Biomass Energy Policy Brief

Biomass and its potential role in South Africa's Energy mix

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CAPEX	Capital Expenditure
FTS	Fischer Tropsch Synthesis
GSA	Government of South Africa
ISO	International Sugar Organization
IEA	International; Energy Agency
OPEX	Operating Expenditure
SAI	South Africa Info
SASA	South African Sugar Association
UCS	Union of Concerned Scientists
USDA	US Department of Agriculture

Introduction

South Africa, like the rest of the world, is in need of increased levels of electricity supply in order to allow for growth. Due to negative environmental effects and the unsustainable future of fossil fuel based electricity generation methods, the world is turning to renewable sources of clean energy. Biomass is an example of such an energy source.

Energy from biomass is considered to be a clean energy source, because the energy in the biomass comes from the sun and the biomass (trees, energy crops etc.) regrow in a relatively short time. Plants convert carbon dioxide from the atmosphere into biomass and release the same amount of carbon dioxide back in to the atmosphere whether it decomposes or is burned, therefore having a very low net effect on the total carbon content of the atmosphere. Biomass differs from the burning of fossil fuels where carbon based fuels that lie dormant below the Earth's crust are brought up and burned, releasing additional carbon into the atmosphere.

Humans have been using biomass as a source of energy since the time when people began burning wood. In 2000, biomass energy still accounted for 7% of the world's energy consumption (Fernandes, et al., 2007). Historically the burning of wood has only been used for small-scale energy release such as lighting a fire to cook food or for space heating. With the increase in utility scale electricity demand, biomass energy is being turned towards as a possible contributor to the clean energy producer market.

There are two main sources of biomass that are under consideration as contributors to South Africa's energy mix; energy crops and agricultural residues. This policy brief investigates the technologies used to convert biomass into heat or electrical energy, the cost implications of biomass energy and its relevance in South Africa.

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1: Introduction to biomass energy

Biomass is converted into two forms of energy that contribute to the South African energy mix, namely heat and electrical energy. Humans have used biomass for energy since humankind started making fires. The heat energy produced by the chemical conversation of the biomass can be used directly or transformed into electrical energy using additional conversion methods.

Plant based biomass is the material resulting from the process of photosynthesis: the process whereby the chlorophyll in an organic life form uses the energy of the sun to convert carbon dioxide and water into carbohydrates – a complex compound composed of carbon, hydrogen and oxygen. These carbohydrates are then burned and the chemical process of splitting the intermolecular bonds releases energy in the form of heat.

Table 1 shows the main categories of biomass material used in bio-energy projects. In order for biomass energy to be termed ''renewable", the fuel used to produce the energy, the biomass, must be replenished on a human timescale. This process of replenishing the biomass on a human timescale is not possible for all types. For this reason, there are only two sources of biomass under consideration for the South African energy mix, namely energy crops and agricultural residues. These two sources are investigated further.

Table 1: Description of various biomass categories, adapted from (gov, 2016).

Biomass category	Description
Wood	This includes wood from forestry, arboriculture activities (including invasive aliens) or wood processing.
Agricultural residues	Residues from agricultural harvesting or processing (the most important part for this context is sugarcane tops and trashes).
Biological waste	This includes compositions such as manure, abattoir waste and human waste (sewage).
Food waste	Includes waste from food and drink manufacturing, preparation, processing and post-consumer waste.
Energy crops	These include high yield crops grown specifically for energy applications.
Industrial waste	Bi-products from manufacturing and industrial processes.

1.1: Energy crops

An energy crop is a crop that is grown for energy purposes and is produced in large quantities. One of the challenges faced by the biomass energy industry, is the supply of biofuel. These fuels are highly dependent on human actions; in many cases they are considered simply as bi-products of other processes. This leads to inconsistency in the production and supply of these fuels. Using energy crops as fuel for biomass energy conversion decreases the inconsistency aspect of the energy source.

