The Energy Potential and Current Utilisation of Agriculture and Logging Wastes in Malaysia

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ABSTRACT

The fuel values and sulphur contents of plant matter wastes from the major agricultural activities in Malaysia were determined. Also determined were corresponding values for sawdust. It was found that the fuel values of these wastes vary from about 14.82 to 24.41 $\times$ 10^6 J per kg dry weight and that their sulphur contents vary from 0.018% to 0.373% by weight of the oven dried sample. Currently the total amount of energy potentially available from the major plant matter wastes in Malaysia is some 1148 $\times$ 10^5 boe per annum with most of this amount being contributed by rubber wood, solid palm oil mill wastes, the prunings of cocoa plants and the residues of the logging and timber industry. If this amount can be converted to usable energy at 20% efficiency it will be equivalent to about 23% of Malaysia's current toal annual energy requirements. It was estimated that, in fact, presently about 7.7% of the nation's energy demand is being met by the utilisation of plant matter wastes. Though not all plant matter wastes generated can feasibly be utilised, it is, however, estimated that the current level of utilisation can reasonably be increased by about another one and a half times.

INTRODUCTION

Since Malaysia is still predominantly an agricultural country, it has been suggested that the possibility of using agricultural wastes as an added source of energy should be explored. However, as far as we are aware, few systematic studies have been done to help determine the feasibility and viability of the suggestion. As a preliminary study we had determined the fuel values of some vegetation found in Malaysia[1] and had also reported on the energy that is potentially available, should wastes from the padi fields, the sugarcane and the oil palm plantations and mills be utilised.[2] We have extended the above investigations to cover most of the agricultural as well as timber wastes generated in Malaysia. In this and the article following we will report on the results of these investigations. These two reports not only estimate the energy that is currently potentially available but in some cases the future potential is also indicated. Wherever possible, the current status of utilisation of these plant matter wastes as a source of energy or otherwise is also outlined.

Table 1 lists the more important agricultural activities as well as the amount of logging currently being carried out in Malaysia.[3,4,5,6] Excluded from the list are smaller scale activities: those whose total cultivated hectarage is about 5 000 hectares or less such as tea and fruit cultiva-

Table 1
Major Agricultural (including logging) Activities in Malaysia Producing Wastes

Type of Cultivation	Area Cultivated (ha)	Statistics for the Year	Reference No.
Rubber	1939700*	1986	3
Oil palm	1440000*	1986	3
Padi	611800*	1986	3
Coconut	315400*	1985	3
Cocoa	237000	1984	3
Sugarcane	25300	1980	4
Tapioca	18009+	1978	5
Pepper	10550	1985	3
Pineapple	10400*	1986	3
Groundnuts	7049+	1975	6
Sawlogs	30.5 million m^3 **	1985	3

*estimated
+more recent data not documented
**indicates volume produced and not area cultivated

tion, as well as those that produce an insignificant amount of waste such as in the cultivation of tobacco.

FUEL VALUE AND SULPHUR CONTENT DETERMINATION

An adiabatic oxygen bomb calorimeter (Parr, model 1241) was used for the determination of the fuel value as well as the sulphur content of wastes from those agricultural activities shown in Table 1. Corresponding values for sawdust were also determined. After procurement, the samples were oven dried to constant weight. Wherever necessary, the samples were cut into fine pieces and then compressed into small cylindrical blocks before they were fired in the calorimeter. From the relevant readings taken, fuel values of the various waste materials were calculated. For sulphur content determination, washings from the bomb were used after completion of the calorific tests. Details of the standard procedure adopted can be found in the *Instruction handbook for the bomb calorimeter.*

Table 2 shows the fuel values and sulphur contents of the waste materials investigated. For each type of waste material at least 5 samples were studied. Though the fuel values of some of these materials had been reported previously by the author,[1] it was deem desirable to repeat the studies using the recently acquired Parr bomb calorimeter.

The results in Table 2 show that the fuel values of the waste materials investigated range from about 14.82 to 24.41 X 10^6 J/kg dry weight of the sample. The fuel value of lignite is on the order of 25.6 X 10^6 J/kg dry weight while the corresponding value for bituminous coal is on the order of 31.4 X 10^6.[7] Thus on the average, the fuel values of the waste materials investigated are about 60% that for coal and the values for rubber seeds and oil palm fruit shells are not very far from the value for lignite.

Table 2
Fuel Value and Sulphur Content of the Major Plant Matter Wastes Found in Malaysia
(S.E. = Standard Error)

