Proceedings of the World Congress on Engineering and Computer Science 2017 Vol II
WCECS 2017, October 25-27, 2017, San Francisco, USA

Evaluation of Potential Substrates for Biogas Production via Anaerobic Digestion: A Review

Noxolo Thandeka Sibiya, Edison Muzenda, *Member, IAENG*, Charles Mbohwa

Abstract— **The anaerobic digestion of organic matter is now a widely-used technology, to address both energy and environment challenges. Biogas can be produced by landfill gas (LG), or produced at sewage treatment plant, in anaerobic digestion of industrial, municipality and agricultural treatment. Biogas contains 50−70% methane and 30−50% carbon dioxide as well as small amounts of other gases, nevertheless, the quality of biogas composition is dependent on the substrate type and technology used. Thus, this paper reviews the methane yield from various feedstocks. Sewage sludge has shown positive methane yield, nevertheless its conversion may be optimized by applying co-digestion process with organic fraction municipality waste (OFMSW) as a co-substrate. Although pulp and paper mill sludge has high methane potential, the amount of methane yield is dependent on the pulp and paper process used and activated sludge plants (ASPs). Generally, methane yield from AD of slaughterhouse range between 160m^3/ton kg VS- 500 m^3/ton kg VS, depending on the amount of blood presented and processes used**.

***Index Terms*—Anaerobic digestion, biogas, feedstock, renewable energy.**

I. INTRODUCTION

ENERGY is a critical factor in overall efforts to achieve sustainable economy and social development of South Africa [1]. More than 90 % of SA energy comes from fossil fuels, however, the dependency on the fossil fuels are anticipated to be the major contributor to local and global environment problems, resulting in climate change [2].

Renewable Energy Sources (RES) can be the answer to the problems created by fossil fuels [3], due to their renewability and environmentally friendly characteristics in comparison to fossil fuels [4], [5], [6], [7]. RES are regarded as those that can be replaced naturally, clean, low risk and inexhaustible [8]. Renewable energy sources include biomass, hydropower, geothermal, solar, wind and biomass [9], [10], [11]. Biomass energy is produced from woody materials, herbaceous materials, agricultural crops, residues and organic wastes [10].

These resources can either be directly combusted for energy production or processed into energy products such as bio-diesel, bio-ethanol and biogas which can be used as production of electricity, transport fuel and heat [12]. Biogas production technology is increasing rapidly, partly, due to their renewability, sustainability and cost effective.

Biogas is the end product from degradation of organic matter by micro-organism by anaerobic process, referred as anaerobic digestion [13]. Practically, biogas is produced at sewage treatment plant, in anaerobic digestion of industrial, municipality and agricultural waste. Biogas is also produced in landfills [14]. Biogas consists mainly as a mixture of methane (CH_4) and carbon dioxide (CO_2), as well as trace amount of other gases [13]. The composition of biogas differs based on the type of substrate used, type of technology used and environmental condition at which the process is operated. Table I shows the biogas composition. Biogas that contains above 45 % methane content is flammable with the caloric value range of 20-25 MJ/m^3 (5.5-8 kWh/m^3) [13]. Biogas can be recovered and transformed into heat in gas turbine or into combined heat and power (CHP). It can also be compressed for vehicle fuel and for the supply via the natural gas grid. The residue from the digester may be further treated and used as soil amendment in agriculture. For all biogas applications except for heating, carbon dioxide must be removed in order to recover higher value of bio-methane [12].

TABLE I
BIOGAS COMPOSITION [13]

Component	Dimensions	AD digester
Methane (CH_4)	%	50-80
Carbon dioxide (CO_2)	%	15-50
Hydrogen sulfide (H_2S)	Mg/m^3	0 - 5000
Ammonia (NH_3)	Mg/m^3	0-450
Caloric value	MJ/m^3	20-35
Caloric value	kWh/m^3	5.5 - 8

II. ANAEROBIC DIGESTION

Anaerobic digestion involves four stages in three phases: hydrolysis phase (hydrolysis stage), acid phase (acitogenesis stage and acidogenesis stage) and methane phase (methanogenesis stage) (Fig 1)[14]. These stages are inter-dependent, therefore the balance in each stage is very important for the effectiveness of the process [15].

Manuscript received June 11, 206. This work was supported in part by University of Johannesburg, Process Energy Environmental Station (PEETS) and City of Johannesburg.

Noxolo Thandeka Sibiya; is with Department of Chemical Engineering; University of Johannesburg; Doornfortein, Johannesburg 2028 South Africa; Cell: +277286918854 (noxolo.sibiya@yahoo.com)

Edison Muzenda; Visiting Professor at Department of Chemical Engineering; University of Johannesburg; Doornfortein, Johannesburg 2028; Tel: +2674900117 (emuzenda@uj.ac.za).