Maize, sugarcane, palm oil and soy are currently the most widely used energy crops, although native trees and grasses are likely to become more popular in the future. Perennial crops require less maintenance and fewer inputs than annual row crops, so they are cheaper and more sustainable to produce. The current most widely used biomass crops used for biofuels, namely; maize, sugarcane, palm oil and soy are evaluated by their yield. The yield of the crop is characterised by the ratio of energy captured to the input of energy required to grow, harvest and process the crop (Coyle, 2007). See Table 2 for the yield of the various crops.

Table 2: Energy crop yield.

Crop type	Global crop mass in 2002 (Mt)	Gross biofuel conversion (GJ/ton)	Gross biofuel energy (EJ)	Gross fossil fuel energy required (EJ)	Energy ratio	Reference
Maize	696	8	5.8	4.64	1.25	(Hill, et al., 2006)
Sugar cane	1324	2	2.8	0.35	8	(IEA, 2004)
Soy	35	30	1	0.19	5.4	(Worldwatch, 2006)
Palm oil	36	30	1.1	0.12	9	(Worldwatch, 2006)

Table 2 depicts a depressing picture for maize, the entire global harvest of maize converted to biofuel for transportation would only yield enough transportation fuel to supply 6% of the global gasoline and diesel demand (BP, 2007). Consulting the energy ratio of maize, it is clear that converting it to biofuel in utility scale quantities just doesn't make sense.

The energy ratios for Soy and Palm prove to be quite high but as the global mass of the crop produced per year shows, these biomass sources are still in infancy stages and have not yet been tested at a scale close to utility. It would be unwise to assume these fuels would achieve the same energy ratios at larger scales. Sugar cane proves to perform the best with an energy ratio of 8 and a global annual crop production that outweighs all of the other sources. Figure 1 shows a field of sugarcane.

Figure 1: Sugarcane field.

1.2: Agricultural residues

Agricultural residues refer to biomass that is left over after agricultural activities. This biomass has the potential to be converted into heat or electrical energy. Crop residues are one of the largest biomass resources in the United States. The Union of Concerned Scientists (2012) projected that annual crop residues in the United States could amount to 150 million tons by 2030.

A large advantage of using agricultural residues as a contribution to any energy mix is that they do not need any additional land to grow as they are a by-product of today's primary crops. Another benefit of using agricultural residues for biofuel is that the cost to grow the biomass is offset heavily due to the crops being grown first and foremost for the production of food. This makes the cost of producing the raw unprocessed biomass very low (USDA, 2009).

A disadvantage of using agricultural residues, is the dependence on other external processes for the biomass thus introducing complexity and uncertainty. For example, residues play an important role in farming, protecting the soil from erosion and loss of soil carbon (UCS, 2014). This means that only a certain amount of residual crop can be removed from the field in order to ensure a sustainable future for the crop. The amount that can be removed is dependent on many factors and therefore differs from field to field. This introduces complexity and unreliability (Muth, et al., 2012).

In addition to the previously mentioned complexity, the form of the crop residue is not consistent and therefore requires processing before it can be burned and the energy extracted. This processing involves compressing the crop residue into a pellet form (UCS, 2014). The three most common forms of biomass residue are wood residues from logging, wood residues generated by management of perennial crop plantations and crop residues generated by agriculture (Koopmans & Koppejan, 1997).

South Africa's agricultural residue is similar in magnitude to that of its logging industry residue. With the aim of reducing redundancies in this report, only agricultural residues are investigated.

Table 3 shows a list of crops that produce agricultural residues suitable for biomass energy conversion.

Table 3: Crops that produce suitable agricultural residue.

