Chapter 33
Prospects and Limitations of Biomass Gasification for Industrial Thermal Applications in Sub-Saharan Africa

Joseph Ndemere Arineitwe, Mackay Okure, Job Mutyaba and Surroop Dinesh

Abstract The paper presents an evaluation of the prospects and limitations of biomass gasification for small-scale industrial thermal applications in sub-Saharan Africa. The evaluation was done through a review of existing biomass conversion technologies that could be replaced by gasifiers and the availability of potential feedstock fuels, an economic analysis of potential gasification projects under different conditions with the use of RETScreen Clean Energy Project Analysis Software, and highlighting possible solutions to the challenges which the technology faces. The findings show a continued heavy reliance on wood fuels for thermal energy together with a high use of inefficient conversion technologies in industries. Furthermore, significant quantities of agricultural residues remain un-utilized which could substitute about 40 % of wood fuel use in industries. The economic analysis shows that the adoption of gasification technologies is economically viable, due to the high potential for revenues from fuel savings and the associated Green House Gas (GHG) emissions reductions when agricultural residues substitute or supplement the use of wood fuel. Some of the identified limitations of biomass gasification technology include liquidity constraints of the potential users, the lack of local knowledge in the design, manufacture and operation of gasifiers as well as the hazard and safety issues of gasifiers. It can be said that biomass gasification can play a major role in energy efficiency and a shift from the wood fuel dependency in small-scale industries, which is important for the environment and beneficial to the users. However, there is need for incentives such as tax holidays, tax waivers on equipment as well as reduced debt payment rates to enable industries afford the required capital investments. Institutional mechanisms for easy access to carbon credit markets are also necessary as GHG emissions reduction revenues contribute a significant portion of the annual

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revenues. Also investment in research and development of local skills in the design, manufacture and operation of gasifiers is vital to further reduce the capital investments and ensure proper management of the gasification-related hazard and safety issues.

Keywords Biomass · Gasification · Thermal energy · Small-scale industries

Symbols and units

Abbreviations

[GHG]	Green house gas
[ICSU]	International council for science
[IEA]	International energy agency
[LHV]	Lower heating value
[MGM]	Maganjo Grain Millers
[NPV]	Net present value
[REEEP]	Renewable energy and energy efficiency partnership

Symbols

[CH_4]	Methane
[CO_2]	Carbondioxide
[N_20]	Nitrous oxide
[$tCO2_{eq}$]	Ton of carbondioxide equivalent
[E_{th}]	Thermal energy output
[$\dot{m}_f$]	Fuel consumption rate
[η_{th}]	Thermal efficiency
[MC_f]	Fuel moisture content

Units

[yr]	year
[kg]	Kilogram
[kW]	Kilo watt
[Mtoe]	Mega tons of oil equivalent
[GJ]	Giga Joules
[MJ/Nm^3]	Mega Joules per normal cubic metre
[MJ/kg]	Mega Joules per kilogram
[PJ]	Penta Joules

Conversions

1 Mtoe =	11.63 TWh
1 Mtoe =	41,868 TJ

Short Introduction

The paper presents an evaluation (trough review) of the prospects and limitations of biomass gasification for small-scale industrial thermal applications in sub-Saharan Africa. The findings show a continued heavy reliance on wood fuels for thermal energy together with a high use of inefficient conversion technologies in industries. The economic analysis shows that the adoption of gasification technologies is economically viable, but still with some limitations. For that reason, investment in research and development of local skills in the design, manufacture and operation of gasifiers is vital to ensure proper management of the gasification-related hazard and safety issues.

Introduction

Sub-Saharan Africa faces many energy challenges, which have impacts on the social-economic aspects of the region. The key challenges include, high energy production-to-consumption ratio partly due to low level of industrialization; and inefficient energy conversion technologies, especially for biomass. Overcoming some of the challenges will require intensive and organized research and development activities to facilitate informed energy decision-making. Although energy research and development is still weak in sub-Saharan Africa (ICSU 2007) research effort and progress are being made in the various countries. One of the many technologies under research in the region is gasification technology. While this technology has been in existence for many years, its adoption and use in sub-Sahara Africa is still limited.

