JASEM ISSN 1119-8362

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://ww.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 22 (10) 1689–1696 October 2018

Review on Synthesis Gas Production in a Downdraft Biomass Gasifier for Use in Internal Combustion Engines in Nigeria

***AKHATOR, PE; OBANOR, AI**

Department of Mechanical Engineering, University of Benin, Benin City, Nigeria.
**Corresponding Author Email: *peter.akhator@uniben.edu; aiobanor@yahoo.com*

ABSTRACT: This paper presents a review on the possibility and potential of synthesis gas production and its utilization as an alternative fuel for internal combustion engines (ICE) in Nigeria. Information on numerous experimental studies and demonstrations on downdraft biomass gasification for synthesis gas production as well as the potential use of synthesis gas as fuel for ICE applications were assessed. The review reveals that there are abundant biomass resources in Nigeria and there is a great potential to produce synthesis gas from these sources using downdraft gasifier as preferable technology.

DOI: https://dx.doi.org/10.4314/jasem.v22i10.28

Dates: Received: 21 September 2018; Revised: 10 October 2018; Accepted 30 October 2018

Keywords: Biomass, Downdraft gasifier, internal combustion engines, Synthesis gas.

Renewable energy is the energy produced from processes that do not involve the use of fossil fuels. The exploration for stable energy supplies from various renewable energy resources has become vital, since most energy consumed currently are from fossil fuels, which are of limited availability and finite in nature. From a technology standpoint, the increasing utilization of alternative fuels from renewable sources such as biomass can directly contribute to improvements in engine performances and pollution abatement. Biomass is a carbon-neutral resource and is the most abundant organic material produced by photosynthesis in plants in the presence of sunlight and from animal (Schoene *et al*, 2007). Biomass currently accounts for about 13% of global renewable energy, and its share is on the increase (Katarina, 2012). Biomass can be processed via gasification technology in which high temperatures and air-fuel ratios are crucial. Gasification is considered as an interesting and efficient process to expand the utilization of biomass. In recent years, biomass gasification has gain huge attention due to the production of synthesis gas which can be utilized in different power facilities (Kumar *et al*., 2009; Devi *et al*., 2003). Biomass gasification converts the intrinsic chemical energy in the biomass into combustible gas known as synthesis gas (syngas); and the major components of syngas are H_2; CO; CH_4; CO_2 and N_2 (Bridgewater, 2003). The quality of synthesis gas could be standardized and used as fuel in internal combustion engines (ICEs) and gas turbines for electricity generation, or as chemical feedstock to produce liquid fuels and chemicals (Erich, 2007). Synthesis gas has a high potential to replace fossil fuels for decentralized off-grid electricity generation, especially in rural and remote areas where a national electricity grid is absent (Siemons, 2001). Biomass gasification systems are being used for rural electrification in developing countries like India, Indonesia, Cambodia and China with a high degree of success (Mukhopadhyay, 2004; Nouni *et al*., 2007; Dasappa *et al*., 2011). Deploying such technology in Nigeria will go a long way to ease the adverse electricity deprivation suffered by Nigerians, especially rural dwellers in the country. Such electrification schemes have led to significant increase in the standard of life of rural dwellers in other climes (Mukhopadhyay, 2004; Nouni *et al*., 2007; Dasappa et al., 2011).

Downdraft gasifier is a type of reactor that is deployed to produce syngas from biomass. Several studies have been conducted on downdraft gasifiers using biomass as feedstock under various operating conditions (Martinez et al., 2012; Zainal et al., 2002; Dogru *et al*., 2002; Jayah *et al*., 2003). The main advantages of downdraft gasifier compared to other gasifier types are its ease of operation and the low tar percentage in the syngas produced. Low tar content is desirable for smooth operation and longevity of internal combustion engines. This paper therefore highlights syngas production in a downdraft biomass gasifier and

**Corresponding Author Email: *peter.akhator@uniben.edu; aiobanor@yahoo.com*

the application of the syngas in ICEs with the intention of presenting the technology as a viable avenue to harness renewable electricity from the vast biomass resources in Nigeria.

MATERIALS AND METHODS

A systematic desk research approach was deployed in this study. Several resources such as journal publications, periodicals, scholarly articles, newspaper publications, published and unpublished reports from government parastatals and agencies were retrieved, examined and analysed for this work. The search was mainly restricted to current materials with the exception of a few scholarly articles that dated back to the eighties.

