International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-2, Issue-4, April 2013

Feasibility of Biomass Energy Conversion Technologies For The Wattle Company's Vumba Sawmill Wood Waste

Kunatsa T, Musademba D

Abstract-A broad range of conversion technologies is currently available for generating a diverse array of energy products from sawmill wood waste. The choice of conversion technology will depend on cost of capital, the volume of wood waste available, access to energy markets, the prices for each renewable energy product and the cost of the wood waste. The purpose of this research project was to investigate the feasibility of the various options of sawmill wood waste conversion technologies at The Wattle Company's Vumba Sawmill so as to value add sustainably in an environmentally friendly manner. The outcome favoured Briquetting as the most feasible conversion technology for the wood waste. The plant capacity will be 2.25 tonnes having an annual output of 689.04 tonnes with a target market of 9-10% regional. The Investment required was US$ 65 472.92 with Payback Period of 1 year 3 months and the Net Present Value was US$ 325 429.08. The project's location is Manicaland Province in the Vumba Eastern Highlands of Zimbabwe.

Index Terms— Bioenergy, Biofuels, Biomass, Renewable Energy, Sawmill wood waste.

I. INTRODUCTION

The intention is to come up with a biomass energy conversion technology that adds value to the Wattle Company's Vumba Sawmill biomass residues and exploit this biomass renewable energy resource in an environmentally friendly manner. The Wattle Company is a forestry and Timber manufacturing Company that produces a lot of forestry and sawmilling wood residues. The Wattle Company owns approximately 45 276 hectares of land in the eastern districts of Zimbabwe of which 26 439 hectares have been developed into pine, wattle and eucalyptus plantations. There is uncertainty in the forestry and timber industry over the appropriate technology to use when producing 'renewable energy' products and the amount as well as type of wood waste that will be required for each conversion technology. Sawmill wood wastes are either non-used or burnt inefficiently in their loose form causing air pollution. Handling, transportation and storage of these materials are also very difficult due to their low density.

The Wattle Company Vumba Sawmill produces huge quantities of biomass wastes but they are used inefficiently causing extensive pollution to the environment. Due to the enormous production of timber, a lot of wood wastes are produced and disposal of these is a problem.

Manuscript received on April,2013.
Kunatsa Tawanda, Fuels & Energy Department, Chinhoyi University of Technology, Chinhoyi, Zimbabwe.
Musademba Downmore, Fuels & Energy Department, Chinhoyi University of Technology, Chinhoyi, Zimbabwe.

The Environmental Management Agency (EMA) and National Social Security Agency (NSSA) have highlighted that something must be done as soon as possible to solve this problem citing risks of fire from the heaps of sawmill wood wastes and the consequences could be devastating. The Wattle Company is showing an increasing interest in Renewable Energy conversion Technologies (RETs) so as to value add and solve the problems of sawmill wood waste disposal as well as energy and power shortages which are adversely affecting on production.

The Wattle Company Limited is into forest and timber products business with five core businesses, namely the production of:

- Pine Sawn timber
- Eucalyptus sawn timber
- Wattle Extract
- Eucalyptus poles, and
- Charcoal

AIM

To come up with a biomass energy conversion technology that adds value to the Wattle company's Vumba Sawmill biomass residues and exploit this biomass renewable energy resource in an environmentally friendly manner.

II. OBJECTIVES

- To assess the Vumba Sawmill wood waste resource base
- To quantify all the sawmill wood waste produced per year at the Wattle Company's Vumba sawmill
- To assess the properties of the sawmill wood waste
- To determine the energy production potential of the sawmill wood waste
- To contrast possible biomass conversion technologies and select the best conversion technology that adds value
- To assess the market, risks, technical and economic viability of the project

III. METHODOLOGY

Assessment of Resource base-field visits were done and data was gathered

i. Quantification of sawmill biomass residues-sawmill recovery and production data was compiled and volume ratios of input logs, timber produced and sawmill waste generated were computed over several months and the average volume and/or mass of sawmill biomass residues was found
ii. Assessment of properties of the Vumba sawmill wood waste-experiments were carried out to ascertain the properties (moisture content and ash content) of a

mixture of the sawmill residues (off cuts, wood chips, wood shavings, bark)

iii. Determination of energy production potential-wood biomass tables and energy conversion factors were used in conjunction with experimental results

iv. Technical and economic viability assessment-technical specifications, technical requirements capital and maintenance costs were analysed for the conversion technologies and Payback Period as well as Net Present Value was calculated.

