THE POTENTIAL FOR
THE PRODUCTION OF ENERGY FROM BIOMASS
IN SOUTH AFRICA

A.T.Williams

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ABSTRACT

The so-called energy crises of the 1970s reawakened interest in the use of biomass as a source of energy. This study investigates the biomass resource base in South Africa, with a view to establishing the extent to which bioenergy could play a role in fulfilling the region's energy demands.

The present agricultural and silvicultural production levels are determined, using data supplied by various government bodies and research establishments. Various assumptions are made as to what proportions of these biomass resources could be diverted from their present end-uses into the production of energy. In order to make these assumptions on as realistic a basis as possible, in depth discussions were held with relevant members of the private and public sectors.

The state-of-the-art in biomass conversion technologies is reviewed, and as far as is possible, the process economics as applicable in the South African context are investigated. Some processes are necessarily covered in more detail than others, as these are locally at a more advanced stage of development, and thus have greater short-term importance in a regional context.

The present potential for bioenergy production is established to be of the order of 444 million Gigajoules per annum, equivalent to 12% of the 1984 primary energy consumption of South Africa. Of this amount just over 219 million Gigajoules per annum is consumed in the form of fuelwood, principally in the less-developed rural and peri-urban areas of the region. As fuelwood is virtually the sole source of energy for a large proportion of the population of the region, and as it is a resource that is fast being depleted in many areas, its development should receive the highest priority in the short-term. Failure to do so could result in dire environmental and social consequences.

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UNITS AND ABBREVIATIONS

Throughout this report SI units have been used except where specifically noted.

ha	hectare
J	Joule (hence kJ=10^3 J, MJ=10^6 J, GJ=10^9 J)
kg	kilogram
l	litre
m	metre
Pa	Pascal
t	ton (10^3 kg)
W	Watt
yr	year
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CV	Calorific value
IC	Internal combustion
OD	Oven dried
SI	Spark-ignition

CHAPTER ONE

INTRODUCTION

Biomass is defined as renewable organic matter produced by photosynthesis. This process produces an amount of stored energy which is almost ten times the world's annual use of energy. Biomass can take the form of trees, crops, aquatic plants and organic wastes of various kinds.

Biomass was humankind's first source of energy, and only relatively recently in history have fossil fuels begun to be used on a large scale, while it is only a matter of decades since nuclear energy was first used. Fossil and nuclear fuels are non-renewable, and will, one day, be exhausted. For this reason a fresh look is being taken at biomass and other renewable sources of energy.

Despite great technological advances, the overuse and undersupply of biomass for energy uses is currently a serious problem, because of the consequent deforestation and its accompanying, serious side-effects. Today 14% of the world's primary energy supply is derived from biomass, equivalent to 20 million bbl/d of oil. Nepal derives nearly 100% of its total energy from biomass sources, Malawi 94%, Kenya 75%, India 50%, China 33%, Brazil 25%, Egypt and Morocco 20% while a number of developed countries also derive a considerable amount from biomass, namely Finland 15%, Sweden 9%, USA 2% and the USSR, 3-4%. A number of studies have shown that about 5-10% of Europe's requirements could be met from this source by the end of the century. In South Africa, biomass provides about 6% of the primary energy supply, mainly in the rural areas.

As can been seen, biomass already contributes considerably to the energy needs of the world, and is likely to continue doing so for the foreseeable future. How much more biomass will contribute in the long term depends very much on the planning decisions made locally and internationally, for both energy and food.

Internationally, the food vs fuel question should rather be rephrased to ask how the world's already ample supply of food can be redistributed to meet the needs. Both food and energy are crucial limiting factors in development, and for stable development, should be available both locally and on a sustainable basis.

This study attempts to answer some questions on the potential for energy from biomass in South Africa. Very briefly, its structure is as follows:

Chapter Two is a review of international activity, looking briefly at those bioenergy programmes that are already in existence elsewhere.

Chapter Three assesses South Africa's biomass resource base, under the following categories:

Agriculture-related.
This looks at the present land use patterns and what work is being done to classify agricultural land.

Various energy crops are evaluated under the following broad categories: starches, sugars and vegetable oils. All forms of agricultural residues are quantified, their present uses (if any) are listed, and their potential as energy feedstocks is evaluated. This section includes livestock wastes.

Forestry-related.
Again the present land use patterns are analyzed, and the potential for forestry development investigated. Forestry operation and timber industry residues are quantified and evaluated in terms of their potential for use in energy production. A section on fuelwood use in underdeveloped areas is included.

Urban wastes.
The quantities and compositions of the solid and liquid wastes generated by urban areas are established. Their potential as energy sources is then evaluated.

Chapter Four takes a look at various biomass energy conversion technologies broken down into the following sections:

Direct Combustion
Thermochemical Processes (Including pyrolysis, gasification and carbonisation)
Biochemical Processes (Including anaerobic digestion, cellulose hydrolysis and fermentation)

Where possible, the economics of the various routes have been included in the relevant sections.

Chapter Five looks at the financial and energy costing of bioenergy in broad terms, outlining some of the principles that should be adhered to when doing costing exercises.

Chapter Six outlines briefly some of the social, environmental and economic impacts of bioenergy use.

Chapter Seven summarises the findings of the study and draws some conclusions. Based on these, recommendations are then made for future work in the field of bioenergy in South Africa.

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CHAPTER TWO

REVIEW OF INTERNATIONAL ACTIVITY

Renewed interest in the use of biomass as a source of energy was stimulated by the oil crises of the 1970s. The initial thrust of research and development was to find alternative supplies of liquid transport fuels. Thus, not surprisingly, the most successful bioenergy projects to date are in this field. Current worldwide government expenditure on biomass energy systems runs at over $2 billion/yr.

This review takes a brief look at some of the most significant and successful bioenergy programmes in the world excluding, for the moment the largest current use, namely fuelwood consumption in underdeveloped areas. To list the research work being done would be an almost impossible task. However, where relevant, this work has been included in the appropriate section in the body of the study.

2.1 ETHANOL

Brazil

The most impressive bioenergy programme in operation is undoubtedly the Brazilian Proalcool project. Brazil's total primary energy supply in 1982 reached 146 million toe, of which 35,7% was supplied by petroleum, hydro-electric power 28,1%, wood and charcoal 21,3% and sugarcane in the form of both bagasse and ethanol, 10,2%, with the balance being made up of coal and natural gas (Trindade, 1984).

The Proalcool programme produces some 20,6 million l/day of ethanol. A 20% blend of ethanol with petrol, requiring no engine modification and incurring no mileage penalty, has been adopted nationwide. Proalcool's future growth, however, is based on the use of neat ethanol in specially designed or modified Otto cycle engines. Already 1,3 million vehicles operate on neat ethanol, incurring a 25% mileage penalty when compared with conventional or blend-powered vehicles.

In spite of efforts to diversify feedstocks for ethanol-manufacture, sugarcane has remained the almost exclusive substrate. Sugarcane cultivation in Brazil dates back to the 1530s, and this country has always played an important role in the world sugar market, because of its low production costs and extensive potential for incremental output. The country now has a well-established distilling industry, capable of competing in international markets. For the harvest season of June 83-May 84, the expected ethanol production was 9 billion l. This was expected to substitute 33% of the petrol and naphtha demand, the equivalent of 38% of the automotive fuel market. Other outlets include the chemical industry, industry in general, and some 5% of the total output, for export.

The present development phase of the Proalcool project is aimed at a production target of 10,7 billion l/yr, which should be reached in harvest year 1985/86 in view of approved commitments for incremental distillation capacity. A target has been set to raise production to 16,6 billion l/yr by the mid-1990s. If accomplished, ethanol would then meet almost 60% of the combined petrol plus naphtha demand.

One of the biggest problems related to the Proalcool programme has been the disposal of the stillage or vinasse produced during distillation. The ratio of stillage to ethanol can be as high as 13:1. In the past this was disposed of by dumping in the wastercourses and rivers, but pollution levels resulting from this high BOD and COD effluent have become unacceptable. Current methods of disposal include stabilisation in lagoons, the recycling to the sugarcane fields as a liquid fertiliser, and in some cases, the production of biogas.

With the introduction of the Proalcool programme the sugarcane-planted area has grown. This has resulted in crop-switching in agriculturally-developed areas of Brazil e.g. Sao Paulo State. In other areas pasture lands have been turned over to cane. In spite of this, the total area under cane is projected to reach 3 million ha, which is only 6% of the 50 million ha under cultivation in the country, while Brazil's total land mass exceeds 850 million ha.

The unresolved issue of middle distillate (diesel) substitution could have a marked effect on the future of ethanol fuels in Brazil. Vegetable oils, in their natural or modified states are being investigated, but it is felt that they have limited prospects in the near future, due primarily to their high cost and limited availability. From the technical viewpoint, the modified oils have proved to be better diesel substitutes than the straight vegetable oils. However a problem is envisaged with the economic disposal of the large amounts of glycerine produced during trans-esterification of the oils.

USA

The USA, also driven by heavy dependence on foreign petroleum, embarked upon an ambitious alcohol fuel programme. In 1980 President Carter announced a goal of producing 9 billion l/yr of ethanol by 1985, and this was taken a step further by Congress which proclaimed a goal of 45 billion l/yr by 1990.

The US alcohol fuels industry has centred on maize-based ethanol, largely because of surplus maize production, and because of the very strong agricultural lobby. The industry is seen by the farmers as a way to increase the demand for maize, and a means of boosting its price. This policy of using bioenergy production as a means of dealing with crop surpluses is also being considered by the other International Energy Agency (IEA) countries (OECD, 1984).

Growing interest in the gasohol programme in the US has kindled lively debate over the relative efficiencies of small on-farm and large-scale central ethanol distilleries. Transporting sufficient feedstocks for large central distilleries is expensive, and such large operations are far more vulnerable to drought-induced shortages and high prices. Smaller on-farm plants could handle the initial fermenting and distilling, with the hydrous alcohol being sent on to a central drying distillery. At present the state subsidies in the US do not encourage this, and as a result some 95% of the fuel ethanol produced in 1980 came from six companies, while thousands of on-farm producers have received no federal subsidy for their efforts.

The growth of the US ethanol industry is seen by some as a real threat to the world grain and grain-fed meat markets. Although the dried distillers' grain by-product can be used as a cattle feed, the world market can absorb only so much of it. Economists predict that ethanol production above 18 billion l/yr will drive maize prices up (Deudney and Flavin, 1983). This could have drastic effects in those parts of the world that depend on the US for their staple maize supply.

Despite its popularity in the so-called corn-belt of the US, grain-based gasohol is unlikely to radically alter the US liquid fuels picture. This is based on the premise that the current US consumption of liquid fuels is too large to be put on a sustainable basis at all, and as a result drastic fuel conservation measures will have to be implemented. Long-term prospects for the Brazilian programme are considerably better since Brazil can produce more, but needs less liquid fuel than the US. Furthermore, Brazil has substantial quantities of uncultivated land, whereas the US does not.

Zimbabwe

The Triangle Ethanol plant, which is backed on to a sugar mill, saves the country about $10-12 million/yr in foreign exchange, by producing 40 million l of ethanol from sugarcane. This provides about 12% of the country's petrol. The plant was designed and its construction supervised by Jager & Associates, a consulting engineering company with offices in Durban.

The plant is run in various modes, depending on the prevailing economic situation. Thus secondary cane juice, and sometimes even primary juice is routed through the fermentation process, while all the molasses is generally fermented. Depending on the routing the yields being achieved are either 860 l plus 14,4 tonne sugar per ha, or 9 000 l/ha of ethanol. The yields of sugarcane are high, at about 120 tonne/ha/yr. The stillage from the fermentation is used as a fertiliser, and it is estimated that yields are increased by about 6% with this practice (pers comm Tongaat-Huletts).

It is important to note that the energy balance for Zimbabwean ethanol from sugar gives a net energy ratio (Energy Output/Energy Input) of 1,52 if all the major outputs are considered and 1,15 if ethanol alone is considered (Lewis, 1984). This is in contrast to the ratio of 2,41 obtained in Brazil ((Da Silva et al, 1978). The low ratio obtained in Zimbabwe is due firstly to the large energy input at the agricultural phase (nearly four times that of Brazil), mainly as a result of a large fertiliser input and year-round irrigation, and secondly to the large fossil-based fuel consumption in the agricultural phase.

Malawi

Malawi entered the fuel ethanol club in 1982 with the commissioning of the Dwangwa Distillery. Like the Triangle plant, this was designed and constructed under the supervision of Jager & Associates, at a cost of R6,5 million. The annual production capacity is 10 million l, with a distilling capacity of 60 000 l/day. The current petrol market of the country is in the region of 50 million l/yr, thus when running at full capacity, some 20% of the requirements are fulfilled by the distillery (pers comm Jager & Associates).

Kenya

There are two sugarcane based ethanol distilleries in operation in Kenya, both producing 60 000 l/day.

Other

There are several other countries with fuel ethanol production facilities, amongst them Argentina and the Philippines, while several are planning facilities, in particular, sugar-producing countries in the Caribbean.

2.2 BIOGAS

Very often organic wastes from plants, animals and humans are regarded as a nuisance. But such wastes contain enough energy to alter the energy picture in many rural areas, particularly those of the Third World. By using anaerobic fermentation in the form of a biogas digester, methane gas and a nitrogen-rich fertiliser can be produced, with improved sanitation as an added bonus.

China

China is the only country to have applied this technology widely, eight million digesters having been constructed thus far. Altogether these produced the energy equivalent of 22 million tonne of coal/yr when they were operating satisfactorily. However, many of the digesters developed leaks, and the lack of technical backup has resulted in them falling into disuse. A more coordinated effort is now being made to disseminate the technology, and train personnel to maintain the digesters. A research and training centre has been set up in Guangdong Province to plan and implement this project. This centre also provides training for biogas technologists from other countries. A target of 70 million digesters by 1985 was set by the central government, but it is doubtful whether this has been achieved.

India

The use of biogas digesters in India has a long, checkered history. Since the late 1940s, the Khadi Village Commission, a government group attempting to implement Gandhi's ideas on village industry, has helped install over 75 000 biogas generators. One of the problems with such digesters in India is that there are not as many pigs as in China - an important factor, since pig wastes are easier to collect than those of roaming cattle. In addition, the Indian digester has steel components, thus requiring more regular maintenance, and costing too much for the average Indian villager. Today only about half of the biogas digesters built in India are still operating.

Others

Opportunities for generating biogas from animal wastes in the industrialised nations are limited mainly to sewage treatment facilities and to large dairy farms and feedlots, where wastes are concentrated and pollution has been a problem. For example in the US, the Mason-Dixon Dairy Farm annually converts 2,7 million tonne of manure into $30 000 worth of gas. In the Philippines, Maya Farms, the biggest piggeries in Asia, derive all their energy from the methane generated using the waste of 15 000 pigs. Throughout the rest of the Third World various projects have begun, but none have yet reached the level of prominence of the Chinese or Indian programmes.

2.3 WOOD

Apart from the almost universal use of wood as a primary source of energy in the developing world, the rise in fuel prices has triggered a renaissance of wood use in the developed world, both in the industrial and domestic sectors.

Logically enough, the forest products industry has led industry's return to wood. In the North America and Western Europe energy-intensive pulp and paper plants are using their residues to generate their steam and electricity. Swedish studies have revealed that the industry in that country could become energy self-sufficient and sell excess cogenerated electricity.

Philippines

One of the most ambitious projects already underway to use wood on a large scale is the Philippines dendrothermal electricity generation programme. The project entails the construction of plants capable of generating 300 MW of power in remote parts of the country. To ensure an adequate supply of fuel, the National Electrification Administration is providing funds for groups of up to ten rural families to set up plantations of fast-growing leucaena - a strategy that hopefully will reverse deforestation and provide employment as well as a source of energy.

Brazil

Large plantations of eucalyptus have been planted specifically for the production of charcoal for use as a reducing agent in the iron smelting industry. Large bee-hive shaped kilns with a capacity of 50t are used to produce the charcoal.

2.4 URBAN WASTES

European countries and Japan have been the most active in the use of urban solid wastes as a source of energy. In 1977 only 6 of the 262 municipal waste-to-energy plants in operation were located outside of these two areas. Munich derives 11,8% of its electricity from refuse, while three plants in the Paris metropolitan area burn 1,7 million tonne of waste per year to produce the equivalent of 480 000 bbl of oil. Japan has more plants (85) and more installed capacity than any other country. Most of the plants in both Europe and Japan are run in a cogeneration mode, generating electricity and supplying steam for district heating systems.

The drawing of methane gas from controlled landfill refuse tips has also begun in various countries. The first such gas recovery system in Palos Verdes, California currently meets the energy needs of 3 500.

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CHAPTER THREE

SOUTHERN AFRICA'S BIOMASS RESOURCE BASE

3.1 AGRICULTURE-RELATED SOURCES OF BIOMASS

3.1.1 LAND USE PATTERNS

To quantify the land area available for the cultivation of bioenergy crops the physical suitability of the land must first be investigated. This can, however, only be done within a techno-economic context. Whether or not land can be used for energy farms depends very much on the system of production to be used. Different crops and cultivation systems imply corresponding differences in yields, land requirements, intensity of inputs and environmental impacts. Thus there are various types of energy farming that can be considered:

Intensive Agriculture
Silviculture, and
Marginal agriculture.

An intensive agricultural energy farm is operated according to conventional agricultural practices, the care of the crop being as mechanised and intensive as possible. This type of farming is only economically viable on high-quality land, the philosophy being that the yield should be as high as possible, as establishment and running costs are appreciable, thus requiring a rapid return on investment. The crops that could be produced by this means would be maize, sorghum, sugarcane, sunflowers, sugarbeet, cassava, etc, while trees can also be farmed on this basis, using quick-rotation forestry methods. Other crops that should also be considered in this context are woody grasses, such as fast-growing canes which are predominantly bagasse, and also weeds which have high biomass contents and are also fast-growing. Environmental impacts such as erosion and run-off will generally be higher for agricultural energy farms, unless carefully controlled, than for less intensive styles of farming.

A silvicultural energy farm or plantation represents a less intensive approach to energy farming, and per hectare yields and environmental impacts are generally correspondingly lower. However, the advantage of silviculture is that it is not restricted to prime agricultural land, as land that has sufficient rainfall and soil depth to support trees being all that is required.

Energy farms on marginal land would typically have less inputs than the above two types, but the yields would be correspondingly lower. Crops suitable for such farms would be those requiring lower water and nutrient inputs.

As can be seen the determination of the bioenergy potential of a country is not a simple one, and depends on the farming techniques to be employed, the land types in the country, the tolerable environmental impact, and the extent to which energy farms can be allowed to displace other forms of agricultural production.

The identification of suitable land for bioenergy production requires the collection of various data. Maps of those areas physically suitable for a particular type of farming can then be compiled using these data which would include parameters such as rainfall, temperature, altitude, soil type and depth, and topography. These maps are then combined to form a single composite map which should reveal areas physically suitable for the various types of farming. Such an exercise can become extremely complicated and the use of computers could greatly simplify the task.

At this stage such maps are available for only a small portion of South Africa, namely, areas of the Transvaal, and North Eastern Cape. The Soil and Irrigation Research Institute of the Dept of Agriculture is in the process of compiling detailed maps of the whole country, concentrating firstly on the most important agricultural regions. These maps will contain all the information mentioned in the previous paragraph, and in addition, information on the current land use patterns of the particular area.

The compilation of these maps into an atlas would be a useful tool for bioenergy planners and policy makers. A task of this magnitude is unfortunately beyond the scope of this study, which will try to point out the areas of Southern Africa that have potential for biomass energy production, based on currently available data. Once these have been identified, the more detailed analyses as outlined above could be carried out for these specific areas.

Present South African Land Use Patterns

South Africa, including the TBVC areas, covers about 122 million ha. The use of this land can be split up as follows (Dept of Agriculture, 1984):

Land Use	1000 ha	%
Cultivated land	13 964	11,4
Permanent crops	773	0,6
Artificial pasture	1 120	0,9
Natural pasture	82 089	67,1
Wood and forest land	1 633	1,3
Other land (yards etc)	3 064	2,6
TOTAL	102 643	83,9
Other uses: Urban areas, roads, Railways, nature reserves	19 468	16,1
TOTAL	122 111	100,0

The area covered by farms, broken down by province, according to the 1976 and 1978 Agricultural Censuses was as follows:

	Area in 1000 ha	
Province	1976	1978
Cape	55 418	55 235
Natal	4 022	4 221
Transvaal	14 737	14 221
OFS	11 542	11 770
TOTAL	85 719	85 447

The following table gives the areas under cultivation with various crops which are of interest from an energy viewpoint (Dept of Agriculture, 1984):

Crop	Season	Area 1000 ha
Maize	82/83	4 065
Grain sorghum	82/83	185
Soya bean	82/83	30
Sugarcane	82/83	405
Sunflower	82/83	275

Agricultural planning

Optimum land use has been the accepted policy of the Dept of Agriculture since 1970, and in order to fulfill this objective the following six steps were formulated as planning guidelines:

The demarcation of areas regarded as reasonably homogeneous in terms of agricultural resources.

The establishment of crop yield norms and production techniques.

The establishment of adapted branches of farming, i.e. adapted to existing conditions.

The development of persuasion programmes to encourage the implementation of these adapted branches of farming.

Measurement of the progress in the application of optimal land use.

Well-directed research to exploit the agricultural potential of areas to the optimum.

Some progress has been made, following these guidelines, in all of the agricultural regions of South Africa, the most significant being in the Highveld (Scheepers, 1984), Natal (Natal Region, 1981) and Eastern Cape (Eastern Cape Region, 1984) Regions of the Dept of Agriculture.

The basis of all South African agricultural planning is the demarcation of the reasonably homogeneous farming areas (RHFA's). These usually consist of one land type, and have a fair degree of uniformity with respect to agricultural use, production techniques and achievable yields. The basic characteristics taken into account in establishing land types are macro-climate, topography, geology, soil pattern, yield potential and vulnerability to wind and water erosion.

Inventories of the available natural resources and descriptions of the agricultural potential in the RHFA's have many possible applications, amongst them:

A projection of the production potential of agricultural areas

The identification of productive agricultural soils that should be used for agricultural purposes only

The comparative production potential of alternative branches of farming

Choosing crops to gain maximum advantage from specific resource combinations

The optimal allocation of the available funds, aid and manpower to stimulate optimum agricultural development

It is significant to note that very little work has been done in areas that could be termed as truly marginal for crop cultivation, e.g. the Karoo Region.

3.1.2 ENERGY CROPS

Solar radiation reaching the outside of the earth's atmosphere is estimated to be 1,35 kW/m^2. The solar beam is then subjected to attenuation and only about half of it reaches the earth's surface. A small portion of this is captured in the photosynthetic process of plants, which may be simply represented as follows:

$$CO_2 + H_2O + \text{light} = (CH_2O) + O_2 + e$$

where e is the energy stored in the photosynthate, and amounts to 468 kJ/mole. The photosynthate takes the form of a carbohydrate; starch, sugar or cellulose. The amount of energy stored annually by this means is about ten times as much as the world's total current use of energy, and about 200 times the world's current food energy consumption (Hall, 1979). On a land basis, the overall efficiency of photosynthetic conversion is about 0,3%. The average efficiency when agricultural techniques are implemented is probably around 0,5%.

The chemistry of photosynthesis is well understood, and is referred to as the C_3 pathway. More recently the C_4 pathway has been elucidated, showing plants that have a superior photosynthetic efficiency (Hatch and Slack, 1966). The maximum crop growth rate for C_4 plants has been determined as 50-54 gm/m^2/day, while that for C_3 plants is 34-39 gm/m^2/day (Monteith, 1978).

When choosing a crop for energy production three major factors should be considered, the yield per unit area, the economics of production, and probably the most important, the net energy ratio (NER):

$$\text{NER} = \frac{\text{Primary Energy Equivalents of all outputs}}{\text{Primary Energy Equivalents of all inputs}}$$

In addition the seasonal variations in production, suitable soil types and topography, the climatic conditions necessary and the relative value of the crop as a food should also be considered.

The energy balance

Net energy analysis is an attempted estimation of the primary energy expended in the extraction of energy from raw materials, and was at one time thought to be so important that the USA required by law that any new energy technology project include such an analysis. However such analyses have been used by opponents and proponents alike in renewable energy polemics, and it has become apparent that by the selection of a suitable energy accounting technique, a range of answers could be arrived at, some more favourable than others to one's chosen position.

In some instances the energy balance studies only consider the energy value of the fuel products in the energy balance, others take into account the energy output of some by-products, such as bagasse, while still others include the energy value of all the useful products; those of value as fuels, animal feeds and feedstocks to other fuel conversion technologies, such as anaerobic digestion. As regards energy inputs, most studies include direct and indirect agricultural energy inputs. Some such studies then relate these inputs to the energy output, to obtain the energy balance. Others include transport and processing energy inputs with the agricultural and relate these to the energy output. Yet another approach is to estimate only the liquid fuel inputs, direct and indirect, and then relate these to liquid fuel output of the process. This last approach has its areas of application, e.g. when trying to determine the degree to which the process is 'subsidised' by fossil-based fuels.

The above comments serve to highlight the care which must be taken when comparing net energy ratios quoted in the literature. The question of which inputs and credits have been included in the accounting procedure should always be asked. The method of expressing the final answer should also be treated with caution, since by using the product fuel to power the process a high net energy return can be achieved.

To sum up by stating the obvious, the higher the energy costs in preparing renewable fuels, the smaller their potential contribution to energy supplies.

3.1.2.1 Starches

Maize

This is a crop that has been grown for centuries, mainly as a source of food, and more recently as a cattle feed. Advantages are that it grows in areas in which other energy crops such as sugarcane and sweet sorghum do not, and the grain can be stored for long periods allowing a longer processing season. The use of the stover as a separate product might present problems, which will be expanded on in the section on crop residues.

In South Africa maize is grown principally in the Highveld Region, where the average annual rainfall varies from 350-750mm. It is a crop subject to moisture stress, and thus performs poorly on soils with a heavy texture or poor drainage. Under the best possible conditions with good soils and high rainfall, yields of 6,5 t/ha/yr should be achievable (Crafford and Nott, 1981). In reality the highest yields obtained are around 5 t/ha/yr, while the national average for 1981, the best in the last 30 years, was 3,4 t/ha/yr.

Production figures for the period 1975 to 1983 are (Dept of Agriculture, 1984):

Year	Area 10^3 ha	Production 10^3 t	Consumption 10^3 t	Export 10^3 t
75/76	4 548	7 472	5 777	3 759
76/77	4 453	9 714	5 999	2 087
77/78	4 499	10 056	5 928	3 170
78/79	4 305	8 332	5 695	3 843
79/80	4 322	10 762	6 050	3 141
80/81	4 339	14 656	5 957	4 414
81/82	4 278	8 358	6 279	5 924
82/83	4 065	3 915	6 657	5 096

The discrepancy between the production, and the consumption and export figures over the last two seasons, is the result of the drought. Maize stockpiled from previous good years was used to make up the deficit, and importation was begun in May 1983, after the end of the 82/83 period shown above. The total quantity imported from then until 31st April 1984 amounted to 2,39 million tons (pers comm Maize Board).

The breakdown by province of production in 10^3 t is as follows:

Province	80/82	81/82	82/83
Cape	814	303	134
Natal	667	443	260
OFS	5 015	2 766	1 309
Transvaal	7 927	4 749	2 133

The area of South Africa under maize peaked at 4,7 million ha in 1967/68, but has fluctuated for the last 20 years between 4,2 million and 4,6 million ha, with the area currently under maize running at just over 4 million ha (Dept of Agriculture, 1984). Production has varied from 7 million to 10 million t/yr, and reached a maximum of 14,6 million t in 1981. The drought of the last few years has, however, hit the maize farming areas hard, and the 1983 crop was only 3,9 million t, while the estimate for the 1984 crop in June 1984 was 4,4 million t. These crop failures have resulted in maize having to be imported, a totally undesirable situation were the country at some future time to be dependent on maize as a source of energy.

The consumption of maize within South Africa over the last ten years has been between 5,2 million and 6,6 million t, with the human:animal consumption ratio very close to 1:1. Export tonnages have fluctuated between 2 million and 5,9 million t over the last ten years, the majority of this going to neighbouring states. It can be seen from this that maize exports are of some political importance, in the Southern African arena.

Rationalisation of the maize producing industry is currently taking place, and it is understood that a quota system for farmers is to be introduced. The purpose behind this is the stabilisation of maize production, by forcing those farmers currently using marginal land for maize cultivation to abandon this practice. In this this land should be released for the cultivation of crops more suited to these areas, e.g. hardier crops such as sunflowers, soya beans and grain sorghum.

There is much debate concerning the net energy analysis of maize. It has been stated that when both the farming operation and the fermentation process are considered, for every three litres of grain alcohol produced, at least one is new energy (Scheller, 1977). In contrast it has been reported that 2,2 GJ are required agriculturally to produce one metric ton of dry maize biomass, and that the NER for grain spirit is only 0,74 even when the stover is used as fuel in the ethanol production process (Thompson, 1979).

An energy balance determined under South African conditions gives the energy input to the agricultural and ethanol production process as 21,4 GJ/t of maize grain, while the energy output in terms of ethanol and cellulosics is 23 GJ/t maize. This gives an NER of 1,077, which is increased to 1,29 when the energy content of the dried distiller's grain by-product, which can be used as a cattle feed is included . When the liquid fuels balance is considered the process appears very positive, with only 25 l diesel equivalent being required per ton of maize produced, while the output is 400 l diesel equivalent/t maize (Robinson, 1979). This last figure may be optimistic, nonetheless, the liquid fuel production is definitely on the credit side.

In 1979 Sentrachem looked at the feasibility of producing ethanol from grain in South Africa and estimated the cost of production from maize to be 39,4c/l (1981) (see Appendix 1). Escalating to 1984 prices, with maize at R187/t, this cost would be 56,7c/l.

Given the uncertain nature of maize production, and in particular its vulnerability to drought conditions, it is difficult to make any estimate for its potential as a feedstock for fuel production. However, considering at the export figures for the past few years, it would appear reasonable to divert 3 million t/yr from this into ethanol production, yielding a total of 1,14 billion l/yr.

The implications of diverting this maize are mainly of a political nature, and rather beyond the scope of this study. However, of particular importance would be the effects on South Africa's relations with its neighbours, and the fact that in times of drought, the ethanol production could become dependent on imports. The latter is the more important from an energy analyst's viewpoint, considering that one of the prime reasons for moving to a biomass-based energy resource being the desire to break this very dependence on foreign suppliers.

Grain sorghum

This is a crop that has a high grain yield potential, higher even than maize under certain conditions. It is able to grow in relatively hostile conditions, being more drought-resistant than maize, and also more adaptable to different soil conditions. In this respect it is a crop that would perform better in the areas now under maize but which are regarded as only marginal for that crop.

The following are the production figures for the period 1975 to 1983 (Dept of Agriculture, 1984):

Year	Area 10^3 ha	Production 10^3 t	Consumption 10^3 t	Export 10^3 t
75/76	213	307	284	189
76/77	227	415	244	-
77/78	259	614	260	59
78/79	208	377	231	299
79/80	243	695	193	155
80/81	193	545	322	230
81/82	170	270	378	-
82/83	185	195	254	37

The area under grain sorghum has varied quite widely over the last 20 years, between 170 000 and 640 000 ha, the majority of the time being around 200 000 to 250 000 ha. Production has as a result also been widely variable, ranging between 195 000 and 728 000 t. Almost 80% of the crop is produced in the Highveld region.

The wide fluctuations in production can largely be attributed to the fact that grain sorghum is regarded as a catch crop in South Africa, and as such is grown on land that is marginal, and therefore not suitable for maize production. In addition, in years in which conditions are not regarded as ideal for maize, sorghum is planted at the stage when it is too late to sow a maize crop.

If land suitable for maize production were to be turned over to grain sorghum, much higher yields per hectare could be achieved, and as a result higher ethanol yields per ha would also be achieved (Kruger and Cilliers, 1981). Internationally yields of 2-5 t/ha/yr are achieved (OECD, 1984), whereas the best South African national average has been 2,8 t/ha/yr, but in good areas yields of 3,5 t/ha/yr have been achieved (Crafford and Nott, 1981).

Birds have always presented a problem in the cultivation of sorghum, as they feed on the grain and reduce the yield. Research has led to the development of bird-resistant types, which have boosted the yields obtainable.

Another problem, in particular with respect to its fermentation to ethanol, is the presence of polyphenolic compounds in the grain. It is necessary to remove these prior to starch hydrolysis and subsequent fermentation. Research is being done by the Dept of Microbiology at the University of the Orange Free State on the production of ethanol from grain sorghum, and data collected thus far indicates that about 380 l ethanol/t of grain can be produced (du Preez et al, in print).

Sentrachem, when considering sources of starch for fuel ethanol production, looked mainly at grain sorghum for reasons of its hardier nature. They estimated that the cost of ethanol from a plant producing 187,5 million l/yr and costing R80 million at 1981 prices was 30c/l (see Appendix 1). Assuming a 60% increase over the period 1979-84, based on manufacturing price indices supplied by the South African Central Statistical Services, and a higher price for sorghum (R152/t), this price is now around 47c/l. This plant alone would consume close to 490 000 t of sorghum/yr, requiring 175 000 ha at present production levels, but this could be reduced to 98 000 ha under improved farming conditions.

If grain sorghum is to be considered as an ethanol fermentation feedstock, it would be essential to stabilise its production and establish recognised areas for its cultivation.

Cassava

Cassava, also known as manioc, mandioca, manihot, yuca and tapioca, is a tuberous crop not generally known in South Africa. Traditionally it is a subsistence crop grown in the tropics and is of value because of its drought tolerance and ability to grow in poor soils. It produces more carbohydrate/ha/yr than any other non-irrigated tropical crop, and in addition the leaves are very rich in protein, making them suitable for animal feed.

Cassava can be grown between the 30° parallels of latitude and up to an altitude of 2000m. Mean winter monthly temperatures should not be less than 13°C, while summer optimum temperatures should be above 22°C. The crop is planted in the period from September to February, and remains in the ground for 18-24 months, but deteriorates rapidly after harvesting. About 1000mm of rainfall should be well distributed through the growing season and soils should be light textured with the land fairly level. The soils must be well drained however, as the crop is very sensitive to waterlogging.

Present yields in Brazil, the world's largest producer, are in the region of 15 t/ha/yr, but this is expected to increase to 25 t/ha/yr (Stumpf, 1978). In Australia harvested experimental crops have yielded between 31 and 62 t/ha/yr.

Cassava growing trials were first carried out in South Africa in the late 1940s, by a Dr T.C.Lloyd. However, the economics were unfavourable at that stage, and no further development was considered. In 1974, a study by the Anglo American Corporation's food and agricultural division indicated the strong likelihood that by the turn of the century a shortage of basic energy (for the human body) foods would be a far greater threat than would lack of protein. The study also revealed that further research on the other more established energy crops, e.g. maize, sorghum etc, would bring diminishing returns, i.e. would not result in significantly higher yields per unit. For this reason a relatively unknown plant was needed, one with genetic potential which could be exploited to make an effective contribution to the production of energy foods. So, in 1974, the Anglo American Corporation Cassava Project was established to look at the potential of the plant as a major staple crop under sub-tropical conditions. It has also been looked at as a source of starch for certain specialised industrial applications, especially since the project has been taken over by African Products of the Tongaat-Hulett Group.

It has been established that cassava can be cultivated successfully in South Africa where the annual average temperature exceeds 20°C. In general terms this restricts cultivation to areas in the eastern part of the country, no further south than latitude 31°S, and at an altitude no higher than 800m (Daphne, 1980). Efforts are currently being concentrated in Northern Natal and Kwazulu, the area with the greatest immediate potential. Although problems are being experienced with mosaic virus, researchers are confident that these will be overcome. Natal and Transvaal together contain two million ha of arable land below 800 m, and an annual rainfall of 750mm. Of this 600 000 ha are already planted to other crops. Allowing a loss of a further 400 000 ha to grazing and settlements, one million ha remains available for the cultivation of cassava.

Cassava has already attracted great attention as a substrate for the production of ethanol, especially in Brazil and Australia. In Brazil's drive to produce ethanol, cassava is seen as complementary to sugarcane, the cassava being cultivated in areas with acid, infertile soils and the cane in more amenable environments.

In Brazil, where the first cassava-based distillery began operations in 1978, it has been reported that a crop of 50 t/ha should yield, 168 l of ethanol/t of tubers containing 30% fermentable solids. Actual production achieved in Brazil is 2700-4500 l ethanol/ha/yr, and the long-term prospects for a cassava-based ethanol industry are not good (pers comm D.O. Hall).

The technology for ethanol production from cassava is more complicated than for other substrates, the process requiring greater fixed investment than that for sugar derived ethanol. The process also requires a greater energy input, the total energy input for ethanol production from cassava is 3,93 GJ/m^3 of ethanol in comparison to 2,76 GJ/m^3 from sugarcane. NER values as wide ranging as 0,44-3,56 have been reported

(Sheehan et al, 1978). It is important to note that an NER of less than, 1,0 will result unless the above-ground parts of the crop are used effectively as an additional source of energy. The mass of the fresh tops of the cassava plant is about 60% of that of the tubers. The tops can also be macerated and mixed with the stillage to produce a high roughage and protein animal fodder.

At a conservative estimate, if all of the one million ha suitable for cassava cultivation were to be developed, and the cassava used for ethanol production, with a biomass yield of 20 t/ha/yr and ethanol yield of 170 l/t, 3,4 billion l/yr of ethanol could be produced.