Crop	Description
Grains & Cereal	Straw is a by-product resulting from the growing of commercial crops, primarily cereal and grain. When calculating the amount of straw residue left over from cereal crops an established rule of thumb is used. This rule of thumb predicts approximately two thirds of the crop yield to be straw residue (Caslin, 2016).
Maize	Agricultural residue generated by the farming of maize is one of the largest in South Africa in terms of tons produced per year. The edible part of the maize crop includes the maize cob that is enveloped by husks and supported by a stem. Much of the residues is burned and used as fertiliser. The agricultural residue generated by the maize industry in South Africa has an energy equivalent of 196 000 tons of coal per year (Potgieter, 2011).
Cassava & Jute	Cassava stalks are sometimes left in the field but often they are used as domestic fuel. A benefit of this residue is that the processing required for the energy conversion phase is simple (Koopmans & Koppejan, 1997).
Sugarcane	The International Sugar Organization (ISO) states that sugarcane is a highly efficient converter of solar energy, and has the highest energy-to-volume ratio among energy crops (also seen in Table 2). Roughly, 1 ton of Sugarcane biomass-based on Bagasse, foliage and ethanol output – has an energy content equivalent to one barrel of crude oil. There are two main parts of residue generated by the farming of the cane; Cane Trash is the field residue remaining after harvesting the Cane stalk and Bagasse is the milling by-product that remains after extracting sugar from the stalk (Zafar, 2016).
Grapes	South Africa is the ninth largest wine producer in the world. Over 110 000ha of land is under cultivation, with over 300-million single vines (SAI, 2008). The major by-product of the wine industry is grape marc, containing grape seeds, stalks and skins left over after the crushing of the grapes. Once dried, this biofuel can be burned and the heat can be converted to electricity.
Rice	Rice straw: Many rice farming countries use the straw of the rice as a source of energy. The straw is burned and used for fertiliser or as a source of heating. Rice husk: The husk of the rice is often burned as a method of disposal but in some countries such as Thailand they use the husks as a source of energy. It is estimated that in Thailand about 50-70% of the husks are used by the rice mills and the remaining residual is used by the brick industry as a source of heat energy (Koopmans & Koppejan, 1997).

As previously mentioned, there is increasing pressure on South Africa's grid to provide utility scale electricity. In order for biomass to become a contributing source of energy for utility scale electricity, efficient and effective conversion technologies and methods are required. The following section investigates the technologies and methods that exist presently.

2: Biomass conversion

Conversion technologies used to convert the energy stored in biomass into a useful form include thermal and chemical processes. Some technologies release the energy stored in the biomass directly in the form of heat energy, this energy is often used to generate electricity. Other technologies convert the biomass into another from such as liquid biofuel or combustible biogas that can then in turn be converted into heat or electrical energy. This section investigates the various technologies and their relevance in South Africa.

2.1: Thermal conversion

Thermal conversion is the process where biomass is converted to heat. This conversion is achieved by making use of various mechanisms, namely combustion, gasification and pyrolysis.

Combustion is a chemical process in which a fuel, in this case the biomass, reacts with an oxidant to produce heat. The conversion process also emits light in the form of a flame. The heat produced by this chemical reaction can be used directly for useful space and water heating or it could be used to convert water into steam to power a steam turbine and generate electricity.

Gasification is a process that breaks biomass down into carbon monoxide, hydrogen carbon dioxide and various hydrocarbon molecules such as methane. The process achieves this by reacting the biomass at high temperatures (above 700°C) without allowing the biomass to combust. The resulting gas is known as Syngas; this gas can then be put through the combustion process in order to release heat. The advantage of Syngas is that it is potentially more efficient than direct combustion of the original biofuel because it can be combusted at higher temperatures (Van Niekerk, et al., 2016).

Pyrolysis is the precursor to gasification and is a hybrid process involving both combustion and gasification. It is an exothermic irreversible reaction that decomposes biomass through a specific thermal treatment in the absence of oxygen. Charcoal is produced as a by-product of the process and depending on the rate of the process can even contribute to additional thermal energy release. This process can therefore transform biomass into a more energy dense type of feedstock appropriate for gasification.

Other forms of conversion include:

- Briquetting and pelletisation - the feedstock is compressed into a dense combustible material.
- Bio-ethanol conversion – the feedstock is converted into bio-ethanol.

- Fischer Tropsch Synthesis (FTS) - a chemical conversion of carbon monoxide gas and hydrogen gas into liquid hydrocarbons.

2.2: Chemical conversion

The most established chemical conversion process is known as anaerobic digestion. This process involves breaking down organic matter using specific bacteria in the absence of air. The product of this process includes biogas (predominantly methane and carbon dioxide) and residue fibre in the form of sludge that can be used as biological fertiliser. The biogas can be used in a gas turbine system to generate electricity.

