INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & MANAGEMENT

A REVIEW OF INTEGRATED SOLUTIONS TO WASTE MANAGEMENT PROBLEMS

Sofoluwe, Adekunle Olushola
Evagreen Professional Services Limited

ABSTRACT

Waste management has been a global concern especially the organic fraction of the waste. This paper examine the current waste management practice and the integration of anaerobic digestion technology into managing the solid organic waste, its benefit. The paper also examine the drivers for integrated waste management strategy, requirement and challenges facing anaerobic digestion technology.

Keywords- *Integrated Waste management; Anaerobic Digestion; Organic waste; Bioreactors.*

I. INTRODUCTION

There has been a global increase in solid organic waste generation with approximately two (2) billion tons per year and presumed estimate of about three (3) billion tons in the year 2025 Charles *et al* (2009), which needs to be managed and controlled in a sustainably approach in order to avoid the depletion of non renewable natural resources, reduce the potential negative effect on the environment and human health thereby balancing together the overall ecosystem.

Although, various kinds of technologies have been used in treating and managing solid organic waste in order to protect human health and the environment via source reduction; recycling and composting; combustion (waste to energy); anaerobic digestion; and landfills (Tchobanoglous and Kreith, 2002; Khald *et al,* 2011). This is a challenge within the developing countries as a result of poor infrastructure and facility (UNESCO, 2003).

The purpose cannot be achieved without a proper and efficient waste management plan of reduce, recover and reused strategy of the discarded waste in ensuring sustainable development Read (1999) which must balance social, economic and environment at a point in time.

According to Arowolo and Sridhar (2005), Integrated Waste Management (IWM) is defined as the combination of various waste management techniques and technologies with the aim of reducing and minimizing the total amount of waste generated in order to protect the environment from any kinds of pollution. Figure 1 shows the general framework for IWM. The waste hierarchy under the IWM includes waste prevention, reuse, recycling (compositing), incineration and landfill. Waste prevention ensures the use of less waste materials with more reused in order to save the finite non-renewable materials, energy and resource cost while the last options which must be avoided is the final disposal to the landfill, the final resting point for most of the wastes.

II. DRIVERS FOR INTEGRATED WASTE MANAGEMENT

Integrated waste management is organised in a systematic channels in order to ensure proper disposal methods which must be acceptable to the general public without having any negative effect on their health and the environment (Kofoworola, 2007).

The efficient way of treating and managing solid waste cannot be achieved without a detailed waste management plan strategy Davoudi (2000) which is explained by Rossel and Jorge (1999) as the techniques developed in order to avoid waste generation by using a cleaner technology, encouraging waste recycling and recovery, using appropriate treatment for the waste generated with efficient final waste disposal without any negative impact on the environment and human health.

The specific drivers for integrated waste management according to findings Wilson (2007) is as a result of resource values for various waste materials; protection of the environment; and safeguard of human health from improper handling, open burning of waste and disposal to landfills and incineration whereby the leachate, dioxin and gases from landfill and incinerator plant causes pollution which is dangerous to human health and the environment.

The international driver on waste management is the emergence of extended producer responsibility (EPR) which makes it a duty for producers to manage and control the potential environmental impacts of their product throughout its lifespan.

Also taking the financial responsibility for the collection, reprocess and safe disposal of each product at the end of their working lifespan. EPR is an economic instrument and policy used in driving changes in waste management among the producers manufacturing products that will be efficient and safe for the environment.

Another important driver for rapid changes in integrated waste management is the new regulatory framework and policy on waste management especially on waste diversion and reduction going to landfills by increasing the landfill tax and the charge on waste going to the landfill. Public awareness is another driver in integrated waste management which helps to re-orientate the general public about the various environmental issues like climate change, pollution and causes in order to ensure the safety of the environment through efficient resource management, recycling, reuse and recovery of waste which help in behaviour change from past ideology about awful waste management practice of open burning, improper waste discharge into water body (Sharp, 2006; METAP, 2000). No matter how clean and sustainable the waste management facility might be because nobody want such facility in his/her backyard.

Finally the occurrence of climate change in the 1990s also trigger drivers for waste management in the developed countries as a result of emission from organic waste sent to the landfills generating methane and uncontrolled anaerobic digestion which emits greenhouse gases.

III. INTEGRATE WASTE MANAGEMENT TECHNIQUES

Waste management techniques have been the methods used in treating solid waste in order to reduce its potential impact on the human health and the environment which is achieved by efficient waste collection system at point source, using different low emission trucks for transportation with different kinds of waste treatment facilities like composting and incineration to ensure sustainable development. But a challenge in the developing countries compared to the developed countries as a result of improper waste management strategy on solid organic waste which constitute higher percentage of their waste.

Waste reduction

Waste reduction/prevention has been the main concern in the principle of waste management with the aim of reducing the quantity and pollution capability of any waste generated, eliminating the need for waste handling, transportation. Any forms of disposal of the solid waste which provide high level of environmental protection by efficiently making use of the available resources and the same time removing the potential environmental impact that may results from any kinds of pollution (Alagir *et al*, 2005). This can only be achieved by total reduction on the amount of materials used for every product without compromising on the quality of the product; extending the lifespan of every product produced; and eliminating the various need for the product (Vesilind *et al*, 2002).

Recycling and reuse

According to Bolaane (2006), recycling is defined as the collection and separation of various kinds of materials that is useful from waste which is later processed to produce a marketable final product to meet our need at a particular time. The Material Recycling Facility (MRF) in is used purposely for sorting of waste into different fractions is common in both developed and few developing countries (UNCRD, 2003). The most waste that is often recycle are paper, plastic, glass, aluminium, steel and some yard wastes though with some challenges as identified by Furedy (1992), as a result of exploitation from waste buyers, poor health and living conditions of the scavengers who deal with the waste.

Friends of the Earth (1997), also highlighted the benefits from recycling which include:

- It helps to reduce the demand for a new raw materials by extending the product life and the same time maximising the value been extracted from them,
- It encourages personal responsibility towards the kinds of waste that we generated.
- It helps in reducing the total amount of waste send to the landfill if more waste is recycled.
- It helps in reducing the total volume of emission into the atmosphere during different kinds of production processes.
- It helps to save and reduce the amount of energy used during production, transportation which normally contribute more environmental damage due to CO_2 emission during production stage compare to the energy require when processing fresh raw materials.
- It helps in saving cost on transportation and reduces the potential impact in the environment like pollution, habitat damage during extraction of raw materials,

Recycling is accepted as efficient means of treating solid waste in a sustainable manner without it causing further deterioration to the environment and human health instead reduces the total amount of waste to be disposed and sent to landfill to conserve the depleted non-renewable resources (Muttamara, 1996; White *et al*, 1995; and Van Beujering *et al*, 1999).

Landfill

Cossu *et al*, (2001) describe land filling as a large holes made into the ground for the purpose of waste disposal. The holes can be a depression, abandoned mines, opening purposely excavated to serve as land filling or a borrowed pit. Due to its low cost of operation and the tendency of acquiring any forms of waste compare to other waste disposal options increases the wider used in both developed and developing countries which emit uncontrolled methane and carbon dioxide into the atmosphere (Daskalopoulos *et al,* 1998).

The various types of landfills are: sanitary; secured landfill and open-dump system or ordinary landfill. Open-dump landfill system is often used for solid waste disposal either to pits, excavated lands or undulating landscapes and a plain flat lands without the waste been covered up which often causes air pollution through odour and continuous burning of the waste which have negative impact on human health; emission of greenhouse gases and groundwater contamination from uncontrolled landfill; littering the surrounding with waste, presence of vermin like rat and mice and a sure breeding for disease vectors like flies and mosquitoes (Adewale, 2011; Tchobanoglous *et al,* 1993).

Incineration

Hester and Harrison, (1993) describe incineration as a method involving the combustion of a solid waste or material in order to convert into more convenient form either by reducing the bulkiness or transforming it into less hazardous component. This is achieved by burning the solid waste at a very high temperature of about 900-1200^{o}C in a high efficiency furnace, producing stream and residual ash as the end product which by weight weigh about 8-10kg per every 100 kg of solid waste. Incineration helps in reducing the total volume of waste; generation of energy in the form of electricity; and heat production (Seo *et al*, 2004) though with higher potential environmental impact both to human health and the ecosystem.

The principal challenges affecting waste incineration plant varies from the construction to operation cost for the facilities which is more expensive for most developing countries to operate. The potential environmental impact from the emissions varies but often will produce carbon dioxide; greenhouse gases; oxide of nitrogen and sulphuric dioxide which causes acid rain; presence of toxic compounds like heavy metals (lead, mercury) and hydrocarbon (dioxin). The ash generated is send to the landfill for disposal which contains hazardous materials like phosphorus and fluorides. Due to various kinds of gaseous emission and its potential negative impact on human health and environment, incineration has been rejected as a means of treating solid waste but can still work efficiently without causing any harm to the environment and human health if properly monitored and maintained.

