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Air Emissions from Non-Hazardous Waste Landfills – Update of 2013 Literature Review

Prepared for: EPA Victoria and the Department of Health and Human Services (DHHS)

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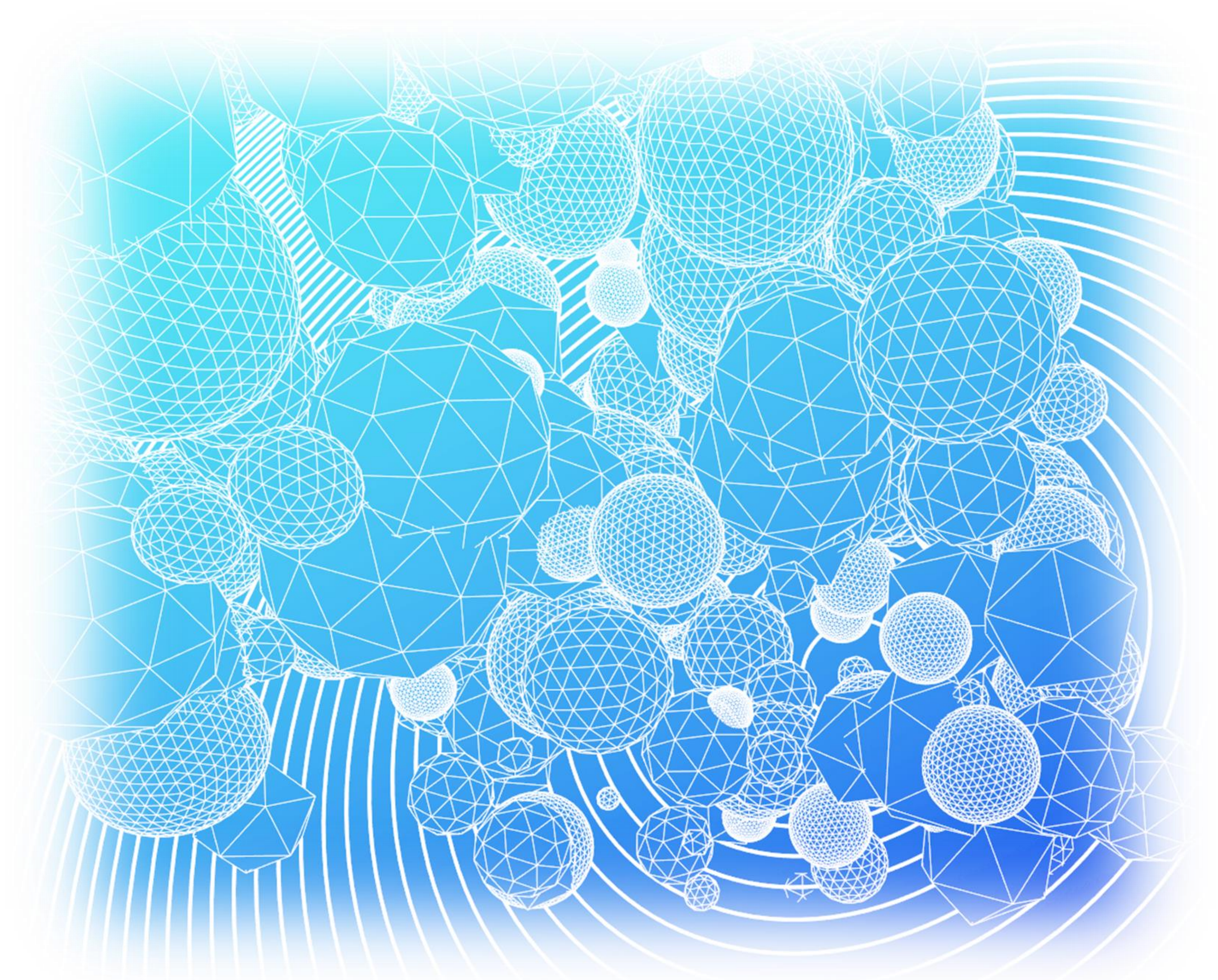

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Limitations

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Executive Summary

Introduction

Environmental Risk Sciences Pty Ltd (enRiskS) has been commissioned by EPA Victoria and the Department of Health and Human Services (DHHS) to update a literature review of national and international research into emissions to air from non-hazardous waste landfills.

In 2013, RMIT completed a literature review to characterise gaseous emissions from non-hazardous waste landfills, and to determine whether there were any reported links between air emissions and the health of residents living near these landfills.

This report has been prepared to provide an update of the available data and studies since the RMIT literature review was completed. This review considered a wide range of data on gases and VOCs that may be derived from non-hazardous waste landfills, the concentrations that may be present in air within adjacent communities, and if these have the potential to be of concern to human health. The review has also critically evaluated published studies, available to 2016, related to evaluating potential links between living near non-hazardous waste landfills and health effects, including the study published by Mataloni et al (2016).

Conclusions

This review has confirmed the findings of the RMIT (2013) review, that the available data and published studies does not show that living near a non-hazardous waste landfill is associated with adverse health effects. It is acknowledged that a number gases and VOCs (individually or as a mixture) released from non-hazardous waste landfills may be odorous and may affect the well-being of the local community.

Recommendations

Given the limited amount of data available that specifically relates to Australian landfills, it is recommended that additional data be collected from Victorian non-hazardous waste landfills to support the conclusions presented in this review. The monitoring program should include the following:

- Collection of ambient air data on landfill sites, near active tipping and handling areas and in covered/closed areas;
- Collection of ambient air data from the boundary and off-site community;
- Data collection protocols should not only target short-term sampling commonly associated with odour events, it should also include data from the closest community areas sampled over a longer period of time (i.e. multiple week sampling times, or repeated 24-hour or longer sampling events) to enable acute or chronic health risk issues to be assessed;
- The air sampling program should also include background air sampling (i.e. from the community but well away from the landfill) and record details on other sources of air emissions in the area (e.g. industry, vehicle traffic, rail etc.).
- The sampling should to target the following gases and VOCs in air:
  - Aldehydes
  - Aromatic hydrocarbons
  - Chlorinated hydrocarbons

- Organosulfur compounds
- Ammonia
- Cyclohexyl isocyanate and cyclohexyl isothiocyanate

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Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been commissioned by EPA Victoria and the Department of Health and Human Services (DHHS) to update a literature review of national and international research into emissions to air from non-hazardous waste landfills.

The literature review was completed by RMIT in 2013 to characterise gaseous emissions from non-hazardous waste landfills, and to determine whether there were any reported links between air emissions and the health of residents living near these landfills. The RMIT review was based on the data and studies available to 2013.

This report has been prepared to provide an update of the available data and studies relevant to the assessment of potential human health effects in local communities that may be associated with emissions to air from non-hazardous waste landfills.

1.2 Objectives

The overall objective of the review is to compile and produce an updated review of the scientific literature on potential health effects in local communities associated with air emissions from non-hazardous waste landfills.

More specifically the project aims to:

1. Identify compounds that are found in the air in the vicinity of non-hazardous waste landfills.
2. Examine the published literature of studies investigating the health of residents living near such landfills and any association with air emissions.
3. Critically review the literature and clearly articulate the potential human health risks posed by air emissions arising from non-hazardous waste landfills in a manner that is readily understood by communities and decision-makers.
4. Develop recommendations for monitoring parameters, including the identification of chemical species to be monitored and monitoring methodology, to assist the technical preparation of a scope for future monitoring of non-hazardous waste landfills to inform the characteristics of any actual risks to human health from such landfills.

The review has built on the RMIT (2013) literature review.

1.3 Methodology

1.3.1 General

The review has been undertaken to specifically evaluate potential health impacts from air emissions from non-hazardous waste landfills within local communities. As such the assessment has been undertaken to comply with national guidelines on assessing environmental health issues within the community as outlined in the following:

- enHealth, Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012).

Additional guidance that is available from the National Environment Protection Council (NEPC) as well as international bodies such as the World Health Organisation (WHO), United Kingdom Environment Agency (UK EA) and United States Environment Protection Agency (USEPA) has been drawn on were required, as referenced.

1.3.2 Key Terms

This review has considered a range of aspects associated with air emissions from non-hazardous waste landfills. The following provides an explanation of the key terms/aspects that are addressed in this review.

Non-hazardous waste:	Waste can be in the form of a solid, liquid or gas and it can be derived from a range of sources, including household waste (municipal), commercial and industrial waste and construction/demolition. Non-hazardous waste comprises waste that is not defined as hazardous. Hazardous waste is waste that is dangerous or potentially harmful to human health or the environment. There are guidelines available in each state of Australia as to what is considered to be hazardous waste, and how/where these waste materials need to be disposed. In terms of the review presented, the term non-hazardous waste landfill refers to municipal landfills that accept household waste and non-hazardous waste from industry including the construction industries. Household waste includes putrescible food and garden waste.
Odour threshold:	This is the concentration of a compound which produces an odour that is detectable by a human being (nose). An odour threshold is a subjective measure and while there are guidelines available for how this is measured, the published values vary. An odour threshold does not provide any information on the intensity (strength), character (what is smells like) or hedonic tone (pleasantness or not) of the odour (USEPA 1992). Nor does an odour threshold provide any indication of how harmful a chemical is to human health. However, where a chemical has a very low odour threshold, below a level that may cause harm to health, it can act as a warning, allowing people to move away from the exposure. The sense of smell is complex and the perception of odour varies between different people.
Air Guideline - community:	An air guideline is a concentration of a chemical in air that, based on the current science, does not present an unacceptable risk to public or community health. These guidelines are based on a range of different studies conducted in animals and humans (from occupational studies or studies in large populations – epidemiological studies), with the application of an uncertainty factors to make sure that the guideline is relevant to the community who may have a range of sensitivities. The uncertainty factors may also take into account any limitations there are with the available studies. Air guidelines are established and peer reviewed by credible Australian and International authorities such as the NEPC, WHO, UK EA and USEPA.

Air Guideline – occupational:	An air guideline, applicable to individuals who are exposed to chemicals in the workplace through use or handling, that does not present an unacceptable risk to worker health or cause undue discomfort. These guidelines relate exposures by healthy workers in the workplace, during work hours. The guidelines are higher than ambient or community air guidelines and may be at levels that are odorous or mildly irritating.

1.3.3 Literature Review

This review has included an update of the literature review conducted by RMIT in 2013. The literature review has been undertaken using the Pubmed, Scopus and GoogleScholar databases to identify published studies and publications that relate to the following search terms: air quality, air monitoring, landfill, waste, putrescible waste, municipal waste, malodourous landfill, volatile organic compounds, gas, community health, human health and health effects.

Publicly available data from Australian landfills has also been included.

The literature review conducted focused on studies and publications relevant to data collected post 2012/2013 to supplement the information presented in the previous review. Previous data (available at the time the 2013 review was undertaken) has also been included for completeness.

Section 2. Air Emissions from Non-Hazardous Landfills

2.1 General

In Victoria, the Victorian EPA regulates the types of waste landfill sites can accept. These wastes are categorised into three types: municipal, commercial and industrial, and prescribed industrial waste (EPA Victoria, 2012b).

Municipal wastes include “any wastes collected by or for a municipal council” and therefore will contain putrescible food and garden waste (EPA Victoria, 2012b). Putrescible waste is organic matter which is broken down through aerobic and anaerobic microbial processes, resulting in odorous compounds (EPA Victoria, 2007). Further information on aerobic and anaerobic microbial processes is provided below.

Air emissions that are derived from a landfill relate to gases and other volatile organic compounds (VOCs) generated from the breakdown of waste, a number of which individually or in combination are odorous. In addition, the operation of a landfill can result in the generation of dust.

The focus of the review presented in this report, consistent with the RMIT (2013) review, is the gases and VOCs that have the potential to be present throughout all stages of the landfill and are the cause of odours and odour complaints.

Methane and carbon dioxide are the dominant gases present in landfill gas. These gases present specific hazards, such as an explosive hazard (i.e. methane) and an asphyxiation hazard (i.e. methane and carbon dioxide in confined spaces), and are routinely monitored and evaluated on landfill sites. These gases are not associated with other odour or other health effects and hence this review has not included methane or carbon dioxide.

2.2 Generation of Volatile Organic Compounds

VOCs may be present in the waste disposed to a non-hazardous waste landfill as there are many VOCs present in household and consumer products disposed of in household waste. Where these wastes are placed in the landfill, particularly in the active tipping zone, they can be released directly to air or be degraded by oxidation and photo degradation, forming other volatile or gaseous compounds.

However, there are also a number of VOCs that are generated from the breakdown of organic waste (i.e. decomposition) that is present within the landfill. This decomposition can occur through a range of different processes, some of which occur only in the presence of oxygen, termed aerobic decomposition, and other can occur where there is no oxygen present, termed anaerobic decomposition. The composition of the VOCs generated will be dependent on the composition of the waste in the landfill, the stage of decomposition and the factors that affect the rate and type of decomposition that is occurring. These factors include the level of moisture, pH, type and volume of waste, quality of the organic materials present and the available microbes/bacteria.

Landfills typically go through two main stages of decomposition:

1. An aerobic stage when there is still oxygen available for aerobic bacteria to be active, and where oxygenated compounds are commonly formed. Common compounds formed during

this phase include odorous compounds such as butanoic acid, methyl ethyl ketone and acetone, as well as terpenes, alpha & beta pinene and limonene;

2. Anaerobic stage in which the anaerobic bacteria take over, which can be divided into two more stages:
    a. Acidic stage which produces enzymes that break down complex molecules to their basic components (amino acids, sugars, glycerol and fatty acids), and the environment in the landfill becomes acidic. Key gases generated are hydrogen and carbon dioxide; and
    b. Methane production stage where the pH becomes more neutral and populations of methanogenic bacteria start to consume the products of earlier decomposition processes. Key gases produced are methane and carbon dioxide.

Factors that can affect the release of gases and VOCs from a landfill to ambient air include the level of onsite compaction (Chiriac et al. 2007) and local weather patterns, with higher VOCs reported under high temperature, high humidity and low air pressure systems (Ying et al. 2012).

A linear relationship between total VOC concentration and odour has also been identified (Dincer, Odabasi & Muezzinoglu 2006). Hence it is expected that odours will be more perceptible during the summer than the winter.

2.3 Community Exposures to Air Emissions

Gases and VOCs can be generated and released when waste is being dumped and handled in the active part of the landfill. Once buried, the gases and VOCs move in the ground through processes of diffusion as well as pressure driven gas movement. Decomposition processes in landfills produce significant quantities of methane and carbon dioxide, which result in a higher pressure of gas in the landfill than in the atmosphere. This pressure will preferentially move gases and VOCs out of the landfill to the atmosphere. Some landfills collect these gases, and VOCs, and flare the gas or use the gas to produce power.

If not collected for processes such as flaring or power generation, the gases and VOCs will move out of the landfill surface and into the ambient air directly above the landfill. Once in ambient air these gases and VOCs can then be blown off the landfill site to off-site communities where they may be smelled by the human nose or inhaled by the community.

The movement of gases and VOCs (i.e. air emissions) from within the landfill to ambient air, and then off-site, results in the dilution of the gases and VOCs with fresh air. Community exposure to air emissions from a landfill will depend on the wind direction and wind speed and the turbulence or stability of the air. Hence concentrations will decrease as the gases and VOCs move into ambient air and then blow across the landfill into the off-site communities.

The community is not directly exposed to gases and VOCs at concentrations that occur inside the landfill, i.e. the landfill gas.

The community is not directly exposed to gases and VOCs at concentrations that are present on the landfill, at the active/tipping face or in air above waste in the landfill.

The community is exposed, via smell or inhalation, to gases and VOCs that move off the landfill and dilute into the community.

Section 3. Review of Air Emissions from Non-Hazardous Waste Landfills

3.1 General

Information that can be used to understand what may be in the air close to non-hazardous waste landfills, the concentrations that may be present, and if these have the potential to affect the health of the community, is derived from a range of studies. Not all of these studies will have data that directly relates to what the community may be exposed to at or beyond the boundary of a landfill. However, the data is important in understanding what gases and VOCs may be generated from landfills, and if these chemicals are of significance to the health of the community should they be able to migrate into the air and off-site.

Data is available to characterise landfill gas emissions relating to gases and VOCs within the landfill, gases and VOCs in air on the landfill it-self (i.e. in active working areas as well as covered waste, or closed landfills) and gases and VOCs on the boundary of the landfill or in off-site community locations. The available data is outlined in **Section 3.2**.

Data is available for large number of gases and VOCs are generated in during normal landfill operating procedures e.g. the UK EA (2002) produced a list of 557 compounds which had been identified in landfill gases. As it is not possible to monitor for every gas or VOC that may be produced in a landfill, one of the objectives of this part of the review was to identify a sub-set of gases and VOCs that are important to inform potential amenity and health or that could be included in a future monitoring program.

3.2 Available Air Data

Data has been published, or is publicly available, that can be used to understand the nature of gases and VOCs from non-hazardous waste landfills. Data has been included in this review from the following papers and reports (including the data considered as part of the 2013 review).

Landfill Gas

A comprehensive review of the composition of landfill gas was undertaken by the UK EA (UK EA 2002). The report presents data collected from a non-hazardous waste UK landfill. The data was collected in 2 different years (2001 and 2002) from 2 different areas of the site, one where the waste had been in place for approximately 17 years (old phase) and the other where the waste was more fresh and had been in place for approximately 3 years. This sampling included the use of a range of different sampling media to cover a wide range of compounds that may be present in the landfill.

Further sampling of landfill gas was undertaken by the UK EA at 2 different municipal non-hazardous waste landfills in the UK (EA 2010). These landfills included open/active areas as well as closed areas.

A comprehensive analysis of landfill gas in fresh waste, old waste and biogas is available for an active municipal waste landfill located in Italy (Davoli et al. 2003).

Data relevant to understanding compounds that may be present in waste, as fresh waste, older waste and in the landfill, are available from a study undertaken at a municipal waste treatment plant in Spain (Moreno et al. 2014).

Other studies are available where a more limited range of gases and VOCs have been reported in landfill gas. These studies include the following:

- Landfill gas was measured in 7 different non-hazardous landfills in the UK (Allen, Braithwaite & Hills 1997); and
- Landfill gas from 3 non-hazardous waste landfills in the US (Saquing et al. 2014).

Appendix A presents a summary of the landfill gas data available from the above references relevant to evaluating concentrations inside a landfill.

Landfill gases that move from within the landfill to ambient air can be measured as a surface flux emission. This is an emission rate of gases and VOCs through the ground surface. This is not a measure of an air concentration, but the mass of these compounds that move through the ground, over a unit area, into ambient air per day (or hour, or other measure of time). Comprehensive data are available from a closed non-hazardous industrial waste landfill in Spain (Gallego et al. 2014). Studies are also available that have evaluated a small range of VOCs in surface flux emissions from municipal waste landfills in China (Liu et al. 2016), Spain (Martí et al. 2014) and India (Majumdar et al. 2014). These studies are of more limited use as they do not characterise a wide enough range of gases and VOCs. These data have been included to assist in understanding how well the compounds detected in the landfill gas can move out of the landfill and into the ambient air.

Ambient air data collected on the landfill

Ambient air data has been collected from landfills, on the landfill site, primarily to evaluate the presence of gases and VOCs in air where workers may be exposed. Some data have been collected to more specifically evaluate ambient air concentrations above a closed landfill.

Data is available for the presence of VOCs in air above a non-hazardous waste landfill located in China (Zou et al. 2003). Ambient air samples were collected from 12 locations on and adjacent to the landfill in winter and summer. The sample locations included areas located both on and away from the active dumping, including 3 boundary locations. It is not possible to separate the boundary air data from the data collected from the landfill, hence this data has been considered representative of air concentrations on the landfill site.

VOCs were also evaluated in air above different non-hazardous waste landfills located in China (Fang et al. 2012; Ying et al. 2012). One of the studies involved ambient air samples were collected from 6 locations immediately after a specific odour pollution incident (Ying et al. 2012). The other study (Fang et al. 2012) involved the collection of air data from 9 locations on an active landfill. The locations included areas of active dumping, near the leachate treatment plant, at the administration office and on the site boundary.

VOCs in air have been characterised from 5 different locations in active dumping areas at a non-hazardous landfill located in Turkey (Dincer, Odabasi & Muezzinoglu 2006). Sampling was conducted in May and September 2005.

Appendix B presents a summary of the data available from the above references relevant to evaluating air concentrations on a landfill site.

Other comprehensive data sets are available, however these specifically relate to occupational exposures within indoor areas used to handle, process and compost waste (Gallego et al. 2012). These processing and composting activities involve a lot of handling and heating of waste, which is not representative of emissions from a non-hazardous waste landfill, where such activities are not undertaken.

Ambient air data collected from a landfill boundary or off-site in the community

A comprehensive analysis of gases and potential VOCs related to emissions to air from an active municipal waste landfill located in Italy (Davoli et al. 2003) has been undertaken. Samples were collected from the landfill entrance/boundary, 1.5 km, 3 km and 6 km downwind from the landfill. No information is available on the local area and whether there are any other significant sources of air emissions (such as industry) in the area.

The sampling of ambient air in areas located on or near the boundary of 2 non-hazardous waste landfills in the UK was undertaken by the UK Environment Agency (EA 2010). These landfills included open/active areas as well as closed areas. The community was located within 30m of the site boundary at one of these landfills. The landfills included landfill gas collection and power generation. Some other industrial facilities are noted to be located in the local areas evaluated. Hence ambient air measurements in the vicinity of these landfill will include combustion emissions from the power generation facilities, as well as other industrial and urban air sources.

Ambient air samples were collected from 6 locations immediately after a specific odour pollution incident, associated with a non-hazardous waste landfill located in China (Ying et al. 2012). This included the sampling of air on the site boundary and off-site in the adjacent community.

A community air sampling program was undertaken by the New York State Department of Environment Conservation (NYS DEC 2013) to address community concerns in relation to air emissions from 2 active landfills. The landfills included active waste disposal, some closed areas and a landfill gas-to-energy plant. In addition, one of the communities was located close to an industrial area. The community air data was collected from the site boundary and at distances of 1 to 1.4 km from the landfills.

Data has been collected from 4 urban/community locations adjacent to a former non-hazardous waste landfill in Spain (Martí et al. 2014). The landfill is located close to a working industrial area and hence the ambient air data reported in this study is also likely to include emissions to air from the industrial and urban area.

Some data is available from Australia, which includes the following:

- An ambient air monitoring program was undertaken at 5 locations around the boundary of a closed non-hazardous waste landfill located in Suntown in Queensland (AECOM 2012). The sampling involved the use of 2 different sampling methods and specifically targeted VOCs in ambient air; and
- The Victorian EPA conducted community air sampling in the vicinity of the Hallam Road Landfill (EPA Victoria 2012). Sampling was undertaken in residential areas in Lynbrook in 2012.

One study from 3 landfills in the US presents a limited range of compounds (Saquing et al. 2014). This data set also presents air concentrations measured on the landfill as well as in ambient air upwind and downwind of the landfill. The range of compounds reported is limited, however for some compounds it does show concentrations that reduce from the landfill surface to off-site areas. In many cases there is little difference between upwind and downwind concentrations, suggesting that the landfill is not significantly changing existing ambient air concentrations. The maximum downwind concentration has been considered in this review. Similar observations, no significant difference between upwind and downwind ambient air data was reported from another study where a limited range of hydrocarbons were reported adjacent to a non-hazardous waste landfill in France (Verriele et al. 2015).

Appendix C presents a summary of the data available from the above references relevant to evaluating air concentrations on the boundary or in the off-site community near non-hazardous waste landfills.

3.3 Key Aspects

When reviewing air data, as outlined in **Section 3.2**, particularly when inferring outcomes that may be applicable to Australian landfills, it is important to consider the following:

Nature of the waste

The nature of the waste that is placed at a landfill will affect the nature and concertation of gases and VOCs that may be generated. Insufficient data is currently available to evaluate VOCs that may be present in landfill gas within the non-hazardous waste landfills in Victoria, or elsewhere in Australia. The range of food, consumer products, household items and building materials disposed in Australia may be similar to that in the UK, some other European countries and the US. However, it is expected that there will be differences with waste disposed in countries such as China.

Landfill design

The age and design of the landfill affects the type and concentration of gases and VOCs that may be present in the landfill, or that may be able to be released to ambient air. Active landfills will involve emissions to air directly where the waste is tipped and handled. When the waste is capped (on open and closed landfills) gases and VOCs can migrate to air from the buried waste. However, if there is a landfill gas collection system, these gases may not migrate to air, but be captured and treated or used to generate power. The age of the waste, and the design of the waste cells will affect the potential to generate gases and VOCs. These aspects differ between landfills.

Climate

The climate of the area where the data is collected will affect the potential for gases and VOCs to be generated and to migrate out of the landfill, and potentially into the community (Ying et al. 2012). Some data is collected from countries that are colder and wetter than Victoria (such as in the UK and some areas of the US). Concentrations of gases and VOCs may be higher in areas with warmer climates.

Measurement of ambient air

The measurement of VOCs in ambient air will report all the VOCs detected, regardless of the source. There are numerous other sources of VOCs in ambient air, other than emissions from a landfill. This includes industrial emissions, emissions from vehicles and service stations, household combustion (heating and cooking), building and renovations and a range of consumer products. When reviewing ambient air data, it is difficult to distinguish emissions from a landfill from other industrial/urban air sources (not on the landfill). The studies included in this review have collected ambient air data close to emission sources, i.e. on the landfill, or in locations noted to be either upwind or downwind of the landfill at the time of sampling. This assists in reviewing the data.

Air sampling methods

The published literature on the data available to characterise air emissions from landfills outline the methods used to collect and analyse the samples collected. Methods that can be used to collect data used to characterise gases and VOCs in a landfill, and in ambient air on or off the landfill are outlined in Australian (CRC CARE 2013; Davis, Wright & Patterson 2009) and UK (UK EA 2002) guidance. The methods involve:

- The collection of a bulk air sample into a canister or tedlar bag, as a grab sample or over a longer period of time; or
- The collection of an air sample by drawing air through a tube, impinge or sorbent (i.e. passive) sampler that contains a specific material or liquid which sorbs a range of chemicals. Different adsorbent materials are used to target different individual chemicals.

Once the sample is collected it is analysed using a combination of gas chromatography with mass spectrometry or flame ionisation detection, or infrared spectrometry. The methods used are well established.

The different sampling and analytical methods used in the various studies report different ranges of individual chemicals. No one sampling and analysis method can be used to target all of the 557 compounds identified by the UK EA (2002) as being present in landfill gas. Hence when reviewing the published data, it is important to note that the data presented in each study will not cover the same list of chemicals.

Averaging time for air sampling

When collecting an air sample, the time period over which the air sample is collected is important as it is used to represent an averaging time, or time over which someone may be exposed to the measured concentration.

When assessing short duration, acute exposures, data is commonly collected over a very short (or instantaneous) period of time, such as an instantaneous grab sample, or a sample collected over a period of a few hours where the sampling is targeting specific conditions such as locations directly downwind of the landfill. Most of the studies included in this review have collected short duration data as they are specifically looking to address odour or irritant issues, which are normally associated with peak exposure events. These data can only be used to represent an acute or short duration exposure. The time period over which the data was collected is not long enough to be representative of concentrations that anyone in the community may be exposed to all of the time.

When assessing long-term or chronic exposures an annual average concentration is typically considered. However, gases and VOCs cannot be continuously monitored for a year, hence the data used to evaluate chronic exposures commonly collected from the one location over a representative day, from repeated 24-hour or longer sampling events or from longer duration sampling (up to a week or two). These data reflect the average concentration in air over this longer period of time, encompassing periods of the day when the wind blows from the landfill to the community as well as other times where the wind blows in other directions. This better reflects how people would normally be exposed within the off-site community and may be inferred to be representative of concentrations that may be present at all times. There is limited data available to assess chronic exposures. One study (AECOM 2012) includes sampling over a 2 week period and another (Martí et al. 2014) includes average concentrations from 3-4 repeated 24-hour average sampling. Sampling undertaken by AECOM (2012) and Vic EPA (2012) included the collection of 24-hour average data. While these samples are not normally considered to be long enough to be representative of exposures that may occur over a whole year, they do reflect exposures over all conditions within a day and are commonly, conservatively assumed to be representative of long-term exposures.

