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*Review*

# The potential for second generation bio-ethanol production from agro-industrial waste in South Africa

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**There has been a sustained and growing interest in the production of liquid fuel from biomass in recent years. South Africa is a large producer of sugar, maize and wheat among other agricultural products that release big quantities of biomass byproducts during postharvest processing operations. This work looks at the energy situation in South Africa and especially the liquid fuel sector and explores the possibility of producing bioethanol from biomass. A brief discussion of the different types of feedstock for bioethanol production is given. A review of possible bio-sources that can be used for bioethanol production with emphasis on those that have potential of replacing conventional fuels with little or minor modification of existing biomass production capacity and trend is presented. Data analysis indicates that the straw from maize, sorghum and wheat can produce up to 601.8 million litres of bioethanol per annum and that it is possible to produce up to 549.4 million litres of bioethanol from sugarcane. The physical ability of mass production from various crop byproducts that are produced in South Africa, as well as the immediately economic effect is also discussed.**

**Key words: Bioenergy, bioethanol, cellulose, potential, South Africa, agricultural residue.**

## INTRODUCTION

The major source of energy in the world today is oil, gas and coal. These fossil fuels contribute 80 to 90% of earths energy needs and although this value may vary from country to country based on the level of development in each country, it is clear that the world is heavily dependent on these dwindling fossil fuels. Since the world must continue to expand its development activities, which in turn cause an increased demand on energy, we must eventually turn to sustainable energy (Nigan and Singh, 2011). According to the United Nation definition, sustainable development is “that which meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987). It is for this reason that we ought to put more emphasis on sustainable ways of producing green energy (Mwithiga et al, 2012).

Renewable energy use in the world today contributes only 13.6% of total energy demand and most of this is hydropower. Biomass continues to be used by more than 1.5 billion people who are usually poor urban dwellers or remote rural communities. These poor people use raw biomass to satisfy their heating and cooking energy requirements. It has also been observed that this type of solid fuel is the least desirable and is used only by communities that cannot afford other types of fuel (Démurgera and Fourniera, 2011). Liquid biofuels still account for less than 0.2% of the energy consumed in the world today, although there has been a steady increase in their production in recent years. Also, the average cost of production (per litre of final product) as well as the retail price of biofuels and especially the price of ethanol has continued to decrease with time over the years (Goldenberg, 2007). Annual world-wide ethanol and bio-diesel production stood at 76 and 17 billion litres, respectively in the year 2009 (REN21, 2010).

Meanwhile, there is no doubt that the South African government is committed to increasing the amount renewable energy, especially if one observes the steps it has taken since the “White Paper on the Production of Energy by Renewables” was introduced (DME, 2003). However, despite the interest shown by the government and industrial corporate players, no bioethanol production