Gasification, by partial combustion, is a thermo-chemical process used for converting a solid fuel into a mixture of combustible gases known as producer gas (Knoef 2006). The generated gas is mainly composed of hydrogen, carbonmonoxide, methane, carbondioxide, nitrogen and water vapor. Condensable hydrocarbons (tars) and ash are also produced. The heating value of producer gas varies from 4 to 6 MJ/Nm^3 for air-blown gasifiers to 13–15 MJ/Nm^3 for oxygen/steam-blown gasifiers (Knoef 2006). The gas can be used for various uses, the ones more relevant to sub-Saharan Africa including provision of thermal energy, generation of electricity and as well as mechanical power through internal combustion engines.

The use of producer gas for provision of energy offers advantages over direct burning the solid fuel such as better combustion efficiency by achieving high temperatures as well as more clean combustion through the use of suitable gas burner technology. It should also be mentioned that gasification has more solid fuel conversion efficiency compared to the traditional open fire technologies that are largely employed in sub-Saharan Africa.

Potential of Biomass Gasification

While the population of the continent continues to grow annually, its energy supply remains low indicating a reduction in energy access on a per capita basis. The total energy consumption in Africa was estimated as 470 Mtoe in 2008 with biomass, mainly wood, contributing the biggest share of 60 % as shown in Fig. 33.1 (IEA 2008). It should also be mentioned that 90 % of the coal in Africa is found in South Africa alone (ICSU 2007). The biggest portion (61 %) of the total energy is used for residential purposes such as cooking, lighting and heating followed by industrial purposes as show in Fig. 33.2. Considering the industrial sector, biomass's contribution was 32.4 % (90.55 Mtoe). The reliance on biomass is highest in Sub-Sahara Africa with over 90 % of the total biomass consumption (Karekyezi 2004) which translates into 81.50 Mtoe in industries in the region.

With the increasing deforestation levels, wood fuel continues to be scarce and expensive. Hence the use of agricultural residues as sources of energy in industries to substitute wood is an important possibility. The potential of agricultural residues in Sub-Sahara Africa was estimated to be 139.5 million tons from 36 out of 48 countries (Gouvello 2008). Using the average heating value of 16.7 MJ/kg (dry fuel), the energy potential was calculated as 2,330 PJ (55.7 Mtoe). It is estimated that bagasse-based cogeneration from sugar industries could meet about 5 % of the total electricity demand in the region (Trade and Development Board 2011). Basing on the projected electricity demand of 680 TWh by 2015 at a demand increase rate of 5 % (Orvika 2009) the amount of bagasse estimate in 2011 was calculated as 2.44 Mtoe. Assuming that 50 % of the residues are used for other purposes—animal feed, cooking/heating, and soil fertility, surplus agricultural residues can be used to substitute about 40 % of wood fuel in industries.

Fig. 33.1 Energy sources in Africa 2008

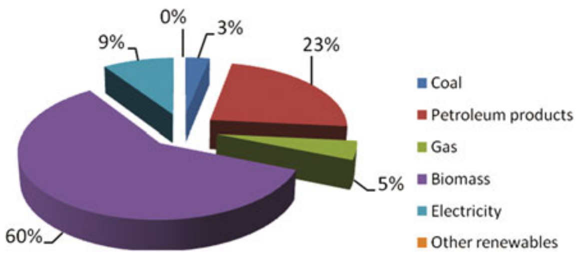
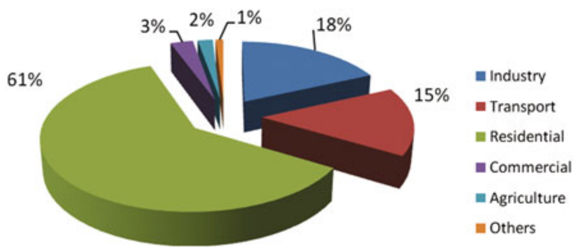


Fig. 33.2 Proportion of energy consumption in various sectors



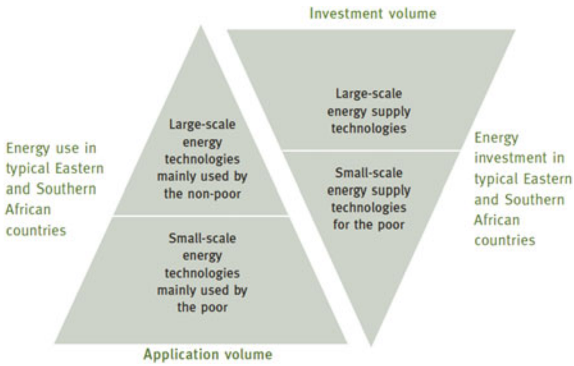


Fig. 33.3 Energy use versus energy expenditure typical in Eastern and Southern Africa