3.4 Approach to Reviewing Air Data

As indicated above, the available air data in relation to non-hazardous waste landfills has been reviewed to identify a sub-set of important gases and VOCs that could be included in a future monitoring program. The review has comprised the following:

- Grouping of detected chemicals into the following sub-groups: organics acids, aldehydes, ketones, alcohols, aromatic hydrocarbons, aliphatic hydrocarbons, chlorinated hydrocarbons, esters, ethers, organosulfur compounds, terpenes and terpenoids, and other;
- Review of air concentrations reported in and on the landfill: the chemicals detected and the range of concentrations reported have been graphically presented in **Section 3.5**. These concentrations are more relevant to occupational exposures (i.e. exposures by workers on the landfill) and have not been compared against community air guidelines as this is not where the community is exposed; and
- Review of air concentrations reported on the boundary or in off-site community areas: the maximum reported from samples collected on the boundary, as well as concentrations reported in the off-site community (from each study where detected) have been graphically presented in **Section 3.5**. These concentrations have then been compared with the following guidelines (also presented in the graph):
    - **Acute Exposures** - These have been reviewed by presenting all the available data from the short-duration sampling events with criteria that are based on the detection of odours, and protection of adverse health effects, as outlined below:
        - **Odour threshold**, as listed from comprehensive published studies (Nagata; USEPA 1992) as well as more current thresholds published by the USEPA and by Leffingwell & Associates[1]. It is noted that these are odour thresholds for individual chemicals. Mixtures of chemicals are expected to have different odour characteristics and thresholds, sometimes lower than the odour thresholds relevant to individual chemicals in the mixture. Hence this value is provided as an indicative measure only and is unlikely to accurately reflect the true odorous nature of landfill gas. It is noted that odour thresholds are not available for all the chemicals detected in air, presented in this review. In addition, different people may have slightly different odour thresholds for the same chemical.
        - **Acute community health guideline**: this is a health based guideline that is protective of all health effects for the community, when exposed to a chemical for a short period of time, typically minutes to a few hours. For most

[1] http://www.leffingwell.com/odorthre.htm

chemicals, the acute health based guideline is based on the protection of irritation effects that would typically be transient (i.e. go away when exposure to the chemical no longer occurs). In some cases, the acute guideline is based on the protection of other short-duration health effects, which may be of greater sensitivity than irritation effects.

- **Chronic exposures –** These exposures have been reviewed by presenting all the data from the longer-duration/chronic sampling events with criteria that are based on the protection of chronic health effects, as detailed below:
    - **Chronic community health guideline**: this is a health based guideline that is protective of all health effects for the community, when exposed to a chemical 24 hours per day, every day. It is noted that even the longer duration sampling time data used in this review is not truly representative of exposures that may occur over a year. Hence comparison against the chronic guideline has been used to provide an indication of which chemicals detected in air have the potential to be present at elevated levels in the community, and require further monitoring.

  It is noted that the review of chronic exposures has also included the odour thresholds, to assist in identifying issues that may be related to longer term odour issues within the community.

The acute and chronic community health guidelines adopted have been selected in accordance with Australian guidance (enHealth 2012), from the following sources (in order of preference):

- NEPM Air Toxics Investigation Levels (NEPC 2004)
- WHO air guidelines (WHO 2000a, 2000b, 2010)
- USEPA Regional Screening Levels for residential air (USEPA 2016)
- California Office of Environmental Health Hazard Assessment, Reference Exposure Levels (OEHHA RELs) (OEHHA 2016)
- Texas Commission on Environmental Quality (TCEQ 2016), noting that the chronic air guideline from this reference has been used in preference to that from the USEPA and OEHHA where TCEQ has reviewed the chemical more recently

The chemicals detected and the range of concentrations reported are presented in **Appendices A, B and C**, and discussed in **Section 3.5**.

It is noted that the graphs presented in **Section 3.5** show the concentrations on a logarithmic scale. The logarithmic scale is not linear (where the scale increases by the same value each notch, e.g. 10,20, 30 etc.), but each notch in the scale is 10 times the previous notch, e.g. 10, 100, 1000 etc. What this means is that concentrations may appear to be close together at first glance however may actually be an order of magnitude apart.

3.5 Review of Air Data

3.5.1 Organic Acids

Organic acids are organic compounds that have acidic properties. Many organic acids are naturally occurring in a range of foods, or they are commonly used in a range of food products.

Acids are characterised by a range of compounds with sharp, sour or pungent, or acidic type odours. These compounds are present in landfill waste from a range of preservatives, flavour and fragrance agents (used in food and other consumer products), paints, adhesives, pharmaceuticals and plastics (Gallego et al. 2012). These compounds may also be formed in a landfill.

The available data on organic acids in landfill gas is limited. Few organic acids have been reported in landfill gas (refer to **Appendix A**), with many sampling programs not testing for many of these acids, or the concentrations not being high enough to be detected. Acetic acid, which is one of the more volatile organic acids, has been detected in the surface flux emissions from a landfill (Gallego et al. 2014).

A range of organic acids have been detected in air on landfill sites, as well as in air on the boundary and in off-site community air sampling.

Figure 1 presents a summary of the concentrations of organic acids reported on a landfill, and on the boundary and off-site. Data relevant to concentrations on the boundary and offsite relate to acute exposures only, and these concentrations have been compared with odour thresholds and the acute community health guidelines (refer to **Section 3.4**). In relation to the assessment of chronic exposures only acetic acid was detected in the longer-term sampling programs. No suitable chronic guideline is available for acetic acid as short-term irritation is the key health effect, and this has been reviewed within the acute exposure data.

Figure 1 shows the following:

- **Data**:
  - Lower concentrations of organic acids are reported on the landfill boundary and offsite, when compared with on the landfill; and
  - For some chemicals there is little difference between concentrations reported on the boundary and off-site.
- **Odour**: The concentration or most organic acids are below the odour thresholds available, with the exception of acetic acid, which has the potential to be odorous;
- **Acute (irritation) health effects**: All short-term/peak concentrations reported are below the acute community health guidelines.

On the basis of the above no health risk issues of concern are identified in relation to the potential presence of organic acids in air from non-hazardous waste landfills.

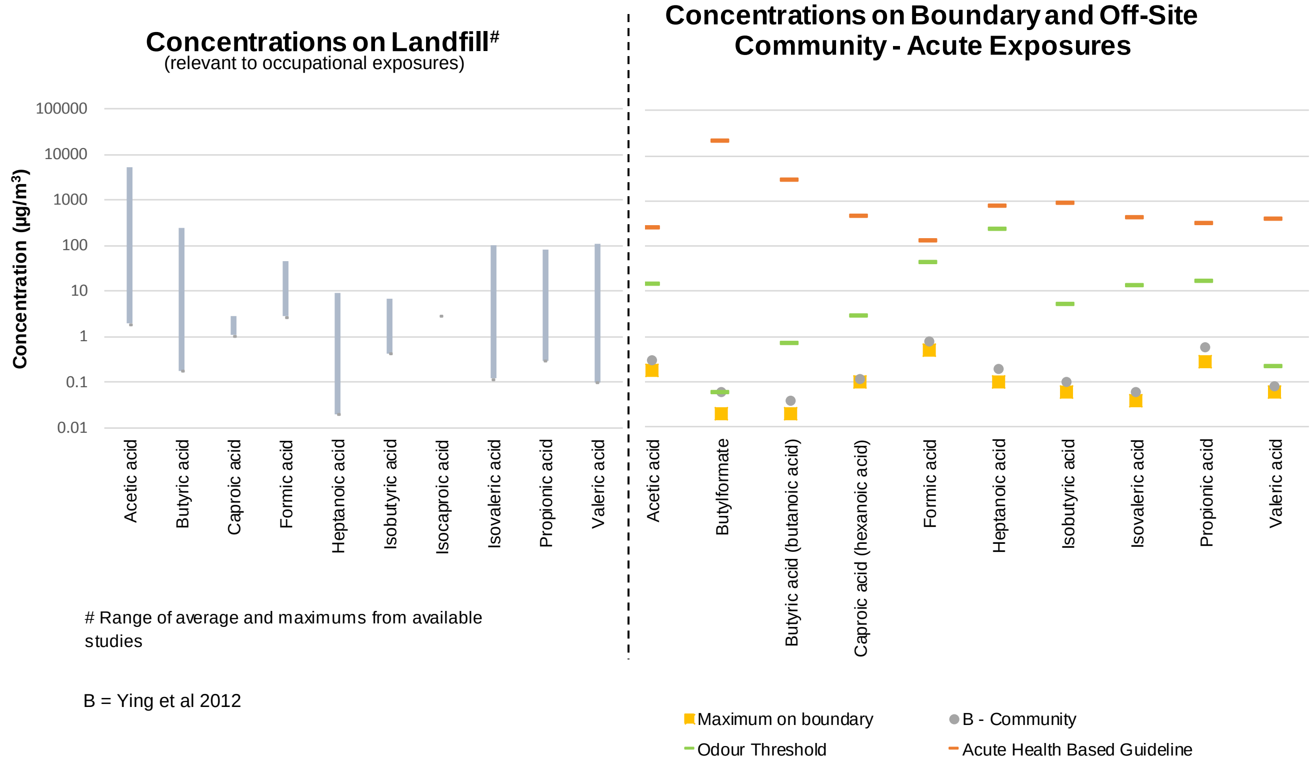


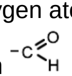
Figure 1: Organic Acids - Review of Reported Air Concentrations

3.5.2 Aldehydes

Aldehydes are organic chemicals that include a carbonyl group[2] attached to the end of a molecule with a carbon chain. Aldehydes are widespread in nature, particularly in plants, and are commonly used in a wide range of industrial processes and to make other chemicals. Some aldehydes (e.g. acetaldehyde) are made in the body, and in plants, as a result of alcohol fermentation.

There are a wide range of aldehydes with diverse chemical and toxicological properties. The smaller molecules are soluble in water and are typically volatile with strong odours. Many aldehydes are used as flavourings in food and fragrances in perfumes and other consumer products. Some aldehydes are considered to be more harmful than others with formaldehyde, acetaldehyde and acrolein of greater concern. Formaldehyde and acetaldehyde (particularly associated with the consumption of alcohol) are classified as a known human carcinogen (IARC 2016).

Aldehydes are characterised by a range of compounds with pungent, ethereal, fresh, fruity, sweet, floral, spicy, fatty, sweaty, fermented, bready, alcoholic, earthy, cocoa or nutty type of odour. These compounds are present in landfill waste from a range of cosmetic, pharmaceuticals, flavour and

[2] A carbonyl group is an oxygen atom attached to a carbon atom by a double covalent bond and a hydrogen atom attached to the carbon atom 

fragrance agents, resins, plastics and disinfectants (Gallego et al. 2012). These compounds may also be formed in a landfill.

There is limited data available on the presence of aldehydes in landfill gas. Only a few compounds have been reported (refer to **Appendix A**), with many sampling programs not testing for many of these compounds, or the concentrations not being high enough to be detected. Some aldehyde compounds (benzaldehyde, decanal, heptanal, hexanal, nonanal and octanal) have been detected in the surface flux emissions from a landfill (Gallego et al. 2014).

Figures 2 and 3 present a summary of the concentrations of aldehydes reported on a landfill (**Figure 2**), and on the boundary and off-site (**Figure 3**). Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

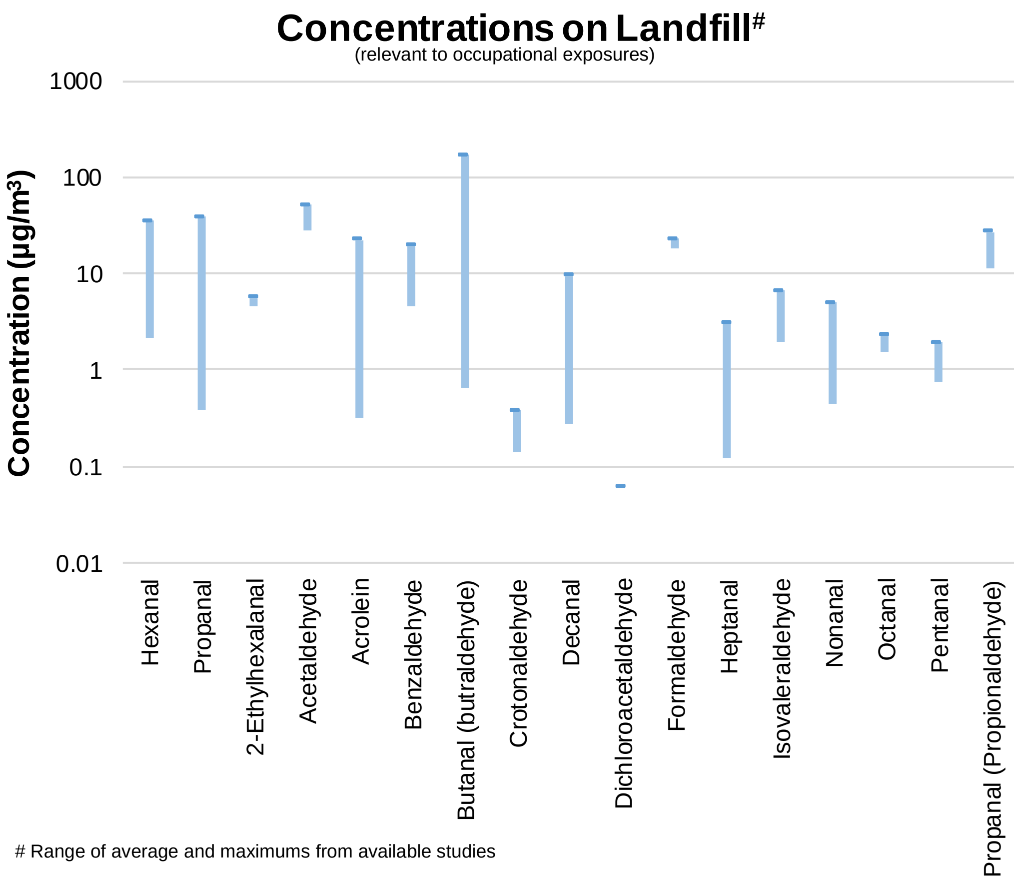


Figure 2: Aldehydes – Summary of Air Concentrations Reported on Landfills

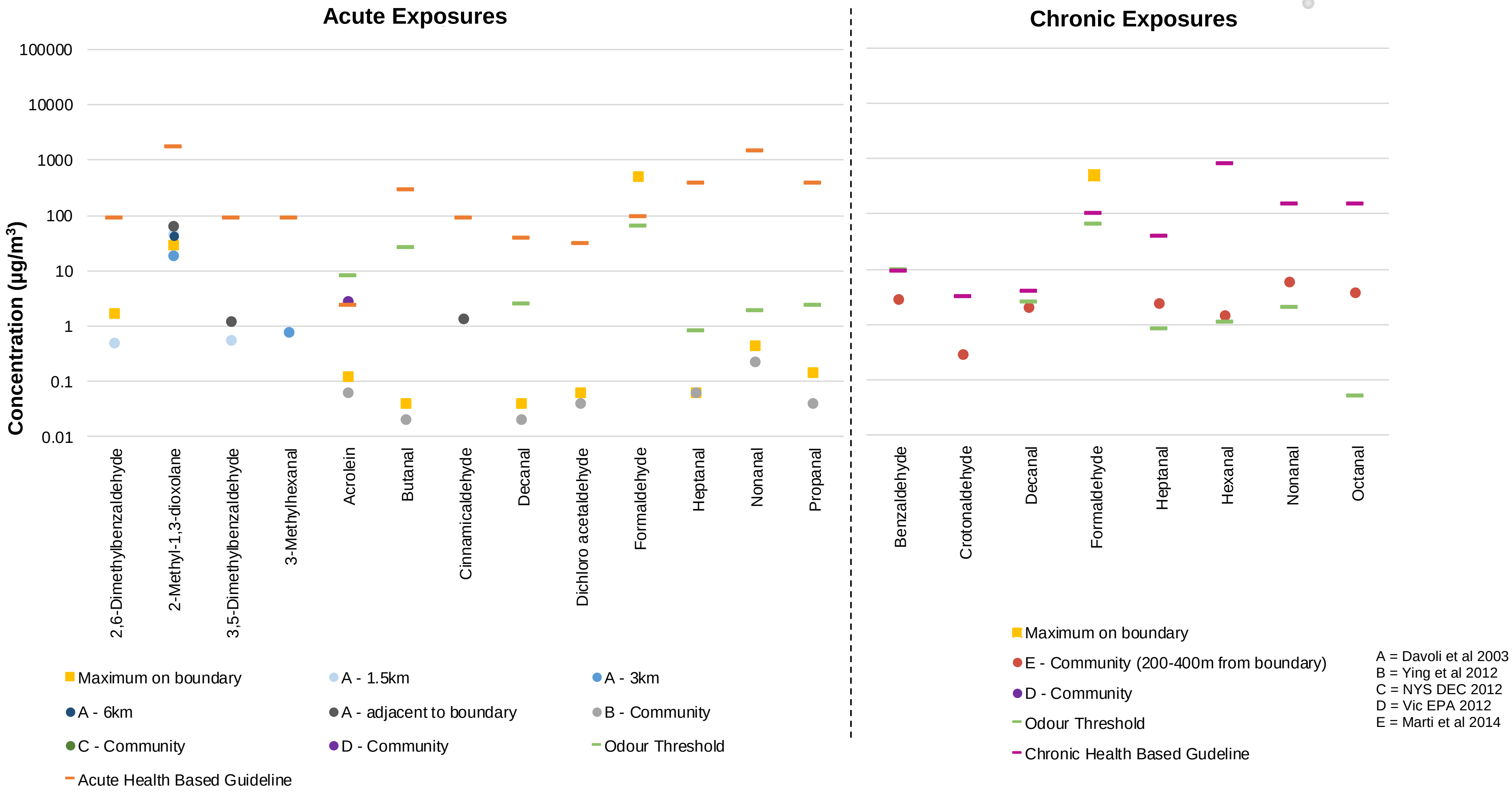


Figure 3: Aldehydes - Review of Reported Air Concentrations on Boundary and in Off-Site Community

Figures 2 and 3 show the following:

- **Data**: The range of concentrations reported on the landfill are similar to those reported on the boundary, with some lower concentrations reported off-site;
- **Odour**: Most of the concentrations reported are lower than the odour thresholds, with the exception formaldehyde, heptanal, hexanal, nonanal and octanal;
- **Acute (irritation) health effects**: Most of the short-term/peak concentrations are below the acute community health guideline. The exception is formaldehyde, where boundary concentrations reported at a UK landfill (from short and longer duration samples) exceeds the acute guideline. This is not where the community lives. However, it is noted that no off-site community data is available for formaldehyde; and
- **Chronic health effects**: Most of the longer duration concentrations are lower than the chronic community health guidelines. The exception is formaldehyde formaldehyde, reported on the landfill boundary. This is not where the community lives, however no data on formaldehyde concentrations in the off-site community is available. Hence formaldehyde has been identified as a chemical that may require further monitoring and assessment of potential chronic health issues.

The above review indicates that the available data in relation to aldehydes in air does not suggest the potential for significant health risk issues.

However, as aldehydes are considered to be harmful, and some data is available that shows some compounds may be present at elevated concentrations at and in the vicinity of landfills overseas, it is important that these are monitored in any future Australian landfill gas (LFG) air monitoring program.

3.5.3 Ketones

Ketones are often grouped with aldehydes as this group of chemicals also have a carbonyl group, however with ketones do not have a hydrogen attached to the carbon atom, rather they have 2 carbon containing groups. Ketones are widespread in nature and a number of ketones are produced in our bodies.

There are a wide range of ketones with diverse chemical and toxicological properties. Ketones are soluble in water and a number are considered to be volatile with distinctive odours. Most ketones are less harmful than aldehydes however some, such are methyl butyl ketone are considered more harmful than other ketones. Ketones are produced at very high scale as pharmaceuticals, solvents and polymers in industries. The most commonly used ketones are acetone, methyl ethyl ketone and cyclohexanone.

Ketones are characterised by a range of compounds with a solvent, ethereal, fruity, sweet, pungent, dairy, spicy and ethereal types of odour. These compounds are present in landfill waste from a range of solvents, cosmetic products, adhesives, plastics, paints, cleaning products, flavour and fragrance agents (Gallego et al. 2012). These compounds may also be formed in a landfill.

A wide range of ketones have been reported in landfill gas (refer to **Appendix A**) with fewer compounds detected in air on the landfill, on the boundary or off-site. Some ketone compounds (acetone, cyclohexanone, methyl ethyl ketone and methyl isobutyl ketone) have been detected in the surface flux emissions from a landfill (Gallego et al. 2014).

Figures 4 and 5 present a summary of the concentrations of ketones reported on a landfill (**Figure 4**), and on the boundary and off-site (**Figure 5**). Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

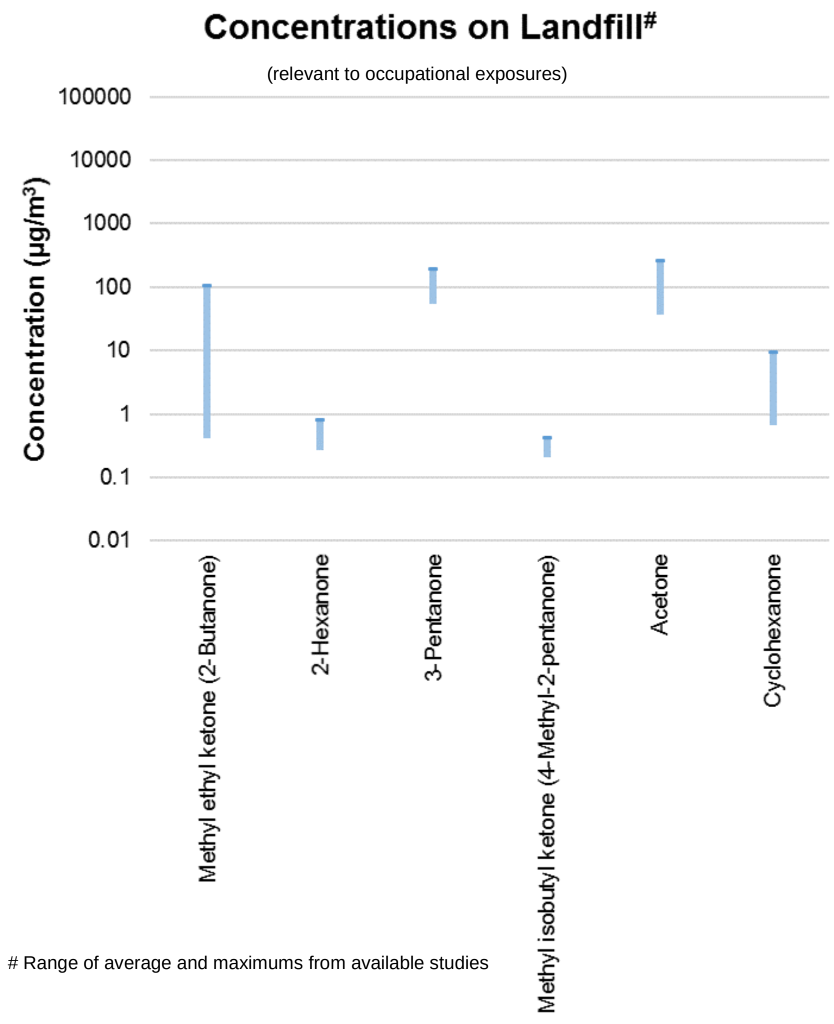


Figure 4: Ketones – Summary of Air Concentrations Reported on Landfills

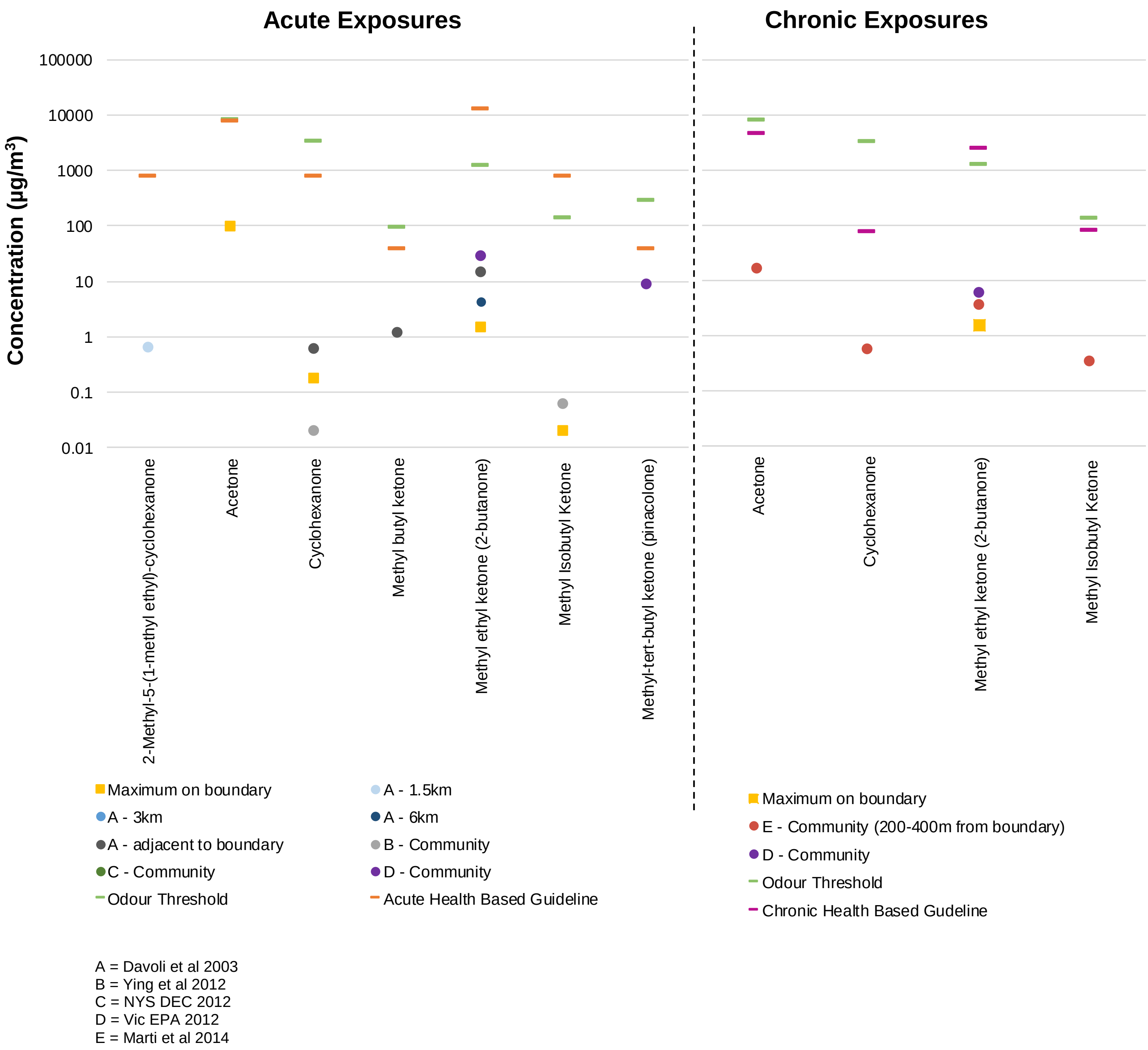


Figure 5: Ketones - Review of Reported Air Concentrations on Boundary and in Off-Site Community

Figures 4 and 5 show the following:

- **Data**: The range of concentrations reported on the landfill are similar to those reported on the boundary and off-site;
- **Odour**: All concentrations reported on the boundary and off-site are lower than the available odour thresholds;
- **Acute (irritation) health effects**: All concentrations reported on the boundary and off-site are lower than the available acute community health guidelines
- **Chronic health effects**: All concentrations reported on the boundary and off-site are lower than the available chronic community health guidelines.

On the basis of the above no health risk issues of concern are identified in relation to the potential presence of ketones in air from non-hazardous waste landfills.

3.5.4 Alcohols

There are a wide range of alcohols ranging from the simplest, ethanol, to complex or higher alcohols. Alcohols are naturally produced from fermentation of fruits and yeast. They are also produced from a range of bacteria. Alcohols have widespread use, being present in a wide range of drinks, food and other consumer products. When alcohols are metabolised in the body they produce aldehydes and acids which are more harmful compounds. In general, the longer the alcohol takes to metabolise in the body, the greater potential for harm. Ethanol, as consumed in alcoholic drinks, is classified as a known human carcinogen (IARC 2016).

Alcohols are characterised by a range of compounds with an alcoholic, fermented, oil, sweet, musty, ethereal, herbal or earthy type of odour. These compounds are present in landfill waste from a range of solvents, cosmetic products, plastics and flavour and fragrance agents (Gallego et al. 2012). These compounds may also be formed in a landfill.

A range of alcohols have been reported in landfill gas (refer to **Appendix A**), with only one alcohol (methanol) detected in air on a landfill, likely due to the sampling programs not looking for alcohols in air (refer to **Appendix B**). Many alcohols are volatile and would be expected to be present in landfill gas. Some alcohols (butanol, propanol, ethanol, ethyhexanol and isopropanol) have been detected in the surface flux emissions from a landfill (Gallego et al. 2014).

Figure 6 presents a summary of the concentrations of alcohols reported on the boundary and off-site. These data have been compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

No data is available for concentrations of alcohols on landfills.

Figure 6 shows the following:

- **Data**: For a number of alcohols reported, the concentration reported on the boundary is similar to off-site;
- **Odour**: All maximum concentrations, except for ethanol reported in one community study, are lower than the available odour thresholds;
- **Acute (irritation) health effects**: All concentrations reported (including ethanol concentrations) are lower than the acute community health guidelines;

- **Chronic health effects**: All concentrations reported are lower than the chronic community health guidelines.

On the basis of the above no health risk issues of concern are identified in relation to the potential presence of alcohols in air from non-hazardous waste landfills.

