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Environmental assessment for management of waste through energy conversion technologies

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A B S T R A C T

Increasing population and changing life style has led to the dramatic increase in waste generation. It has been estimated that global generation of post recycling MSW in populated centers amounts about 1.2 billion ton per year. India alone produces about 90 million tons of MSW per year. If this large amount of waste can be converted into energy then the problem of its management and energy crisis can be solved to some extent. The paper gives detailed description of various technologies used for deriving energy from waste along with their advantages and disadvantages. The papers also deals with the challenges faced by these technologies and also provide an overview of issues regarding WTE technologies in India.

Introduction

Waste treatment has become a significant problem due to the large volumes generated worldwide and its impact on the environment. The main impacts relate to atmospheric emissions and aqueous effluents from landfills and activities for waste collection, transportation, and processing. Nemet, A et al., Waste-to-energy (WtE) or energy-from-waste (EfW) in its strictest sense refers to any waste treatment that creates energy in the form of electricity or heat from a waste source that would have been disposed of in landfill**.**

More advanced waste-to-energy processes result in usable fuel commodity, such as hydrogen or ethanol. The term Waste-to-Energy" means the use of modern combustion technologies to recover energy, usually in the form of electricity and steam, from mixed municipal solid wastes. These new technologies can reduce the volume of the original waste by 90%, depending upon composition and use of outputs. In OECD countries all new WtE plants must meet strict emission standards. Wagner, L. (2007).

Waste to Energy Technologies

Fossil fuel consumption has increased over the past century, becoming a primary source of energy for many countries around the world and accounting for over 85% of the global energy produced. In combination with a rise in energy demands, this dependence on fossil fuels is leading to high carbon emissions resulting in climate change problems. In addition, because fossil fuels are a finite source of energy, energy prices are continuing to rise due to the depletion of fossil fuel reserves Caruso, W et al. Thus there is urgent need to think about some alternative sources of energy. Energy recovery from wastes is consistent with and complementary to modern integrated waste management practices. Modern WtE is considered to be a source of partly renewable energy by the U.S. federal government and 15 U.S. states that have established renewable energy programs. Also some European countries that have established renewable energy programs consider energy production through WtE as renewable. Approximately 130 million tonnes of MSW are combusted annually in over 600 wastes to energy (WtE) facilities that produce electricity and/or steam for district heating.

1) Anaerobic digestion

Anaerobic digestion (AD) is a biochemical process in which biogas is produced from organic matter by microorganisms in the absence of oxygen Pongrácz, E, et al.The AD process generates three by-products including biogas, bio liquid or liquid digestate, and fibre digestate. Biogas is a gaseous mixture composed of 60% methane (CH_4) and about 40% carbon dioxide (CO_2), with trace amounts of hydrogen sulfide and ammonia. Biogas can be used in combustion engines or micro-turbines in combined heat and power (CHP) plants to generate heat and electricity. In addition, liquid and fibre digestate can be used as a fertilizer or compost to improve soils Friends of the Earth. (2002). The final product (biogas) can be used for combined heat and power production. The biogas can be also purified to methane and used as a fuel for vehicles. The residues from the anaerobic digestion can provide further benefits as a fertilizer Micre (2011).

Biogas plant

The design process of a biogas plant starts by defining the properties of raw materials. Raw material can include products from a farm, such as manure, sludge and grass but it also includes external raw material sources. External raw material sources tend to have stricter requirements than raw materials straight from the farm. However, additional payments can be required from external inputs Toni, T. (2006). One important step is the determination of the computational biogas potential of a biogas plant. Calculation is done by multiplying the annual solid raw material production with the methane productivity potential Toni, T. (2006). Determination of heat and power consumption of the plant is also an essential operation in the beginning. Electricity and heat produced by the plant can be used to run the plant and to heat up households that are nearby. Excess electricity can be transferred to the electric grid and sold to a local electric company Toni, T. (2006).

Safety issues

There are always some inhibitors and hazardous compounds related to every process. In the case of a biogas plant, they are highly dependent on the feedstock and the process equipment. The best way to avoid accidents is to follow security instructions and do a preliminary risk evaluation. A rescue plan is also necessary to have (Hazardous Waste Resource Center) Biogas consists mainly of methane (CH4) and carbon dioxide (CO2). The desired final product, methane, is a highly flammable gas and it can explode when meeting a spark and reacting with oxygen. Risks can be avoided by designing tanks, reactor and pipes properly to prevent methane leaks. In addition, efficient ventilation is also contributing to preventing the risk of explosion. An alarm instrument detenting high methane concentrations is hence necessary Toni, T. (2006).