3.1.2.2 Sugars

Sugarcane

Sugar is essentially a food crop, but in general escapes the conflicts that would normally arise from its diversion to energy production, unlike other food crops such as maize. The sugar industry is well established in this country, being the twelfth largest producer in the world, and enjoys a good reputation internationally for its product.

In South Africa cane yields of 9 t/ha/100mm rainfall are sometimes attained under good management, although the industrial average is closer to 6 t. The rainfall in the cane growing areas varies about a mean of 900mm/yr. The national average yields were high during the 70s, at the 90 t/ha mark, but have recently fallen to around 73 t/ha. This is partly attributable to the weather and partly to a pest known as eldana borer that has been plaguing the industry in recent years. There are at present just over 400 000 ha under cane about 65% of which is harvested for milling every year, yielding about 19 million t of cane (Morgan, 1983).

The following are the figures for cane and sugar production for the last ten years (Morgan, 1983):

	Area 10^3 ha		Sugar in 10^3 t	
Year	Under cane	Harvested	Production	Export
73/74	322,8	180,7	981,5	750,0
74/75	337,8	187,4	1 099,8	783,4
75/76	340,8	186,6	1 115,5	685,6
76/77	341,9	201,4	1 159,2	882,3
77/78	357,4	217,1	1 085,4	998,5
78/79	362,4	212,1	1 035,0	1 047,5
79/80	370,6	218,1	1 081,7	997,1
80/81	383,7	212,6	1 174,4	436,5
81/82	392,6	257,6	1 213,3	842,2
82/83	405,2	266,1	1 181,4	944,6

Discrepancies may be evident between production and export figures in any one year e.g. 78/79. This is due to the fact that sugar is stockpiled, and then released on the world sugar market when prices are more favourable.

The principal sugarcane growing areas are the Natal coastlands and the Eastern Transvaal Lowveld. There is also room for expansion of the latter region, around Komatipoort and Hoedspruit. Other areas with expansion potential include the Makatini Flats, Pongola/Mkuze and the KwaZulu dryland areas.

Based on various estimates made by officials of the SA Sugar Industry, a total of about 270 000 ha are available for expansion of the industry (Ortmann, 1985). This figure is based on the assumption that the present uses of this land are of a less strategic nature. The current uses include grassland, vegetables, fruit cotton, dry beans and timber.

In Australia, estimates of ethanol yield from their high quality canes run at around 90 l/t of cane, fermenting all the sugar present (Bull and Batstone, 1978), while the Brazilians have achieved yields of 70 l/t (Stumpf, 1978). Based on these, on dryland farms a commercial yield of 4000 l/ha/yr could reasonably be expected, while irrigated farms could produce 7000 l/ha/yr (Ardington, 1979).

The NER for cane is always above unity when the bagasse is used as fuel in the fermentation and distillation process. Assuming an ethanol yield of 70 l/t the following data are obtained (Thompson, 1979):

Type of Farm	Input, MJ/t cane	NER
Rainfed farms	558	2,7
Irrigated farms	808	1,9
All farms	595	2,5

Experimental programmes and management techniques in the South African sugar industry have always been aimed at maximizing the yield of sucrose/ha and more specifically, the maximizing of estimated recoverable crystal (ERC). If ethanol production is introduced it may become more important to maximise the production of biomass/ha and the proportions of cellulose, lignin and pentoses in the cane fibre. This will depend on how the technology for the production of ethanol from cellulose progresses. For the immediate future, however, it is likely that the total fermentable sugars in the harvestable stalks per hectare will be the important criterion as far as ethanol production is concerned.

Total fermentable sugars may be affected by the choice of variety and the crop management but the maximisation method will differ depending on whether the ethanol is to be produced by a distillery backing on to an existing sugar mill, or a mill and distillery dedicated to ethanol production. For the former, crystallisable sugars will still be the priority, while for the latter, fermentables will be of importance. In all cases the determining factor will naturally be the marketability of the final product.

In terms of future research the sugarcane species being cultivated purely for energy production purposes in certain areas of the world e.g. Jamaica, should be considered for local cultivation. These so-called energy canes yield something of the order of 95 dry tons/ha/yr, containing three times the bagasse of normal sugarcane, and 25% less crystallisable sugar (pers comm D.O. Hall).

In terms of crop management, although an optimum harvest season can be defined by yield and quality criteria, the season is invariably extended to satisfy economic rather than agronomic considerations. In the summer months, poor quality gives rise to low sucrose yields in mature cane, but the reducing or invert sugar content is high during this period. Thus, although the ERC is low, the fermentables are not nearly as badly depressed, and it would be feasible to begin harvesting up to two months earlier, if the cane were to be used purely for ethanol production. This would have the added bonus of improving the utilisation factor of the milling plant by extending the season. Another change that could be made would be to leave the tops on the cane, as this portion is also high in invert sugars. These changes can basically be summed up as optimisation of fermentable as opposed to the optimisation of crystallisable sugars, the current practice.

The practice in South Africa has been to use moderate amounts of nitrogen fertiliser for sugarcane, and not to apply it late in the life of the crop for fear of suppressing sucrose content and reducing cane quality (Thompson, 1979). These restraints might not apply to the same extent if ethanol were the end product. However with ethanol production, the overall energy balance, rather than the economics would probably be the constraining factor when considering fertiliser application.

With regard to the development of new varieties of sugarcane lead times, using conventional breeding methods, are in the region of 12-14 years. With the advances that are being made in the fields of genetic engineering and tissue culture this process could, in the foreseeable future, be substantially speeded up.

The state of the South African sugar industry

The South African sugar industry has been experiencing one of the leanest periods in its history, the 1983/84 crop was 38% down on the previous year's, and the lowest since 1965. The local prices for sugar are not giving the producers their expected 14% return on historical capital, while world prices are extremely low. The major reason for this being an oversupply of some 40% that exists in the world market at the moment. Despite the fact that South Africa is the third lowest-cost producer in the world, the local industry's export prices have been higher than the cost of production in only four of the last 10 years, and only one of the last five.

The South African industry stopped pinning its hopes on the export market some years ago, but because of the high quality of the local product and reliability of supply, South Africa's sugar is sought after by certain international buyers. In addition to the problems on the international market, the domestic market prospects look less bright for the future. The market is already well-developed and growth in consumption is expected to slow in the future.

An interesting feature of the local market is that 70% is purchased directly by the consumer, while in the US, by contrast, 70% is purchased by industry for use in soft drinks, confectioneries etc. The local market represents about 58% of the total production, and this percentage is growing.

These two features are pleasing to the producers for the following reasons. As usage swings away from direct consumption, so the substitution of sugar by corn syrup and other sweeteners increases. This is partly due to the greater convenience in handling of these substitutes, and partly because of the international swing away from sugar as a sweetener, for health reasons. As local prices are controlled by the government, in consultation with the sugar industry, there is greater stability, thus making the industry less vulnerable than on the international market.

As of 31st December 1984, the International Sugar Agreement ceased to exist, and the international market is open to all comers. Because of the depressed world market South Africa is at present stockpiling as much as possible, while still meeting certain long-standing commitments. These amount to about 700 000 t/yr, 360 000 t of which is for Japan, while the balance is exported to the US, Canada and Korea. It is expected that these contracts, although renegotiated on an annual basis, should remain unchanged for the foreseeable future (pers comm SA Sugar Association).

Two structural changes to the sugar industry, now being implemented, should have important effects on the future shape of the industry. Firstly, the responsibility for the cost of cane haulage has been transferred from the millers to the growers, a change recommended by the Rorich Commission of Inquiry. The intention of the Commission was to reduce the industry's output by some 5-10% by exposing "long-distance" growers to increased costs, thus forcing them to change to other crops. In addition it is hoped that the average distance from canefield to mill will be reduced over some years, thereby reducing the transport cost component, which presently amount to about 10% of total costs.

The second change, to be implemented in the 1985/86 season, is the introduction of a dual-pool system of sugar pricing. At the moment producers are paid a weighted average of the local and export price. The aim of the new system is to confront millers and growers with the real conditions of the market in which their product is sold. With the two pools, an "A" pool of about 1,85 million t consisting of local market sales with approximately 0,5 million t of export sugar, which may have to be underwritten when world prices are depressed, and a "B" pool comprising the balance of about 0,5 million t, for which producers would receive a price based on the export proceeds of the previous five years. The overall effect should be to discourage the production of marginal sugar at high cost. This will result in a smaller, but more viable industry with only the low-cost producers continuing to produce to the full.

The introduction of an ethanol-from-sugar industry would help in the rationalisation of the industry's production, by giving millers the flexibility to produce according to the most favourable market. A very close watch is being kept on the economics of ethanol-from-sugar by people representing all sections of the industry, in particular officials of the Sugar Association, Cane Growers' Association and the Millers' Association. According to various people consulted, the economics are beginning to look favourable, in particular because of the weakening in the value of the Rand, and the resulting increase in petroleum import costs. More details on the economics are included in the section on ethanol fermentation, in Chapter Four.

The potential for ethanol production from sugar

A recent in-depth study has been carried out, and considers the interactions of factors such as the demand for other crops, the structure of the sugar market, socio-economic impacts and government intervention through subsidisation of ethanol production (Ortmann, 1985). According to this study ethanol could only be produced under the present dual pool market system if the pump price were subsidised by the government. Such a subsidy could either take the form of a fixed payment per unit of output or a deficiency of payment in which the government makes up the difference between the guaranteed price and the average market price. These supports would therefore come at some cost to society, which could arguably be offset by the advantages of using ethanol as a fuel e.g. the reduction in the lead content of petrol, less noxious emissions, decentralised fuel production etc.

Various scenarios have been investigated with respect to future developments in the sugar industry. These include the previously mentioned dual-pool scheme, and free edible sugar market. The latter refers to a market in which all quotas are abolished and an ethanol market is introduced, with the price supported at a certain level. With the introduction of the dual-pool scheme, cane growing area is predicted to fall by 27%, while if a free sugar market were to be introduced the total area would drop by 49% from current levels and by 30% relative to the dual-pool scheme (Ortmann, 1985). With the introduction of ethanol production amounting to 1 billion l/yr, the cane area under the dual-pool and free edible sugar market schemes would rise by 39% and 19% respectively, relative to the area under the single market scheme.

There is a strong positive correlation between sugarcane production and employment. The addition of an ethanol industry to the dual-pool scheme has been shown to increase employment by 34% (45 000 jobs) from current levels. Under the free edible sugar scheme and supported ethanol production employment would increase by 19% relative to current policy figures. In addition the development costs per worker in the ethanol fermentation industry are R20 000 - R35 000 as compared with over R1 million per SASOL workplace.

Looking simply at the potential land area available for expansion the ethanol production potential could be calculated as follows. Assuming conservative yields of 50 t cane/ha and 1 t sugar/10 t cane, the potential extra 270 000 ha could produce at least 1,08 billion l/yr of ethanol, based on a dryland farming yield of 4000 l/ha/yr. In addition, given current export commitments, and the quantity that is usually produced in excess of local demand, 200 000 t/yr could reasonably be diverted to ethanol production. At an ethanol yield of 580 l/t, this would give another 116 million l/yr of ethanol. Thus a total of 1,17 billion l/yr could be produced.

Sugar beet

This is considered to be a crop most suited to the temperate climates in latitudes ranging from 40° to 45°. In practice however it is grown successfully under a much wider range of climates, to the extent that it is now found in countries south of the 35° parallel in the northern hemisphere.

Average yields in Europe are 45 t/ha (6,3 t sucrose/ha). It has been experimented with under South African conditions and found to yield 7-15 t sucrose/ha in Natal in the Highland Sourveld and the Mistbelt (Inman-Barber, 1977). It must be remembered that these yields were obtained under test conditions, and would not necessarily be achieved in the field. They are nonetheless high by world standards. The world's highest average yield achieved in Greece, in the 1976/77 season was 9,9 t sucrose/ha under irrigation.

There is little doubt that sugar beet would require more attention than many crops grown on a large scale in South Africa. However it could be grown in the Highland Sourveld, where the incidence of disease would be lower, and hence the level of care as well.

The biggest drawback of sugar beet as an ethanol feedstock is that it lacks fibrous residue to provide the heat energy for its processing. For this reason it is not being considered for energy production in the USA where it has been estimated to have a NER of 0,56. This was calculated excluding the energy value of the tops left in the field (Sheehan et al, 1978).

Sweet sorghum

The sugar variety of sorghum has only recently begun to be studied, therefore not much data is available. This is despite the fact that the syrup variety has been grown in the USA for more than a century, mainly for the production of sweet table syrups. It was only during World War II that interest in this crop as a sugar source was aroused.

Sweet sorghum stalks remain in the millable state for too short a time to justify a mill for this crop alone. It has an application, however, as an off-season supply for the sugar mills. It was with this in mind that growth trials were started at Greytown, Natal in 1977 (Thompson, 1979). The yields of six imported varieties after 130 days varied from 25-62 t/ha with sucrose contents of 3,5-7,3%. Being a fibrous crop it provides the fuel requirements for processing the extracted juice and the NER has been estimated to exceed unity. It reputedly requires less rainfall and nutrients than sugarcane, but can only be harvested over a relatively short period. It would therefore have to be integrated into a programme incorporating other crops if it were to be considered for ethanol production.

Assuming that all the area in Natal presently under maize and grain sorghum could be turned over to sweet sorghum, this would amount to 190 000 ha (Natal Region, 1981). If a yield of 30 t/ha could be achieved, at sucrose levels of 5,5%, at an ethanol yield of 580 l/t this would yield 182 million l/yr of ethanol. These figures are of course hypothetical, and the realisation of this production figure would be dependent on a host of factors.

Jerusalem artichoke

This tuberous plant, native to eastern North America, has the botanical name Helianthus tuberosus L., indicating that the above ground plant resembles the sunflower, while the root portion is something like a potato. It is a strong plant able to withstand adverse conditions, especially with respect to cold, drought conditions, and relatively poor soils. This makes it a good crop for cultivation on marginal lands.

The tuber is rich in the polymer, inulin, which can be subjected to acid or enzymatic hydrolysis to yield fructose. Experiments in France and the US have produced about 85 l ethanol/ t of tubers, which with yields of around 40 t/ha gives an ethanol yield of 3 400 l/ha (OECD, 1984). In addition, the production of 7-8 t/ha of dried tops could contribute to the energy self-sufficiency of the process. Nothing is known about its suitability for cultivation in South Africa.

3.1.2.3 Vegetable oils

Vegetable oils can be used on their own or blended with diesel oil as a diesel engine fuel. South Africa has recently been at the forefront of developments in this field, the most significant work has done by the Division of Agricultural Engineering of the Dept of Agriculture. This was prompted mainly by the increasingly acute problem of the petrol-diesel consumption imbalance, and the fact that the agricultural sector would be among the hardest hit were a diesel shortage to arise.

Since a diesel-cycle engine was first demonstrated running on peanut oil at the Paris Exposition in 1900, over 40 different plant-derived oils have been evaluated in short-term diesel engine tests. However long-term tests were not successful in unmodified direct-injection diesel engines. Tests on indirect-injection engines, however, gave good results, with little evidence of injector coking or abnormal wear.

Because of the experience already gained with the cultivation of sunflowers in South Africa, this has been the oil used in the tests carried out in this country. The calorific value of sunflower oil is about 14% lower by mass than diesel, however, because its density is 8,8% higher, its calorific value per litre is only 6,5% lower than diesel. Its cetane number compares very favourably, but its kinematic viscosity at low temperatures is significantly higher than that of diesel.

Trans-esterification of sunflower oil with alcohol changes both its physical and chemical properties to something closer to diesel. The most significant change being a viscosity reduction. Promising results were obtained using ester fuels produced with various catalysts (sulphuric acid, para-toluene sulphonic acid, sodium hydroxide and others), and showed that injector coking problems can be solved, but that the catalysts can result in corrosion of the injection system (Bruwer et al, 1981).

Engineers at the Division of Agricultural Engineering at Silverton are working on the development of a small-scale esterification plant. The intention being to develop a plant cheap enough and simple enough for a farmer to construct and operate on his farm, and produce his own fuel.

The potential for sunflower seed cultivation in South Africa is estimated to be 1,3 million ha, the oil content of the seeds varying between 20 and 60%, yielding between 200 and 1 000 l/ha, and requiring approximately 60 l of the sunflower oil to produce 600 l i.e. a 1000% return (Bruwer et al, 1981). These figures make sunflower oil an attractive proposition.

A comprehensive survey of the potential for and economics of sunflower-derived fuel in South Africa has been carried out by various government departments, in particular the Dept of Agriculture and the Dept of Mineral and Energy Affairs. The results are being kept confidential.

The present production levels of sunflower seed are (Dept of Agriculture, 1984):

Year	Area 10^3 ha	Production 10^3 t	Consumption 10^3 t	Export 10^3 t
75/76	288	271	215	-
76/77	389	481	258	0,78
77/78	449	452	426	44,00
78/79	306	313	334	13,00
79/80	288	330	312	0,15
80/81	320	518	328	0,77
81/82	261	256	351	95,00
82/83	275	207	-	-

The figures for soya bean production over the same period were (Dept of Agriculture, 1984):

Year	Area 10^3 ha	Production 10^3 t	Consumption 10^3 t	Export 10^3 t
75/76	22	17,9	-	-
76/77	25	29,7	15,9	1,0
77/78	25	40,1	16,9	10,7
78/79	26	26,4	29,2	1,0
79/80	28	39,9	23,3	0,5
80/81	22	25,7	45,0	0,5
81/82	22	21,3	18,0	-
82/83	30	23,0	-	-

The bulk of both of these oilseeds are presently being expressed to produce vegetable oils for human consumption. The seedcake and other residues are used as cattle fodder.

There are important and attractive benefits to be derived from a plant oil fuel industry. These are among others (Bruwer et al, 1981):

National and individual farm production of most plant oils could rapidly be increased if a demand developed, requiring only one growing season's lead time.

Most plant oil crops require the same agricultural techniques as those applied to maize.

One hectare of a good plant oil crop can yield sufficient fuel to grow 8-20 ha of other crops.

Because of the relatively simple technology required for pressing and filtering plant oils, they can be produced right on the farm, or on a cooperative or industrial scale.

Most plant oil crops are very adaptable and hardy.

Plant oils are safe to store and handle.

The by-products from the oil press can be used as a high protein animal feed.

Hydrocarbon plants

Proposals have been made to use plants directly to produce gasoline. Studies on the Euphorbia lathyrus, for the extraction of hydrocarbons which have molecular weights very close to petroleum, have been carried out by the University of California. Under irrigation, yields of about 10 bbl/ha/yr have been produced. There are at least five other trials in the world to try and assess the economic viability of this route (Hall, 1979).

The Materials Programme of the CSIR is looking at the production of rubber from guayule. Although this is not a source of energy, its use in the production of rubber would reduce the consumption of fossil fuels presently used for this purpose. Experience gained from its cultivation should also help in the agricultural development of semi-desert marginal land, such as the Karoo.

3.1.2.4 Future possible agricultural developments

The agricultural revolution began in the late 19th century and has extended to the present. During that period, thanks to plant breeding, mechanisation, the development of commercial fertilisers and pesticides, the yields of most crops have doubled or trebled.

Agriculture now stands on the brink of another revolution. The results of biotechnology research and its potential contribution to agriculture and a variety of other fields can not be understated. The breeding of plants containing desired characteristics can be accelerated substantially. The most important of these are nitrogen fixation, plant photosynthetic enhancement, salt tolerance, increased protein content and resistance to diseases, insects, drought and herbicides.

How close are some of these possibilities? Some tests on plants modified through the use of tissue culture and genetic engineering are already being carried out. However, it is unlikely that any large scale commercial uses will be seen before the end of this decade.

Another field that has received a lot of attention is the cultivation and harvesting of seaweed and marine algae as sources of biomass. The major problems that exist are technical. These include methods of growing and harvesting in coastal and open ocean water, and of building, maintaining and operating large floating structures on the open sea. Furthermore, fertilizing in such large open systems is not very effective.

For the above reasons, amongst others, a working group of EEC scientists looked at the feasibility of growing marine algae in shallow ponds located in coastal deserts (Wagener,1981). Fresh seawater is pumped through these ponds at a rate sufficient to provide the carbon supply for intensive cultures. The energy required to pump this water, per unit volume, requires only one thousandth of the energy that would be required for desalination.

The following are examples of some of the work being done with algae. In Australia, Botryococcus braunii has been shown to yield 70% of its extract as a hydrocarbon liquid closely resembling crude oil. This has led to work in France on its immobilisation in solid matrices and to then operate on a flow-through system. A green algae Dunaliella, discovered in the Dead Sea produces glycerol, beta-carotene, and also protein. This algae does not have a cell wall, and as it grows in very high salt concentrations it produces glycerol internally to compensate for the high external salt concentration.

3.1.3 AGRICULTURAL RESIDUES

3.1.3.1 Crops

A coefficient to estimate the total heat energy which can theoretically be obtained from the dry residues of crop 'c' has been developed by researchers in Europe (OECD, 1984). The output in millions of t, or in some cases the area in millions of ha, of the main product can be multiplied by a coefficient 'C_c' specific to each crop. Caution should be exercised in the use of these coefficients when applying them to South African crops. Although, they do help to give a first estimate, it would be beneficial to develop such coefficients for South African crops. The general expression for the coefficient is:

$$C_c = a_c \times b_c \times c$$

Where C_c = the coefficient relating to a specific crop has the units of tonnes of oil equivalent (toe)/t or toe/ha of the main product

a_c = quantity of residues in t/t or t/ha of dry matter of main product

b_c = the dry matter content of the main product at 15% moisture content

c_c = 0,4 toe/t (for most cases) which is lowest calorific value of dry residues in air per t of dry matter expressed in toe/t of residue.

When estimating the energy potential theoretically obtainable from crop residues, the quantities that can actually be used are in practice much lower than the total produced, for the following reasons:

Livestock farming takes a considerable share of these residues, either as feed or litter. In the latter case, this will appear as a plus in the livestock farming residues.

Returning harvest residues to the soil is an organic improvement which can not be dispensed with altogether without jeopardising the renewable nature of agricultural production.

Their dispersed production and the intermittent nature of harvest times make it difficult to collect certain residues. Also there is little chance that residues available at very busy periods of the farm year will be recovered unless incentives of some kind exist.

Bagasse

Bagasse is the fibrous residue of sugarcane crushed to extract the sugar-rich juices. It is a unique agricultural residue in that it is centrally collected where the infrastructure already exists for its further processing. The South African sugar industry has a further advantage in that its cane has a higher fibre content (15-16%) than the 11-12% found in most countries. In addition there are only 17 mills, 8 of which are concentrated in an area within 100km of either Stanger or Tongaat, and produce 48% of the total bagasse (Purchase, 1983). Bagasse consists of 40% cellulose, 30% pentoses and 22% lignin on a dry basis.

The fuel value of bagasse increases as the moisture content decreases. The most energy-efficient method of removing water is mechanically in a press or a mill, but there is a practical lower limit. The local average for bagasse is a moisture of around 51%, however, mills have been known to operate with yearly averages of below 40%. This is very much a function of the milling rate, however, and at high rates, 45% is considered the lowest practicable average moisture (Payne, 1982). The calorific value of local bagasse is just above 7 MJ/kg at 51,5% moisture.

In addition to the bagasse there is a quantity of potential fuel that can be made available to the factory from fibrous cane trash i.e. the tops and leaves. During a two-year growth period a cane plant produces close to twice as much fibre in its leaves as is present in the millable stalk at harvest. Most of the leaves drop off before harvesting and become ground trash. In the past, this, together with the leaves left on the cane, were burnt before the cane was harvested. However, the pollution resulting from this is becoming increasingly unacceptable, especially with the increase in the residential areas close to the canefields, and there is pressure to discontinue this practice.

If the trash is burned, only the partially dried tops are left, which average about 3% by mass of the total cane harvested. Thus from 100 t of burnt cane of 15% fibre, there is roughly another tonne of fibrous material. If the cane is not burned however, the tops and leaves will yield another 7,5 t of fibre. However, to process this unburned cane, without first removing the trash would necessitate roughly a 50% increase in extraction plant capacity to achieve the same efficiency of extraction.

Two options are available for the handling of the trash from the cane cleaning plant. In one, the trash may be shredded and partially dewatered in a mill and then returned to the bagasse. The moisture content of the trash is usually around 62%, so the moisture of the bagasse would have to be low in order to provide a boiler feed of combined bagasse and trash of 50% moisture. In another option, the trash is trucked to an open storage area where it is allowed to air-dry. It can then be returned to the bagasse supply for feed to the boiler.

At present there are only limited markets for excess bagasse in South Africa, and as a result it is not used very efficiently as a fuel. If a market were to come into being it is difficult to estimate how much surplus could be generated, because this would depend substantially on the boiler equipment installed at the various mills. The market value would determine the investment that millers would be prepared to make to generate the excess. Felixton II mill, the biggest and newest in South Africa, uses only 50% of its bagasse to generate steam and electricity. This is the result of its energy-efficient design, as a market exists for the excess bagasse as a raw material for a neighbouring paper mill.

The savings at Felixton II are in line with those achieved in Taiwan, where a similar market exists. Mills there use only 16 t wet bagasse/ 100 t of cane processed for steam raising (Purchase, 1983). In South Africa 100 t of cane produces 32-34 t of wet bagasse, so the potential exists to create a significant surplus. If a financial incentive were to be introduced it could be assumed that most mills could save one third of their bagasse. This would amount to approximately 2 million t of wet bagasse (1 million t bone dry) (Purchase, 1983). If the tops and trash were to be added to this there would be approximately another one million t of material. This gives a total of 2 million t of cellulosic feedstock for hydrolysis and other conversion processes.

The coefficients for the C expression for bagasse are:

a = 0,33 t wet bagasse/t cane   c = 0,170 toe/t of bagasse

Giving an overall coefficient:

C = 0,055 toe/t of cane

Using an average cane production of 18 million t/yr (averaged over last 10 years), this gives an energy equivalent of 41,4 million GJ/yr (one million toe/yr) from all the bagasse produced. However, the surplus energy available, assuming the incentive were to be provided, would be that produced from 2 million t of bagasse (50% moisture) i.e. 14 million GJ/yr.

Based on the ethanol yield figure, used by the CSIR's Materials Programme, of 187 l/t of bone dry bagasse (Ramsay, 1983), the surplus bagasse could be converted into 187 million l of ethanol, were the plant available. This is assuming 80% of the theoretical conversion of cellulose to glucose, and a yield of 580 l ethanol/t of glucose. If the xylose fraction were to be fermented as well, the ethanol yield would be boosted by another 76 million l/yr. This is based on the conservative yield of 20% ethanol from xylose on a mass basis (du Preez and van der Walt, 1983).

Maize stover and cobs

The common practice in South Africa at the moment is to plough back maize stover into the fields, indeed, in some areas this is required in terms of the soil conservation legislation. In this connection it has been calculated that some 2,5 million ha of soil in the South Africa is exposed to wind erosion (Joubert, 1979). A large percentage of this land occurs in the maize-producing areas. As a result, one of the most important measures used for the prevention of this erosion is the strewing and ploughing back of crop residues which provide good protection for the upper soil layers. This organic material also improves the water penetration and retention properties of the soil. Were it not necessary to protect the soil against wind erosion, even then it would not be possible to remove all the maize stover. It has been shown in the USA that it is necessary to plough back about one third of the stover to avoid nutrient depletion (Robinson, 1979).

At present, the maize residues that are collected are being used as animal fodder during droughts and the winter months. Much of it is mixed with molasses to produce silage feed. A product known as Rumensoda is produced from maize residues that have been treated with caustic soda or ammonia to give a highly digestible animal-feed roughage material.

The coefficients for the C expression for maize cobs and husks are:

a = 0,3 t residue/t of grain   c = 0,4 toe/t of residue

Giving an overall coefficient:

C = 0,12 toe/t maize grain

The coefficients for the stems and leaves are:

a = 0,45 t residue/t of grain   c = 0,11 toe/t of residue

Giving an overall coefficient:

C = 0,05 toe/t maize grain

Taking the average production of maize as 8,5 million t/yr, the stover from this quantity of maize would amount to 3,8 million t/yr, while the cobs and husks would be in the region of 2,5 million t/yr. Assuming that only two-thirds of this were collected for bioenergy production, this gives an energy equivalent of 28,2 million GJ/yr (0,67 million toe/yr) from the cobs and husks, and 11,2 million GJ/yr (0,28 million toe/yr) from the maize stover (stems and leaves).

This material has a total cellulose content of 3,47 million t. If two-thirds of this were to be hydrolyzed, and used as fermentation feedstock for the production of ethanol, the annual production would be in the region of 1,06 billion l, based on an 80% conversion of cellulose to glucose, and 580 l ethanol/t glucose, i.e. the same as for bagasse.

Wheat straw

Most of the wheat straw produced in South Africa is ploughed back into the soil or used as animal bedding material. Some is used for the production of silage as animal fodder.

The coefficients for the C expression for wheat straw are:

a = 0,8 t straw/t wheat   b = 0,85 t dry matter/t wheat

Giving an overall coefficient:

C = 0,27 toe/t wheat grain

The average annual production of wheat in South Africa has been around 1,9 million t/yr, giving an energy potential in terms of wheat straw of $2,15 \times 10^7$ GJ/yr (0,5 million toe/yr). Hydrolyzing two-thirds of this, and fermenting the resulting sugars would yield approximately 331 million l/yr of ethanol, based on a 47% cellulose content, and the same conversion efficiencies as for bagasse.

Sorghum straw

The coefficients for the C expression for sorghum straw are:

a = 1,92 t straw/t sorghum   c = 0,4 toe/t straw

Giving an overall coefficient:

C = 0,77 toe/t sorghum grain

Taking an average production of 675 000 t/yr, the energy value of the straw can be calculated to be 2,0 x 10^7 GJ/yr (0,5 million toe/yr). Again, taking two-thirds of this straw and following the hydrolysis route to ethanol, the annual production would be 157 million l, based on 39,6% cellulose and the same conversion efficiencies as for bagasse.

3.1.3.2 Agricultural products processing industries

Sugar industry

Bagasse has already been dealt with under the crop residue section. Another important by-product from the sugarcane processing industry is molasses. This is the residue left after the exhaustion of as much of the sugar as is economically possible from the cane juice. It is produced in quantities equivalent to roughly 3,6% of the mass of the sugarcane crushed. With crushing tonnages currently running at around 19 million t/yr, molasses production is about 680 000 t/yr.

Although most of the sucrose has been removed from molasses, it still contains in the region of 40-45% by mass of fermentables. This makes it a very suitable feedstock for ethanol fermentation and yeast culturing. The ethanol yield is about 245 l/t of molasses. Both potable and industrial grade ethanol are produced from this feedstock by NCP of the Sentrachem Group, and Natal Cane By-Products. These two companies, together with KWV supply the total local market, which is in the region of 50 million l/yr. This market has also been eaten into by SASOL on the industrial grade side, and as a result there is at present an excess of production capacity.

At present, a large proportion of the molasses is used for cattle feed production. However, it is possible to use the vinasse or stillage from a molasses-based distillery to produce a high protein cattle feed, as is being done by NCP with their product Rumevite. Thus it would be possible to use all the molasses for ethanol fermentation, and still be able to supply the cattle feed market. Based on this assumption, it would appear that the potential exists at present for the production of 166 million l/yr of ethanol from molasses. After the potable and industrial market are satisfied, this would leave, at a conservative estimate, 110 million l/yr of ethanol for fuel purposes. Under the dual-pool scheme this would rise to about 132 million l/yr (Ortmann, 1985).

Dairy products industry

This sector is mainly concerned with the production of cheese, butter, condensed milk and milk powder. As the production of one often leads to the production of another, the only real by-products of the industry are whey and buttermilk from the cheese- and buttermaking respectively.

Whey is the watery part of the milk that remains liquid during cheesemaking, and is unfit for human consumption, while buttermilk, the somewhat acid liquid left after butter churning, enjoys a limited market.

During 1980, approximately 310 000 t of whey and 16 000 t of buttermilk were produced (van Rensburg, 1983). The majority of the whey was used as pig feed or discarded, and the remainder processed into whey powder, while nearly all the buttermilk was used either for human consumption or for the production of buttermilk powder.

The main factors influencing the current methods of disposal are of an economic nature. In many cases the quantities produced are too small to justify further processing, and they are then disposed of at nil or low return. In cases such as these, the possibility of disposal methods such as anaerobic digestion could be considered, and in the case of whey in particular, ethanol and butanol fermentation. The yield of ethanol is one litre per 42 l of whey permeate (Reesen and Strube, 1978). The warm effluent from the distillation still has a high BOD in the order of 7 000 mg/l, and therefore requires further treatment before disposal. Anaerobic digestion of this waste stream was shown to yield about 0,5 m^3 gas/kg COD and to contain 63% methane.

Based on the above figures, the yield of ethanol from the whey produced in South Africa would total about 7 million l/yr.

Winemaking

In the production of wine appreciable quantities of various by-products are produced, consisting of stalks, skins, pips, wine lees and tartar. During 1980, approximately 20 460 t of stalks, 78 840 t of skins and pips, 14 990 t of wine lees and 300 t of tartar were produced by cellars (van Rensburg, 1983). The stalks, skins and pips were mainly used for soil conditioning and the lees for tartar and yeast recovery, fertilizing or distilling.

In Europe the skins are fermented to produce alcohol for human or industrial consumption, while edible oils and resins are recovered from the pips. The skin and pip residues are then dried and used as fuel for steam and electricity generation. Skins, pips and wine lees can also be dried and used as animal feed or as a fuel. None of these processes are yet considered an economic proposition in South Africa.

Deciduous fruit juice extraction

The most significant by-product from this industry is the pomace and the filter lees. Analysis indicates that the pomace has a high fibre content, a relatively high sugar content and useful levels of protein and pectin. During 1980, approximately 8 000 t of pomace were produced, and 2 400 t of filter lees. These were either discarded or used as compost substrate or animal feed.

All these wastes, solid and liquid alike could be fermented to produce alcohol, and the effluent then used as a fertilizer. Let us look more specifically at the process for the fermentation of apple pomace (Miller et al, 1982). Apple pomace is 18% solids, of which 20-26% is cellulose and 28-49% may be pectin. Of the net mass of pomace, at least 10% is soluble sugars, mainly glucose and fructose in roughly equal proportions.

A 5% w/w 10:1:1,5 (Novo cellulase-pectinase-cellobiase) enzyme treatment for 24 hrs maximises saccharification mass loss and ethanol production. Reduction of soluble sugar concentration by washing or by including yeast in the saccharification step, enhances dry mass loss by about 20%. Ethanol production can be enhanced by microwaving the enzyme preparation only, prior to saccharification.

Montrachet strains of Saccharomyces yeast yield the most ethanol, up to 5,1% w/w without saccharification and up to 6,0% with saccharification. Based on these yields, the pomace produced in South Africa could be used to produce about 600 000 l/yr of ethanol.

Dried fruit processing

The principal waste product from this industry is the fruit stones. It was not possible to obtain a figure for these. However, there is potential for their use as a charcoal feedstock, for activated carbon production. Attempts have been made to use peach pips in this way, but technical problems have prevented the industry from achieving any measure of success.

Pineapple processing

This industry is mainly concerned with the production of canned rings, cubes and pulp, and juice. The principal by-product is again pomace, of which 90 000 t were produced in 1980 (van Rensburg, 1983). Close to 90% of this was used as animal feed, while the remainder was dumped.

Langeberg Coop, the largest processor of pineapples in the country looked at the possibility of producing ethanol from their wastes. A feasibility study was carried out by Engineering Management Services (EMS) in 1981. The plant design was based on the microbiological work of the University of the Orange Free State and technical experience of the Swiss company Chemap. Two schemes were investigated, one using only the pineapple wastes and the other using molasses to supplement the feedstock, and thus boost the ethanol production. Both plants were designed to handle all the waste from the pineapple processing industry in East London, i.e. Langeberg plus the two other factories in the area, in total 50 000 t/yr. The production levels of the two schemes were 3,6 million and 9,11 million l/yr of ethanol respectively with capital costs, in 1980 money, of R3,35 million and R4,28 million, while the calculated factory gate price of the ethanol was 31,5c/l (pers comm Langeberg Coop).

After evaluating the project, Langeberg decided not to go ahead, and are now committed to a process for recovery of the sugar from the wastes, the residues being used for animal fodder.

Based on the yield figures, used by EMS for their plant design, of 67,1 l ethanol/t waste, the total potential in South Africa for ethanol production from pineapple wastes is around 6 million l/yr.

3.1.3.3 Livestock farming

This section looks at the potential for energy from animal wastes which can be used to generate methane gas using the anaerobic digestion process. It must be remembered that the following factors, which could not be taken into account in this survey, could have a significant effect on the figures stated here:

The use of straw as litter, which increases the energy potential, and also, in most cases, helps to improve the carbon/nitrogen ratio of the waste. The latter is of importance in the anaerobic digestion process (see section 4.3.1).

Keeping animals in the open air for all or part of the year presents a problem with collection of their manure.

The existence of small-scale livestock farming results in areas where animal density is low, therefore not permitting the installation of digesters, even on a collective basis.