It was also found out that large energy investments are mainly concentrated on the large-scale energy technologies whose application volume is small compared to small-scale energy technologies that are mainly used by the majority of the population as illustrated in Fig. 33.3 (REEEP 2006). It is therefore important to that significant investment be made in small-scale technologies which comprise the majority of industries in the region.

Therefore the potential of gasification technologies utilizing surplus agricultural residues for industrial thermal applications is significant.

Economic Evaluation of Biomass Gasifiers

The Approach Used

The study evaluated the economics of biomass gasification technology in the provision of thermal energy in small scale industries using the RETScreen Clean Energy Project Analysis Software (Version 4) that is freely available online (RETScreen International 2011). This considered the project's fuel savings, revenues from emissions reductions trading against the capital investment and operation costs of the system.

A case study of MGM, a small-scale food processing industry in Uganda was used. MGM is engaged in agro-processing of grain to produce flour, bread and cakes. The factory produces a number of pre-cooked flour products made from maize, soy, silver fish, millet and rice. An oven of capacity of 180 kg confectioneries per day is made from brick and cement-sand mortar with steel baking compartments. The oven is fed with large logs of firewood. The factory also employs two roasters made of steel drums driven by a small electric motor to provide rotary motion along the longitudinal axis. The drums are filled in batches with grains and heated directly with an open fire. The combined total production of the roasters was reported to be 2,000 kg/day.

MGM operates 6 days a week and 8 h per day throughout the year. The wood consumption was estimated to be 97.4 t/year at the cost of US $56/t of wood. These estimates were made based on the fuel wood records as well as the actual daily wood measurement. The wood moisture content was measured as 31.4 % (wb). The wood combustion system used at MGM is similar to the inefficient 3-stone open fires, and hence its thermal efficiency was conservatively assumed to be 20 % (Umogbai 2011). The installed thermal capacity of MGM factory was calculated from Eq. (33.1) where E_{th} (kW) is the thermal output, η_{th} is the thermal efficiency(%), $\dot{m}_f$is the fuel consumption rate (kg/s), MC_f is the wood moisture content (%wb) and $LHV_f$is the wood heating value (MJ/kg). The heating value for dry wood was taken as 19.5 MJ/kg (Yorwoods 2008).

$$E_{th} = \eta_{th} \cdot \dot{m}_f \left(1 - MC_f\right) \cdot LHV_f \tag{33.1}$$

Fixed bed gasifiers, because of their suitability for small-scale use, have been suggested. The gasifier system overall efficiency of 40 % and its unit capital cost of US $200/kW (Ghost 2006) were used.

The key parameters used in the evaluation are average inflation rate of 6.2 % over the past 15 years was applied (International Monetary Fund 2011), income tax rate of 25 % and depreciation tax basis of 20 % (PKF 2011) with Straight-line method over 20 years. Other parameters assumed include fuel price escalation rate of 7 % discount rate of 12.0 % and project life of 25 years. The capital investment costs used are also summarized in Table 33.1.

The study evaluated the financial viability of the project considering that the scenario where agricultural residues substitute 40 % of the wood fuel. While the prices of agricultural residues range from US $3/t to 14/t (Ashden Award 2009) depending on the source in Uganda, the evaluation considered a conservative price of US $15 per ton. Assuming the LHV of 16.5 MJ/kg and the moisture content of 15 % (wb) for air dry agricultural residues (Bingh 2004), the amount of residues required would be 18.6 t/year in addition to 29.0 t/year of wood fuel. Without the use of agricultural residues, MGM would continue to use 48.3 t/year of wood.

The evaluation considered five cases to determine how they could affect the economic viability of the project.

- Case 1 assumes that MGM fully finances the project without getting a bank loan, incentive/grant or tax holiday.
- Case 2 assumes that MGM fully finances the capital investments but gets a tax holiday spread over 5 years.

