VALORISATION OF TEXTILE RESIDUES FOR ENERGY PRODUCTION IN KENYA

(Charles Nzila[a], Jo Dewulf[a], Henri Spanjers[b], Sheila Odhiambo[c], Henry Kiriamiti[d], Herman van Langenhove[a])

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ABSTRACT

Kenya is an energy intensive developing country largely dependent on petroleum oil imports and hydropower for her energy needs. The unrelenting decline in the national hydropower capacity coupled with the continued rise of crude oil prices thus adversely affects all sectors of the country's economy with the manufacturing sector suffering the most. The need for the country to strive for self sufficiency with respect to energy calls for urgent intervention so as to forestall the imminent stagnation in development. Indeed the availability of secure, affordable, reliable, clean and sustainable energy supply is regarded as one of the key drivers for the improvement of the quality of life and national development. Competitive locally produced biofuels can to a large extend supplement the country's energy needs. Indeed locally produced biofuels such as biodiesel, bioalcohol and biogas have a potential of becoming a significant source of energy thus reducing the country's dependence on fossil oil imports.

This paper reviews the valorisation potential of two textile based agro residues namely cotton and sisal waste (CSW) for energy production. In addition, the technologies for transforming the CSW into secondary energy sources are also evaluated. While many different technologies portray capacity to utilise the textile residues for energy production, the biochemical transformation processes of alcoholic fermentation and anaerobic fermentation offer a very attractive route to utilize the CSW for energy production.

Key words: valorisation, bioconversion, cotton and sisal wsate, biofuels, Kenya

[a] Laboratory for Environmental and Organic Chemistry, Gent University, Belgium.
[b] Lettinga Associates Foundation, Wageningen, The Netherlands.
[c] Department of Manufacturing, Industrial and Textile Engineering, Moi university, Kenya.
[d] Department of Chemical and Process Engineering, Moi university, Kenya.

INTRODUCTION

Availability of secure, affordable, reliable, clean and sustainable energy supply is one of the key drivers of development and improves the quality of life. Currently the main source of energy worldwide is non-renewable fossil fuel, the use of which results in emission of gases that have a negative impact on the environment. The effects of global warming, diminished natural resources, uneven distribution of energy resources, rising energy prices and hence increased energy demand constitute an energy crisis of global magnitude. The crisis demands an immediate paradigm shift in energy policies with a view of not only revising the existing technologies but paying greater attention to alternative energy sources. Thus, there is a need to identify new technologies as well as alternative renewable and environmental friendly sources of energy. The development of cost-effective renewable energy technologies for energy production is a priority for many private firms, research centres and even governments. To this end, biofuel technology has been identified as quite a promising technology [1, 2] due to its potential of being a significant source of energy.

In the recent past a lot of research has emerged worldwide on the utilization of biomass for generation of energy [2, 3]. Indeed, biomass in all its forms is researched to account for over 16% of the world's final energy consumption by 2020 and almost 30% of the total global primary energy consumption in 2050 will be covered by regenerative energy sources [4]. Already in developing countries, biomass currently provides over 35% of the final energy consumption [5] and its utilization is expected to increase as a strategy for carbon dioxide reduction. The consideration of biomass as a green fuel is further attributed to its low contents of sulphur, nitrogen and ash. Indeed a lot of efforts have been expended in the studies of biofuel production leading to development of technologies with varying degrees of success. The main challenge has been on the production cost which is found to be higher than that of fossil fuels. In addition, the cultivation and use of energy crops for energy production may contravene the drive towards food security especially in most developing countries [4, 6].

However, a substantial reduction in the cost of biofuel production can be achieved by addressing the problems associated with raw materials and product separation process. Indeed the future of biofuels in most developing countries lies on the identification of non-food plants that can be grown in underutilized land and cascade utilization of the available but underexploited resources such as crop residues as well as optimization of the biofuel production processes.

