DESIGN PRINCIPLES AND REGULATORY REQUIREMENT FOR MSW LANDFILL GAS MANAGEMENT SYSTEM IN WESTERN CANADA

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Abstract: Landfill gas management system reduces methane gas emissions and carbon footprints, and minimizes fire and explosion hazards on the landfill property and adjacent areas. This paper discussed the design methods and regulatory framework for landfill gas management systems in British Columbia, Alberta and Saskatchewan. The purpose of this study is to examine the design standards and approaches and to compare the legislative regulations associated with the design and operation of landfill gas management system. The results of literature review suggested that the design principles and regulations are wildly different from province to province. Both British Columbia and Alberta have adopted regulations for landfill gas management. Gas monitoring program and methane gas migration control measures are required in British Columbia and these facilities must be approved by the regulatory agencies. Methane concentration is limited to 12,500 ppm (25% Lower Explosive Limit) in any on or off-site building and 50,000 ppm (100% Lower Explosive Limit) at the property boundary. Similarly, subsurface landfill gas contingency plan is required at Alberta landfills. Lateral migration of methane gas at landfill sites is common due to the properties of local geological materials. Subsurface landfill gas explosive limit is 50% at the property, 20% in an on-site building and 1% in an off-site building. Saskatchewan had adopted a new environmental code (SEC) at the end of 2014. The result-based approach to environmental regulation was used throughout the new SEC. Gas monitoring devices and migration control systems are both required, but specifications on the methane concentrations or explosive limits are not given.

Keywords: Landfill Gas Extraction, Western Canada, Regulatory Requirements

1 INTRODUCTION

According to British Columbia Environmental Management Act, municipal solid waste (MSW) means refuse that generates from residential, commercial, institutional, demolition, land clearing or construction sources, those waste degrades and breaks down into two major bi-products as gas and bio-mass. The bio-mass is retained in the landfill and a portion of the bio-mass with the addition of water forming leachate. Those gases were generated by the decomposition of municipal solid waste, which called landfill gas. Landfill gas is produced as a result of physical, chemical, and microbial processes happening within the waste as most of the waste has organic nature. Due to the organic nature of most waste, it is the microbial processes that direct the gas generation process (Christensen, 1989).

Mature landfill gas is mostly composed of methane (CH_4) and carbon dioxide (CO_2). Since the global warming potential (GWP) of methane is 25 times that of carbon dioxide over the 100-year time horizon (Jayasinghe, et al. 2014), there is a considerable interest to reduce methane emissions in the environment. However, the gas when found in certain concentrations and quantity causes mounding problems as well as the possibilities for explosions with in landfills. Methane gas migration from landfill to adjacent land properties may cause the serious explosions as well.

The purpose of this study is to compare the design methods and regulatory requirements for landfill gas management in British Columbia, Alberta and Saskatchewan. The recent study shows the landfill gas extraction methods which can reduce methane gas emissions in the atmospheric environment, and also compare the regulatory laws to prevent fire and explosion hazards for methane gas migration on the landfill property and adjacent areas.

2 BACKGROUND

Landfill gas is generated by the microbiological decomposition of wastes and chemical reactions between wastes in a landfill. The landfill gas quality also depends on the microbial process, the waste being decomposed and site specific variables such as oxygen accessibility and moisture content (Ham and Barlaz 1989). Short-term studies carried out on full-size landfills, LFG production between 0.05 and 0.40 m^3 of LFG per kilogram of waste placed into a landfill (Ham 1989)

The Maximum probable volume of Landfill gas generation is dependent on the quantity and type of organic content within the waste mass (Environment Canada 1996), since the decomposing organic wastes are the source for all Landfill gas produced. Moisture is the primary limiting factor in the rate of waste decomposition (McBean et al. 1995, Reinhart 1996). The amount of gas produced in landfills is a function of the waste quantity, waste type, and waste age, landfill moisture content, temperature, and management practices at the site. Generally, LFG consists of approximately 50% methane and 50% carbon dioxide. (Cooper et. al. 2009)

The Intergovernmental Panel on Climate Change 2007 defines methane as an important greenhouse gas with a global warming potential 21 times greater than carbon dioxide. Its current contribution potential to global warming is estimated at 15% and continues to escalate (Themelis and Ulloa, 2007). Methane released into the atmosphere by natural and anthropogenic emissions. According to Khalil (2000), Figure 1a shows the anthropogenic emission sources include agriculture, waste disposal, and fossil fuels extraction, biomass burning, animal and human wastes in the world and Figure 1b shows the natural methane emissions which includes wet lands, termites, oceans and others.