Charles Mbohwa; Professor and Vice Dean at Faculty of Engineering and Build Environment (FEBE); University of Johannesburg; Johannesburg 2028 South Africa; Tel: +2711 559 6165 (cmbohwa@uj.ac.za).

ISBN: 978-988-14048-4-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

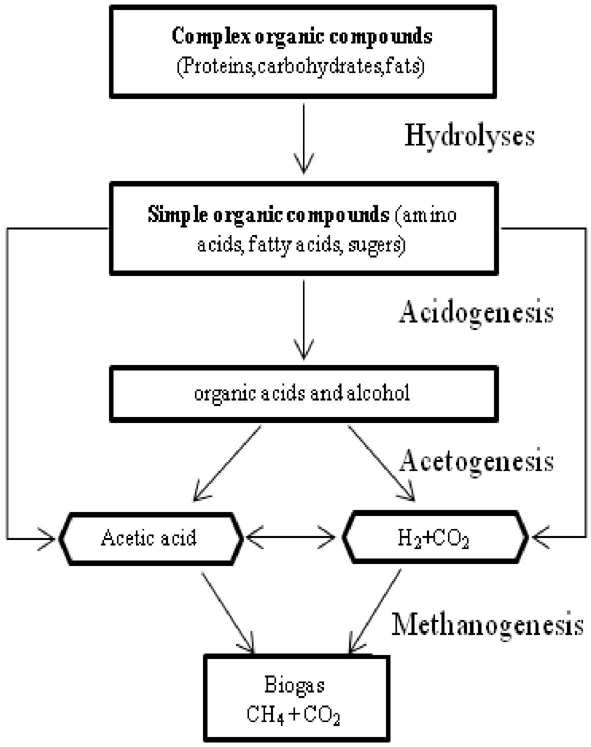

Fig 1. Schematic figure of biogas production via anaerobic digestion [13].

A. *Feedstock for biogas*

As mentioned earlier, biogas can be produced from different biodegradable materials such as:

- Agricultural waste include, animal manure, crops residues (i.e wheat straw) and energy crops (grass, maize, etc)
- Organic Municipality waste include, sewage and organic fractions of MSW
- Organic industrial and commercial waste such as: beverage/ food / tobacco processing waste, slaughterhouse/ rending waste and dairy waste

Although the choice of feedstock for anaerobic digestion is mostly govern by its availability, the characteristics of a feedstock are very important for the efficiency of biogas production [13]. According to reference [16] total solids (TS), total volatile solids (TVS), moisture content (MC), chemical and oxygen demand COD) have a direct effect on biogas production.

Agricultural waste

Animal manure

Animal manure is the biggest source of organic waste within agricultural sector. Animal manure contains plant nutrients, thus most famers used it for soil conditioning on their fields [17], [18]. Nevertheless, it could be instead used for biogas production and afterwards the digestate may be used as a soil conditioner. According to reference [19] the digestion of manure may increase the amount of available nitrogen that plant can recover, and subsequently resulting in a more efficient soil conditioner. Although animal manure can be beneficial in some activities, when not handled suitably it could be harmful to the environment [20]−[22]. Reference [23] reported that animal manure has a high concentration of nitrogen (N) and phosphorus (P), which may lead to nutrients imbalance and environmental pollution. It also contains the residue of some dangerous substances such as heavy metals, antibiotics and growth hormones. Furthermore, micro-organisms contained in animal manure could contaminate the environment, which in turn leads to the eruption of the human diseases [19]. In this regard, it has been discovered that the dumping of the animal manure has a polluting influence on the environment.

Previous studies have been performed to investigate the potential of biogas generation from different manures [24]−[26]. TABLE II shows the potential biogas production from various animal manure in different countries. The results showed that Iran produced maximum biogas of about 6,059,600, 573,600 and 1,966,600 m^3/y from cattle, goats and sheep and poultry manure respectively.

TABLE II
BIOGAS PRODUCTION POTENTIAL FROM VARIOUS ANIMAL WASTES IN DIFFERENT COUNTRY [27]

Region	Biogas production potential (1000 m^3/y)		
	Cattle	Goats and Sheep	Poultry
Denmark	242,200-509,000	-	11,300-41,700
Turkey	1,477,451	108,003	592,099
Finland	197,600-438,000	-	6440-23,900
Iran	6,059,600	573,600	1,966,600
Sweden	214,100-462,00	-	8380-19,700

Manure could be used in the form of liquid or solid, however it has been proven that liquid manure produces more biogas in comparison to solid state manure [28]. Each manure has its own properties, which makes it different with regards to its performance during anaerobic digestion. Table III shows biogas and methane potential from various manure with different characteristics. Although pig manure had high methane yield in comparison to other manures, due to better characteristics, such as balanced carbon to nitrogen (C/N) ratio, all manure produces outstanding methane.