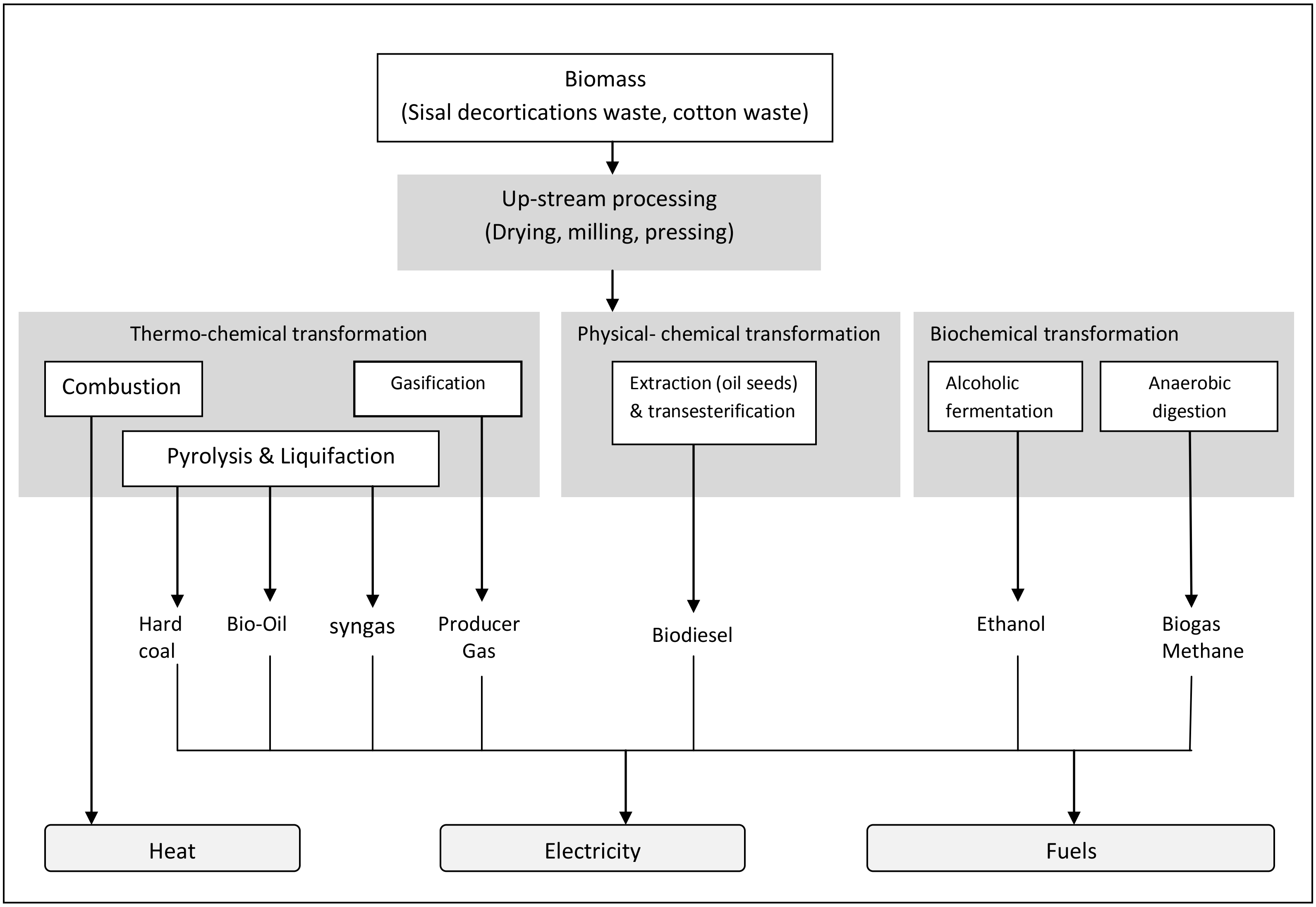

Figure 1 Applied technologies options for transforming biomass into secondary energy carriers [4].

Textile residues are some of the most unexploited resources in Kenya in spite of the fact that the textile industry utilises less than 20 % of the agro biomass produced entirely for textile use. Textile oriented agro biomass residues such as CSW theoretically have high energy potential primarily owing to their high cellulose content. Besides, there are several conversion options for transforming the biomass of CSW into solid, liquid or gaseous secondary energy carriers (Figure 1): these include thermo-chemical transformation via combustion, pyrolysis, liquefaction or gasification; physic-chemical transformation by compression, extraction, transesterification and biochemical transformation via alcoholic fermentation and anaerobic digestion.

Thermochemical transformation

The energy stored in CSW is released when the biomass is combusted. When the requirement is purely thermal, it can be met by using combustion systems and appropriately transferring heat to the required devices. The use of CSW biomass for energy production can be achieved commercially through boiler and steam turbines though this route is only efficient and economical at large power levels of the order of 5 MW or more. However due to the high capital investment required for large thermal power plants coupled with treatment costs in the range of 50 – 150 €`/tonne[7] and the low bulk density of CSW as well as the presence of agrochemical residues especially in the cotton residue fraction, combustion may not be a viable option for CSW. Gasification of biomass on the other hand provides means for power generation at lower levels of cost per mega watt comparable to large thermal power plants. During gasification, the solid biomass residues are converted to a gaseous fuel called the producer gas. The producer gas thus generated can be used just like other gaseous fuels such as natural gas, besides, it can also be used for power generation in internal combustion engines or gas turbines. Pyrolysis converts biomass at temperatures around 500°C in the absence of oxygen to solid (hard coal), liquid (bio-oil) and gaseous fractions [7]. Liquifaction is another way of converting biomass under high pressure into raw intermediate liquids (bio-oils). To date, pyrolysis and liquefaction are still quite expensive hence less well developed and the actual market implementation is so far negligible.

