P: ISSN NO.: 2394-0344 RNI No.UPBIL/2016/67980 VOL-2* ISSUE-1* April - 2017
E: ISSN NO.: 2455-0817 *Remarking An Analisation*

Broad Area : Energy Conservation Gasification- The Most Promising Approach to Waste -To- Energy Technology

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Abstract

Waste-to-Energy (WtE) is the process by which the waste materials are converted into different forms of energy such as heat, steam or syngas. These principal sources of energy are either used to generate electricity or synthetic fuels or can be utilized directly. The processes carried out using WtE technologies brings about the transformation of caloric energy present in the waste materials into energy that can be efficiently used. Waste-to-Energy operation liberates this energy from waste material present in residual solid waste like scrap timber, textiles, different types of organic waste and inorganic waste items or municipal solid waste (MSW) that are difficult to be recovered. Various technologies are available to convert the municipal corporation waste (MSW) feedstock into heat, electricity or steam. Incineration is the most common method implemented in WtE technology which is known to be the direct combustion of organic materials. Other new WtE processes include thermal technologies such as gasification, plasma-arc gasification, pyrolysis and certain biological methods consisting of anaerobic digestion and aerobic digestion combustion of organic materials. It has been found that in the year 2011, 2 million tons of municipal solid waste (MSW) was produced by the rising urban population and this estimate is said to increase to approximately 2.9 billion tons by the year 2022 which has an unused potential. Both Asia-Pacific and Europe operates approximately 800 thermal WtE plants in around 40 countries worldwide. The number of WtE plants is expected to increase rapidly within the next 20 years and it would be capable of producing 151 terawatt hours (tWh) of electricity by treating 396 million tons of MSW annually by 2022. Hence, waste-to-energy technology is quickly becoming an important and attractive idea of waste treatment, encouraging a scenario of renewable energy production with the reduction in global carbon emission. It also provides jobs along with good paying and promotes achievement of recycling goals.

Keywords: Waste-To-Energy, Municipal Solid Waste, Energy Recovery, Incineration, Gasification, Plasma-Arc Gasification, Anaerobic Digestion

Introduction

The retrieval or recovery of materials and energy by using waste as a resource has become an interesting alternative for many of the local and national governments throughout the world. Waste-to-Energy (WtE) is a general term which describes a process by which energy stored in the waste (chemical energy) is withdrawn in a decomposed energy producing plant, in the form of heat, electricity and fuel for use. Such process of energy recovery includes numerous technologies which are carried out largely on a commercial basis in many countries, especially in countries like the USA, Denmark, the Netherlands, Germany, Switzerland and the UK (Wood et al. 2013).

By traditional means, Waste-to-energy (WtE) is known to be the implementation of incineration of garbage or trash or municipal solid waste (MSW) (Cleantech 2007). It is also called as Energy-from-waste (EFW) (REA 2011). This energy produced could be in form of electricity and/or heat. Such process includes the primary treatment of waste resulting in the formation of energy, hence the term Waste-to-Energy (WtE) or Energy-from-waste (EFW) is used. Waste-to-energy technologies are designed to treat all types of waste including commercial and industrial waste (C&I) waste, municipal solid waste (MSW) and various other types of organic and inorganic wastes. However, municipal solid waste (MSW) is known to be the best source of renewable energy (Pourali 2010). As MSW has been seen to be rapidly increasing with the rising population and their daily activities, hence it has become mandatory to treat this particular waste type (Lal and Singh 2012). WtE technologies generates renewable,baseload energy; decreases the emission of green house gases; generate green jobs and quality payment; higher level environmental conduct is carried out and the phenomena of recycling is encouraged (Michaels 2014).

Municipal solid waste (MSW) is generally referred to as trash or garbage. In the year 2010 in the US, 250 million tons of MSW was produced (Funk et al. 2013). It mostly comprises of organic waste materials like food, cardboard, paper, yard-trimmings, and plastics (Figure 1). The inorganic portion of such waste material includes metals and glass.MSW can be utilized to generate electricity and heat in the following four ways:- (i) Collecting waste material or resource; (ii) Retention, operation and transportation of resource; (iii) Production of heat and the driving of gas turbine, steam turbine or internal combustion engine by conversion of the energy stored in the waste (chemical energy) to thermal or electrical energy on utilization of the procedures of combustion, thermal conversion, or biochemical conversion; and finally (iv) The thermal or electrical energy is distributed (Funk et al. 2013).

