Ghana J. Sci. **51** (2011), 65-72

CROP RESIDUES AS POTENTIAL FEEDSTOCK FOR BIO-OIL PRODUCTION IN GHANA

B. MENSAH AND, R. ABDUL-SAMII
Institute of Industrial Research, Council Scientific and Industrial Research.
P.O. Box LG 576, Legon, Accra, Ghana

Abstract

Many Ghanaians living in rural communities do not have easy access to electricity for developmental needs. They depend largely on biomass for their domestic and commercial activities that require heat. The limited areas of applications of heat energy derived directly from biomass such as fuel wood retards the pace of development. However, there is potential for harnessing these readily available biomass to produce other forms of energy for wider applications. The production of five crops (maize, rice, millet, sorghum and groundnuts) in Ghana and the potential magnitude of their residues as feedstock for bio-fuels in each region of Ghana was analysed in the study. It is evident that there is significant potential for using crop residues to produce bio-oils for wider application to accelerate regional development. The Northern Region was found to have the most potential followed by the Brong Ahafo Region. The renewable energy policy in the country must be geared towards utilizing these crop residues to abate the energy requirements in the regions with most potential.

Introduction

The role of bio-fuels has been strongly enhanced by the debate in climate change. However, recent increases in production of crop-based (or first-generation) biofuels have engendered increasing concerns about potential conflicts with food supplies and land protection, as well as disputes over greenhouse gas reduction. This has heightened a sense of urgency around the development of biofuels produced from non-food biomass (second-generation biofuels) such as crop residues.

Biomass, feedstock for biofuels, is a source of renewable energy that has been widely accepted for its potential to satisfy environmental concerns over the use of fossil fuels. There are several benefits of using biomass as a source of energy including the following – decentralisation of energy production system to improve accessibility, opportunities for rural development and improved energy security, and provision of a cleaner fuel in terms of emissions compared with fossil fuels.

Biomass is traditionally the dominant energy resource in Ghana. In terms of total energy equivalent, biomass (fuelwood and charcoal) constituted 65.6 per cent of energy consumed, with petroleum products and electricity accounting for 26.0 per cent and 8.4 per cent respectively, in the year 2008 (Ministry of Energy, 2010). Rural dwellers also depend on other biomass resources such as crop residues for their energy needs. Rural populations are generally poor and have limited access to modern forms of energy. Low energy density solid biomass such as crop residues can thus be effectively harnessed by converting them through fast pyrolysis into bio-oils that can be readily stored and transported. Pyrolysis is one of the most promising technologies of biomass utilisation, which converts the biomass to bio-oil, char and gases, and may be described as a thermal decomposition of biomass occurring in the absence of oxygen. (Bridgwater, 2004).

The objective of the study is to estimate the potential of using different crop residues in different regions to supply bio-oils to promote regional development. Since the sustainable development of each region depends on adequate, reliable, and secure energy, local production of energy such as bio-oil, will go a long way to boost growth in all the regions especially in the rural areas. With abundant crop residues available in these areas converting these into bio-oil through fast pyrolysis would provide such reliable energy locally. The range of bio-oil applications are shown in Fig. 1.