TABLE III
BIOGAS AND METHANE POTENTIAL OF VARIOS MANURE WITH DIFFERENCE CHARACTERISTICS [29]

Manure	TS(%)	VS(%)	C/N ratio	Biogas yield (M3 kg/VS)	CH4 content
Pig slurry	3-8^d	70-80	3-10	0.25-0.50	70-80
cow slurry	5-12^d	75-85	6-20	0.20-0.30	55-75
chicken slurry	10-30^d	70-80	3-10	0.35-0.60	60-80

According to reference [30] mono-digestion of animal manure does not yield sufficient gas to make anaerobic digestion feasible. Furthermore few livestock farms have been reported to keep the cattle indoors all year, resulting in lack of feedstock to keep the digester going oversummer [31]. Therefore, in most commercial plants, manure is normally mixed with other substrates. Methane yield was increased from 0.23 to 0.45 CH_4/gVS when chicken manure

ISBN: 978-988-14048-4-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

was co-digested with fruit and veggie at an organic loading rate (OLR) of 3.19-5.01 kgVS/m^{3}d under mesophilic condition (35 ºC) for 21 days [32]. Reference [33] also reported methane increase of 16−65 % when cattle manure was co-digested with grass silage, sugar beets tops and outs straw at the organic loading rate of 2 KgVS/m^{3}d at 35 ºC.

Energy crops

Energy crops and crops residues represents an important source of biomass that can serve as a substrate for biogas production. Among energy crops, grass is considered more suitable feedstock, hence its availability is not limited to season change. Moreover, according to reference [34] methane from grass has revealed to be suitable for vehicle fuel. Reference [35] reported methane content of about 70−80 % from grass silage stream. According to the South Africa Biogas Industry Association (SABIA), the energy that can be produced from Giant Grass is excellent at 7900 BTU per bone dry pound (4400 kcal per kilogram or 18.4 MJ per kilogram) [36], [37].

The biogas and methane potential from energy crops have been evaluated [38]. Reference [39] evaluated the potential of biogas production from maize grains and maize silage. The authors reported maximum biogas production of about 0.72 m^3/kg of volatile suspended solids (VSS) (nonacidified maize) (at 35ºC) and 0.770 m^3/kg VSS (acidified maize) during anaerobic digestion of maize grains. The authors further reported maximum specific biogas production of about 0.655m^3/kg from maize silage. Methane yield of about 5 − 181 Nm^3/ton$_{fm}$ was observed during anaerobic digestion of difference types of sugarcane [40]. Although energy crops shows positive methane potential, its biodegradability is limited due to that energy crops are lignocellulosic biomass. For example, average grass composition ranges between 10−30 % of lignin, 15−50 % hemicellulose, 24−40 % cellulose [41]. Thus, energy crops with feebly lignified cell walls are degraded easily, while crops with vastly lignified walls may restrain degradation [42]. In this regard, pre-treatment of energy crops prior AD is recommended for enhanced biogas production.

An increase methane production (from 8 % to 19 %) was observed when sorghum was pretreated with sodium hydroxide (NaOH)[43], prior anaerobic digestion. Moreover, reference [44] also reported an increase in the first order kinetic constant when NaOH dosage was increase by 40 %, 61 %, 64 %, 54 %, and 40 % for sorghum.

Municipal waste

Municipal solid waste (MSW) is the waste produced in a society with the exclusion of agricultural waste and industrial wastes [45]. MSW comprises of residential waste, institutional waste and commercial waste. South Africa generates millions of tons of MSW per year and normally collected as mixed stream and disposed on the landfill sites. This act is considered as a waste of energy and nutrients, hence most of organic fraction has a potential to be used as substrate for AD. MSW is normally comprises of about 65 % of biodegradable (33.9 % paper, 12.9 % yard trimming, 12.4 foodscraps, 5.5 % wood) food waste from the kitchen. The methane yield from anaerobic digestion of organic fraction of municipality waste (OFMSW) has been studied in lately, for example, reference [46] evaluated methane yield in source-sorted organic fraction of municipal solid waste. Methane yield of about 300-400 Nm^3 CH_4/ tons VS$_{in}$ were with 80 % VS-degradation were reported. Reference [47] also evaluated biogas production potential from municipal solid waste in a tropical climate. The authors reported 0.17 m^3/ kg VS with the caloric value of +17 kWh/cap/day. Moreover, reference [48] evaluated bio-methane production potential from restaurant food waste in megacities and project level-bottlenecks in Beijing. The authors reported that the 2015 production of about 956,300 tons of food waste could produce about 300 milliom Nm^3 of CH_4.