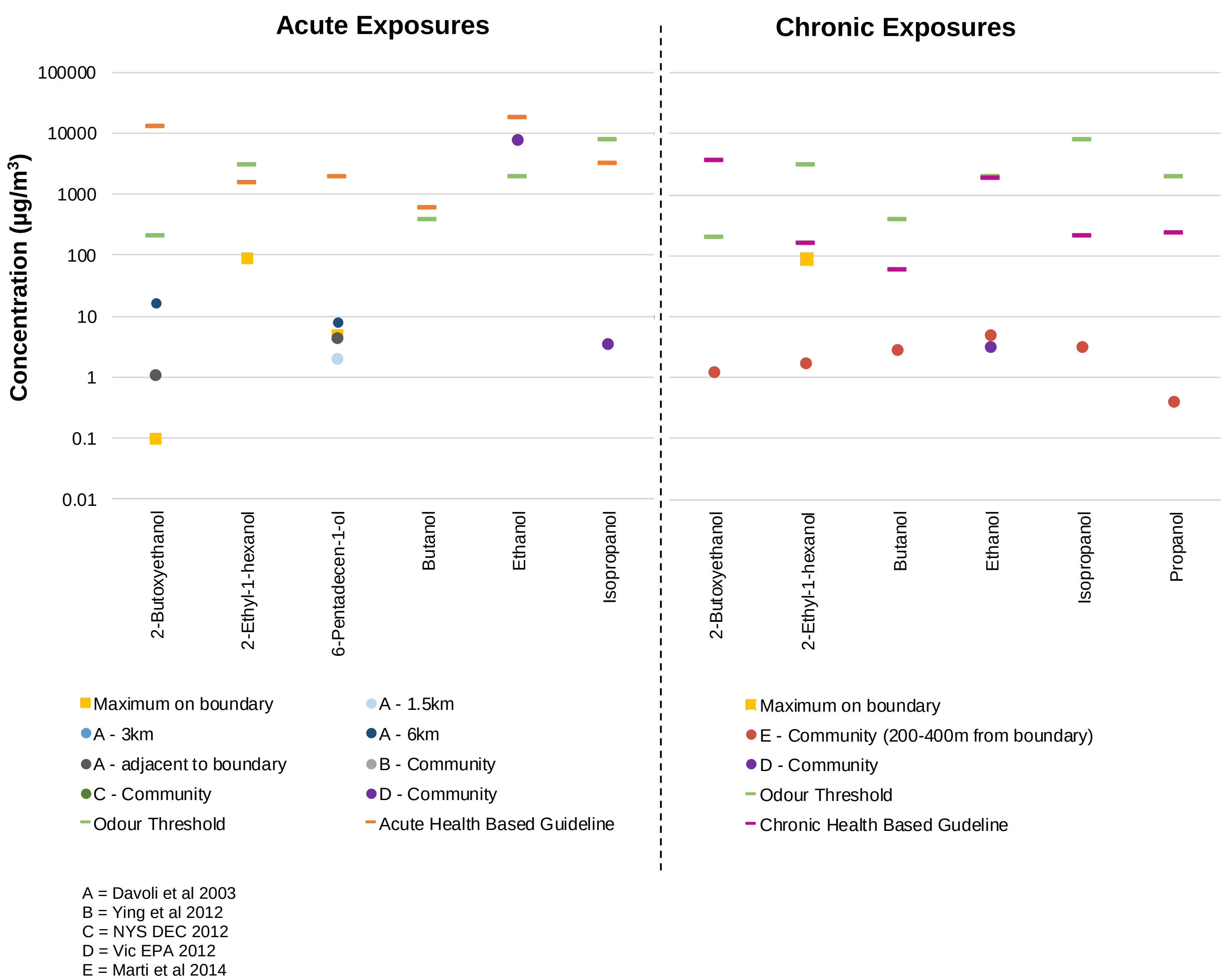


Figure 6: Alcohols - Review of Reported Air Concentrations on Boundary and in Off-Site Community

3.5.5 Aromatic Hydrocarbons

Aromatic hydrocarbons are group of compounds based on a carbon ring with the simplest being the benzene ring. Aromatic hydrocarbons include monoaromatic, diaromatic and polynuclear aromatic hydrocarbons (PAHs). Aromatic compounds are considered to be fragrant chemicals.

Aromatic hydrocarbons are derived from crude oil and associated refined petroleum products. They are also produced from the incomplete combustion of organic fuels, such as vehicle exhaust and wood fires, as well as from volcanic eruptions. Aromatic hydrocarbons are commonly reported in urban/ambient air, mainly from vehicle exhaust and industrial emissions.

There are hundreds of individual aromatic hydrocarbons that include a range of light, volatile chemicals, as well as larger more complex and less volatile chemicals. Aromatic hydrocarbons may be present in landfill from a range of fuels, lubricants, solvents, glues and adhesives, plastics, propellants, refrigerants, insecticides/pesticides, dyes, detergents, flavour and fragrance agents. These compounds may also be formed in a landfill.

These compounds have been reported to have an aromatic, sweet, plastic, chemical and/or petroleum-type odour (Gallego et al. 2012).

Aromatic hydrocarbons include benzene which is a known human carcinogen (IARC 2016). In general, aromatic hydrocarbons are considered to be more harmful than aliphatic hydrocarbons.

A wide range of aromatic hydrocarbons have been reported in landfill gas (refer to **Appendix A**), with a significant range of concentrations reported. Most of the aromatic hydrocarbons detected in landfill gas are volatile and hence these are commonly also detected in the surface flux emissions from a landfill (Gallego et al. 2014).

Figures 7 and 8 presents a summary of the concentrations of aromatic hydrocarbons reported on a landfill (**Figure 7**), and on the boundary and off-site (**Figure 8**). Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

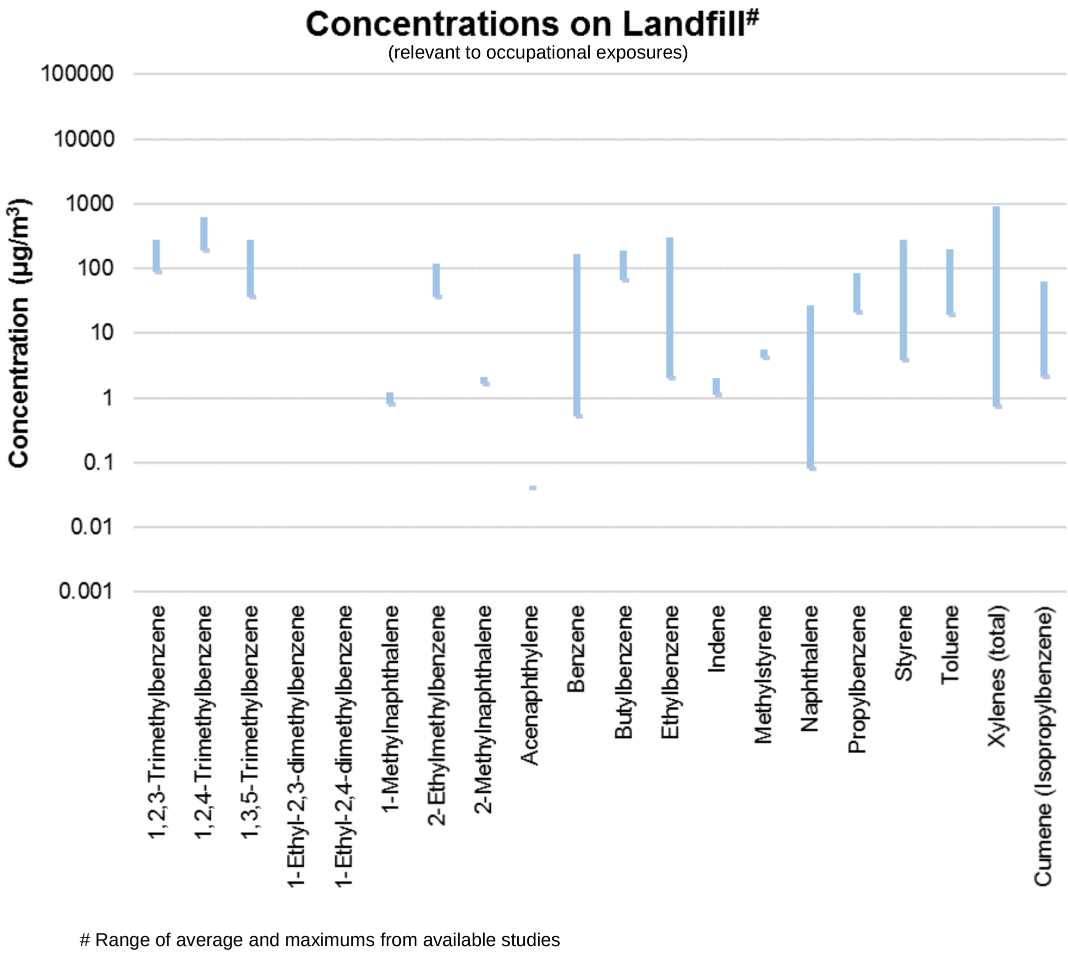


Figure 7: Aromatic Hydrocarbons – Summary of Air Concentrations Reported on Landfills

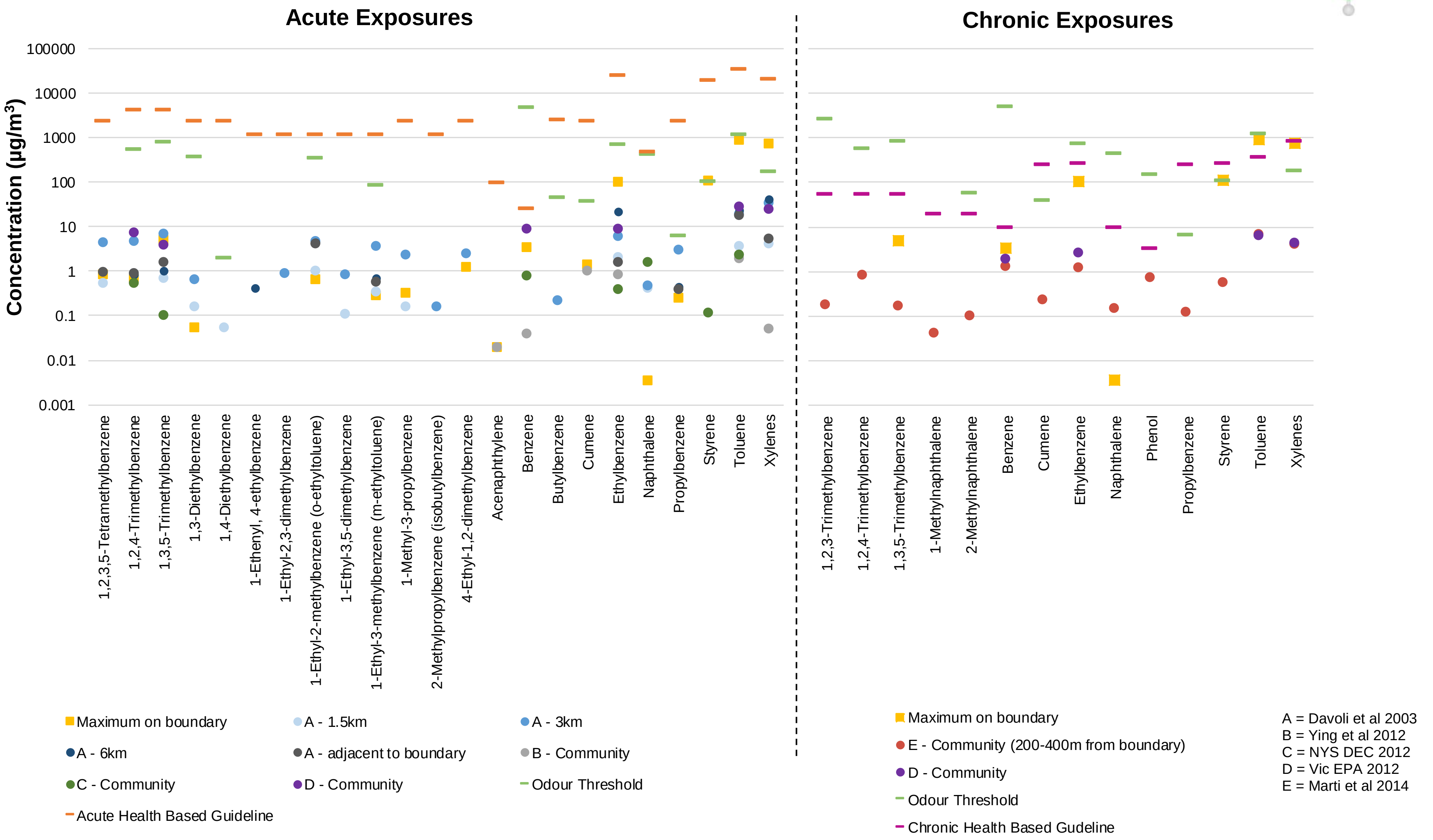


Figure 8: Aromatic Hydrocarbons - Review of Reported Air Concentrations on Boundary and in Off-Site Community

Figures 7 and 8 show the following:

- **Data**: In general, the range of concentrations reported in air on the landfill are higher than reported on the boundary and off-site;
- **Odour**: All concentrations are equal to or lower than the available odour thresholds;
- **Acute (irritation) health effects**: All concentrations reported are lower than the acute community health guidelines;
- **Chronic health effects**: Most concentrations reported from longer duration samples are lower than the chronic community health guidelines. The exception is the maximum concentration of toluene reported on a landfill boundary. This is not where the community is exposed on a long-term basis, and data from within the community areas indicate concentrations are below the chronic community health guideline.

The above review indicates that the available data does not suggest the potential for significant health risk issues associated with aromatic hydrocarbons in air.

However, as aromatic hydrocarbons are considered to be harmful, and some data is available that shows some compounds may be present at elevated concentrations at and in the vicinity of landfills overseas, it is important that these are monitored in any future Australian LFG air monitoring program.

3.5.6 Aliphatic Hydrocarbons

Aliphatic hydrocarbons are a group of carbon compounds that range from simple molecules such as methane to complex cyclic molecules. Aliphatic hydrocarbons can be further split into alkanes, alkenes and cycloalkanes.

Aliphatic hydrocarbons are mainly derived from crude oil and associated refined petroleum products. They can also be derived from natural sources such as terrestrial plant waxes, marine phytoplankton and bacteria.

There are hundreds of individual aliphatic hydrocarbons that include a range of light, volatile chemicals, as well as larger more complex and less volatile chemicals. In general, aliphatic hydrocarbons are less harmful than aliphatic and chlorinated hydrocarbons.

Aliphatic hydrocarbons may be present in landfill from a range of fuels, lubricants, solvents, glues and adhesives, plastics, propellants, refrigerants, flavour and fragrance agents. These compounds have been reported to have a sweet, sometimes aromatic, ethereal, waxy and/or petroleum-type odour (Gallego et al. 2012). These compounds may also be formed in a landfill.

A wide range of aliphatic hydrocarbons have been reported in landfill gas (refer to **Appendix A**), with a significant range of concentrations reported. Most of the aliphatic hydrocarbons detected in landfill gas are volatile and hence these are commonly also detected in the surface flux emissions from a landfill (Gallego et al. 2014).

Figure 9 presents a summary of the concentrations of aliphatic hydrocarbons reported on a landfill, and on the boundary and off-site. Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

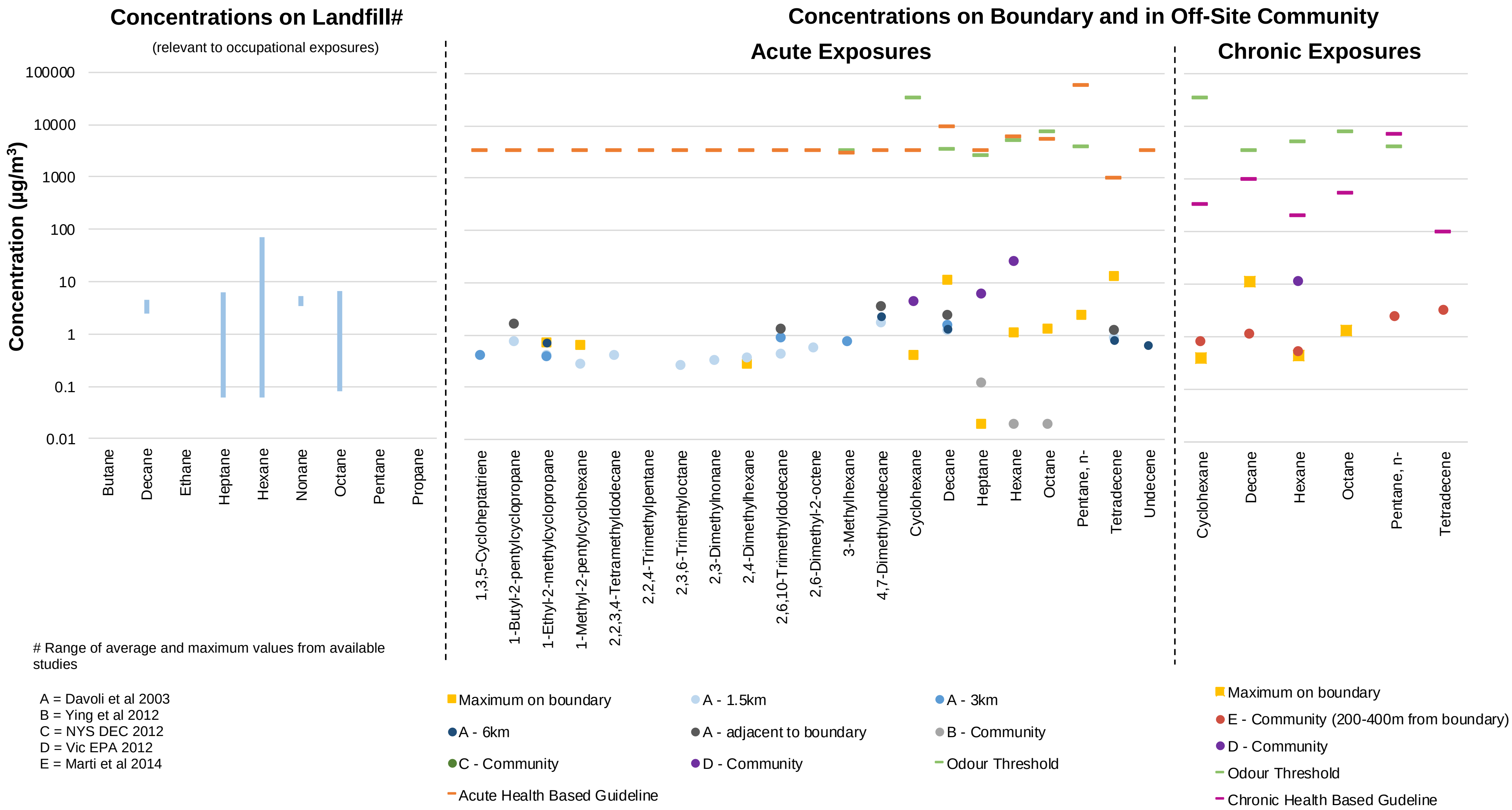


Figure 9: Aliphatic Hydrocarbons - Review of Reported Air Concentrations

Figure 9 shows the following:

- **Data**:
    - There is limited data available on the concentration of aliphatic hydrocarbons on landfill sites
    - Some concentrations reported in the landfill boundary are higher than in the community, however there are also a number where the concentrations on the boundary and off-site are the same;
- **Odour**: All concentrations reported on the boundary and in the off-site community are well below the available odour thresholds;
- **Acute (irritation) health effects**: All concentrations reported on the boundary and in the off-site community are well below the available acute community health guidelines;
- **Chronic health effects**: All concentrations reported on the boundary and in the off-site community are well below the available chronic community health guidelines.

On the basis of the above no health risk issues of concern are identified in relation to the potential presence of aliphatic hydrocarbons in air from non-hazardous waste landfills.

3.5.7 Chlorinated Hydrocarbons

This is a group of chemicals where some or most of the hydrogen atoms have been replaced with chlorine atoms. Some chlorinated hydrocarbons are naturally produced, e.g. chloromethane is naturally produced by biological decomposition, forest fires and volcanic eruptions. However, many of the chlorinated hydrocarbons are man-made, with the manufacture of polyvinylchloride (PVC), cleaning/degreasing products and pesticides being the more significant sources of these compounds.

Chlorinated hydrocarbons include a number of volatile chemicals that are considered harmful. This includes known human carcinogens such as 1,2-dichloropropane, trichloroethene and vinyl chloride (IARC 2016).

Chlorinated hydrocarbons may be present in landfill from a range of solvents, adhesives, paints, cleaning products, degreasers, aerosols, plastics, deodorisers, dry-cleaning, refrigerants and pesticides. These compounds may also be formed in a landfill. These compounds have been reported to have a sharp, sweet or ethereal type odour (Gallego et al. 2012). The compounds include small molecules ranging up to longer/larger and more complex molecules. The size of the molecule will affect how easily it can move out of the landfill and waste, into the air and travel offsite.

A wide range of chlorinated hydrocarbons have been reported in landfill gas (refer to **Appendix A**), with a significant range of concentrations reported. Most of the chlorinated hydrocarbons detected in landfill gas are volatile and hence these are commonly also detected in the surface flux emissions from a landfill (Gallego et al. 2014).

Figures 10 and 11 present a summary of the concentrations of chlorinated hydrocarbons reported on a landfill (**Figure 10**) and on the boundary and off-site (**Figure 11**). Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

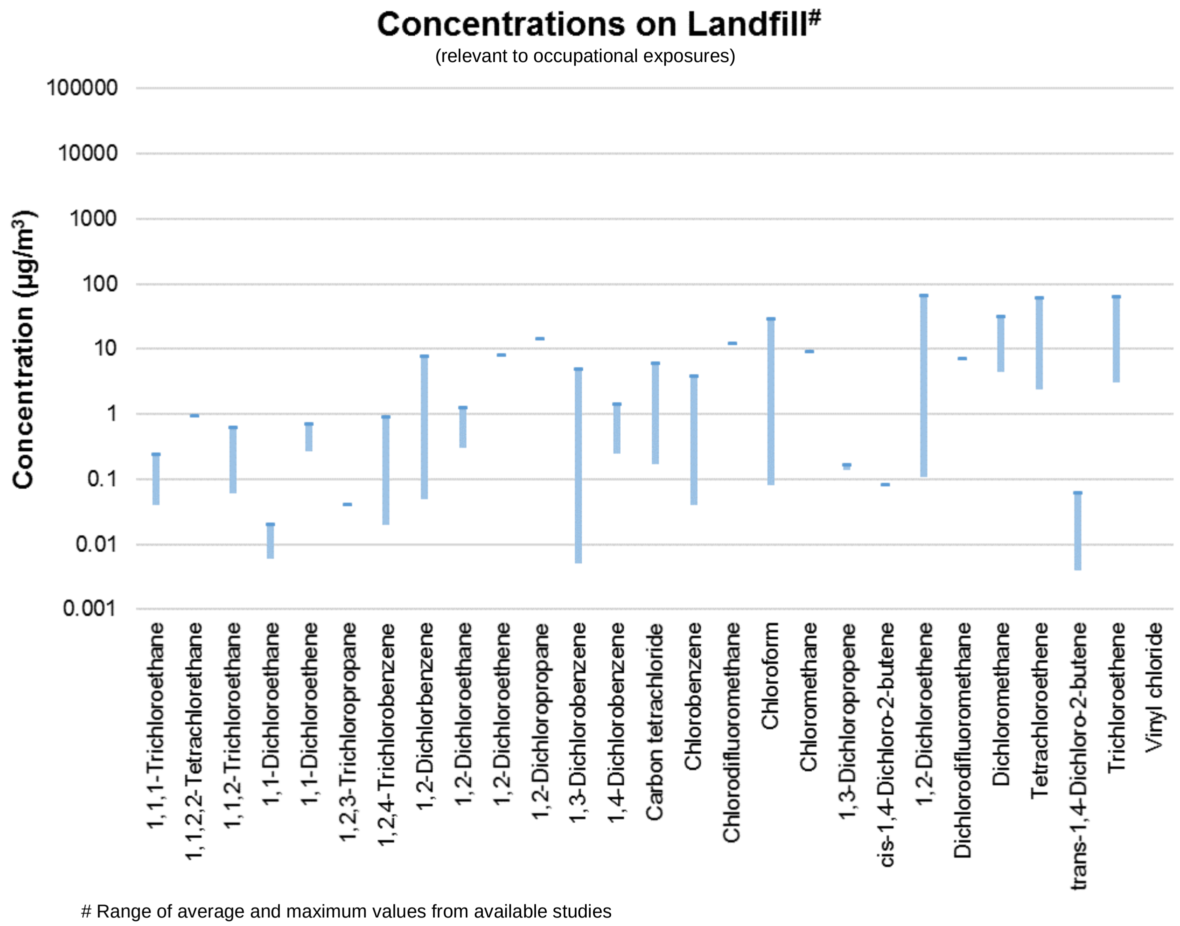


Figure 10: Chlorinated Hydrocarbons – Summary of Air Concentrations Reported on Landfills

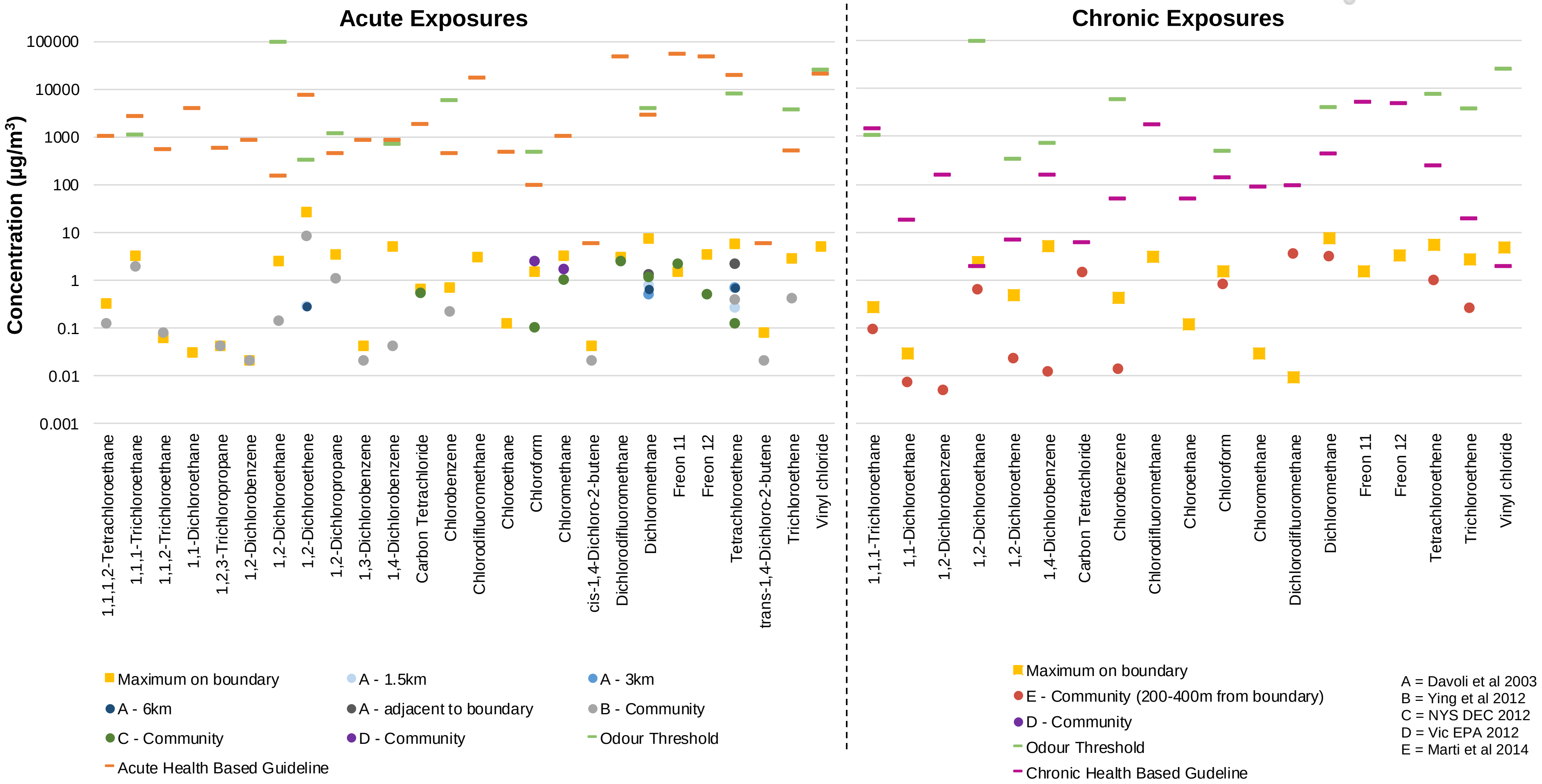


Figure 11: Chlorinated Hydrocarbons - Review of Reported Air Concentrations on Boundary and in Off-Site Community

Figures 10 and 11 show the following:

- **Data**: A range of chlorinated hydrocarbons have been reported in air on landfills, as well as on the boundary and off-site. The maximum concentrations reported on the landfill, and on the boundary are generally higher than reported in off-site community areas;
- **Odour**: All concentrations reported on the boundary and off-site are below the available odour thresholds;
- **Acute (irritation) health effects**: All short-term/peak concentrations are below the acute community health guideline;
- **Chronic**: Most concentrations reported from longer duration samples are lower than the chronic community health guidelines. The exceptions are the maximum concentrations of 1,2-dichloroethane and vinyl chloride reported on a landfill boundary. This is not where the community is exposed on a long-term basis, and data from within the community areas indicate concentrations are below the chronic community health guideline.

