PYROLYSIS OF WOOD IN THE SUPPLY AND CONSERVATION OF FUEL IN KENYA

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Abstract

Wood and its charcoal derivative occupy top position in the order of major fuels consumed by the Nation, It is estimated that it constitutes 72 percent of total energy consumed as fuel. In terms of useful energy recovered from the fuels, estimates are that wood constitutes 41 percent while petroleum products constitute 59% of the total useful energy consumption in the country. This is due primarily to the low energy recovery efficiencies of wood appliances vis a vis appliances used for other fuels.

It is shown that locally employed charcoal making methods are also energy inefficient but other known processes are relatively expensive alternatives.

It seems that wood will continue to be a dominant fuel for the forseeable future and work should be directed at inter alia, improving wood-burning appliance efficiencies, charcoal stove efficiencies, and employing charcoal making processes which allow up to 70 percent energy recovery instead of the present methods which generally allow less than 10 percent energy recovery. Due to higher capital costs and the inherent larger capacities of such processing devices community scale plant sizes are suggested in preference to the very small scale household operations. Such plants would open up opportunties for manufacturing of acetic acid, methanol, and possibly other chemicals from wood and stimulate development of local technological capacity in addition to charcoal fuel production.

INTRODUCTION

Since the beginning of the so called 'Oil crisis' Kenya, like most of the oil non-producing Countries, has been forced to bear an increasingly impossible burden of foreign exchange payments arising from crude oil imports. In addition to this, it has been argued that the continued supply of wood is under serious threat. It would therefore seem that the possibility of a future, crippling, energy problem is not too far-fetched.

Apart from stimulating a search for alternative energy sources, the above observed trends have also made it imperative to look at ways of conserving such energy as is available. In the case of wood, possible modes of use include burning it directly or converting it to charcoal with, or without, liquid by-products recovery. For the present, conversion of wood to fuel gas is not feasible. (There are no national gas grids through which such gas could be supplied).

This paper attempts to set out advantages and problems of energy conservation and stimulation of the local industrial capacity through production of both charcoal and wood oils by pyrolysis of wood.

1. WOOD AND WOOD DERIVED FUELS AND THE NATIONAL DEMAND OF ALL FUEL TYPES

1.a. Wood Energy as the major energy source in Kenya.

There can be little doubt that wood-and its derivative-charcoal is the most important energy source in Kenya. A few figures illustrate this clearly.

Wood consumption, directly or as charcoal, is estimated at 1.2 - 1.3 m^3 per capita per annum for rural areas and at about 2 m^3 per capita per annum for urban areas (Western & Ssemakula, Arnold). Assuming that wood consumption is of 1.2 m^3 per capita/annum and taking the population in 1977 as 14 million people total wood consumption for this year was 16.8 million cubic metres. In terms of potential fuel energy in wood this amounts to about [1] 182.3 giga MJ ie 182.3 $\times 10^{12}$ KJ or 182.3 $\times 10^{15}$J.

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1. One cubic metre of wood is taken as equivalant to 0.7 metric tons. The lower calorific value of wood is taken as 15.5 MJ/kg. Note that 1 giga = 10^9., J = Joule.

During that year sales of petroleum based energy forms amounted to about 1.544 million metric tons. The energy equivalent represented by this amounts to about[2] 65.6 giga MJ. In the same year 63000 metric tons of coal, equivalent to 2.2 giga MJ, were imported. Total electrical energy consumed is given as 1203 GWh ie 1203 x 10^9 Watts hours (Wh) (Githinji) and is equivalent to 4.331 giga MJ.

Consumption of other forms of energy such as solar, biogas, nuclear, etc. was either non-existence or negligible.

Now, as per cent of total energy consumed in 1977 consumption of major forms of energy is seen to have been as in the following Table.

TABLE 1:

Energy form	As Per cent of Total Energy (%)
Wood	71.6
Petroleum Product	25.8
Electricity	1.7
Coal and Coke	0.9

Estimates for wood consumption used above are considered conservative. Nevertheless, wood emerges clearly as the dominant fuel form in Kenya.

It is important to bear in mind that not all of the potential energy in any fuel is actually recovered for the use to which it is put. In other words some of the potential energy in fuels is wasted. This wastage or loss occurs during processing of the basic fuel to other forms of the fuel and, or, during conversion of the latent chemical or electrical energy to a final end use such as heat, light, mechnaical power etc.