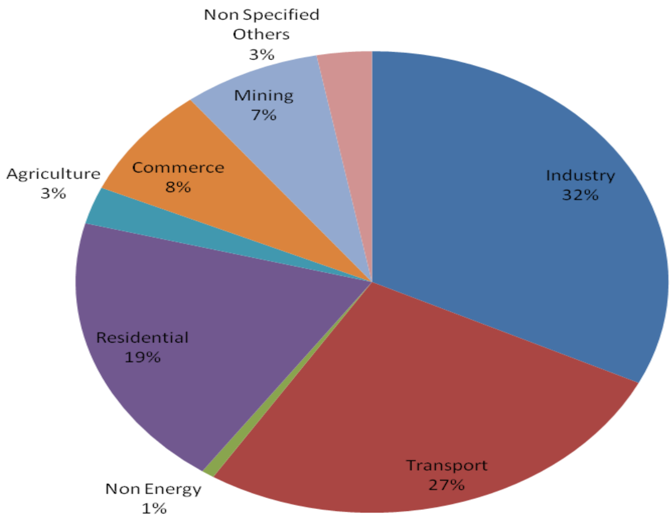


**Figure 1.** Final energy consumption in South Africa in 2006 Source: Based on Department of energy (2010).

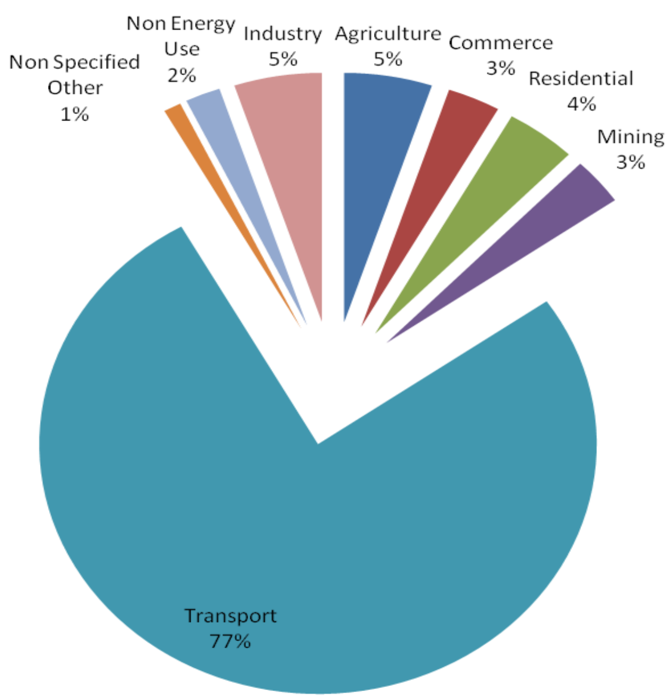


**Figure 2.** Sectoral consumption of petroleum products in 2006, Source: Digest of South African Energy Statistics, 2010.

destined for the energy sector is currently taking place. On the other hand, there are reports of small scale production of biodiesel by individual farmers and that this biodiesel is subsequently being used to drive equipment at farm level. There are also South African companies that have developed complete biodiesel production plants (Chetty, 2007). It is therefore necessary that we continue to review and implore alternative ways that can be used to establish a sustainable liquid bio-fuels industry in South Africa.

There are two main bio-based potential fuels of the future and both have attracted significant global interests in the last few years. These are bioethanol and biodiesel. In most cases, large commercial farms have been commissioned for the production of the biomass feedstock that is required in the manufacture of biofuels. Some researchers have put very strong cases for the continued development of liquid fuels for the total replacement of fossil fuels or for at least a reduction of our dependence on petroleum based fossil fuels (Demirbas, 2007; Raymonds et al., 2004). Others researchers have also argued strongly that the use of certain feedstock in the production of liquid fuels is potentially dangerous because it uses land that would have otherwise been used to produce food for human consumption. In some cases, virgin land that has not previously been cultivated was earmarked for biofuel feedstock production and yet the use of such land is likely to upset the environment and hence the ecological balance. A worst case scenario would be when certain food products are converted into biofuels while there are still many hungry people in this world (Reijnders and Huijbregts, 2007; Yang et al., 2009).

## The energy situation in South Africa

Coal is the main source of energy as it accounts for up to 75% of all primary energy consumed in South Africa. This primary energy is used in various sectors as presented in Figure 1. It can be observed that the industry and transport sectors make up a big proportional of the total energy. Transport in particular, is one of the areas that consume a lot of the liquid fuel as can be deduced from Figure 2. Since almost all the liquid fuel is imported into South Africa, the development of a sustainable local production industry that produces some if not all liquid fuels is desirable (Banks and Schaffler, 2006). The South African government has continued to encourage the use of renewable energy as evidenced through its policies and subsidies to the sector (Banks and Schaffler, 2006; Inmam-Bamber et al., 2002). Also, it can be noted here that the drive by the government towards sustainable energy is due to the need to create additional jobs and reduce unemployment rather than a need for energy security as is currently the reason among many developed countries.

This work seeks to show that South Africa can produce substantial amounts of bioethanol without having to deviate from its normal agricultural production activity. This report concentrates on already available biomass material. The figures used to compute certain production capacities have avoided the use of any food materials and have used only residues materials from grain crop production. The byproducts of the agric-food industry are used in a way that allows the primary product normally produced by the industry in each case not to be affected by the production of bioethanol. It can also been argued