Composting

According to Seo *et al*. (2004); Renkow and Rubin (1998), composting is described as a controlled biological method that uses both natural aerobic process and microbial organisms to fasten the rate of decomposition of organic materials presence in any solid organic waste. The microbial organisms break down the solid organic waste into carbon dioxide, minerals, water and more stable organic matter. Both the water and carbon dioxide are released into the atmosphere while the organic matter and the minerals are converted and reused as soil amendment called compost.

The end product is beneficial to remediate soil and serves as fertilizer or nutrient Poincelot (1974); Airan and Bell (1980). Composting of solid organic matter so far has efficiently remediated the soil and sediments with presence of hydrocarbons, contaminated land and also toxic organic materials present in the waste are remediated through composting (Williams and Keeham, 1993; Chaney *et al*, 2001). But the accumulation of the heavy metals and pathogens have been the negative effect of composting which could be hazardous to human health and the environment (water, land and air).
This can only be avoided by proper separation of the organic waste at point source and probably with addition of lime to reduce the potential availability of heavy metal (Ciavatta *et al,* 1993).

Anaerobic digestion

Anaerobic digestion technology for treating solid organic waste has been receiving global attention since early 1990s and considered to be more sustainable compare to other techniques used in treating waste (Karaglannidis and Perkoulidis, 2009).
According to Lastella *et al*, (2002); Lata et al, (2002); Khald *et al,* (2011) it is a process involving the breakdown of organic wastes ,biologically into biogas in the absence of oxygen but under the action of facultative and obligate microbes with the residual digestate utilised as fertilisers.

IV. INTEGRATED WASTE MANAGEMENT STRATEGY

The waste hierarchy presents an efficient method in the integrated waste management strategy which emphasises that waste should be managed by various methods based on the waste quality and characteristics. The most preferred options in the waste hierarchy as shown in figure 2 are waste prevention; reuse; Recycling while the least options which is not acceptable is the opening burning and dumping of waste. The hierarchal structure was designed to safeguard and improve the quality of environmental health from any kinds of waste disposal with the waste streams responsible for negative impacts on the environment constituting the least form of acceptance.

The ranking of integrated waste management (IWM) strategy can be efficient and effective when considering the environmental aspects but the economic and social aspects may not support the rankings in most cases. Waste prevention is considered the best option; recycling may not be economically feasible in some cases thereby deviating from the basic general hierarchy. Incineration will be difficult to accepted socially as a result of public acceptance for such technology to be place within mile of their residential area.
It will be more efficient to recycle some category of waste like refrigerator than to reuse because more energy will be used in the old state and more environmental damages will been caused which will be almost equivalent when processing a new raw material. It can be deduce that IWM strategy should be more flexible in order to achieve its aim of protecting environment and the human health.

In considering the environmental aspect, waste prevention is considered first in the IWM strategy because it reduces the total amount of waste that is produced at point source, example is surcharging excess bags or household waste as to reduce and save energy which help in conserving our resources and also reducing the volume of the waste stream.

The reuse strategy ensures the use of any waste product more than once either for the same or different purposes. For instance taking wastes generated by one company and use as a raw materials in another company which helps in reducing the negative impact of various activities on the environment but ensuring sustainable development. Example is “by-product synergy” using steel slag could be converted to a raw material used in cement production; using waste CO_2 generated by other companies which can be reused as carbonated beverages or in agricultural applications.

The third strategy is recycling which entails reprocessing of different waste materials into the same form or different product entirely and to make it more efficient, there must be an effective system for the waste collection, scavenging and processing with a higher percentage for reuse, with special market structures and incentives to encourage recycling and composting.

The fourth strategy is the waste recovery which has to do with incineration of different kinds of waste to generate energy and heat, combining both material recovery and energy recovery do extend the lifespan of the incineration plant. The last option that is least considered in IWM where all kinds of residues and ash from various kinds of materials that can never be recovered, reused are been disposed to the landfill constituting higher environmental damage, though single approach on waste management practice cannot achieve the aim of IWM strategy due to different waste quality and characteristics. Therefore all the waste management methods must be used efficiently in ensuring the safety of our environment and human health in a sustainable manner.

V. ANAEROBIC DIGESTION TECHNOLOGY (ADT)

Anaerobic digestion is considered as a better option in dealing with organic portion of the solid waste in a more sustainable way by reducing the negative impact of waste (Lee et al, 2009).
The organic fraction of the waste will be converted into useful end products like biogas and energy-rich compounds which will play a major part in meeting the ever increasing global demand of energy for the future. This will reduce the dependent on fossil fuel and non-renewable natural resources; greenhouse gas emissions causing climate changes and guarantee a safe environment for the present and future generation. Anaerobic digestion (AD) is one of the oldest digestion plant technologies on the planet that uses some specific bacterial to break down organic fraction of a

solid waste into a more stable solid (digestate) and biogas which comprises of carbon dioxide and methane. The AD process occur naturally in an oxygen-depleted organic environment likes the bogs; landfill and rice paddies which have been harnessed because of its benefit in processing farm waste and sludge from sewage treatments facility since the year 1850s in India and China (Mahony and O'Flherty, 2002).

There are different kind of stages and metabolic reaction in anaerobic digestion which include hydrolysis, acidogenesis, acetogenesis and methanogenesis (Batstone et al, 2002; Themelis and Ulloa, 2007). Comparing the enclosed and open system of anaerobic digestion of organic solid waste in landfills where there is escape of greenhouse gases like methane gases and carbon dioxide into the atmosphere causing pollution to the environment (Zhu et al, 2009).

Under enclosed and a monitor system, biofuel and organic digestate as biofertilizer for soil with methane and hydrogen will be the end product in the absence of oxygen Chanakya et al, (2007); Guermoud et al, (2009) making anaerobic digestion in enclosed system more cleaner than the fossil fuel which emits greenhouse gases during combustion compared to anaerobic digestion which emits carbon-neutral carbon dioxide without any direct negative effect on the atmospheric carbon dioxide and reduces the over dependent on fossil fuel for energy generation and consumption (Jingura and Matengaifa, 2009).

ISSN 2277 – 5528
Impact Factor- 3.145

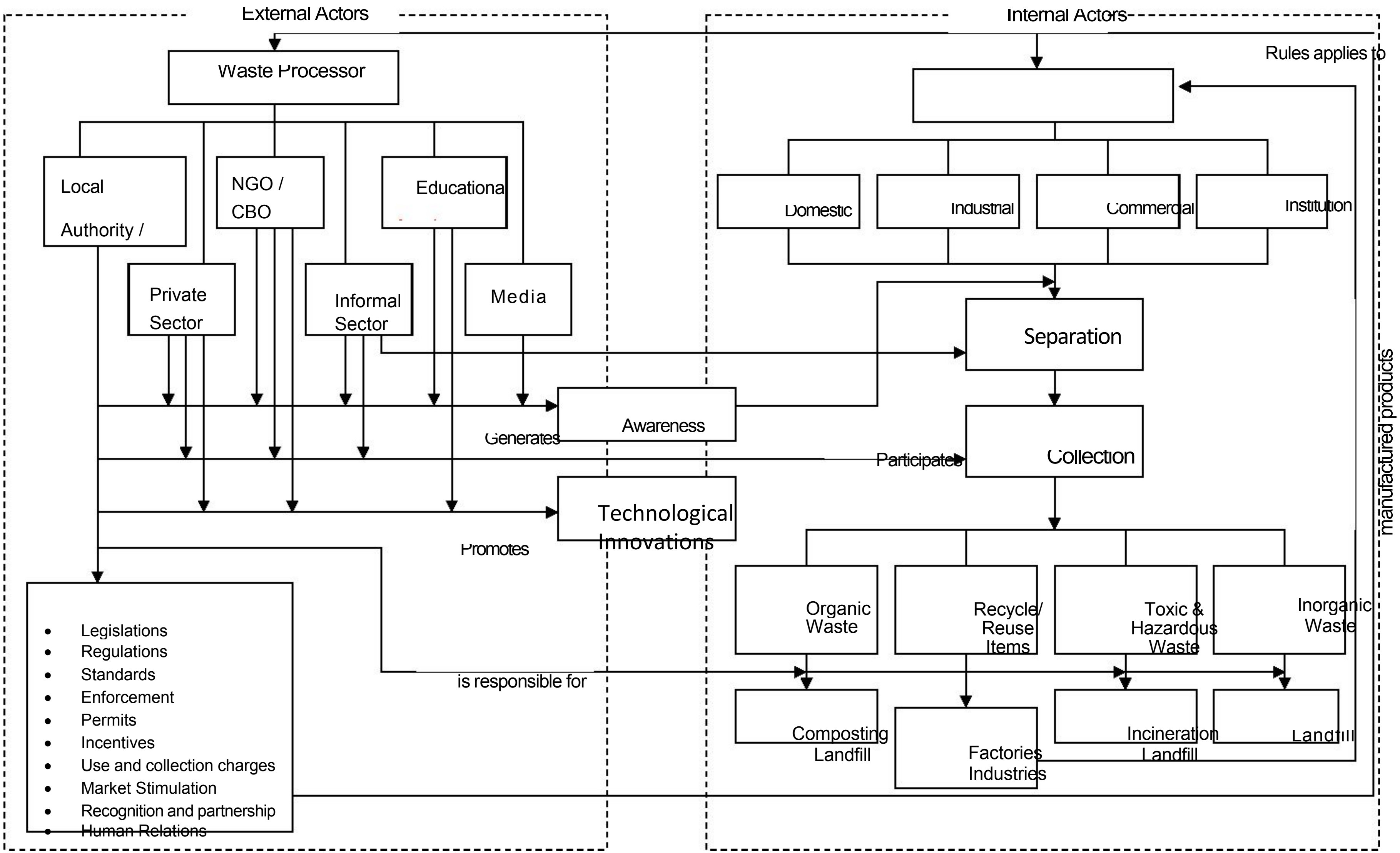

Figure 1: Conceptual Framework of Integrated Solid Waste Management adopted from (UNCHS, 2000)