Advantages Friends of the Earth (2002).

- Can process a variety of biomass materials
- Produces practical by-products which can easily be captured and used for soil fertilization and the generation of heat and/or electricity
- Produces the least amount of air and solid emissions in comparison to typical waste management processes such as incineration, pyrolysis and gasification;
- AD plants can be small and unobtrusive, which makes them suitable for location within towns
- Digestion of sewage waste via AD results in 10% reduction in carbon dioxide emissions
- AD with CHP produces net reductions in pollutant emissions

Disadvantages Friends of the Earth. (2002).

- If AD does not completely digest all the waste, the resulting digestate may not meet Government standards
- Poor feedstock used in the AD process can result in the production of unusable by-products
- Depending on the feedstock, AD may create contaminated digestates that are high in metals such as mercury
- Combustion of biogas produces nitrogen oxides, which are associated with lung problems and allergies
- Biogas is composed of high concentrations of methane and carbon dioxide which are toxic greenhouse gases associated with climate change
- AD plants generate lots of waste water high in nitrites
- AD plants may cause environmental problems such as odour, dust and pollutants due to the burning of methane for power generation

2) Gasification

Gasification is a process that chemically and physically changes biomass through the addition of heat in an oxygen-starved environment. The end products of gasification include solids, ash and slag, liquids and synthesis gas, or syngas. The gas has a calorific value, or potential heat content, equivalent to 25% that of natural gas if ambient air is used or 40% if oxygen-enriched air is used Update on Pyrolysis, (2002). A conventional gasification process consists of biomass drying, pyrolysis, oxidation and reduction steps. In the pyrolysis chamber, large hydrocarbon molecules of biomass break up into smaller molecules in the absence of oxygen. Therefore, relatively volatile compounds of the biomass are separated from the char. Temperature in the pyrolysis chamber varies between 400–650°C Micre (2011), Prabir, B. (2010).

Endothermic pyrolysis and gasification reactions occur in the oxidation chamber at temperatures between 900–1200°C. Syngas is formed in the reduction chamber through several reactions. Gasification processes can be divided to updraft and downdraft gasifiers. Furthermore, reactors can be roughly classified to moving bed reactor, fluidized bed reactor and entrained flow reactor Micre (2011), Prabir, B. (2010). The most significant impurities, such as tars and particulates are separated from the final product. Conventional separation processes for tar and particulate removal are usually cyclones, filters, electrostatic precipitators and scrubbers. Tar can also be treated by catalyst or thermal cracking. Companies have been developing also a plasma technique for the gasification process Prabir, B. (2010). The final product, syngas (a mixture of hydrogen and carbon monoxide) can be utilized as a fuel in the internal combustion engine or to run a gas turbine. Ash from the process can be utilized as a fertilizer or as an additive in construction materials. Pongrácz, E, Micre (2011).

Gasification plant

Firstly, a construction permit is needed for a plant. Regulation of land use planning is taken into account in order to find an appropriate place for the gasification plant. It is also possible that city plan is also taken into consideration here Ministry of Environment (2011a). Environmental permit for the gasification plant is essential. To this end, an environmental impact assessment is necessary to conduct in order to ascertain possible impacts to the environment such as emissions to the atmosphere, noise pollution, soil protection, waste generation and possible waste water discharges. Obligations related to the IPPC Directive vary from country to country and can depend on the size of the gasification plant. Ministry of Environment (2011a), Gasification guide (2009).

Safety issues

The gasification process is inwardly related to production, utilization and handling of toxic and flammable compounds. Carbon monoxide (CO) is a very poisonous compound, which can be dangerous for life. Very small concentrations of CO can cause headache, dizziness and nausea. Therefore, an alarm system for too high CO concentrations is necessary. In addition, due to possible CO leaks, a ventilation system is necessary Gasification guide (2009). Overpressure can also lead to gas escaping, leading to gas intoxication. In addition to CO, also other compounds from the process can be hazardous. For example polycyclic aromatic hydrocarbon (PAH) compounds are toxic and carcinogenic, and can leak from the process. Inadequate control system programming can cause severe consequences. Other malfunction, for example in the reactor and pumps, can cause gas leaks leading to mentioned outcomes Gasification guide (2009). Fluctuating and too high pressure can cause material damage to process equipment and hence it can be a safety hazard, causing leakages, for example. Also too high temperature can cause problems to process material and cause malfunctions or even self-ignition of some gas mixtures. In addition, occupational health and safety hazards have to be considered as a part of risk assessment. The best way to avoid these safety hazards is to follow the ATEX Directive. Gasification facilities should be constructed by following international standards. Also having appropriate equipment to monitor concentration of chemicals is essential. In addition, the education of staff is mandatory. Pongrácz, E, Gasification guide (2009).

