or the possible equipment which could lead to higher efficiencies; (c) the NPK contents of different organic fertilizers, and the fertilizer-yield response under different agronomic conditions and crop rotations; and (d) behavioural aspects of the energy sources or organic fertilizers such as current use patterns etc.

The first comprehensive economic cost-benefit analysis of Indian biogas plants was written by Parikh (1963) and revised in 1976, in which it was concluded that family-sized biogas plants were highly profitable with a gross return of about 14- 18 per cent purely in financial terms. Recently, Sinha and Kandpal (1990, p. 52) concluded from their study that the "use of incremental benefits from the biogas plants would indicate that biogas technology is a viable option for many end-uses in rural areas". They note that: "(a) the viability of the 1 m^3 plant without subsidy is conditional; and (b) lighting is the most profitable end-use of biogas, followed by cooking and motive power, at the prevailing prices for alternate energy sources." The study of the Pura community-sized plant (Rajabapaiah et al, 1992) showed that the plant would pay for its operating costs once operating time exceeded 6 hrs/day, and that it would be competitive with grid electricity at 15.1 hrs/day. Daxiong et al (1990) found from their study of digesters in China that there is a high internal rate of return of 59- 114 per cent, and a short gay-back time of 14 yrs.

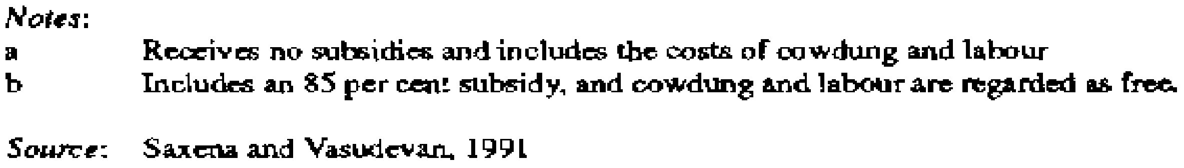
The financial analysis of a 3-m biogas plant is summarized in table 20. The costs of installation are based on current market rates (1990) prevalent in the project villages and with different subsidy components. According to Saxena and Vasudevan (1991), in terms of market reasoning, these biogas plants are uneconomic since they give a negative rate of return, even with an 85-per cent subsidy. However, economic viability can be achieved if dung and labour are regarded as being free. The viability will further improve if other social costs are considered, e.g., employment, self-sufficiency etc. Thus, biogas plants, although technically feasible, still require a high degree of subsidy, particularly given the fact that other competing energy sources such as kerosene and diesel are highly subsidized.

5. Gasification

Gasification is already economic in some situations as was shown by Mahin's (1989) study in Mali. The unit cost of electricity for the gasifier was DM0.26/kWh which was only 54 per cent that of a diesel plant. With new technology, gasification is becoming even more economic. Williams and Larson (1990) have estimated the cost of BIG/STIG cogeneration based on a hypothetical sugarcane factory modelled after the Monymusk factory in Jamaica processing 175 t/d of sugarcane. According to their calculations, the



		Cost ($US, 1990)				
		Year				
		1	2	3	4	5-11
Benefits:	a,b					
Cooking and lighting		60	66	73	80	88
Slurry as a fertilizer		40	44	48	53	58
	Subtotals	100	110	121	133	146
Plant cost:	a	456				
	b	68				
Gas stove and lamp	a,b	50				
Cost of cowdung	a	54	60	66	73	80
Cost of labour	a	92	101	111	122	134
Depreciation	a,b	45	45	45	45	45
Maintenance:	a	-	6	12	18	24
	b	-	6	12	18	18
	Totals a	677	212	234	258	283
	b	163	51	57	63	63
Net financial benefits	a,b	-577	-102	-113	-125	-137
	b	-63	59	64	70	83
Discount factor	a,b	0.870	0.756	0.658	0.572	2.378
Present value:	a	-501	-77	-74	-71.5	-328.8
	b	58.4	44.6	42	40	199
Net present value:	a	$1052 (negative rate of return)				
	b	$167.2 (positive rate of return)				



Notes:

a Receives no subsidies and includes the costs of cowdung and labour

b Includes an 85 per cent subsidy, and cowdung and labour are regarded as free.

Source: Saxena and Vasudevan, 1991

Table 20. Financial analysis of 3m³ in India

BIG/STIG could produce over 460 kWh per ton of cane, or more than 20 times current electricity production (20kWh/t). A 53 MW BIG/STIG plant (operating year-round on briquetted sugarcane residues at sugar factories in Sao Paulo State) would be able to provide exportable electricity at $0.041/kWh, a substantially lower cost for electricity than the coal-fired option (even with a low coal price), and in the mid-range of costs estimated for new hydroelectric supplies from the Amazon, estimated to cost $0.032 to $0.058 kWh. Also, a BIG/STIG plant could produce electricity at a total cost lower than the operating cost with oil, even with oil at $2.9/GJ ($ 19/bbl). The investment in a BIG/STIG plus steam-conserving retrofits would provide an estimated rate of return of 18 to 23 per cent. However, the environmental impacts of using so many cane residues need careful consideration.

H. Policy

Although economics play a significant role in biofuel production and use, it is often the case that clear political objectives and commitment will lead to success, and the opposite usually results in failure. In fact, successes and failures are usually the consequence of a mix of economic, political and technical factors. Government intervention should be largely regulatory to create favourable conditions, and the private sector should be directly involved. The government should, in particular, play a prime role in providing clear objectives and commitment, developing an appropriate regulatory and legislative framework, providing financial and economic incentives etc. On the other hand, too much government intervention, either directly or indirectly, e.g., through regulation, taxation, subsidies etc., will distort economics.