The above review indicates that the available data does not suggest the potential for significant health risk issues in relation to chlorinated hydrocarbons in air.

However, as the chlorinated hydrocarbons are considered to be harmful, and some data is available that shows some compounds may be present at elevated concentrations it is important that these are monitored in any Australian LFG air monitoring program.

3.5.8 Esters

Esters are derived from alcohols or acids, and are widespread in nature, and are responsible for the aroma of many fruits. These chemicals are also man-made. Esters comprise some smaller volatile chemicals as well as larger more complex long-chain esters such as vegetable fats and oils.

In general esters are not considered to be particularly harmful as many of these are commonly present in fruits and other food products.

Esters are characterised by a range of compounds with an ethereal, sweet, fruity, solvent and sometimes pungent type of odour. These compounds are present in landfill waste from a range of flavour and fragrance agents, solvents, cosmetics, pharmaceuticals, cleaning products, paints and adhesives (Gallego et al. 2012). These compounds may also be formed in a landfill.

A range of esters have been reported in landfill gas (refer to **Appendix A**), with a significant range of concentrations reported. Some of the common volatile esters (butyl acetate, ethyl acetate and methyl acetate) have also been detected in the surface flux emissions from a landfill (Gallego et al. 2014).

Figure 12 presents a summary of the concentrations of esters reported on a landfill, and on the boundary and off-site. Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

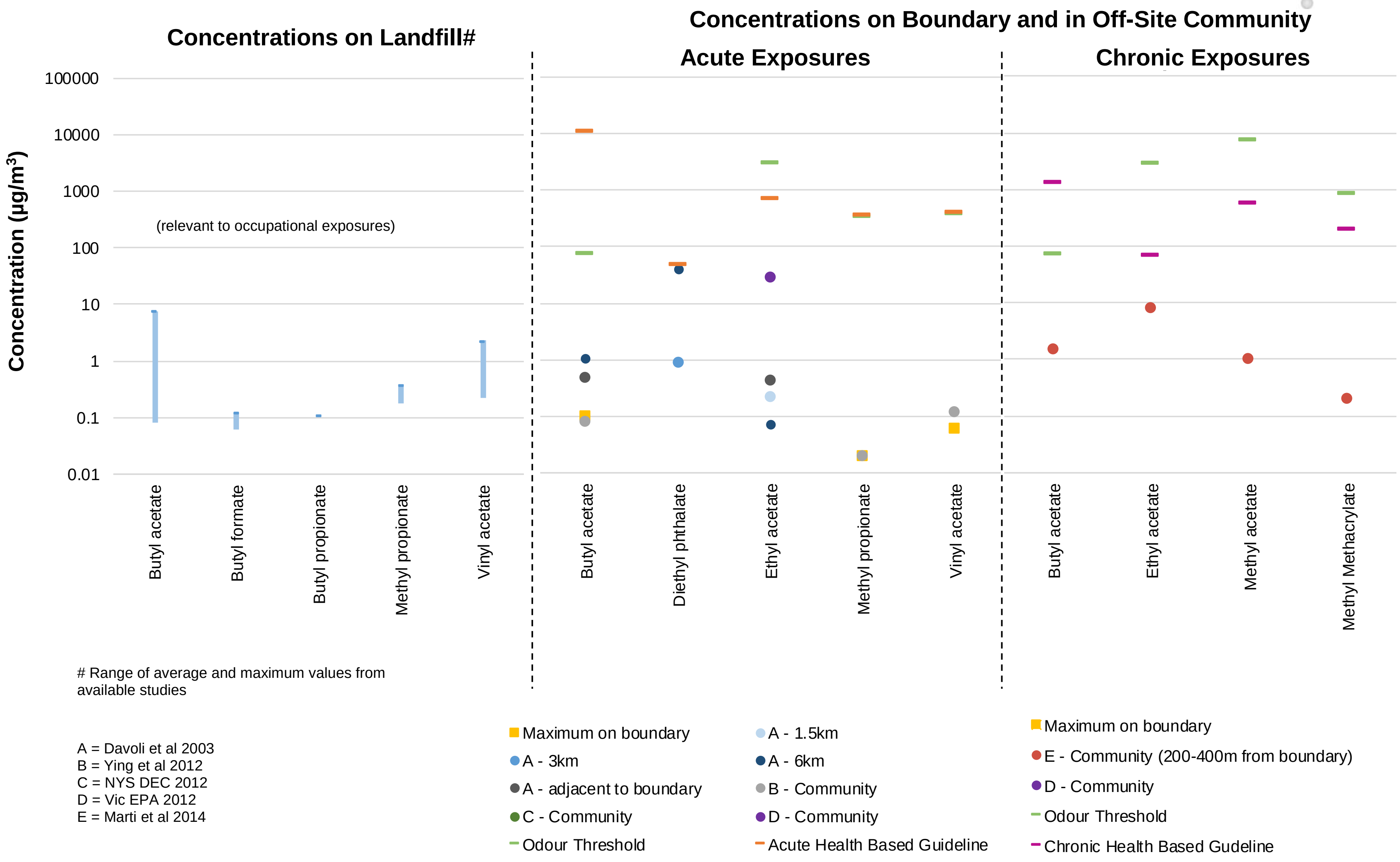


Figure 12: Esters - Review of Reported Air Concentrations

Figure 12 shows the following:

- **Data**: There is limited data available on the concentration of esters in air on and around landfill sites;
- **Odour:** All concentrations reported on the boundary and in the off-site community are well below the available odour thresholds;
- **Acute (irritation) health effects**: All concentrations reported on the boundary and in the off-site community are below the available acute community health guidelines;
- **Chronic health effects**: All concentrations reported on the boundary and in the off-site community are well below the available chronic community health guidelines.

On the basis of the above no health risk issues of concern are identified in relation to the potential presence of esters in air from non-hazardous waste landfills.

3.5.9 Ethers

This is a group of chemicals that include an ether group. Many ethers are gaseous at room temperature or are considered to be volatile. Ethers are characterised by a range of compounds with an ethereal, terpene-like, minty and sometimes unpleasant odour. These compounds are present in landfill waste from a range of fuels, solvents, plastics and flavour agents (Gallego et al. 2012). These compounds may also be formed in a landfill.

Limited data is available for ethers so a graph has not been prepared for these chemicals. A limited number of ether compounds have been reported in landfill gas (refer to **Appendix A**) and in surface flux emissions from a landfill (Gallego et al. 2014).

No data is available on ethers present in air on a landfill. Data is only available for boundary concentrations from one landfill in Spain (refer to **Appendix C**). The concentrations reported are all well below the available odour thresholds as well as the acute and chronic community health guidelines.

3.5.10 Sulfur Compounds

This is a group of chemicals that include sulfur. There are a number of sulfur compounds that are volatile and are generally characterised by strong, disagreeable, sulphurous, vegetable, eggy, cheese or dairy types of odours. Humans and other animals are highly sensitive to the odour of some sulfides. Most sulfur compounds are naturally occurring.

Sulfides are generally considered to be harmful, with the thiol, or mercaptan, compounds of more concern.

These compounds are present in landfill waste from flavour and fragrance agents, cosmetics, rubbers, textiles and insecticides (Gallego et al. 2012). These compounds may also be formed in a landfill.

A range of sulfur compounds have been reported in landfill gas (refer to **Appendix A**), with a significant range of concentrations reported. A limited amount of data is available on concentrations that may be present on the boundary and off-site.

Figure 13 presents a summary of the concentrations of sulfur compounds reported on a landfill, and on the boundary and off-site. Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

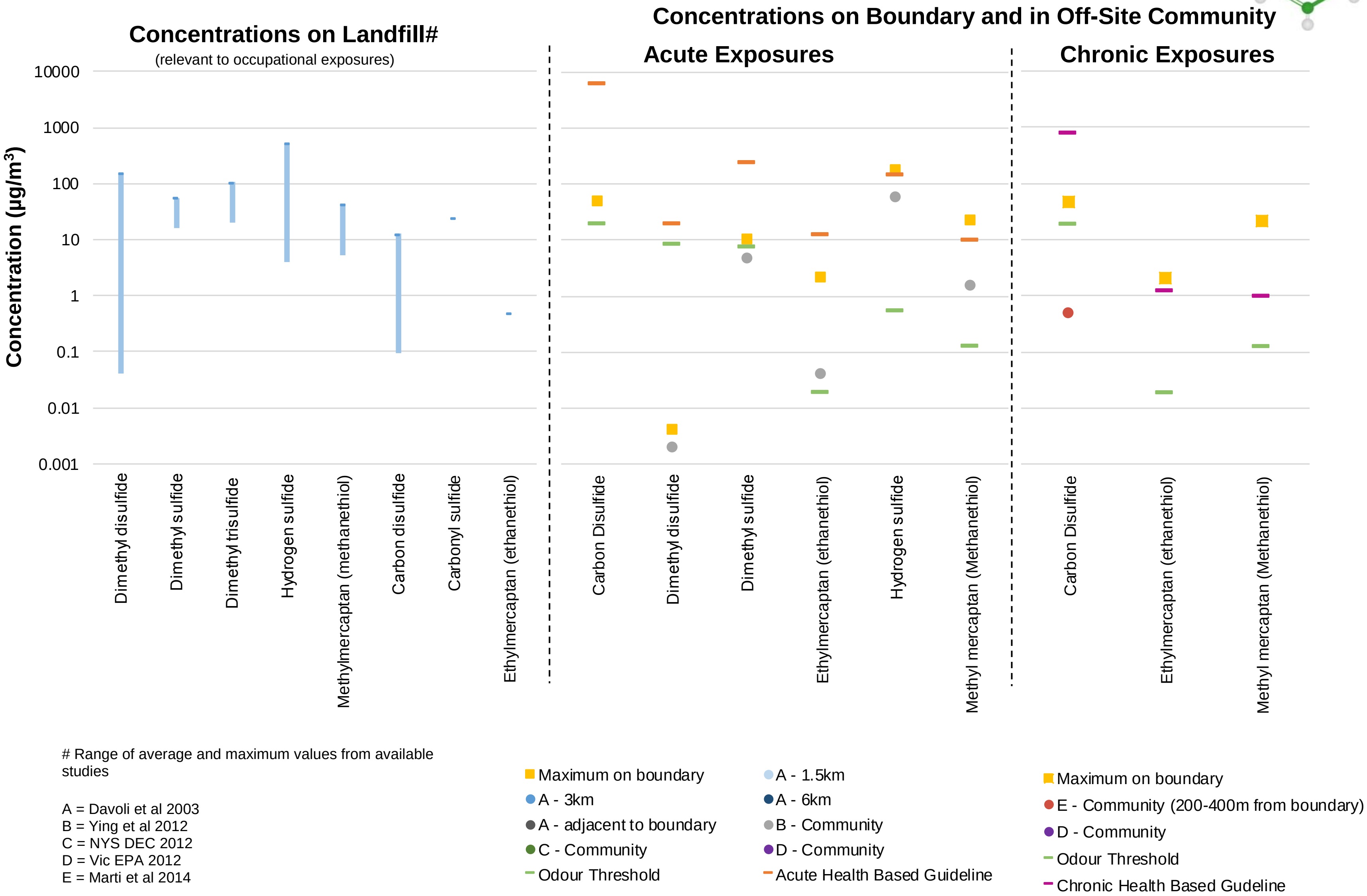


Figure 13: Sulfur Compounds - Review of Reported Air Concentrations

Figure 13 shows the following:

- **Data**: Concentrations reported on a landfill and on the boundary are generally higher than in off-site areas;
- **Odour**: The maximum concentrations reported on the boundary, and in some cases off-site, exceed the available odour thresholds for carbon disulphide, dimethyl sulfide, hydrogen sulfide, methyl mercaptan and ethyl mercaptan;
- **Acute (irritation) health effects**: Most short-term/peak concentrations are below the acute community health guideline, with the exception of hydrogen sulphide and methyl mercaptan, where the maximum concentration on a landfill boundary in China exceeded the guideline. The community is not exposed on the landfill boundary. The maximum concentrations reported from the same study, further down-wind in the community were below the acute community health guideline;
- **Chronic health effects**: Concentrations reported from longer duration samples are lower than the chronic community health guideline for carbon disulphide, however the maximum concentrations of ethyl mercaptan and methyl mercaptan exceed the chronic health guidelines on a landfill boundary in the UK. This is not where the community is exposed on a long-term basis, however data is not available from the study (where elevated concentrations were reported) to determine concentrations that may be within the off-site community. These chemicals may require further monitoring and assessment for chronic health issues.

The above review indicates that the available data does not suggest the potential for significant health risk issues.

However, it is noted that the key sulfur compounds detected are considered to be odorous and harmful and given the elevated concentrations reported at landfills in the UK and China, it is important that these are monitored in any Australian LFG air monitoring program

3.5.11 Terpenes and Terpenoids

This is a wide range of organic chemicals produced by a variety of plants, in particular conifers. They are also produced by some insects. These compounds have strong odours, with may being produced to protect the plants by deterring herbivores and attracting predators. Terpene and terpenoids are the major component of the essential oils present in many plants and flowers. As such these compounds are commonly used as fragrances. The compounds include a range of complex molecules that have a range of volatilities.

In general terpenes and terpenoids are not significantly harmful.

The range of odours associated with terpenes and tepenoids include woody, herbal, minty, fruity, citrus, sweet, pine, eucalyptus, tropical, spicy/peppery, balsam or camphor. These compounds are present in landfill waste primarily from a range of flavour and fragrance agents with other sources including insecticides, air fresheners, solvents, resins and pharmaceuticals (Gallego et al. 2012). These compounds may also be formed in a landfill.

A range of terpenes and terpenoids have been reported in landfill gas (refer to **Appendix A**), with a significant range of concentrations reported.

Figure 14 presents a summary of the concentrations of terpenes and terpenoids reported on a landfill, and on the boundary and off-site. Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

Figure 14 shows the following:

- **Data**: There is limited data available on the range of compounds that may be present or the concentration of terpenes and terpenoids in air on landfill sites; and
- **Odour:** All concentrations reported on the boundary and in the off-site community are well below the available odour thresholds;
- **Acute (irritation) health effects**: All concentrations reported on the boundary and in the off-site community are well below the available acute community health guidelines;
- **Chronic health effects**: All concentrations reported on the boundary and in the off-site community are well below the available chronic community health guidelines.

On the basis of the above no health risk issues of concern are identified in relation to the potential presence of terpenes and terpenoids in air from non-hazardous waste landfills.

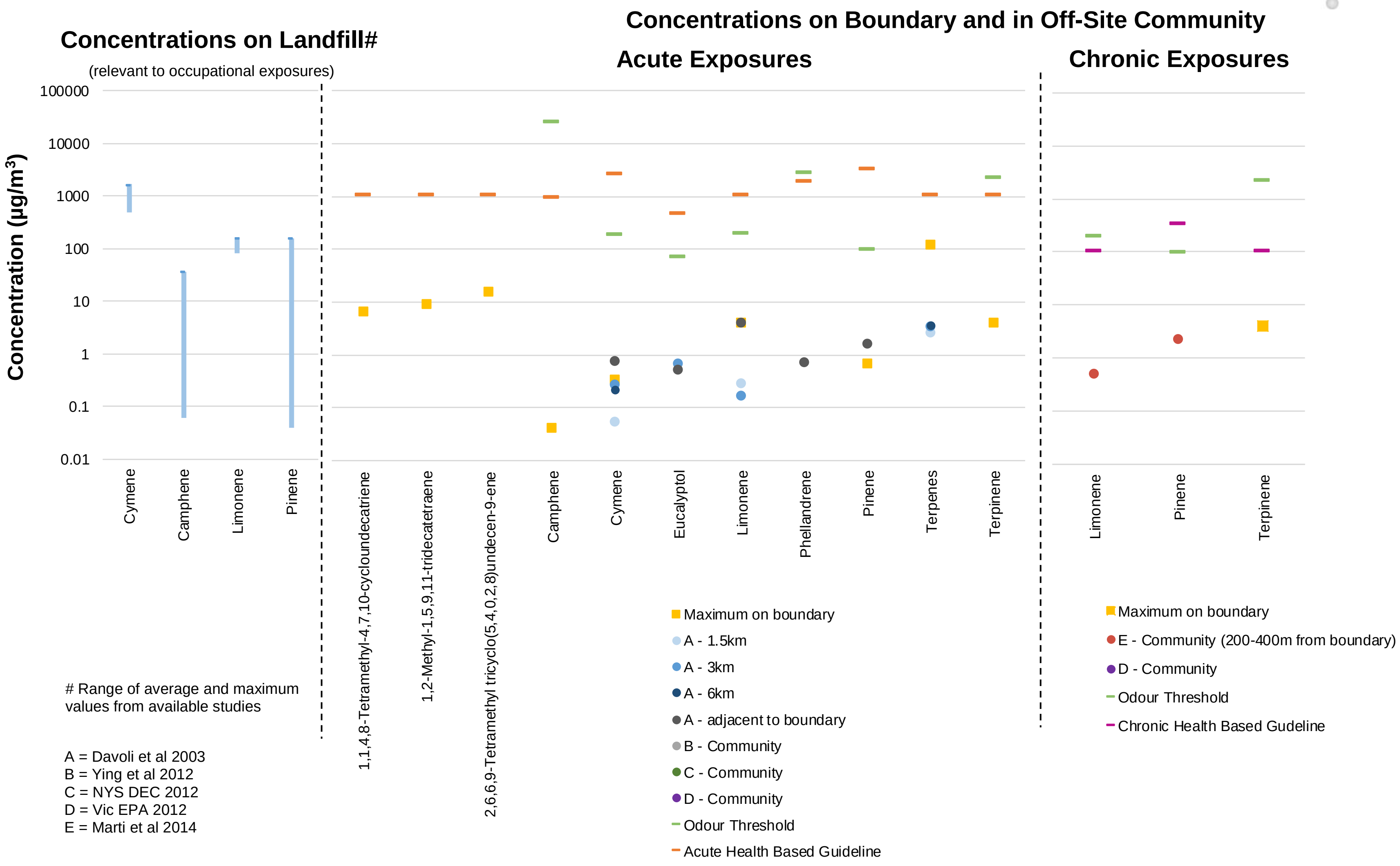


Figure 14: Terpenes and Terpenoids - Review of Reported Air Concentrations

3.5.12 Others

There are a range of other compounds reported in landfill gas or ambient air on a landfill, on the landfill boundary or in the community. These include a range of compounds commonly found in solvents, paints, fuels, cosmetics, pharmaceuticals, consumer products, personal care products as well as flavour and fragrance agents. Some of these chemicals are odorous and some are considered more harmful than others, in particular the isocyanate compounds, acrylonitrile, trichloroaniline and 1,3-butadiene (also classified as a known human carcinogen (IARC 2016)).

A range other compounds have been reported in landfill gas (refer to **Appendix A**).

Figure 15 presents a summary of the concentrations of these other compounds reported on a landfill, and on the boundary and off-site. Data relevant to concentrations on the boundary and offsite have been reviewed in relation to acute exposures, with the data compared against odour thresholds and acute community health guidelines, and chronic exposures, with the data compared against odour thresholds and chronic community health based guidelines (refer to **Section 3.4**).

Figure 15 shows the following:

- **Data**: There is limited data available from landfill sites; and
- **Odour**: Most concentrations are below the available odour thresholds, with the exception of ammonia reported on a landfill boundary;
- **Acute (irritation) health effects**: All concentrations reported on the boundary and in the off-site community are well below the available acute community health guidelines;
- **Chronic health effects**: Most of the concentrations reported from longer duration samples are lower than the chronic community health guideline. The exceptions are for concentrations of cyclohexyl isocyanate and cyclohexyl isothiocyanate reported in air approximately 200-400m from a landfill boundary in Spain. While the data used in the review of chronic health effects is limited and does not reflect concentrations that may be in the community over a full year, these compounds are considered to be harmful and hence they may require further monitoring and assessment of chronic health issues.

The above review indicates that the available data does not suggest the potential for significant health risk issues.

However, limited data is available to evaluate these compounds in air at landfills. It is therefore important that some of these other compounds, specifically cyclohexyl isocyanate and cyclohexyl isothiocyanate, are monitored in any Australian LFG air monitoring program.

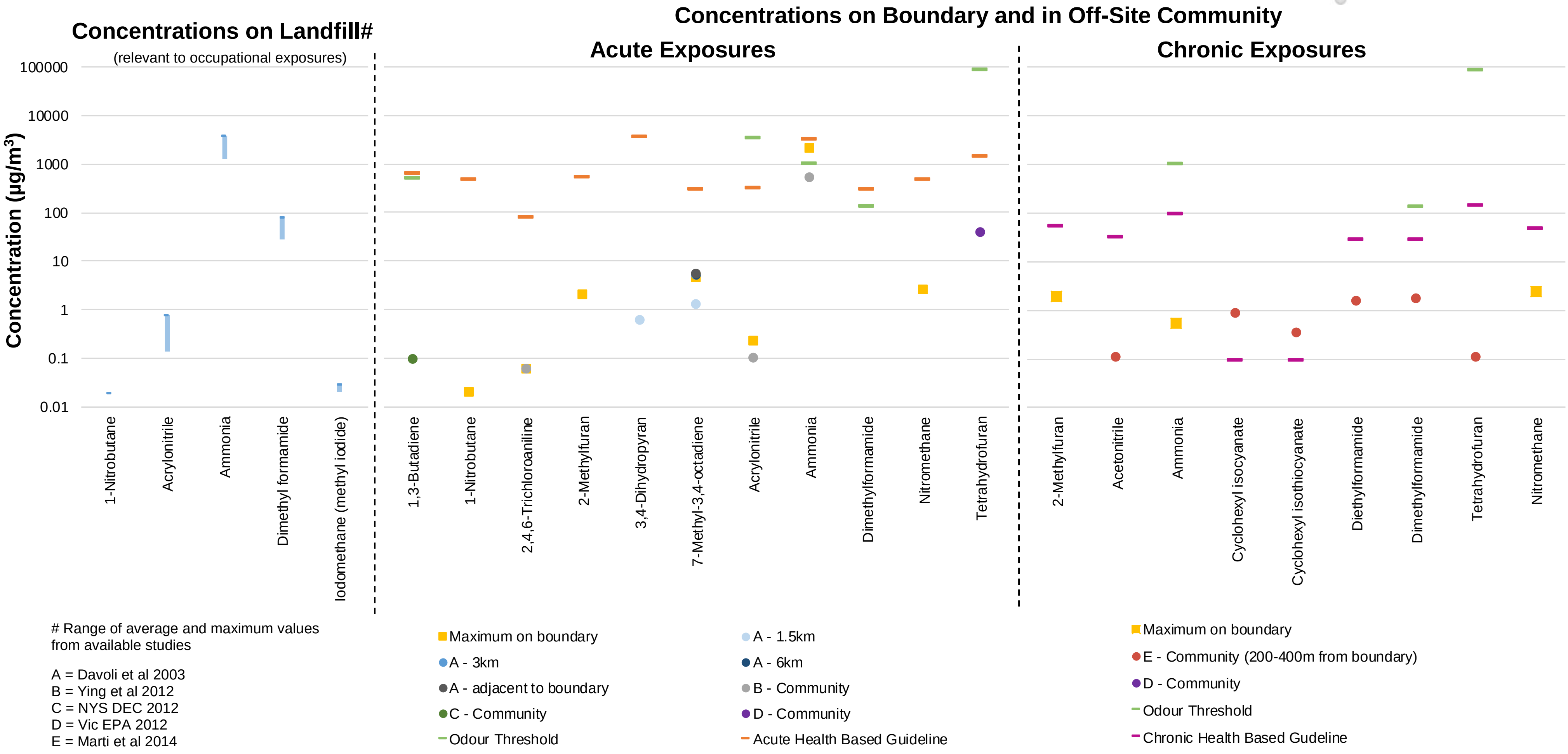


Figure 15: Other Compounds - Review of Reported Air Concentrations

3.6 Overview of Landfill Gas Data

Data is available from non-hazardous waste landfills that has been used to understand the nature and range of concentrations that may be present in gases inside, and released to ambient air from these landfills.

Much of the available data relates to landfills located in the UK, Spain, Italy, China and the US. Limited data is available from landfills in Australia. Hence there are limitations to the relevance of the data to landfills located in Australia.

The review has identified that there are a number of gases and VOCs detected in air that exceed the available odour thresholds for the individual chemicals. This indicates that landfill gas on the boundary, and at times in the community, may be odorous. It is more difficult to define odours associated with the presence of mixtures of gases and VOCs, which may be more odorous than the individual chemicals.

In addition, the data has been reviewed to determine if there are any gases or VOCs that have the potential to be present at concentrations that may be of particular concern to the health of off-site communities. Most of the gases and VOCs reported in ambient air on the boundary and in off-site communities are not of concern in relation to health. However, there is limited data for some compounds (especially data that is relevant for the assessment of chronic exposures) and some compounds are close to the guidelines. Given this, it is recommended that additional data be collected from Australian, or Victorian non-hazardous waste landfills. The monitoring program should include the following:

- Collection of ambient air data on landfill sites, near active tipping and handling areas and in covered/closed areas;
- Collection of ambient air data from the boundary and off-site community;
- Data collection protocols should not only target short-term sampling commonly associated with odour events, it should also include data from the closest community areas sampled over a longer period of time (i.e. multiple week sampling times, or repeated 24-hour or longer sampling events) to enable acute or chronic health risk issues to be assessed;
- The air sampling program should also include background air sampling (i.e. from the community but well away from the landfill) and record details on other sources of air emissions in the area (e.g. industry, vehicle traffic, rail etc.).
- The sampling should to target the following gases and VOCs in air:
    - Aldehydes
    - Aromatic hydrocarbons
    - Chlorinated hydrocarbons
    - Organosulfur compounds
    - Ammonia
    - Cyclohexyl isocyanate and cyclohexyl isothiocyanate

Section 4. Health Effects Associated with Living near Non-Hazardous Waste Landfills

4.1 General

In **Section 3**, concentrations of chemicals measured in gases and VOCs at, and adjacent to, landfill sites overseas were compared to the available and relevant odour threshold and acute and chronic community health guidelines. This review indicated there were no health risk issues of immediate concern for the community in the vicinity of non-hazardous waste landfills, however recommendations for monitoring in Australia were provided.

Another way to determine if there may be health effects due to living near non-hazardous waste landfills is to review the available literature in relation to this issue. The RMIT (2013) review provided a summary of the available literature in relation to the assessment of health effects in areas located near non-hazardous waste landfills. The review included available studies to 2013 and concluded that living near a non-hazardous waste landfill does not have an adverse effect on the health of near-by residents. A summary of the review presented by RMIT (2013) is included in **Section 4.3**.

Since completion of the RMIT (2013) review, additional studies have been published. The largest of these studies relates to the assessment of health effects associated with living within 5km of landfills in Italy (Mataloni et al. 2016). Other, smaller studies are also available post 2013 (Ancona et al. 2015; Di Ciaula 2016; Mattiello et al. 2013) and these have also been considered in this review. Review of these studies is summarised in **Section 4.4**.

4.2 Reviewing Health Studies

The assessment of health effects in communities living near landfills has been largely undertaken through the use of epidemiology studies. When considering environmental health issues, these studies typically examine associations between an exposure variable (from a specific source or event) and a health outcome in a population e.g. lung cancer.

Epidemiology studies can present robust associations, and sometimes causations, between exposure to a source, or event, and effects on the health of the population. However, as these studies are very complex they need to be interpreted with care as there are many factors that can affect the validity of the study. The main factors that need to be considered are: bias (including prejudice or preconceived ideas), confounding factors (other exposures and behaviours that may cause the same effect) and chance (the random possibility of something happening). The most common, and more difficult factors to address are confounding factors. These are typically external factors (i.e. not the exposure being evaluated) that also affects the health effects being evaluated e.g. an assessment of a specific exposure on rates of lung cancer is confounded by smoking related exposures.

To ensure that the outcomes of these studies can be relied on there are a number of publications that outline tools that should be used to review the study (Zaccai 2004). It is important to review these studies to determine if they support a cause (i.e. exposure) and effect (i.e. specific health effects) relationship.

Most diseases are caused by multiple factors and hence it is difficult to show a specific exposure changes the prevalence or progression of disease in the community. Most studies are undertaken with populations who are freely living in their normal environment, which has many factors that can affect disease (i.e. confounding factors).

When determining if the study can support a cause and effect relationship for a specific exposure, the Bradford Hill (Hill 1965) criteria are used. This provides 9 criteria that are the minimum required to be able to establish a cause and effect relationship. These criteria were originally presented by Austin Bradford Hill (1897-1991), a British medical statistician, as a way of determining the causal link between a specific factor (e.g., cigarette smoking) and a disease (such as emphysema or lung cancer). Hill's criteria form the basis of establishing scientifically valid causal connections between potential disease agents and the many diseases that afflict humankind. Hill (Hill 1965) states:

> *"None of these nine viewpoints can bring indisputable evidence for or against a cause and effect hypothesis …. What they can do, with greater or less strength, is to help answer the fundamental question - is there any other way of explaining the set of facts before us, is there any other answer equally, or more, likely than cause and effect?"*

Reviews presented in **Section 4.4** have included more general reviews of the robustness of the study, with the larger study presented by Mataloni et al (2016) reviewed in conjunction with the Bradford Hill criteria.