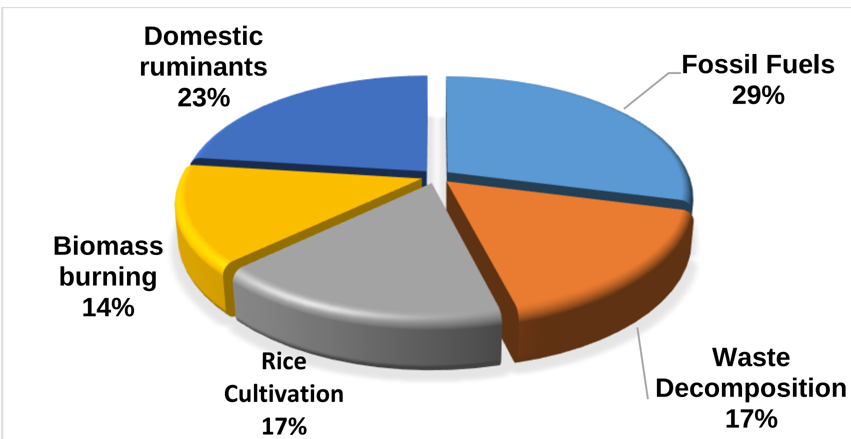

Figure1a. Anthropogenic methane emissions (Data from Khalil, 2000)

Based on recent estimates, current human-related biogenic and fossil fuel-related sources for methane are approximately 275 and 100 tgch$_4$/year, while total natural sources are around 160 tg CH_4/year. (IPCC 1996). Landfill is considered the fourth largest anthropogenic source of CH_4 worldwide. It contributes 20–70 Tg of CH_4 to annual global CH_4 emissions (Boeckx et al.1996)

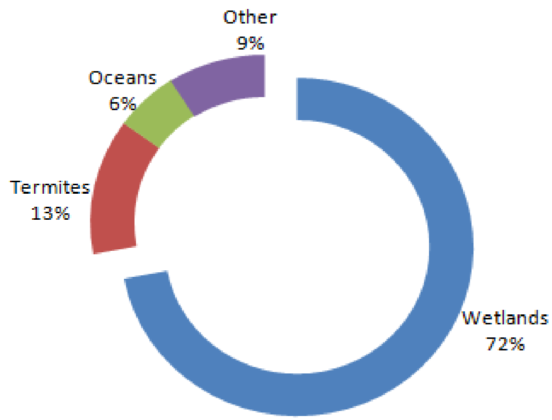

Figure 1b. Natural methane emissions (Data from Khalil, 2000)

The landfill gas lateral migration form landfill site to adjacent land property which may result in serious safety and health hazards. Two mechanisms are necessary for gas migration those are the pressure gradients and diffusion processes. Landfill gas migrates from the refuse through soil surfaces into adjacent areas which produced explosions and may have resulted in extensive property damage and, in some cases, loss of fire (Moore et al. 1979). An explosion hazard advanced when methane migrates from a landfill and mixes with air in a confined space. Table 1 shows some landfill gas explosion accidents were happened in different landfill sites and landfill adjacent property as well**.**

Table 1. Landfill gas explosions or accidents happened in many different places

Accidents time and place	Description	Sources
Skellingsted Landfill, Denmark, 1995	The fire explosion happened in the houses of landfill adjacent property due to lateral migration of landfill gases	kjeldsen, Peter; Fischer, Erling V (1995) Landfill Gas Migration—Field Investgation At Skellingsted Landfill, Denmark. Waste Management & Reseach 13.5 (1995): 467-484.
Wellington, New Zealand, 1998	Three neighbouring factories from Wellington Landfill were evacuated and several streets were closed off.	Evacuation follows gas explosion, New Zealand Press Association, April 30, 1998.
Istanbul, Turkey, 1993	18 killed in landfill gas explosion series	St. Petersburg Times, April 29, 1993, 13.A
Toronto, Canada, 1966 and 1969	A garage in Toronto, Canada situated near a former dump site exploded twice	Mc Bean, E et al. 1995
Kitchner, Canada, in 1969.	Explosions took place in two houses in the vicinity of a 12-year-old dump site	Mc Bean, E et al. 1995
Montreal, Quebec, 1969	Longeuil parking lot was paved over a former dump site during the World's Fair in1969. Workmen were found setting fire to gas escaping through cracks in the pavement to heat their lunch.	Mc Bean, E et al. 1995

Table 1 indicated that a number of accidents were happened in many different places for methane gas explosion in landfill sites and landfill adjacent properties.