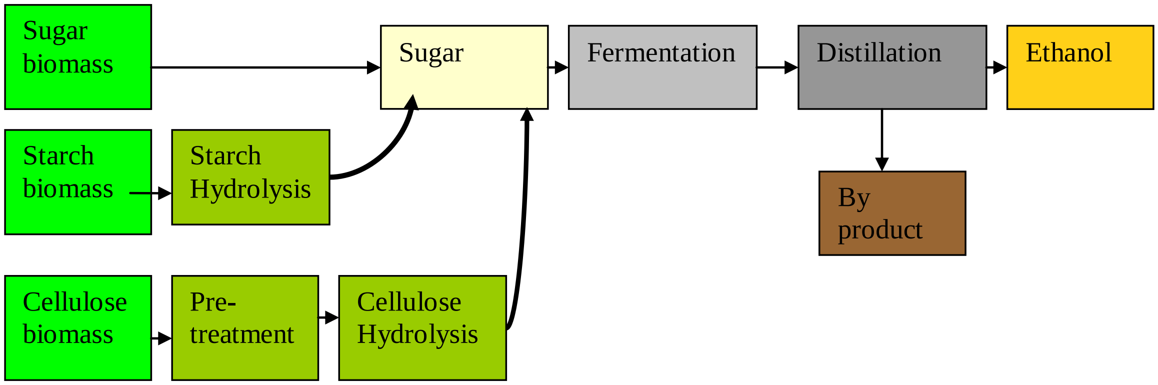


**Figure 3.** The ethanol production routes for different types of feedstock.

that the use of these byproducts and residues causes an increase in the monetary income per unit area of land. Also, such an increase in income might lead to an increase in the acreage under the particular crop, thus resulting in higher food production.

## BIOETHANOL PRODUCTION PATHWAYS

Bioethanol can be produced from three main types of biomass feedstock as shown in Figure 3 (Rojan et al., 2011; Balat and Balat, 2009; Larsen et al., 2008; Demirbas, 2007). Biomass resources that are sugar-based in nature are the easiest to process. The sugar juice is extracted and taken straight to the fermentation process. However, minor processes such as washing and slicing of feedstock before extraction and the adjustment of juice concentration after extraction are steps that are necessary and that are also highly dependent on the properties of the feedstock (Santek et al., 2010; Guigou et al., 2011).

Lin and Tanaka (2005) discussed the different types of microorganisms, bacteria, yeasts and fungi that are capable of producing alcohol in the fermentation process. While some of them convert sugar into alcohol even at high concentrations of alcohol, others have the advantage of being able to convert a wider variety of sugars into alcohol. Another import aspect that has been considered is the ability of a microbe to produce ethanol rapidly since this ability can enhance the throughput (Reddy and Reddy, 2006). These factors, together with other factors such as temperature of fermentation, kinetic and process design, and size and number of fermentation tanks are important in the industrial production of bioethanol. The industrial production of bioethanol uses the *Saccharomyces cerevisiae* yeast extensively (Balat, 2011; Bai et al., 2008). The yeast and glucose are inputs of the fermentation process while ethanol and carbon dioxide are products. Only a small amount of yeast is require in order to kick start the multiplication of yeast cells. However, ethanol production and yeast growth are tightly tied together and each is a co-product in the production process (Bai et al., 2008; Galanakis et al. 2012). Also, too high sugar content might prevent the reaction on the one hand, while on the other hand, too high an alcohol concentration will inhibit yeast cell production.

Biomass that is derived from starchy feedstock has to undergo a process that converts the starch into sugar in a process called hydrolysis, before the fermentation process can occur (Chuck-Hernadez et al., 2009; Dodić, 2009; Smith et al., 2006). Due to this additional process, bioethanol production from starchy materials is generally more complicated when compared to the process of producing bioethanol from sugars based feedstock. Production of bioethanol from sugar and starch based feedstock is economically viable and commercial industries already exist in some countries. Cellulose feedstock such as woody material and fibre are the most difficult to process. In most cases, these materials have to be ground using heavy duty machinery in order to reduce the size of particles. The ground material is in one common practice heated to high temperatures in order to break down the large carbohydrate molecules into smaller molecules. Other methods that may be used to breakdown the material to simpler molecules include the use of a chemical or a combination of several chemicals. Some approaches also employ a combination of mechanical and thermal methods such as the use of high pressured superheated steam (Lamsala et al., 2010; Banerjee et al., 2010). All this is necessary in order to produce molecules that will yield fermentable sugar during the cellulose hydrolysis step.