Advantages Gasification guide (2009).

- Gasification produces which can be burned for heat or power generation.
- Gasification reduce solid waste volume by 85% to 92%.
- Gasification is economically viable at a small scale and tends to emit lower

amounts of SOx, NOx and dioxins than combustion.

Disadvantages Gasification guide (2009).

- Gasification process adds greenhouse gases to the atmosphere.
- The ash which remains after gasification, 8% to 15% of the original volume, is toxic and presents special problems because of the acidic, or low pH conditions in landfills.
- Leaching of toxic metals cadmium, lead, and mercury occurs more rapidly at low pH, resulting in contamination of groundwater.

3) Combustion

Also referred to as waste-to-energy, this technology involves burning waste in a chamber at high temperature, usually 1800 degrees Fahrenheit. While old combustion facilities often had high emissions toxic compounds, recent technological advances and tighter pollution regulations ensure that modern waste-to-energy facilities are cleaner than almost all major manufacturing industries Hazardous Waste Resource Center. In general, combustion processes can be divided to batch and continuous processes. In households, wood-stove is a conventional batch combustion process, when larger continuous combustion reactors, with higher technological properties and larger scale, are more common in industry. These combustion reactors can be divided to fixed bed, bubbling fluidized bed, circulating fluidized bed and pulverized fuel reactors. Furthermore, several types of wood-fired stoves are also available commercially. Combustion can be utilized to produce heat for households and for industrial processes. In addition, hot gases from the process can also heat up water in heating boilers in order to produce electricity. In some cases combustion can also produce gaseous and liquid fuels. Ash from the process can be utilized as fertilizer Sjaak, L, V and Jaap, K. (2008).

Combustion plant

Permissions for the installation of a combustion plant vary depending on the scale of the plant. In small-scale applications, such as stoves, no significant requirements are needed. Small-scale combustion stoves usually need only construction permission. After construction, the stove needs to be verified by a rescue authority Pongrácz. E

Environmental permits are compulsory for larger combustion plants. Air emissions, such as CO_2 as well as output ash amounts, are significant. Environmental Impact Assessment will have to be conducted to estimate overall emissions and impacts to environment. The combustion process produces mainly heat, however, when electricity is also generated, the excess electricity can be sold to electricity companies. Before distributing electricity or heat, agreements and permits will have to be done with receiving companies. Standards and regulations related to possible boilers, turbines and CHP-unit are compulsory to follow. Pongrácz. E

Safety issues

In small-scale applications, the main safetyrelated issues originate from the spillage or backdraft of exhaust gas, which should be led outside. Carbon monoxide (CO) is one of the most hazardous compounds from the combustion process. CO forms when combustion temperature is low and available oxygen levels are low. CO is an odorless, tasteless and initially non-irritating and, therefore, difficult to detect.

Yet even at relatively low concentrations, CO can cause lightheadedness and confusion. A CO detector, adequate ventilation and appropriate combustion conditions are essential to avoid problems with CO Energy Efficiency and Renewable Energy Clearinghouse EREC (2008), Rob, D. (1995). To ensure the safe operation of a combustion plant, especially in larger units, proper ventilation system, automatic fuel turn-off valve, gas detectors and flame sensing devices are valuable. These devices need to be inspected and tested at times. Furthermore, accidents prevention may also require education of staff and clients. It is also necessary to clean process equipment at times and check for possible structural damage energy efficiency and renewable energy clearinghouse EREC (2008).

Advantages of combustion

- Municipal waste can be directly combusted with minimal processing.
- Heat from the combustion process is used to turn water into steam, which is used to power a steam-turbine generator to produce electricity.
- Next-generation waste incinerators also incorporate air-pollution control system thus preventing air pollution.