An important problem is that biomass energy is not taken seriously enough by planners and politicians because its main use is in the rural areas of developing countries and it is a diffuse and difficult energy problem to deal with. Biomass is generally and wrongly regarded as a low-status or inferior fuel for poor people only, and carries little or no prestige among decision-makers. It is, therefore, rarely included in energy statistics, and when it is, it tends to be downgraded. The fact that it also provides an important fuel source for the urban poor and many rural and small-scale industries is also infrequently recognized. Thus policy interactions are usually based on imprecise information and distorted subsidies for alternative fuels. For example, an FAO (1990) report on Asian countries notes that many central governments do not appear fully to realize the significance of wood energy use in rural industries, the importance of these industries to national economies, the viable long-term energy alternatives for them, and the opportunities presented by the potential development of biomass fuel for industry.

Constraints the implementation of biomass projects, apart from lack of appropriate and consistent data to allow informed decision-making, include: lack of skilled and experienced advisors; scepticism born of past disappointments; and failure of scientists etc. to transfer the results of technical assessments to the energy policy makers in ways which influence energy projections and implementation (NRC, 1982). Biomass-based technologies are only seen as possible longer-term solutions with delayed benefits. Governments also do not normally consider biomass energy as capable of significantly reducing a country's fossilfuel requirements (although it can provide most of the energy for the poor), unless largescale, very specific projects are implemented. Finally, other high-technology projects receive more attention for political and prestige reasons. These factors inevitably result in most biomass-energy-related projects receiving low priority and/or ineffective implementation.

Developing countries tend to follow the same economic development philosophy as the industrialized countries. The local environmental impacts of cheap, dirty energy are seen as a necessary trade-off for meeting basic human needs. Thus prevailing energy policies promote fossil fuels to the detriment of most other energy resources, particularly for verylarge-scale developments. A large number of developing countries have maintained energy pricing policies which discourage investment in renewable energy, by artificially depressing the price of electricity and liquid fuels, e.g., in India where the grid electricity tariff is only a fifth of the cost of rural energy provision (Bhatia, 1990). National pricing policies of conventional sources of energy can greatly influence the pace of introduction of new energy technologies. Thus initial political and financial support for renewable energy is an important prerequisite to the market development of these technologies (Goldemberg et al, 1992; Reddy and Goldemberg, 1990).

The private sector is unlikely to invest in renewable technologies as a whole because the benefits are long-term, energy costs will usually not be significantly lower than those of conventional energy and the sector does not have to consider the external benefits. It is imperative that a balanced system of taxes and subsidies is put in place to ensure that new energy sources are not discriminated against. According to Grubb (1990) policy changes need to be made to change energy-consumption patterns as market forces alone would not be sufficient, e.g., the use of carbon taxes is widely advocated as the most efficient and flexible way of limiting carbon emissions. The preferred policy instruments should reflect differences in endowments of renewable resources, stages of economic development, and cultural characteristics, and should be aimed at promoting sustainable development (Johansson et al, 1992).

Johansson et al (1992) cite the following policy initiatives as necessary to encourage investment in renewables:

- Remove subsidies from conventional fuels and/or give renewables equivalent incentives.
- Taxes, regulations and other policy instruments should be used to include the external costs in market prices.
- Increasing government support for renewables R&D, which should be carried out in close cooperation with the private sector.
- Regulation of electric utilities to encourage renewables.
- Policies for the development of biofuels must be closely coordinated with national agricultural and land-restoration programmes.
- Creation/strengthening of national institutions to implement/promote renewables.
- International development funds for the energy sector should be directed increasingly to renewables.
- Creation of a strong international institution to assist and coordinate increased use of renewables, support assessment of energy options, and support R&D centres.

The role of government incentives and energy security in a number of following examples can have relevance to many other countries. India, for example, is a country where successive governments have recognized the importance of small-scale production. However, despite official interest in the development of small-scale industries, Indian policy-making and investment has generally promoted Large-scale and capital-intensive methods of production which is readily seen in the energy sector. According to Reddy and Goldemberg (1990) the small-scale sector has received only about 2 per cent of the total public-sector outlay since 1966, in contrast to about 22 per cent for the large-scale sector.

Comparing the ethanol programmes in Kenya, Malawi and Zimbabwe, despite the initial similarities in their socio-economic setting and plant-specific technical parameters, Kenya followed different implementation routes from Malawi and Zimbabwe, with sharply different results. For example, the Madhavani project in Kenya was approved by the Government without adequate evaluation of the key adaptive conditions such as the availability of raw material before the project was approved. In Malawi and Zimbabwe the availability of molasses was guaranteed before construction was started. The Malawi and Zimbabwe projects were funded entirely privately, the State playing a largely regulatory role to create the ideal conditions for the project to succeed.

The Brazilian ethanol production case demonstrated the political issues, and the perseverance with which governments must act to assist the establishment of an alcohol fuel programme. However, while subsidies designed to encourage the establishment of the sugarcane industry were effective, they had longer-lasting impacts in suppressing entrepreneurial development of the industry. As with other new enterprises, political, social and institutional factors and market penetration barriers all play a key role in the development and introduction of a bioethanol fuel programme. Without the stabilizing influence of a coherent public sector, uncertainty in the market will be so great as to discourage investment in non-petroleum fuels. Until recently, the development of alternative transport-fuels policy has seen emphasis placed on technical and economic issues. But governments are beginning to recognize the importance of "non-technical" aspects of energy policy.