Another approach that is attracting researchers is simultaneous saccharification and fermentation (SSF), where the sugar and alcohol are being produce at the same time. In industries, the sugar is produced and immediately made available for the fermentation process. If the alcohol is also continuously removed from the site of production, the concentration of both sugar and ethanol can remain constant. Since it is also desirable to keep the concentration of sugar and alcohol low in order to maximize alcohol production, the SSF method is likely to attract even more researchers. The process of cellulose extraction and subsequent conversion into bioethanol consumes more energy and is therefore more expensive when compared to the process of converting either sugar or starch based feedstock. Only a few research entities have reported being close to attaining a production cost that will allow bioethanol from cellulosic crops to compete with fossil fuels (Banerjee et al., 2010; Larsen, 2008). However, the potential when a breakthrough occurs will simply be enormous.

## Cellulose biomass ethanol

There are large quantities of biomass materials that are produced in normal commercial farming in South Africa. This cellulose biomass that is readily available in South Africa may be derived from straw produced by the three main grain crops (corn, wheat and sorghum) or from the byproduct of sugarcane processing. In order to estimate the quantity of bioethanol that can be produced from agricultural residue and waste, data on agricultural production was accessed from several sources (NDA, 2009; World Statistics, 2010; Dredge, 2009; South African Sugar Association, 2010). This data was then used to calculate biomass yield for different product depending on composition and also depending on known grain to biomass ratios. The total biomass was then adjusted by allowing some of the straw to be left in the field because of conservation and environmental issues. In the case of sugarcane, the figure was adjusted in order to cater for use of the byproduct in other ways other than the production of bioethanol. The adjusted value was then multiplied by a constant representing the amount of bioethanol (under industrial settings) that a unit mass of the biomass would be expected to yield.

## Stover and straw

For known values of grain production, the amount of dry matter (stover or straw) that is simultaneously produced can be estimated using the straw-to-grain ratio. This is the ratio of the mass of dry matter to the mass of dry grain for the particular crop. Nelson (2002), Nelson et al. (2004), Sokhansanj et al. (2002) and Faraco and Hadar (2011) used the ratio 1:1 to estimate the biomass produced in corn farming activity. However, Eniko (2003) reported a dry matter to grain ratio of 1.3:1 for corn. The straw to grain ratio for wheat appears to be dependent on the season of production. Nelson et al. (2004) reported a straw to grain ratio of 1.3:1 and 1.7:1 for winter and spring wheat, respectively. Faraco and Hadar (2011) have also reported a straw to grain ratio of 1.3:1 for wheat without specifying the season of growth while also reporting a dry matter to grain ratio of 1.5:1 for sorghum. For the current study, a conservative dry matter to grain ratio of 1:1, 1.3:1 and 1:1 for corn, wheat and sorghum, respectively, has been used to estimate the total mass of dry matter that can be produced from commercial farming activities.

The dry matter biomass produced during normal farming activity is not entirely available for removal from the field. There are indeed many researchers who have observed and recorded the adverse effects of dry matter removal (Lemke et al., 2010; Lal, 2009; Lal et al., 2005). Sokhansanj et al. (2002) found out that the amount of corn stover dry matter that can be collected from the field over the whole harvesting period varies with time and that the averages is about 45% of the amount that is actually on the ground. Lemke et al. (2010) simulated the effect of removing 50 and 95% of the above ground wheat residues. The results suggested that removing 50% of the straw would likely have a detectable effect on the soil carbon, while removing 95% of the straw would certainly affect the soil carbon. Faraco and Hadar (2011) and Lal (2005) do not recommend the removal of more than 15% of the dry matter mass due to adverse soil effects that higher removal rates might have. The mass fraction used for computation of residue available for ethanol production in this work is therefore 15% of the dry matter mass.

Studies have shown that dry biomass yields higher amounts of ethanol during hydrolysis when compared to wet biomass. Also, although there are some differences in the cellulose content of different residue materials, nearly all material will require a pre-treatment in which the product is cut and shredded. After hydrolysis and fermentation of the pre-treated biomass, the yield of ethanol from corn according to Sokhansanj (2002) should be 280 $Lt^{-1}$ (litres per ton) of corn dry matter residue. Segundo and Dale (2003) and Eniko (2003) also reported values of 290 $Lt^{-1}$ for corn stover, while Faraco and Hadar (2011) used an average estimate value of 300 $Lt^{-1}$ for all types of cellulosic biomass. A bioethanol yield of 280 $Lt^{-1}$ of dry residue for corn, sorghum and wheat was assumed in the present computation.