A similar coefficient expression to the one for crop residues has been developed for animal residues. The C-expression (toe/animal) is as follows:

$$C_a = a_a \times b_a \times c_a \times d_a \times e_a$$

Where C_a = the coefficient relating to a specific species, in t oil equivalent (toe)/t

a_a = t fresh waste/animal type a/year

b_a = t of dry matter/t of fresh waste

c_a = t organic matter/t of dry matter

d_a = m^3 biogas produced/t of organic matter

e_a = energy equivalent of the biogas in toe/m^3

Beef and dairy cattle

The total number of cattle in South Africa, including the TBVC states, at the end of 1978 was 11,7 million (Dept of Agriculture, 1984); 9,3 million of these were in South Africa itself. The 1983/84 estimate was 8,3 million for South Africa, reflecting the reduction as a result of losses due to drought. The number in the TBVC areas has remained around the 2 million mark, as far as can be assessed.

Very few of the cattle in South Africa spend much time in areas where their manure can be collected with relative ease. The only ones in this category would be those in intensive feedlots, and dairy cattle, which spend at least some of the day in a confined area.

The total cattle in feedlots in South Africa varies from 300 000 to 320 000 (pers comm Meat Board). The largest of these, owned by Kanhym Karoo, holds 80 000 and is situated some 20km from Middelburg in the Transvaal. The next biggest holds about 15 000 head, and then there are another nine holding around 10 000 head. The manure in these feedlots is all collected, and usually used as fertiliser after undergoing mild composting treatment. At the Kanhym Karoo feedlot it is used on the adjacent fields for the cultivation of fodder for the cattle.

The following table shows the distribution of dairy cattle by dairy region (SA Dairy Foundation, 1985):

Dairy Region	Dairies	Cattle
W and SW Cape	2 479	268 044
Eastern Cape	592	36 297
S OFS and NE Cape	2 191	198 154
W Highveld and N Cape	4 295	419 276
E Highveld	6 257	728 496
Natal	864	76 118
Cape (Remainder)	153	6 314
Transvaal (Remainder)	194	13 488
TOTAL	17 015	1 746 187

The number of dairy cattle in the country totals 1,75 million. This figure is actually the number of dairy livestock units[1] on the dairy farms in South Africa. Because these cattle are not constantly in an area where their manure can be collected easily, the amount of energy able to be produced from this waste must be scaled down accordingly. Assuming that these cattle spend two hours out of every day in the dairy, only 8% of their manure can be used for methane digestion.

The coefficients for the C-expression for South African cattle are:

a = 5,7 (young), 8,0 (feedlot) and 15,0 (dairy) t/yr
b = 0,12
c = 0,8
d = 310
e = $5,5 \times 10^{-4}$

These give the technical coefficients:

C = 0,093 (young), 0,13 (feedlot), 0,25 (dairy) toe/animal/yr

Using these coefficients the energy potential from the Kanhym Karoo cattle is $4,4 \times 10^{5}$ GJ/yr (10 400 toe/yr), while the potential from all feedlots in the country is 1,7 million GJ/yr (41 600 toe/yr).

For the dairy cattle in the country, assuming that all their dung could be collected, the energy that would result would be in the region of 18 million GJ/yr (436 550 toe/yr). However, as was mentioned earlier, it is not realistic to assume that all the manure could be collected for use, and the more probable figure would be 8% of the above, i.e. 1,5 million GJ/yr.

Pigs

The total number of pigs in South Africa is just over one million. It is assumed that these are all in sties, making their manure easily collectable.

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[1] A livestock unit is equivalent to one adult animal, e.g. Three heifers and one calf = one livestock unit.

The coefficients for the C-expression for South African pigs are as follows:

$a = 1{,}5$ t/yr
$b = 0{,}09$
$c = 0{,}8$
$d = 400$
$e = 6{,}2 \times 10-4$

These give the technical coefficient:

$C = 0{,}027$ toe/animal/yr

Based on this and the above figure, the total potential energy from pig waste is 1,1 million GJ/yr (27 000 toe/yr).

Poultry

The number of battery fowls in South Africa is estimated at 50 million. It is assumed for this study that the collection of their wastes is relatively easy.

The coefficients for the C-expression for South African poultry, averaged for layers and slaughter fowls are as follows:

$a = 0{,}03$ t/yr
$b = 0{,}28$
$c = 0{,}7$
$d = 416$
$e = 6{,}7 \times 10^{-4}$

These give the technical coefficient:

$C = 0{,}0016$ toe/bird/yr

Using this coefficient, the total energy potential of the poultry wastes is 3,3 million GJ/yr (80 000 toe/yr).

3.2 FORESTRY-RELATED SOURCES OF BIOMASS

3.2.1 LAND USE PATTERNS

As was mentioned earlier, of the total land area of the country, agriculture and forestry comprise 102,6 million ha, 1,2 million ha of which are under commercial timber plantations (Dept of Environment Affairs, 1981/1982). Of this, 48% falls within the Transvaal and OFS, 35% is in Natal, 11% is in the Cape, and the remaining 6% is in the TBVC areas. Indigenous forests cover 300 000 ha, while the area covered by nature reserves comprises about 3 million ha. Although the area of land under agriculture and forestry has tended to drop with time, the area under commercial timber plantations has risen over the last two decades. This has normally occurred at the expense of natural pasture areas.

Traditionally forestry was practised on land with relatively low agricultural potential. This has been the approach adopted by the Dept of Forestry in its purchase of land for commercial afforestation (Dept of Environment Affairs, 1982). From time to time a maximum price per unit area was laid down, and then accepted as a standard for the acquisition of any land for forestry. This policy no longer applies because of the increasing scarcity of land, and the fact that forestry will now have to compete on an equal basis with agriculture.

The development of the South African forestry industry was prompted mainly by the need to become independent of imported wood supplies. The use of land for forestry purposes is not irrevocable, and such land can at any time be turned over to food production should the need arise.

In the private sector the choice of land use rests with the owner, and is dictated mainly by economics. Commercial afforestation with short-rotation crops by private undertakings is an agricultural practice which differs little from general farming. The continuous switching over from forestry to agriculture and vice versa is a natural process in a free market economy. However, as land becomes more scarce, a more centralised approach to land use planning will have to be adopted.

The general policy adopted by the state with respect to private forestry is that only those areas not eminently suitable for food and/or water production should be planted. In other words the aim is to develop forestry alongside agriculture and water conservation. It is estimated that at present about 22% of the total plantation area in private ownership is in lots of less than 1000 ha in extent, in the form of woodlots alongside agricultural activities (Dept of Environment Affairs, 1982).

The Forest Act, Act 72 of 1968, was amended to ensure that water conservation receives the required attention and that without the prior approval of the Department of Environment Affairs, no land which has not previously been utilised for the establishment of a commercial timber plantation, or for which a permit has not been obtained for afforestation in a specific catchment area, may be utilised for the planting of trees with a view to producing forest products (Dept of Environment Affairs, 1982).

3.2.2 TIMBER RESOURCES

Commercial plantations

Annual surveys of all timber plantations in South Africa are undertaken. These reflect information on timber resources in terms of forestry zones, magisterial districts and catchment areas. Particulars are also given of the main timber species, age classes, type of ownership, main purpose of management, sales in the main roundwood categories and new plantings during the year.

Of all the commercial plantations, 71% or 853 497 ha are in private ownership, while the other 348 611 ha are state-owned. Taking only softwood species into account, 54% of the area is in private ownership, while in the case of hardwood, 90% is in private ownership. The ownership patterns also reveal that 11% of the total commercial plantation area is owned by altogether 1 263 individuals and partnerships, each holding having an area of 550 ha or less. In addition, companies own some 54% of the total commercial area (Dept of Environment Affairs, 1981/1982).

On an overall basis, there is a preponderance of plantation units in small pockets of less than 50 ha, i.e. 34% of the 2050 plantations in the country. On the other hand, the area represented by this size group is less than 2% of the total commercial plantation area. In terms of area, ownerships are predominantly in the 2 000 to 4 999 ha size group, and account for 25% of the total commercial area.

Pine and softwood species occupy 51% of the total commercial forestry area, eucalyptus 35% and wattle 13%, while the remaining one percent is occupied by other broadleaved species.

The regional distribution of species is as follows:

Species	Area ha	Tvl & OFS %	Natal %	Cape %	TBVC %
Pine & other soft	647 721	48	25	19	8
Eucalyptus	396 646	56	38	3	3
Wattle	146 173	28	71	0,8	0,2
Other hardwoods	7 185	44	45	10	1

As can be seen, commercial afforestation in South Africa is based on exotic timber species. The coniferous or softwood plantations yield sawlogs for construction and industrial timber, other sawn timber, as well as logs for the production of veneer, plywood and other wood panel products. These plantations are also the country's main source of raw materials for the pulp, paper and board industries. Certain species of pine are also in demand for telephone, transmission, fencing and building poles.

Demand exists for certain eucalyptus species for sawn timber, but it is principally used by the mining industry, as mine struts and packs. Eucalyptus is also used on a large scale by the pulp industry, as well as in the manufacture of panel products from wood pulp. A large proportion of the various poles mentioned above also come from these species, which are well suited to chemical treatment by creosote.

The main purpose of wattle cultivation is for its bark, from which leather tanning agents are extracted. The timber is used in the mining and pulp industries, for charcoal production and as fuelwood.

Commercial timber plantations are managed in such a way as to produce a particular roundwood product at maturity. In some cases, different roundwood products are obtained from the thinnings, e.g. pine plantations managed for sawlogs can yield considerable amounts of pulpwood and poles from thinnings, significantly affecting the financial yield. Of the commercial timber plantations, 43% are managed for the production of sawtimber. Stands of both hard and softwoods, comprising 30% of the area are managed solely for the production of pulpwood,and a further 20% is under hardwood for the mining industry.

Invader Plant Species

Invasive exotic plants are found all over Southern Africa, the density depending on the region. Some of these exotic species were introduced with a purpose, but have since spread in an uncontrolled manner, and are threatening the delicate ecology of certain areas.

Under the auspices of the CSIR's National Programme for Environmental Sciences, researchers all over the country are attempting to quantify the biomass volume of these alien plants. The most prolific of these plants are from the acacia family, and are found mainly in the Western and Eastern Cape and Natal. In the densest populated areas, amounts of up to 104 t/ha (dry mass) of biomass have been recorded (Milton and Siegfried, 1981).

As yet there is no comprehensive data bank on the distribution, densities and impacts of these invasive aliens as a basis for quantification of the energy potential of their biomass. It would appear from the literature that the best approach would be for energy experts and the botanists to get together and find a solution appropriate to each area. Charcoal production using portable kilns would be one possibility. In SWA/Namibia large tracts of thornbush are being cleared near Tsumeb, and the bush used to feed gasifiers, which in turn are supply the fuel for steam raising boilers (pers comm National Timber Research Institute).

3.2.3 FUTURE DEMAND FOR TIMBER

The demand for timber is closely related to economic activity, and has historically been shown to cycle more widely than the GDP. Based on an analysis of its major end-use markets, the demand for roundwood is forecast to grow at an average annual rate of 3,9% to the year 2000 (Louis Heyl Associates, 1982). Softwood will become more important, increasing its market share from about 42% in 1980 to 50% in 2000. This is due mainly to the fact that pulpwood is forecast to become the single most important market for roundwood in South Africa, increasing its market share from 15% in 1980 to 31% in 2000. This is the result of huge expansions that have recently been realised by the pulp and paper industry.

The forecast developments in each end-use market are summarised below (Louis Heyl Associates, 1982):

	Roundwood Demand ($10^3 m^3$)			Average Growth
End-Use Market	1980	1990	2000	1980 - 2000
Sawn timber	4 305	6 255	8 700	3,6% p.a.
Mining timber	3 495	3 955	4 000	0,7
Paper and board	2 050	6 250	8 770	7,5
Pulpwood for export	2 020	3 640	4 080	3,6
Particle and fibreboard	550	910	1 400	4,8
Charcoal	455	660	900	3,5
Poles	405	515	615	2,1
Veneer and plywood	110	160	225	3,6
Matchwood	40	45	55	1,6
TOTAL	13 430	22 390	28 745	3,9

The regional share of the roundwood demand in the year 2000 is expected to be as follows:

Region	% of Total
Transvaal	45
Natal	46
E Cape	4
S & W Cape	5

The most important factors contributing to future growth in demand for roundwood will be:

> The demand for housing as the result of increasing urbanisation, where the requirements for sawn timber are expected to grow at the rate of more than 8% per annum.
>
> Pulp and paper production, due to large scale expansion by Sappi, Mondi and Saiccor. Increased use of sawmill waste and chips, and of other raw materials such as bagasse and waste paper could however result in reductions of growth in the future demand for roundwood.

According to studies by the Division of National Forestry Planning (Dept of Environment Affairs, 1982), an afforestation rate of 39 000 ha per annum had to be achieved up to 1985, in order to reach the production levels required in 2000. To this end new areas had to be identified for forestry development.

The regional offices of the Dept of Forestry, in close collaboration with regional representatives of the Dept of Agriculture, undertook surveys of the areas still available and suitable for commercial afforestation. A general directive stated that a distinction was to be made between good and marginal land. The report from this survey identified 28 priority areas for afforestation, 1 489 100 ha in total. Of this, 954 500 ha was readily available, good forestry land, while the rest consists of good land with restricted availability, or land with marginal forestry use.

Having completed this study the Dept of Forestry then identified forestry growth point according to various criteria. Ten areas were identified in order of priority, as follows:

Richards Bay, Donnybrook-Umkomaas, Ugie-Umtata, Ngodwana, Weza, Estcourt-Colenso, Tugela-Mandini, Piet Retief, Belfast-Middelburg, and Durban-Pietermaritzburg.

From the foregoing it can be seen that South Africa has sufficient good land to provide for its commercial forestry requirements for some years to come.

3.2.4 WOOD RESIDUES

The timber industry is characterised by a relatively low yield of the primary product. This is particularly true of the sawmilling sector of the industry, where at least half, and usually more, of the raw material is converted into residues of low or no commercial value. Currently, the sale of residues, when practised, does not even recover the cost of the raw material. This means that the sale of pulp chips, for example, is only a means of reducing loss, and is not commercially viable. Thus, a significant improvement in sawmill profitability can only be achieved by the conversion of residues into value added products. This has led to research into the use of the residues in products which may be in demand in the areas around a mill.

The residues generated by the forestry industry as a whole can be split into three groups, forest residues, residues from primary timber processors and those from secondary timber processors.

3.2.4.1 Forest Residues

These consist mainly of stumps, roots, branches (with bark), tops (with bark) and stem bark removed in the forest. The amounts generated can be estimated by using factors based on log volume demands as follows:

Stumps and roots	21,6% of net log volume
Tops and branches	13,6% of net log volume
Hardwood bark	10,0% of hardwood log volume

Using these factors, the following estimates were made (Sorfa, 1983) :

		Volume generated p.a. ($10^3 m^3$)	
Residue type	Species	1985	1990
Roots & stumps	Softwoods	1 805	2 224
	Eucalyptus	1 836	2 057
	Wattle	488	532
Total		4 129	4 813
Tops & branches	Softwoods	1 136	1 400
	Eucalyptus	1 156	1 295
	Wattle	307	335
Total		2 599	3 030
Bark	Eucalyptus	850	953
TOTAL RESIDUES		7 578	8 796

It is clear that the roots and the stumps are the most significant of the forest residues. However, it is unlikely that these will be used in the foreseeable future, as their removal from the ground would require capital investment which can not be easily justified. In the case of eucalyptus cultivation, where coppicing is practised, root and stump use is not feasible at all.

Considerable research and development has been done in forest residue utilisation in Scandanavia and North America. The important aspects, apart from the technology required, are studies on the effects of total biomass removal on the ecology of the forest. For certain sites, estimates have been made of the number of crop rotations that can be obtained, before soil nutrient depletion retards normal tree growth sufficiently for normal forestry to become uneconomical. The effect of whole tree utilisation on natural regeneration and soil conservation has also been studied. No conclusions have been reached, but it would appear that the ecological implications are great, and care should be taken, especially where marginal land is being used for silviculture.

In the case of tops and branches, the situation is very different, although their low bulk density presented a transport problem in the past, with the advent of mobile chippers, they can now easily be hogged in the forest, and the less bulky chips economically transported to processing points. These methods of harvesting have resulted in increased wood fibre yields of 25% in some European countries. The capital investment required is, however, quite significant, amounting to something in the order of R500 000 per harvesting team.

The energy equivalence of these residues can be broken down as follows (Assuming a 50% moisture content):

	Energy equivalent in 10^7 GJ/yr	
Residue	1985	1990
Roots & stumps	2,42	2,82
Tops, branches & bark	2,02	2,33
TOTAL	4,44	5,15

These figures are based on the assumptions that the wet residues have, on average, a 50% moisture content (density 515 kg/m^3), and the dry residues a 10% moisture content (density 480 kg/m^3). The calorific values are, 11,37 and 16,5 GJ/t respectively.

Taking into account the problems that might arise from the use of the roots and stumps, the forest residues that could realistically be used as a source of energy are the tops and branches. This is assuming that there are no competing uses with greater financial returns.

3.2.4.2 Residues from primary timber processing

Primary timber processors are those using roundwood as their major raw material. The most significant producers of residues are:

Sawmilling
Paper and board manufacturers
Mining timber producers

It must be remembered that some of these sectors often use the residues of others.

Sawmilling

The sawmilling industry is divided into the soft and hardwood sectors, the former being the more developed of the two. It produces a greater proportion of kiln-dried timber, and as a result, softwood sawmills generally have a greater thermal energy demand, most of which is met by their own residues. The hardwood mills on the other hand have little need of heat, and thus have a residue disposal problem.

The softwood mills are mainly producing structural and industrial timber and most have drying kilns fired principally with sawdust. Studies have shown that this is sufficient to supply all the drying energy requirements, but should self-generation of electricity also be desired, all the mill residues (excluding the bark) must be used.

There is also a growing tendency to carry out drymilling operations at the sawmills, thus generating dry residues there, rather than at the timber merchants situated in the market areas. The majority of these residues will be in the form of sawdust and shavings, thus being ideal for use as fuel.

The average volumes of residue generated by the milling of one cubic metre of round softwood are (Sorfa, 1983):

Wet residues	Volume
Bark	0,12 m^3
Sawdust	0,13
Solid residue	0,39
Total	0,62 m^3
Dry residues	
Sawdust and shavings	0,030 m^3
Solid residues	0,015
Total	0,045 m^3
TOTAL RESIDUES	0,665 m^3

Using these factors, the following estimates were made for the volumes of softwood milling residues produced:

Residue type	Volume generated p.a. ($10^3 m^3$)	
	1985	1990
Wet: Bark	538	672
Sawdust	582	728
Solid	1 399	2 072
Total wet residues	2 778	3 472
Dry: Sawdust & shavings	134	168
Solid	67	84
Total dry residues	201	252
TOTAL RESIDUES	2 979	3 724

More efficient milling techniques could of course have an effect on the volumes of milling residues produced, but this will not be considered here.

The total energy value of these residues, assuming they were available and able to be collected, were estimated to be 17,9 million GJ in 1985 and 22,3 million GJ in 1990.

Some of the uses to which residues can be put are the following:

Bark (Pine)

Fuel for boilers and producer gas units
Charcoal production

Source of pine tannin extract for adhesives and resins
Compost and other soil conditioners
Animal litter
Bark-cement composites

Bark is already used extensively as a boiler fuel, however, its high sand content often causes problems with clinker build-up. These problems can be overcome with more sophisticated combustion techniques. It is potentially a very good fuel for producer gas generation, and if this route were to be adopted, the efficiency of bark use as a fuel would be significantly improved.

Charcoal production from pine bark is possible, provided that a high ash content (mainly silica) is acceptable.

In considering the use of these residues for energy purposes, the other alternative uses would have to be taken into account, and decisions would be based on economic considerations.

Sawdust (wet)

Fuel for boilers and producer gas units

Wood-cement composites
Chipboard
Agriculture
Paper production

Wet sawdust is currently used to a large extent as a fuel, but those mills that do not have a large energy requirement are dumping it, and thus have a disposal problem. It is a relatively poor fuel, difficult to use alone. For use in producer gas units it has to be dried first, and probably briquetted.

Wet solid residues are the most valuable of the sawmill residues, and consist of slabs, edgings and board trimmings. They are of relatively large dimensions and can be reprocessed into many useful products. The most popular current use is as chips for pulp or particleboard mills. The demand for these chips is expected to increase dramatically because of the recent increase in pulp production capacity.

Other uses being considered, such as composite and structural boards, should give a higher financial return, and should therefore become more attractive with time. The increasing demand for cheaper building materials will especially help to boost interest in these products.

The hardwood mills are predominantly eucalyptus sawmills, most of which are producing shooks, boxwood and sleepers. Only a small proportion of hardwood is used as industrial or structural timber, with the result that very little is kiln-dried. Thus, energy demand is low and the residues are usually incinerated or dumped. Larger mills are sometimes in a position to supply chipped residues to pulpmills.

If the current drive to boost eucalyptus production, in a bid to reduce dependence on imported hardwood (mainly meranti), is successful, then the hardwood sawmilling residue problems will become more akin to those of the softwood industry. With the exception that there will be no bark generated in the sawmills, as debarking of hardwood is carried out in the plantation.

Projections for the production of hardwood have yielded the following figures (Sorfa, 1983):

Volume generated in 10^3 m^3/yr

	Log input	Wet residues	Dry residues	Total
1990	860	456	52	508
2000	1 250	626	75	701

The uses of the hardwood residues will not differ greatly from those of the softwood sawmills. Use of solid residues for charcoal production could become significant, especially if the current charcoal demand trends continue.

Assuming a 50% moisture content for the wet residues, and 10% for the dry, the total energy content of these residues would be approximately 3,0 million GJ in 1990 and 4,3 million GJ in 2000.

Mining timber

This is again a significant producer of hardwood residues, about 5% of the input volume being turned into sawdust and 15% into solid slabs and off-cuts. These sawmills have no process heat demand, and so all residues are incinerated, with the exception of a small quantity that is chipped and sold to particleboard manufacturers.

Projections for the production of mining timber have yielded the following figures (Sorfa, 1983):

Volume generated in 10^3 m^3

	Log input	Sawdust	Solid residues	Total
1985	3 770	188	565	753
1990	3 950	198	593	791

Assuming a 50% moisture content these residues would have energy values of 4,4 million GJ in 1985 and 4,6 million GJ in 1990.

Potential uses for these residues are the following:

Producer gas fuel
Charcoal production

Pulpchips
Chipboard chips
Animal feed
Wood-cement composites

Mining timber off-cuts do not produce a good pulpchip, with the result that this resource may not be used as soon as others by the pulpmills, and will thus be available for other uses.

Paper and board manufacturing

The only residue of significance here is pine bark. This is currently used as a fuel, and there is no foreseeable change in this practice. A potential development is that pine tannin will be extracted before the bark is burnt.

As the pulping industry is expanding tremendously at the moment, the demand for chips from sawmilling solid residues is expected to increase dramatically, the following being the forecast demands for chips from the sawmills (Sorfa, 1983):

1985	730 000 t	83% of sawmill solid residues
1990	800 000 t	73%

Only 60% of the sawmills are within economic distances (150 kms) of pulpmills, and from all predictions, it would appear that after 1985, all solid residues from the Eastern Transvaal and Natal sawmills will be chipped and sold to pulpmills. The situation could arise where the demand could exceed the supply, and there will be stiff competition for the solid residues.

3.2.4.3 Energy end uses of wood currently practised in South Africa

Boiler fuel

A large proportion of the softwood mill output is in the form of kiln-dried timber, as was mentioned earlier. These mills thus have a large demand for thermal energy, and tend to use their residues as boiler fuel for steam generation, some even practicing cogeneration. The average consumption of energy per cubic metre of roundwood intake is 560 kWh of steam, and 24 kWh of electricity. These requirements can be met by a mill using its own wastes. However, if the energy requirements of a whole mill complex are taken into account, including secondary processing and connected users, additional wastes will have to be added to the fuel supply.

A recent survey (Taylor, 1983) showed that 99% of softwood mills produce their own steam, but that only 8% generate all of their electricity requirements. A further 10% meet a part of their power requirements. In the past nearly 64% generated their own electricity, but only 50% would be able to do so again, if the need arose.

There is much potential for both improved reliability of energy supply and better utilisation of wood residues to promote energy self-sufficiency in the milling industry. The economics of upgraded boiler installations with back-pressure turbine generators are favourable if wood is not costed - electricity can be produced at 4,3 c/kWh. The use of low moisture wood residues can reduce these costs to 3,8 c/kWh, and they will drop even further if the efficiency of energy recovery is increased by using wood gasification for pre-combustion (Taylor, 1983). Of course, if the wood residues have a negative cost i.e. a disposal cost, then the economics are even more favourable.

Charcoal manufacturing

Charcoal has been used in many parts of the world for centuries. In South Africa production in 1981/82 reached 104 000 t, and there are currently 42 producers - 25 farmers and 17 companies, geographically distributed as follows (Huy, 1984):

Region	Producers	Production %
Natal Midlands	12	57
SE Transvaal	18	33
Central Tvl	5	5
N & E Transvaal	7	5
TOTAL	42	100

Of the charcoal produced, 39% is used for the silicon smelting industry, situated in the Northern Transvaal, and 6% for other industrial purposes. Another 24% is exported to Europe mainly for barbecues, and 31% is used for domestic purposes in South Africa. As is evident from the above, charcoal is in demand, and as a result is a fairly high cost fuel in comparison to other countries where it is used by the rural population. The export market is apparently growing rapidly, and seems to be constrained only by raw material supply (Sorfa, 1983).

Wood of any size or shape can be converted into charcoal, the optimum size varies depending on the process being used. In South Africa there are three main groups of raw material, namely roundwood, forest residues and wattle thickets. At the moment, roundwood, (370 000 m^3 and 259 000 m^3 in 1980/81 and 1981/82 respectively) and wattle are used. The source not yet used is the timber residues, both in the plantations and at the sawmills.

As far as the forest residues are concerned, these would best be converted in situ, thus reducing the transport needed. Using a portable kiln (see Chapter Four) the residues could be collected at various central points in the plantation and the kiln moved from one to the other.

Residues generated in the sawmilling industry that are not being snapped up by other users, e.g. sawdust and bark, are also suitable for carbonisation. The former would of course have to be compressed first, thus requiring additional energy input. Given the right economics, and with the careful planning of energy use in the sawmill, it is possible that this route could be viable.

Forecasts for charcoal production have been made (Sorfa, 1983):

	Production (t)	Wood (t)
1985	220 000	880 000
1990	500 000	1 758 900

It is foreseen that this demand will most likely be met by the use of forest residues and non-commercial species, such as the acacias. Another possibility is the use of briquetted bagasse.

3.2.4.4 Summary and Conclusion

The data for the residues generated, and the expected levels of demand for these can be combined to give the following table of forecasted residue surpluses (Sorfa, 1983):

		Residue surplus (m^3)		
	Roundwood Demand (m^3)	Tops & branches	Sawdust & smalls	Total
1985	18 624 000	1 555 000	316 000	1 871 000
1990	20 970 000	893 000	353 000	1 246 000

From the preceding sections it can be seen that the use of forestry and timber residues as a source of energy could be in competition with a wide range of other products. Many of the potential uses mentioned have not yet been implemented in South Africa. However, in the long-term, the economics of each route will determine the end-use of the residues, unless there is intervention at government level.

The above table contains an estimate of those residues that are expected to be available after the pulp and board mills have taken those which are useful to them. The realisable energy potential of forest and timber residues, based on these projections, is therefore 11,0 million GJ for 1985 and 7,3 million GJ for 1990 (Assuming a 50% moisture content). The drop from 1985 to 1990, despite the increase in production, can be attributed to the greater use of forest residues for pulping purposes.

The hardwood and mining timber mills, both of which have no process heat requirements, have the greatest waste disposal problem and are the greatest potential suppliers of centrally collected biomass for energy use. The use of the forest residues is the most significant in terms of quantities, but the problems with collection and transport have to be overcome to make their use economically viable.

3.2.5 FUELWOOD

The use of fuelwood in the rural less-developed areas of the country is the biggest single use of bioenergy in South Africa. Although many recognise the fact that the majority of the rural population use wood as a primary source of fuel, it is not universally accepted that specific and urgent measures are required to retard rapid denudation of vegetation, and to provide an economical source of energy for rural consumers.

3.2.5.1 Fuelwood consumption

It is interesting to compare the demand for fuelwood in Third World countries with that in the industrialised world. In 1850, wood met 91% of the fuel needs in the USA (Eckholm, 1975). As recently as 1974, more energy was supplied by wood in the USA than by nuclear power, and wood still contributes significantly to energy supply in Scandanavian countries, amounting to 8% in Sweden and 15% in Finland (National Academy of Science, 1980). In 1980, 52% of the total commercial wood production in the world was still consumed as fuel, with by far the largest portion being consumed in the Third World - 1,14 billion m^3 as compared to 188 million m^3 in the industrialised countries (FAO, 1982).

Surprisingly, very little work has been done in South Africa to determine non-commercial fuel consumption. Clearly, much of South Africa's population live in conditions similar to those found in many Third World countries, and it is thus to be expected that many people in the underdeveloped rural and peri-urban areas will rely heavily on fuelwood to meet their primary energy requirements. All energy planning documents to date have completely ignored the supply and demand of traditional fuels.

Various studies have been conducted on the daily use of fuelwood by rural people and the types of wood most commonly collected in various areas. Gandar of the Institute for Natural Resources (INR) is researching the situation in KwaZulu and Liengme did work in Gazankulu while attached to the Botanical Research Institute. Similar studies have also been conducted in Botswana by Jelenic and Van Vegten while Best investigated the use of fuel (including fuelwood) in three rural villages in Transkei, Lesotho and KwaZulu. The most comprehensive survey to date is that conducted by Eberhard of the Energy Research Institute (Eberhard, 1986).

The following table puts South African rural energy consumption, based on the limited work that has been done, into a regional context.

Nett Energy Consumption in Southern Africa in 1980

Country	GNP/Cap US $	Population Millions	Rural Pop %	Tot Energy PJ	% Share of Trad Fuel
Malawi	230	6,2	90	165,2	94,3
Mozambique	230	12,1	91	281,7	89,1
Tanzania	280	18,7	88	439,9	91,5
Lesotho	420	1,3	88	24,2	78,6
Angola	470	7,1	79	105,5	77,4
Zambia	560	5,8	57	150,8	58,3
Zimbabwe	630	7,4	77	244,1	52,0
Swaziland	680	0,6	85	24,0	60,0
Botswana	910	0,8	86	22,1	56,1
Tot SADCC	370	60,0	83	1456,5	79,0
S Africa	2300	29,3	50	1775,0	10,5

Source: Beijer Institute (1982), World Bank Development Report (1982) and Eberhard (1984)

The following table summarises the rural energy consumption data collected thusfar in Southern Africa.

Domestic Rural Energy Consumption/cap/yr in Southern Africa

Area	Fuelwood tonne	Agric Residues tonne	Dung tonne	Paraffin litre	Overall GJ
Angola	,523	,025	-	3	9,35
Botswana	,797	,059	-	2,3	14,46
Lesotho	,463	,348	-	11,1	13,44
Lesotho	,288	,260	-	5,08	10,33
Malawi	,628	,033	-	0,3	11,16
Malawi	,587	x	-	x	9,98
Mozam	1,135	,134	-	3,1	21,35
Transkei	,960	x	x	x	16,32
Transkei	,271	x	,08	10,24	7,69
KwaZulu	1,124	x	-	5,68	23,86
KwaZulu	,62	x	,012	2%	10,68
KwaZulu	,74	x	,2%	2%	12,58
Gazankulu	,76	x	x	x	12,92
S Africa	,43	x	,058	x	8,0
Swaziland	,495	,033	-	5,1	9,37
Zambia	,94	,035	-	1,7	17,32
Zimbabwe	1,031	,013	-	3,1	17,89
Zimbabwe	,616	x	-	x	10,47

x : Not reported

Source: Eberhard, 1984

As can be seen from the last table there are wide variations in the figures reported. The fuelwood figures range from 0,27 t/capita/yr in Jozanna's Nek in the Transkei to 1,135 t/capita/yr in Mozambique. The differences may be explained chiefly in terms of the fuelwood availability and to a lesser extent in terms of climate. In areas of fuelwood scarcity, dung and agricultural residues are substituted.

The study carried out in the Mahlabatini District of KwaZulu was over a period of three years. It was established that 90% of the wood used in the district was for fuel, and amounted to about 0,75 t/capita/yr being consumed (Gandar, 1983). Approximately 2 million t/yr are burned in KwaZulu, while 150 million man/woman-hours are spent collecting it. Because of the pressures on wood supply green trees are being cut in some areas and in many regions the environmental consequences are already serious.

Wood collecting is a group activity which in some areas is a three to six hour operation twice a week and in others, because of ever-receding vegetation, in excess of one day per family per week is required, involving a round trip of 19 km each time wood is needed. Naturally wood is consumed in greater quantities during the winter, as the cooking fires are kept going most of the day for heating. Throughout the remainder of the year three cooking fires are made per day, while just before the harvesting or planting season, wood is stockpiled. This is because of the added work burden carried by the women during this period.

The average headload measured in Gazankulu was 30 kg, while in KwaZulu many loads close to 40 kg were found and some in excess of 50 kg were noted. The huge number of man/woman hours of work taken up by wood gathering allows less time for more productive developmental activities. The establishment of woodlots could relieve this problem to a large extent. However, a disturbing finding in some areas was that where woodlots were in existence, these were only made use of after the natural woody vegetation has disappeared. Thus the present form of woodlot serves little purpose and is not acceptable especially when it is established at the expense of grazing land. The land to be used must therefore be carefully selected, with the close involvement of the affected community.

It has been estimated that current fuelwood consumption in the so-called homelands totals about 7 million t/yr (air dried), a further 3,6 million t/yr is consumed, mainly on white commercial farms, and about 2 million t/yr is consumed in towns and urban areas (Eberhard, 1986). This amounts to $219{,}3 \times 10^6$ GJ, or about 6% of the primary energy consumption of the country. This is based on a consumption figure of $3{,}58 \times 10^9$ GJ for 1984 (pers comm Dept of Mineral and Energy Affairs). If it is assumed that urban and commercial farm domestic energy demand will increasingly be met from sources other than wood, then the major requirement for fuelwood will continue to be in rural homeland areas, where the introduction of electricity or renewable energy technologies is unlikely to make a major impact in the short to medium term, without massive state intervention.

If it is further assumed that about half of the current rural consumption can be met from natural woodland and forest on a sustained yield basis, then the supplementary woodlot requirement is currently about 3,5 million t/yr (air dried) wood or 4,4 million m^3/yr which is equivalent to about 5,95 x 10^7 GJ/yr.

3.2.5.2 Woodlot Development Strategies

While tree plantations for the provision of industrial roundwood i.e. for pulpwood and timber, are found all over the world, energy plantations are a relatively recent development, except in some Scandanavian and Far Eastern agricultural systems. An energy plantation does not have to differ much from a pulpwood plantation, the aim with both being to maximise bulk growth, and operate on fairly short rotations. The only real difference is that in energy plantations smaller sizes can be used than for pulpwood applications.

It is worth stressing that fuelwood production also does not necessarily have to be separated from other wood production. The thinnings from commercial timber plantations can be used as fuelwood, and light timber for construction purposes can be extracted from energy plantations. Some examples of such practices are given later. The important point to remember is to allow leaves, twigs and possibly bark to return to the soil, thus maintaining the fertility of the plantation region.

The the design of an appropriate fuelwood production system necessitates a thorough understanding of the present fuelwood utilisation as well as the priorities and resources of the final end-user. Ideally every case should be researched, but it is safe to make several observations on the basis of experience. Rural inhabitants in developing countries are more interested in the production of fuelwood sticks than in the production of trees with large trunks. Thus tree-shrub species that respond well to pollarding or coppicing are preferred. Trees tend to be managed on short rotation with small planting distances, similar to the way in which crops are managed.

The social aspects of planning fuelwood plantations are probably the most important of all. Third World countries are littered with failed woodlot projects, most of which have collapsed because of insufficient awareness of the importance of the social inputs required in the planning process. When one considers that between 200 and 500 trees (Kristoferson et al, 1984), depending on the climate, are required to satisfy the fuelwood needs of one household, the scale of afforestation that is required to provide this is way beyond the capabilities of conventional forestry practices.

A number of different approaches, some of which are outlined below, have been used to overcome the various problems that exist in different areas around the world (Foley and Barnard, 1984).

Farm forestry

Farm forestry is the term usually applied to programmes which rely on the desire of individual farmers to become involved in commercial tree production, using their own land, such as the Sappi project mentioned below. To encourage such undertakings, various forms of assistance may be provided, including technical help, free or subsidised seedlings, loans and various market support measures. Experience in countries such as the Philippines, India and Ethiopia has shown that under the appropriate conditions, where there is a significant demand for wood, tree growing can be a profitable and successful venture.

These programmes tend to be more effective in terms of numbers of trees planted, while they are also simpler and cheaper to implement than community based projects, relying as they do, on the entrepreneural spirit of the individuals concerned. However, for this very reason they are not automatically associated with social and environmental benefits. Because of the commercial nature of their venture, the farmers will generally grow those trees that give them the highest rate of return, which could favour construction and furniture timber over fuelwood production. In addition, the benefits of farm forestry tend to devolve on the richer farmers who can spare the land for tree growing and more easily provide the necessary inputs. Environmentally speaking, tree growing for individual profit will also tend not to occur on the poorest and most degraded land in need of rehabilitation and conservation.