According to reference [49] individual anaerobic digestion of OFMSW sometimes results in low stability and low efficiency of operation due to its low C/N ratio. Thus, co-digestion of OFMSW with other substrates, such as sludge, agricultural waste and animal manure is recommended. Co-digestion is the concurrent anaerobic digestion of a mixture of two or more substrate with balancing characteristics in order to enhance the performance of the degradation process [50]. Studies of co-digestion of municipality waste have been reported in the literature. An increase of 41.1 % methane with the corresponding methane yield of 388 mL/gVS was achieved when food waste was co-digested with cattle manure [51]. Furthermore, reference [52] reported an increase of 39.5 % and 149.7 % of methane production when food waste was co-digested with straw at a total loading rate of 5g VS/L compared to when food waste was individually anaerobic digested. Methane yield reached 0.392 m^3/kg.VS.

Fruit and Vegetable

Fruit and vegetable wastes are generated largely in markets and many companies in food industry [53]−[54] . Due to their high biodegradability their handling and dumping are quite critical to community acceptance [54] . Anaerobic digestion is suitable for wastes containing moisture content above 50 % than the thermo- conversion processes. Fruit and Vegetable wastes have very high moisture contents (75 – 90 %), nevertheless, the use of fruit and vegetable as a single substrate for biogas production is a challenging process , due to poor substrate composition[54]-[58]Thus, to maximize biogas and methane production from fruit and vegetable different pre-treatment can be applied [54].

Reference [56] evaluated methane yield potential on various fruits including oranges, mangosteen, bananas, and rambutan under mesophilic condition(35 ºC).The level of methane yield from the tested fruit fractions was in the order of seed > pulp > peel. The methane yields from the seed, pulp, and peel were in the range of 504.11 ± 21.15 to 657.89 ± 63.58 ml CH_4/g VS, 287.89 ± 38.79 to 468.91 ± 27.62 ml CH_4/g VS, and 0.00 ± 0.00 to 202.75 ± 40.86 ml CH_4/g VS, respectively.

Reference [57] evaluated biogas recovery from anaerobic digestion process of mixed fruit -vegetable wastes in a single stage fed-batch anaerobic digester at ambient temperature for 14 weeks. The wastes consist of ± 78 %

vegetable waste, ± 4 % tuber waste and ±18 % fruit wastes. The total waste weight was160 kg, mixed manually once in the feeding. The highest methane content was found to be 65 % with the biogas flow of 20–40 ml/min.

The major limitation of AD of fruit and vegetable process was reported to be the rapid acidification. This is attributed to the poorer pH of wastes and the accumulation of volatile fatty acids (VFA), which lessen the methanogenic activity of the digester. In this regard, preliminary treatment is necessary to reduce organic loading rate [58][59][60].

Sewage waste

The management of sewage sludge is an increasing problem worldwide; hence sludge production will continue to increase as industries are increasing [58]. Sewage sludge is generally produced from sludge process, such as municipal and industrial wastewater treatment plants (WWTPs) [59]. Sewage sludge may be used as manure, as it contains similar quantities of nitrogen, phosphorus and organic matter. Nevertheless, sewage sludge also contains micro-pollutants and pathogens, which makes its management to be expensive and environmentally sensitive [59]. Among sludge treatment, anaerobic digestion is the best suitable and extensively applied to sludge treatment. Reference [60] evaluated the biogas generation from sewage in four public universities in Ghana. The authors reported the estimated population for the four universities to be 100,313 when in Session and 20,903 on vacation and the estimated daily sewage generated was1379.9 m^3 and 327.8 m^3, when the universities were in session and on vacation respectively. This study further shows that an annual biogas potential of about 815,109 m^3 could be obtained which is equivalent to about 4,891 MWh of energy or can replace about 4532 tonnes of firewood or 326.4 tonnes of LPG which can reduce the pressure on the forest and the use of LPG.

Although anaerobic treatment of sewage sludge is traditionally implemented in municipal wastewater treatment plants operational data have indicated possible reserves of the digesters' capacity, frequently as much as 30 % [61]. Thus, biogas from sludge is usually optimized, by mixing sludge with one or two substrates under the process referred as co-digestion [61]. The most suitable co-substrate for sludge treatment is OFMSW, as sludge supplies sufficient moisture content, micro/macronutrients, and alkalinity, but a low carbon–nitrogen (C/N) ratio. While OFMSW is characterized by its high solid concentration and high C/N ratio [45]. Reference [62] observed an increase of methane yield between 110 % and 180 % when OFMSW (fruits) were introduced in the digester.

