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**BIOGAS TECHNOLOGY IN TANZANIA:
A FEASIBILITY STUDY**

by

ELIZABETH A. HENDERSON, BSc. Hons

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Arts

Norman Paterson School of International Affairs
Carleton University
Ottawa, Ontario, Canada

September 1991

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The undersigned hereby recommend to the Faculty of Graduate Studies and Research acceptance of this thesis, submitted by Elizabeth Henderson, in partial fulfilment of the requirements for the degree of Master of Arts.

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Biogas Technology in Tanzania: A Feasibility Study

CHAPTER 1: INTRODUCTION

Statement of Thesis

The initial intention of this thesis was to investigate the barriers to biogas technology diffusion in Tanzania. The hypothesis was that technical constraints were the primary impediment to widespread biogas adoption.

The research was based on the assumption that there was a need for the technology. Certainly the government of Tanzania has felt it necessary to investigate alternative energy sources. The nation is facing the double energy crisis of a dwindling fuelwood supply and a increasing burden of oil imports. Traditional fuels - wood and charcoal - account for 86% of the nation's energy consumption. The rate of deforestation continues to rise, causing soil erosion and desertification particularly in densely populated areas and regions with large livestock populations.

Petroleum products account for only 14% of total energy consumption, yet nearly 60% of Tanzania's foreign currency earnings are spent on oil imports. There are clearly some very persuasive economic and ecological reasons for

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CHAPTER 1: INTRODUCTION

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considering biogas technology as a possible rural energy solution.

There are also social reasons. Women spend long hours collecting fuelwood. Their time may be better spent more productively in other activities. There are health considerations too. The smoke of the open-fire causes eye and lung irritations.

The government of Tanzania seemed reasonably convinced that biogas technology was an appropriate choice. In 1973, they began providing digesters for rural-based social institutions such as schools, colleges dispensaries, clinics and mission stations. By 1982, approximately 300 biogas units had been installed, 8% of which were single family-units. By 1985, 30-40% of these units were disfunctioning. Furthermore, the institutional models did not appear to have the demonstration effect they were expected to have among local villagers.

The question which arose was why, given the need for a solution to the rural fuel crisis, was biogas technology in Tanzania not succeeding? Biogas technology appeared to be highly effective in China, and had enjoyed moderate success in India. It was not clear why Tanzania was experiencing difficulties.

This thesis is based upon an IDRC-funded survey conducted in May 1987 by a joint Carleton University/University of Dar-es-Salaam team to assess the performance of biogas units in Tanzania to test the hypothesis that technical problems were the main constraint to biogas diffusion. My own involvement in the project was of a voluntary nature and as such, my expenses were covered by an outside grant (refer to "Acknowledgements").

The project was beset by a variety of problems which are outlined in more detail in chapter 5. These difficulties made it impossible to arrive at any firm conclusions concerning why biogas was not working. It was apparent by the end of the study that technical problems were not the primary constraints to widespread adoption of biogas technology. The research did provide a clearer picture of the problem and raised further hypotheses to be tested, namely that it was an integrated problem of management, participation, education, training, and culture, and was influenced by a variety of social, economic, and political considerations.

The research intentions of this thesis have been modified in response to the inconclusive results of the Carleton/Dar-es-Salaam project. The purpose of this work is now to provide an overall picture or framework for future studies by examining the parameters which modulate biogas promotion and

adoption in rural Tanzania. For such a study, a broad background is required. Those readers familiar with Tanzania could skip chapter 2. This chapter establishes a political, social, economic and historical framework for the subsequent discussions on biogas technology. Chapter 3 is an overview of the energy sector in Tanzania. Chapter 4 introduces biogas technology and examines at the biogas programs in India and China for comparative purposes. It concludes with an overview of biogas in Tanzania up to the present day. Chapter 5 covers the May 1987 Field Study. Chapter 6 focuses on the economics of biogas with reference to the Tanzanian situation. This chapter in particular, is merely a framework or base for further economic analyses of biogas in Tanzania. Chapter 7, the concluding chapter, is a summation of the parameters relevant to biogas technology diffusion in Tanzania.

The Rural Fuel Crisis and The Subsistence Sector

Tanzania is not unique in its acute dependence on fuelwood in the subsistence sector. Over 1500 million people worldwide rely on fuelwood as their primary energy source.¹ The FAO estimates that 90 million people in rural areas are experiencing severe fuelwood shortages and a further 800 million are consuming fuelwood resources faster than they are being regenerated naturally or replaced by afforestation

schemes.² These figures are projected to rise to 140 million suffering scarcity and 2200 million "overconsuming" existing reserves by the year 2000.

The increasing pressures on global fuelwood resources are not due simply to over-consumption by rural inhabitants. Farm mechanization leading to the removal of trees to "tractor-ize" large plots of farm land, grazing of animals, excessive trimming or pruning of trees and the clearing of land for extended food crop growing have all contributed to the decimation of existing forest land.³

Scarcity affects the different sectors of the rural community in varied ways. Wealthier land owners often have the option of adopting alternative fuel sources, or paying for fuelwood. The poorer members of society have less manoeuvrability - the women will walk further to collect wood, cook less and use substitute fuels only if they are free goods.⁴ The poor cannot afford the commercialization of what was a free commodity; they will adjust their lifestyle and lower their nutritional standards to compensate for the scarcity.

The problem of fuelwood scarcity is compounded by the fact that wood is gathered without cost. There is no immediate incentive for individuals to replant trees. It is

not until the shortage is acute and fuelwood enters the market economy, that villagers are keen to replenish local fuelwood reserves. By then it is too late. The rate of consumption will continue to outstrip the rate of replacement. It is difficult to monitor the rates of depletion of standing wood stock because fuelwood by-passes formal market transactions.

The fuelwood problem suffers what has been termed "economic invisibility".⁵ This is a reflection of the nature of the subsistence economy itself. When scarcity prevails, any solution requiring a cash outlay, whether for a new, more efficient cookstove, alternative fuels, or for purchasing fuelwood, remains outside the options of the cashless sector of rural society.⁶ The imperviousness of the domestic fuel sector is not due therefore to technical or socio-cultural problems associated with alternative energy solutions, but to the socio-economic character of the subsistence society. Any capital available in this sector will invariably be spent on resources to improve productivity such as transport, fertilizer and pesticides, rather than on improvements in energy utilization.⁷

The fuel crisis is only one facet of the poverty crisis. Scarcity is inextricably linked to the lack of economic and political power within the subsistence sector. Those members of society with reasonable incomes do not have any serious

shortage of domestic fuel. "The energy crisis is not that wood is disappearing, but that those who rely upon it cannot afford substitutes".⁸ It seems obvious therefore, that any solution to the domestic fuel problem must also address the larger issue of rural poverty. The opposite is also true: solutions which aim to increase rural incomes can improve rural energy utilization.

Unfortunately, technologists and policy-makers have tended to isolate the rural energy problem from its social, economic and political context, with the misguided view that "appropriate" technology is the missing factor holding rural societies back from effective energy strategies. The result has been a graveyard of seemingly perfect technical solutions that have failed to alter rural energy consumption patterns.

Schumacher, the founding father of the appropriate technology movement, believed that correct technology could effect an eradication of mass poverty even if the power structures and economic relationships of the society into which it was introduced were left intact.⁹ Similarly, Frances Stewart maintains that "the introduction of a more appropriate technology would reduce the large disparities in control of resources, labour production and income distribution between different parts of the economy".¹⁰ Stewart fails to offer suggestions of how the poor are to wrest control of this

"appropriate" technology for themselves. These examples reflect a major flaw in appropriate technology thinking: the target group, be it the poor, women, or small farmers, have the ability to improve their economic condition simply by being given a new technology. To assert that the majority excluded from the development process are left out because of their inappropriate technology reinforces the false notion that proper technology is the key to the alleviation of poverty. In reality, the reverse is true: the alleviation of poverty is the key to greater acceptance of the "proper" technology. Afforestation alone will not meet projected rural energy demands. Substitute fuels and the technologies they embody are needed, but they must form part of a larger strategy to provide economic security for subsistence sector, otherwise they will not gain wide acceptance.

There are several other barriers to the diffusion of rural energy technologies aside from inadequate rural income and the difficulty of introducing commercialized substitutes into a non-monetized energy sector. First is insufficient knowledge of users needs; as consumption and production of energy in the rural areas is outside the market economy, there are no price signals to monitor energy use patterns and no effective means of conducting market surveys.¹¹ Second, environmental, economic and socio-cultural conditions differ between localities and even within villages. It is difficult

to implement general or national strategies. Third, there is frequently a lack of participation by rural inhabitants in the technological process. Far too often the energy technologies introduced into rural economies have been designed by foreign technologists who have little understanding of the socio-cultural, political, and economic structures of the recipient society.¹² The end-users actual needs are not considered, but their perceived needs - those perceived by outsiders - are earmarked for attention. This gives rather paternalistic overtones to the A.T. movement. Sadly in the past, the failure of the hardware to meet expectations was often blamed on the lack of software - indigenous education, organisation and technical knowledge - rather than on the experts and their myopia.

One of the underlying assumptions of this "expert" approach is that indigenous technology is inefficient and unproductive. The open fire method of cooking is frequently cited as a poor technology because of its low thermal efficiency. This may be true, but it is still the most effective means of using available resources - it relies on labour rather capital, and it can burn a variety of fuels. It is a technology adapted to the realities of subsistence living; better adapted perhaps than the technologies which seek to displace it.

How then do rural societies break out of the subsistence fuel trap? Economic growth and the movement towards a cash economy seems to initiate the transition from subsistence to substitute fuels. South Korea for instance, has shifted from complete dependence on fuelwood in the rural sector in the 1960's to a diversified fuel base of kerosene, electricity and coal, as the national economy has prospered.¹³ This transition is not merely a case of elevating rural incomes through a general economic progression. It is a painful process in which fuel becomes monetarized and forces rural dwellers to expend their limited cash on what was previously a zero-cost item. New energy technologies are more readily received in rural communities once this transition has occurred - when people are already investing capital in fuel procurement. This likely will be true for biogas acceptance in Tanzania. As the following chapter shows, the economic status and the degree of fuel commercialisation varies widely in Tanzania. Some regions are experiencing the transition to market fuels while others are not. As long as fuelwood is available at the cost of labour and time alone, and as long as the subsistence sector continues to stagnate in a cashless and impoverished state, biogas technology will not capture the interest of the poor.

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CHAPTER 2: TANZANIA

Tanzania became an independent state in 1961. In 1964, the mainland joined with the republic of Zanzibar to form the United Republic of Tanzania.

The total area of the republic is 945,087 square kilometres, covering some of the most varied and spectacular landscape on the african continent. To the north, are the highland areas, where the rainfall is high, the climate is temperate, and the soils fertile. Africa's highest mountain, Mount Kilimanjaro, 5,895 metres high graces the northern border with Kenya. The coastal areas are low lying, with a hot and humid climate. Rainfall is plentiful. The centre of the country is covered by a large plateau 1000 meters above sea level traversing Tanzania to its western border. The central plateau has unreliable rainfall, poor soils, and is covered by a thorny scrub bush and grass woodlands. The Lake Victoria region to the northwest has good rainfall on its western borders and less on the eastern side of the lake. The soils are fertile, and the vegetation is grassy woodland. To the south, the mountain system which sprawls across the country from north to southwest, culminates in the southern highlands. As in the north, the climate is temperate, the soils are fertile and the rainfall is high.

The population of Tanzania was estimated at 24.5 million as of mid-1990¹ and is expected to increase to 34 million by the year 2000 (an average of 2.8% per annum).² The urban population is estimated to grow from 2.6 million to 10.9 million.³ The population density varies between geographical regions. The areas of high rainfall - the highlands, the lake region and the coast - have higher population densities than the central and western plateau regions. Kilimanjaro and Mwanza have the highest densities.

Ethnically, Tanzania is one of the least homogenous nations in the world. It has over 130 tribes representing five major ethnic groups; Bantu, Nilotic, Nilo-Hamitic, Khoisan, and Iraqw. The Bantu tribes include the Sukuma, Nyamwezi, Ha, Makonde, Gogo, Haya, Chagga, Arusha, Pare, Yao and the Hehe. The Luo are a Nilotic tribe and the Masai and Tatog are Nilotic-Hamitic. The Iraqw include the Burungi, Gorowa, and Iraqw tribes among others. The Khoisan are related to the San people of the Kalahari and Namib deserts.

The major tribal groups in the north are the Chagga, Arusha and Pare. The Nyakuku and Ngoni dominate the southern highlands, while the Masai and the Gogo are found in the Central Plateau region. The Sukuma and the Nyamwezi are the largest tribes around Lake Victoria. The coastal area varies distinctively from the rest of the country because of the

strong Arab influence over the last four centuries. The Makonde and Yao tribes dominate the southern coastal regions. With such a diversity of people groups, cultures and languages, it is to Tanzania's credit that internal strife has been avoided considering the external pressures the nation has faced - drought, famine, war, refugees, oil price shocks and a heavy debt burden.

Agriculture is the mainstay of the Tanzanian economy, accounting for over 50% of the GDP according to 1988 figures⁴. Eight percent of the country (6.2 million hectares) has been cultivated and less than 3% of this acreage is irrigated⁵. Peasant producers grow most of the cash crops -coffee, cotton, tobacco and cashew nuts. Tea and sisal are grown on large state-run plantations. Subsistence food crops -maize, rice, millet and sorghum, are grown on family smallholdings.

Manufacturing accounted for only 4% of GDP in 1987, a drop of 3.7% from 1980⁶. The decline was due to low capacity utilisation in Tanzania's major industries. The textile industry in particular suffered from poor productivity levels as did the agro-industries such as fertilizer production, food processing and farm implement manufacturing⁷.

The per capita income in 1987 was US\$405⁸. Perhaps a better indication of Tanzania's socio-economic status is the

UNDP's Human-Development Index (HDI) which measures life expectancy, adult literacy and purchasing power against both minimum and desirable values. Tanzania is ranked thirty-fifth in the world according to 1987 figures. Canada, by comparison scores 126 on the index, and Japan is at the top with 130⁹.

The political system in Tanzania is based on a single party system. The Tanganyika African National Union (TANU) led by Julius Nyerere took over the government when British rule was brought to a close. The TANU leadership was comprised of merchants, colonial civil servants, and teachers¹⁰. TANU merged with the Afro Shirazi Party of Zanzibar in 1977 to form Chama Cha Mapinduzi (CCM) - the Revolutionary Party. The party structure is highly organised. At the apex is the National Executive Committee (NEC) which is responsible for policy-making. The National Assembly is the parliamentary body made up of elected representatives from the twenty mainland regions as well as the Zanzibari islands. The president holds the executive powers within the National Assembly. He is also the chairman of the party and the commander in chief of the armed forces. There are two vice-presidents. One is the leader of the National Assembly. The selection of the other vice-president must ensure that Zanzibar is represented in one of the top three positions. The president of Zanzibar will therefore be either the president or a vice-president of the United Republic in addition to his

executive role in the Zanzibari parliament. The Zanzibar parliament is led by the Zanzibar Revolutionary Council. It has legislative authority over internal and nonunion affairs.

Elections occur every five years. There is universal suffrage in Tanzania, although evidence suggests that certain groups, the poor and rural women for example, do not have the freedom to participate fully in the political process¹¹. There is a choice of candidate in each constituency, but every candidate must be approved by NEC.

Each region has a Regional Commissioner who oversees regional administration. Twenty-five *ex officio* Regional Commissioners are appointed to the National Assembly¹². Beneath the Regional Commissioner is the Regional Development Director, the District Commissioners, the District Executive Directors, and the District Councils, headed by the District Council Chairmen. In each village there is a CCM party leader or Headman. Village households are organised into a cell groups of ten families each, led by a locally elected CCM cell group leader. Every villager is encouraged to be a card carrying member of the party. There are also party branches organised in urban residential areas, and in most workplaces.

There is no official opposition to the government aside from a small exile group based in London¹³.

A Political History

To understand Tanzanian society today, one must examine the historical factors which have influenced and shaped the nation. As MacDonald so aptly put it, we need to "understand the past from which Tanzania is struggling to escape"¹⁴.

Illiffe speaks of the "periodization of Tanganyikan history"¹⁵, where several pronounced and discernible periods of change occurred within the boundaries of what would become the nation of Tanzania. During these times of social, economic and political upheaval, the old and the new tended to co-exist in what was often a contradictory and ambiguous relationship¹⁶. One could similarly classify the post-independent years of Tanzanian history using Illiffe's terminology. At least two phases of economic restructuring are distinguishable in which the dialectical relationship between past and present policies is evident.

The settlement patterns of the pre-colonial Tanzanian societies tended to be dispersed. The land had a low carrying capacity and the land tenure system operating in most of the tribal groups meant that individual holdings were continually being subdivided into smaller units, often widely spaced apart.

It would be wrong to view pre-colonial Tanzania simply as a multitude of discrete chiefdoms, each occupying a particular region of the country. They tended to merge imperceptibly with one another adopting the culture, rituals, and habits of their neighbours, although differing in language and social organisation. The social structures of these various tribes were organized around the economic means of production; land being the most significant, followed by cattle¹⁷.

1. The first restructuring of Tanzanian societies came in the eighteenth and nineteenth centuries when long-distance trade with the coast opened up insular tribal groups to relations with the outside world. Not only did these trade relations introduce new goods to inland societies, they exposed them to new ideas, new languages, and fostered their interest in entrepreneurial activities, travel and exploration. The Nyamwezi, for example, were quick to adopt the mercantile habits of the Arab traders drawing caravans across their land. They soon established themselves as traders in their own right, trafficking goods from the coast to buyers in the interior.

2. The second period of change was caused by the arrival of the European colonialists. They imposed their own forms of administration and control on the existing framework of tribal

law and order to further the economic and political interests of their homeland.

German Rule

The Imperial Chancellor of Germany, Otto Von Bismarck, declared Tanganyika a German colony on February 23, 1885. The subjugation of Tanganyika to German rule was a piecemeal process. The extension of German control occurred primarily through military ventures where compliant leaders joined forces with the Germans to defeat their local enemies. As Iliffe notes, the early German regime grew, not through policy considerations, but through bargaining and tribal conquest where ignorance, ambition and sheer accident were the primary determinants of German success¹⁸.

German occupation in the 1890's caused a realignment of traditional power structures within and between societies. They constantly sought allies among the African leaders and maintained their authority over them by violent means.

In 1889, the Germans adopted a more "conventional" colonialist position; they imposed a tax to facilitate administration. When a chief surrendered to German rule, a hut tax of three rupees was put into effect in his area.¹⁹ The shift to a greater administrative role by the Germans was

coupled with the disintegration of the political authority of the native chiefs. The erosion of their traditional power base came through the administration's abolishment of tribute payments; the chiefs could no longer enjoy free produce nor corvee labour for their fields²⁰.

The superimposition of the colonial power structure on tribal society caused an economic evolution. Where the underpinnings of a capitalist society existed pre-German intrusion, it now blossomed in all its exploitive forms, and for the first time in Tanzanian history, a peasant society developed. The Germans were careful to suppress any visible display of capitalist behaviour among their African subjects by prohibiting the employment of fellow tribesmen. Unfortunately for the German authorities, the missionaries in the Arusha and the Bukoba regions took no heed of their desire to restrain African capitalism. In the 1850's Roman Catholic priests introduced Arabica coffee to the Kilimanjaro area. The mission stations became centres of experimentation and gave rise to the development of localised coffee growing technology²¹. The popularity of coffee grew quickly. In 1916 there were 100,000 African -owned coffee trees in the Kilimanjaro area²². Cotton provided a similar though less illustrious escape from the confines of subsistence cultivation. The Germans enforced cotton growing in the Mwanza district to meet their domestic needs. The chiefs were

given seed, ordered to distribute it and to ensure that every able-bodied man planted a certain acreage. This placed considerable strain on labour as the cotton crop had to be planted at the same time as grain. Nevertheless, it did provide cash which enabled some Sukuma to abandon labour migration to pay their tax requirements²³.

The incentive to plant cash crops was greatest where they did not interfere with subsistence farming. Coffee was more acceptable than cotton because it could be intercropped with the staple crop, banana. Cotton placed heavy demands on land and labour at critical times of the year and thus impinged on local food production.

To the end, German rule was marked by aggression and a certain precariousness of control. Their occupation never quite subdued the Tanzanians and their power was unevenly exercised over the country²⁴. In comparison, British rule appears almost genteel in nature. In some respects it was. The restraining hand of the League of Nations made it clear that Britain's administration of Tanganyika was for the 'material and moral well-being and the social progress of its inhabitants'²⁵. Certainly the British thought their "civilizing mission in far lands was not only well-meant, at its best it was also noble"²⁶.

British Rule

By 1920, Tanzanians were worse off than they had been in 1850. Famine, World War 1, the loss of cattle to outbreaks of rinderpest and the invasion of the tsetse fly into depopulated areas of the country had taken its toll on the subsistence way of life²⁷. The British inherited a colony undergoing immense change both socially and economically. German rule had brought both development and underdevelopment and had given birth to regional differentiation. The early years of British domination continued this trend. The Kilimanjaro region continued to prosper while areas such as Dodoma with no cash crop base, suffered under the burden of taxation, military recruitment and the export of food crops to support British troops²⁸.

The greatest concern of the British was how to bring about the "civilizing" of the Tanzanian population, which they firmly believed was their mandate. Sir Donald Cameron, Governor of Mwanza stated that British aim was "not to convert the natives into cultivators and stockowners...our present object is to lay the foundations of a system of administration and education"²⁹. Britain imported this "system of administration" from Nigeria. Indirect rule, which purported to function through traditional authority structures, was never as successful in Tanzania as in Nigeria. The British

failed to account for the political upheavals of the German era which had undermined these traditional institutions.