RESULTS AND DISCUSSION

Current electricity situation in Nigeria: In Nigeria, demand for electricity has been on a steady increase over the years due to population growth, however, electricity generation and supply have been unable to match demand. Historically, electricity sector in Nigeria has never been able to operate at full capacity. Aging infrastructure, poor maintenance, vandalism and gas supply constraints have all had negative impact on the sector's performance. Presently, Nigeria's electricity sector has an estimated installed capacity of 11GW of which maximum available capacity is under 6GW. This quantity is grossly inadequate to satisfy the demand of the country.

Figure 1 shows the predicted demand profile for electricity in Nigeria based on GDP growth rate. Currently, there are twenty-five grid-connected and operational power plants in Nigeria. Twenty-two of these plants are gas fired with three hydropower plants providing the balance. Operations of about 80% of the gas power plants are adversely affected on a regular basis by gas deprivation due to sabotage of gas pipelines and the lack of operational Gas Purchase Agreement (GPA) leading to loss of power (Asu, 2017; Kalejaye, 2016; Obasi, 2016). Figure 2 shows monthly power loss due to gas constraints. This is a clear case for expanding the energy mix in the country to achieve sustainable electricity security. Over the years, the Nigerian government has rolled out several policies and action plans aimed at creating energy security through the inclusion of renewable energy resources in the national energy mix. Of recent is the National Renewable Energy and Energy Efficiency Policy (NREEEP) approved in April 2015. The NREEEP sets a target of 18% renewable energy contribution by 2020 and 20% by 2030 (NACOP, 2016). Table 1 shows expected contributions from renewables to electricity generation in Nigeria.

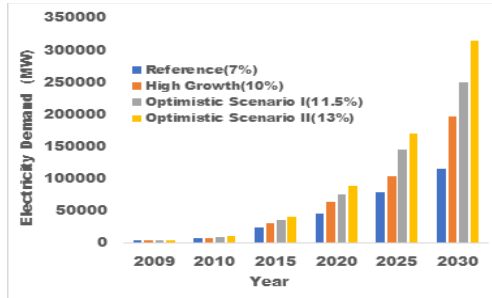

Fig 1: Electricity Demand Projections for Nigeria (ECN, 2005)

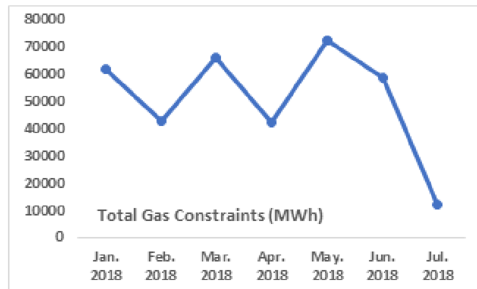

Fig 2: Monthly power loss due to gas constraints [NESISTATS, 2018]

Biomass potential as an energy source in Nigeria: Nigeria is blessed with vast biomass resources that can be harnessed for energy applications. Biomass available in Nigeria comprises four major types: agricultural crops and residues, forest resources and residues, rural and urban wastes and animal residues (Mohammed, 2012). The use of agricultural crop residues, animal residues and forest residues for syngas production poses no threat to food security and forest preservation; therefore, they are deemed suitable and viable feedstock for bio-refining processes such as gasification for producing energy carriers (synthesis gas) and energy (heat and electricity). Rural and urban wastes are also considered viable for syngas production; however, the combustible fraction of these wastes is desirable as feedstock for downdraft gasifiers due to their low moisture content. Modern biomass processing methods for energy production differ technically from traditional methods; that are commonly used in Nigeria, especially in the rural areas. The modern approach involves the use of advanced technologies (such as gasification) to process the biomass more efficiently and reduce environmental hazards. The pursuit of food and energy security has made tons of residual biomass resources readily available. Biomass utilization for energy purposes deserves huge attention in Nigeria, considering the electricity crisis and poor biomass management bedevilling the country. Tables 2 shows biomass resources in Nigeria and their energy potential.