Industrial waste

Industrial waste is the waste resulting from manufacturing and industrial plants, including pulp and paper, slaughter house, grain mills, and dairies. AD is a widely-used method of industrial residues treatment. Among industrial waste mentioned, pulp and paper and slaughter house waste have been evaluated for the biogas and methane potential [63]. According to reference [64] utilizing sludge from pulp and paper mill in biogas plants provides several benefits. Hence, pulp and paper mill sludge has high organic content, thus making its easily biodegradable.

Large amount of sludge are produced from point sources and therefore it is not essential to combined material to achieve feasible quantities for AD. Moreover, AD of pulp and paper mill sludge provides economic benefits to mills, including low cost of transport, the potential to co-ordinate operation and maintenance with the existing organization [64]. The pulp and paper process and activated sludge plants (ASPs) used have significant impact on the methane yield produced during anaerobic digestion process [65] i.e. methane yield for bleaching kraft pulp and paper mill secondary sludge was reported to be 50 m^3/ VS $_{add.}$ Range between 89-197 m^3/t VS $_{added}$ was observed for secondary sludge of thermo-mechanical pulp mill, 159 m^3/t VS $_{added}$ for secondary sludge sulphite pulp mill, 145 m^3/t VS added for secondary sludge kraft pulp mill and 97-199 m^3/t VS added for chemo-thermomechanical secondary sludge pulp and kraft pulp mill [66]. Pre-treatment of pulp and paper sludge, prior AD can be applied to decrease the necessary retention time to produce biogas from pulp and paper mill.

According to reference [67] slaughter house waste contains similar chemical characteristic as those of household sewage, nevertheless are significantly more concentrated. Slaughter house waste is wholly organic, which make it more suitable feedstock for biogas production. The success of anaerobic digestion of slaughterhouse is generally dependent on the effective removal of BOD (Biochemical oxygen demand) [68]. Generally methane yield from AD of slaughterhouse range between 160 m^3/ton kg VS- 500 m^3/ton kg VS, depending on the amount of blood presented and processes used [69].

III. Conclusion

This paper reviewed various feedstocks for the biogas production by anaerobic digestion. All feedstock have shown to have biogas and methane potential. Sewage sludge has high methane production in comparison to other feedstocks. Individual anaerobic digestion of several feedstocks including animal manure, energy crops, fruit and veggies and food waste has been reported to result in process instability and low process efficiency, thus co-digestion process has been recommended for enhanced process performance.

Acknowledgment

This work was supported by a City of Johannesburg (COJ) and university of Johannesburg (UJ). The Botswana International University of Science and Technology is also acknowledged for financial and technical support.

References

[1] H. Winkler, "Renewable energy policy in South Africa: policy options for renewable electricity," *Energy Policy*, vol. 33, no.1, pp. 27-38, 2005.

[2] S. Mwakasonda, "South Africa low carbon scenario report," *University of Cape Town: Energy Research Centre*, 2007.

[3] S. Karytsas, and H. Theodoropoulou, "Socioeconomic and demographic factors that influence publics' awareness on the different forms of renewable energy sources," *Renewable Energy*, vol. 71, pp. 480-485, 2014.

[4] F. Galembeck, "Synergy in food, fuels and materials production from biomass," *Energy & Environmental Science*, vol.3, pp.393-399, 2010.

[5] A. Evans, V. Strezov, and T.J. Evans, "Sustainability considerations for electricity generation from biomass," *Renewable and Sustainable Energy Reviews*, vol.14, pp.1419-1427, 2010.

[6] R. Singh, and A. D. Setiawan," Biomass energy policies and strategies: Harvesting potential in India and Indonesia," *Renewable and Sustainable Energy Reviews*, vol.22,pp.332-345,2013.

[7] S.E. Hosseini, and M.A. Wahid, "Utilization of palm solid residue as a source of renewable and sustainable energy in Malaysia," *Renewable and Sustainable Energy Reviews*, vol.40, pp.621-632,2014.

[8] N.Y. Amponsah, M. Troldborg, B. Kington, I. Aalders, and R.L. Hough, "Greenhouse gas emissions from renewable energy sources: A review of lifecycle considerations," *Renewable and Sustainable Energy Reviews*, vol.39,pp.461-475, 2014.

[9] T.B, Johansson, *Renewable energy: sources for fuels and electricity*. Island press, Washington, pp.123-213., 1993.

