The generation of energy from landfill gas environmental sciences essay

AbstractThis paper reviews the energy recovery from landfill gas. It is divided into 3 parts: the first give background information on landfill gas including the source of it and the composition; the second emphasises various issues brought by landfill gas; while the third part focus on technical design of converting landfill gas into energy and a solution to deal with practical considerations regarding the design of monitoring systems and filtration process will also be discussed at the end. 1. IntroductionThe most common mitigation strategy is the capture of LFG for flaring or combustion to recover energy as this present significant environmental, economic and energy benefits (El-Fadel and Sbayti, 2000). Current industries using LFG include automobile manufacturing, chemical production, food processing, pharmaceutical, cement and brick manufacturing, wastewater treatment, consumer electronics and products, and prisons and hospitals(U. S. EPA, 2009c). if not properly collected and utilized, can potentially be asignificant source of pollution. It can migrate undergroundand contaminate the ground water resources. As fugitive2. The composition of landfill gas: The bulk of research investigated in this section. However, the composition of the landfill gas varies with the different type of waste and the period of emplace. Landfill gas is composed of a mixture of hundreds of different gases (Wang-Yao et al., 2006)1. Typically, it contains 45% to 60% methane, 30% to 40% carbon dioxide, 2% to 10% nitrogen and a small amount of oxygen, moisture and trace species such as sulphides, ammonia, carbon monoxide, hydrogen and nonmethane organic compounds (NMOCs).. 2Table 1. 1: Typical Landfill Gas componentsComponentPercentage by Volume (%)CharacteristicsMethaneUp to 65%Colourless and odourless; Flammable, forming potentially explosive mixtures in certain conditions; Resulting in concern about its uncontrolled migration and release. Carbon dioxide30-40%Colourless odourless and slightly acidic; Only 0. 03% in atmosthere3; Resulting in concern about migration and release. Nitrogen2-10%Odourless, tasteless and colourless; Approximately 79% of the atmosphere. Oxygen0. 1-1%Odourless, tasteless and colourless; Approximately 21% of the atmosphere. Trace species0. 1-0. 2%Between 50 and 200 minor components at trace level concentrations, such as NMOCs, hydrogen sulphide, ammonia, mercury and volatile metallic compounds. The composition of trace components in landfill gasFrom 1980s, much research into landfill gas emissions began to focus on the trace component composition because of the potential environmental impact of trace landfill gases on emissions (Mitchell et al., 1993). The compositional profiles of trace gases generated at different sites tend to differ. In the most cited study on trace landfill gas, work by Scott et al. (1988), the trace components in landfill gas was subdivided into12 distinct generic chemical groups. 5GroupCharacteristicsAlkanesAlkanes other than methane are an important portion of trace landfill gas. Predominating during early aerobic process and low molecular weight, low solubility alkanes dominated composition at the same time. Higher molecular weight alkanes like nonane and decane appear to dominate under anaerobic conditiongs. AlkenesAlkenes appear at peak levels during the early stages of refuse decay, but their levels are generally lower thanalkanes. Nonene and decene are detected at low concentrations under anaerobic conditions. Hydrogen sulphideHydrogen sulphide has the highest concentrations in the early stage of refuse degradation, but levels drop steadily with time unless there is a sulphate rich co-disposal in the waste. As its low odour threshold, it is believed to be a source of odour problems. Cyclic organic compoundsCycloalkenes, cycloalkanes and aromatic compounds are detected amongst trace components. Limonene has the highest concentration amongst cycloalkanes, while toluene was the most abundant aromatic compound after refuse deposition. The level and diversity of aromatic compounds tend to increase under anaerobic conditions. Halogenated compounds22 to 25 kinds of halocarbons are found in low molecular weight compounds of one or two carbon atoms. AlcoholsThese are one of the most significant groups of trace components and mainly arise from fermentation of putrescible materials. It is probable believed that alcohols are important intermediates for formation of hydrogen and carboxylic acids that undergo subsequent conversion to CO2 and CH4. EstersAs the most diverse group, 30 esters with very odorous smell are detected. Highest concentrations appear within a few days of waste emplacement. They may come from direct degradation of waste or from reaction between alcohols and carboxylic acids. Carboxylic acidsThey are only detected in the vapour phase in early samples. These remain in the leachate or convert to esters, or are dissolved in the fine moisture droplets. AminesOnly dimethyl amine is detected in one