Energy Potential of Anaerobic Digestion of Food Waste In U.A.E

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Abstract— **With the population of countries growing yearly by a 5% rate, thus leading to the dwindling fuel sources it has become imperative to find an alternate source of renewable energy to help sustain for the generations to come. Biofuels have proved their efficiency and contribution to a clean and greener environment. Hence the need of investing in organic waste to gain energy in the form of biogas is gaining importance over the world. This paper focuses on the potential of converting waste to energy and its role in managing waste; it also reveals the potential of food waste to energy project development in a high income country such as the United Arab Emirates.**

***Keywords*— Biogas, Anaerobic Digester (AD), food waste, Municipal Solid Waste (MSW), Greenhouse Gases (GHG)**

I. INTRODUCTION

Waste management has evolved over the years in order to incorporate waste prevention and recycling. Despite significant increase in recycling and energy recovery, only about one fourth of the total MSW is recovered leaving the remaining three-fourths to be disposed of in landfills or incinerated (burned). Landfill disposal is one of the most popular methods of waste management globally we produce 1.3 billion tons of landfill waste yearly which is projected to increase to 2.2 billion tons by 2025 [1]. However there are many problems associated with landfill disposal, which includes:

-Greenhouse gas pollution: the disposal of biodegradable waste at landfills is known to create an undesirable odor, unhygienic conditions and the release of landfill gases such as methane and carbon dioxide in the atmosphere thus squandering useful organic contents.

-Public health issues poorly managed waste accumulated on open spaces adds to the pollution of air and groundwater [2]. This affects human as well as aquatic life. Growth of microbial pathogens on unmanaged accumulated waste poses threat to waste workers. Moreover it also poses threat to the future generation, as buried garbage which includes plastics and polystyrene degrades at very slow rates with the realize of known toxins thus proving that today's landfill waste will lead to difficulties and problems for the generations to come.

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-Economic concerns: the disposal of waste in landfills prove to be fairly expensive, landfill disposal costs fall into the following categories - site development, construction, equipment purchases, operation, closure, and post-closure [3]. In some countries, where there is limited landfill space, or where new laws and regulations either ban disposal of MSW in landfills or require very high landfill disposal fees, the traditional options of landfilling and incineration are becoming less feasible.

With the rapid technological advancement energy recovery from waste is gaining momentum, the production of methane from wastes is receiving renewed attention as it can potentially reduce CO2 emissions via the production of renewable energy and limit the emission of the greenhouse gas methane especially from organic waste. This study aims on discussing the importance of organic waste recovery and it potential in a country such as the United Arab Emirates..

II. TYPES OF WASTE GENERATED IN UAE

The segregation of waste to be converted to energy plays an important role in waste to energy plants. The growing demands and technology advancement has led to the generation of a diversity of waste. This includes the following:

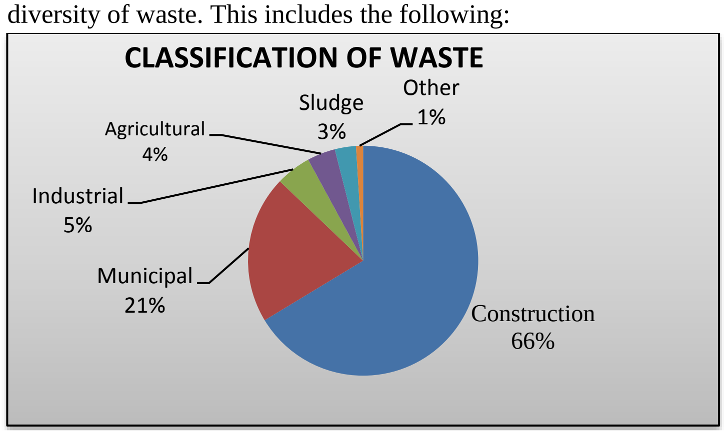

Fig. 1: Types of Waste

Construction waste accounts for almost 70% of the total solid waste generate in the UAE as shown in Fig 1 above. Dubai alone is known to produce 5000 tons of construction and demolition(C&D) waste. This includes rubble, asbestos, lead, cement waste, debris, etc. The amount of construction and demolition (C&D) waste generated in the U.A.E. has led to the increased recycling of the waste rather than disposal in landfills. Timber and steel are the two most recycled materials. Cost and technology requirements hinder on-site recycling in the projects. However, recycling has significant social, economic, and environmental benefits that the industry should embrace [5].