Table 1: Anticipated renewable energy contribution to Nigeria energy mix (Sambo, 2010)

Renewable energy resources	2015 (MW)	2020 (MW)	2030 (MW)
Large hydropower	4000	9000	11,250
Small hydropower	100	760	3500
Solar photovoltaic	300	4000	30,005
Solar thermal	200	2136	18,127
Biomass	5	30	100
Wind	23	40	50
All renewable resources	4728	15,966	63,032
All energy sources	47,490	88,698	315,158
% of all energy resources	**10%**	**18%**	**20%**

Table 2: Biomass resources in Nigeria (Adapted from Simonyan and Fasina, 2013; FAOSTATS, 2012; FAOSTATS, 2015; Hemstock and Hall, 1995; Ben-Iwo *et al.*, 2016)

Biomass	Quantity (millions tonnes)	Energy potential
Agro-residues	150.092	2013.54 petajoule
Forest & wood processing residues	5.20	17.73 megajoule
Animal residues (dry dung)	388.391	525.266 petajoule
Municipal solid waste (combustible fraction)	1.46	Non-available

Information contained in Table 2 is an indication that Nigeria has enough biomass resources for syngas production in a downdraft gasifier should she choose to adopt such technology. Besides benefits on the energy front, Nigeria also stand to gain improved sanitation, as the biomass (which currently constitutes environmental nuisances in the country due to poor disposal methods) will be converted to bio-energy. Figure 3 presents the fuel properties of various types of biomass currently used for energy production. The figure gives the relationship between heating value and percentage moisture content of each biomass type: as moisture content (MC) decreases, the lower heating value (LHV) increases.

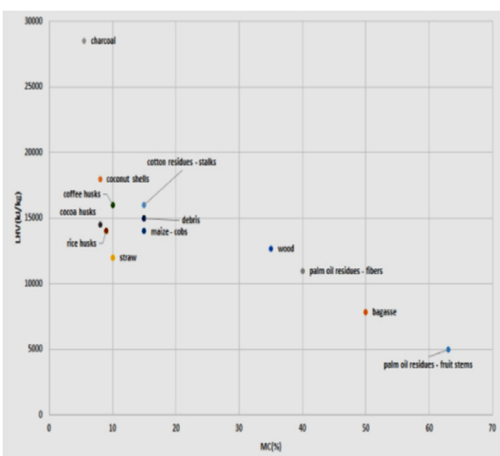

Fig 3: Relationship between moisture content (MC) and lower heating value LHV (kJ/kg) (Yoon *et al.*, 2013)

Fixed-bed downdraft gasifier: Fixed-bed gasifiers are the most commonly used reactors for biomass gasification. During the gasification process, biomass are exposed to different reaction zones: drying, pyrolysis, combustion/oxidation and gasification (OFA, 2012; Reed and Das, 1988). Drying: moisture is removed from the biomass, Pyrolysis: volatile matters are released from continued heating and their reaction with oxygen. The biomass pyrolysis process is represented by the reaction in Eq. (1) (Basu, 2010).

$C_n H_m O_p$ (Biomass) + heat $\longrightarrow \Sigma_{liq} C_x H_y O_z + \Sigma_{gas} C_a H_b O_c + H_2O$ + Char (1)

Oxidation: reaction between carbon and oxygen to form carbon dioxide and carbon monoxide. Partial oxidation of char (C) produces carbon monoxide and heat (Eq. (2)), while total oxidation of char produces carbon dioxide and more heat (Eq. (3)) (Basu, 2010)
Partial oxidation

$C + 0.5O_2 \rightarrow CO - 110{,}530$ kJ/kmol (2)

Total oxidation

$C + O_2 \rightarrow CO_2 - 393{,}770$ kJ/kmol (3)

Gasification: series of reduction reactions occur in this zone. (Basu, 2010). Combustible gases in the syngas are formed during reduction through the following reactions.

Bouduard reaction

$C + CO_2 \rightarrow 2CO + 172{,}000$ kJ/kmol (4)

Water-Gas reaction

$C + H_2O \rightarrow CO + H_2 + 131{,}000$ kJ/kmol (5)

Water-Gas Shift reaction

$CO + H_2O \rightarrow CO_2 + H_2 - 41{,}000$ kJ/kmol (6)

Methanation reaction

$C + 2H_2 \rightarrow CH_4 - 74{,}800$kJ/kmol (7)

Various types of fixed-bed gasifiers exist with different configuration of the gasification and combustion zones. Fixed-bed gasifiers are either co-current (biomass and gasifying agent flow in the same direction) or counter-current (biomass and gasifying agent flow in opposite direction). They can also be categorized by the method of syngas collection from the reactor: giving rise to updraft and downdraft configurations for syngas collection from the top or bottom of the reactor respectively (Dogru, 2013). Figure 4 shows the various types of fixed-bed gasifiers.