landfill site after waste being emplaced 3 days. EthersEthers are extremely volatile compounds. Diethyl ether is only detected and the peak of concentrations appears after refuse emplacement. Organosulphur compoundsMethanethiol dominates in organosulphur group and to a lesser extent by dimethyl sulphide. Other oxygenated compoundsThese principally are composed of ketones and furan derivatives which are usually in relatively low concentrations. Up to maximum of 5% of total trace emissions. In the recent research (after 1988), more and more raw landfill gas from various waste disposal sites were sampled. Whereas there is often investigation in gas composition in pre-1988 research, there are also concentrating on other aspects of trace landfill gas in post-1988 papers, especially the concentrations of trace components of landfill gas. The most diverse spatial sampling including seven UK waste disposal sites (only accepting domestic and trade waste) was reported in Allen et al (1997). In his study, 140 compounds are identified of which 90 are common to all seven waste sites. The concentration of six chemical groups is determined: Chemical groupsConcentrations (mg/m3)Alkanes302 - 1543 mg/m3Aromatic94 - 1905 mg/m3Cycloalkanes8 - 487 mg/m3Terpenes35 - 652 mg/m3Alcohols and ketones2 - 2069 mg/m3Halogenated compounds327 - 1239 mg/m3*The data in table 1-2 need to be discussed due to the effect of air ingress (6% oxygen) or compressor oil when landfill gas sampled through a compressor5. The source of landfill gas: Landfill gas is a mixture of different released gases which mainly contain methane and carbon dioxide produced by chemical reactions and bacterial degradation of organic matter within a landfill. Most landfill gas is generated via three process- bacterial decomposition, volatilization, and chemical reactions. Bacterial decompositionBacterial degradation is the most significant way to produce landfill gas1. The organic waste is degraded by natural bacteria which present in the soil and the waste used to cover landfill2. The whole process of decomposition is undergoing in four phases successively: Phase I. Aerobic; Phase II Anaerobic Non- Methanogenic; Phase III Anaerobic Methanogenic Unsteady and Phase IVAnaerobic Methanogenic Steady3. In Phase I, aerobic decomposition takes place in the presence of oxygen and aerobic bacteria, which survive require oxygen in order to grow. The various refuses comprise long molecular chains of carbohydrates, proteins and lipids are broken down by consuming O_2. According to the study of Ludwig (1961), carbon dioxide is the primary byproduct of this process and it has approximate molar equivalents to the oxygen depleted[4]. The displacement of nitrogen also occurs in Phase I. The decomposition of Phase I can last for days or months, depending on how much oxygen is available to consume in the landfill. However, the factors such as how loose or compressed the waste was when it buried affect the level of oxygen. Therefore, the period of this phase is undeterminable. In Phase II, anaerobic activity becomes dominant when the oxygen has been used up. In this process, the highly acid landfill is conformed because aerobic bacteria convert organic compounds into lactic, acetic, formic acids and alcohols such as ethanol and methanol. A carbon dioxide bloom occurs and hydrogen is produced during this phase. Displacement of N_2 is also in evidence in this process, but the acids mixing with the moisture which presents in the landfill dissolve nutrients and denitrification may cause N_2 exist[5]. Methane has not been emitted in this process and the reason of phase lag in CH_4 after anaerobiosis was first stated by McCarty (1963): methanogenesis cannot happen if the amount of CO_2, which act as an accepter of H_2, was not enough in solution[6]. Methanogenesis starts in Phase III. The content of each gas varies during this process, thus, unsteady is used to describe this phase. At the beginning, organic acids produced in Phase II convert to acetate via anaerobic bacteria consumption. Therefore, methanogenic bacteria are available in this phase to consume carbon dioxide and acetate to form methane under anaerobic conditions (Williams, 2005). However, the concentration of CH_4 increases relate to the decline of other gases. The disappearance of hydrogen which occurs in the initial portion of this phase indicates it is used by the methanogenic bacteria in a very rapid rate (Toerien and Hattingh, 1969). Both CO_2 and N_2 concentrations decrease due to anaerobic reactions. In Phase IV, the composition of produced gases and the production rates of fermentation remain relatively constant, which steady at their peak for the prevailing conditions. According to the investigation from Dunn, Bevan and Bekyche (Dunn, 1960; Bevan, 1967; Beluche, 1968; Ramaswamy, 1970), landfill gas typically contains approximately 40% to 60% CH_4 by volume, 45% to 60% CO_2 and 2% to 9% other gases for instance hydrogen sulphides. However, the variations in gas production cannot be precluded due to the change of environmental