Utilising Biogas as an Alternative Fuel for Transportation in Nigeria

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Abstract
There is growing interest in the use of petroleum fuels in the transport sector, with advocates pointing to the energy security benefits of diversifying supplies of transport fuel and potential carbon and air quality benefits. The use of biogas as a transport fuel could deliver substantial greenhouse gas savings, compared to natural gas, petrol and diesel.The importance of petroleum products to the growth of Nigeria's economy cannot be overemphasized. For almost half a century, the country has been depending on petroleum as fuel used by vehicles for transportation. In this regard, there is need for diversification to the use of biogas since from present conditions (Niger Delta Avengers attack of petroleum installations, and the exorbitant exchange rate of naira), the supply of petroleum products will gradually decrease and there will be need for its gradual replacement by renewable energy sources. Biogas is a renewable energy source which when used as vehicle fuel, it gives the lowest emissions of carbon dioxide and particles of all the fuel.This paper examines the utilization of biogas as an alternative fuel for transportation. The objectives is to encourage the use of biogas for transportation due to its low price index; to create awareness on alternative vehicle fuels; to reduce reliance on petroleum in transportation, and to encourage environmental biotechnology (biogas) as a way of managing natural resources.
In addition, biogas can be efficiently utilised as a vehicle fuel, but it has to be upgraded to natural gas quality through technologies like the water scrubber technology and the PSA-technology. Secondary data obtained from the Energy Economic Newsletters Oil and Gas Analysis and Forecast was used in this research work and Time series analysis was applied in forecasting the amount of savings in dollars compared to petroleum products within a period of thirteen (13) months.The relationship in price between biogas and petroleum was examined between the year 2015 and 2016 and it was observed that in the corresponding year, that they will be a downward trend in the prices of both commodities thereby encouraging demand for both commodities especially biogas which will be least expensive.This paper recommends that government should encourage investors to invest in biogas production so that there would be an abundance of the product thereby leading to a reduction in price.
Keywords: Biogas, Fuel, Transport

1. Introduction

Utilisation of biogas in the transport sector is a technology with great potential and with important socio-economic benefits. Biogas is already used as vehicle fuel in countries like Sweden, Germany and Switzerland (California Energy Commission, 2011).

According to the Canadian Natural Gas Vehicle Alliance (CNGVA) (2010), the number of private cars, public transportation vehicles and trucks driven on biogas (Bio-methane) is increasing. Bio-methane can be used as fuel in the same way and by the same vehicles like the natural gas. An increasing number of European cities are exchanging their diesel buses with Bio-methane driven ones.

There are also specially built biogas vehicles, which are optimised for better efficiency and more convenient placement of gas cylinders, without losing luggage space. The biogas is stored at 200 to 250 bars, in pressure vessels, made of steel or aluminium composite materials. Today, more than 50 manufacturers worldwide offer some 250 models of commuter, light and heavy duty gas driven vehicles (Chahbazpour, 2010).

Bio-methane vehicles have substantial overall advantages compared to vehicles equipped with petrol or diesel engines. The overall carbon dioxide emissions are drastically reduced, depending on the feedstock substrate and origin of electricity (fossil or renewable) used for gas upgrading and compressing. Emission of particles and soot are also drastically reduced, even compared with very modern diesel engines, equipped with particle filters. Emissions of NO_2 and Non-Methane Hydrocarbons (NMHC) are also drastically reduced (Clean Fuels Development Coalition, 2011).

Upgraded biogas (Bio-methane) is considered to have the highest potential as vehicle fuel, even when compared to other biofuels. The potential of biogas for the transport sector is even higher, if waste is used as feedstock, instead of energy crops (Landahl, 2003).

Aim and Objectives

The aim of this study is to examine how biogas can be utilised as an alternative fuel for transportation. This is to be achieved through the following specific objectives:

- To encourage the use of biogas for transportation due to its low price index.
- To create awareness on alternative vehicle fuels.

- To reduce reliance on petroleum in transportation.
- To encourage environmental biotechnology (biogas) as a way of managing natural resources.

