Landfill gas study performance on a IC Engine with addition of Syngas

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EXECUTIVE SUMMARY

In this research, Chapter 1 is dedicated to analytical evaluation of landfill gas recovery. The majority of the world's municipal solid waste in is still going to the landfills, US being no exception. According to BioCycle and Earth Engineering Center, about 270 million tons of waste are landfilled annually in US. Anaerobic degradation, a naturally occurring process on the landfills, generates landfill gas which mainly consists of methane and carbon dioxide. Methane is a highly potent greenhouse gas that can be captured and used in a variety of applications. When methane from the landfill is collected and used it not only prevents the gas from escaping into the atmosphere, but also displaces the Carbon Dioxide emissions from the fossil fuels that would otherwise have been used. Methane can be used directly as gas or used to generate electricity and be sold to the grid.

Electricity generation makes up about three–fourths of currently operational landfill gas capture projects in the United States. Besides the revenue from electricity sale, creation of new jobs associated with the design, construction, and operation as well as air quality improvement are other benefits of landfill gas utilization. While there are lots of environmental and economic advantages, from a technical point of view, utilization of landfill gas for energy presents technical challenges due to low and fluctuating energy content which results in flame instability.

One of the methods of catalytic reforming of portion of landfill gas and an experiment conducted to validate it are described in Chapter 2 of this research. A mixture of Hydrogen and Carbon Monoxide (syngas) was injected at the different ratios to the stream of landfill gas and the resulting gas mixture was then introduced to an internal combustion engine. Results were measured in terms of exhaust emissions and engine performance at different ratios of landfill gas and syngas.

Despite the difficulties with laboratory equipment, this experiment proved that the addition of syngas to Landfill gas changes characteristics of combustion process and results in increased reactivity of the fuel mixture and decreased exhaust emissions.

Review of waste management in Russia and in Moscow: In Appendix D of this report (p.41 et seq.), the author reviews briefly the current state of waste management in Russia and the means of disposal of municipal solid waste in the metropolitan area of Moscow.

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Chapter I. Current state of Landfilling and Landfill gas usage analyses

I.1. Municipal Solid Waste in the World

The current annual world Municipal Solid Waste (MSW) generation, estimated by D-Waste is 1.9 billion tons with almost 30% of it going uncollected. Of the collected MSW, 70% is taken to landfills and dumpsites, 19% is recycled or recovered and 11% goes to energy recovery facilities [1]

Of the total amount of waste treated in European Union-27, disposal, which includes landfilling as well as land treatment and release into water bodies, represents slightly more than 50% [21]. The other main waste treatment options are incineration, energy recovery and material recovery. In some European countries, restrictions on the landfill of certain types of waste have been imposed and much more waste is now recovered or incinerated.