Under British rule, coffee and cotton production continued to rise. In the Bukoba region, wage relations developed as coffee growers hired labour from neighbouring tribes. Over 20,000 landless workers were employed by Bukoba farmers in 1924³⁰. Coffee growing, capitalism, and class differentiation also flourished among the waChagga of Kilimanjaro. In 1925, 987,195 trees were under cultivation by 6716 Chagga farmers, and by 1930, the total had soared to nearly six million³¹. Ninety-six percent of Chagga coffee growers owned less than one thousand trees. The remaining four percent qualified as emergent capitalists. They had distinct coffee plantations of a hectare or more in size and hired labour. Shangali Ndeserwa, the retired chief of the Machame, owned 12,682 trees³². Hereditary leaders and educated Christians formed the bulk of this small entrepreneurial class, as they had the greatest exposure to European influence and to the colonial transport system³³.

Cotton production never reached the same level of commercialisation as coffee. Productivity was low and increased only through extending the acreage under cultivation³⁴.

3. The third significant period in pre-independent Tanzania was the rise of indigenous political movements in the interlude between the world wars (1929-1945). The presence of a colonial overlord did provide some benefits; it united fragmented Tanganyikan tribal groups and gave them a national identity. At the same time, however, the rise of nationalism and the nascent awareness of nationhood sounded the death knell for the colonial society. As the general populace became politicized, they were able to articulate their dissatisfaction with the colonial government in a consolidated fashion. The disintegration of the colonial system had begun.

It was the emergence of capitalist relations and values which laid the foundation for the politicization of the peasantry. Coffee growers in the Kilimanjaro region were aided by the local administration officer, Sir Charles Dundas, in the establishment of the first cooperative society; The Kilimanjaro Native Planters Association in 1924. By 1932 it had spawned eighteen primary societies. The KNPA soon developed a political voice and was seen as a threat to both the white settlers in the area and the traditional chiefs whose authority it challenged.³⁵ The government took over the association. The depression in the early thirties closed down the KNPA as world coffee prices fell. Despite the failure of the association to commandeer any real economic or

political clout, it marked the induction of rural african capitalism into international trade relations.

The government resurrected the KNPA after the depression as the KNCU; the Kilimanjaro Native Co-operative Union. It was viewed by the waChagga as a government institution - not to be trusted. The chiefs aligned themselves with the government in support of the tightly controlled KNCU as it did not threaten their authority. This led to riots and demonstrations against the chiefs and the KNCU - which was, according to Iliffe, an important step in the development of political consciousness³⁶.

In Bukoba, it was the coffee purchasing monopoly held by Asian merchants which led to the formation of a growers union. The government favoured Asian middlemen, and the chiefs, as in Kilimanjaro, aligned themselves with the government. It was a clash between the old order and the dissident unionists. Defiance of government regulations became more open and more vocal. The British found they no longer had control over the peasantry and neither did their Tanzanian subordinates. Again, as in the north of the country, it was the economic ambitions of the cash crop farmers which provided the platform for political issues.

The cooperative movement spread to other cash crop regions; Meru, Arusha, Bugufi, Ungoni, and Buzinza³⁷. It sparked off similar labour movements among urban workers; motor drivers and dock workers, teachers and civil servants³⁸. The fire had been lit; there was no turning back now. The politization of the wage-earning classes and the educated elite carried the independence struggle to its final victory in 1961:

"In no other part of the world had the cooperative movement so quickly and so completely effected social and economic change as it had within the past generation in Tanganyika. It also served the vital purpose of grooming leadership for the country, while other channels - in business and in government particularly - were being denied to them. From graduates of such training and experience in cooperatives, Julius Nyerere was to recruit the nucleus of his cabinet and his government department heads."³⁹

In 1929, the African Association was formed in Dar-es-Salaam - a loosely organised fellowship with strong nationalist ideals. This was the beginning of the end of colonial rule. The association became the bulwark of nationalist politics and mass dissent against colonialism and was later renamed the Tanganyika African National Union (TANU) in 1954. TANU took over from the British as the ruling party in 1962.

4. Post-independence marked a further period of transition as the new government attempted to dispatch the

capitalist legacy it had inherited and replace it with a more suitable scheme of development. The capitalist mantle has been difficult to discard. Although, as Iliffe noted, few Tanzanians became capitalists during the colonial era, capitalist values and aspirations were widespread⁴⁰. The socialist plan of action as outlined in such landmark directives as the Arusha Declaration of 1967 have had to exist cheek and jowl with the capitalist tendencies inherently engrained in the economy.

In 1964, Nyerere presented the nation with its first five year development plan. The plan sought to transform the economy through capital intensive industrialisation, import substitution, mechanised agriculture, and heavy investment in secondary and technical education⁴¹. The results were less than satisfactory. The gap between urban wage-earners and rural producers grew. Agricultural employment declined, and the GDP growth rate was only 5.3% not the expected 6.7%⁴². The primary reason for the Plan's failure was that the economy was still locked into an externally controlled development system. The plan relied heavily on foreign aid and investment, as well as foreign technology and expertise.

The second Five Year Plan (1969-74), was a step away from capitalist development. The Plan emphasized "Watu Na Juhudi Yao Ndio Shina La Maendeleo": people and their hard work are

the foundation of development. Self-reliance, voluntary villagization and labour-intensive agriculture were given priority. Industrial policy continued to promote capital-intensive manufacturing, import substitution, and a dependence on foreign raw materials⁴³. Growth during this five year period was as unspectacular as the first five years, as the rural sector failed to break free of subsistence production levels. The agricultural policy stifled producer incentives by controlled pricing of staple food crops and food subsidies for urban workers⁴⁴.

The third Five Year Plan continued the trend towards the socialist development outlined by Nyerere in his prolific writings of the previous decade⁴⁵. The goals of the plan were the "consolidation of the rural revolution" and national self-reliance, particularly in food production by 1981. The government extended their control over crop processing and marketing, but at the same time, loosened their grip on the private sector with higher producer prices, and lower taxes⁴⁶. There were some notable achievements during the five years; adult literacy and primary school enrolment increased as did the number of rural health clinics and the percentage of villages with a safe water supply.⁴⁷

These advancements were overshadowed in many respects by the economic deterioration of the late 1970's. The oil price

shocks, the world recession and the severe decline in export commodity prices caused economic stagnation. The Ugandan war in 1978 and the disintegration of the East African Community in 1977 placed a further strain on the country's finances. Tanzania limped into the 1980's with its foreign exchange reserves near depletion and its export base too import-dependent to pull it out of its economic straits⁴⁸.

5. Julius Nyerere's voluntary relinquishment of the presidency in late 1985 and his replacement by Ali Hassan Mwinyi ushered in a new era of change for Tanzania. Mwinyi, a long-standing capitalist of Zanzibari extraction, has slowly steered the nation away from the socialist ideology of his predecessor. Since Nyerere's resignation as CCM party chairman in 1990, Mwinyi has had little opposition to his "trade liberalization" approach to Tanzania's economic woes. It has taken Nyerere five years to hand over the reins of power completely to Mwinyi. His reluctance to yield his authority stems, in all probability, from his mistrust of Mwinyi's liberal free-market "IMFisms" and his fear that the socialist gains made under his tenureship will be lost in the scramble for capital recovery. The dialectical relationship between capitalist and socialist agendas continues in Tanzania but only now capitalism seems to have gained ascendancy. President Mwinyi has begun to introduce tough economic reforms to meet IMF criteria for continued financial assistance. The

last credit agreement expired in October 1990, with the IMF pressing the government to further its amendments of the economy - the agricultural marketing and the banking sectors in particular⁴⁹. It has been long recognised - although not publicly admitted - that the inefficiency of the National Milling Corporation, the crop marketing institution, has been a major limitation to the revitalisation of the agricultural sector. From the mid-1970's NMC's producer prices declined steadily in relation to inflation, and stifled production incentives for the farmer. Mwinyi's crop purchase reforms of 1985 and 1990, have liberalised the agricultural sector. Farmers can now sell to cooperatives or to private traders. The banking sector too has been commercialised with the floating of shares in the National Bank of Commerce and the National Insurance Company. They have also undergone a radical slimming and trimming to curb the parastatal bloat suffered by many of the government institutions. Some parastatals have not been so fortunate. In a remarkable volte-face, the government has initiated steps to dismantle loss-making parastatals. The state-run industries were the acme of the socialist policies. The economic and political outcome of this ideological shift remains to be seen. It is certain, though, that the latter part of this century will be one of the most interesting periods of Tanzanian history.

Rural Tanzania: Policies, Politics and Socio-Economic Structures

The following section examines the policies and politics which shaped the rural sector during the Nyerere years. The aim is to provide an understanding of the socio-economic structures which have resulted from these policies and which still exist today. Once this framework is established, it will be possible to hypothesize the impact of new technologies - in this case, biogas - on rural Tanzania.

The Arusha Declaration of 1967

The Arusha Declaration was the hallmark of the post-independent government. It stressed a policy of self-reliance as opposed to foreign dominance, it declared war on poverty and oppression and it sought to redress the damage caused in the agricultural sector by the colonial modernisation/mechanisation mentality. More than an economic manifesto, it was a call for a change of attitude and social organisation. While Nyerere sought to appeal to "traditional" socialist values, in reality, the Arusha Declaration was the blueprint of a completely new social order - one that was based neither on capitalism nor on kinship in the narrow sense, but on brotherhood and cooperation beyond the constraints of clan obligations. Goren Hyden noted that it

was a measure not only aimed against capitalism but also against the economy of affection⁵⁰ - the nepotism of clan relations. The peasantry were not the only ones urged to consider their neighbour in a new light. The party leadership were called to forgo self-interests such as high salaries, involvement in private enterprise and were to consider themselves as peasants or workers of the state⁵¹.

The Declaration stated that in order to ensure economic justice, the state must control the principle means of production. The government then began to purge the industrial and financial sectors of foreign control; all the commercial banks, insurance companies and manufacturing industries were nationalised.

The Decentralization Plan of 1972

In response to the bureaucratic quagmire created by rural projects requiring approval and administration from Dar-es-Salaam, the government devised a means of localising authority. Senior administration officers were moved to regional headquarters. Each region was given control its own budget, and all district level institutions were subject to the regional office. "Democratic" participation by the local populace was limited to advisory committees which were to make suggestions to the district and regional governing

authorities. The decentralization plan did not bring about the mass political participation it had planned for. Rather than increase peasant involvement it extended the central government's web of control deeper into the rural areas. Development funding and technical expertise remained under the jurisdiction of appointed regional officials⁵². Villagers had less decision-making authority than before as their "advice" was frequently ignored⁵³. The "provincialization" of the bureaucracy paved the way for the government's most ignominious display of heavy-handed governing; the Villages and Ujamaa Villages Act of 1975.

Ujamaa and Villagization

If the Arusha Declaration was the ideological directive, the ujamaa and villagization scheme was the outworking of the socialist agenda. The main purpose of the ujamaa program was to reorganise farmers into self reliant productive units. The government anticipated three stages of ujamaa development: the peasants voluntarily group themselves into villages; the village evolves into a productive unit as villagers learn to live and work together, and finally; the village registers as a "producer and marketing cooperative society" where most of the production is through communal effort⁵⁴. There were a number of reasons why villagization was thought to be necessary. The main argument was that it would increase

agricultural production. It would also facilitate the supply of essential services such as health care, piped water, and primary education. The ideological justification - that "planned villages would contribute to the birth of a development conscience" and "bring the seat of power and nucleus of participation nearer to the people"⁵⁵ - would be almost laughable in retrospect were it not for the tragic consequences of the villagization program.

Voluntary villagization was unsuccessful. By 1973, only 6% of the rural population had regrouped themselves⁵⁶. The government's inducements failed to attract peasants, mainly because they were slow in honouring their promise of basic services. Out of the 2,668 villages formed, 2,410 had no collective production at all⁵⁷. The government then opted for a "national campaign of persuasion" which became an embarrassing episode of coercion, harassment, and on occasion, violence⁵⁸. Between 1973 and 1975, nearly the entire rural population was moved into villages on sites chosen by village leaders and ward councillors. The peasants were rarely consulted. By the end of 1976, 13 million people had been moved, making "operation villagization" one of largest human migrations in history. By 1978 there were over 8000 registered villages⁵⁹.

The results at first, were an unmitigated disaster. Crop production was so severely disrupted that food imports and foreign aid were necessary to cover the shortfall. There was an estimated cereal deficit of over one million tons during the 1974 to 1977 period⁶⁰. Epidemics of typhoid and cholera increased as villagers were left without the basic amenities the government had promised. Many villagers were resettled on unproductive land, or far from a suitable water source⁶¹. The ideological promises of villagization never materialised. Rather than increasing the political involvement of the peasantry, it subverted their interests to an impassive bureaucracy. It was a obvious exercise in the extension of centralist-control over a recalcitrant peasantry who were not "modern" enough to see the obvious benefits of communal living⁶². As Frances Hill observed, ujamaa villages openly legitimized economic stratification by the elitist party-state initiative⁶³. A consequence of the top down implementation was the shifting of village level production decisions - targets, division of labour, sharing of returns - from the villagers to the district authorities⁶⁴.

In 1976, all primary agricultural cooperatives were dismantled. The villages were expected to take over their functions. Crop marketing was relegated to parastatal authorities such as the National Milling Corporation. The cooperatives were re-instated in 1983⁶⁵ and the parastatals

scuttled in 1990⁶⁶. This is not surprising. The agricultural objectives of villagization have not been realised. The communal shamba represents on average 8% of village land, uses only 20% of village labour, and accounts for less than 2% of village agricultural output⁶⁷.

There have been some achievements during the ujamaa years, as noted earlier. Primary school enrolment tripled (but has since declined to just over double the 1967 figures), life expectancy has risen from forty-four years to fifty-three years, the infant mortality rate has declined steadily to two-thirds of the 1967 rate, and forty percent of the population has access to safe water⁶⁸.

It is difficult to justify the social, moral and financial cost of the villagization scheme. It has only aggravated relations between peasants and bureaucrats whose political *raison-d'etre* is enhanced by paternalism and control. To use Hyden's terminology, the uncaptured peasant is still uncaptured. Perhaps Mwinyi realises the mistake; the government appears committed to the dissolution of every political apparatus and institution associated with the 1973 blunder.

Class Divisions In Post-Independent Tanzania

Class divisions have remained entrenched in Tanzanian society despite the government's attempts to eradicate them. The most notable social and economic stratification is found in Kilimanjaro, Bukoba and Mbeya areas. They all have good soils, reliable rainfall, high population densities, and most importantly, they were not subject to the upheavals of villagization. Villages were already well-established. There was no need to boost productivity through communal farming⁶⁹ and land redistribution as coffee surpluses were generated under the current arrangements. The capitalist relations which had developed over the colonial era were left untouched.

The dominant class in the Kilimanjaro region is comprised of an alliance of prosperous farmers, merchants and educated urban employees⁷⁰. Their privileged position is firmly established in the agricultural sector. They have large land holdings, hired labourers, and they tend to run the cooperatives⁷¹. Their sphere of influence was extended when the European coffee plantations were nationalized and handed over to the cooperatives⁷². They have not played a visible role in party politics, but certainly do have political influence. Kilimanjaro was a hotbed of antagonism towards the government's socialist transformation⁷³ as it attacked the ethos of the kulak class. Now that the government has made

capitalism an acceptable doctrine of development it is likely that they will be openly involved in politics if only to consolidate their economic control of the region. The development of a ruling class has led to exploitive relations over the years. There is now a substantial number of landless labourers in the Kilimanjaro area⁷⁴.

Sukumaland, Mwanza province also has a strong kulak class, although it is not based on cash crop production and land control, but on mercantile activities. Cotton production has resisted commercialization because of the labour constraint on productivity. Many of jobs must be done by hand - weeding, picking and grading for example. The surpluses are generated through related activities such as transportation and trading. The mercantile class is comprised of Asian and African traders who have "expanded their control everywhere else except in production"⁷⁵.

While class differentiation is particularly obvious in certain regions of the country, there exists varying degrees of inequality in nearly every village. Collier et al⁷⁶ found that 84% of the inequalities in household incomes was due to differences *within* villages. Wealthier villagers had preferential access to primary education, to extension services, and tended to dominate village committees⁷⁷. They also ran the village politics. Those with economic influence,

wealthy farmers or traders were frequently elected as village headmen and CCM party representatives (cell leaders). Kulaks in the Handeni region, for example, determined where ujamaa villages would be established, and controlled all communal activities⁷⁸. Collier found that the wealthier village members generally worked fewer hours per week on communal shambas, and usually delegated someone else to do the work⁷⁹. The picture which emerges is one of privilege and position in the hands of those families who historically retained power and authority either through hereditary means or through capitalist initiatives during the colonial era. Shivji accuses the government of ignoring the different strata among the peasantry and allowing the rich to seize control⁸⁰. Whether they seized it or whether they always had it, it is clear that ujamaa has failed to alter the village power structure.

Collier et al noted that there were also inequalities between villages. Some villages were notably poorer than others. Visits by government officials, access to agricultural inputs and to basic commodities differed throughout the districts⁸¹. This may indicate that the regional officials have been negligent in administering funds and expertise in a judicious manner; in other words, they have been playing favourites.

The Relationship Between The Bureaucracy and The Peasantry

The bureaucracy has been accused of authoritarian paternalism. Certainly, the publically expressed attitudes of the bureaucracy lend some credence to the accusation. As Prime Minister Kawawa said in 1962, "one of the inhibiting factors (concerning the implementation of government policy) is the failure of the rural cultivator to identify himself in the broad process of nation-building combined with a lack of knowledge and understanding of what is required of him"⁸². It is this inherent attitude of superiority, seeing themselves as a fount of wisdom, knowledge and expertise that has set the governing class at odds with the peasantry. It provides the bureaucracy with the ideological rationale for leadership; "through education and leadership only can people be helped to understand both their own needs and the things which TANU should be giving the people" wrote Nyerere in 1967⁸³. Sadly party control has created a parent-child dependence, where villages "behave" and make the appearance of conforming to government wishes to gain basic amenities. The peasantry tends to treat development projects with the same caution and suspicion they felt for the colonial government initiatives. Given the record of disastrous agricultural policies under the British, in particular the coercive "Grow More Crops" campaign of the 1930's, the damaging soil conservation practices demanded in the rice growing areas, the forced culling of

livestock in areas of overgrazing, and the mega-failures such as the ground-nut scheme of 1946⁸⁴, the reluctance of farmers to obey orders from above is understandable. From the peasants perspective, there is little difference between being told what to do by a chief representing the colonial government and a regional official representing an unseen central bureaucracy in Dar-es-Salaam. Collectivization, the mainstay of socialist agricultural policy, is a case in point. The communal shamba uses twice as much labour as private plots and produces substantially less output. The returns per acre are low. Funds are frequently mismanaged or not distributed according to labour input. Work on the communal shamba is done disproportionately by the poorer half of the community who can least afford to spare the time and labour⁸⁵. It is in fact, a form of regressive taxation. Collier estimates that if this communal labour were shifted back into peasant agriculture it would increase the labour input in this sector by as much as 36%⁸⁶. Clearly, the foot-dragging by the peasantry is justified.

Mwinyi's approach to the peasantry is likely to differ from his predecessor. Already there appear to be signs that he seeking to capture the peasant as a consumer rather than as a producer⁸⁷. The 1984 budget liberalised imports, removed subsidies on staple foods and increased producer prices⁸⁸.

Basic goods, which had long been absent from village shops are now filling the shelves.

Women in Rural Tanzania

The political and legislative status of women in Tanzania stands in stark contrast to their political, social, and economic involvement in Tanzanian society.

Women played an active role in the struggle for independence. Their widespread support of TANU was influential in ushering Nyerere into power⁸⁹. Their influence, however has not continued. Women have little involvement in decision-making at the village level. They tend to be excluded from village committees, and where included, they are relegated to "female" matters such as education, health, and culture⁹⁰. In a 1983-85 survey of three districts, only one village had a female chairperson⁹¹.

There have been some legislative victories for women in Tanzania. Unfortunately, as with the political promises, their implementation has been constrained by social and cultural attitudes. The Marriage Act of 1971, for example, gave women the legal right to own and inherit property in the case of death or divorce of their spouse. In practice however, in virtually every tribe, the land is under male

jurisdiction. Women who inherit land often find themselves in a subordinate position to male family members⁹².

Women given a shamba to work on in a patriarchal marriage have only usufruct rights over the land. Men control the income from the land, even if women and children supply the productive labour⁹³.

Women have limited access to credit because of their lack of collateral (traditionally land or cattle), and lack of expertise in applying for loans. Illiteracy has been a major deterrent, preventing women from making use of the banking system. They have very little purchasing power as they receive no remuneration for the labour they provide for their husbands, and very little from their own income-generating activities. They frequently can not afford agricultural inputs. The government has provided subsidized fertilizers and seeds for the cash crop sector, but has largely ignored female subsistence production. Access to agricultural extension services is also biased against women and against the subsistence sector. The cash crop sector - controlled by men - receives a lions share of the inputs.⁹⁴

The productive and reproductive roles of Tanzanian women have remained unchanged despite the socialist "revolution" which followed Independence. They still provide a far greater

share of rural labour not only in the household but on the shamba.⁹⁵

Nearly 90% of all Tanzanian women are engaged in subsistence agriculture. Subsistence farming is their primary productive role. They are responsible for planting, weeding, ploughing, harvesting, transporting, and occasionally the selling of food crops.⁹⁶

Domestic responsibilities, such as the collection of fuelwood and water, food storage, processing and preparation, child-bearing and rearing, comprise the second major role of Tanzanian women. These activities occupy from fourteen to sixteen hours a day⁹⁷.

The third role filled by rural women is that of a self-employed business person. In the little spare time that they have, women will produce items to generate cash. Beer brewing and the selling of fuelwood are two common income-generating activities⁹⁸.