I. Institutions

The following institutional constraints have been identified: "regulatory, financial, infrastructural and perceived" (USDOE, 1990 p. 15). Despite the fact that a large range of organizations have been created to promote the development of small-scale production which is especially relevant to biomass energy, such institutions have generally not been very effective, if at all, mainly due to the lack of finance and trained personnel, and lack of influence and follow-up. Success and failure also depends very much on the understanding of local incentives and barriers to change and involvement of local people at all levels; these are invisible barriers that development people often fail to see such as culture, local bureaucracies, lack of incentives, and so on.

Development planners and workers often want things to be done their way rather than the way people might prefer. Many new innovations are introduced not because they are needed but because they interest the introducer rather than answering people's needs as shown in sections on the Philippines and the South Pacific. This is an especially detrimental attitude towards biomass projects which require very careful planning and long term implementation (Barrett, 1990). Furthermore, when projects that are funded through foreign-aid sources are not followed up, there is often no real commitment or incentive on the part of the endusers to utilize the technology and keep plants operational. Therefore, such projects have to be far more carefully planned to ensure that they are actually of enough benefit to endusers that they will wish to maintain them, and that the infrastructure support is available to enable them to do so.

VIII. Conclusion

There is an enormous untapped biomass potential, particularly in improved utilization of existing residues, and forest and other land resources, and in higher plant productivity. Modernization of bioenergy production and use could bring substantial social and economic benefits to both rural urban areas. As Paszior and Kristoferson (1990, p. 28) put it, "if biomass energy systems are well managed, they can form part of a matrix of energy supply which is environmentally sound and also contributes to sustainable development." If biomass is to make any significant energy contribution to development however, it must be produced in greater quantities. It must also provide efficient, sustainable, economically justifiable and environmentally-sound energy systems whilst ensuring that other more traditional modes of production and uses also are efficient and sustainable.

It is expected that demand for biomass will rise considerably in the future, because of: (a) population growth, particularly in developing countries; (b) greater use in the industrialized countries due partly to environmental considerations; and (c) technological developments which could allow either the production of new or improved biomass fuels, or the improved conversion of biofuels into more efficient energy carriers thus stimulating demand for feedstock. But biomass energy still faces many barriers - economic, social, institutional and technical. It is a large and varied source of energy at very uneven stages of development, both with respect to scale and technological requirements. Enhanced biomass availability on a sustainable basis will require support and development of new biomass systems.

Wider commercial exploitation on a sustainable basis awaits the development and application of modern technology to enable biomass to compete with conventional energy carriers. It is most likely that many developments and deployment of modernized renewable resources will be led by the industrialized countries, particularly the United States, Western Europe and Japan (Grubb, 1990). The extent of the near-term contribution of renewable energy will, in turn, be largely determined by the length to which North Americans, Western Europeans and Japanese are successful in directing their institutes to foster the growth of renewables.

> "This will determine whether renewable energy supplies in general, and biomass in particular, will grow incrementally by the sheer force of their market competitiveness, or whether policies will be developed now to recognize their inherent environmental benefits as well and allow them to develop more rapidly (Racer et al, 1989, p.15).

Application of modern biomass energy technologies in many developing countries will usually also depend strongly on foreign finance, because of the capital and other requirements of many modernized renewable energies (Grubb, 1990). However, in the case of the more traditional and also less capital-intensive technologies, innovation and adaptations, local skills and entrepreneurs can play a leading role. Biomass production and use, in an economic and sustainable manner, should thus be seen as an opportunity for entrepreneurs of all descriptions especially since biomass is so widely distributed and used throughout the world.

Many attempts have been made to introduce new energy technologies, but in most cases, factors external to the technology seem to have played a greater role with respect to acceptability than the technology itself. This is particularly true with respect to economics. It can be argued that one of the major barriers to the commercialization of renewable energy technologies is that current energy markets in most cases ignore and/or do not pay the social and environmental costs and risks associated with fossil fuel use. This is especially relevant to biomass energy which has many environmental and social benefits. If "externalities" such as employment, import substitution, energy security, environment and so on are considered, then the economics change usually in favour of the biomass systems. Social and Land-use policies must also be given high priority.

Programmes which are currently commercial, such as ethanol and electricity production, can be analysed in both developing and developed countries and some general conclusions can be drawn. The Brazilian ethanol case demonstrates the need for a clear government commitment, the vulnerability of such large programmes to short-term market fluctuations and the inherent difficulty of long-term energy planning. In Zimbabwe, the State played Largely a regulatory role to create the acceptable market conditions for the ethanol project to succeed, leaving the funding entirely to the private sector. The success of the Pura biogas project in India and the failure of the gasification projects in the Philippines highlight the importance of social factors and long-term commitment in successful energy and development projects.

Finally, from the results of the analysis of biomass energy projects in developing countries it can be concluded that the requirements for successful biomass projects depend mainly on the careful consideration of local socioeconomic factors, maximum participation and control by local people from the outset (including initiation and planning), the generation of shortterm local benefits within a longer-term context, and economic viability. It is of paramount importance to take a long-term view that includes sustainable development and environmental accountability, whilst allowing for flexible aims, replicability and multiple benefits.

References

Abracave (Charcoal Producers Association) (1992). Statistical Yearbook, 1992 (Belo Horizonte, 1992).

Agarwal, A., and Narain, S. (1990). Towards Green Villages (New Delhi, Centre For Science and Environment).

Akapelwa, J.S. (1990). "National Survey of Biomass/Woodfuel Activities in Zambia" (SADCC Energy Sector - TAU, Angola).