Waste-to-energy technology comprises of various types of operations for processing different kinds of municipal solid waste and biomass to produce energy in the form of electricity or heat or steam (Arena 2012). Incineration, gasification, and pyrolysis are thermal based technologies.

The biological or non-thermal technologies include anaerobic digestion and aerobic digestion of biomass.The thermal technologies are way more superior to biological methods because the latter processes are not capable of recovering energy successfully (Brunner et al. 2004; Porteous 2005; Psomopoulous et al. 2009). The thermal methods employ higher temperatures that lead to the higher efficiency of conversion rates of various types of waste materials. They drastically reduce the waste by 70-80 per cent in mass and 80-90 per cent by volume (Consonni et al. 2005).

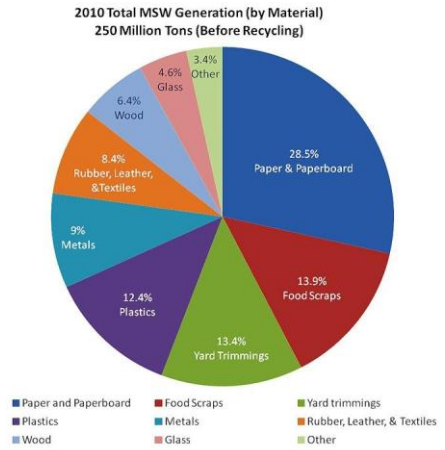


Fig 1. Disintegration of MSW produced in the United States in the year 2010 (Funk et al. 2013)

However, the wet organic materials like wet organic biomass, food waste and green waste are converted using biological operation of WtE technology. Even though, incineration is a broadly utilized thermal technology yet USEPA and the US department of energy recognized gasification as the best thermal-based WtE technology (Wilson et al. 2013), incineration is shown to have severe negative environmental impacts. Incineration also generates very high amount of dioxin and furan which pose serious health problems as this process has no cleanup operation whereas the syngas released during the process of gasification can be efficiently cleaned up of impurities and further converted into valuable products like transportation fuels, chemical fertilizers and substitute natural gas. Several studies also reported that on an average, incineration processes one ton of MSW to produce 550 kilowatt-hours of electricity whereas the process of gasification of MSW generates up to 1,000 kilowatt-hours of electricity.

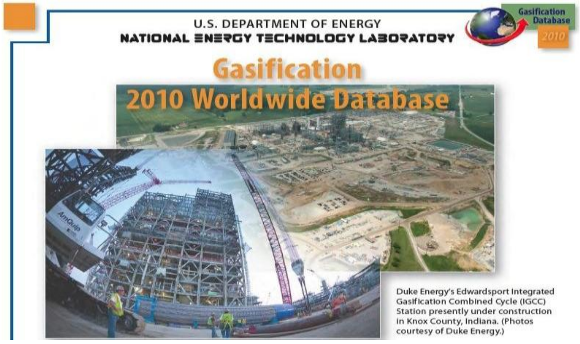
Gasification

Gasification process is one of the best thermal-based operations in Waste-to-Energy technology (Figure 2). It is also known as indirect combustion and is a process by which solid waste material is converted to fuel or synthetic gas (syngas) through various chemical reactions (Arena 2012). It has been shown to be successfully producing energy from biomass (Belgiorno et al. 2003). Several physical and chemical interactions take place during the complicated operation of gasification of solid waste, which employs a temperature of more than 600 degree Celsius. However, reactor type and the waste composition decide the actual temperature (Arena and Mastellone 2009; Higman and van der Burgt 2003; E4tech 2009).

Gasification process was discovered by Dean Clayton in 1699. It was implemented during the nineteenth century in factories for producing town gas (Belgiorno et al. 2003). The first gas plant was established in 1812 in London.