4.3 Summary of Health Studies as Reviewed by RMIT

A detailed review of 66 studies between 1981 and 1998 related to the assessment of health impacts for individuals living near specific hazardous waste sites has been undertaken (Vrijheid 2000). This review relates to impacts associated with emissions from hazardous waste site, including a number of contaminated sites (not landfills). While these studies, and the review is helpful in understanding the range of bias and confounding issue that are inherent in many of these studies, the outcomes are not relevant to evaluating health impacts from non-hazardous waste landfills.

Saffron et al. (Saffron, Giusti & Pheby 2003) prepared a balanced appraisal of the literature of the human health impact of various waste management practices using epidemiology studies published between 1982 and 1992. They reviewed epidemiology studies describing the health effects and exposure evidence for five key waste management processes, including landfill. The authors were very clear about their criteria for making judgements about the inclusion of the study in the review and the strength and reliability of the evidence for determining causality. They used an algorithm for deciding if the evidence was 'convincing', 'probable', 'possible' or 'insufficient'.

The authors (Saffron, Giusti & Pheby 2003) point out that the health impacts described in epidemiology studies are very non-specific and subject to the normal wide range of human variation. This makes attribution of a given health impact to the hazard in question virtually impossible.

When examining the evidence related to landfill studies, Saffron et al. (Saffron, Giusti & Pheby 2003) indicate that there are many studies in human populations (220 papers) looking at a variety of health outcomes. However, the main weakness of the studies is the complete lack of exposure data. As a result, despite a very large number of studies, the data for determining a causal association between landfills and health effects is deemed to be insufficient.

To specifically address the health effects associated with landfilling of municipal solid waste, the UK Department of Environment, Food and Rural Affairs (DEFRA) prepared a report in 2004 (DEFRA 2004). The DEFRA (2004) report focuses on emissions to air and deals with each substance of concern in turn, describing the reason for concern and ascribing the portion of the concern which is attributable to solid municipal waste, indicating whether there were other sources of exposure to that compound in the environment.

With respect to landfills, the report indicates that a single epidemiology study (albeit a large study) showed that there is a very small increased risk of adverse reproductive outcomes such as a birth defects and low birth weight for people living within 2 km of a landfill. However, other studies provide evidence that make this observation confusing (other studies show reduced levels of birth abnormalities after the opening of a landfill). The Defra report (2004) suggests that more research is required to confirm a causal relationship between living near a landfill and adverse reproductive outcomes.

With respect to cancer rates for people living within 2 km of a landfill, the DEFRA report (2004) found no evidence that living close to landfill sites increases the chance of getting cancer to a level that can be measured.

The DEFRA (2004) report concluded "..*that, on the evidence from studies so far, the treatment of municipal solid waste has at most a minor effect on health in this country particularly when compared with other health risks associated with ordinary day to day living*."

The DEFRA (2004) report points out that while there is information about emissions from landfills, there are very little data available on actual human exposure through eating, drinking or inhalation to these emissions, so they have used mathematical models to estimate this exposure. In the conclusion of the report, the authors suggest that a field study of population exposure to substances emitted from landfill sites is required to underpin the mathematical models and to ensure that there is strong evidence to confirm the lack of effect on human health due to landfills.

The Health Protection Agency (HPA 2011) produced a follow-up report to the DEFRA (2004) study. The report outlines the process they have undertaken and the data gathered on emissions from modern, controlled landfills in response to the data gaps and concerns raised in the 2004 Defra report. The data were evaluated by the UK Committee on Toxicity of Chemicals in Food (2009) which reviewed more recent epidemiology studies concerning birth defects, cancers and self-reported complaints, and developed Health Criteria Values (HCV) for the chemicals found on the sites.

The HPA report summarises the Environment Agency UK (EA 2010) study of four typical municipal waste landfill sites where concentrations were monitored of airborne chemicals, dusts and microorganisms at the boundaries of the sites. Over 90 chemicals were monitored. All potential exposure pathways were considered (e.g. water, land, air) during different times of day and differing weather conditions. Combined exposure to the measured chemicals was then compared with the UK health based guidelines (Health Criteria Values, HCV).

With respect to the concerns raised in the DEFRA (2004) report about increased adverse reproductive effects, the HPA commissioned an independent analysis of the areas reporting excessive rates of birth defects. While not perfectly clear, the re-evaluation of the sites suggests that these areas had high rates of birth defects even before the opening of the landfill sites. Other studies in Europe failed to find a correlation between living near landfills and adverse reproductive outcomes. After reviewing this and other evidence, the COT and the HPA indicate that there is no need for 'specific concerns or recommendations relating to pregnant women or those wishing to start a family who live in the vicinity of a landfill site'. The HPA review reaffirm that studies have shown that there is no excess risk of cancer in the population living close to landfill sites.

The HPA report concludes that: *After considering the current information on landfill sites, including the result of a number of epidemiological studies, the detailed monitoring study by the EA and advice sought from the Committee on Toxicity, the HPA concludes that a well-managed modern landfill site does not pose a significant risk to human health.*

4.4 Review of Recent Health Studies

4.4.1 Mataloni el al (2016)

Overview of paper:

This study (Mataloni et al. 2016) reports associations between health effects, specifically mortality from lung cancer and respiratory diseases; hospitalization for respiratory diseases and acute respiratory infections among children (0–14 years) and living in close proximity (taken to be within 5km) to landfills in the Lazio area in central Italy.

The study included all residents living within 5 km of the borders of landfills in the region on 1 January 1996, or those who later moved to the areas until 31 December 2008. The study included 242 409 individuals. Data was collected for natural and cause-specific mortality and hospital admissions for cardiorespiratory diseases. Respiratory hospital admissions for children (residents under 14 years) were also analysed.

Hydrogen sulfide (H_2S) was used as a surrogate marker for exposure to emissions from landfills.

Confounders, specifically gender, age, socioeconomic position, outdoor coarse particulates (PM_{10}) concentration and distance from busy roads and industries were reported to have been considered in the review of the data. No information on lifestyle factors were available.

The assessment utilised statistical evaluations of the information with the data evaluated for associations between hydrogen sulfide concentrations and health effects, as well as distance from the landfill and health effects.

Exposure issues:

A major flaw in this study is the lack of any evidence or indeed any measurement of exposure to emissions from landfill in the study area.

The study has used hydrogen sulfide as a surrogate/indicator measure of all contaminants emitted by landfills however the authors do not appear to attribute the reported health effects to exposure to hydrogen sulfide, but rather to some unknown and unquantified group of compounds emitted from the landfills. Landfill emissions are highly variable and strongly dependent on the type of waste and landfill management measures implemented (refer to **Section 3**). Therefore, hydrogen sulfide concentrations may not be a good indicator of concentrations of chemicals in air that have the potential to affect health in areas located adjacent to a landfill.

Further, the use of hydrogen sulfide as a surrogate is not based on any measurements of this gas in landfill gas, on the landfill or in the study area. The assessment is only based on modelled emissions of hydrogen sulfide from the landfills in the area. The modelling involved the following:

- Estimation of hydrogen sulfide emissions to air using a model, that uses emission rates and data from a USEPA inventory (i.e. not from any measurements from the landfills themselves, but from information on US landfills); and
- Modelling of the hydrogen sulfide emissions from the landfills to the community in the study area. Weather data from 2005 was used to estimate how hydrogen sulfide moved into the off-site community. This resulted in an annual average concentration of hydrogen sulfide being assigned to each person/location in the study area. The modelled average concentration does not make any allowance for variation over time or any time spent away from the home (i.e. going to work).

The authors note that nine municipal solid waste landfills have been operating in Lazio for several decades and for the last two decades (i.e. most of the study period) they were equipped with containment facilities (including leachate collection and treatment, landfill cap construction and landfill gas collection and treatment) which are designed to minimise release of harmful emissions. However, the measure of exposure used in the study does not relate to the landfills themselves, nor does the data reflect what the composition may be of landfill gas from these facilities, and the exposure is averaged such that no variability throughout a day or year could be considered.

Confounding factors:

The Mataloni et al (2016) study has indicated that it has taken into account a range of confounding factors. This includes gender, age, socioeconomic position, outdoor coarse particulates (PM_{10}) concentration and distance from busy roads and industries.

In relation to urban air pollution, the study has only considered exposure to PM_{10}. These are coarse particulates that have a weak association between exposure and the health effects considered in this assessment. Strong and causal associations have been found between exposure to fine particulate ($PM_{2.5}$) (USEPA 2009, 2012) and ozone (WHO 2013) and the same health effects considered in the Mataloni et al (2016) study. Exposure to fine particulates varies not only with what is measured in urban air, but daily activities undertaken by individuals. These exposures have not been addressed in the study.

The impact of emissions from local industries has not been well accounted for in the study. These emissions are not defined or characterised and it is expected that they include chemicals that lung cancer and respiratory health effects. The data provided in the supplementary materials to the Mataloni et al (2016) paper have been evaluated and where the populations that are located close to industry are removed from the analysis, there are no statistical associations remaining between hydrogen sulfide and health effects. This suggests that the health effects reported may be associated with living near the industrial areas, rather than living near a landfill.

Review of cause-effect relationship:

The following presents a review of the data and evaluation presented in the Mataloni et al (2016) paper against the 9 Bradford-Hill viewpoints/criteria:

1. Strength (effect size): *A small association does not mean that there is not a causal effect, though the larger the association, the more likely that it is causal*.

The statistically significant associations between exposure to hydrogen sulfide that have been reported in the paper are:

- Mortality from lung cancer; and

- Hospitalization for respiratory diseases especially acute respiratory infections among children (0–14 years).

The statistical associations presented are considered to be weak, and when populations living near industrial areas are removed, the statistical associations are no longer present.

2. Consistency (reproducibility): *Consistent findings observed by different persons in different places with different samples strengthens the likelihood of an effect*.

Reviews available to 2013 did not find sound associations between landfills and health effects in individuals living in close proximity (refer to **Section 4.3**). This related to the rates of cancer as well as hospitalisations for respiratory disease. An extensive review of the relevant literature (Mattiello et al. 2013) found several papers citing an increase in hospitalisation for respiratory diseases such as asthma in areas nearby special waste dumps receiving industrial waste but not for ordinary municipal landfills, i.e. non-hazardous waste landfills.

While there are limitations identified for the earlier studies, specifically in relation to the characterisation of exposure, these do not support the outcomes of the current study (Mataloni et al. 2016). It is noted that the current study also has limitations associated with the characterisation of exposure (as discussed above).

The findings in the Mataloni et al (2016) study are not consistent with the extensive literature previously published and reviewed.

3. Specificity in the causes. *In the ideal situation, the effect has only one cause. In other words, showing that an outcome is best predicted by one primary factor adds credibility to a causal claim*.

The claimed specific effects are lung cancer and hospitalization for respiratory diseases especially acute respiratory infections among children (0–14 years) hospitalisation. Lung cancer is primarily and overwhelmingly a disease of smokers (accounting for 90% of cases in men and 75% of cases in women) and can be synergised by co-exposure to substances such as asbestos and radon (note radon is not relevant in Australian settings). Various hazardous air pollutants such as PIC (products of incomplete combustion including diesel exhaust fumes), 1,3-butadiene, hexavalent chromium, benzene and others also contribute to lung cancer rates. Similarly, hospitalisations for asthma and respiratory diseases are strongly associated with photochemical pollution (e.g. ozone) and exposure to fine particulate matter ($PM_{2.5}$).

There is strong evidence linking lung cancer and respiratory hospitalisations in children to primary causes expected to also be present in the study area, other than proximity to landfill sites.

4. Temporality: *The effect has to occur after the cause (and if there is an expected delay between the cause and expected effect, then the effect must occur after that delay).*

Minimum latency period[3] estimates have been reported in the literature for lung cancer associated with exposure to asbestos (19 years), hexavalent chromium (5 years) and soot (9 years). The latency period for smoking induced lung cancer is reported as 13.6 years.

The latency period considered in the Mataloni et al (2016) study for mortality is 5 years, and for hospitalisations no latency period is used. These latency periods are not associated with any specific exposure related to landfill emissions as the study has not been specific in defining exposure, other than using modelled non-site specific hydrogen sulfide as a surrogate.

There is no means by which the temporality of exposure to an unknown suite of compounds from landfill emissions (that have not been characterised) and reported health effects (asthma, respiratory hospitalisations and asthma) can be deduced from the Mataloni et al (2016) study.

5. Dose Response Relationship. *There should be a direct relationship between the risk factor (i.e., the independent variable) and people's status on the disease variable (i.e., the dependent variable).*

The Mataloni et al (2016) paper uses non-site specific modelling to simulate hydrogen sulfide concentrations around the landfills and to produce maps of annual average concentrations around the sites. Weather data was from 2005 and was presumed to represent each year of the study. Each subject in the cohort was assigned a hydrogen sulfide exposure value corresponding to the estimated annual average value from the dispersion model at the baseline address. No actual exposure measurements were taken.

Further, the modelled exposure data is compromised by:

- The use of meteorological data from one year rather than each specific year of exposure. i.e. no exposure variation over time was considered and each person remained at the same exposure level during the all study period; and
- No allowance has been made for possible zero exposure for a significant part of the day if a worker travelled away from the area during the working day.

This uncertainty in exposure data makes drawing a link between exposure, assumed to be from landfills, and health effects (e.g. lung cancer) very problematic and a dose-response relationship (which defines any relationship between the two things) unable to be confirmed.

[3] A latency period is the time that passes between exposure to something that causes disease and having symptoms.

6. Plausibility: *A plausible mechanism between cause and effect is helpful (but Hill noted that knowledge of the mechanism is limited by current knowledge).*

The nature of the cause (landfill emissions) is un-measured and unknown as no specific pollutants are described. The effects (lung cancer, respiratory admissions and asthma) are defined but have biological plausible alternative causes. e.g. smoking and general urban air pollution. There is no attempt in the Mataloni et al (2016) paper to provide a mechanistic link between cause and effect.

7. Coherence: *A cause-and-effect interpretation for an association is clearest when it does not conflict with what is known about the variables under study and when there are no plausible competing theories or rival hypotheses. In other words, the association must be coherent with other knowledge.*

As noted previously, there is a conflict between the cause (unknown in nature) and the effects (associated with specific behaviours or air pollutants).

Additionally, it is noted that the communities around the Albano and Guidonia landfills (see supplementary data) are in close proximity to industrial areas. If either of these communities is left out of the analysis, then the association between hydrogen sulfide and respiratory morbidity for children disappears. Similarly, removing Guidonia from the analysis removes the association between hydrogen sulfide and lung cancer mortality. This means that it is possible that pollutants associated with the industrial areas rather than the landfills are associated with the adverse health effects reported.

8. Experiment evidence: *Any related research that is based on experiments will make a causal inference more plausible.*

There does not seem to be any experimental evidence (e.g. human volunteer studies, animal exposure chambers) which exists to link general non-hazardous waste landfill emissions and the reported health effects. There is experimental evidence for individual pollutants expected to be released from landfills as gases and VOCs, and these form the basis of the individual acute and chronic community health guidelines adopted in the review presented in **Section 3**. Some of the individual chemicals have been associated with lung cancer and respiratory disease. These chemicals also have sources other than landfills, being commonly released to air from industry, combustion sources and also commonly present in household items. The level of individual exposure to these chemicals, and the presence of these chemicals in landfill gas emissions in the study area is not known.

9. Analogy: *The effect of similar factors may be considered*.

Special or hazardous waste landfills and incinerators could be considered analogous situations to municipal wastes. The former two types of sites have fairly strong associations with adverse health effects including the ones reported in this paper. However, the reviews of the research (Mattiello et al. 2013) that identified those associations specifically dismisses a similar link between ordinary municipal landfills and health effects.

Overall the conclusions of the Mataloni et al (2016) paper cannot be supported. When reviewed in detail the paper does not show that living near non-hazardous waste landfills is associated with increased incidence of lung cancer or hospitalisations for respiratory disease.

4.4.2 Other Studies

An earlier study (Ancona et al. 2015) undertaken by the same team that completed the Mataloni et al (2016) paper involved a retrospective review of a population in a suburb of Rome (Italy), living near a municipal waste landfill, medical waste incinerator and petrochemical refinery. The study modelled emissions to air from the landfill using hydrogen sulfide as an indicator compound. In addition, the study used PM_{10} as an indicator for emissions from the incinerator and sulfur dioxide as an indicator for the refinery emissions. This paper has similar issues in relation to defining exposure as outlined for the Mataloni et al (2016) paper. However, unlike the Mataloni et al (2016) paper, the study did not find an association between exposure and all-cancer mortality. The paper suggests a weak association between air contamination and cardio-respiratory disease, but there is no clear understanding of the specific nature of the exposure that may be linked with this observed effect (i.e. not known if this is from landfill emissions, emissions from the incinerator or petrochemical plant).

Mattiello et al (Mattiello et al. 2013) conducted a review of the available evidence (from 19 papers on landfills and 13 papers on incinerators) related to potential health effects and living near landfills and incinerators. Overall the review identified a possible increased risk of newborns with defects associated with hazardous (mixed waste or special waste) landfills but little evidence for an effect where the landfill accepts non-hazardous or urban waste. The study also found an excess cancer risk for older technology incinerators and hazardous waste incinerators.

A study was undertaken to evaluate potential links between living near municipal waste landfills and gastric cancers (Di Ciaula 2016). This study considered a large number of individuals (4,099,547) living within 3 km of 16 regional landfills located in the Apulia region in southern Italy. The study did not find any statistical difference between individuals living near landfills and those in the control groups, although it notes a higher rate in males than females. It is noted that gastric cancer is strongly linked to lifestyle factors, high salt intakes and smoking, where the background incidence of these cancers is typically higher in males than females. Overall the study does not show a link between living near landfills and gastric cancers.

4.5 Overview of Health Studies

In summary, a number of studies are available that have the aim of determining if there are any specific health effects that can be associated with, or caused by, living near landfills. There is only one study, Mataloni et al (2016), that reported a link between health effects and proximity of non-hazardous waste landfills. However as noted above, the conclusion of this study cannot be supported upon detailed review. Overall, the available studies, including studies published to 2016, do not provide evidence that emissions to air from non-hazardous waste landfills have an adverse effect on the health of residents living nearby.

Section 5. Conclusions

An update of the RMIT (2013) review on the characteristics of gaseous emissions from non-hazardous waste landfills, whether there were any reported links between air emissions and the health of residents living near these landfills.

This review has considered a wide range of data on gases and VOCs that may be derived from non-hazardous waste landfills, the concentrations that may be present in air within adjacent communities, and if these have the potential to be of concern to human health. The review has also considered published studies, available to 2016, related to evaluating potential links between living near non-hazardous waste landfills and health effects.

The review has confirmed the findings of the RMIT (2013) review, that the available data does not show that living near a non-hazardous waste landfill is associated with adverse health effects. It is acknowledged that a number gases and VOCs (individually or as a mixture) released from non-hazardous waste landfills may be odorous and may affect the well-being of the local community.

Given the limited amount of data available that specifically relates to Australian landfills, it is recommended that additional data be collected from Victorian non-hazardous waste landfills to support the conclusions presented in this review. The monitoring program should include the following:

- Collection of ambient air data on landfill sites, near active tipping and handling areas and in covered/closed areas;
- Collection of ambient air data from the boundary and off-site community;
- Data collection protocols should not only target short-term sampling commonly associated with odour events, it should also include data from the closest community areas sampled over a longer period of time (i.e. multiple week sampling times, or repeated 24-hour or longer sampling events) to enable acute and chronic health risk issues to be assessed;
- The air sampling program should also include background air sampling (i.e. from the community but well away from the landfill) and record details on other sources of air emissions in the area (e.g. industry, vehicle traffic, rail etc.).
- The sampling should to target the following gases and VOCs in air:
    - Aldehydes
    - Aromatic hydrocarbons
    - Chlorinated hydrocarbons
    - Organosulfur compounds
    - Ammonia
    - Cyclohexyl isocyanate and cyclohexyl isothiocyanate

Section 6. References

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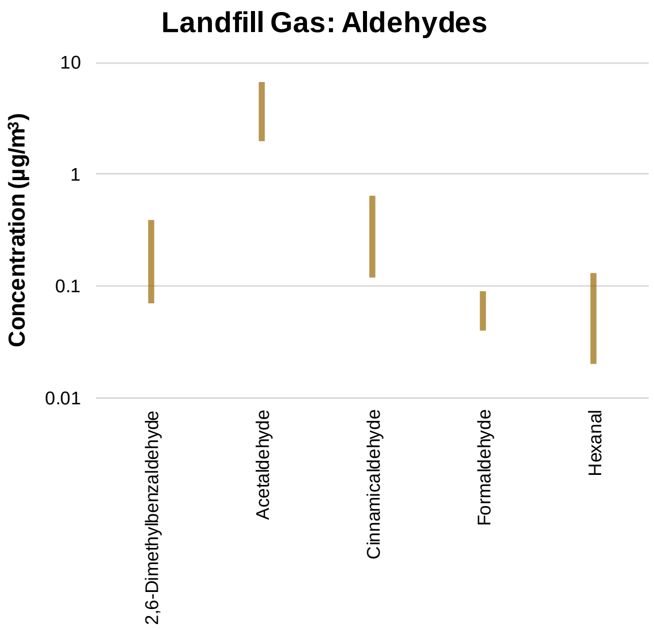
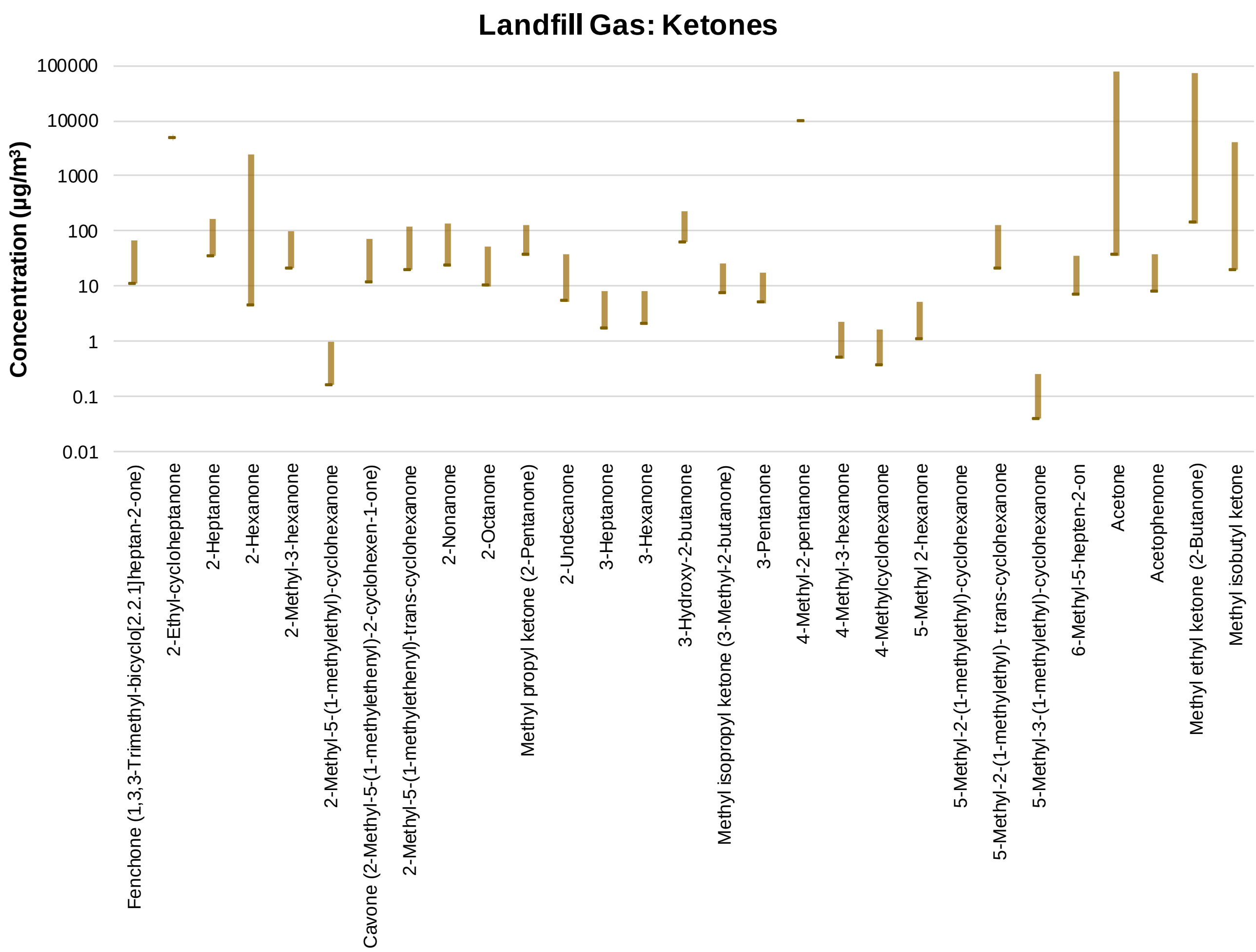
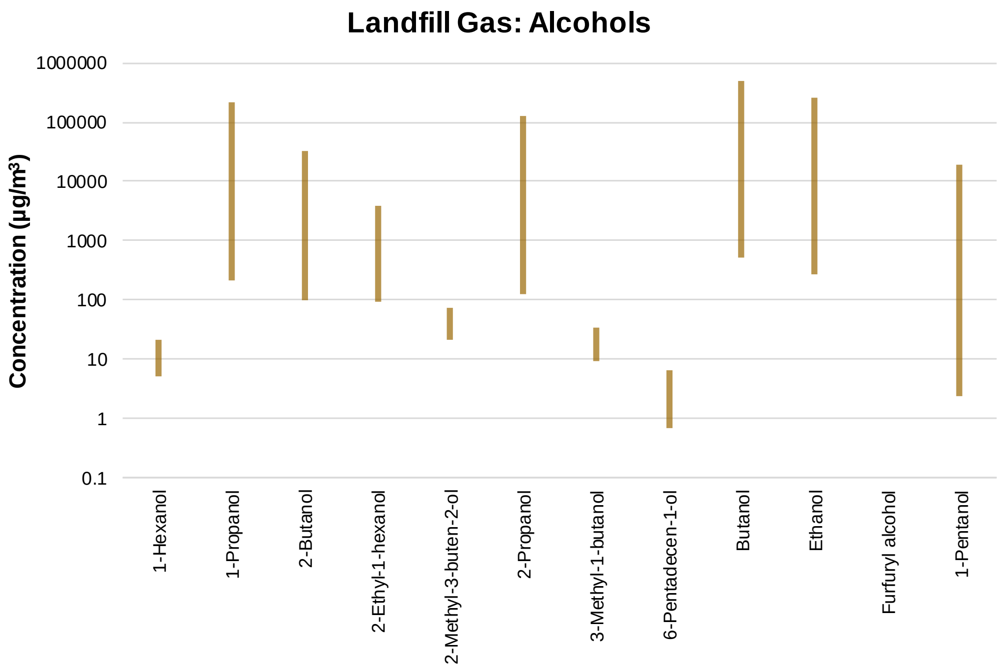
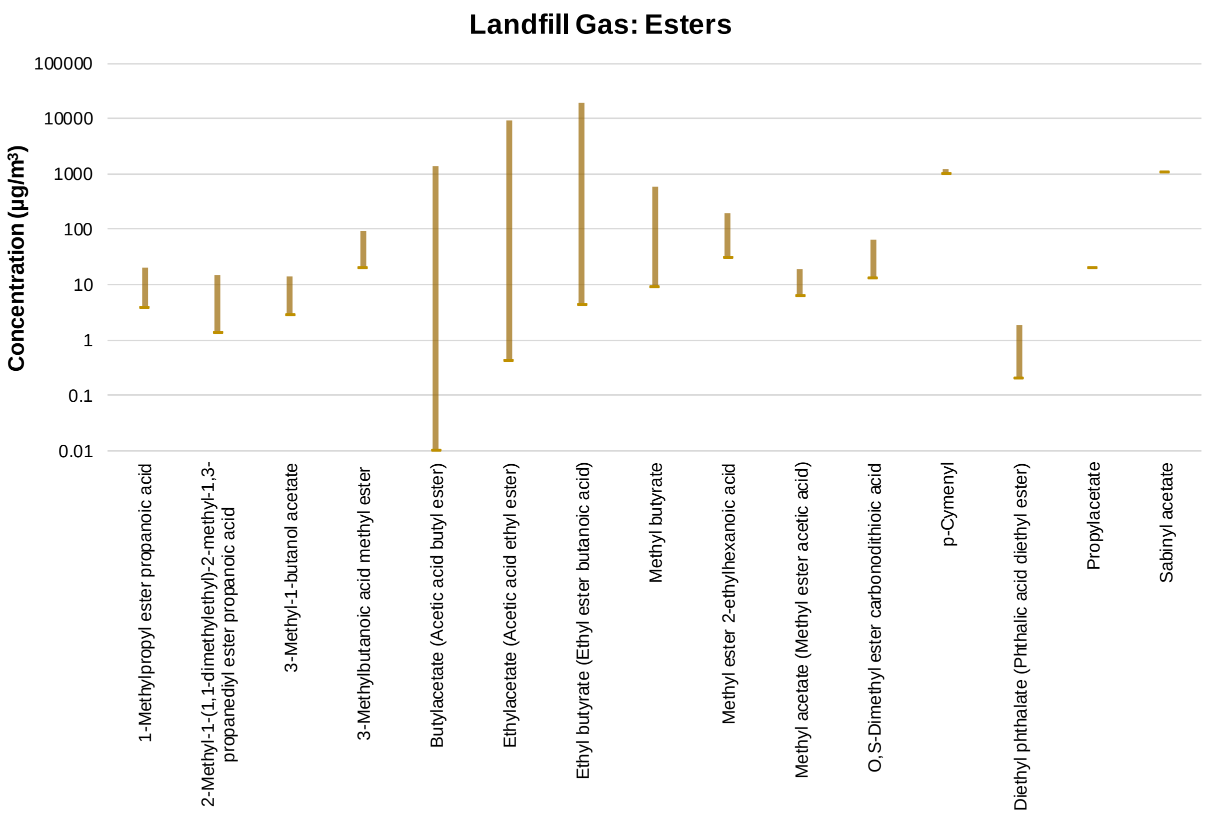
Appendix A Summary of Data: Landfill gas