Tree growing for family uses

A number of programmes have concentrated on the the stimulation of tree growing by families to meet their own needs. However, these programmes have generally been less successful than farm forestry. Probably the most significant lesson that has been learnt, is that a shortage of fuelwood alone rarely seems to be a sufficient incentive for people to grow trees. This is particularly true in those areas where natural bush or trees are still available, albeit at increased distances and effort for collection. In areas where survival is a daily concern, environmental conservation, an abstract concept at the best of times, becomes something of a luxury, and the planting of trees is a low priority. One area which seems to negate this argument is that around Bizana in the Transkei, more details of which are given in a later section.

Agroforestry

This a term and concept that has become firmly established as part of rural development strategy in a surprisingly short time. There are probably many interrelated reasons for this, one undoubtedly being the dynamics of fashion. However, there is definitely more to it than that. Agroforestry is the first concrete concept to come from the synthesis of much of the practical experience and scientific knowledge acquired over past decades in tropical agriculture, forestry, ecology, soil science and rural socio-economics. However, it is important to remember that agroforestry has been practised for years, and it is only really the name that is new e.g. the taungya afforestation practice has been use for many years in tropical countries.

Many definitions of agroforestry have been proposed, many of which make the unfortunate and presumptuous claim that it is a better and more successful approach to land development than any other. Here is one definition which avoids this pitfall (Kristoferson et al, 1984):

> "Agroforestry is a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems

> there are both ecological and economical interactions between the different components."

This definition captures the essential elements of agroforestry:

> Agroforestry usually involves two or more species of plants, or plants and animals, and at least one of the plants is a source of wood.
>
> There are always at least two outputs from an agroforestry system.
>
> The agroforestry cycle is always longer than a year.
>
> Even the simplest agroforestry system is more complex, ecologically and economically, but not necessarily in execution, than monocrop agriculture.

The rationale behind agroforestry is the optimisation of positive interaction between all the biological components, whether it be trees/shrubs and crops/animals. These interactions promote a higher total, more diversified production from available resources, while at the same time having a beneficial effect on the ecology of the area.

Agroforestry promotes voluntary adoption of tree planting by rural populations, basically because it recognises a whole range of problems facing the farmer, and attempts to satisfy all the basic needs usually satisfied by the earth. This is achieved by choosing multi-purpose tree or shrub species which, at the same time as yielding fuelwood, serve other functions and provide other useful products. Examples of these are dry season fodder, construction poles, windbreaks and if leguminous species are chosen, nitrogenous fertilisation of the soil.

Agroforestry can be implemented using various spatial arrangements of trees and shrubs. Woodlots can be set up, which are basically closed tree stands. These can take the form of a farm forest, home garden or woody fallows rotated with other crops. Tree rows can be introduced into the farm layout to serve a variety of purposes, such as windbreaks, shelterbelts, living fences, alley rows in fields, or could be planted along roads and rivers on land that would not normally be put to any use. Lastly, open tree stands can be planted to provide shade over crops or as shade trees in grazing land.

Generally speaking, the humid tropics are the areas where the closed tree stands are found, while the tree rows are planted in the drier, open areas where windbreaks may be desirable as preventative measure against wind soil erosion.

Agroforestry has two obvious advantages over other solutions to the fuelwood crisis. Probably the most important is the fact that it allows for the integration of fuelwood production into existing farming systems. By careful selection of species and spatial/temporal arrangements, trees can be integrated in a manner compatible, both ecologically and culturally, with local practices. This is of some importance when one considers the scale of the fuelwood scarcity problem. In terms of this it is unrealistic to believe that a long-term, large-scale solution to the fuelwood crisis will be found, unless it is predominantly based on a strategy of individual land users catering for their own needs.

Secondly, agroforestry allows a flexibility of fuelwood production not provided by other solutions, in that it allows the land users the opportunity to provide for all their needs from their limited land resources. In addition there is almost unlimited potential for the development of improved agroforestry systems and techniques, both through the identification and scientific improvement of multi-purpose trees and shrubs, and through the introduction of improved spatial and temporal management of these trees.

To conclude, the advantages of agroforestry go beyond the material benefits it can have. Because of its interdisciplinary nature, pulling social, forestry and agricultural planners together, it can hopefully provide a more holistic approach to development problem solving.

Public or State woodlots

These programmes are organised and funded by agencies completely external to the community being provided for, and the community is seldom actively involved in their implementation. Despite this, land is often expropriated from the community for these projects. The wood produced by the woodlot is sold at market rates to recoup the establishment and running costs.

Examples of these schemes are the old Transkei Tribal Authority woodlots and the Lesotho Woodlots Project. From the point of view of state planners this approach may meet conservation objectives, provide increased supplies of fuelwood, as well as some employment opportunities, however it is the most costly option. In addition, because of differing perceptions of ownership that may exist, and alienation of the community through its being excluded from the planning process, there is no guarantee that households will buy fuelwood at the rates demanded. This has indeed been the experience with the Lesotho Woodlots Project which has now had to embark on a marketing campaign. The problem is of course greatly aggravated where land has had to be forfeited and where other options for fuelwood collection from natural bush or forests still exist.

There seems to be merit in establishing woodlots close to towns and cities to supply the population in these areas with fuelwood and building timber. An successful example of this is the forest development which began spontaneously on the outskirts of Addis Ababa in Ethiopia (Kristoferson et al, 1984). Certain landowners set aside areas for eucalypt cultivation for the commercial production of fuelwood. The state, realising the potential of this market, then encouraged other landowners to follow suit by providing tax relief and free seed. The result has been a proliferation of these commercial woodlots, to the extent that the city is now almost completely surrounded by a wide area of forestland, providing fuelwood and a much needed greenbelt.

Another impressive example of a state-run woodlot scheme is the afforestation programme in Gujarat state in India (Kristoferson et al, 1984). This project makes use of the unused land along the roads and canals, and 1978 some 5 000 km had been planted with mostly triple lines of trees on both sides, and has been continued at the rate of almost 1 500 km/yr since. The local people are allowed to mow fodder grass under the trees, thus controlling the weeds, and will eventually be entitled to the wood.

Community forestry

These programmes are based on the use of commonage for tree growing, with the local community actively involved in the planning, financing, establishment and management of the woodlot. State agencies will generally play a background role in stimulating project organisation by the community, as well as providing seedlings and technical assistance. This is the approach that has been used at Embongolwane in Kwa-Zulu. Outside agencies may subsidise the cost of seedlings and fencing, but most communal schemes rely on the voluntary contribution of labour and various 'food for work' arrangements.

"Such programmes, in principle, offer a number of advantages over individual tree growing. By using community lands and resources they can permit landless and poor households to share in the benefits of tree growing. They can also provide a focus for community action to halt the gradual degradation of common lands through over-grazing and excessive wood cutting.

Nevertheless, many community programmes have run into severe problems. This is generally because they require a degree of commitment to a common effort which is often very hard to achieve. Obtaining the necessary collaboration and ensuring that there is an equitable distribution of benefits requires the establishment of democratic community organisations.

One significant problem in the Southern African context is that the felling of trees on communal lands has generally been under the control of the tribal authorities. Thus for village organisations to be committed to a communal forestry project they need to be assured that they will have control over and access to fuelwood benefits." (pers comm A.A.Eberhard)

Factors hampering woodlot development

It is useful to try and determine why trees are not being planted widely. The following are some of the main constraints (Gandar, 1983).

Tree planting involves an investment of time, energy and money. These are in short supply and people prefer to invest them in opportunities which bring quicker returns than trees.

Land tenure systems without privatisation of land or formal security of tenure discourages individual initiative but the system is flexible and the problem it poses is sometimes exaggerated. It can actually assist implementation of community woodlots. However, community projects require social organisation and extension input which is often lacking.

While traditionally free fuel resources like dung and the remaining natural woodland are available, motivation to establish woodlots will be weak.

People will have to forego some benefit such as loss of grazing so woodlot development should go hand in hand with a livestock improvement scheme.

Seeds and seedlings are not readily available. If a concerted woodlot programme is to be implemented, many regional nurseries will be required.

Fencing is a crippling expense and for small woodlots with a high perimeter to area ratio it is the main expense. Solutions might be to avoid very small woodlots, or to them next to a community garden, say, with which it can share a fence. Alternatively fences can be removed as soon as trees are established and re-used to start other woodlots.

Another factor which may play a role in impeding woodlot development is the constant pressure as the population increases in certain areas, to convert forest land to agricultural land for food crops - however, the potential for an agroforestry cash crop could be a valuable source of income.

3.2.5.3 Southern African woodlot development (pers comm A.A.Eberhard)

The Lesotho Woodlots Project

The most advanced woodlot project in Southern Africa is the one established in Lesotho some years ago. Reports have been published on a number of species, fertiliser and container trials. Funding for this project came from a number of sources and totalled over R4 million.

The long range objectives of this project are to determine a rational afforestation policy for Lesotho in terms of its economic and ecological needs, and to create an administrative and technical infrastructure for the support and implementation of a continuing afforestation programme. The immediate objectives were to establish woodlots throughout Lesotho for the provision of fuel and building materials, and to provide trees for catchment area stabilisation.

Provision of fuelwood and building materials was seen as one of the primary objectives, both for reasons of conservation (reduction of the use of dung as a fuel and to retard scrub removal on erodable sites) and import substitution for fuels, fencing, hut and other poles and building materials. Initial estimates of the area required were 17 000 -20 000 ha but this was subsequently increased to 50 000 ha. Recent consumption surveys, combined with population growth and estimates of plantation productivity indicate that this estimate is low.

Initially much of the planting programme was based upon eucalypts and in particular on E.viminalis. Unfortunately this became susceptible to attack by the Snout Beetle. Many of the earlier eucalypt species were on a trial basis and some proved uneconomical. The emphasis on eucalypts was in part due to their coppicing ability and growth potential. It was only from 1979 that research commenced and then much of this effort was devoted to species and provenance trials. The recent drought years have put the selections to the test and as a result planting rules have been adopted for specific species. There is now much greater emphasis on conifers in the programme and except in the case of Cypressus, so that plantations will have to be replanted after harvesting. The rotation anticipated for fuel production is 7-12 years.

Considering the staff available the research programme has been large and successful. Modifications to nursery practice, establishment procedures, stocking rate and fertiliser application have been identified. The research staff also control pre-felling evaluation of trees and carry out the resource inventory work necessary for identification of site potential.

The total area planted by the project from 1973 to 1983 was 4 100 ha and in 1983/84 696 ha, and there are currently over 250 Forest Reserves. The area clear-felled from 1979 to 1984 was 188 ha and revenue totalling R41 900 was received from fuelwood sales - 30kg headloads are currently sold for about 50c. Under recent legislation 20% of revenue will be used for community development in the area of the woodlot whilst the remainder goes into the Forest Fund for afforestation work.

Many of the older plantations are now ready for felling but the project is experiencing some difficulty in selling fuelwood. Part of the problem appears to be the difficulty of transport to and from the plantations, many of which are situated on top of koppies. These problems were largely unanticipated because of the apparent scarcity of fuel for most households. The fact that the project is now forced to give attention to marketing strategies perhaps questions the basis upon which woodlots are planned, implemented and managed and the degree of community participation.

At present there is very little in the way of establishment of private or community woodlots. Problems over land tenure are a probable reason why there is so little interest. However, to encourage persons or schools interested in planting 2-5 ha the cost of plants has been reduced to 5c each. In addition, under the scheme, technical advice will be given free whilst the land will also be ploughed free subject to its suitability and the availability of tractor and plough. So far this scheme has met with very little response.

It seems likely that the Lesotho Woodlot Project as such will continue possibly 2-3 years beyond March 1985. Developments depend in part upon different strategies, changes of attitude and possibly land tenure; in particular the greater involvement of individuals and communities in establishing their own woodlots. The development of silvo-pastoral systems in grazing lands is a possible solution to the land tenure problem. This system involves the planting of widely spaced trees or blocks of trees which can serve as shelter to stock. Another possibility is the development of wind breaks in arable lands which reduce wind erosion and improve crop yields by development of a microclimate.

One Lesotho fuelwood consumption survey (Steele and Ncholu, 1983) concluded that the demand for woodlot products was good but would be sensitive to price and the location of the sales. Annual consumption of fuelwood by households questioned was 1,8 to 2,6 tons/yr. Approximately 50% of households appeared to have their own source of supply of fuel, either from their own trees or from communal forests or reclaimed dongas. Even so collection times of only 20% of households were less than one hour, all the others taking considerably longer periods.

A similar survey has been undertaken in the southern districts of Lesotho (Wickstead, 1984). The most commonly used fuels in this region are wood, paraffin and dung. Fuels are matched to the various domestic tasks according to the quality of heat they provide, although this obviously occurs within the constraints of the availability of each fuel. Few people rely on one fuel only. Wood is generally preferred over dung. Logs are the preferred form of fuelwood, but they are not widely available, households collect bushes and shrubs.

The average household consumption of wood is 1,1 to 1,5 tons/yr. Reaction to the possibility of buying fuelwood from woodlots has been positive; the wood offered by woodlots clearly being seen as a superior product to the bushes found locally.

Embongolwane Woodlot Project

Limited information is available on well-controlled demonstration projects. The forest planted by the Embongolwane community in KwaZulu, under supervision of the Institute for Natural Resources, can be considered as the start of such a demonstration project. An interesting feature of this project is that after long consultations and searching for a suitable site, the headman of the area gave up some of his own grazing land for woodlot development.

No results from the project have as yet been documented, but its progress is being closely monitored. An interesting development is that households not involved in the original development work have subsequently joined the project by paying a certain fee which is used to expand the woodlot. BP Southern Africa have sponsored the production of a video film documenting the development of this woodlot for use in further woodlot extension work.

Sappi Woodlot Project

This project, being funded partly by the Gencor Development Fund is aimed at encouraging afforestation in Kwazulu, creating job opportunities, assisting growers to earn a living, and to secure timber supplies to Sappi's pulpmill at Mandini. The project has a firm commercial basis and although fuelwood production is not the main objective, as growers have to sell the timber to Sappi's mill, fuelwood is obtained from thinnings and pruning. There are the added advantages of soil conservation and the bringing into production of previously underutilised land.

A grower wishing to join the scheme must sign an agreement to sell the timber to Sappi at the prevailing market rate. Sappi in return undertakes to donate seedlings, and to pay a grower the cost of establishing his plantation, plus an annual maintenance fee and 'voorskot'. This loan is free of interest and must be paid upon the sale of the timber.

An extension officer signs interested growers on, gives advice and sees to the delivery of seedlings and fertiliser. It is estimated that at present prices a grower will make a profit of R2 500/ha over 10 years. By February 1985, 67 growers had joined the scheme with a total of 104 ha under trees. The largest individual woodlot is 5,7 ha and the smallest 0,6 ha with the average being 1,7 ha. The project is growing fast and impressive woodlots have been established within a short time.

The project has potential for replication in other favourable plantation areas close to commercial mills. Where local fuelwood supplies are scarce, thought could be given to allocating a portion of the individual woodlot for personal pole and fuelwood production.

The Agricultural and Rural Development Research Institute (ARDRI)

This institute at the University of Fort Hare has already begun a programme of woodlot development research, based mainly on the cultivation of Leucaena Leucocephela. Originally from southern Mexico, this is an impressive tree which has produced among the highest annual total yields of biomass ever recorded (National Academy of Sciences, 1980). It is a legume and offers a wide assortment of uses, nutritious forage, fuelwood, building timber and rich organic fertiliser. Its wood has an uncommonly high density and calorific value for such a fast-growing tree, thus making it ideal for fuelwood and charcoal.

A number of small woodlots have been planted in various places in the Ciskei and Border area. Agroforestry techniques are also being investigated. The work being done by ARDRI will also form a major input to the woodlots project being planned by the Transkei government.

Transkei Woodlots Project

The Transkei Government recently made an application for several million Rand to the Development Bank of Southern Africa to fund the countrywide LEAF afforestation project. Afforestation has been given a high priority in Transkei and from a coverage of 471 km^2 in 1980 it is hoped to achieve 9000 km^2 of afforested area by 2020. The approach advocated in the funding application is the establishment and management of relatively large woodlots (100-200 ha) by the Transkei Dept of Forestry, with minimal community involvement. The justification for this approach is based on the 'failure' of a previous community woodlot project in the 1950s. In this case 260 woodlots with a total of 12 000 ha were established and then handed over to the Tribal Authorities for management. Because of the poor management and utilisation, this approach is regarded as non-viable and these woodlots have reverted to the Dept of Forestry's control.

The proposal from the Transkei Government has offered no analysis of why the previous project failed. Certain questions are left unanswered. For example, did the communities have any involvement in the allocation of land for woodlots; were they involved at all in the establishment and management of the woodlots; was there any animosity between the department and communities which had to forfeit grazing land; were the Tribal Authorities the appropriate institutions to take over control of the woodlots; did the people feel that they had any control over the use of the wood or did the Tribal Authorities use this added resource for self enrichment or patronage purposes; was there any transfer of knowledge on woodlot management techniques on handover and were there any backup extension services? To argue that local community involvement proved to be a failure in the past, does not hold water if the communities were never involved in the first place.

The proposal also fails to examine alternative fuelwood supply strategies, which is surprising, given the size and scope of the grant application. There is a long history of afforestation initiatives in the Transkei and the different approaches employed in the past need to properly assessed. For example, how well are the numerous small household wattle stands being utilised? These 'spontaneous' woodlots are particularly prominent in the eastern areas of the Transkei, around Bizana (pers comm M.V.Gandar). Apparently they arose from the foresight of some migrant mineworkers who brought back seeds and propagated them. Subsequently seedlings have been distributed informally. The advantage of this system is that allocation of land use is the choice of each household and conflicts can not arise.

The only alternative considered in the Transkei government proposal is a vaguely defined "social development and education programme". This consists merely of the hiring of an administrator who will be based at a rural development agency such as the Transkei Appropriate Technology Unit (TATU) and will "attempt to coordinate rural silviculturally orientated training development projects undertaken by the Transkei government and private institutions".

Part of the problem here is that alternative approaches demand unfamiliar skills and changes in attitude on the part of many officers who have been trained in traditional forestry. However, exploring such alternatives as agro- and community or social forestry opens new and challenging possibilities. It creates the opportunity to break down the barriers of mistrust and antagonism which often exist between forestry departments and the public. This would enable the resources and expertise of foresters to be utilised more efficiently and extensively in meeting fuelwood demand.

The Development Bank's pre-appraisal report recognised the importance of exploring alternative "local community" approaches but in the project reformulation only R50 000 has been allocated for "Technical Assistance" to explore alternatives (no details given). This is only 1,5% of the revised project loan application for R3 million. In the following section some alternatives which have been explored elsewhere are outlined.

Other Woodlots

According to a report the following is an inventory of existing woodlots in South Africa totalling some 25 790 ha (Journal of Dendrology, Vol. 3, 1983 and Gandar, 1983):

Bophuthatswana	1 000 ha
Ciskei	650 ha
Gazankulu	140 ha
KaNgwane	2 400 ha
KwaNdebele	0 ha
KwaZulu	7 600 ha
Lebowa	1 100 ha
Qwaqwa	400 ha
Transkei	12 000 ha
Venda	500 ha

Official policy on woodlots

There does not seem to be a specific policy with regard to the provision of fuelwood with the exception of the statement of intent referred to in the President's Council report mentioned earlier. In a paper on a proposed forestry plan for South Africa it is stated that the Republic has an understanding for cooperation on forestry matters with Transkei, Bophuthatswana and Venda and it is expected that this pattern is being followed with the other so-called homelands. Nowhere in the plan is the concept of woodlots for energy supply addressed, commercial timber being the major concern (pers comm J.A.Basson).

3.2.5.4 The future of woodlots

It has been estimated that current fuelwood sales from commercial plantations in South Africa total 430 000 m^3 (Directorate of Forestry, 1983). If we add estimated fuelwood sales of about 150 000 m^3 from so-called homeland woodlots, then the national total is about 580 000 m^3, way below the requirement of 4,4 million m^3. The area required to produce this latter amount, assuming a yield of 7,5 m^3/ha/yr, is nearly 600 000 ha - clearly a huge task when it is recognised that the total area under commercial plantations in South Africa is close to 1,2 million ha, and that the total area currently under woodlots is only about 26 000 ha.

The potential for the large scale establishment of woodlots is limited by the lack of suitable land within homelands and competing demands by commercial forestry. It is forecast that South Africa will soon experience an overall timber shortage. As mentioned earlier, the forestry guide plan for South Africa identifies about 28 priority areas and 954 500 ha of good land without restrictions which could be used for afforestation. Of this, about 180 000 ha is in the homelands and is the area where plantations could reasonably be dedicated to fuelwood production, rather than commercial timber production. Such an area could produce up to 1,35 million m^3/yr, still leaving us with a shortfall of some 3 million m^3/yr.

Probably the only way of increasing the potential of afforestation to meet fuelwood requirements is to adopt more innovative approaches such as a multitude of small community woodlots and agroforestry which could be integrated with annual cultivation practices. However, this calls for a level of imaginative management, and a will to solve problems in a socially acceptable and democratic fashion, qualities which are not typical of the agencies of development in this country.

May be there is some hope to be gleaned from the following. The Planning Committee of the President's Council on Nature Conservation in South Africa (P.C. 2/1984), noted that the over-exploitation of fuelwood could lead to the development of deserts. The report also noted that wood was the sole source of energy for cooking and heating for the majority of people in third world countries, and that trees contributed 58% of the energy needs in Africa.

Two of the recommendations made to combat vegetation denudation were:

> "(a) The imaginative efforts of the Dendrological Society of South Africa to promote the planting of suitable trees in rural areas that have become almost denuded of trees should be supported and emulated by all the authorities concerned.
>
> (b) The Department of Cooperation and Development should investigate possibilities of implementing the advanced research done by the CSIR on alternative energy resources, particularly solar energy, to reduce the destruction of trees in these areas for fuelwood."

Thus far there is no coordinated effort with regard to either research into species, management or other aspects regarding fuelwood. Present work is fragmented, limited and carried out in isolation. This could, however, change with the increasing interest being shown by various sectors, including the SA Forestry Research Institute, the Southern African Development Bank, and the private sector.

3.3 URBAN WASTES AS A SOURCE OF BIOMASS

3.3.1 SOLID WASTES

Urban solid wastes come mainly from four sources, domestic, commercial, industrial and litter. At this stage the majority is collected and deposited on urban dumps. Most of it could be used in some way as an input for energy production, recycled goods or compost, leaving only relatively small quantities to be disposed of.

3.3.1.1 Domestic Refuse

This component includes all those solid wastes generated on a regular basis by households, businesses and industries in the execution of normal housekeeping activities, such as cleaning, maintenance and food preparation, and which are disposed of in municipal waste bins. Garden refuse and other bulky refuse generated by the same institutions but on an intermittent basis also fall into this category.

It is estimated that the generation of domestic refuse in South Africa currently amounts to 11,6 million t/yr, and that this quantity will increase to around 25,0 million t/yr by the end of the century (van Rensburg, 1983).

The following is an analysis of domestic refuse deposited in bins in various Johannesburg suburbs in July/August 1983 (Equivalent dry mass as a percentage of total equivalent dry mass) (Cleansing Branch, City Engineer's Department, Johannesburg Municipality):

Putrescibles	22,6 %
Common paper	15,9 %
Newsprint	12,9 %
Kraft paper	7,4 %
Plastics	7,4 %
Rags, rubber, leather	1,7 %
Glass	11,1 %
Metals	8,5 %
Unclassified	8,6 %
Fines/ash	3,9 %
	100,0 %

3.3.1.2 Secondary industry waste

This differs from primary industrial waste in that it consists mainly of scrap and spent materials. These industries are also generally located within or just outside urban areas, and thus usually make use of municipal refuse disposal facilities. Primary industries on the other hand usually make use of special dumping facilities.

The majority of secondary industries generate waste containing metals and/or paper and/or plastics. A relatively large number of them, however, also generate chemical waste products which have to be diposed of in a specialised fashion.

3.3.1.3 Management of urban waste

Once it has been collected, urban waste can be disposed of in a variety of ways, the most important consideration being that this is carried out in an as environmentally sound a manner as is possible. The ultimate objective should be that only the unwanted or non-reusable waste is actually disposed of. In this regard the present level of technology applied to waste disopsal in South Africa is generally extremely low, general land disposal and straight surface dumping still being the general practice almost country-wide.

Alternative, but more costly and more sophisticated methods of disposal include composting, salvaging and recycling, incineration, refuse derived fuel (RDF), pyrolysis and hydrolysis.

Any of the above methods will require separation and preprocessing to recover as much usable material as possible. A process for such recovery has been developed and patented by the City Engineer's Dept of the Municipality of Cape Town, but is applied only on a small scale at present (van Rensburg, 1983). The process differs from others in that the main constituents such as plastic and paper, which have a fuel value, are recovered in a manner which lends itself to cost optimisation. It is also independent of fluctuating material prices as it ensures a minimum recovery value which is determined by the fuel value of the material. The developers' contention is that the flexibility of the process is likely to make recovery projects more viable.

Once the separation has been effected the desired disposal method or methods can be applied. In the case of incineration the wastes may either be burned in bulk in specially designed power plants, often making use of fluidised combustion principles, or it may be processed into a shredded or pelletised form (RDF) for burning in conventional power stations. The principles of pyrolysis and hydrolysis will be discussed at greater length in the chapter on conversion technologies.

3.3.1.4 The energy value of refuse

The calorific value of domestic refuse will differ significantly from area to area, and from one income group to another. This is borne out by the following figures giving the ranges for the USA and West Germany; 7 to 14 MJ/kg (Burton and Bailie, 1974) and 4,2 to 10 MJ/kg (Martin and Weiand, 1975) respectively.

Taking the above figures and those given earlier for the total domestic refuse generated in South Africa, the energy value of this waste could be anywhere between $4,87 \times 10^{7}$ to $1,62 \times 10^{8}$ GJ/yr at present. Using a calorific value of 8,3 MJ/kg based on the typical analysis of Johannesburg domestic refuse, the total energy potential for South Africa would be $9,63 \times 10^{7}$ GJ/yr.

3.3.2 LIQUID WASTES

The sewage produced by human settlements has great energy potential. In the same way that animal manure can be anaerobically digested to produce methane gas, so to can sewage. Anaerobic treatment of sewage has been practised for years, and in the past much of the gas produced was use to power machinery and even to provide energy for street lighting. However, only relatively recently has this gas been regarded as a source of energy by South African municipalities.

In many parts of the world, the gas generated is used to provide the energy requirements of the treatment plant itself by burning it to provide the heat necessary for heating the digester. Alternatively the gas can be used to run an engine to drive a generator. The electricity generated is then used in the plant.

In South Africa very little of the methane produced by sewage plants is used. In most cases it is released to atmosphere, or at best, flared. In Johannesburg, the gas from the southern treatment plant is sold to the AECI plant adjoining the sewage works as a feedstock for cyanide production. The same company is investigating the possibility of compressing and liquifying the gas from the northern works, for transport to this plant.

The two Johannesburg sewage plants, one to the north and the other to the south, treat a total volume of about 320 Ml/day of sewage. The volume of gas produced by them totals about 36 000 m^3/day, and has a 66% methane content. The energy value of this gas is approximately $3,27 \times 10^5$ GJ/yr.

An estimate of the energy available from sewage-derived methane gas, based on a metropolitan urban population of 8,5 million (Central Statistical Services, 1982), is of the order of $1,8 \times 10^6$ GJ/yr. It is difficult to obtain an accurate figure of the present methane production by sewage treatment works, because of the lack of data on the installed anaerobic digester capacity, and the volume of sewage fed to them.

Water hyacinth

Water hyacinth or Eichornia crassipes is a native of the American tropics, but has spread to all the warmer regions of the world, and today is one of the major aquatic weeds. It was introduced to South Africa at the beginning of this century and is now well established in all four provinces, especially in the eastern and southern regions. Particularly large concentrations are found in the coastal regions of Natal and along the Crocodile and Vaal Rivers. It has been declared a noxious weed and it is now an offence to encourage its growth in this country.

The plant grows under a wide range of environmental conditions, but best when air and water temperatures are between about 21° and 27°C. It is able to withstand extremes of 0° and 40°C for short periods. It is primarily a fresh water plant but can survive in sea water for up to 13 days. Increase in the nutrient content of the water causes a corresponding increase in the mass of the fresh plant, and actively growing colonies may double their numbers every 11 to 18 days. The largest concentrations are found in waters enriched by sewage and industrial effluent or by run-off from fertilised agricultural land.

Since the plants effectively absorb excess nutrients, the removal of the plant constitutes water treatment, and it has been estimated that under optimum conditions, one hectare of plant could absorb the nitrogen and phosphorus waste products of 800 people (Botanical Res Inst, 1980). In addition they provide a surface for microbial attachment and subsequent organic waste oxidation. The plant's prolific growth and the ease of harvest techniques make it a suitable carbon source feedstock for anaerobic fermentation.

Research is being conducted into the feasibility of secondary and tertiary treatment of primary effluent by means of hyacinth ponds (Chynoweth et al, 1982). Collected primary sludge and harvested water hyacinth are added as a blend to the anaerobic digestion process for methane production. Figures are not available for the production of biogas from water hyacinth alone. It is envisaged as a feedstock for the improvement of the C:N ratio of the total feed to the anaerobic digester.

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CHAPTER FOUR

BIOMASS ENERGY CONVERSION TECHNOLOGIES

Biomass conversion technologies can be separated into three basic categories:

Direct Combustion Processes.
Thermochemical Processes.
Biochemical Processes.

4.1 DIRECT COMBUSTION PROCESSES

Direct combustion is the process whereby heat is evolved, through the combination of the carbon and hydrogen in the fuel with the oxygen in air, to produce carbon dioxide and water. If combustion is incomplete and some of the carbon and hydrogen does not react entirely with oxygen, amounts of carbon monoxide, hydrocarbons, and other gases are formed.

There are three successive and overlapping processes that take place in the direct combustion of most biomass fuels. These stages are water evaporation, vapourisation and combustion of volatile matter, and the reaction of fixed carbon with oxygen.

The technologies for direct combustion of biomass are well-developed and for many years, the wood products and cane sugar industries have used conventional boiler systems to burn wood wastes and bagasse. Municipal waste disposal agencies are also using incinerators as a source of additional energy for city power generation.

There are a variety of furnace designs used for burning hogged wood, wood residues and other forms of biomass. It must be borne in mind that an auxiliary fuel is required for all of them, even those having an adequate supply of dry fuel. This auxiliary fuel is required for startup, to cover for interruptions in the usual fuel supply, and to handle rapid swings in energy demand.

4.1.1 Dutch Ovens

These are amongst the most common, but their basic technology is old, consisting of a two-stage furnace. In the first stage, the moisture is evaporated and the fuel gasified, while in the secondary furnace the fuel is burnt. The primary furnace is gravity fed, thus forming a conical fuel pile over which the primary combustion air is passed. These furnaces were used almost exclusively until the late 1940s, but have been superseded to a large extent by more efficient systems.

4.1.2 Spreader-Stoker Furnaces

Newer steam plants fuelled by wood and bark use this design. The fuel is fed into the furnace above the grate either by a pneumatic or mechanical spreader system. Some of the fuel is burnt while in suspension and the remainder falls to a series of grates where the combustion is completed. This type of furnace is employed with smaller furnaces, with steam capacities of typically 10 t/hr, right up to capacities in excess of 200 t/hr.

4.1.3 Fuel Cell Furnaces

This system consists of two stages, the fuel being introduced from above onto a water-cooled grate in the primary furnace. Gases pass from here into a secondary combustion chamber, where combustion to completion occurs. These furnaces operate in the low pressure regime (less than 200 kPa), with capacities ranging from 5 t/hr to 12 t/hr. A large number of these systems are used all over the world for steam generation for timber drying kilns.

4.1.4 Inclined Grate Furnace

In these furnaces fuel is introduced at the top of the grate in a continuous ribbon, and passes over the upper drying section where moisture is evaporated. From here it falls into the lower combustion section, and the ash is removed at the lowest part of the grate.

4.1.5 Suspension Furnaces

In these systems, fine fuel particles burn quickly in a turbulent air stream. They may be of the injection type, where the fuel and air are mixed inside the firebox, or they may be of the cyclonic type, where the fuel and air are mixed in an external cyclone burner.

Advantages of suspension burners include reduced capital costs since grates are not required, and ease of operation as grate cleaning is not necessary. They can achieve higher combustion efficiencies on the whole, but are more sensitive to particle size and moisture content.

4.1.6 Fluidised Bed Combustion

Fluid bed combustion systems use a heated bed of refractory type sand in constant motion, which essentially replaces the grate. The bed is automatically preheated by an oil-, gas- or pulverised coal-fired burner, to a temperature capable of sustaining combustion of the main fuel to be fed to it. At this point, air flow through the bed is increased until the point at which the bed just begins to 'boil' i.e. it is fluidised. This provides an environment for highly efficient combustion in and above the bed, allowing a wide range of fuels to be burnt. As most biomass fuels contain moisture, part of which is bound into the structure, and part of which is free, fluidised bed combustion is an ideal means of using them efficiently.

The method of introduction of fuel depends mainly on its characteristics. Solid material with a mass greater than that of the bed material can be dropped onto the bed's surface, where it will be engulfed. Materials with low mass, such as sawdust or wood chips are introduced below the bed's surface. Liquids can even be introduced by means of water-cooled injectors.

Other advantages of fluidised bed combustion systems are that the combustibles are kept in the bed almost indefinitely to ensure complete oxidation. The operating temperature of the bed can be carefully controlled to avoid both clinker and tar formation. Also the amount of fuel contained in the combustion chamber is relatively small, thus facilitating rapid restarting after shutdowns, because the heat is retained by the bed itself.

For a fluid bed to operate, the gas passing upward through the bed must be at some minimum velocity, this being a function of the size shape and density of the bed medium. Gas velocities in excess of this minimum do not necessarily improve operation as they can cause localised spouting, excessive bed material carryover, and a shorter time for proper combustion to take place.

Moisture content of the fuel has a significant effect on the efficiency of operation of a fluidised bed furnace. As the moisture content increases, so the total material available for combustion decreases, and the more water has to be driven off. The combination of these factors results in a drop in the bed temperature, until a point is eventually reached where combustion can no longer be supported.

4.1.7 Cogeneration

This section does not deal with combustion systems as such, but rather with an application of the various direct combustion systems available, the equipment discussed here being suitable for addition to boiler plants.

Cogeneration is really just a new word for a time-honoured practice that was rediscovered when the energy 'crisis' struck. In general terms it means the simultaneous, or concurrent use of power and heat. The power is normally mechanical or electrical, while the heat is usually that contained in steam.

The application of this principle is particularly appropriate to industries that generate their own steam for process applications, and more specifically, those that are burning a waste product to do so. In Europe this technology is used by urban authorities for the combined generation of electricity and provision of district heating. The fundamental components of a cogeneration system are:

A combustion chamber to burn the fuel.
A steam generator.
A steam turbine.
A heat sink.

The type of furnace/boiler used will be strongly influenced by the kind of fuel available, ranging from sawdust through slab bark to urban wastes. The two most significant waste characteristics are particle size and moisture content. The best fuel for electricity generation is dry and finely divided, with a moisture content of 15% or less, and any hogged material matchstick size or smaller. Any waste containing more than one material should be uniformly blended.

The turbines available can be divided into two categories - condensing turbines, and non-condensing or back-pressure turbines.

Condensing turbines. With these units, the steam raised in the boiler is expanded in the turbine to a pressure considerably below atmospheric, and useful power is produced. On leaving the turbine, the steam is condensed and returned to the boiler.

Back-pressure turbines. Steam from the boiler is expanded through these turbines, to the pressure required for the downstream factory processes. The turbine takes the place of a reducing valve and generates useful electrical or mechanical power. This type of turbine is used where there is a large downstream demand for process steam.

Pass-out condensing turbines combine the attributes of both the above. A portion of the steam is extracted at an intermediate pressure, suitable for process use, while the remaining steam is expanded to the lowest possible pressure, and condensed.

The shaft work available from the steam turbine can be used to directly drive a mechanical device such as a fan, pump, wood chipper, or most large pieces of machinery requiring such a drive. Alternately it can be hooked up to a generator to provide the electricity requirements of the plant.

4.2 THERMOCHEMICAL PROCESSES

These processes chemically decompose biomass into solid, liquid and gaseous fuels by exposing it to high temperatures, usually in a low oxygen environment. The quantity and types of fuel produced depend on the temperature and pressure of the process, the composition of the feedstock, and the length of time it is retained in the system.

The gaseous products consist primarily of hydrogen, methane and carbon monoxide, constituting a low energy value producer gas. The liquid products are viscous tars and oils containing methanol, acetone, phenols and other organic substances, while the solids are of a charcoal type.

Various thermochemical systems have been developed, only some of which have real commercial potential at this stage.

4.2.1 PYROLYSIS

Pyrolytic conversion, or destructive distillation, is the process whereby organic materials are broken down under conditions of high temperature in an oxygen-deficient atmosphere. The products formed are basically:

A hydrogen, carbon monoxide and methane gas.
An oil-like liquid which includes acetic acid, acetone and methanol.
A nearly pure carbon char.

The distribution of these products is dependent on the feedstock, temperature and pressure of reaction, and the time spent in the reaction zone.

