

# Sustainable Energy from Waste: Opportunities and Technologies for a Cleaner World

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**Abstract:**

Energy generation from waste plays a vital role in sustainable energy security and waste management. Energy production and environmental aspects are analyzed for four alternatives based on different technologies: combustion with energy recovery, gasification, anaerobic digestion, and fermentation. The advantages of these technologies are mainly the significantly reduced waste volume for landfilling, the reduction of total greenhouse gas emissions, for generating electricity or co-generation of electricity and heat. With waste to energy, waste becomes an important source of renewable energy, moderating the climate change effects and saving earth's valuable raw materials and resources. The integration of renewable energy sources within the boundaries of existing energy production systems has emerged as a promising and sustainable policy towards addressing the growing global energy demand. This paper provides technologies that can be incorporated into real world solutions and can serve as the foundations for future research.

**Key Words:** Anaerobic digestion, Combustion, Fermentation, Gasification, Municipal solid waste, Pyrolysis, Waste to Energy.

## 1 INTRODUCTION

Managing waste is one of the biggest challenges around the world. Technologically advanced economies generate vast amounts of waste materials, many of which are disposed to landfills, creating grave environmental issues. To solve the problem of ever growing energy demand and waste management for communities globally, the waste to energy (WTE) technology is a practically feasible method of energy generation that takes care of two environmental issues with one process [1]. Figure 1 shows a schematic on how the energy from waste can be recovered and produce fuel, gas and electricity.

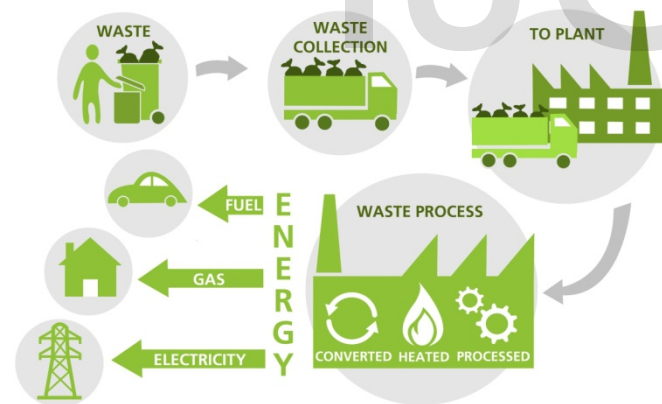


Fig.1. Energy from waste [2]

## 2 FACTS ABOUT WASTE

World's population crossing 7 billion people is not only growing in number, but its tendency to consume is also accelerating. Waste is a by-product of consumer based lifestyles that drive much of the world's economies. Population growth and urbanization are not the only

indicators of waste generation, but they are critical ones. Projections for waste generation in 2025 were made by factoring expected growth in population, income groups and estimated per capita waste generation. Figure 2 shows the projections for each country were made based on the level of expected income (high, middle, or low-income) and an average range of municipal solid waste (MSW) generation based on that income level.

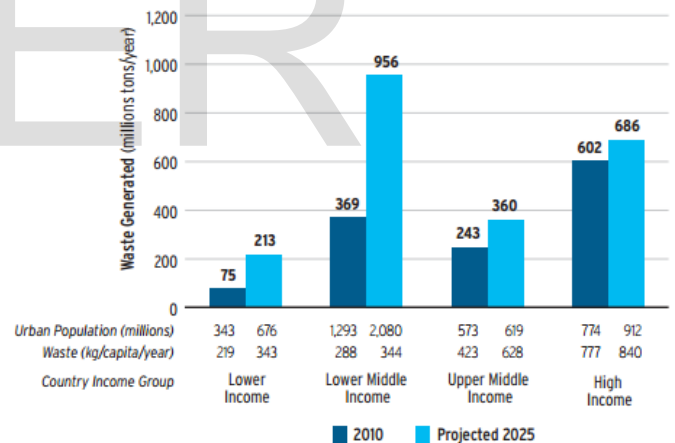


Fig.2. Projection of waste generation [3]

Few facts which illustrate the magnitude of the challenges and benefits associated with waste are listed below.

- Waste generation: Every year, an estimated 1.3 billion tons of solid waste is collected worldwide and is expected to increase to 2.2 billion tons by 2025
- Market size: The global waste market with waste management is estimated at US\$410 billion a year, excluding developing countries.
- Employment: In European Union, jobs in waste managing activities increased with an annual growth rate of 10.57% between 2000 and 2008 [3].