The effect of these losses can be more clearly demonstrated by considering the two major forms of fuel in Table.1.

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2. See table A1 for breakdown of the petroleum products. The average lower calorific value of the products has been calculated and found equal/42.493 MJ/kg. Table A2 (appendix) gives the calculated energy contents for different petroleum products.

Direct burning of wood in a hearth for useful energy - say for cooking - is considered to have a conversion efficiency of between 7 per cent and 10 per cent. The typical conversion efficiencies for kerosine and gas stoves can be taken as 35 and 70 per cent respectively (McGranahan et al). Taking the conversion efficiencies of wood hearths as 10% and of appliances used in conjuction with petroleum products as 40% it can be seen that consumption of 'useful energy' from these fuels becomes:

Wood ∿ 18.23 giga MJ = 41%

Petroleum products[3] ∿ 26.24 giga MJ = 59%

The role of wood as the dominant fuel form is then taken by petroleum products.

This example shows the importance of adopting energy conserving measures to ensure maximum utilisation of the latent heat in a given fuel and particularly in wood fuel.

1.b. Consumer's energy cots.

From the point of view of the consumer, the particular energy form used for any given purpose is determined mainly by the availability of various forms and his economic conditions.

It is generally accepted that by far the greatest uses of energy in Kenya are in domestic heating and lighting. On the basis of an average 'useful energy' consumption by an average household of 4.8 million kJ per annum (McGranahan)[4] the cost of alternative energy forms for domestic heating and lighting is estimated as shown on Table 2.

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3. Losses during processing of crude petroleum oil are ignored as inevitable ones.

4. McGranahan et al estimate that for households with per capita incomes of K£ 0- 1,200., the basic energy consumption for cooking and lighting is in the region of 4.2 - 5.4 GJ per annum.

Table 2:

Fuel	Appliance Efficiency[5] (per cent (%))	Gross Energy required. (MJ)	Quantity fuel.	Estimated Costs (Shs. per annum)
Wood oil	40	12000	0.46 t	-
Wood[6]	10	48000	6.2 m^3	600
Charcoal[7]	20	24000	0.83 t	800
Kerosene[8]	35	14000	3.9 m^3	9.500
Butane gas[8]	70	7000	0.15 t	750
Bio-gas[9]	70	7000	3000 m^3	1,500
Electricity[10]	30	16000	4400 kWh	2,800

From Table 2 it is clear that wood and charcoal fuels are very attractive to consumers of low to medium incomes. The cost advantage of charcoal and wood as well as the low cost of necessary appliances (jikos are much cheaper than electric cookers) are likely to ensure continued high demand for charcoal and wood as domestic fuels. Furthermore as long as the'oil crisis' continues prices for petroleum derived fuels will continue rising making these fuels economically unsuitable alternatives.

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5. Except for biogas stoves efficiency which is an estimate based on butane gas stoves efficiency, these figures are averages of those given by McGranahan et al.

6. The wood volume is that of stacked wood. The price used assumes that wood is supplied from areas under the Department of Forestry. Forest royalty charges are of between Shs.10. and ·18" Shs 13 per cubic metre (Figures of the forestry department). Transport costs are considered to constitute the balance of the price.

7. Openshaw gives the price of charcoal in Kenya as Shs. 880/= per ton (1978). Price used is the estimate for 1980.

8. Prices used are the retail ones for Oct. 1980.

9. The cost of biogas has been taken as Shs. 2,500/= discounted over five years. Then collection (raw materials) and operation costs are taken as Shs. 90/= per month.

10. Electricity charges are taken as Shs. 0.6125 per KWh. This rate is for non-lighting domestic appliances (E.A.P.L. tariff code A0). Government tax at 2% of the charges has been added. (September 1980).

It is noteworthy that the very high conversion efficiency of gas burners renders use of petroleum gas quite competitive vis a vis use of charcoal. However these stoves are more expensive and gas cylinders are generally difficult to obtain locally.

1.c. Use of wood products in meeting nation wide domestic fuel needs.

Apart from elements of energy conservation through use of wood oil and, or charcoal vis a vis use of unprocessed fuelwood, other factors come into play when considering supply of energy nation wide.