2.3: Conversion technologies

The previous section touches on conversion processes including combustion, gasification, pyrolysis and anaerobic digestion. In addition to these processes there are other less used conversion techniques. These include:

- Hydrolysis – chemical breakdown of a compound due its reaction with water
- Refining – the physical separation of a substance
- Crushing – the deformation of a substance
- Fermentation – metabolic process which converts sugars to acids, gasses or alcohol

Figure 2 presents the conversion path of biomass that the technologies in Table 4 carry out.

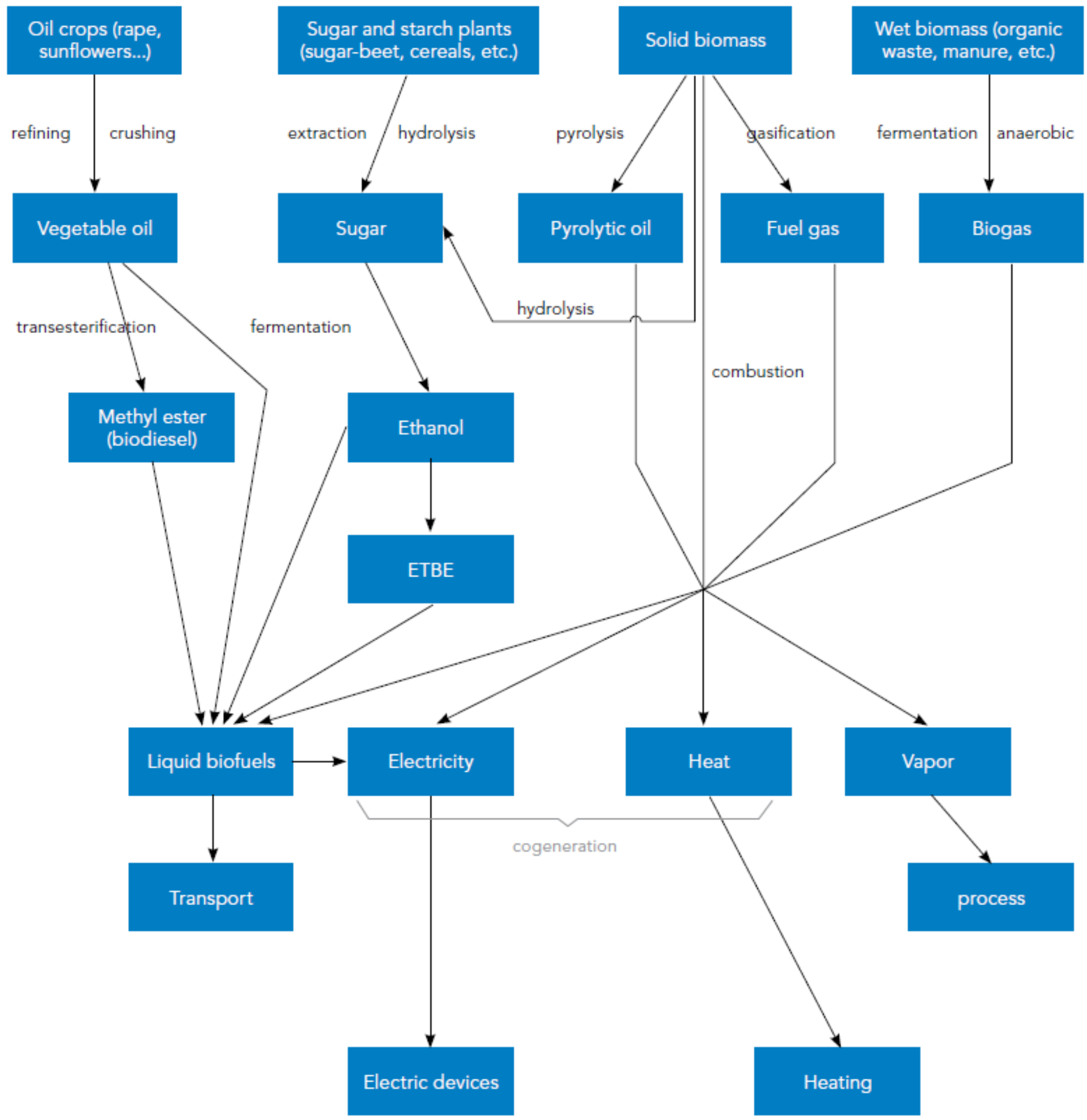

Figure 2: Biomass conversion flow (Kimble, et al., 2008).