Municipal waste this includes variety of items disposed of at a household level as well as from hotels and supermarkets. MSW is classified into organic and inorganic waste. Organic waste includes waste that can be decomposed by microorganism in the absence of oxygen this includes waste such as paper, food, etc. Food waste account for 50% of the MSW [6], the disposal of food waste into landfills poses threats of greenhouse gas emission and climate change. It is found that food waste is a typical type of organic matter containing high potential for energy production through anaerobic degradation. Inorganic waste includes other waste such as metal, glass, plastics etc., these wastes need to be reduced as they have a very slow decomposition rate and tend to accumulate in the environment thus posing a threat to generations to come.

Industrial waste produced due to various manufacturing processes such as mining, waste generate in mills this constitutes for roughly 5% of the total solid waste generated in the country which is known to be disposed in water bodies close to the factories. As UAE has fairly less manufacturing plants in comparison to countries such as India, industrial waste mostly includes waste in the form of oil, recycling of waste oil includes waste oil into lower end base oils and furnace fuels [7].

III. FOOD WASTE GENERATION IN THE UAE

Urban waste generation and disposal is a growing concern we find that in GCC countries which rank in the top 10 world waste producers with 120 million tons of waste generated per year(2nd Middle East Waste Summit 2010). As of 2015, UAE alone generates around 27 million tons of waste per year. With the population of the country increasing to number as high as 9.346 million in 2016, the waste generated in only bound to increase reports released by the Emirates Environmental Group states that food worth \$4 billion (Dh14.69 billion) is wasted from UAE homes, eateries and large events and is being dumped in shrinking landfill space every year. Municipal solid waste in UAE comprises of organic fraction, paper, glass, metal, wood, etc. However as of 2015 3.27 million tons of food alone was wasted, the estimated cost of a truck load of food is worth on average Dh100,000, meaning that the annual cost of food waste in the UAE is a staggering Dh13.6 billion. Food amounts to 40% of the average household bin. Statistically food waste alone accounts for 55% of all the waste in the emirate Dubai. Reports state that every resident of the UAE generates an average of 2.5 kg of waste per day [8] this number is exceedingly high when compared to a country like India where a person generates .5 kg of waste per day in a few states. 60% of this waste generated is recyclable. But this number doubles to 5.4 kg per day during the month of Ramadan, thus when organic and food waste in disposed in landfills the methane emissions can be alarming, contributing to around 700 metric tons of CO2 equivalent per year (Dubai Carbon Report 2015). Hence if food waste is converted to energy depending on the plant capacity up to 50000 homes can be powered up with such waste.

IV. TYPES OF TREATMENT GIVEN FOR FOOD WASTE

Energy from food waste can be generated in many ways (biochemical, thermochemical and chemical conversion). Of which few methods have been put into use by the U.A.E. government (State of Energy Report U.A.E. 2015):

A. *Incineration:*

Waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities. Modern refuse combustors have tall stacks and specially designed combustion chambers, which provide high combustion temperatures, long residence times, and efficient waste agitation while introducing air for more complete combustion [9]. Types of waste incinerated include municipal solid waste (MSW), industrial waste, hazardous waste, clinical waste and sewage sludge, this waste is burned to form energy in the form of heat that can be converted to electricity. Sharjah (Bee'ah) and Abu Dhabi (Abu Dhabi National Energy Company) have invested millions in waste to energy incinerators, the plant will work by burning a mixture of municipal solid waste and commercial and industrial waste then using the heat to generate steam, which can be used to drive a turbine and produce electricity.

B. *Gasification:*

Gasification can be considered a process between pyrolysis and combustion in that it involves the partial oxidation of a substance. This means that oxygen is added but the amounts are not sufficient to allow the fuel to be completely oxidized and full combustion to occur. Gasification is the process of converting biomass primarily into syngas. This is accomplished at high temperatures and in the controlled presence of oxygen, which is the major difference between gasification and incineration. The temperatures employed are typically above 650°C. The process is largely exothermic (heat producing) but some heat may be required to initialize and sustain the gasification process. Raw municipal waste is usually not appropriate for gasification and typically would require some mechanical preparation and separation of glass, metals and inert materials (such as rubble) prior to processing the remaining waste. The main product is a syngas, which contains carbon monoxide, hydrogen and methane [10].

V. ANAEROBIC DIGESTION

Biogas production from anaerobic digestion: Anaerobic digestion is a process of decomposition of organic matter with the help of microorganisms without the presence of oxygen. The basic steps involved in anaerobic digestion are as follows:

- Hydrolysis: conversion of non-soluble biopolymers to soluble organic compounds
- Acidogenesis: conversion of soluble organic compounds to volatile fatty acids (VFA) and CO_2
- Acetogenesis: conversion of volatile fatty acids to acetate and H_2
- Methanogenesis: conversion of acetate and CO_2 plus H_2 to methane gas

The main products of anaerobic digestion are: biogas which is known to be rich in energy and the digest residue which can be reused in agricultural industries. The digest can also be utilized in many different ways depending on its composition.

