Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Cellulosic ethanol production from agricultural residues in Nigeria

Edward Iye, Paul Bilsborrow*

School of Agriculture Food and Rural Development, Newcastle University, Newcastle upon Tyne, NE1 7RU, United Kingdom

HIGHLIGHTS

- Nigeria's Biofuels Policy mandates a 10% blend of bioethanol with gasoline.
- Total bioethanol production from agricultural residues was 7556 km^3 per annum.
- Process residues offer the greatest potential accounting for 62% of production.
- Nigeria has the potential for 12 large- and 11 medium scale commercial.
- The use of mixed feedstocks significantly increases the potential for production.

ARTICLE INFO

Article history:
Received 4 March 2013
Accepted 12 August 2013

Keywords:
Cellulosic ethanol
Agricultural residues
Nigeria

ABSTRACT

Nigeria's Biofuels Policy introduced in 2007 mandates a 10% blend (E10) of bioethanol with gasoline. This study investigates the potential for the development of a cellulosic ethanol industry based on the availability of agricultural residues and models the number of commercial processing facilities that could be sited in the six Geo-political zones. The potential for cellulosic ethanol production from agricultural residues in Nigeria is 7556 km^3 per annum exceeding the mandate of 10% renewable fuel required and providing the potential for 12 large- and 11 medium-scale processing facilities based on the use of a single feedstock. Cassava and yam peelings provided in excess of 80% of the process residues available with enough feedstock to supply 10 large-scale facilities with a fairly even distribution across the zones. Sorghum straw, millet straw and maize stalks represented 75% of the potential resource available from field residues with the potential to supply 2 large- and 7 medium-scale processing facilities, all of which would be located in the north of the country. When a multi-feedstock approach is used, this provides the potential for either 29 large- or 58 medium-scale facilities based on outputs of 250 and 125 km^3 per annum respectively.

1. Introduction

The Nigerian economy is heavily dependent on oil with the country in 2011 being the 14th largest oil producer globally and accounting for about 3% of total world production (EIA, 2012). Nearly all of this crude oil is exported and refined overseas because the countries four refineries (Port Harcourt I and II, Warri, and Kaduna) are all currently operating at a low percentage of refining capacity as a result of poor maintenance, theft, and fire (EIA, 2012). As a result, the country is currently importing most of its refined petroleum products which together with subsidized consumption is costing the Nigerian government $3–4 billion per year (IEA, 2010).

In the 1950s, agriculture was the main stay of the Nigerian economy and contributed to over 94% of government revenue and 60–70% of total exports (Daramola et al., 2008). Since the discovery of Nigerian oil in the 1970s, agriculture's significance has declined, and oil now totals 95% of exports and 40% of government revenues (EIA, 2012); while agriculture only accounts for 0.2% of exports (Daramola et al., 2008). Declining agricultural production arising from a new total dependence on crude oil export as a means of growing the economy together with an inefficient food marketing system has over the years resulted in Nigeria being dependent on food imports to feed the rapidly growing population.

Despite the large fossil fuel production capacity, Nigeria joined other nations in their quest for biofuel production by promoting and implementing a biofuel development and adoption program (Biofuels Policy and Incentives) in 2007 (NNPC, 2007). The policy

Abbreviations: CBP, Consolidated bio-processing; GHG, Greenhouse gas; km^3, kilo m^3 ($m^3 \times 10^3$); Mg, Megagram ($g \times 10^6$); Mm^3, ($m^3 \times 10^6$); MSW, Municipal solid waste; NNPC, Nigerian National Petroleum Council; PMS, Petroleum Motor Spirit i.e. gasoline/petrol; RFS, Renewable Fuel Standard; RED, Renewable Energy Directive; RPR, Residue to production ratio; SSF, Simultaneous saccharification and fermentation; VAT, Value added tax

* Corresponding author. Tel.: +44 191 222 6868; fax: +44 191 222 7811.
E-mail address: paul.bilsborrow@ncl.ac.uk (P. Bilsborrow).

0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.08.048

gives the NNPC (Nigerian National Petroleum Council) a mandate to reduce dependence on imported gasoline, reduce environmental pollution while, at the same time creating a commercially viable industry that can precipitate sustainable domestic jobs especially in the rural sector. The move towards biofuel production provides a considerable opportunity for farmers as 70% of the 150 million inhabitants of Nigeria are employed in the agricultural sector (Sunmonu, 2011). In addition, there is an opportunity of integrating the agricultural and downstream petroleum sectors of the economy.

2. Global biofuel production and policies

Global biofuel production grew from 16 Mm^3 in 2000 to more than 100 Mm^3 (volumetric) in 2010 and today, biofuels provide around 3% of total road transport fuel globally (on an energy basis) with considerably higher shares achieved in certain countries (IEA, 2011). Major changes in biofuel production have occurred in many countries as a result of government policies introduced to incentivise biofuel production and/or consumption. The Brazilian government launched their successful bioethanol programme, the National Fuel Alcohol Programme, or, Proálcool in 1975 (Berg, 2004) in response to the oil crisis of the 1970s. The policy mandated that all gasoline sold in Brazil should contain 22–25% ethanol and by 2008 the number of ethanol plants in Brazil had risen to 378 (Balat, 2007). The United States has promoted biofuels since 1978 with a variety of policies and subsidies to become currently the global leader in bioethanol production (Tyner, 2008). The Energy Policy Act of 2005 established a Renewable Fuel Standard (RFS) which mandates specific targets for renewable fuel use based on type of feedstock and their GHG intensity relative to fossil fuels (Huang et al., 2013). The current RFS calls for 57 billion litres of 1st generation biofuel (mainly corn based ethanol) by 2015 and 60.5 billion l of cellulosic ethanol by 2022. In Europe, the European Commission in 2003 set the goal (Directive 2003/30/EC) of reaching a 5.75% share of renewable energy in the transport sector of member countries by 2010 with a further increase as part of the Renewable Energy Directive (RED, Directive 2009/28/EC) in 2009 to a minimum of 10% by 2020.