Definition

Gasification can be generally defined as the process in which a solid or liquid carbon-based material such as MSW feedstock undergoes thermo-chemical conversion into a combustible gas in the presence of a gaseous compound (Belgiorno et al. 2003). The gaseous compound undergoes various heterogeneous reactions which bring about the rapid conversion of the biomass feedstock into gas (Di Blasi 2000; Hauserman et al. 1997; Barducci 1992; Baykara and Bilgen 1981).



U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
Gasification Database 2010
Gasification
2010 Worldwide Database

Duke Energy's Edwardsport Integrated Gasification Combined Cycle (IGCC) Station presently under construction in Knox County, Indiana. (Photos courtesy of Duke Energy.)

Fig 2. 2010 Worldwide database of Gasification system (Consonni 2013)

Outputs in gasification

Several pollutants like small char particles, ash and tars, carbon dioxide, carbon monoxide, hydrogen, methane, water, very small quantity of higher hydrocarbons is contained within the combustible gas called as syngas produced during the gasification process (Bridgwater 1994a; Heermann et al. 2001; Knoef 2005).

Steps in Gasification Process

Knoef (2005) and de Souza-Santos (2004) described a chain of consecutive, endothermic and exothermic steps involved in the gasification of solid waste. The successive steps are:-

1. Heating and drying- a group of phases that includes liquid water, along with steam and porous solid phase which allows the movement of liquid and steam. This process takes place at a temperature of about 160 degree Celsius.
2. De-volatilization- It is also known as thermal decomposition or pyrolysis and takes place at a temperature of about 700 degree Celsius. It involves the thermal cracking events causing a mass and heat transfer. This event also marks the production of gases like hydrogen, carbon monoxide, carbon dioxide, methane, water, ammonia, tar and char.

Fundamental elements of a Gasification System

The three primary elements of a typical gasification equipment are:- (i) the gasifier, which releases the combustible gas, (ii) the gas cleanup system that cleans the combustible gas, and (iii) the system of recovering energy (Gershman et al. 2011) (Figure 3).

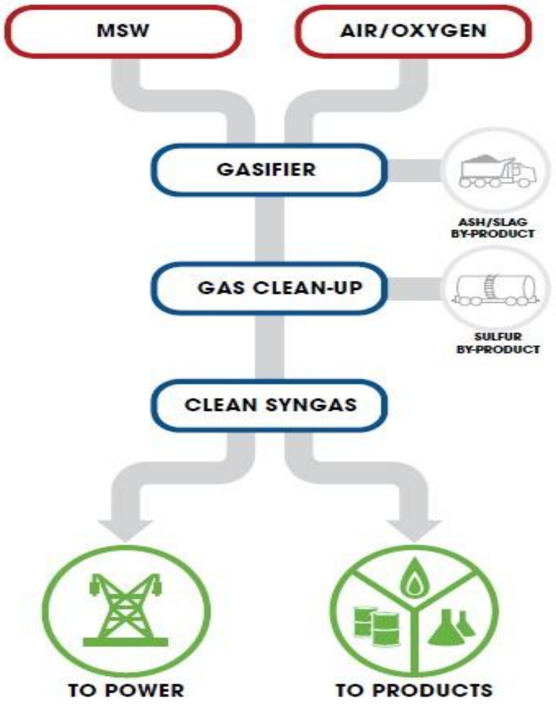


Fig 3. Schematic diagram showing the general process of gasification (Gershman et al. 2011)

Chemical reactions in gasification process

The gasification process involves various types of chemical reactions which are dependent on the operation conditions and the gasification agent like air, oxygen, steam, carbon dioxide and hydrogen. The energy required to drive the reactions is provided through the partial oxidation within the gasifier. The chemical reactions occurring in the gasification process of MSW and especially the carbonaceous char remaining after volatilization steps are listed below (Arena 2012; Wilson et al. 2013)

(1) $C + CO_2 = 2CO$ (gasification with carbon dioxide)
(2) $C + H_2O(g) = CO + H_2$ (gasification with steam)
(3) $C + 2H_2O(g) = CO_2 + 2H_2$ (gasification with steam)
(4) $C + 2H_2 = CH4$ (gasification with hydrogen)
(5) $CO + H2O(g) = CO_2 + H_2$ (water gas shift reaction)
(6) $C + \frac{1}{2} O2 = CO$ (gasification with oxygen)
(7) $CO + 3H_2 = CH_4 + H_2O(g)$ (gasification with hydrogen)
(8) $S + H_2 = H_2S$ (gasification with hydrogen)
(9) $C + O_2 = CO_2$ (gasification with oxygen)