Women's time is strictly regimented by the sheer number of tasks they are required to perform. Many of the tasks, according to the women themselves, could be done by men. They in turn, were quite willing to take over the traditional male

task of "surveying and roaming the village to keep up to date with public affairs".⁹⁹

The subordination of women in Tanzanian society is clearly evident in their lack of control over productive resources and labour output. They face discrimination in access to credit, agricultural extension, and in ownership of land.

This restricted access applies to technology as well:

"Women's uncertain access to land, credit and education prevents their access to and control of new technologies which might help them out of the mire of poverty so that they could afford land, credit, and education."¹⁰⁰

An evaluation of the impact of biogas technology on rural Tanzania must take into consideration its impact on women and on their daily time allotments. Otherwise women may find their lives impinged upon by a technology they have no control over and perhaps no desire for.

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**CHAPTER 3: TANZANIA'S ENERGY SECTOR:
CONSUMPTION PATTERNS AND ENERGY POLICIES**

Tanzania, like many African nations, is facing the double energy crisis of rising oil import prices and dwindling fuelwood supplies. The first oil price shock of the 1970's left Tanzania reeling from a severe blow to its balance of payments; the trade deficit grew from Tsh 422 million (\$US 59 million) in 1970 to Tsh2,920 million (\$US 396 million) in 1975¹. The second oil price shock of 1979-80 had a similar effect on the economy. The trade deficit rose precipitously to Tsh 6,120 million (\$US 746 million) and stabilized in 1983 at Tsh 4,738 million (\$US 425 million)². The IMF reforms of 1986 have lowered the trade deficit to Tsh 53,560 million (\$US 374 million).

In 1981, over 60% of foreign exchange earnings were spent on petroleum imports, although oil consumption represented only 8% of total energy consumption.³ Biomass energy resources, or what are frequently referred to as traditional fuels (fuelwood, charcoal, animal dung, and agricultural waste) provide 91% of national energy requirements.⁴ Domestic households are the largest energy consumers (85%), followed by the industrial sector. Rural households depend mainly on fuelwood, while urban dwellers rely on charcoal. This

tremendous dependence on biomass to meet domestic energy requirements has led to a rapid deforestation of the rural areas.⁵ Energy sector policies will therefore have a significant impact not only on Tanzania's future energy consumption patterns, but as well, on the country's balance of payments and on the preservation of national forest land. Government policies and long term strategies should reflect the duality of national energy demand - a small but growing commercial energy sector, requiring substantial financial commitment, and the large traditional energy sector with its related environmental problems.

The following section will examine consumption patterns of both commercial and non-commercial energy in Tanzania.

Commercial Energy

Petroleum Products

Petroleum imports provide 70% of the commercial energy demand. The principal consumer of petroleum energy is the transport sector, accounting for 54% of total usage.⁶ The industrial sector has the second highest demand (24%), followed by household consumption at 11%. Within the

industrial sector, cement manufacturers are the largest single users of petroleum.⁷

Petroleum consumption has been estimated at 837,000 tonnes per year⁸, up from 650,000 tonnes per year in 1974. This represents a growth rate of 3.6% per annum. In 1980, Tanzania imported 31.50 petajoules of crude oil.⁹ The Tiper Oil Refinery (Dar-es-Salaam) has a refining capacity of 32.85 PJ¹, or 2000 tonnes per day.¹⁰ Production output in 1987 was 485,000 tonnes.¹¹ Imports of crude petroleum therefore, were at the maximum limit given the fairly modest indigenous refining capacity. National demand for petroleum continues to exceed refining capacity. Tanzania must import some refined products, but it also exports 50% of heavy end products because of low domestic demand and mis-matched refining capacity.¹²

The forecasted demand for petroleum is estimated to reach 71 PJ (1.57 million tonnes per year) by the year 2000.¹³ The Tiper refinery will only be able to supply 43% of total requirements. It is currently undergoing major rehabilitation work at a cost of \$US 18 million to improve its output capacity.¹⁴ A new 3000 tonnes per day refinery with an

¹ 1 petajoule = 10¹⁵ joules; 1 joule = 0.24 calories.

attached cracking plant (to refine heavy end products) would still be needed to meet expected demand.¹⁵

The oil price increases have placed a severe financial strain on the economy. With 60% of foreign exchange earnings expended to meet current oil costs, Tanzania can ill-afford a dramatic rise in consumption. This highlights the paradoxical dilemma that debt-ridden LDC's find themselves embroiled in; an increase in economic activity through an expansion of the industrial sector requires an increase in energy use and/or in efficiency of use. A rise in energy consumption will, at least in the short-term, lead to a heightened dependence on foreign imports and a growing debt burden.

Tanzania may be able to extricate itself from the yoke of foreign energy dependence through the substitution of hydro-electric power for petroleum, as the country does have substantial hydropower potential. This is not an option for the immediate future, however; the country's hydro power sector is only marginally developed.

Electricity

Electrical energy is a versatile energy source with a high end use efficiency. For this reason, it is an important component of industrial development planning.

Sixty percent of Tanzania's electricity is generated from hydro power. The main centre of generation is Kidatu, with an installed capacity of 200 megawatts.¹⁶ This centre provides electricity for the major urban centres through a coastal grid.¹⁷

Tanzania's hydro-electric potential has been estimated at 3,800 MW (installed capacity).¹⁸ However, as of 1989, only 333 MW had been exploited.¹⁹ Most of this (all but 14.5 MW) had been generated by the Tanzanian Electricity State Company (TANESCO). Further development of hydropower resources is needed to exploit the national installed capacity.

While electricity consumption has increased from 215 gigawatts² or 18 Kwh\capita in 1966 to 714 Gwh or 32 Kwh\capita in 1981, this is extremely modest by world standards. It is one tenth of the average consumption of LDCs, and one one-hundredth of the energy demand of most developed nations.²⁰

The major consumers of electrical power are the industrial, the household and the service sectors. The largest consumers of electricity by activity are the food

² 1 Gigawatt = 10^9 watts.

processing and the textile industries, accounting for nearly 40% of total electrical demand.²¹

Rural electrification continues at a slow pace. In 1983, only 7% of the population had access to electricity.²² A \$US 300 million electrification expansion programme was agreed to by aid donors at a 1989 donors conference.²³ This will relieve the financial pressure on the government to step up the rate of connections.

Tanzania has begun to develop a hydro power project at Stiegler's Gorge in the Rufiji Basin. At the time of the feasibility study on the hydro-electric potential of the gorge area (1971-72), there was no power market available to absorb the output.²⁴ However, Tanzania's forecasted energy demands for the 1990's make Stiegler's Gorge an attractive energy source. The gorge has a capacity of 400MW which is double the national energy capacity of 1983.²⁵

Coal

Tanzania has nine coalfields located in the southern highlands in the Nyasa, Ufipa, and Rukwa regions.²⁶ Recoverable reserves are estimated at 9000PJ or 300 million tonnes.²⁷ At present, there are two collieries in operation, both extracting coal from the Songwe-Kiwira coalfield. The

Ilima colliery had an annual output of 3000 tonnes in 1981²⁸, and was scheduled to increase production to 20,000 tonnes by 1983.²⁹ Present output has fallen short of anticipated production levels; output was only 6,900 tonnes in 1985, falling to 5,033 tonnes in 1986.³⁰ Ilima could produce 150,000 tonnes per year if operated at full capacity.³¹

A new mine was opened at Songwe-Kiwira in 1988. It has an output capacity of 100,000 tonnes per year and was producing at a rate of 40,000 tonnes per year in early 1989.³²

Domestic demand for coal is low because of high transportation costs.³³ Industries and users need to be located near to collieries in order for coal to be a cost-effective energy alternative. At present, the major coal consumers are the Mufundi Pulp and Paper factory, the Mbeya Cement Plant, as well as several tea factories in and around Mbeya. Mbeya is the largest urban centre near the Ilima colliery.

Natural Gas

Natural gas deposits have been discovered along the coast near Songo-Songo on Kilwa Island, and at Kimbiyi forty kilometres south of Dar es Salaam. The Kilwa reserves are

estimated to contain 32.77 billion m³ of gas and the Kimbiyi deposits, 130 billion m³ of gas.³⁴ Due to the high capital investment required to exploit the gas reserves, Tanzania has no immediate plans to continue further development of this resource. It is unclear to what extent these deposits are commercially viable and at what price level. It has been proposed however, that natural gas could be used as an economic feedstock for nitrogen fertilizer production. This would have obvious benefits for the agricultural sector, but could have a negative impact on the use of biogas slurry as fertilizer, which in turn, may impede widespread acceptance of the technology. This issue will be discussed in a subsequent section.

Traditional Fuels

Fuelwood and charcoal are by far the most important energy sources in both the subsistence and the industrial sectors, accounting for 85% of total demand.

Fuelwood

Although household consumption represents the major fuelwood use, industry and agricultural processing also rely on wood energy. There has been a recent rise in fuelwood

consumption in these two sectors to meet the energy demands of tobacco curing, tea drying, tile production, pottery and brewing. Tea processing for example, requires one m³ of fuelwood for every 150 kg of tea dried. Total consumption of fuelwood in the tea industry is approximately 43,000 m³ annually.³⁵

Within households, fuelwood provides energy for cooking, heating, lighting as well as ironing, brewing, and the boiling of water for washing.

Fuelwood demand averages 2.5 m³ per capita per year. National fuelwood demand is 42 million m³ or 28 million tonnes per year.³⁶ No surveys have been conducted to determine Tanzania's sustainable supply, although the growing woodstock is estimated to be 1900 million tonnes (roundwood). The annual yield of harvestable wood is 19.50 million m³.³⁷ Current fuelwood demand is leading to a depletion of standing stocks. Unfortunately, supply does not match demand in many regions.³⁸ Afforestation schemes have been unable to retard the accelerated rate of fuelwood consumption.³⁹ More than 15,000 kilometres squared of forest is disappearing every year.⁴⁰ The rapid population growth rate (2.8% per year) and the population density in certain areas has put acute pressure on local supplies. Annual consumption is higher than assessed yields. Deforestation is causing soil erosion and loss of

cropland. Fuelwood collection has become a major time-consuming activity, as distances travelled are steadily increasing. Women spend between eight and eleven hours per week walking, cutting, and collecting fuelwood.⁴¹

All estimates concede that fuelwood will remain the single most important fuel source well into the next century, accounting for 83% of total energy demand.⁴² The forecasted demand for the year 2000 is 41 million tonnes, of which twenty million tonnes could ostensibly be supplied from existing reserves. Tree planting schemes will be able to provide only a portion of the remaining demand. They are highly unlikely to yield the requisite 21 million tonnes; demand will have to be lowered through more efficient use of fuelwood reserves and alternative energy technologies such as biogas will have to be introduced on a mass scale to alleviate the projected shortages.

The government initiated the Village Afforestation Programme in the 1970's to encourage villages to establish communal woodlots. Tree planting, as a communal activity, has not been very successful. Villagers are reluctant to participate in afforestation projects where they do not benefit personally, and have frequently voiced concerns over the management and possible mis-use of the mature woodlot. The emphasis of the forestry programme has now shifted to the

promotion of individual woodlots within family compounds. Villagers have been more willing to exert time and effort in tree growing when they control the output. Despite the success of these efforts, they barely make a dent in the fuelwood shortage and its ancillary problems of soil erosion and desertification. Trees are grown only within village confines where saplings can be protected from grazing animals. This limits the extent of afforestation tremendously. Shamba woodlots are too small to meet current user needs and to replenish depleted wood stock as well. The government has experimented with large scale tree plantations, but these require expertise, a large capital outlay, properly functioning farming equipment and reliable rains or methods of irrigation. It has not always been possible to coordinate all these factors in one place at one time. Consequently, the plantations have not been as successful as initially hoped.

Charcoal

Charcoal is used for domestic purposes (cooking and heating) mainly in the urban areas. Only 5-15% of rural dwellers use charcoal as compared to 85% of urban dwellers. The depletion of forests in the vicinity of the larger centres has created a demand for charcoal. The fuelwood is usually collected at some distance from the urban areas and is transported by truck to central markets.

Charcoal has twice the energy content of wood, which makes it attractive to consumers. Unfortunately, 50-80% of the energy value of the original wood is lost in the kiln-drying process. Charcoal is therefore a highly inefficient way of utilizing fuelwood.

Crop Residues and Dung

Approximately 1.84 million tonnes of crop residue and 6 million tonnes of dung are produced annually.⁴³ Most of this will go unused, but when fuelwood supplies are low or unavailable for any reason, farmers will burn the residues directly. In 1980, an estimated 7.61 petajoules or 0.58 million tonnes of waste was burnt by rural households.⁴⁴ Crop residues and dung produce less energy per tonne of material than fuelwood or charcoal; 12.8 GJ for crop residues and 13.9 GJ for dung, as opposed to 16.0 GJ for fuelwood and 33.1 GJ per tonne for charcoal.⁴⁵ The burning of residues is therefore not a suitable long term substitute for fuelwood, except as a stop-gap measure when wood supplies are low.

Policies and Recommendations

The Tanzanian government is promoting policies of energy substitution and energy conservation. For example, where

economically feasible, the government is recommending a substitution of coal for oil in the industrial sector. Due to the high transport costs of coal, this measure will apply only to industries located near the nation's coal reserves in the southern highlands. There is no national pricing policy for coal, nor are there adequate storage and transport facilities. Further development of the coal sector will require government subsidization.⁴⁶

Hydro-electric power has also been suggested as a possible substitute for petroleum. The extension of the electrical grid system in larger towns would lower oil import costs.⁴⁷ Tanzania does have a long term plan to use hydro-electricity as the main source of energy, even in the rural areas,⁴⁸ however it is, and will continue to be, an expensive alternative due to high capital and maintenance costs.

Tanzania's mid-term potential for hydro-power is four times the current installed capacity. The existing installed capacity could generate more electricity if the minimum water head in the dams was maintained.⁴⁹ This of course, is contingent on adequate annual rainfall. During the dry season, water levels drop causing a decrease in electrical output. Improvement in production and end-use efficiency in the commercial sector will yield significant savings for the country.

Most conservation policies have been directed to the commercial energy sector. There remains to be a concerted effort directed at the traditional energy sector. There is an urgent need in Tanzania to develop a long-term strategy for sustained fuelwood supplies, for both household and non-household use. Improvement of end-use efficiency of fuelwood and charcoal would have a significant impact on traditional fuel consumption. The use of fuelwood for cooking has great potential for energy conservation; only ten percent of the available energy is used to heat the food. Improved stove designs can yield fuel savings of up to fifty percent.⁵⁰ CAMARTEC, the University of Dar es Salaam Forestry Division, and the National Science Research Council (UTAFITI) have devised new fuelwood and charcoal stoves designed to save fuel, time and money. For example, the UTAFITI charcoal stove, UMEME JIKO, is constructed locally from scrap metal. The initial costs per unit are Tsh 250 (\$US 14), which is paid back after three to six months.⁵¹ The stoves are easy to light and cook food quickly. The major constraint to the widespread diffusion of the stoves is the availability of discarded metal drums; the stove manufacturing industry must compete with local brewers for the scrap metal.⁵² There is not, as yet, a strong national commitment to small scale energy technologies.

Traditional fuel sector planning and research is extremely fragmented in nature. Although many institutions are involved in rural energy studies, there is no centralized coordination of activities. This is perhaps true of the entire energy sector; the responsibility for energy planning has been apportioned to various governmental ministries. The Prime Minister's Office is in charge of village woodlots, the Ministry of Natural Resources and Tourism is responsible for forests and fuelwood, the State Mining Corporation plans the development of coal reserves, the Tanzanian Electrical Supply Company (TANESCO) runs the electricity sub-sector, The Rufiji Basin Development Authority (RUBADA) plans for the Rufiji Basin and the Tanzanian Petroleum Company (TPDC) is responsible for the development of natural gas and petroleum reserves.⁵³ There is, more than likely, unnecessary duplication of effort between departments, as well as possible contradictions in policies. For example, the flooding of the Rufiji Basin to develop its hydro-electric potential would destroy woodland that might otherwise provide energy for the rural sector. Central energy planning would define Tanzania's priorities in choosing energy development policies.

Regional Cooperation

The SADCC (Southern African Development Coordination Conference) energy committee has conducted feasibility studies

of all energy sub-sectors to improve regional energy cooperation and to increase installed capacity within member states.

As a member state, Tanzania has specific problems with regional cooperation. Its economic and urban centres are far from the borders of its SADCC neighbours. There is a project underway to extend the Zambian electrical grid to the Malawi and Tanzanian borders. The 220kv line running from Dar es Salaam to Iringa will be extended southeast to Mbeya, thus making an interconnection between Zambia and Tanzania a future possibility.⁵⁴

Tanzania has entered into an intergovernmental agreement with Burundi, Rwanda, and Uganda to develop the Kagera Basin adjoining the northwestern Tanzanian border. This agreement, known as the KBO plan (Kagera Basin Organisation), is centred on the exploitation of hydro power resources especially that of Rusomo Falls.

The energy potential of the Kagera Basin has been estimated to be 6.2 million Kw hours. As none of the proposed development sites are in Tanzania, the country will buy rather than supply hydro-electric energy to the other three member states. Tanzania's energy demand from the Kagera Basin is

projected to rise from 62.2 Gwh in 1980 to 1077.5 Gwh in the year 2000⁵⁵ .

Aside from SADCC and KBO initiatives, Tanzania has joined Burundi and Kenya in conducting aeromagnetic surveys over Lakes Tanganyika and Victoria in search of petroleum reserves.⁵⁶

Regional cooperation for the development of the power sector will benefit Tanzania by;

- 1) providing access to energy sources outside the nation's boundaries and
- 2) supplying both the financial requirements and the export markets to expand domestic energy production.

Energy sector policy planning in Tanzania for the next two decades will need to take into account the following issues:

1. There is a need for greater integration between ministries and the coordination of energy policy-making between sub-sectors.
2. A higher priority should be given to energy conservation, especially that of fuelwood, and should be reflected in specific strategies to

promote fuel-efficient stoves and renewable energy alternatives.

3. Energy research needs to be complemented with the strengthening of indigenous technical expertise through energy training programs.
4. Careful central planning of fuelwood resources is required to sustain the national stock of woody biomass, as Tanzania will continue to rely heavily on fuelwood and charcoal to meet energy demands well into the next century.
5. Regional cooperation should be encouraged, especially where it will lessen dependence on imported petroleum, and will develop indigenous energy capacity.

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CHAPTER 4: BIOGAS TECHNOLOGY

Biogas energy production refers to the anaerobic fermentation of organic matter to produce methane and carbon in an air-free digester. The combustion of the resulting methane-rich gas provides the energy source. The calorific value of the gas ranges from 20,000 to 26,000 $\text{kJ}\cdot\text{m}^{-3}$, depending on its methane content.¹ Thus simple organic residues such as crop by-products, and animal and human waste can be converted into a viable fuel source through a natural biological decomposition process in an oxygen-free environment.

The degradation of organic substrates through microbial action occurs in two major stages. In the first stage, fats, carbohydrates and proteins are hydrolysed to form soluble monomers which are then converted into organic acids such as acetic and propionic acid. In the second stage, methanogenic bacteria (methane-loving bacteria) convert the acids to methane and carbon dioxide. Both these processes occur simultaneously.

The chemical equation for the production of biogas from carbohydrates is as follows:

Figure 1. Methane Production From Organic Waste

adapted from B. Sorensen, "Renewable Energy", Academic Press, London, (1979), p.473.

Certain bacterial species are also able to produce methane from carbon dioxide and hydrogen gas.

The micro-organisms able to produce biogas are common inhabitants of both soil and organic waste. They tend to lie dormant until provided with an oxygen-free environment. Under anaerobic conditions they begin to decompose their organic substrates. Despite the fact that methanogenic bacteria are indigenous to most organic matter, it is common practice when setting up a digester, to "seed" the initial feedstock with an active bacterial culture from an operating unit. This ensures that gas production begins quickly and provides a stimulus for the decomposition process.

The methanogenic bacteria, often simply referred to as "methanogens", require a fairly stable environment and cannot tolerate significant changes in pH and temperature.² They are relatively slow-growing, tend to be fewer in number than the

acid-forming bacteria and are extremely sensitive to the presence of oxygen.³ Maintaining optimal growth conditions by regulating temperature, pH and the loading rate of feedstock into the digester, ensures that the methanogens are kept in balance with the faster growing acidophiles.

The quality and quantity of the gas produced is directly related to bacterial performance. It is necessary from both a biological and an economic viewpoint to regulate growth conditions. For example, biogas production is possible at temperatures ranging from 0 - 60° C, however methanogens are inhibited below 20° C and above 55° C.⁴ There are two temperature ranges for optimal gas production, 1) the mesophilic range (20 - 45°C), 2) the thermophilic range (above 45°C). Certain bacteria prefer the mesophilic temperatures such as *Methanosarcina barkeri* and *Methanobacterium soehngenii*, while others perform best at thermophilic temperatures such as *Lactobacillus thermophilis* and *Methanobacterium thermoautotrophicum*.⁵ Thermophilic digestion has a higher digestion efficiency and a higher pathogen kill-off rate than mesophilic digestion. The disadvantage is that the thermophilic microbes are more sensitive to temperature fluctuations than mesophiles.⁶

pH must also be carefully monitored. If the pH drops and there is an acid build-up, the methanogenic bacteria will be

inhibited. This results in low gas yields and a higher carbon dioxide content. Carbon dioxide should not rise above 45% as the calorific value will decline and the gas does not burn effectively. The optimal pH range lies between 6 - 8. Feedstocks such as animal wastes, tend to have sufficient alkalinity to buffer the acids produced by the acidophiles and therefore a neutral pH range is maintained.

