Waste-to-Energy: Solution for Municipal Solid Waste Challenges—Global Annual Investment

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Abstract—Current global Municipal Solid Waste (MSW) generation level is 1.3 billion tons per year, and is expected to increase to approximately 2.2 billion tons per year in 2025. This amount may result in significant health, environmental, aesthetic, land-use resources, and economic concerns if not managed properly. Waste to Energy (WTE) is a viable option for disposal of MSW and energy generation. This paper presents a brief review of WTE technologies; reviews the current market status of the WTE; and forecasts the potential global annual investment in this sector. The research findings show that incineration is the dominant technology utilized to date. Advanced technologies such as Plasma Arc Gasification are gaining momentum in developed countries, whereas biomethanation technology is expanding at a high rate in developing countries in the last decade. Globally, WTE will play a significant role in minimizing MSW challenges and will contribute to the emerging renewable energy market in the near future.

Keywords—Waste-to-Energy; Municipal Solid Waste; Renewable Energy

I. INTRODUCTION

The 2013 world population was about 7.2 billion and is projected to increase by 1 billion by the year 2025 with an average growth rate of 1% per year. The growth will be mainly in developing countries, with more than half in Africa [1]. Urban population increases at a higher rate than population growth where the world urban population is expected to grow roughly 1.5% per year in the same period [2]. The increase in urban population will be mainly in developing countries, with majority in Asia, where industrialization has caused population shift form villages to cities. Population growth, urbanization, and the increase in the standards of living are the three ingredients that govern the increase of municipal solid waste (MSW) generation [3, 4]. Current global MSW generation level is 1.3 billion tons per year, and is expected to increase to approximately 2.2 billion tons per year by 2025 [5]. This resulted from population growth and the increase of per capita waste generation rates from 1.2 to 1.42 kg per person per day in the next fifteen years [5]. Worth to mention that global averages are broad estimates only, as the rates varies considerably by region, country, city, and even within cities. For example MSW generation ranges from 0.9 to 1.6 kg/day in European Union and Asia and 0.7 to 1.5 kg/day [4]. These results in millions of tons of MSW produced globally every day [3]. The main purposes of municipal solid waste (MSW) management strategies are to handle the health, environmental, aesthetic, land-use resources, and economic concern related to improper disposal of waste [6-8]. The proper handling and disposal of MSW is necessary not only from sanitation point of view but also due to its economic value, including the contribution to the energy sector [9]. Despite this fact, landfilling remains the world’s most implemented method of MSW disposal: WTE is a proven and efficient option to handle the MSW disposal challenges and has the capacity to contribute to the ever increasing global energy demand. This paper presents a brief review of WTE, review of the current market status of the WTE and forecasts the potential growth in this sector.

II. WASTE TO ENERGY TECHNOLOGIES

A. Incineration

Incineration is the production of energy from waste through combustion. There are a number of well-developed techniques across the globe [10]. Incineration has remained to be the most integral part of MSW management in many countries. In the incineration process, waste feedstock is mixed thoroughly to maintain a more constant heating value and then loaded into a large hopper, bunker, or other delivery system. Feedstock is then delivered along a conveyor or other mechanism into the furnace, typically onto a graded stoker or other bed for combustion. This consists of directly burning the waste in excess oxygen with temperatures in excess of 800°C. As the waste is incinerated, released heat travels upward and heats water in a boiler system, which in turn drives a steam cycle and steam turbine. The most important byproduct of incineration is the bottom ash which consists of silicon, iron, calcium, aluminum, sodium and potassium in their oxide state. These materials are present within a range of 80-87% by mass in the bottom ash [11]. This process also has the advantage of reducing waste by 80% and mass by 70% and relatively lower cost in comparison to other technologies [12]. Additionally, this process can handle all type of waste including organic materials and requires a low level of technology and human resource skills. The major drawback of incinerator is the generation of high levels of air and waterborne pollutants. Modern technologies are available that help in minimizing the environmental impacts. The cost of these environmental
protection methods constitutes about 40% to 70% of total project cost. In spite of the public opposition to incineration projects which are still a major barrier facing project deployment; the relatively low cost, high efficiency and proven technology made incineration as the dominant WTE in the Global. Fig. 1 above shows the incineration market trend of in Asia, Europe and North America.

B. Pyrolysis

Pyrolysis is a thermal decomposition of waste into volatile gases and solid char [14]. This technology consists of two stages Pyrolysis and Gasification. Pyrolysis is generally defined as the process of heating MSW in an oxygen-deficient environment. Pyrolysis produces char consisting of carbon and inorganic compounds in the feed. In Gasification stage, the carbon reacts with steam to produce carbon dioxide and hydrogen. The reaction between carbon and oxygen is exothermic and provides the thermal energy required to drive the process. The basic gasification reactions are either endothermic or exothermic and their rates depend on temperature, pressure and oxygen concentration [15]. Gasification converts carbonaceous material into a synthesis gas or “syngas” composed primarily of carbon monoxide and hydrogen. Theoretically following a cleaning process to remove contaminants, this syngas can be used as a fuel to generate electricity directly in a combustion turbine or engine. The overall efficiency for this technology has been reported to be around 17% [16].