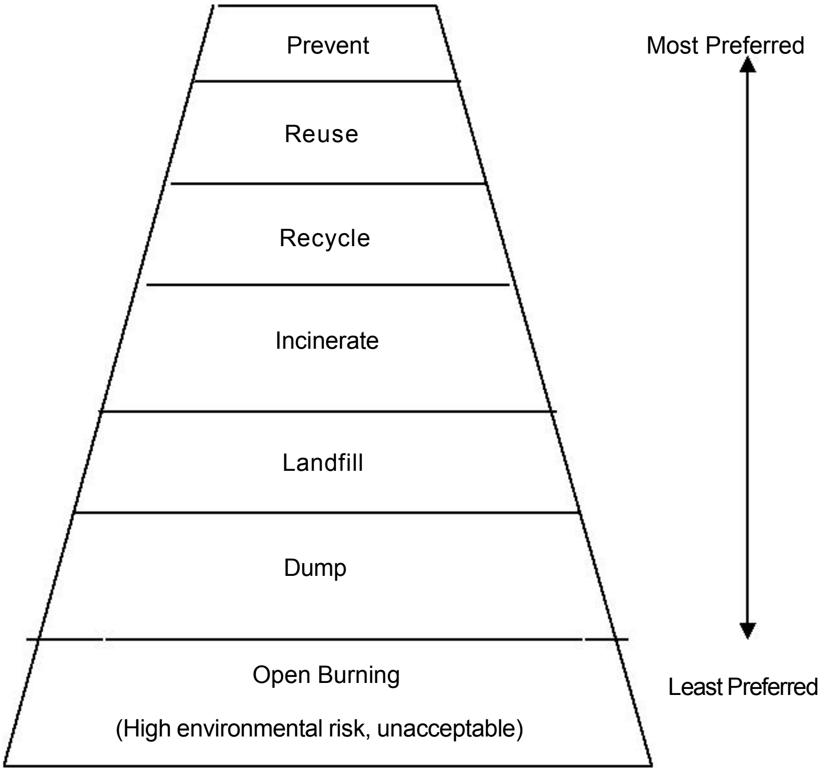

Figure 2: Integrated waste management hierarchy (Heimlich *et al.* 2005)

Though treatment of organic waste by anaerobic digestion is not well known or popular like that of aerobic digestion due to long retention time before bio-stabilization is achieved and high sensitivity to high concentration of free ammonia during biodegradation of nitrogen rich organic waste (Fernandez et al, 2010) limiting the overall performance of methanogenic bacteria as the ammonia concentration increases (Chen et al, 2008). Rate in the development of bioreactor designs so far have helped to increase the use of anaerobic digestion in treating solid organic waste and its performance compare to the conventional method. Though some limiting factors can affect the overall performance of anaerobic digestion in the bioreactor which includes temperature, moisture content, pH, different types of substrate and microbial composition, and poor design due to lack of the understanding to determine whether the digester is economical from energy generation perspective (Jeong et al, 2010).

The AD is widely used in treating different both solid organic waste and wastewater which includes municipal waste; industrial waste (breweries, milk, feed); agricultural waste (piggeries, farm wastes, plant and animal waste) which encourage its integration into solid waste management with involvement of little amount of energy compare to aerobic process during the conversion (biodegradation) stages (Gallert et al, 1998; Chen et al, 2008). This makes anaerobic digestion environment friendly technology capable of treating organic waste and generation of renewable energy (biofuel) simultaneous thereby reducing environmental pollution by preventing direct escape of greenhouse gases into the atmosphere (Jingura and Matengaifa, 2009; Kim et al, 2006; Ward et al, 2008).

VI. IMPOTANCE OF ANAEROBIC DIGESTION IN WASTE MANAGEMENT

Anaerobic digestion technology have helped in treating and managing organic fraction of waste in a more sustainable manner thereby reducing the potential negative impact from various kinds of uncontrolled organic waste emissions which are more dangerous to human health and the environment but with the production of final products called biogas and digestate, a renewable energy and a bio-fertilizer which is environmental friendly with zero effect on atmosphere and the ecosystem.

The production of biogas which comprises of methane, carbon dioxide and hydrogen sulphide from the solid organic waste in a more sustainable manner without any environmental nuisance have made anaerobic digestion an edge over other means for treating solid organic waste which produces clean energy which ensure less dependence on fossil fuel or non renewable natural resources for electricity generation; total reduction of greenhouse gas emissions into the atmosphere and reduce the total amount of waste to be sent to the landfill thereby reducing air pollution and groundwater contamination in order to ensure the safe environment to sustain the present and future generation.

VII. PROCESS FUNDAMENTALS

Anaerobic digestion involves decomposition of organic waste like household waste; agricultural waste; paper; sewage and other waste in depleted oxygen environment in the presence of microorganisms which often may undergo pre-treatment in order to (Verma, 2002):

- remove the non biodegradable materials that may affect the overall digestion and occupy space.
- provide uniform particle size to enhanced efficient digestion.
- remove the solid materials that may reduce the quality of digestate
- protect the downstream plant from any component that may cause physical damage.

Although the whole process occurs in stages: hydrolysis; acidogensis; acetogenesis and methanogenesis. The microorganisms responsible for the breaking down processes occur in phases according to the different stages in AD. The first set of microorganism secrets enzymes which hydrolyses the polymeric material or complex molecules present into a simple monomers like glucose, lipids, carbohydrate and amino acid which is subsequently fermented (sugars and amino acids) by acidogenic bacteria into alcohols, hydrogen and volatile fatty acid (propionic, valeric and acetic acid). The acetogenic bacteria convert the volatile fatty acids except for acetic acid to hydrogen and acetic acid and finally the methanogenic bacteria convert the acetic acid, hydrogen and carbon dioxide to methane which constitutes approximately 70 per cent of methane production. All these stages are further explained in detail below and also shown in Figure 3 below.

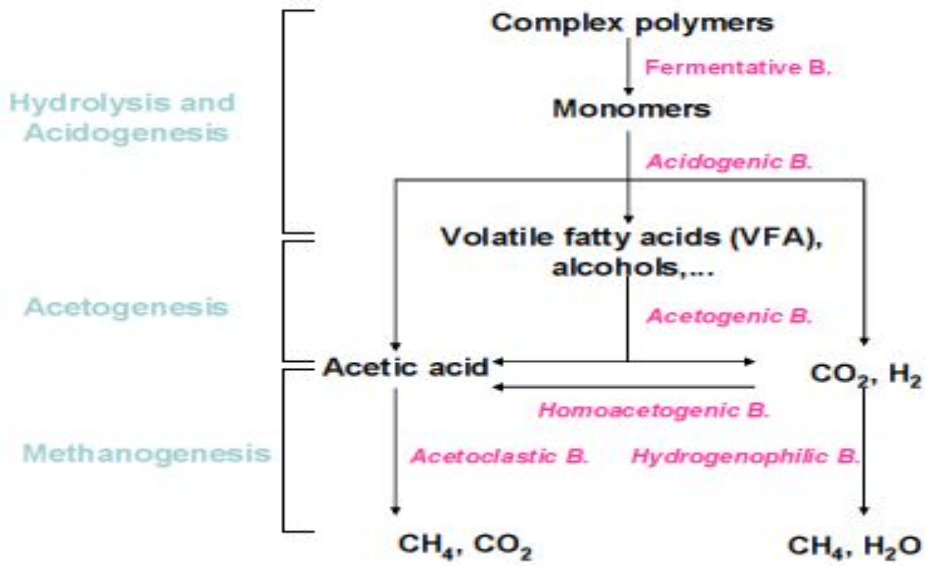

Figure 3: The reaction stages in anaerobic digestion (Akunna, 2011)

Hydrolysis

Hydrolysis is the breaking down of complex polymers or complex insoluble organic matter such as cellulose, lipids and carbohydrate into simple soluble products like sugar, fatty and amino acid with the help of fermentative bacteria. All the complex polymers are hydrolyzed into simple monomers though the hydrolysis is catalyzed by various kinds of enzymes which is been secreted by different bacteria such as protease, lipase cellulose, and amylase. Hydrolytic stage is the most important stage in AD process whereby all other stages depends upon it for efficient and effective digestion and most importance for high organic waste.