Three other factors affect the quality and composition of gas produced: 1) the biodegradability of the substrate and 2) its carbon to nitrogen ratio, 3) the retention time. The biodegradability of a substance is a function of the nature and complexity of its molecular structure, its concentration of suspended solids and the surface area to mass ratio of its solid particles. Dung, with its relatively simple organic structure, and a high concentration of suspended solids, is an ideal substrate. The carbon to nitrogen ratio reflects a substrate's molecular composition - how much carbon and how much nitrogen it contains. The optimal carbon to nitrogen ratio for gas production is 25-30:1.⁷ Crop residues, for example, have a high carbon to nitrogen ratio. To increase gas yields, nitrogen-rich manure should be added to the digester. Poultry dung, on the other hand, has a very low carbon to nitrogen ratio. Gas yields are improved by adding crop residues.⁸

The retention time refers to the time the substrate must be exposed to microbial attack to ensure maximum gas production. Retention times vary with the type of substrate, the size of digester, and the temperature at which decomposition takes place. They range from 15 - 100 days. While technically all organic waste can be used as feedstock, certain residues will provide higher gas yields.

The most common organic wastes used as feedstocks are dung and crop residues. It has been found that mixed feedstocks generally yield higher gas levels than single substance feedstocks.⁹ The Chinese continue to experiment in this area. Rural Chinese farmers usually mix pig dung, human excreta and crop wastes or water hyacinth in their digesters.¹⁰ In the Kilimanjaro area of Tanzania some farmers mix coffee pulp with cow dung.¹¹

The biogas yields of individual substrates are listed below:

<u>Materials</u> <u>m/t</u>	<u>Gas Yields</u>
cow dung	22-40
pig manure	40-60
poultry manure	60-115
human waste	20-28
crop residues	30-40
water hyacinth	40-50

Table 1. Gas Yields

Economic and Social
Commission for Asia and the
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Biogas Technology

Digester Models

There have been many designs of biogas digesters tested and promoted. The two most popular models have been the Indian floating dome design and the Chinese fixed dome model. Both designs are currently in use in Tanzania in modified forms.

The Indian floating dome digester consists of a concrete pit 3 - 4 meters deep, partially sunk into the ground. The lid of the digester is a steel dome which floats in the digester liquid and acts as a gas trap. As gas is produced the dome rises. Gas is siphoned from the digester through a pipe from the apex of the dome and can be used directly for cooking, lighting and other purposes. The organic waste is fed into the digester through a loading inlet and the spent slurry is removed through an outlet pipe. The cost of construction of a family sized digester ranges from \$500 - \$1000 depending on the volume of the plant.¹² The dome accounts for 35% of the cost of the biogas plant.¹³

Figure 2.

The
Chinese
fixed dome
model
works on a

different principle of gas collection. The unit is built of brick or concrete and is usually housed underground. The gas is stored in a permanently fixed space between the liquid and the roof of the digester.¹⁴ Gas pressure is regulated by the adjustment of slurry levels in the slurry outlet and in the loading inlet.

Family-sized digesters in China are usually built in a "three-in-one" design which incorporates the family latrine and the pigsty. Frequently the floor of the pigsty serves as the roof of the digester.¹⁵

Figure 3.

The advantage of the Chinese fixed dome model is the cost. Family-size units vary in price from \$70 - \$130 U.S.¹⁶

The cost is kept low by the absence of expensive metal parts, as found with the Indian design. Metal or plastic are only used for piping and valves.¹⁷ Construction materials vary from location to location; whatever is cheap and readily available. These include stone slabs, bricks, cobble, pebbles, slate, concrete and "Chinese concrete" (lime, sand and clay).¹⁸ Labour is generally free. Plants are constructed with the help of friends and neighbours.¹⁹

The one disadvantage of the Chinese model is that it requires fairly well developed masonry skills. If the unit is not built carefully gas leakages will occur. This has important implications for countries like Tanzania where such technical skills are not widespread in rural areas. The choice of appropriate digester designs narrows to the more costly but simpler to build Indian model and the cheaper but technically demanding Chinese model. Tanzania has experimented with and modified both, which will be discussed in further detail later in this chapter.

Biogas End Products

The two main products of the digestion process are biogas and spent slurry. The gas is colourless and odourless and can be used for cooking and lighting, as well as for running engines. China for example, has experimented with dual diesel - biogas engines to run electrical power stations with great success.²⁰

When used for cooking, the biogas is connected by a pipe to a simple burner which regulates gas flow and mixes it with air. Often these burners are made locally in village industries. Biogas for lighting requires a pressure mantle lamp. The gas is burned under pressure within the mantle and emits a white light. The strength of the light depends on the

gas pressure and is therefore a function of the digester's operational state.

The spent slurry can be used as a fertilizer. Theoretically, the nutrient value of the slurry should be no less than undigested manure. Losses of nitrogen can occur in the form of ammonia gas if the slurry is left exposed.²¹ Tanks or lagoons are the best method of storage of slurry, however in practice, most biogas owners collect slurry in pits where it is dried before its application on the fields.²²

The treatment of waste and dung in a biogas digester can significantly reduce the number of pathogenic organisms in the slurry as compared to the raw feedstock. The traditional rural practices of defecating in the bush or in open pits are sanitary hazards, especially during the rainy season. Biogas technology offers a solution to the problem of rural sanitation and has therefore a potential impact on rural health. China has had the most success with latrines attached to digesters.

Sanitary Aspects of Biogas Technology

Biogas plants in Puming Township in China have proven to control hookworm disease when coupled with a mass treatment program. The infection rate dropped from 58.5% to 7.0% in

1979 and remained steady at that level until 1984. In another township used as a control group where there were no digesters, mass treatment caused the infection rate to drop to 5%, but due to reinfection the rate climbed to its original level in three years.²³ Biogas digesters have been used in Chinese cities to reduce pathogens in and around latrines. In Mianyang city, Sichuan Province, a digester was built adjoining public latrines. The feedstock included distillery waste as well as human excreta. As the excreta passed through the buffer tank to three chambers of the digester, parasitic ova decreased from an average of 1158 ova/ml in the buffer tank to 54 ova/ml in the effluent in the final storage tank.

Most rural digesters, whether in India, China or Tanzania will have an ambient temperature fermentation operating at 8 to 29° C. Usually the retention time of the slurry in the digester is greater than thirty days which is adequate to ensure a sufficient "kill"-rate of pathogenic organisms.

The other observation Chinese researchers have made concerning the hygienic effects of biogas digesters is a remarkable reduction in the fly density around latrines and in the maggot population in the adjacent latrine soil.

China has been actively promoting digesters not only to control human waste but also livestock excreta on farms, slaughterhouse waste and distillery effluent.

Farmers have noticed a complete disappearance of infectious pathogenic diseases such as Foot and Mouth disease of the pig (*Apthae epiizooticae*) within a one year period after the installation of a biogas unit to treat livestock waste.

The following table gives the fatality rate of various pathogenic organisms during the fermentation process in an experimental digester at the Institute of Anti-Parasitic diseases, Sichuan Academy of Medical Sciences, China.

Table 2. The Fatality Rate of Pathogens in Biogas Digestion:

	Thermophilic fermentation 53 - 35 C		Mesophilic fermentation 35 - 37 C		Ambient temp. fermentation 8 - 25 C	
	Fatality Days Rate(%)		Fatality Days Rate(%)		Fatality Days Rate(%)	
Salmonella	1 - 2	100.0	7	100.0	44	100.0
Shigella	1	100.0	5	100.0	30	100.0
Polyviruses			9	100.0		
Coliform Count	2	10^{-1} - 10^{-2}	21	10^{-4}	40 - 60	10^{-5} - 10^{-4} (red. in)
Schistosoma ova	3hrs	100.0	7	100.0	7 - 22	100.0
Hookworm ova	1	100.0	10	100	30	90.0
Ascaris ova	2	100.0	36	98.6	100	53.0

Adapted from "The Hygienic and Environmental Protection Effect of Biogas Digester (sic) in China" Zhao. Xi - hui. Institute of Anti- Parasitic Diseases, Sichuan Academy of Medical Sciences, Sichuan Province, China, 1985.

Lessons from the Chinese and Indian Experiences

While it is beyond the scope of this paper to examine the biogas programs and experiences of China and India at any great length, it is necessary to mention them briefly for three reasons:

- 1) These countries have had the most experience with biogas technology dissemination; they lead the world in biogas popularization.
- 2) Tanzania has imported biogas technology from both China and India. Technicians from both countries have also trained Tanzanian artisans at home and abroad.
- 3) There are valuable lessons both negative and positive to be learned from the Chinese and Indian experiences which are directly relevant to Tanzanian biogas initiatives.

India

Biogas dissemination progressed rapidly in India between 1975 and 1980. Seventy thousand new biogas plants were constructed. By 1985 the total had risen to 0.2 million plants and by 1990, the government had hoped to have built 1.5

million new plants.²⁴ While this sounds impressive, it should be noted that only 0.8% of rural households benefitted from a biogas digester in 1985. The impact of biogas technology on the rural sector remains minimal. The main reason for biogas technology limitations is purely economical. The cost of digester construction and installation are beyond the means of the poor farmer.²⁵ The Khadi and Village Industries Commission steel floating gas holder design (adapted from Mr Patel) requires an initial investment of \$500 - \$1000 depending on the size of the plant.²⁶ Aside from capital outlay, the potential owner must have at least 3 - 4 cows to provide enough feedstock for even the smallest KVIC digester. This effectively bars 88 million out of 100 million rural dwellers from adopting biogas technology.²⁷ Agarwal maintains that small family size digesters can be used only by the richest 10 - 12 % of rural families.²⁸

A study conducted in Gujarat in 1982 emphasized the elitism of biogas adoption in India. The average acreage by farmers with biogas units in a sampling of 3 million households was 30.78 acres.²⁹ The level of education among the plant owners averaged 10.8 years of schooling. Singh found that 66% of the farmers installing digesters in the early 1970's owned more than 10 acres of land.³⁰

The floating dome digester requires 27m³ of land for the plant and slurry pits. In most villages the homes are so closely clustered together, farmers cannot spare land for a digester. Capital, cows and land: the criteria for owning a plant are so high that India really has few potential customers for the family size units. These wealthy farmers are few in number in each area. A promotion scheme to single them out is costly and time consuming and would lead to little overall impact on rural fuel consumption. It has in fact been argued that the widespread dissemination of family size digesters may have a detrimental effect on socio-economic patterns of energy use in villages. The poor, who rely on cowdung as a fuel and an income source would be forced to turn to firewood. Dung may become a scarce commodity as wealthy cattle owners pen their livestock and forbid dung collection on their properties.³¹

The government has recognised biogas technology's bias against the poor and has sought to redress the problem in several ways. They provide a central government subsidy of 50% on digester capital costs for those individuals they categorize as "underprivileged" - namely those living in hill and desert districts, tribal Indians, marginal farmers, and landless and migratory labourers. The remaining categories receive a 20% subsidy.³² In addition, there are state subsidies available covering 8 - 20 % of the costs. The

poor are still overlooked. Many, if not most of the subsistence farmers cannot even afford the subsidy. It is virtually impossible to introduce any new energy technology into the subsistence sector if it requires a cash outlay no matter how small. The money is just not there. While credit facilities are available to enable farmers to meet their payments, most require a minimum of two cows as collateral.³³ Those without livestock are effectively excluded. Government policies do not clarify how landless labourers are to take advantage of these subsidies in view of the fact a digester requires 27m² of land.³⁴

The second method the government has employed to increase the relevance of biogas for the poor has been the promotion of community biogas plants. These digesters range in size from 100 - 300m³ and are designed to provide gas to individual households in exchange for dung. The government supplies a 100% subsidy for those villages willing to install a unit. The community plants have had little success. They require careful management of plant operation, maintenance, dung collection and purchase, sale of gas and fixing of prices. Low-income villagers are not in favour of community plants mainly because the existing social and political infrastructure of rural villages is biased against them.³⁵ The poor have limited influence in village affairs and little control over the running of village digesters.³⁶

Since the 1970's India has experimented with cheaper designs. The Department of Science and Technology had a support role in the research and development of low cost models.

PRAD, The Planning, Research and Action Division of the state of Uttar Pradesh has introduced the JANATA model, an improved version of the fixed dome Chinese design supplied to Pakistan. Results have been varied. Gas leaks and poor construction marred initial efforts, but PRAD now claims their JANATA version is as efficient as the KVIC floating dome design and is only half the cost. KVIC has been experimenting with ferrocement digesters and gas holders. These models are said to be 20% cheaper than the traditional KVIC unit.³⁷ It is doubtful that these savings will make much difference to poorer farmers facing land and livestock constraints.

The exclusivity of India's biogas program is not limited only to its target market. Rather the entire research and development endeavour has been a "top-down" effort. The biogas initiative came from the scientific community whose primary aim was to develop a technically sound digester. From the outset it was an institutional venture. The result has been a design which is economically unfeasible for most of rural India.³⁸ Unlike China who encouraged mass participation in technology innovation and modification, India

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

has kept biogas research and development firmly in the hands of the experts. KVIC began a "self-employment" scheme in the early 1970's to train "educated unemployed" in biogas construction. These trained "motivators" were expected to promote biogas, supervise construction and educate owners on plant operation.³⁹ The poorest peasants have been discriminated against yet again. Most of them lack the educational criterion to be trained by KVIC.

The situation is improving. India is attempting to decentralize the biogas program. The government is now promoting a multi-model, multi-agency, strategy and is trying to involve greater numbers of local villagers in the biogas technology dissemination process. Several agencies are looking at mixed feedstocks as a means of lessening the need for cowdung, the poor man's fuel. KVIC is experimenting with wheat and rice crop residues. PRAD has found that a mix of water hyacinth and dung in a 2:3 ratio, creates a slurry richer in nitrogen, potassium and potash and yields 40 - 50% more gas.⁴⁰ Unfortunately, unlike China, human excreta is not an acceptable feedstock. Villagers do not like the idea of cooking over nightsoil gas.⁴¹ This means that animal dung, primarily cowdung, will continue to be a major feedstock even in mixed feeds. The opportunity cost of dung increases the expense of the biogas technology.

Several obstacles remain to be overcome before biogas can be considered an appropriate energy alternative.

- 1) The technology needs improvement. One of the biggest complaints among owners has been the corrosion of the gas holder. Burst pipes and cracked digester walls are equally common. Low gas pressure in winter is another problem.⁴²
- 2) The second major hindrance has been the lack of adequate maintenance and servicing facilities.⁴³
- 3) The high cost of installation is not recoverable in less than four to five years even with subsidies. The benefits are indirect and do not usually augment cash income. The technology does not directly affect productivity.⁴⁴

It is quite possible for the government to address these constraints with a modicum of success; however, it is doubtful that biogas will ever be an effective solution to the fuel crisis in India. Unless the gross inequalities of the rural sector -economic, political and social- are eradicated, biogas will remain an elitist alternative, at best benefitting only the wealthy, and at worst, exacerbating the condition of the poor.

China

China's biogas promotion schemes dwarf every other nation's effort. The sheer number of digesters built over the last forty years has made China a formidable expert in rural biogas technology diffusion. By 1989, China had an estimated 5 million family-size digesters in operation⁴⁵. Approximately 25 million Chinese are currently benefitting directly from biogas technology.⁴⁶ Although biogas production is heavily concentrated in Sichuan, digesters are found in more than half of China's provinces, municipalities and autonomous regions and more than one thousand of China's two thousand one hundred counties.⁴⁷

China's rural digesters provide a variety of different services. Household digesters are used mainly for cooking. Special biogas burners, designed by local communes, have been found to increase the thermal efficiency by 30 - 50% over a conventional cook stove.⁴⁸ Biogas also provides lighting to supplement electricity in rural villages. The main emphasis of the biogas program has been small family-size digesters, however large scale digesters have also been introduced with success. Small industries use biogas infrared heaters for drying agricultural products such as silkworm cocoons.⁴⁹ Approximately ten thousand large and medium size digesters are used in wineries, poultry and livestock farms. The biogas

generated by these institutional plants is fed into centralized supply stations. Some of these supply stations provide gas to local households; the number of homes connected to a centralized biogas supply is now twenty thousand. The other supply stations feed into power stations. China has eight hundred and twenty-two biogas/electrical power stations with a total installed capacity of 7836 kw.⁵⁰ Electricity generated from biogas/diesel pumps is used for domestic lighting and for the operation of communal machinery. It is more economical to produce electricity from biogas than to use biogas directly as a light source.⁵¹

China's successful biogas dissemination has frequently been attributed to the nation's social, political and economic structure.⁵² The collectivization of land and labour, the intensity of agricultural production, the patterns of land tenure, and the disciplined labour of the Chinese people combine to make China a nation unique in many respects. To what degree China's biogas experience can be transposed to other developing nations, Tanzania in particular, is a question which remains to be answered.

The well-structured commune system with its carefully organization of land, peasants and production is conducive to the diffusion of new technology, if given strong government

backing. The Chinese have adopted effective, aggressive and organized methods of technology dissemination.⁵³

Biogas popularization in China is implemented in stages. First, demonstration models are built by biogas research centres or promotion offices in areas with favourable environmental and agricultural conditions, such as ambient temperatures, suitable water and availability of feedstock, usually in those provinces facing fuel shortages.⁵⁴ The demonstration models are promoted by active propaganda campaigns to involve the communes and raise the awareness of biogas among farmers. Communes are encouraged to experiment with different designs and different feedstocks. Each local group adapts and modifies the technology to its own needs. The experimental stage is followed by extensive training of local peasants by state biogas offices and institutions. Normally only a few farmers from the commune are trained. They in turn act as extension agents, training others on their communes.⁵⁵

China's biogas technology development scheme has placed great priority on building digesters using low cost, locally available resources; cement, stone, pebbles, brick and "triple concrete" are the most common digester materials.⁵⁶ China's cement industry has been decentralized into district based rural enterprises. Building supplies are easily accessible for most communes, and transportation costs are generally low.

A consequence of China's well-ordered communal structure and its effective biogas popularization methods has been the clearly defined duties and responsibilities of the individual households, the production teams, the commune and the state.

State: The overhead costs of China's biogas project are borne by the state; approximately \$ US 2.5 million is spent yearly on research and development, on the establishment of product test centres (for testing equipment) and regional biogas information and promotion offices, and on bonuses for state trained technicians who surpass a given construction quota.⁵⁷ The state also supplies subsidies to the communes for the digester promotion in underprivileged areas.⁵⁸

Communes: The communes are the primary sites for biogas innovation. It is at this level that the peasants are trained, new digester designs are tested, and accessories such as cookers and light fixtures are manufactured.⁵⁹

Production Teams: The relation between the production team and the individual household is the most intimate. The production team provides labour for building construction, transportation of building materials to the site and is responsible for restocking the feedstock supplies of the digester in bulk during each planting season.⁶⁰ In return for their services the production team collects the spent

slurry for fertilizing crops. On a daily or weekly basis the production team provides crop residues for the farmer to supplement household feedstocks.

Owners: The greatest responsibility for the biogas unit lies with the owners. They must bear the direct cost of construction. A typical 6m^3 digester costs approximately \$ US 120.⁶¹ The pay back period depends on the size and cost of the unit installed, but usually ranges from one to four years.⁶²

Labour costs for construction are zero. Labour in China is considered an investment; an opportunity for production team members to acquire masonry skills. The households themselves contribute providing the bulk of the labour, especially for such activities as digging the digester pit. Labour requirements for construction are thirty-five worker days.⁶³ The use of free labour is paramount in keeping construction costs at a minimum.

Each individual household is responsible for the management of its digester. They are required to regulate gas pressure, to feed the plant daily with kitchen waste, nightsoil and rinsings from the pigsty floor.⁶⁴ In exchange they have full use of the gas for lighting and cooking. The production team supplements the household feedstocks with crop

residues. They in turn collect the slurry as fertilizer for application on the collective fields. The sludge is also added to commune fishponds to promote algal growth for fish food. Communal poultry are fed a diet of earthworms grown on sludge nutrients.⁶⁵

Certain cultural factors have also played a prominent role in China's successful biogas dissemination. The Chinese have no taboos concerning the use of human excreta in the digesters. China has a long history of aerobic composting of fecal waste for use as fertilizer.⁶⁶

This highlights the third major reason for China's success with biogas technology development: the technology has been fully integrated into the productive sector of the economy. By emphasizing the potential of the spent slurry, China has lessened her dependence on chemical fertilizer and has increased the agricultural self-sufficiency of the communes and the production teams, as they are no longer required to purchase fertilizer from regional centres. This has a direct impact on the incomes of individual household. As agricultural yields improve with slurry application, the economic returns to each member of the production team increase. In addition, households realize savings by the replacement of coal bought at the market with biogas for cooking and kerosene for lighting. "China's program was

designed to provide meaningful cash income for the individual".⁶⁷ While this undoubtedly played a role in the biogas popularization, it is more likely that the state gave national objectives priority over individual interests in its rationale of biogas promotion. The government first promulgated biogas technology, not for its fuel potential, but for its fertilizer properties, and for its possible role in rural sanitation. China differs from India and Tanzania where national economic objectives have centred on lessening the dependency on foreign energy imports (India) and curbing the threat of deforestation (India and Tanzania). The national biogas schemes in each of these countries have been shaped by the policies resulting from these differing objectives. China's ability to successfully link biogas to agricultural production has only been possible because of the prominence given to sludge over gas in the government promotion policies. In no other developing nation has biogas been introduced primarily for the purpose of providing fertilizer as opposed to fuel. In both India and Tanzania there has been expressed reluctance to the use of spent slurry as fertilizer. There are certainly cultural and social obstacles to be overcome in both countries concerning the handling of fermented manure. If China's advances in biogas technology development are to be transposed to Africa, it would seem that the integration of slurry and fertilizer into agricultural production is a necessary requisite. Interestingly enough, the one district

in Tanzania studied by the Canadian and Tanzanian team, where the sludge was used to fertilize cash crops, was also the district where biogas dissemination had been most successful. This does not negate the influence of the socio-economic and political factors in biogas popularization, but it does perhaps indicate the necessity of integrating biogas technology fully into the fabric of rural society - not merely as a fuel alternative, but as an instrument to enhance the productive means of the peasantry.