Updraft gasifier: In updraft (or counter-current) gasifier, gasifying agents such as air, oxygen and steam are introduced at the bottom and allow the interaction of biomass with combustible gases in the counter current direction. In addition to pyrolysis products and drying zone steam, the gas produced in the reduction zone leaves the reactor with a high calorific value. This type of gasifier has a high thermal efficiency since the hot gas pass through the fuel bed, but the producer gas can become contaminated with tar particles when leaving the low-temperature pyrolysis and drying zones (Milne *et al*., 1998; Neeft, 1999). The high tar level in updraft gasification is a major challenge and the gas output cannot be used as such in engine or turbine applications unless it passes through intensive conditioning to reduce the tar content to an acceptable range. However, gas conditioning requires high investment costs, making the entire system economically unviable. Therefore, updraft gasifiers are not suitable for engine or turbine applications, although they are widely used in direct thermal applications such as furnace heating, gas burner and cooking (Beenackers, 1999).

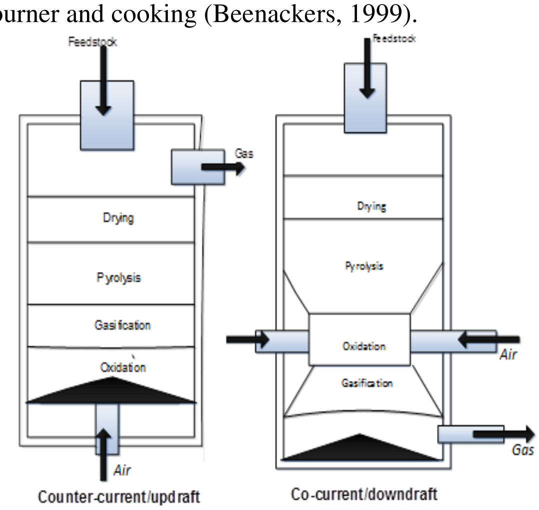

Fig 4: Fixed-bed gasifiers

Downdraft gasifier: In a downdraft gasifier, air interacts with solid biomass in the downward direction, with the flow of wastes and gases in a co-current direction. All the decomposition products from the pyrolysis and drying zones are forced to pass through the oxidation zone for thermal cracking of volatile materials, producing a gaseous fuel with less tar (Chopra and Jain, 2007). Here, the air interacts with pyrolyzing biomass before making contact with char and accelerates the flame to maintain the process of pyrolysis. At the end of the pyrolysis zone, the gases obtained in the absence of oxygen are CO_2, H_2O, CO and H_2. This process is called flaming pyrolysis. In flaming pyrolysis, the gases yielded during downdraft gasification account for the consumption of 99% of the tar at high temperatures (around 1000°C), leading to low particulate and tar content in produced syngas compared to the updraft gasifier (Chopra and Jain, 2007; Gautam *et al*., 2011). Also, the uniform distribution of gasifying agent in the throat area of the downdraft gasifier leads to the maximum temperature limits inside the reactor (Bhavanam and Sastry, 2011). Therefore, downdraft gasifiers are observed to be well suited for IC engines and gas turbines for power generation applications (Reed and Das, 1988; Gautam *et al*., 2011). However, the gas obtained from the reactor is required to be cooled before end use because the high temperature of the producer gas affects the engine efficiency. The heating value of syngas produced in a downdraft gasifier ranges between 4 – 7 MJ/Nm^3. (Asadullah, 2014).

Fluidized bed reactor: In a fluidized bed reactor the biomass is fed in relatively quickly from the top, onto the whole of the fluidized bed. The gasifying agent is provided in the form of a fluidizing gas fed in from the bottom of the reactor. In a typical fluidized bed reactor fresh, solid particles of feedstock come into contact with the hot bed of solids, which rapidly bring the newly arrived particles up to the bed temperature, so that they undergo rapid drying and pyrolysis, producing char and gases (condensable and non-condensable). Even if the bed of solids is thoroughly mixed, the fluidizing gas is generally kept in continuous mode, entering through the bottom and exiting through the top. Fluidized bed reactors cannot achieve full conversion of char due to the continuous mixing of solids. The high degree of mixing of solids helps to maintain an even temperature, but the close mixture of gasified and partially gasified particles means that any solid that leaves the bed contains partially gasified char. The particles of char in trained from the fluidized bed can cause losses in the gasifier.