Type of Waste	Fuel Value in cal. per gm. oven dry weight ± S.E.	Fuel Value in (X 10^6) J per kg. oven dry weight ± S.E.	Sulphur content % by Weight of Oven Dry Sample ± S.E.
Rubber			
wood	4719 ± 4	19.773 ± 0.017	0.047 ± 0.005
seed	5825 ± 11	24.407 ± 0.046	0.170 ± 0.008
leaves	4629 ± 51	19.400 ± 0.210	0.260 ± 0.003
Oil Palm			
trunk	3552 ± 11	14.883 ± 0.046	0.127 ± 0.007
leaves	4469 ± 28	18.730 ± 0.120	0.134 ± 0.004
shell of fruit	5379 ± 11	22.538 ± 0.046	0.090 ± 0.006
fibres of fruit	4658 ± 29	19.520 ± 0.120	0.177 ± 0.005
stalk of fruit bunch	4881 ± 17	20.451 ± 0.071	0.151 ± 0.008
effluent	4215 ± 22	17.661 ± 0.092	0.373 ± 0.026
Padi			
husks	3564 ± 15	14.933 ± 0.063	0.167 ± 0.041
straw	3783 ± 39	15.850 ± 0.160	0.133 ± 0.007
Coconut			
trunk	3866 ± 17	16.199 ± 0.071	0.100 ± 0.006
leaves	4400 ± 10	18.436 ± 0.042	0.150 ± 0.004
shell of fruit	4425 ± 6	18.541 ± 0.025	0.054 ± 0.009
husk of fruit	3930 ± 8	16.467 ± 0.034	0.066 ± 0.005
Cocoa			
branches	4123 ± 54	17.280 ± 0.230	0.082 ± 0.013
leaves	4255 ± 47	17.830 ± 0.200	0.286 ± 0.012
pod husks	3536 ± 27	14.820 ± 0.110	0.138 ± 0.005
Sugarcane			
bagasse	4135 ± 33	17.330 ± 0.140	0.058 ± 0.003
leaves	4266 ± 32	17.880 ± 0.130	0.196 ± 0.011
Tapioca			
stem and leaves	4080 ± 16	17.095 ± 0.067	0.135 ± 0.006
skin of tubers	3609 ± 16	15.122 ± 0.067	0.143 ± 0.005
Pepper			
black pepper stalks	4206 ± 22	17.623 ± 0.092	0.220 ± 0.003
black pepper dust, pericarps & leaves	4153 ± 19	17.401 ± 0.080	0.213 ± 0.011
white pepper dust, pericarps & leaves	4136 ± 60	17.330 ± 0.250	0.165 ± 0.005
Pineapple			
leaves	4118 ± 23	17.254 ± 0.096	0.159 ± 0.009
skin of fruit	3761 ± 8	15.759 ± 0.034	0.070 ± 0.007
Groundnuts			
plant	3980 ± 11	16.676 ± 0.046	0.280 ± 0.011
shells	3952 ± 49	16.560 ± 0.210	0.301 ± 0.006
Logging			
sawdust	4500 ± 17	18.855 ± 0.071	0.018 ± 0.005

The sulphur contents of these same waste materials, on the other hand, vary from 0.018% to 0.373% by weight of the oven dried sample. The former is for sawdusts while the latter is for oil palm effluents. These figures are rather low when compared to the sulphur content of bituminous coal which varied from 0.6 to 4.3% by weight, while the value for liginite is on the order of 0.7%.[7] Thus from the environmental point of view, burning the waste materials of Table 2 for fuel is seen to be far more desirable than burning coal.

CURRENT POTENTIAL AND UTILISATION OF AGRICULTURE AND LOGGING WASTES

In this section we will estimate the energy that is potentially available from wastes listed in Table 2. The current status on the utilisation of these wastes will also be outlined wherever possible.

Rubber Cultivation and Processing

In 1980 the area cultivated with rubber was about 2.02 million ha and this is expected to decline to about 1.94 million ha in 1986.[3,4] Trees can continue to be tapped for 25 to 30 years before replanting becomes necessary.

Wastes generated by the rubber industry can be classified into three main sources. The first, being generated in the fields, consists of fallen branches and twigs, leaves, and rubber seeds. Presently, most of these are left in the fields to rot though some branches and twigs are collected for domestic fuel. Since these wastes are generated in the fields and their production is dependent on the clones planted, it is rather difficult to estimate the amount produced annually. However, Arope and Subramaniam[8] reported that about 150 000 tonnes of seeds are presently being produced in Malaysia annually. Using the fuel value of rubber seeds in Table 2, it is estimated that the amount of energy potentially available from seeds is about 3.66×10^{15} J or 5.93×10^{5} barrels of oil equivalent (boe) per year. Seeds are scattered all over the fields, thus collection is difficult.

The second source of wastes is that of non-rubber substances, mainly organic, that are discharged into waterways as effluents during latex processing. The current amount discharged is about 100,000 to 150,000 tonnes per annum and it has been estimated that this amount, if converted into biogas, will have an energy value of about 250,000 boe per year.[8]

The third source of wastes is rubber wood. Large quantities of this is available during replanting. Gomez et al.[9] estimated that currently about 10.454 million m^3 of rubber wood is available annually. Since the moisture content* of green rubber wood is about 60%[10] and since 1 m^3 of such wood weighs about 0.72 tonnes, the amount of dry rubber wood potentially available is some 4700×10^3 tonnes per annum. Thus the energy potentially available from it is some 9300×10^{13} J (or 15.073×10^6 boe) per year. The current status of utilisation of rubber wood, shown in Table 3, indicates that presently about 67% of all available wood is being utilised in one form or another.

$$\text{*Moisture content (\%)} = \frac{\text{weight of water}}{\text{weight of oven dry sample}} \times 100$$

Table 3
Annual Current Estimated Utilisation of Rubberwood[9]

Product	Amount of Wood (m^3)
Fuelwood	4 220 000
Charcoal	2 200 000
Chips	162 000
Logs for export	40 000
Sawn timber	120 000
Cement board	11 000
SMR pallets	10 000
Blockboard	7 000
Chipboard	5 000
Furniture	200 000
Total	6 975 000

Oil Palm Cultivation and Processing

The area now under oil palm cultivation is some 1.4 million ha.[3] Harvesting of fruits usually commences about 3 years after field planting.[11] Because of declining yields, palms are replanted after 25 to 30 years.[11] Wastes produced by oil palm cultivation and palm oil processing come from two main sources, namely those that are generated in the processing of palm oil at the mills and replanting wastes.