The general chemical formula for different kinds of organic waste present is $C_6H_{10}O_4$ (Themelis and Verma, 2004) and when broken down into a simple monomers like sugar will give the subsequent equation (1):

$$C_6H_{10}O_4 + 2H_2O \longrightarrow C_6H_{12}O_6 + 2H_2 \quad (1)$$

Acidogenesis

Acidogenesis is the next stage after hydrolysis which is the acid-forming stage. The acidogenic bacteria ferments all the hydrolysis products like simple sugars, amino acids into simpler organic compounds such as chained volatile fatty acid (valeric, butyric, acetic, propionic lactic acids); alcohols; hydrogen and ketones (acetone, glycerol, ethanol). Temperature and optimum pH of 6.0 determine how efficient the acidogenic bacteria can be at this stage although different concentration of product is formed at this stage. The general chemical equations for acid-forming stage are shown in equations 2 and 3 below where glucose is converted to ethanol and propionic acid respectively.

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \quad (2)$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \quad (3)$$

Acetogenesis

The next stage is acetogensis which convert volatile fatty acid to hydrogen and acetic acid and often do considered together with the acidogenesis to form in a single phase. It also occurs from fermentation of carbohydrate where acetate is the key product and few other metabolic processes. Hydrogen plays a significant role in this stage which serves as inhibitors in the oxidation state and the reaction can only take place if the partial hydrogen pressure is lower enough thermodynamically to allow the conversion taking place and the concentration of hydrogen measured by partial pressure shows how healthy and efficient the digester is. (Mouneimne and Carrer, 2003). The subsequent equation shows the reaction that is present in the acetogenic stage which involve the conversion of ethanol; bicarbonate and glucose to acetate, hydrogen and carbon dioxide$_2$ as shown in equation 5, and 6 which normally occur during fermentation. The acetogenesis stage performs excellently in slightly acidic environment with pH ranging from 4.5 to 6.0 and less sensitive to any changes in environment on incoming feed stream (Gas Technology, 2003).

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+ \quad (4)$$

Ethanol Acetic acid

$$2HCO_3^- + 4H_2 + H^+ \leftrightarrow CH_3COO^- + 4H_2O \quad (5)$$

Bicarbonate Acetic acid

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad (6)$$

Glucose Acetic acid

Methanogenesis

The final stage is the methane generation, produce by methanogenic bacteria called methane formers which normally takes place in two ways either by converting the acetic acid molecules to produce methane and carbon dioxide; or by reducing carbon dioxide and hydrogen. The methanogenic bacteria are the same bacteria in rumen of herbivores animals. Methane generation is higher during the reduction in carbon dioxide and limited concentration of hydrogen in the digester results in the formation of acetate reaction which is the primary producer of methane (Omstead *et al*, 1980) and some of the methanogenic bacteria are *methanobacillus*, *methanococcus* which can be further divided into groups: H_2/CO_2 and acetate consumers. The chemical reactions present in methanogenesis stage are shown in equations 7, 8 and 9 below (Verma, 2002):

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (7)$$

Acetic acid Methane Carbon dioxide

$$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \quad (8)$$

Ethanol

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (9)$$

Hydrogen Water

VIII. FACTORS AFFECTING ANAEROBIC DIGESTION PROCESS

The biogas production from solid organic waste is carried out by different anaerobic bacteria with each performing efficiently in certain environmental condition and any changes may limit and affect the total biogas yield within the AD system. The different factors that affect the total biogas yield in the AD system vary but the principal ones are: microbial composition; temperature; moisture contents; retention time, pH; and types of substrate (total solid content), carbon to nitrogen ratio (C:N), Mixing, and organic loading rate which are discussed below. The rate of methane production is high during a moisture content of about 70 per cent and a decrease in biogas production was also identified from fruit and vegetables as a results of high acidification from the organic waste which lowers the pH in the bioreactor (Bouallagui *et al*, 2009).

Microbial composition

Anaerobic digestion is catalyzed by different kinds of microorganism converting complex macromolecules into simple monomers which is also reported by Fricke *et al*. (2007); Ike *et al.* (2010)) that organic material do undergo decomposition with the help of heterotrophic bacteria (microorganisms) such as *actinomyces, Ralstonia, Themo-monospora* into volatile fatty acid and *methanoculleus thermophilus, methanosarcina thermophila* helps in forming methane production. All microorganisms have certain kinds of environment they are adapted to and any change at any of the stages in the AD system (biodigester) may inhibit the growth of the microorganisms to its full capacity and affecting the overall biogas production or yield because all the stages depends on each other for efficient biogas yield.

pH

Researchers have reported different pH values for anaerobic digestion which often changes during biological conversion at various stages in the AD system and for an AD system to be stable and maintain its equilibrium, the pH must be stable; unstable pH will result to acid accumulation and digester instability. For example the methanogens are more sensitive to acid concentration which inhibit the performance of the bacteria though it has been established that the optimal pH value for bacteria in AD varies from 5.5 to 8.5 (Huber *et al,* 1982; Agdag and Sponza, 2007). The closer of the pH to neutral, the higher the chance for methanogenic bacteria to perform efficiently (Guermoud *et al,* 2009) which is between 6.7 and 7.4, and optimally is between 7.0 and 7.2. Hydrolysis and acidogenesis occurs at pH of 5.5 and 6.5 respectively (Kim *et al,* 2003).

Prolific methanogenesis do resulted to high concentration of ammonia which increases the pH beyond 8.0 thereby impeding acidogenesis but can be opposed by adding fresh substrate that will spur the acideogensis and the acid formation (Lusk, 1999). Maintaining the pH level is difficult, during the start-up the fresh feedstock must undergo acid forming process prior before methane formation stage begin which certainly will lower the pH and can be raise by adding buffers to the AD system like calcium carbonate and making sure the addition of bicarbonate is high in order to allow the methanogens to survives through high pH (Vlyssides and Karlis 2003; Dong *et al*, 2009).

Temperature

Anaerobic digestion strongly depends on temperature which plays a significant effect on microbial process, stability and the total biogas yield (Riau *et al*, 2010). The different anaerobic bacteria survives at different temperature from freezing point to approximately 70^oC but often thrives in two (2) stage of temperature which are: mesophilic temperature 25^oC to 40^oC and thermophilic temperature 50^oC to 65^oC. The optimal temperature for mesophilic digestion is 35^oC and the standard temperature for the digester which must be maintained should be between 30^oC and 35^oC for the system to perform efficiently (Chae *et al*, 2008). Any drop in temperature during the AD process will reduce the biogas production and microbial growth Trzcinski and Stuckey (2010), while the high temperature will lower the total biogas yield as a result of volatile gases that is produced like ammonia which restrain methanogenic activities (Fezzani and Cheikh, 2010).

Anaerobic digestion is often carried out under mesophilic condition because is more stable and require little amount of energy Fernandez *et al* (2008) with a digestion time of 18days while under thermophilic condition, degradation of organic waste and biogas production occur faster with low effluent viscosity and high destruction of pathogens during the process Zhu *et al* (2009) but the optimum temperature for some methanogenic bacteria growth are: *Methanobrevibacter* (37-40^oC); *Methanolobus*, *Mthanoculleus*, *Methanospirillum* (35-40^oC); and thermophilic methanohalobium from 50^oC to 55^oC and any drop in temperature will reduce their efficiency within the AD system (Ward *et al*, 2008).

Composition of substrate

Anaerobic digestion is often affected by availability and various types of substrate characterized by protein, carbohydrate and lipid rich in carbon and different microbes degrade each of the substrate (Zhao *et al,* 2010). Of all the substrate or feedstock used in AD, carbohydrate is considered the most important because of its organic constituent mostly from municipal solid organic waste which is rich for the production of biogas and also starch can be used as a substrate due to its minimum cost compare to glucose and sucrose for biogas production (Dong *et al*, 2009; Su *et al*, 2009). The initial and the total organic feedstock present in a bioreactor could affect the overall performance of the system and also limit the production of methane (Fernandez *et al*, 2008).

Toxic Compound

Toxic compounds like ammonia, hydrogen sulphide, nirates, antibiotics and nitrites present in a higher proportion could reduce the total percentage of biogas produce in the AD system. The ammonia and nitrogen contribute towards the stability of the pH value in the digester and microorganism take in ammonia to produce new cell but higher concentration of ammonia will limit the biological processes within the AD system and limit methanogenesis bacteria if it exceeds 100mM (Fricke *et al*, 2007). Presence of ammonia in the bioreactor also affect the production of hydrogen and the removal of volatile solid (Sterling *et al*, 2001).

The increase in ammonia concentration will reduces the biogas production by 50%; methane production decreases with ammonium level greater than 6000mg NH_4-N/L and methanogenic bacteria is reduced by approximately 10% at ammonium concentration of about 1670-3720NH_4-N/L and 50% at approximately 4090-5550mg NH_4-N/L (Sawayama *et al*, 2004). To have efficient and effective AD system, the available toxic compounds must be controlled and monitor.

IX. POTENTIAL BIOGAS AND UTLISATION OPTIONS

The potential biogas yield depends on the type and characteristics of the feedstock used; percentage of organic matter content and the percentage of the moisture content. Different reports have shown that anaerobic digestion of solid organic waste yields some promising yields of biogas which is shown in Table 1.