Disadvantages

- High moisture content leads to incomplete combustion and high amounts emissions thus drying of raw material are be needed.
- Impregnated and painted woods are not suitable for the combustion process.
- Ash from biomass combustion process can contain high alkali and heavy metal concentrations, causing corrosive effects to a boiler.
- Agglomeration of ash particles can also inhibit the combustion equipment and lead to poor combustion conditions.

4) Pyrolysis

Waste material is heated in the absence of oxygen at temperatures ranging from 550 to 1300 degrees Fahrenheit. This releases a gaseous mixture called syngas and a liquid output, both of which can be used for electricity, heat, or fuel production. The process also creates a relatively small amount of charcoal. While this process results in relatively low net greenhouse gas emissions and has high conversion efficiency, technical difficulties have prevented its implementation on a commercial scale. The biggest barrier has been the difficulty of removing enough oxygen from the MSW to sustain a strong reaction Schilli. (2004). Pyrolysis can be divided to slow and fast pyrolysis. In slow pyrolysis, biomass is heated slowly to pyrolysis temperature (400-800 °C) with long residence time. Slow pyrolysis produces more tar and charcoal and less gases. The purpose of fast pyrolysis is to maximize the yield of liquid or gases. In fast pyrolysis, biomass is heated rapidly to the adequate temperature (up to 650°C), and held there only for few seconds or less than second. Also flash and ultra-rapid pyrolysis has been researched. Known reactor types are fixed bed, moving bed, bubbling fluidized bed and circulating fluidized bed reactors Prabir, B. (2010).

Pyrolysis plant

Installation of a pyrolysis plant starts with determining the amounts and properties of feedstock, so the circumstances, catalysts, reactor size etc. can be considered. Also it is good to define desired end product, which can be gas, charcoal or bio-oil, so operating temperatures, residence time, product yield and heating rate can be thought out. In addition, raw material suppliers are essential to find and make agreements with them Prabir, B. (2010). Environmental permit for the pyrolysis plant is compulsory, due to its potential environmental hazards. Environmental Impact Assessment is necessary to compose, and regulations and legislative systems related to waste streams are taken into account.

Safety issues

The pyrolysis process is producing and handling hazardous compounds, such ase CO, H_2 and hydrocarbons. Carbon monoxide is very toxic compound; it can cause dizziness and even in low. For the possible leaks of CO, a ventilation system and a CO detection device are necessary. Furthermore, glowing particles can ignite or cause an explosion, if there is a source for ignition presents Gasification guide (2009). hazards include, among others, hot surfaces, noise emissions and electrical, machinery and exhaust gas hazards. Electrical hazards can lead to static electricity build up and sparks, causing an explosion in the worst case Pongrácz, E, Prabir, B. (2010), and Gasification guide (2009).

Advantages Friends of the Earth. (2002).

- Produces few air emissions due to limited use of oxygen
- Contamination of air emissions is easy to control because syngas is cleaned after production to rid it of any contaminants
- Replaces coal and natural gas as viable fuel sources, causing a reduction in climate change
- Produces useful products for multiple applications
- Can be easily implemented in CHP systems
- More efficient than incineration (70% vs. 40%)
- Pyrolysis plants are flexible and easy to operate because they are modular. They are made up of small units which can be added to or taken away when the mass or volume of organic matter changes

Disadvantages Friends of the Earth. (2002).

Generates possible toxic residues such as inert mineral ash, inorganic compounds, and unreformed carbon

- Potential to produce a number of possible toxic air emission such as acid gases, dioxins and furans, nitrogen oxides, sulfur dioxide, particulates, etc.
- Pyrolysis plants require a certain amount of materials to work effectively

5) Alcohol fermentation

Alcohol fermentation is a process in which sugar containing biomass is converted to alcohol, e.g. ethanol by the metabolism of microorganisms. The fermentation is usually anaerobic, but also aerobic conditions can be feasible. Fermentation processes can be batch, fed-batch or continuous processes Nag., Ahindra (2007). Raw materials with high sugar content, such as corn and sugar beet, are the most suitable for the fermentation process. In addition, lignocellulosic raw materials, like wood and straw can be also utilized in order to produce ethanol. However, lignocellulosic raw materials require acid or enzyme pre-treatment, because cellulose and hemicelluloses need to be converted into sugars that the microbes can use. Notwithstanding, lignocellulosic raw materials are considered to be more sustainable since they do not use food resources Nag., Ahindra (2007). The conventional fermentation process consists of hydrolysis, fermentation, separation and purification steps. If the process uses lignocellulosic raw materials, milling and acid or enzymatic hydrolysis is required. After pre-treatment, sugars go through the fermentation process. The produced alcohol is removed from the process at concentrations around 6%, because ethanol concentration at 15% and above start to be toxic for the microbes. In the end, ethanol is enriched to 99% bioethanol Pongrácz, E, Micre (2011), Nag., Ahindra (2007).

