ENVIRONMENTAL SUSTAINABILITY Efficient Implementation of Waste Management

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ABSTRACT
While acknowledging the need for 'sustainability', this paper delves deep into the ideal methods that can be implemented for efficiently creating a sustainable environment, predominantly by the concept of 'waste management' and the various modus operandi that are to be utilized to carry out this waste management. It explores the various advantages that can be perceived by systematically managing waste and also brings forth the applications of waste management systems and how they can be effective in the long run to create a sustainable environment for generations to follow.

KEYWORDS
Sustainable environment, Advantages of sustainable environment, Waste Management and its implementation, Benefits of proper waste treatment

I. INTRODUCTION

Waste management is the process of treating solid wastes and offers variety of solutions for recycling items that don’t belong to trash. It is about how garbage can be used as a valuable resource. Waste management is something that each and every household and business owner in the world needs. Waste management disposes of the products and substances that you have use in a safe and efficient manner.

According to Wikipedia, “Waste management or Waste disposal is all the activities and actions required to manage waste from its inception to its final disposal. This includes amongst other things, collection, transport, treatment and disposal of waste together with monitoring and regulation. It also encompasses the legal and regulatory framework that relates to waste management encompassing guidance on recycling etc.”

The need for waste management to promote a sustainable environment

To study more about waste management, we must first learn why do we have to manage the disposal of waste – what are the benefits of waste management. These various benefits can be divided into the following sub-groups:
**Better Environment**

Probably the biggest advantage of managing waste is that it eventually leads to a better and fresher environment. Waste disposal units also contribute to the well-being of people by helping them become disease-free. The best part: all of this happens while the unnecessary is duly disposed in a proper and sanitary manner. Multiple waste disposal units should be placed in tier-1 and tier-2 cities in a bid to prep up the process of waste disposal. This will also help implement remarkable safety measures in the long run.

**Reduces Pollution**

When waste is managed the right way, it doesn’t merely eliminate the subsequent waste but also reduces the impact and intensity of harmful greenhouse gases like CO, CO$_2$ and methane that are often exuded from accumulated wastes in landfills. Managing waste reduces our reliance on landfills while also significantly cutting down the many factors that adversely impact our environment.

**Conserves energy**

Recycling is one of the biggest aspects of waste management, and over time it helps conserve energy. One of the biggest instances of this advantage can be traced to the practice of recycling paper.

All of us are probably aware that thousands of trees are cut to produce paper. When a used paper is recycled to create new paper, the need of cutting trees is significantly minimized. This helps conserve energy while also reducing your carbon footprints.

**Creates Employment**

The recycling industry alone creates thousands of jobs alone. As more people adopt this eco-friendly practice, organizations creating and selling recycled products come to the forefront. This helps boost their business while also creating hundreds of jobs.

**Helps Make a Difference**

By managing waste, we are also making a difference to the society and the world in general. While none of us can completely get rid of garbage, we can always adapt eco-friendly practices of reducing and reusing waste. This way, you create an example for the people around you, who in turn are now motivated to embrace a sustainable approach.

**II. WASTE MANAGEMENT**

Coming to the suitable implementation of managing waste, we find there are eight major groups of waste management methods, each of them divided into numerous categories. Those groups include source reduction and reuse, animal feeding, recycling,
composting, fermentation, landfills, incineration and land application. We can start using many techniques right at home, like reduction and reuse, which works to reduce the amount of disposable material used.

There are various methods of Waste Management, but however, the detailed structure of a few methods of waste management are described as below:

i. **LANDFILLS**

The term landfill is usually shorthand for a municipal landfill or sanitary landfill. These facilities were first introduced early in the 20th century, but gained wide use in the 1960s and 1970s, in an effort to eliminate open dumps and other "unsanitary" waste disposal practices. The sanitary landfill is an engineered facility that separates and confines waste. Sanitary landfills are intended as biological reactors (bioreactors) in which microbes will break down complex organic waste into simpler, less toxic compounds over time. These reactors must be designed and operated according to regulatory standards and guidelines.

Usually, aerobic decomposition is the first stage by which wastes are broken down in a landfill. These are followed by four stages of anaerobic degradation. Usually, solid organic material in solid phase decays rapidly as larger organic molecules degrade into smaller molecules. These smaller organic molecules begin to dissolve and move to the liquid phase, followed by hydrolysis of these organic molecules, and the hydrolyzed compounds then undergo transformation and volatilization as carbon dioxide (CO$_2$) and methane (CH$_4$), with rest of the waste remaining in solid and liquid phases.