3 DISCUSSION

A review of Alberta, British Columbia and Saskatchewan legislation and related literature was conducted. Landfill gas extraction design codes are compared. This paper only studied for Municipal Solid Waste regulatory requirements for landfill gas extraction systems .This paper reviews the regulations for methane gas management strategies and monitoring programs specific to landfill properties and landfill adjacent properties.The regulatory frameworks have shown below in Table 2 for three different provinces (e.g. Saskatchewan, British Columbia and Alberta) in western Canada.

Table 2. Summary of Regulatory Framework on MSW landfill gas management for Saskatchewan, British Columbia, and Alberta

Province	Key Highlights	List of codes and guidelines
Saskatchewan (SEC-2015)	▪ Gas monitoring devices to reduce adverse effects ▪ Gas migration control systems ▪ Gas Collection systems	Landfill Chapter, Chapter E.1.1 Saskatchewan Environmental Code (SEC) (Part 3-6) under the Environmental Management and Protection Act, 2010. http://www.environment.gov.sk.ca/Default.aspx?DN=3498650f-a7f8-49d8-b8a7-a2fc8a1423a1
British Columbia greenhouse gas reduction (Emissions Standards) statutes amendment Act - Jan 2009	▪ Managing migration of LFG; ▪ Operation of LFG management facilities; ▪ Landfill gas collection equipment; ▪ LFG flaring equipment; ▪ LFG management facilities maintenance; ▪ LFG generation assessment Guideline ▪ LFG generation assessment modeling ▪ Landfill gas generation assessment calculation procedure ▪ Landfill gas explosive limits	The British Columbia Environmental Management Act, SBC 2003, Chapter 23, approved by October 23, 2003. British Columbia Landfill Gas Management Regulation, Order in Council No. 903, Ordered and Approved December 8, 2008. Landfill Gas Generation Assessment Procedure Guidelines, March 2009. This document is prepared according to Section 4: Landfill Gas Management Regulation, Ministry of Environment, British Columbia Section 6.4 http://www.env.gov.bc.ca/epd/codes/landfill_gas/index.htm www.bclaws.ca/.../05_regulations/28_391_2008.xml - 45k - 2015-02-19 http://www.env.gov.bc.ca/epd/codes/landfill_gas/pdf/lg-reg-12-08.pdf
Alberta Waste control regulations – Sept 1993	▪ Develop, maintain and implement an operations plan for the management of landfill gas, which may include detection, interception, venting and recovery; ▪ Landfill gas explosive limits ▪ (Class II landfills only)	Guidance Document on Management of methane Gas Adjacent to Landfills; December, 1999. Standards for Landfills in Alberta, February, 2010 (Section 3.1), Government of Alberta. Section 5.11: Subsurface Landfill Gas Monitoring Program. Section 5.12:Implementation of the Subsurface Landfill Gas Contigency Plan. http://environment.gov.ab.ca/info/library/7: Code of Practice for Landfills, Waste Control Regulation (A.R. 192/96) section 36: Environmental protection and Enhancement Act. Alberta Government.

Saskatchewan's regulatory bodies give priority to gas monitoring devices, gas collection systems, and gas migration control systems to provide adequate control and management of surface emissions and subsurface migration of landfill gases.

British Columbia has more regulatory requirements than Alberta and Saskatchewan (Table 2). According to British Columbia's regulations, the regulatory body must fulfill requirements such as controlling the migration of landfill gas, an operation plan for LFG management facilities, LFG collection and storing equipment, LFG flaring equipment, LFG management facilities maintenance. The operation plan must include the total number of days per year that the LFG management facilities may be shut down. However, LFG generation assessment guidelines, LFG generation assessment modeling, landfill gas generation assessment calculation procedure, and landfill gas explosive limits are the necessary information to provide the director as set out in the British Columbia Landfill Gas Management Regulations (2008).