conditions and long-term variations caused by nutrient depletion or the accumulation of inhibitory materials12. A completion time for Phases I, II and III has been widely investigated from 1960s. The earliest study was reported by Beluche(1968), in his research, the period for these three phases in 500days, while the data from Crawford and Smith(1985) suggest that 180 days are required. In addition, the work of Rovers and Farquhar (1972) demonstrates a period of 250 days. The experiment that they used to investigate the corresponding time was conducted in cylinders filled with refuse to simulate a landfill and fermentation process. Consequently, compared to the actual landfill conditions, those results are atypical. Figure 2-1: Production phases of typical landfill gasVolatilizationThe organic compound either state of liquid or solid in refuses evaporates into landfill gas through volatilization until the equilibrium vapour concentration is reached. A certain amount of nonmethane organic compounds (NMOCs) in landfill gas come from this process. NMOCs are known as hazardous air pollutants (HAPs) and volatile organic compounds (VOCs) such as trichloroethylene, benzene and vinyl chloride. Chemical reactionsChemical reactions can be also happened in landfill. For example, when chlorine bleach and ammonia come in contact with each other within the landfill, the harmful gas-chloramine vapour is produced and has the potential for hydrazine formation12. From the study of Baedecker and Back13, the decomposition process of organic materials which is conducted by biological activity provides an extremely high concentration of organic compounds in landfill leachate. Thus, the landfill leachate is a suitable environment for the interrelation of organic compounds and inorganic reactions to produce landfill gas. According to the data of Langmuir (1972), main LFG (landfill gas) products from chemical reactions are CO_2, CH_4, NH_3 and in some cases H_2S and H_2 organic compounds. 2. 3 Factors influence Landfill gas productionSeveral abiotic factors affecting the rate and volume of the landfill gas production20. These factors include the composition and the age of the refuse, temperature, pH and moisture content, as well as the landfill operation procedures which are compaction, soil cover and recirculation of leachate. (Christensen et al., 1996) The description of these factors will be briefly introduced in the following. Waste composition-The amount of landfill gas (e. g. CO_2, CH_4, N_2 and NMOCs) produced principally depending on the amount of organic waste (e. g. inorganic elements, cellulose proteins and lipids) present in a landfill. On the one hand, nutrients in organic refuse, such as calcium, sodium, magnesium and potassium, have a positive effect on biogas production rate as a result of bacteria thriving. (Isci and Demirer, 2007) On the other hand, cellulose-to-lignin ratio (CLR) in organic waste has a negative effect on methane production due to the presence of readily degradable carbon sources. (Gurijala et al., 1997)The age of refuse- Usually, the appreciable amount of landfill gas is generated within 1 to 3 years after burying refuse, while the peak level usually appears in 5 to 7 years after wastes are dumped. Therefore, the gas produced from recently buried waste is more than older landfill. At one landfill site, different phases of waste decomposition can exist in different portions of the landfill at the same time, depending on how long the refuse has been dumped in each area. 15 Though almost the all gas is produced within first 20 years, small quantities of gas still continue to be released from slowly decomposing landfill over 50-year period. The most important factor affecting the amount of landfill gas and the lifetime of gas production is the amount of organic material in the refuse. (Crawford and Smith 1985; DOE 1995; EPA 1993)Temperature- Typically, the active temperature for methanogenic bacteria in the range30-50???. The active temperature for thermophilic microorganisms in the range 45-65???, while 30- 35??? for mesophilic bacteria. (Williams, 2005) Thus, the rate of landfill gas rises under warm temperatures because of the optimum temperature for bacterial activity. In addition, temperature increases also promote volatilization and chemical reaction in landfill. As a general rule, the best temperature range for gas generation is between 30-45??? during the main landfill gas production phases. PH- The optimum pH condition for methanogenic bacteria activity is 6-8 pH. (Christensen et al., 1996) However, with the accumulation of acetic acid and hydrogen, the pH value decreases, which inhibits the activity of methanogenic microorganism to produce methane. Oxygen in the landfill-According to the decomposition process we explained in the last section, oxygen plays a negative role in methane formation by anaerobic bacteria. Only when O2 is used up, the methanogenic bacteria can begin to produce CH4. In addition, as we can see in chart 2-1, the more oxygen exist in waste, the longer decomposition