Performance of Gasification Process on a Commercial Scale

The process of gasification has been used globally since 200 years in order to generate energy, heat, chemicals and fuels by the conversion of carbonaceous materials like biomass, waste materials, coal and fossil fuels (Breault 2010). Countries such as North America and Europe process the wood waste, agricultural waste materials and chips of wood by gasification method so as to release electricity and heat. Commercialization of gasification of MSW and various industrial wastes has occurred since last 20 years in Asia, mostly in Japan and South Korea (Gershman et al. 2013). A SWOT analysis of Gasification as a waste-to-energy technology was also carried out (Table 1) .

Table 1. SWOT analysis of Gasification as a technology (Warren et al. 2013)

Technology	Strengths	Weaknesses	Opportunities	Threats
Gasification	1. The technology is currently available. 2. Gasification allows efficient power generating technologies (i.e. reciprocating engines and gas turbines) to be used. 3. The process has low dioxin furan & VOC emissions as reactions occur under a homogenous low oxygenatmosphere at high temperature. 4. Low NOx & SOxemissions due to process occurring in a low oxygen environment. 5. Process has better volume reduction performance than combustion or pyrolysis due to the higher operating temperatures and the longer residencetimes. 6. Hazardous heavy metals vitrifiedinleach resistance slag. 7. The technology is available in a semi-modular format.	1. Process carries safety risks that would be new to the waste management industry. 2. Significant technical residual risk in gas cleaning for power production. 3. Some limitations on the type and mix of input feedstock to ensurethe syngas has a high calorificvalue of syngas and that flue gas emissions limits are not exceeded. This limits feedstock flexibility and availability. 4. Limited experiencein operating gasifiers with MSW feedstock. 5. Conversion Process requires the input of energy (equivalent to 20-25% of input energy) to sustain gasification process.	1. Diversion of bio degradable materials from landfill and associated reduction in green house gas generation potential. 2. Opportunities for electricity and heat generation. 3. Syngas produced has the potential to be used as a versatile fuel. 4. Ash (if produced) has potential uses as an aggregate substitute.	1. Previous experience of gasification has predominantly been on industrial locations (i.e. petro chemicals refineries) where the impacts have been minimised. 2. Community resistance to gasification due to the perception that itis another form ofincineration. 3. Attainment of syngas with a sufficiently high syngas may place constraints on feedstock. Wastes with a low CV may not be suitable.

Utilization of syngas

Synthetic gas or syngas is composed of carbon monoxide and hydrogen (Blees 2008). These gases are generated at higher temperature biomass gasification. Syngas releases products like synthetic natural gas or synthetic diesel on undergoing cleanup process (Figure 4) (Chiti and Kemiha 2013; Heermann et al. 2001; E4tech 2009; Stantec 2010).

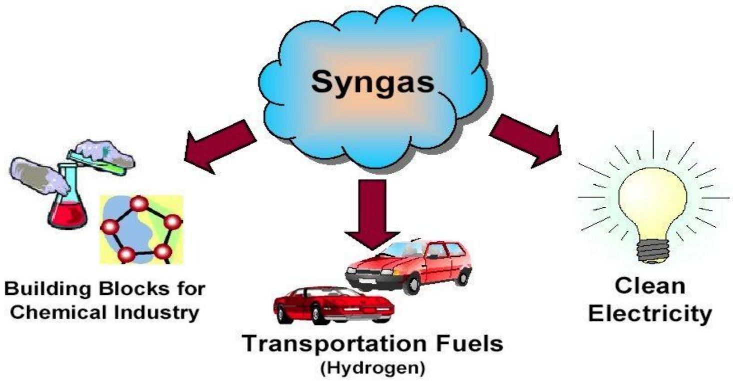


Fig 4. Utilization of syngas (Consonni et al. 2005)