Anithkumar, C.S. (1990). "Bioenergy eco farming", in A.A.M. Sayigh (ad.), Proceedings 1st World Renewable Energy Congress (Oxford, Pergamon Press), pp. 2042-

2046.

Anon. (1989). "Agroindustria canavieira: um perfil" (Sao Paulo, Centro de Tecnologia Copersucar) (internal report).

Anon. (1991). "Biogas: big business In China", Our Planet (Nairobi, UNEP),vol.3,No.3,p.9.

Arnold, J. E.M. (1991). "Community forestry - ten years", Review (Rome, FAO).

Baguant, J. (1990). Personal communication, Department of Chemical Engineering, University of Mauritius, Mauritius.

Barnard, G., and Kristoferson, L. (1985), Agricultural Residues as Fuel in the Third World (London, Earthscan).

Barnett, A. (1990). "The diffusion of energy technology in the rural areas of developing countries: a synthesis of recent experience", World Development, vol. 18, pp. 539-553.

Bernardo, F.P., and Kilayko, G.U. (1990). "Promoting rural energy technology: the case of gasifiers in the Philippines", World Development, vol. 18, pp. 565-574.

Betters, D.R., Wright, L.L., and Couto, L. (1991). "Short rotation woody crop plantations in Brazil and the United States", Biomass and Bioenergy, vol. 1, No. 6, pp. 305-316.

Beyea, J., Cook, J., Hall, D.O., Socolow, R.H., and Williams, R.H. (1992). Toward Ecological Guidelines for Large-Scale Biomass Energy Development (New York, National Audubon Society).

Bhatia, R. (1990). "Diffusion of renewable energy technologies in developing countries: a case study of biogas engines in India", World Development, vol. 18, pp. 575-590.

Borges, J.M.M., and Campos, R.M. (1990). "Economic feasibility of the Brazilian fuel alcohol programme" in: Grassi, G. Gosse and G. dos Santos (eds.), Biomass for Energy and Industry, 5th EC Conference on Biomass for Energy (London, Elsevier Applied Science), pp. 1622-1626.

Brower, M. (1990). Cool Energy- The Renewable Solution to Global Warming, A report by the Union of Concerned Scientists (Cambridge, MA).

Bruinsma. (1991). Agricultural Land Use. Inventory of Agroecological Zones Studies (Rome, FAO).

Bureau of Environmental Protection and Energy (China) (1991). China Rural Energy Construction System, Its Development and Utilization (Beijing, Ministry of Agriculture).

Carpentieri, E. (1991). "An assessment of sustainable bioenergy in Brazil: national overview and case study for the northeast", CEES Working Paper No. 119 (Princeton University).

Carpentieri, E., Larson, E.D., and Woods, J. (1992). "Prospects for sustainable, utilityscale, biomass-based electricity supply in northeast Brazil", Biomass and Bioenergy (in press).

Centro de Tecnologia Copersuca (1991). "Relatorio tecnico interno: Convenio ElectrobrasCopersucar, altemativas de cogeracao, Piracicaba, Sao Paulo" (cited by Goldemberg et al, 1992).

Chanakya, H.N., and Deshpande, Kiran (1993). "Energy in stratified society. Case study of firewood in Bangalore", Economic Policy Weekly, vol. XVIII, No. 41, pp. 1757-1770.

CHESF. (1990). "Biomassa Forestal pare geraçao de energia electrica" (Recife).

Chidumayo, E.N. (1989). Biomass Survey Report, GTZ/World Bank Household Energy Project (Washington, D.C., World Bank).

Chiyenda, S., Jensen, B.T., Raunio, A.L., Semu, L., and Refsdal, T. (1989). "Blantyre City Fuelwood Project Malawi - Joint mid-term review" (Oslo, The Norwegian Forestry Society).

Conroy, C. (1992). "Can eucalyptus be appropriate for small farmers?, Appropriate Technology, vol. 19, No. 1, pp. 22-25.

Constant, M., Naveau, H., Ferrero, G-L., and Nyns, E-J. (1989). Biogas. End-Use in the European Community (London, Elsevier Applied Science).

Davidson, O., and Karekezi, S. (1991). A New, Environmentally-Sound Energy Strategy for the Development of Sub-Saharan Africa (Nairobi, AFREPREN)

Daxiong, Q., Shuhua, G., Baofen, L., and Gehua, W. (1990). "Diffusion and innovation in the Chinese biogas programme", World Development, vol.18, pp. 555-563.

De Bell, D.S., Whitesell, C.D., and Schubert, T.H. (1989). "Using N2-Fixing Albizia to Increase growth of eucalyptus Plantations in Hawaii", Forest Science, vol. 25, pp. 64-75.

De Montalembert, M.R., and J. Clement. 1983., "Fuelwood supplies in developing countries, Forestry Paper No. 42 (Rome, FAO).

Department of Non-Conventional Energy Sources (DNES), 1991-92 Annual Report (New Delhi, Ministry of Power and Non-Conventional Energy Sources).

Dinneen, R. (1990). "Ethanol: clean fuel for the "90s", Biologue (National Wood Association, Arlington, VA) (Sept/Oct.) pp. 10-12.

Durning, A., and Brough, H. (1991). "Sugar's sour deal for the third world", World Watch, vol. 4, No. 2, pp. 9-10.

Dyal Chand, A. (1989). "District level monitoring system for NPBD", Moving Technology, vol. 4, No. 5, pp. 9-12.

Dyal Chand, A., and Nirmala Murthy (1988). "District level management system for biogas program", Economic Policy Weekly, M-80.

Eckholm, E.P. (1975). "The other energy crisis: firewood", Worldwatch Paper I (Washington, D.C., Worldwatch Institute).