[10] J. Cheng, *Biomass to renewable energy processes*. CRC press, United State of America,pp.151, 2009.

[11] D. Deublein, and A. Steinhauser, *Biogas from waste and renewable resources: an introduction*. John Wiley & Sons, 2011.

[12] R.L. Bain, and R.P. Overend, "Biomass for heat and power," *Forest Products Journal*, vol.*52*,pp.12-19, 2002.

[13] Edison Muzenda, "Bio-methane Generation from Organic Waste: A Review," Lecture Notes in Engineering and Computer Science: Proceedings of The World Congress on Engineering and Computer Science 2014, WCECS 2014, 22-24 October, 2014, San Francisco, USA, pp647-652,

[14] O. Alsayegh, S. Alhajraf and H. Albusairi, "Grid-connected renewable energy source systems: challenges and proposed management schemes," Energy Conversion and Management, vol. 51(8), pp.1690-1693, 2010.

[15] S.K. Khanal, *Anaerobic biotechnology for bioenergy production.* Principles and Application Willey and Blackwell,pp.161-86, 2008.

[16] R. Kigozi, A. Aboyade, and E. Muzenda. "Biogas production using the organic fraction of municipal solid waste as feedstock." 2013.

[17] G. Yorgey, C. Frear, C. Kruger, and T. Zimmerman, "The Rationale for Recovery of Phosphorus and Nitrogen from Dairy Manure," 2014.

[18] L. Cooperband, "Building soil organic matter with organic amendments," *Center for Integrated Agricultural Systems*, 2002.

[19] B. LeaMaster, J.R. Hollyer, and J.L. Sullivan, "Composted animal manures: Precautions and processing," 1998.

[20] Livestock manure to energy- inbiom. http://www.inbiom.dk/Files//Files/Publikationer/Manure-to-Energy_UK_web.pdf accessed on 11/05/2016

[21] N. Phetyim, T. Wanthong, P. Kannika, and A. Supngam, "Biogas Production from Vegetable Waste by Using Dog and Cattle Manure," *Energy Procedia*, vol.79, pp.436-44, 2015.

[22] Group report. Quantification of feedstock Anaerobic Digestion in Northen Ireland case study. http://questor.qub.ac.uk/GeneralFileStorenew/DO-Bioenergy/Filetoupload,465975,en.pdf. accessed on 11/05/2016.

[23] T.Q. Sudduth, and M.J. Loveless, "Decreasing Nitrogen and Phosphorus Excretion by Dairy Cattle," 2004

[24] P. Abdeshahian, J. S. Lim, W. S. Ho, H. Hashim, and C. T. Lee, "Potential of biogas production from farm animal waste in Malaysia." *Renewable and Sustainable Energy Reviews* 60, pp.714-723, 2016.

[25] A. O. Avcioğlu, and U. Türker, "Status and potential of biogas energy from animal wastes in Turkey," *Renewable and Sustainable Energy Reviews* 16, no. 3 , pp.1557-1561, 2012.

[26] H. Afazeli, A. Jafari, S. Rafiee, M. Nosrati, " An investigation of biogas production potential from livestock and slaughterhouse waste," *Renewable and Sustainable Energ review* 34, pp.380 , 2014.

[27] A. Peyman, J. S. Lim, W. S. Ho, H. Hashim, and C. T. Lee. "Potential of biogas production from farm animal waste in Malaysia," *Renewable and Sustainable Energy Reviews* 60 ,pp. 714-723, 2016.

[28] Livestock manure to energy- inbiom. http://www.inbiom.dk/Files//Files/Publikationer/Manure-to-Energy_UK_web.pdf accessed on 11/05/2016

[29] R. Sebola, "Studies on the improvement of biogas production from anaerobic digestion of animal waste," Department of chemical engineering, University of Johannesburg, Master of technology, Dissertation, p 23, 2015.

[30] N. Phetyim, T. Wanthong, P. Kannika, and A. Supngam, "Biogas Production from Vegetable Waste by Using Dog and Cattle Manure," *Energy Procedia*, vol.79, pp.436-44, 2015.

[31] Group report. Quantification of feedstock Anaerobic Digestion in Northen Ireland case study. http://questor.qub.ac.uk/GeneralFileStorenew/DO-Bioenergy/Filetoupload,465975,en.pdf

[32] F.J. Callaghan, D.A.J. Wase, K. Thayanithy, and C.F. Forster, "Continuous-co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure," *Biomass and Bioenergy*, vol. 27, pp. 71–77, 2002.

[33] A. Lehtomäki, S. Huttunena and J.A. Rintala, "Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio," *Resources, Conservation and Recycling*, vol. 51(3), pp. 591– 609, 2007.