There has been a move during the 1980's to bring standardization and professionalism to the biogas program.⁶⁸ Forty thousand technicians have been trained as "biogas doctors". They manage seven thousand digester construction teams. Not only do they build plants, but they are hired to operate and maintain them.

The government has commercialized biogas service. Stations which operate as profit seeking enterprises have been formed. They construct digesters, sell materials and accessories and provide management and technology consultancy.⁶⁹

Whereas China's initial efforts stressed grassroot level participation in research and development, implementation and dissemination of technology, they are moving towards India's

type of specialist approach. This may not be a step backwards. Aside from the problem of inadequately built units, China has faced further constraints in biogas diffusion. Labour migration from the rural areas to economically developed regions has led to a shortage of biogas technicians within the communes. By making specialist training a priority the government is attempting to counter the flow of semi-skilled labour from the countryside. Secondly, as households experience greater economic freedoms, there has been a return to coal in preference to biogas for cooking in some regions. More efficient digester construction and management could reverse the trend to favour biogas again. It also remains to be seen how the communal farming reforms affect the demands for slurry fertilizer. Problems have arisen when production teams remove the slurry from a household's digester and give no aid in replacing the feedstock. There have been cases of families refusing to give slurry to the collective.⁷⁰ Now that the farmer is responsible for his own plot, the ownership of fermenting dung may be the source of dispute.

Biogas technology seems to be an appropriate energy choice for rural China. It has lessened dependence on dwindling fuelwood reserves and has cleverly played upon China's long tradition of waste utilization. The commune system has facilitated the widespread dissemination of the

technology, and has provided an ideal environment for the training of artisans. The government has made a strong commitment to biogas diffusion as part of rural energy sector policy planning. All of these factors have contributed to biogas technology's success in China.

Biogas Technology in Tanzania

Biogas technology was first introduced into Tanzania by priests at the Kipalapala Catholic Mission in Tabora and the Malya Mission in the Mwanza area in the early 1960's. These units operated for several years but were then abandoned for unknown reasons. The gas from the units was used for cooking meals for mission staff.

The oil price shocks of the 1970's forced the government to take a closer look at energy consumption in both the commercial and rural domestic sector. One of the outcomes was the founding of a national biogas dissemination programme in 1975, following a bilateral agreement with the government of India. SIDO, the Small Industries Development Organization, was appointed to administer the programme with technical assistance from KVIC, the Khadi and Village Industries Commission, of India.

The first stage of the collaboration effort was the training of Tanzanian artisans and technicians in India. Upon their return, they were sent to Mwanza, Mara, Arusha, Shinyanga, Singida and Dodoma provinces to supervise the construction of six Indian floating dome digesters.

The biogas units were built mainly at rural health institutions and were designed to serve as demonstration plants to encourage local interest in biogas technology. The gas from the units was used primarily for heating water, sterilizing needles and lighting medical wards. The construction costs averaged Tsh 7000/= per unit, and were met by the government through the Regional Development Fund office.

SIDO's big mistake was to recall the technicians back to the head office in Dar es Salaam once the units were operative. They failed to provide training and maintenance advice for the biogas users. Consequently, the plants worked well for five to six years after which a variety of problems emerged, such as clogging of pipes, cracks in the walls, and lack of spare parts. These problems would have been relatively easy to rectify if SIDO had provided follow-up assistance to the institutions.

A further obstacle arose from the dissolution of District Councils who were providing the recurrent funds to pay biogas attendants. The institutions suddenly found themselves forced to allot money to biogas from their limited budgets. The result was confusion over who was really responsible for the plants, SIDO or the health centres, leading to poor management and neglect of maintenance duties.

SIDO's next venture took into consideration the shortcomings of its initial biogas efforts. In 1977, the Arusha Appropriate Technology Project was established under the auspices of SIDO, with financial assistance from the Swedish International Development Agency. AATP's primary agenda was to promote appropriate rural and village technologies such as windmills, water pumps, and food storage bins, as well as low cost biogas digesters.

In 1977-78, AATP began field testing a biogas prototype whose design was loosely based on the Indian floating dome model. It consisted of an arrangement of five or seven interconnected oil drums floating in round cement tank. The unit was put on public display. This gave rise to numerous requests for personal generators. To meet local demand, AATP assisted a local cooperative, Ujuzi-Leo, to begin manufacturing the generators.⁷¹ Unfortunately, the units suffered from recurrent leakages and the design was eventually

abandoned in favour of a more conventional Indian Gobar design. These were more popular but more costly - \$US750 as compared to \$US 100 for the interconnected drum design. The new Indian Gobar plants appealed to villagers able to afford the initial capital outlay because they could provide enough gas for daily cooking requirements from the manure of only two animals.⁷²

By 1978 there were only twenty working biogas plants in the entire country. Most were in the Arusha area, and a few were in Mwanza province. SIDO had also built several demonstration plants in Iringa province at public institutions in the late 1970's but as with the Mwanza units, there was no follow-up and little general interest in biogas developed. At the end of 1982, SIDO and its affiliate, AATP, had constructed 105 units of which 92 were operative. By mid-1983, the total had grown to 180 units. These units were all modified Indian floating dome generators.

In the early 1980's biogas popularisation in Tanzania entered a new phase. It began with the merger of AATP and TAMTU, the Tanzanian Agricultural Mechanisation Unit, to form CAMARTEC. CAMARTEC'S objectives resembled that of its predecessor, AATP; to popularize appropriate village technologies in the Arusha region.

In 1983, CAMARTEC began a biogas extension service to develop and disseminate family-size biogas units. The difference between this new venture and AATP's previous efforts was a shift from the use of the Indian design to the Chinese fixed dome model. West Germany's GTZ (an affiliate of the German Appropriate Technology Exchange) was asked to assist in the implementation and management of the biogas programme. At present there are three German and three Tanzanian staff on the biogas team. Their responsibilities include conducting surveys of farms and households to determine water and energy supply and demand, providing village demonstrations, training of masons to construct plants as well as training of owners and family in the operation and maintenance of their biogas systems.

The CAMARTEC Chinese model has been modified to Tanzanian conditions and standardized to 8, 12, and 16 m³ capacities. The units are sold as part of a biogas package which includes an inclined cement stable floor, gas piping, burner, lamps and other appliances as well as the accompanying software - information on running the system and on using the slurry as fertilizer. The cost of the units ranges from Tsh 40,000/= to Tsh 100,000/= depending on the plant size. Customers are expected to pay for all construction and material costs as well as most of the overhead such as design, supervision and the purchase of accessories. Prospective buyers must pay a

50% deposit before construction begins and complete the payment before taking possession of the unit.

The advantage of the CAMARTEC model is its low maintenance demands. The concept of a "cow to cooker" package ensures that the system is simple to operate, and in the words of one of the staff, "relatively human-proof". The waste from the stabled livestock is rinsed off the inclined cement floor into the underground unit through a pipe and drain system. The end product gas is then piped from the plant into the home to a gas outlet with an attached burner plate, and to mounted pressure lamps. The waste slurry collects in an outlet tank for removal to the fields.

The major constraint of the CAMARTEC system is the cost. Those who can afford a unit tend to be rich farmers, businessmen or politicians. GTZ staff openly admit that the target group for biogas dissemination is the small to medium size farmer who produces for the market and therefore has access to ready cash. The poorer farmers can not afford the cash outlay. Unless the government chooses to subsidize construction costs, the poor will be excluded from CAMARTEC's diffusion programme.

Despite the cost constraint, CAMARTEC has successfully marketed biogas technology in Arusha, Arumeru, and

Kilimanjaro. By mid-1987 there were sixty-one installed units in full operation and over seventy customers on a waiting list.

The other side of CAMARTEC's biogas programme is the research and development work carried out at the headquarters in Arusha. The biogas team have been studying the use of mixed feedstocks to augment gas yields. They have found that coffee pulp and banana peels when added to the dung can enhance gas production, but if in too large a concentration, will produce excessive carbon dioxide and will disrupt the flow of methane. The team is also investigating potential slurry use, and improvements in building materials; in particular, the use of clay and cement/clay bricks to reduce the building costs. CAMARTEC burners have also been subject to research and modification. It was found that the addition of an oxygen inlet below the ignition point solved the problem of a weak flame.

A third important component of the CAMARTEC biogas programme is its training scheme. Construction skills, namely plumbing and masonry, are taught at the main centre in Arusha. Operators and maintenance technicians are trained in the villages to follow-up on new biogas owners and ensure that their units are in working order. The Tanzanian National Science Research Council, (UTAFITI), has also involved itself

in biogas diffusion efforts. In 1980, UTAFITI established the Dodoma Rural Energy Research Centre (RERC) to study the growing fuelwood problem in Dodoma and to introduce new energy technologies to villagers. Initially it concentrated on solar energy technologies, however, it soon diversified its research objectives to include biogas.

Unlike CAMARTEC's consumer demand approach, UTAFITI/RERC ran its biogas popularisation programme on a demonstration basis, much like SIDO in the 1970's. They began by supplying five Indian Gobar units to various public institutions, including a leprosy centre, a college, and a health centre. RERC bore all the costs on the understanding that the institutions would take over all responsibility for the plants after two years. The units have not had the demonstration effect they were expected to have. There has been little interest among villagers to obtain a biogas plant for themselves. The units are still operative, but RERC has not been able to transfer full responsibility to the recipient institutions. One gets the impression that the plants are working because RERC continues to prop up and support the institutions by continuing to cover wages of attendants (one case) and to pester them with frequent visits and check-ups.

RERC's biogas popularisation efforts have essentially ground to a halt. There are no plans to any further units. In

fact, the RERC officer admitted that the focus of research had shifted to the design and dissemination of fuel-efficient charcoal cookstoves.

Similarly, SIDO has made a quiet but deliberate move away from biogas R & D. With much of Tanzania's early biogas efforts in a state of stagnation or regression, it is encouraging that CAMARTEC is still actively engaged in biogas promotion. Another promising centre for biogas work is Msingwi Technical College in Mwanza province, where students are training in construction, maintenance and repair of digesters. This will be discussed in greater detail in the following chapter which outlines the field survey conducted by the Tanzanian/Canadian team in May 1987.

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Biogas Technology in Tanzania: A Feasibility Study

CHAPTER 5: BIOGAS FIELD STUDY MAY 1987

In 1987, IDRC agreed to fund a joint Canadian/Tanzanian research effort to assess the current performance of biogas units in Tanzania. This preliminary evaluation was seen as a possible prelude to further IDRC involvement in biogas dissemination. Twenty biogas sites in four provinces were chosen by the Tanzanian team for analysis. Their selection was based on the advice of government officials and biogas workers in each of the provinces, and was modulated by such practicalities as accessibility, and presence or absence of knowledgeable interviewees. Digester performance was not a criterion for selection as this would have biased the study. All of the units surveyed were either institutional models or private family-owned units.

The Canadian team was headed by Professor J. O'Manique of the Norman Paterson School of International Affairs, Carleton University, Ottawa, and included Dr C. Prakash P.eng. of Environment Canada, Ottawa, Ms. M. Barker, a graduate of NPSIA, and myself.

The Tanzanian counterpart team was led by Professor S. Nkonoki of the Institute of Development Studies, University of Dar-es-Salaam, and included Dr. S. Kagaruki of the Chemistry

Department, University of Dar-es-Salaam, Dr. S. Chambua, Mr. L. Msimbe, and Dr. I. Shao of IDS, Dr. R. Mabele of the Economic Research Bureau, University of Dar-es-Salaam, and Dr. P. Biswalo of the Social Science Department, University of Dar-es-Salaam.

The project was due to commence May 20, 1987 with an "induction seminar" for all the Tanzanian researchers as well as Ms Barker and myself. The purpose of this meeting was to familiarize the team with one another, discuss the main objectives of the project and to draft a questionnaire (see appendix C) for use during the field survey. Dr. Prakash was to join the team at a later date, having spent two weeks in India reviewing the KHIV biogas programme beforehand.

British Airways was unexpectantly denied landing rights in Tanzania during the month of May 1987, and as a consequence, Ms Barker and myself were unable to attend the inaugural meeting. There was therefore no Canadian input in the drafting of survey questionnaire, nor in the overall strategy and methodology of the research.

The questionnaire was fairly comprehensive, but did have some weaknesses. It tended to neglect women's views on biogas; whether biogas had altered their role at home and in the community, its impact on their workload, their cooking

habits and its effect on the division of labour in the household. The content of the survey is not solely to blame for these shortcomings. The choice of respondents was also a factor; the majority were male. In several of the villages with institutional digesters the men of the village were quite willing to express their opinions on biogas technology and on the prospect of owning their own plant. It would have been helpful to ask the women their opinions too - whether those who did not have access to a digester would be interested in using one. A further weakness of the questionnaire was the absence of questions on socio-cultural costs. The type of questions asked implied that biogas would provide socio-cultural benefits to biogas users, and the only costs were therefore, of an economic nature. The technical questions were quite rigorous, but produced little solid data, as most units were not monitored regularly. This indicated a major flaw in the research strategy. As the technical expertise was available on the team, efforts should have been made to measure the inputs and outputs of the digesters in order to rate their performance. Many digesters, by visual assessment only, appeared to be functioning at a substandard capacity.

The results of the survey are not conclusive enough within themselves to determine whether biogas is an appropriate energy choice for rural Tanzania. While the findings of the project are central to this thesis, the

conclusions are based more on a survey of the literature concerning the political, economic, socio-cultural parameters which will influence the adoption of biogas technology in Tanzania.

Methodology

The main evaluation format for this biogas study was the questionnaire designed by the Tanzanian researchers (May,1987). The questionnaire covered four main areas:

- 1) General information. This section included questions on the location and ownership of biogas units, as well as the economic and environmental characteristics of each location.
- 2) Socio-cultural Section. These questions examined the level of training given to biogas users and artisans, the degree of biogas diffusion in the area, the use of outputs and the perceived benefits of biogas according to the respondents.
- 3) Economics Section. The costs of labour and materials, source of funds, source of labour, recurrent costs were surveyed in this section.

- 4) Technical Section. The downtime of the digester, the type of feedstock, mode and frequency of feeding, monitoring of pH, temperature, pressure, quantity and quality of biogas, maintenance and operational costs were covered in this section.

The Arusha province sites were visited in Arusha municipality proper and in the Arumeru district by Dr. Kagaruki, Dr. Mabele, Dr. Chambua, Dr Prakash and Ms. Barker.

The municipal district of Dodoma in the Dodoma province was visited by Dr. Chambua, Dr. Kagaruki, Dr. Msimbe, Dr. Prakash, Ms. Barker and myself.

The team travelling to the Iringa municipality was short two members. Ms. Barker and I were unable to get seats on the Dar es Salaam - Irinja bus and missed the site visits conducted by Dr. Biswalo and Dr. Msimbe.

In the Mwanza province seven biogas sites were inspected. Three were in Magu district and four in Kwimba district. A side trip was made to the Sengerema district to interview the District Medical Officer regarding the digesters in his area, but no sites were actually visited. The Mwanza team was comprised of Dr. Nkonoki, Dr Shao and myself.

Although there was a project vehicle allocated for the field surveys, it did not arrive until after the site visits had been concluded. Team members were flown to each province, and then required to hire local transport or take buses to the sites.

At each biogas site the objective was to interview someone intimate with the running of the digester, either the biogas attendant responsible for maintaining the unit, the owner, or the supervisor. This was not always possible, as these individuals frequently were not warned of our impending visit and were not available to be interviewed. In general, however, we found knowledgeable individuals at the biogas sites and were able to complete our questionnaires with few omissions. Most of the interviews were conducted in Kiswahili and were translated by a Tanzanian team member for the benefit of the Canadians.

The following section examines the survey findings in detail.

Arusha Province Field Report

Mr. Stephen of Kimandoli Village

The first plant, was owned by a private farmer, Mr. Stephen, of Kimandoli village. He had a 15m³ CAMARTEC fixed dome unit with a covered expansion chamber built in 1986 at a cost of TSh 66000/=.¹

The unit included the inclined concrete stable floor for Mr. Stephen's five cows, five goats and six chickens. The stable was regularly washed down to wash all dung and urine into the digester which runs on a semi- automatic feeding system. Mr. Stephen's zero grazing livestock provided most of the feedstock for his digester, but he was also experimenting with agricultural residues, in particular coffee pulp. CAMARTEC was carefully monitoring Mr. Stephen's unit to study the effect of these mixed feeds on the gas output and on the slurry quality. When there was too much coffee pulp the stove flame tended to be weak, probably because of a high concentration of carbon dioxide in the gas. The Stephen's family used biogas for cooking beans, bananas and meat, as well as for lighting their family house and children's study quarters.

Mr. Stephen was well aware of the advantages of using the slurry as manure. His three acre shamba was carefully fertilized with his digester waste. He said that pasture grass had benefitted as did his papaya trees. It was too early to tell whether Mr. Stephen's coffee bushes had improved at all.

The Stephen family liked their unit because it gave better lighting and facilitated cooking. Mrs Stephen was particularly pleased to spend less time and labour collecting firewood. It gave her more time for other activities (unspecified). They were spending less money on kerosene, firewood and charcoal.

Mr. Kilasara of Moivaro Village

Mr. Kilasara is the "absencee" owner of a 16m³ CAMARTEC fixed dome digester with an open expansion chamber. He lives in Arusha and leases his Moivari shamba to tenants. The current tenants have three cattle and six pigs housed in the zero-grazing stable attached to the unit. They used a mixed feed in the digester, adding some banana and coffee residues to the livestock dung. The gas is used for cooking. Since its installation in 1985, the unit had worked well, but had needed TSh 700/= in repair for breakage in the feeder and slurry channels, bringing its total cost to TSh 36700/=.

The slurry was used as fertilizer on banana and coffee crops. The biogas attendants, however, did not like carrying buckets of wet slurry around the hilly shamba.

The tenants found that the primary benefit of the biogas was a reduction in their firewood collection time. They also appreciated spending less on kerosene and firewood.

Mr. Zakaria of Moivaro Village

Mr. Zakaria's 8m³ CAMARTEC fixed dome design digester was the first plant to be built in Moivaro. Construction was completed in July 1984 and the plant was operational by October 1984. It was built by CAMARTEC as a demonstration model with funding from the African Regional Centre for Technology in Senegal. The cost of the unit, including the stove, was TSh 11000/=.

Mr. Zakaria is a ten cell CCM leader. Choosing his shamba as the site for the first demonstration model was an appropriate measure as his status and political leadership in the village would have inclined wealthier villagers to emulate his "progressive" example.

Mr. Zakaria kept nine cows, three goats and one sheep in a very untidy stable.

The feedstock for the unit was mainly from the zero-grazing livestock, but the family also added coffee pulp (in unspecified proportions). The resultant gas was used for

boiling water and served mainly as a supplement to firewood cooking. The family were satisfied with the performance of their unit although gas pressure seemed very low. There was no gas being produced at the time of the visit which may indicate leakages in the digester. Mrs. Zakaria used the slurry for her vegetables and recommended it as a good fertilizer.

St. Constantine's Boarding school

The original digester at the school was an AATP five interconnected drum design installed in 1979. By 1984 it had developed numerous leaks and was inoperational. It was altered by CAMARTEC to a fixed dome design in 1985 at a cost of TSh 35000/=.

The unit had a 16m³ capacity. It was used mainly for the cooking of school meals for the 250 students. One of the four burners in the kitchen and one oven was attached to the biogas plant. The other three burners ran on firewood. The unit was maintained by two biogas attendants who fed the unit manually with dung from the two hundred cattle enclosed in a fenced cattle "boma". They carried the dung daily by cart from the boma to the plant 300 metres away. The unit appeared to be working at less than full capacity. The gas pressure was quite weak.

The school headmaster saw fuel reduction cost as the primary benefit of biogas, but he also appreciated the time and labour savings in regard to firewood collection (the school required a lot of wood). He viewed biogas as an improved cooking source and is currently working with CAMARTEC to build two 100m³ fixed dome units fuelled by pig dung from a stable holding twenty pigs. The cost of the package; stable digester, pipes, fittings and appliances is estimated at TSh 750000/= (1987 prices).

TABLE.3. ARUSHA PROVINCE SITE VISITS

LOCATION	DESIGN & CAPACITY AND YEAR	COST IN \$ US.	USE OF GAS	FEED STOCK	MODE OF FEEDING	BENE-FITS
Baraa Village	CFD; 1985 16m ³	\$2003	L	mixed	S/A	A/D/C/E
CAMARTEC Tengeru	IGD; 1983 10m ³	\$2693	L	cow dung	M	C
St. Constantine School	IDD/CFD; 1979/85 16m ³	\$2003	WH/C	cow dung	M	C/A/D
Kimandolu Village	CFD; 1986 16m ³	\$2018	C/L	mixed feed	S/A	D/A/C/E
Moivaro Village	CFD; 1984 8m ³	\$719	WH	mixed feed	S/A	D/A/C
Moivaro Village	CFD; 1985 16m ³	\$2061	C	mixed feed	S/A	A/C/D

KEY: CFD = Chinese Fixed Dome
 IDD = Interconnecting Drum Design
 L = Lighting
 WH = Water Heating
 C = Cooking
 S/A = Semi- Automatic
 M = Manual

PERCEIVED BENEFITS:

- A = Reduction in fuelwood collection time and labour.
- B = Improvement of health services in the community.
- C = Fuel cost reduction.
- D = Improved lighting and cooking.