The Government of Alberta has regulatory requirements to develop, maintain, and implement a landfill gas management operation plan for the detection and management of subsurface landfill gas. Alberta's government has regulations for landfill gas explosive limits as well.

Table 3. Requirements on landfill gas management systems in Western Canada

Landfill gas Management tools	British Columbia	Alberta	Saskatchewan
LFG generation assessment guidelines	LFG generation assessment is provided	N/A	N/A
LFG generation assessment modeling	LFG generation assessment modeling is provided	Specific information not provided	Specific information not provided
LFG generation assessment calculation procedure	LFG generation calculation procedure provided.	Specific information not provided	Specific information not provided

Table 3 illustrates the landfill gas management systems for the three different provinces. According to BC regulations, landfill gas generation assessment guidelines, landfill gas generation assessment modeling, and a landfill gas generation assessment calculation procedure are the necessary factors for managing landfill gas. Saskatchewan and Alberta regulatory bodies do not mention landfill gas generation assessment guidelines, or an assessment modeling and calculation procedure.

Table 4. Required components in landfill gas management operation plan

Operation plan	British Columbia	Alberta	Saskatchewan
Landfill gas management	Detailed LFG operational plan “accepted design plan” for all landfill gas management facilities	LFG management plan includes detection, interception, venting and recovery systems	LFG migration control systems includes barriers and venting system
Landfill gas contingency	Detailed landfill gas contingency plan for emergency	Subsurface landfill gas contingency plan only	No explicit requirements for LFG contingency plan

In BC, the LFG generation assessment Guideline was prepared to estimate annual methane gas generation in accordance with the BC Landfill gas Management Regulation, approved and ordered on December 8, 2008.