Fermentation plant

An essential part of the installation of a fermentation plant is having a construction permit for it. Land use planning regulation and city plans will also need to considered. Landscape permission may also be necessary in some countries. Ministry of Environment (2011a). Environmental permits, including Environmental Impact Assessment is essential to complete before further planning of a plant. Legislation related to water and water supply may also be considered, if the process water is taken from a lake or river. In addition, regulations related to wastes and emissions to the atmosphere and possible noise emissions need to be taken into account Pöyry. Environment (2006).

Permits to execute both the process and the production of high concentrate ethanol are required. Ethanol is a dangerous chemical with flammable properties, therefore, requirements, standards and permissions related to processing, transportation and storing of a hazardous chemical and waste need to be followed. Pöyry. Environment (2006).

Safety issues

Ethanol is a harmful and highly flammable compound, which is in liquid phase in normal temperature and pressure conditions. This organic compound is also toxic for humans and animals, especially in high concentrations. Because of these properties, ethanol must be handled, stored and transported properly. Following safety requirements, considering ventilation and keeping sources from ignition away prevents accidents. Bringing a safety professional to check and evaluate the safety of the process is necessary Pongrácz, E.

Acidic or chemical hydrolysis as a pre-treatment process for starchy and lingocellulosic material can cause safety hazard depending on the type and concentration of the compounds. Sulfuric acid is a conventional chemical compound to hydrolyze starchy feedstock, and it poses a safety hazard being highly toxic and corrosive. Furthermore, some enzymes can also be hazardous Nag., Ahindra (2007).

Advantages

- The produced alcohol canbe used for heat and power production and preferably as transportation fuel.
- Cellulosic ethanol, produced by fermentation currently exists at a “pilot” and “commercial demonstration” scale.

Disadvantages

- Ethanol is a dangerous chemical with flammable properties thus causes safety hazard.
- Starchy and lignocellulosic feedstock require pretreatment.
- Sulfuric acid, used as a pretreatment chemical poses a safety hazard being highly toxic and corrosive.

Characteristics of various waste to energy technologies is summarized in table 8

Challenges

Technology challenges

• **Lack of versatility.** Many waste-to-energy technologies are designed to handle only one or a few types of waste (whether plastic, biomass, or others). However, it is often impossible to fully separate different types of waste or to determine the exact composition of a waste source. For many waste-to-energy technologies to be successful, they will also have to become more versatile or be supplemented by material handling and sorting systems.

• **Waste-gas cleanup.** The gas generated by processes like pyrolysis and thermal gasification must be cleaned of tars and particulates in order to produce clean, efficient fuel gas.

• **Conversion efficiency.** Some waste-to-energy pilot plants, particularly those using energy-intensive techniques like plasma, have functioned with low efficiency or actually consumed more energy than they were able to produce. For example, many sites in India have been forced to shut down because they were not financially sustainable once government subsidies ran out.

Strategic challenges

• **Regulatory hurdles.** The regulatory climate for waste-to energy technologies can be extremely complex. At one end are regulations that may prohibit a particular method, typically incineration, due to air-quality concerns, or classify ash byproducts of waste-to-energy technologies as hazardous materials. At the other end, while changes in the power industry have allowed small producers to compete with established power utilities in many areas, the electrical grid is still protected by yet more regulations, presenting obstacles to would-be waste-energy producers.

• **High capital costs.** Waste-to-energy systems are often quite expensive to install. Despite the financial benefits they promise due to reductions in waste and production of energy, assembling the financing packages for installations is a major hurdle, particularly for new technologies that aren't widely established in the market.

• **Opposition from environmental and citizen groups.** Because traditional incineration based waste-to-energy technologies can produce significant pollution from the burning of waste, environmental and citizen groups have often opposed such systems. Developers argue that advanced technologies like pyrolysis release few emissions, and that any pollution that is released is captured with emissions-control systems. However, many activists remain unconvinced, and some express concern that using waste as a feedstock for energy generation will cause municipalities to abandon their efforts in waste reduction, recycling, and composting Waste to Energy**,** 2007.

