Landfill Gas-to-Energy
Evaluating the Level of Risk from Formaldehyde Emissions

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A brief discussion of the associated health risks from long- and short-term exposure to formaldehyde emissions from landfill gas-to-energy.

Landfill gas (LFG) can be used beneficially to fuel landfill gas-to-energy (LFGTE) engines that produce electricity, which offsets greenhouse gas (GHG) emissions from fossil-fuel electric generation. However, increasingly stringent air quality standards are making it difficult to permit and operate LFGTE engines. The combustion of LFG creates byproducts such as carbon monoxide, nitrous oxides, sulfur dioxide, particulate matter, and other hazardous air pollutants such as formaldehyde. Probably best known as an indoor air toxin that off-gases from new building materials and wood products, formaldehyde is also ubiquitous at trace levels in outdoor air due to its emission from the combustion of hydrocarbon-based fuels, natural emissions from vegetation, and formation in atmospheric chemistry.[1]

While there is a small amount of formaldehyde present in LFG, it is the combustion byproducts from LFGTE engines that generally represent the larger source of formaldehyde emissions, particularly if the LFG is not "cleaned" prior to combustion (i.e., reduction of siloxane concentrations) and/or the engine is not properly maintained. As these formaldehyde emissions are exhausted to the atmosphere, the incremental concentrations of formaldehyde that result in ambient air depend on a variety of factors that influence dispersion and dilution, including stack height, exhaust temperature and velocity, and meteorological conditions. Available post-combustion controls for formaldehyde such as catalytic oxidation are costly and not yet well proven.

LFGTE engine emissions of formaldehyde can be of regulatory significance. A 1.6-MWe engine has potential formaldehyde emissions of 8.7 tons/year at a typical engine emission guarantee of 0.42 g/bhp-hr, and hence multi-engine installations, or even a single engine that is poorly maintained, can easily exceed the major-source emissions threshold of 10 tons/year for a regulated hazardous air pollutant (HAP).

Moreover, combined with low stack heights, potential emissions of a typical LFTGE installation can lead to exceedances of stringent air toxics standards. As illustrated in Table 1, many state-specific standards/guidelines are below typical background concentrations in ambient air, which are on the order of a few µg/m³.[2] An *EM* article published in 2017 described the inability of a LFGTE engine to demonstrate compliance with formaldehyde ambient air standards.[3] In this article, we demonstrate how a site-specific health risk assessment can be used as an alternate method of compliance demonstration. First, an overview is provided of acceptable techniques for conservatively assessing health risks associated with formaldehyde emissions from LFGTE facilities. Then, a case study is presented that illustrates how these risk assessment techniques can be successfully applied as an alternate means of compliance demonstration. The alternative approach entails back-calculating the maximum permissible emission rate of

formaldehyde from a LFGTE facility that results in acceptably-low health risks.

One of the challenges associated with formaldehyde is the need to address both long-term and short-term exposures, for which potential health concerns differ. We provide a brief discussion of risk assessment equations, then follow with a case-specific example of using risk assessment and air dispersion modeling in a "backwards mode" to derive facility-specific allowable emissions of formaldehyde.

Long-Term Exposures

The additional chance of getting cancer is one type of risk relevant to formaldehyde emissions from LFGTE engines. Formaldehyde is recognized by the U.S. Environmental Protection Agency (EPA) as a probable human carcinogen after long-term exposure to it. Potential health risks due to long-term formaldehyde exposure are estimated according to standard EPA methods adapted from the National Air Toxics Assessment[2] and regional screening level spreadsheets for air/inhalation exposure.[4]

Long-term estimates of the formaldehyde concentration in the ambient air, C_{Long} are typically based on use of the maximum, projected annual (1-year) impact as a conservative representation of the chronic, cumulative exposure over an extended period of time. For assessing long-term health impacts, the incremental (increased) risk of contracting cancer is used as the critical health "endpoint" (health effect). Incremental cancer risk due to potential exposure to LFGTE engine emissions can be calculated as:

$$ILCR = C_{Long} \times f_{Life} \times IUR$$

where the terms are:

ILCR   Incremental lifetime cancer risk (unit less probability);

C_{Long} Highest annual-average concentration of formaldehyde in air (µg/m³) due to engine emissions based on air dispersion modeling;

f_{Life} Fraction of a human lifetime over which exposure occurs; and

IUR   Inhalation unit risk factor (m³/µg).