The production of maize and sorghum over the period of 2000/01 to 2007/08 and wheat production over the period 2000/01 to 2008/09 was extracted from the abstracts of agricultural statistics (NDA, 2009) and is presented in Table 1. The average grain yield over this period was 3.07, 2.53 and 3.11 tons of grain per hectare for corn, wheat and sorghum, respectively. From these values of average grain yield and from projected planted areas in 2009, the expected bioethanol yield can be computed using Equation 1. The projected planted area (A) was obtained from the national production statistics of the Republic of South Africa for the year 2009 (World Statistics, 2010; Dredge, 2009) and is presented in column two of Table 2. The coefficient $C_1$ of Equation 1 is equal to 1.1 for corn and sorghum, and is 1.3 for wheat. The coefficients $C_2$ and $C_3$ were fixed at 0.15 and 0.28, respectively, for all three grains. The computed amounts of bioethanol that can be produced from the three main South African grains are presented in column three of Table 2.

**Table 1.** Annual production of maize, wheat and sorghum in the republic of South Africa.

| Year | Area (1000 ha) | Total yield (1000 tons) | Yield per ha |
|---|---|---|---|
| **Maize** | | | |
| 2000/01 | 3189 | 7772 | 2.44 |
| 2001/02 | 3533 | 10076 | 2.85 |
| 2002/03 | 3651 | 9705 | 2.66 |
| 2003/04 | 3204 | 9737 | 3.04 |
| 2004/05 | 3223 | 11749 | 3.65 |
| 2005/06 | 2032 | 6947 | 3.42 |
| 2006/07 | 2897 | 7339 | 2.53 |
| 2007/08 | 3297 | 13164 | 3.99 |
| Average | | | 3.07 |
| | | | |
| **Wheat** | | | |
| 2000/01 | 934 | 2428 | 2.60 |
| 2001/02 | 974 | 2504 | 2.57 |
| 2002/03 | 941 | 2438 | 2.59 |
| 2003/04 | 748 | 1547 | 2.07 |
| 2004/05 | 830 | 1687 | 2.03 |
| 2005/06 | 805 | 1913 | 2.38 |
| 2006/07 | 765 | 2114 | 2.76 |
| 2007/08 | 632 | 1913 | 3.03 |
| 2008/09 | 748 | 2031 | 2.72 |
| Average | | | 2.53 |
| | | | |
| **Sorghum** | | | |
| 2000/01 | 88 | 206 | 2.34 |
| 2001/02 | 75 | 258 | 3.44 |
| 2002/03 | 95 | 260 | 2.74 |
| 2003/04 | 130 | 449 | 3.45 |
| 2004/05 | 86 | 313 | 3.64 |
| 2005/06 | 37 | 110 | 2.97 |
| 2006/07 | 69 | 202 | 2.93 |
| 2007/08 | 87 | 293 | 3.37 |
| Average | | | 3.11 |

**Table 2.** Potential production of bioethanol from straw and stover in South Africa using already established crops.

| Product | Area (ha) | Yield grain (mt/ha) | Total alcohol yield (L) | Yield (L/ha) |
|---|---|---|---|---|
| Corn | 3,300,000 | 3.07 | 468,052,200 | 141.8 |
| Wheat | 750,000 | 2.53 | 103,603,500 | 138.1 |
| sorghum | 120,000 | 3.11 | 30,173,220 | 143.7 |
| Total | | | 601,828,920 | |

$$Q_S = AYC_1C_2C_3 \quad (1)$$

Where, $Q_s$ is the bioethanol yield in L; A is the total planted area in ha, Y is the 1000*Grain yield in tons per hectare in $kgha^{-1}$, $C_1$ is the ratio of straw dry matter mass to grain dry matter mass, $C_2$ is the mass fraction of the straw actually retrieved from the field, and $C_3$ is the yield of ethanol in litres per kg of dry matter.

The combined yield of the three crops is 601.8 million litres of bioethanol per annum. Also, it can be observed that corn alone contributes 84.1% of the estimated yield from these three crops. The last column in Table 2 shows the amount of alcohol that can be expected from each hectare of land and both corn and sorghum residue are able to produce 141.8 and 143 L $ha^{-1}$, respectively, each season, while wheat produces 138.1 L $ha^{-1}$.