Pyrolysis is not a new process, but has received a lot of attention in recent years as a method for size reduction of urban wastes, while at the same time generating useful products. The various processes may be classified according to the degree of pretreatment the feedstock requires, reactor type, process temperature and the nature of the residue produced. The types of reactor are also many and varied, the basic categories being, shaft furnaces, rotary kilns and fluidised beds. The heating of the reactor may be direct (by heat transfer media such as sand, ceramic balls, and inert gases) or indirect (through the reactor wall). The heat may be obtained by recirculation of process gases or burning of fossil fuel and process gas. Feeding of the reactors may be intermittent, and the feed can be co- or counter-current to the process gas.

Three pyrolysis temperature ranges can be identified, the product distribution for each one varying from the others. The low temperature process develops temperatures of up to 600°C and produces relatively small volumes of gas, but much tar, oil and solid residues. The intermediate temperature processes operate at temperatures between 600 and 1000°C, resulting in less tar, oil and solid residues, but a greater volume of gas. The high temperature process, operating above 1000°C produces a predominantly gaseous product. The temperature will also affect the compositions of each fraction produced.

The following are two plants representative of the current commercialised pyrolysis processes.

4.2.1.1 Garrett Flash Pyrolysis

This process developed by Garrett R&D is designed to produce a liquid fuel, comparable to No 6 fuel oil, for use in power plants. Although developed to convert municipal solid waste (MSW) into liquid fuel, the process can be used to convert wood and other cellulosic feedstocks.

The feedstock is fed into a shredder and conveyed to a storage hopper where waste heat from the reactor is used to dry it. From here it moves into a secondary shredder and is ground to a very fine mesh (80% through 14 mesh), and then pneumatically blown into the pyrolysis reactor. Heat is applied to produce gases and char, but the reaction temperature is kept as low as 500°C to ensure liquid fuel production. The gases are quickly quenched with No 2 fuel oil to halt the chemical reaction taking place in the gases, and to maximise the yield of condensates.

After quenching, the liquid product is passed through a centrifuge to remove solids, while any gases remaining are burnt to provide process heat for the system. Similarly, most of the char is fed back into the reactor to provide the energy for the pyrolysis reaction. It is not considered suitable as a solid fuel because of its high ash content, so some is used in the plant itself, while the excess is landfilled.

The fuel oil produced is similar to No 6 fuel oil, but has a different stoichiometry. It contains oxygenated organics, including tar acids, which will necessitate corrosion-resistant materials for storage and combustion equipment. The conversion efficiency when using wood as a feedstock is estimated at 46% (Blake, 1977).

A 200 t/day plant commissioned in 1976 is operating in San Diego, California, and feeds the fuel oil produced to a nearby oil-fired power station. The process has also been used to pyrolise tree bark, rice hulls, feedlot wastes, sewage sludge and used tyres.

4.2.1.2 Union Carbide Purox Process

This system was developed to convert unclassified municipal solid waste into a clean-burning fuel gas, and is therefore strictly speaking, a gasification process.

Refuse is fed into the top of the vertical shaft furnace, while oxygen is injected into the bottom where it reacts with char to produce temperatures of up to 1 600°C. These high temperatures melt and fuse the glass and metals present. This molten mixture is drained continuously into a water tank where it is quenched to form a hard granular frit.

The hot gases formed rise up through the descending column of feed, drying and pyrolizing it, and thereby cooling the gases. The off-gases leave the reactor at approximately 100°C, and the impurities it contains (water vapour, oil mist etc) are removed by the gas cleaning system.

In its application as a refuse treatment plant, the Purox system has certain distinct disadvantages. It is a very sophisticated process, thus being prone to breakdown, and requires a supply of pure oxygen. On the plus side, the gas produced is a clean-burning fuel, free of sulphur compounds and nitrogen oxides. When used for the pyrolysis of refuse, approximately 83% of its energy content can be recovered in the form of gas. Some of this is used in the operation of the plant itself, so that close to 75% is available for other uses.

From the environmental point of view, it has one great advantage in that the volume of off-gas is very small in comparison to that obtained by incineration with air. This means that the capacity of the cleaning system is much smaller, thus reducing both the capital and running costs. A 200 t/day plant has been operated successfully in South Charlestown, West Virginia.

4.2.2 GASIFICATION

Gasification is an established technology, and is the thermal decomposition of organic material in the presence of a limited supply of oxygen to produce combustible fuel gases. When air is used as the only gasifying agent, the product gas mainly consists of carbon monoxide, carbon dioxide and nitrogen, with small amounts of hydrogen, methane and liquids. The quantity of hydrogen can be increased by using steam along with air. Because of the nitrogen dilution, the product gas has a low calorific value, usually less than 5 600 kJ/m^3. The nitrogen dilution can be avoided by using pure oxygen instead of air as the oxidant. The gas produced by an oxygen-blown gasifier has medium-heating value, usually less than 13 055 kJ/m^3, and is known as synthesis or medium-heat-value gas. This section will concentrate mainly on the latter process, with a short reference to the National Timber Research Institute's work in the field of producer gas generation.

The bulk of research and development work has been conducted on coal and municipal waste gasification. Both of these technologies appear to be transferrable to biomass feedstocks in general.

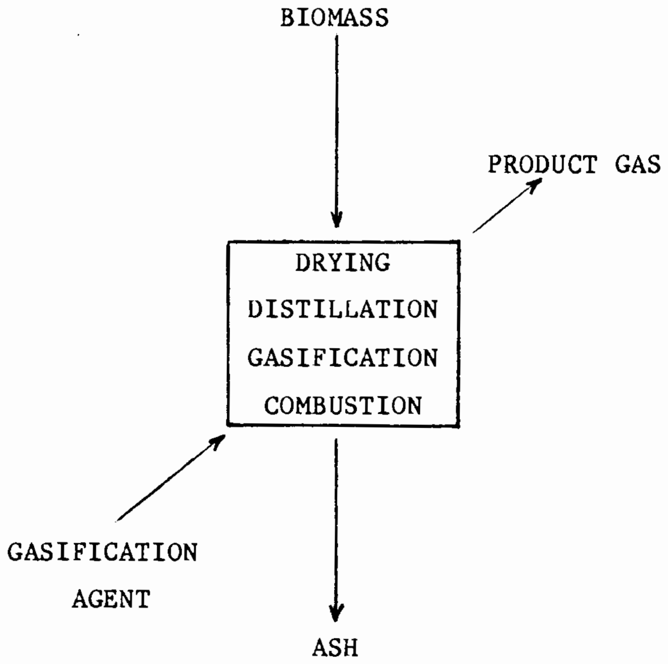
An extensive survey has been conducted on the request of the SA Forestry Council to find those gasifiers that are suited to cellulosics, with the emphasis being placed on the gasification of South

African woods (Cohen Bahr Lindsell & Partners, 1980). This work was carried out in conjunction with Raphael Katzen Associates, a US consulting group well versed in the gasification technologies, and Foster Wheeler. The purpose of this study was to establish the best technology for the conversion of cellulosics to liquid fuels on an industrial scale.

The best established of all gasifiers are the fixed bed type, also referred to as vertical shaft gasifiers. There are three basic types, being counter-current, co-current and cross-current (also referred to as up-draft, down-draft and cross-flow).

Because the fixed bed gasifiers are well established for coal, scale up factors are well-known, and as long as the critical limiting diameter of about 3,5 m for updraft gasifiers is not exceeded no problems are expected. This limit exists because of the cooling effects at the wall of the gasifier and the possibility of channelling through the bed.

The following diagram shows simply how the gasification process takes place in a counter-current gasifier.



As the solid feedstock passes down the gasifier it passes through the various stages shown above, until it is eventually reduced to ash. This ash must be mechanically strong enough to support the bed, and at the same time maintain an open structure to allow the distribution of the gases. Because biomass usually has a much lower ash content than coal, some modification to the grate of the gasifier are sometimes necessary to allow for this.

All fixed bed gasifiers tend to have certain features in common. They are all able to accept a fairly wide range of feed sizes, ranging from 10mm up to at least 200mm, although the quantity of fines (less than 10mm) they can handle is limited to between 5 and 10% maximum in most cases. Higher levels of fines tend to block the bed, making gas transfer less even, and increasing the pressure drop across the bed. A notable exception are the modern downdraft gasifiers which are able to operate on 100% fines smaller than 10mm. Most gasifiers are, however, able to tolerate fairly high moisture contents, thus allowing the use of undried biomass. The downdraft gasifiers are however sensitive to moisture content, and can not accept more than 25% moisture. Several co-current or downdraft gasifiers are known but they tended to be small in scale, and were mainly developed during World War II for use as gas producers for IC engines. More recently they have found application in small scale power generation, and the NTRI has successfully developed a unit with a thermal output of 1MW. They all operate at atmospheric pressure, using air/steam as the gasifying agent.

The main disadvantage of the co-current mode of operation is that drying and distillation occur by radiation and conduction. This, together with the fact that all the steam produced must pass through the gasification zone means that temperatures are reduced, and more carbon has to be burnt to counteract these effects. On the other hand the level of tars and other condensibles are significantly reduced, or possibly even eliminated. This is due to their having to pass through the gasification and combustion zones before leaving the gasifier.

It was generally considered unlikely that co-current gasification in fixed beds would develop to any great extent for anything but small scale gasifiers. However, the NTRI is confident that their successes with downdraft gasifiers will lead to commercialisation of this technology on both the small and large scale.

The following is a list of those fixed bed, counter-current gasifiers considered suitable for the gasification of biomass (Cohen Bahr Lindsell & Partners, 1980):

	Single Stage	Two Stage
Slagging	Andco Torrax Purox	Motala Pyrogas
Non Slagging	Davy single stage Moore-Canada SFW - Funk	Wellman two stage Stoic

Slagging or non-slagging operation has to do with the temperature of gasification, and generally depends on whether the process is operated with air or oxygen. Generally speaking, if air is used as the oxidant, it is possible, without the addition of large quantities of steam, to keep the temperatures down, and avoid ash fusion. When oxygen is used, the reaction is more intense, and temperatures can only be kept below the ash fusion point by the addition of large quantities of steam. The Purox gasifier uses oxygen and no steam, therefore operating in the slagging mode, while the Andco Torrax uses preheated air.

The advantage of slagging gasifiers is their greater volume reduction capability, 95-98% as compared with a 90% reduction for non-slagging units. (This is of importance when considering a process for waste disposal applications). However, the high operating temperatures can present problems and the following factors need to be considered when operating slagging gasifiers (Cohen Bahr Lindsell & Partners, 1980).

> The proper formation of slag at the hearth zone is necessary, to prevent unreacted organic material from falling into the slag quench water below the hearth. With wood feedstocks, some ash or other fluxing agent may have to be added to the feed to encourage proper formation of the slag. Addition of ash may have further benefit in increasing the rate of gasification.

If slag tapping is performed on a discontinuous basis it represents a labour intensive operation. On a continuous basis, there will be auxiliary fuel requirements in order to maintain a clear slag-tap hole.

Refractory maintenance could be high because of slag reactivity, and physical wear on discharge to the quench. High purity refractory may be required.

Although problems may occur when operating a fixed bed gasifier in the slagging mode, it has certain advantages.

The gasifier has a higher efficiency because of the reduction in steam consumption. It is possible that none will be required.

The operating temperature of the gasifier will be higher, leading to lower levels of methane formation, and other hydrocarbons.

The throughput of slagging gasifiers is higher than for the non-slagging.

Slagging operation is generally regarded in a more favourable light when the gas produced is to be used downstream for synthesis of other fuels or chemicals. This is because of the lower methane and other hydrocarbon production levels.

Two stage gasifiers have been developed more recently to improve the gasification of volatile feedstocks. In these gasifiers, some of the gas is removed from the top distillation zone as before, but gas is also removed directly from the bottom gasification zone. The advantage of doing this is that the volatiles are distilled off more slowly and gently without cracking, polymerizing, or forming other undesirable by-products. Experience with these on coal has revealed thermal efficiencies about 10% higher than single stage gasifiers. The Motala-Pyrogas unit is the only one that has been commercialised with biomass.

4.2.2.1 Methanol Synthesis

The synthesis of methanol from carbon monoxide and hydrogen is an established industrial process. Conventional high-pressure synthesis, which was discovered in 1923, is performed at pressures around 30 MPa. Chrome oxide/zinc oxide catalysts are generally used in the high pressure synthesis that convert the carbon monoxide and hydrogen-rich gas mixture, known as synthesis gas, at temperatures between 320°C and 380°C according to the following equation:

$$CO + 2H_2 = CH_3OH$$

In a carbon monoxide and hydrogen reaction system many other reactions can also take place. For example, higher alcohols, formaldehyde, methane, and other heavier hydrocarbons can be formed during methanol synthesis. The operating conditions, i.e. temperature and pressure, and use of a selective catalyst suppress the formation of these undesirable products. A large portion of the carbon dioxide present in the system, either coming from the synthesis gas or produced during the methanol synthesis, is converted to methanol as follows:

$$CO_2 + 3H_2 = CH_3OH + H_2O$$

The major achievement in the methanol synthesis technology was the development of a low-pressure process. In the 1960s, ICI developed a new copper-based catalyst that is much more active than the conventional chrome oxide/zinc oxide catalyst at low pressures. The development of this new catalyst made it possible for the methanol synthesis reaction to take place at low pressures in the range of 5,1 to 10,3 MPa. Since this development, many commercial methanol synthesis plants, have been designed, constructed, and successfully operated. In all new methanol plant construction, the low-pressure technology is being used.

Currently, methanol synthesis is used exclusively in the chemical industry, where the product methanol is used in the production of other chemicals (particulary formaldehyde) and solvents. The use of methanol as a fuel is not practised at present. However, it is considered to be a potentially attractive substitute for petroleum-derived liquid fuels. It also offers the potential of direct gasoline synthesis using the Mobil conversion process.

The synthesis gas required for methanol synthesis can be produced from a variety of carbonaceous feedstocks. The methanol plants around the world today use natural gas, naphtha, fuel oil and increasingly, coal as feedstocks. The gasification of certain biomass feedstocks can also produce a synthesis gas suitable for methanol production. The potential use of such a gas is good, especially as most biomass feedstocks are low in sulphur compounds.

Biomass feedstocks have been considered for methanol synthesis in the past. For example, a wood to methanol pilot plant, producing about 5 t/day of methanol from 16 t/day of dry wood was operated in France during World War II. Present day calculations estimate that the optimum biomass-based plants should produce more than 140 million l/yr of methanol.

The CSIR has indicated that there might be scope for a methanol plant in the Eastern Transvaal (White, 1978). Investigations have also been carried out on behalf of the SA Forestry Council (Cohen, Bahr, Lindsell & Partners, 1980). The results of their analysis were that three forestry zones are candidates for methanol plants. The areas investigated are within a 60km radius of Graskop in the Eastern Transvaal, Lothair in the South Eastern Transvaal and Pietermaritzburg in the Natal Midlands. The potential surplus for each of these areas was estimated to be over 2 million m^3 of timber. However, these figures should be treated with caution, as it was not known whether this timber was already committed or not, and the final recommendation of the report was that a more extensive investigation was necessary to determine the best location for such a plant.

4.2.2.2 The National Producer Gas Project

In 1979 the Steering Committee for the Application of Producer Gas was established, and consisted of members from a broad spectrum of interests, including timber producers, gasification equipment manufacturers, various government departments, and members of various CSIR institutes.

The committee's first task was to establish the potential for application in South Africa. A survey involving 8 000 questionnaires, 4 210 (659 replies) to industry and 4 000 (793 replies) to the agricultural sector was carried out. The results revealed a very high acceptance rate of the concept, and a very large potential market in the agricultural sector should the equipment become available, and providing that the payback period was less than two years (Gore, 1981). The major potential applications are for well and irrigation pumps, and electricity generation, with 47% of the requirement being for engines with outputs from 10-30 kW.

Because equipment to meet this low energy requirement application had not been developed overseas a woodgas generation project was established by the NTRI to coordinate and carry out research, development and demonstration activities to meet this need. This programme is also coordinating the development of larger scale gasifiers for use in industrial heating applications. Examples of such uses are the heating of timber drying kilns at sawmills and cogeneration plants at sawmills and on industrial sites that might have large quantities of biomass wastes e.g. furniture factories.

To expand on the above, as more and more industrial areas are opening up, so the problems of waste disposal increase. However, with careful planning of these areas the wastes generated could be put to use on site. A case in point is a timber processing factory located next to a car spraypainting works. The latter has a heat requirement for the baking of the paintwork, while the former is generating a large quantity of sawdust and off-cuts that would otherwise have to be disposed of at some cost. By installing a gasifier, this waste can be put to use, and in fact generate income, while at the same time reducing the spraypainting works' power bill. Such a scheme also has the advantage of decentralizing the energy production and distribution network. However, caution must be exercised, and for such a scheme to be successful careful planning is of utmost importance.

To return to the producer gas project, an objective was set by the committee to replace 1,75 million l of imported crude by 1985. This would involve the gasification of some 4 million t/yr of biomass.

Although the NTRI is still confident that this target will be met, the programme has been slower in its realisation than was hoped. This has been mainly due to technical problems, athough economics have been a contributing factor. The feeling is that by the end of 1986, the country's total wood gasification rate may be in the order of 1 000 green tonnes/month, and will only then begin to rise sharply, as potential users and financiers accept the woodgas concept.

To give an idea of the economics, the cost of electricity generation using an internal combustion engine run off producer gas is about 11c/kWh if wood is not costed, and 15c/kWh if costed at R30/dry t (Hose, 1984). By contrast, a diesel generating set produces electricity at about 29c/kWh (with diesel at 51c/l - bulk price), while ESCOM grid power ranges between 3,5 and 10c/kWh depending on locality, demand and extension charges, with the price going as high as 13c/kWh in some rural areas.

4.2.3 CARBONISATION

The carbonisation of biomass, or charcoal production has been going on for centuries. The conversion of the biomass is actually a pyrolytic process,and the technologies available for charcoal manufacture can be split into two groups:

Kiln processes
Retort processes

Both processes involve the heating of the wood to high temperatures, causing thermal degradation producing charcoal, condensable and noncondensable volatiles. In the kiln process, part of the wood is burnt to sustain the temperatures required for the pyrolysis. Once the temperature reaches 280°C, the process becomes exothermic and oxygen supply to the kiln can be cut off. In most kilns, the carbonisation zone is drawn through the kiln by sequential opening and closing of air inlets.

In the retort process, the wood is packed in a closed vessel while heat is applied from outside, either through the retort wall, or through heating coils leading through the wood. Using retorts none of the wood is lost through uncontrolled burning, and usually 33-34% charcoal is produced, the maximum theoretically obtainable yield. The heat needed can be produced by burning coal, oil, or volatiles from the pyrolysis process. Obviously, the latter is the most desirable, but requires careful control and is easiest when continuous retorts are used. Alternatively, a bank of batch retorts can be operated in this fashion, with staggered processing times.

4.2.3.1 The Brazilian beehive kiln

Large quantities of charcoal are produced in Brazil for iron ore reduction. For this purpose large $50m^3$ beehive-shaped kilns, capable of taking about 20 t of wood are used. The charge is ignited through a hole in the roof and air flows are controlled through air inlets situated all over the roof at 0,7m intervals. The carbonisation zone is drawn downwards through the kiln, and temperatures of 400-450°C are achieved. These kilns have an average life of five years, and achieve yields of 25%.

4.2.3.2 The Mark V kiln

This consists of two interlocking cylinders with a capacity of about $7m^3$, and is portable. It was developed in Uganda by the FAO in the early seventies, but has subsequently spread all over the world. The kiln has eight air inlets which are used to control the carbonisation, while the lid is conical and has a hole for igniting the charge. Each batch operation will produce between 0,5 and 0,8 t of charcoal every two days, depending on the moisture content and density of the wood. Conversions of 22-30% are achievable.

4.2.3.3 The Nichols-Herreshoff Furnace process

The basic system consists of the Herreshoff multiple-hearth furnace, which has long been used for roasting operations in the minerals industry. Current US technology for charcoal production is based primarily on this process, using wood or wood residue as feedstock. One of these furnaces is currently in use at Piet Retief in the Eastern Transvaal.

4.3 BIOCHEMICAL PROCESSES

These processes make use of the biochemistry of the raw materials, and the metabolic action of microbial organisms, to produce fuels.

4.3.1 ANAEROBIC FERMENTATION

In the process of anaerobic fermentation, organic matter is completely degraded to the gaseous products, CH_4 and CO_2, with about 90% of the energy content of the substrate being retained in the methane. Although a large amount of organic matter is degraded, only a relatively low yield of microbial cells is obtained. This process is very important for the carbon and nitrogen cycles in nature and it has long been used for the stabilisation of sewage and other organic wastes. In addition it great potential for use in converting biomass sources such as animal manures, agricultural products and residues, and municipal wastes into an energy-rich fuel.

Bacteria are primarily responsible for the fermentation, but anaerobic fermentative protozoa, some anaerobic fungi, and other organisms may also be important in certain environments. The metabolism and growth of one species is often dependent on its interactions with other microbial species. The complete fermentation occurs in a large number of anaerobic environments that have a slow turnover of material and where the main electron acceptor, CO_2, is produced from the degraded substrates e.g. swamps, aquatic sediments of lakes. It does not occur in environments where other electron acceptors such as oxygen, nitrate, sulphur or sulphates are readily available.

Biochemically, this process is fairly complex, consisting of three phases of microbiological transformation. However, it must be remembered that the physiology and metabolism of the microorganisms involved can not be separated, as the effective metabolism of the one group is dependent on the others.

In the first phase, fermentative bacteria hydrolyse primary substrate polymers such as polysaccharides, proteins and lipids, and ferment the products, mainly to acetate and other saturated fatty acids, CO_2 and H_2. The second group called obligate H_2-producing acetogenic bacteria produce acetate, H_2, and in some cases, CO_2, from the end-products of the first group. Methanogens catabolise mainly acetate, CO_2, and H_2 to the terminal products.

Cellulose is the most prominent of the higher molecular mass compounds, comprising over 35% of the total solids content of most organic feedstocks. The digestibility of the feedstocks is affected by the amount of lignin and other indigestible plant wall components. The efficiency of the fermentation is related to the retention time of the material in the reactor and to the volumetric loading rate. In most fermentations, the rate-limiting step is the degradation of fatty acids. Environmental and nutrient parameters must be maintained at optimal levels for efficient fermentation.

Distinctly different groups of methanogenic bacteria exist, depending on the temperature range in which the fermentation is taking place. Thermophilic microbial species are active in fermentation at temperatures of about 45-60°C, as compared to the mesophilic species found in the 30-45°C range and the cryophilic which are found at temperatures between 0 and 30°C. The bacteria in each group are very temperature-sensitive, and changes of as little as 3°C over a short time span, can result in the destruction of the microbial population.

The optimum feed for biogas production should have a carbon to nitrogen ratio of between 25:1 and 30:1. Experience has shown that gas production can be boosted by supplementing substrates that have a high carbon content with substrates containing nitrogen, and vice versa. The nitrogen is essential for the reproduction of the bacteria, as it is one of the prime building blocks of their cell walls. If on the other hand there is too much nitrogen present, ammonia will be formed. Its concentration may rise to the point where it inhibits further growth, and methane production will be seriously affected. Thus to optimise methane production feedstocks should be mixed to obtain a C:N of as close to 30:1 as possible.

Approximate nitrogen content and C:N ratios of various waste materials (Dry-mass basis)

Material	N%	C:N
Animal wastes		
Urine	15-18	0,8
Blood	10-14	3
Fish scraps	6,5-10	5,1
Mixed abbatoir wastes	7-10	2
Pig manure	3,8	13
Horse manure	2,3	25
Cow manure	1,7	18
Farmyard manure (average)	2,15	14
Plant wastes		
Hay	4,0	12
Lucerne	3,0	20
Seaweed	1,9	19
Wheat straw	0,3	128
Raw sawdust	0,1	511
Rotted sawdust	0,25	208
Household wastes		
Raw refuse	2,2	25

The water content is also very important and should be around 80-90% of the total feed mass to the fermenter. With too little water, acids accumulate, inhibiting fermentation, while too much water dilutes the contents, resulting in a drop in gas production.

4.3.1.1 Anaerobic digester types and their operation

The most publicised anaerobic digesters are those used in rural China, of which there are reported to be 8 million in use (van Buren, 1979), and India. In China they were initially conceived of as a means of stabilising the sewage of rural communities, thereby reducing the incidence of disease caused by parasites and pathogens,but they have subsequently been optimised for the production of biogas. The Indian gobar (cow dung) gas project, on the other hand, was initiated with the intention of producing gas to try and alleviate rural energy problems.

The Chinese digester has no moving parts, the digester itself acting as the gasometer, with the liquid level providing the gas compression. These digesters were originally designed to be operated on a family basis, or at most with three families and their animals providing the feed for the unit. However, problems with the maintenance of these digesters, in particular the repair of leaks, has caused many of them to fall into disrepair. Larger digesters serving a community or village do however make use of separate gas storage tanks, and large polythene balloons have been used for this purpose, with good results (van Buren, 1979).

Research on the commercial application of anaerobic digestion commenced as early as 1814 when Davy, in a study of the fertiliser value of raw and digested cattle manure, collected biogas in a retort under vacuum. The first exploitation of anaerobic digestion as a fuel-production system is attributed to Cameron, who used the gas from a "carefully designed" septic tank for street lighting in the vicinity of the sewage treatment works in Exeter in 1895. Since then, anaerobic digestion has been associated with the treatment of domestic sewage sludge using specifically constructed, heated digesters of a size appropriate for the digestion of municipal sewage sludges.

The conventional sludge digestion reactor consists essentially of a completely mixed, one step process operating on a continuous basis without solids recycle. Due to the low specific growth rate of the methanogenic bacteria, effective digestion of the waste in a conventional reactor can only be obtained at long retention times. In practice, liquid retention times of 20 days or longer are considered to be essential for efficient waste stabilisation with the result that conventional digesters tend to be of large size involving high initial capital costs.

The concept of biological solids recycle, which led to the introduction of the anaerobic contact or anaerobic activated sludge process, permits a longer residence time for the active flora within the digester and results in more efficient waste stabilisation and significantly higher gas volume efficiencies. Retention of the active biomass, independently of waste flow, considerably reduces the liquid retention time necessary for effective treatment, thereby resulting in a smaller volume unit and more favourable economics.

The development of the anaerobic contact reactor encouraged the application of anaerobic digestion to the treatment of a variety of wastewaters of varying solids content and COD strength. Efficient operation of this design is, however, critically dependent on effective separation of the solids from the effluent stream and this can be both troublesome and costly. Solids separation is particularly difficult with soluble wastes since the biological solids often remain dispersed or only lightly flocculated and a significant fraction may be lost with the liquid effluent stream. Furthermore, high rates of solids recycle are often required, in order to maintain a satisfactory treatment efficiency.

Increasingly stringent pollution control regulations coupled with the rising energy costs of aerobic treatment systems in the early seventies greatly stimulated interest in anaerobic digestion as an energy-saving waste treatment technology. This interest led to the development of a range of digester designs suitable for the treatment of high and low strength soluble wastewaters of industrial origin.

These second generation reactors have in common, a retention of the microbial biomass within the reactor, by mechanisms which avoid the costly operational problems associated with the solids recycle system of the anaerobic contact process. In contrast to the earlier designs, the new digesters are retained-biomass reactors and their mode of operation relies on the propensity of bacteria, especially the methanogens, for attachment to solid surfaces. In the upflow anaerobic sludge blanket (UASB) reactor, the microbial flora attach themselves to each other or to small particles of suspended matter to form conglomerates or granules. The granules are retained within the reactor for extremely long periods by an efficient liquid-solids separator device.

Retention and maintenance of biological growth on a purposefully introduced inert support material also forms the theoretical basis for the operation of the upflow anaerobic filter, downflow fixed film reactor and fluidised bed process. In the anaerobic filter, the bacteria become attached to the support surfaces and are entrapped as granules or flocs in the void spaces between the support matrix particles.

The downflow fixed film reactor retains the active biomass as an attached film on an inert support material such as glass, fired clay or plastic. The fluidised bed process also relies on the retention, within the digester, of an expanded or fluidised bed of particles consisting of a film of active bacteria attached to a particle of sand, activated carbon, glass or some other inert material.

The performance of these four digester designs is obviously largely dependent on the extent to which the biomass is retained within the reactor. In the UASB process, retention of the biomass is rendered feasible by the inclusion of an efficient built-in settler device and the amount of retained biomass is generally larger per unit reactor volume than in downflow fixed film or upflow filter digesters. Retention is, however, limited by the settling rate of the particles and by the fluid properties of concentrated biomass suspensions. The amount of retained biomass in a downflow fixed film reactor depends on the surface to volume ratio and is therefore limited by the support matrix area. The fixed film reactor has the advantage, however, that, whereas suspended biomass is susceptible to washout by hydraulic shock loading rates, biomass attached to stationary supports is not. The anaerobic filter can maintain a higher biomass content than the downflow fixed film reactor due to the presence of both surface attached bacteria and conglomerate forms retained in the interstitial spaces within the support bed. Washout of the suspended biomass from the filter is not considered to pose any operational problems since the support matrix should physically impede washout during hydraulic shock loads.

The upflow operational mode of the UASB, the anaerobic filter and the fluidised bed reactor may pose problems during digestion of wastes containing appreciable levels of suspended solids. Although suspended solids of a largely digestible organic content may be tolerated to varying extents by these three designs, suspended particles which are indigestible and/or inorganic in nature may seriously decrease reactor efficiency by plugging or clogging the sludge blanket or the filter matrix.

Although the four designs differ significantly from one another with respect to layout and operational parameters, their common characteristic of active biomass retention permits reduction of the liquid retention time from the 10-20 days characteristic of conventional and anaerobic contact digesters, to periods ranging from several hours to several days. Reduction of the retention time ensures that these reactors are capable of methane production rates per volume of reactor which are significantly higher (by 2-10 times) than the rates previously obtainable by first generation designs. Reduction of the liquid retention time also implies considerable initial capital cost savings due to the decreased size requirement for the reactor.

The conventional and anaerobic contact reactor designs are applicable to the digestion of reasonably concentrated wastes with an appreciable suspended solids content. Retained biomass digesters provide a range of reactor designs ideally suited to the digestion of soluble low and high strength wastewaters and, as such, significantly increase the scope and potential application of anaerobic digestion both as an alternative energy production system and as an energy-saving, effluent treatment system.

The application of second generation digesters to biogas production from agricultural wastes appears, at first sight, to be severely limited by the high solids content of these wastes. This limitation would, however, be greatly diminished by a two-stage system in which hydrolysis and liquification of the solid polymeric material occurs, outside the methane reactor, in a first stage unit of simple design. The liquified material could then be passes to a second stage methanation reactor for efficient conversion to CH_4 and CO_2. Two-stage systems using conventional mixed reactors have been studied with encouraging results. Since the liquified material should have a low suspended solids content, the incorporation of a retained biomass reactor as the second stage reactor should allow more efficient methanation at short liquid retention times.

Research has been done on the use of an anaerobic filter for the digestion of agricultural wastes, and encouraging results have been obtained (Colleran et al, 1982). The substrates used were pig slurry, silage effluent and milk washing wastes. The temperatures of operation were in the mesophilic range, around 30°C and liquid retention times were three days for the first two, and half a day for the third feedstock, while the yields of biogas obtained were the following:

Substrate	Yield of biogas		CH4 content
Pig slurry	$6{,}7m^3/m^3$	digester/day	80-85%
Silage effluent	4,4	ditto	85%
Milk wastes (eg. whey)	1,8	ditto	82%

By comparison, a South African pig farmer who, in the 1950s and 1960s designed and operated two large plugflow digesters on his farm near Rustenburg, obtained a gas yield of $1m^3/m^3$ digester/day at an operating temperature of 35°C, and retention time of 15 days (Fry, 1974).

The yields obtained from the anaerobic filter based on volatile solids fed to it were as follows:

Substrate	Yield of biogas
Pig slurry	0,714 m^3/kg VS
Silage effluent	1,1 ditto

Typical values from the literature would be in the range 0,4-0,5 m^3/kg VS added, using primarily animal manures, human waste and crop residues as feed, with retention times of between 10 and 20 days. The methane content of the gas is usually expected to be about 60%, thus giving a CH_4 yield of 0,22-0,3 m^3/kg VS added, over an average retention time of 15 days (National Academy of Sciences, 1977).

It must be remembered that the anaerobic filter results were obtained from pilot scale digesters of 9 000-litre capacity, operating under laboratory conditions. Nonetheless, the results are very encouraging, and no problems are envisaged in the scaling up of the process to commercial size plants.

The anaerobic filter design has a variety of operational characteristics which make it particularly suitable for on-farm operation:

Inexpensive to construct and maintain compared to more conventional designs.

Rapid start-up with a minimum of operational problems.

Ability to withstand shock loadings without a significant loss in digestion efficiency.

Tolerance to pH variation.

High COD removal rates, 70-80%.

High CH_4 content (more than 70%) in the biogas product.

4.3.1.2 Methane production in a landfill

Sanitary landfilling is a method of controlled solid waste disposal in which four basic functions are performed:

The landfill site is prepared to accept the municipal solid wastes,

The wastes are deposited, spread out, and compacted in thin layers,

These wastes are regularly covered; and

The cover material is then compacted.

The final recovered site could be developed into recreational, storage or agricultural facilities.

The basic operation is comprised of the processes of spreading, compacting, and covering the solid wastes. Two common sanitary landfill methods, are the area and trench methods. A third method, the slope or ramp landfill, is sometimes used in combination with the area or trench methods.

The area sanitary landfill requires the solid wastes to be deposited on the land and then be spread and compacted by a bulldozer or other equipment. The wastes are then covered with a layer of soil which is compacted. This is best applied to flat or gently sloping terrain, and is also used to fill land depressions such as quarries, ravines, valleys, etc. Normally, the soil and other cover material must be trucked to the sanitary landfill sites, but sometimes it is available at the site.

The trench sanitary landfill requires a trench into which the wastes are deposited to be dug. These wastes are spread in thin layers, compacted, and covered with the dirt originally removed from the trench. The trench method is best applied to flat terrains with water tables that are relatively deep. Under normal conditions the material originally removed from the trench are utilised, requiring a minimum of hauling for cover.

The ramp or slope method (a variation of the area and trench landfills) requires the solid wastes to be deposited on the side of an existing slope. The wastes are spread in thin layers and compacted on the slope by bulldozing equipment. The cover material is usually obtained just ahead of the working face and spread and compacted on the slope. This variation of landfilling is generally acceptable to all terrains and is commonly used with either area or trench sanitary landfill techniques.

A typical gas production process in a landfill can be achieved, providing two basic criteria are met. Firstly, after the solid waste is placed in the landfill no aeration occurs, and secondly, environmental conditions within the landfill are sufficient to encourage and sustain anaerobic digestion.

Methane gas production in a sanitary landfill involves four stages:

Stage I - Aerobic,

Stage II - Anaerobic Non-Methanogenic,

Stage III - Anaerobic Methanogenic Unsteady, and

Stage IV - Anaerobic Methanogenic Steady.

Stage I occurs at the time of placement of the solid wastes in the landfill, as the oxygen present in them is utilised effecting aerobic decomposition.

The stage II process of anaerobic activity begins after the oxygen supply is depleted. During this period the maximum concentration of carbon dioxide occurs and hydrogen production begins. Nitrogen is simultaneously displaced and then produced by a denitrification process. The lag in methane production after the anaerobic process begins is probably due to the need for adequate amounts of CO_2 to act as a hydrogen acceptor. This is similar to the acid formation stage of methane fermentation previously discussed.

Studies at landfill sites have shown the gases generated to have peak CO_2 concentrations of 70% within 11 days of deposition, indicating a rapid decomposition of certain carbohydrates and other readily decomposable materials. In similar studies maximum CO_2 concentrations of 95% after 45 days in a simulated test cells were observed.

Stage II hydrogen concentrations are approximately 20% by volume.

Stage III is characterised by increasing concentrations of methane until its generation stabilises. The methanogenic bacteria become increasingly active and use up the available landfill hydrogen. Carbon dioxide and nitrogen concentrations are also reduced.

The completion time for all three stages varies widely with each solid waste. Time intervals of 180, 250, and 500 days have been observed.

During Stage IV the gas production rate and composition should remain constant. Landfill gas compositions of this stage have a methane content of 50 to 70% and a carbon dioxide content of 30 to 50%.

These stages of decomposition do not occur in succession, but usually in combinations, where one or two processes become dominant depending on environmental conditions and then another one takes over, etc. For example, should oxygen be made available to the solid waste by external means, Stages III and IV anaerobic decomposition will cease and Stage I will begin.

Estimating the potential energy (the amount of methane) available in a landfill is a difficult if not impossible task. The structural, physical, and chemical characteristics of landfills are infinitely variable. To estimate the methane potential the following parameters must be known:

The type and extent of biological decomposition (i.e. the amount of methane generated),

The amount of methane which has escaped or is escaping, and

The rate of methane generation.

Since each of these considerations is affected by a multitude of factors it is highly probable that no two landfills would exhibit exactly the same gassing patterns.

Recovery process

The logical method to extract methane from a landfill is by means of a well. In order to obtain the negative gas pressure gradient necessary for extraction a pump is also required. For a continuous operation the volume of gas extracted will ultimately have to be equal to the volume of the gaseous products of decomposition per unit time. The zone of influence of the negative pressure gradient caused by the pumping will determine the volume of gaseous products extracted. Limited test well data are available on pumping rates and the corresponding zones of influence.