2. Review of Related Literature

The incessant dependency on petroleum fuel in the transport sector is now a cause of worry with advocates pointing to the energy security benefits of diversifying supplies of transport fuel and potential carbon and air quality benefits. The use of biogas as a transport fuel could deliver substantial greenhouse gas savings, compared to natural gas, petrol and diesel. However at present, a very limited amount of biogas is produced for the transport sector. The potential demand for Bio-methane as a transport fuel in developed countries has plummeted as part of broader government analysis of options for reaching the 2020 10% renewable energy in transport target and for meeting longer term economy-wide CO2 targets. It is assumed that a demand will exist for both compressed Bio-methane (CBM) and liquefied Bio-methane (LBM) as part of an increased demand for gaseous fuels in the transport sector(Ricardo-AEA, 2015).

Biogas can be used in both heavy duty and light duty vehicles. Light duty vehicles can normally run both on natural gas and biogas without any modifications, whereas heavy duty vehicles without closed loop control may have to be adjusted, if they run alternately on biogas and natural gas. The standard essentially states that the methane content must be higher than 95% and also sets limits for dew point, sulphur content and some other minor constituents (O. Jönsson, M. P, 2003).

Biogas is considered an interesting fuel alternative from an environmental perspective because biogas is an environmentally hazardous by-product to traditional waste treatment methods such as landfilling of organic waste. When biogas is released to the atmosphere, the methane content, a greenhouse gas, has about 20 times the global warming potential of carbon dioxide. Methane, hydrogen sulphide and siloxane present in biogas needs to be reduced to less harmful substances before been released to the environment thus the need to upgrade biogas for use as fuel. After enrichment, bio-methane when used as fuel in vehicles, offer some positive properties regarding emissions. Bio-methane creates lesser emissions when compared to other fossil fuel source like petrol and diesel. The combustion of 1kg of any hydrocarbon fuel theoretically emits about 2.7kg of carbon dioxide. The fumes from petrol and diesel contain benzene and toluene which are not present in fumes from biogas. Furthermore, bio-methane has lower emission of carbon monoxide, hydrocarbons, carbon dioxide, particulates and sulphide compounds as compared to diesel, petrol and natural gas which is valid for both light and heavy duty vehicle (Masebinu, 2014).

For bio-methane to be used as fuel for internal combustion engines, it has been recommended a methane concentration greater than 90%. There is currently only one standard adopted within the European Union (EU) member state for the use of biogas as a transport fuel. Sweden has a published standard - SS 15 54 38: "Motor fuels– biogas as fuel for high- speed Otto engines". The standard deals with specific characteristics relevant to the use and storage of biogas produced by anaerobic digestion for use as a motor fuel. It does not cover fuel which might be mixed with other compounds, e.g. hydrogen, propane, etc. Consequently the standard reflects a fuel with a high methane number (California Air Resources Board, 2011).Human engagements both at the domestic front and in industrial operations are inevitably accompanied by waste generation. Even in compliance to the goal or concept of cleaner production which requires that a higher percentage of raw materials are converted into products, solid waste generation is unavoidable. But the recycling option of cleaner production can be considered appropriate means of combating the menace of solid wastes. This usually involves the collection of the waste and reuse in the same or a different part of production (on-site recovery and reuse) or collection and treating wastes so that they can be sold to consumers or other companies. In line with this, biogas technology employs the use of anaerobic digestion of wastes to produce methane-rich gas known as biogas (Bates. J, 2015)

This has been an emerging technology that has become a major focus of interest even in waste management throughout the world (Elango *et al*, 2007). It is an identified veritable option in the integrated waste management of municipal solid waste involved in waste-to-energy transformation (Igoni *et al*, 2008).

Upgraded biogas when used as fuel provides much benefit to the ecosystem by reducing greenhouse gas emission and ensuring a more sustainable environment (Arespacochaga, 2010).

Biogas Production

Anaerobic digestion (AD) is a biochemical process during which complex organic matter is decomposed in absence of oxygen, by various types of anaerobic microorganisms. The process of AD is common to many natural environments such as the marine water sediments, the stomach of ruminants or the peat bogs. In a biogas installation, the result of the AD process is biogas and digestate.

Biogas is a combustible gas, consisting primarily of methane and carbon dioxide. Digestate is the decomposed substrate, resulted from the production of biogas.

During AD, very little heat is generated in contrast to aerobic decomposition (in presence of oxygen), like it is the case of composting. The energy, which is chemically bounded in the substrate, remains mainly in the produced biogas, in form of methane.