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The use of WTE technologies is experiencing strong international growth with the following statistics:

- Thirty-five nations are currently using WTE technology.
- More than 600 WTE plants are in operation.
- WTE industry processes approximately 170 million metric tons of waste per year globally [4].

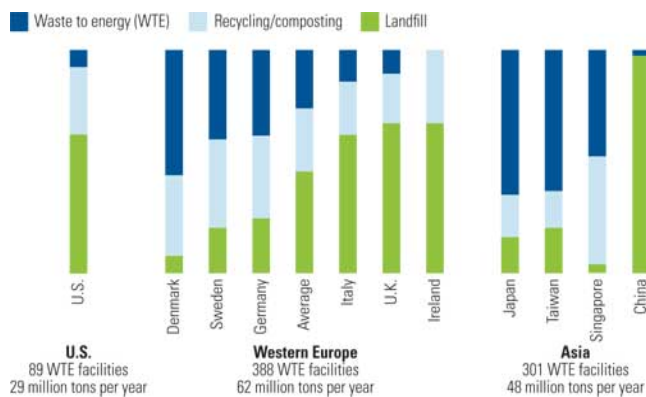


Fig.3. Utilization of WTE [4]

Figure 3 shows the comparison of utilization of WTE in US, Western Europe and Asia. This paper is mainly focused on to the utilization of municipal solid wastes and its related technologies to convert into energy.

### 3 WASTE CATEGORIES AND SOURCES

Waste is classified as identifiable waste categories generated from a number of identifiable sources. Different waste categories are composed of different materials and therefore have different health and environmental impacts. The quantities to be managed differ with waste category. Consequently, the methods by which various waste categories are collected, recovered, processed, treated or disposed of may vary broadly. Waste sources and waste categories are not mutually exclusive: some waste categories overlap with or are sub-categories of others.

#### 3.1 Waste categories

The main categories of solid waste are:

- Municipal Solid Waste: Waste from the household, commercial waste and institutional waste.
- Agriculture waste: Wastes and residues resulting from diverse agricultural activities include plant residue and animal waste including food processing waste.
- Industrial waste: Waste from industrial processes
- Hazardous waste: Wastes that pose a substantial presence or potential hazard to human.
- Medical waste: Includes hazardous (clinical waste) and non-hazardous waste. Clinical wastes are any waste consist human tissue, blood or other body fluids, excretion include infectious waste.

#### 3.2 Waste sources

The sources of solid wastes are dependent on the socio-economic and the technological levels of a community. Known types of solid wastes from known sources are defined as homogenous wastes, examples are the wastes from a small rural community or the wastes from industrial areas. Heterogeneous wastes have many sources and can be from urban communities/ metropolitan cities.

Sources of solid wastes in a community are:

- Residential: Generated from living households generally contain non-hazardous solid wastes-kitchen waste.
- Agricultural: Solid wastes due to agricultural activities such as food residues, animal dung, crop residues, etc. Such wastes are usually non-hazardous.
- Commercial: Wastes generated from business centers such food establishments, shops, etc., that generate generally non-hazardous waste such as paper, cardboard, wood, metals and plastic.
- Industrial wastes: from various types of industrial processes. The nature of the waste depends on the type of industry and kind of raw material involved. There may be toxic and hazardous wastes that have adverse effects to the environment.
- Institutional solid waste: generating from public and government institutions: offices, schools, universities, etc.
- Hospital solid wastes: discarded, unwanted solid wastes from hospitals. It consists of both non-hazardous and hazardous waste [5].

### 4 THE MSW OPPORTUNITY

The municipal solid waste (MSW) opportunity with regard to conversion into energy is considerable across all geographies. . Subsequently, the amount of MSW generated throughout the world will continue to accelerate despite stabilizing volume growth in many high-income economies. The waste generation rates are set to more than double over the next 20 years. Cost increases will be most severe in low-income countries (more than fivefold increases) followed by middle-income countries (more than fourfold increases), according to World Bank.