The single most important other factor is that of transportation of a fuel - be it wood, charcoal, or oil - to areas where it is consumed but not locally produced. Since calorific values of wood oil and of charcoal are twice that of wood, transportation costs for wood would be more than those for charcoal/wood oil. In addition, the shape of charcoal makes it easier to pack compactly. This is not true of wood; a fact that would tend to increase further transportation costs of wood."[11]

Another important factor to the consumer is that charcoal is a much more convenient fuel to burn than wood. It is almost smokeless while wood is very smokey. It has less moisture content than wood and burns more slowly than wood. In addition charcoal jikos are more convenient appliances than wood hearths in the urban centres (with regard to house designs); and are not fixed at one location inside the house. Charcoal does, however, have the disadvantage of being dirty compared to wood but this fact seems not to deter most of its users in towns.

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11. It is worth noting in passing that even if surplus supply of biogas from the rural areas were available for consumption in urban areas, its transportation requires substantial investments in compression equipment. These equipment could easily outprice it out of the fuel market.

When considering possible substitutes for petroleum products used as industrial fuels charcoal again becomes superior to wood. It has higher calorific value and is more uniform in chemical composition than wood. Equipment for use with charcoal would be smaller than those for use with wood. For some industrial uses, for example in the cement industry, wood could not even be considered while certain qualities of charcoal could be used.

Considerations such as the above indicate that charcoal is likely to remain an important fuel in urban areas for some time to come. As petroleum derived liquid (kerosine) and gas (butane and propane) fuels become more and more expensive charcoal demand will correspondingly rise, althou although other energy forms like electricity and solar may well be close competitors.

2. WOOD COMPARED TO CHARCOAL AND WOOD OIL AS FUELS.

In terms of 'useful energy' recovery the viability of processing wood to charcoal or to charcoal and wood oils can be simply investigated. As mentioned earlier there are two main causes of energy losses in a fuel:

(i) Losses during wood processing. The process itself consumes energy inorder to work. Unrecovered by-products of the process contain energy. In addition some heat loss through walls of the processing equipment is almost inevitable.

(ii) Losses during burning of the fuel. Some of the heat in the fuel goes to evaporation of the moisture in the fuel. In addition the equipment - hearth, stoves, etc. - used to convert chemical energy in the fuel to heat allows heat losses.

In the case of wood burnt directly, losses occur due to the in eficiency of the burning equipment. Useful energy recovered from fuel wood is then given by the expression:

$$E_{rw} = a_w K_w$$

where

a = fraction of potential energy in fuel recovered as useful energy

K = the calorific value of fuel

E = useful energy in consistent units.

and subscripts

r and w denote recovery and wood respectively.

Useful energy recovered from original wood when it has been converted to charcoal plus wood oil and burnt as such is given by the expression

$$E_{rco} = a_c b_c K_c + a_o b_o K_o$$

where now

b = weigh fraction of original wood recovered as either charcoal or wood oil after pyrolysis of wood (in the same equipment).

and subscripts,

c and o denote charcoal and wood oil respectively.

All other things being equal, direct burning of wood becomes undesirable when the following inequality holds:

$E_{rco} > E_{rw}$ and vice versa.

Now, efficiency[12] of production of charcoal with or without by-product oils recovery varies with the process used. In addition some processes allow liquid by-product recovery while others such as earth kilns, mark V kiln, CUSAB etc, do not. It is useful, therefore to examine under what circumstances are the various available processes better than others.

2.a. Useful energy from wood compared to useful energy from charcoal.

Calculations can be done with 'a' and 'b' as variables i.e. with production process efficiency, b, and energy conversion appliance efficiency, a, as variables. The calorific values of wood, charcoal and wood oil can be assumed constant using average values[13].

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12. This efficiency gives rise to variable b in the equations above.

13. For. wood K_w = 15.5 MJ/kg Source: Andre' Mayer
Charcoal K_c = 29 MJ/kg Source: Andre' Mayer
Wood oil K_o = 26 MJ/kg Source: Chiang et al

For varying values of hearth efficiency, a_w, the useful energy recovery[14], E_{rw}, is as shown in Table 3.

Table 3:

Hearth efficiency, a_w, fraction	0.10.	0.15	0.20	0.25	0.30	0.35
Useful Energy recovery, E_{rw}, MJ/kg.	1.55	2.33	3.10	3.88	4.65	5.33

Normally, hearth conversion efficiency is less than 10 per cent (Arnold).

For purposes of comparison here it is assumed optimistically, that the normal hearth efficiency is 10 per cent.