The composition of biogas is typically 40% carbon dioxide and 60% methane. The gas mixture is saturated with water vapor and may contain dust particles and trace amounts of H_2, N_2, CO and halogenated compounds depending on the feedstock and process conditions. This biogas is mainly used to generate heat and electricity or as a source of fuel. This methane can be separated from carbon dioxide and be compressed to be used directly as a transport fuel in vehicles which are designed to be fueled by gas thus proving to save fossil diesel levels. The digestate (effluent in wet systems) is another valuable product from the anaerobic treatment process. The digestate is a liquid slurry because of its high water content as well as the decomposition of solids during digestion. Storing and handling of this liquid is more complex than solid material such as compost. The digest residue is known to be rich in nutrients such as nitrogen and phosphorous and can be used as bio fertilizers for crops thus proving to be beneficial to the agricultural industry as it helps to reduce reliability on phosphate fertilizers that are obtained from non-renewable sources, it also helps in reducing GHG emissions that are caused by mining activities and the cost of transport and production services involved in the manufacturing of inorganic fertilizers.

However various environmental and physical parameters affect the process such as pH, retention time, temperature, loading rate and composition of food waste [12], thus by controlling microbial activity and other environmental and operating conditions the process can be optimized.

As the technology of anaerobic digestion has already proved to be beneficial in the treatment of sewage sludge, research and various waste projects have begun to use this technology for the treatment of organic waste especially for the treatment of food waste. Few of its benefits include [13]:

Increasing the space in landfills i.e. diverting organic waste from landfills to anaerobic digestion plants leads to the generation of less waste in landfill that can be strictly used for the disposal of non-biodegradable waste such as plastics and polymer compounds.

The residue obtained from the digester are known to be rich nutrients such as nitrogen and phosphorous thus are used as bio fertilizers for crops thus proving to be beneficial to the agricultural industry.

The disadvantages of anaerobic treatment are summarized below:

Formation of H_2S: In addition to methane and carbon dioxide anaerobic digestion leads to the production of trace quantities of ammonia, nitrogen and oxygen and hydrogen sulfide which need to be removed in order to improve the quality of biogas [14].

High initial set up cost according the capacity of waste aimed to be treated per day the cost of AD plant set up ranges from a million or billion dollars added to this is the cost of pre-treatment of waste that needs to be segregated and removed of all non-biodegradable waste thus making the initial expense high.

Odor control**:** the odor released from anaerobic plants due to the composting and pre-treatment process serve as a threat as it leads to location constraints s they need to be built in places away from residential sites to avoid disturbing the public from the odor and emissions.

VI. RESULTS AND DISCUSSION

In view of the country's aim to target zero landfill waste by 2020 there is a need to invest in food waste by means of anaerobic digestion, the optimization of an anaerobic process yields the following results as shown in Table 1 below:
1 ton of food waste = 99.7 m3 [15]

Table I: METHANE CAPACITY OF FOOD WASTE

Year	MSW (million tons)	Food waste (million tons)	Recycle %	Methane produced (million m^3)
2012	5.32	2.9	20%	289
2015	6.6	3.27	25%	326
2020	8.4	4.62	75%	460

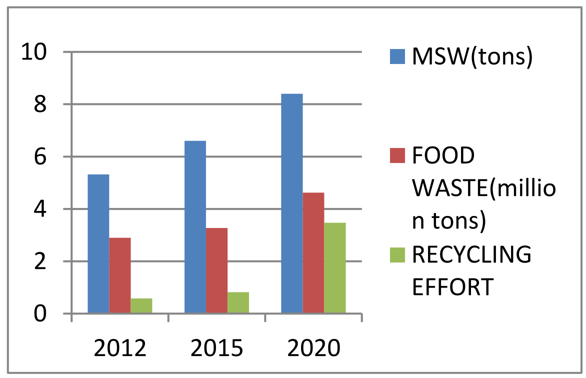

Fig. 2 -UAE waste statistics

Fig. 3- Trend between food waste and methane production

Fig. 2 gives the overall waste generated in U.A.E. in 2012 and 2015, as well as the estimated amount of MSW and food waste that will be generated by 2020. It also shows the increase in efforts to recycle waste generated over the years. The estimation of methane production from the food waste generated is shown in Fig. 3. However even though anaerobic digestion is pronounced to be one of the feasible options of food waste treatment, there are various limitations associated with it as discussed in the above section however the factor that needs to be considered the most important is the release of greenhouse gases into the atmosphere due to the depleting ozone layer as well as the climate change that it causes. Thus while designing a waste to energy treatment plant GHG emissions need to be kept at minimal amounts.