[34] P.A. Gerin, F. Vliegen, and J.M. Jossart, "Energy and CO 2 balance of maize and grass as energy crops for anaerobic digestion," *Bioresource Technology*, vol. 99, pp.2620-262, 2008.

[35] J. Abu-Dahrich, A. Orozco, M. Ahmad, and D. Rooney, "The Potential of Biogas Production from Grass," In *Proceedings of the Jordan International Energy Conference, Amman*, 2011.

[36] E. Cooke, "Gas production from waste and crops," *City of Johannesburg gas for mobility summit*, October 1, Johannesburg, South Africa, 2014.

[37] D. De Clercq, Z. Wen, F. Fan, and L. Caicedo, "Biomethane production potential from restaurant food waste in megacities and project level-bottlenecks: A case study in Beijing." *Renewable and Sustainable Energy Reviews* 59, pp.1676-1685, 2016.

[38] T. Amon, B. Amon, V. Kryvoruchko, W. Zollitsch, K. Mayer, and L. Gruber, "Biogas production from maize and dairy cattle manure—influence of biomass composition on the methane yield," *Agriculture, Ecosystems & Environment*, vol.118, pp.173-182, 2007.

[39] M. Hutňan, V. Špalková, I. Bodík, N. Kolesárová, and M. Lazor. "Biogas production from maize grains and maize silage." *Polish J Environ Stud* 19,pp.323-329,2010.

[40] L. Janke, A. Leite, M. Nikolausz, T. Schmidt, J. Liebetrau, M. Nelles, and W. Stinner. "Biogas production from sugarcane waste: Assessment on kinetic challenges for process designing." *International journal of molecular sciences* 16, no. 9,pp.20685-20703,2015.

[41] A.S. Nizami, N.E. Korres, and J.D. Murphy, "Review of the integrated process for the production of grass biomethane," *Environmental science & technology*, vol.43, pp. 8496-8508, 2009.

[42] J.R. Wilson, and D.R. Mertens, "Cell wall accessibility and cell structure limitations to microbial digestion of forage," *Crop Science*, vol.35, pp.251-259, 1995.

[43] C. Sambusiti, E. Ficara, F. Malpei, J. P. Steyer, and H. Carrere, "Influence of alkaline pre-treatment conditions on structural features and methane production from ensiled sorghum forage," *Chemical Engineering Journal*, *211*, pp. 488-492, 2012.

[44] C. Sambusiti, E. Ficara, F. Malpei, J.P. Steyer, and H. Carrère, "Effect of sodium hydroxide pretreatment on physical, chemical characteristics and methane production of five varieties of sorghum," *Energy*, *55*,pp. 449-456, 2013.

[45] G. Tchobanoglous, H. Theisen, and S. Vigil, "Integrated solid waste management: engineering principles and management issues," McGraw-Hill, Inc, 1993

[46] A. Davidson, C Lövstedt, J. la Cour Jansen, C. Gruvberger, and H. Aspegren, "Co-digestion of grease trap sludge and sewage sludge," *Waste Management*, vol.28, pp.986-992, 2008.

[47] T. Getahun, M. Gebrehiwot, A, Ambelu, T. Van Gerven, and B. Van der Bruggen, "The potential of biogas production from municipal solid waste in a tropical climate," *Environmental monitoring and assessment*, vol.186, no .7, pp.4637-4646,2014.

[48] D. De Clercq, Z. Wen, F. Fan, and L. Caicedo, "Biomethane production potential from restaurant food waste in megacities and project level-bottlenecks: A case study in Beijing." *Renewable and Sustainable Energy Reviews* 59, pp.1676-1685, 2016.

ISBN: 978-988-14048-4-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

[49] J. Lin, J. Zuo, L. Gan, P. Li, F. Liu , K. Wang, L. Chen, and H. Gan, " Effects of mixture ratio on anaerobic co-digestion with fruit and vegetable waste and food waste of china," *Journal of Environment Science*, vol.23, no.8,pp.1403-1408, 2011.

[50] J. Pagés-Díaz, I Pereda-Reyes, M.J. Taherzadeh,I. Sárvári-Horváth, and M. Lundin, "Anaerobic co-digestion of solid slaughterhouse wastes with agro-residues: synergistic and antagonistic interactions determined in batch digestion assays," *Chemical Engineering Journal*, vol.245,pp. 89-98, 2014.

[51] C. Zhang, G. Xiao, L. Peng, H. Su, and T. Tan, "The anaerobic co-digestion of food waste and cattle manure," *Bioresource technology*, vol.*129*, pp.170-176, 2013.