A comparative summary of the gasifier types: The following general technical points can be made concerning the types of gasifier currently available:

a) Downdraft gasifiers are easy to construct. Their technology is simple, robust and reliable. They are used for small-scale power applications (up to $1MW_e$) although there are no problems of scale-up. Downdraft and updraft gasifiers have relative low investment cost unlike fluidized bed gasifiers with high investment cost (Kramreiter *et al*., 2008; Puig-Arnavat *et al*., 2010).

b) Downdraft and updraft gasifiers have high carbon conversion efficiency, however, downdraft gasifiers produce less tars than updraft gasifiers. Fluidized bed gasifiers produce intermediate quantities between the two. Downdraft gasifiers are more sensitive to biomass types, and have little flexibility in this regard (Zhou *et al*., 2009).

c) Updraft gasifiers are suitable for applications where heat must be generated but the existence of tars is not important (Beenackers, 1999).

d) Fluidized bed gasifiers have the advantage that they enable consistent temperatures to be maintained just below problematic levels that could lead to sintering or a build-up of ash. They produce less char than fixed bed reactors, but could find it difficult to entrain certain particles, which reduces the biomass conversion efficiency (Wang *et al*., 2008).

e) Fluidized bed gasifiers have complex construction and technology. They are proven technology mainly for coal gasification and are used for large-scale power outputs (up to $100MW_e$) (Wang *et al*., 2008).

Selection of gasifier for Nigeria: Based on the merits and demerits of the various types of gasifiers, downdraft gasifier technology will be preferable for Nigeria. This is because Nigeria has little experience in the design, construction, installation and operation of biomass gasifiers for syngas production. Another reason is that bioenergy will be most appreciated in rural areas that are uneconomical to connect to the national electricity grid. Rural settlements in Nigeria are mostly small and requires small quantity of electricity for daily usage; hence, downdraft gasification technology with its ease of operation and low tar content in the produced syngas will be most appropriate. In 2016, the United Nations Industrial Organisation (UNIDO) installed a 32 kW downdraft gasifier at Ebonyi State, Nigeria. The gasifier uses wood chips as feedstock and provides electricity to productive users such as rice and flour mills. The gasifier, which was manufactured by an Indian company, Ankur Scientific, only operates intermittently and requires an Indian engineer to come in for essential repairs (DFID, 2017). However, researchers in Nigeria have attempted to produce syngas using lab-scale downdraft gasifiers. Salisu (2016) produced syngas form rice husk while Ojolo and Orisaleye (2010) obtained syngas using wood chips and palm kernel shells as feedstock.

Synthesis gas application in internal combustion engines: Internal combustion engines represent one of the earliest attempts to generate electricity from syngas due to their established technology and reliability. The quality of syngas is important; but considerably lower than gasoline and natural gas, hence engines need some modifications to enable them run on syngas (Martinez *et al*., 2012). Spark ignition (SI) and compression ignition (CI) engines are the most utilized internal combustion engines for syngas to electricity conversion, and there exist extensive practical (experimental and commercial) experience of such gasifier-ICE systems around the globe. The quality of the syngas must be such that it contains a high proportion of combustible components (H_2, CO and CH_4) and little or no impurities (dust particles and tars). The most common impurities in the syngas are tars and dust particles; dust particles are usually removed with cyclones and/or fabric filters. The most critical impurities to be handled, however, are tars. Tars can be removed from the product gas by thermal, chemical and physical methods. Thermal and chemical methods decompose the tars to combustible gases, while physical methods purify the syngas of tars. Hasler and Nussbaumer (1999) reported that the allowed particle and tar concentration in syngas for satisfactory internal combustion engine operation must be less than 50 mg/Nm^3 and 100 mg/Nm^3, respectively. However, (Bridgewater, 2003) stated that the syngas quality depends on the type and design features of the internal combustion engine being used. Spark ignition engines, normally operated with petrol, can be adapted to run on syngas alone. To modified diesel engines to run on syngas, reduce the compression ratio and the install a spark ignition system. Diesel engines can run on syngas in a dual fuel mode; where the diesel engine is started with diesel oil and syngas used to produce majority of its output. The advantage of dual fuel mode lies in its flexibility: in case of gasifier malfunctioning or lack of biomass, an immediate switch to full diesel operation is generally possible. The dual fuel configuration could also be applied to petrol engines.