Iringa Province Field Report**Huruma Baptist Centre**

The digester at the Huruma Baptist Centre was a SIDO-built Indian Gobar design, installed in 1985 at a cost of TSh 56000/=. It had a 39m³ capacity and was manually fed. The feedstock was cow-dung. The gas produced was used for cooking in the centre's commercial restaurant. There was no information gathered on the maintenance schedule of the unit, nor who was responsible for its upkeep. The unit was fully operational at the time of the survey. The centre was hoping to build a new digester attached to a coil unit for hot water and steam circulation. The head of the centre saw time and labour savings of fuelwood collection as the prime benefit accrued from the centre's digester. He saw fuel cost reduction as a secondary, but also very important advantage of the unit.

Ruaha College for Training in Rural Development

The biogas plant at Ruaha was built by SIDO in 1981 as a demonstration plant at a cost of TSh 55000/=. It was an Indian Gobar design with a 35m³ capacity. It was used for cooking, lighting and pumping water at the college. There had been some problems with cracking of the digester walls, but the college seemed to have mastered the problem by buttressing the walls. The unit was manually fed with cowdung. The college officials cited fuel cost reduction as the main benefit of their unit. The unit had been in good working order, but was inoperational at the time of inspection due to lack of feedstock. No explanation was given.

Ilula Folk Development College

The principal of the college, Mr. B. Kinyasi, gave the researchers a tour of the college and the biogas unit. It was inoperational. The gas and slurry channels had blocked because of prolonged disuse. The main cause of disfunction, however, was simply the lack of spare parts for the lights and the stove burners. Prior to breakdown, the unit had supplied lighting in the college during hall for two hours daily and was used for cooking porridge and boiling water for tea on a single burner in the college kitchen. The unit was an Indian Gobar design installed by SIDO. The date of installation and the cost was not recorded by the researchers.

Mr. A. Kilibika of Kihesa Village

Mr. A. Kilibika, an accountant at TANCUT, had an interconnected drum design digester consisting of three drums with a total capacity of 2m^3 . The unit cost TSh 4000/= in 1985. The researchers did not report who built the unit. The main feedstock was chicken and rabbit excreta. The gas output was not large. Only simple and quick meals were cooked on the biogas stove (an ingenious homemade invention looking like a bunsen burner with an inverted shoe polish tin on top).

TABLE 4. IRINGA PROVINCE SITE VISITS

LOCATION	DESIGN; CAPACITY YEAR	COST IN \$ US	USE OF GAS	FEED STOCK	MODE OF FEEDING	BENE- FITS
Huruma Baptist Centre	IGD;1985 30m ³	\$4923	C	cow dung	M	A,C
College of Training -Ruaha	IGD;1981 35m ³	\$3597	C/L	cow dung	M	C/A
Kihesa	IDP;1985 2m ³	\$229	C	cow dung	M	-----

KEY: IGD = Indian Floating Dome
 IDD = Interconnecting Drum Design
 L = Lighting
 WH = Water Heating
 C = Cooking
 M = Manual

PERCEIVED BENEFITS:

A = Reduction in fuelwood collection time and labour.
 B = Improvement of health services in the community.
 C = Fuel cost reduction.
 D = Improved lighting and cooking.

Mwanza Province Field Report**Nyashimo Health Centre - Nassa**

SIDO installed this 20m³ Indian Gobar design digester in 1979 at a cost of TSh 25000/=. It was inoperational at the time of our visit. It had been used to light the patients' ward and to sterilize needles.

Originally dung for the digester was brought to the clinic from the state owned Mabuki Dairy farm 80 km away. The farm lorry transported 7 tons of dung on a regular basis. However, the lorry broke down, the dung did not arrive and the unit fell into disuse.

Ngudu District Hospital

The Ngudu digester is a SIDO built Indian Gobar design installed in 1975 at a cost of TSh 18000/=. It has a capacity of 8m³.

The unit was currently in working order, but had experienced some problems in 1982 when the walls began to crack. These were repaired for TSh 30000 in 1987.

The feedstock is cow manure. Mabuki Dairy farm provided the first lorry load and villages in surrounding areas have since been providing dung free of charge. There has been some reluctance on the part of the villagers to supply the hospital with dung as they now recognise its benefits as a fertilizer. The hospital has had to resort to supplementing their feedstock requirements with manure bought at the local market.

Two paid biogas attendants (trained at Misingwi Institute) maintain the plant on a part-time basis. They feed the plant with two wheelbarrows of dung and sixteen buckets of water daily.

The nursing officers check from time to time to insure that the plant is fully operational.

The end product gas is used for lighting the maternity ward, labour ward and operating theatre for 4 hours each evening. It is also used for sterilizing needles and for light cooking. The slurry is not used and drains into a pit. Mr. Marumbo saw the unit as essential for providing improved lighting in the wards. Before the unit was installed the hospital was forced to search for scarce firewood, or buy it locally. For emergency operations they would "borrow" electricity from the nearby Medical Training Centre's generator.

Kabila Health Centre, Ndagalu

The Kabila digester is a SIDO-built Indian Gobar design with an 8m³ capacity. It was installed in 1980 at a cost of TSh 22000/=. It was inoperational at the time of inspection. It had been used for cooking and sterilizing needles. The main feedstock was cowdung. The slurry was thrown away. An attendant had been trained to maintain the unit. He claimed a connecting pipe had broken and had never been repaired. It appeared to be quite difficult to procure spare parts for the plant. The villagers were experiencing severe water problems. The district had built them a water storage tank on a nearby incline, but the tank was empty. The water which was supposed to have been pumped from Kwimba district had never appeared.

The medical assistant at the centre explained that they had been forced to switch to kerosene and charcoal, which was a financial strain as there was no fuel allotment in their budget. He saw biogas as a positive solution, but recognised that it needed recurrent funds, a steady water supply and a paid attendant to maintain it. None of these conditions could be met at Kabula at the present.

Misasi Health Clinic

The Misasi unit was also inoperable. It was, as was the Kabila unit, a SIDO -installed, Indian design with a 10m^3 capacity. It was built in 1974 at a cost of TSh 18000/=. The top plug of the dome had been stolen in 1986. Otherwise the unit was in working order. The midwife interviewed had no idea whether any attempts had been made to replace the stolen part. The digester had been maintained by an attendant. It did not run continuously - it usually ceased operation for three months in the dry season when water is scarce. The feedstock was dung, collected in the vicinity by the attendant. During the wet season rain water is used to fuel the unit. The gas had been used for sterilization.

Misingwi Community Development Technical Training Institute

We interviewed Mr. Sakafu, Principal of the Institute. The Institute had four generators, all in working order. One was a SIDO-built Indian design installed in 1975, and the other three were Chinese models installed in 1986, following the visit of a technical team from China. The Indian design had a capacity of 10m^3 . Two of the Chinese models were 10m^3 units, and the third was a 6m^3 unit.

The costs of the Chinese plants were Tsh 30000/= each for the 10m^3 units and Tsh 22000 for the 6m^3 unit. These costs

included cement (20 kg and 15 kg respectively), labour, one gas pipe, and one lamp.

The biogas produced was used for cooking and lighting the student hostels.

The feedstocks, water and dung were easily available. Water was collected from standpipes at the Institute. Dung was collected locally. The digesters were fed every five days. The Chinese models required 50 L/day of water and the Indian model, 87 L/day. The ratio of dung to water was 1:1. No artificial mixing was done.

The sludge from all the plants is used by Mr. Sakafu to fertilize his personal plots. He cited cultural barriers regarding the handling of liquid sludge as the main constraint to widespread use of slurry as fertilizer.

The Indian model had been out of service for over four years, but has recently been reactivated.

The only recurrent operational problem mentioned was the build up of water vapour in the pipes which can sometimes block gas flow completely. These can be cleared by applying pressure to the pipes.

Aside from the three Chinese digesters at the college, there is a fourth plant at a private home in Butiama. In the near future, another three Chinese units will be constructed. One will be institutional (at a college staff house) and the other two will be built at private homes. The financing for the construction material and equipment comes from the Mission Administered Fund of the Canadian High Commission.

The college believes that a crucial element of biogas technology diffusion is the training of technicians. Last year nineteen technicians were trained; six from the Institute, nine from the region of Mwanza, as well as four teachers. The Chinese technical team offered the original course.

Sengerema District

We interviewed Dr. E. Masesa, District Medical Officer. No biogas plants were visited in the Sengerema District, however, information was gathered on the digesters at the Katungura and Kagaru health clinics. Both plants were temporarily out of order. They required minor repair - the replacement of corroded pipes and old biogas lamp wicks. The spares have now been ordered.

The Katungura digester was used to light two wards, the mother and child health clinic, the laboratory and a corridor, as well as to sterilize equipment.

The Kaguru unit was used primarily for cooking and the sterilization of needles.

At both clinics, the units were maintained by trained biogas attendants. These attendants were already part-time clinic employees, therefore, labour costs for maintenance are already covered in the clinic budget.

The attendant collected dung daily (by wheelbarrow). Water was fetched from a nearby standpipe. The sludge was not used as far as Dr. Masesa was aware.

Dr. Masesa mentioned that there was also a unit at the Sengerema Medical Training Centre and at the home of an individual in the area. The former, he believed, was in working order. The latter, however, was inoperational.

The village response to the units has been positive. Residents in Katungura have expressed an interest in reviving the clinic digester.

Dr. Masesa, as District Medical Officer, was anxious to expand the number of clinics using biogas plants in the Sengerema area. As labour maintenance costs are zero, and the feedstocks are readily available, it is an appropriate energy alternative to kerosene and charcoal.

TABLE 5. MWANZA PROVINCE SITE VISITS

LOCATION	DESIGN; CAPACITY YEAR	COST IN \$ US	USE OF GAS	FEED STOCK	MODE OF FEEDING	BENE- FITS
Kabila Health Centre	IGD; 1980 8m ³	\$2683	WH/SS	cow dung	M	B
Nassa Health Centre	IGD; 1979 20m ³	\$3041	L/SS	cow dung	M	C/D/B/A
Magu District Hospital	IGD; 1975 8m ³	\$2442	L/SS	cow dung	M	D/B/C
Misingwi Training Institute	CFD; 1986 10m ³ IGD; 1975 8m ³	\$917 \$2714	L L	cow dung	M	C/D
Misasi Health Centre	IGD; 1974 8m ³	\$2521	SS/WH	cow dung	M	B/C
Ngudu District Hospital	IGD; 1975 8m ³	\$2442	L/C/SS	cow dung	M	D/C

KEY: CFD = Chinese Fixed Dome
 IGD = Indian Floating Dome
 L = Lighting
 WH = Water Heating
 C = Cooking
 SS = Sterilizing syringes
 M = Manual

PERCEIVED BENEFITS:

- A = Reduction in fuelwood collection time and labour.
- B = Improvement of health services in the community.
- C = Fuel cost reduction.
- D = Improved lighting and cooking.

Dodoma Province Field Report**Hombolo Health Clinic: UTAFITI demonstration plant**

The Hombolo Health Clinic biogas plant is an Indian fixed dome model which was installed in 1980. The unit is used primarily for the sterilization of needles, however, there is sufficient gas produced daily for boiling tea water. The stove burner is an UTAFITI design.

The feedstocks for the digester are collected by a female attendant hired by UTAFITI at a wage rate of Tsh. 650/= per month. Four wheelbarrows of dung are collected daily and mixed with an equal amount of water. The water is fetched from near-by springs. The sludge is used to fertilize the clinic's maize plot.

The digester was built by local builders. The brick and mortar were locally supplied. The dome was built in Dodoma, on order, from imported steel.

Part of the funding for the UTAFITI biogas program came from the Commonwealth Science Council's Africa Energy Program. In 1980 the digester cost Tsh. 10000/= to construct. Mr. Mkwawa of UTAFITI-Dodoma estimates that the same digester would cost Tsh. 15000 in 1987. The dome was the major expense, representing one-half of the total expenditure.

There have been no major repairs to the unit in the last seven years, aside from some minor patching to seal small leaks in the dome.

Hombolo Leprosy Clinic and Farm

This unit was another UTAFITI demonstration model, installed in 1983. It was originally built as a Chinese fixed dome model, however due to excessive leakage, it was modified to a floating dome model in 1984. The dome was made in Dodoma from imported steel. It cost Tsh.9000 in 1983.

The biogas produced was used for cooking breakfast for the seventy leprosy patients. Fuelwood was used for cooking the rest of the day.

The biogas attendant had been promoted to cook, so now, all the cooks are responsible for maintaining the unit. Dung collection took two hours per day. Water was piped into the

clinic from Lake Hombolo, and collected from a nearby standpipe. There was no artificial mixing of feedstocks before they were added to the digester. There were some complaints from the cooks regarding these additional biogas duties for which they are not being paid.

UTAFITI is usually notified when the digester needs repair, although the work is done by technicians at the Leprosy Centre.

Hombolo CCM Chairman's House

The chairman expressed interest in having his own digester after seeing the Hombolo Clinic biogas plant. There was a technical problem with the outlet valve at first, but this was later rectified. At this point however, the chairman had lost interest in filling the tank. The dome was eventually removed and used at the Leprosy Centre when the Centre's biogas plant was converted to an Indian model.

Msanga Women's Centre

The biogas plant at the UWT canteen is used for cooking chappatis and tea. The cooking plate attached to the biogas pipe was designed by UTAFFITI. There is a biogas lamp attached to the pipe, but is not used because the filament burns out

regularly. A male attendant hired by UTAFITI collects the dung and water daily. Dung collection takes two hours per day and water collection, three hours. There had been no major repairs to the unit, although it had shut down for two weeks recently due to water shortages.

The women at the centre seemed more interested in obtaining a Dodoma charcoal stove to cook with, than expanding the biogas production of their digester, perhaps because the male attendant was neglecting his duties and cooking on the biogas stove became a nuisance. His lack of enthusiasm was likely due to his wages not paid for the previous two months.

TABLE 6. DODOMA PROVINCE SITE VISITS

LOCATION	DESIGN; CAPACITY YEAR	COST IN \$US	USE OF GAS	FEED STOCK	MODE OF FEEDING	BENE- FITS
Hombolo Leprosy Centre	IGD ₃ ; 1983 20m ³	\$2693	C	cow dung	M	C
Hombolo CCM College	IGD ₃ ; 1981 10m ³	\$1112	C	cow dung	M	C/I
Hombolo Bwawani Village	IGD ₃ ; 1980 6m ³	\$1210	SS	cow dung	M	B/C/A
Msanga Village	IGD ₃ ; 1981 8m ³	\$981	L/WH	cow dung	M	D/C/A

KEY: CFD = Chinese Fixed Dome

IGD = Indian Gobar Design
L = Lighting
WH = Water Heating
C = Cooking
SS = Sterilizing syringes
M = Manual

PERCEIVED BENEFITS:

A = Reduction in fuelwood collection time and labour.
B = Improvement of health services in the community.
C = Fuel cost reduction.
D = Improved lighting and cooking.

Analysis of the Biogas Survey Results

The results of the survey recorded in tables 3 - 6, are summarised below:

Location

Of the twenty digesters included in the study, only six were family-owned. Of these six, four were found in the Arusha district, one in Iringa and one in the Mwanza region. The rest of the units were located at institutions. Seven were found at health facilities - either clinics or hospitals, five at educational centres, one at a women's centre and one at a religious centre.

Digester type and Installation Date

Thirteen of the digesters were of the Indian floating dome design. Seven had been installed between 1974 and 1980. The remaining six were installed between 1981 and 1985. One digester was an interconnected drum design, installed in 1985. Six of the units viewed by the team were based on the Chinese fixed dome model and had been installed between 1984 and 1986.

Type of Feedstock

Four units were fed with mixed feedstock. All of the remaining sixteen plants used cow dung except one Iringa unit which ran on chicken and rabbit excreta. The mixed feedstock units had a semi-automatic feeding system, while of the other sixteen, fourteen were fed manually without gloves, one with gloves and one had a mechanised feeding system.

Use of Gas

Gas from ten of the digesters was used for lighting. Eight units supplied gas for cooking, and four units supplied gas for water heating. Gas was used to sterilize syringes at five locations. Nine of digesters had a mixed end-use for the gas produced. Of the remaining eleven, four were used for lighting only, one for heating water, one for sterilizing, and five for cooking only.

Perceived Benefits of Biogas

According to the survey, the most important benefit of biogas was the cash savings on kerosene and charcoal purchases. Seven respondents ranked this benefit first and six others ranked it second. The second most popular choice was improved lighting and cooking. Five respondents ranked this number one and four respondents listed it as a second benefit.

Operational Problems and Downtimes

The three most common complaints mentioned by respondents were the leakage of connecting pipes, the clogging of gas pipes and the difficulty of obtaining manure. Six respondents cited leakage as a problem, six found clogging a problem and five listed dung collection as an operational difficulty. Corrosion of the digester cover was mentioned in two instances, as was the cracking of digester walls. Lack of spare parts was cited as a problem at three locations, and mismanagement at two locations. More significant perhaps, is that six digesters appeared to have no operational difficulties at all. Four of these were the Chinese fixed dome design, one was the interconnected drum model and one the Indian Gobar design.

Five units were inoperational at the time of the survey in June 1987. The Mwanza region had the worst down-time record. Four of the five non-functioning digesters were in this district. Down-times ranged from four months to four years. The other digester with a significant down-time was located at the Hombolo CCM College in the Dodoma region. The digester had lain dormant for two years.

Discussion

The sample size of this study was too small to provide any concrete conclusions regarding the overall state of biogas technology in Tanzania. This survey is best seen as a preliminary and very selective assessment of digester function in four regions only. Several observations and inferences can be made from the data collected.

First of all, the demonstration effect of the institutional SIDO models built in the 1970's has been virtually nonexistent. There was no evidence that people sought to own a digester having seen one at their local health clinic or educational centre. In fact, there were only two family-owned digesters visited in the SIDO catchment area. This was not out of choice - there were no other private units to be found.

Second, most of the operational problems were easily rectifiable. Leakage, clogging and cracking are normal "wear and tear" phenomenon given the nature of the anaerobic process and the pressure of gas produced under optimum conditions. These technical shortcomings actually hide the root of the problem; a poor maintenance and repair system, and inadequate extension services. CAMARTEC must be excluded from this indictment as all their digesters were fully operational. Furthermore although two of the CAMARTEC models had mentioned a short down-time, their problems had obviously been sorted out, indicating successful delivery of maintenance and repair services. The difficulties of dung collection cited by several institutions did not appear to be caused by free range grazing practices, rather, the problem seemed to be more managerial in nature. The institutions expected local cattle owners to provide cow dung free of charge, while the farmers in turn were miffed that they had not been consulted prior to the installation of the digesters. Many of the units were maintained quite haphazardly. There were no paid attendants, no trained extension workers and no organised acquisition of spare parts. It is understandable that institutions such as the Hombolo CCM College are losing interest in biogas.

Third, the cost of the family-size units particularly the CAMARTEC package models was beyond the means of the poor. It came as no surprise therefore, that all the owners of non-

institutional digesters we interviewed were either business men or successful cash crop farmers. CAMARTEC does not hide the fact that it is purposely targeting farmers with commercial interests - they are the only ones who could afford a US\$ 2000 cash outlay.

Fourth, the perceived benefits of biogas cited in the survey do not necessarily reflect the actual benefits. Although cash savings was the number one choice, it is questionable whether biogas owners had actually calculated their net savings per annum on purchased fuels in relation to their capital investment in biogas. Financial benefits are even more meaningless in the case of institutional units. The capital costs were borne entirely by the government. Respondents therefore, tended to compare only biogas maintenance costs to the cost of purchasing alternative fuels. Biogas would certainly appear to be more cost-effective than it actually was under these circumstances. The second most important benefit as cited in the study - improved lighting and cooking - is a highly subjective choice given the absence of any substantial data on the subject. It is important that the recipients of biogas technology do perceive some benefits in owning a digester otherwise the technology will never enjoy widespread acceptance. Their perceptions must be based however, on certain quantifiable facts the most salient of which is the economic feasibility of owning and

maintaining a unit. Once a digester is seen to be a financially viable investment, the other benefits can then be considered. If biogas does not pay its way, there is no point eulogizing its less quantifiable virtues. The following chapter offers a hypothetical model for a cost-benefit analysis of biogas in Tanzania.

NOTES

1. The exchange rates in Tsh per US dollar for the years 1967 to 1987 are listed in Appendix B.

**CHAPTER 6: ECONOMIC ASSESSMENT OF BIOGAS
TECHNOLOGY IN TANZANIA**

There has been no full-scale study of the economic viability of biogas technology in Tanzania to date. The University of Dar-es Salaam/Carleton University project, though it sought to address social and economic issues, failed to gather sufficient information to conduct a proper cost-benefit analysis. This discussion is therefore limited to the theoretical. It should however, provide a guideline for future analyses of biogas potential in Tanzania.

To assess the economic feasibility of biogas in rural areas, it is necessary to establish a set of alternatives against which biogas can be compared. Assuming rural resources to be of a limited nature, the choice of investment in biogas must be weighed against other possible investments-what might be termed "the next best alternatives". In order to do this, one must first determine who is making the investment decisions as this will undoubtedly affect the range of choice.

Decision-Making

There are two separate and discrete levels at which the investment potential of biogas can be examined; the macro or national level, and the micro or village/individual level.

Investment decisions at the macro-level reflect the government's national fuel and rural development policies and programs. The allocation of public resources for biogas technology diffusion may compete with government investments in village water supplies, educational and health facilities, agricultural inputs, or even other fuel choices. Even when biogas is selected as an appropriate and desirable investment, its adoption is far from guaranteed. Within the government structure, investment priorities may differ and at times conflict. National economic policy may seek to promote the technology while regional administrative interest in biogas popularisation may be weak. This discrepancy highlights the most important feature of macro-level investments - they are primarily political decisions subject to the political agendas of the decision-makers.

Who then are the decision-makers ? In Tanzania, political decisions are made by the President, the cabinet, and the National Executive Committee and are ratified by the party. Central government is represented in each province by

district and regional administrations. The flow of resources to the regions is centrally governed although local offices control the disposal of budget allocations for given sectors. There is thus a certain amount of district autonomy in the decision-making process. This has, in fact, hampered biogas dissemination efforts as district councils have preferred to spend their energy allotments on other fuels, namely charcoal, fuelwood and electricity.