The composition of the biogas are "48-70% methane; 36-41% carbon dioxide, 17% nitrogen, <1% oxygen, 32-169 ppm hydrogen sulphide and traces of other gases" (Ward *et al*, 2008).

Although, co-digestion is mostly used because it increases yield from anaerobic digestion of solid organic wastes, also fasten the rate of biodegradation of organic waste, providing excess and balance nutrients for microorganisms in order to get a better and efficient biogas yield (Hartmann and Ahring, 2005; Lo *et al*, 2010). Based on the type of substrates, substrate with low nitrogen and lipids content increase the production biogas due to the characteristics of the organic waste and its reduces problem associated with high ammonia concentration in the bioreactor (Castillo *et al,* 2006). Different studies have also shown that mixture of agricultural, industrial and municipal waste can be digested together to get a higher percentage of biogas which is shown in Table 2 but ratio 1:2 of municipal organic waste with industrial sludge yields the highest amount of biogas compare to municipal organic waste alone. Fezzani and Cheikh (2010) also reported that high methane yield when olive mill solid waste and olive mill wastewater were mixed and co-digested together.

Table 1:

The biogas yield from different solid organic waste *(Modified from Khalid et al, 2011).*

Substrate	Methane yield (l/kg VS)	References
Municipal solid waste	360	Vogt *et al*, 2002
Fruit and vegetable waste	420	Bouallagui *et al*, 2005
Municipal solid waste	530	Forster-Carneiro *et al*, 2007
Fruits and vegetable waste, and abattoir wastewater	850	Forster-Carneiro *et al*, 2007
Swine manure	337	Ahn *et al*, 2009
Municipal solid waste	200	Walker *et al*, 2009
Food waste leachate	294	Behera *et al*, 2010
Rice straw	350	Lei *et al*, 2010
Maize silage and straw	312	Mumme *et al*, 2010
Jatropha oil seedcate	422	Chandra *et al*, 2011
Palm oil mill waste	610	Fang *et al*,, 2011
Household waste	350	Fang *et al*, 2011
Lignin-rich organic waste	200	Jay-asinghe *et al*, 2011

Swine manure and winery wastewater	348	Riano *et al*, 2011
Food waste	396	Zhang *et al*, 2011

The biogas utilisation varies provided the CO_2 and other impurities present like hydrogen sulphide, water vapour which causes corrosion of metals and engines are removed via cleaning by internal combustion engines and a gas boiler before it can be used efficiently apart from reciprocate engines. The potential biogas after cleaning can be used in electricity generation; transportation fuel and also sent to the existing natural gas grid for household cooking thereby reducing the potential environmental impact from greenhouse gases emissions from fossil fuels.

Table 2: The rate of biogas production and methane yield from co-digestion of solid organic wastes (Modified from Khalid *et al*, 2011)

Substrate	Co-substrate	Biogas production rate (l/d)	Methane yield (l/kg.VS)	Comments	References
Cattle excreta	Olive mill waste	1.10	179	Co-digestion produce 337% biogas higher than that of excreta alone	Goberna *et al*, 2010
Cattle manure	Agricultural waste and energy crops	2.70	620	Considerable increase in biogas yield from co-digestion	Cavinato *et al*, 2010
Fruit and vegetable waste	Abattoir wastewater	2.53	611	Addition of wastewater from abattoir increase the biogas yield by 51.5%	Bouallagui *et al*, 2009
Municipal solid waste	Fly ash	6.50	222	Addition of fly ash increase the biogas yield from municipal solid waste	Lo *et al,* 2010
Municipal solid wastes	Fat, oil and grease waste from sewage plants	13.6	350	Co-digestion increase the biogas production by 72% and 46% methane yield compare to municipal solid waste	Martin-Gonzalez *et al*, 2010
Pig manure	Fish and biodiesel waste	16.4	620	Increase in biogas production was obtained by mixing different organic wastes together	Alveraz *et al*, 2010
Potato waste	Sugar beet waste	4.40	680	Co-digestion increase the methane yield by 62% compare to when potato alone is digested	Parawira *et al*, 2004
Primary sludge	Fruit and vegetable waste	3.00	600	More biogas is produced when co-digested compare to primary sludge alone	Gornez *et al*, 2006
Sewage sludge	Municipal solid waste	3.00	532	Increase in different proportions of municipal solid organic waste increases biogas production	Sosnowski *et al*, 2003
Slaughter house waste	Municipal solid waste	8.60	500	Co-digestion doubled the biogas yield compare to that of slaughter waste digested system	Cuetos *et al*, 2008

X. TYPES OF ANAEROBICS BIOREACTORS

Anaerobic bioreactors have been developed more efficiently to fasten the rate of solid organic waste digestion compare to conventional sanitary landfills (Agdag and Sponza, 2007). Table 2 shows the various kinds of bioreactors developed to facilitate the reaction and treatment of solid organic waste (Xing *et al*, 2010). According to Ward *et al*. (2008), for anaerobic bioreactor to be sustainable, it must be design to allow continuous high rate of organic load with a shorter retention time to produce maximum methane yield. Different types of bioreactors has been designed and used but the most widely used bioreactors are "batch reactors; one stage continuous fed system and two/multiple stage continuous fed system".

Anaerobic batch reactors are simple to operate, is often filled with feedstock and leave for certain period known as hydraulic retention time which later is been empted. It is importance because it encourages quick digestion for the organic feedstock, less expensive and helps to determine the rate of digestion easily (Weiland, 2006). Although with some challenges like high instability in gas production which normally affects the gas quality; lose of biogas during the process of emptying from the bioreactors and the restricted height for the bioreactors (Linke *et al*, 2006).

Another type of bioreactor is the one-stage continuous fed system where all the biochemical reaction occurs in one bioreactor and finally the two or multiple stage continuous fed systems where different biochemical reactions like "hydrolysis; acidification; acetogenesis and methanogenesis occurs in different bioreactor (Ward *et al*, 2008). The two stage system is mostly considered to be the promising process when treating organic wastes which resulted into high rate of degradation, biogas yield and methane production.
It also allow bacteria at different stage to perform efficiently like acidogenic bacteria degrading organic materials to volatile acids which can then be easy for methanogens to convert it to methane and carbon dioxide. Furthermore, it ensure stability in the bioreactor by controlling the acidification stage by optimising the retention time in order to avoid overloading and build-up for toxic compounds (Demirer and Chen, 2005).

Apart from the most used bioreactors as discussed above, other methanizers still exists such as "tubular bioreactor; continuous stirred tank bioreactor; up flow anaerobic sludge blanket; anaerobic sequencing batch bioreactor and anaerobic filters" used for treating different kinds of waste (Bouallagui *et al,* 2005) and Table 3 shows the different types of bioreactors used for digesting solid organic waste.

Bioreactors can also be group into "dry or wet" based on the kinds of solid waste digested but according to Karagiannidis and Perkoulidis (2009; Ward *et al.* (2008), wet bioreactors constitute total organic solid waste of at least 10% to approximately 25% while the dry bioreactor is between 22 percent of total solid to approximately 40 per cent and it has been proven that some bioreactor are grouped based on their operating temperatures like thermophilic or mesophilic temperature.

Table 3: The different kinds of bioreactors used in anaerobic digestion for organic waste *(modified from Khalid et al, 2011)*

Bioreactor types	Type of substrate	Organic loading rate (kg/m^3/d)	Comments	References
Anaerobic sequencing batch bioreactor	Fruit and vegetable waste and abattoir wastewater	2.6	Reduction in biogas production occurs as a result of high amount of free ammonia at high loading of organic waste	Bouallgui *et al*, 2009b
Continuous stirred tank reactors	Municipal solid waste	15	Reactor have increase the performance of organic loading rate (OLR) by 15kg/m^3/d	Angelidaki *et al*, 2006
Full-scale anaerobic digester	Industrial food waste	17	Increase in methane yield by 360l/kg feedstock with 40 days retention time is noticed	Ike *et al,* 2010
Integrative biological reactor	Kitchen waste	8.0	Integrated biological reactor proved that the rate of increase in biogas production is higher compare to single reactor	Guo *et al,* 2011
Laboratory-scale semi continuous rectors	Municipal solid waste and press water from municipal composting plant	20	The performance of the reactor for biogas yield is 20 OLR and increase in OLR will not affect the biogas production	Nayono *et al,* 2010

New starch based flocculant-anaerobic fluidized bed bioreactor	Primary treated sewage effluent with or without refractory organic pollutants	43	The microbial activity during high OLR is higher than that of conventional anaerobic fluidized bed bioreactor	Xing *et al,* 2010
Rotating drum mesh filter bioreactor	Municipal solid waste	15	The reactor is stable, help mixing waste at high OLR which is not possible in mechanical stirred digesters.	Walker *et al,* 2009
Self mixing anaerobic digesters	Poultry litter	16	Self mixing at high biomethanization and OLR of the poultry litter was noticed.	Rao *et al*, 2011
Submerged anaerobic membrane bioreactor	Sewage sludge, food waste and livestock wastewater	1.8	The reactor is not stable but get more stable after acclimation formation	Jepng *et al*. 2010
Two-phase anaerobic semi-continuous digester	Olive mill wastewater and olive mill solid waste	14	High performance in term of methane production, efficiency in removing phenol and different effluent quality	Fezzani and Cheikh, 2010
Two stage anaerobic hydrogen and methane production reactor	Organic waste	3.0	High energy like 12% was achieved compare to single-stage methanogenic reactor.	Luo *et al*, 2011
Up flow anaerobic solid-state bioreactor	Mixture of maize silage and straw	17	The highest methanogenic performance fro digesting solid organic waste is the UASS reactor	Mummer *et al*, 2010

XI. REQUIREMENT AND CHALLENGES FOR ANAEROBIC DIGESTION TECHNOLOGY

There are some basic requirements and conditions for anaerobic digestion technology before it can be considered treating any organic wastes in a sustainable way without any hindrances, although most of the requirements should be the roles of government in any countries but how efficient the role is carried out will determine the feasibility for AD system in treating solid organic waste.