By assigning values to the target maximum *ILCR*, f_{Life}, and *IUR*, we can solve the above equation for C_{Long} and target that value as the maximum allowable concentration during air dispersion modeling. EPA's current *IUR* is 1.3×10^{-5} m³/µg.[5] A representative site-specific value for f_{Life}, is 0.429, based on an average lifetime of 70 years and an assumed exposure period of 30 years (both an upper-end estimate of the length of time an individual remains at a single residence and a reasonable high-end estimate of the period that LFGTE engines might operate).[4] The choice of the *ILCR* reflects the degree of

Table 1. Formaldehyde Toxicity: Concentrations of Concern.

Regulatory Authority	Risk-Based Concentration of Concern ($\mu g/m^3$)		
	Acute (≤1-hr)	Short-Term (≤8-24 hr)	Chronic ≤1-yr
EPA Acute Exposure Guideline (AEGL-1)[1] and Regional Screening Levels (RSLs)[2]	1,100	n/a	0.22 (cancer)
			10 (non-cancer)
California Reference Exposure Levels (RELs)[3]	55	9	9
ATSDR Minimum Risk Levels (MRLs)[4]	49	37	9.8
OSHA Short-Term Exposure Limit (STEL) and Permissible Exposure Limit (PEL)[5]	2,460	n/a	920
New Hampshire Ambient Air Limit (AALs)[6]	n/a	1.3	0.88
Louisiana Toxic Air Pollutant Ambient Air Standard[7]	n/a	n/a	7.69
Massachusetts Allowable Ambient Limit and Threshold Effects Exposure Level[8]	n/a	2	0.08

Sources

1. U.S. Environmental Protection Agency (EPA)'s Compiled Acute Exposure Guideline (AEGL) Update, July 27, 2018.
2. EPA's Regional Screening Level (RSL) Resident Ambient Air Table, May 2018.
3. California Office of Environmental Health Hazard Assessment (OEHHA) Acute, 8-hr and Chronic Reference Exposure Level (REL) Summary, June 28, 2016; https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary.
4. Agency for Toxic Substances and Disease Registry (ATSDR); https://www.atsdr.cdc.gov/mrls/mrllist.asp. *Note:* ATSDR defines acute exposure as 1-14 days, short-term (intermediate) exposure as 15-364 days, and chronic exposure as ≥ 1 year.
5. 29 CFR 1910.1048.
6. New Hampshire Code of Administrative Rules, Part Env-A 1450.01, Table of all Regulated Toxic Air Pollutants.
7. Louisiana Environmental Regulatory Code, April 2014, Title 33, Part III, Section 5112, Table 51.2.
8. Massachusetts Allowable Ambient Limits and Threshold Effects Exposure Levels; https://www.mass.gov/service details/massdep-ambient-air-toxics-guidelines.

desired protection. Many state air toxics standards are based on an allowable incremental risk of 1 in a million, but in site-specific applications, higher permissible risks of 10 to 100 per million may be acceptable. For perspective, these risks add to a person's overall chance of death from cancer, which is currently about 1 in 4, or 250,000 per million.

Short-Term Exposures

Short-term exposures to formaldehyde may cause irritation to the eyes, nose, throat, and skin in addition to exacerbating health issues for people with underlying conditions such as asthma. Problematically, there is no uniform agreement on the appropriate exposure period to consider. Therefore, short-term impacts over 1-hour and 24-hours (typical of a number of state-specific air toxic standards) are examined for evaluating non-cancer respiratory irritation effects. In correspondence with dispersion modeling, short-term concentration estimates C_{Short} are based on the maximum predicted 1-hr daily and 24-hr impact concentrations.

The potential for adverse non-cancer health effects is characterized through the calculation of a hazard quotient. Because respiratory irritation (the key health endpoint for formaldehyde) can occur over short periods, risk is evaluated on a short-term (sub-chronic) basis assuming continuous exposure.