Relevant work on syngas application in IC engines for electricity generation: Numerous researches on application of syngas in internal combustion engines for electricity generation have been conducted over the years via modelling and experimental/practical approaches. However, only results of experimental/practical studies are reported in this section. Warren *et al*. (1995) developed a $30kW_{el}$ small-scale wood gasifier coupled to a spark ignition engine for electricity generation. His plant obtained an electrical efficiency of about 20%. Lee *et al*. (2013) ran an unmodified spark ignition engine on syngas produced from various biomass in a downdraft gasifier at 800˚C. Pine, red oak, horse manure and cardboard gave different electrical outputs and efficiencies with maximum values of 13.10 kW_{el} for red oak and 23% for pine respectively. Wu *et al*., (2002) presented a detailed insight into small-scale gasification plants in China, using a 200 kW_{el} downdraft and 1000 kW_{el} circulating fluidized bed (CFB) gasifiers fed with rice husk and coupled to spark ignition engines. He reported that biomass gasification systems are more economical compared to small-scale coal-fired power plants (with a lower specific cost of about 50% for the 1000 kW_{el} system) and that electricity cost depends mainly on the cost of biomass. Zhou *et al*., (2012) analysed the gasification power plants developed by Tianyan Green Energy Development and the Guangzhou Institute of Energy Conversion (GIEC). Tianyan developed biomass gasification systems with engine generators with capacities from 140 to 1000 $kW_{el.}$ Downdraft gasifier was used to produce syngas for gas engines with 200 kW_{el} and below, while CFB was used for 400 kW_{el} capacity and above. GIEC developed CFB coupled to modified diesel engines for 200-1200 kW_{el} capacities. The report revealed that Tianyan plants obtained electrical efficiencies between 15 and 16%, while GIEC plants recorded 15% to 20% electrical efficiencies. Dasappa *et al*., (2011) reported the operational experiences from 100 kW_{el} biomass power plant as part of the Biomass Energy for Rural India programme. In that case 18% electrical efficiency with a downdraft gasifier was recorded. Buchholz *et al*., (2012) investigated the functionality and economic feasibility of two wood-fired downdraft gasification power plants (250kW and 10kW) installed in Uganda. They reported that both plants proved their potential to compete economically with diesel generated electricity when operating close to their rated capacities. Both plants recorded electrical efficiencies of 14% and 11% respectively. Table 3 summarizes some important downdraft biomass gasifier-internal combustion engine power plants.

Table 3: Biomass gasification-internal combustion engine power plants data

Gasifying agent	Type of Biomass	LHV of Biomass (MJ/kg)	LHV of Syngas (MJ/Nm^3)	Power output kW_{el}	Reference
Air	Wood chips	18	n.a	30.0	Warren *et al*., 1995
Air	Pine	19.38	4.53	11.7	Lee *et al*., 2015
	Red oak	18.72	5.06	13.1	
	Horse manure	18.14	5.22	10.1	
	Cardboard	17.09	4.21	9.6	
Air	Rice hull	n.a	3.8-4.6	200.0	Wu *et al*., 2002
Air	Agro-forestry residues	14	4.8	200.0	Zhou *et al*., 2012
Air	Wood	n.a	n.a	100.0	Dasappa *et al*., 2011

n.a – non available

*Conclusion***:** Conversion of biomass to synthesis gas using a downdraft gasifier was presented in this paper. The paper reveals that despite the low heating value of synthesis gas, it can be conditioned and applied as an alternative fuel for internal combustion engines to produce electricity. Several practical examples of downdraft biomass gasification systems for electricity production around the world indicates that Nigeria stands to benefit immensely if her vast biomass resources are converted into syngas using a downdraft gasifier for electricity generation.

REFERENCES

Asadullah, M. (2014). Biomass gasification gas cleaning for downstream applications: a comparative critical review. Renewable and Sustainable Energy Reviews, 40: 118-132.

Asu, F. 2017. 13 power plants lose 3,124MW to gas shortage. http://punchng.com/13powerplantslose3124mwgasshortage/, (Accessed on February/15/2017)

Basu, P. (2010). Biomass gasification and pyrolysis: practical design and theory. Academic Press, Burlington, MA 01803, USA.

Beenackers, A. (1999). Biomass gasification in moving beds: A review of European technologies.

Renew. Energy, 16: 1180-1186.

Ben-Iwo, J., Manovic, V. and Longhurst, P. (2016). Biomass resources and biofuels potential for the production of transportation fuels in Nigeria. Renewable and Sustainable Energy Reviews, 63: 172-192.

Bhavanam, A, Sastry, R.C. (2011). Biomass gasification processes in downdraft fixed bed reactors: a review. Int J Chem Eng Appl, 2(6): 425–33.

Bridgewater, A.V. (1995). The technical and economic feasibility of biomass gasification for power generation. Fuel, 74 (5): 631-653.

Bridgewater, A.V. (2003). Renewable fuels and chemicals by thermal processing of biomass. Chemical Engineering Journal, 91: 87-102.