Wastes produced in the mills consist of fruit shells, fruit fibres, stalks of the fruit bunches and liquid effluents. The amount produced annually from the processing of fruits from one hectare of crop has been previously estimated[2] and the data including their fuel values are shown in Table 4. Since only palms planted about 3 years ago are in production today, the 1983 hectarage

Table 4
Dry Matter and Energy Potentially Available from Wastes Generated in Palm Oil Mills

Waste Material	Dry Matter Yield (kg per ha per yr)	Fuel Value ($\times 10^6$ J per kg dry wt)	Energy Potentially Available	
			in $\times 10^9$ J per ha per yr.	in boe per ha per yr.
Fruit shells	2.780×10^3	22.538	62.656	10.15
Fruit fibres	1.853×10^3	19.520	36.165	5.86
Stalks of fruit bunches	1.483×10^3	20.451	30.329	4.92
Effluent	0.222×10^3	17.661	3.921	0.64
TOTAL	6.338×10^3		133.071	21.57

of 1.258 million ha[3] is used to estimate the energy that is now potentially available from these wastes. The amount works out to be about 1.674×10^{17} (or 27.135×10^{6} boe) per year. However, these mill wastes are not simply discarded. Except for stalks and liquid effluents, shells and fibres are used by the mills for the generation of process steam and electricity. In fact, shells and fibres are more than sufficient to meet the power needs of mills producing crude palm oil. In some mills, the excess shells are sold to mills refining crude palm oil. Presently, stalks which have a higher moisture content are simply incinerated. The potassium rich ash is then used as a fertiliser. For the liquid effluents, efforts are being made by both the government and private sectors to utilise this product for the generation of biogas. In fact, the Malaysian government is finalising plans for constructing a commercial scale demonstration plant capable of generating 2.8 million kWh of electricity per year in a plantation scheme.[12]

The average density of planting is about 142 trees per ha.[13] Since during replanting about 85% of the trees are still standing,[13] the density in areas due for replanting is thus about 120 trees per ha. It has been estimated that, the dry weight of tree trunks is about 500 to 600 kg per trunk and the dry weight of fronds (leaves) per palm is about 120 kg.[13] From these figures and their fuel values, it is estimated that the energy potentially available from one tree is about 10.433×10^{9} J and therefore about 1.252×10^{12} J (or 203 boe) of energy is available from replanting one hectare. Assuming that replanting occurs after about 25 years, it is estimated that presently about 2468 ha are due for replanting. Thus the current total amount of energy that is potentially available from felled palm trees during replanting is some 3.09×10^{15} J or 501×10^{3} boe. At present, felled trees are normally sectioned and stacked in the fields for eventual burning.[14]

Padi Cultivation and Processing

Wastes generated by the cultivation and milling of padi consist mainly of husks and straws. Table 5 shows the total area under padi cultivation as well as the production of padi for 1983 to 1986.[3] Since about 20% of padi is husk,[15] and since the moisture content of husks is about 9%,[16] the current amount of dry husks produced annually is about 330 000 tonnes. Thus the energy potentially available from husks alone is some 49.28×10^{14} J (or 7.99×10^{5} boe) per year.

Table 5
Area Cultivated with Padi and its Production

Year	Total Area (ha)	Production of Padi ($\times 10^3$ tonnes)
1983	665 800	1 734.3
1984	646 100	1 713.5
1985*	628 500	1 773.5
1986*	611 800	1 808.9

*estimated.

Compared to the amount generated, current utilisation of husks as a source of energy or otherwise is minimal. Most of the rice mills in Malaysia use electricity or diesel. Only a small number of mills use husks as fuel.[15] Two fairly large mills operated by the National Padi and Rice

Board utilise about 21 000 tonnes of husks per annum.[17] One fish meal factory was found to use about 2 400 tonnes of husk per annum as fuel for their operations.[15] In one small mill husks are processed into dusts and fine and coarse grains which are respectively used in mosquito coils, as chicken feed and as bedding material in chicken coops.[18] However, the extent of processing husks into non-energy uses such as the above is unknown. As far as we are aware, large quantities of husks are burnt in the vicinity of the mills. About 20% of the husks burnt end up as ash.[17,19] Thus burning of husks for energy or disposal creates a new problem which is still unresolved though efforts are being made to further use the ash, for example as a cement substitute.[19]

The ratio of straw production to grain yield under local cultivation practices is about 1:2. Since the moisture content of straw is about 7%,[16] the current amount of dry straws produced annually is about 8.4×10^5 tonnes. Thus the energy potentially available from straws is some 13.31×10^{15} J (or 2.157×10^6 boe) per year. While some straws are used in mushroom cultivation and the manufacture of paper and boards, the rest are burnt or left to rot in the open fields.