The hazard quotient is calculated as:

$$HQ_{Short} = \frac{C_{Short}}{C_{Ref}}$$

where the terms are:

HQ_{Short} Non-cancer hazard quotient (dimensionless);

C_{Short} Maximum short-term 1-hr or 24-hr average concentration of formaldehyde in air ($\mu g/m^3$) due to engine emissions based on air dispersion modeling; and

C_{Ref} Concentration of formaldehyde that can be safely breathed ($\mu g/m^3$) for periods of either 1 hr or 24 hr.

The short-term reference concentration (C_{Ref}) is intended to connote a "safe" exposure level, and often embodies a margin of safety placed there by a regulatory agency. This provides a greater level of confidence that a target hazard quotient (HQ_{Short}) of 1 will not result in adverse health effects.

The value to choose for C_{Ref} in the framework of risk assessment is challenging because there is no shared threshold value accepted by all regulatory agencies. The following are examples of candidates for formaldehyde C_{Ref}:

- For the 1-hr averaging period, the California Office of Environmental Health Hazard Assessment's (CA OEHHA's) Reference Exposure Level (REL) is 55 µg/m³;

- CA OEHHA's REL of 9 µg/m³ applies to both 8-hr and annual periods, and hence is an appropriate value (C_{Ref}) for the 24-hr averaging period; and

Interestingly, CA OEHHA's REL of 9 µg/m3 is similar to the chronic Minimum Risk Level (MRL) of 9.8 µg/m3 derived by the Agency for Toxic Substances and Disease Registry6 for evaluating long-term exposure of a year or longer. The ATSDR MRL for acute exposure from 1 to 14 days duration is 49 µg/m3, and the MRL for intermediate exposure from 15 days to 364 days is and 37 µg/m3. These values are similar in magnitude to CA OEHHA's acute 1-hr REL, emphasizing the conservative/protective bias inherent to deriving CRef values.

Both the 24-hr REL of 9 µg/m³ and the chronic MRL of 9.8 µg/m³ were derived from a study of furniture workers exposed to characteristically high levels of formaldehyde.[6] That study showed that an exposure of 294 µg/m³ of formaldehyde in factory air over a period of about 10 years was sufficient to cause clinical symptoms of mild irritation of the eyes and upper respiratory tract and mild damage to certain nasal tissue. Hence, the margin of safety between the concentrations that was found to cause mild respiratory effects (294 µg/m³) and the REL or MRL (9 or 9.8 µg/m³) is about 30. The lowest concentration of 294 µg/m³ found in the factory

study to cause observable adverse effects is considerably greater than the concentrations of formaldehyde typically found in ambient air, inclusive of local increases due to emissions from LFGTE engines.

Case Study Example

Given worst-case maximum concentrations from air dispersion modeling, the long- and short-term framework equations will provide quantitative estimates of risk. However, the equations can be recast to solve for the maximum concentrations of formaldehyde allowable to meet given target, maximum risk levels. Then, working backward, air dispersion modeling is used to calculate the maximum allowable emission rates of formaldehyde that correspond to the allowable, risk-based concentrations.

As a case study example, a two-engine LFGTE facility was required by the state regulatory air agency to demonstrate compliance with state ambient air limits for formaldehyde as part of an air permit renewal application. Similar to the previous case study cited above,[3] this air dispersion modeling study demonstrated that at the formaldehyde emission rate guaranteed by the engine manufacturer, the stringent 1-hr, 24-hr, and annual ambient air limits could not be met. Therefore, the risk assessment approach equations described above, linked to the facility-specific air dispersion modeling study, were implemented to back-calculate the allowable, case-specific, risk-based emission factors:

- **Long-Term Cancer Risk:** Based on a target maximum *ILCR* of 10⁻⁵ (incremental lifetime cancer risk of 10 per million) and parameters described above, the equation for *ILCR* was solved to yield the concentration C_{Long} of 1.79 µg/m³, which from the dispersion modeling, corresponded to a formaldehyde emission factor of 1.34 g/bhp-hr. Hence, limiting emissions to this value would keep the incremental cancer risk below the regulatory "acceptable" level of 10 chances per million.