C. Plasma Arc Gasification

Plasma is called the fourth state of matter, as it is distinctly different from solid, liquid and gaseous states. Plasmas are hot ionized gases created by an electrical discharge. Plasma can create an ionized gas by electrical forces whereby the temperatures can reach between 2000°C to 5000°C (3632°F to 9032°F) [19]. This reason promotes Plasma as a very viable option to waste treatment. For plasma to be used at atmospheric pressure, plasma torches are used. The quality of waste decomposition through plasma depends upon plasma density and its temperature. During the process, hot plasma gas flows into the gasifier/reactor to gasify municipal solid waste (MSW) and melt the inorganic materials. The plasma arc gasifier is operated with an injection of a carbonaceous material like coal or coke into the plasma arc gasification reactor. This material reacts quickly with the oxygen to produce heat for the pyrolysis reactions in an oxygen-starved environment. Steam is added to the reactor to promote syngas reactions [20]. The combustion reactions (exothermic reactions) supply heat with additional heat from the plasma arc torches for the pyrolysis reactions (endothermic reactions) yielding a temperature typically between 4000°C – 7000°C. The bottoms from the reactor results in a vitrified slag since operating conditions are very high. The inorganic and mineral elements present in the MSW produce a rock like by-product – a vitrified slag typically of metals and silica glass. The efficiency of this technology is reported as 32% [21]. The use of plasma arc gasification for MSW has been mostly applied in Japan, where their lack of space forced them to find alternatives to landfilling. This technology requires a very high capital cost and technological capabilities. This limits its use and expansion in both developed and developing countries.

D. Refused Derived Fuel

Refuse Derived Fuel (RDF) is a clean and efficient method of producing an eco-friendly and an alternative fuel for power generating industries, which run on coal fuel [22].
operations involved in RDF, sorting, casting or crushing, drying operations and formation. Size reduction includes shredding the waste to a manageable size, where sorting aims to remove all protein containing materials from the waste stream. The refuse utilized for RDF shall mainly contain cardboard, paper, various plastic streams, glass, metallic and non-metallic materials. Crushing involves the process of destroying the larger particles of municipal waste into smaller particles for easy handling and transporting. Finally there are drying and forming processes. The drying operation needs a large quantity of energy, and the performance improvement governs the energy efficiency of process. The RDF particles are mixed thoroughly with binders such as calcium hydroxide. CaO is added to the refuse during the RDF production [23]. CaO reacts with water to become Ca(OH)₂. When flue gas is used as the drying gas, Ca(OH)₂ is reacted with CO₂ to be CaCO₃ [24]. Then it is converted into pellets into required size and shapes. The RDF is formed into a chalk-like shape or pellet with a diameter at 15mm to 50mm long. A RDF pellet having about 11% or more particulate calcium hydroxide is utilized in a combustible mixture. Combustion of the mixture is effective to produce an effluent gas from the combustion zone having a reduced SO₂ and polycyclic aromatic hydrocarbon content of effluent gas from similar combustion materials not containing the calcium hydroxide. The overall efficiency for this methodology is reported to be around 18% [25]. RDF technology is globally popular. The growth of RDF in Europe is tremendously fast from 1.4 million tons per annum (Mtpa) in year 2000 to 12.4 Mtpa in year 2005 [26]. In Austria alone there are around 180 industrial facilities which co-incinerate more than 1.8 million tpa of secondary fuels and/or RDF [26]. In Asia, Japan currently has 1900 incineration plants and most of the RDF plants are near to these incineration plants [27]. In India, with RDF alone generates up to 7.5MW of electricity [28]. RDF is mostly utilized for pulp, paper industry and the wood industry followed, by the saw-mill industry. Accordingly the RDF facilities are relatively small and utilized specifically by industrial sector.

E. Biomethanation

Biomethanation converts the Organic Fraction of Municipal Solid Waste (OFMSW) into useful energy [28]. The basic raw materials for biomethanation may vary and studies show that this may contain vegetable market waste, agricultural waste, whey, dairy waste and restaurant waste [29, 30]. The biomethanation process consists of three anaerobic organisms, which convert waste to methane. The initial stage is known as ‘hydrolysis’ which converts complex organic matter like carbohydrates, proteins and fats in the waste to soluble organic molecules which contain sugars, amino and fatty acids. The second stage of the process is ‘fermentation’ and the organisms involved in this stage further breakdown the organic structures of first stage to acetic acid, hydrogen and carbon dioxide. Finally, the methanogenesis stage, where organism covert the acetic acid and hydrogen to hydrogen to methane [31]. The effective efficiency of this technology is around 25% [32]. The low cost of this technology and ease of operation has made Biomethanation to be the most popular techniques for waste disposal and methane gas generation in rural areas in Europe, Asia, South America, and Africa specifically for agricultural waste treatment. This technology has been applied on a limited scale in Europe on mixed MSW and on a larger scale on source separated organics (SSO) or agricultural-based processes, but there is very limited commercial-scale application in any form in North America.