Coconut Cultivation and Processing

Table 6 shows the total area under coconut cultivation for 1969-1985.[3,20,21] At present, more than 91% of the total cultivated areas are under small holder management. Most of the coconut trees in Malaysia are of the Malayan Tall variety as this variety is popular among traditional small scale planters;[20] thus the discussion that follows will refer mainly to this variety.

Table 6
Total Area Under Coconuts in Malaysia (1969-1985)

Year	Area ($\times 10^3$ ha)
1969	304.3
1970	310.4
1971	312.6
1972	316.7
1973	315.8
1974	320.0
1975	336.4
1976	339.0
1977	347.7
1978	352.1
1979	354.3
1980	349.0
1981	318.0
1982	319.5
1983	314.1
1984	298.4
1985	315.4 (estimated)

The Malayan Talls begin to fruit after about 7 years[20,22] and mature trees are between 40 and 100 ft tall.[23] Trees can live for 80 to 100 years,[22] though in commercial plantations replanting after about 50 years is usual.[20,24] Wastes from coconut plantations can be classified into 3 categories, namely, fronds and debris that are shed throughout the year, wastes generated by the processing of fruits and wastes generated during replanting.

About 12 to 14 fronds are shed by a tree in a year.[22] Since the average dry weight of one frond is about 1.5 kg,[25] and the normal planting density is about 120 trees per ha,[22] the total amount of fronds and debris generated by about 300 000 ha of plantation is some 7.2×10^8 kg per annum. Thus the amount of energy potentially available from fronds and debris is about 1.33×10^{16} J (or 2.156×10^6 boe) per annum. Though some fronds and debris are left unattended in the fields, a fair proportion is used as domestic fuel as well as for the manufacture of articles such as brooms. The amount that can be collected for further utilisation is, however, unknown.

A handbook on coconuts[22] reported that the production of dry husks and dry shells amounts to about 2220 and 1040 kg per ha per year respectively. From a rough estimate done on an estate,[24] the respective figures were 5280 and 2510 kg. Since most of the plantations in Malaysia are small holdings, let us take 3000 kg as the figure for dry husk and 1500 kg as the average figure for dry shells. Thus current production of husks and shells is about 8.95×10^8 kg per year and 4.48×10^8 kg per year respectively. Hence, the amount of energy potentially available from husks is about 14.74×10^{15} J (or 2.389×10^6 boe) per year, and that from shells is about 83.06×10^{14} J (or 13.46×10^5 boe) per annum.

While most of the coconuts produced in Malaysia are processed into copra to be consumed almost totally by local oil mills, a significant though unknown amount is also consumed as fresh nuts[20] whose husks and shells end up as municipal wastes or as domestic fuels.

In copra production, the husks are first removed before the nuts are split and then dried. In small scale operations, the split nuts are spread on the ground for sun drying, while in large scale operations the nuts are dried in kilns which use coconut shells as fuel. Though at times husks are also used, the supply of shells more than meets the needs of the kilns. In larger operations, excess shells are sold for the production of charcoal, and coconut shell flour. It is estimated that in Malaysia, 70% of the shells are used in copra kiln dryers.[20] Besides being burnt as fuel, husks are also left in the fields, used as a mulch, or piled on wet grounds. These practices return the potash content of the husks to the soil. In addition, fibres from husks are also used for the manufacture of brush, ropes and as filling material for mattresses.

At present, replanting of coconuts is not carried out on a large scale. This will only take place well into the 21st century if more estate scale plantations are cultivated, or if the operations of small holdings are coordinated. As such we will not attempt to estimate the amount of energy that is potentially available at replanting. At any rate tree trunks that have been felled are used in a variety of ways; as posts, as bridges over streams, as land fill and others. If unused, felled trees are stacked and burnt on the plantation site.

Cocoa Cultivation and Processing

Planted areas have increased tremendously over the last twenty five years and it is estimated that the hectarage will reach 250 000 by the turn of the century.[20] In Malaysia, cocoa is cultivated as a sole crop, a main crop or an intercrop, principally with coconuts.

Intercropped with coconuts, planting densities varying from 470 to 1065 trees per ha have been reported.[20,24] Thus, on a sole crop equivalent basis, the density of cultivation should average about 1200 trees per ha. Mature trees are kept at a height of about 3 to 4 m so as to allow easy access for spraying and fruit harvesting.[24] As such, mature trees must be constantly pruned. It has been estimated that about 21 kg of dry organic matter per annum are removed from each tree.[24] Pruning, therefore, generates about 25.2 $\times$ 10^3 kg of dry organic matter per ha per year and these are left to rot in the fields. Presently there are about 195,455 ha of mature trees.[20] Using this figure and the fuel value of cocoa stems, it is estimated that the energy potentially obtainable from pruning wastes is about 8.52 $\times$ 10^{16} J (or 1.381 $\times$ 10^7 boe) per year.