Eckholm, E.P. (1976). Losing Ground: Environmental Stress and World Food Prospects (Oxford, Pergammon Press).

EPA (Environmental Protection Agency) (1990). "Analysis of the economic and environmental effects of ethanol as an automotive fuel", special report, Office of Mobile Sources.

FAO (1984). "Tanzania fuelwood consumption and supply in semi-arid areas", FAO/SIDA Forestry for local Community Development Programme (GCP/INT/363/SWE) (Rome).

FAO (1990). "Wood-based energy system for rural industries and village applications", Report GCP/RAS/131/NET (Bangkok).

Fernades, Marcio de Paula (1991). "Charcoal production technologies: environmental and socio-economic impacts with Brazilian examples," ATA Bulletin, issue 6, December 1991.

Flavin, C., and Lenssen, N. (1990). Beyond the Petroleum Age. Designing a Solar Economy Worldwatch Paper 100 (Washington, D.C., Worldwatch Institute).

Foley, G., and Barnard, G. (1983). Biomass Gasification in Developing Countries, Earthscan Energy Information Programme (London, International Institute for Environment and Development).

French, D. (1984). "The economics of bioenergy in developing countries", in H. Engneus et al (ads.), Bioenergy 84 Proceedings of the International Conference on Bioenergy (London, Elsevier Applied Science Publications), vol. 5, pp.161-177.

Gilliuson, R., and B.K. Kaale. (1985). Plan for Planting and Conservation of Trees in Shinyanga Region - Tanzania 1986-2010 (Dar-es-Salaam, Ministry of Natural Resources and Tourism, Forestry Division).

Goldemberg, J., Monaco, L.C., and Macedo, l.C. (1992). "The Brazilian Fuel Alcohol Programme", in B.J. Johansson, H. Kelly, A.K.N. Reddy and R.H. Williams (eds.), Renewables for Fuels and Electricity (Washington, D.C., island Press), chap. 20.

Gotelli, C.A. (1988). "Ethanol as substitute of tetraethyl lead in gasoline", Proceedings of the VIII International Symposium on Alcohol Fuels (Tokyo, NEITDO), pp. 1099-1103.

Gowen, M.M. (1989). "Biofuel v fossil fuel economics in developing countries. How green is the pasture?", Energy Policy, vol. 17, pp. 455-470.

Grainger, A. (1988). "Estimating areas of degraded tropical lands requiring replenishment of forest cover", International Tree Crop Journal, vol. 5, pp. 31-61 (cited by Hall et al, 1992a).

Green, T.J. (1990). National Survey of Biomass/Woodfuel Activities in Lesotho, (SADCO Energy Sector- TAU, Angola).

Grubb, M.J. (1990). "The Cinderella options. A study of modernized renewable energy technologies. Part I- A technical assessment", Energy Policy, vol. 18, No. 6, p. 525.

Gunnerson, C.G., and Stuckey, D.C. (1986). Integrated Resource Recovery. Anaerobic Digestion- Principles and Practices for Biogas Systems, World Bank Technical Paper No. 49 (Washington, D.C., The World Bank).

Hall, D., and Green, T. (1989). Community forestry in Lesotho: The People's Perspective (Maseru, Sechaba Consultants).

Hall, D.O., Mynick, H.E., and Williams, R.H. (1990). Carbon Sequestration vs. Fossil Fuel Substitution- Alternative Roles for Biomass in Coping with Greenhouse Warming, Report No. 255 (Princeton, Center for Energy and Environmental Studies, Princeton University).

Hall, D.O., and Rosillo-Calle, F. (1991). "Biomass energy resources and policy (Biomass in developing countries)", report to the United States Congress Office of Technology Assessment (Energy in Developing Countries) (unpublished).

Hall, D.O., Rosillo-Calle, F., and De Groot, P. (1992a). "Biomass energy - lessons from case studies in developing countries", Energy Policy, vol. 20, pp. 62-73.

Hall, D.O., Rosillo-Calle, F., Williams, R.H., and Woods, J. (1992b). "Biomass for energy: supply prospects", in B.J. Johansson, H. Kelly, A.K.N. Reddy and R.H. Williams (eds.), Renewables for Fuels and Electricity (Washington, D.C., Island Press), chap. 14.

Hoffmann, R.T., and McNelis, B. (1986). Building the Renewable Energy Market in Developing Countries (Brussels, Commission of the European Communities, Directorate General for Development).

Hohmeyer, O. (1988). Social Costs of Energy Consumption (Berlin, Springer-Verlag).

Holdren, J. P. (1990). "Energy in transition", Scientific American, vol. 263, No. 3, pp. 109115.

Houghton, R.A. (1990). "The future role of tropical forests in affecting the carbon dioxide concentration of the atmosphere", Ambio, vol. 19, No. 4, pp. 204-209.

IBGE (Instituto Brasileiro de Geografia e Estatistica) (1989). Various censuses (personal communication), cited by Hall and Rosillo-Calle (1991).

ITDG (1986-88). "Kuni Mbili Stove", project report by Peter Young; "Charcoal stove development in Kenya - the Present and the Future" report by Simon Bume (Rugby, ITDG).

Jain, B.C. (1989). "Assessment of current status and potential for commercial exploitation of biomass gasification in India", Biomass, vol.18, pp. 205-219.

Johansson, T.B.J., Kelly, H., Reddy, A.K.N., and Williams, R.H. (1992). "Renewable fuels and electricity for a growing world economy", in B.J. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams (eds.), Renewables for Fuels and Electricity (Washington, D.C., Island Press), chap.1.