Calculations of useful energy recovered from charcoal also be made taking b_o as zero since wood oil is not recovered, i.e. using the equation.

$E_{rc} = a_c b_c K_c$ for charcoal without wood oils production.

Charcoal stove (jiko) efficiency a_c and wood hearth efficiency can be varied. It is interesting then to calculate the required charcoal production[15] efficiency for wood processing to be energy viable i.e. for the following inequality to hold

$E_{rc} > E_{rw}$.

Table 4 shows the results of such calculations.

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14. Useful energy recovered when wood is burnt directly.

15. Charcoal production without by-product oils and gases recovery is done in a process or equipment which will be described as a kiln. This will be distinguished from a retort which is used here to refer to a process that incorporates production of both charcoal and wood oil. The distinction is, however, largely for convenience.

Table 4: Required Kiln efficiency for $E_{rc} > E_{rw}$

	Required Kiln efficiency, b_c, for given charcoal jiko efficiency a_c							
Jiko Eff. a_c	.10	.15	.20	.25	.30	.35	.40	.45
Hearth Efficiency a_w								
.10	53	.36	.27	.21	.18	.15	.13	.17
.15	. 30	.53	.40	.32	.27	.23	.20	.10
.20	NV	.71	.53	.43	.36	.31	.27	.24
.25	NV	.89	.67	.53	.45	.38	.33	.30
.30	NV	NV	.80	.64	.53	.46	.40	.36

Using results of Table 4 a few remarks can be made as follows:

(1) With current wood burning hearths (efficiency < 10 per cent) and current charcoal jiko efficiencies of 15 - 25 per cent charcoal making is viable - in terms of energy - only if the kiln efficiency are 21 - 36 per cent. (i.e. charcoal recovered is 21-36% of weight of air dry wood used). The currently available kilns have efficiencies of 8-23 per cent. Most have efficiencies of only up to 15 per cent.

It would seem therefore that purely in terms of useful energy recovery the majority of these kilns are not viable.

(2) Improvement of direct wood burning appliances to about 20 per cent makes use of any of the available charcoal kilns redundant in terms of energy recovery. With charcoal jikos of 25 per cent efficiency the required kiln efficiency is over 32 per cent.

(3) Traditional method of making charcoal using earth pits or stocks and with kiln efficiency of 8-10 per cent is very wasteful. It is not viable when used in conjuction with charcoal jikos

whose efficiencies are equal or less than 50 per cent[16].

2.b. Useful energy from wood compared to useful energy from both charcoal and wood oil.

Processes incorporating liquid by-product recovery in charcoal production - retorts - have yields of charcoal in the range 25 - 35 per cent weight of wood feed. They also have wood oil yields of 16-20 per cent weight of wood feed. On the basis of previous discussion these retorts seem energy-viable.

A table of required retort production efficiency (charcoal basis) similar to Table 4 could be drawn. But it is perhaps more instructive now to examine the per cent excess energy recovered from combined charcoal and wood oil fuels relative to energy from wood when burnt as such. This is given by the following expression:

$$e_{rco} = \left[\frac{a_c b_c K_c + a_o b_o K_o}{a_w K_w} \right] - 1 \quad \times 100 \qquad (\%).$$

where the additional notation e = the excess energy recovered expressed as per cent.

If b_o is held constant at 0.16 while other variables a_w, a_c, a_o, and b_c are varied calculations for e_{rco}, yield results as shown in Table 5.

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16. Jikos with reportedly, up to 40 per cent efficiency have been exhibited, but not successfully adopted yet.

Table 5: Percent excess energy e_{rco} recovered from charcoal and wood oil.

		Excess energy from charcoal and wood, e_{rco} (%) For varying jiko and oil stove efficiencies a_c and a_o and retort eff. b_c								
Jiko a_c		a_c = 0.15			a_c = 0.20			a_c = 0.30		
Oil Stove a_o		a_o = .20	a_o = .30	a_o = .40	a_o = .20	a_o = .30	a_o = .40	a_o = .20	a_o = .30	a_o = .40
Charcoal yield, b_c	Hearth Eff. a_w									
b_c = .25	a_w = .10	24	51	78	47	74	101	94	120	148
	.15	-17	0.5	18	-2	16	34	29	47	65
	.20	-38	-24	-11	-26	-13	0.5	-13	10	24
	.25	-50	-40	-29	-41	-30	-20	-22	-12	-9
b_c = .30	a_w = .10	38	65	92	66	93	120	122	149	176
	.15	-8	10	28	11	29	46	48	66	84
	.20	-31	-18	-4	-17	-4	10	11	24	38
	.25	-45	-34	-23	-34	-23	-12	-11	-0.4	10
b_c = .35	a_w = .10	52	79	106	85	111	138	150	177	204
	.15	1	19	37	23	41	59	67	85	103
	.20	-24	-11	3	-8	6	19	25	38	52
	.25	-39	-29	78	-26	-15	-5	0.1	11	22