The requirements are as follow:

- Availability and type of substrate which must be continuous through efficient waste collection and segregation of organic waste system, is an important factor that will determine the yield and any wrong input of substrate may inhibit the process and will reduce the yield of biogas. All the system parameters for AD system must be balanced.
- Land availability to construct the AD facilities
- Availability of financial incentives: Cost of energy generated from biogas is higher compare to other non-renewable energy resources like natural gas and crude oil. Incentives should be in place from government to support the development of renewable energy infrastructure under the Renewable Obligations and Feed-in-Tariffs Scheme that will provide the part of revenue for investors or individuals to invent into renewable energy like anaerobic digestion technology
- Personnel specialist in AD technology to monitor and control the operation
- Availability of infrastructure and technology to unify the biogas into natural gas grid system and making sure the infrastructure is generally accepted within the communities.
- The end use option of both the biogas and the digestate should be known and market failure, barriers that might affects the market outputs of energy from waste from attaining it aim of sustainable development should be removed.
- Prevailing climatic conditions and digester: The prevailing climatic condition of an area should be known because it will determine the type of digester used. If the digester will be house with heat installation system that will provides a constant temperature needed for digestion and mixing of various organic substrate in order to increase the biogas yield

- Ensuring that regulation governing waste management does not affect any development of renewable energies like AD operation or any energy recovery facility though there must be a functional regulatory framework that will guide AD operation.

The major problem affecting AD technology is inconsistency in energy policy especially renewable energies as a result often change of government with individuals interested in different renewable energies leading to budget cut on one technology to promote another but the major challenge of AD technology are:

- Technical challenge: the technical problem do start from prolong delay in construction and operation of the plants; wrong design of the biogas plant; overloading and accumulation of feedstock into the biogas plant may lead to gas leakage from the pipeline which normally have higher negative effect on equipment and human life as a result of explosive property for methane gas

A proper training and monitoring programme must be established for the biogas plant facilities including the distribution pipelines and safety procedures during the design and operation phase must be provided in order to control various technical issues.

- Economic challenge: due to the cost of installation, there should be financial incentives like grants, loans from the government for research and development on AD technology and a reduction in this grant or incentives will also limit the investment and research on biogas plant.

XII. POTENTIAL ENVIRONMENTAL CONCERN USING ANAEROBIC DIGESTION

The potential environmental impacts of AD technology vary from the construction stage to the operational stage. Both stages will generate effluents, emissions and pollution to land, air, and discharges into water environment. The various potential impacts of the different activities on the environment will be highlighted below:

Impact of Construction activities

- Noise pollution: Noise can be defined as any unwanted sounds that do affects our daily activities which normally causes irritation, trauma and do rendered humans and its ecosystem uncomfortable at a point in time and noise is a major impact during the construction phase starting from excavation and dredging by machineries traffic and transport noise by moving in and out of trucks from the site which often cause fatigue, disturb communication and the natural habitats (EPUK, 2011)
- Air Pollution: presumed to come from the machinery and trucks on site as a result of exhaust CO_2 during the construction activity which normally disturbs the local air quality. The effects on human is as a result of inhaling high concentration of the pollutant will result to premature death, change the overall chemical balance in the environment which will results to acidification and eutophication; and covering of the vegetation by dust.
- Water pollution: The impact of the construction activity on the water environment which can lead to water pollution derives from the movement of sediments or stockpiles into the water body as a result of erosion which could be carried by either by wind and water which can choke aquatic animals like spawn and can result to death for fishes if their gills is been coated and covered by finer particle (WHO, 2008)

Impact of Operational Activities

- Air Pollution: The air quality can be affected as a result of emissions from energy generation plant, agricultural waste and transport; all this can threat the human health, depleting of ozone layer and the environment. Odour from feedstock waste, air emission from the digester and burring of the biogas to generate electricity produces knox, sulphur dioxide, particulates and carbon monoxide (FOE, 2007).
- Contaminated Land: The major sources of land contamination comes from "solvents, oil, petrol, agricultural activities and improper waste disposal" but potential environmental impact on land by operating AD plant is the disposal of the digestate which is made up of solid and liquid residue on the land if not treated to the required standard will have a negative effect on the environment and effects vary, depending on the level of contamination and how it has been discharged onto the land (Mata-Alvarez *et al*, 2010)
- Water Pollution : The potential environmental impact on the water environment from operating AD plant normally occur as a result of a point discharge "(sewage and trade effluent)" of waste water from the digestate from the AD plant into the water environment without it been treated. The digestate which contains a high concentration of organic matters, and pathogens, if not properly discharged and treated before been use on land the high concentrations of phosphorus, nitrogen and ammonia when wash into

the water environment during surface run-off can affect aquatic animals and lower the water quality that is meant for drinking due to the increase in concentration of organic effluent in the water environment which reduces the oxygen level and increases the biochemical oxygen demand, it endanger lives and habitat especially if its contain bacteria, viruses which will put a threat on the water recreation (EA, 2008).

The AD plant and its digestate when controlled using Best Available Technique (BAT) will yield socio-economic and environmental benefits, which will be controlled and treated to the required standard under waste regulatory controls.

XIII. CONCLUSION

The management of organic waste in a sustainable manner has been a global concern in order to balance the ecosystem and avoid the depletion of natural resources which have led to integrated waste management strategy with the aim of using different technologies and techniques to reduce and minimize the total amount of waste generated.

As various methods and technologies have been used for treating and managing solid organic waste in order to protect human health and the environment via by: source reduction; recycling and composting; combustion (waste to energy); and landfills under the integrated waste management strategy which cannot be achieved without the use of a waste management plan strategy as the techniques that avoid waste generation by using a cleaner technology, encouraging waste recycling and recovery, using appropriate treatment for different kinds of waste generated with efficient final waste disposal without any negative impact on the environment and human health, though each techniques with their own potential negative impact on human health and environment.

Anaerobic digestion technology is perfect to be integrated into waste strategy because is considered as a better option in dealing with organic solid waste and other wastewater treatments in a more sustainable way by reducing the potential impact of waste on the environment and human health; reducing greenhouse gases and diverting waste away from landfill. The organic waste will be converted into a useful end products like biogas and energy-rich compounds which will play a major part in meeting the ever increasing global demand of energy for the future and thereby reducing the dependent on fossil fuel and non-renewable natural resources, reducing greenhouse gas emissions causing climate changes and guarantee a safe environment and good human health for the present and future generation, though with its own challenges about non functional regulatory framework to guide the technology from further deteriorating the environment but is design using the BAT principle without causing further damage to the environment and the product under monitoring before it been used on farm land.

REFERENCE

1. *Adewale, M. 2011. Compositing as a sustainable waste management technique in developing countries. Journal of Environmental Science and Technology 4 (2): 93-102.*
2. *Agdag, O.N., Sponza, D.T. 2007. Co-digestion of mixed industrial sludge with municipal solid wastes in anaerobic simulated landfilling bioreactors. J. Hazard. Mat. 140: pp.75–85.*
3. *Airan, D.S. and Bell, J.H. 1980. Resource recovery through compositing a sleeping giant. Proceedings of the National Conference on Waste Processing, May 11-14. New York: Washington, DC. Pp. 121-129.*
4. *Akunna, J. 2011. Understanding anaerobic digestion process/ [Online]. Available from: http://www.ciwm.co.uk/web/FILES/ScotlandRDO/Joseph_Akunna.pdf [Accessed 03 August 2011].*
5. *Alamgir, M., McDonald, C., Roehl E.K. and Ahsan, A. 2005. Integrated management and safe disposal of municipal solid waste in Least Developed Asian Countries: A feasibility study. 1ed. Enrich Printers: Bangladesh.*
6. *Alvarez, J.A., Otero, L., Lema, J.M. 2010. A methodology for optimizing feed composition for anaerobic co-digestion of agro-industrial wastes. Bioresour.Technol. 101: pp.1153–1158*
7. *Arowolo, T.A. and Sridhar, M.K. 2005. Options in urban waste conversion: Organo-mineral fertilizers to integrated waste management. The experience so far. A paper presented at one day technical session organized by Ogun Sate Ministry of Environment.*
8. *Batstone, D.J., Keller, K., Angelidaki, I., Kalyuzhnyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders, W.T.M., Siegrist, H. and Vavilin, V.A. 2002. Anaerobic Digestion Model No. 1. Scientific and Technical Report No. 13. IWA Publishing, Cornwall, UK.*