In order for biomass to be a useful source of energy it needs to be converted into a form that can be utilised. As mentioned previously these forms are usually heat and electrical energy. The technologies and methods for conversion differ in sophistication and cost although producing heat is usually cheaper than producing electricity. This is due to the production of electricity usually requiring an additional conversion step.

Electricity is generated when the required use of the energy is unknown and wide spread, for example, supplying for residential or industrial use. In addition, the biomass will also only be converted into electricity if the kWh price is affordable for the consumer. For a generalised analysis of biomass power generation technologies and the applicable feedstock required, see

Table 4.

Table 4: Biomass power generation technologies and feedstock requirements (Van Niekerk, et al., 2016).

Biomass conversion technology	Commonly used fuel types	Particle size requirements	Moisture content requirements (wet basis)	Average capacity range
Stoker grate boilers	Sawdust, non-stringy bark, shavings, end cuts, chips, hog fuel, bagasse, rice husks and other agricultural residues	6 – 50 mm	10 – 50%	4 to 300 MW many in 20 to 50 MW range
Fluidised bed combustor (BFB or CFB)	Bagasse, low alkali content fuels, mostly wood residues with high moisture content, other. no flour or stringy materials	< 50 mm	< 60%	Up to 300 MW (many at 20 to 25 MW)
Co-firing: pulverised coal boiler	Sawdust, non-stringy bark, shavings, flour, sander dust	< 6 mm	< 25%	Up to 1 500 MW
Co-firing: stokers, fluidised bed	Sawdust, non-stringy bark, shavings, flour, hog fuel, bagasse	< 72 mm	10 – 50%	Up to 300 MW
Fixed bed (updraft) gasifier	Chipped wood or hog fuel, rice hulls, dried sewage sludge	6 – 100 mm	< 20%	5 to 90 MW, + up to 12 MW_e
Downdraught, moving bed gasifier	Wood chips, pellets, wood scrapes, nut shells	< 50 mm	< 15%	~ 25 – 100 kW
Circulating fluidised bed, dual vessel, gasifier	Most wood and chipped agricultural residues but no flour or stringy materials	6 – 50 mm	15 – 50%	~ 5 – 10 MW
Anaerobic digesters	Animal manures & bedding, food processing residues, MSW, other industry organic residues	n/a	65% to 99.9% liquid depending on type (i.e. from 0.1 to 35% solids)	

3: Biomass energy in South Africa

The potential for biomass energy in South Africa is investigated in this section. Biomass energy conversion is often a complex process and successful operation is dependent on many factors. These factors are investigated in a South African context in order to unpack its potential in the country.

The two most important factors are the feedstock availability and the ability to convert this feedstock into a usable form of energy. The most promising option for the current situation in South Africa is proposed by making use of an evaluation matrix for both conversion techniques and feedstock types.

3.1: Feedstock analysis

South Africa is one of the largest agriculturally active countries in the world. With large quantities of production comes large quantities of agricultural residue. When comparing agricultural crops in South Africa with the crops proposed for energy crop farming they turn out to be the same. For this reason and the fact that South Africa produces large quantities of agricultural residues (which will be more cost effective to generate energy from than from growing energy crops), only agricultural residues are evaluated. The crops that have the largest potential for agricultural residue in South Africa are investigated and evaluated in Table 5.

Note that the cells are coloured from green (good) to red (bad). There is a physical constraint on the maximum economic size of a biomass to energy plant due to the availability radius of the feedstock. As soon as the feedstock needs to be transported over a too long distance, the economies of scale of larger plants are over-shadowed by the higher transport cost of the feedstock (Van Niekerk, et al., 2016). For this reason, the spread across the country is also presented.

The criteria used to evaluate the various feedstock is:

- Annual production – Biomass energy can only be utilised if there is a sufficient amount of biomass feedstock. For this reason, it is important to have an abundant amount of biomass resource.
- Annual usable residue – This characteristic shares the same value as the previous one but also suggests the ratio of crops produced to residues generated.