During the early phases, little material volume reaches the leachate, as the biodegradable organic matter of the waste undergoes a rapid decrease in volume. Meanwhile, the leachate's chemical oxygen demand increases with increasing concentrations of the more recalcitrant compounds compared to the more reactive compounds in the leachate. Successful conversion and stabilization of the waste depends on how well microbial populations function in syntropy, i.e. an interaction of different populations to provide each other's nutritional needs.

The life cycle of a municipal landfill undergoes five distinct phases:

*Phase 1 – Initial adjustment:*

As the waste is placed in the landfill, the void spaces contain high volumes of molecular oxygen (O$_2$). With added and compacted wastes, the O$_2$ content of the landfill bioreactor strata gradually decreases. Microbial populations grow, density increases. Aerobic biodegradation dominates, i.e. the primary electron acceptor is O$_2$. 
**Phase II – Transition:**
The O\(_2\) is rapidly degraded by the existing microbial populations. The decreasing O\(_2\) leads to less aerobic and more anaerobic conditions in the layers. The primary electron acceptors during transition are nitrates and sulphates, since O\(_2\) is rapidly displaced by CO\(_2\) in the effluent gas.

**Phase III – Acid formation:**
Hydrolysis of the biodegradable fraction of the solid waste begins in the acid formation phase, which leads to rapid accumulation of volatile fatty acids (VFAs) in the leachate. The increased organic acid content decreases the leachate pH from approximately 7.5 to 5.6. During this phase, the decomposition intermediate compounds like the VFAs contribute much chemical oxygen demand (COD). Long-chain volatile organic acids (VOAs) are converted to acetic acid (C\(_2\)H\(_4\)O\(_2\)), CO\(_2\), and hydrogen gas (H\(_2\)). High concentrations of VFAs increase both the biochemical oxygen demand (BOD) and VOA concentrations, which initiates H\(_2\) production by fermentative bacteria, which stimulates the growth of H\(_2\)-oxidizing bacteria. The H\(_2\) generation phase is relatively short because it is complete by the end of the acid formation phase. The increase in the biomass of acidogenic bacteria increases the amount of degradation of the waste material and consuming nutrients. Metals, which are generally more water-soluble at lower pH, may become more mobile during this phase, leading to increasing metal concentrations in the leachate.

**Phase IV – Methane fermentation:**
The acid formation phase intermediary products (e.g. acetic, propionic, and butyric acids) are converted to CH\(_4\) and CO\(_2\) by methanogenic microorganisms. As VFAs are metabolized by the methanogens, the landfill water pH returns to neutrality. The leachate's organic strength, expressed as oxygen demand, decreases at a rapid rate with increases in CH\(_4\) and CO\(_2\) gas production. This is the longest decomposition phase.

**Phase V – Final maturation and stabilization:**
The rate of microbiological activity slows during the last phase of waste decomposition as the supply of nutrients limits the chemical reactions, e.g. as bioavailable phosphorus becomes increasingly scarce. CH\(_4\) production almost completely disappears, with O\(_2\) and oxidized species gradually reappearing in the gas wells as O\(_2\) permeates downwardly from the troposphere. This transforms the oxidation–reduction potential (ORP) in the leachate toward oxidative processes. The residual organic materials may incrementally be converted to the gas phase, and as organic matter is composted; i.e. the organic matter is converted to humic-like compounds.
ii. **INCINERATION**

Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high-temperature waste treatment systems are described as "thermal treatment". Incineration of waste materials converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power.

Incinerators reduce the solid mass of the original waste by 80%–85% and the volume (already compressed somewhat in garbage trucks) by 95%–96%, depending on composition and degree of recovery of materials such as metals from the ash for recycling. This means that while incineration does not completely replace landfilling, it significantly reduces the necessary volume for disposal. Garbage trucks often reduce the volume of waste in a built-in compressor before delivery to the incinerator. Alternatively, at landfills, the volume of the uncompressed garbage can be reduced by approximately 70% by using a stationary steel compressor, albeit with a significant energy cost. In many countries, simpler waste compaction is a common practice for compaction at landfills.

**Debate**

Use of incinerators for waste management is controversial. The debate over incinerators typically involves business interests (representing both waste generators and incinerator firms), government regulators, environmental activists and local citizens who must weigh the economic appeal of local industrial activity with their concerns over health and environmental risk.

People and organizations professionally involved in this issue include the U.S. Environmental Protection Agency and a great many local and national air quality regulatory agencies worldwide.