Buchholz, T., Silva, I.D. and Furtado, J. (2012). Electricity from wood-fired gasification in Uganda- A 250 and 100kW case study. Prooceedings of the 20th Domestic Use of Energy Conference, 3-4 April, Cape Town, South Africa.

Chopra, S., Jain, A.K. (2007). A review of fixed bed gasification systems for biomass. Agric. Eng Int: CIGR E-J, 9, [ISSN: 1682-1130].

Dasappa, S., Subbukrichna, D.N., Suresh, K.C., Paul, P.J and Prabhu, G.S. (2011). Operational experience on a grid converted $100kW_{el}$ biomass gasification power plant in Karnataka, India. Energy for Sustainable Development, 15 (3): 231-239.

Devi, L.; Ptasinski, K.J.; Jenssen, F.J.J.G. (2003). A review of the primary measures for tar elimination in biomass gasification processes. Biomass Bioenergy, *24*, 125–140.

DFID. (2017). Bioenergy for sustainable energy access in Africa, a technology value chain prioritisation report. PO 7420.

Dogru, M. (2013). Experimental results of olive pits gasification in a fixed-bed downdraft gasifier system. International Journal of Green Energy, 10 (4): 348-361.

Dogru, M., Howarth, C.R., Akay, G., Keskinler, B et al. (2002). Gasification of hazelnut shells in a downdraft gasifier. Energy, 27: 415-427.

Energy Commission of Nigeria (ECN), 2005. National energy policy: Federal Republic of Nigeria.

Erich, E. (2007). Decentralized Gasification of Biomass—Variant Processes to Produce Low-Tar Product Gases from Biomass. In Energy from Waste, 1st ed.; Thomé-Kozmiensky, K.J., Beckmann, M., Eds., TK-Publishing Inc., Nietwerder, Germany, 503–518.

FAOSTATS (2012). FAO statistics division. Available at https://www.faostats.fao.org (Accessed on 15/08/18).

FAOSTATS (2015). FAO Statistics of animal production. Available at https://www.faostat.fao.org (Accessed on 31/08/18).

Gautam, G., Adhikari, S., Gopalkumar, S.T., Brodbeck, C, Bhavnani, S., Taylor, S. (2011). Tar analysis in syngas derived from pelletized biomass in a commercial stratified biomass in a commercial stratified downdraft gasifier. Bioresources, 6(4): 4652–61.

Hasler, P and Nussbaumer, Y. (1999). Gas cleaning for IC engines applications from fixed bed biomass gasification. Biomass and Bioenergy, 16 (6): 385-395.

Hemstock, S.I and Hall, D.O. (1995). Biomass energy flows in Zimbabwe. Biomass and Bioenergy, 8: 151-173.

Jayah, T.H., Aye, L., Fuller, R.J and Stewart, D.F. (2003). Computer simulation of a downdraft wood gasifier for tea drying. Biomass and Bioenergy, 25: 459-469.

Kalejaye K. 2016. Gas pipelines vandalism truncates power generation – Eko DISCO. http://sweetcrudereports.com/2016/03/01/gaspipelinesvandalismtruncatespowergenerationekodisco/, (Accessed on February/15/2017)

Katarina, E.J., Ekerholm, H and Marad, E. (2012). Promoting ethanol in the shadow of oil dependence: 100 years of arguments and frictions in Swedish polities. Scandinavian Journal of History, 37 (5): 621-645.

Kramreiter, R., Url, M., Kotik, J., Hofbauer, H. (2008). Experimental investigation of a 125 kW twin-fire fixed bed gasification pilot plant and comparison to the results of a 2 MW combined heat and power plant (CHP). Fuel Processing Technology, 89: 90–102.

Kumar, A.; Jones, D.D.; Hanna. M.A. (2009).Thermochemical biomass gasification: A review of the current status of the technology. Energies, 2, 556–581.

Lee, U., Balu, E and Chung, J.N. (2013). An experimental evaluation of an integrated biomass gasification and power generation system for distributed power applications. Applied Energy, 101: 699-708.

Martinez, J.D., Mahkamou, K., Andrade, R.V and Silva Lora, E.E. (2012). Syngas production in downdraft biomass gasifiers and its application using internal combustion engines. Renewable Energy, 38 (1): 1-9.

Milne, T.A., Abatzoglou, N., Evans, R.J. (1998). Biomass gasifier tar: their nature, formation, and conversion. NREL/TP-570-25357

Mohammed, Y.S. (2012). The estimation and projection of the electric power in Nigeria from corn residues based on linear regression. Published Master's Thesis, Electrical Power Engineering, Universiti Teknologi, Malaysia.