Micro-level investment refers to the returns on a single investment within a given locality. Micro-level decisions are influenced by many factors - social, political, cultural and economic - but by far, the most important parameter seems to be access to capital.¹ Farmers, when they have capital, tend to choose investments which enhance their productive capabilities and provide increased income. For this reason biogas digesters are viewed as a luxury in India, and as a necessity in China - in the former, the returns on investment are largely non-financial, while in the latter, the use of slurry fertilizer improves crop production and raises family income.

An individual's access to capital is determined by the social, political and economic structure of the society in which he lives. It would be a false assumption that every peasant can freely make investment decisions. Tanzanian

villages are far from egalitarian despite over twenty-three years of socialist ujamaa policy. Village income distribution remains skewed, especially in the Arusha-Kilimanjaro region where capitalist modes of production existed prior to Independence and have weathered the Nyerere years relatively unscathed. The result is a society with distinct power bases holding sway over investment decisions. Village leadership including the headman and local CCM party members, comprise one such power base. Wealthy farmers and traders constitute a second (although not always separate) group. At the family level, the males of the household generally determine investment priorities. As with macro-level decisions, there are often conflicting agendas at work. The position of the decision-makers in the social structure strongly influence their views on how investment should be used.² In addition the social structure modulates the distribution of effects of investment among various groups within a village. It is important when considering investment objectives to look beyond the decision-makers to the "invisible strata" of the village structure. The impact of investment choice on women, on the landless and on the poor in general must be taken into account if not by individuals, at least by village authorities -formal and informal-as well as by decision-makers at the macro-level. As Barnett notes, " where some factors of production are monopolized, the introduction of a new technology may increase the surplus expropriated by

monopolists or investment in new technologies may break dependencies and alter village power structures"³. Thus it is possible for biogas technology to have a deleterious effect on income distribution under certain conditions. Whether the village structures in Tanzania are sufficiently inequalitarian to meet these conditions will be discussed in the concluding chapter.

Costs and Benefits - Valuation of Parameters

The most frequently used method of evaluation is economic cost-benefit analysis, which assesses investment potential at the micro-level. Obviously, unless a technology such as biogas is economically viable in the village, it will fail at the macro-level.

The preliminary stage of analysis is the selection of the alternatives against which biogas will be compared. Researchers should attempt to simulate the decision-making process of the potential buyer - the selected range must represent realistic micro-investment opportunities, and should include non-fuel options. It would be futile to compare biogas to electricity if electrification was an unlikely scenario for the given village or area. In Tanzania, the only viable energy alternatives to biogas at the village level are

fuelwood, and charcoal for cooking, kerosene and electricity (in certain areas) for lighting.

Once the framework has been established, the physical quantities of inputs and outputs in the biogas system must be measured and assigned an economic value. The amount of dung and water a digester requires and the amount of gas and slurry it produces can be calculated with careful monitoring. The difficulty lies in assigning them accurate economic values. There is no market demand for the inputs and outputs of the system; shadow prices rather than market prices are normally used in calculation. These values tend to be rather artificial and highly subjective. The India studies for example,⁴ produced conflicting conclusions on the viability of the KVIC digester because their valuation of inputs and outputs differed.

The second and certainly more challenging problem is that many of the benefits and costs of biogas are non-quantifiable. The impact of biogas on self-sufficiency, labour utilisation, social status, environmental pollution, and disease levels for example, is extremely difficult to measure. Nevertheless, these factors may determine the widespread acceptance or rejection of the technology. These are known as second round effects: they are essentially hidden costs or benefits which

may be insignificant to a single micro-investment but important when investment is extensive in a given area.⁵

Third, assuming the first two hurdles have been overcome, the results would be location-specific. One could not assume that the economic feasibility of biogas in one area would hold true for another region or another country. Even digesters of a similar design will produce variable amounts of gas and slurry under the same conditions and thus alter the analytical data.

Despite these limitations, cost-benefit analysis is still the best tool of assessment available, but researchers, technologists and government officials must treat their results with caution - it would be unwise to embark on a national promotion scheme until biogas proves cost effective in a number of studies conducted in different regions. Of course, in order to evaluate biogas in the first place, someone must take the risk and invest in it. The Tanzanian government has done this, but the economics of institutional demonstration models are very different from those of the privately owned family-size units they now wish to promote.

There is arguably, enough data available to conduct cost-benefit studies in the Arusha-Kilimanjaro region, however it

would be folly to apply those conclusions to Mwanza, to Iringa or to any other region of the country.

Valuation of Inputs

The inputs in the biogas system can be divided into the following general categories: equipment and materials, feedstocks, and labour.

Equipment

The valuation of the digester is subject to several factors - the type of design, the capacity of the unit, and the source of materials, whether local or foreign.

The digester design is the major determinant of equipment cost. The Indian floating dome model is priced at \$US 2300, while the Chinese fixed dome model costs an estimated \$US 700. The valuation of equipment will be sensitive to foreign exchange rates when imported parts are used, rather than local materials. The SIDO digester had high capital costs because its dome was made from imported steel. The AATP seven drum design relied almost entirely on local materials and was significantly cheaper but unfortunately, less reliable. The current CAMARTEC fixed dome designs are quite expensive as they are an all-inclusive package complete with stable floor.

Spare parts and accessories will vary in cost depending on their source. Most of these are available nationally - plastic hose pipes for example - and some are designed and produced locally such as the CAMARTEC burners. The lamp fixtures were originally imported from India but now are manufactured by Tanzanian firms.

Transportation costs for materials and accessories should be included in the calculations, especially if biogas is expected to replace a locally available fuel.

Organic Feedstocks

The organic inputs to the digester include dung, water, and crop wastes.

Dung

The valuation of dung can be calculated in different ways depending on its alternative uses.

When dung is freely available or is considered as waste, it will have a zero opportunity cost. In Tanzania, this is largely the case. Livestock are generally non-zero grazing, and dung is plentiful.

There will be an opportunity cost to consider when dung is applied to the fields as fertilizer, as it is in the Arusha Kilimanjaro region. The use of slurry- which has been found to be a better fertilizer- should counter this, but the opportunity cost of diverting dung to the digester for slurry fertilizer, as compared to using chemical fertilizers must be assessed. Dung in Tanzania will not have as high an opportunity cost as in India where it is bought and sold as a domestic fuel by the poor. This is a major reason why the results of the Indian analyses are not directly applicable to Tanzanian biogas systems.

In circumstances where dung creates disposal problems, such as livestock ranching, the valuation may warrant a negative opportunity cost. This would have been the case at the Mabuki Dairy farm had a digester been installed on the premises. Unfortunately, any advantages gained from their centralised manure stockpile were lost through the transport costs incurred by moving dung ridiculous distances to semi-functioning health clinic digesters.

The valuation of dung will obviously vary between localities as it reflects local agricultural and ranching practices.

Water

Analysts frequently assign a zero cost to the water requirements of the biogas system. While it is true that there is usually no monetary charge for water use in rural areas, costs are expressed in other forms, such as labour investment in water collection. Certainly, in times of acute water shortage, the opportunity cost of supplying water to a digester may be prohibitively high. Water availability in Tanzania varies nationwide. It is a scarce commodity for several months of the year in the semi-arid regions around Dodoma and Mwanza. This could mean that a digester will lie dormant for a significant period of time each year.

Valuation of water in Tanzanian biogas systems must account for regional differences as well as the seasonal fluctuations in its availability.

Crop Residues

Crop waste is not used extensively in Tanzania. The CAMARTEC team have tried mixed feedstocks in their units, but little experimentation has taken place in other regions of the country. Nevertheless, the valuation of crop waste -if and when it is used- will be fairly straight forward. It will have a zero opportunity cost as it is a free good. In contrast, in countries such as China with a long history of waste composting, there will be a cost of diverting waste to the digester, but as with dung, this should be compensated by the substitution of slurry as fertilizer.

Labour

Labour is one of the most difficult parameters to evaluate accurately. First, it is not a homogenous input; skilled labour is required for construction, maintenance and repair, and information dissemination, while unskilled labour is normally used for collection of water and dung, simple maintenance, and disposal of slurry. These two types of labour will have differing opportunity costs.

Second, it can not be assumed that a zero shadow wage is valid in the case of unskilled labour, even if the labour input comes from family members. Unless the labour is completely idle due to the absence of work opportunities,

there will be a cost in diverting manpower to the biogas system. At two Tanzanian health clinics, Katungura and Kagaru in the Sengerema district, the biogas digesters were maintained by part-time clinic employees whose wages were already covered in the clinic budget. It could be argued that labour costs in these instances is zero, however one wonders what other productive activities these assistants might be involved in were they not supplying free labour for biogas. There may be an opportunity cost after all.

Third, while it is frequently assumed in the literature that the time required for dung collection is the same for biogas as for alternative end-uses, there is no evidence that this is true. In India this would imply that the amount of dung burnt as fuel is equivalent to the amount fed into the digester over a specified period of time. This assumption is even less plausible in Tanzania, where dung is never used as fuel and rarely as fertilizer. Of more importance in Tanzania is the labour input into dung collection as compared to fuelwood collection, especially in areas of rapid deforestation.

This raises the issue of the value of women and children's labour as they are the primary fuel collectors. There has been deplorably little research on the impact of biogas on women and on their work load in particular. Female

labour is chronically undervalued. The gathering of dung, together with the added burden of water collection, may represent a significant opportunity cost to women whose time might be more gainfully employed in other ways. Thus there may be certain advantages to the continued use of an increasingly scarce fuel commodity - at least in the short term - if it means that women spend less time looking for wood than collecting dung and water.

Labour requirements for maintenance and repair must also be considered in biogas feasibility studies. Again, these responsibilities are often borne by women in the case of family-owned digesters.

Finally, labour input in extension services such as the provision of technical assistance, training programs and literature must be included as a cost item. There is increasing evidence that the economics of biogas plants once constructed, are closely tied to the availability of extension services.⁶

The Valuation of Outputs

The quantifiable outputs of the biogas system are gas and slurry.

Gas

The valuation of gas is dependant upon three parameters; its energy yield or calorific value, its end-uses, and the economic values assigned to its replacements (alternative fuels).

The calorific value is function of the type and volume of the feedstock, the temperature, the loading rate, and the methane content of the gas produced. The variability of gas output in both quality and quantity makes the standardisation of results difficult. The methane content is generally assumed to be 60% by volume in the Indian field studies.⁷ This value is probably much lower in Tanzania as the digesters, particularly the institutional models, are less reliable. Unfortunately, there has been little monitoring of gas production, so the average energy yields remain purely speculative. Until they are calculated with some accuracy, it will be impossible to evaluate the feasibility of biogas as in Tanzania.

Tanzanian digesters could be, for example, operating at a loss because of insufficient gas output. Low gas yields may be a cost rather than a benefit if they evoke the need for a back-up fuel source. Barnett refers to this as the "unreliability factor".⁸ Certainly in Tanzania during the dry

season this is a cost to be considered. Furthermore, an improvement in gas output cannot always be exploited. The extra gas produced may have marginal utility depending on its end-use and whether further capital investment is required. Digester owners may not be able to take full advantage of economies of scale if they have to purchase additional light fixtures or cookers.

The valuation of gas in terms of the thermal equivalent of another fuel is often controversial. The problem is two-fold; determining the appropriate alternative, and assigning it a realistic price. In some instances there may be more than one replacement. Biogas for lighting could be valued according to kerosene or electricity, for example. Researchers need to ascertain the most likely option for the targeted users as fuel choices will differ among social classes.

Where the end-uses are mixed, the analysis is more complicated. Each option will have a different valuation based on its replacement costs. If all the gas produced from a digester is used for cooking, it will have lower value than if half is used for lighting and half for cooking. Researchers have a certain amount of freedom therefore, to alter the valuations to give the technology a positive net present value.

Biogas in Tanzania is used for cooking and lighting almost without exception. The valuation of gas will be in terms of thermal equivalents of fuelwood, charcoal, kerosene and possibly, in some areas, electricity.

The most common replacement for biogas as a cooking fuel in Tanzania is fuelwood. As wood is a free commodity, or sold in the market on a limited scale, valuation will tend to be based on social cost -time and labour, more specifically. The opportunity costs for collection have already been mentioned. Cooking times and labour involvement in food preparation must also be calculated. Again labour costs for these activities affect women almost exclusively. It should be apparent by now that the overall demand on women's time to keep a family digester operative will play a major role in the acceptance or rejection of the technology. If biogas duties infringe on the time allotted to productive activities the system will have a high labour valuation, whereas, if biogas frees women to pursue other interests the opportunity costs will be lower.

Charcoal is used for cooking mainly in the urban areas, although the wealthier rural dwellers will also use it as a fuelwood substitute. Gas valuation in charcoal equivalents will be higher than fuelwood because it is a marketable commodity.

Kerosene pricing is fairly straightforward as it too has a market value.

Electricity is a bugbear as far as pricing is concerned, and is better left out of the analysis if possible. Costs will vary according to government subsidies, distance to mainline grids, capacity of the power plants and capital cost of transmission equipment.

Slurry

The valuation of slurry is based upon its benefits as fertilizer. It can be measured in two ways ; in terms of its nitrogen content, and in terms of the labour cost in spreading it on the fields.

Biogas treatment of dung increases the amount of nitrogen available to plants as compared to raw manure, however the nitrogen content of slurry will vary, depending on the post-digestion storage practices. If the liquid effluent is allowed to dry in an open pit, as is common practice in Asia, there will be a loss of ammonia gas through evaporation. Ideally, the liquid effluent should be applied to the fields as soon as possible, otherwise the advantages of dung treatment could be lost. The value of slurry will be particularly sensitive to

local farming practices and how they govern the handling of liquid waste.

Slurry use in Tanzania is extremely limited. In most cases, the slurry has been treated as a nuisance and left to dry on the ground or in an overflow pit. A realistic assessment of its value under current practices would indicate a zero or negative utility expressed as the cost of removing it as waste. However, one would hope that the efforts of CAMARTEC and Misingwi Technical College to promote slurry use will alter existing practices. It should be compared to the cost of using chemical fertilizer.

Even when the sludge is used, there will be labour costs in transporting it from the digester to the fields, and spreading it on the crops. This can be calculated in terms of opportunity cost for the manpower involved, or in terms of real wage, where the labourers are paid, as is the case on several farms in the Arusha-Kilimanjaro region.

It is also possible to value slurry in terms of its reduced pathogen count as compared to raw sewage. In China, the digestion of night soil has improved rural sanitation.⁹ As night soil is not used in Tanzanian digesters at present, it is not possible to quantify sanitation improvements. This could however, be a second round benefit with significant

impact if the cultural barriers concerning the handling of fecal matter were overcome. This is unlikely to be the case in the short-run.

The following section provides a theoretical model for a cost-benefit analysis of biogas in Tanzania.

Theoretical Model

The net return from a biogas digester per year is equivalent to the gross value of the outputs per year minus the gross value of the inputs per year.

$$R = O - I$$

where $O = \text{Gas} + \text{Slurry}$

and $I = \text{Dung} + \text{Water} + \text{Recurring maintenance costs per year}$

Each of these parameters will be valued according to the choices laid out in the above sections. The following provides a sample valuation for a biogas analysis:

1. The opportunity cost of dung - assuming prior to biogas, all dung was used as manure;

$$D = P_m \times M$$

P_m = price of manure per kg

M = amount of manure in kg which could be derived from the dung equivalent fed into the digester per annum

2. The opportunity cost of water

$$W = P_w \times w$$

P_w = price of water

w = amount water required in m

3. The opportunity cost of the generator

$$G = P_{gg} \times K \times (1 - \% \text{ downtime}) \times 365$$

P_{gg} = cost of generating gas - including labour cost of running the plant, and recurrent maintenance costs

K = capacity of digester, expressed as amount of gas produced in m^3/day

4. The opportunity cost of methane gas

$$MG = P_{gt} \times C \times K \times 365$$

P_{gt} = price of gas in thermal equivalent of substitute fuel

C = efficiency of gas production expressed as percent methane content

K = capacity

5. The opportunity cost of slurry

S = Ps x Ms

Ps = price of slurry

Ms = slurry manure produced in kg/year

The net present value of the digester can then be calculated as the discounted value of R minus the investment cost (Ic).

$$NPV = Rd - Ic$$

The formula for Rd is;

$$\sum_{t=0}^n \frac{O_t - I_t}{1+r^t}$$

where r = the interest rate, n = the economic life of the digester, and t = a given year.

NOTES

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CHAPTER 7: CONCLUSION

Our research has shown, despite the problems associated with the survey, that Tanzania is facing a rural fuel crisis which needs immediate attention. The continuing dependence on fuelwood to meet domestic energy requirements has placed environmental and economic pressures on the rural sector. Energy consumption patterns will have to change. The questions are how to change them, what to change and when. Fuelwood will continue to be the primary energy source for the majority of rural dwellers well into the next century. It will not be easy to wean villagers off of wood and on to another fuel. Wood and charcoal are part of a rich traditional culture -the family hearth being a focal point of community activity and tribal ritual. It is hard to imagine the same sort of convivial gatherings around a biogas digester. Obviously in the long run, dependency on wood must be minimized. Even if fuelwood consumption per capita remains constant (680 W/capita) the burgeoning population can not be sustained on the existing and projected woodland.¹ The transition to alternative energies is likely to be painful and exceedingly disruptive to village life. This is one reason why we can conclude that rural energy solutions for Tanzania must be part of a multi-pronged attack on poverty. An

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improvement in rural standards of living will cushion the blow caused by the demise of the open fire.

The solution to Tanzania's energy problems will entail both short-term, stop gap measures, and long-term strategies. The most successful stop gap measure to date has been the improved cookstove. In both Kenya and Tanzania, locally designed stoves have been readily accepted by villagers. A new technology using the old fuel - this is a gentle step towards further change. Our field survey has shown that biogas technology is not a suitable short-term solution for Tanzania. It would require widespread acceptance to produce any real effect on rural energy consumption patterns. A shift from wood to dung and gas is far too disruptive to occur quickly. The adoption of technology is always slower when a large number of people need to change their behaviour and attitudes simultaneously.² The short term measures must centre on fuelwood and land conservation-afforestation projects, woodland preservation, introduction of improved cookstoves, better livestock management, and soil erosion prevention.

Long term strategies must include renewable energy technologies, as well as a continuation of all the above measures. This is where biogas technology may play a role -

providing it is found to be an appropriate investment. The following section reviews the potential of biogas for rural development in Tanzania by assessing the various parameters linked to technology diffusion.

Technical Considerations

Our study supports the hypothesis that technical problems are not the primary impediment to technology diffusion. The hardware can be manufactured locally, and the skills required for digester construction are potentially available within the rural sector.

The Chinese Fixed Dome design is more appropriate technically than the Indian Gobar plant. The Chinese model is cheaper than its Indian counterpart and can be constructed from locally available materials. Construction of the fixed dome requires some specialist training particularly in masonry. The Chinese digester therefore, has the potential to improve indigenous building skills. This can have a positive spin-off effect on village industries. CAMARTEC is hoping to encourage local cooperatives to build digesters as they can not keep up with the demand.

Geographical Considerations

The main geographical criteria for successful biogas adoption are adequate rainfall, ambient temperatures, and population pressure on local woodland areas (in other words a sufficiently serious deforestation problem). In these respects, Tanzanian provinces vary greatly from one another.

Mwanza

Mwanza province, on the southern shores of Lake Victoria has a fairly flat terrain. The soils are relative y good and the rainfall is moderate during the rainy season December to May. Much of the natural vegetation has been lost through overgrazing and extensive cultivation.

Deforestation is an acute problem. Fuelwood demand exceeded supply by 3,178,000 m³ or 95% in 1983.³ The population density is the second highest in the country with over one hundred and twenty people per square mile. Mwanza is a suitable region for biogas investment from a geographical perspective.

Dodoma

Dodoma, on the other hand is not suitable, at least for initial investment. Rainfall is low -500-610 mm per year, and is unreliable.⁴ The plateau area has a high evaporation and transpiration rate. There are no permanent streams. Dodoma does have a fuelwood shortage. Regional supply was 1,332,000 m³ or 60% less than the demand in 1983.⁵ Dodoma is in need of a stop-gap emergency solution to combat deforestation, but because of the water constraints, biogas is not an appropriate choice. It is here that Barnett's "unreliability factor" would most certainly be a cost consideration.⁶

Iringa

Iringa, in the southern highlands, has reasonable rainfall and a temperate climate. It has less of a deforestation problem than Dodoma and Mwanza, with a supply-demand deficit of 613,000 m³ in 1983. Demand exceeded supply by 30%.⁷ Iringa is geographically suited to biogas technology.

Arusha

The temperate climate, the high annual rainfall and the high population density in the Arusha region provide appropriate geographical conditions for biogas digestion.

The fuelwood shortfall in 1983 was 1,450,000 m³ or 65% of the demand.⁸ Together with the neighbouring Kilimanjaro region (demand deficit of 95%), this area is well-suited to further biogas investment.

Economic Considerations

The economic viability of biogas digestion is a critical parameter for consideration. Even if the technology is technically appropriate, and the locale geographically suitable, diffusion efforts will fail if a digester is not found to be a cost-saving device and initial investment is not recouped in a reasonable period of time (four to five years). There are several issues which must be taken into account;

1. Capital Costs

At the moment, the cost of a family-sized digester, on average US \$2000,⁹ is far too high. The per capita income in 1987 figures is US \$405.¹⁰ A good portion of the population will be excluded from the possibility of owning a digester. The diffusion scheme in Arusha certainly reflects this skewed ownership pattern. Ten percent of farmers in the region could afford a biogas plant.¹¹ Presumably the rest could not manage to produce the

down payment. The social implications of stratified ownership will be discussed further on.