IV. RESULTS

Results of Resource Base Assessment

The Wattle Company (WACO) owns the Vumba Eucalyptus resource of 1900Ha consisting of E. *Grandis* and *E. Cloeziana*. This represents 8% of the total WACO resource. Vumba Timbers utilize this for Treated and untreated Poles, Charcoal and Sawlogs. The sustainable timber resource is 25000m^3 / annum up to 2014 and 40000m^3 / annum after 2014.

There are three main products from the 1900Ha of eucalyptus plantation, these are:

Poles

A sustainable yield of 700m^3 per month is obtained. This is from the middle part of a fully grown tree and from thinings.

Charcoal

A yield of 800 tonnes per month is obtained. This is from the top most part of the tree from diameter 13 to 7cm. This utilizes the small diameter parts of the tree, 13cm to 7cm. This is primarily the waste that cannot be utilized as sawlogs or poles.

Sawlogs

The sustainable yield for the next 5 years is 25000 m^3 per annum thereafter it is going to be 50000m^3 per annum. This utilizes the lower part of the tree up to 20cm diameter.

Results on assessment of sawmill residue conversion technologies

1. Direct combustion of biomass to generate super-heated steam by heat transfer

Direct combustion is the process used by over 90% of the world's bioenergy plants. In general, the hot gases derived from biomass combustion flow over a set of tube banks, heat the water in the tube banks to produce steam. This is similar to the technology employed by many timber mills that use their wood waste to produce heat and steam for drying or to operate fiberboard presses. Direct combustion of biomass to generate electricity and heat is termed cogeneration of Combined Heat and Power (CHP). By adding a steam turbine to the direct combustion processes it is possible to generate electricity which can be used on site or sold into the grid.

2. *Co-firing* - Combustion of wood waste with coal and/or bagasse (from sugar refineries) to generate electricity. Wood waste can be supplied in multiple forms, including wood chips, wood gas (from gasification) or bio-oil (from pyrolysis).

3. *Pyrolysis* - The heating of wood waste in a controlled environment (with no oxygen) to produce varying quantities of oil, gas and charcoal. The gas can be burnt to produce electricity and the bio-oil can be used as a chemical feedstock or as a substitute for diesel fuel by stationary power generators, which can be transferred between sites by tankers.

***4. Gasification* -** The heating of wood with a small amount of oxygen under conditions that turn a high proportion of the wood into a gas. It is a highly efficient process and some early commercial applications of the technology are available. There are still some technical difficulties associated with the combined cycle gas power plants to be overcome. However, it is possible to use the wood gas for co-firing operations in coal furnaces.

***5. Pelletisation/briquetting* -** Engineered fuels such as pellets and briquettes are made by compressing fine wood particles and resinous compounds in the presence of heat to produce small blocks that can be co-fired in coal-fired power stations or used directly in home heating units. Large quantities of wood pellets and briquettes can be as a commercial and home heating resource.

***6. Chemical-biological production of liquid fuels* –** The production of liquid fuels such as ethanol from wood waste is based on a series of chemical reactions and biological processes which convert wood into chemically-simple sugars and then ethanol.