Gasification of waste as a superior alternative to waste incineration

Incineration is a thermal process in Waste-to-Energy technology which brings about the thermal oxidation of combustible constituent of solid waste material to generate heat energy that can be further utilized for producing electricity, for various industrial processes or for the purpose of district heating (Wilson et al. 2013).There are several important reasons that considers waste gasification a better technology option in comparison to waste incineration (Arena 2012):-

1. Incineration processes burn the feedstocks directly with the release of harmful gases such as carbon dioxide, dioxin, furan, particulate matters where as gasification releases syngas, which is an intermediate product and can be utilized to produce various transportation fuels and chemicals (Mckay 2002). According to various report and data, incineration is estimated to release nearly 1.6 kg of carbon dioxide produced per kWh of power generated, more than 192 grams of NOx and 94 grams of SOx as compared to 1 kg of carbon dioxide produced per KWh of power generated and more than 31 grams of NOx with more than 9 grams of SOx released per ton of waste processed by Gasification and also releases less dioxin and furan.
2. Gasification usually operates at lower temperature conditions as compared to direct combustion or incineration which decreases the chance of volatilization of alkali and heavy metals along with fouling and slagging.
3. Gasification systems or plants can be built easily and quickly. Such plants allow the feasibility of changing the amount of solid waste feedstocks. The system’s efficiency overshadows the capital cost.

Plasma-arc gasification

Plasma-arc gasification of Waste-to-Energy has currently appeared to be a powerful and budding treatment for the disposal of almost all types of waste material including radioactive waste vitrification and chemical absorbs successfully (Huang et al. 2003; Chang et al. 1996) with the release of high amount of energy (Lal and Singh 2012). At high temperature of about 1500- 5000 degree Celsius, syngas is produced which is of very high quality (Arena 2012). It is extremely fast in operation and has the potential of removing hazardous items. One ton of waste feedstock generates 108 MWh/day of electrical energy (Wilson et al. 2013). Arc plasma torch is utilized as their heat source in plasma treatment of waste (Williams et al. 2003; Willis et al. 2010). In order to maintain high temperatures, plasma discharge needs a higher flow of electrical energy (Khongkrapan et al. 2013) (Figure 5). Pourali (2010) introduced this technique many decades ago.Various types of organic waste material are processed to produce syngas which in turn powers boilers, gas turbines to generate energy. It also forms metals that can be reused by the vitrification of the inorganic waste feedstocks (Blees 2008).Camacho (1996) proposed that the atmosphere showed limited amount of harmful gases on operation of this treatment process.

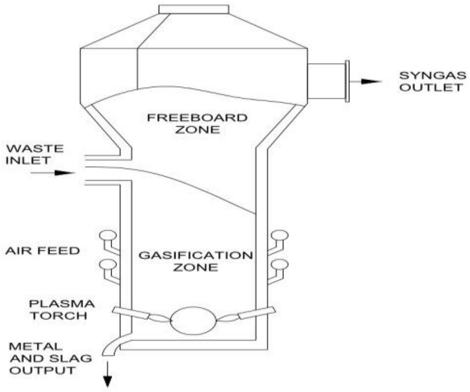


Fig 5. Diagram showing plasma arc-gasification system (Wilson et al. 2013)

Gasification industry

More than 272 operating gasification plants are found worldwide with 686 gasifiers. At present 74 plants are there under construction worldwide that will have a total of 238 gasifiers and produce 83 MWth. United States has 33 gasification plants. China has the largest number of gasification plants right now.

Gasification Industry based on Geographic region

There has been a noteworthy change in the regional distribution of gasification in the last four years. Unifrom distribution of Gasification plants has occured between Asia or Australia, Africa or Middle East and North America (Figure 6). The gasification capacity that includes both operational and under construction in the Asia or Australia region now exceeds the rest of the world put together.