time is required in Phase I. if landfill is frequently disturbed or loosely buried, more O2 will enter the landfill from the atmosphere by diffusion or advection, so that CO2 and water are produced by aerobic microorganism in a longer period. In contrast, if landfill is highly compacted, CH4 production in Phases III will begin earlier as the aerobic bacteria activity is low and replaced by methanogenic bacteria. Therefore, oxygen is inhibitory for methane formation. Moisture content- In the report of Moss (1997), the range of moisture content in a typical landfill is 15% to 40% with an average 30% (Williams, 2005). There are also some other studies reported that landfill samples containing higher moisture content which over 55% (wt%) produces greater amount of methane while those that contains lower than 33% (wt%) moisture content do not generate any methane. (Gurijala et al., 1997) The presence of water in a landfill promotes bacterial growth, spread and the diffusion of nutrients which result in the increase of gas production. (Naranjo et al., 2004; Williams, 2005; and Sormunen et al., 2008)Compaction- Relatively moisture content, lack of compaction may have a negative effect on acid phase, while the start of methane production is earlier. In contrast, high compaction slows the process of methane production due to the high density of refuse, decreasing the rate at which water infiltrates the waste. (Christensen et al., 1996)Soil cover- The physical, chemical and biological components of soil cover is relative to amount of landfill gas venting from landfill. (Tecle et al., 2008) The LFG emission is dependent on the thickness and permeability of soil cover. The longer retention time of transported LFG uses, the higher oxidation probability increases. (Spokas et al., 2003; and Zhang et al., 2008)Leachate recirculation- Leachate recirculation can play a positive role in the process of methane production. It can boost methane formation by increasing the moisture content, adjusting pH wolue, supplying and distributing nutrients and biomass, and diluting high concentrations of inhibitors. The emission of landfill gas can be also enhanced by leachate recirculation and subsurface irrigation. (Zhang et al., 2008)3. The issues come from LFGThe storage of landfill gas (LFG) in a landfill site contributes to environmental, safety and health issues- specifically, greenhouse gases (GHG) emission, potential explosion and asphyxiation hazards and problems related to odours emanating from LFG. 30 In this section, these effects of landfill gas or associated with landfill fires, which may or not be the direct result of LFG, will be discussed from different aspects. 3. 1 GHG emission from landfill gasAs we know, greenhouse gases are the largest reason we are facing global warming today. Greenhouse gases (GHG) refer to the gases that trap heat in the atmosphere. The most common GHGs include CH4, CO2 and NO2 and other fluorinated gases. The properties of these GHGs are shown in table 3. 1. 11 Environment Agency (1999) Methane Emissions from Different Landfill Categories. R&D Technical Report P233a (CWM 141/97), Published July 1999 Because methane and carbon dioxide gases are the main end products of the degradation of landfill under anaerobic process, raw landfill gas has a crucial effect on global warming when it is released to atmosphere. Whereas the concentration of carbon dioxide (30-40%)- primary greenhouse gas in air, landfill gases contain more methane (45%-60%)whose global worming potential more than 20 times carbon dioxide. (Ishigaki et al., 2005) The research conducted by Stern et al (2007) shows that the concentration of atmospheric methane has more than doubled in the past 150 years. 31Table 3-1: Properties of GHGsChemical FormulaLifetime in

AtmosphereGlobal Warming Potential(100-year)CO250-200 years1CH412 years21N2O120 years310HFCs, PFCs, SF6HFCs: 1-270 years; PFCs: 800-50, 000 years; SF6: 3, 200 yearsHFCs: 140-11, 700PFCs: 6, 500-9, 200SF6: 23, 900*Global warming potential (GWP) of the different gases as proposed by the International Panel on Climatic Change (IPCC 1995, 1996). Environmental Management Vol. 27, No. 5, pp. 697??? 704However, the areal emission rate of GHG from LFG is very difficult to control and the evaluation of emission process is affected by many meteorological factors which contribute to the gas production rate and gas migration properties through the landfill layers. (Cernuschi and Giugliano, 1996) The factors to gas production have been discussed in section 2. The properties of landfill gas migration will be demonstrated in next section. 3. 1. 