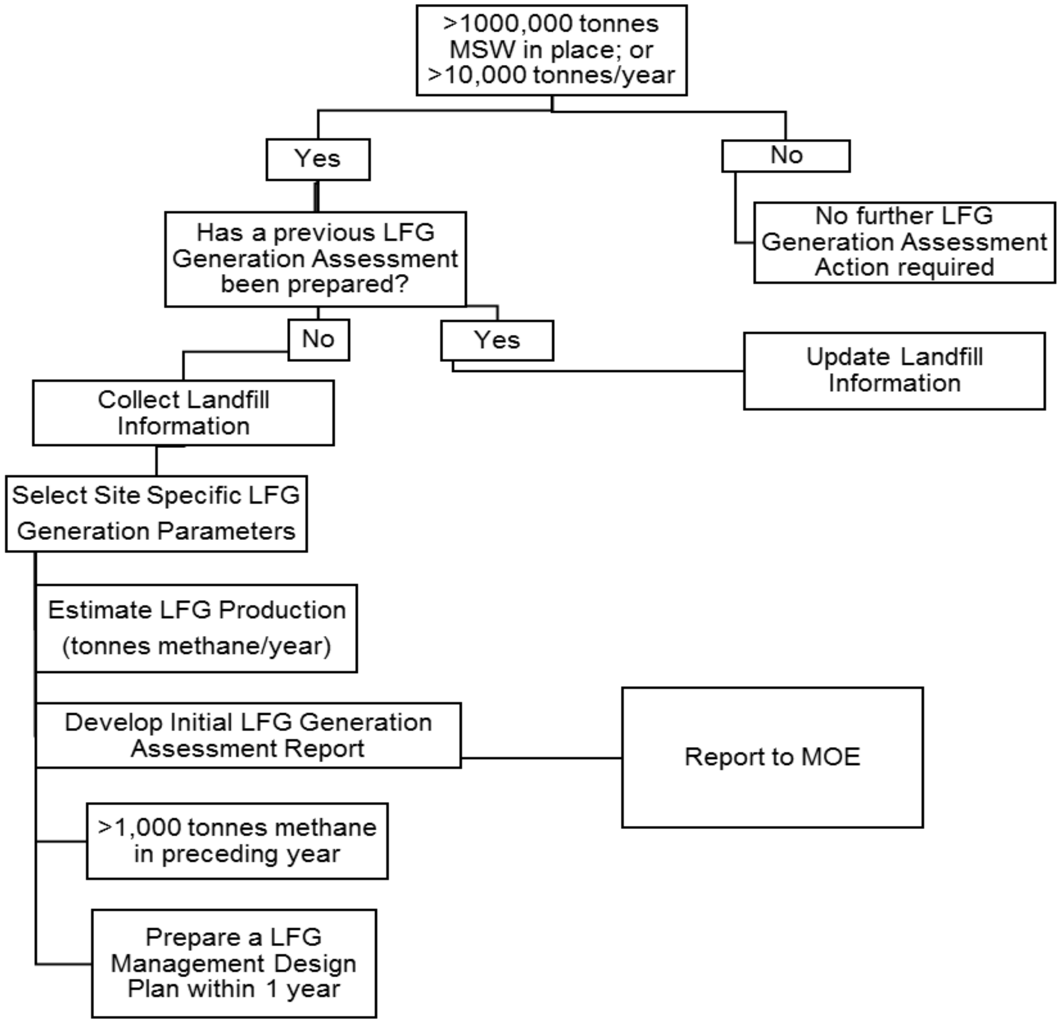

Figure 2. Flow Chart for LFG Generation Assessment Procedure (British Columbia ministry of environment)

Figure 2 shows the LFG Generation Assessment Procedure in British Columbia. The procedure depends on waste generation tonnages, or the amount of waste placed in the landfill. If the waste quantity is more than 100,000 tonnes, or 10,000 tonnes/year, then a Landfill Gas Generation Assessment should be prepared. Otherwise, it is not necessary to follow the LFG Generation Assessment Guidelines, or the procedure. The BC Ministry of Environment provided the Landfill Gas Generation Assessment Procedure Guidelines (March 2009) for landfill designers. In British Columbia, the Landfill Gas Generation Assessment calculation procedure is explicitly stated. Calculations must be provided to the regulatory agencies. The parameters used in the BC gas generation assessment include historical and projected waste quantities (i.e. tonnage estimates), waste characteristics (i.e. waste types and engineering properties), meteorological data (i.e. average annual precipitation), water addition factor information, etc.

Landfill gas generation assessment models are widely used by designers to predict gas generation during and after the operation period of landfills. Some popular models include Palos Verdes Kinetic Model, Sheldon Arleta Kinetic Model, Landfill Odor Characterization Model, EMCON Methane Generation Model UCF LFGGEN, EPA LandGEM and Scholl Canyon Model. The latter is adopted by the British Columbia regulation agencies. Scholl Canyon Model is a first order kinetic model:

$$Q_{CH_{4i}} = k \cdot L_0 \cdot m_i \cdot e^{-kt}$$

Where, Q_{CH4i} = methane produced in year i from the i[th] section of waste
k = methane generation constant
L_o = methane generation potential
m_i =waste mass disposed of in year i
t_i = years after closure

Scholl Canyon Model assumes a standard LFG composition. Site specific parameters are required, such as waste categorization; methane generation constant, LFG generation potential and water addition factor. According to BC's regulations, if a landfill site generates 1000 tonnes or more of methane in one calendar year, a landfill gas management facilities design plan must be prepared for the landfill site. This plan must include a landfill gas contingency plan for emergency maintenance, which must not exceed the landfill explosive limits. On the contrary, the Saskatchewan Environmental Code's (SEC) result-based regulations, implemented in 2015, do not explicitly require landfill gas contingency plans for emergency.

Alberta's regulations require both a landfill gas management operation plan, and a landfill gas contingency plan in case of emergency. The subsurface landfill gas management operation plan must include the following information: a detailed description of landfill gas monitoring sites and their locations; the lateral migration of subsurface landfill gas measurement and detection methods; the measurement frequency of subsurface landfill gas; and the Gas Contingency Plan for the mitigation of subsurface landfill gas migration.

The subsurface landfill Gas Monitoring Program data must be examined by professional engineers or the professionals authorized by the landfill director, as stated in the Standards for Landfills in Alberta, in section 5.5. The numbers stated in the subsurface landfill gas contingency plan shall not exceed the landfill gas explosive limits as described by the regulations.