Jones, M.R. (1989). "Biomass energy (general)", in: O. Kitani, and C.W. Hall (eds.), Biomass Handbook (New York, Gordon & Breach Science Publishers), pp. 97-106.

Joseph, S., Krishna, Prasad, and Van der Zann, H.B. (1990). Bringing Stoves to the People (Nairobi, ACT Press and Foundation for Woodstove Dissemination).

Kaale, B.K. (1983). Tanzania Five Year National Village Afforestation Plan 1982/831986;/87 (Dar-es-Salaam, Forest Division, Ministry of Natural Resources and Tourism).

Kaale, B.K. (1984). Trees for Village Forestry (Dar-es-Salaam, Ministry of Natural Resources and Tourism).

Kalia, Anjan K., and Kanwar, Sarabjit S (1991). "Biogas technology in Himachal Pradesh: an evaluation study", SES/Journal, vol. 1, No. 1 , pp. 1 -1 1.

Khandelwal, K.C. (1990). "Biogas technology development and implementation strategies Indian Experience" Proceedings of the International Conference on Biogas Technology, Implementation Strategies, 10-15th Jan. 1990, Pune, India (Bremen, Ed. Borda).

Kleinhanss, W. and Kogl, H. (1989). "Economics of biomass systems", in: O. Kitani and C.W. Hall (eds.), Biomass Handbook (New York, Gordon & Breach Science Publishers), pp. 745760.

Kosmo, M. (1987). Money to Bum?. The High Costs of Energy Subsidies (Washington, D.C., World Resources Institute).

Kristofferson, L.A., and Bokalders, V. (1986). Renewable Energy Technologies: Their Applications in Developing Countries, a Study of the Beijer Institute and the Royal Swedish Academy of Sciences (Oxford, Pergamon).

KSCST (1983). Annual Report 1982-83 (Bangalore, KSCST).

KSCST (1984). Pura Community Biogas Plant - Mid-term Report (Bangalore, KSCST).

Leach, G., and Gowen, M. (1987). Household Energy Handbook. An Interim Guide and Reference Manual, World Bank Technical Report No. 67 (Washington, D.C., The World Bank).

Lima, L.R. (1989). "Produçao de alcool carburante - estudos alternatives", Annals, 11 Simposio Nacional sobre Fontes Novas e Renovaveis de Energia -11 (Curitiba, SINERGE) (forthcoming).

Lohmann, L. (1990). "Commercial tree plantations in Thailand: Deforestation by any other name", The Ecologist, vol. 20, No. 1, pp. 9-17.

Magumba, D.T.G. (1990). National Survey of Biomass/Woodfuel Activities in Swaziland (SADCC Energy Sector - TAU, Angola).

Mahin, D.B. (1989). "Economic analysis of a husk-fueled gasifier power plant at a rice mill in African, Biomass, vol. 19, pp. 57-60.

Makoni, J.I. (1990). National Survey of Biomass/Woodfuel Activities in Zimbabwe (SADCC Energy Sector - TAU, Angola).

Manurung, R., and Beenackers A.A.C.M. (1990). "Field test performance of open core down draft rice husk gasifiers", in G. Grassi, G. Gosse and G. dos Santos (eds.), Biomass for Energy and Industry, 5th EC Conference (London, Elsevier Applied Science), pp. 25122523.

Mascarenhans, A., Kikula, l. and Nilsson, P. (1983). "Support to village afforestation in Tanzania. MITI project" (Dar-es-Salaam, Institute of Resource Assessment, University of Dar-es-Salaam).

Mazzone, J. (1989). "Brazil's sucro-alcohol industry at crossroads", Sugay Azucar, Sept., pp. 66-76.

Mendis, M.S. (undated). "Biomass gasification: past experiences and future prospects in developing countries" (Washington, D.C., The World Bank).

Mnzava, E.M. (1983). Tree Planting in Tanzania; A Voice from Villagers (Dar-es-Salaam, Forest Division).

Mnzava, E.M. (1990). National Survey of Biomass/Woodfuel Activities in Tanzania (SADCC Energy Sector - TAU, Angola).

Moncrieff, I.D., and Walker, F.G.B. (1988). "Retrofit adaptation of vehicles to ethanol fuelling: a practical implementation programme", Proceedings of the VIII International Symposium on Alcohol Fuels (Tokyo, NEITDO), pp. 399-404.

Moulik, T.K. (1990). "Diffusion of biogas technology: strategies and policies", Proceedings of the International Conference on Biogas Technology, Implementation Strategies, 10-15 January 1990, Rune, India (Bremen, Ed. Borda).

Moulik, T.K., and Swati Mehta (1991). "Family biogas plants - a case study", Rural Technologies, vol. 9, No. 1.

Moyo, S., Robinson, P., Katerere, Y., Stevenson, S., and Gumbo, D. (1991). Zimbabwe's Environmental Dilemma: Balancing Resource Inequities (Harare, ZERO, Natprint).

Murray, C.H., and De Montalembert, M.R. (1992). "Wood still a neglected energy source", Energy Policy, vol. 20 (1992), No. 6, special issue, pp. 516-521 (Butterworth-Heinemann).

MWEML (1991). Lesotho Energy Master Plan (update) (Maseru, Department of Energy, Ministry of Water and Mining).

MWEMT (1991). Energy Master Plan and Programmes (1990 - 2005) (Dar-es-Salaam, Ministry of Water, Energy and Minerals).

Myers, N. (ed.) (1984). Gaia: an Atlas of Planet Management (New York, Anchor Press).

NAS (National Academy of Sciences) (1983). Alcohol Fuels - Options for Developing Countries (Washington, D.C., National Academy Press).