It should be noted that upon initial operation of a well there is a considerable supply of gaseous products stored from time past. After a certain period of time this backlog of gaseous products will be exhausted, and extraction of a higher volume of gases than generated by decomposition will only serve to draw air into the landfill and cease anaerobic activity. High extraction rates probably can be sustained in continual operation. Therefore, the calculation of the maximum possible volume of gaseous products capable of sustained extraction for a well is made. This is done by calculating the stoichiometric products of decomposition of the solid waste, and using mathematical models that have been developed to predict gas generation rates (Cheremisinoff and Morresi, 1976).

The gaseous products of decomposition consist almost exclusively of carbon dioxide and methane. The landfill gases content of methane and carbon dioxide varies with the progressing stages of decomposition. However, for a reasonably progressed stage of decomposition the respective percentages are about 50:50. This gas mixture has a heating value of approximately 18,6 MJ/m^3.

4.3.1.3 Biogas Composition

The major constituents of biogas generated by stable fermentations are given below:

Constituent	Concentration
Methane	50-65% by vol
Carbon dioxide	35-50%
Moisture	30-160 g/m^3
Hydrogen sulphide	5 g/m3

As shown in the table, methane comprises about 50% to 65% of the biogas produced during anaerobic fermentation. It is a colourless, odourless, flammable gas which has an energy value of 37,3 MJ/m^3. Natural gas contains about 95% methane. The critical temperature and pressure of methane are -82°C and 4,6 MPa, respectively. Thus liquification of methane is not a practical alternative. Methane is flammable when mixed with air at concentrations between 5 to 15%, and because of this caution must be exercised to prevent accidental ignition.

Carbon dioxide is the other major constituent of biogas, and its predominant effect is to dilute the energy value from 37,3 MJ/m^3 to between 18 and 24 MJ/m^3, and to increase the volume of gas to be handled and stored. The lower energy value of biogas decreases the efficiency of internal combustion engines and requires minor burner modification for efficient combustion.

Water vapour in the biogas is an important contaminant which must be removed prior to use in most applications. Condensed water tends to accumulate in gas handling equipment and meters, causing malfunctions, potential for frozen pipes, and corrodes most metal parts when combined with the hydrogen sulphide and carbon dioxide.

Hydrogen sulphide is easily oxidised to sulphuric acid in the presence of water, and can cause significant corrosion if allowed to accumulate. The limit for use in internal combustion engines is 1,4 g/m^3. An average H_2S concentration of 1,9 g/m^3 (range: 1,7 to 2,1 g/m^3) in biogas from dairy manure fermented at 35°C (Pigg, 1977), while H_2S concentrations ranging from 4,0 to 12,5 g/m^3 in biogas from poultry manure fermented at 35°C have been reported (Converse et al, 1977). Data from the Roman L Hruska US Meat Animal Research centre shows an average H_2S concentration of 1,52 g/m^3 (standard deviation = 0.64) and no effect of fermentation temperature (range 45 to 65°C) on its concentration.

4.3.1.4 Biogas Cleaning

The degree of biogas cleaning needed depends on its eventual application, the least demanding in this respect being for on-farm direct burning. The minimum requirement in this case is moisture removal to prevent condensation in gas lines and excessive corrosion. This can be accomplished by simple frost-proof condensers and strategically located condensate traps. The concentration of H_2S in the biogas is generally not high enough to be a health or environmental hazard when oxidised during burning.

Available methods to clean biogas able to meet very stringent standards have been evaluated (Ashare et al, 1977). This assessment showed that water scrubbing was the most economical process used commercially. Two other processes, the phosphate buffer and membrane separation processes, look promising and were comparable in cost to water scrubbing. However, both of these processes have not been extensively field tested.

The water scrubbing process is relatively simple. The hydrogen sulphide-free biogas is compressed, and is then made to flow counter-current to water in a pressurised packed column. The scrubbed CO_2 is vented to the atmosphere and the water recycled back to the stripping column. The scrubbed gas is then dehumidified.

One of the simplest and most common methods to remove hydrogen sulphide is the iron oxide (or iron sponge) process. In this process, the hydrogen sulphide reacts chemically with ferric oxide to form ferric sulphide. Regeneration is accomplished by passing oxygen through the sponge to oxidise the ferric sulphide to elemental sulphur and ferric oxide. The ferric oxide is usually impregnated on wood shavings as a low-cost medium. Periodically, the ferric oxide must be recharged because the sulphur accumulation tends to reduce activity and increase the pressure drop through the bed. One cubic metre of iron sponge can clean approximately 33,000 m^3 of biogas containing 2 g H_2S/m^3.

Dehydration of biogas is best accomplished by absorption in ethylene or triethylene glycol solutions, in a counter-current pack or bubble tray column. The glycol is regenerated by inert gas stripping under heat.

4.3.1.5 Biogas Use

The two predominant uses of biogas are direct burning and fuelling of internal combustion engines. Examples of direct burning are for space heating of residential, commercial, or livestock facilities; crop drying and processing; and steam production. Use in stationary internal combustion engines is for prime movers and for generating electricity. Biogas is unlikely to be used to fuel mobile vehicles on a large scale because of its relatively incompressible properties.

The ultimate use of the biogas will depend upon the specific on-site energy requirements and the scale of operation. Facilities producing large amounts of gas could sell it to neighbouring users, while smaller facilities will generally have sufficient on-site use for the energy. The advantages of selling the biogas to large users are that the biogas is consumed as it is produced (minimum gas storage facilities are required) and the sales cover the costs of gas production. Disadvantages are that there are few locations where enough biogas could be produced to interest large users. In addition, in most cases more stringent gas quality requirements must be met, requiring gas cleaning and compression.

Examples of on-site use of biogas could be for adjacent meat packing facilities, steam flaking of grain for feedlots, heating livestock confinement facilities, and generating electricity for on-farm use. Specific on-farm use of the biogas will be described in more detail in a later section.

There are several advantages in using biogas as a fuel for internal combustion engines. Methane has a high octane rating and therefore, excellent anti-knocking qualities. It mixes well with air and results in more complete combustion, less residue in oil or exhaust gas, and less fouling of spark plugs. The only limitations on the use of gases in internal combustion engines are that they should be free of dust, noncorrosive (i.e. less than 1,4 g H_2S/m^3), not detonate, and not pre-ignite during the compression stroke. The gas can be used directly in Otto cycle engines while a pilot quantity of diesel oil is required to provide the ignition in a Diesel cycle engine.

The overall efficiency of the internal combustion engine can be increased by recovering and using the heat losses from the engine. The recoverable heat as a percentage of the heat input are shown below:

Engine heat losses	Efficiency %
Jacket cooling	20-30
Exhaust gases	26-30
Lubricating oil	5-7

These heat losses can be reclaimed as low temperature (75 to 85°C) process heat, which is ideally suited to maintaining optimum digester temperatures during methane fermentation.

During 1985 a University of Cape Town Mechanical Engineering final year student successfully converted a three-cylinder diesel engine to run in a dual-fuel mode on biogas produced from chicken manure. Work is also being done on the use of biogas in internal combustion engines by the Dept of Mechanical Engineering at the University of the Witwatersrand. This includes the use of straight biogas, and dual-fuel systems. Future work is planned on dual-fuelling a diesel engine. Several dual-fuelled and straight gas engine generators are in operation at various municipal sewage treatment works around the country (pers comm NIWR).

4.3.2 CELLULOSE HYDROLYSIS

Cellulose comprises the major part of all plant biomass. It is continuously being produced by photosynthesis, and is by far the most common naturally occurring carbohydrate. It is the basic building block of all woody substances, and for this reason is very seldom found in its pure form in nature. It occurs in natural fibres in close association with lignin and hemicelluloses, this material being referred to as holocellulose or lignocellulose.

Hydrolysis is the conversion of wood and other lignocellulosic feedstocks into fermentable sugars by means of either chemical or biological processes. Chemical processes use a mineral acid catalyst at relatively high pressures and temperatures, to break the large cellulose polymer down into it basic building blocks - glucose molecules, while biological processes make use of selective enzymes to perform the same. The chemistry can be simply represented as follows:

$$(C_6H_{10}O_5)_n + nH_2O = nC_6H_{12}O_6$$

Glucose is the major final product of any cellulose hydrolysis process. Stoichiometrically the yield of glucose should be 1,1 times the mass of cellulose in the feedstock.

Lignocellulosics are notably resistant to mild hydrolytic conditions and the real problems have arisen in attempting to perfect processes that carry out thorough hydrolysis of the cellulose to glucose, without the formation of glucose degradation products, some of which are harmful to many organisms.

The hemicellulose fraction of wood hydrolyses more readily than cellulose and yields mainly five carbon sugars (pentoses), the most common of which is xylose. The cellulose yields hexoses, of which glucose is the most common. During hydrolysis, the lignin fraction of the wood remains almost untouched, and is one of the major barriers to the hydrolysis process, especially when enzymes are used.

The glucose produced may find a direct nutritional use in cattle feeds or food, or be used as a substrate for fermentation, to produce other organic chemicals such as ethanol or acetic acid. Since most of the cellulosics of interest are lignocellulose residues, components other than cellulose are present and their degradation must also be considered. In fact, hemicelluloses occur in amounts almost equal to cellulose in some important residues, so pentoses will appear as products as will the other major component, lignin. While we speak of cellulose hydrolysis processes as producing glucose, it must be recognised that all components of the material used as a raw material must be effectively utilised.

The pentoses are not fermented to ethanol by the usual alcohol-producing yeasts. Although research is being carried out on the fermentation of pentoses to ethanol, at this stage, if wood is used as a feedstock for ethanol production, it is advisable to remove the pentoses by means of a mild pre-hydrolysis step. If they are not removed, they will be largely destroyed during the hydrolysis of cellulose and can inhibit the subsequent ethanol fermentation.

4.3.2.1 Acid Hydrolysis Processes

Processes using acids to hydrolyse lignocelluloses have been known since as early as 1851, when wood hydrolysis was attempted by Melsius, using dilute sulphuric acid under high temperature and pressure. The first commercial plant, based on this technology was built in the USA prior to World War I. Improvements by Heinrich Scholler to the basic process resulted in the construction of three plants in Germany during World War II. This dilute acid process was further improved by the Forest Products Laboratories in Madison, USA, and the Tennessee Valley Authority Laboratories in Alabama. Present activity in dilute acid hydrolysis is greatest in New Zealand, in the West, while commercial plants are operational in the USSR.

The acid hydrolysis process itself is quite simple and straightforward, but has several important limitations and disadvantages:

> The process often produces a mixed product stream of glucose, cellobiose and higher oligosaccharides of cellulose, hemicellulose hydrolysis products, and degradation products from the breakdown of sugar monomers into aldehydes and ketones.

Equipment is required that is resistant to acids at high temperature, and the waste or spent acid is difficult and expensive to recover.

Acid hydrolysis processes fall very broadly into three categories:

Dilute acid hydrolysis without separation of the product as it is formed.

Percolation of the acid and continuous removal of sugars as they are produced.

Concentrated acid used first to disrupt physical structure, after which acid is diluted for hydrolysis at less severe conditions.

All of these processes may be operated in several sequential stages to permit the separate removal of hemicelluloses, which hydrolyse under less severe conditions than cellulose, followed by an increase in the severity of process conditions to yield glucose from cellulose. As with all acid processes lignin is left as an insoluble residue. In commercial applications this lignin has always been burned as a fuel.

Acid hydrolysis technology has been modernised to some degree and several designs have been presented for processes that are claimed to be more efficient and economical than those used previously. Several of these processes are described hereafter.

Dilute acid hydrolysis

Acid hydrolysis processes, using both hydrochloric and sulphuric acid were used commercially during World War II. The most widely used is still the German Scholler process, where dilute sulphuric acid promotes the hydrolysis of the cellulosic fraction of the lignocellulosic feedstock to produce the sugars. Briefly, during the Scholler process, biomass feedstock, containing a high cellulosic fraction is fed into a digester. Steam is then used to raise the temperature to a specific point, at which stage a dilute sulphuric acid and recycle stream of hydrolysate are introduced, followed by the addition of hot water. The contents of the digester are kept at a constant temperature for a short time, during which most of the hemicellulose fraction is hydrolysed and removed from the digester.

Once the prehydrolysis is complete, dilute sulphuric with high pressure steam provides the necessary temperature and pressure for the main hydrolysis reaction. The reaction time for this stage is longer. Once it is complete, the contents of the digester are brought back to atmospheric pressure in a couple of stages.

The Scholler process was modified by the Forest Products Laboratory (Madison, Wisconsin, USA) during World War II. These modifications resulted in a shorter residence time for hydrolysis reactions, which prevented the excessive sugar degradation associated with the original Scholler process. Consequently, the Madison wood-sugar process yielded higher levels of fermentable sugars.

Percolation hydrolysis

This conventional acid hydrolysis process is based on the reaction of dilute 0,5% sulphuric acid with wood in a percolation reactor. The temperature of the reactor is raised slowly from an initial temperature of 150°C to a final temperature of 190°C, although the exact temperature range may vary depending on the wood species. Initially, the hemicellulose is hydrolysed. This is followed by cellulose conversion at higher temperatures.

However, the maximum sugar yields that can be obtained by this process are limited to 70% of the stoichiometric potential, as part of the sugars are decomposed at above 170°C under acidic conditions. Short residence times increase sugar yields, but result in low sugar concentrations. At the New Zealand Forest Research Institute (FRI), this problem has been partially overcome by recycling hydrolysates from cellulose conversion for hemicellulose hydrolysis, thereby increasing sugar concentrations to approximately 6% by mass in the hydrolysate. Yields of 245-260 l ethanol/t of pine wood have been reported by the New Zealand researchers, compared with about 200-230 l/t reported by others (Wayman and Dzenis, 1984).

The acid hydrolysis process plants in the Soviet Union are fed predominantly with wood wastes, but some cottonseed hulls and sunflower seed processing wastes are also used. The scope of this industry in Russia is thought to be of the order of 44 commercial plants, which produce both alcohol and fodder yeast. Apparently about 500 000 t/yr of yeast is produced.

The Russian process is largely unpublicised, but is apparently based on a modified version of the Scholler-Madison process. The lignocellulosic wastes are fed into the top of a cylindrical digester that has an open centre throughout its vertical height. As the lignocellulosic works its way down this annular space, sulphuric acid is passed from the inside of the annulus to the outside in a path that is almost 90° to the flow of the solids. Conditions at the top of the digester are relatively mild and hemicelluloses are hydrolysed. This hydrolysate is processed to yield xylose and xylanol. As the solids move lower, the digester conditions are more severe and cellulose is hydrolysed. All of the glucose syrup that is produced goes to the fermentation sections of the plant and the lignin residue exiting the bottom of the digester is burned for fuel.

There are no published economic studies of these plants, and it is recognised that their economic feasibility would be calculated differently in an open economy than it is in Russia.

Concentrated H_2SO_4 Solvent

In this process (Tsao et al, 1978), which is of type 3 as defined above, the lignocellulose is first contacted with dilute sulphuric acid and subjected to a prehydrolysis step where hemicelluloses are removed. Concentrated acid is then added and acts as a solvent for the cellulose. The swollen cellulose is then hydrolysed by dilute acid and glucose is precipitated with addition of methanol. Lime is used to neutralise the acid, and both the methanol and acid are recycled.

For 50 t of a lignocellulosic initially containing 34% cellulose, 40% hemicellulose, and 20% lignin, the projected products are 15 t of glucose (94% recovery of theoretical glucose) and 22 t of pentoses.

In a preliminary cost estimate it was assumed that cellulose residue was obtainable at $30/t, and the cost of raw material, less a credit given for fuel replacement by lignin, resulted in a cost of 3,5c/kg of sugar. Both pentoses and hexoses were counted as products and no costs of labour, depreciation of capital, interest, taxes, or return on investment were assigned.

Decrystallisation-hydrolysis, a process being developed at Purdue University, also by Tsao and his associates, is a refinement of the concentrated acid processes, which failed due to the difficulties in acid recycle. It aims at minimising the acid consumption, yet increasing yields and reducing by-product formation. This is achieved by reacting the dried lignocellulosic material with limited amount of concentrated sulphuric acid under controlled conditions. Cellulose hydrolysis is carried out under mild temperatures after dilution, and glucose solution can be recycled for hemicellulose hydrolysis. Stoichiometric yields are claimed for hemicellulose conversion, but only 60-80% for cellulose (Husain, 1984).

Major disadvantages of this process are low yields, and high acid consumption. However, it is being tested by Tennessee Valley Authority for agricultural waste processing.

Hydrogen Fluoride Process

This process, has been selected by Canertech for development to demonstration stage under a program funded by the Dept of Energy, Mines & Resources, Canada (Husain, 1984). Hydrogen fluoride (HF) was used in the early thirties in Germany, and a pilot plant based on liquid HF-wood reaction was built and operated for a short period. It was shut down because of the difficulties in recovering the acid. Recently, a number of research laboratories in North America and Europe have tested this process for a number of feedstocks, and have demonstrated that high yields and minimum HF losses with the reacted lignocellulosic material can be achieved. Work by Canertech to date has produced highly encouraging results.

The major feature of the HF process is the solvolysis of wood polysaccharides with anhydrous HF vapours to form fluoride compounds. HF can be recovered by increasing the temperature to approximately 80°C, leaving oligomeric sugars behind. Thus beta linkage, responsible for cellulose crystallinity, is broken, and the resulting oligomeric sugars can be hydrolysed to monomers through dilute acid hydrolysis under mild conditions. The major advantage gained through HF pretreatment is the yield, which is claimed to be in excess of 90% for all wood polysaccharides.

Recovery of HF is the single most important factor from an economic standpoint. A vapour phase reaction recycles HF within a closed adsorption-desorption loop, thus HF losses with the reacted wood are minimised. This process avoids the use of aqueous HF, as recovery from a liquid phase is expected to be very expensive and perhaps impractical because of the potentially severe materials problems.

Major disadvantages of the HF process are safety and environmental concerns related to HF handling.

Rapid acid hydrolysis

Two designs have been presented for rapid acid hydrolysis processes, both of which use newsprint as a feedstock (Grethlein, 1978). These are both dilute acid processes that are of type 1 as discussed above. The processes differ mainly in the concentration of newsprint used in the feed stream.

Both processes add sulphuric acid to the cellulose up to a strength of 1%. The slurry is heated very rapidly by steam injection to a reactor pressure of 35 kPa and temperature of 230°C. After a residence time of less than a second under these conditions, the stream is flashed and cooled to 135°C in a tank where lime is used to neutralise the acid. The insolubles are centrifuged from the product liquor and burned. The liquor itself contains 10% by mass sugars.

A comprehensive cost analysis on the process, which includes all costs except that of the newsprint, resulted in an estimate of 3,85c/kg glucose (with glucose in a 10% syrup).

Since the plant is designed to recover about one half of the theoretical glucose from the cellulose in newsprint, the cost contribution of the raw material cellulosic could easily be calculated. With current prices of waste news at about $24/t in the US, the cost of the substrate would add about 3,2c/lb of glucose.

4.3.2.2 Enzymatic Hydrolysis Processes

Certain enzymes are capable of hydrolysing cellulose to fermentable sugars. However, as was mentioned earlier, the cellulose in wood is relatively immune to attack by selected enzymes.

The major hurdles to enzymatic hydrolysis of wood are the lignin-cellulose bond, and the highly crystalline nature of cellulose. There are several thermochemical, mechanical and chemical pretreatment processes that are used to break up the lignocellulosic complex, and thereby render the cellulose susceptible to enzymatic hydrolysis. A steam explosion process proposed by a Canadian inventor, De Long, has proven to be successful at both breaking down the lignin-cellulose bond, and partially reducing the crystallinity of cellulose.

Enzymatic hydrolysis has the advantages of mild reaction conditions, moderate to high overall yields, and a solvent soluble lignin by-product. The biggest challenge is to reduce the cost of enzyme production, or alternatively find satisfactory ways of suspending the enzyme on some support, as a substantial percentage of enzymes are lost with unreacted cellulose. It appears that yields of glucose in excess of 90% can only be achieved by increasing enzyme dosages to a very high level, or by increasing residence time. Both of these features have negative economic consequences.

Processes that use cellulase enzymes to hydrolyse cellulose claim an advantage over acid processes on the basis that the product sugar stream is more homogeneous and does not contain aldehydic or ketonic glucose degradation products. This is, of course, of major importance if the product is intended for some nutritional or fermentation use. These processes additionally are operated at lower temperatures and pressures and produce no acid wastes.

Disadvantages of the enzyme hydrolysis processes are that an extensive plant section is needed to produce the enzyme, and the process is relatively slow compared to acid hydrolysis. Lignocelluloses must receive some pretreatment to yield commercially viable hydrolytic efficiencies and rates, and the treatment may be quite expensive. In fact, the lack of a standard pretreatment process with known effects and economics is a major reason for lack of commercialisation of this process at the present time.

General designs for enzymatic hydrolysis processes have been prepared and some of these are reviewed hereafter.

University of California

A process to hydrolyse waste newsprint to glucose has been designed by the research group at this university (Wilke et al, 1976). The newsprint is first shredded and hammer-milled to §20 mesh. The material is slurried with an enzyme and buffer solution and pumped through a series of hydrolysis tanks. The solid flow is counter-current to the liquid and residence time in the hydrolyser is 40 hr at 45°C. A solid to liquid ratio of 1:20 is fed to the hydrolyser.

Solids exiting the hydrolyser are washed and fed to a furnace to recover fuel value. A cellulose conversion of 50% is assumed and an enzyme concentration of 3,5 FPA (filter paper activity units - this is a measure of the enzyme activity) is used in the reactor. The liquid hydrolysate is contacted with the new cellulose feed stream, thus allowing enzymes to be adsorbed on to this material and be recycled back to the hydrolyser. An enzyme recovery of 95% is thought to be possible.

Design calculations have been done for a plant to handle 885 t/day of newsprint, and producing 238 t/day of a 4% glucose syrup. An extensive economic analysis was carried out for this process and glucose costs of from 8 to 13c/kg were calculated, depending on cellulose costs and operational variables.

US Army - Natick Process

Most early work dealing with the production of cellulases from *Trichoderma viride* (a fungus, first discovered on cotton cloth in the East during World War II) was done at the US Army Natick Research and Development Laboratories, and Nystrom and Allen, and Allen presented a plant design based on the use of *T. viride* cellulase on waste newsprint.

The process was designed to handle 58 t/day of newsprint and to produce 31,8 t/day of glucose in a 2,8% syrup. A 5% slurry of ball-milled newspaper was fed to hydrolysis tanks with a 24-hr residence time. A 50% conversion of cellulose to glucose was assumed, and no enzyme was recovered.

The CSIR bagasse enzymatic hydrolysis programme

A nationally coordinated research effort was initiated in 1979. The reasons for opting for enzymatic hydrolysis were (Purchase, 1983a):

> High temperatures are not involved thus preventing end-product degradation, and high yields of glucose, free from inhibitors, are theoretically possible.
>
> Corrosion problems associated with acid are avoided to a large extent.
>
> There is more scope for advance because of the novel nature of the concept.

Bagasse was chosen as the raw material because of its already developed collection system, and ethanol was seen as the most promising product, given its fuel value and usefulness as an organic chemical building block. However, because it consists of only 40% cellulose with 33% hemicellulose and 22% lignin, it was soon realised that the research effort could not be confined to the conversion of cellulose alone. The hemicellulose fraction was found to be relatively easily hydrolysed with dilute acid, xylose being the main hydrolysis product.

Until recently xylose was not considered a suitable feedstock for ethanol production. Various useful organisms, including a few yeasts, have now been isolated, amongst them Pachysolen tannophilus and Candida shehatae. Although the discovery of these pentose fermenting yeasts has paved the way for more complete use of plant residues, various problems such as the slow rate of fermentation, and the production of xylitol as well as ethanol during fermentation have to be overcome before a successful ethanol process can be devised. Valuable work in this latter field is being done by researchers at the Dept of Microbiology, University of the Orange Free State.

An alternative approach is to use an enzyme to isomerise xylose to xylulose and to then use an existing ethanol producing yeast. The isomerase enzyme is presently used on a large scale to make high fructose corn syrup, and the potential of the approach has been demonstrated but the process is not yet efficient. Attempts are being made to genetically modify yeasts to produce the necessary xylose isomerase enzyme itself (Purchase, 1983a).

The cellulose in raw bagasse, and in bagasse which has been treated to remove hemicellulose, is not very susceptible to enzymatic hydrolysis. Some form of pretreatment is necessary to increase its accessibility to the enzyme. Various chemical methods are effective, but tend to remove part of the cellulose (Neytzell-de Wilde and Lussi, 1981). Physical pretreatments are also effective, but generally too costly in terms of energy. Work at the Sugar Milling Research Institute (SMRI) has concentrated on pretreatments and it was noticed that when prehydrolysed bagasse (from which most of the hemicellulose has been removed) was milled, there was a substantial reduction in milling energy consumption (Purchase, 1983b).

Furfural is produced from bagasse by steaming it at a temperature high enough to hydrolyse the hemicellulose and convert the xylose to furfural. After steaming the bagasse is explosively decompressed. This is usually a good pretreatment for hydrolysis, but enzymatic hydrolysis tests on bagasse from a furfural plant gave conversion yields of only 30%. It was suspected that the harsh steaming methods produced phenols which interfered with the enzyme (Purchase, 1983a). This showed that if an economical method of phenol removal can be found, the bagasse residue from a furfural plant provides an excellent hydrolysis substrate requiring the minimum of further pretreatment. The CG Smith plant at Sezela would provide enough to produce approximately 15 million l of ethanol/yr (Purchase, 1983a).

The major barrier to the commercialisation of the enzymatic hydrolysis process is the high cost of the enzyme. However, recently considerable progress has been made by research workers at the National Food Research Institute of the CSIR, using a microorganism known as Trichoderma reesei RUT-C30, and in fact their present yields of cellulase are the highest in the world (Watson et al, 1984).

At this stage sufficient basic research has been done to warrant the setting up of a small-scale plant for bagasse hydrolysis. This is currently in progress at the SMRI at the University of Natal. This work should provide more valuable information regarding the whole process, and hopefully help to develop the expertise necessary for the setting up of a pilot plant and subsequent full-scale plants.

4.3.2.3 Direct microbial conversion of cellulose

The concept of direct microbial conversion of cellulose is rather simple. In its most elegant form it involves the production of a single product by a single organism growing on a cellulose-rich substrate. A slightly more elaborate approach calls for two organisms, one which degrades cellulose and yields product from the hexose sugars while making available pentose sugars for consumption by a second organism which also produces the desired product. In both schemes it is assumed that hexose and pentose sugars will be converted to the desired product, allowing more complete utilisation of the lignocellulose.

This concept is not easily realised in practice. Although there are thousands of cellulosic microbes, none have been found to be particularly efficient producers of ethanol. Efforts have focused on finding efficient dual microbe systems or improving the efficiency of the few candidates for a single microbe system. As a result, the concept of direct microbial conversion has been pursued exclusively as a basic research effort. There are currently no integrated processes for direct microbial conversion.

The basic process consists of five essential operations: pretreatment of the cellulosic feedstock, preparation of the fermentation wort, fermentation of the cellulose, recovery of the ethanol, and processing of the by-products and/or wastes.

The cellulosic material is first milled to facilitate its handling and allow it to be slurried, pumped and stirred in the subsequent unit operations. The degree of milling required is not accurately known. Additional pretreatment to enhance the susceptibility of the feedstock to microbial attack may be required. The more recalcitrant substrates may have to undergo crude pulping treatment before further processing.

The pretreated material is mixed with nutrients and water to produce a fermentable wort. This is then thermally sterilised and sent to the fermentation tanks.

The fermentation operation employs either a mixed or monoculture of microorganisms and can be batch or continuous. The length of fermentation varies, depending on the microbial system and the degree of cellulose conversion desired. Typical fermentation times for bacterial systems are between 24 and 36 hours, while fungal cultures require 5 to 10 days. After fermentation the beer is filtered and sent to distillation for recovery of alcohol. The recovery of ethanol from the beer can be handled in a manner similar to that described for acid or enzyme hydrolysis.

Fermentation by-products (e.g. lactate and acetate for Clostridium-based technology) are present in the stillage and must be treated. A favoured approach could be anaerobic waste treatment to produce methane to supplement the energy requirements for the process. Since the pentose sugars are fermented to alcohol or organic acids, there is little benefit in concentrating the stillage for recovery of solubles.

In theory, nearly any cellulosic feedstock can be converted. However, as with enzymatic conversion, the materials must be in a form easily degraded by the microbes and their enzymes. Since most work has been limited to laboratory studies with highly treated or refined cellulosic materials, it is impossible to determine which of the feedstocks and pretreatments will be most desirable for direct conversion.

The hexosan and pentosan composition of the feedstock should theoretically make no difference, since both hexose and pentose are converted with equal efficiency to products (ethanol). There would therefore seem to be an advantage to processing hardwoods over softwoods, particularly if they are first treated by explosive decompression with steam. As previously mentioned, hardwoods are higher in total carbohydrate (hemicellulose and cellulose) than softwoods and are made more readily digestible by this pretreatment process.

There are three potential advantages to a process based on direct microbial conversion. Since both pentosan and hexosan fractions of the feedstock can be used, direct conversion offers the highest theoretical yields of the processes discussed here. Another advantage is that fewer unit operations are needed, since cellulose conversion and alcohol production occur in the same step; likewise, there is no requirement for enzyme production or recovery. In addition, the thermophilic bacterial fermentations have low cooling water requirements.

Despite these advantages, direct conversion also has several potential limitations. The major difficulties have been caused by the low tolerance of the microbes for ethanol and the production of unwanted by-products (lactate and acetate). Ethanol tolerance has been increased and may in time approach the levels of conventional yeasts. The production of lactate and acetate has been greatly suppressed through microbial mutation, but the occasional reversion of these mutants and contamination by other nonhomofermentative bacteria are recurring problems.

4.3.2.4 Uses of by-product lignin

Lignin constitutes about 20% of photosynthetic biomass and as such also represents an abundant renewable resource. In the pulp and paper industry, large quantities of lignin are generated by the kraft and sulphite processes. Although some of the sulphite lignin is used for speciality chemicals, most of it is burned as fuel.

As can be imagined, if a cellulose to ethanol route is to be followed, large quantities of lignin are probably going to be generated in the hydrolysis process. As this route is now marginal, a by-product credit for these lignins will significantly enhance the economics of the fuels from lignocellulosics processes.

Since lignin can be used as a fuel, its fuel value becomes the economic lower bound for comparison of its various applications. The lignin-rich residue from bagasse hydrolysis, for example, dries to coal-like lumps and contains at least 30% of the fuel value of the original bagasse.

Existing markets for lignins are polymers, modified polymers, prepolymers, low-molecular-mass chemicals, and fuels. Polymers are high-molecular-mass lignins, which can be used as fillers, extenders, and encapsulants. Modified polymers require the attachment of chemical groups to produce surfactants, dispersants and coagulants. Prepolymers represent compounds with low degrees of polymerisation, which are then converted to high molecular mass during processing.

The value of lignin depends on the specific product, the yield, the processing cost, and the market size. When lignin is used as a source for low-molecular-mass chemical feedstocks, it is worth very little above its fuel value. The process for degradation of the lignin can involve hydrogenation, pyrolysis, hydrolysis and alkaline oxidation. The products from these processes include phenol and substituted phenolic compounds, cresols, acetic acid, methane, charcoal, acetylene and ethylene. Although phenols represent a high-value product, yield and processing costs limit the lignin value.

The potential large volume uses of lignin are the following (Sundstrom and Klei, 1982):

Binder for animal feeds.
Encapsulant for agricultural chemicals to give slow release.
Feed grain coating to reduce nutrient loss.
Road treatment to hold down dust.
Reinforcing filler in rubbers, replacing carbon black.
Setting time control in Portland cements.
Partial replacement of asphalt in paving.
Surfactants for tertiary oil recovery.
Viscosity control in drilling muds.
Organic source for activated carbon manufacture.
Adhesives for plywood and particleboard.
Pesticides.

The above twelve products represent the best potential markets for lignin-based products, and their expansion could lead to a significant alteration in the economics of the ethanol from cellulose route. Much research is being done on the processes to produce the above products.

Another important aspect is the investigation of improved means of lignin extraction thus yielding a better quality by-product in the first place, and leading to a higher value product.

4.3.2.5 Current commercial status of hydrolysis technology

Industrial-scale and development plants using acid hydrolysis of cellulose are in existence. As mentioned earlier about 44 plants using the Scholler-Madison technology are reported to be operating in the USSR, and demonstration plants have been built and operated in Japan (Henry et al, 1984). Brazil is currently seriously looking at the development of a commercial scale plant for acid wood hydrolysis, based on Russian technology.

Enzymatic hydrolysis is at an advanced stage on the path to commercialisation, and research is being focused on the production of inexpensive and recyclable enzymes.

4.3.3 ALCOHOL FERMENTATION

Alcohol fermentation from carbohydrates is probably one of the oldest processes known to mankind. Today, alcohol production from sugar, grain and other starches is widely regarded as an alternative source of liquid fuels for the transport sector. As has already been mentioned, Brazil has already embarked on large scale production of ethanol from sugar, while in the USA maize is being used to produce alcohol for gasohol blends in certain states.

Let us first consider some of the fundamentals of fermentation. Ethanol is produced by the fermentation of invert sugar by yeasts.

$$\begin{array}{ccccc} C_6H_{12}O_6 & \overset{\text{Yeast}}{=} & 2C_2H_5OH & + & 2CO_2 \\ 180\text{g} & & 92\text{g} & & 88\text{g} \end{array}$$

Where sucrose is used, the fermentation is preceded by the hydrolysis of the sucrose to invert sugar. The stoichiometric yield of ethanol from glucose is 51,11% on a mass basis. The efficiency of fermentation is expressed in terms of actual ethanol yield as a percentage of the theoretical stoichiometric yield, assuming that only ethanol and carbon dioxide are produced. In practice, yields of 85-90% are achieved. This is affected by the state of the sugars in the fermentation substrate.

4.3.3.1 Fermentation process options

Various fermentation routes can be followed. Most processes are still run on the batch basis with fermentation times of from 20 to 72 hours. For potable alcohol great care has to be taken to minimise the evolution of undesirable co-products. However, with the production of fuel alcohol, where the requirements are not as stringent, the process can be run on a semi-continuous basis (Melle-Boinet) which involves the recovery and recycle of the yeast. This permits the use of much higher yeast concentrations which enables a reduction in fermentation times. The use of continuous fermentation is on the increase, but it requires very close process and microbiological control. It is however reputed to result in a substantial reduction in capital and operating costs.

The fermentation process is sensitive to both temperature and alcohol concentration, the ideal temperature being in the range 32-36°C. One of the main constraints in conventional fermentation systems is that an alcohol concentration above 10-11% v/v in the fermenter inhibits the yeast activity. This requires dilution of the substrate to a sugar concentration equivalent to this alcohol concentration after fermentation, and results in large volumes of effluent being generated. In addition, there is an increased energy requirement in the distillation step of the ethanol production process. Through yeast selection, this alcohol tolerance has been increased quite significantly, but this unfortunately represents only a small improvement in total ethanol yield.

The distillation of an ethanol and water mixture is not straightforward, because of the ethanol/water azeotrope that forms under atmospheric pressure conditions. The maximum ethanol concentration obtainable by straightforward single stage atmospheric distillation is therefore about 95% v/v. If higher concentrations, up to anhydrous 99,7% v/v ethanol, are required as product, more complex secondary distillation systems become necessary.

To circumvent all the above complications an integrated fermentation and distillation system can be used. This involves the continuous removal of ethanol from the fermenting substrate in a secondary system operating under vacuum. This permits the fermentation of high concentration undiluted feedstocks at atmospheric pressure.

A property of the ethanol/water system that has only recently begun to be exploited on a commercial scale is the modification of the vapour-liquid equilibrium conditions when distillation is carried out under vacuum conditions. At atmospheric pressure, the ethanol/water azeotrope occurs at 97,2% v/v ethanol. As the pressure is reduced, the azeotropic composition moves progressively to higher ethanol concentrations and disappears at pressures below 12 kPa.

The ATPAL process

This is an example of the application of continuous vacuum fermentation, which allows the removal of alcohol directly from the fermenter. This reduces the effect of alcohol inhibition of the yeast in the fermenter.

This process has been worked on extensively by a group of scientists from the WS Atkins Group and Rolls Royce in the UK. The results of their work is known as the ATPAL process. It is a continuous fermentation process using high concentration feedstocks and high yeast concentration at atmospheric pressure. The undiluted substrate, after sterilisation, is fed directly to the fermentation vessel. The fermenting liquor is then circulated via a heater to the separator vessel, which is operated under vacuum. A vapourised ethanol/water mixture is liberated at approximately 42% v/v ethanol, depending on the concentration in the liquor. This is fed to the rectifying column where it is distilled under vacuum. The separator vessel and the rectifying column may be constructed as a single integrated facility.

Concentration of the ethanol product from the rectifying column can be controlled up to a near anhydrous state by control of the top vacuum, and appropriate column design. This obviates the necessity for the normal secondary azeotropic distillation system.

The ATPAL process definitely has advantages over the conventional fermentation and distillation processes, briefly (English, 1984):

> Direct production of up to 98% v/v ethanol without recourse to secondary azeotropic distillation.
>
> Considerable reduction in effluent volumes by avoidance of dilution water addition prior to fermentation.
>
> Reduced fouling of heat exchangers due to lower operating temperatures, and hence reduced denaturing of proteins.
>
> Low cooling requirements.
>
> Small fermenter capacity.