- **Short-Term Irritation Risk:** Based on a target maxi-
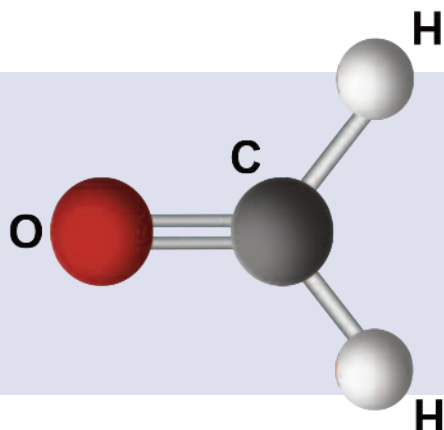
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mum short-term hazard quotient HQ_{Short} of 1, the short-term reference concentrations C_{Ref}, of 55 µg/m³ (1-hr) and 9.8 µg/m³ (24-hr), when used as the critical values of C_{short} in the dispersion modeling analysis, corresponded to formaldehyde emission factors of 0.60 g/bhp-hr and 0.42 g/bh-hr, respectively. Limiting emissions to these 1-hr and 24-hr values would result in acceptably-low risks of irritation health effects from short-term exposure.

The lowest of the emission rates that meet all of the three risk scenarios addressed above is 0.42 g/bhp-hr. Therefore, this value is the limiting formaldehyde risk-based emission factor. Facility-specific stack testing, as well as test results from similar engines, indicate formaldehyde emissions of the order of 0.3 g/bhp-hr. Hence, based on typical engine performance, the site-specific evaluation indicates no significant risks to health for residents living around the landfill and LFGTE facility, and no additional permit requirements for formaldehyde were deemed necessary. The site-specific risk assessment approach as an alternate compliance method allowed for the use of less conservative, though still highly protective, assumptions. Meeting the state-specific air standards would have demanded a formaldehyde emission factor limit of 0.03 g/bhp-hr, which would have required costly post-combustion emission controls that may not have been operationally sustainable.

Conclusion

Formaldehyde is a regulated HAP that is ubiquitous in trace levels in outdoor air. Formaldehyde is of concern because it is a probable human carcinogen and is also known to cause irritation-related health effects with sufficient short-term exposure. Formaldehyde emitted by LFGTE engines can be significant and lead to exceedances of stringent state air toxics standards set for this pollutant. In fact, ambient background levels alone sometimes exceed those state standards. At LFGTE facilities where the formaldehyde emissions impacts would exceed the allowable state standards, a site-specific health risk assessment may be useful as an alternate method for compliance demonstration. **em**

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References

1. Zemba, S.; Damiano, L.; Little, H.; Doris, J.; Estabrooks, M. Formaldehyde—A Leading Air Toxic; *EM Magazine*, January 2019.
2. 2011 National Air Toxics Assessment; U.S. Environmental Protection Agency, 2015; http://www.epa.gov/national-air-toxics-assessment/2011-national-air-toxics-assessment (accessed January and February 2016).
3. Damiano, L.; Zemba, S. What's the Best Way to manage Landfill Gas?; *EM Magazine*, March 2017.
4. Regional Screening Levels, default assumptions; U.S. Environmental Protection Agency, 2017; http://www.epa.gov/risk/regional-screening-levels-rsls (accessed September 2017).
5. Integrated Risk Information System (IRIS); U.S. Environmental Protection Agency, 2017; http://www.epa.gov/iris (accessed September 2017).
6. Toxicological Profile for Formaldehyde; Agency for Toxic Substances and Disease Registry (ATSDR), Atlanta, GA: 1999; https://www.atsdr.cdc.gov/toxprofiles/tp111.pdf (accessed November 2018).

In Next Month's Issue...

Short-Lived Climate Pollutants

Some short-lived climate pollutants (SLCPs), such as methane, are more-or-less covered by agreements that aim to reduce greenhouse gases (e.g., the Paris Accord); others, like black carbon, are left out because they are particles and not gases. SLCPs stay in the atmosphere for much shorter periods than long-lived climate pollutants like carbon dioxide (CO2), but pound-for-pound, they warm the atmosphere much more than CO2. The upside is that reducing SLCP emissions has a more immediate climate benefit than reducing CO2 emissions alone. This issue will identify sources of SLCPs and discuss how they are controlled and what can be done to better address their impacts.