- Spread - A measure of how widespread the resource is across the country. It is important to have a widespread resource as there is an upper limit on the size of a biomass plant and the decentralisation of electricity supply is an important factor in South Africa.
- Energy content – The energy content of the residue conveys the energy density of the resource.
- Ethanol yield – Similar to energy content this value conveys the spatial energy density of the crop in terms of litres of ethanol.
- Cost per litre ethanol – This aspect provides insight into the cost of processing the raw material.

Table 5 shows that the sugarcane crop scores the best with the specific evaluation criteria used. Maize comes a close second, as it is a commonly produced crop in South Africa with a high energy content, almost in line with the production of Sugarcane. The following section evaluates the various conversion technologies.

Table 5: Evaluation of various feedstocks

Crop	Annual production (Mt)	Annual usable residues (Mt)	Spread	Energy content (MJ/kg)	Ethanol yield (l/ha)	Cost per litre ethanol produced	Reference
Grains and cereals	1-3	0.6-2	Northern Cape Western Cape	18	1000-1500	R7.00	(GSA, 2016) (Caslin, 2016) (IEA, 2007)
Maize	9-13	3-4	Free State KwaZulu-Natal Mpumalanga North-West	17	3000-5000	R5.00	(GSA, 2016) (IEA, 2007) (Potgieter, 2011)
Sugarcane	18-20	6-7	Eastern Cape KwaZulu-Natal Limpopo Mpumalanga	17.5	5000-10000	R3.00	(SASA, 2012) (IEA, 2007) (Potgieter, 2011)
Grapes	1-2	0.2-0.4	Eastern Cape Western Cape	15	3000-3900	NA	(GSA, 2016) (IEA, 2007) (van Eyk & Ashman, 2010) (Burg, et al., 2016)

3.2: Conversion analysis

Potgieter (2011) carried out a study on the future of biomass in South Africa, evaluating various biomass conversions relevant to South Africa. The conversion techniques are rated on the following characteristics:

- The current (2011) status of development.
- Technically feasibility and robustness.
- Capital cost per unit energy compared to other conversion technologies.
- Conversion rate of raw feedstock to product.
- Energy efficiency of conversion process.
- Ability to be implemented on small scale.

Each technology was given a relative rating ranging from 0 (bad) to 2 (good). Table 6 shows that the four technologies with the highest potential according to the above criteria are combustion, pyrolysis, gasification and briquetting.

Table 6: High-level evaluation of technologies (Potgieter, 2011).

Technology / Characteristic	Combustion	Briquetting	Pyrolysis	Gasification	Bio-ethanol	FTS	Anaerobic digestion
Current (2011) status	2	2	1	1	1	1	2
Feasibility	2	2	2	2	1	1	2
Capital cost	2	2	1	1	0	0	1
Conversion rate	1	1	2	2	2	2	0
Energy efficiency	2	1	2	2	1	1	1
Small scale implementation	2	2	2	2	0	0	2
Total	**11**	**10**	**10**	**10**	**5**	**5**	**8**

4: Cost of biomass

As with most sources of energy, the one aspect that dictates implementation and survivability is cost. If the biomass conversion process does not prove to be cost effective, it will either not be implemented or it will simply not survive. A high-level cost analysis is carried out with a theoretical maize and sugarcane conversion scenario for South Africa.

Due to sugarcane and maize proving to be the most promising feedstock available in South Africa, the high-level cost analysis of crop residue conversion is carried out for these specifically. The analysis is carried out for crop residues instead of energy cropping due to the reduced price of the biomass resource. A best-case scenario is used where the resource is presented as 'sourced for free', by analysing the best case scenario the limits of the resource conversion are made clear.

Both maize and sugarcane biomass is utilised through the conversion into bio-ethanol, and the conversion into electricity through direct combustion-electricity generation (Sugarcane.org, 2016). The combustion process scored the best in the evaluation stage and for this reason it is used to evaluate the cost of biomass conversion in South Africa. Potgieter (2011) investigated the capital cost and operating cost for a combustion plant. Figure 3 shows the capital cost for various sizes of plants and Figure 4 shows the operating costs for various sized plants.