Quantity of Vumba Sawmill wood waste

Table 1 represents data on Vumba sawmill wood waste as derived from the input logs. Vumba Sawmill operates for 22 days a month thus no operations are undertaken during the weekends. Table 1 summarizes the production data as from February to July 2009.

$$\text{Average sawmill wastes} = \frac{\sum(\text{tonnes of wastes})}{\text{No.of months}}$$

$$= \frac{382.88}{6}$$

$$= 63.81 \text{ tonnes/month}$$

$$= \frac{63.81\ tonnes/month}{days22}$$

Average sawmill wastes = 2900.61 kg/day

DATE	FEB	MAR	APR	MAY	JUN	JUL
Log Deliveries (m^3)	142.53	242.28	169.2	172.46	141.34	46.69
Log Stocks(m^3)	26.35	12.17	57.49	66.57	36.53	9.55
Sawmill input(m^3)	139.18	231.43	141.73	163.38	171.38	73.67
Sawmill output(m^3)	53.67	90.16	48.45	73.34	89.26	29.49
Sawmill Recovery	38.56%	38.96%	35%	45%	52%	40.03
Sawmill waste (m^3)	85.51	141.27	93.28	90.04	82.12	44.18
Waste in tonnes	**61.08**	**100.91**	**66.63**	**64.31**	**58.66**	**31.56**

Table: 1 Quantity of Vumba Sawmill biomass residues

Oven drying experimental results on moisture content

3 samples of sawmill waste were oven dried for several hours to a constant mass (all the water evaporated), the results are summarized in table 2 below:

Table 2: Moisture content experimental results

		Sample1 (g)	**Sample 2 (g)**	**Sample 3 (g)**
INITIAL	WEIGHT	828	1236	1089
TEST	**TIME**			
1	1300 hrs	632.0	777.0	749.5

2	1900 hrs	583.5	718.0	738.5
3	2300 hrs	563.5	690.0	734.0
4	0100 hrs	549.5	685.5	732.0
5	0300 hrs	548.5	680.0	731.0
6	0500 hrs	548.0	680.0	728.5
7	1100 hrs	548.5	680.0	728.0
8	1400 hrs	547.5	679.0	724.5

Moisture content on wet basis (MC_{wb})

$$MC_{wb} = \frac{W}{W+D} \times 100$$

Where : MC_{wb} is the moisture content on wet basis
: W is the weight of water
: D is the weight of dry material

SAMPLE 1

$$MC_{wb} = \frac{828-548.5}{279+548.5} \times 100 = 34\%$$

SAMPLE 2

$$MC_{wb} = \frac{1236-680}{556+680} \times 100 = 45\%$$

SAMPLE 3

$$MC_{wb} = \frac{1089-728}{361+728} \times 100 = 33\%$$

$$\text{Average moisture content} = \frac{34+45+33}{3} = 37.3\%$$

Moisture content for Vumba sawmill residues = 37.3%
This moisture content shall be used to calculate the energy production potential of the biomass residues.

Experimental results on determination of ash content

2 samples of oven dried sawmill biomass mixture (chips, bark, sawdust and shavings) were measured, burnt completely the oven dried sample to ash and the mass of ash was measured. Table 3 shows the ash content experimental results

Table 3: Ash content experimental results

	Sample 1	Sample 2
Mass of empty crucible (g)	42.43	41.72
Mass of sample (0% water) (g)	10.00	13.60
Gross mass after burning (g)	42.85	42.25
Mass of ash only (g)	0.42	0.53

Calculation of Ash Content

$$\%\ \boldsymbol{ash} = \frac{\text{mass of ash only}}{(1+\ \%\ \text{water})\text{x mass of dry sample}}$$

For sample 1:

$$\%\ \text{of ash} = \frac{0.42}{\frac{137.3}{100}*10} * 100$$

$$\%\ \text{of ash} = 3.06\ \%$$

For sample 2:

$$\%\ \text{of ash} = \frac{0.53}{\frac{137.3}{100}*13.60} * 100$$

$$\%\ \text{of ash} = 2.84\ \%$$

$$\text{average ash content} = \frac{3.06+2.84}{2} = 2.95$$

average ash content of Vumba Sawmill residue = 2.95 %

This ash content will be used below to calculate the energy production potential of the biomass residues.