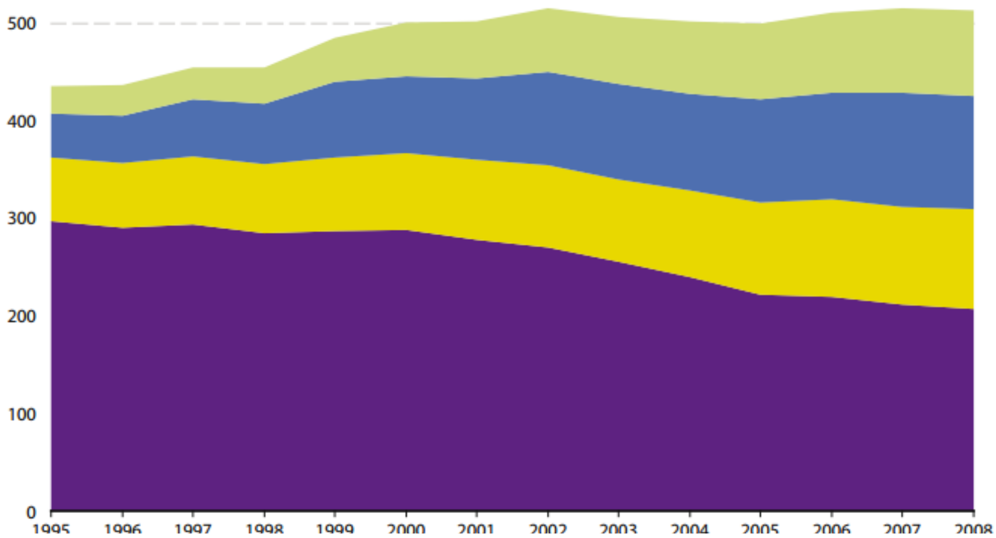
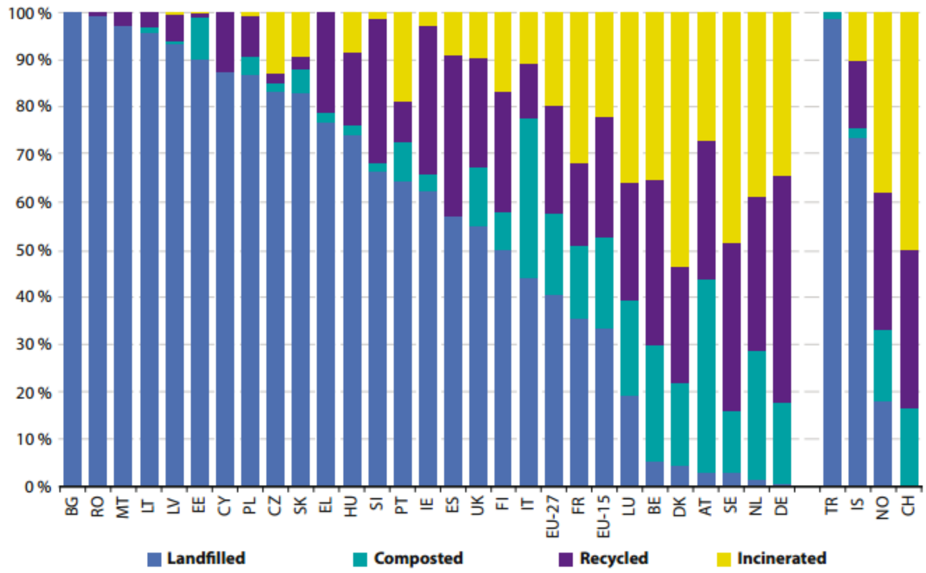


Figure 1. Municipal waste treatment, EU-27, kg per capita

Source: Eurostat

Currently Belgium, Denmark, Austria, Sweden, Nederland and Germany manage municipal solid waste systems to minimize landfilling resulting in less than 10% of their waste stream going to landfill. Austria emphasizes composting organic waste; while the other five countries incinerate majority of their waste. Other European countries lag behind the six leaders, with landfilling rate of more than 90%. Among those countries are Bulgaria, Turkey, Romania, Malta, Latvia and Lithuania. Reviewing this data reveals that that counties incinerating their waste, are also the ones with higher rates of recycling and composting. Countries with no waste to energy are most likely to have very little or no recycling and composting .



Source: Eurostat,2012

Figure 2. Municipal Solid Waste treatment, EU-27, % of total

I.2. Municipal Solid Waste in the USA

The majority of the world's municipal solid waste is still going to the landfill even in the most economically developed countries, including the US. The actual amount of MSW generated in the US is still subject to debate. According to the latest EPA data, there was 250 million tons of MSW generated in 2008, while BioCycle and Earth Engineering Center cites much higher numbers of 390 million tons generated and 270 million tons being landfilled[4].