Physical-chemical transformation

When cotton seeds are crushed, the resulting cottonseed oil can be processed through transesterification to produce a high-quality biodiesel that can be used in a standard diesel car. The residue (press cake) can also be processed and used as biomass feedstock to power electricity plants or used as feedstock for biogas production while the resultant digestate can be used as fertilizer. However production of biodiesel from cotton seed oil is not probable at the moment due to the current use of cotton seed oil and cake for animal feed production in the country. In Europe biodiesel production using rapeseed oil and waste vegetable oil is an established technology, while in Kenya biodiesel production from non edible oil seeds such as jatropha curcas is gaining immense attention.

Biochemical transformation

Biochemical transformation via alcoholic fermentation and anaerobic digestion offers a very attractive route to utilize diverse categories of biomass and biowaste for meeting energy needs as well as contributing to resource and environmental conservation. Alcoholic fermentation and anaerobic digestion of the textile biowaste into ethanol and biogas respectively can serve as a vital tool in closing the sisal and cotton value chain thus contributing to the development of the textile industry.

The role of biochemical transformation in a cascade system utilization of sisal and cotton biomass.

Utilization of the potential presented by the sisal and cotton residues via a cascade system for biogas energy production and the subsequent use of the digestate as green manure can provide multiple environmental [8]and socio-economic benefits to the users and the community thus alleviating poverty. In Kenya, a simple yet all inclusive strategy for promoting sisal and cotton might be the closed loop cascade system for the utilization of sisal and cotton biomass (figure 3).

Bioconversion processes such as ethanol and biogas production can be employed in energy production systems utilising sisal and cotton waste. The production of ethanol from sisal and cotton biowaste can improve energy security and decrease pollution. Ethanol is an excellent transportation fuel and when blended with gasoline it leads to reduced gasoline use, thus lowering the need for fossil fuels. Besides the ethanol–gasoline blend has a better performance since ethanol provides oxygen for the fuel resulting in a more complete combustion with a low atmospheric photochemical reactivity. The ability of the biowaste derived glucose to be fermented by yeasts into bioethanol does not only address the issue of renewable energy but could also serve to control the sisal and cotton biowaste.