Results of Table 5 reinforce the previous observations that viability of charcoal and wood oil production is strongly influenced by:

(i) direct wood burning stove's or hearth's conversion efficiency, a_w,

(ii) wood oil and charcoal stove (jiko) conversion efficiencies

(iii) retort efficiency.

Under the present circumstances of jiko efficiencies of 15-25 per cent, oil stove efficiences of 30-40 per cent, and hearth efficiencies of 8-10 per cent retorts with charcoal yields of 16-20% of weight of original wood feed are 'energy viable'.

It is worth noting that as oil and charcoal stove efficiencies are improved the case for production of these fuels gets even stronger. However, it would be hard to justify production of these fuels primarily on energy grounds, were the hearth efficiency to rise to about 60 per cent. This value is probably difficult to realise for wood stoves or hearths acceptable to potential users.

3. WOOD PYROLYSIS PROCESS

As is well known several processes or equipment for production of charcoal or of charcoal and fluid by-products exist. This section looks at those processes used in Kenya as well as those that are not but could be used.

3.a. Production of charcoal without by-product recovery.

Among the available equipment are earth kilns, metal kilns, and brick kilns.

3.a.i. Earth Kilns

Use of earth kilns is the most common method of charcoal making in Kenya. It is practised largely on a very small scale and on occasional basis by most small farmers with trees to spare. The method is highly wasteful with a charcoal yield of less than 10 per cent of the weight of wood used. The quality of charcoal produced is also unsuitable for uses other than as domestic fuel. An earth kiln is however attractive for the following two reasons:-

(i) It involves no capital expenditure other than provision of axes, hoes, and 'pangas'.

(ii) Labour for making the pit or stack, for wood cutting and collection, and transportation of charcoal, is available at negligible cost to the producer (family of lowly paid, otherwise unemployed, labourers) This form of labour organisation is made possible by the small scale and intermittent nature of charcoal making operation.

Even where production involves purchase of wood and is on a more regular basis the cost of wood is still very low and labour charges are not high.

3.a.ii. Metal and brick kilns.

Metal and brick kilns which have been at least tried in Kenya include Masonry kilns, portable Mark V.steel kilns and CUSAB kilns (Uhart, Foust).

Apart from the construction materials used the main difference between the kilns is of size. They all operate on the principle of burning of part of the charge to provide heat required to start the exothermic charcoal making reaction at about 280°C. Differences in charcoal yield arise from differing heat losses through the kiln walls and from the degree of control of the combustion process required to generate heat for initiating the exothermic reaction.

Neither the CUSAB nor Mark V kiln has been commercially sucessful. Both of these kiln types are designed primarily for regular, small scale charcoal producers.

The missiouri type of masonry kilns are used by a company in Eldoret. This company has an assured supply of wood and charcoal making is part of an integrated processing operation including use of wood bark for leather tauning operations. No other users of brick kilns have been reported.

A company near Nairobi has been reported to be planning to make charcoal briquettes from coffee husks, using imported carbonisation equipment (1980). Here like in the case of the Eldoret firm the : raw material is concentrated near the charcoal plant and the charcoal process is part of a wider integrated processing operation.

3.b. Production of Charcoal with liquid by-product recovery: Retorts for Charcoal and by-product recovery.

There are no known cases of use of retorts in Kenya. However, retorts for charcoal making with recovery of wood oils and tars are widely used in Australia and have been used in USA and Europe particularly in the period prior to 1950. Then wood was a main source of acetic acid, methanol, and acetone. Creosote oil is an excellent timber preservative and pitch when mixed with asphalt can be used to make roads. Availability of cheap petroleum oil has made wood a less attractive source of the above products. Essentially wood could substitute petroleum.