Table 33.1 Capital investment costs

Initial costs	%	USD
Feasibility study	7.1	2,000
Development	14.2	4,000
Engineering	63.3	17,860
Balance of system and misc.	15.4	4,343
Total initial costs	100.0	*28,203*

- Case 3 assumes that MGM acquires a loan equivalent to 50 % the total investment cost at debt interest rate of 23 % (UMA 2009) over a period of 5 years.
- Case 4 assumes that MGM acquires a loan as in Case 3 and receives an income tax holiday over 5 years.
- Case 5 assumes that MGM gets incentives/grants equivalent to 20 % of the total investment cost.

The results of the evaluation were compared with the scenario where MGM continues to use 100 % wood fuel with the adoption of the gasification system.

The emission factors for CO_2, CH_4 and N_2O of 109.6, 0.03 and 0.004 kg/GJ respectively for biomass combustion (National Inventory Report 2010) were used in the calculation of GHG emission reduction that would be achieved by switching to the use of a gasifier at MGM. Other parameters assumed in the emissions analysis are shown in Table 33.2.

It should be noted that the calculation of GHG emissions reductions did not put into consideration leakages that come with the transportation and preparation of fuel, use of electricity to run the gasifier, and the possibility that the revenues from the emission reductions will be invested in activities which lead to generation of GHG emissions.

Results and Discussion

With the use of the gasifier, MGM's annual operating costs and savings/income are shown in Tables 33.3 and 33.4 respectively. In effect, it means that the annual income of MGM—excluding interest on loans or depreciation—would be US $ 3,008—and US $1,427—when using a mix of wood and agricultural residues and using wood only respectively.

The results have also shown that the project with substitution of 40 % wood fuel with agricultural residues is economically viable with significantly shorter equity payback periods and positive NPV values in comparison with the continued use of wood fuel only as shown in Table 33.5. The cumulative cash flows for both scenarios are also shown in Figs. 33.4, 33.5. A tax holiday of 5 years has more impact on the case when MGM finances all the investments costs. Given the possibility of liquidity constraints in small-scale industries, it is most likely that

Table 33.2 Emission analysis parameters

Parameter	Unit	Quantity
GHG credit transaction rate	%	2.5
GHG reduction credit rate	$/tCO2 eq	20
GHG reduction credit escalation rate	%	3.0
GHG reduction credit duration	Year	25

Table 33.3 MGM's annual operating costs

Annual costs	Amount (US$)	
	Using wood/agricultural residues	Using only wood
O&M	3,308	3,308
Fuel cost—proposed case	1,918	2,729
Total annual costs	*5,225*	*6,036*

Table 33.4 MGM's annual savings/income

Income source	Using wood/agricultural residues		Using wood only	
	Saving	Income (US$)	Saving	Income (US$)
Fuel cost—base case	97.4 t/year	5,503	97.4 t/year	5,503
GHG reduction income	136t$CO2_{eq}$/year	2,730	98t$CO2_{eq}$/year	1,960
Total		*8,233*		*7,463*

loans have to be acquired in order to finance the implementation of the gasifier projects. A lower interest rate may help to reduce the payback period. The sensitivity analysis showed that variations in the fuel cost (proposed case) and the emission reduction credit rate can significantly affect the payback period and the NPV.

The MGM gasifier project scenario presents opportunities for addressing the core challenges of sub Saharan African. Firstly, it addresses the issue of use of inefficient combustion technologies that are common in the region. This would help to reduce deforestation rate as well as reducing on emissions. Putting the project into perspective, the possible use of a gasifier by MGM would lead to annual GHG emissions reduction which is comparable to 31 acres of forest absorbing carbon every year. There would be great impact on the environment with the adoption of these technologies in many small-scale industries in the region. Specifically for thermal applications, the only modification that may be necessary to integrate with a gasifier is a properly designed gas burner/combustion chamber. The rest of the exiting system remains largely unmodified with tax holidays and reduced lending rates, small-scale industries should be able to acquire gasifiers for their thermal needs.

