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Waste-to-Energy (WTE) Technology Applications for Municipal Solid Waste (MSW) Treatment in the Urban Environment

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Abstract—Proper treatment of Municipal Solid Waste (MSW) is one of major challenges achieving adequate sustainability especially in the urban environment. The amount of MSW typically increases as consuming more goods and services for high standard of living. In the United States, the majority of MSW is landfilled and less than 35 percent of total MSW is recycle. New energy technology provides an opportunity to lessen the increasing burden of MSW. MSW can be converted into valuable energy sources using Waste-to-Energy (WTE) technologies such as incineration, pyrolysis, gasification, and plasma arc gasification. Various energy sources produced from the WTE technologies can be used in lieu of fossil energy resources. It is expected that various aspects of sustainability related to energy and waste treatment can be improved. The paper introduces various WTE technologies and applications in terms of sustainable urban energy development and MSW treatment.

Keywords—Municipal Solid Waste (MSW), Waste-to-Energy (WTE), Pyrolysis, Gasification, Plasma Arc Gasification.

I. INTRODUCTION

Ecological footprint for today’s humanity uses 1.5 planet equivalents to provide the resources that absorb the waste [2]. Humanity development including population, urbanization, and economic growth increases the amount of municipal solid waste (MSW). The two most significant contributors to the ecological footprint are food and energy. Papers and plastics are nearly 50% of the MSW composition in high income countries [8]. Industrial processed food packaging is one of the largest contributors of paper and plastic MSW.

There are several options to treat MSW. Conventional methods are landfilling, recycling, and incineration. MSW gives a huge burden to the municipal government. 20-50% of the recurring budget of municipalities is often spent on MSW management and collection is uses 80-90% of the total MSW budget. Landfill is the most economic method to handle significant amount of MSW. Over 50% of MSW in the United States is dumped in landfill. Recycling and incineration follow after landfill [1]. The methane emissions from MSW landfills are around 3-19% of methane emissions [3]. Methane is the leading contributor of important Green House Gases (GHSs) and it is 20 times more effective in trapping heat in the atmosphere than carbon dioxide. Methane can be collected by a collection system and used as energy source. However, significant up-front investment for a methane collection system makes it difficult to implement. Besides landfilling, incineration is an efficient way to reduce the waste volume and demand for landfill space. Incineration reduces the volume of waste by about 80-95% according to The World Bank [13]. Incineration can produce energy for steam generation and heat exchange, but it generates more carbon dioxide emissions than coal, natural gas, or oil [4].

According to the U.S. Energy Information Administration (EIA), the world energy demand will increase by 30% by the year 2025 [10]. Currently, the leading source of energy in the world is fossil fuel which is a non-renewable and limited natural resource. Fortunately, there are revolutionizing technologies which simultaneously, process MSW and generate energy. Waste-to-Energy (WTE) is a concept of significantly reducing volume of MSW and transforming carbons to energy sources such as synthetic gas, bio oil, steam, and heat. Incineration is the most popular existing WTE technology, which effectively reduces waste disposal to landfill and produces energy.
However, incineration is not always effective when removing pollutants, processing small batch, and requiring high operation costs. Pyrolysis, gasification, and plasma arc gasification are new WTE technologies providing some advantages in regards to sustainable MSW treatment in urban environment. This paper introduces the three new WTE technologies and provides guidance to make a more sustainable alternative choice for MSW treatment.

II. WASTE TO ENERGY (WTE): AN INTEGRATION OF TWO INDUSTRIES

According to a 2001 study by the United Nations Environmental Program (UNEP), “The increasing volumes of waste being generated would not be a problem if waste was viewed as a resource and managed properly” [9]. Waste to Energy (WTE) technology is a green opportunity to continue the path of human ingenuity and technical advancement.