The essential difference between retorts and kilns is that when using retorts provision is also made to recover gaseous and liquid by-products. Normally the gases are used to provide the heat required to carbonise wood to charcoal. The retorts can either be internally or externally heated by hot inert gases.

Typical products of wood pyrolysis using retorts incorporating by-product recovery facilities are given on table A3 of Appendix. In summary 1000 Kg of wood yields 300 kg of charcoal, 140 cubic metre of wood gas, about 160 kg of wood oils, 12 litres of creosote oil and 30 kg of pitch.

3.c. Production equipment Capital Costs and their effect on small Producers.

Based on available scanty data, capital costs are as shown in Table 6.

Table 6. Equipment cost and charcoal capacity for kilns and retorts.

Kiln/Retort	Charcoal yield, %	Capacity (Charcoal)	Useful life (Years)	Capital Costs. (Shs.) (Years)
Earth Pit	8 - 10	Variable	0.1	-
Mark V[1]	12 - 15	50 - 55 tpa	3	14,000 (1975) 20,000 (1980 estimate)
CUSAB[2]	13 - 15	210 - 240 tpa	4	6,000 (1972) 12,000 (1980 Est.)
Brick[1]	20 - 25	300 - 330 tpa	7	8,000 (1980) 18,000 (1980 Est.)
Lambiotti Retort[3]	> 25	2000 tpa charcoal 1380 tpa wood oils + tar 200 tpa pitch	20	2,400,000 (1975) 3,000,000 (1980 Estimate).

Source: Uhart; [2]Foust;

[3]Uhart (cost), Andre' Mayer (Yield).

It is evident from the figures given in Table 6 that the different equipment differ in scale, useful life, and in capital costs.

Apart from the earth kiln, equipment costs exceed what an average occasional charcoal producer in the rural area would be willing or able to pay. Considering the Mark V and earth kilns the former has a charcoal yield of up to 15% weight of air-dry wood feed while the latter has a yield of only up to 10%. The capital cost differential is however of Shs 14,000/-, (1975 prices). In addition the earth kiln is extremely flexible. It can be of any desired size and incurs no transportation costs when using in different areas. By contrast Mar V and other metal and brick kilns have fixed sizes which must be utilised to full capacity. Under utilisation of this capacity would affect both the kiln performance and the unit fixed costs of kiln. Again for economic reasons these metal and brick kilns must be in operation throughout the year. It has already been mentioned that charcoal production in the rural areas is largely on irregular basis.

It does not come as a surprise therefore to learn that these metal and brick kilns have not been adopted by rural charcoal producers. Further, it wcould be argued that they will remain unacceptable to this section of the economy for as long as the present system of charcoal production organisation (or lack of it) is maintained.

3.c.ii. Importance of small scale rural producers.

Estimates of charcoal demand for 1975 were placed at 140,000 tons for rural areas and 120,000 tons for the urban areas (Chlala). Chlala also reported sales of charcoal from areas under the control of the forest department ranging from 29,000 tons/year to 59000 tons/year for the period 1965-70.

Using these figures it is estimated that charcoal production by small scale farmers with unpredictable raw material supply could amount to up to 200,000 tons/year. This level of production would cater for the bulk of the demand. It seems, therefore, that the occasional, small rural producers constitute the major consumer of wood for charcoal production. Any effort to conserve energy could then ill-afford to ignore the role of and possible contribution by such producers.

It is commonly argued that supply of wood from areas where agricultural crop production is also carried out, is threatened, This real threat would be checked by instituting efficient measures that would ensure continued supply of wood. In this connection, research on fast growing tree species suitable for use under various soil and rainfall conditions will be important. Work on eucalyptus varieties and the tropical legume tree-leucaena leucocephala - with possible rotation cycles of 7 and 4 years respectively (Kamweti) seem to offer much hope.

3.d. Charcoal Production using wood from gazetted forests.

As of 1972 land area under forest and woodlands gazetted by the Government amounted to 1.8 million hectare. Sixty per cent of this was closed forest, twenty percent woodland and the balance was bamboo grassland and mangrove forests. (Chlala). Chlala also estimated that the available woody raw materials from areas under control of forest department is as in Table 7.

Table 7.