The process of biogas formation is a result of linked process steps, in which the initial material is continuously broken down into smaller units. Specific groups of micro-organisms are involved in each individual step. These organisms successively decompose the products of the previous steps. The four main process steps include hydrolysis, acidogenesis, acetogenesis, and methanogenesis.

The efficiency of AD is influenced by some critical parameters, thus it is crucial that appropriate conditions for anaerobic microorganisms are provided. The growth and activity of anaerobic microorganisms is significantly influenced by conditions such as exclusion of oxygen, constant temperature, and pH-value, nutrient supply, stirring intensity as well as presence and amount of inhibitors (e.g. ammonia). The methane bacteria are fastidious anaerobes, so that the presence of oxygen into the digestion process must be strictly avoided.

Biogas Properties

The energy content of biogas from AD is chemically bounded in methane. The composition and properties of biogas varies to some degree depending on feedstock types, digestion systems, temperature, and retention time. The table below contains some average biogas composition values considering biogas with the standard methane content of 50%, the heating value is of 21 MJ/Nm³, the density is of 1.22 kg/Nm³ and the mass is similar to air (1.29 kg/Nm³).

Table 1: Composition of Biogas

Compound	Chemical symbol	Content (Vol.-%)
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-45
Water vapour	H_2O	2 (20°C) -7 (40°C)
Oxygen	O_2	<2
Nitrogen	N_2	<2
Ammonia	NH_3	<1
Hydrogen	H_2	<1
Hydrogen sulphide	H_2S	<1

Source: (Teodorita, 2008)

Biogas Plant Components

A biogas plant is a complex installation, consisting of a variety of elements. The layout of such a plant depends to a large extent on the types and amounts of feedstock supplied. As there are many different feedstock types suitable for digestion in biogas plants, there are, correspondingly, various techniques for treating these feedstock types and different digester constructions and systems of operation. Furthermore, depending on the type, size and operational conditions of each biogas plant, various technologies for conditioning, storage and utilisation of biogas are possible to implement.

Biogas Utilisation

The simplest way of utilising biogas is direct burning in boilers or burners, extensively used for the biogas produced by small family digesters. Direct combustion, in natural gas burners, is applied in many countries as well. Biogas can be burned for heat production either on site, or transported by pipeline to the end users. For heating purposes biogas does not need any upgrading, and the contamination level does not restrict the gas utilisation as much as in the case of other applications. However, if biogas is to be compressed and used as renewable vehicle fuel, biogas must undergo an upgrading process, where all contaminants as well as carbon dioxide are removed and the content of methane must increase from the usual 50-75% to more than 95%. The upgraded biogas is often named Bio-methane (Matthew, 2016).

Upgrading of Biogas to Natural Gas Quality

Biogas has to be upgraded to natural gas quality in order to be used in normal vehicles designed to use natural gas (Lear, 2008). The most common technologies are the water scrubber technology and the PSA-technology. Gas upgrading is normally performed in two steps where the main step Sulfatreat ® H2S-removal is the process that removes the CO_2 from the gas. Minor contaminants are normally removed before the CO_2removal and the water dew point can be adjusted before or after the upgrading (depending on the process).

- **Water Scrubber Technology**

Two types of water absorption processes are commonly used for upgrading of gas from anaerobic digestion, single pass absorption and regenerative absorption. The major difference between the two processes is that the water in the single pass process is used only once. A typical installation as shown in figure 1 below is at a sewage water treatment plant. Water can also be recycled and in this case a stripper column has to be integrated in the process (regenerative absorption). Cleaned sewage water has a sufficient quality for use in the absorption column. After the flash tank, the water is depressurised by a regulator valve and returned to the sewage water treatment system.