Calculation of energy production potential

Data:
The author used average wood biomass values and other relevant information as follows:

- The moisture content (MC_w) of wood waste is 37.3%
- The ash content (AC_w) of wood waste is 2.95%
- The dry ash free matter is 59.75%
- The Hydrogen content is 5.5%
- HHV_{daf} = 20400kJ/kg
- For 1kg of wood the composition is as follows:
  Mass of water in wood = 0.5kg
  Mass of ash in wood = 0.01kg
  Mass of dry ash free material = 0.49kg

(i) Moisture content on dry ash free basis, (MC_{daf})

$$= \frac{M_w}{M_{daf}} = \frac{M_w}{M_{tot}-M_w-M_{ash}}$$

$$= \frac{0.37}{1-0.37-0.03}$$

$$= \mathbf{0.62}$$

(ii) Ash content on dry basis (AC_d)

$$= \frac{M_{ash}}{M_{daf}+M_{ash}} = \frac{M_{ash}}{M_{tot}-M_w} = \frac{0.03}{1-0.37}$$

$$\mathbf{= 0.05}$$

(iii) Lower Heating Value on dry and ash free basis,

$$(LHV_{daf}) = HHV_{daf} - [H]_{daf} \text{ x } 20300 - MC_{daf} \text{ x} 2260\text{kJ/kg}$$
$$= 20400 - 0.055 \text{ x } 20300 - 0.62 \text{ x } 2260$$
$$= \mathbf{17882.3\ kJ/kg}$$

(iv) Lower heating value on wet basis, $LHV_w = LHV_{daf} \text{ x } \frac{M_{daf}}{M_{tot}}$

$$= 17882.3 \text{ x } \frac{0.597}{1}$$

Lower heating value on wet basis, LHV_w=**10684.67kJ/kg**

(v) Wood waste energy = LHV_w x mass
= 10684.67 x 2900.61
= 30992018.56KJ/day
= 30 992 MJ/day

Vumba Sawmill Energy Production Potential= 30 992 MJ/day

(vi) Power production potential $= \dfrac{energy}{time}$

$= \dfrac{30992018560}{24x60x60}$

= 358796.2963

= 0.3587MW

Vumba Sawmill Power Production Potential = 359 kW

Vumba Sawmill Power Production Potential = 359 kW

This value shows that if all the Vumba Sawmill biomass residues are utilized to produce electricity, the maximum power output using any biomass conversion technology without considering conversion efficiencies will be 359 kW.

Interpretation of data and discussion of results

A total of 8181.88 (30.992 x 22 x 12) GJ per annum energy production potential shows that quite a considerable amount of energy was being used inefficiently. This energy could be made use of by converting it to some form of fuel and/or energy. A calculation of the power production potential assisted in choosing the alternative conversion technologies to consider for the Vumba Sawmill biomass waste.

Vumba sawmill power requirement is 316.648 kW. To produce 30MW using Cogeneration and Direct Combustion, 300 000 tonnes of wood waste are needed. The quantification of Vumba Sawmill biomass waste yielded 2.9 tonnes of residue per day. The amount of residue required for Vumba sawmill will be: $\dfrac{316.648}{30000} x300000$ = 9499.44 tonnes/year, but the quatification of the residues shows 2.9 tonnes/day x 22days x 12 months = 765.6 tonnes/yr. This rules out Cogeneration Co-firing and Direct Combustion conversion technologies.

Most Pyrolysis and Gasification plants start from a generation capacity of 500kW upwards. Though the available raw material is able to meet the sawmill power requirements the technological requirements are a drawback to these biomass conversion technologies with regard to Vumba sawmill wood waste.

The computed Power Production Potential of 359 kW shows that the raw material available is adequate to power the sawmill but the technology resource requirements are a limitation. This promotes shifting to a conversion technology that caters for the thermal needs of the sawmill and excess fuel to be sold as a form of value addition. The study outcome above leads the author to consider Direct Combustion and Fuel Briquetting. From the research results, the many advantages of fuel briquetting over Direct Combustion and other biomass conversion technologies and their environmentally friendly impacts, it is quite a better option to briquette the biomass residues and the researcher chooses this as the most feasible conversion technology with regard to Vumba Sawmill wood waste.