1 LFG migration properties through waste layersOnce gases are produced through a series of decomposition process, they generally move away from the landfill and tend to expand and fill the available space, so they migrate through the pores of waste and soils covering. Usually, the natural tendency of LFG is to move upward because some gases, such as methane, are lighter than air. But there are also some other gases like carbon dioxide are denser than air and can be collected in subsurface areas. There are three main factors affecting the migration properties of LFGs: the properties of the gas itself like diffusivity, the physical and chemical characteristics of buried waste like pressure and the previous properties of soil cover like permeability. (Cernuschi and Giugliano, 1996)Diffusion flux- Diffusion flux is used to describe the natural tendency of gas to reach a uniform concentration in a place. The value of it depends on the gas filled porosity, diffusion coefficient and the concentration gradient. (Kjeldsen, 1996) Usually, the surrounding area of landfill has a lower gas concentration than the inside of landfill. Hence, landfill gases always diffuse out of landfill to the surrounding areas. The diffusion coefficient is a function pressure and temperature. Pressure- When the movement of gas is restricted by compacted waste or soil covers, the high pressure place is created with the accumulation of landfill gases in a landfill. Then, the pressure difference is created and leads to movement of gases from higher pressure area to lower pressure area, which is known as convection. (Mor et al., 2006). Permeability- The flowing ability of gases and liquids through connected spaces or pores in waste and soils is measured by permeability. The permeability of landfill gas depends on the compaction degree, which restrict the movement of the gas. In addition, the variability of it in soil cover is highly related to the grain size distribution, organic matter content. Thus, dry, sandy soils are highly permeable while moist clay is much less permeable. Gases from landfill tend to move through places of high permeability rather than through places of low permeability and gases in a covered landfill are more likely to move horizontally than vertically. (Tecle et al., 2008)3. 2 Explosion hazard of landfill gasAs discussed in the previous section, landfill gases can migrate through landfill layers to the ambient air, and then it can be carried to the community with the wind. When landfill gas combines with air in certain proportions, an explosive hazard is formed. Though the explosions of landfill gas are by no means common occurrences, there are also a number of explosive accidents have been known or suspected to be caused by landfill explosions during last 50 years. For example, in 1986, a methane gas explosion occurred in Loscoe, Derbyshire, caused by the migration of methane from an adjacent landfill into a bungalow. (G. M. Williams & N. Aitkenhead) Thus, in order to prevent uncontrolled landfill gas leading to an explosion hazard, it is important to determine the transmission pathway of landfill gas and the explosive limit of flammable gases in LGF. 3. 2. 1 The conditions for LFG to pose an explosion hazardGas production- the explosion hazard is able to be occurred when the flammable chemicals contained in landfill gas that are present at explosive levels. Thus, ??? explosive limits??? is used to define a concentration level at which gas has the potential to explode. The explosive potential is determined by lower explosive limit (LEL) and upper explosive limit (UEL). LEL and UEL represent the lowest and highest concentration (volume percentage) of a gas or a vapour in air capable of producing an explosion in presence of an ignition source respectively. In other words, the explosion may exist if the concentration of a gas in the air is between LEL and UEL and also an ignition source is introduced. The flammable gases in landfill gas and their potential to pose an explosion hazard are shown in the following table. Table 3-2 Potential explosion hazards from common landfill gas componentsComponentsPotential to pose an explosion hazardMethaneFlammable gas; Methane is the constituent of LFG that is likely to pose the explosion hazard when mixed with air at a concentration (vol%) between 5% (LEL) and 15% (UEL); Methane is unlikely to explode within the landfill site due to its high concentration (up to 65%) in original LFG; As methane migrates, it is mixed with air and may reach explosive levels. AmmoniaFlammable gas; The LEL and UEL of ammonia are 15% and 28% respectively; However, the concentration of ammonia in LFG is quite low; hence it is unlikely to reach such high concentration to pose an explosion hazard by ammonia. NMOCsPotential explosion hazards vary by chemicals. For instance, the LEL of benzene is 1. 2% and its UEL is 7. 8; It is unlikely to reach LEL to pose explosion hazards by each NMOC alone. Hydrogen sulphideFlammable gas; The LEL and UEL of ammonia are 4% and 44% respectively; It is also difficult reach the LEL of hydrogen sulphide to pose an explosion hazards. OxygenNon-flammable gas, but its presence is necessary to support explosion. 3. 2. 2 The migration pathways of LFGThere are three main conditions must be met for landfill gas to create an explosion hazard: flammable gas production; landfill gas migration; gas collection in a confined space. 