A. Pyrolysis Process

The Pyrolysis process begins when MSW, after pre-sorting and shredding, is metered into a reactor with little or no oxygen. The temperature in the reactor is increased to a range between 1,200 and 2,200ºF. Combustion (“burning”) does not occur in this process. When carbon-based materials are exposed to high temperatures, chemical bonds begin to break. Depending on the temperature, this process results in the generation of solid char, oily liquids, and gases such as hydrogen (H2), carbon monoxide (CO), and volatile hydrocarbons such as methane (CH4). Such a mixture of these flammable gases is known as syngas. Syngas is further treated to remove harmful substances including mercury, hydrochloric acid, sulfur oxides, and particulate matter. After this process, the syngas may be used to generate electricity using a gas turbine. The resultant solid and fluid residues (ash, char, metals, bio-oils, etc.) can be further processed to produce solid fuels for power plants, a petroleum substitute (bio-oil), and concrete filler. Pyrolysis typically generates 571 kWh per ton of MSW [14].

B. Gasification Process

Similar to pyrolysis, conventional gasification often begins after removing recyclables and large items such as refrigerators and car bumpers. The remaining MSW is fed into a gasifier. The gasification reactor is heated to temperatures between 1450-3000ºF. In contrast to incineration, gasification uses a sub-stoichiometric volume of oxygen, often called a “starved-air” process. This creates a smoldering reaction which generates syngas mixed with combustion products such as CO2 and water vapor. Often, steam is added into the process in order to enhance production of hydrogen and hydrocarbon gases. The syngas is cleaned up to remove hazardous components and can then be used to generate electricity. Due to the small amount of air involved in the gasification process, the produced gas has a higher caloric value than the pyrolysis process. The conventional gasification process can generate 685 kWh per ton of MSW [14]. Mixed gases, ash, slag, and metals are produced at the end of the reactions in the gasification reactor. The remaining solids are useful as concrete and asphalt aggregates. As in the pyrolysis process, mixed gases should be filtered to get high quality syngas and to remove hazardous gases such as sulfur, chlorides, and mercury. To get high quality syngas from the gasification process, preprocessing of raw MSW is required.
C. Plasma Arc Gasification Process

The Plasma arc gasification process is the most advanced and efficient technology available. Its name is due to the process of generating plasma (the so-called “4th state of matter”) by ionizing a gas in the reactor. The plasma flames generated are essentially lightning bolts, created by high-voltage arcs. Temperatures in this process range from 7,200 to 12,600 ºF. MSW is generally shredded, then fed into the plasma reactor with sub-stoichiometric volumes of oxygen or air. The syngas produced can be cleaned, and used to make electricity. The solid residue from plasma arc gasification is unique. A glass-like by-product, known as vitrified slag, extrudes from the bottom of the reactor. An attractive characteristic of this material is that its components do not leach out. The vitrified slag consists of metals and silicate glasses which fuse together into an inert solid. Vitrified slag has more uses than ash from conventional gasification, including as insulation material, flooring tiles, and garden blocks. By utilizing plasma arc technology it is possible to generate 816 kWh per ton of MSW.

Table I summarizes WTE operating temperature ranges, typical energy production rate, and other usable resources. It is noted that incineration method is not able to produce syngas and pyrolysis and gasification technologies produces both syngas and bio-oil as by-products.

### TABLE I

<table>
<thead>
<tr>
<th>WTE Technology</th>
<th>Operating Temperatures (ºF)</th>
<th>Energy Production (kWh/ton MSW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incineration</td>
<td>1,000 - 2,000</td>
<td>544</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>1,200 - 2,200</td>
<td>571</td>
</tr>
<tr>
<td>Conventional Gasification</td>
<td>1,450 - 3,000</td>
<td>685</td>
</tr>
<tr>
<td>Plasma Arc Gasification</td>
<td>7,200 - 12,600</td>
<td>816</td>
</tr>
</tbody>
</table>

III. WTE IMPLEMENTATION IN URBAN ENVIRONMENT

Pyrolysis, conventional gasification, and plasma arc gasification are revolutionary technologies that can effectively reverse the negative results of two primary human activities: 1) MSW transportation and disposal, and 2) fossil energy production and consumption. The revolutionary WTE technologies provide a sustainable alternative solution especially as compared to landfill and conventional incineration methods. Table II summarizes degree of sustainability from seven aspects. New WTE technologies can be made relatively small size, effectively process small batch in decentralized WTE facility, and produce relatively small amount of pollutants due to high temperature. Not only do WTE technologies provide syngas and oil as alternative energy sources, but also it requires smaller footprint for MSW treatment. Conventional recycling can be the most environmentally friendly alternative in terms of resource conservation. However, this method is labor intensive to process large quantity of MSW.