**Arguments for Incineration**

(i) The U.K. Health Protection Agency concluded in 2009 that "Modern, well managed incinerators make only a small contribution to local concentrations of air pollutants. It is possible that such small additions could have an impact on health but such effects, if they exist, are likely to be very small and not detectable."
(ii) Incineration plants can generate electricity and heat that can substitute power plants powered by other fuels at the regional electric and district heating grid, and steam supply for industrial customers. Incinerators and other waste-to-energy plants generate at least partially biomass-based renewable energy that offsets greenhouse gas pollution from coal, oil and gas-fired power plants. The E.U. considers energy generated from biogenic waste (waste with biological origin) by incinerators as non-fossil renewable energy under its emissions caps. These greenhouse gas reductions are in addition to those generated by the avoidance of landfill methane.

(iii) Fine particles can be efficiently removed from the flue gases with baghouse filters. Even though approximately 40% of the incinerated waste in Denmark was incinerated at plants with no baghouse filters, estimates based on measurements by the Danish Environmental Research Institute showed that incinerators were only responsible for approximately 0.3% of the total domestic emissions of particulate smaller than 2.5 micrometers (PM2.5) to the atmosphere in 2006.

**Arguments against Incineration**

(i) The Scottish Protection Agency's (SEPA) comprehensive health effects research concluded "inconclusively" on health effects in October 2009. The authors stress, that even though no conclusive evidence of non-occupational health effects from incinerators were found in the existing literature, "small but important effects might be virtually impossible to detect". The report highlights epidemiological deficiencies in previous UK health studies and suggests areas for future studies.

(ii) Erection of incinerators compete with the development and introduction of other emerging technologies. A UK government WRAP report, August 2008 found that in the UK median incinerator costs per ton were generally higher than those for MBT treatments by £18 per metric ton; and £27 per metric ton for most modern (post 2000) incinerators.

(iii) A 2008 Eunomia report found that under some circumstances and assumptions, incineration causes less CO2 reduction than other emerging EfW and CHP technology combinations for treating residual mixed waste. The authors found that CHP incinerator technology without waste recycling ranked 19 out of 24 combinations (where all alternatives to incineration were combined with advanced waste recycling plants); being 228% less efficient than the ranked 1 Advanced MBT maturation technology; or 211% less efficient than plasma gasification/autoclaving combination ranked 2.
iii. **PLASMA GASIFICATION**

Plasma gasification is an extreme thermal process using plasma which converts organic matter into a syngas (synthesis gas) which is primarily made up of hydrogen and carbon monoxide. A plasma torch powered by an electric arc is used to ionize gas and catalyze organic matter into syngas, with slag remaining as a byproduct. It is used commercially as a form of waste treatment and has been tested for the gasification of refuse-derived fuel, biomass, industrial waste, hazardous waste, and solid hydrocarbons, such as coal, oil sands, petcoke and oil shale.

Small plasma torches typically use an inert gas such as argon where larger torches require nitrogen. The electrodes vary from copper or tungsten to hafnium or zirconium, along with various other alloys. A strong electric current under high voltage passes between the two electrodes as an electric arc.

Pressurized inert gas is ionized passing through the plasma created by the arc. The torch's temperature ranges from 2,000 to 14,000 °C (3,600 to 25,200 °F). The temperature of the plasma reaction determines the structure of the plasma and forming gas. The waste is heated, melted and finally vaporized. Only at these extreme conditions can molecular dissociation occur by breaking apart molecular bonds. Complex molecules are separated into individual atoms. The resulting elemental components are in a gaseous phase (syngas). Molecular dissociation using plasma is referred to as "plasma pyrolysis."

**Feedstocks**

The feedstock for plasma waste treatment is most often refuse-derived fuel, biomass waste, or both. Feedstocks may also include biomedical waste and hazmat materials. Content and consistency of the waste directly impacts performance of a plasma facility. Pre-sorting to extract treatable material for the gasification provides consistency. Too much inorganic material such as metal and construction waste increases slag production, which in turn decreases syngas production. However, a benefit is that the slag itself is chemically inert and safe to handle (certain materials may affect the content of the gas produced, however). Shredding waste to small uniform particles before entering the main chamber is generally required. This creates an efficient transfer of energy which enable sufficient breakdown of the materials.

Some plasma gasification reactors operate at negative pressure, but most attempt to recover gaseous and/or solid resources.
Advantages
The main advantages of plasma torch technologies for waste treatment are:

(i) Preventing hazardous waste from reaching landfills.
(ii) Potential production of vitrified slag which could be used as construction material.
(iii) Safe means to destroy both medical and many other hazardous wastes.
(iv) Gasification with starved combustion and rapid quenching of syngas from elevated temperatures can avoid the production of dioxins and furans that are common to incinerators.
(v) Air emissions can be cleaner than landfills and similar to that of incinerators.