50Flammable gas production- The flammable gases such as CH4, NMOCs must be produced constantly and present at high level of concentration in the landfill gas. Gas migration- The landfill gas must be able to escape from the landfill. There are two pathways for gas migration: one is through underground pipes which are used to transport LFG to utility tunnel for further treatment; another is releasing from the natural subsurface geology. Gas collection in a confine space- the escaped gas must be collected in a confine space and reach a certain concentration at which it can potentially explode. A confined space can be a subsurface space, a utility room in a house, a manhole, or a basement51. The concentration at which a gas has the potential to explode is determined by its LEL and UEL. Figure 3-1: Potential Exposure Pathways to Landfill GasFigure 3-1: Potential exposure pathways of LFGTherefore, in order to reduce the potential explosion from landfill gas, controlling method can be applied according to the conditions mentioned above. First of all, the suitable material for landfill cover and transportation pipes should be selected to reduce LFG emission rate. Then the proper operation of collection and treatment systems can also reduce the amount of escaped gas from the landfill. Finally, an effective monitoring method should be used to analyse the components and flammable gas concentration in LFG. 3. 3 Health hazard of landfill gasThere are two main health hazard can be caused by landfill gas: Asphyxiation hazards and odours trigger symptoms. 3. 3. 1 AsphyxiationWhen the oxygen in enclosed spaces (e. g. a basement or utility corridor) is displaced by a certain amount of landfill gas, an oxygen-deficient environment is created, which result in an asphyxiation hazard. According to the definition from Occupational Safety and Health Administration (OSHA), an oxygen-deficient environment as one that has less than 19. 5% oxygen by volume52. The health effects include a faster heartbeat, fatigue, nausea, unconsciousness or even death in minutes53. Because methane and carbon dioxide are colourless, odourless and have high concentrations in landfill gas, the oxygen-deficient environment is not easy to perceive at the beginning. Therefore, health hazards associated with both CH4 and CO2 result from the lack of oxygen rather than direct exposure to these gases. In order to prevent the health hazard caused by landfill gas, the presence of buried utility lines and storm sewers on or adjacent to landfills should be investigated. These structures not only provide a pathway for migration of LFG, but also pose an asphyxiation potential for workers who fail to follow confined space entry procedures prescribed by OSHA. 543. 2. 2 Odours trigger symptomsThe unpleasant odour is another concern related to uncontrolled LFG. Compounds found in LFG are associated with strong, pungent odours. These smells can be transmitted off landfill site to the nearby community that may cause undesirable health effects such as headaches and nausea. Typical sources of landfill odours are sulphides, ammonia and NMOCs, but they can also come from the disposal of certain types of wastes like manures and fermented grains. 55Sulphides- The most common odours from sulphides in

LFG are hydrogen sulphide, dimethyl sulphide and mercaptans and hydrogen sulphide has the highest emission rate and concentrations in landfills56. All of these gases produce a very strong rotten-egg smell-even at a very low concentration. Ammonia- Ammonia is an important compound to maintain plant and animal life, thus, most ammonia in LFG is generated by the decomposition of organic matter in the landfill. But humans are much less sensitive to the odour of ammonia than they are to odours of sulphides and the concentration of ammonia in ambient air at or near a landfill site is expected to be much lower than its odour threshold. 57NMOCs- Some NMOCs, such as hydrocarbons and vinyl chloride may cause unpleasant odours, but the concentrations of them are at trace level. Therefore, it is unlikely to pose a sever odour problem by NMOCs in LFG. 58Table 3-3 Common landfill gas components and their odour thresholds59 Ruth (1986), ComponentOdour descriptionOder threshold (ppb)Hydrogen sulphideStrong rotten-egg smell0. 5 to 1AmmoniaPungent acidic or suffocation odour1, 000 to 5000BenzenePaint-thinner- like odour840DichloroethyleneSweet, ether-like, slightly acrid odour85DichloromenthaneSweet, chloroform-like odour205, 000 to 307, 000EthylbenzeneAromatic odour like benzene90 to 600TolueneAromatic odour like benzene10, 000 to 15, 000TrichloroethyleneSweet, chloroform-like odour21, 400TetrachloroethyleneSweet, ether-or chloroform-like odour50, 000Vinyl ChlorideFaintly sweet odour10, 000 to 20, 000As the description above, the raw landfill gas has various potential dangers which affect the environment and the health of living beings. Thus, in the next section, the treatment method to reduce these issues and energy recovery from LFG will be introduced. 