The Puente Hills Landfill outside Los Angeles just closed forever. The second largest municipality in the United States just lost its largest trash dump, a man-made mountain 500 feet tall and covering 700 acres [5]. The largest city in the US, New York, ships its sewer sludge to Texas for disposal [7]. Until recently, Americans have been able to throw out garbage indiscriminately. Per Table I and EIA data, the impact of converting a typical US citizen’s home MSW can be calculated with the following equation [11]:

\[
\text{Impact of converting a typical US citizen’s home MSW is calculated as:}
\]

\[
\text{Impact = Energy Produced (kWh) x 0.861 (kWh/ton MSW)}
\]
Total Annual Household WTE Energy Available = Household Size \times MSW Per Person \times (365 \text{ days/Year}) \times (1 \text{ Tons/2000 Pound}) \times WTE Energy Production.

Total Annual Household WTE Energy Available = 2,609 kWh

Thus utilizing WTE technology could reduce electrical production from other sources by approximately 24% [12]. Now, with disposal costs soaring, with electricity prices rising, and with demand for petroleum ever-increasing, time is right to expand application and develop of the WTE technologies.

<table>
<thead>
<tr>
<th>MSW Treatment</th>
<th>Footprint</th>
<th>Degree of Pollution</th>
<th>Energy Input</th>
<th>Energy Output</th>
<th>Initial Capital Investment</th>
<th>Process Capacity</th>
<th>O&amp;M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>None</td>
<td>Medium</td>
<td>Very large</td>
<td>Low</td>
</tr>
<tr>
<td>Conventional Recycling</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>None</td>
<td>Small</td>
<td>Small</td>
<td>High</td>
</tr>
<tr>
<td>Conventional Incineration</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Large</td>
<td>High</td>
</tr>
<tr>
<td>New WTE Technologies</td>
<td>Medium/Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>High</td>
</tr>
</tbody>
</table>

Sustainability requires forward thinking for the ability of future generations to meet their needs. Oslo, Norway, faces a current “ironic problem”. They are running out of MSW to power their WTE facilities. To solve this problem, the Norwegian authorities are importing trash from other surrounding countries. Sweden is also fighting to get a share of trash imports. These two countries are great examples of what WTE technologies can accomplish. Some other countries, like Germany, Denmark, and Austria, where humans have lived and buried their garbage for millennia, are getting more interested in WTE [6]. Expectantly, this rise of interest in WTE may create a domino effect in which these technologies become an essential component of the energy generation that powers our global economy.

IV. Conclusions

The correct approach towards waste is to manage MSW as a resource, and not merely as an object of zero value. By implementing a strategic plan, MSW can be utilized to the benefit of the society. WTE is a broad topic, which includes various types of energy conversion processes, see Table III. It is a new generation management system that is going to make both environmental and energy industries work together to come up with solutions for the waste and energy problems.

The significance of these waste management technologies for urban environment includes: reducing the need for landfills, discarding capability of hazardous waste, reducing hazardous emissions, and generating alternative energy sources. Local authorities are constantly investing in MSW management techniques. The utilization of WTE technologies not only resolves the Waste management issue but also generates energy that can be sold for profit; making the WTE technologies a profitable solution that tackles to major challenges waste management and energy demand.

Consequently, society will gain benefit by disposing of their waste in a clean and environmental manner; and also by acquiring an alternative energy that is sustainable, clean, and affordable. It is up to authorities to make smart investments, stop burning the assets instead of investing in reliable technologies that offer great solutions, or in other words, don’t trash it…cash it!

REFERENCES