MSW goes hand in hand with of three of the global challenges associated with population growth: energy supply, climate change, and waste generation. All three challenges are compounded by increasing urbanization rates and rising incomes, particularly in developing countries throughout Asia Pacific, Latin America, and Africa. With nearly 2 billion tons of MSW generated in urbanized areas – a volume expected to grow at an annual rate of 4% worldwide over the next decade – opportunities to leverage smart MSW technologies are widespread [6].

### 5 WASTE MANAGEMENT PROCESS

Waste management process involves waste collection, processing, recovery, and disposal in the most efficient and effective manner. Waste management focuses on recycling, reducing, and reusing wastes.

Managing waste is a complex task that requires the harmonization of changes in consumption and waste production patterns, appropriate technology and organizational capacity. Incentives and regulations around how waste is managed will play a central role in driving investment in waste management and in further developing the smart MSW technologies [7].

### 5.1 The Waste Management Hierarchy

The waste management hierarchy (waste management pyramid) has attracted popularity globally as a communication tool used by governments and organizations to encourage sustainability and responsible towards of waste resources management. Figure 4 shows listing of waste management strategies starting from the most favored strategy (prevention) to the least favored strategy.

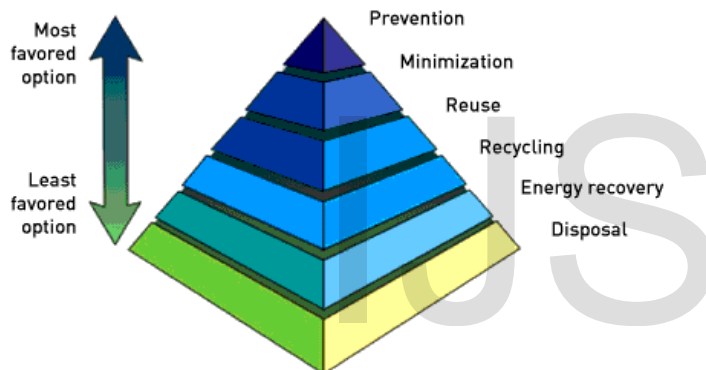


Fig.4. Waste Management Hierarchy [8]

The application of the waste hierarchy has several benefits like prevents emissions of Greenhouse gases, reduces pollutants, saves energy, conserves natural resources and creates jobs by stimulating the development of green technologies.

#### 5.1.1 Zero Waste Initiatives

Zero waste is one of the initiatives as a policy tool for driving compliance with the waste management hierarchy. While it is impossible to eliminate waste entirely, zero waste goals to eliminate or reduce wastes are effective drivers of innovation across the waste management value chain.

#### 5.1.2 Incentives

Incentives are the motivation factors that encourage greater utilization of waste as a resource and discourage reliance on landfilling and other last resort disposal practices. Countries like Japan with more landfilling constraints and

with stringent regulations around disposal relies on incentives to divert MSW away from or reduce the volume of MSW disposed in landfills.

#### 5.1.3 Landfill Taxes

A landfill tax is a form of tax that is applied in some countries to increase the cost of landfill. Landfill taxes are typically imposed in addition to the overall landfill cost to raise general revenue, reduce disposal by raising the cost in comparison to better alternatives.

#### 5.1.4 Pay-as-You-Throw

Pay-as-you-throw (PAYT) is a usage pricing model for disposing of MSW in which users are charged a rate based on how much waste they discard for collection to the municipality or local waste collector. Prices are determined by the weight or size of waste discarded. Units are typically identified using different types of bags, tags, containers.

#### 5.1.5 Cradle to Cradle

Cradle-to-cradle focuses on designing products so that materials flow in closed loop cycles which mean that waste is minimized, and waste products can be recycled and reused. The cradle-to-cradle model is sustainable and considerate of life and future generations.

Other way of managing the wastes:

*Renewable Power and Thermal Targets:*

Renewable energy targets set goals for the integration of renewable energy from waste in national electricity and thermal production portfolios. These targets are an important mechanism for directing long-term policy around MSW for energy generation.

*Next-Generation Fuels:*

Biofuels are becoming big policy and big business as countries around the world look to decrease dependence on fossil fuel, reduce greenhouse gas emissions, and support agricultural interests. Among potential feed-stocks, MSW is considered to be one of the vital feed-stocks for advanced biofuels [6], [9].