Disadvantages
The main disadvantages of plasma torch technologies for waste treatment are:

(i) Large initial investment costs relative to that of alternatives, including landfill and incineration.
(ii) Operational costs are high relative to that of incineration.
(iii) Little or even negative net energy production.
(iv) Wet feedstock results in less syngas production and higher energy consumption.
(v) Frequent maintenance and limited plant availability.

Much research and effort is being put into developing more selective catalysts and productive enzymes which will raise system efficiencies to levels needed to be competitive. Currently, ethanol from gasification costs more than $2 a gallon (equivalent of €0.37 per litre), and it is estimated that production needs to cost closer to $1.25 (€0.90) or $1.50 (€1.10). Production of ethanol at demonstration scale has shown that one US ton of MSW can produce around 100 gallons (equivalent of 0.9 tons producing 380 litres) of ethanol, give or take 20%. Cost estimation for ethanol production is difficult, but rough calculations indicate that ethanol could potentially be more profitable than electricity.

iv. COMPOSTING

The process of natural decomposition is very important to one type of waste disposal. Composting is a form of waste disposal where organic waste decomposes naturally under oxygen-rich conditions. Although all waste will eventually decompose, only certain waste items are considered compostable and should be added to compost containers. Food waste, such as banana peels, coffee grinds and eggshells, are great items to compost. Adding meat products to compost should be avoided because as it decomposes, it will attract large animals and will smell very badly!
In addition to food waste, yard waste, such as grass clippings and leaves, can also be added to compost containers. These items will help increase decomposition and help reduce odor as materials break down. As with household food waste, there are also some types of yard waste that should be avoided. Perennial weeds, which are plants that come back year after year, should not be added to compost because they will grow back and spread.

Once these waste items are placed in a pile, the composting process can start. The organic materials are broken down naturally by earthworms, bacteria and other organisms that live in soil. Although the composting process can occur without any further human involvement, most composting involves the addition of water and oxygen - which occurs by turning the compost - to speed up the overall process. After several months, when all the organic material is broken down, the final product is created and is often referred to as humus.

1. **Identify Your Composting Spot**
   Composting can be done at various places ranging from your kitchen, balcony, terrace or roof, tabletop or sink. While the best place to start composting is outdoors, you can even start the process of composting inside your home.

2. **Segregate your Waste**
   Start separating your edible kitchen waste like vegetable peels, fruit peels, small amounts of wasted cooked food, etc. in one container. Fill another container with dry waste like dried leaves, sawdust, newspaper chunks, packaging material etc. Close both containers to avoid infiltration of bugs, flies, and worms.

3. **Construct Your Composting Bin**
   Select a container - it can be anything, from a bucket to a normal dustbin or a garden pot. Drill around 4-5 holes around the container at different levels so as to let some air in easily. To avoid any spills place a newspaper or tray underneath your container. Layer the bottom of the container with soil.

4. **Initiate the Composting Process**
   To maintain the dry waste and wet waste balance, add food waste and wet waste at alternate levels in the bin. For example if you add one cup of food wastes like vegetables or fruits, add one cup of dry wastes like dry leaves, sawdust, newspaper scrap too. Do not forget to add soil once every week. To fasten the process, you can add semi composted soil to your compost.

5. **Dos and Don'ts**
   Increase the components of newspapers or add extra holes when your compost smells due to imbalance of waste in the bin. Sprinkle some waster if the compost turns too dry. After every few days, use a rake to give the pile of waste a quick turn. This will provide
enough aeration for the waste to decompose successfully. Start using your compost once it gets ready within a period of 2-3 months in garden areas or potted plants once the dry, dark brown waste-turned-compost is ready.

v. **WASTE TO ENERGY (WtE)**

Waste to Energy, also widely recognized by its acronym WtE is the generation of energy in the form of heat or electricity from waste. WtE process involves the conversion of non-recyclable waste items into useable heat, electricity or fuel through a variety of processes. This type of so energy is a renewable energy source as non-recyclable waste can be used and over again to clear it.

WtE can also help reduce carbon emissions by offsetting the need for energy from fossil sources. Over time, this reduces global warming and makes our environment better. Most waste-to-energy plants burn municipal solid waste, but some burn industrial waste or hazardous waste. A modern, properly run waste-to-energy plant sorts material before burning it and can co-exist with recycling. The only items that are burned are not recyclable, by design or economically, and are not hazardous.