Landfill Gas: Aldehydes
Concentration (µg/m³)
10
1
0.1
0.01
2,6-Dimethylbenzaldehyde
Acetaldehyde
Cinnamicaldehyde
Formaldehyde
Hexanal

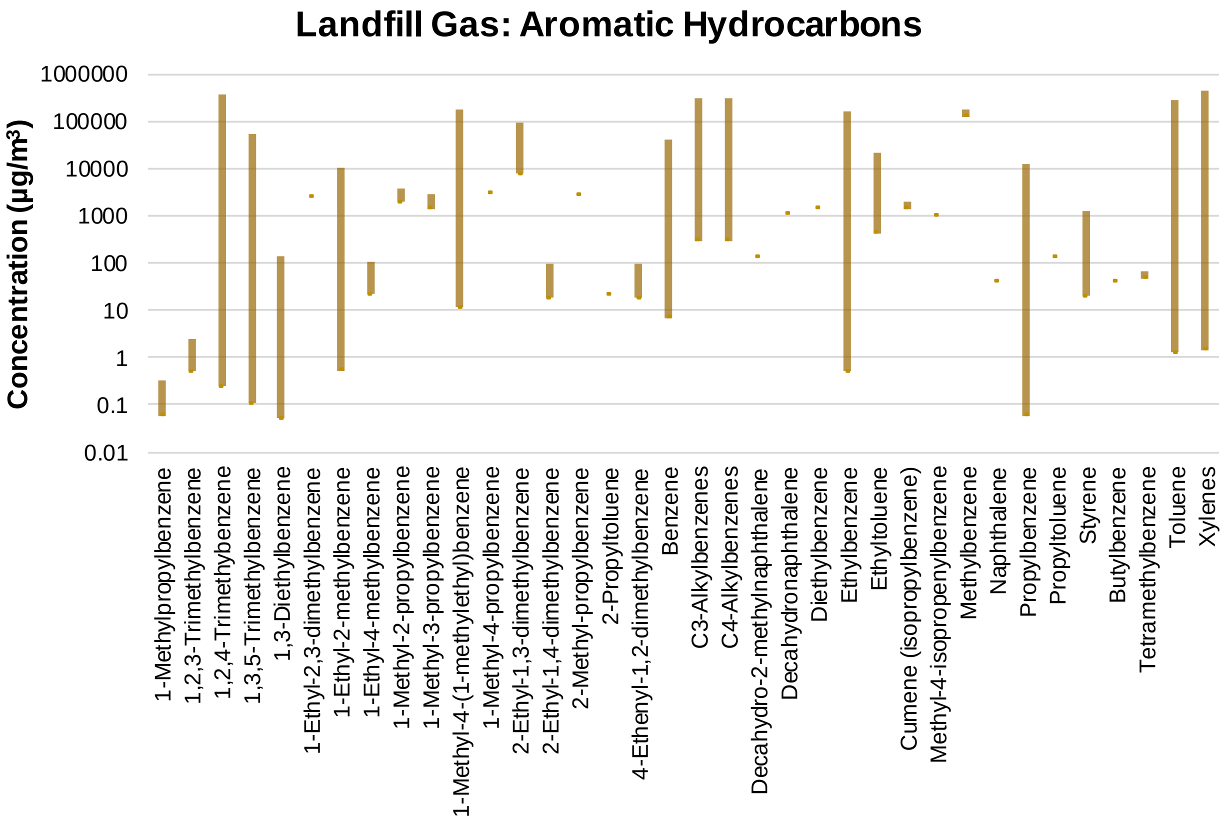

Landfill Gas: Ketones
Concentration (µg/m³)
100000
10000
1000
100
10
1
0.1
0.01
Fenchone (1,3,3-Trimethyl-bicyclo[2.2.1]heptan-2-one)
2-Ethyl-cycloheptanone
2-Heptanone
2-Hexanone
2-Methyl-3-hexanone
2-Methyl-5-(1-methylethyl)-cyclohexanone
Cavone (2-Methyl-5-(1-methylethenyl)-2-cyclohexen-1-one)
2-Methyl-5-(1-methylethenyl)-trans-cyclohexanone
2-Nonanone
2-Octanone
Methyl propyl ketone (2-Pentanone)
2-Undecanone
3-Heptanone
3-Hexanone
3-Hydroxy-2-butanone
Methyl isopropyl ketone (3-Methyl-2-butanone)
3-Pentanone
4-Methyl-2-pentanone
4-Methyl-3-hexanone
4-Methylcyclohexanone
5-Methyl 2-hexanone
5-Methyl-2-(1-methylethyl)-cyclohexanone
5-Methyl-2-(1-methylethyl)- trans-cyclohexanone
5-Methyl-3-(1-methylethyl)-cyclohexanone
6-Methyl-5-hepten-2-on
Acetone
Acetophenone
Methyl ethyl ketone (2-Butanone)
Methyl isobutyl ketone

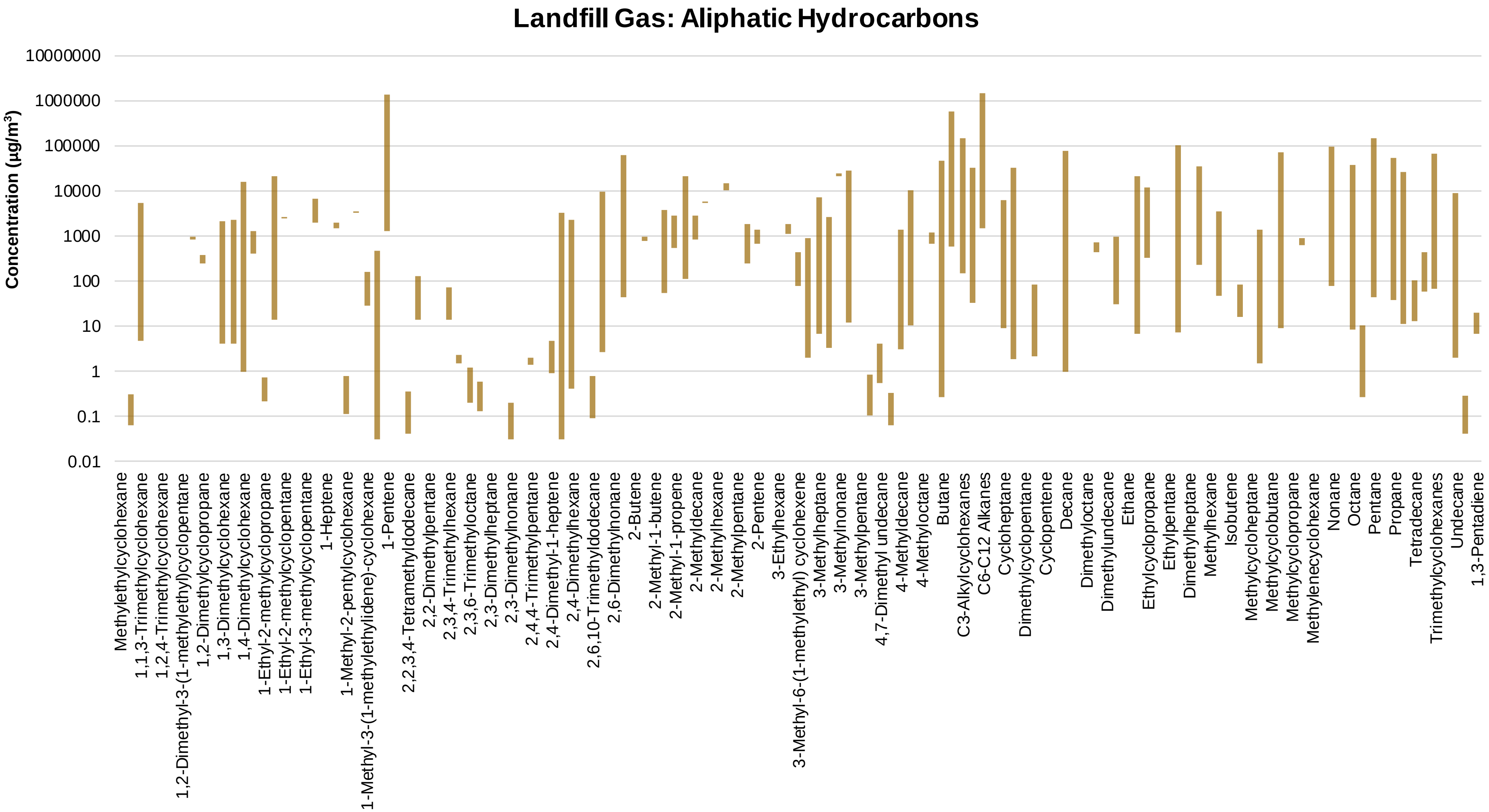


Landfill Gas: Alcohols
Concentration (μg/m³)
1000000
100000
10000
1000
100
10
1
0.1
1-Hexanol
1-Propanol
2-Butanol
2-Ethyl-1-hexanol
2-Methyl-3-buten-2-ol
2-Propanol
3-Methyl-1-butanol
6-Pentadecen-1-ol
Butanol
Ethanol
Furfuryl alcohol
1-Pentanol



Landfill Gas: Esters
Concentration (μg/m³)
100000
10000
1000
100
10
1
0.1
0.01
1-Methylpropyl ester propanoic acid
2-Methyl-1-(1,1-dimethylethyl)-2-methyl-1,3-propanediyl ester propanoic acid
3-Methyl-1-butanol acetate
3-Methylbutanoic acid methyl ester
Butylacetate (Acetic acid butyl ester)
Ethylacetate (Acetic acid ethyl ester)
Ethyl butyrate (Ethyl ester butanoic acid)
Methyl butyrate
Methyl ester 2-ethylhexanoic acid
Methyl acetate (Methyl ester acetic acid)
O,S-Dimethyl ester carbonodithioic acid
p-Cymenyl
Diethyl phthalate (Phthalic acid diethyl ester)
Propylacetate
Sabinyl acetate


Landfill Gas: Aromatic Hydrocarbons
Concentration (µg/m³)
1000000
100000
10000
1000
100
10
1
0.1
0.01
1-Methylpropylbenzene
1,2,3-Trimethylbenzene
1,2,4-Trimethybenzene
1,3,5-Trimethylbenzene
1,3-Diethylbenzene
1-Ethyl-2,3-dimethylbenzene
1-Ethyl-2-methylbenzene
1-Ethyl-4-methylbenzene
1-Methyl-2-propylbenzene
1-Methyl-3-propylbenzene
1-Methyl-4-(1-methylethyl)benzene
1-Methyl-4-propylbenzene
2-Ethyl-1,3-dimethylbenzene
2-Ethyl-1,4-dimethylbenzene
2-Methyl-propylbenzene
2-Propyltoluene
4-Ethenyl-1,2-dimethylbenzene
Benzene
C3-Alkylbenzenes
C4-Alkylbenzenes
Decahydro-2-methylnaphthalene
Decahydronaphthalene
Diethylbenzene
Ethylbenzene
Ethyltoluene
Cumene (isopropylbenzene)
Methyl-4-isopropenylbenzene
Methylbenzene
Naphthalene
Propylbenzene
Propyltoluene
Styrene
Butylbenzene
Tetramethylbenzene
Toluene
Xylenes


Landfill Gas: Aliphatic Hydrocarbons
Concentration (µg/m³)
10000000
1000000
100000
10000
1000
100
10
1
0.1
0.01
Methylethylcyclohexane
1,1,3-Trimethylcyclohexane
1,2,4-Trimethylcyclohexane
1,2-Dimethyl-3-(1-methylethyl)cyclopentane
1,2-Dimethylcyclopropane
1,3-Dimethylcyclohexane
1,4-Dimethylcyclohexane
1-Ethyl-2-methylcyclopropane
1-Ethyl-2-methylcyclopentane
1-Ethyl-3-methylcyclopentane
1-Heptene
1-Methyl-2-pentylcyclohexane
1-Methyl-3-(1-methylethylidene)-cyclohexane
1-Pentene
2,2,3,4-Tetramethyldodecane
2,2-Dimethylpentane
2,3,4-Trimethylhexane
2,3,6-Trimethyloctane
2,3-Dimethylheptane
2,3-Dimethylnonane
2,4,4-Trimethylpentane
2,4-Dimethyl-1-heptene
2,4-Dimethylhexane
2,6,10-Trimethyldodecane
2,6-Dimethylnonane
2-Butene
2-Methyl-1-butene
2-Methyl-1-propene
2-Methyldecane
2-Methylhexane
2-Methylpentane
2-Pentene
3-Ethylhexane
3-Methyl-6-(1-methylethyl) cyclohexene
3-Methylheptane
3-Methylnonane
3-Methylpentane
4,7-Dimethyl undecane
4-Methyldecane
4-Methyloctane
Butane
C3-Alkylcyclohexanes
C6-C12 Alkanes
Cycloheptane
Dimethylcyclopentane
Cyclopentene
Decane
Dimethyloctane
Dimethylundecane
Ethane
Ethylcyclopropane
Ethylpentane
Dimethylheptane
Methylhexane
Isobutene
Methylcycloheptane
Methylcyclobutane
Methylcyclopropane
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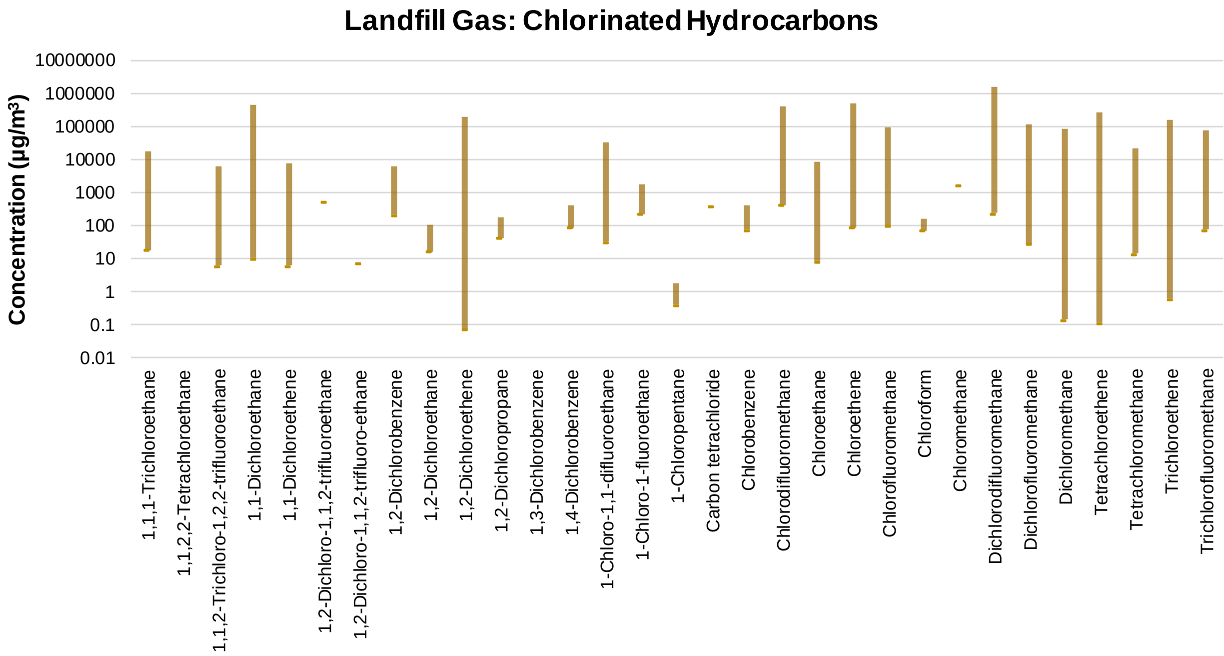
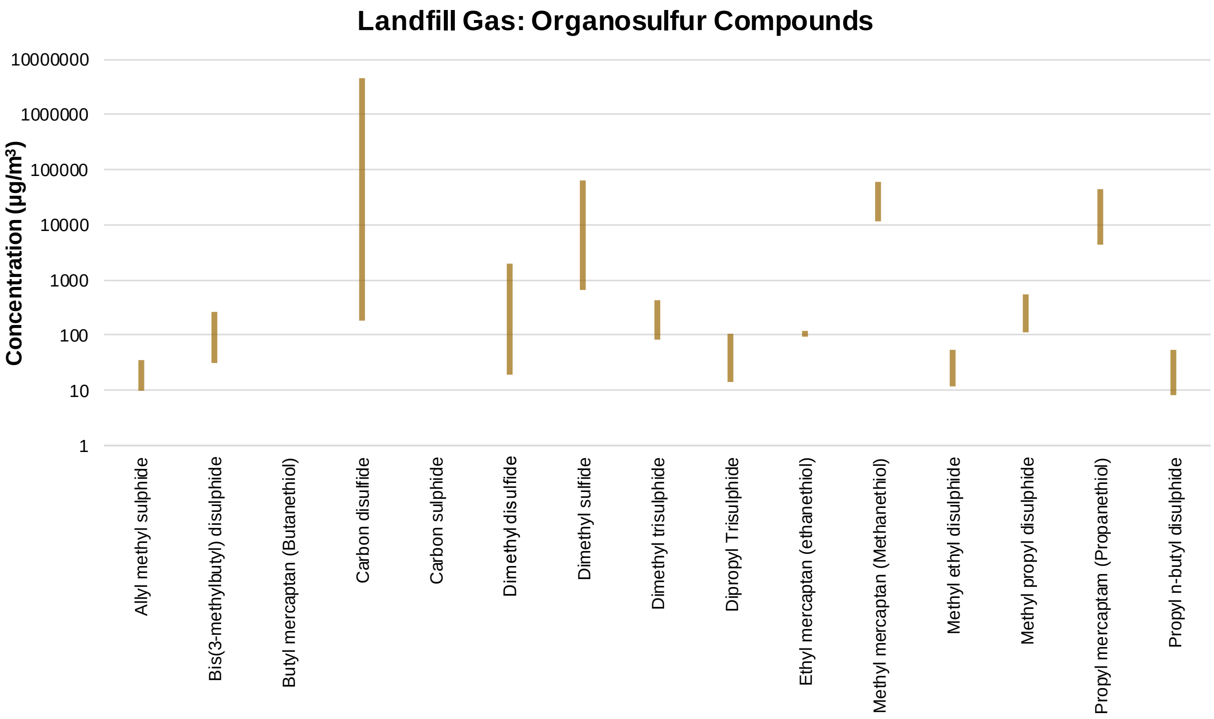
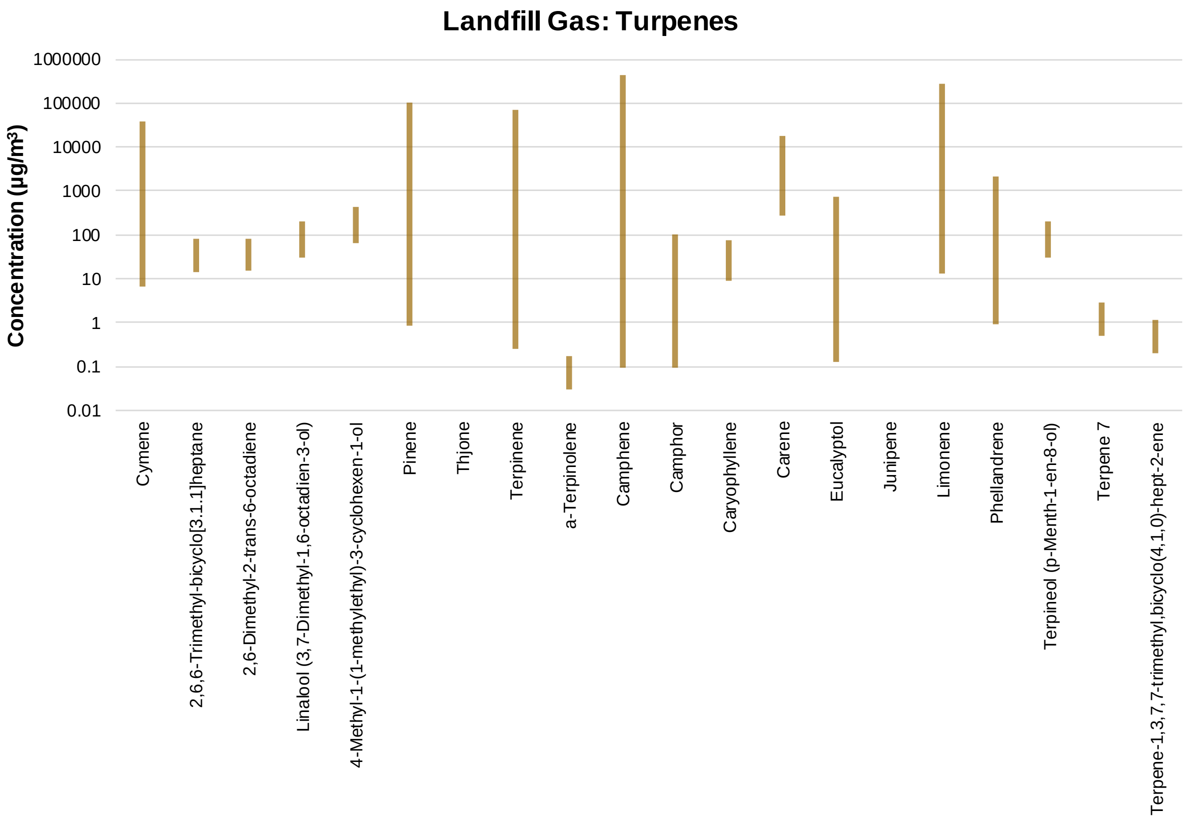
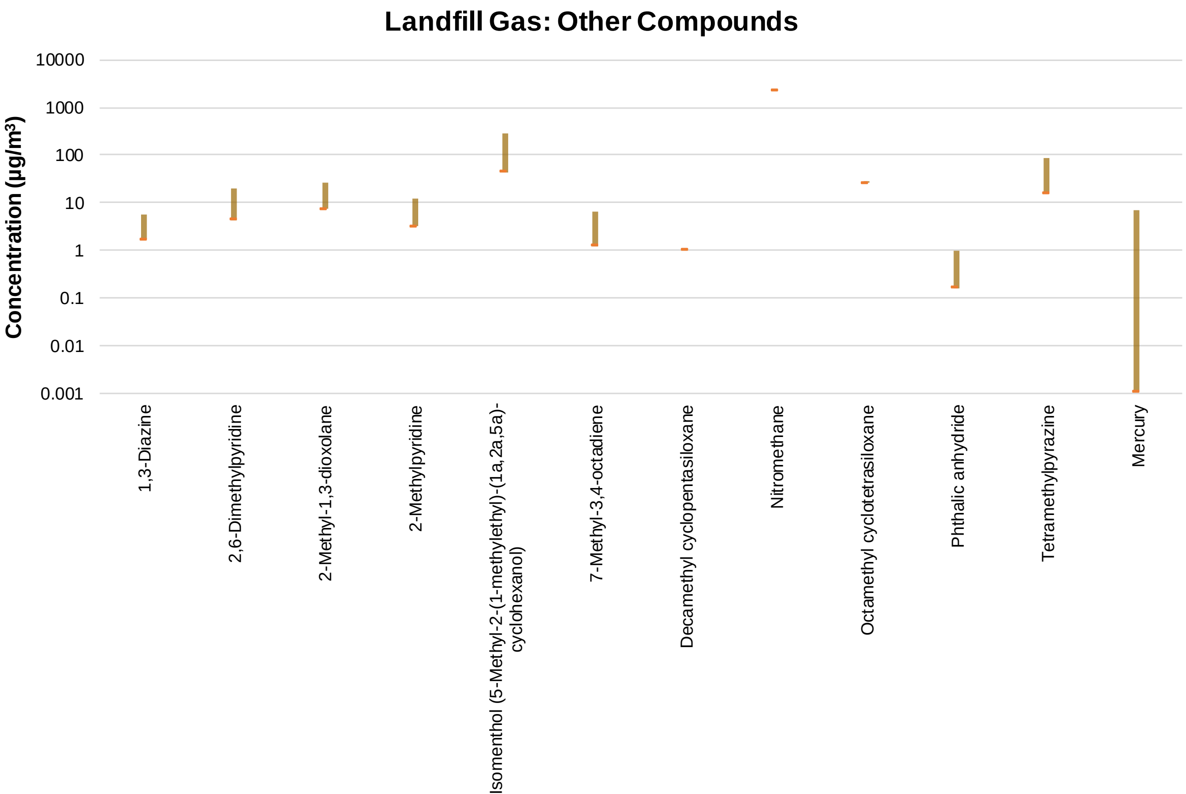
Nonane
Octane
Pentane
Propane
Tetradecane
Trimethylcyclohexanes
Undecane
1,3-Pentadiene


Landfill Gas: Chlorinated Hydrocarbons
Concentration (µg/m³)
10000000
1000000
100000
10000
1000
100
10
1
0.1
0.01
1,1,1-Trichloroethane
1,1,2,2-Tetrachloroethane
1,1,2-Trichloro-1,2,2-trifluoroethane
1,1-Dichloroethane
1,1-Dichloroethene
1,2-Dichloro-1,1,2-trifluoroethane
1,2-Dichloro-1,1,2-trifluoro-ethane
1,2-Dichlorobenzene
1,2-Dichloroethane
1,2-Dichloroethene
1,2-Dichloropropane
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1-Chloro-1,1-difluoroethane
1-Chloro-1-fluoroethane
1-Chloropentane
Carbon tetrachloride
Chlorobenzene
Chlorodifluoromethane
Chloroethane
Chloroethene
Chlorofluoromethane
Chloroform
Chloromethane
Dichlorodifluoromethane
Dichlorofluoromethane
Dichloromethane
Tetrachloroethene
Tetrachloromethane
Trichloroethene
Trichlorofluoromethane


Landfill Gas: Organosulfur Compounds
Concentration (µg/m³)
10000000
1000000
100000
10000
1000
100
10
1
Allyl methyl sulphide
Bis(3-methylbutyl) disulphide
Butyl mercaptan (Butanethiol)
Carbon disulfide
Carbon sulphide
Dimethyl disulfide
Dimethyl sulfide
Dimethyl trisulphide
Dipropyl Trisulphide
Ethyl mercaptan (ethanethiol)
Methyl mercaptan (Methanethiol)
Methyl ethyl disulphide
Methyl propyl disulphide
Propyl mercaptam (Propanethiol)
Propyl n-butyl disulphide


Landfill Gas: Turpenes
Concentration (µg/m³)
1000000
100000
10000
1000
100
10
1
0.1
0.01
Cymene
2,6,6-Trimethyl-bicyclo[3.1.1]heptane
2,6-Dimethyl-2-trans-6-octadiene
Linalool (3,7-Dimethyl-1,6-octadien-3-ol)
4-Methyl-1-(1-methylethyl)-3-cyclohexen-1-ol
Pinene
Thjone
Terpinene
a-Terpinolene
Camphene
Camphor
Caryophyllene
Carene
Eucalyptol
Junipene
Limonene
Phellandrene
Terpineol (p-Menth-1-en-8-ol)
Terpene 7
Terpene-1,3,7,7-trimethyl,bicyclo(4,1,0)-hept-2-ene


Landfill Gas: Other Compounds
Concentration (µg/m³)
10000
1000
100
10
1
0.1
0.01
0.001
1,3-Diazine
2,6-Dimethylpyridine
2-Methyl-1,3-dioxolane
2-Methylpyridine
Isomenthol (5-Methyl-2-(1-methylethyl)-(1a,2a,5a)-cyclohexanol)
7-Methyl-3,4-octadiene
Decamethyl cyclopentasiloxane
Nitromethane
Octamethyl cyclotetrasiloxane
Phthalic anhydride
Tetramethylpyrazine
Mercury

Concentrations Reported in Landfill Gas ($\mu g/m^3$)