## 6 TECHNOLOGIES

The main categories of waste-to-energy technologies are thermal and biochemical technologies. Thermal technologies are those which process waste to make it more useful as fuel, which can yield heat, fuel oil, or syngas from both organic and inorganic wastes. Biochemical technologies are in which bacterial fermentation is used to digest organic wastes to yield fuel and in turn energy. Figure 5 show the schematic representation of the waste processing technologies.

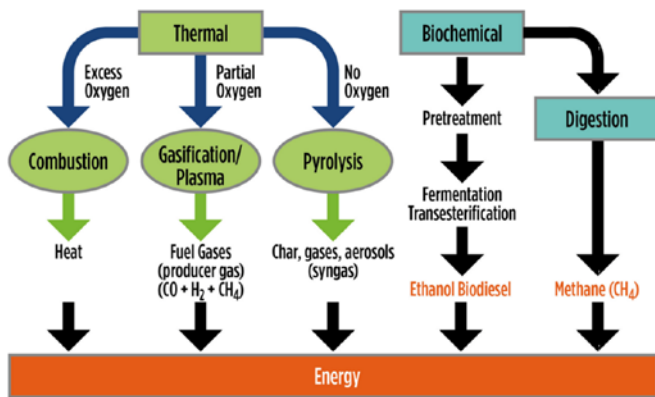


Fig. 5 Waste processing technologies [10]

The major Components of Waste-to-Energy Processes for MSW are a pre-processing unit to prepare MSW for treatment and separate recyclables, Conversion unit or a reactor, Gas and residue treatment plant, Energy recovery plant: Energy production system includes gas turbine, boiler, and internal combustion engines for power production and an efficient Emissions cleanup system. The main infrastructures needed for a sustainable waste to energy supply chain includes road and land accessibility, water availability, solid waste disposal, and an electrical grid to upload power supply.

### 6.1 Combustion

Combustion is one a thermal treatment technology to convert wastes to energy. This technology treats about 15 to 20% of municipal solid waste globally. The common combustion technologies used around the world included pile combustion, stoker combustion, suspension combustion, and fluidized bed combustion. Figure 6 illustrates the process of the waste-to-energy by an Incineration plant [10].

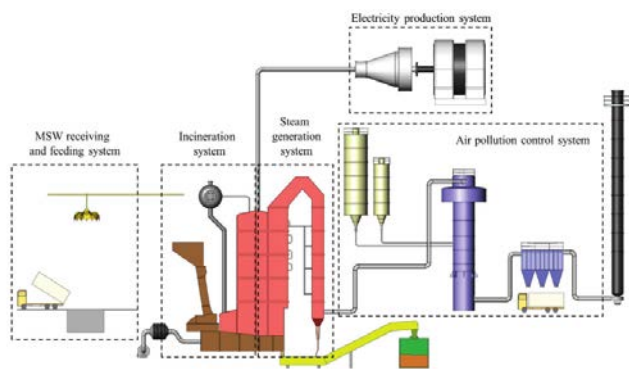


Fig. 6 Combustion technology [11]

The combustion plant consists of a receiving and feeding system for receiving MSW from collection trucks and feeding MSW into the incineration system by crane. The second stage is the Incineration system in which MSW is burned leading to reduction in mass and volume of MSW.

Next stage consists of steam generation system for producing superheated steam at high temperature and pressure. The steam produced is utilized in next stage for electricity production system with steam turbine and generator for power production. Typical air pollution control system in the last stage consists of semi-dry scrubber and bag filter with activated carbon to remove acid gas, dioxin and particulate from the flue gas before discharging into the atmosphere [12].

### 6.2 Gasification

Gasification process is a thermochemical process to utilize MSW to generate energy. This process involves partial oxidation. Oxygen is added but at low amounts not sufficient for full oxidation and full combustion. Main product is syngas with other products like solid residue of non-combustible materials (ash) which contains low level of carbon. Figure 7 shows the waste-to-energy conversion by gasification process. The syngas, if purified and cleaned, can be further converted to a liquid fuel using a catalytic process, which can feed into an internal combustion engine-generator for electricity production, combusted for heat recovery, used in fuel cell applications, or used for the production of a variety of chemicals [13].