Fire wood	50,000 tons per annum
Forest residues	120,000 " " "
Saw mill off-cuts	120,000 " " "
Wood shavings and saw dust	50,000 " " "
Total	340,000 tons per annum

Using traditional earth kilns the above quantity of woody material would give only 34,000 tons per annum of charcoal (max.). However, sales of charcoal from areas controlled by the forest department have been reported (Chlala) to be as high as 59,000 tons in one year (1966). It would seem possible that considerably more wood, than the quantity estimated by Chlala, is available from areas under forest department control.

For purposes of further discussions here it is assumed that the forest area could provide woody material for charcoal production amounting to a million tons per year. Under this assumption the amount of charcoal that could be produced would vary between 80,000 tons per annum and 350,000 tons per annum depending on the processing method adopted.

Evidently if processes incorporating by-product recovery had been used the estimated, entire charcoal demand for 1975 could have been met by use of the wood available from areas under forest control. Conversely by use of traditional earth or inefficient metal kilns, only one quarter of the estimated demand could have been met.

In addition to a high yield of charcoal, use of the efficient charcoal retorts processing 1 million tons of wood per annum[17] would also yield about 160,000 tons of liquid fuel, 12 million litres of creosote oil and 30,000 tons of pitch.

As shown in table A1 of the appendix sales of fuel oil derived from distillation of crude petroleum amounted to about 0.515 million tons in 1977. The stipulated production of oil from wood in gazetted forests alone could supply up to 25 per cent of the fuel oil energy requirements. Any such relief from total dependency on petroleum oil would seem a desirable welcome bonus.

With wood from forest reserves - large wood concentrations - large retorts could conceivably, be used.

4. INTRODUCTION OF CHARCOAL - PLUS - OIL PLANTS IN KENYA

From the foregoing review it seems likely that charcoal will remain a major fuel form in the country. It is also evident that where hearth efficiencies are likely to remain low charcoal production with by-products recovery should, in fact, be encouraged in place of direct burning of wood.

In terms of general policy this suggestion is not without problems. The two main ones are:-

(a) Economic: capital costs, raw material availability and capacity utilization.

(b) Technological requirements.

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17. If, as proposed by Kamweti, only 168,000 tons of fuel wood can be supplied from forest reserves and, as estimated by Chlala, 300,000 tons of forest residues, wood shavings, etc. are available, the total available woody material, from this source becomes 0.5 million. This would obviously affect the above calculations.

4.a. Economic Problems

It has been noted that available wood retorts for production of charcoal and recovery of by-products are extremely expensive. They are also large with a normal annual capacity of 2,000 tons p.a. charcoal output or more. This means that operation costs are also quite high. Because of the accompanying financial requirements these plants would not be feasible under the present charcoal making practice by individual small scale farmers.

A plant with charcoal output of 2,000 tons p.a. requires about 7,000 tons p.a. of dry wood. A community of 1,500 heads supplying, on average, 1.3 cubic metres of wood per capita per year would have only about 400 tons p.a. for processing. Clearly, inadequate raw material supply would form an insurmountable bottle neck in the adoption of this scale of production. Otherwise maximum capacity utilisation becomes only 6 percent!

The only possible use of these retorts is by a large organisation (including government) with the required initial capital and with access to adequate raw material supply concentrated in one area. The company in Eldoret using brick kilns, and the one near Nairobi proposing to use coffee husks are cases in point. Such companies would, however, be primarily concerned with financial return on investment and the much higher cost of retorts vis a vis kilns could well discourage use of the energy conserving retorts.

4.b. Technological requirements.

Some plants for by-product recovery require electric power for operation of the fans and liquid pumps (if any). Such plants could not be used in remote rural locations. Others would generate the required power within the battery limits. This has the effect of increasing the number of accessory equipment required and hence also the overall plant complexity.

Apart from the above point, plants incorporating by-product recovery are more complex than simple metal or brick kilns.

Where gases are used to provide process heat, the process must include gas burners as well as the retort, a condenser, a separator, possibly a scrubber, and a fan for providing energy for gas flow.

The moist gases are slightly corrosive and this must be considered in choice of materials for construction. The retort itself must be able to withstand medium - high temperatures. In addition, start-up procedures are more demanding than for simple kilns, and the overall operation and maintenance requires a much higher degree of technical skills than would be necessary for kiln operation.

Notwithstanding, the plants are simple, relative to other processing plants found in the process industry. There are advantages in introduction of such simple processes in terms of stimulating and extending technical know-how base in the country, particularly with regard to taking these skills to remote rural areas. The technology could conceivably have linkages with local equipment manufacturing industry as well as stimulating further chemical processing of, say, the liquid by-products should their fuel value cease to be crucial.