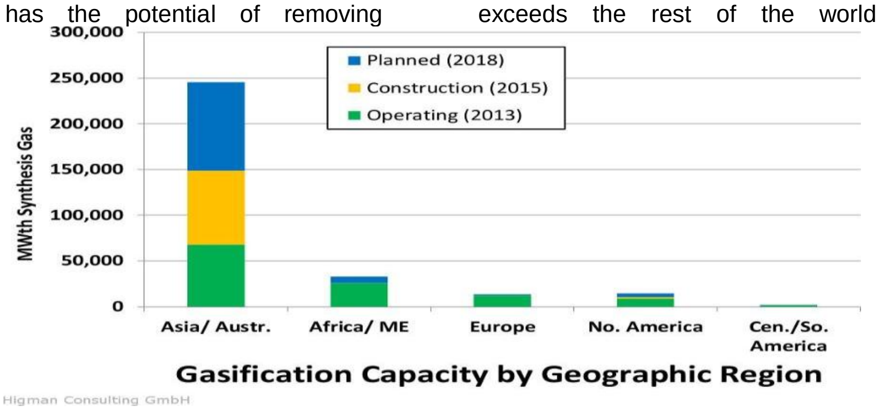


Fig 6. Graph depicting Gasification capacity by geographic region (GSTC, 2016)

Gasification Industry based on Application

The majority of chief gasification application that has been, and will remain, for the probable future is the Gasification for chemicals. According to Higman and Tam's current study, it was seen that about 25% of the world's ammonia and over 30% of the world's methanol are now being created by means of gasification (as compared to 10 % in each case ten years ago).

Gasification for liquid and gaseous fuels is becoming progressively more imperative. The demand for transportation fuels (particularly gasoline) has been rising stridently in other parts of the world, principally Asia, whereas it has declined in the United States (Figure 7).

Now, Asia also has Gasification for substitute natural gas. The United States has become a visionary due to its abundant supply of cheaper natural gas with little interest in any type of coal project (gasification or otherwise) or the production of "substitute" natural gas. In comparison, the natural gas (in the form of Liquefied Natural Gas or LNG) is extremely expensive in Asia and Africa. A number of new gasification plants under construction in Asia has been encouraged due to the high cost of importing LNG and the concerns about energy security.

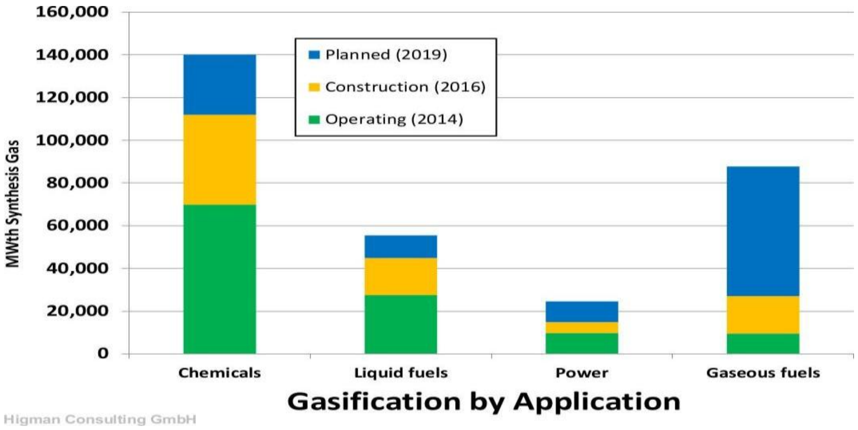


Fig 7. Graph depicting Gasification capacity by application (GSTC, 2016)

Gasification Industry based on feedstock

The leading feedstock that will continue to be so in the expected future is coal. Even though, there are gasification plants using oil as a feedstock, but that number has reduced significantly due to increase in the price of crude oil. The figure for gas feedstock plants consists largely two "gas to liquids or GTL" plants-Bintulu and Pearl. Even as biomass and waste feed is at present very small, this feedstock category is expected to grow in the future (Figure 8).