604. Energy recovery from LFGCurrently, various projects are designed to recover energy from LFG. In addition, these energy projects can also capture CH4 to prevent it from being emitted to the atmosphere. In this section, the common technologies and strategies for recovering and using LFG as an energy will be introduced. Specially, the process of generating electricity by using LFG will be emphasized. 4. 1 Methodologies for energy recoveryTo achieve GHGs control and energy generation, there are a number of technologies for converting landfill gas to energy. The technologies include: direct use of LFG, combined heat and power, alternate fuels, and electricity generation. 60 LOCAL GOVERNMENT CLIMATE AND ENERGY STRATEGY GUIDES Landfill Gas Energy4. 1. 1 Direct use of LFGThe direct use of LFG is similar to the use of natural gas, which involves transmitting LFG via pipeline to be combusted and fuel dryers, boilers and kilns. These end users can maximize utilization of landfill gas which just needs limited treatment and can use it mixed with other fuels. Typically, the piping distance from a landfill to its LFG end user is within 5 miles (8. 0 km). Most direct use projects use boilers. In a boiler system, the heat from burning LFG is used to heat the water in a boiler system. Subsequently, the water is transformed into steam and can be used in various applications, for instance, infrared heaters, greenhouses and artisan studios. This is a relatively efficient and simple way to use LFG. 4. 1. 2 Combined heat and power (CHP)CHP is a specific type of using LFG as a fuel source for combined heat and power or cogeneration system that produces both thermal energy and electricity60. Compared with only power production, CHP system is more efficient for utilizing the energy from LFG. In a number of European countries, it is normal to use thermal energy cogenerated by LFG energy projects for on-site heating, cooling, or piped to nearby industrial users to provide a second revenue stream for the project61. The stream of energy is shown in figure 3. Figure 3. Sankey- diagram describing the energy flows of the CHP plants4. 1. 3 Alternate fuelsWhen LFG is used as an alternate fuel, the natural gas quality needs to be met by upgrading process. The main procedure of upgrading LFG is separation CH4 form the CO2 component of LFG and three methods are applied in this process: Chemical absorptionPressure swing absorption (PSA)Membrane separationThe alternate fuels from LFG are usually used as vehicles fuel and pipeline fuel. Vehicle fuel- For vehicle fuel application, CO2 and other trace impurities should be removed from LFG to produce a high-grade fuel that is at least 90% CH4. Subsequently, compressed natural gas (CNG), liquefied natural gas (LNG) or methanol can be produced as vehicle fuel. Currently, only a few number of vehicles using GNG and LNG as fuel around world due to the relatively expensive investment in upgrading system65. However, with growing interest in alternative fuels, demand is expected to increase. Pipeline fuel- Prior to delivering upgrading LFG to the natural gas pipeline system, it is also required that the gas is free from particles and liquid. Furthermore, the gas should be odorized66. Although the separated methane can be sold as high-Btu fuel, the production is much expensive than natural gas. Therefore, to minimize the investment, the ideal landfills for this project are large landfills located near natural gas networks. 674. 1. 4 Electricity generationUpon removal CO2, moisture and most trace compounds, LFG mainly contains CH4 can be used as fuel in internal combustion engines and generate electricity. The whole process of generating electricity from LFG will be introduced in next section. There are a variety of technologies can be used in this process, including internal combustion engines, gas turbines and microturbines.(utilization). TechnologiesEfficiencyCapacityCharacteristicsInternal combustion engine(ICE)25%-35%100 kW ??? 3 MWrelatively high maintenance costs and air emissions (compared to gas turbines)Over 70% landfill electricity projects use. Gas turbines20%-28%800 kW ??? 10. 5 MWEfficiencies drop when operating at partial loadLow maintenance costs and nitrogen oxide emissions (compared to ICE)Requiring more electricity to compress gas which result in efficiency dropMore resistant to corrosive damage than ICE. Microturbines20%-35%30 kW ??? 250 kWGenerate electricity with lower amount of landfill gas than IC engines and gas turbine; Functioning with low methane content (as little as 35%)Less nitrogen oxides emission than ICE; Requiring extensive gas treatment; 4. 2 The process of electricity generation from LFGThe main procedures for generating electricity from LFG include: LFG collection-aspiration; Treatment and analysis; Conversion into electrical energy. Initially, LFG is extracted from landfill by a series of wells and a blower or vacuum system. The path of LFG collection stars at the vertical wells (Figure) and then the gas flows through horizontal piping to an intermediate manifold. From here, the gas is leaded to the treatment area by another pipe. In the treatment area, the gas collected from the body of the landfill undergoes a pretreatment to remove the components which may cause interfere with the aspiration and electrical energy or damage to the equipment. Normally, the pretreatment depends on the ultimate use for the gas. From this point, the gas can be flared to generate electricity or upgraded to pipeline-quality gas. Therefore, to ensure the function efficiency of the system and optimize the energy recovery, a series of filter system and analytic methods are design to purify the collected LFG. 4. 