Nature Special (1992). "If the rains don't come", BBC2, 22 September 1992.

Nkaonja, R.S.W. (1990). National Survey of Biomass/Woodfuel Activities in Malawi (SADCC Energy Sector - TAU, Angola).

NRC (1982). Diffusion of Biomass Energy Technologies in Developing Countries, Board on Science and Technology for International Development. Office of International Affairs, National Research Council (Washington, D.C., National Academic Press).

OECD (1987). Renewable Sources of Energy (Paris, OECD/International Energy Agency).

OECD (1988). Environmental Impacts of Renewable Energy (Paris, OECD), pp. 44-59.

OECD (1990). Policies end Programmes of IEA Countries, 1989 Review (Paris, OECD/lnternational Energy Agency).

OECD (1991). Agricultural Subsidies (Paris, OECD).

Office of Technology Assessment (1980). Energy from Biological Processes, vol .2, Technical and Environmental Analysis (Washington, D.C., Congress of the United States of America).

Ogden, C.L. 1991., "Guidelines for integrating nutrition concerns into forestry projects", Community Forestry Field Manual No. 3 (Rome, FAO).

Ogden, J.M., Williams, R.H., and Fulmer, M.E. (1990). "Cogeneration applications of biomass gasifier/gas turbine technologies in the cane sugar and alcohol industries", paper presented at the PACER Conference, New Delhi, India, 24-26 April 1990 (Princeton, Center for Environmental Studies, Princeton University).

Openshaw, K. (1990). Energy and the Environment in Africa (Washington, D.C., The World Bank).

Otiti, T. (1991). Household Stoves in Tanzania (Nairobi, African Centre for Technology Studies and FOOD).

Parikh, K.S. (1963). "Benefit cost analysis of big-gas plants in India", MSc. Thesis, Massachusetts Institute of Technology (quoted in Gunnerson and Stuckey, 1986).

Pasztor, J., and Kristoferson, L.A. (eds.) (1990). Bioenergy and the Environment (Boulder, CO, Westview Press).

Pereira, R.C. (1990). National Survey of Biomass/Woodfuel Activities in Mozambique (SADCC Energy Sector - TAU, Angola).

Poulsen, G. (1983). "Using farm trees for fuelwood", Unasylva, vol. 35, pp. 141 (Rome, FAO).

Rader, N., Boley, K., Borson, D., Bossong, K., and Saleska (1989). Power Surge. The Status and Near Term Potential of Renewable Energy Technologies (Washington, D.C., Public Citizen).

Rajabapaiah, P., Jayakumar, S., and Reddy, A.K.N. (1992). "Biogas electricity - the Pura village case study", in T.B.J. Johansson et al (eds.) Renewables for Fuels and Electricity (Washington, D.C., Island Press), chap. 18.

Ravindranath, N.H., and Mukunda, H.S. (1990). "Village electrification using a small wood gasifier", Current Science (India), September.

Ravindranath, N.H., Prasad, H.L.D., and Mukunda, H.S. (1990). "A decentralized village energy system based on wood gasifiers", A.A.M. Sayigh (ed.) Energy and the Environment, 1st World Renewable Energy Congress (Oxford, Pergamon Press), vol. 3, pp. 1872-1876.

Reddy, A.K.N., and Goldemberg, J. (1990). "Energy in the developing world", Scientific American, vol. 263, No. 3, pp. 62-72.

Reddy, A.K.N., Sumithra, G.D., Balachandra, P., and D'Sa, A. (1990). "The comparative costs of electricity conservation and centralized and decentralized electricity generation" (Bangalore, Indian Institute of Science) (unpublished manuscript) (cited by Hall and RosilloCalle, 1991).

Rosillo-Calle, F. (1986). "The Brazilian ethanol chemistry industry (a review)", Biomass, vol. 11, pp. 19-38.

Rosillo-Calle, F. (1990). "Liquid fuels" in J. Pasztor and L.A. Kristoferson (eds.) Bioenergy and the Environment (Boulder, Westview Press).

Rosillo-Calle, F., and Hall, D.O. (1987). "Brazilian alcohol: food versus fuel?", Biomass, vol. 12, pp. 97-128.

Rosilio-Calle, F., Hall, D.O., Arora, H.L., and Carioca, J.O.B. (1991). "Bioethanol production: economic and social considerations in failures and successes", in E.G. da Silva and C. Retledge (eds.), Microbial Technologies. Economic and Social Aspects (Cambridge, Cambridge University Press) (in press).

SADCC Energy Sector (1989a). Proceedings of a Workshop on National Biomass Surveys in the SADCC Region. April 12 - 14 1989, Harare, Zimbabwe (TAU, Angola).

SADCC Energy Sector (1989b). Proceedings of a Seminar on Woodfuel in the SADCC Region, Arusha, Tanzania, September 25-29, 1989 (TAU, Angola).

SADCC Energy Sector (1992a). Proceedings of the Woodfuel Working Group on the Specialised Sub-committee on Woodfuel and New and Renewable Sources of Energy, Mbabane - Swaziland, 24-27 February 1992 (SADCC Energy Sector - TAU, Angola).

SADCC Energy Sector (1992b). Model for Development of National Woodfuel Strategies and Plans (SADCC Energy Sector - TAU, Angola).

SADCC Forestry Sector (1988). Report of the Workshop on Urban Fuelwood Development in the SADCC Region with particular reference to the Blantyre City Fuelwood Project, June 27 to July 1, 1988 (Blantyre, Government of the Republic of Malawi).