Cocoa trees usually start bearing fruit in the second year after planting and harvested fruit may be left in the fields for up to 3 days before they are split and the beans removed. The pod husks are then left in small heaps in the fields. This practice provides the fields with potash.[24,26] The average yield of dry husks on a sole crop basis is estimated to be about 150 kg per ha per annum.[24] This, therefore, means that with a cultivation of 195,455 ha, the energy that is currently potentially available from pod husks is some 4.34 $\times$ 10^{14} J (or 7.03 $\times$ 10^4 boe) per annum.

Since cocoa trees are usually replanted after about 25 years,[24] replanting can be said to be minimal at the present moment. The above calculations show that, at present, pruning of trees produces a large amount of wastes, while wastes generated by pod husks and by replanting are relatively less, though in years to come the latter will increase. In the processing of cocoa into dry beans, hot air is used and dryers are usually operated using diesel as fuel. It does appear worthwhile to investigate the possible utilisation of pruning wastes in dryer operations.

Sugarcane Cultivation and Processing

The total area under sugarcane cultivation for 1976 to 1980 is shown in Table 7.[27] Unfortunately, documented data for more recent years are not available. Under local cultivation conditions, it has been estimated that about 54 tonnes of clean cane per annum can be produced on one hectare of land.[2] From these, about 12.3 tonnes are dry bagasse and 11.2 tonnes are dry leaves and cane tops.[2] Thus the energy potentially available from bagasse is estimated to be about 2.13 $\times$ 10^{11} J (or 34.5 boe) per ha per year and that from leaves and tops is about 2 $\times$ 10^{11} J (or 32.4 boe) per ha per year. The latter figure was estimated by assuming that tops have comparable fuel values as leaves. Assuming that presently about 25,000 ha are under sugarcane cultivation, the total energy potentially available from sugarcane wastes is about 10.33 $\times$ 10^{15} J (or 16.73 $\times$ 10^5 boe) per year.

While bagasse is used as fuel in the sugar mills, the leaves and tops are burnt before harvest. Firing of the canes is practised in Malaysia as the machines used are not designed to work on stand-

Table 7
Area Under Sugarcane Cultivation

Year	Area (ha)
1976	18 600
1977	21 400
1978	22 622
1979	23 800
1980	25 300

ing canes with adhering leaves.[2] Since the above estimate indicates that the energy potentially available from leaves and tops is substantial, it may be reasonable for the industry to consider harvesting the cane whole so that leaves and tops can be utilised too. This is possible as in some countries, canes are cut whole with cleaning done at the factory while canes are cut into short pieces and the leaves and tops are then separated by airblast.[28] In this way, the energy potentially obtainable from leaves and tops can be used to supplement or replace some of the bagasse which can then be channelled into developing other products such as board and paper.

Tapioca Cultivation and Processing

Mature tapioca plants, which are harvested about 12 months after planting, are about 3 m tall.[29] At harvest, plants are first 'topped' before being uprooted. About 2/3 of the stem is retained for replanting while the remaining 1/3 is discarded.[30] Most of the tops, as well as the discarded stems, are left in the fields and later burnt. The ashes produced are used as fertilisers. Yeoh and Chew[29] reported that leaf yields are between 7 000-20 000 kg per ha per year, while Kanapathy[30] reported stem yields to vary from 10.4 tonnes/acre to 21.1 tonnes/acre. Private communication with farmers indicated that a reasonable estimate for stems is about 25 tonnes/ha per year.[31] Of this amount about 8 tonnes/ha per year are discarded and burnt. While the moisture content of leaves is about 78-80%,[32] that for stems has not been documented. Nevertheless, an assumed average of about 60% is reasonable since the mositure of roots themselves varies from 48% to 76%.[33] Thus the amount of dry matter that is discarded and eventually burnt is about 6 tonnes per ha per year. Latest figures on the acreage under tapioca cultivation in Malaysia are not available but, in 1978, 44 500 acres were cultivated in Peninsular Malaysia.[5] With this acreage, the fuel value of the discarded matter works out to be some 1.846×10^{15} J (or 2.992×10^{5} boe) per annum.

Locally tapioca tubers are used for domestic consumption, for the production of chips for animal feed, for the production of pearls and flakes for industrial uses and for the production of tapioca starch. In fact, more than 60% of the tubers grown go into the production of starch flour.[5] Wastes generated in the starch factory consist mainly of tuber peels (skin) and liquid effluents. The latter is discharged into steams and drains.[33] At present, tapioca peels are thrown away or used as landfill. Peels represent 2 to 3% of the weight of the tapioca tuber.[30]

Since each plant yields about 3 kg of tubers[30] and since the density of cultivation is roughly 10 000 to 15 000 per ha,[33] the tuber yield is about 30 to 45 tonnes per ha. Thus the quantity of wastes generated from peels is about 1 tonne per ha. This means that peels generated from the total cultivated area is about 18 000 tonnes per annum. The moisture content of peels has not been documented but tubers have moisture between 48 to 76%.[33] Thus if one assumes that the moisture of peels is on the order of 50% then the total amount of dry peels is about 9 000 tonnes per annum. Thus the energy value of all discarded peels is some 1.361×10^{14} J (or 2.206×10^{4} boe) per annum. Not all peels are concentrated on factory grounds, some will end up as domestic or municipal wastes.

Liquid effluents discharged into streams and drains can give rise to pollution problems. Whether or not the effluents can be utilised for gainful purposes, such as the production of biogas, is still uncertain and its economic feasibility and viability still unknown.