CAMARTEC estimates that a biogas plant will break even in three to four years with running costs and interest payments covered as well as the initial investment.¹²

2. Livestock Requirements

In all four of the provinces visited, livestock ownership was not a constraint on biogas diffusion. Arusha has the second highest livestock population according to a 1984 Ministry of Agriculture survey, Mwanza had the third highest, while Dodoma and Iringa were fourth and tenth respectively (Refer to Table 4, Appendix B). The number of livestock per family will vary, but it is reasonable to assume that a majority in each province will have the minimal two or three animals required for gas production from a small family digester.¹³ A study of cattle ownership in the Dodoma region in 1973 found that 75-90% of households in the villages surveyed owned an average of five cattle.¹⁴

Livestock ownership is the first criterion. The second related requirement is suitable grazing practices. Biogas will be more appropriate from an economic point of view in regions which practice zero grazing, such as Arusha and Kilimanjaro. The time and labour needed for dung collection should be minimal. CAMARTEC insists that fully stabled livestock (twenty-four hours a day) are a necessary requisite for adequate gas production. Free-grazing animals should however, provide enough manure if corralled at night. This is the practice in the Mwanza region. In the Dodoma region, livestock are generally not stabled at all because of the shortage of grass. Time and labour for dung collection are greatly increased. This seriously jeopardizes the economic viability of biogas technology in this region. Further studies are needed to determine whether corralling at night produces enough dung to feed a family-sized unit, and whether it is possible to collect enough manure from free range animals.

3. Positive Net Present Value

As a proper economic-cost benefit analysis has not yet been completed in Tanzania, it is difficult to gauge the economic feasibility of widespread

biogas dissemination. Studies in Kenya have shown that the net present value of the biogas system is extremely sensitive to the value placed on slurry.¹⁵ The economic benefits of biogas will increase when the slurry is incorporated into traditional farming practices, as it is in China. If slurry fertilizer can improve productivity in the cash crop and subsistence crop sector, it will mean greater economic returns for the farmer. China's promotion of biogas digestion for its fertilizer properties rather than for its fuel potential has given the technology broad appeal among peasant producers. Qui Da Xiong states that the benefit of a readily available fuel source is not enough to attract peasants to build biogas digesters. Biogas production must be linked to the agricultural system, and must offer a financial incentive to users by raising incomes.¹⁶ Tanzania needs to copy China's example and encourage slurry application on the fields.

4. Economies of Scale

There is evidence in the Arusha region that biogas owners are using surplus gas to run home-based industries such as bread-making and beer brewing.¹⁷ There is great potential for biogas

technology in small agra-industries such as tea-drying and coffee roasting. Arusha and Mwanza have a sufficiently well diversified economic base to allow the integration of large scale digesters into commercial activities.

Government institutions in Tanzania, on the other hand, have failed to take advantage of the economies of scale provided by the larger units because they were not involved in income-generating activities. The failure is not primarily an economic one but a political one. The interest and commitment to biogas was, by and large, absent.

5. Credit and Subsidies

If the government of Tanzania is serious about promoting biogas, it will have to introduce a credit and subsidy system to relieve the financial burden on small farmers. The problem with these facilities is that they are generally too narrow in scope - they do not help the most underprivileged. India's 50% subsidy on digester capital costs was very generous, but still excluded those who could not produce the other fifty percent. Similarly, the credit system requiring livestock as collateral barred those without cattle. Tanzania may find

itself in a similar dilemma if it tries to introduce biogas into the subsistence sector. In areas like Arusha with a substantial number of landless labourers, the land requirements for a digester will prohibit them from owning a unit. These inequalities can not be redressed without tackling the power structure within villages and breaking the hold of the kulak class on land, services, and commodities. If twenty years of socialism failed to accomplish this, it is highly improbable that capitalism will now do so. Nevertheless, credit and subsidies are worthwhile. They will aid the small farmer or business man who has some capital-but not enough, a few cows and a small shamba.

Social Considerations

There are two separate areas to consider here. The first, as alluded to in the previous section, is the impact of biogas on the socio-economic stratification in rural Tanzania. The second pertains more to the technology itself; the social costs and benefits as perceived by the users.

Biogas technology in the short-term is going to benefit the wealthier members of the community. This could have one of a number of effects:

1. It will lower their firewood requirements. This will decrease the income and employment opportunities for the poor who collect wood for the rich.¹⁸
2. It will lower their fuelwood requirements and increase the availability of wood for others, and perhaps lower the market price. This will reduce the income of those who collect for the market.¹⁹
3. It will lower their charcoal and kerosene requirements. The savings accrued are used in productive activities or in conspicuous consumption.
4. It will lower their charcoal requirements and reduce the market demand. As with fuelwood, the incomes of the charcoal producers will decrease. A study in the Lushoto District, Usambara mountains, found that poorer women spent 63% more time producing charcoal for sale than did wealthier women.²⁰

The changes in fuel consumption patterns can only be surmised at this point. Biogas technology is not going to eliminate the socio-economic inequalities in Tanzanian villages. If anything it will consolidate the dominance of the kulak class. The degree to which fuelwood has entered the market in rural Tanzania needs to be assessed in any area where biogas is likely to be introduced. If most of the fuelwood is still collected freely, switching to biogas will augment the supply for the poor. If a sizable portion of the local fuel demand is met through the market, adoption of biogas will discriminate against the poor who produce or collect fuel for the market. Presumably there is a threshold level of fuel commercialisation above which biogas adoption ceases to help and begins to injure the poor. The problem with trying to measure such values is that fuelwood continually creeps into the market as scarcity increases in an area.

The solution to the discrimination against the poor would be to provide alternative income generating activities for them, and 50% subsidies on family-size digesters that they might enjoy the benefits of biogas too. This raises all sorts of conundrums for the local authorities in providing education and training for the poor, in determining the genuinely underprivileged who deserve a subsidy, in managing the extensive biogas scheme which would develop, and, most

important of all, in persuading the general populace that a biogas unit is just what they need.

The Tanzanian government has not had great success in convincing the peasantry that the bureaucracy knows best, as outlined in chapter 2. The failure of the SIDO-installed institutional digesters to elicit more than mild interest among villagers could have been due to their wariness of becoming embroiled in another bureaucratic "scheme". Similarly, an attempt to foist fully subsidised digesters on an unsuspecting population could raise the same suspicions. CAMARTEC's consumer approach has had great success. This may be due to the status associated with owning a new technology or simply that people value what they have to pay for.

Community plants are not likely to succeed in Tanzania. The poor, as they lack political and socio-economic power, would probably have little control over the running of the digesters and the distribution of outputs. The failure of the communal shamba to provide fair and just remuneration to the under privileged, as noted in chapter 2, is an indication of the problems a communal digester might cause.

Not only will biogas adoption affect fuel consumption patterns, it will also affect labour - the household division of labour in particular.

As noted in chapter 6, female labour is chronically undervalued. Labour surveys show that women contribute a disproportionate amount of time to productive and domestic activities compared to men.²¹ Women in the Lushoto District work on average sixty-four hours per week. Cooking and housework occupy twenty-seven hours, agricultural work takes twenty hours, and fuelwood collection, eleven hours.²² Biogas technology - introduced in those regions which fulfil the geographical criteria and the livestock requirements - should provide women with substantial time-savings by simplifying cooking and cutting out the long hours of wood collection. Whether women are able to use the time saved for productive activities or whether their labour is controlled by others needs to be examined.²³ Wealthier women tend to work more hours on income-generating activities than poorer women²⁴, thus are more likely to benefit financially from the time-savings.

Biogas can add extra duties to the ~~men's~~ workload. They may have a direct involvement in daily operations particularly if they are the only family members to have been trained in maintenance and repair.

Women are, and will continue to be, the major beneficiaries of biogas technology as long as biogas is introduced primarily as a cooking fuel. It is ironic that the

technology is largely directed towards men. Training, management, construction, and marketing are all male dominated. It is encouraging that CAMARTEC uses females on their survey teams. Women are much more likely to show an interest in biogas if approached by a female surveyor.

Male attitudes will have a significant impact on the diffusion of biogas technology. Women, because of their subordination in Tanzanian society, and their dependence on male remittances, lack the cash outlay to purchase biogas units. They must rely on their husbands' benevolence. If women are providing a reasonable fuelwood collection service, men may not be interested in purchasing a piece of equipment that would ostensibly lessen the female workload (and increase their own) - unless there is a certain prestige attached to owning a digester.

Male attitudes will differ between social classes. As incomes rise, a greater proportion of the family's energy needs are met by commercial fuels. Wealthy families are more likely to realise cash savings by switching from charcoal and kerosene to biogas. Poor families are substituting a free commodity. Wealthier men are therefore more likely to be interested in biogas if it increases their incomes, then poorer men who will derive little or no financial benefits from owning a digester.

The socio-cultural costs and benefits of biogas as perceived by users are not normally included in economic analyses because their valuation is highly subjective or virtually impossible to determine. It cannot be over-emphasised, however; they have the power to make or break a technology. In more concrete terms, even if biogas is economically viable as a micro-investment, unless these non-quantifiable benefits are socially and culturally compatible with rural life in Tanzania, the technology will not be widely accepted.

One of the primary benefits of biogas according to women, concerns the improvements in cooking practices. Biogas is a relatively clean fuel. There is very little, if any smoke produced as compared to the open fire. This lowers the incidence of eye and lung irritation. Cooking utensils are not blackened by the biogas flame and are therefore easier to clean. The heat produced from a biogas burner is more controllable than a wood fire and certain foods cook more quickly.²⁵

The low smoke levels produced by the biogas flame may lessen health problems, but they also increase vermin and insect infestation of hut roofs. The smoke of the open hearth fire dries the thatch, prevents it rotting and keeps it pest-free. Perhaps roof re-thatching ought to be included as a

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PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
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cost item in the long term - in densely populated areas such as Arusha, thatching grass is a scarce commodity because of overgrazing of the surrounding plains.

As neither the Carleton-Dar-es-Salaam survey, nor the studies prior to it sought women's opinions on the socio-cultural issues related to biogas, it is impossible to guess whether rural women consider that the cooking and health benefits outweigh the roof infestations.

Other non-quantifiable benefits which could stimulate interest in biogas are improved social status, increased self-sufficiency, and access to training and education. As no full-scale study has been conducted to date, the importance of these parameters in biogas dissemination in Tanzania is not known.

Cultural taboos concerning the handling of dung do not appear to hinder the acceptance of biogas technology. Survey results from the Carleton-Dar-es-Salaam study indicate that villagers are quite willing to use animal waste. This confers with the findings of a Ministry of Health report in which 70% of village leaders and villagers interviewed recognized the importance of cattle manure, and were willing to use it as fertilizer.²⁶ The handling of the liquid slurry is more problematic. Biogas owners have found the sludge difficult to

transport in wheelbarrows or buckets. For optimum plant growth it is best applied seasonally to the roots. This presents storage problems as the slurry is produced continuously. These concerns need to be addressed. Perhaps Tanzania needs to establish village slurry depots where the liquid waste can be stored until needed.

The problems with sludge management in Africa highlight the efficiency of China's commune system, where the production teams not only assist in digester construction but in the systematic removal of slurry for communal plots. Without a similar organisational structure in the rural sector, Tanzania is not likely to emulate China's successful integration of biogas into the productive agricultural sector.

There are cultural and religious restrictions (Muslim in particular) on the handling of night soil in Tanzania. It is unlikely to be an acceptable feedstock in the near future. There are signs however that attitudes are changing. Fifty-nine percent of the fifty-five respondents in the Ministry of Health survey in the Dodoma area expressed a willingness to use human refuse as fertilizer.²⁷

Management Considerations

There are several plausible benefits to large-scale biogas investment which make it an attractive technology for governments to consider. It has the potential to reduce deforestation and soil erosion; to improve rural sanitation, to decrease dependence on chemical fertilizers, and to create linkages with domestic manufacturing firms to supply digester components.

Political considerations must be subordinate to economics: in order to secure widespread adoption of biogas technology, the Tanzanian government will have to provide subsidies and establish credit facilities, as noted earlier. The issue then is whether the funding might be better used in subsidizing another fuel alternative such as charcoal cookstoves. Cost-benefit analyses of biogas versus alternative fuels in several provinces would provide the framework for a government decision on nationwide investment. Certainly national strategies will have to take into account regional differences. It is encouraging that RERC have abandoned biogas in Dodoma and have concentrated on the diffusion of cookstoves. It is obvious even without a comprehensive cost-benefit analysis that biogas technology is an inappropriate choice for the Dodoma region.

Successful biogas diffusion must effective include management strategies - the burden of providing such an organizational structure for falls primarily on the government. There must be a central coordinating body overseeing biogas technology R & D, dissemination, and training of artisans. It need not control the operations of the various organizations involved in biogas work, but it must have a fairly intimate knowledge of the biogas projects underway in each district. It should also provide a forum for the exchange of ideas, designs, and strategies.

A national biogas office might also aid in establishing a successful institutional digester scheme. The failure of many of the original SIDO demonstration models has been blamed on technical faults. Most interviewees cited corrosion of gas pipes and steel domes, and cracks in the digester walls as the main causes of digester malfunction. In actual fact, the technical shortcomings merely hide the root of the problem; poor infrastructure and mismanagement. Corrosion and cracking are normal "wear and tear" phenomenon given the nature of the anaerobic process and the pressure of gas produced. The solution would be to develop a successful maintenance and repair system. The national biogas office could organise on site teams, similar to China's biogas doctors, to train biogas workers in digester management.

The confusion surrounding the ownership of and responsibility for the SIDO institutional digesters reflects the lack of political commitment to biogas at the local level. As noted in Chapter 5, district authorities did not allocate funds from the district budgets for digester maintenance or for wages of biogas attendants. It was easier and simpler for the institutions to use their fuelwood allotment than to struggle with a biogas digester. It is imperative therefore, that in the event of large-scale investment in biogas, there is a commitment to digester diffusion at all levels of government. Again, the promotion of biogas technology among government workers as well as villagers could fall under the jurisdiction of a national biogas organization.

Within each biogas agency there must be a similar commitment to managerial issues. A successful organization will offer an in situ extension service for trouble shooting, a locally available supply of spare parts, and a training scheme for potential owners. CAMARTEC has been the most effective agency in the country in providing these services.

In conclusion, the Carleton\Dar-es-Salaam study, despite its limitations, has confirmed that the problem is a multifaceted one and that technical shortcomings have played a minor role. There needs to be further research into the impact of biogas technology on the poor and on women.

Household fuel studies, and women's opinion surveys must be conducted to evaluate the socio-cultural parameters in potential biogas investment areas - Mwanza, Iringa, and Arusha in particular.

CAMARTEC has done the ground work in Arusha for the fore-mentioned studies. There is a sufficiently large number of digesters in the region already - the impact of biogas on the subsistence fuel sector could therefore be determined with careful analysis.

Biogas technology will be appropriate for rural development in Tanzania under the following provisos:

1. Low cost digester models are produced.
2. The poor receive subsidies.
3. It provides time-savings for rural women.
4. It does not decrease the incomes of the poor.
5. It is integrated into agricultural production.
6. It increases family incomes.
7. Biogas extension services, training schemes and spare parts are available locally.
8. There is a national commitment to biogas popularisation.

Until these conditions are met, biogas technology may be both inappropriate and undesirable.

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6. Chapter 6 deals more fully with the "unreliability factor".
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8. Ibid.
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Biogas Technology in Tanzania: A Feasibility Study

Appendix A.

Map of Tanzania

Appendix B.

Year	1967	1968	1969	1970	1971	1972
Tanzanian Shillings Per US Dollar - Conversion Factor	7.14	7.14	7.14	7.14	7.14	7.14

Year	1973	1974	1975	1976	1977	1978
Tanzanian Shillings Per US Dollar - Conversion Factor	7.02	7.37	8.38	8.29	7.71	8.22

Year	1979	1980	1981	1982	1983
Tanzanian Shillings Per US Dollar - Conversion Factor	8.22	8.20	8.28	9.28	11.14

Year	1984	1985	1986	1987
Tanzanian Shillings Per US Dollar - Conversion Factor	15.29	17.47	32.70	64.26

Appendix C.**Questionnaire For Biogas Field Survey.**

1. Location of biogas plant:.....
2. Date of installation:.....
3. Population served by digester:.....
4. Environmental conditions:.....
5. How have the local inhabitants been educated in biogas
technology?.....
6. Have any local inhabitants been trained to construct, operate,
maintain and repair biogas units?.....
7. Who collect the animal dung and from what distance?.....
8. Who manages and maintains the biogas plant?.....

Appendix C. (Continued)

9. List purposes for which biogas is used.....
10. Types of foods which are most frequently cooked using biogas technology:.....
11. What are the benefits of biogas?
12. Is the sludge from the BGP used as fertilizer?.....
13. Would you recommend the use of biogas technology in Tanzania?..
14. Who paid for the materials for the construction of the biogas unit?.....
15. What was the cost of each material?.....
16. What was the cost of constructing the gas holder tank?.....
17. Where were the major construction materials obtained?.....
18. Was there a government subsidy or credit advanced by the government or another agency?.....
19. Who provided the labour for the construction of the biogas plant?.....
20. Give the average recurrent costs for the biogas plant per month.....
21. Are the biogas and sludge sold to other people?.....
22. Describe the major problems with biogas implementation in your locality.....
23. What was the down-time during the last three years? What caused the stoppages?.....
24. What feedstock is used?.....
25. Mode of feeding the biogas unit.....
26. Waste feeding rate (kg/day).....
27. Water feeding rate (litres/day).....
28. Source of water.....
29. Mode of mixing.....
30. Monitoring frequency: temperature & pH.....
31. Quantity of gas (m^3 /day).....
32. Gas pressure.....
33. Quality of gas.....
34. Maintenance schedule.....
35. Are there written maintenance instructions for the biogas unit?
36. Give the technical information on digester design.....
37. Mention the operational problems encountered and briefly describe how these were solved.....
38. Have there been any health problems?.....
39. Have there been any pollution problems?.....

Appendix D. SITE VISITS: DOWN-TIMES AND OPERATIONAL DIFFICULTIES

LOCATION	DESIGN CAPACITY YEAR	PRESENT STATUS	DOWN-TIME	PROBLEMS
Baraa Village	CFD ₃ ; 1985 16m	OPERATIONAL	NIL	NIL
CAMARTEC-Tengeru	IGD ₃ ; 1975 10m	OPERATIONAL	3/4 MONTH	A
St. Constantine School	IGD ₃ ; 1985 16m	OPERATIONAL	NIL	C/H
Kimandolu Village	CFD; 1986	OPERATIONAL	NIL	NIL
Moivaro Village	CFD ₃ ; 1984 8m	OPERATIONAL	NIL	NIL
" "	CFD ₃ ; 1985 16m	OPERATIONAL	3 MONTHS	C/D
Hombolo Leprosy Centre	IGD ₃ ; 1983 20m	OPERATIONAL	NIL	F
Hombolo CCM College	IGD ₃ ; 1981 10m	NOT-WORKING	2 YEARS	A/B/H
Hombolo Bwawani Village	IGD ₃ ; 1980 6m	OPERATIONAL	NIL	C/E
Msanga Village	IGD ₃ ; 1981 8m	OPERATIONAL	IN THE DRY SEASON	H/I
Huruma Baptist Centre	IGD ₃ ; 1985 30m	OPERATIONAL	NIL	F
Ruaha Training College	IGD ₃ ; 1981 35m	OPERATIONAL	NIL	E
Kabila Health Centre	IGD ₃ ; 1980 8m	NOT WORKING	3 YEARS	B/D/F

Appendix D. (Continued)

Nassa Health Centre	IGD ₃ ; 1979 20m	NOT WORKING	4 YEARS	B/D/F
Magu District Hospital	IGD ₃ ; 1975 8m	NOT WORKING	3 YEARS	B/D/F/G
Misungwe Training Institute	CFD ₃ ; 1986 10m IGD ₃ ; 1975 10m	OPERATIONAL	3 MONTHS NIL	NIL
Kihesa	IDD ₃ ; 1985 2m	OPERATIONAL	NIL	NIL
Misasi Health Centre	IGD ₃ ; 1974 8m	NOT WORKING	4-5 MONTHS	B/G
Ngudu District Hospital	IGD ₃ ; 1975 8m	OPERATIONAL	5 YEARS	E/D/B

KEY: A = Corrosion of Digester Cover
 B = Clogging of Gas Pipes
 C = Clogging of Feeder Channels
 D = Leakage in Connecting Pipes
 E = Cracks in Digester Walls
 F = Difficulty in Obtaining Feedstock
 G = Lack of Spare Parts
 H = Management Problems
 I = Other Problems

CFD = Chinese Fixed Dome digester
 IGD = Indian Gobar Design digester

Appendix E. LIVESTOCK POPULATION IN TANZANIA; 1984.

REGION	CATTLE	SHEEP	GOATS
ARUSHA	1835880	758476	1231014
COAST	87542	4938	18682
DAR-ES-SALAAM	6158	1449	9324
DODOMA	1000184	169779	339648
IRINGA	480410	91633	197110
KAGERA	364795	53784	344262
KIGOMA	62319	36428	167348
KILIMANJARO	408457	221059	431757
LINDI	6217	8582	13205
MARA	969766	215558	394444
MBEYA	901077	101365	171486
MOROGORO	332683	53274	139948
MTWARA	15046	14519	84864
MWANZA	1357535	249943	570142
RUKWA	392234	21115	75319
RUVUMA	39010	19716	138435
SHINYANGA	1882081	486798	871826
SINGIDA	939821	280349	476532
TABORA	925904	174540	309836
TANGA	472909	116840	258284
MAINLAND TOTAL	12500028	3080147	6443666

Source: Ministry of Agriculture and Livestock Development, Dar-es-Salaam, 1987.

END

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FIN