Secondly, the project is itself a source of income for the industries. Increasing the capital base of industries through fuel saving and GHG emission reduction

Table 33.5 Pay back periods and NPVs for the two project scenarios

Scenario	Wood and agricultural residue		Wood only	
Case	Equity payback (years)	NPV (US$)	Equity payback (years)	NPV (US$)
1	8.1	3,421	15.4	−10,998
2	6.9	6,185	14.6	−9,864
3	10.5	1,498	19.4	−12.922
4	10.2	2,244	19.4	−12.862
5	6.8	7,652	13.1	−6,768

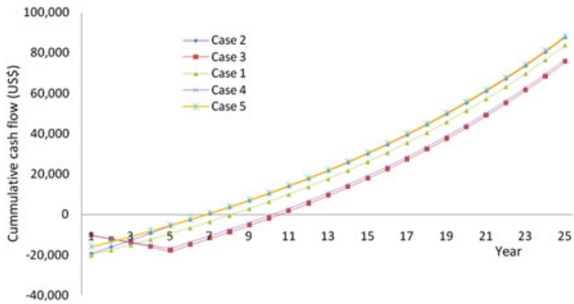


Fig. 33.4 Cumulative cash flows of with both wood and agricultural residues as fuels

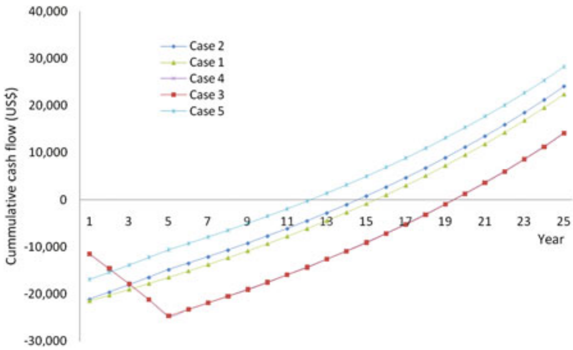


Fig. 33.5 Cumulative cash flows with wood as the only fuel

trading directly leads to economic and industrial growth. This is achieved through diversification and increased employment opportunities.

Thirdly, for industries that can have access to agricultural residues in large quantities all year around, complete substitution of wood fuel would further reduce the annual operation costs and increase the annual income hence impacting greatly on the equity payback period. It should be mentioned that there may be additional investment costs that need to be met to accommodate the large quantities of the residues. They could include storage and handling facilities and pre-treatment systems where applicable.

Limitations of Biomass Gasification Technology

Due to the diverging capacities of different small-scale industries in sub-Saharan African, biomass gasification systems need to be designed in appropriate scales according to the user demands. This remains a key challenge because of the various factors that need to be considered such properties and types of feedstock materials, energy requirement etc. At the same time, biomass gasification systems need to be made economically affordable to small-scales industries. This however risks compromising the efficiency hence leading to operation difficulties and environmental problems.

Successful adoption of biomass gasification in sub-Sahara Africa requires additional support other than the fuel savings, GHG emissions trading and the way of energy utilization. Government or institutional policies on capital cost subsidies and tax cuts or tax holidays for are necessary. There is a challenge of high interest rates on bank loans which drive away the industries that may be interested in acquiring the systems. These all remain big challenges.

There still remain significant levels of lack of awareness of gasification technology in the region. Awareness campaigns by governments and institutions need to be put in place to educate potential users about the technology and its benefits. The development of skills in the design and operation of gasifiers in the region need to be emphasized.

Conclusions

The potential of biomass gasification for provision of thermal energy in small scale industrial applications exists with the availability of agricultural residues which could substitute about 40 % of wood fuel use in industries. It has also been shown that the adoption of biomass gasifiers for provision of thermal energy in small-scale industries by replacing the traditional inefficient technologies currently in use is economically viable and has positive significant environmental and economic impacts when agricultural residues are used to supplement or substitute wood fuel.

In order to increase the rate of adoption of gasifiers, policies such as tax holidays, reduced debt payment rates, tax waivers on gasifier equipment supplies or any meaningful incentives should be put in place. With these, many small-scale industries that wouldn't ordinarily afford such high investments can be brought on board.

Given that the sources of revenue to help cover investment and operational costs are hinged around fuel savings and GHG emission reductions, governments and institutions in sub-Sahara Africa need to put in place mechanisms that can help industries access carbon credit markets relatively easily. Without the revenues from GHG emission reductions, most small-scale industries would need high incentives or subsidies and longer tax breaks in order to find adoption of gasification technology an economically sound venture.

It is also important that governments and institutions invest in research and skills development in the design and operation of gasification systems. This would go long away in reducing the high capital investments and ensuring high performance of the technologies.

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