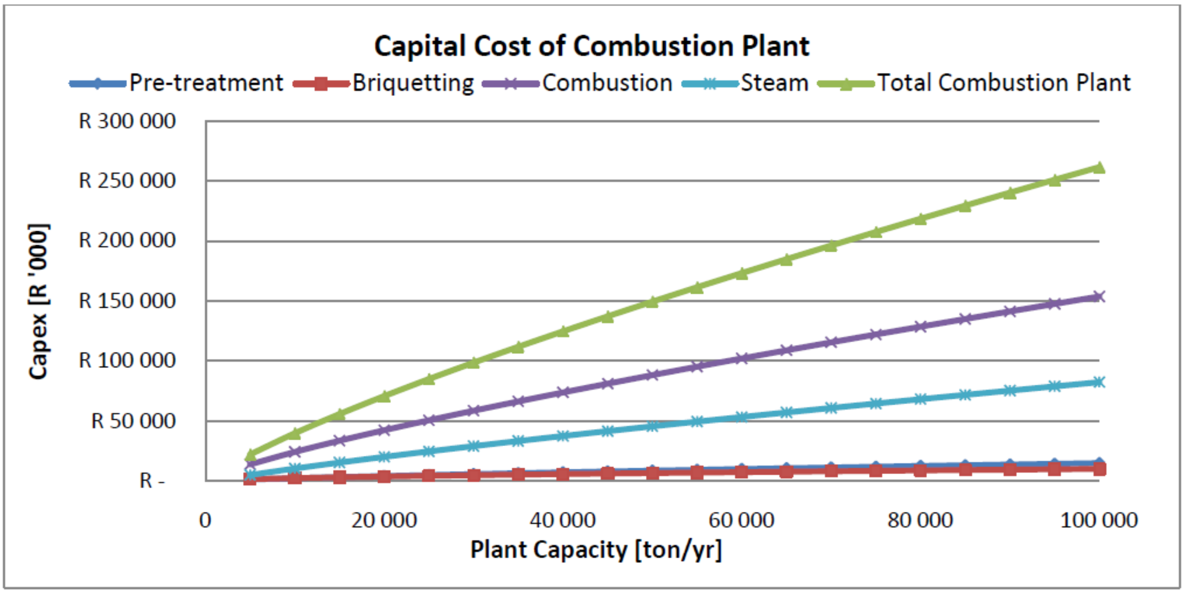

Figure 3: Capital cost of a combustion plant (Potgieter, 2011).