VII. DESIGN OF WASTE TO ENERGY PLANT USING ASPEN

The whole MSW management system has been considered, which meant that in some cases the complete MSW treatment involved the combination of different processes. For instance, the non-fermentable fraction of a biological system has to be incinerated or disposed in a landfill. The MSW systems considered have been:

• Landfill
• Incineration
• Sorting + Composting + Landfill
• Sorting + Composting + Incineration
• Sorting + Dry Biogasification + Landfill
• Sorting + Wet Biogasification + Incineration +Landfill

Table II - Emission factors from different MSW management systems [18]

MSW Treatment	Emission Factor (t eq. CO_2/t MSW)
Landfill	1.97
Incineration	1.67
Sorting + Composting + Landfill	1.61
Sorting + Composting + Incineration	1.41
Sorting + Dry Biogasification + Landfill	1.42
Sorting + Wet Biogasification + Incineration +Landfill	1.19

As shown in table 2 the emission factor of different waste management systems, this shows that a mixed approach of waste management reduces greenhouse gas emissions by 70% factor as compared landfill disposal. Thus such an approach will be profitable to the environment.

This using Aspen Plus a basic model of such a plant has been designed.

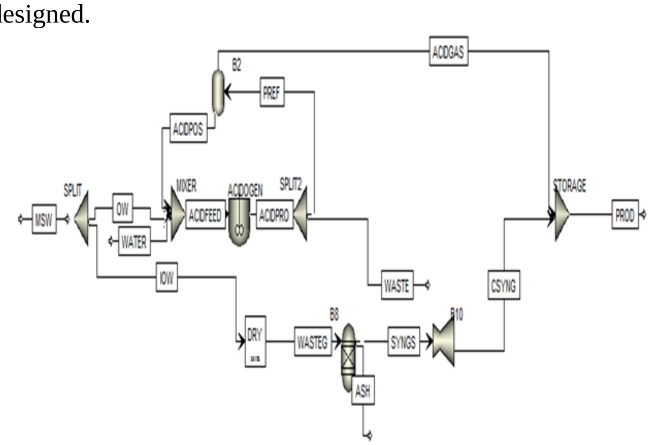

Fig. 4 - Simulation of proposed waste to energy plant

Aspen plus software helps in the simulation as well as modelling of the proposed waste to energy plant as shown above in Fig. 4. It showcases the splitting of food waste (segregation) to organic and in organic waste. The organic waste is then treated by anaerobic digestion whereas the inorganic waste is treated by incineration method. Lastly the waste and ash collected from the two processes respectively can be disposed-off in landfills.

LIST OF COMPONENTS AND THEIR FUNCTION:

COMPONENT	FUNCTION
SPLIT	Segregates organic and inorganic waste
MIXER	Mixes water + organic waste (hydrolysis)
ACIDOGEN	CSTR reactor in which acidogenisis takes place
SPLIT 2	Splits volatile fatty acids to acetate
B2	Flash reactor in which carbon dioxide acetate and hydrogen undergo methanogenesis
DRY	Dries the inorganic waste
B8	Waste undergoes incineration at high temperature (600-800 C)
B10	Scrubber helps in separating solid particles from syngas
STORAGE	Gas produced from both process stored and can be used as fuel

VIII. CONCLUSION

Even though the popularity of Anaerobic Digestion has increased over the years there are a limitation that need to be overcome in this process of anaerobic digestion of food waste to increase the efficiency of the process thus research show that co-digestion of sludge and food waste helps to optimize the process [16,17]. In particular these studies have demonstrated that combining different organic wastes results in a substrate better balanced and assorted in terms of nutrients, pre-treatments making organic solids more accessible and degradable to microorganisms. However it is found that since sewage sludge as well as food waste can undergo anaerobic digestion, the production of methane is known to increase when both these feedstocks are combined, thus helping to optimize the process.

Secondly, on researching the various options of waste to energy process it is found that when treating municipal solid waste, best results in terms of least greenhouse gas emissions was obtained when all the different treatments are combined [18] i.e. sorting of waste followed by anaerobic digestion of organic waste, incineration of other waste and landfilling. Thus with use of Aspen software such a plant can be modeled that involves both the design of an anaerobic digester for the organic waste as well as an incinerator for the non-fermentable waste as this method helps to reduce the GHG emissions by a large factor as compared to using these processes individually thus increasing the efficiency of the waste to energy conversion process.

Lastly not only should these waste management techniques be encouraged but also the need to reduce the waste generated at households by buying food just to fulfill our everyday needs, so that we can prevent the excess wastage of food.

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