4.c.i. Possible Approach

In view of these problems and the desirability of recovery of by products in wood pyrolysis, a possible approach might be to develop small scale-under 400 tons p.a. wood capacity - processing plants. A major requirement for these plants would be maximum use of local construction materials in order to bring capital costs down. Another requirement would be design for autonomy in power requirements because electricity cannot otherwise always be assured. Such plants could be operated at the community level.

Organisation of charcoal production at community level could be done in form of charcoal producing co-operatives organised like coffee and tea co-operatives. Members would have to show that they have some surplus wood to start with or have land for planting trees and they would be assisted in replacing and/or increasing their stock of trees over time. The pyrolysis plants would belong to the co-operatives and the products would be primarily for meeting local demand. Surplus charcoal and, in particular, wood oil could be sold. One would envisage a situation where wood oil and pitch were sold as feed to a central, larger, processing plant for recovery of chemicals, or taken to a central collecting station from where the rest of the Country would be supplied with liquid fuels and pitch. The latter scheme would serve chiefly as a means of minimising transportation costs. Such co-operatives might have teams of engineers who were available to help deal with major operation and maintenance problems and who covered a large area over which the plants were used.

Another form of organisation could be the use of such plants by individual small scale entrepreneurs using raw materials from forest reserves and range lands scattered throughout the republic. It would again be important to have technical services available to back efforts by the entrepreneurs. These services might be provided by the forest department.

5. CONCLUSION

In conclusion it could be re-stated that for the foreseeable future charcoal production will remain an important aspect of meeting energy demand particularly in urban centres. Under unfavourable circumstances of very low hearth efficiencies even the rural areas should be encouraged to use charcoal instead of direct burning of wood. Also:

Work aimed at improving conversion efficiencies of all fuel appliances must be done to reduce the current energy wastage.

Where charcoal making is concerned kilns with less than 25 per cent fuel recovery efficiency should not be encouraged and the earth kiln should be strongly discouraged.

The main challenge lies in developing small-scale, low cost charcoal-oil plants. Large processes are available but are expensive and impractical for use in the Kenyan setting-except in a few isolated cases. Such plants would act as a medium for rural industrialisation, provide rural employment, and offer a wider spread of income benefits than that which would be offered by a few large-scale production schemes.

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A P P E N D I X

Table A1:

Product	Quantity x 10^3	
Kerosine	81,977	litres
Turbo fuel + aviation spirit	428,755	"
Motor Spirit	370,556	"
Gas Oil	371,329	"
LPG	29,607	"
Diesel	38,424	"
Fuel oil	541,875	"

Table A2: Energy Content of petroleum products sold in 1977

Table A2:

Product	Density (Kg/Litre)	WQuantity (10^3 x kg)	Proportion of Total Products (fraction)	LCV (MJ/Kg)	Energy Content GJ
Kerosine	0.78	63,942	.0414	43.5	2,781,477
Turbo fuel	0.78	334,429	.2166	44.0	14,714,876
Motor Spirit	0.74	274,211	.1776	43.0	11,791,073
Gas Oil	0.83	308,203	.1996	42.8	13,191,088
LPG	0.54	15,988	.0104	46.0	735,448
Diesel Oil	0.84	32,276	.0209	42.9	1,384,640
Fuel Oil	0.95	514,781	.3335	40.8	21,003,065
TOTAL	-	1543,830	1	42.4928	65,601,667

Source: Table A1.
Rose and Cooper (ed.)

A2 Appendix

Products of wood pyrolysis could be as those reported for a Lambiotte retort as follows:

Table A3

item	quantity	estimated calorific value
Wood Processed	1000 kg.	15.5 MJ/kg
Products:		
Charcoal	300 kg	29 MJ/kg
Wood gas (mainly Co, Co_2, H_2 and CH_4)	140 m^3	10.5 MJ/m^3 (Pyle)
Methyl alcohol	14 litre	
Acetic Acid	53 litre	
Esters	8 litre (≈ 160kg)	≈ 26 MJ/kg (Chiang et al)
Acetone	3 litre	
Wood oils and tars	76 litre	
Creosote oil	12 litre	.....
Pitch	30 kg	.....

Source: Andre' Mayer;
Calorific value for liquid fuels from Chiang et al;
C.V. For wood gas from Pyle.