Mukhopadhyay, K. (2004). An assessment of a biomass gasification based power plant in the Sunderbans. Biomass and Bio-energy, 27(3): 253-264.

National Council on Power (NACOP), 2016. National Energy Efficiency Action Plans, NEEAP (2015-2030). Federal Republic of Nigeria.

Neeft, J.P.A., Knoef, H.A.M., Onaji, P. (1999). Behaviour of tar in biomass gasification systems: tar related problems and their solutions [November Report No. 9919]. Netherland: Energy from Waste and Biomass (EWAB).

NESISTATS, 2018. Electricity supply statistics. Available at http://mypower.ng/investors/statistics2/ (Accessed on 4/09/18).

Nouni, M.R., Mullick, S.C., Kandpal, T.C. (2007). Biomass gasifier projects for decentralized power supply in India: A financial evaluation. Energy Policy, 35(2): 1373-1385.

Obasi S. 2016. Electricity: 1,000MW of IPP capacity idle due to gas shortage. http://www.vanguardngr.com/2016/06/electricity1000mwippcapacityidleduegasshortage/, (Accessed on February/15/2017)

Ojolo, S.J., and Orisaleye, J.I. (2010). Design and development of a laboratory scale biomass gasifier. Journal of Enegy and Power Engineering, 4(8): 16-23.

Olarenwaju, O.O and Ilemobade, A.A. (2009). Waste to wealth: a case study of the Ondo State integrated waste recycling and treatment project, Nigeria. Eur J Soc Sci, 8 (1): 7-16.

Ontario Federation of Agriculture, OFA (2012). Alternative technologies to transform biomass into energy. Available at https://ofa.on.ca/wp-content/uploads/2017/11/Alternative-Technologies-to-Transform-Biomass-into-Energy-Jan-2013.pdf (Accessed on 17/08/18).

Puig-Arnavat, M., Bruno, J.C., Coronas, A. (2010). Review and analysis of biomass gasification models. Renew Sustain Energy Rev, 14(9): 2841–51.

Reed, T.B and Das, A. (1988). Handbook of biomass downdraft gasifier engine systems, 1st Ed, Solar Energy Research Institute.

Sambo, A.S. (2010). Renewable energy development in Nigeria. World Future Council Strategy Workshop on Renewable Energy.

Salisu, J. (2016). Performance evaluation of downdraft gasifier for syngas production using rice husk. Published Master's Thesis, Chemical Engineering, Ahmadu Bello University, Zaria.

Schoene, D., Killmann, W., Von Lupke, H and Loychewilkie, M. (2007). Definitional issues related to reducing emissions from deforestation in developing countries. FAO, 5: 1-26.

Siemons, V.R. (2001). Identifying a role for biomass gasification in rural electrification in developing countries: The economic perspective. Biomass and Bioenergy, 20(4), 272-285.

Simonyan, K and Fasina, O. (2013). Biomass resources and bioenergy potentials in Nigeria. African Journal of Agricultural Research, 8 (40): 4975 – 4989.

Wang, L., Weller, C.L., Jones, D.D., Hanna, M.A. (2008). Contemporary issues in thermal gasification of biomass and its application to electricity and fuel production. Biomass Bioenergy, 32: 573–81.

Warren, T.J.B., Poulter, R and Perfitt, R.I. (1995). Converting biomass to electricity on a farm-sized scale using downdraft gasification and a spark ignition engine. Bioresource Technology, 52 (1): 95-98.

Wu, C., Huang, H., Zheng, S and Yin, X. (2002). An economic analysis of biomass gasification and power generation in China. Bioresource Technology, 83 (1): 65-70.

Yoon, S., Yun, Y., Seo, M., Kim, Y et al. (2013). Hydrogen and syngas production from glycerol through microwave plasma gasification. International Journal of Hydrogen Energy, 38(4):559-567.

Zainal, Z.A., Rifau, A., Quadir, G.A and Seetharamu, K.N. (2002). Experimental investigation of a downdraft biomass gasifier. Biomass and Bioenergy, 23: 283-288.Zhou, J., Chen, Q., Zhao, H., Cao, X., Mei, Q.,

Luo, Z., et al. (2009). Biomass–oxygen gasification in a high-temperature entrained-flow gasifier. Biotechnology Advances, 27: 606–11.

Zhou, Z., Yin, X., Xu, J and Ma, L. (2012). The development of biomass gasification power generation in China. Energy Policy, 51: 52-57.