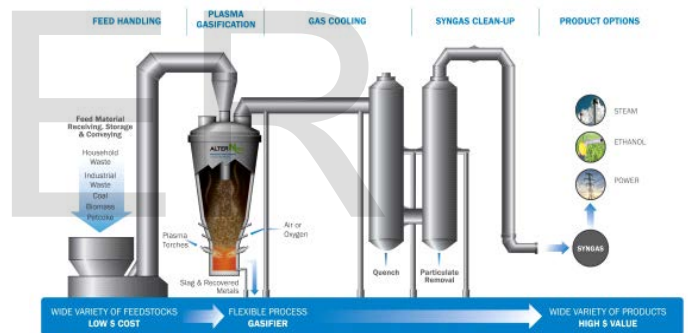


Fig. 7 Gasification technology [14]

#### 6.2.1 Plasma Gasification

Plasma gasification is a process which converts organic matter into synthetic gas, electricity, and slag using plasma. A plasma torch powered by an electric arc is used to ionize gas and catalyze organic matter into synthetic gas (syngas composed of  $H_2$ ,  $CO$ ) Inorganic materials are converted to solid waste (slag). Figure 8 shows the waste-to-energy conversion by plasma gasification process. The Syngas can be utilized for energy production or can be condensed to produce oils and waxes.



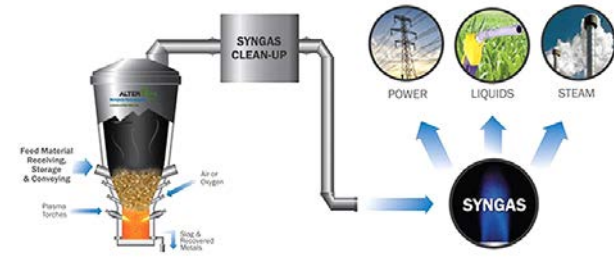


Fig. 8 Plasma Gasification technology [15]

### 6.3 Pyrolysis

Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen (or any halogen). It involves the simultaneous change of chemical composition and physical phase, and the process is irreversible. Figure 9 shows the waste-to-energy conversion by pyrolysis process. Thermal degradation of wastes occurs through use of indirect, external source of heat. Temperatures between 300 to 850°C are maintained for several seconds in the absence of oxygen. The resulting Syngas which has very high calorific value can be utilized for energy production or proportions can be condensed to produce oils and waxes [16].

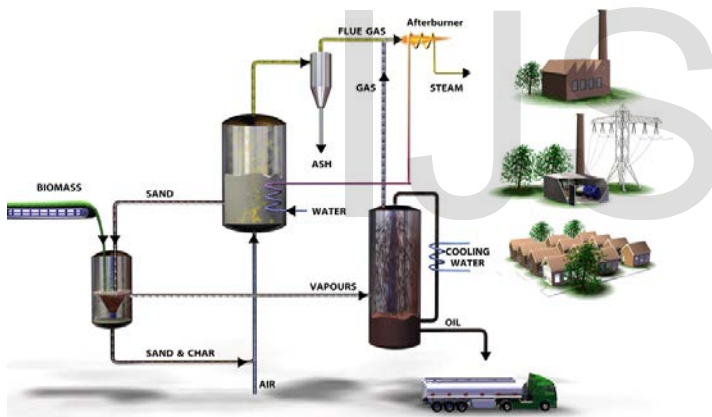


Fig. 9 Pyrolysis technology [17]

### 6.4 Biochemical

Biochemical conversion of MSW involves use of bacteria, microorganisms and enzymes to breakdown MSW into gaseous or liquid fuels, such as biogas or bioethanol. The most popular biochemical technologies are fermentation and anaerobic digestion.

#### 6.4.1 Fermentation

The resource base for biofuel production is composed of municipal solid waste and a wide variety of forestry and agricultural resources. A variety of fuels can be produced from waste resources including liquid fuels, such as ethanol, methanol and biodiesel. Figure 10 shows the waste-to-energy conversion by fermentation process.

The major steps involved are pretreatment, enzymatic hydrolysis, and fermentation. Biomass is pretreated to improve the accessibility of enzymes. After pretreatment, biomass undergoes enzymatic hydrolysis for conversion sugars, such as glucose and xylose. Consequently, sugars are fermented to ethanol by the use of different microorganisms [18].