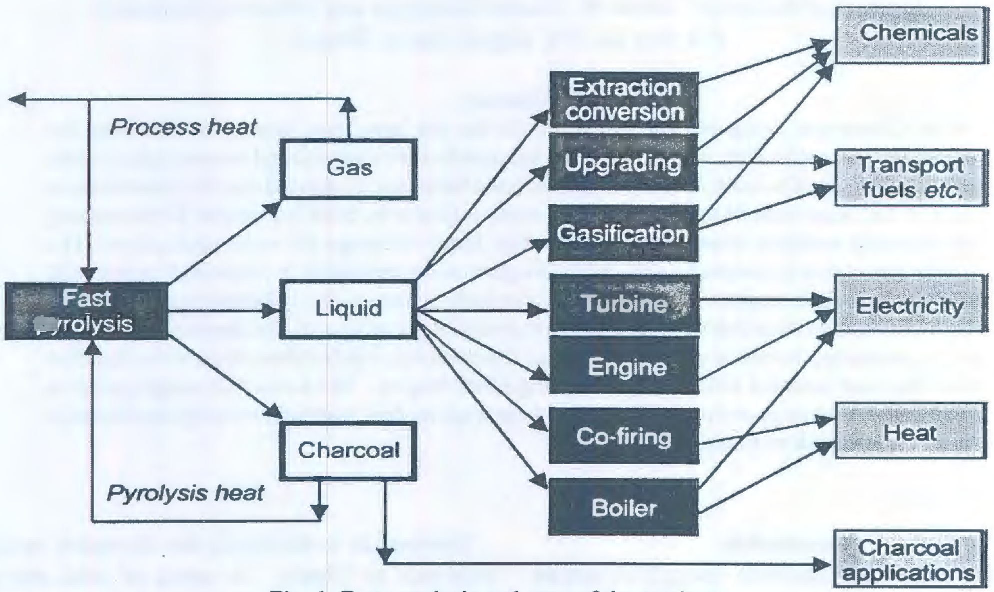

Fig. 1. Fast pyrolysis and uses of the products

Experimental

The study attempts to quantify residues from five purposively selected major crops grown in Ghana with residues suitable for fast pyrolysis, and also to estimate the quantity of bio-oil that can be produced. The crops selected are maize, rice, millet , sorghum and groundnuts.

Crop residues for biofuel production

There are two main types of crop residues - field residues and process residues. Field residues are residues obtained after crop harvesting and mainly consist of roots, stems and leaves. After harvesting most crops are transported from the field for further processing. Crop processing also generate crop process residues such as rice husks, maize cobs and husks, nut shells and husks.

Crop residues are used for many purposes and are often site specific. They are used as fuel, protection against soil erosion and for maintenance of soil fertility. The amount of field crop residues, that can be conveniently removed from the field without affecting soil fertility is often debated. Cooper & Laing (2007) quoted 35 per cent as the percentage of residue that can be removed from the field without affecting soil fertility. Lynd *et al,* (2002), also indicated that removal of up to 50 per cent of crop residues would not have any significant impact on soil fertility or erosion.

Data on the amount of exact crop residues produced are usually unavailable and are, thus, approximated using the ratio between residue and crop production for each commodity. Crop residue production can be estimated from the following formula:

Residue production (tonnes/year) =

Crop production(tonnes/year) x RPR(residue to product ratio) (1)

Values of residue to product ratio for various crops have been reported in the literature. However, due to the large number of factors , such as seed variety, soil and irrigation that impact on crop yields and residue production, such RPR values can only serve as available potential in the absence of specific field measurement (Fischer *et al.,* (2007).

In estimating the amount of residue producted a conservative figure of 35 per cent removal was used in the study. However, no allowance was made for other uses as a result of lack of data though the importance of these uses are recognised. Figures obtained are indicative only as residue potential for bio-oil. Thus the formula employed in the study is as follows:

Residue production (ty^{-1}) = Crop production(tyr^{-1}) x RPR x M (2)

where M is the maximum proportion of residue that can be removed from field without affecting soil fertility. M is assumed to be 0.35 for field residues and 1 for process residues. Crop production data used in the study were from MoFA, (2009).