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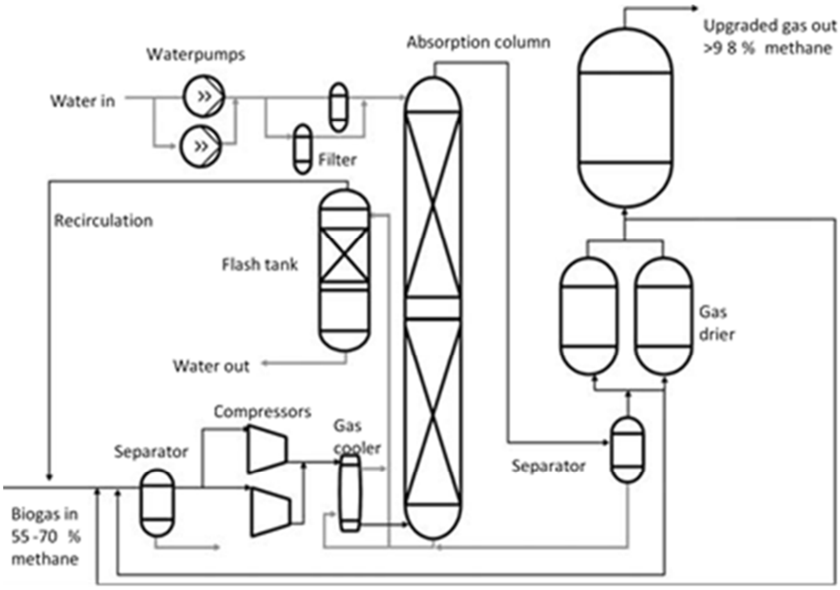


Source: (Jönsson, 2003)

Figure 1: Removal of carbon dioxide using water wash without regeneration

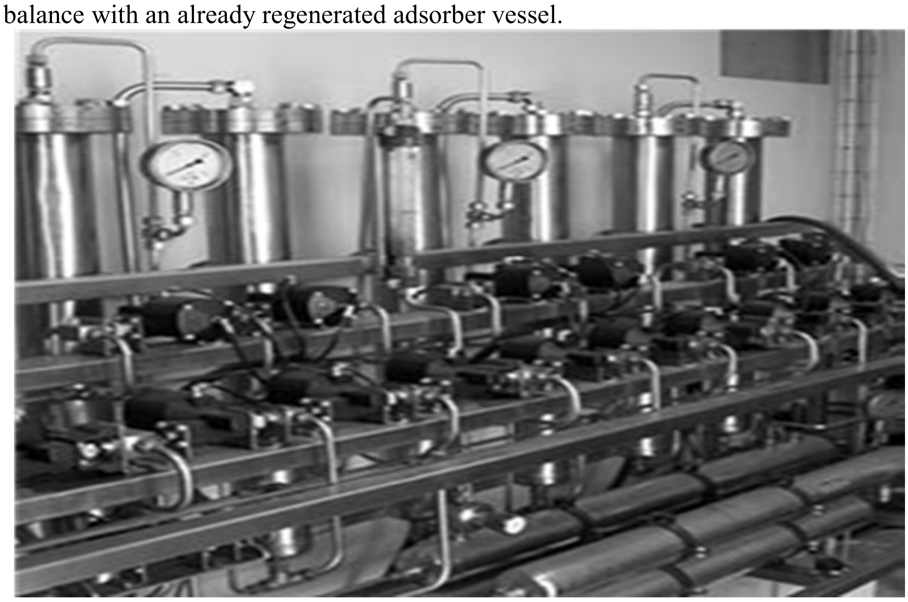
- **PSA (Pressure Swing Adsorption) Technology**

Pressure Swing Adsorption, or PSA, is a method for the separation of carbon dioxide from methane by adsorption/ desorption of carbon dioxide on zeolites or activated carbon at different pressure levels. The adsorption material adsorbs hydrogen sulphide irreversibly and thus is poisoned by hydrogen sulphide. For this reason a hydrogen sulphide removing step is often included in the PSA process.

The upgrading system as shown in figure 2 below consists of four adsorber vessels filled with adsorption material. During normal operation each adsorber operates in an alternating cycle of adsorption, regeneration and pressure build-up. During the adsorption phase biogas enters from the bottom into one of the adsorbers. When passing the adsorber vessel, carbon dioxide, oxygen and nitrogen are adsorbed on the adsorbent material surface. The gas leaving the top of the adsorber vessel contains >97% methane.

Before the adsorbent material is completely saturated with the adsorbed feed gas components, the adsorption phase is stopped and another adsorber vessel that has been regenerated is switched into adsorption mode to achieve continuous operation.