	Reference:	UK EA (2002)	UK EA (2002)	Moreno et al (2014)	Davoli et al (2003)	Allen (1997)	UK EA (2010)	UK EA (2010)	Saquing et al (2014)
	Location of landfill:	UK	UK	Spain	Italy	UK	UK	UK	US
	Type of landfill:	MSW	MSW	MSW	MSW	MSW	MSW	MSW	MSW
	Status of landfill:	Old waste area (17 years old)	New waste area (3 years old)	Open	Open	Open	Open	Open	Open - 4 landfills
	Notes on landfil operation:	Gas collection and electricity generation	Gas collection and electricity generation	Gas collection and power generation		7 landfills, 4 with extraction and power generation, 2 with extraction and flare and 1 with no extraction	Gas collection and flare	Gas collection and flare	
	Notes on landfill gas sampling:	Sampling may include leachate and GW	Sampling from gas collection system	Tank experiments with fresh, older waste and leaking landfill gas					
	Sampling method (duration)	Tubes (20-120 mins)	Tubes (20-120 mins)	Passive samplers (4 days)	Grab sample into Nalophan bag	Tubes (10 mins)	Tubes (grab)	Tubes (grab)	Canisters (grab)
	Data presented (average, maximum etc):	Max from different methods and sampling in 2001 and 2002	Max from different methods and sampling in 2001 and 2002	Max from fresh, older waste and landfill gas	max from data from fresh waste, old waste and biogas	Max from all sites	Average	Max	Max
Group	**Compound**								
A	Butanoic acid				0.11				
A	Butyric acid						55	55	
AH	1-Methylpropylbenzene				0.33				
AH	1,2,3-Trimethylbenzene				2.46				
AH	1,2,4-Trimethybenzene	12000	1100		1.18	187000	21073	370000	
AH	1,3,5-Trimethylbenzene	52990	26131		0.11				
AH	1,3-Diethylbenzene			137.16	0.27				
AH	1-Ethyl-2,3-dimethylbenzene	2400							
AH	1-Ethyl-2-methylbenzene	10670	3458	157.25	2.56				
AH	1-Ethyl-4-methylbenzene			108.11					
AH	1-Methyl-2-propylbenzene	3779	1925						
AH	1-Methyl-3-propylbenzene	2951	1439		ND				
AH	1-Methyl-4-(1-methylethyl)benzene	171041	11.46						
AH	1-Methyl-4-propylbenzene	3100							
AH	2-Ethyl-1,3-dimethylbenzene	7780	90042						
AH	2-Ethyl-1,4-dimethylbenzene			98.76					
AH	2-Methyl-propylbenzene		2797						
AH	2-Propyltoluene		22						
AH	4-Ethenyl-1,2-dimethylbenzene			98.76					
AH	Benzene	11871	7448	83.03		7000	3497	40000	
AH	C3-Alkylbenzenes					295000			
AH	C4-Alkylbenzenes					294000			
AH	Decahydro-2-methylnaphthalene	137							
AH	Decahydronaphthalene		1045						
AH	Diethylbenzene	1442							
AH	Ethylbenzene	59358	51860	629.56	2.17	156000	2947	15000	21701
AH	Ethyltoluene	22000	2524				423	2400	
AH	Cumene (isopropylbenzene)	1409	2019						
AH	Methyl-4-isopropenylbenzene		1000						
AH	Methylbenzene	181612	124803						
AH	Naphthalene		41						
AH	Propylbenzene	12757			0.29		335	2100	
AH	Propyltoluene		131						
AH	Styrene			85.16			229	1200	
AH	Butylbenzene	40							
AH	Tetramethylbenzene						48	65	
AH	Toluene	53000	133680	1897.73	4.82	287000	26378	220000	
AH	Xylenes	419851	120441	954.76	6.25	440000	8360	49000	86802
AL	Methylethylcyclohexane	46							
AL	1,1,3,3-Tetramethylcyclopentane				0.31				
AL	1,1,3-Trimethylcyclohexane	4599	5505						
AL	1,1-Dimethylcyclopropane		684						

Concentrations Reported in Landfill Gas (μg/m³)

	Reference:	UK EA (2002)	UK EA (2002)	Moreno et al (2014)	Davoli et al (2003)	Allen (1997)	UK EA (2010)	UK EA (2010)	Saquing et al (2014)
	Location of landfill:	UK	UK	Spain	Italy	UK	UK	UK	US
AL	1,2,4-Trimethylcyclohexane	537	3363	61.86					
AL	1,2,4-Trimethylcyclopentane	1.41							
AL	1,2-Dimethyl-3-(1-methylethyl)cyclopentane		6.6						
AL	1,2-Dimethylcyclopentane	842	932						
AL	1,2-Dimethylcyclopropane	247	364						
AL	1,3,5-Trimethylcyclohexane	5.86							
AL	1,3-Dimethylcyclohexane	2085	3.97						
AL	1,3-Dimethylcyclopentane	329	2227						
AL	1,4-Dimethylcyclohexane	1023	1367			16000			
AL	1-Butene	1266	398						
AL	1-Ethyl-2-methylcyclopropane				0.72				
AL	1-Ethyl-2-methylcyclohexane	20869	937	72.23					
AL	1-Ethyl-2-methylcyclopentane	2340	2667						
AL	1-Ethyl-3-methylcyclohexane	13.38							
AL	1-Ethyl-3-methylcyclopentane	2.38							
AL	1-Ethyl-4-methylcyclohexane	1877	6425	ND					
AL	1-Heptene	2860							
AL	Hexene	1943	1415						
AL	1-Methyl-2-pentylcyclohexane				0.76				
AL	1-Methyl-2-propylcyclopentane	3124	3342						
AL	1-Methyl-3-(1-methylethylidene)-cyclohexane			155.91					
AL	1-Methyl-4-(1-methylethyl)-cyclohexane		6.47	470.34	0.17				
AL	1-Pentene	1300					163506	1335000	
AL	1-Propene	11							
AL	2,2,3,4-Tetramethyldodecane				0.35				
AL	2,2,4,4,6,8,8-Heptamethylnonane			129.58					
AL	2,2-Dimethylpentane	1595							
AL	2,3,3-Trimethylpentane	1.4							
AL	2,3,4-Trimethylhexane			73.43					
AL	2,3,4-trimethylpentane	2.27	1.48						
AL	2,3,6-Trimethyloctane				1.21				
AL	2,3-Dimethylcyclohexane				0.60				
AL	2,3-Dimethylheptane	11558	11558						
AL	2,3-Dimethylhexane	1.87							
AL	2,3-Dimethylnonane				0.19				
AL	2,3-Dimethyloctane	5499							
AL	2,4,4-Trimethylpentane	1.89	1.41	ND					
AL	2,4,6-Trimethylheptane	6.63							
AL	2,4-Dimethyl-1-heptene			4.64					
AL	2,4-Dimethylheptane	3323	1268	51.39	0.16				
AL	2,4-Dimethylhexane	1610	2177		1.91				
AL	2,5-Dimethylhexane	419	419						
AL	2,6,10-Trimethyldodecane				0.78				
AL	2,6-Dimethylheptane	9759	3559						
AL	2,6-Dimethylnonane		8002						
AL	2,6-Dimethyloctane	60294	32582	250.16					
AL	2-Butene	766							
AL	2-Hexene	776	950						
AL	2-Methyl-1-butene	221							
AL	2-Methyl-1-pentene	54	3594	ND					
AL	2-Methyl-1-propene	535	2796	ND					
AL	2-Methylbutane	4914	20590	318.57					
AL	2-Methyldecane	2789	849						
AL	2-Methylheptane	5261	5730						
AL	2-Methylhexane		2965						
AL	2-Methylnonane	14393	10073						
AL	2-Methylpentane		680						
AL	2-Methylpropane	237	1821						
AL	2-Pentene	660	1392						
AL	3,5-dimethyloctane		2496						

Concentrations Reported in Landfill Gas ($\mu g/m^3$)

	Reference:	UK EA (2002)	UK EA (2002)	Moreno et al (2014)	Davoli et al (2003)	Allen (1997)	UK EA (2010)	UK EA (2010)	Saquing et al (2014)
	Location of landfill:	UK	UK	Spain	Italy	UK	UK	UK	US
AL	3-Ethylhexane		571						
AL	3-Ethylpentane	1091	1808						
AL	3-Methyl-6-(1-methylethyl) cyclohexene			418.10					
AL	3-Methyldecane	882	129	ND					
AL	3-Methylheptane		6882						
AL	3-Methylhexane	1842	2523						
AL	3-Methylnonane	23538	21158						
AL	3-Methyloctane	27783		62.92					
AL	3-Methylpentane	4.97	333						
AL	4,5-Dipropyloctane				0.81				
AL	4,7-Dimethyl undecane				4.15				
AL	4-Methyl-1-(methyl ethyl)-byciclo-(3,10)-hex-3-ene				0.33				
AL	4-Methyldecane	1335	634						
AL	4-Methylnonane	10200	8918	58.18					
AL	4-Methyloctane	621							
AL	5-Methyldecane	1167	668						
AL	Butane	18272	3676	187.65	0.62				47506
AL	C2-C5 Alkanes					553000			
AL	C3-Alkylcyclohexanes					149000			
AL	C4-Alkylcyclohexanes					33000			
AL	C6-C12 Alkanes					1415000			
AL	Cyclobutane	486							
AL	Cycloheptane	9	6019						
AL	Cyclohexane	3600	1186	6.20		31000			
AL	Dimethylcyclopentane	104							
AL	Ethylcyclopentane	81	2.09						
AL	Cyclopentene	3							
AL	Cyclopropane, ethyl-		28						
AL	Decane	73704	49246	714.06	5.46		2541	16000	
AL	Dimethylbutane	33							
AL	Dimethyloctane		1800						
AL	Dimethylpentane	431	711						
AL	Dimethylundecane	49							
AL	Dodecane	978	160	208.87					
AL	Ethane								8605
AL	Ethylcyclohexane	16263	20328				1414	9900	
AL	Ethylcyclopropane	11531	329						
AL	Ethyl-methylcyclohexane	2446							
AL	Ethylpentane	1370							
AL	Heptane	21243	15755	61.45			10085	98000	
AL	Dimethylheptane		630						
AL	Hexane	14012	14356				1752	5300	35231
AL	Methylhexane	70							
AL	Isobutane	3544	47						
AL	Isobutene	280							
AL	Isopentane	85	16						
AL	Methylcycloheptane	1.03							
AL	Methylcyclopentane	1401	1296						
AL	Methylcyclobutane		114						
AL	Methylcyclohexane	8600	9343			45000	9873	73000	
AL	Methylcyclopropane		81704						
AL	Methyldecane	599	867						
AL	Methylenecyclohexane	10.56							
AL	Methylpropylcyclohexane	10650							
AL	Nonane	94866	90083	398.33			3445	24000	
AL	Methylnonane		1300						
AL	Octane	27376	26893	154.07			4929	37000	
AL	Pentadecane			10.42	2.34				
AL	Pentane	33052	10200	129.79					147485
AL	Methylpentane	290							

		Concentrations Reported in Landfill Gas ($\mu g/m^3$)							
	Reference:	**UK EA (2002)**	**UK EA (2002)**	**Moreno et al (2014)**	**Davoli et al (2003)**	**Allen (1997)**	**UK EA (2010)**	**UK EA (2010)**	**Saquing et al (2014)**
	Location of landfill:	UK	UK	Spain	Italy	UK	UK	UK	US
AL	Propane		38						54088
AL	Propylcyclohexane		25219	56.75					
AL	Tetradecane			105.45					
AL	Tridecane			437.25					
AL	Trimethylcyclohexanes					66000			
AL	Trimethylhexane		1030						
AL	Undecane	8600	3675	178.92					
AL	Undecene				0.28				
AL	1,3-Pentadiene	18		18.93					
ALCOHOL	1-Hexanol			21.73					
ALCOHOL	1-Propanol	1395	5472			213000			
ALCOHOL	2-Butanol		32695	354.54			100	240	
ALCOHOL	2-Ethyl-1-hexanol			489.71			1221	3800	
ALCOHOL	2-Methyl-3-buten-2-ol			73.95					
ALCOHOL	2-Propanol	883	10901			127000	7232	23000	
ALCOHOL	3-Methyl-1-butanol			33.16					
ALCOHOL	6-Pentadecen-1-ol				6.48				
ALCOHOL	Butanol	14973				510000	7594	43000	
ALCOHOL	Ethanol	1292				262000			
ALCOHOL	Furfuryl alcohol	9.09							
ALCOHOL	1-Pentanol			8.64		19000			
ALD	2,6-Dimethylbenzaldehyde				0.38				
ALD	Acetaldehyde						2	6.6	
ALD	Cinnamicaldehyde				0.65				
ALD	Formaldehyde						0.04	0.09	
ALD	Hexanal				0.13				
BR	Bromoethane						99	150	
BR	Bromodichloromethane								0.03
CH	1,1,1-Trichloroethane	275	171			18000			272.7
CH	1,1,2,2-Tetrachloroethane						ND	ND	
CH	1,1,2-Trichloro-1,2,2-trifluoroethane	1224				6000			
CH	1,1-Dichloroethane	441809	4152			62000	531	2400	
CH	1,1-Dichloroethene	1100	940			6000	1145	7300	
CH	1,2-Dichloro-1,1,2-trifluoroethane	542							
CH	1,2-Dichloro-1,1,2-trifluoro-ethane	7							
CH	1,2-Dichlorobenzene	5915					209	1000	
CH	1,2-Dichloroethane	102					16	16	
CH	1,2-Dichloroethene	9017	8154	35.26	0.28	182000	2979	19200	11890
CH	1,2-Dichloropropane						42	180	
CH	1,3-Dichlorobenzene								
CH	1,4-Dichlorobenzene						85	390	
CH	1-Chloro-1,1-difluoroethane					31000			
CH	1-Chloro-1-fluoroethane		1738						
CH	1-Chloropentane			1.74					
CH	Carbon tetrachloride								371
CH	Chlorobenzene						72	400	
CH	Chlorodifluoromethane					404000			3181
CH	Chloroethane	119	163			8000	410	410	
CH	Chloroethene	448				87000	139722	497000	
CH	Chlorofluoromethane	338				96000			
CH	Chloroform						71	150	146
CH	Chloromethane						ND	ND	1645
CH	Dichlorodifluoromethane	3558	1964			231000	361006	1594000	6795
CH	Dichlorofluoromethane	26673	16695			114000	1365	8900	
CH	Dichloromethane	1557	606		0.49	85000	4898	30000	21250
CH	Tetrachloroethene	8500	8297		0.75	255000	2925	21000	54237
CH	Tetrachloromethane					21000	14	14	
CH	Trichloroethene	17692	11144	3.22		153000	2163	15000	5091
CH	Trichlorofluoromethane	954	708			74000	1663	7500	
DIENE	1,3-Butadiene						ND	ND	

Concentrations Reported in Landfill Gas ($\mu g/m^3$)

	Reference:	UK EA (2002)	UK EA (2002)	Moreno et al (2014)	Davoli et al (2003)	Allen (1997)	UK EA (2010)	UK EA (2010)	Saquing et al (2014)
	Location of landfill:	UK	UK	Spain	Italy	UK	UK	UK	US
DIENE	2-Methyl-1,3-butadiene	120	290						
ESTER	1-Methylpropyl ester propanoic acid			19.70					
ESTER	2-Methyl-1-(1,1-dimethylethyl)-2-methyl-1,3-propanediyl ester propanoic acid			14.48					
ESTER	3-Methyl-1-butanol acetate			14.37					
ESTER	3-Methylbutanoic acid methyl ester			94.97					
ESTER	Butylacetate (Acetic acid butyl ester)	39		43.22	0.05		243	1400	
ESTER	Ethylacetate (Acetic acid ethyl ester)	556		20.17	1.51		2153	9200	
ESTER	Ethyl butyrate (Ethyl ester butanoic acid)			20.43			3276	19000	
ESTER	Methyl butyrate	588							
ESTER	Methyl ester 2-ethylhexanoic acid			194.03					
ESTER	Methyl acetate (Methyl ester acetic acid)			18.78					
ESTER	O,S-Dimethyl ester carbonodithioic acid			64.95					
ESTER	p-Cymenyl	1010	1255						
ESTER	Diethyl phthalate (Phthalic acid diethyl ester)				1.82				
ESTER	Propylacetate	20							
ESTER	Sabinyl acetate	1080							
ETHER	1,2-Dimetoxybenzene			62.15					
ETHER	2-Butoxyethanol				0.19		ND	ND	
ETHER	Diethoxymethane				0.55				
ETHER	Diethyl ether	2300	570						
ETHER	Dimethyl ether		410						
FURAN	2,5-Dimethylfuran	4667							
FURAN	2-Ethylfuran				0.03				
FURAN	2-n-Heptylfuran			46.91					
FURAN	2-Pentylfuran			186.45					
FURAN	Furan	6000	5722				5973	37000	
FURAN	Methylfuran	380	190	61.76					
FURAN	Tetrahydrofuran	731	2812						
K	Fenchone (1,3,3-Trimethyl-bicyclo[2.2.1]heptan-2-one)			68.45					
K	2-Ethyl-cycloheptanone	5017	4896						
K	2-Heptanone			163.41					
K	2-Hexanone	2413		18.43					
K	2-Methyl-3-hexanone			98.05					
K	2-Methyl-5-(1-methylethyl)-cyclohexanone				1.01				
K	Cavone (2-Methyl-5-(1-methylethenyl)-2-cyclohexen-1-one)			73.69					
K	2-Methyl-5-(1-methylethenyl)-trans-cyclohexanone			124.45					
K	2-Nonanone			133.71					
K	2-Octanone			52.41					
K	Methyl propyl ketone (2-Pentanone)			126.77	ND				
K	2-Undecanone			36.90					
K	3-Heptanone			7.94					
K	3-Hexanone			8.19					
K	3-Hydroxy-2-butanone			223.34					
K	Methyl isopropyl ketone (3-Methyl-2-butanone)			26.41					
K	3-Pentanone			17.61					
K	4-Methyl-2-pentanone		9900						
K	4-Methyl-3-hexanone			2.33					
K	4-Methylcyclohexanone				1.70				
K	5-Methyl 2-hexanone			5.14					
K	5-Methyl-2-(1-methylethyl)-cyclohexanone				ND				
K	5-Methyl-2-(1-methylethyl)- trans-cyclohexanone			132.39					
K	5-Methyl-3-(1-methylethyl)-cyclohexanone				0.25				
K	6-Methyl-5-hepten-2-on			36.12					
K	Acetone			85.01			15777	76000	18996
K	Acetophenone			38.79					
K	Methyl ethyl ketone (2-Butanone)	4524	49416	1786.54	ND		13944	72000	
K	Methyl isobutyl ketone			81.93			613	4100	
PYRAZINE	2,3-Dimethylpyrazine			21.21					
PYRAZINE	Methyl pyrazine			18.85					
S	Allyl methyl sulphide			35.70					

Concentrations Reported in Landfill Gas (μg/m^3)

	Reference:	UK EA (2002)	UK EA (2002)	Moreno et al (2014)	Davoli et al (2003)	Allen (1997)	UK EA (2010)	UK EA (2010)	Saquing et al (2014)
	Location of landfill:	UK	UK	Spain	Italy	UK	UK	UK	US
S	Bis(3-methylbutyl) disulphide			261.59					
S	Butyl mercaptan (Butanethiol)						ND	ND	
S	Carbon disulfide	668	1080	ND			602988	4681000	186
S	Carbon sulphide								
S	Dimethyl disulfide	19			ND		457	2000	
S	Dimethyl sulfide	1300	903				ND	4650	63884
S	Dimethyl trisulphide			423.41					
S	Dipropyl Trisulphide			104.40					
S	Ethyl mercaptan (ethanethiol)						96	120	
S	Methyl mercaptan (Methanethiol)						11533	59000	
S	Methyl ethyl disulphide			53.08					
S	Methyl propyl disulphide			544.78					
S	Propyl mercaptam (Propanethiol)						4346	45000	
S	Propyl n-butyl disulphide			54.41					
T	Cymene	37000	6000	21715.60	34.89				
T	2,6,6-Trimethyl-bicyclo[3.1.1]heptane			79.13					
T	2,6-Dimethyl-2-trans-6-octadiene			78.65					
T	Linalool (3,7-Dimethyl-1,6-octadien-3-ol)			195.49					
T	4-Methyl-1-(1-methylethyl)-3-cyclohexen-1-ol			416.08					
T	Pinene	99958	8984	8624.79	4.50				
T	Thjone	1921							
T	Terpinene	38829			1.45		23058	71000	
T	a-Terpinolene				0.17				
T	Camphene	13319	423345	357.48	0.50				
T	Camphor			105.78	0.56				
T	Caryophyllene			76.88					
T	Carene	14000	17810	1553.55					
T	Eucalyptol			743.89	0.82				
T	Junipene		11						
T	Limonene	37619	16409	24043.81	74.84	287000	2159	13000	
T	Phellandrene		1256	2183.40	4.96				
T	Terpineol (p-Menth-1-en-8-ol)			195.43					
T	Terpene 7				2.78				
T	Terpene-1,3,7,7-trimethyl,bicyclo(4,1,0)-hept-2-ene				1.11				
THIOPHENE	2-Methylthiophene			88.32					
THIOPHENE	Propylthiophene	6.74	18000						
THIOPHENE	Thiophene		150						
V	1,3-Diazine			5.57					
V	2,6-Dimethylpyridine			19.27					
V	2-Methyl-1,3-dioxolane				26.26				
V	2-Methylpyridine			12.18					
V	Isomenthol (5-Methyl-2-(1-methylethyl)-(1a,2a,5a)-cyclohexanol)			274.60					
V	7-Methyl-3,4-octadiene				6.30				
V	Decamethyl cyclopentasiloxane	1							
V	Nitromethane						2200	2200	
V	Octamethyl cyclotetrasiloxane	25.79	28.09						
V	Phthalic anhydride				0.97				
V	Tetramethylpyrazine			89.09					
V	Mercury	7	4				0.0011	0.0042	
XX	1-Methylethylbenzene				ND				
XX	2-Methylpropylbenzene								
XX	1,2,3,5-Tetramethylbenzene				ND				
XX	1,3,5-Cycloheptatriene								
XX	1-Butyl-2-pentyl cyclopropane								
XX	1-Ethyl-3-methylbenzene				ND				
XX	1-Methoxy, 4-methyl-2-(1-methylethyl)-benzene				ND				
XX	1-Methoxy-2-propanol				ND				
XX	1-Methyl, 4-(1-methyethyl)-3-cyclohexen-1-olo-a-terpineol				ND				
XX	1-Methyl-4-(1-methylethyl)-7-oxabicyclo[2.2.1]heptane			ND					
XX	2,2,4-Trimethylpentane			ND					

Concentrations Reported in Landfill Gas ($\mu g/m^3$)

	Reference:	UK EA (2002)	UK EA (2002)	Moreno et al (2014)	Davoli et al (2003)	Allen (1997)	UK EA (2010)	UK EA (2010)	Saquing et al (2014)
	Location of landfill:	UK	UK	Spain	Italy	UK	UK	UK	US
XX	2,3,3-Trimethyl-1-hexene			ND					
XX	2,3-Dimethyl-1-hexene			ND					
XX	2,3-Dimethyl-2-heptene			ND					
XX	2,4,5-Trimethyl-1,3-dioxolane			ND					
XX	2-Methyl butanal				ND				
XX	2-Methyl-5-(1-methyl ethyl)-byciclo-(3,1,0)-hex-2-ene				ND				
XX	2-Octene			ND					
XX	3,4-Dihydropyran				ND				
XX	3,5,5-Trimethyl-1-hexanol			ND					
XX	3,5-Dimethyl-3-heptene			ND					
XX	3,5-Dimethylbenzaldehyde				ND				
XX	3,6,6-Trimethylbicyclo[3.1.1]heptan-2-one			ND					
XX	3,7,11-Trimethyl-1-dodecanol			ND					
XX	3-Ethyl-2-methylheptane			ND					
XX	3-Ethyl-3-heptene			ND					
XX	3-Methylhexane								
XX	3-Nonene			ND					
XX	4,4-Dimethyl-2-pentanone			ND					
XX	4-Nonene			ND					
XX	4-Propylheptane			ND					
XX	6-Isopropylidene, 1-methyl, bicyclo-(3,1,0)-hexane				ND				
XX	Acetic acid				ND				
XX	Butanoic acid ethyl ester				ND				
XX	cis-4-Nonene								
XX	Cyclohexanone								
XX	Diethylsulphide						ND	ND	
XX	Ethyl caproate (Ethyl ester hexanoic acid)			ND					
XX	Ethyl propionate (Ethyl ester propanoic acid)			ND					
XX	Geranyl isovalerate			ND					
XX	Hexanoic acid				ND				
XX	Isobornyl acetate				ND				
XX	Methyl ester 2,5-octadecadiynoic acid			ND					
XX	Nonanal			ND					

Key

Some groups have ful names, otherwise the groups are as follows

A = Organic acids
AH = Aromatic hydrocarbons
AL = Aliphatic hydrocarbons
CH = Chlorinated hydrocarbons
BH = Brominated hydrocarbons
ALD = Aldehydes
K = Ketones
S = Organosulfur compounds
T = Terpenes and terpenoids
V = Other (ungroups) compounds
XX = Compoiund not detected in any sampling program (not included in groups)

ND = Not detected in sampling program

Appendix B Summary of Data: Ambient air on landfill

Concentrations Reported in Ambient Air on Landfills (μg/m^3)

Reference:		Dincer et al (2006)	Dincer et al (2006)	Zou et al (2003)	Zou et al (2003)	Ying et al (2012)	Fang et al (2012)	Saquing et al (2014)
Location of landfill:		Turkey	Turkey	China	China	China	China	US
Type of landfill:		MSW	MSW	MSW	MSW	MSW	MSW and sewage sludge	MSW
Status of landfill:		Open	Open	Open	Open	Open	Open	Open - 3 sites
Notes on landfill:				leachate collection	leachate collection	leachate treatment plant	landfill gas collection and leachate collection	
Duration of air sampling:		Grab samples	Grab samples	40 minutes	40 minutes	Grab samples	Grab samples	Grab samples
Data presented (average, maximum etc):		Avg	Max	Avg	max	Avg	Max	Max
Group	**Compound**							
A	Acetic acid	1.92	5.34			2.22	5133	
A	Butyric acid	2.22	4.39			0.18	233.9	
A	Caproic acid	2.14	2.91			1.08		
A	Formic acid	24.22	43.71			2.78		
A	Heptanoic acid	3.39	8.85			0.02		
A	Isobutyric acid	3.56	6.61			0.42		
A	Isocaproic acid	ND	2.84					
A	Isovaleric acid	2.34	6.05			0.12	101	
A	Propionic acid	1.86	3.52			0.3	79.7	
A	Valeric acid	1.86	4.99			0.1	109.4	
AH	1,2,3-Trimethylbenzene			89	273			
AH	1,2,4-Trimethylbenzene			188	614			
AH	1,3,5-Trimethylbenzene			37	283			
AH	1-Ethyl-2,3-dimethylbenzene			ND	ND			
AH	1-Ethyl-2,4-dimethylbenzene			ND	ND			
AH	1-Methylnaphthalene			0.8	1.2			
AH	2-Ethylmethylbenzene			37	120			
AH	2-Methylnaphthalene			1.6	2.1			
AH	Acenaphthylene					0.04		
AH	Benzene	0.53	1.06	73	167	3.82	28.1	
AH	Butylbenzene			66	192			
AH	Ethylbenzene	2.03	4.94	100	297	23.3	ND	58
AH	Indene			1.1	2			
AH	Methylstyrene			4.2	5.6			
AH	Naphthalene			11	27	0.08		
AH	Propylbenzene			21	85			
AH	Styrene	3.88	14.44	28	48		281	
AH	Toluene	18.97	47.42	113	202	60.04	173.7	
AH	Xylenes (total)	7.92	19.71	75	169	0.72	895	173
AH	Cumene (Isopropylbenzene)			14	63	2.1		
AL	Butane							104
AL	Decane			2.5	4.5			
AL	Ethane							16
AL	Heptane			4.3	6.3	0.06		
AL	Hexane			ND	ND	0.06		70
AL	Nonane			3.4	5.2			
AL	Octane			5.1	6.5	0.08		
AL	Pentane							137
AL	Propane							34
ALCOHOL	Methanol						76.3	
ALD	Hexanal	2.59	5.94	2.1	2.8		35.5	
ALD	Propanal	21.13	38.55			0.38		
ALD	2-Ethylhexanal			4.6	5.6			
ALD	Acetaldehyde						51.17	
ALD	Acrolein	1.83	2.66			0.32	22.2	
ALD	Benzaldehyde						19.5	
ALD	Butanal (butraldehyde)	1.01	1.7			0.66	169	
ALD	Crotonaldehyde	0.14	0.38					
ALD	Decanal	3.95	9.42			0.28		
ALD	Dichloroacetaldehyde					0.06		
ALD	Formaldehyde						23	
ALD	Heptanal	0.73	1.51	2.3	3.1	0.12		
ALD	Isovaleraldehyde						6.7	
ALD	Nonanal	2.64	5.01			0.44		
ALD	Octanal	1.54	2.28					
ALD	Pentanal	0.75	1.92					
ALD	Propanal (Propionaldehyde)						27.3	
AMINE	2,4,6-Trichloroaniline					0.02		
AMINE	Aniline						7.2	
AMINE	Methylamine						8.8	
AMINE	Pyridine	ND	ND			0.38		
AMINE	Trimethylamine						14.3	
BH	1,2,4-Tribromobenzene					0.06		
BH	Bromoform	ND	ND			0.44		
BH	Bromodichloromethane	ND	ND					0.053
CH	1,1,1-Trichloroethane	0.04	0.1					0.24
CH	1,1,2,2-Tetrachlorethane	ND	ND			0.92		
CH	1,1,2-Trichloroethane	0.06	0.08			0.62		
CH	1,1-Dichloroethane	0.006	0.02					
CH	1,1-Dichloroethene	0.27	0.7					
CH	1,2,3-Trichloropropane					0.04		
CH	1,2,4-Trichlorobenzene			0.4	0.9	0.02		
CH	1,2-Dichlorbenzene	0.05	0.09	2.1	7.7	0.06		
CH	1,2-Dichloroethane	0.3	1.22			0.44		
CH	1,2-Dichloroethene							8
CH	1,2-Dichloropropane	ND	ND			13.92		
CH	1,3-Dichlorobenzene	0.005	0.01	3.3	4.9	0.08		
CH	1,4-Dichlorobenzene	0.25	0.4	0.5	0.7	1.4		
CH	Carbon tetrachloride	0.17	0.23	3.7	6			0.61
CH	Chlorobenzene	0.04	0.12	2.2	3.7	1.28		
CH	Chlorodifluoromethane							12
CH	Chloroform	0.08	0.16	13	29			0.8
CH	Chloromethane							9
CH	1,3-Dichloropropene	0.14	0.16					
CH	cis-1,4-Dichloro-2-butene	ND	ND			0.08		