Maize residues

Maize is a stable crop in Ghana with an annual production of 1619590 metric tonnes in the year 2009 and a production growth rate of 5.6 pre cent. It is grown in almost all regions in Ghana and planted on a total area of 9544300 ha. Residues from maize are stalks, cob and husks and estimated potentials for these residues in each of the ten regions of Ghana are presented in Table 1. Using formula 2 and average RPR values (Koopman & Koppejan 1997; Maither, 2009) the following RPR values were used in the study: maize stalk – 1.85 and a percentage removal of 35 from the field; cobs – 025 and a percentage removal of 100; husk

TABLE 1

Reional summary of available maize residue (Mt) as feedstock for fast Pyrolysis

Region	*Crop*	*Cobs*	*Stalks*	*Husk*	*Total Residue*
Wesrern	79010	19752.5	51158.98	15802	86713.48
Central	226420	56605	146607	45284	248496
Eastern	303400	75850	196451.5	60680	332981.5
Greater Accra	3310	827.5	2143.225	662	3632.725
Volta	97060	24265	62846.35	19412	106523.4
Ashanti	186830	46707.5	120972.4	37366	205045.9
Brong Ahafo	446260	111565	288953.4	89252	489770.4
Northern	155500	38875	100686.3	31100	170661.3
Upper West	70660	17665	45752.35	14132	77549.35
Upper East	51140	12785	33113.15	10228	56126.15
Total	1619590	404897.5	1048685	323918	1777500

– 0.2 and a percentage removal of 100 (cobs and husk are processed residues).

Rice residues

Rice is also grown in all the 10 regions of Ghana with an annual production of 391440 Mt in the year 2009 and a production growth rate of 6.8 per cent. Rice covers a total area of 162,360 ha. Residues from rice production are husks and straw. The estimated potential of these residues are presented in Table 2. Using formula 2 and average RPR value of 2.2 (Koopman & Koppeejan, 1997; Maither, 2009) the following RPR values were used: rice straw-1.70 and 35 per cent removal from field; husk (processed residue)– 0.28 and 100 per cent removal from field is assumed..

TABLE 2

Regional summary of available rice residue (Mt) as feedstock for fast Pyrolysis

Region	*Crop*	*Husks*	*Straw*	*Total Residue*
Western	20110	5630.8	11965.45	17596.25
Central	5090	1425.2	3028.55	4453.75
Eastern	19740	5527.2	11745.3	17272.5
Greater Accra	2940	823.2	1749.3	2572.5
Volta	60700	16996	36116.5	53112.5
Ashanti	12440	3483.2	7401.8	10885
Brong Ahafo	5790	1621.2	3445.05	5066.25
Northern	145750	40810	86721.25	127531.3
Upper West	7610	2130.8	4527.95	6658.75
Upper East	111272	31156.16	66206.84	97363
Total	391442	109603.8	232908	342511.8

Millet residue

Millet is grown in three regions of Ghana with an annual production of 245550 Mt in the year 2009, a production growth rate of 5.1 per cent and planted on a total area of 186700 ha. Potential residue from millet for bio- oil production is the stalk. The estimated potential of the stalk in the three regions is presented in Table 4. Using formula 2 and an average RPR value of 2.2 (Koopman & Koppenjan 1997; Maither, 2009, Hagan, 1997), a removal proportion of 35 per cent was assumed.

Sorghum residue

Sorghum is grown in four regions of Ghana with an annual production of 350550 Mt in year 2009 and planted on an area of 26721000 ha. Production of sorghum, however, decreased by 3.3 per cent over the period 2007-2009. The stalk is the main potential residue for bio oil production, The estimated potential of the stalk in the four regions is presented in Table 5. Using formula 2 and an average RPR value of 2.2 (Hagan, 1997) a removal fraction of 0.35 from the field was assumed.

Groundnut residue

Groundnut is one of the major legumes grown in four regions of Ghana with an annual production of 526040 Mt in the year 2009 and a production growth rate of 1.3 per cent. It is planted on a total area of 342550 ha. Potential residues from groundnut production for bio-oil production are the straw and shells. The estimated potential of the straw and shells in the four regions is presented in Table 3. Using formula 2 and an average straw RPR value of 2.5 (Koopman & Koppenjan 1997, Maither, 2009) 35 per cent removal from field was assumed. Groundnut shell is a process residue and a small proportion of it is sold directly to consumers in