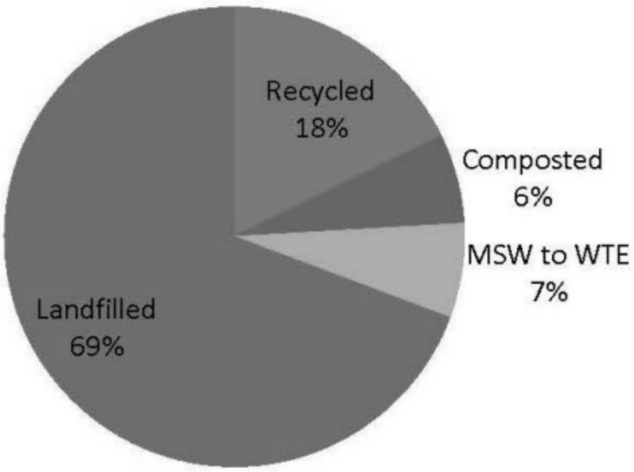


Figure 3. Management of MSW in the US

Source: BioCycle 2010 [4]

Disposing of solid waste in modern, managed landfills is the most commonly used waste management technique in the United States. Disposing of waste in illegal dumping sites is not considered to have occurred in years since 1980 and these sites are not considered to contribute to net emissions in this section for the inventory time frame of 1990 to 2011. MSW landfills, or sanitary landfills, are sites where MSW is managed to prevent or minimize health, safety, and environmental impacts. Waste is deposited in different cells and covered daily with soil, clay or other material. There are numerous environmental monitoring systems implemented at sanitary landfills to track performance, collect and neutralize leachate, and collect landfill gas.

The United States is at a critical juncture in its energy portfolio. There is renewed attention to producing energy domestically, reliably and environmentally responsibly. Bringing new energy online to meet projected demand will require a combination of conventional sources with an increased contribution from renewable, distributed sources such as wind, solar and biomass. In addition low quality (low BTU) and unconventional fuels are increasingly being considered. Two significant issues with using low quality and unconventional fuels are the combustion performance and the emissions generated. One example of a low quality, unconventional fuel is landfill gas (LFG), a significant source of energy from municipal solid waste (MSW). The average MSW generation per capita is nearly 5 pounds per day. If that waste is converted to energy it has the potential to offset approximately 20% of oil imports.

Nearly 70% of MSW goes to landfills (see figure 3) where it anaerobically decomposes to produce mostly CH_4 and CO_2 gas in a one-to-one ratio. Capturing that gas for landfill gas-to-energy (LFGTE) projects turns landfills into a source of clean, renewable energy and has been demonstrated on a commercial scale. However, many small and mid-sized landfills are prevented from installing LFGTE projects by the low and/or fluctuating BTU content of the LFG resulting in poor combustion performance and increased emissions.