Concentrations Reported in Ambient Air on Landfills (µg/m^3)

	Reference:	Dincer et al (2006)	Dincer et al (2006)	Zou et al (2003)	Zou et al (2003)	Ying et al (2012)	Fang et al (2012)	Saquing et al (2014)
	Location of landfill:	Turkey	Turkey	China	China	China	China	US
CH	1,2-Dichloroethene	0.11	ND	ND	ND	65.18		
CH	Dichlorodifluoromethane							7
CH	Dichloromethane	4.42	7.95	5.1	31			26
CH	Tetrachloroethene	2.37	9.16	16.8	59	13.9		12
CH	trans-1,4-Dichloro-2-butene	0.004	ND			0.06		
CH	Trichloroethene	13.06	62.91	9.3	24	3.9		3.1
CH	Vinyl chloride			ND	ND			
E	Butyl acetate	2.7	7.54			0.08		
E	Butyl formate	0.06	0.12			0.1		
E	Butyl propionate	0.1	0.11					
E	Methyl propionate	0.18	ND			0.38		
E	Vinyl acetate	0.65	2.29			0.22		
K	Methyl ethyl ketone (2-Butanone)	ND	ND			0.42	105.3	
K	2-Hexanone	0.27	0.8					
K	3-Pentanone						189	
K	Methyl isobutyl ketone (4-Methyl-2-pentan	0.21	0.42			0.22		
K	Acetone	37.17	67.6				254	123
K	Cyclohexanone	3.15	9.13			0.66		
S	Dimethyl disulfide					0.04	151	
S	Dimethyl sulfide					18.52	54.9	16
S	Dimethyl trisulfide						105.9	
S	Hydrogen sulfide					514.52	5.4	
S	Methylmercaptan (methanethiol)					5.3	43.1	
S	Carbon disulfide			ND	ND	0.66	12.8	0.093
S	Carbonyl sulfide							24
S	Ethylmercaptan (ethanethiol)					0.48		
T	Cymene			492	1667			
T	Camphene			12	37	0.06		
T	Limonene			80	162			
T	Pinene			52.6	159	0.04		
V	1-Nitrobutane					0.02		
V	Acrylonitrile	0.14	0.2			0.78		
V	Ammonia					3960	1251	
V	Dimethyl formamide						83.7	
V	Iodomethane (methyl iodide)	0.02	0.03					
XX	1,2,3,5-Tetramethylbenzene			ND	ND			
XX	1,2,4,5-Tetramethylbenzene			ND	ND			
XX	1,2-Dihydroindene			ND	ND			
XX	2,3-Dihydro-4-Methylindene (4-methylindane)			ND	ND			
XX	2,3-Dihydro-5-Methylindene (5-methylindane)			ND	ND			
XX	4-Ethyl-1,2-dimethylbenzene			ND	ND			
XX	Acetobutylester			ND	ND			
XX	Acylbenzene			ND	ND			
XX	Ciphenylsulfone			ND	ND			
XX	Dibromochloromethane	ND	ND					
XX	Octyl aldehyde			ND	ND			
XX	p-Tolualdehyde						ND	

Key

Some groups have ful names, otherwise the groups are as follows

A = Organic acids
AH = Aromatic hydrocarbons
AL = Aliphatic hydrocarbons
CH = Chlorinated hydrocarbons
BH = Brominated hydrocarbons
ALD = Aldehydes
K = Ketones
S = Organosulfur compounds
T = Terpenes and terpenoids
V = Other (ungroups) compounds
XX = Compoiund not detected in any sampling program (not included in groups)

ND = Not detected in sampling program

Appendix C Summary of Data: Ambient air on landfill boundary and in off-site communities

		Concentrations Reported on Landfill Boundary and in Off-Site Community (µg/m³)																						
	Reference:	**Marti et al (2014)**	**Davoli et al (2003)**					**Ying et al (2012)**		**UK EA (2010)**		**NYS DEC (2013)**	**Saquing et al (2014)**	**AECOM (2012)**		**Vic EPA (2012)**		**Odour Threshold (µg/m³)**		**Health Based Air Guidelines (µg/m₃)**				
	Location of landfill:	Spain	Italy					China		UK		US	US	Australia - Qld		Australia - Vic				**Acute**		**Chronic**		
	Type of landfill:	MSW	MSW					MSW		MSW		MSW	MSW	MSW		MSW								
	Status of landfill:	Closed	Open					Open		Open		Open	Open	Open		Open								
	Notes on landfill:		LFG Treatment					leachate treatment plant		LFG generator and flare		LFG to energy												
	Duration of air sampling:	24 hour - average from 3-4 events	Grab					Grab - average		4 to 8 hours - Average	4 to 8 hours - Max	1 hour	Grab	24 hours	2 weeks	24 hours	grab							
	Location of air sampling:	Community 200-500m	Entrance	1.5km	3km	6km	Nth of Entrance	Boundary	offsite community 200m	Boundary	Boundary	Community	Boundary	Boundary	Boundary	Community	Community							
Group	**Compound**																							
A	Acetic acid	42						0.18	0.12									15	NO	250	TH			1
A	Butylformate							0.02	0.04											21000	TH	2100	TH	
A	Butyric acid (butanoic acid)							0.02	0.02									0.7	NO	3000	TH	300	TH	
A	Caproic acid (hexanoic acid)							0.1	0.02									2.8	NO	480	X	48	TH	
A	Formic acid							0.52	0.24									45	NO	90	TH	9	TH	
A	Heptanoic acid							0.1	0.1									240	TO	530	X	53	TH	
A	Isobutyric acid							0.06	0.04									5.4	NO	900	X	90	TH	
A	Isovaleric acid							0.04	0.02									14	TO	420	X	42	TH	
A	Propionic acid							0.28	0.3									17	NO	300	X	30	TH	
A	Valeric acid							0.06	0.02									0.15	NO	420	X	42	TH	
AH	1,2,3,5-Tetramethylbenzene		0.82	0.55	4.33	ND	0.99													2450	TH	245	TH	
AH	1,2,3-Trimethylbenzene	0.18																2700	UO	4400	TH	54	TH	
AH	1,2,4-Trimethylbenzene	0.81	0.69	0.88	4.82	0.84	0.93					0.54		ND		ND	7.37	590	NO	4400	TH	54	TH	
AH	1,3,5-Trimethylbenzene	0.17	0.74	0.69	7.03	1.03	1.57			1.3	5	0.1		ND		ND	3.93	840	NO	4400	TH	54	TH	
AH	1,3-Diethylbenzene		0.05	0.16	0.66	ND	ND									ND	ND	383	NO	2500	TH	250	TH	
AH	1,4-Diethylbenzene		ND	0.05	ND	ND	ND											2.1	NO	2500	TH	250	TH	
AH	1-Ethenyl, 4-ethylbenzene		ND	ND	ND	0.43	ND													1250	TH	125	TH	2
AH	1-Ethyl-2,3-dimethylbenzene		ND	ND	0.88	ND	ND													1250	TH	125	TH	2
AH	1-Ethyl-2-methylbenzene (o-ethyltoluene)		0.64	1.03	4.87	4.52	4.18											363	NO	1250	TH	125	TH	
AH	1-Ethyl-3,5-dimethylbenzene		ND	0.11	0.82	ND	ND													1250	TH	125	TH	2
AH	1-Ethyl-3-methylbenzene (m-ethyltoluene)		0.29	0.34	3.73	0.69	0.59											88	NO	1250	TH	125	TH	
AH	1-Methyl-3-propylbenzene		0.33	0.16	2.30	ND	ND													2450	TH	245	TH	
AH	1-Methylnaphthalene	0.04																		200	TH	20	TH	
AH	2-Methylnaphthalene	0.1																58	UO	200	TH	20	TH	
AH	2-Methylpropylbenzene (isobutylbenzene)		ND	ND	0.16	ND	ND													1250	TH	125	TH	2
AH	4-Ethyl-1,2-dimethylbenzene		1.26	ND	2.58	ND	ND													2450	TH	245	TH	
AH	Acenaphthylene							0.02	0.02											100	TH	10	TH	
AH	Benzene	1.3						0.06	0.04	0.66	3.4	0.8		ND	0.2	1.92	8.94	5000	UO	27	C	9.6	N	
AH	Butylbenzene		ND	ND	0.22	ND	ND							ND				47	NO	2740	TH	274	TH	
AH	Cumene	0.23	0.25	ND	ND	ND	ND	1.38	1.02					ND	ND			40	UO	2500	X	250	TH	
AH	Ethylbenzene	1.2	0.69	2.13	6.04	22.58	1.65	1.38	0.84	7.4	104	0.4	0.9	ND	0.43	2.61	9.12	740	NO	26000	TH	270	N	
AH	Naphthalene	0.15	ND	0.42	0.47	ND	ND	ND	ND	0.00087	0.0036	1.6		ND	ND	ND	ND	440	TO	500	TH	10	W	
AH	Phenol	0.7																150	TO	290	TH	3.3	TH	
AH	Propylbenzene	0.12	0.25	0.39	3.05	0.44	0.39							ND				6.5	NO	2500	TH	250	TH	
AH	Styrene	0.57								7.7	109	0.12		ND	ND	ND	ND	110	TO	21000	C	260	W	
AH	Toluene	6.7	2.90	3.77	18.83	23.83	18.49	3.3	1.92	65	923	2.41		ND	1.4	6.40	28.99	1240	NO	37000	C	376	N	
AH	Xylenes	3.9	2.47	4.12	34.08	42.46	5.56	0.07	0.05	41	754		2.2	ND	4.03	4.34	25.62	180	NO	22000	C	868	N	
AL	1,3,5-Cycloheptatriene		ND	ND	0.41	ND	ND													3500	TH	350	TH	2
AL	1-Butyl-2-pentylcyclopropane		ND	0.76	ND	ND	1.65													3500	TH	350	TH	2
AL	1-Ethyl-2-methylcyclopropane		0.69	0.41	0.38	0.72	ND													3500	TH	350	TH	2
AL	1-Methyl-2-pentylcyclohexane		0.62	0.28	ND	ND	ND													3500	TH	350	TH	2
AL	2,2,3,4-Tetramethyldodecane		ND	0.42	ND	ND	ND													3500	TH	350	TH	2
AL	2,2,4-Trimethylpentane													ND						3500	TH	350	TH	
AL	2,3,6-Trimethyloctane		ND	0.26	ND	ND	ND													3500	TH	350	TH	2
AL	2,3-Dimethylnonane		ND	0.32	ND	ND	ND													3500	TH	350	TH	
AL	2,4-Dimethylhexane		0.28	0.37	ND	ND	ND													3500	TH	350	TH	
AL	2,6,10-Trimethyldodecane		ND	0.43	0.87	ND	1.30													3500	TH	350	TH	
AL	2,6-Dimethyl-2-octene		ND	0.57	ND	ND	ND													3500	TH	350	TH	2
AL	3-Methylhexane		ND	ND	0.74	ND	ND											3442	NO	3070	TH	307	TH	
AL	4,7-Dimethylundecane		ND	1.73	ND	2.26	3.47													3500	TH	350	TH	2
AL	Cyclohexane	0.8												ND	0.4	ND	4.48	35600	NO	3400	TH	340	TH	
AL	Decane	1.1	0.64	1.22	1.51	1.28	2.38								11			3610	NO	10000	TH	1000	TH	
AL	Heptane							0.02	0.12					ND		ND	6.14	2745	NO	3500	TH	350	TH	
AL	Hexane	0.51						0.04	0.02				1.1	ND	0.44	10.92	26.08	5300	NO	6200	TH	200	TH	

Concentrations Reported on Landfill Boundary and in Off-Site Community ($\mu g/m^3$)

	Reference:	Marti et al (2014)	Davoli et al (2003)					Ying et al (2012)		UK EA (2010)		NYS DEC (2013)	Saquing et al (2014)	AECOM (2012)		Vic EPA (2012)		Odour Threshold ($\mu g/m^3$)		Health Based Air Guidelines ($\mu g/m_3$)				
AL	Octane							0.02	0.02						1.3			7900	NO	5600	TH	540	TH	
AL	Pentane, n-	2.4											2.4					4131	NO	59000	TH	7100	TH	
AL	Tetradecene	3.1	12.77	0.88	ND	0.81	1.26						2.4							1000	TH	100	TH	
AL	Undecene		ND	ND	ND	0.64	ND													3500	TH	350	TH	
ALCOHOL	2-Butoxyethanol	1.2	0.10	ND	ND	16.48	1.06								ND			207	NO	13100	W	3700	TH	
ALCOHOL	2-Ethyl-1-hexanol	1.7								7.4	86							3090	NO	1600	TH	160	TH	
ALCOHOL	6-Pentadecen-1-ol		4.72	1.94	ND	7.68	4.17													2000	TH	200	TH	2
ALCOHOL	Butanol	2.7												ND	ND			400	NO	610	TH	61	TH	
ALCOHOL	Ethanol	4.8												ND		3.01	7522.49	2000	NO	18800	TH	1880	TH	
ALCOHOL	Isopropanol	3														ND	3.44	8000	NO	3200	C	210	U	
ALCOHOL	Propanol	0.4																2000	NO	2460	TH	246	TH	
ALD	2,6-Dimethylbenzaldehyde		1.65	0.49	ND	ND	ND													90	TH	9	TH	4h
ALD	2-Methyl-1,3-dioxolane		28.35	45.31	17.72	42.97	61.84													1800	TH	80	TH	2
ALD	3,5-Dimethylbenzaldehyde		ND	0.55	ND	ND	1.15													90	TH	9	TH	4h
ALD	3-Methylhexanal		ND	ND	0.75	ND	ND													90	TH	9	TH	2
ALD	Acrolein							0.12	0.06					ND		ND	2.75	8.2	NO	2.5	C	0.35	C	
ALD	Benzaldehyde	2.7																10	NO	90	TH	9	TH	
ALD	Butanal							0.04	0.02									27	TO	300	X	30	TH	
ALD	Cinnamicaldehyde		ND	ND	ND	ND	1.35													90	TH	9	TH	2
ALD	Crotonaldehyde	0.27																		8.6	TH	3.2	TH	
ALD	Decanal	1.9						0.04	0.02									2.56	NO	40	TH	4	TH	
ALD	Dichloro acetaldehyde							0.06	0.04											32	TH	3.2	TH	
ALD	Formaldehyde									185	487							65	UO	100	W	100	W	
ALD	Heptanal	2.3						0.06	0.06						ND			0.84	NO	400	X	40	TH	
ALD	Hexanal	1.4																1.1	NO	8180	X	818	TH	
ALD	Nonanal	5.6						0.42	0.22									2	NO	1500	TH	150	TH	
ALD	Octanal	3.5																0.05	NO	1500	TH	150	TH	
ALD	Propanal							0.14	0.04									2.4	NO	400	X	40	TH	
BH	Bromoform							0.26	0.02					ND		ND	ND	2200	UO	50	TH	5	TH	
CH	1,1,1,2-Tetrachloroethane							0.32	0.12					ND		ND	ND			1050	TH	4	U	
CH	1,1,1-Trichloroethane	0.09						3.22	1.92	0.047	0.27		0.052		ND	ND	ND	1130	UO	2800	TH	1500	TH	
CH	1,1,2-Trichloroethane							0.06	0.08							ND	ND			550	TH	0.2	U	
CH	1,1-Dichloroethane	0.007								0.02	0.03			ND		ND	ND	446000	UO	4000	TH	18	U	
CH	1,2,3-Trichloropropane							0.04	0.04											600	TH	60	TH	
CH	1,2-Dichlorobenzene	0.005						0.02	0.02					ND		ND	ND			900	TH	160	TH	
CH	1,2-Dichloroethane	0.62						0.22	0.14	0.38	2.4			ND		ND	ND	100000	UO	160	TH	2	W	
CH	1,2-Dichloroethene	0.023	0.28	0.28	ND	0.28	ND	26.52	8.06	0.26	0.5		0.4			ND	ND	340	UO	7900	TH	7	N	
CH	1,2-Dichloropropane							3.38	1.04						ND	ND	ND	1200	UO	460	TH	2.8	U	
CH	1,3-Dichlorobenzene							0.04	0.02					ND		ND	ND			900	TH	160	TH	
CH	1,4-Dichlorobenzene	0.012						0.04	0.04	1	5			ND		ND	ND	730	UO	900	TH	160	TH	
CH	Carbon Tetrachloride	1.4										0.52	0.63	ND		ND	ND	500000	UO	1900	C	6.1	W	
CH	Chlorobenzene	0.014						0.68	0.22	0.18	0.44			ND		ND	ND	6000	UO	460	TH	52	U	
CH	Chlorodifluoromethane									0.46	3		1.6							18000	TH	1800	TH	
CH	Chloroethane									0.025	0.12			ND		ND	ND			500	TH	50	TH	
CH	Chloroform	0.8								0.28	1.5	0.1	0.11			ND	2.44	500	UO	100	TH	140	W	
CH	Chloromethane									0.02	0.029	1	3.1	ND		ND	1.65			1030	TH	94	U	
CH	cis-1,4-Dichloro-2-butene							0.04	0.02											6	TH	0.6	TH	
CH	Dichlorodifluoromethane	3.4								0.008	0.009	2.4	3			ND	ND			50000	TH	100	U	
CH	Dichloromethane	3	0.31	0.76	0.49	0.66	1.28			2.2	7.4	1.15				ND	ND	4100	UO	3000	W	450	W	
CH	Freon 11											2.1		1.5						56000	TH	5600	TH	
CH	Freon 12											0.5		3.3						50000	TH	5000	TH	
CH	Tetrachloroethene	0.95	0.41	0.27	0.68	0.68	2.10	4.72	0.38	0.69	5.6	0.12	0.61	ND	ND	ND	ND	8000	W	20000	C	250	W	
CH	trans-1,4-Dichloro-2-butene							0.08	0.02											6	TH	0.6	TH	
CH	Trichloroethene	0.26						2.38	0.42	1.4	2.8		0.1		ND	ND	ND	3900	NO	540	TH	20	W	
CH	Vinyl chloride									0.63	4.9			ND		ND	ND	26000	UO	22000	C	2	W	
E	Butyl acetate	1.5	ND	ND	ND	1.05	0.48	0.1	0.08						ND			76	NO	11000	TH	1400	TH	
E	Diethyl phthalate		ND	ND	0.91	39.52	ND													50	TH	5	TH	
E	Ethyl acetate	8.1	ND	0.22	ND	0.07	0.43							ND	ND	ND	28.46	3100	TO	730	X	73	U	
E	Methyl acetate	1																8000	NO	6000	TH	600	TH	
E	Methyl Methacrylate	0.2												ND	ND	ND	ND	860	TO	2100	X	210	TH	
E	Methyl propionate							0.02	0.02									352	NO	370	TH	37	TH	
E	Vinyl acetate							0.06	0.12					ND		ND	ND	400	UO	420	TH	210	U	
ETHER	Butylether, tert-	4.3																		21000	TH	2100	TH	
ETHER	Methyl tert-Butyl Ether (MTBE)	0.06												ND	ND			630	TO	1100	X	110	U	
ETHER	Propylene Glycol Monomethyl Ether	0.6																		1000	TH	100	TH	
FURAN	Tetrahydrofuran	0.11														ND	37.73	90000	UO	1500	TH	150	TH	
K	2-Methyl-5-(1-methyl ethyl)-cyclohexanone		ND	0.63	ND	ND	ND													800	TH	80	TH	4a

		Concentrations Reported on Landfill Boundary and in Off-Site Community (µg/m³)																						
	Reference:	Marti et al (2014)	Davoli et al (2003)					Ying et al (2012)		UK EA (2010)		NYS DEC (2013)	Saquing et al (2014)	AECOM (2012)		Vic EPA (2012)		Odour Threshold (µg/m³)		Health Based Air Guidelines (µg/m₃)				
K	Acetone	16											95			ND	ND	8600	NO	7800	TH	4800	TH	
K	Cyclohexanone	0.56	ND	ND	ND	ND	0.60	0.18	0.02						ND			3500	UO	800	TH	80	TH	
K	Methyl butyl ketone		ND	ND	ND	ND	1.19									ND	ND	98	NO	40	TH	4	TH	
K	Methyl ethyl ketone (2-butanone)	3.5	ND	ND	ND	4.16	14.59			0.9	1.5				ND	5.90	28.60	1300	NO	13000	C	2600	TH	
K	Methyl Isobutyl Ketone	0.33						0.02	0.06					ND	ND	ND	ND	140	NO	820	TH	82	TH	
K	Methyl-tert-butyl ketone (pinacolone)															ND	8.60	300	NO	40	TH	4	TH	
S	Carbon Disulfide	0.5								4	48		0.06			ND	ND	20	W	6200	C	800	C	
S	Dimethyl disulfide							0.004	0.002									8.5	NO	20	TH	2	TH	
S	Dimethyl sulfide							10.46	4.64				0.59					7.6	TO	250	X	25	TH	
S	Ethylmercaptan (ethanethiol)							0.04	0.04	0.41	2.1							0.02	NO	13	X	1.3	TH	
S	Hydrogen sulfide							178.46	56.58						ND			0.57	NO	150	W	2	U	
S	Methyl mercaptan (Methanethiol)							2.04	1.56	3.3	22							0.13	NO	10	X	1	TH	
T	1,1,4,8-Tetramethyl-4,7,10-cycloundecatriene		6.60	ND	ND	ND	ND													1100	TH	110	TH	2
T	1,2-Methyl-1,5,9,11-tridecatetraene		8.79	ND	ND	ND	ND													1100	TH	110	TH	2
T	2,6,6,9-Tetramethyl tricyclo(5,4,0,2,8)undecen-9-ene		15.87	ND	ND	ND	ND													1100	TH	110	TH	2
T	Camphene							0.04	ND									26000	UO	1000	TH	100	TH	
T	Cymene		0.33	0.05	0.27	0.22	0.77							ND				200	UO	2750	TH	275	TH	
T	Eucalyptol		ND	ND	0.69	ND	0.50											75	LO	500	X	50	TH	
T	Limonene	0.5	4.01	0.28	0.17	ND	4.01											210	NO	1100	TH	110	TH	
T	Phellandrene		ND	ND	ND	ND	0.72											2900	UO	2000	TH	200	TH	
T	Pinene	2.3	0.66	ND	ND	ND	1.65	0.002	ND									100	NO	3500	TH	350	TH	
T	Terpenes		119.93	2.61	3.34	3.56	ND													1100	TH	110	TH	
T	Terpinene		ND	ND	ND	ND	ND			1.8	4.1							2350	UO	1100	TH	110	TH	
V	1,3-Butadiene									ND	ND	0.095		ND		ND	ND	510	TO	660	C	2	C	
V	1-Nitrobutane							0.02	ND											500	TH	50	TH	4b
V	2,4,6-Trichloroaniline							0.06	0.06											80	TH	8	TH	4c
V	2-Methylfuran									1.3	2									550	TH	55	TH	
V	3,4-Dihydropyran		ND	0.58	ND	ND	ND													3600	TH	360	TH	4d
V	7-Methyl-3,4-octadiene		4.62	1.27	5.18	5.13	5.33													300	TH	30	TH	4e
V	Acetonitrile	0.11																2705000	UO	340	TH	34	TH	
V	Acrylonitrile							0.22	0.1					ND				3472	UO	330	TH	0.5	W	
V	Ammonia							2020	520						0.56			1042	NO	3200	C	100	U	
V	Cyclohexyl isocyanate	0.9																		0.7	TH	0.1	TH	
V	Cyclohexyl isothiocyanate	0.35																		0.7	TH	0.1	TH	4f
V	Diethylformamide	1.6																		300	TH	30	TH	4g
V	Dimethylformamide	1.8																140	UO	300	TH	30	TH	
V	Nitromethane									1.6	2.5									500	TH	50	TH	
XX	(5,4,0,2,8)undecen-9-ene		ND	ND	ND	ND	ND																	
XX	1,1,2-Trichloro-1,2,2-trifluoroethane															ND	ND							
XX	1,1-Dichloroethene													ND		ND	ND							
XX	1,2,4-Tribromobenzene							ND	ND															
XX	1,2,4-Trichlorobenzene							ND	ND							ND	ND							
XX	1,2-Dibromoethane															ND	ND							
XX	1,4 -Dioxane													ND		ND	ND							
XX	1-Ethylpropylbenzene		ND	ND	ND	ND	ND																	
XX	1-Methyl-2-propanol														ND									
XX	1-Methyl-2-propylacetate														ND									
XX	2-Chloroprene													ND										
XX	2-chlorotolulene													ND										
XX	2-Methylpentane														ND									
XX	2-Propanol													ND										
XX	3-Chloropropene													ND										
XX	3-MethylPentane														ND									
XX	4-Ethyltoluene													ND		ND	ND							
XX	alpha-Chlorotolulene													ND										
XX	Benzyl chloride															ND	ND							
XX	Bromodichloromethane													ND	ND	ND	ND							
XX	Bromomethane													ND		ND	ND							
XX	cis-1,3-Dichloroethene													ND										
XX	cis-1,3-dichloropropene													ND		ND	ND							
XX	decatriene		ND	ND	ND	ND	ND																	
XX	Dibromochloromethane													ND		ND	ND							
XX	Dichlorofluoromethane									ND	ND													
XX	Dichlorotetrafluoroethane															ND	ND							
XX	Diisopropyl Ether													ND										
XX	Ethyl tert-Butyl Ether														ND									
XX	Freon 113													ND										

	Reference:	Marti et al (2014)	Davoli et al (2003)					Ying et al (2012)		UK EA (2010)		NYS DEC (2013)	Saquing et al (2014)	AECOM (2012)		Vic EPA (2012)		Odour Threshold (µg/m^3)		Health Based Air Guidelines (µg/m$_3$)				
		Concentrations Reported on Landfill Boundary and in Off-Site Community (µg/m^3)																						
XX	Freon 114													ND										
XX	Hexachlorobutadiene													ND		ND								
XX	hexanone		ND	ND	ND	ND	ND																	
XX	Isobutanol														ND									
XX	Isooctane														ND									
XX	Propene													ND										
XX	Pyridine							ND	ND															
XX	tert-Amyl Methyl ether													ND										
XX	tert-Butylbenzene													ND										
XX	trans-1,3-dichloropropene													ND		ND	ND							
XX	Trichlorofluoromethane															ND	ND							
XX	Vinyl bromide													ND										

Key

Some groups have full names, otherwise the groups are as follows

A = Organic acids
AH = Aromatic hydrocarbons
AL = Aliphatic hydrocarbons
CH = Chlorinated hydrocarbons
BH = Brominated hydrocarbons
ALD = Aldehydes
K = Ketones
S = Organosulfur compounds
T = Terpenes and terpenoids
V = Other (ungroups) compounds
XX = Compound not detected in any sampling program (not included in groups)

ND = Not detected in sampling program

Sources of guidelines:

N = NEPM Air Toxics Investigation Levels (NEPC 2004)
W = WHO air guidelines (WHO 200a, 200b and 2010)
U = USEPA Regional Screening Level for residential air (USEPA 2016)
C = California Office of Environmental Health Hazard Assessment, Reference Exposure Levels (OEHHA RELs) (OEHHA 2016)
TH = Texas Commission on Environmental Quality (TCEQ 2016), based on the protection of adverse health effects
X = Acute guideline adopted is 10 times the chronic, consistent with the approach adopted in the development of TCEQ values
TO = TCEQ (2016), based on protection of odours
UO = Odour threshold based on values published by the USEPA (1992) and other more recent publications (OSHA, ATSDR etc.)
NO = Odour threshold based on values published by Nagata
LO = Odour threshold based on values listed in the summary table, presented by Leffingwell & Associates

1 = No chronic value presented as compound has low chronic toxicity. Health effects more significant for short-duration irritation
2 = No toxicity value available. Values adopted are those relevant to the chemical group.
3 = Extrapolated from oral value (available from WHO), assuming inhalation of 10% of TDI
4 = No toxicity data available and no toxicity value available for the group, hence a surrogate value has been adopted, as below:
a = Adopted value for cyclohexanone
b = Adopted value for nitromethane
c = Adopted value for dichloroaniline
d = Adopted value for 2-ethoxy-3,4-dihydro-1,2-pyran
e = Adopted value for myrcene
f = Adopted value for chlorohexyl isocyanate
g = Adopted value for dimethylformamide
h = Adopted value for 2,5-dimethylbenzaldehyde