TABLE 3

Regional summary of available groundnut residue (Mt) as feedstock for fast Pyrolysis

Region	*crop*	*shell*	*straw*	*Total residue*
Western				
Central				
Eastern				
Greater Accra				
Volta				
Ashanti	6560	3017.6	5740	8757.6
Brong Ahafo				
Northern	213940	98412.4	187197.5	285609.9
Upper West	200710	92326.6	175621.3	267947.9
Upper East	63870	29380.2	55886.25	85266.45
Total	485080	223136.8	424445	647581.8

Table 4

Regional summary of available millet residue (Mt) as feedstock for fast Pyrolysis

Region	*Crop*	*Stalk*
Western		
Central		
Eastern		
Greater Accra		
Volta		
Ashanti		
Brong Ahafo		
Northern	94,080	72441.6
Upper West	71,840	55316.8
Upper East	79,630	61315.1
Total	245,550	189073.5

shells which cannot be readily available as raw materials stock. However, in the absence of data on quantities sold in shells, total amount generated would be considered as potential. An RPR value of 0.46 (Hagan, 1997, Koopman & Koppenjan 1997; Maither, 2009) was used.

Results

Estimation of potential bio-oil from crop residues

The amount of bio-oil that can be produced from available crop residues in each region was estimated. Bio-oil yields from fast pyrolysis have been reported to be between 60 and 75 per cent weight per weight bio-mass (Brigewater, 2004) depending on type of feedstock and process conditions. Typical products yields (dry biomass basis) obtained from fast pyrolysis was 75 per cent liquid ,12 per cent char and 13 per cent gases (Brigewater, 2004). Using an average bio-oil yield of 67.5 per cent, estimated potential bio-oil that can be produced in each region from the available crop residues is presented in Table 6.

Discussion

Potential availability of selected crop residues and bio-oil production in each of the 10 regions

Table 6 shows regional amounts of crop residues and the corresponding levels of potential bio-oil production. Fig. 2 shows the relative energy potential that can be available in the various regions from pyrolysis of crop residues. All estimates are based on crop data for the year 2009.

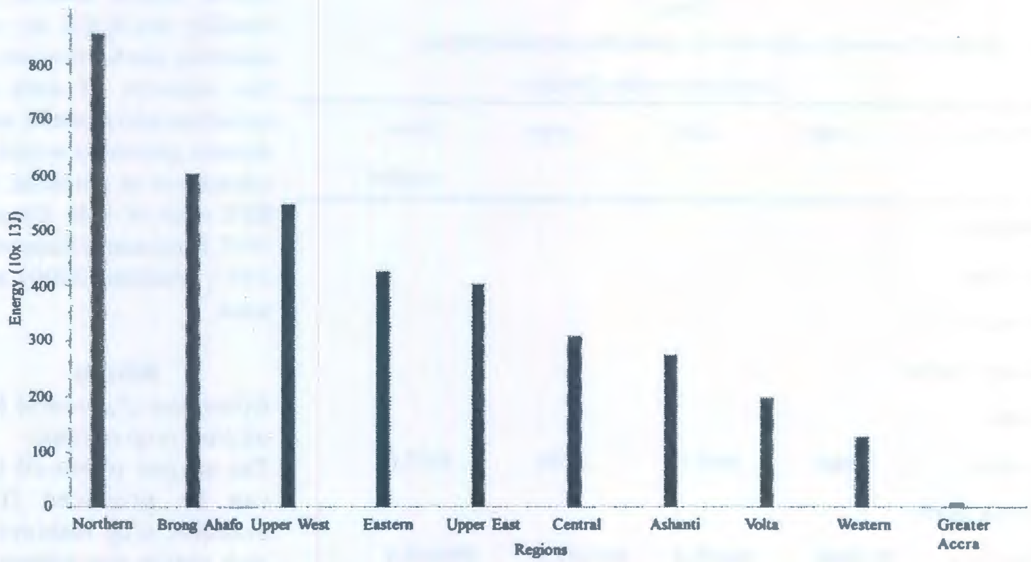

Fig. 2. Potential energy equivalents (10^{13}J) of bio-oils that can be produced in each region