Pepper Cultivation and Processing

Wastes generated by the cultivation of pepper come from 2 main sources, namely field and harvest wastes and wastes produced at replanting. Wastes generated in the fields and during harvest consist mainly of rachis of flower spikes, pericarps, branches and leaves.[34] The last two are due to annual shedding. The amount of dry matter generated for each of the above has been estimated to be 300, 500, 400 and 1 000 kg per ha per year, respectively.[34] Pericarps rot away during pepper processing and hence are difficult to recover. The fuel values of pepper wastes have been found to be between 17.33 to 17.62 $\times 10^6$ J per kg dry weight. It is thus conservatively estimated that the energy potentially available from these field and harvesting wastes is currently some 2.92 $\times 10^{14}$ J (or 4.73 $\times 10^4$ boe) per year.

The amount of dry organic matter that is generated at replanting is estimated to be about 13 900 kg per ha.[34] Using the fuel value of stalks, it is estimated that about 2.44 $\times 10^{11}$ J (or 39.5 boe) per ha of energy is potentially available. Taking the economic life of vines as about 12 years, the area that is due for replanting now is some 850 ha.[35] Thus currently, the energy that is potentially available from replanting wastes is some 20.74 $\times 10^{13}$ J (or 3.36 $\times 10^4$ boe) per year. It must be remembered that most of the pepper cultivation is done by small holders on land of a few acres each. In these small holdings, replanting is carried out piecemeal in that vines are replaced when they become uneconomical or when the vines die. This replanting practice therefore needs to be taken into account when utilisation of replanting wastes is being considered.

Currently very little waste is utilised. A very small amount of waste is used by farmers for mixing with soil[36] while a small quantity of pepper roots is used for medicinal purposes.[34]

Pineapple Cultivation and Processing

Most of the pineapple fruits produced in Malaysia are destined for canning. For 1985, it is estimated that estates produced about 87% of the total amount of fruits harvested while the rest are produced by small holders.[3] In 1984, about 59% of the total cultivated area is estates while the rest of the area is planted by small holders.[35] Plants are harvested after about 18 months and in 60% of estates, replanting is practised after every 18 months while in 40% of estates and in small holdings, plants are allowed to continue fruiting for about 5 years before replanting is attempted.[37] This therefore means that for a current total cultivated area of about 10 400 ha (Table 1) an average of about 4 000 ha are being replanted annually.

Wastes from the pineapple industry can be divided into 2 main sources, namely those that are generated in the fields at replanting and those that are generated by the processing of fruits in canneries. It has been estimated that during replanting about 70-80 tonnes of wet organic matter is generated in each acre of land.[37] The moisture content of leaves and stalks as determined in our laboratory is about 90%. This means that about 7.41 $\times 10^4$ tonnes per annum of dry matter is generated during replanting. These replanting wastes which are usually burnt in the fields have an energy potential of 12.79 $\times 10^{14}$ J (or 2.07 $\times 10^5$ boe) per year.

Wastes generated by the canneries consist mainly of peels and fruit cores. It has been estimated that peels and cores account for about 75% of the weight of the fruit.[37] Thus for a harvest of about 150 000 tonnes of fruit per year, 112 500 tonnes of peels and cores are produced. The peels and cores have a moisture content of 70-80%.[37] This amount of waste has an energy content of about 44.12 $\times 10^{13}$ J (or 7.15 $\times 10^4$ boe) per year. For this estimate, the fuel value of the pineapple skin is used. In some canneries, the peels and cores after juice extraction are used as cattle feed while in others, they are thrown away. In situations where the fruit is consumed fresh, peels and cores will end up as municipal wastes.

In a cannery whose fruit is supplied by 7 000 acres of plantations, the total energy requirements of the cannery are about 6.32×10^{13} J per year. If we were to extrapolate this requirement to service all the planted areas, an amount of 2.45×10^{14} J per year will be consumed by all canneries. Since the wastes generated by canneries in processing 150 000 tonnes of fresh fruit per year have an energy content of about 4.41×10^{14} J, it appears that a substantial proportion of the energy requirements of the canneries can be supplied through the utilisation of the wastes generated.

Groundnut Cultivation and Processing

Eighty-three percent of the locally grown groundnuts are roasted, then packaged for direct consumption while very little is processed into oil.[6] Groundnut plants are about 1 to 3 feet high and they are ready for harvesting about 3 months after sowing.

It has been reported that on the average the yield is about 3 tonnes of fresh nuts per hectare per crop.[38] Since, normally, two crops are planted in a year, the average annual yield is therefore about 6 tonnes. Chandapillai and Yeow[39] reported that on the average 1.5 tonnes of fresh organic matter (above ground matter and roots) are produced for every tonne of fresh nut produced. Thus annually about 9 tonnes of non-nut organic matter is being produced on one hectare. Since the moisture content of fresh nuts is about 45%,[39] it is reasonable to assume that the fresh organic matter also has a comparable moisture content. Recent statistics on the actual acreage cultivated is not available; however in 1975, 17 413 acres in Peninsular Malaysia were cultivated.[6] Thus, the total amount of dry non-nut organic wastes produced is about 35 000 tonnes per annum. This amount which has an energy content of about 5.837×10^{14} J (or 9.46×10^4 boe) per annum is burnt in the fields.The ashes so produced are used as fertilisers.