## Sugarcane

The national (South Africa) amount of sugarcane crushed in 2009 was 18.178 million metric tons (18.178 Tera grams [Tg]), yielding 2.141 Tg of sugar. The yield is equivalent to 11.8% of the mass of fresh sugarcane (South African Sugar Association, 2010). A total of 291,770 thousand hectares were harvested in the June 2009 to June 2010 season and the total area under sugarcane in South Africa in the 2010 to 2011 season was 391, 566 thousand hectares. The aforementioned percentage in sugar yield is reasonable considering that the dry matter content of sugarcane averages 30% and that many studies indicate that sugar content in dry matter basis is close to 0.5 in many regions of the world (Beeharry, 1996; Preston, 1986).

## Molasses

Molasses is the byproduct obtained when sugar is produced from sugarcane syrup by repeated crystallization and sugar crystal separation from the syrup. This end product of the refining process is composed of sucrose and invert sugars that make up a major portion (40 to 60%) as well as other crop nutrients including vitamins. There are large variations in the yield of molasses per unit mass of processed cane and this might depend on the variety of sugarcane or on the way each of the production processes at the factory are carried out. The yield of molasses per unit mass of sugarcane ranges from 3.5 to 4.5% (Olguín et al., 1995; Pandey et al., 2000). Bradley and Runnion (1984) and Bai et al. (2008) observed that the conversion of glucose to ethanol has a maximum theoretical efficiency of 51%, although conversion is normally much lower under industrial production conditions. For molasses (which is not a pure sugar), the fermentation process can be estimated to yield 0.45 l of ethanol per kg of molasses. This analysis also recognizes that some of the molasses produced may be required in other industrial activities and therefore apportions only 60% of the available molasses to bioethanol production. If we also assume an average yield equivalent to 4% of molasses per unit mass of crushed sugarcane, then the potential yield of bioethanol from molasses can be expressed in form of Equation 2:

$$Q_m = BY_1Y_2C_4 \quad (2)$$

Where, $Q_m$ is the total bioethanol yield in litres; B is the total crushed cane in kg; $Y_1$ is the yield of molasses per unit mass of crushed cane, with ratio 0.04; $Y_2$ is the fraction of molasses biomass to be used in bioethanol production, ratio, 0.6; $C_4$ is the yield of ethanol in litres per kg of molasses, 0.45 l.

## Bagasse

Bagasse is a fibrous residue of cane stalk that is obtained after crushing and extraction of sugar juice. The composition of bagasse varies and the variation is based on the variety and maturity of sugarcane, method of harvesting and the efficiency of the juice extraction process. The usual bagasse composition has a moisture content of 46 to 52%, fiber content of 43 to 52% and 2 to 6% solids (Beeharry, 1996; Cardona et al., 2010). It is normal to use bagasse as a combustible material in furnaces that produce steam. The steam is in turn used to generate electric power for the factory or for sale to the electric grid. The utilization of bagasse as fuel depends upon its calorific value, which is in turn affected bythe composition and in particularly the moisture content. Bagasse can also be used as the raw material for production of paper and as feed for cattle.

It is also possible to make liquid fuel from bagasse. The cellulosic material in bagasse can be modified using certain procedures of biomass-pretreatment that often use heat and acid in order to break down the longer carbon molecules. The resulting product is easier to convert during the hydrolysis and fermentation process and up to 0.27 - 0.37 litres of ethanol can be produced from each kilogram of Bagasse (Pandey et al., 2000). Cuzens and Miller (1997) also estimated a production rate at 370 L $t^{-1}$ at industrial scale and showed that 50% of all bagasse is used for steam generation. If we allow that 21% of harvested cane biomass is bagasse, that 50% of this Bagasse is to be used for bioethanol production and that the average moisture content of bagasse is 50% (wb), then total potential for the production of bioethanol from bagasse in the republic of South Africa can be presented as shown in Equation 3:

$$Q_b = BY_1Y_2C_5C_6 \quad (3)$$

Where, B is the total crushed cane in kg; $Y_1$ is the yield of bagasse per kg of crushed cane, 0.21; $Y_2$ is the fraction of available bagasse converted to bioethanol, 0.5; $C_5$ is the dry matter content of bagasse, ratio, 0.5; $C_6$ is the yield of ethanol in litres per kg of bagasse dry matter, 0.37.