[52] Z. Yong, Y. Dong, X. Zhang, and T. Tan, "Anaerobic co-digestion of food waste and straw for biogas production," *Renewable Energy*, vol.78, pp.527-530, 2015.

[53] E. A. Scano, A. Carla , P. Agata , O. Luca, D. Valeria and C. Daniele, "Biogas from anaerobic digestion of fruit and vegetable wastes: experimental results on pilot-scale and preliminary performance evaluation of a full-scale power plant." *Energy Conversion and Management* 77, pp.22-30, 2014.

[54] C. Asquer, A. Pistis, and E.A. Scano, "CHARACTERIZATION OF FRUIT AND VEGETABLE WASTES AS A SINGLE SUBSTRATE FOR THE ANAEROBIC DIGESTION Extended abstract," *Environmental Engineering and Management Journal*, vol.12,pp.89-92, 2013..

[55] H. Bouallagui, R.B. Cheikh, L. Marouani, and M. Hamdi, "Mesophilic biogas production from fruit and vegetable waste in a tubular digester."*Bioresource Technology*, vol.86, pp. 85-89, 2003.

[56] A.P. Sanjaya, M.N. Cahyanto, and R. Millati, "Mesophilic batch anaerobic digestion from fruit fragments," *Renewable Energy*, 2016.

[57] B. Sitorus, and D. P. Seno, "Biogas recovery from anaerobic digestion process of mixed fruit-vegetable wastes." *Energy Procedia* 32, pp.176-182, 2013.

[58] J.E. Hall, "Sewage sludge production, treatment and disposal in the European Union," *Water and Environment Journal*, vol.9, pp. 335-343, 1995.

[59] L. Appels, J. Baeyens, J. Degrève, and R. Dewil, "Principles and potential of the anaerobic digestion of waste-activated sludge," *Progress in energy and combustion science*, vol.34,pp.755-781, 2008.

[60] R. Arthur, M. F. Baidoo, A. Brew-Hammond, and E.C. Bensah, "Biogas generation from sewage in four public universities in Ghana: A solution to potential health risk," *Biomass and bioenergy* 35, no. 7,pp.3086-3093, 2011.

[61] L.L. Pastor, A.P. Ruiz, and B. Ruiz, "Co-digestion of used oils and urban landfill leachates with sewage sludge and the effect on the biogas production." *Applied energy* 107, pp.438-445, 2013.

[62] F. M. A. Raposo, De la Rubia, V. Fernández-Cegrí, and R. Borja. "Anaerobic digestion of solid organic substrates in batch mode: an overview relating to methane yields and experimental procedures." *Renewable and Sustainable Energy Reviews* 16, no.1, pp.861-877, 2012.

[63] J. Jia, S. Zhao, X. Kong, Y. Li, G. Zhao, W. He, and R. Jing, "Aegilops tauschii draft genome sequence reveals a gene repertoire for wheat adaptation," *Nature*, vol.496, no.7443, pp.91-95, 2013.

[64] P. Hagelqvist, "Batchwise mesophilic anaerobic co-digestion of secondary sludge from pulp and paper industry and municipal sewage sludge," *Waste management*, vol.33, no.4, pp.820-824, 2013.

[65] S. Bayr, P. Kaparaju, and J. Rintala, "Screening pretreatment methods to enhance thermophilic anaerobic digestion of pulp and paper mill wastewater treatment secondary sludge," *Chemical engineering journal*, vol.223, pp.479-486, 2013.

[66] A. Karlsson, X.B. Truong, J. Gustavsson, B.H. Svensson, F. Nilsson, and J. Ejlertsson, "Anaerobic treatment of activated sludge from Swedish pulp and paper mills–biogas production potential and limitations," *Environmental technology*, vol.32, pp.1559-1571, 2011.

[67] J. Ahmad, and T.A. Ansari, "Biogas from Slaughterhouse Waste: Towards an Energy Self-Sufficient Industry with Economical Analysis in India," *Journal of Microbial & Biochemical Technology*, 2013.

[68] M. Ortner, M. Rameder, L. Rachbauer, G. Bochmann, and W. Fuchs, " Bioavailability of essential trace elements and their impact on anaerobic digestion of slaughterhouse waste," *Biochemical Engineering Journal*, vol.99,pp. 107-113, 2015.

[69] P.D. Jensen, T. Sullivan, C. Carney, and D. J. Batstone, "Analysis of the potential to recover energy and nutrient resources from cattle slaughterhouses in Australia by employing anaerobic digestion," *Applied Energy*, vol.136, pp.23-31, 2014.

ISBN: 978-988-14048-4-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)