The Biostil process

The first commercial-scale Biostil continuous plant went on line in Brazil in 1983 (Alternative Sources of Energy, 1984). The plant, designed by Alfa-Laval of Sweden produces 150 000 l/day of 96% ethanol from a feedstock known as melmisto, consisting of around 30% final molasses and 70% cane juice syrup. The plant uses an integrated fermentation and distillation process, and can accept much more concentrated feedstocks than the conventional process. Alcohol yields are raised and the process gives a concentrated stillage that requires little or no additional energy-input for by-product recovery. Plans were going ahead for the installation of 24 more such plants throughout Brazil by the end of 1984. Plants of this type, using starch based feedstocks are planned for use in the USA.

4.3.3.2 Grain prefermentation processing for ethanol production

Processes for the conversion of grain to ethanol are generally divided into those using dry and those using wet milling.

Dry milling

This is relatively straightforward, and as the name implies, the milling is done in the absence of water. The entire kernel is reduced in size, usually to pass through a 20 mesh screen, without any attempt to separate the various components of the grain. The output from the dry milling process with a distillery is fuel grade ethanol and dried distillers' grains and solids (DDGS), also known as dark distillers' grain (DDG). When maize is used as feedstock the DDGS production is about 0,7t/kl of ethanol, while grain sorghum produces slightly less, but with a higher protein value.

Wet milling

This is a more complex process, with variations from mill to mill, the critical item from an energy viewpoint being the water balance. The more water that can be recycled and used within the process, the less the evaporation requirement.

Wet milling involves the separation of the starch, gluten and germ fractions of the grain, resulting in the by-products of corn-oil from the germ, gluten feed and gluten meal. The separation is achieved by first softening the grain through soaking, a process called steeping, for 30-50 hours. The wet grain can then be split up into its fractions by careful milling and centrifugation.

The gluten feed by-product consists of the grain husk or fibre, mixed with the concentrated steep liquor, which contains significant quantities of the grain's soluble proteins, and the concentrated clarified stillage. The by-products are produced in the following quantities when maize is used:

Corn oil	0,06	t/kl of ethanol
Gluten meal	0,11	ditto
Gluten feed	0,55	ditto

When grain sorghum is used, the same total amount of gluten meal and gluten feed are produced, with the gluten meal having a higher protein content than that from maize. The oil from sorghum is much lower however, at about 0,037t/kl.

Energy consumption for the milling of grain

The energy consumption for the two processes and their distilleries is nearly the same, being 0,77kJ/kJ of ethanol for the dry mill and 0,75kJ/kJ of ethanol for the wet process (Weinblatt et al, 1982). This excludes the energy needed for the production of the feedstock, the feedstock's energy content and that of the by-products.

4.3.3.3 Ethanol yield from selected crops (OECD, 1984)

Carbohydrate-rich plants

Raw material	t/ha	Carb. %	Ethanol l/t	Ethanol hl/ha
Beet	40-50	16	90-100	38-48
Sugar cane	50-100	13	60-80	35-70
Maize	4-8	60	360-400	15-30
Wheat	2-5	62	370-420	8-20
Barley	2-4	52	310-350	7-13
Grain sorghum	2-5	70	330-370	7-18
Potatoes	20-30	18	100-120	22-33
Sweet potato	10-20	26	140-170	16-31
Cassava	12-15	27	175-190	22-23
Jerusalem artichoke	30-60	17	80-100	27-54

Ligno-cellulosic products

Raw material (hydrolytic agent)	Dry matter t/ha	Ethanol l/t	Ethanol hl/ha
Softwood			
(Dilute acids)	9-15	190-220	18-31
(concentrated acids)	9-15	230-270	22-38
Hardwood			
(Dilute acids)	9-15	160-180	15-25
(concentrated acids)	9-15	190-220	18-30
Straw			
(Dilute acids)	1,5-3,5	140-160	2-5
(concentrated acids)	1,5-3,5	160-180	3-6

4.3.3.4 The recovery of ethanol from the fermentation broth

The aqueous ethanol solution that results from the fermentation of the sugar feedstock is dilute, and ethanol forms a constant-boiling azeotrope with water. The separation and concentration of this solution requires considerable energy input, which can often be from 40-60% of the total plant process energy requirement.

The traditional process

This consists of a preliminary distillation step, in a beer/rectifying column, to separate the ethanol from the fermentation broth and concentrate it to 95% v/v. This column is reboiled by steam injection, with condensing duty rejected to cooling water. The feed is preheated throughout countercurrent contact with the tower bottoms to approximately 94°C.

The overhead product is then dehydrated to 99+% v/v in an azeotropic distillation step, requiring two columns, an anhydrous and a recovery column. The first removes the water from the 95% ethanol by azeotropic distillation with an entrainment agent, either benzene or cyclohexane. The fuel grade product is removed from the reboiler of the anhydrous column, while the water is forced into the overheads together with the entrainer and some ethanol. This ternary azeotrope is condensed and decanted into two phases, the upper organic phase being removed to provide a portion of the anhydrous column reflux, while the lower aqueous phase is pumped to the recovery column. The recovery column strips the entrainer and ethanol as overhead and side-draw products respectively, to be added to the reflux of the anhydrous column, while water goes out as the bottoms.

The total energy consumption of this configuration is 7,63 MJ/l, with the second azeotropic distillation step accounting for about 45% of this.

Integrated distillation unit

Process modifications can of course be made to the traditional configuration, to give an integrated distillation unit that will benefit from energy re-use. In this system the overhead vapour from the beer/rectifying column is used to reboil the two azeotropic distillation columns. In order to satisfy the temperature approach requirements of the two reboilers, however, it is necessary to raise the pressure of the beer/rectifying column. As mentioned above, the azeotropic distillation requires about 45% of the total energy. Re-use of the energy in the beer/rectifying column overhead allows for the recovery of all but 7% of this process energy, reducing the total energy requirement to 62% of that for the traditional process (Dzenis and McNab, 1984).

Comparison of the two systems shows that very little extra equipment is required to implement the integrated unit by comparison with the traditional process. The addition of a pressure vessel as the first column, anhydrous system reboilers and the associated equipment represent a small investment, able to be recovered quickly through the operating savings. The system is still relatively simple and does not require any more maintenance than the traditional process.

Molecular sieve dehydration with jet compressor system

To further reduce the energy requirements, the azeotropic distillation step can be replaced by molecular sieve dehydration. The beer/rectifying column can be split into two, the beer column stripping ethanol from the fermentation broth, and the rectifying column bringing this up to 95% v/v ethanol. This split brings advantages in terms of feed preheating.

With this configuration, the rectifying column can be operated at atmospheric pressure, allowing a jet compressor to be installed at the beer column's sump, to re-use a portion of the heat normally rejected in its bottoms. Also, overhead condensing duty, normally rejected to cooling water, can be used to preheat the feed to the rectifying column.

Vapour phase molecular sieve dehydration has been selected as the most energy efficient absorption method for concentrating ethanol from 95 to 99+% v/v fuel grade. This process eliminates the need for high pressures, temperatures and chemical feeds of any kind (Dzenis and McNab, 1984). The unit is easily linked up to the rectifying column. Gaseous fuel grade ethanol is produced for one bed with a small portion being recycled for regeneration of the other. The regeneration stream is then condensed and re-distilled in the rectifying column. The energy requirement for this system is 58% of that of the traditional process, and the capital expenditure is similar to that of the above two configurations (Dzenis and McNab, 1984). Physically the system is smaller, and it is simple to operate. Eventually the desiccant degenerates, and the beds must be replaced. A service life of three years can be expected, while projections of as high as ten years have been made.

Mechanical vapour recompression with molecular sieve dehydration

Adding mechanical vapour recompression to the rectifying column, when using molecular sieve dehydration, allows a further reduction in energy input to 36% of that required by the traditional process (Dzenis and McNab, 1984). The vapour recompression upgrades low level overheads heat from both columns to enable it to be re-used in the column reboilers.

The most efficient incorporation of the vapour recompression is achieved by splitting the rectifying distillation into two columns, and applying compression to each. Even with this configuration there is a shortage of overheads heat, and supplemental steam must be added to the beer column reboiler.

Although this configuration is by far the most energy efficient, requiring only 2,78 MJ/l (Dzenis and McNab, 1984), it is also capital intensive, and requires a higher level of maintenance and operational skill. Also, because the compressors will probably be powered by electricity, the economics of operation are dependent on the plant's location.

Water absorption using cracked maize or maize meal

Cracked maize or maize meal can be used as an absorbant to remove water from ethanol (Weinblatt et al, 1982). The technology is still being developed, but it appears that the energy consumption to regenerate the meal when drying from the azeotrope to fuel grade ethanol is only 139 kJ/l. Furthermore, the regeneration temperature is low (120°C), which enhances the opportunity to use low grade heat. It is possible that the overall process energy can be reduced by stopping the distillation with 10-15% water remaining, and then dry by absorption on corn meal.

4.3.3.5 Distillery by-products and waste disposal

Ethanol fermentation produces considerable quantities of carbon dioxide, which can be easily recovered, compressed and used as an additive in the beverage and food industries. Alternatively it can be made into dry ice and used for refrigeration purposes, a useful product for tropical countries.

The fermentation yeast and other insoluble components of the fermented wort are rejected from the stills as stillage (also known as slops or vinasse). When starch is used as a feedstock, this has a high protein content, and can be sold as a livestock feed after evaporation and drying. In the USA, the economic viability of the industrial ethanol fermentation industry are determined to a large extent by the market value of this dried distillers grains and solids (DDGS). Because this contains both the yeast cells and the protein from the maize, it has a higher protein content than the original grain, 30% as compared to 12%. A great deal of research has been carried out in the USA into the use of DDGS as a cattle feed. It has been shown that a feed containing 20% DDGS, with the balance maize increases meat production by 13% over the quantity produced using straight maize as feed (Robinson, 1979).

The stillage from sugar fermentation is of lower value, and also constitutes a major waste problem, since a large water load is transported through the system to emerge as an effluent stream of roughly 10-15 l/l ethanol. The polluting load varies widely depending on the substrate, process and efficiency, but levels of BOD between 10 000 and 60 000 ppm have been recorded. The effluent from a 100 000 l/day distillery is equivalent to the pollution load from a population of about 1,7 million people.

Some of the effluent disposal techniques are the following:

> Irrigation This is the simplest, provided that the land is available. It has been estimated that where the average cane yield is 60 t/ha/yr, an application of 5,4 mm/ha would return to the land the stillage resulting from fermentation of the cane harvested from that hectare (Thompson, 1979). It would contain nearly 1,5 t of organic material, and the major mineral component would be potassium (92 kg K/ha). Only about 5 kg N/ha would be returned, whereas something in the order of 200 kg N/ha are required for cane cultivation. Application of stillage in this manner has to be carried out under very controlled conditions so as to obviate the possibility of watercourse contamination, and to prevent acidification and salination of the soil.
>
> Evaporation This method can be used either to reduce the volume for removal by road or to produce a concentrated syrup for use as a binder in animal feed.

Spray drying This process is used by NCP to produce their ethyl concentrate cattle feed, Rumevite.

Incineration This requires a special furnace design. The heat is used in the distillation, while a crude potash is recovered from the ash.

Fermentation Anaerobic fermentation to yield methane for use in the upstream processes as a fuel, or aerobic fermentation to yield single cell protein (SCP). Torula yeast is produced extensively in Taiwan using aerobic fermentation.

4.3.3.6 The prospects for ethanol production

In a statement made in February 1980 the government announced its decision to permit the use of agricultural products for the production of ethanol, and furthermore, to provide assistance in this regard. This decision was based on the conviction that should manufacturers find it economical the fraction produced would not be so large as to endanger the country's existing fuel industry. The Cabinet made the following decisions regarding liquid fuels (de Klerk, 1980):

> Uniform excise and other duties shall apply to all motor fuels, produced from indigenous raw materials, used for the fuelling of internal combustion engines. For the purposes of calculation, the energy content of such fuels, as compared to that of petroleum will apply. In practice this means that any fuel replacing petroleum will enjoy an advantage of approximately 4c/l petroleum equivalent, over fuel derived from imported crude.
>
> In addition an incentive shall be given in respect of efforts and actual contributions to the replacement of diesel fuel only. These will take the form of reductions in duties and shall be granted to licensed producers. Licences would be granted to those applicants satisfying various criteria with respect to their expertise in the field of fuel production and distribution.

> Except for these incentives the government would take no responsibility for the profitability of the undertaking, the acceptability of the fuel, the continuity of demand, the availability of the raw material, nor provide any other form of protection or assistance.
>
> No excise would be charged on fuels produced for experimental purposes.
>
> Existing legislation regarding the production of alcohol would be scrutinised so as to ensure that no undue difficulties are placed in the way of alcohol production for fuel purposes.
>
> The importation of reasonable quantities of locally unavailable liquid fuels would be allowed for experimental purposes.

It is against this backdrop that all ethanol production from biomass should be considered. Because of the classified nature of information relating to liquid fuels, it is not possible to quantify the potential market for ethanol as a fuel. The information that is available indicates the following (Kamper et al, 1983):

> The Transvaal and OFS together constitute about 60% of the country's petrol and diesel markets. However, both these provinces and the north western part of Natal fall within the SASOL marketing area. By implication this means that all the petrol sold in these areas could already, to a greater or lesser degree, be blended with the alcohol by-products from the SASOL process, and would therefore not be able to absorb ethanol from other sources.
>
> Natal as a whole constitutes only about 18% of the total petrol market. However, that part of it not included in the above, plus the Eastern Cape areas as far south as Port Elizabeth, the adjoining interior and the Transkei could be regarded as a potential market for fuel ethanol produced from sugar, molasses or bagasse in Natal.

The transport costs of a fuel in a particular area are calculated as if the fuel was landed at the nearest port. The railage to many of the aforementioned areas from Natal would therefore be unfavourable. The most attractive market for ethanol would therefore be those areas near enough to the distillery to make the ethanol competitive with petrol.

The need in South Africa is for a fuel to extend diesel rather than petrol, and ethanol is not yet regarded as suitable for this purpose.

The economics of ethanol production

Determining an ethanol production cost is not an easy exercise because of the large number of variables involved. Taking, for example, an ethanol distillery backed on to a sugar mill, depending on the market prices prevailing for sugar and ethanol, the fractions leaving the plant can be programmed to give the best return. Thus, when the sugar price is high, the molasses is exhausted as far as is possible and then only turned over to the distillery for ethanol production. Alternately, should ethanol be in demand, part of the cane juice might even be directed to the distillery along with the molasses, which would also not be as totally exhausted of fermentables as usual.

Until as recently as the latter half of the 70s, the price of the fermentation feedstock alone was higher than the net petrol price (Ravno, 1979). Since then, a series of sharp rises in fuel costs have brought the economics more into line. The following ethanol production costs are based on sugarcane as feedstock (Ravno, 1979). These figures will give some idea of where the bulk of the costs lie.

Cost element	Cents/l	%	Note
Raw material	18,0	50,3	2
Juice extraction	9,2	25,7	3
Process chemicals	0,4	1,1	
Utilities	0,2	0,6	
Salaries	0,4	1,1	
Maintenance	0,5	1,4	4
Depreciation	1,8	5,0	5
General expenses	0,1	0,3	
Industrial levy	1,4	3,9	6
Return on capital	3,8	10,6	7
	35,8	100,0	

Notes

1. Basis - 220 000 l/day module

Fixed capital	R9 million
Working capital	R2 million

2. Basis - Cane price R13,50/t
Ethanol yield 75 l/t cane

3. Based on the assumption that 2/3 of the total millers cost claim (including transport) is associated with processing up to the juice scales; to this figure is added the full "return on capital" element for both the extraction plant and the boiling house equipment rendered redundant due to the diversion of juice to the distillery.

4. Basis - 3% per annum on fixed capital cost

5. Basis - 10% per annum on plant and machinery.
5% per annum on buildings.

6. Based on assumption that 30% of full industrial levy of R1,50 per t cane is associated exclusively with export sugar and can be deducted from levy applicable to alcohol production.

7. Basis - 14% return p.a. on full (undepreciated) fixed plus working capital over 10 year period.

In order to compare various raw materials, using 1983 prices, the following figures were generated:

Raw material	Price R/t	Ethanol price c/l	Note
Sugarcane	22,16	47,8	1
Molasses	45,00	27,0	2
Bagasse	10,00	72,1	3
Bagasse	10,00	69,5	4
Bagasse	10,00	52,4	5
Grain sorghum	123,00	40,2	6
Maize	135,00	43,3	6
Pineapple waste	-	35,3	7
Sugar	-	41,0	8

Notes

1. This figure was calculated by substituting the 1983 sugarcane price in Ravno's figures, with no escalation of the other costs.

2. This was also obtained from Ravno's basic costs, excluding the juice extraction costs, and without escalation.

3. This is for enzymatic hydrolysis of bagasse (Ramsay, 1983), without credit for yeast by-product sales.

4. Same as Note 3, but with yeast sales credited.

5. Same as Note 4, but with enhanced enzyme production (Watson et al, 1984) substituted into previous calculations of enzyme production costs (Watson, 1983).

6. Based on Sentrachem calculations (see Appendix 1), with 1983 grain prices (Dept of Agriculture, 1984).

7. From feasibility study carried out by EMS for Langeberg Coop (see Chapter Three).

8. This figure is the result of a feasibility study by Jager Associates in the Eastern Transvaal. It is based on the full 1984 sugar price (pers comm E.Buchanan).

To make fuel ethanol attractive to the fuel companies its price will have to be related to that of petrol. SASOL apparently was selling their fuel alcohols at prices ranging between R400 and R500/t, which on average gives a price of about 36c/l on the Reef when the price of petrol was 59,6c/l for 93 octane (Kamper et al, 1983). The cost of petrol at the coast was at that time 54,3c/l, the wholesale price being 47,5c/l, of which 21,4c were customs and excise, equalisation and surcharge.

To persuade an oil company to purchase ethanol for admixing with petrol, ethanol must compete with the wholesale price of petrol. Using the petrol price as of 2nd May 1984, the wholesale price in coastal areas was 47,4c/l (Hansard, 2nd May 1984), thus to make ethanol competitive the following pricing structure would be necessary:

	Wholesale price to fuel company	47,4c
Less		
	65% of customs and excise, etc	8,3c
	Gate price of ethanol	39,1c

This is based on the assumption that the customs and excise charges will be tied to the energy content of the fuel.

Other costs might be claimed by the oil company, such as the cost of installation of special equipment for the fuel blending. Taking this as another 1,5c/l (Kamper et al, 1983) would give a gate price of 37,6c/l. With the more recent petrol price increase, the situation will have altered yet again, and a quite substantially higher gate price will probably be possible.

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CHAPTER FIVE

THE FINANCIAL AND ENERGY ACCOUNTING OF BIOENERGY

It is not possible in a study as wide-ranging as this to include detailed costs for all the bioenergy processes. Where possible the economics of processes have been included under the relevant section. As many processes have not even reached commercialisation it is difficult to determine a South African cost for them, even though theoretical cost accountings may have been made elsewhere. A local cost would depend to a large extent on what proportion of the technology and equipment would have to be imported. This chapter therefore serves purely to give some pointers as to how the costing of bioenergy processes should be approached.

5.1 BIO-COMMODITY PRICES AND COSTS

Biomass prices

The practical difficulties experienced with regard to fuels in recent years have been more concerned with cost than with absolute availability. The oil-producing nations did not 'run out' of oil but restricted its flow to the world markets and thereby managed to increase the price. The cost of biomass for processing to fuel has not received similar attention although a great deal of thought has been given to the upgrading processes themselves. In many cases a low or nil cost feedstock is assumed, especially where this is a by-product or 'waste' from other activities. Before we consider what in the future could be or what ought to be its cost, it is of interest to know the current price of biomass. What do we have to pay for commodities produced in forestry and agriculture? Relevant prices have been included in the sections on specific feedstocks, and here a more generalised approach to the costing of biomass for energy production will be taken.

The monetary cost of producing biomass (as distinct from the price) is not always easy to establish. In some instances the price is artificial in that it is influenced by subsidies and tariffs in the agricultural system. However, if we have to buy cereals, etc. to make biofuels these prices become feedstock costs. Price concessions to the industrial users of these materials are not generally made. In addition, studies elsewhere have shown that the cost of energy in the raw biomass is similar to, or greater than that of coal, oil or gas supplied to industry (UK Dept of Energy, 1982).

Biomass production costs

The cost of producing grass silage is instructive, since the process is perhaps the simplest type of biomass cultivation, harvesting and storage practised. A cost breakdown is shown in the following table. The results of the cost survey from which these figures are quoted (Purdy, 1979) were said by the UK agricultural service (ADAS) to be among the most accurate yet achieved in on-farm recording. The costs were not considered excessively high by the farmers.

Total costs of producing silage 1979
(Pounds Sterling/dry ton silage)

Labour	2,98
Machinery depreciation	7,05
Fuel	0,79
Seed	1,55
Fertiliser	11,52
Silage additives	2,19
Buildings, other materials	2,65
Rent @ 60 Pounds Sterling/ha/yr	6,81
Total (excluding overheads)	35,54

The cost of seaweed, shown in an earlier table, is also informative since this material is generally considered as 'free' and carries no cultivation or fertilisation costs. Collection off European coasts is partially mechanised. The raw biomass is, however, largely composed of water and is bulky and difficult to handle. If costs are so high where there are no cultivation and fertilisation contributions, what will happen when these are present, as in certain ocean-farming proposals?

The cost of wastes

It is in one sense a contradiction to speak of using wastes in biofuel processes because as soon as we use a residue or by-product it ceases to be wasted and allows the owner to negotiate a selling price. If we have a waste from our own process, the possibility of using it as a source of fuel is seen as an overall cost optimisation and depends on many factors including the size of the resource compared with current energy requirements, the cost of the equipment to utilise the waste and the environmental nuisance the waste causes.

Two examples of wastes which exist in sizable quantities are waste paper and straw, the latter particularly in Europe. As a result both have been the subject of extensive investigation to find some viable process for their utilisation. These materials can be converted by physical and chemical means to a wide range of products potentially more valuable than energy e.g. paper, sugars, alcohol, furfural, etc. The cost of the material is, however, often too high for these applications. The economic problem of converting them to energy is even greater. Even wastes such as animal excreta may have a value. Prices mentioned for feedlot cattle manure in the US were about $6-8/ton when transport costs were included (Varani, 1980).

Perhaps in desperation to make money from 'wastes' that have to be paid for, attention has focussed on those wastes that someone might pay to have removed, e.g. refuse, human and animal sewage, and process effluents. The need to dispose of these materials in an acceptable manner may provide a subsidy to processes which use them. The overall justification for the processes is environmental - fuel is a possible by-product. The economics of the total clean-up/energy processes are complicated. Refuse and sewage treatment are often government responsibilities and a decision by the government or local authorities to install the processes would not necessarily be based on the same criteria as those considered for a commercial venture. Credits to a company offering to dispose of the wastes would also not necessarily reflect the equivalent costs of disposal.

5.2 BIOENERGY CONVERSION PROCESS COSTS

Approach to costing

The purpose of economic evaluations of biofuel proposals is to compare the costs of resource and effort required with the value of the anticipated benefits. Techniques for carrying out such evaluations with well-defined processes are reasonably well formalised and a degree of accuracy in predicting these costs and benefits is possible. For new processes and products however, where much uncertainty exists regarding the technology and the markets for the products, predictive ability in costing is poor and spectacular cost over-runs may result when the plant is built. A number of cost accountings for biofuel manufacturing routes have appeared in the literature among which the claimed net benefits vary greatly.

It is impossible in a short study to explore all the details of process costs, but some general principles applicable to most of the proposals are worth stating. Such principles may help to identify major cost/benefit components, to evaluate new proposals for original features and to assess their impact on total costs. A careful reading of cost analyses for bioenergy often reveals an unusual dependence on some feature such as tax subsidies or by-product credits and the credibility of the process shifts from the biofuel itself to these credits.

Cost Breakdowns

Costs are normally broken down into component parts relating to raw materials, to operation of the process and to capital-related charges. Materials and certain operating costs vary with the output of products. The capital-related costs and certain operating costs are 'fixed' since they remain the same whether product is made or not. Obviously to minimise costs, the plant should operate as near to full capacity as possible.

Process cost components	
Raw materials	Biomass Other process ingredients e.g. catalyst
Operating costs	Utilities Maintenance Labour and supervision Royalties
Capital costs	Depreciation and return on investment on capital required for: Land Off-site plant Working capital
By-product credits	

The relative size of each of the major cost categories is important in a number of respects. Capital may be difficult to acquire and becomes increasingly more so with increasing risks and uncertainties attached to a project.

In many of the biofuel processes the feedstock constitutes the largest single cost component. This is an embarrassment since often little can be done to reduce its cost, thus low-cost biomass not required in higher value applications is needed. Competition from these higher value applications, e.g. food, feed, timber, fibre etc., would deny the biofuel process its feedstock. Fuel industries are very large compared with those for food, feed and other commodities and the provision of cheap biomass on a large scale would radically change the fortunes of the latter industries. Conversely a subsidy for biomass as a raw material for fuels will increase the price of biomass for its other uses.

Operating costs are often small in comparison with capital and feedstock costs. However, much effort has been devoted to reducing these costs for biofuels, perhaps owing to the attraction of introducing new techniques from other areas, e.g. energy-saving engineering concepts, new types of fermenter developed in biotechnology research and new separation processes. The reasoning behind intensive research efforts to reduce operating costs without a similar effort to reduce total capital and feedstock costs is hard to understand.

Cost Sensitivities

The sensitivity of total costs per ton of biofuel to variations in one or more cost-determining variables, including feedstock cost, reactor productivity, reaction yield etc., is of major interest in assessing processes. For example, feedstocks may vary in price between different locations and times. A cost model providing sensitivity analyses allows an identification of circumstances which favour the viability of the process, but it is found that, in some cases, the extrapolation of a cost component to zero still does not yield a profitable process. Sensitivity analyses are helpful in evaluating research proposals. The 'stretch' needed in some process parameter to lower total costs to an acceptable level may or may not have technical credibility.

Total costs may be sensitive to the value of process variables in a linear or non-linear fashion. A comprehensive costing for a given process may be extremely complex and require a large number of input details. However, since biofuels are in many cases non-viable commercially by a substantial margin, it is often sufficient to draw a broad-brush picture and illustrate the economic problems of the process with simple cost models.

5.2.1 BIOLOGICAL VERSUS CHEMICAL PROCESS ROUTES

Indications are that techniques developed through biotechnology research have potential for producing fuels, bulk chemicals and a wide range of higher value products. The advantages of biological processes are undeniable, however, they are accompanied by countervailing disadvantages, as are shown by the following tables.

Advantages of biological conversion processes
Low activation energies
Multi-step conversions in one reactor
High yield
Versatility with different feedstocks
Structural specificity
Chiral products
Dilute feedstocks
Complex molecules converted
Food, feed and drug applications

Disadvantages of biological conversion processes
Slow reactions
Product recovery from dilute aqueous phase
Complicated reaction conditions
Sterility requirements
Batch operation preferred
High catalyst (cells) regeneration cost

It has been said that, in general, feedstock and operating costs for biological processes are three times that of their chemical counterparts. Some of the causes of these extra costs are low productivity (i.e. tons product/m^3/hr), the need for corrosion-proof and non-toxic reactor vessels, the sensitivity of biological reactions to physical conditions, and the presence of large quantities of process water. As a result, biological processes have, with some exceptions, been found more suitable for higher value products and for products unobtainable or only obtainable with difficulty from fossil carbon feedstocks. However, products such as foods, ethanol and acetic acid destined for human consumption are for aesthetic and political reasons produced by biological routes even where the synthetic product is cheaper and of higher quality.

Biological cells can effect many of the transformations that are at the heart of current chemicals manufacture, but these reactions are not used because of their relative slowness, complexity and high costs. Biological processes come into their own, therefore, where versatility, specificity, mild conditions and the ability to cope with complexity have maximum value. Biological processes thus complement chemical processes, each having their appropriate applications.

5.3 COSTS, INFLATION AND RISING ENERGY PRICES

Accounting methods are available which take into account the present value of money, the effects of inflation and of differential inflation of different cost components. It is widely assumed that the costs in renewable energy proposals become relatively lower in an environment of inflation and rising energy prices. Even renewable capital cost elements are not seen to rise with other prices i.e. inflation is seen to subsidise renewable energies. This argument is commonly used by salesmen selling energy conservation devices who claim that if you install energy-saving devices now, you will save money in the future.

However, all capital equipment has a finite lifetime and maintenance and replacement costs mean that any advantage of inflation will eventually disappear. In addition, capital is less available in times of rising energy costs and inflation, when interest rates tend to be high. Accelerated inflation has in fact been a response to increasing oil import costs. Inflation is not constant and a fall in the inflation rate, besides being accompanied by lower energy price rises, leaves a legacy of high interest loans. Inflation also increases risks associated with loans and thus correspondingly higher returns are required. This is in addition to the fact that benefits from many renewable energy processes are poorly quantified, and already represent substantial risks to investors.

5.4 THE ENERGY COSTS OF BIOMASS

The mechanisation of agriculture in the twentieth century may fairly be described as spectacular. The energy to till the land, plant and weed crops and to harvest and transport the products is now supplied directly or indirectly by fossil fuels. These fuels are needed to power the tractors and other farm machinery, to build this machinery, to manufacture fertilisers and other agricultural chemicals and for the processing of the agricultural products.

In 1901, in the UK 1,1 million horses were employed on farms and approximately 30% of lowland farm area was devoted to their keep (Leach, 1975). These horses are now replaced by half a million tractors. In 1885, farmland in southern England required one person for every eleven hectares and an army of casual labourers at harvest-time. By the 1970s one person was required for each 37 hectares. Between 1920 and 1970 the energy input per hectare increased from 0,5 to 9 GJ/ha, reflecting both the change from animal and human labour to machines and the increased intensity of farming practices leading to increased yields. Energy inputs per person in the agricultural sector are similar in developed countries to those in heavy industry. The revolution has been less in the amount of biomass harvested in agriculture but more in the way such material is grown and collected.

High energy inputs are now an essential part of agricultural practice and cannot be dispensed with if high yield and quality of products is to be maintained. The revolution in farming has occurred not only because energy, in real terms became cheaper, but also because the machines and chemicals necessary for production of high yield and high quality crops are now available. Direct fuel costs are only a small part of the monetary costs of agricultural products and the present technology could continue to be used economically even if fuel prices were higher.

The phenomenon of changing type and quantities of agriculturally required energy sources has attracted considerable attention in the literature. Many dislike the dependence of the production of such a basic human need as food on fossil fuels. Since food is also a fuel and its energy value to humans can be expressed in the same units as are fossil fuels, simple energy ratios are possible to express energy inputs of food and feed production. In these terms the foods we now eat are produced in a highly energy-inefficient manner. Since much of the biomass proposed for biofuels would be grown using techniques not greatly different from current food product methods, the amount of energy expended in biomass cultivation becomes a crucial question in net energy analyses of the final fuels.

At a local level, the cost of renewable fuels in terms of the fossil fuels used in their preparation, is relevant to plans for augmenting national energy supplies and for reducing foreign exchange payments for imported primary energy. A good proportion of the primary energy used by the nation is already consumed by the energy industries themselves. For example, the SASOL 1 process uses 2 400 tons/day of coal in its power plant, while 2 000 tons/day are gasified to produce 3 660 bbl/day of 86-90 research octane number petrol and 370 bbl/day of diesel (Hottel and Howard, 1974). This proportion will undoubtedly increase as the use of lower quality and more difficult to process raw energy sources increases. The fear also exists that processing of useful fuels at a reasonable rate will, for thermodynamic reasons, eventually become impossible. Detailed accounting of the use of energy in making fuels is therefore an important tool in judging the merits of alternative energy routes.

Net energy analysis is an attempted estimation of the primary energy expended in fabricating fuels and was at one time thought to be so important that the US required such an analysis of all new energy projects by law. Net energy analyses have been used by opponent and proponent alike in renewable energy polemics and it has become evident that by choosing a suitable energy accounting method, a range of answers was possible, some more favourable than others, depending on the particular point of view. Eventually the basic philosophy of energy analysis was questioned, and the ability of any methodology, to answer the questions on the limits imposed by thermodynamics on the productivity of human societies, was brought into doubt.

The end result has been that a particular energy return on a fuel-making process does not determine the commercial viability of the fuel and is often not taken as an overriding factor. There is still, however, considerable interest in calculating the fossil fuel 'subsidy' needed to manufacture biologically renewable fuels. Although of little relevance in economic arguments for producing new fuels, the information may be useful in the often emotive proposals for 'political' subsidies and for any state incentives felt necessary to make renewable energy sources viable.

Allowable Energy Inputs

A number of basic problems exist in rigorously assessing the energy cost in making fuels. Firstly there is no consensus on the number and type of energy inputs to a given process. Besides the obvious usage of energy utilities and other fuels, there are many other inputs which can be, and often are included. For example, there is the energy used in manufacturing equipment, buildings, and other materials, the energy used in research and development and energy needed in environmental clean-up after the process.

Capital, profits, human labour and wages all involve an expending of energy and may be allocated some cost in terms of energy. The energy value of each of these items is often most conveniently expressed as an energy equivalence of the financial cost incurred in purchasing that category of item. The equivalence is derived from the national monetary expenditure on a class of items and the total allocation of energy to these items in their manufacture and delivery. Some examples of these money/energy ratios for agricultural inputs and estimation methods may be found in the following references (Chapman, 1974), (Leach, 1975) and (Wright, 1974).

Energy Credits for By-products

A second problem in energy analysis is the allocation of energy credits for by-products of renewable fuel processes. Examples are found in energy assessments for gasohol where the carbohydrate residues from fermentation and distillation may have a calorific value comparable with that of the product alcohol. The use of these residues as cattle fodder is often claimed as an energy credit on the basis that they avoid the expending of substantial quantities of energy needed to process alternative cattle feeds.

5.4.1 ENERGY COST BREAKDOWNS

5.4.1.1 Energy inputs to biomass cultivation

The first major question on energy costs in biomass cultivation concerns the relative importance of different energy inputs to the growth process. Direct fuels, and the indirect energy inputs to manufacture fertiliser and farm machinery account for the bulk of the energy input to the agricultural process in the UK (Leach, 1975). This analysis takes no account of energy associated with labour, profits, capital etc. Nevertheless the total energy requirement for UK farming is considerable and represents about 3% of the total primary energy budget of the country. The net result is that in the UK, for every Joule of food produced by agriculture an average of about 3 Joules of fossil fuel has been expended in direct energy requirements for fuels and materials.

Where does the energy go in terms of each ton of biomass? A breakdown for maize cultivation in the United States is shown in the following table (Heichel, 1976).

Energy Inputs -	US Maize GJ/dry ton
Fertiliser and lime	2,28
Pesticides	0,01
Machinery	1,27
Crop establishment	0,23
Harvesting	1,22
Total	5,01

Conventional fertilisation and tillage practices are used giving an average yield of 2,54 t/ha. Liquid fuel use occurs in crop establishment and harvesting. Machinery also represents a large indirect energy sink. The most important single energy use, however, is in the provision of fertiliser. In these estimates, no allowance is made for farm buildings, labour and other energy inputs. Nevertheless, even in terms of these limited inputs, to grow and deliver a ton of maize to the farm gate requires energy input equivalent to approximately one-third of the calorific content of the dry grain. However, to put this in perspective, direct fuel monetary costs are only about 10% of the costs of grain production.

According to the Dept of Agriculture, the following are the theoretical direct fuel consumption figures for the cultivation of maize in sandy loam soil in South Africa (Boshoff and Heyns, 1979).

Diesel Consumption for Maize Cultivation

Operation	l/ha
Mouldboard ploughing	18
Disc harrowing	6
Disc harrow before plough	6
Planting	4
Millipede operation	3
Cultivator operation	4
Second cultivation	4
Harvesting	12
Transportation	5
Lime or fertiliser spreading	1
Stubble cutting with disc harrow	6
Total	68

With an average yield of 3,4 t/ha this would give a direct theoretical fuel consumption of 20 l/t, equivalent to 0,74 GJ/t. This is half of the US consumption for crop establishment and harvesting. The difference is probably attributable to the greater manual labour component in this country. One hopes that our farmers are achieving these figures in practice!

5.4.1.2 Energy inputs to bioenergy conversion processes

Thermal upgrading processes

Surprisingly little could be found in the literature on comprehensive energy analyses for thermal upgrading processes for biomass. Simple heat balances are often calculated over processes and a large proportion of the calorific value of the feedstock may find its way into the product. The thermal efficiency of such processes is clearly of interest in comparing the merits of different proposals and in obtaining the greatest yield of useful products. It does not, however, answer the question of the total fossil fuel expended in providing substitutes for fossil fuels.

The heat balance for the production of synthetic natural gas from wood is shown in the following table. About a third of the calorific value of wet biomass is lost in the process. To this heat loss should be added all the indirect energy inputs associated with the hardware and financing of the process itself and of ancillary activities such as effluent clean-up etc.

Heat balance for wood gasification

	% Calorific value of wet wood
SNG	63,0
Rejected to cooling	31,4
Stack	4,4
Ash and unconverted carbon	0,9
Miscellaneous	0,3
TOTAL	100,0

Biochemical Processes

The energy inputs associated with the fermentation of alcohol have received considerable attention in the literature and have been dealt with already. The other major biochemical process, anaerobic digestion, has been found to be a net energy producer where the simple systems such as those employed in the East are used, although accurate data are not readily obtainable.