TABLE 5

Regional summary of available sorghum residue (Mt) as feedstock for fast Pyrolysis

Region	*Crop*	*Stalk*
Western		
Central		
Eastern		
Greater Accra		
Volta	5050	1767.5
Ashanti		
Brong Ahafo		
Northern	136580	47803
Upper West	121420	42497
Upper East	87500	30625
Total	350550	122692.5

The Northern Region is the biggest region in Ghana. Table 6 shows that the region generates the highest amount of crop residues from all the five crops investigated in the study. A total of 704,047 Mt of crop residues were generated of which 41 per cent were from groudnut, 24 per cent from maize, and 18 per cent from rice. The rest (17%) were from millet and sorghum. The total bio-oil that can be produced from all these residues would be 475232 Mt with an energy content of 855×10^{13}J. The energy would then be available for both domestic and industrial purposes to improve quality of life in the region.

The Brong Ahafo Region generates the second highest total crop residues from only two of the five crops investigated in the study. The crops are maize and rice. The total tonnage of crop residues generated in the region was 494837 Mt with residues from maize constituting 99 per cent. The Brong Ahafo Region is the biggest producer of maize in Ghana, producing 28 per cent of total national production. The bio-oil potential from the region is 334015 Mt with an energy content

Table 6
Potential crop residues (MT) and bio-oils (MT) production in the Regions

	Rice	*Maize*	*Millet*	*Sorghum*	*Groundnut*	*Total*	*Bio-oil potential*	*Energy equivalent of bio-oil (10^3J)*
Western	17596	86713				104310	70409	126736
Central	4454	248496				252950	170741	307334
Eastern	17273	332982				350254	236421	425559
Greater Accra	2573	3633				6205	4189	7539
Volta	53113	106523		1768		161403	108947	196105
Ashanti	10885	205046			8758	224689	151665	272997
Brong Ahafo	5066	489770				494837	334015	601226
Northern	127531	170661	72442	47803	285610	704047	475232	855417
Upper West	6659	77549	55317	42497	267948	449970	303730	546713
Upper East	97363	56126	61315	30625	85266	330696	223220	401795
Total	342512	1777500	189074	122693	647582	3079360	2078568	3741422

of 601 $\times 10^{13}$J. This can go a long way to supplement the energy needs of the region.

The Upper West Region has the 3rd highest amount of crop residues suitable for bio-oil production. An estimated amount of 449970 Mt of crop residues was generated in the region. Residue from groundnuts constituted 60 per cent of the total, maize, 17 per cent, millet 12 per cent, sorghum 9 per cent and rice 1per cent. The total bio-oil that can be produced in the region would be 303730 Mt with an estimated energy content of 547 $\times 10^{13}$J to contribute to regional development.

The Eastern Region has residues from only two of the crops investigated i.e. maize and rice. The total potential of tonnage of residues from the crops is 350254 Mt with that from maize constituting about 95 per cent of total. The associated tonnage of bio-oil that can be produced is 236421 MT with an equivalent energy potential of 426 $\times 10^{13}$J.

The Upper East Region generated a total of 330696 Mt of residue mostly from rice, 29 per cent and groundnut 26 per cent. The total bio-oil that can be produced in the region is 223220 Mt with an energy content of 402 $\times 10^{13}$J.

The Central Region, generated a total of 252950 Mt of residue with that from maize constituting 98 per cent of total. It was estimated that 170741Mt of bio-oil with an energy content of 307 $\times 10^{13}$J can be produced to improve on local energy supply.

Ashanti Region generated 224689 Mt of residues from three crops namely maize, rice and groundnuts, made up of 91 per cent maize residues, 5 per cent rice and 4 per cent groundnut residues. A total of 151665 Mt of bio-oil with a potential energy content of 273 $\times 10^{13}$J can be produced from the residues to supplement the Regions energy requirement.