From the resource base and quantification of Vumba Sawmill waste results as well as from the biomass energy assessment it can be deduced that there is more than enough raw material for the briquetting project. The summation of all biomass residues gives:

2.9 tonnes/day x 22days x 12 months = 765.6 tonnes/yr. The binderless briquetting technology which the author wants to use has an output of 750kg/hr.

Given that the conversion efficiency of the briquetting machine is 90%, the required input is as computed below:

Input $= \dfrac{output}{efficiency}$

$= \dfrac{750}{0.9}$

Input = 833.33kg/hr

The raw material can supply the machine to be run:

$\dfrac{2900.61}{833.33}$

= 3.48 times per day

This implies that the raw material available is adequate to embark on the proposed binderless briquetting technology giving 3.48 x 750kg/hr = 2.61ton/day of briquettes. Annual briquette production will be: 2.61ton/day x 22 days x 12 months = 689.04 tonnes.

An important component for briquetting is moisture content. The moisture content experimental result of 37.3 % is too high. For briquetting moisture content should be as low as possible, generally in the range of 10 – 15 %. Hence a drier is needed to reduce the moisture content.

The 2.95% ash content experimental result implies that the raw material is conducive for briquetting. Usually slagging takes place with biomass fuels containing more than 4% ash content. The ash content is an indicator of slagging behaviour of the biomass, the greater the ash content the greater the slagging behaviour. Vumba Sawmill wood waste ash constituencies will not have a tendency to devolatalise during combustion and condense on tubes, especially those of super heaters. Hence the sintering temperature of ash will not be lowered and therefore ash deposition on the boiler's exposed surfaces will not take place if the briquettes are used as fuel for boilers.

Technical and economic viability of briquetting/pelletisation

Capacity

Basis: Three machines each 750 kg/hr

Production capacity = 2.25 t/hr (20 hrs/day operation)

Operating days per year	264
Operating hours per year	5280
Capacity utilization	90%
Raw material	765.6 t/yr
Moisture losses	285.6 t/yr
Briquettes produced	689.04 t/yr
Briquettes consumed (Dryer)(7.8% of production)	54.04 t/yr
Saleable production	635 t/yr

Infrastructural facilities

Power	225 kW
Land area	4500m²
Operational shed area	360 m²
Briquetting storage (covered area)	375 m²
Investments	**(US$)**
Installed cost of plant & machinery (based on US$19170 for each machine)	57510

Land	3317.88
Building	4645
Total investment	**65472.92**

Cost of production	**(US$)**
Power	3009.43
Manpower	1486
Water	176.12
Maintenance (including consumables)	1688.54
Total cost of production	**6360.09**

Total sales (US$96.439/ per tonne x 635tonnes)	61238.765
Less Production cost	6360.09
Less Raw material	-
Gross profit	**54878.68**

Less expenses	US$	
Administrative overheads	946.64	
Depreciation (Plant 10% Building 5%)	5983.25	
Financial cost/interest paid	2014.36	8944.25
Net Profit		**45934.43**

Calculation of Payback Period

$$Payback\ period = \frac{\text{Initial investment}}{\text{Net cash flows}}$$

Net cash flows = Net Profit + depreciation
= 45934.43 + 5983.25
= 51917.68

$$\text{Payback period} = \frac{65472.92}{51917.68}$$

Pay-back period = 1 year 3 months

Calculation of Net Present Value (NPV)

$$\text{NPV} = -I_0 + \sum_{1}^{n} \frac{B-C}{(1+r)^n}$$

$$= -I_0 + [\text{PWAF x } (B - C)]$$

where: I_0 is the initial investment
B represents the benefits
C represents the costs
PWAF is the Present Worth Annuity Factor
B – C is equivalent to the Net Profit

$$\text{PWAF} = \frac{1-(1+r)^{-n}}{r}$$

$$\text{PWAF} = \frac{1-(1+0.1)^{-20}}{0.1} = 8.51$$

NPV = -65472.92+ (8.51 x 45934.43)

NPV = 325 429.08

The Payback Period of 1 year 3 months and a positive Net Present Value (NPV) of US$ 325 429.08 shows that the project is economically viable/feasible.