Regeneration of the saturated adsorbent material is performed by a stepwise depressurisation of the adsorber vessel to atmospheric pressure and finally to near vacuum conditions. Initially the pressure is reduced by a pressure balance with an already regenerated adsorber vessel.



Source: (Jönsson, 2003)

Figure 2: Biogas upgrading with PSA technology – pilot system

This is followed by a second depressurisation step to almost atmospheric pressure. The gas leaving the

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vessel during this step contains significant amounts of methane and is recycled to the gas inlet.
Before the adsorption phase starts again, the adsorber vessel is repressurised stepwise to the final adsorption pressure. After a pressure balance with an adsorber that has been in adsorption mode before, the final pressure build-up is achieved with feed gas.

3. Methodology

Time series analysis comprises methods for analysing time data in order to extract meaningful statistics and other characteristics of the data. Time series forecasting is the use of a model to predict future values based on previously observed values. While regression analysis is often employed in such a way as to test theories that the current values of one or more independent time series affect the current value of another time series, this type of analysis of time series is not called "time series analysis", which focuses on comparing values of a single time series or multiple dependent time series at different points of time (Shumway, 1988)
A number of notations are in use for time series analysis. A common notation specifying a time series X that is indexed by the natural numbers is written

$$X = \{X_1, X2\ldots\}$$

Another common notation is

$$Y = \{Y_t; t \in T\}$$

Where T is the index set

Trend $Y = a + bx$ (1)

$b = \frac{t\sum xy-(\sum x)(\sum y)}{t\sum x^2-(\sum x)^2}$ (2)

$a = \bar{y} - b\bar{x}$ (3)

Secondary data obtained from the Energy Economic Newsletters Oil and Gas Analysis and Forecast was used in this research work.

One Million British Thermal Unit (MMBTU) is widely recognised in the international market as the unit for trading in gas whereas a barrel which is equivalent to 42 gallons is also internationally recognised for petroleum (crude oil) trade and these parameters have been incorporated in this research work.

Dollars is the recognised currency for international trade and as such, it is the basis for this research work.

Table 2: prices of Biogas and Petroleum between July, 2015 to July, 2016

Month	Biogas($/MMBTU)	Petroleum($/barrel)
July	2.80	63
August	2.87	56
September	2.80	49
October	2.69	43
November	2.28	48
December	2.34	38
January	2.20	36
February	1.79	34
March	2.11	42
April	1.65	46
May	2.06	52
June	2.08	53
July	2.80	45

Source: Energy Economic Newsletters Oil and Gas Analysis and Forecast (2016)

Investors and government are always interested in the trend of any investment they will probably dabble into, that is why the likely prices of biogas and petroleum next year will be calculated to see if they will be price friendly in the coming year.

Table 3: Trend method of least square forecast

Month (X)	Biogas (Y)	XY	X^2
1	2.80	2.80	1
2	2.87	5.74	4
3	2.80	8.40	9
4	2.69	10.76	16
5	2.28	11.40	25
6	2.34	14.04	36
7	2.20	15.40	49
8	1.79	14.32	64
9	2.11	18.99	81
10	1.65	16.50	100
11	2.06	22.66	121
12	2.08	24.96	144
13	2.80	36.40	169
∑ 91	∑ 30.47	∑ 202.31	∑ 819

Source: Researcher's Forecast (2016)

Trend (Y) = a + bx

b = $\frac{t\sum xy-(\sum x)(\sum y)}{t\sum x^2-(\sum x)^2}$ = $\frac{13\ x\ 202.31-(91)(30.47)}{13\ x\ 819^2-(91)^2}$ = -0.06

$a = \bar{y} - b\bar{x}$ $= 2.34 - (-0.06)$ = 2.76

For August 2016 Trend (Y) = a +bx =$2.76 + (-0.06)(14)$ = 1.92

For September 2016 Trend (Y) = a +bx = $2.76 + (-0.06)(15)$ = 1.86

Table 4: Trend method of least square forecast

Month (X)	Petroleum (Y)	XY	X^2
1	63	63	1
2	56	112	4
3	49	147	9
4	43	172	16
5	48	240	25
6	38	228	36
7	36	252	49
8	34	272	64
9	42	378	81
10	46	460	100
11	52	572	121
12	53	636	144
13	45	585	169
∑ 91	∑ 605	∑ 4117	∑ 819