Lower Explosive Limits (LEL) denotes the lowest percentage of an explosive vapour or gas by volume which must be present in air to ignite. Landfill gas explosive limits are 50% at the property boundary according to BC and Alberta's regulations. In an on-site building, enclosed structure, or in the area immediately outside the foundation of the building or structure, lower explosive limits are 25% for BC regulations, and 20% for Alberta regulations. In an off-site building, enclosed structure, or the area immediately outside the foundation of the building or structure, lower explosive limits are 25% for BC regulations, and 1% for Alberta regulations. These values are reported in Figure 3. Saskatchewan's regulations are omitted since they do not have LEL or methane concentration limit regulations.

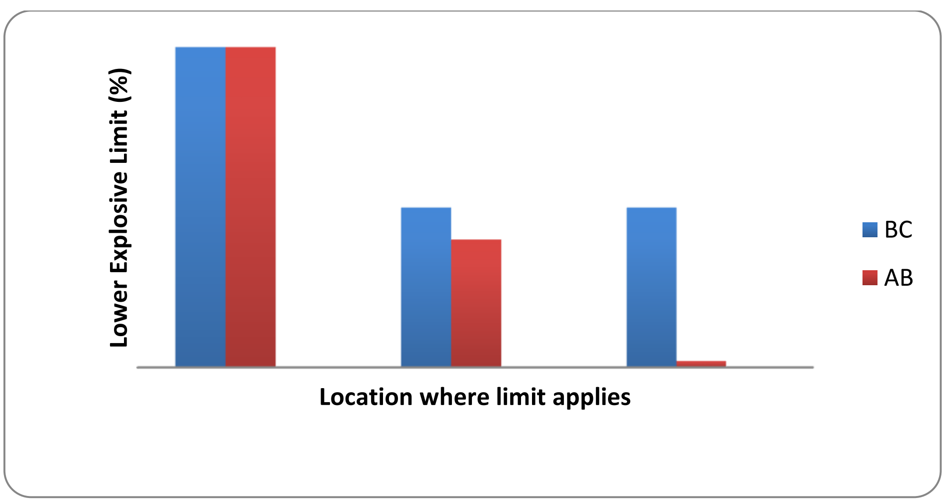

Figure 3. Subsurface Landfill Gas Explosive Limits

According to Alberta's regulations, if at any time throughout the active landfill life, final landfill closure, and until the end of the post-closure period, if the gas explosive limits are exceeded, the responsible party must inform the director immediately. Afterward, they must implement the Subsurface Landfill Gas Contingency Plan which was previously developed in accordance with regulations.

4 CONCLUSIONS

This paper discusses various landfill gas management systems in three Canadian Western provinces: British Columbia, Alberta, and Saskatchewan. The results from this study show that only British Columbia and Alberta have landfill gas monitoring systems, and a landfill contingency plan, while Saskatchewan's regulations do not have explicit requirements on monitoring systems and landfill gas contingency plans under the newly implemented Saskatchewan Environmental Code. Also, British Columbia has more regulations for landfill gas management, specifically (i) landfill gas generation assessment guidelines; (ii) landfill gas generation assessment modeling; and (iii) landfill gas calculation procedures. According to BC legislation, the methane concentration limit is 50% LEL (Lower Explosive Limit) at the property line, and 12,500 ppm (25% Lower Explosive Limit) in any on-site or off-site building. If this regulatory limit is exceeded, the regulatory body must take action. Landfill owners must have gas monitoring programs and methane gas migration control measures, which need to be approved by BC Environment authorities.

In Alberta, lateral migration of methane is high because many areas of the province have highly permeable soils, such as sand, gravel, and fractured clay till. They have a subsurface landfill gas contingency plan. The subsurface landfill gas explosive limit at the site property line is 50%. Within on-site buildings, the limit is 20%, while the limit in off-site buildings is 1%. On the other hand, there are only two design specifications required under Saskatchewan landfill regulations. One is gas monitoring devices, and the other is a gas migration control system. The general design principles of various landfill gas components are provided. The regulations do not mention specific methane concentration, or gas explosive limits. It is found that detailed information regarding the design and operation of the landfill gas management system is missing.

5 RECOMMENDATIONS

The following items are suggested to the regulatory authorities in Saskatchewan on the management of landfill gas: Saskatchewan regulations need to be reviewed, and adjustments are required for landfill gas monitoring systems; emergency landfill gas contingency plans should be mandated; Saskatchewan regulations need to include landfill methane concentration limits or landfill gas explosive limits in order to prevent methane explosions/fires on-site.

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