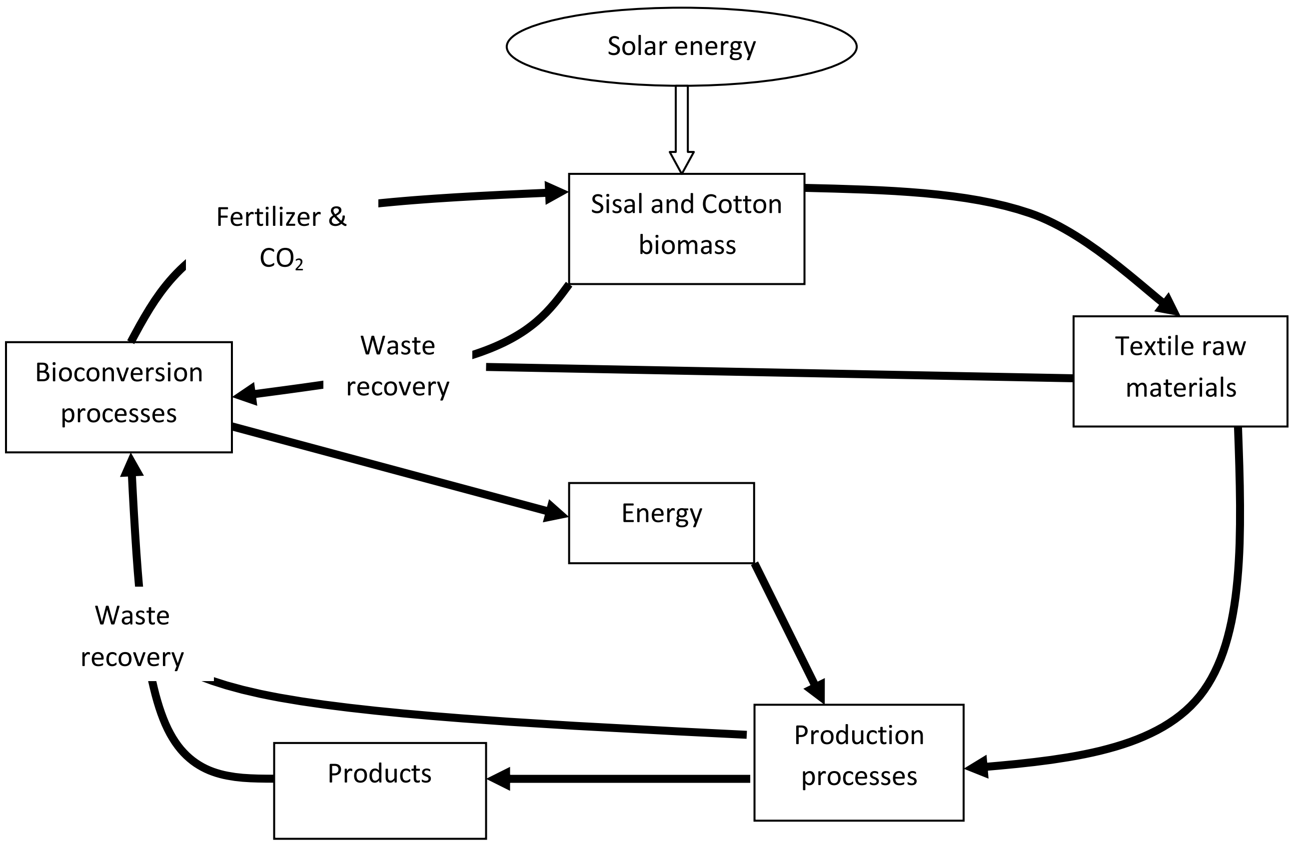

Figure 3: Cascade system for the utilization of sisal and cotton biomass showing the role of bioconversion process in closing the loop.

Two main approaches i.e., phased and direct microbial conversion, have been examined for the hydrolysis of waste cellulose into glucose and the successive fermentation into bioethanol and other bioproducts [9]. The phased microbial conversion makes use of separate hydrolysis and fermentation processes whereby cellulase is added to pretreated biowaste resulting in the formation of glucose from the cellulose fraction after which yeast is added to ferment glucose into ethanol [1]. With the direct microbial conversion, the microorganisms simultaneously produce cellulase, hydrolyze cellulose and ferment glucose into ethanol while at the same time, co-fermentation converts the hemicellulose sugars into bioethanol[3, 10]. Over the years there have been substantial advances in enzyme-based technology for ethanol production.

Biogas on the other hand is produced through biomethanation process which is a biological transformation through which organic matter is degraded to methane and carbon dioxide [11]. The biomethanation process consists of a series of discrete reactions catalysed by a consortium of metabolic groups of different bacterial species through which organic matter is converted to the main products of methane and carbon dioxide[12]. Indeed most biomass based upgrading and production processes release organic by-products and wastes thus biomethanation can be advantageously implemented into these technologies as an energy, fertilizer recovery and waste stabilization process. In addition, biomethanation could eventually contribute a significant portion of the country's lighting requirements especially in the rural areas.

The bio-energy produced through biomethanation of sisal and cotton wastes can supplement the energy needs of the textile production processes while the energy savings can be used to enhance the profit of the farmers. Besides, the subsequent use of the digestate as green manure can provide a multiple environmental and socio-economic benefits to the users and the community thus alleviating poverty in the country. Moreover, realization of high-efficient bioconversion processes at places where the sisal and cotton biomass can be grown, gathered and or translocated and where the 'green' products can be sold to a cluster of end users can be a vital key towards meeting the longer term policy goals in the country.

The status of cotton and sisal industry in Kenya

Cotton and sisal occupy the 1st and the 2nd place respectively among Kenya's fibre plants. The average annual production of cotton and sisal in the country is 28,200 and 25,444 tonnes respectively [13] although the reported annual potential of the country is 200,000 tonnes of cotton and 300,000 tonnes of sisal. The total area under the two crops stands at over 200,000 hectares[14]. During the last 10 years the production of seedcotton increased by 63% from 23,440 tonnes in 1998 to 38,300 tonnes in 2007 while the area under cotton increased by 123% however the production per hectare decreased by 33% from 0.6 tonnes/ha to 0.4 tonnes/ha. Over the same ten year period, the production of sisal increased by 35% from 18,216 tonnes in 1998 to 24,602 tonnes in 2007 while the area under sisal increased by 59% nevertheless the production per hectare decreased by 11% from 0.9 tonnes/ha to 0.8 tonnes/ha[13]. Reduction in the yield of the two crops has been attributed to poor farming practices which is a consequence of low returns. A recent study on the sisal and cotton value chain in the country established that the chain consists of a one way system for the utilization of sisal and cotton biomass and the respective products (figure 2).