Waste-to-energy plants are similar in their design and equipment with other steam-electric power plants, particularly biomass plants. First, the waste is brought to the facility. Then, the waste is sorted to remove recyclable and hazardous materials. The waste is then stored until it is time for burning. A few plants use gasification, but most combust the waste directly because it is a mature, efficient technology. The waste can be added to the boiler continuously or in batches, depending on the design of the plant. In terms of volume, waste-to-energy plants incinerate 80 to 90 percent of waste. Sometimes, the residue ash is clean enough to be used for some purposes such as raw materials for use in manufacturing cinder blocks or for road construction. In addition, the metals that may be burned are collected from the bottom of the furnace and sold to foundries. Some waste-to-energy plants convert salt water to potable fresh water as a by-product of cooling processes.

**Cost of Operation**

The typical plant with capacity of 400GWh energy production annually costs about 440 million dollars to build. Waste-to-energy plants may have a significant cost advantage over traditional power options, as the waste-to-energy operator may receive revenue for receiving waste as an alternative to the cost of disposing of waste in a landfill, typically referred to as a "tipping fee" per ton basis, versus having to pay for the cost of fuel, whereas fuel cost can account for as much as 45 percent of the cost to produce electricity in a coal-powered plant, and 75 percent or more of the cost in a
natural gas-powered plant. The National Solid Waste Management Association estimates that the average United States tipping fee for 2002 was $33.70 per ton.

Global Development

During the 2001–2007 period, the waste-to-energy capacity increased by about four million metric tons per year. Japan and China each built several plants based on direct smelting or on fluidized bed combustion of solid waste. In China there are about 434 waste-to-energy plants in early 2016. Japan is the largest user in thermal treatment of municipal solid waste in the world, with 40 million tons. Some of the newest plants use stoker technology and others use the advanced oxygen enrichment technology. Several treatment plants exist worldwide using relatively novel processes such as direct smelting, the Ebara fluidization process and the Thermoselect JFE gasification and melting technology process.[15] As of June 2014, Indonesia had a total of 93.5 MW installed capacity of waste-to-energy, with a pipeline of projects in different preparation phases together amounting to another 373MW of capacity.

Biofuel Energy Corporation of Denver, CO, opened two new biofuel plants in Wood River, Nebraska, and Fairmont, Minnesota, in July 2008. These plants use distillation to make ethanol for use in motor vehicles and other engines. Both plants are currently reported to be working at over 90% capacity. Fulcrum BioEnergy incorporated located in Pleasanton, California, is building a WtE plant near Reno, NV. The plant is scheduled to open in 2019 under the name of Sierra BioFuels plant. BioEnergy incorporated predicts that the plant will produce approximately 10.5 million gallons per year of ethanol from nearly 200,000 tons per year of MSW.

Waste to energy technology includes fermentation, which can take biomass and create ethanol, using waste cellulosic or organic material. In the fermentation process, the sugar in the waste is converted to carbon dioxide and alcohol, in the same general process that is used to make wine. Normally fermentation occurs with no air present. Esterification can also be done using waste to energy technologies, and the result of this process is biodiesel. The cost effectiveness of esterification will depend on the feedstock being used, and all the other relevant factors such as transportation distance, amount of oil present in the feedstock, and others. Gasification and pyrolysis by now can reach gross thermal conversion efficiencies (fuel to gas) up to 75%, however a complete combustion is superior in terms of fuel conversion efficiency. Some pyrolysis processes need an outside heat source which may be supplied by the gasification process, making the combined process self-sustaining.
Benefits of Waste to Energy

Waste to Energy (or energy from waste) facilities provide a safe, technologically advanced means of waste disposal that reduces greenhouse gases, generates clean energy and recycles metal. It is widely recognized as a technology that can help mitigate climate change. This is because the waste combusted at a WtE facility does not generate methane, as it would at a landfill; the metals that would have been sent to the landfill are recovered for recycling instead of being thrown out; and the electricity generated offsets the greenhouse gases that would otherwise have been generated from coal and natural gas plants. WtE facilities are the only form of energy generation that actually reduces greenhouse gases.

Additionally, the energy produced at WtE facilities is reliable baseload power, meaning that it is generated 24 hours a day, seven days a week. That provides the opportunity to not only sell electricity onto the grid, but also provide steam delivered to houses, public buildings and industries.

III. CONCLUSION

As we can see there are plenty of important things that we should know about waste management and disposal in order to ensure that we and the environment around us are safe.

While it may not be apparent, it is our choice that paves the way towards a better world and a healthier environment. That is why always be sustainable and make actionable efforts to manage and treat waste.

Since multiple waste management methods have been listed, let us explore our options, before making a final choice.

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V. REFERENCES

7. https://www.epa.gov/recycle/composting-home
11. https://www.epa.gov/landfills/basic-information-about-landfills