The glaring disadvantage of using this process is with the space requirement. The waste that is collected for this technique has to be properly covered for the anaerobic processes to take place and cannot be opened for the next few years, making that space unavailable for the next lot of MSW [33]. This fact has limited its application in urban areas.

III. WTE GLOBAL ANNUAL INVESTMENT

Management of MSW may include source reduction, reuse, recycling and composting, combustion with or without energy recovery, and finally landfilling. Integrated MSW management approach aims to help guide decisions about the generation of wastes, waste source reduction, reuse, recycling of materials, and ultimate disposal of the waste residues with optimum objective to increase diversion rates from landfills. Most of European and North American countries have developed new policies embracing integrated MSW management solutions. MSW policy changes in the rest of the world are slower but the momentum of change exists and is growing. The slow policy changes resulted from underdeveloped status of waste management infrastructure and the socio-economic condition in these countries. Population and Urbanization growth, international agreement such as Kyoto protocol, international financial institutional pressures will motivate developing countries to accelerate the development of new MSW policies. MSW policy reform will result in substantial growth in WTE market annual investment from about 2.1 billion US dollar in 2010 to about 26.1 billion US dollar in 2025 as shown in Fig.3. This situation, if occurred, will trigger massive development in WTE market and technologies across the globe.

WTE technologies are a viable option for WTE disposal based on its environmental values and energy generation potential. Identifying the proper technology for a certain area shall depend on the: MSW management maturity level, waste characteristics, land area availability, available capital, technological complexity coupled with labor skill requirements, geographical locations of the plants and technology’s efficiency. Incineration fits both urban and rural areas and utilizes all type of waste. It has a relatively low capital requirements and labor skill levels in comparison Plasma Arc Gasification, Pyrolysis and RDF technologies. It has also a good efficiency of about 27%. These reasons make incineration the most dominant technology in the world. Pyrolysis has the least pollution emissions and produces the best environmental value in comparison to other technologies except Plasma Arc gasification. This make the technology best fit for developed countries with high public awareness level.
such as Germany. Plasma Arc Gasification is the most technologically advanced and expensive technology. Characterized by low land area requirements and has the highest efficiency. This technology best fits for highly developed countries with limited land resources such as Japan. RDF technology cannot handle organic waste with high protein contents but has a relatively low cost and good efficiency. The technology is also very cost efficient at a small scale. This makes it the best technology for industrial waste handling and disposal. Biomethanation characterized by low capital requirements, unsophisticated technology and ease of operation, very efficient with organic waste, highest land area requirement, and can be developed in all sizes. These conditions make Biomethanation as the optimum technology for rural and agricultural area in developed and developing countries.

IV. CONCLUSION

Current global Municipal Solid Waste (MSW) generation level is 1.3 billion tons per year, and is expected to increase to approximately 2.2 billion tons per year in 2025. This amount may result in significant health, environmental, aesthetic, land-use resources, and economic concerns if not managed properly. Integrated MSW management approach aims to help guide decisions about the generation of wastes, waste source reduction, reuse, recycling of materials, and ultimate disposal of the waste residues with optimum objective to increase diversion rates from landfills is prevailing globally. Waste to Energy (WTE) is a viable option for disposal of MSW and energy generation. This paper presents a brief review of WTE technologies; reviews the current market investment of the WTE; and forecasts the potential global annual investment in this sector. The research findings show that MSW policy reform is spreading globally in each and every nation. The reform rate is varied among countries based on the status of MSW infrastructure and the socio-economic characteristics. The MSW policy reform will result in substantial growth in WTE market annual investment from about 2.1 billion US dollar in 2010 to about 26.1 billion US dollar in 2025. This situation, if occurred, will trigger massive development in WTE market and technologies across the globe.

Identifying the proper technology for a certain area shall depend on the: MSW management maturity level, waste characteristics, land area availability, available capital, technological complexity coupled with labor skill requirements, geographical locations of the plants and technologies efficiency. Incineration is the dominant technology utilized to date and is expected to continue in the next decade. Advanced technologies such as Plasma Arc Gasification are gaining momentum in developed countries, whereas biomethanation technology is expanding in rural and agricultural areas.

REFERENCES