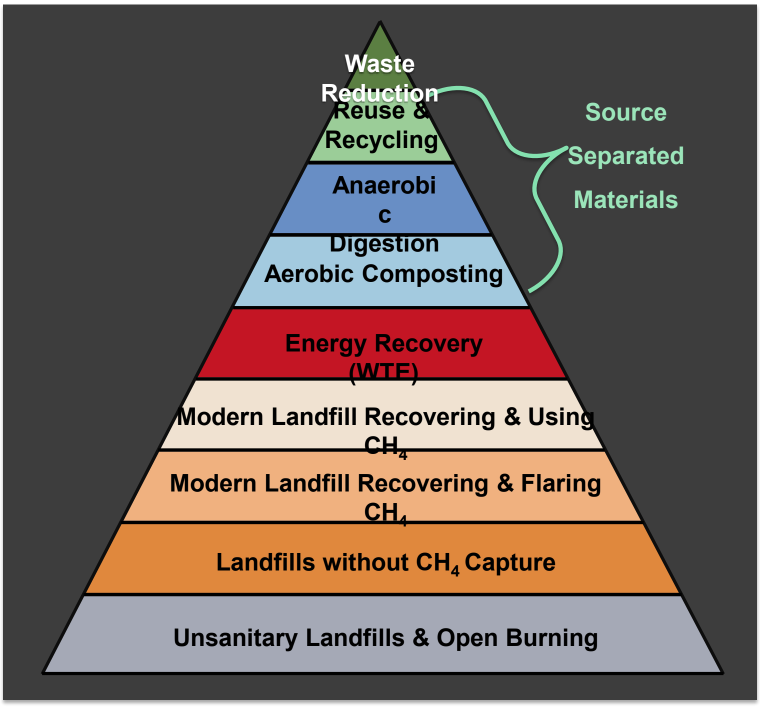


Figure 4. Waste hierarchy, IPCC

There are only two proven methods to dispose of MSW at the rate it is generated – landfill and waste-to-energy. The extraction of materials and energy from MSW must be done to achieve sustainable practices in managing and disposal of waste. The hierarchy of waste management, fig 4, shows that after reduce, reuse and recycle, energy extraction is the next best disposal method. Energy extraction can come from gas collection of composting the organic fraction of the waste or from landfills (yielding 120 MWh/ton) or combustion of MSW (yielding ~620 MWh/ton). As consumer awareness of environmental issues and the demand for renewable energy such as LFGTE increase, LFGTE projects are becoming especially valuable to utilities and thus require continued development.

I.3. Landfill gas feasibility

Because of the presence of organic content in the landfilled waste, landfill gas and leachate are generated by the process of anaerobic decomposition. To be more specific, after being placed in a landfill, organic waste is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria [19]. These Methane- producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent biogenic Carbon Dioxide and 50 percent Methane, by volume.

$$C_6H_{10}O_4 + 2H_20 \rightarrow 3CH_4 + 3CO_2$$

Landfill biogas also contains trace amounts of non-methane organic compounds (NMOC) and volatile organic compounds (VOC) that either result from decomposition by-products or volatilization of biodegradable wastes [19] . See figure 5. It also contains trace amounts of ammonia and sulfides, both of which cause unpleasant odors even at very low concentrations.

Landfill gas composition is highly dependent on climate at the landfill location, season, landfill conditions and age, type of landfilled waste and moisture content. However, regardless of the local conditions, almost half of the generated gas is methane. Methane is well known as Green House Gas (GHG). Despite the fact that Methane's lifetime in the atmosphere is much shorter than Carbon Dioxide, Methane is much more efficient at trapping radiation than Carbon Dioxide. The comparative impact of Methane on climate change is over 20 times greater than that of Carbon Dioxide over a 100-year period [3]. If uncontrolled, Landfill Gas contributes to smog and global warming, and may cause health problems.

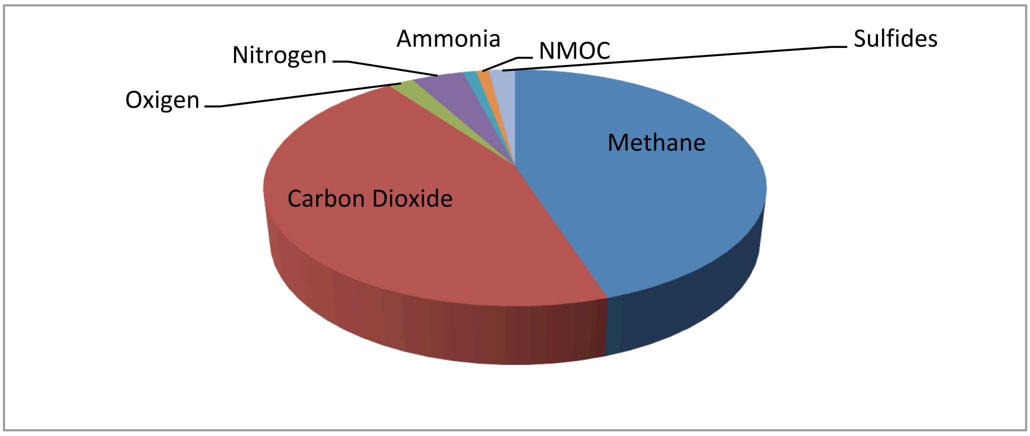


Figure 5. Landfill gas composition

But at the same time, landfill gas is a potential alternative energy source. Landfill Gas to Energy (LFGTE) process has attracted a lot of interest as a source of energy and heat with an additional benefit of reducing methane emissions into the atmosphere. One ton of biodegradable waste produces between 50 m^3 and 270 m^3 of landfill gas. [14], [15],[20].