3 LFG treatment system4. 3. 1 Primary treatmentPrimary treatment is the first stage to remove contaminates such as water and particulates in LFG. Typically, it uses simple physical process operations and the technology in this process is a relative standard element in LFG management plants now. [8]The presence of moisture in collected LFG has a detrimental effect on equipment performance. It not only contributes to the pressure loss, but also leads to deposition on the pipe walls, which may make LFG difficult to achieve a steady and controllable operation.[] Thus, the presence of water in LFG should be both controlled and minimized. According to the source and the application or proposed use of the gas, there are two steps to remove particulates and water: Particulates removal- Particles in LFG can be eliminated by a 10000cm2 preliminary filter which consists of a stainless steel filter element with a 1000 micron mesh. Water removal- The dehumidifier system can be used for drying LFG. Water can be condensed via this system which includes a closed water circuit system, a refrigerating and air condensing system. 4. 3. 2 Siloxanes removalSiloxanes are a class of man-made organic compounds that consist of silicon, oxygen and methyl groups (see figure). Structures of D4, D5 and D6Structural formulas of D4, D5 and D6 doi: 10. 1002/ieam. 1299. In the recent 5 years, Siloxanes are increasingly used in the manufacture of personal care products, health care and industrial products. since siloxanes are regarded as environmentally frendlu products, increasing nembers of siloxanes are used to replace chrlorofluorosolvents in dry cleaning industries. Therefore, the waste from these industries is frequently disposed of in landfill sites and volatile methl siloxanes (VMS) are produced. The VMS blending with LFG is pumped into fuel engines. When the gas is combusted in engines, VMS are convert to silicon dioxide, which can deposit in the combustion or even exhaust stages of the equipment. According to the data from(), VMS of cyclic D3, D4, D5 and the linear L2 are the most common siloxanes which will produce silicon dioxide during the flare process. The properties of thhen are list in table???. The effects of VMS in LFGWhen silicon dioxide is produced by gas combustion in the engine, a hard matrix that accumulates on the conbustion surface due to the combination between silicon dioxide and the lubrication oil. Additionally, according to pratical experience from PPtek compeny, severe damage can also occur to positons, piston rings, liners, valves, cylinder heads, spark plugs and turbochargers.(see the picture below) The repiaraion of this damage is costly and necessitating premature servicing. VMS removal technologiesCarbon adsorption-Refrigeration-Advanced refrigeration-Liquid absorption- Selexol, a dimethylether of polyethylene glycol is used as solvent to absorb the siloxanes. According to the current research, about 99% siloxane is removed in a tray tower. Thus, it is considered that liquid absorption may be cost effective for large scale installations. Other liquids such as carbon dioxide are also being tested by researchers. Silica gel- Silica gel may prove to be a better adsorbent than activated carbon, because from the study of Schweigkofler, silica gel has a higher affinity for L2 than carbon70 and can increase 50% removal capacity compared to carbon on LFG. 4. 3. 3 Hydrogen sulphide removalHydrogen sulphide in LFG can reacts with steam to produce shlphiric acid which has a high corrosive effect on the equipment (even in trace quantities) 69. Currently, there are amount of studies focus on the technologies of hydrogen sulphide removal. According to the type of agent, they can be classified into biological, chemical and physical desulphurisation process. Table . A comparison of warious techniques of hydrogen sulphide removal [19]The choice of hydrogen sulphide removal technology can depend on the composition of LFG and the concentration of hydrogen sulphide in the LFG. 4. 3. 4 Other landfill gas contaminatsThe other contaminants such as ammonia, aromatic hydrocarbons, and halogens are usually present in LFG. However, the concentrations of these gases are below the detection level (normally below 0. 1 mg/m3)70. Therefore, it is unnecessary to use any addition treatment system to remove them. 5. ConclusionWisegeehttp://www. epa. gov/lmop/basic-info/index. htmlkhttp://www. dem. ri. gov/programs/benviron/waste/central/lfgfact. pdfhttp://www. nrdc. org/air/energy/lfg/execsum. asphttp://www. epa. gov/lmop/faq/public. html