Issues in India

India has large markets for waste-to-energy projects, a large urban poor population, and both countries is industrializing quickly. Like the Philippines, India passed national legislation encouraging municipalities to segregate and compost household waste. Waste-to energy projects also have a poor reputation in India. For example, in 1984, the Ministry of Non-Conventional Energy Sources (MNES) installed a waste incinerator using Danish technology as a pilot project to demonstrate waste-to-energy in Timarpur, Delhi. Unfortunately, the project miscalculated the moisture content of the available waste in Delhi, and consequently the technology did not work unless diesel was added to the waste. According to reports, the incinerator operated for less than a month, and its last day of operation was when the project was visited by the then- Prime Minister, Rajiv Gandhi, after which the incinerator was closed down, and the Danish suppliers issued a lawsuit for failure to implement the agreed contract.

In India, national legislation relating to waste-to-energy and incineration is less prominent. Local governments have apparently had more influence on shaping the terms for CEG (cooperative environmental governance) than actions by citizens or poor waste pickers Tim. F. (2006).

Table.1 Efficiency of energy conversion technology Friends of the Earth, (2002) Caruso, W et al.

Technologies	Energy (kWh/Ton of Waste)
Landfill gas	41-84
Combustion	470-930
Pyrolysis	450-530
Gasification	400-650
Plasma Arc Gasification	400-1,250

Source: Alternative Resources inc.

Table.2 Air pollutants from starved- air Combustion / Gasification

Pollutant	Uncontrolled	Electrostatic precipitator
Particulate matter	125,195 pounds	*
Sulfur dioxide	117,895 pounds	*
Nitrogen	115, 340 pounds	*
Hydrochloric acid	78,475 pounds	*
Carbon monoxide	10, 913 pounds	*
Mercury	204 pounds	37 pounds
Nickel	121 pounds	22 pounds
Chromium	103 pounds	-
Lead	88 pounds	17 pounds
Arsenic	24 pounds	4 pounds
Dioxins/ furans	0.11 pounds	0.14 pound

*same as uncontrolled

Source: Impacts on the Environment and Public Health

Table.3 Characteristics of biomass-to-energy technologies(based on Austerman et al.2007, Austerman & whiting 2007, kauriinoja 2010)

	Anaerobic	**Gasification**	**Combustion**	**Pyrolysis**	**Fermentation**
Scale	Reactor size 50-10.000 m^2	1kWe – 150 mWe depending on the teachnology used	Small to large scale	Pilot plant of 200kg/h, with 66% energy yield	Ethanol yield 102-105 m^2 annually
Input materials (preferable)	Biowaste & waste waters, by products, emergy crops	Forest products, energy crops, biowaste	Pellets, biomass, wood wastes,	Forest products energy crops, mill wood waste, agriculture and urdan organic wastes	Food crops and by products, forest crops blowaste
Limiting factors	Total solids 4-40%	Moisture <45% Ash < 15%	Moisture < 50%	Moisture < 45% Ash < 25%	Homogenous input nutrients, pH, MOsiture
Operating temperature	Optimum 35^0C or 55^0C	650-1200^0C	> 800^0C	400-800^0C	15-60^0C
Oxygen requirements	Absence of oxygen	Partial oxidation	Excess of oxygen	Absence of oxygen	Depends on Microbes
Product	Biogas	Biogas	Syngas	Heat	Pyrolysis oils alcohol
By- products	Reject, water	Char	Ash	Gases, char	Reject, gases, water
Post treatment	Mosisture removal	Particulates ters removal	No	Oxygen removal	Water removal
Applications and use	Transportation fuel, CHP digestates as fertilizer of soil conditioner	CHP, synthetic fuel production	Electricity and heat production liquid or gaseous fuels	CHP and fuel for engines	Transportation fuel, CHP, digestate as fertilizer or animal feed

Conclusions

Waste to energy is a novel approach in order to conserve fossil fuel, to minimize environmental liabilities, to reduce green house gas emission. This technology act as a renewable source of energy thus helps in tackling the problem of energy crisis to some extent. There are various waste to energy technologies which are equally efficient in extracting energy from waste but the choice depends on the economic viability of the technology and the nature of waste to be treated. These technologies are no doubt good enough for solving the problem of solid waste management as well as energy crisis but at the same time suffer some challenges as well such as lack of versatility, waste gas clean up, conversion efficiency etc.

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