In 2011, world bioethanol production reached 84.6 Mm^3 with the US and Brazil accounting for 87.1% of this production from maize and sugar cane feedstock, respectively (RFA, 2012). The production of 1st generation biofuels such as sugar cane ethanol in Brazil and corn ethanol in the US is characterized by mature commercial markets and well understood technologies (IEA, 2008a), with little or no room for process improvement. In the future, it is therefore unlikely that the costs of production can be significantly decreased.

3. Biofuels policy and production in Nigeria

The Nigerian Biofuels Policy and Incentives programme introduced in 2007 mandates a 10% blend (E10) of gasoline with bioethanol (NNPC, 2007). There are two phases to the biofuel programme: initially fuel ethanol will be imported from Brazil via an official agreement between Petrobras (an oil company located in Brazil) and NNPC until sufficient capacity and capability have been developed for large-scale biofuel production. The second phase will run concurrently with the first phase and involves the establishment of plantations and the construction of biofuel processing facilities (NNPC, 2007).

Consumption of Petroleum Motor Spirit (PMS i.e. petrol/gasoline) in Nigeria between 2001 and 2006 varied between 6.28 and 9.57 Mm^3 per annum (NNPC, 2001) which would have a requirement for production of a minimum of 628 km^3 of bioethanol per annum in order to achieve a 10% blend (Table 1). In 2020 the consumption of PMS is expected to increase to 26.2 Mm^3 per annum (Chikaosolu, 2011) which would have a requirement for 2.6 Mm^3 per annum of bioethanol as a 10% blend. Due to the high reliance on PMS as a transport fuel bioethanol utilization in Nigeria, as in other countries is likely to have a considerable impact on reducing the use of fossil fuels and CO_2 emissions.

Table 1
Annual consumption of Petroleum Motor Spirit in Nigeria (2001–06) and the projected bioethanol requirement for blending. Data was derived from NNPC annual reports 2001–06 (NNPC 2001–06) and the projected consumption in 2020 from Sunmonu (2011).

Year	Petroleum Motor Spirit consumption (km^3)	Bioethanol requirement or E10 (km^3)
2001	6,288.12	628.81
2002	8,687.60	868.76
2003	7,437.52	743.75
2004	8,047.13	804.71
2005	9,572.01	957.20
2006	8,859.80	885.98
2020	26,259.20	2625.92

Current 1st generation ethanol production in Nigeria is reported to be about 134 km^3 per annum from five major commercial scale ethanol distilleries located in Lagos, Sango–Ota and Bacita mostly arising from the processing of crude ethanol imported from Brazil (Ohimain, 2010). In response to the Nigerian Biofuel Policy calling for the domestic production of bioethanol to meet the national demand of 5.14 Mm^3 per annum (gasoline blend together with paraffin and industrial ethanol replacement), funders have responded by investing over $3.86 billion in the construction of 19 ethanol bio-refineries and feedstock plantations for the production of over 2.66 Mm^3 of fuel grade ethanol per annum (Ohimain, 2010) using sugar cane, cassava and sweet sorghum as feedstocks. However, to meet the 10% replacement (E10) in Petroleum Motor Spirit will require about 1 million hectares of land which is about 5% of the 34 million hectares under cultivation (Ohimain, 2010).

4. Benefits and technological challenges of cellulosic ethanol

The production of 1st generation biofuels as well as offering a number of potential benefits, has raised many concerns with respect to displacing agricultural production thereby increasing the price of agricultural commodities and resulting in changes leading to increased net greenhouse gas emissions (Gallagher, 2008). In addition, it is increasingly understood that 1st generation biofuels produced primarily from crops which compete with their uses for food (Pimentel et al., 2008) are limited in their ability to achieve targets for fossil fuel substitution, climate change mitigation, economic growth and sustainability (IEA, 2008b). In addition, the use of crop products for 1st generation bioethanol production and their supply is unlikely to be sufficient to cope with the increasing global demand for bioethanol. The cumulative impact of these concerns have increased the need for developing 2nd generation biofuels from alternative biomass resources.

Lignocellulosic materials are particularly attractive as feedstocks for biofuel production because of their relatively low cost, great abundance and sustainable supply. Cellulosic ethanol from agricultural residues offers an attractive alternative especially in countries with a large arable land area and where residues are currently underutilised. Globally, lignocellulosic biomass could produce up to 442 billion litres per year of bioethanol (Bohlmann, 2006) which is significantly higher than current world bioethanol production.

Please cite this article as: Iye, E., Bilsborrow, P., Cellulosic ethanol production from agricultural residues in Nigeria. Energy Policy (2013), http://dx.doi.org/10.1016/j.enpol.2013.08.048