Where more sophisticated systems are employed, total direct and indirect energy inputs may exceed the energy obtained as methane. In one example using livestock waste, 32 GJ of methane was obtained for an overall energy input of 82,5 GJ. For cultivated algae 3 GJ of energy was required to produce each GJ of methane. Even these figures were said to be estimates of what should be possible within a few years and not what has been achieved already.

Anaerobic digestion is thus a dubious candidate for a fossil fuel replacer. Only limited energy inputs were used in these studies. The energy credit which might be allowed for the technique as an effluent treatment process has not, however, been assessed.

Vegetable Oils

The processes for manufacturing vegetable oils have, been subjected to comprehensive energy analyses in studies carried out by the Division of Agricultural Engineering. This information has not been released and can be found in the confidential report submitted to the Dept of Mineral and Energy Affairs.

Total energy costs for these potential fuels are thought to be quite low elsewhere in the world. The energy costs for soybeans were quoted in the previous section to be about 4 GJ/dry t and extraction of the oil involves relatively small expenditures of energy. Soybean oil has been estimated by the method of input/output analysis of industries involved to have an energy cost of about 18 GJ/t whereas the calorific value of the oil is about 43 GJ/t. Again energy inputs were limited, but these values rank the vegetable oils with wood as possible net energy producers.

5.5 CONCLUSION

The objective of the comments in this chapter has been to create a climate of healthy skepticism with regard to energy analyses quoted in the literature. Hopefully the reader will immediately begin asking questions about the inputs, outputs and credits included in the calculations. The method of expressing the final answer should also be treated with caution since by using the product fuel to power the process a high net energy return can be achieved. The calorific value of the biomass itself is not normally an energy input and unlimited amounts could theoretically be used to fuel the process, thus incurring only a minimal fossil energy cost.

Such politically dependent judgements such as the benefit (or lack thereof) of the renewable processes augmenting national energy supplies, avoiding foreign exchange expenditure or prolonging the time before the oil 'runs out' are not rigorously quantifiable. The best that can be said, leaving assessment of the facts to the reader, is that the higher the energy costs in preparing renewable fuels, the smaller their ultimate contribution to world energy supplies. If a net expenditure of fossil energy is necessary, no argument is possible for promoting the particular renewable energy source as an answer to humankind's energy needs.

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CHAPTER SIX

THE ENVIRONMENTAL AND SOCIAL IMPACT OF BIOENERGY USE

Biomass-based energy systems very often have other advantages in addition to their impact on the energy supply situation. These can include rehabilitation of the environment, the creation of jobs, and the stimulation of rural development through the injection of capital and energy. However, it is important to note that these benefits are not guaranteed, and unless careful consideration of the needs of the local population is taken, and the possible environmental impacts carefully assessed, the effects of bioenergy systems could well be negative.

Some of the problems and advantages of bioenergy, very generally speaking, are:

Advantages

1. Stores energy
2. Renewable
3. Versatile conversion and products
4. Dependent on technology already available, with minimum capital input; available to most income groups
5. Can be developed with present manpower and materials
6. Large biological and engineering development potential
7. Creates employment and helps develop skills
8. Allows for decentralised energy production
9. Ecologically harmonious

Disadvantages

1. Land and water use competition
2. Large land areas required
3. Supply uncertainty in initial phases
4. Costs often uncertain
5. Fertiliser, soil and water requirements
6. Conflict with existing agricultural, silvicultural and social norms
7. Bulky resources; transport and storage problems
8. Subject to climatic variations
9. Low conversion efficiencies
10. Seasonal

It is tempting to think that because biomass forms part of the major ecological cycles and offers a 'natural' way of producing energy, its use will not be harmful to the environment. By replacing fossil fuels with bioenergy, it would be thought that a good deal of the pollution problems usually associated with energy production or use might be avoided. The fact is that the ecological balance is far more sensitive and complex than is often thought, and the use of biomass as an energy source can also have serious environmental consequences.

It is true that the pollution resulting from fossil-based fuels would be reduced, but although tests carried out with engines run on alcohol or vegetable oils show sharp reductions in CO, CO_2, NO, SO_2, and lead emissions, these fuels produce greater quantities of aldehydes and ketones. Further research is being done in this field to determine just how serious a problem this is, and what can be done to reduce the evolution of these pollutants.

In addition to these more readily apparent problems, there are others of a less obvious nature that might arise from bioenergy production, and could have environmental, social and economic impacts. To minimise the possibility of these occurring, or to reduce their impact, it is necessary to plan production systems very carefully, basing decisions on sound scientific and socio-economic research.

Environmental constraints

A key consideration for evaluating the potential of bioenergy is land availability. This will depend not only on how much land is physically suitable for growing the biomass crop, but also on the environmental implications of an energy farm, and the extent to which the land can be freed from competing uses. Bioenergy planning should include inventories which realistically assess the amount of land potentially available for biomass production, and the advantages of using such land for biomass farms as opposed to other farming.

A suitable methodology for carrying out such an assessment was developed by a group of scientists and engineers from Pacific Ring countries (Marten, 1982), who spent some months addressing the question, 'How can environmental considerations be incorporated meaningfully into the bioenergy development process?

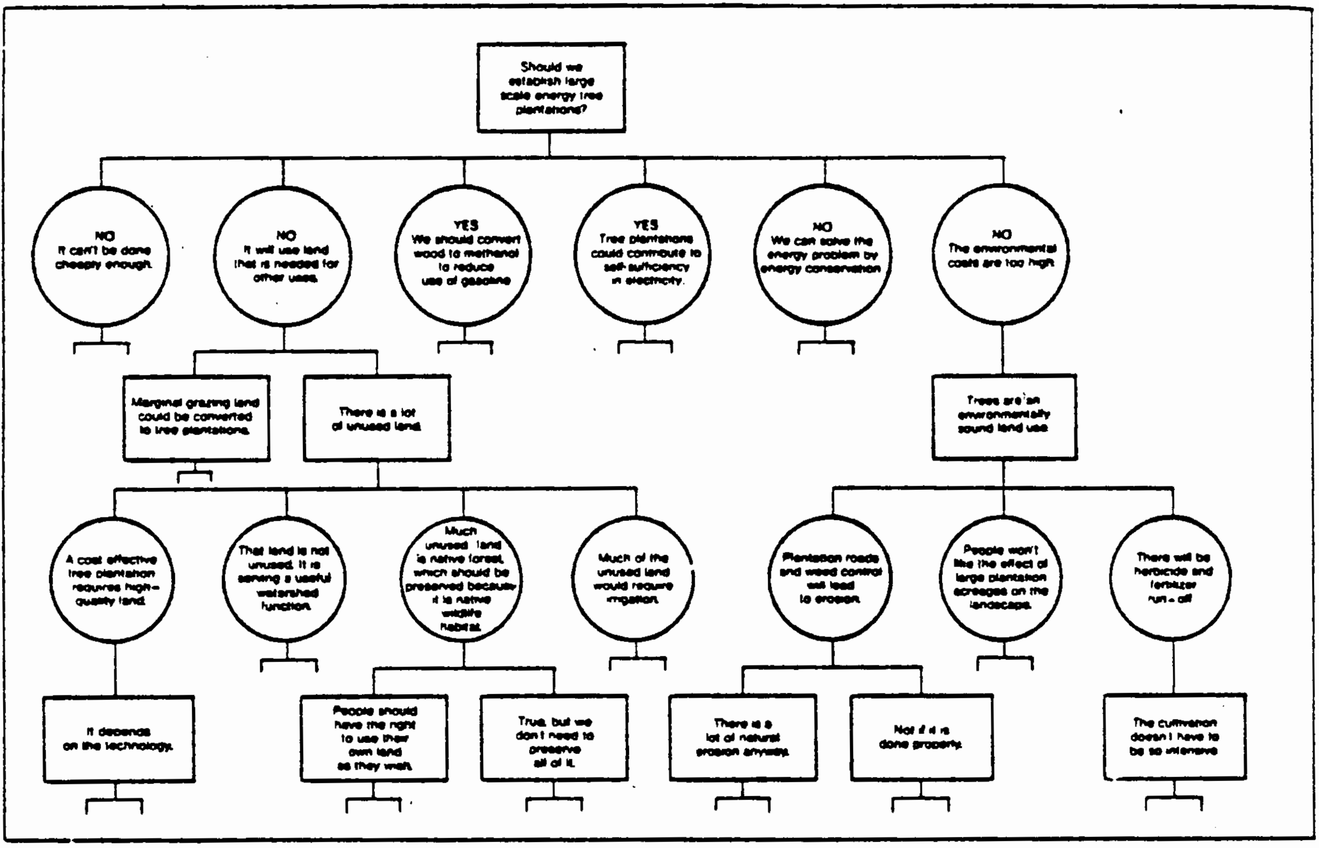

FIGURE 6.1 Issue tree for land issues associated with energy forestry

The tree proceeds from top to bottom as a dialogue between the squares and the circles. Policy questions occur at the top, and management questions develop as the tree proceeds downwards (Marten, 1982).

This diagram represents a hypothetical dialogue on bioenergy that might take place in the course of making policy and planning decisions. Much of it bears on a fundamental question in deciding what role biomass will play in the energy policy of a nation or region, 'How much bioenergy can potentially be produced?'.

The physical suitability maps being developed by the Dept of Agriculture (see Chapter Three) do not take account of whether the land is environmentally suitable for the particular type of farm under consideration. Most of the environmental impacts are similar to those resulting from any other form of agriculture, the most important being soil conservation and the leaching of agricultural chemicals into waterways and groundwater. However there are several other impacts which are unique to bioenergy farming practices.

Since all of the crop is generally useful for energy production, the harvesting may emphasize the removal of as much of the biomass as possible, meaning that there will be less residual cover to protect the soil from erosion and less organic litter to decompose and maintain soil quality and return nutrients to the soil. In addition, because marginal land will often be developed for energy farming it may require higher chemical inputs, and it is likely to be more susceptible to erosion, run-off and soil degradation than higher quality agricultural land.

Graphical means can be used to show these environmental effects, and make them more understandable to decision makers, who may not be experts in environmental impact assessment (see Figure 6.2). In this way a large amount of information can be conveyed relatively easily to a wide cross-section of people. By using these diagrams the impact of various options can be weighed up and undesirable effects can be minimised by matching the right type of energy farm to the available land.

However, this is not the end of the suitability assessment. Whether land can be used for an energy farm depends not only on its physical and environmental suitability, but also on its practical availability and its legal situation. In addition there is the very important question of competition between energy and food or fibre production, especially in the less-developed areas of the world.

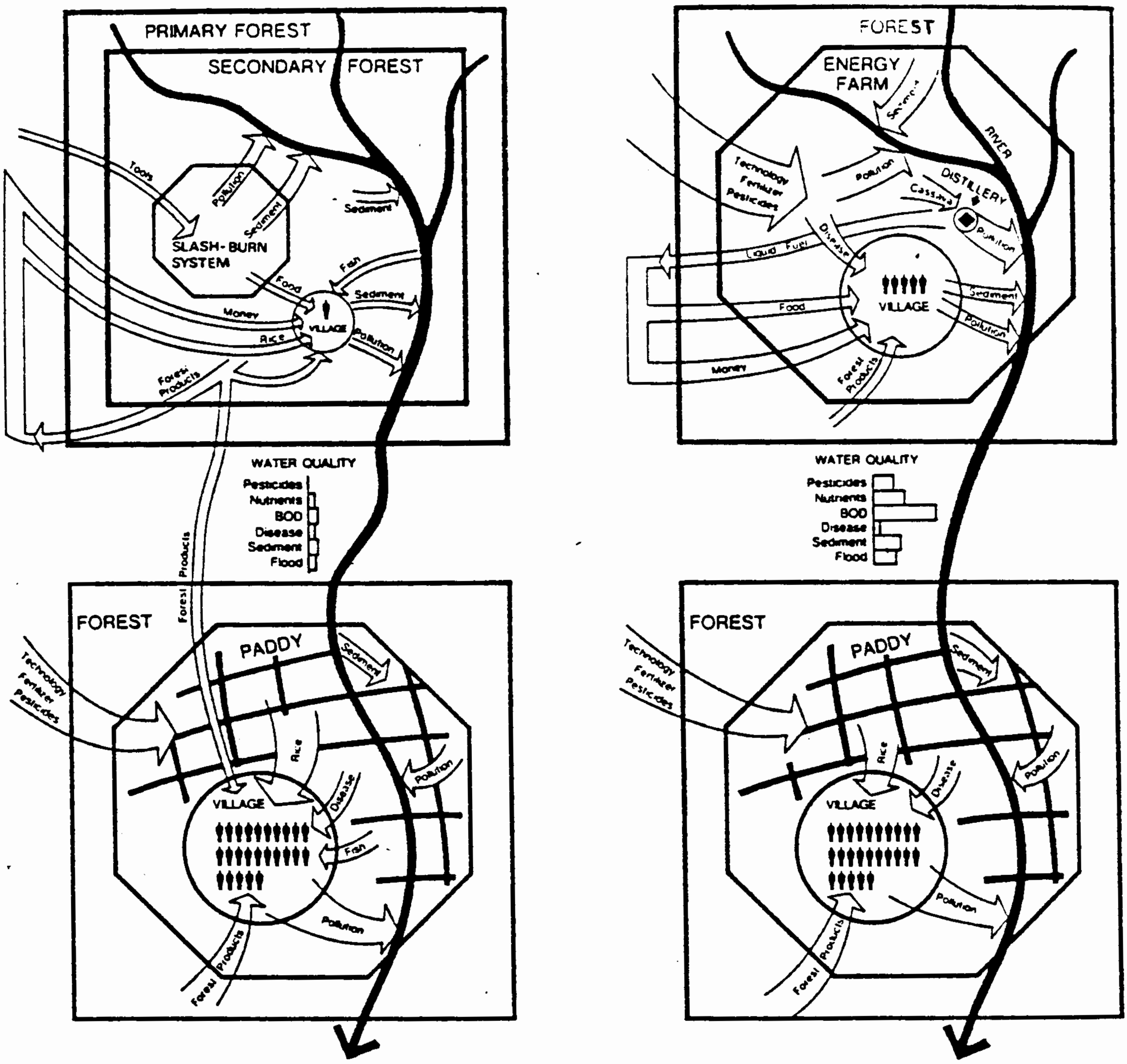

FIGURE 6.2 A comparison of the environmental effects of a cassava-ethanol energy farm with a slash-burn agricultural system The total area of each square is 1 000 ha, while each human figure represents 100 inhabitants, and the widths of the arrows reflect magnitudes of transfers.

Although maps are useful for determining the location of energy farms, they may not be effective for the policy makers who wish to see the possibilities and trade-offs without being distracted by the detail that a map provides. Another approach is to use diagrams which graphically summarise the amount of available land in different suitability and present-use categories.

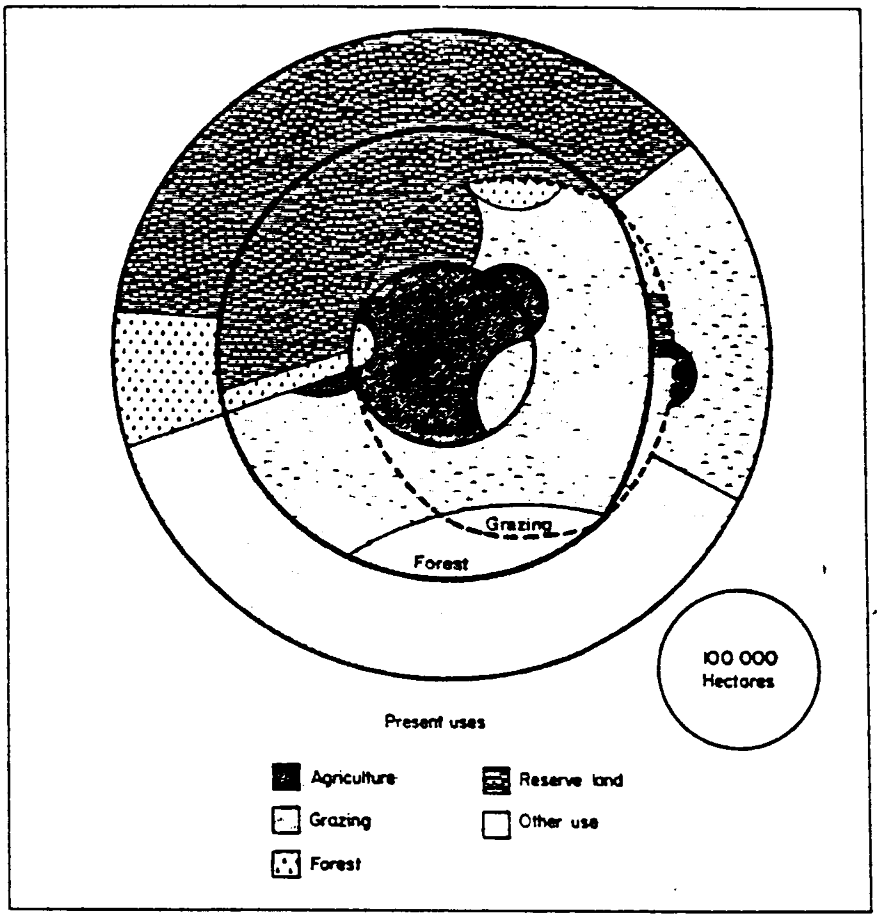

FIGURE 6.3 Diagrammatic presentation of the quantities of land of different suitability categories in different present uses. The total area of the circle represents the total land area of a selected region.

With such a diagram one can visualise the amount of land that can be used for energy farming without serious displacement of other important land users. Different diagrams can be prepared for different styles of energy farms, thus allowing an evaluation of the land use implications of these different styles.

Social constraints

Although there are obvious advantages to bioenergy systems in terms of the creation of jobs, especially in the rural sector, they can also be the source of social problems, especially in less-developed areas. Because of the dominant position of agriculture as a source of income and employment in these rural areas, the importance of a broad-based pattern of agricultural development in such areas can not be overemphasised. Such development would be characterised by gradual, but widespread increases in productivity by small farmers adopting innovations appropriate to their labour-abundant and capital-scarce situation.

Many Third World countries have historically had agricultural sectors based on monocultures, which have resulted in the formation of large estates. The latifundia, for example, large estates for the cultivation of coffee and sugarcane, are a legacy of Brazil's colonial past. Such large-scale farming is economically most appropriate for the agro-industry systems necessary for energy crops, but by necessity the creation of new estates on this scale will, in many cases, cause the displacement of smaller farmers, and increase migration to the urban areas. This has in fact been the case in Brazil, and the Brazilians are looking at alternatives, such as the creation of agricultural communities, agro-energetic villages and cooperatives.

An attempt was made by the Kwazulu Government to implement communal farming in 1972 (Gilbert, 1982), using the 'betterment' planning techniques used in other homeland areas. This is applied in an area in which scattered residences are regrouped in a relatively close settlement. The best arable land in terms of soil studies is then set aside in blocks for agricultural use, and the pastures are demarcated and fenced into camps. The intention was for the residents to cultivate sugarcane for supply to a nearby mill. However, the idea was rejected by the people who were resistant to the social changes it would bring.

In another scheme, in 1974, with the boom in the sugar industry, finance became available to small farmers through the Small Cane Grower's Financial Aid Fund. The Tongaat Sugar Company undertook to act as agents, and later set up the Sukumani Development Company, which has as its function the development of planting and harvesting of sugarcane in Ndwedwe, in Kwazulu. However, the scheme has not been as successful as was hoped, and the types of social problems that have to be overcome are well documented in Gilbert's paper.

The food vs fuel debate

It is ironical that the significant increases in agricultural production that have been achieved in recent history, are mainly attributable to the increase in the energy input to the farming process. Now that energy has become a major issue, the development and stimulation of less energy-intensive, but more scientific agricultural methods, making use of crop rotation, genetic improvements in seeds and the use of marginal lands to grow appropriate crops, has become a priority.

At present the world produces 10-20% more food than is required to feed its population, yet 10% of the world's population is undernourished (Hall, 1984). More equitable distribution of this food or the diversion of grain production away from animal feeding to humans would solve this problem. The problem exists in North America and Europe that there is over-production and over-consumption, and with the real problem being the logistics of distribution of this food to those who need it. The long-term solution is to achieve adequate production of both food and biomass locally, and on a sustainable basis.

In many parts of the world the potential land use conflicts may be more imaginary than real, if new land can be brought into production at relatively low cost. This situation does exist to a certain extent in Southern Africa, in particular in the homeland areas, but here the obstacles that may arise would be of a social nature, as mentioned earlier.

Probably the most important measures needed to avoid the food vs fuel conflict are those that reduce the economic value of the raw materials used in bioenergy production. These measures would tend to reduce the incentive for good agricultural land to be turned over to energy crop cultivation, and rather encourage the development of marginal areas. Such measures would, by necessity, have to be initiated through centralised planning and possibly require the offering of incentives.

A sound long-term approach to deal with the land use conflict is to concentrate on the use of raw materials such as wood and cassava that can be grown on land generally considered as marginal. This requires a carefully focussed and sustained research and development effort. Support of this type of research, involving both the production and use of biomass, should be an integral part of a bioenergy programme.

Political considerations

One of the most noticeable features of bioenergy, and more generally, renewable energy sources, is the diversity of resources and conversion technologies. This feature allows a region or country to obtain its energy supply from an aggregate of many individually modest and decentralised sources. In addition the conversion technologies are in general easily understandable and therefore accessible to a wider range of users.

The advantages to be gained from such a decentralised energy supply are many. Of particular importance from a strategic viewpoint is this very decentralisation, which makes the country's energy network less 'brittle', i.e. vulnerable to disruption. The economic impact in case of error, accidents or sabotage is minimised and the network is more flexible than a centralised supply system.

The technologies used also tend to match the energy quality to the end use more closely than is the case with conventional, centrally-controlled energy supply systems. In addition, the energy is generally able to be produced at the point of use, thus increasing the efficiency of utilisation, and reducing the possibility of transmission losses. This also has important implications in terms of the development of remote rural areas, allowing them to be less dependent on energy imported over long distances, usually at great cost.

Conclusion

The above has necessarily been a brief outline of some of the social and environmental issues associated with the development of bioenergy resources. A more detailed impact assessment can only be made once a context exists for it i.e. a specific project for the conversion of a particular biomass resource in a designated area of the country.

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CHAPTER SEVEN

SUMMARY OF FINDINGS, DISCUSSION AND RECOMMENDATIONS

7.1 SUMMARY OF POTENTIAL CONTRIBUTIONS

The search for alternative sources of liquid fuels for transport has provided the stimulus for the majority of the bioenergy programmes in existence in the world today. Southern Africa is no different in this regard, and independence of petroleum imports is a high priority. For this reason attention has been focussed in this study on the potential volume of ethanol that can be produced from biomass sources.

	Volume 10^6 l/yr	Energy Content 10^6 GJ/yr	Notes
AGRICULTURE			
Energy Crops			
Starches			
Cassava	3 400	72,3	p 24
Sugars			
Sugarcane	521	11,1	p 26
Residues			
Crops			
Bagasse	263	5,6	p 41
Maize	1 056	22,4	p 43
Sorghum straw	157	3,3	p 45
Wheat straw	218	4,6	p 45
Processing			
Molasses	110	2,3	p 46
FORESTRY			
Available residues			
Forest	167	3,6	p 70
Sawmills	32	0,68	p 70
TOTALS	5 924	125,88	

The assumptions stated in the body of the study all hold (see page references). The above figures are based on the use of those resources that could be relied upon as feedstocks. Of these, only cassava would require reallocation of land for its development as a bioenergy resources. In addition to these there are three others that could also be considered, but are not included for various reasons. Maize could be diverted from the export market to ethanol fermentation. However, given its uncertainty of production in drought years, it is an unreliable feedstock. With reference to production and export figures, it would seem reasonable that in years of good production sufficient grain could be diverted to produce in the region of 1,1 billion l of ethanol (24,3 GJ), assuming that it was expedient to reduce exports.

Grain sorghum is not yet firmly established as a crop in Southern Africa, playing very much a secondary role to maize. However, it has potentially greater value than maize as an energy crop, mainly because of its higher per ha yield rates, and hardier nature giving it greater reliability in drought seasons. No figures for its potential in terms of ethanol volume have been calculated, mainly because production levels would depend on the area of maize-producing land that could be released for grain sorghum cultivation.

Sweet sorghum has been considered by the sugar industry for filling sugar mill capacity during the cane off-season. An estimate was made of the potential for ethanol production from this crop, based on its large-scale cultivation in Natal, yielding the figure of 182 million l (3,9 GJ). This figure is very tentative as it is dependent on a number of assumptions, not least of which is the availability of land.

The potential contribution of vegetable oils to the liquid fuel supply has not been included. As was mentioned earlier, this is the subject of another study being conducted by various government bodies. As was mentioned earlier, an estimate of the quantity of diesel-type fuel that could be produced from this source is around 650 million l/yr.

The following table summarises the primary energy contribution of biomass sources that could be used to produce fuel forms other than or in addition to ethanol.

	Energy Content 10^6 GJ/yr	Technology	Notes
AGRICULTURE			
Residues			
Crops			
Bagasse	41,4	A,B,C,D,E	p 41
Maize	39,4	A,B,C,D,E,F	p 43
Sorghum straw	13,2	A,B,C,D,E,F	p 45
Wheat straw	14,2	A,B,C,D,E,F	p 45
Animals			
Cattle: Beef	1,7	F	p 51
Dairy	1,5	F	p 51
Pigs	1,1	F	p 52
Poultry	3,3	F	p 53
FORESTRY			
Fuelwood			
All sources[2]	219,3	A	p 71
Available residues			
Forest	9,2	A,B,C,D,E	p 70
Sawmills	1,8	A,B,C,D,E	p 70
URBAN			
Solid waste	96,3	A,B,C,F	p 92
Liquid waste	1,8	F	p 94
TOTAL	444,2		

KEY TO CONVERSION TECHNOLOGIES

A - Direct combustion
B - Pyrolysis
C - Gasification (including methanol synthesis)
D - Carbonisation
E - Fermentation to ethanol
F - Anaerobic digestion

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[2] Natural forests, plantations, large and small woodlots, and agroforestry

7.2 DISCUSSION AND RECOMMENDATIONS

All the figures in this study should be viewed against South Africa's current primary energy consumption. According to the Dept of Mineral and Energy Affairs (pers comm) this amounted to 3,58 x 10^9 GJ in 1984. The nett energy consumption over the same period was 1,94 x 10^9 GJ. The figure for ethanol production should be compared against this latter figure. There is little doubt that biomass can and will be used to meet part of this energy demand. Existing uses of biomass will undoubtedly increase, particularly in rural Southern Africa. Its consumption in these areas, and the related problems are already being investigated. Once they are better understood, solutions must be found and implemented as a matter of urgency, if the dire environmental and social consequences are to be alleviated, and hopefully avoided.

Biomass production

The basis of any bioenergy programme is the biomass production. A brief summary of the groundwork required for the development of a biomass production programme follows. Some of this work has already been done, or is in progress:

Preparation of comprehensive maps of soils, topography, climate and chosen crop types.

Investigation of the use of marginal land, and the development of the appropriate agricultural techniques for such areas.

Assessment and evaluation of food/fuel/fibre requirements of the region.

Compatibility studies of a particular resource's biomass potential and its energy/nonenergy uses.

Identification and development of appropriate plant species for energy/nonenergy end uses.

Development of agricultural equipment and implements appropriate to biomass production systems.

Research into plant genetics with the intention of increasing productivity without deleterious effects on the environment.

A top priority for a national bioenergy programme is the establishment of a comprehensive biomass database, for which this study can form the basis. The paucity of adequate, centralised data for a reliable assessment of present biomass production is evident. In addition there is little or no information on the agricultural potential of large areas of the region, in particular, the potential of the areas which can be regarded as agriculturally marginal. Included in the database should be an assessment of the agricultural residues that can be released from their present uses, with particular attention being paid to the ecological impact of their removal from the environment.

Much of the strategy outlined above refers to biomass resources that have yet to be developed in this country. Cassava is an example of one of these with which a start has already been made. However effort with this crop has been concentrated on its development as a feedstock for specialised starch production. Its use for ethanol production locally should be assessed in more detail, given the apparent potential that exists for its cultivation.

Biomass conversion

With regard to the conversion technologies, the logical steps to be followed in a local bioenergy programme are:

A review of the state of the art of biomass conversion processes.

Research and development of processes for optimal conversion under local conditions.

Design and installation of demonstration units with a view to studying the engineering and economic aspects of suitable processes.

This and other studies have covered the first step. Progress has been made locally with the other two, focussing on those biomass resources already available (see Appendix 2).

The gasification of wood has passed the pilot plant stage, and is close to commercialisation. This experience should now be applied to other biomass feedstocks, in particular crop residues. The technology should find widespread application in rural areas, both for powering agricultural processes and for electricity generation.

Indications are that other bioenergy uses could become a reality in the short to medium term, in particular the production of liquid fuels, namely ethanol from sugar and diesel-substitutes from vegetable oils. The use of bagasse as a source of cellulose for hydrolysis and subsequent fermentation to ethanol is part of an ongoing national research programme. Research has reached the pilot plant stage of the cellulose hydrolysis step, while parallel research into the problems associated with fermentation of the resultant sugars is continuing.

Other areas that would appear to have short-term potential, and are not receiving sufficient attention, are the production of charcoal from forestry wastes and the anaerobic digestion of animal residues. Obviously, techno-economic surveys should be the starting point in both cases. Charcoal production should focus on the use of low-cost transportable kilns in the plantations themselves, with the emphasis on production for the rural and peri-urban domestic markets.

Although the potential overall contribution of animal wastes is not large, 3,2 GJ/yr, its point of use is significant, in that it will very often be replacing liquid fuels used for generators in rural areas. The recommendation is that digesters should initially be established at large-scale facilities such as feedlots, dairies and food processing plants. The scale of these plants should make the economics more favourable, and the capital would probably be more easily obtainable. The experience gained with these, and their hopeful success will provide the momentum for the development of a wider ranging and smaller scale biogas programme.

Biofuel utilisation

Along with biomass production and its conversion into a suitable energy form, the technicalities of its utilisation must be considered:

Modification of various units to run on biofuels.

Studies of the use of by-products from bioenergy systems.

Extensive work has already been done on the first of the above, in particular, with the modification of internal combustion engines to run on various alternative fuels (see Appendix 2).

The use of nonenergy by-products is often a very important part of any bioenergy conversion process, as the process economics can be drastically altered by a valuable by-product.

General considerations

Some points of a more general nature that should be considered in the implementation of a bioenergy programme are the following:

Definition and determination of the appropriate energy mix between fossil fuels, biofuels and other sources of energy, in terms of sustainability of supply, decentralisation and minimising of social and environmental costs:

Social: fostering of more equitable distribution of income and wealth, possibly making use of cooperatives.

Environmental: minimum proliferation of pollution and the maintenance of good agricultural conditions.

Economical: labour rather than capital intensivity.

Technological: science- rather than energy-intensive farming.

7.3 CONCLUSION

There is no doubt that the greatest current need for bioenergy in Southern Africa exists in the less developed areas, which are mainly rural. Fuelwood is the basic energy source essential to the very survival of the large majority of the rural dwellers in the region. Already this demand, currently running at $219,3 \times 10^6$ GJ/yr, has had some dire consequences, and will be the cause of further environmental degradation, unless timeous action is taken to supplement and regenerate traditional sources of rural energy supply.

As has been outlined, some projects have already been initiated, notably in the Transkei and KwaZulu. However, the projected demand for fuelwood far outstrips the scale of these, and considerably more effort and capital will have to be devoted to the development of fuelwood resources. This is a task which must be carried out with great care, and with due regard to its complexity.

Most of the problems which can beset fuelwood supply programmes have been detailed in the relevant section. The nature of these ranges from varying perceptions of needs through to insufficient funding of projects. As with many other development projects, the majority of the problems can be overcome by maintaining good communication between all parties involved. In this way the real needs and expectations of the community for which the fuelwood is destined will not be lost sight of, and hopefully problems will be anticipated before they arise.

In the light of the above it should be a national priority to formulate an integrated fuelwood supply policy. This should avoid being prescriptive, and rather provide the framework within which individual projects can be implemented. The essential elements of this policy should allow for the mobilisation of financial and manpower resources and outline procedures for allocation of land for woodlot development. Expressed in another manner, this policy statement should create the awareness of the need for woodlot development, and open up the relevant channels to reduce obstacles to its realisation.

In conclusion, biomass is certainly a resource that could be used to provide a greater proportion of Southern Africa's energy. However, the lead times for the development of bioenergy systems can be long, in particular where agricultural development is required. The following outlines the scenario that could unfold over the next quarter century, if some national priority were to be given to the development of bioenergy supply.

Time scale	Aims of RD & D	Bioenergy Technology
Short term (next 5 yrs)	To advance a technology to commercial viability; to promote consumer acceptance; and to promote conditions for the the establishment of a supply and distribution infrastructure for feedstocks and products.	Woodlot development including research into the technical and social parameters. Gasification of various residues Fermentation of sugar and grains to ethanol
Medium term (5 to 20 yrs)	To bring a technology to the prototype stage and so gain an understanding of costs, reliability and performance.	Preparation of solid fuels from forestry, agricultural and urban wastes. Anaerobic digestion to produce biogas. Fermentation of cellulose to ethanol, via hydrolysis. Development of cassava as an energy crop.
Long term (20+ yrs)	To advance a technology from an idea to the pilot plant or pilot scheme stage.	Development of new energy crops

APPENDICES

APPENDIX 1

Cost study of ethanol from grain (Kruger and Cilliers, 1981)

The costs given by Sentrachem are based on a plant costing of the order of R80 million at 1981 prices, and producing 187,5 million l of ethanol/yr from grain sorghum.

Variable costs

Raw material - grain sorghum 2,6t/kl @ R84/t	218 R/kl
Other	25
	243
Minus by-product credit	-100
Nett variable costs	143
Fixed costs	
Running costs	21
Depreciation	56
15% ROI before tax	80
Ethanol selling price needed	R300/kl

The comparable selling price for ethanol produced from maize at R120/t would be R394/kl.

APPENDIX 2

BIOENERGY-RELATED RESEARCH AND EXPERTISE IN SOUTH AFRICA

While collecting information for this study it became apparent that various organisations, institutions and government bodies have investigated the feasibility of using various forms of biomass, generally those related to their sphere of interest. The relevant parts of all past work have been included in this report and, where possible, brought up to date.

In addition to the feasibility study work, fundamental research has also been done in a wide range of fields, and expertise with certain technologies has been acquired. The following is a list of the work encountered during the course of the study:

CSIR

National Materials Programme

Fundamental and practical research is being done under the auspices of the renewable feedstocks section of this Foundation for Research Development (FRD) programme. The work centres around the use of bagasse as a feedstock and is looking at its conversion, via enzymatic hydrolysis and fermentation, to ethanol. The main institutions involved at this stage of the programme are the National Food Research Institute (NFRI), the Dept of Microbiology at the University of the Orange Free State and the Sugar Milling Research Institute (SMRI) in Durban. A point has now been reached where all the work to date is being pulled together at the SMRI, and a hydrolysing plant, somewhere between laboratory and pilot scale, is being constructed.

It should be mentioned, that the work being done by Dr Watson of the NFRI is at the forefront of the field of cellulase production research internationally.

Also under the auspices of this programme is a national investigation into solid waste management. No specific work has been done on the use of refuse as an energy source, but a watch is being kept on developments locally and internationally.

National Timber Research Institute

The wood gasification programme being coordinated by the NTRI is dealt with in more depth in Chapter Four, Section 4.2.2.2.

National Institute for Water Research

Although not directed specifically at the optimisation of gas production, a good basis of understanding of the anaerobic digestion process has been built up by the NIWR. The bulk of this experience has been gained in the Western Cape, where there are high BOD effluents, mainly from fruit and food processing plants. This is all very much on a large scale. However, it is a technology that can easily be scaled down and simplified.

DEPT OF AGRICULTURE

Division of Agricultural Engineering

Engineers at Silverton have carried out extensive tests on the use of vegetable oils in Diesel cycle engines. They are also looking at the possibility of transesterification of these oils in small scale, farm-based plants.

JOHANNESBURG CITY COUNCIL

Tenders have been received for the investigation of methane production from a controlled landfill site. Preliminary test have been conducted, but no figures have been released as yets.

SA SUGAR ASSOCIATION EXPERIMENT STATION

Some work has been done on the gasification of bagasse, and its use in an internal combustion engine. A car and tractor converted by the Energy Research Institute to run on ethanol have been monitored here for a number of years.

UNIVERSITY OF CAPE TOWN

Energy Research Institute

The use of alcohol fuels, in particular, methanol, has been assessed for a number of years, and expertise has been built up in the conversion of both spark-ignition and Diesel engines to run on these fuels.

The fluidised combustion technology section is looking at the combustion of municipal solid waste on behalf of the City Council of Cape Town.

UNIVERSITY OF NATAL

Dept of Agricultural Engineering

The use of alternative liquid fuels in tractor engines has been investigated.

UNIVERSITY OF THE WITWATERSRAND

Dept of Mechanical Engineering

The use of alternative fuels for internal combustion engines has been investigated. Of particular interest is the use of biogas in spark-ignition engines in both a pure and dual-fuel mode. Diesel engine dual-fuelling with biogas is to be looked at in the near future.