A total of 161403 Mt of crop residues was generated in the Volta Region from three of the crops namely maize, rice and sorghum. Most of the residues came from maize, 66 per cent, followed by rice, 33 per cent. The total bio-oil potential in the region amounted to 108947 Mt with an energy content of 196×10^{13}J which can be used to supplement the regions energy needs.

Western Region generated the second lowest amount of residues from two of the crops investigated, namely maize and rice. A total of 104310 Mt residues, were generated. Residues from maize constituted 83 per cent with the rest coming from rice. Total bio-oil to be produced from the residues would amount to 70409 Mt with an energy content of 127×10^{13}J.

The Greater Accra region has the lowest potential for residue generation. A total of 6205 Mt of residues from two crop namely maize and rice. Residues from maize constituted 59 per cent . The potential for bio-oil production from these residues is 4189 Mt giving an energy equivalent of 8×10^{13}J.

Conclusion

The paper presents estimates of the potential of crop residues as feedstock for fast pyrolysis of various crop residues to produce bio-oil which can be used in the 10 regions of Ghana. The analyses shows that converting raw crop residues into fuel with a high energy density (such as pyrolysis oil) is one of the most convenient ways of tapping the biomass potential in the various regions of the country. Since crop residues are locally available in all the regions, especially in the rural areas, these residues offer an opportunity to produce clean and versatile energy source to enhance energy security in the regions. The oil can be stored and used for both domestic and industrial purposes to promote growth and improve quality of life in the regions.

The analysis shows that maize residues abound in almost all the 10 regions of Ghana and small pyrolysis plants can be installed to process residues from maize in all the regions. Furthermore, pyrolysis plants that can process multiple biomass feedstock will be able to utilize all the available crop residues for maximum exploitation. In some areas, mobile modular plants can be to reduce cost of transporting feedstock.

References

BRIDGWATER, A. V. (2004) Biomass Fast Pyrolysis, *Thermal Science,* **8**, (2) pp 21-49.

COOPER, C. J. & LAING, C.A., (2007) A Macro Analysis of Crop Residue and Animal Waste as a Potential Energy Source in Africa. *J. Energ. S. Africa,* **18** (1).

LYND L.R., HAIMING, J., JOSEPH G.M., CHARLES E.W.1, & BRUCE D. (2002) Bioenergy: Background, Potential, and Policy Policy briefing prepared for the Center for Strategic and International Studies. 2002,*http://i-farmtools.org/ref/Lynd_et_al_2002.pdf.*

MAITHEL, S., (2009) *Biomass Energy, Resource Assessment Handbook,* Prepared for APCTT, Asian and Pacific Centre for Transfer of Technology of the United Nations- Economic and Social Commission for Asia and the Pacific, 2010.

Ministry of Energy, (2010) *National Energy Policy,* Ghana.

MOFA (2009) *Facts and Figures. Ministry of Food and Agriculture,* Statistics, Research and Information Directorate, Accra, Ghana.

FISCHER, G, HIZSNYIK, E., PRIELER, S., HARRIJ VAN (2007) *Assessment of Biomass Potentials for Bio-fuel Feedstock Production in Europe: Methodology and Results.* REFUEL Project, European Commission, Intelligent Energy.

KOOPMANS, A & KOPPEJAN, J.(1997) *Agricultural and Forest Residues –Generation, utilization and availability. Regional Consultation on Modern Applications of Biomass Energy,* Kuala Lumpur, Malaysia.

KISHORE V. V. N. (2008) (editor) *Renewable Energy Engineering and Technology a Knowledge* Compendium. The Energy and Resources Institute.

HAGAN, E. B., (1997) *Prefeasibilty Study on Proposed Letus Power Plant,* Building and Road Research Institute, Kumasi, Ghana.

Received 11 Apr 11; revised 21 Jun 11.