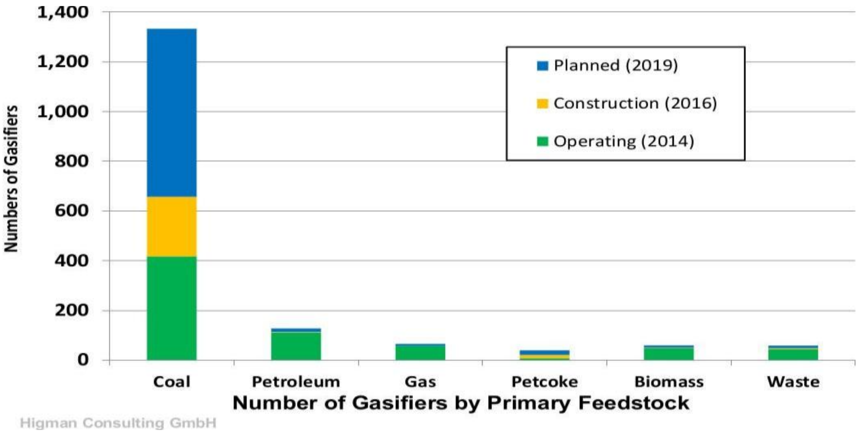


Fig 8. Graph depicting Gasification capacity by feedstock (GSTC, 2016)

Gasification as a technology holds a promising Future.....

Gasification projects are becoming both superior and smaller. The large industrial coal and petroleum coke gasification projects for chemicals, hydrogen, power are getting larger. These projects are usually seen in Asia and the Middle East. Although the size of the gasifier is normally not increasing in size, the number of gasifiers used in a project is rising. By 2018, the Worldwide gasification capacity is anticipated to grow drastically with the principal growth occurring in Asia (primarily China, India, South Korea, and Mongolia) (Figure 9).

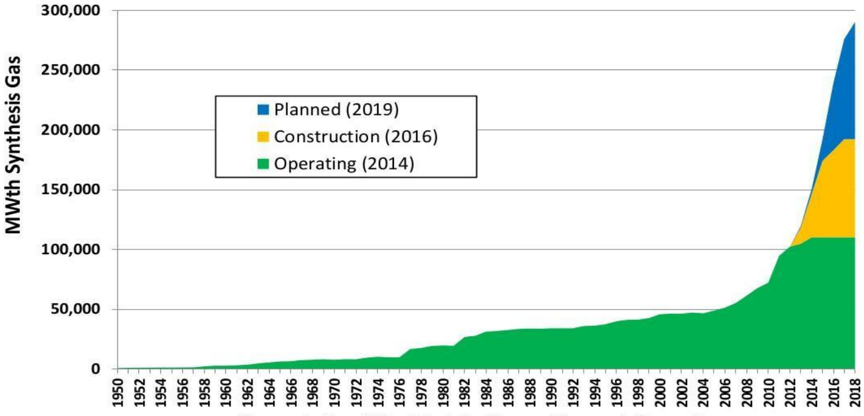


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Fig 9. Graph depicting Cumulative Worldwide Capacity and Growth (GSTC, 2016)

Fig 10. Some Gasification plants found around the world.

A. Shin moji gasification plant in Davao city, Phillipines (Padillo 2016), **B.** McNeil Generating Station in Burlington, Vermont,uses gasification technology to convert wood chips to power (Funk et a. 2013), **C.** Micro Scale Fixed Bed Gasifier in Istanbul, Turkey (Ellyin 2012), **D.** Plasma Gasification plants in Teesside, Norway (Jozefek 2016), **E.** Plaswa power based waste gasification plant in Swindon, England (Messenger 2016), **F.** Sarpsborg gasification plant supplied by Energos in Norway (Wood et al. 2013)

Conclusion

Due to high prices of energy, overpopulation and rise in greenhouse gas emissions,there is a necessity of replacing landfilling of wastes which disturbs the environment and health of people. Waste to energy technology is an emerging waste management option that promises efficient disposal of waste along with recovery of energy. Of the 230 million waste produced in US, 14 per cent is incinerated that provides 2.8 million homes with electricity. Europe also operates 400 incineration plants to process 50 million tons of MSW per year. Gasification and anaerobic digestion are considered to be the most appropriate waste to energy technology option. Biogas produced during anaerobic digestion is being used for powering the biofuel refineries which is an incentive to new waste-to-fuel technologies. Plasma technologies are also being operated successfully in countries like Japan, Canada, India and US. Therefore, waste to energy plants are capable of being an alternative choice to landfill that can simultaneously dispose the non-recyclable wastes along with the recovery of stored energy in the waste material. Waste to energy plants can also work meeting the strict emission standards without posing any harmful effect on the health and environment of the people.

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