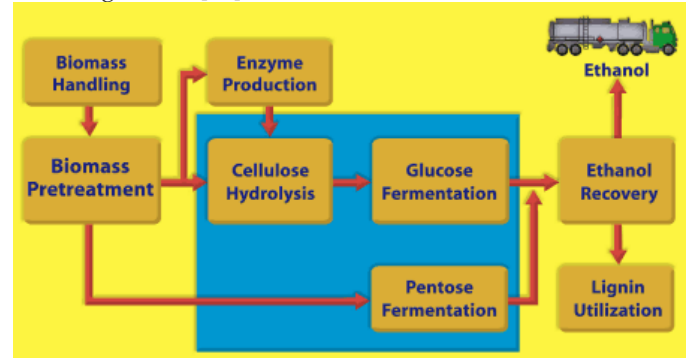


Fig. 10 Fermentation process [18]

#### 6.4.2 Anaerobic Digestion

It has been reported that 1.3 billion tons of edible materials, which represent one-third of the global food production, turn into waste every year world-wide [19]. Anaerobic digestion is a well-known technology for domestic sewage and organic wastes treatment. Figure 11 shows the waste-to-energy conversion by anaerobic digester process. Biological conversion of biodegradable organic materials occurs in the absence of oxygen at temperatures 55 to 75°C. The residue of the process is stabilized organic matter that can be used as soil improvement after proper dewatering. Digestion is used primarily to reduce quantity of sludge for disposal. Methane gas generated used for electricity generation [20].

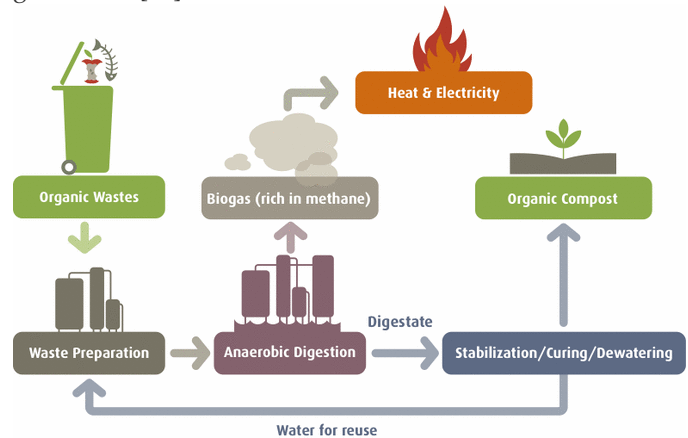


Fig. 11 Anaerobic digestion process [21]

The adoption of a particular technology or a combination of technologies is based on the detailed analysis considering the Benefits, Opportunities and Risks for each country or region [22].

## 7 SUMMARY

Waste to energy technologies uses trash to generate electricity and its environmental benefits are many. Waste to energy facilities adds a 4th "R" to "reduce, reuse, and recycle" hierarchy with "Recover". After maximizing reduction, reuses, and recycling, waste to energy facilities recover energy from the remaining trash and generate electricity [23].

The various advantages of waste to energy conversion are listed as below:

- Production and use of energy
- Reduction of waste going to landfills
- Avoidance of disposal cost and landfill taxes
- Use of by-products as fertilizers
- Avoid methane emissions from landfills
- Reduction in carbon emitted
- Reduction of reliance on fossil fuel
- Domestic production of energy
- Employment creation in local community
- Stability in availability of energy and its price
- Reduction in greenhouse gas emission [24].

The major contributions of WTE facility implementation and functioning are towards better Health and Environment, Economic and Social opportunities. Conceptual level analysis indicates that gasification, anaerobic digestion, and fermentation technologies lead to positive economic results. The success of a waste to energy project is highly dependent on a country's socio-economic and technological environment [25].

## 8 CONCLUSION

The waste to energy technology market to generate energy will remain highly dynamic, with significant upside potential in energy management value chain. The described technologies of converting waste to energy with robust waste management system implemented will contribute to further develop the energy sector towards a more sustainable scenario in energy management.

The availability of commercially viable waste to energy technologies and increasing interest in renewable energy solutions across all global regions will drive growth and sustenance in energy segment. With limiting space for landfills, strong regulations, high energy prices and strong incentives for adoption of renewables increased awareness of environmental protection is expected to be drivers for the utilization of waste to energy in the coming decades. Proper waste management with waste converted to energy without detrimental effect on nature has a major contribution to make the world towards a sustainable energy efficient and clean future.

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