Source: Researchers Forecast (year)

Trend (Y) = a + bx

b = $\frac{t\sum xy-(\sum x)(\sum y)}{t\sum x^2-(\sum x)^2}$ = $\frac{13\ x\ 4117-(91)(605)}{13\ x\ 819^2-(91)^2}$ = -0.65

$a = \bar{y} - b\bar{x}$ $= 2.34 - (-0.06)$ = 51.09

For August 2016 Trend (Y) = a +bx = $51.09 + (-0.65)(14)$ = 41.99

For September 2016 Trend (Y) = a +bx = $51.09 + (-0.65)(15)$ = 41.34

Table 5: prices of Biogas and Petroleum between August 2016 and August 2017

Month	Biogas($/MMBTU)	Petroleum($/barrel)
August	1.92	41.99
September	1.86	41.34
October	1.80	40.69
November	1.74	40.04
December	1.68	39.39
January	1.62	38.74
February	1.56	38.09
March	1.50	37.44
April	1.44	36.79
May	1.38	36.14
June	1.32	35.49
July	1.26	34.84
August	1.20	34.19

Source: Researchers Forecast (2016)

4. Discussion of Results

In previous years, it was observed that there were fluctuations in the prices of biogas and petroleum with the highest price of biogas at $2.87/MMBTU noticed in August 2015 and the lowest price of biogas at $1.65/MMBTU noticed in April 2016 meanwhile the highest price of petroleum was $65/barrel noticed in July 2015 and the lowest price of petroleum was $34/barrel noticed in February 2016.

However, it was observed that they will be a downward trend in the prices of biogas and petroleum in the future with the highest price of biogas at $1.86/MMBTU noticed in August 2016 and the lowest price of biogas at $1.20/MMBTU noticed in August 2017 meanwhile the highest price of petroleum was $41.99/barrel noticed in August 2016 and the lowest price of petroleum was $34.19/barrel noticed in August 2017.

The downward trend in biogas prices will be triggered by the foray of investors into the biogas sector which will bring about an abundance of the product thereby causing a reduction in price meanwhile with the diversity of energy demands, they will be a reduction in the prices of petroleum so that it can still remain competitive in the global market.

Moreover, in the previous years analysed, that is, July 2015 to July 2016, a total of $30.47/MMBTU was spent on biogas whereas in the future, $20.24/MMBTU will be spent on biogas which therefore reveals a $10.23/MMBTU profit. In ten years' time, more than $100/MMBTU will be saved if biogas is utilized as fuel for transportation. This amount can be used in resuscitating other aspects of the economy like agriculture, infrastructure, education etc. Biogas is economical and coupled with the fact that it is a renewable and environmental friendly energy, it will go a long way to curb greenhouse gas effect and release of dangerous gases into the atmosphere.

5. Conclusion

Natural gas is a fossil fuel that has many advantages (high security of supply, low emissions, etc.) compared to liquid fuels like diesel and gasoline and has also been pointed out as a major alternative in the changeover to sustainable fuels. Biogas has the same advantages as natural gas, but additionally is a sustainable fuel that can be manufactured from local waste streams thereby also solving local waste problems.

Production of biogas is a mature technology that is well established in many European countries and the biogas potential is considerable, especially when taking into account the possibilities to use set aside land for production of crops for biogas.

Upgrading of biogas is a relatively new technology but experience from Sweden and other countries shows that it is possible now to upgrade biogas with high reliability and at reasonable costs.

The Swedish experience shows that biogas can be an economical sustainable fuel with a potential to drastically reduce emissions in urban transport.

In conclusion, if Nigeria should key into the use of biogas as an alternative fuel for transportation, the country will serve a lot of money in dollars ($100/MMBTU can be saved) and this can be channelled into other sectors of the economy.

6. Recommendation

The following recommendations can be deduced from the study:

I. Government should adopt biogas for transportation as a way of curbing fuel scarcity and saving cost due to the cheap cost of biogas.

II. Government should encourage investors to invest in biogas production so that they would be an abundance of the product thereby causing a reduction in price meanwhile with the diversity of energy demands, they will be a reduction in the prices of petroleum so that it can still remain competitive in the global market.
III. Government should endeavour to support biogas projects.

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