Collection and use of Landfill gas should not be considered as the best Waste-To-Energy way in every country where landfilling is used. The diversion of biodegradable municipal waste from landfill is a key objective under the European Union landfill directive. This directive aims to reduce negative impact of landfilling waste on the environment and requires Member States to reduce the amount of biodegradable waste going to landfills in order to reduce methane emissions. The goal of the directive is to achieve a 50% reduction of landfilled biodegradable waste by 2013 and 65% reduction by 2020 as measured against the 1995 levels [22]. The emphasis on composting and other technologies to deal with this waste stream is growing in European Union. However, this reduction in organic material reaching the landfills will also reduce the methane stream available to LFGTE projects in the EU by as much as 1/3 making them economically unfeasible by 2020.

Until there is no separate collection and recycling of the organic waste stream in the US, landfill gas to energy projects will remain feasible.

I.4. Landfill gas utilization

US laws requiring collection of landfill gas are not based on global warming impact of methane, but rather on the toxic hazards of NMOCs. Federal regulations require that landfills with total permitted capacity greater than or equal to 2.5 million cubic meters of waste, to have their annual Non-Methane Organic Compound emissions estimated. If the NMOCs are estimated at more than 55 tons per year, the landfill must adhere to rules that include submitting compliance reports and installa gas collection system [3].

LFG electricity projects capture ~85% of the methane emitted from a MSW landfill. In addition to reduced price volatility, an LFG to electricity project provides two GHG emissions reduction opportunities. First, it requires methane from the landfill to be collected, thereby preventing the gas from escaping into the atmosphere. Second, it displaces the CO_2 emissions from the fossil fuels that would otherwise have been used. There are other broader benefits such as air quality improvement of the surrounding community by reducing landfill odors. LFGTE projects generate revenue from the sale of the electricity and create jobs associated with the design, construction, and operation of energy recovery systems that include engineers, construction firms, equipment vendors, and utilities or end–users of the power produced. Much of this cost is spent locally for drilling, piping, construction, and operational personnel, helping communities to realize economic benefits from increased employment and local sales. Besides electricity production, gas, captured from Landfills can be used directly. Landfill gas can offset the use of fossil fuel thus reduce current dependency rate from primary energy sources. It also can be used on the landfill itself to evaporate leachate. Innovative direct uses include firing pottery and glass–blowing kilns; powering and heating greenhouses and an ice rink; and heating water for an aquaculture (fish farming) operation [2].

Another benefit of LFGTE is education and increasing of public awareness of positive sides of Landfills and of waste treatment in general. A lot of people may not be aware of environmental benefits of waste to energy projects and suppose that everything beyond recycling is not environmental friendly. Implementing LFGTE projects increase public awareness and make people from local community become familiar with environmental friendly engineered waste treatment.

I.5. Landfill gas to energy in the US

Currently there are 621 operational LFGTE projects in the US generating 1,978 MW and 311 mmscfd. There are also about 450 LFGTE candidate landfills, which are expected to create additional 850 MW or 470 mmscfd [12]. There are two maps representing direct usage of Landfill gas (see fig 7) and electricity generation LFGTE projects (see fig 6)in the US. Colored background of both maps represents population density, where blue is the lowest and red is the highest. Each county with a LFGTE project allocated in that map is bordered in green color. The diameter of the circles represents power output, fig 6, and gas generation, fig7.

The generation of electricity from LFG makes up about three–fourths of the currently operational projects in the United States, see the distribution of those projects of the map- fig6. The bigger the diameter- the more megawatts are generated from landfill gas combustion. From maps it is easy to see how LFGTE projects located where the population is the densest. LFGTE projects require both, source of waste as big landfill and a market for the product- power or gas. That is why there are projects located next to the biggest cities in the country: New York great area, Chicago area, Los Angeles and San Francisco areas and Dallas.