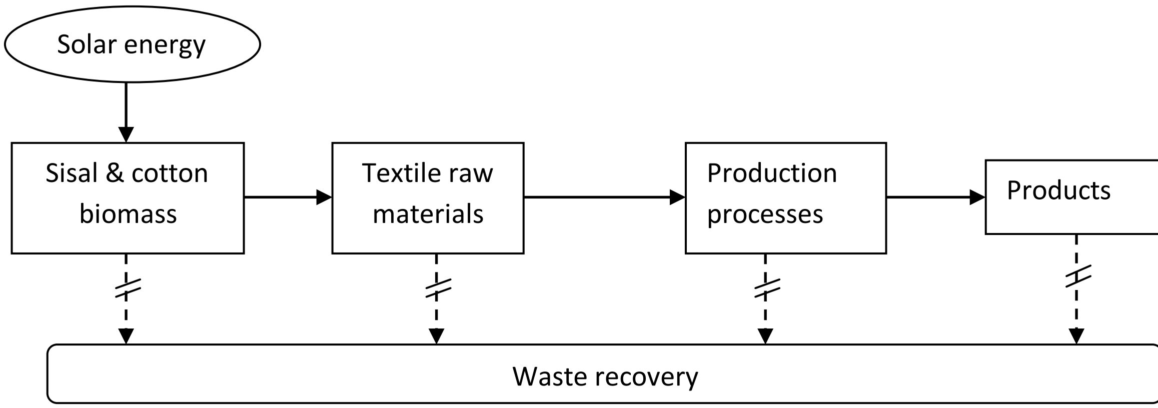

Figure 2: One way system for the utilization of sisal and cotton in Kenya showing non utilization of residues.

However the one-way sisal and cotton value chain was found to be weakest at the bottom as evidenced by the decreased output per hectare. Similar reports indicate that value addition measures along the chain are imperative for any interventions in the sector to have a major impact. Besides, strategies that are geared towards looping the value chain stand a greater chance of success owing to their inclusivity and sustainability potential.

Energy potential of sisal and cotton residues

Using the current production methods, only 4% and 15% of the actual sisal and cotton plant biomass is recovered as textile fibre. The residue is either bunt, producing carbon dioxide, or rots naturally, thus contributing to odour and the green house gas (GHG) problem through release of volatile hydrocarbons such methane. Since over 80% of both plants biomass is suitable for bioconversion process, the use of the waste for bio-energy is deemed to be environmentally beneficial. If 50% of the sisal and cotton residue can be harnessed for bioconversion into energy, about 94,000 MW of electricity and 141,000 MW of thermal energy can be generated (Table 1). It is therefore theoretically possible to produce about 2% of the country's annual power production of 5307 GWh from anaerobic digestion of CSW and if alcoholic fermentation is factored the energy potential of CSW can even be higher.

Table 1: Sisal and cotton residue energy potential in Kenya at 50% residue recovery factor [13, 15]

Sisal and cotton residue energy potential		
	Sisal	Cotton
Annual production (metric tonnes/yr)	25,444	28,200
Residue (metric tonnes/yr)	50,889	65,800
Biomethane potential (thousand M^3/yr)	7,531	24,017
Electrical energy potential (MW/yr)	22,443	71,570
Thermal energy potential (MW/yr)	33,741	107,596

Conclusions

Valorisation of cotton and sisal residues for energy production is possible in Kenya. A simple but all inclusive strategy for promoting sisal and cotton industry in the country is the closed loop cascade system for the utilization of sisal and cotton biomass where alcoholic fermentation and biogas technology serves as a vital tool in closing the value chains of both textile fibres. Indeed bioconversion can be advantageously implemented as an all inclusive energy, fertilizer recovery and waste stabilization process in the cotton and sisal textile industry. As with any development the sustainable re-use of textile biowaste resources would not be without challenges, but it would open up the opportunity for technological developments. Moreover, realization of high-efficient bioconversion processes at places where the sisal and cotton biomass can be grown, gathered and or translocated and where the 'green' products can be sold to a cluster of end users is key to meeting the longer term policy goals in the country.

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