Sanday, H., and Lloyd, C.R. (1991). Biomass Gasifiers in the Pacific, Report ESU C1991/91 Suva, Energy Studies Unit, Institute of Natural Resources, University of the South Pacific).

Saxena, N.C. (1992). "India's eucalyptus craze: the god that failed", PS (May).

Scurlock, J.M.O., Rosenschein, A., and Hall D.O. (1991). Fuelling The Future: Power Alcohol in Zimbabwe(Nairobi, BUN/ACTS Press) (in press).

Seroa-da-Motta. (1989). "O Programa Nacional do Alcool: reliazacoes e reformulacoes", Estadistica Economica (Sao Paulo), vol. 19, No. 1, pp. 63-74 (cited by Hall and Rosillo-Calle (1991)).

Singh, A. (1988). "Socio economic problems of CBPs in India", Journal of Rural Development, vol. 7, No. 5, pp. 591-599.

Sinha, C.S., and Kandpal, T.C. (1990). "A framework for the financial evaluation of household biogas plants in India", Biomass, vol. 23, pp. 39-53.

Smith, K.R. (1987a)."Thebiofueltransition", Pacific and Asian Journal of Energy, vol. 1, pp. 13-31.

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

Smith, K.R. (1990). Indoor Air Quality and Pollution Transition (Berlin and Heidelberg, Springer- Verlag 1990).

Soussan, J., O'Keefe, P., and Munslow, B. (1990). "Urban fuelwood: challenges and dilemmas", Energy Policy, pp. 572-582.

Steingass, H., et al (1988). Electricity and Ethanol Options in Southern Africa, Report No. 88-21 USAID, Office of Energy, Bureau for Science and Technology.

Tanticharoen, M. (1990). "Anaerobic treatment of tapioca starch wastewater with biogas production", paper presented at the Seminar on Biotechnology for Agro-Industrial Wastes Management, 5-6 February, King Mongkut Institute of Technology, Bangkok.

Teplitz-Sembitzky, Witold 1990). The Malawi Charcoal Project Experiences and Lessons, Industry and Energy Department Working Paper, Energy Series Paper No. 20 (Washington, D.C., The World Bank).

TERI (1991), Energy Directory, Database and Yearbook (TEDDY) 1990-91 (New Delhi, Tata Energy Research Institute).

Thomas, S. (1990). Evaluation of Plant Biomass Research for Liquid Fuels (Brighton, Science Policy Research Unit, University of Sussex), report, 2 vols.

UNCHS (Habitat) (1984). Energy Requirements and Utilization in Rural and Urban Lowincome Settiments (Nairobi, 1984) (HS/61/84).

UNCHS (Habitat) (1990). Use of New and Renewable Energy Sources with Emphasis on Shelter Requirements (Nairobi, 1990) (HS/183/89E).

USDOE (1989). "Energy technology R&D: what could make a difference?", Supply Technology (Oak Ridge, Energy Division, Oak Ridge National Laboratories).

USDOE (1990). "The potential of renewable energy" an Interdisciplinary White Paper, SERI/TP-260-3674; (Golden, CO).

Veena Joshi, Raman P., Mande, S.P., and Kishore, V.V.N. (1992). Technoeconomic Viability of the Mobile Unit for Repair and Maintenance of Biogas Plants (New Delhi, Tata Energy Research Institute).

Venkata Ramana, P. (1992). Community Biogas System in Methane, Gujarat - A Case Study (New Delhi, Tata Energy Research Institute).

Walker, K.P. (1990). National Survey of Biomass/Woodfue/Activities in Botswana (SADCC Energy Sector, TAU Angola).

Weinberg, C.J., Williams, R.H. (1990). "Energy from the Sun", Scientific American, 263 (3): 99-106.

Weiss, C. (1990). "Ethyl alcohol as a motor fuel in Brazil: a case study in industrial policy", Technology in Society, vol. 12, pp. 255-282.

Williams, R.H. (1989). "Biomass gasifier/gas turbine power and the greenhouse warming", paper presented at IEA/OECD seminar, OECD Headquarters, Paris 12-14 April 1989.

Williams, R.H., and Larson, E.D. (1992). "Advanced gasification-based biomass power generation", in B.J. Johansson, H. Kelly, A.K.N. Reddy and R.H. Williams (eds.), Renewables for Fuels and Electricity (Washington, D.C., Island Press), chap. 17.

World Bank (1985). China: Long-Term Development Issues and Options, a World Bank country economic report (Baltimore, The Johns Hopkins University Press).

World Bank 1988. Tanzania - Woodfuel/Forestry Project, Activity Completion Report No. 086/88 (Washington, D.C., Joint UNDP/World Bank Energy Sector

Management Assistance Program).

World Resources Institute (WRI) (1988). World Resources 198849 (Washington, D.C., World Resources Institute).

Yasuhisa, M. (1989). "Developments in alcohol manufacturing technology", Intemational Journal of Solar Energy, vol. 7, pp. 93-109.

Young, K.R. (1989). "The Brazilian sugar and alcohol industry - an uncertain future", International Sugar Journal, vol. 19, pp. 208-209.

Zabel, M. (1990). "Utilization of agricultural raw material as an energy source - a case study of the alcohol industry in Sao Paulo State, Brazil", in A.A.M. Sayigh (ad.) Energy and the Environment into the 1990s. Proceedings of the 1st World Renewable Energy Congress (Oxford, Pergamon Press) vol. 3, pp. 1892-1896.

Zong, W.I. (1989). "Development of biogas technology in China", Energy for Tomorrow; World Energy Conference Digest (London, World Energy Conference Office).

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