In the processing of roasted groundnuts, it has been estimated that after drying, about 3% by weight will end up as wastes in the form of fine roots, empty shells and rotten nuts.[40] These are usually burnt on the factory grounds.

Since shells form about 20-40% of the unshelled nut,[41] the amount of wet shells produced per hectare per year is about 1.8 tonnes. Thus the total fuel value of all shells produced amounts to 1.159×10^{14} J (or 1.879×10^4 boe) per annum. Unfortunately, this amount cannot be centrally utilised as most shells are packaged together with the groundnuts and they end up as part of the domestic and municipal wastes. Thus wastes generated by the local groundnut industry are not well utilised.

Logging and Timber Industry

The production of sawlogs in the whole of Malaysia for the years 1979 to 1985 is as shown in Table 8.[35] In the timber production industry, wood residues are produced mainly at two locations, that is during the harvesting of trees and in mill operations. At the felling sites the residues produced are mainly stumps, branches, offcuts, leaves, defect logs and sawdust while in the mills wood residues are in the form of sawdust, offcuts, rejects, cores, slabs, shavings and barks. In addition, there are also the unwanted species that are intentionally or unintentionally felled during logging operations.

Jalaluddin et al.[42] reported that about 66% by volume of wood is extracted from commercial tree species for further processing. Assuming that future sawlog productions in Malaysia will average 30 million m^3 per annum, this means that about 15.5 million m^3 of organic matter will

Table 8
Production of Sawlogs

Year	Production (m^3)
1979	26 795 000
1980	26 192 000
1981	30 750 000
1982	32 907 000
1983	32 648 000
1984	31 500 000 (estimated)
1985	30 500 000 (forecasted)

continue to be left to rot on the logging sites. If we were to also take into consideration those unwanted species that are intentionally or accidentally felled the figure will be higher. With the assumption that about one in ten trees felled will be unwanted, the amount of unwanted trees felled would be about 4.5 million m^3. Thus, in total, it is estimated that future logging activities will generate residues of about 20 million m^3 per annum, most of which, with current practice, are to be left on the logging sites.[43] It must, however, be admitted that a relatively small amount is beginning to be collected for the manufacture of particle board.[42]

From the data of Grewal[44] it is estimated that the average green weight of one m^3 of recently felled logs is about 977 kg and that their average moisture content is about 70%.[44] This means that presently about 1.172×10^7 tonnes of dry organic matter are being left behind on the logging sites and that the energy value that is potentially available from them is about 2.21×10^{17} J (or 3.582×10^7 boe) per annum.

Locally, sawlogs are processed in 2 types of mills. In sawmills, the logs are processed into sawn timber while in plywood mills, plywood and veneer are produced. It was estimated that in 1984, 7.4 million m^3 of sawn timber was produced while the corresponding figures for plywood and veneer were 0.72 million m^3 and 0.69 million m^3 respectively.[35] Since the average recovery in sawmills is about 65.2%,[42] this would mean that dry wood residues generated by local sawmills is about 2.315×10^6 tonnes per annum. Also, the recovery in plywood mills averages about 44%.[42] Using the plywood and veneer production figures of 1984, the amount of dry wood residus generated in plywood mills is some 1.052×10^6 tonnes per annum. If the total amount of dry wood residues generated by both the sawmills and the plywood mills were to be used as fuel, the energy potentially available is about 6.349×10^{16} J (or 1.029×10^7 boe) per annum.

Currently wood residues generated in the sawmills and plywood mills are already being utilised as fuel for kiln drying operations, for brick manufacturing as well as by locals as domestic fuel. In addition, some are also being converted into charcoal. Besides being used as fuel, the wood residues are also chipped for the manufacture of particle board, for the production of small wooden items as well as for fencing and posts. Barks, on the other hand, are used for mulching, potting medium and soil improver. Thus sawmill and plywood mill residues are not wasted though, in situations of excess, they are incinerated.[42] The actual amount used for each of the above operations is not well documented. In addition, whether or not the above operations represent optimal utilisation of the wood residues is difficult to ascertain. For this, further investigations are needed.

From the point of further energy harvesting from wood residues, one perhaps has to concentrate efforts on the residues produced at the logging sites. In this, problems related to collection and transportation need to be further studied. Perhaps systems that utilise the residues on site may be attractive considerations.

DISCUSSION AND CONCLUSION

Table 9 shows that currently the total amount of energy potentially available from the major plant matter wastes in Malaysia is some 1148 X 10^5 boe annually. Most of this amount being contributed by rubber wood, solid palm oil mill wastes, the prunings of cocoa plants and residues of the logging and timber industry. If this amount can be converted at say 20% efficiency to usable energy, the current amount available for utilisation is some 230 X 10^5 boe annually.