Market, Risks and Technical analysis

A larger part of the briquettes will be sold to local Zimbabwean consumers as well as export markets. It can be deduced from the Literature Review that briquetting is economically feasible. Water is readily available close to the project site in the Vumba Eastern Highlands and the Briquetting plant is to utilise power from the ZESA grid. There is high risk of interruption of the production processes due to power cuts and a standby generator has to be made available specifically for this project.

There is a risk in that the existing thermal energy market is dominated by coal, charcoal, firewood and gases. However, Briquettes are expected to penetrate the market and constitute a larger market share due to their high calorific value of 4000Kcal/kg as compared to other competing goods. (P.D. Grover and S.K.Mishra, FAO 1996). The target market is aimed for in households, commercial and industrial operations.

V. CONCLUSION

The aim of the project was to come up with a biomass energy conversion technology that adds value to the Wattle Company's Vumba Sawmill biomass residues and exploit this biomass renewable energy resource in an environmentally friendly manner. The sustainable quantity of wood waste available is 2.9 tonnes/day. There are quite proven technologies to utilize this biomass but the amount of resource available and the scale of required amounts by each conversion technology are a limitation to most of the conversion technologies. The costs of briquettes and other renewable, wood energy derived products are much higher as compared to the competitive low prices of coal, diesel and charcoal. This study observed that this poor competitiveness arises mainly from the very high capital cost of the plants or the low price of coal and diesel; probably the balance between the two and this might obscure customer acceptability of the briquettes.

The outcome of this study favours Biomass Briquetting as the most feasible conversion technology to use for Vumba Sawmill wood waste. The plant capacity will be 2.25 tonnes having annual output of 689.04 tonnes with a target market of 9-10% regional. The Investment required is US$ 65472.92, the Payback Period shall be 1 year 3 months and the Net Present Value (NPV) is US$ 325 429.08. The project's location is Manicaland Province in the Vumba Eastern Highlands of Zimbabwe.

VI. RECOMMENDATIONS

- In the light of the above conclusion, it is recommended that The Wattle Company's Vumba Timbers go for the economically feasible and value adding fuel briquetting project to meet its thermal needs, solve the problem of sawmill residue storage and deposition. The selling of the surplus briquettes will generate revenue for the Company.
- It is also recommended that an Environmental Impact Assessment (EIA) be carried out to assess the developmental impacts of the briquetting project. In the same notion it is recommended that the Company take detailed feasibility studies for alternative power generation projects for forestry and sawmilling biomass residues that will promote demand for and supply of energy in an environmentally-friendly manner.

VII. ACKNOWLEDGEMENTS

The authors hereby acknowledge Mr J. Musemwa, The Wattle Company Projects Director and the entire Wattle

Company personnel for their cooperation and provision of research data used in the various stages of this research project.