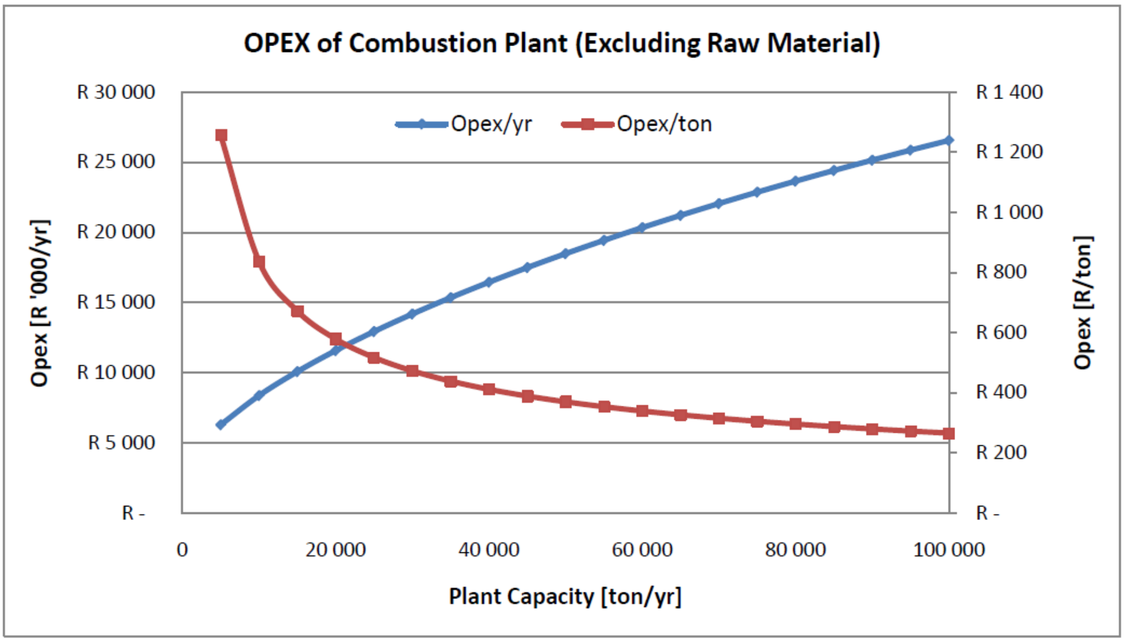

Figure 4: Operating cost of a combustion plant

The amount of annually available residue for sugarcane and maize can be found in Table 5. These amounts together with the capital expenditure (CAPEX) and operating expenditure (OPEX) are used to develop the cost model found in Table 7. Note the number of plants specified for each feedstock: this number is used due to the spread of the resources. As already mentioned, the high-level model is presented in a best cases scenario and therefore the agricultural residues are assumed to be sourced free of charge. This will not be the case in reality as there are always costs involved with collection and transport.

It is assumed that a specific plant is designed to process a specific type of feedstock and therefore the feedstocks are separated in Table 7. The efficiency of the combustion plant is dependent on the size of the plant. The efficiencies used in this case are present by Potgieter (2011).

The cost analysis in Table 7 proposes using 8 sugarcane and 6 maize plants to convert the available agricultural residue into electricity. The analysis shows that in order to recover the expenses of a single plant within 15 years, the electricity would have to be sold at R3.33 for the sugarcane plants and R1.94 for the maize plants. These prices for electricity are not competitive with other forms of renewable energy such as wind and solar and the 15-year period is also comparatively long. The analysis shows very high operating costs even though the resource is assumed to be free of charge.

Although the cost analysis does not fully support the implementation of the proposed plant scenario it does display the ability of biomass contributing to the grid on a utility scale. The plants don't have very high efficiencies (35%) but the capacity factors are high, thus supporting the reliability of the technology (Tidball, et al., 2010). A positive for biomass conversion shown by the high-level analysis is the potential for the technology to contribute 18.4 TWh of electricity to the grid annually, amounting to 7.6 % of South Africa's annual electrical generation.

Table 7: High-level cost analysis

	Sugarcane	Maize
Annual residue (t/y)	7 000 000	4 000 000
Number of plants	8	6
Plant size (MW)	3.5	2.5
Capacity factor	0.8	0.8
Residue per plant (t/y)	875 000	650 000
Energy density (MJ/ton)	17 500	17 000
Efficiency of a plant	35%	34%
Annual electrical energy generated per plant (GWh)	1 496	1 065
Total electrical energy generated (TWh)	12	6.4
CAPEX (R Billion) per plant	R2.32	R1.77
Annual OPEX (R Billion) per plant	R4.99	R1.95
Years to recover expenses	15	15
Price of electricity (R/kWh)	R3.33	R1.94

Conclusions and Recommendations

Increased generation of energy from biomass has the potential to offset substantial use of fossil fuels. However, as with all industries, it needs to be sustainable, both environmentally and economically. This policy document identifies agricultural residues as the source of biomass with the most potential for South Africa, specifically sugarcane due to its abundance and high energy content.

The method of conversion that proved to make the most sense is combustion. The cost analysis shows the potential for maize and sugarcane residues to contribute 7.6% of the current South African electricity production. The downside of the cost analysis showed that even in a best-case scenario the method of combustion combined with the feedstocks of maize and sugarcane is not feasible currently. This is mostly due to the high operating costs involved with the conversion plants.

South Africa is consuming more food than it grows. This means there is currently a need to grow more food on our own soil. With increased agricultural production comes more agricultural residue. Once more research and optimisation studies have been carried out on the collection and conversion of these residues, biomass conversion could become a major role player in the South African energy mix. However, economic viability is required before any large-scale implementation takes place.

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