9. Behera, S.K., Park, J.M., Kim, K.H., Park, H. 2010. Methane production from food waste leachate in laboratory-scale simulated landfill. Waste Manage. 30: pp.1502–1508.
10. Bolaane, B. (2006) Constraints to promoting people centred approaches in recycling. Habitat International 30:731-740.
11. Bouallagui, H., Touhami, Y., Cheikh, R.B., Hamdi, M. 2005. Bioreactor performance in anaerobic digestion of fruit and vegetable wastes. Process Biochem. 40: pp.989–995.
12. Castillo, E.F.M., Cristancho, D.E., Arellano, V.A. 2006. Study of the operational conditions for anaerobic digestion of urban solid wastes. Waste Manage. 26: pp.546–556.
13. Chanakya, H.N., Ramachandra, T.V. and Vijayachamundeeswari, M. 2007. Resource recovery potential from secondary components of segregated municipal solid wastes. Environ. Monit. Assess. 135: pp.119-127
14. Chaney, R.L., Ryan, J.A., Kukier, U., Brown, S.L., Siebielc, G., Malik, M., and Angle, J.S. 2001. Heavy metals aspect of compost use. In: P.J. Stofella and B.A. Kahn. eds. Compost utilization in horticulture cropping systems. USA: Lewis Publishers, pp: 323-359.
15. Charles, W., Walker, L., Cord-Ruwisch, R. 2009. Effect of pre-aeration and inoculums on the start-up of batch thermophilic anaerobic digestion of municipal solid waste. Bioresour. Technol. 100: pp. 2329-233.
16. Chen, Y., Cheng, J.J. and Creamer, K.S. 2008. Inhibition of anaerobic digestion process: a review. Bioresour. Technol. 99: pp.4044-4064.
17. Ciavatta, C., Govi, M., Simoni, A., and Sequi, P. 1993. Evaluation of heavy metals during stabilization of organic matter in compost produced with municipal solid waste. Bioresour. Technol, 43: pp.147-153.
18. Cossu, R., Raga, R and Rossetti, D. 2001. Reduction if environmental impacts based on different landfill concepts. The PAF model. In: Proceedings of Sardinia 2001. Eighth International Waste Management and Landfill Symposium. S. Margheritia di Pula, Italy.
19. Daskalopoulos, E., Badr, O and Probert, S.D. 1998. An integrated approach to municipal solid waste management. Resour. Conserv. Recycling, 24: 33-50.
20. Davoudi, S. (2000) Planning for waste management: Changing discourses and institutional relationships. Progress in Planning 53:165-216.
21. Demirer, G.N., Chen, S. 2005. Two-phase anaerobic digestion of unscreened dairy manure. Process Biochem. 40: pp.3542–3549.
22. Dong, L., Zhenhong, Y., Yongming, S., Xiaoying, K., Yu, Z. 2009. Hydrogen production characteristics of organic fraction of municipal solid wastes by anaerobic mixed culture fermentation. Int. J. Hydr. Energy 34: pp.812–820.
23. Environment Agency (EA). 2008. Anaerobic digestate: Quality control. [online]. Available from: http://www.environmentagency.gov.uk/static/documents/business/w524anearobicdigestatev4(1).pdf [Accessed 04 August 2011]
24. Environmental Protection United Kingdom (EPUK). 2011. Noise pollution. [online]. Available from: http://www.environmental-protection.org.uk/noise/environmental-noise/noise-pollution/ [Accessed 04 August 2011].
25. Fernandez, J., Perez, M. and Romero, L.I. 2010. Kinetics of mesophilic anaerobic digestion of the organic fraction of municipal solid waste: influence of initial total solid concentration. Bioresour. Technol. 101: pp. 6322-6328.
26. Fernandez, J., Perez, M., Romero, L.I. 2008. Effect of substrate concentration on dry mesophilic anaerobic digestion of organic fraction of municipal solid waste (OFMSW). Bioresour. Technol. 99: pp.6075–6080.
27. Fezzani, B., Cheikh, R.B. 2010. Two-phase anaerobic co-digestion of olive mill wastes in semi-continuous digesters at mesophilic temperature. Bioresour. Technol. 101: pp.1628–1634.
28. Fricke, K., Santen, H., Wallmann, R., Huttner, A., Dichtl, N. 2007. Operating problems in anaerobic digestion plants resulting from nitrogen in MSW. Waste Manage.27: pp.30–43.
29. Friend of the Earth (1997). Landfill campaign guide. [Online]. Available from: http://www.foe.co.uk/resource/reports/landfill_campaign_guide.pdf [Accessed 20 July 2013]
30. Friends of the Earth (2007). Briefing anaerobic digestion. [Online]. Available from: http://www.foe.co.uk/resource/briefings/anearobic_digestion.pdf [Accessed 02 August 2011]
31. Furedy, C. (1992). "Garbage: exploring non-conventional options in Asian cities." Environment and Urbanization, vol. 4, no.2, pp.: 42-61. [Online]. Available from: http://www.yorku.ca/furedy/papers/es/garbage92.doc [Accessed 03 August 20110]
32. Gallert, C., Bauer, S. and Winter, J. 1998. Effect of ammonia on the anaerobic degradation of protein by a mesophilic and thermophilic biowaste population. Appl. Microbiol. Biotechnol. 50: pp.495-501.
33. Guermoud, N., Ouagjnia, F., Avdelmalek, F., Taleb, F. and Addou, A. 2009. Municipal solid waste in Mostagnem city (Western Algeria). Waste Manage. 29: pp.896-902.

34. *Hartmann, H., Ahring, B.K., 2005. Anaerobic digestion of the organic fraction of municipal solid waste: influence of co-digestion with manure. Water Res. 39: pp.1543–1552*
35. *Heimlich, J.E., Hughes, K.L., and Christy, A.D. 2005. Integrated waste management. 1st ed. OSU Extension, Ohio.*
36. *Hester, R.E., and Harrison, R.M. 1993. Issus in environmental science and technology: Waste incineration and the environment. The Royal Society of Chemistry, Thomas Graham House, Cambridge. [Online]. Available from:*
37. *http://Inweb18.worldbank.org/mena.ns/Attachments/SW+Public+Awareness/$File/REPORT.Issue+Paper+1.doc [Accessed 05 July 2013].*
38. *Huber, H., Thomm, M., Konig, H., Thies, G., Stetter, K.O. 1982. Methanococeus thermolithotrophicus, a novel thermophilic lithotrophic methanogen. Arch. Microbiol. 132: pp.47–50.*
39. *Ike, M., Inoue, D., Miyano, T., Liu, T.T., Sei, K., Soda, S., Kadoshin, S. 2010. Microbial population dynamics during startup of a full-scale anaerobic digester treating industrial food waste in Kyoto eco-energy project. Bioresour. Technol. 101; pp.3952–3957*
40. *Jeong, E., Kim, H., Nam, J. and Shin, H. 2010. Enhancement of bioenergy production and effluent quality by integrating optimized acidification with submerged anaerobic membrane bioreactor. Bioresour. Technol. 101: pp.1873-2976.*
41. *Jingura, R.M. and Matengaifa, R. 2009. Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. Renew. Sust. Energy Rev. 13: pp.1116-1120.*
42. *Karagiannidis, A. and Perkoulidis, G. 2009. A multi-criteria ranking of different technologies for the anaerobic digestion for energy recovery of the organic fraction of municipal solid wastes. Bioresour. Technol. 100: pp.2355-2360.*
43. *Khalid, A., Arshad, M., Anjum, M., Mahmood, T., and Dawson, L. 2011. The anaerobic digestion of solid organic waste. Waste Management. 31 (8): pp. 1737-1744.*
44. *Kim, J., Park, C., Kim, T.H., Lee, M., Kim, S., Kim, S.W., Lee, J. 2003. Effects of various pretreatments for enhanced anaerobic digestion with waste activated sludge. J. Biosci. Bioeng. 95: pp.271–275.*
45. *Kim, J.K., Oh, B.R., Chun, Y.N. and Kim, S.W. 2006. Effects of temperature and hydraulic retention time on anaerobic digestion of food waste. J. Biosci. Bioeng. 102: pp. 328-332.*
46. *Kofoworola, O.F. 2007. Recovery and recycling practices In municipal solid waste management In Lagos Nigeria. Waste Management 27:1139-1143.*
47. *Kuo, W., Cheng, K. 2007. Use of respirometer in evaluation of process and toxicity of thermophilic anaerobic digestion for treating kitchen waste. Bioresour. Technol. 98: 1805–1811.*
48. *Lastella, G., Testa, C., Cornacchia, G., Notornicola, M., Voltasio, F and Sharma, V.K. 2002. Anaerobic digestion of semi-solid organic waste: biogas production and its purification. Energy Conserv. Manage. 43: pp. 63-75.*
49. *Lata, K., Rajeshwari, K.V., Pant, D.C. and Kishore, V.V.N. 2002. Volatile fatty acid production during anaerobic mesophilic digestion of tea and vegetable market wastes. W. J. Microbiol. Biotechnol. 18: pp.589-592.*
50. *Lee, M., Hidaka, T., Hagiwara, W. and Tsuno, H. 2009. Comparative performance and microbial diversity of hyperthermophiclic and thermophilic co-digestion of kitchen garbage and excess sludge. Bioresour. Technol. 100: pp.578–585.*
51. *Linke, B., Heiermann, M., Mumme, J. 2006. Results of monitoring the pilot plants Pirow and Clausnitz. In: F.N. Rohstoffe, eds. Solid-State Digestion–State of the art and further R&D requirements. Gülzower Fachgespräche. 24: pp.112–130.*
52. *Lo, H.M., Kurniawan, T.A., Sillanpaa, M.E.T., Pai, T.Y., Chiang, C.F., Chao, K.P., Liu, M.H., Chuang, S.H., Banks, C.J., Wang, S.C., Lin, K.C., Lin, C.Y., Liu, W.F., Cheng, P.H., Chen, C.K., Chiu, H.Y., Wu, H.Y. 2010. Modeling biogas production from organic fraction of MSW co-digested with MSWI ashes in anaerobic bioreactors. Bioresour. Technol. 101: pp.6329–6335.*
53. *Lusk, P. 1999. Latest progress in anaerobic digestion. Biocycle 40(7): pp.289- 296.*
54. *Mahony, T. and O'Flaherty, V. 2002. Feasibility study for centralised anaerobic digestion for the treatment of various wastes and wastewaters in sensitive catchment areas. Ireland Environmental Protection Agency. IEPA Publication.*
55. *Mahony, T. and O'Flaherty, V. 2002. Feasibility study for centralised anaerobic digestion for the treatment of various wastes and wastewaters in sensitive catchment areas. Ireland Environmental Protection Agency. IEPA Publication.*