REFERENCES

1. Bridgwater, A.V. (1999). A Guide to Fast Pyrolysis of Biomass for Fuels and Chemicals. Bioenergy Research Group – Aston University, United Kingdom.
2. Demirbaş, A., A. Şahin-Demirbaş and A. Hilal Demirbaş. 2004. Briquetting properties of biomass waste materials. *Energy Sources* 26: 83-91.
3. Jamie Morton, July 2001, Forest and Wood Products Research and Development Corporation (2001) Bioenergy: A future for the Australian Forest Industry.
4. Li, Y. and H. Liu. 2000. High pressure densification of wood residues to form an upgraded fuel. *Biomass and Bioenergy* 19: 177-186.
5. National Environmental Policy, Government of Zimbabwe-Ministry of Environment and Tourism (September 2003)
6. Ndiema, C.K.W., P.N. Manga and C.R. Ruttoh. 2002. Influence of die pressure on relaxation characteristics of briquetted biomass. *Energy Conversion and Management* 43: 2157-2161.
7. Nupur Sengupta, 2002, Use of Wood as a Fuel in Combined Heat and Power
8. P.D. Grover and S.K.Mishra, FAO 1996Biomass Briquetting: Technology and Practices
9. Stucley C.R, Schuck S.M, Sims R.E.H, Larsen P.L, Turvey N.D and Marino B.E(2004) Biomass energy production in Australia Status costs and opportunities for major technologies. A report for JVAP in conjunction with the AGO
10. Sustainable Energy Development Authority (1999) Investigation of Potential for Electricity Generation from Forestry By-products in New South Wales. By Enecon Pty Ltd & CSIRO Australia, June 1999
11. UNEP Collaborating Centre on Energy and Environment (January 1997), Implementation strategy to reduce environmental impact on energy related activities in Zimbabwe
12. Wyman, C.E., B.E. Dale, R.T. Elander, M. Holtzapple, M.R. Ladisch and Y.Y. Lee. 2005. Comparative sugar recovery data from laboratory scale application of leading pretreatment technologies to corn stover. *Bioresource Technology* 96: 2026-2032.
13. Yaman, S., M. Şahan, H. Haykiri-açma, K. Şeşen and S. Küçükbayrak. 2000. Production of fuel briquettes from olive refuse and paper mill waste. *Fuel Processing Technology* 68: 23-31.
14. Zandersons, J., J. Gravitis, A. Zhurinsh, A. Kokorevics, U. Kallavus and C.K. Suzuki. 2004. Carbon materials obtained from self-binding sugar cane bagasse and deciduous wood residues plastics. *Biomass and Bioenergy* 26: 345-360.

Tawanda Kunatsa

Lecturer, Chinhoyi University of Technology, Department of Fuels & Energy

Educational details:
B.Eng (Hons) Renewable Energy (Chinhoyi University of Technology) ; MSc Renewable Energy (University of Zimbabwe)

Published papers, workshop presentations & conference papers

1. *Feasibility study of Biogas production from Water Hyacinth. A case of Lake Chivero–Harare, Zimbabwe*; **Kunatsa T** , Madiye L, Chikuku T, Shonhiwa C, **Musademba D** - International Journal of Engineering and Technology Volume 3 No. 2, February, 2013 pge 119-128

Downmore Musademba

Lecturer, Chinhoyi University of Technology, Department of Fuels & Energy

Educational details:
BSc Physics (University of Zimbabwe); MSc Renewable Energy (University of Zimbabwe)

Publications

1. **Musademba Downmore**, Musiyandaka Shepherd, Muzinda Andrew, Nhemachena Barbara and Jambwa Daniel (2011) Municipality Solid Waste (MSW) Management Challenges of Chinhoyi Town in Zimbabwe: Opportunities of Waste Reduction and Recycling. *Journal of Sustainable Development in Africa, Volume 13, No. 2 (2011)*
2. Raphael M. Jingura, Rutendo Matengaifa, **Downmore Musademba** and Kumbirai Musiyiwa (2011) Characterisation of land types and agro-ecological conditions for production of Jatropha as a feedstock for biofuels in Zimbabwe. ELSEVIER: *Journal of Biomass and Bioenergy, Volume 35, (2011):pp2080 -2086*
3. Raphael M. Jingura, **Downmore Musademba**, and Rutendo Matengaifa (2010) Jatropha curcas L. as a source of multiple energy carriers. *International Journal of Engineering Science and Technology, Volume 2, No. 7:pp115-122*
4. *Feasibility study of Biogas production from Water Hyacinth. A case of Lake Chivero–Harare, Zimbabwe*; **Kunatsa T** , Madiye L, Chikuku T, Shonhiwa C, **Musademba D** - International Journal of Engineering and Technology Volume 3 No. 2, February, 2013 pge 119-128