The amounts of bioethanol from molasses and bagasse that can be produced are presented in Table 3. It is quite clear that bagasse has a much higher potential when compared to molasses. Also, the sugarcane grown in South Africa has the potential of producing up to 549 million litres of ethanol, which is close to the amount of ethanol that can be produced from the three main grain crops grown in South Africa. Considering that this computation procedure has also not included cane tops and leaves which make up 20% of cane biomass (Beeharry, 1996) and which can also be used in the production of ethanol, the potential ethanol yield from sugarcane can be even much higher. Table 3 also shows

**Table 3.** Potential bioethanol yield from byproducts of the sugarcane industry in South Africa.

| Product | B (tons) | Y1 (kg ton$^{-1}$) | C2 (kg kg$^{-1}$) | Total yield (L) | Yield (L ha$^{-1}$) |
|---|---|---|---|---|---|
| molasses | 18,178,000 | 40 | 0.45 | 196,322,400 | 672 |
| Bagasse | 18,178,000 | 210 | 0.37 | 353,107,650 | 1,209 |
| Total | | | | 549,430,050 | 1,881 |

that the estimated ethanol yield per hectare of sugarcane crop is over 1,881 litres and this is quite high when compare to that of about 140 litres for grains. The total amount of bioethanol that can be produced per annum from the field residue and processing waste of both the grain crops and sugarcane crop is 1.15 billion litres.

The annual petrol consumption in the year 2013 is estimated to be 12 billion litres per year when the available data for the consumption period of 1989 to 2000 is extrapolated to the year 2013 using the Winkler method (Winkler, 2006). Official statistical data on petrol consumption for the period 2003 to 2006 that are provided by the South African National Energy Association (SANEA, 2003), and other data provided by the Department of energy (DOE, 2010) tend to support Winkler's predictions since the annual petrol consumption is of approximately the same magnitude as that projected by Winkler. The energy content of petrol is 30 MJL$^{-1}$ while that of ethanol is 21 MJL$^{-1}$ (Power et al., 2008). This means that the1.15 billion litres of ethanol can only replace 0.805 billion litres of petrol and this represents 6.7% of the national (South Africa) liquid fuels requirements.

## DISCUSSION

The biggest problem today in relation to the production of fuels from cellulose materials is the cost of conversion when this is compared to the cost of producing regular fossil fuels (Cardona et al., 2010). This is mainly because the pretreatment stage of the feedstock requires large amounts of heat energy and expensive chemicals. However, interest in these production processes is at its peak and it is hoped that ways of bringing down the cost will be found and that this will allow this sector to attract more investments.There is already enough evidence that production is about to shift from laboratory to industrial production (Banerjee et al., 2010; Larsen et al., 2008; Nigam and Singh, 2011; Margeot et al., 2009).

The production of ethanol from corn stover, wheat straw and sorghum stover is unlikely to have a major impact on the production of the components of these commodities that are for human consumption. In fact, the production of the biofuels from these grain crops is more likely to cause an increase in food production when farmers realize higher income from their harvest because of the added income from the straw. Studies, however, must be done to clearly establish how much straw must be left at the farm. The straw left on the farm need to be recycled into the soil in order to ensure that constant straw removal does not eventually cause soil degradation and other negative environmental effects. Therefore, a study on the cost of transportationof the biomass from the farm to the factory, as well as a study on how the resulting waste at factory level can be handled is necessary. On the other hand, the use of byproducts of sugar factories presents fewer problems because these byproducts are already at the factories. All that needs to be done is to expand the factory in order to include these processing streams. In fact, where bagasse once used to be a waste product which cost money to dispose (Phillips, 2012) it can be turned around to create more income. The governments are also encouraged to continue giving more incentives to potential investors in this sector (Department of minerals and energy, 2010).

## Conclusion

The worldwide use of large quantities of bioethanol will lead to a cleaner environment and to more secure and stable economies because governments will have better control of their energy needs. In South Africa, the government is facing a problem of increased unemployment in a time when many economies in the world are undergoing recession. However, the combined potential of producing food products as well as bioethanol without any disruptions to normal farming operations has the capacity to create additional jobs. The production of up to 1.15 billion litres of bioethanol from agricultural residue and agro-industry has itself the capacity to create additional jobs and wealth.

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