56. *Mediterranean Environmental Technical Assistance Program (METAP). 2000. METAP Regional Solid Waste Management Project: Public Awareness, Policy and Institutional Frameworks. Issue Paper 1. [Online]. Available from:*
57. *Mouneimne, A. H., and Carrer, H. 2003.Effect of saponification on the anaerobic digestion of solid fat residues. Bioresource Technology. 90(1): pp.89-94.*
58. *Muttamara, S. 1996. Solid waste recycling and reuse in Bangalore. Recycling in Asia: Partnerships for Responsive Solid Waste Management. Nagoya: UNCRD*
59. *Omstead, D.R., Jeffries, T.W., Naughton, R., Harry, P. 1980. Membrane controlled digestion: Anaerobic production of methane and organic acids. Biotechnology and Bioengineering Symposium. 10: pp.247-258.*
60. *Poincelot, R.P. 1974. A scientific examination of the principle and practice of composting. Compost Sci. 15: pp.24-31.*
61. *Read, A.D. 1999. Making waste work: Making UK national solid waste strategy work at the local scale. Resources, Conservation and Recycling 26:259-285.*
62. *Renkow, M and Rubin, A.R. 1998. Does municipal solid waste composting make economic sense? Journal of Environmental Management. 53: pp.339-347.*
63. *Riau, V., De la Rubia, M.A., Pérez, M. 2010. Temperature-phased anaerobic digestion (TPAD) to obtain class A biosolids: a semi-continuous study. Bioresour. Technol. 101: pp.2706–2712*
64. *Rossel, S.A. and Jorge, M.F. 1999. Cuban strategy for management and control of waste. In: A. Barrage and X. Edelmann, eds. Recovery, Recycling, Re-integration (R '99) Congress Proceedings, Vol. 1. EMPA, Switzerland, pp. 287–290.*
65. *Sawayama, S., Tada, C., Tsukahara, K., Yagishita, T. 2004. Effect of ammonium addition on methanogenic community in a fluidized bed anaerobic digestion. Biosci. Bioen. 97: pp.65–70.*
66. *Seo, S.A., Aramaki, T., Hwang, Y., Hanaki, K. 2004. Environmental impact of solid waste treatment methods in Korea. J. Environ. Eng., 130: 81-89.*
67. *Sharp, V. 2006. Emerging evidence from waste prevention and behaviour change research. In changing the face of waste management, proceedings of the CIWM conference, Paignton, UK, June 12–16 2006, Session BSA, Paper 2.*
68. *Sterling, M.C.Jr., Lacey, R.E., Engler, C.R., Ricke, S.C. 2001. Effects of ammonia nitrogen on H2 and CH4 production during anaerobic digestion of dairy cattle manure. Bioresour. Technol. 77: pp.9–18*
69. *Su, H., Cheng, J., Zhou, J., Song, W., Cen, K. 2009. Improving hydrogen production from cassava starch by combination of dark and photo fermentation. Int. J. Hydr. Energy. 34: pp.1780–1786.*
70. *Tchobanoglous, G and Kreith, F. 2002. Handbook of solid waste 2nd ed. USA: McGraw-Hill*
71. *Tchobanoglous, G., Theisen, H., and Vigil, S. 1993. Integrated solid waste management engineering principles and management issues. New York: London: McGraw-Hill*
72. *Themelis, N.J. and Verma, S. 2004. The better option: Anaerobic digestion of organic waste in MSW. Waste management world. 2: pp.64-70.*
73. *Themelis, N.J., Ulloa, P.A., 2007. Methane generation in landfills. Renew. Energy 32: 1243-1257.*
74. *Trzcinski, A.P., Stuckey, D.C. 2010. Treatment of municipal solid waste leachate using a submerged anaerobic membrane bioreactor at mesophilic and psychrophilic temperatures: analysis of recalcitrants in the permeate using GC-MS. Water Res. 44: pp.671–680.*
75. *UNESCO, 2003 Environment and development in coastal regions and in small islands. Nigeria: UNESCO Publication.*
76. *United Nation Centre for Human Settlements (UNCHS), 2000. Integrated solid waste collection system in the city of Olangapo Philippines. Best practice database. [Online]. Available from: http://www.bestpractices.org [Accessed 09 July 2011].*
77. *United Nation Centre for Human Settlements (UNCHS), 2000. Integrated solid waste collection system in the city of Olangapo Philippines. Best practice database. [Online]. Available from: http://www.bestpractices.org [Accessed 09 July 2011].*
78. *United Nation Centre Regional Development UNCRD (2003). Solid Waste Recycling and Reuse In Bangalore. Recycling in Asia: Partnerships for Responsive Solid Waste Management.*
79. *Van Beukering, P., Sehker, M., Gerlagh, R. and Kumar V. (1999) Analysing urban solid waste in developing countries: A perspective of Bangalore, India. CREED Working Paper No. 24. Amsterdam.*
80. *Verma, S. 2002. Anaerobic digestion of biodegradable organics in municipal solid wastes. [Online]. Available from: http://www.seas.columbia.edu/earth/vermathesis.pdf [Accessed 31 July 2011]*
81. *Vesilind, P.A., Worrell, W., and Reinhart, D. 2002. Solid Waste Engineering. Brooks/Cole, Pacific Grove, California, USA.*

82. *Vlyssides, A. G. and P. K. Karlis. 2003. Thermal-alkaline solubilization of waste activated sludge as a pre-treatment stage for anaerobic digestion. Bioresource Technology. 25: pp. 57-66.*
83. *Ward, A.J., Hobbs, P.J., Holliman, P.J. and Jones, D.L. 2008. Optimization of the anaerobic digestion of agricultural resources. Bioresour. Technol. 99: pp.7928-7940.*
84. *Weiland, P. 2006. State of the art of solid-state digestion–recent developments. In: F.N. Rohstoffe, eds. Solid-State Digestion–State of the art and further R&D requirements. Gulzower Fachgespräche. 24: pp.22–38.*
85. *White, P. R., Franke, M. and Hindle, P. (1995) Integrated Solid Waste Management: A lifecycle inventory. London: Blackie Academic Publishers and Professional.*
86. *Williams, R.T. and Keeham, K.R. 1993. Hazardous and industrial composting. In H.A.J. Hoitink and H.M. Keener, eds. Science and engineering of composting. Worthington OH: Renaissance Press., pp:363-382.*
87. *Wilson, D.C. 2007, Development drivers for waste management. Waste Management Research 25:198-207*
88. *World Health Organisation. 2008. Air quality and health. [online]. Available from: http://www.who.int/mediacentre/factsheets/fs313/en/ [Accessed 03 August 2011]*
89. *Xing, W., Ngo, H.H., Guo, W., Wu, Z., Nguyen, T.T., Cullum, P., Listowski, A., Yang, N. 2010. Enhancement of the performance of anaerobic fluidized bed bioreactors (AFBBRs) by a new starch based flocculant. Separat. Purif. Technol. 72: pp.140–146.*
90. *Zhao, Y., Wang, A., Ren, N., 2010. Effect of carbon sources on sulfidogenic bacterial communities during the starting-up of acidogenic sulfate-reducing bioreactors. Bioresour. Technol. 101: pp.2952–2959.*
91. *Zhu, B., Gikas, P., Zhang, R., Lord, J., Jenkins, B., Li, X. 2009. Characteristics and biogas production potential of municipal solid wastes pretreated with a rotary drum reactor. Bioresour. Technol. 100: pp.1122–1129.*