For 1986 it has been estimated that the total energy demand for Malaysia is about 10^8 boe.[45] Thus 230 X 10^5 boe will be able to satisfy about 23% of the nation's current total demand if indeed most plant matter wastes currently produced can be utilised. Column 3 of Table 9 shows that, in fact, a substantial quantity of plant matter wastes is already being utilised at the present moment. If again a conversion efficiency of 20% is assumed, then presently about 7.7% of Malaysia's total energy demand is being met by the utilisation of plant matter wastes. For 1980 it was reported that plant wastes contribute about 2.4% of the country's total energy demand.[45] The figure 7.7%, however, does imply that utilisation of plant matter wastes has indeed increased. The total potential (i.e. about 23% of the nation's total demand) mentioned earlier is, however, not really attainable in that not all the wastes produced can viably and feasibly be utilised. The comments in column 6 of Table 9, however, do indicate that the current level of utilisation can in fact be increased by more than one and a half times. This can be attained by concentrating efforts on the use of rubber wood, further utilisation of palm oil mill wastes, use of padi wastes, wastes generated by the pruning of cocoa plants and logging residues. Utilisation of palm oil mill wastes can be stepped up without much difficulty while collection, and to some extent transportation, are the principal problems that need to be overcome before any increase in utilisation of the others can be effected.

As mentioned in the introductory section, cultivation of crops producing negligible wastes such as tobacco and vegetables (1985 hectarage are 15 749 and 23 546 ha, respectively)[46] have been excluded in our estimation. Also excluded are crops whose individual total cultivated hectarage is small. In this latter catagory are tea cultivation and orchards whose total cultivated area in 1985 is less than 100 000 ha.[46] Since crops in this catagory are mainly planted by small holders it is, therefore, difficult to coordinate utilisation of wastes produced by this sector. Moreover, when compared to the major crops listed in Table 1, the total area of 100 000 ha is not really substantial. Thus the data provided in Table 9 can indeed be consid ed to be a fairly reliable estimate of the current total amount of energy potentially available from agriculture and logging wastes in Malaysia.

Except for rubber replanting, wastes generated during the replanting of oil palm, coconut, cocoa and pepper are not very substantial at the present moment, but in the years ahead the amount will inevitably increase. This will be discussed in the next paper.

Table 9
Energy Potentially Available from Plant Matter Wastes in Malaysia and its Current Status of Utilization

Nature of Wastes	Total Energy Potentially Available. Current annual basis in (X 10^5 boe)	% of Total Presently Used as Fuel	% of Total Presently Utilised for Other Economic Considerations	Amount Wasted in (X 10^5 boe)	Comments
Rubber					
Wood	150.73	~ 62	~ 5	49.74	Possibility for further utilization as fuel and others.
Seeds	5.93	–	–	5.93	Scattered, thus collection is a problem.
Processing wastes	2.50	–	–	2.50	Possibility for use as fuel.
Oil Palm					
Trunk & leaves	5.01	–	–	5.01	Possibility for use as fuel and others.
Shell of fruit	127.69	~100	–	–	–
Fibres of fruit	73.72	~100	–	–	–
Stalk of fruit bunch	61.89	–	–	61.89	Possibility for use as fuel and others.
Effluent	8.05	< 1	–	7.97	Possibility for use as fuel.
Padi					
Husks	7.99	~ 10*	~ 5*	6.79	Possibility for use as fuel and others.
Straw	21.57	–	~ 5*	20.49	Possibility for use as fuel and others.
Coconut					
Shell of fruit	13.46	~ 80*	~ 20*	–	–
Husk of fruit	23.89	~ 20*	~ 30*	11.95	Limited possibility for use as fuel because of small holdings.
Fronds & debris	21.56	~ 70*	~ 30*	–	–
Cocoa					
Pruning wastes	138.09	–	–	138.09	Possibility for use as fuel.
Pod husks	0.70	–	–	0.70	Possibility for use as fuel.

Table 9 (Continued)

Nature of Wastes	Total Energy Potentially Available. Current annual basis in (X 10^5 boe)	% of Total Presently Used as Fuel	% of Total Presently Utilised for Other Economic Considerations	Amount Wasted in (X 10^5 boe)	Comments
Sugarcane					
Bagasse	8.63	~100	–	–	
Leaves & tops	8.10	–	–	8.10	Possibility for use as fuel.
Topioca					
Stem & leaves	2.99	–	–	2.99	Limited possibility for use as fuel because of small holdings.
Skin of tubers	0.22	–	–	0.22	Some possibility for use as fuel and others.
Pepper					
Field & harvest wastes	0.47	–	–	0.47	Mainly small holdings. Collection is difficult.
Replanting wastes	0.34	–	–	0.34	Mainly small holdings. Replanting not organised.
Pineapple					
Peels and cores	0.72	–	~ 50*	0.36	Possibility for use as animal feed.
Replanting wastes	2.07	–	–	2.07	Possibility for use as fuel.
Groundnuts					
Plants	0.95	–	–	0.95	Limited possibility for use as fuel because of small holdings.
Shells	0.19	–	–	0.19	Mostly end up as municipal wastes.
Logging					
Logging residues	358.20	–	~ 2*	351.04	Possibility for use as fuel and others.
Mill residues	102.90	~ 50*	~ 50**	–	–
GRAND TOTAL	1148.56	386.46	84.32		

*Author's own estimate.
**In the absence of concrete data, utilization is divided equally among the 2 categories.

ACKNOWLEDGEMENT

This work was carried out with a short-term research grant from Universiti Sains Malaysia. The author wishes to express his gratitude to the University.

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