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A review of the scientific literature on potential health effects in local communities associated with air emissions from Waste to Energy facilities

Prepared for: EPA Victoria

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EPA commissioned Environmental Risk Sciences (enRiskS) to provide an understanding of research on potential health effects in local communities from waste-to-energy facility air emissions.

The review was commissioned to ensure there was access to an independent review of studies, considering the potential health effects internationally from regulated waste-to-energy facilities, similar to what would be expected in Victoria.

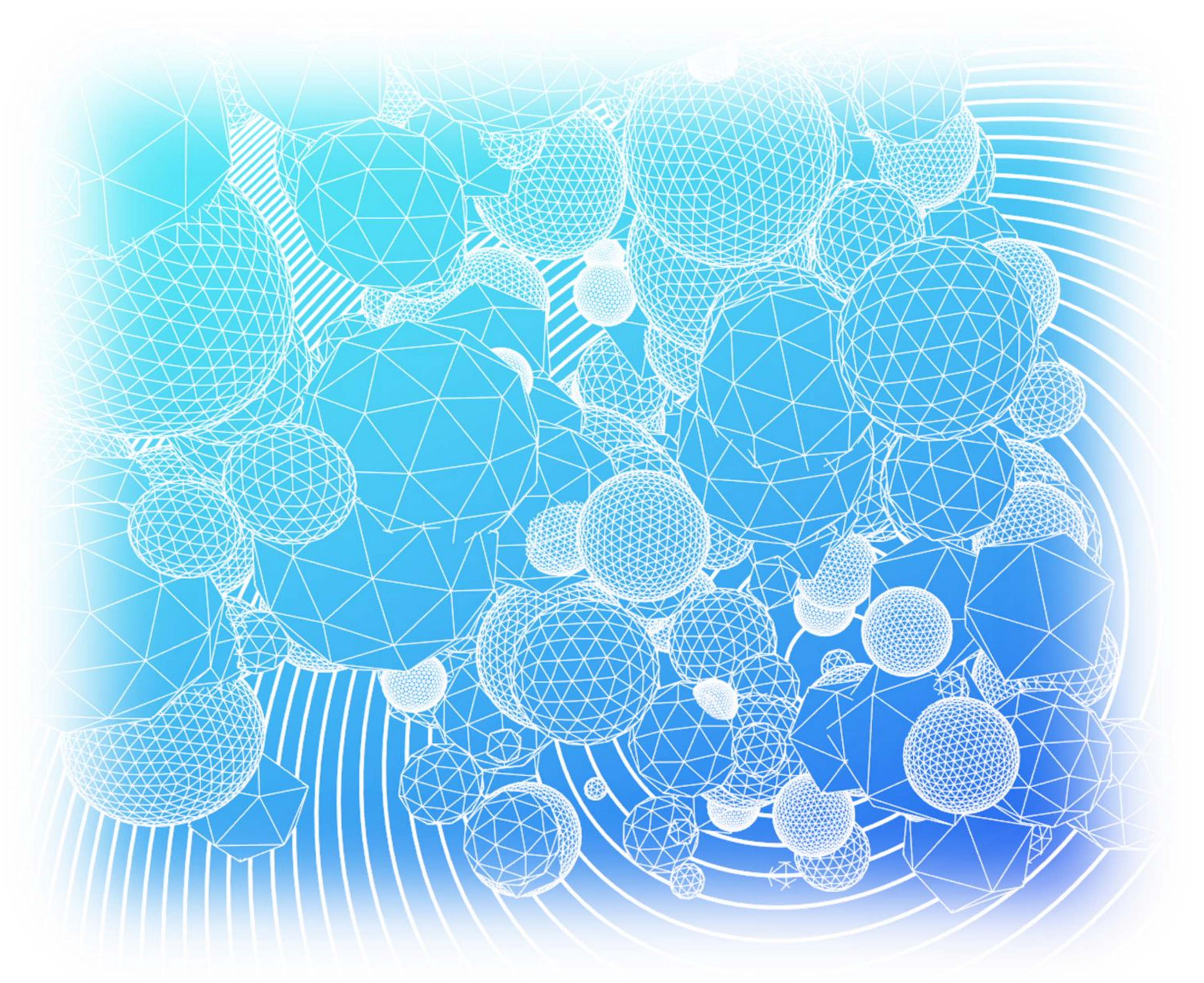
This preliminary review looked at available literature associated with modern waste-to-energy facilities that meet international best practice design requirements – the European Union's Industrial Emissions Directive or IED.

The assessment shows that while health effects associated with emissions from such facilities cannot be discounted, due to limitations with the available published studies, there was no consistent or strong evidence that health effects from incinerator emissions per EU IED standards occur.

The independent review identified few studies that reported associated health effects such as adverse birth outcomes with incinerator emissions. However, there were methodological issues with those studies and it is likely that the reported emissions were from older plants with less stringent standards than any new facilities in Victoria.

The review was independently peer-reviewed by Professor Brian Priestly, a regulatory toxicologist and health risk assessor.

EPA will consider the independent review in assessments undertaken for all future works approval and licence applications for waste-to-energy facilities within Victoria. It will also be used to help develop future monitoring programs around such facilities.



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Document History and Status

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Limitations

Environmental Risk Sciences Pty Ltd has prepared this report for the use of EPA Victoria in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the objectives outlined in **Section 1** of this report taking into consideration the timeframe and funding.

The methodology adopted and sources of information used are outlined in this report. Environmental Risk Sciences Pty Ltd has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information contained in the sources of information for use in this assessment was false.

This report was prepared from July to September 2018 and updated in October 2018 after review by Dr Brian Priestly and is based on the information provided and reviewed at that time. Environmental Risk Sciences Pty Ltd disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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Executive Summary

Introduction

Environmental Risk Sciences Pty Ltd (enRiskS) has been commissioned by EPA Victoria to undertake a literature review on potential health effects in local communities associated with air emissions from 'Waste-to-Energy' facilities.

The literature review has been undertaken to identify national and international published papers that examine compounds (and compound properties) that are found in the air in the vicinity of operational waste to energy facilities designed to meet EU IED or equivalent emissions standards have been reviewed. In addition, the literature has been reviewed to identify papers that describe studies investigating potential short and long-term health impacts on residents living near operational waste to energy facilities designed to meet EU IED or equivalent emissions standards.

Conclusion

This review has found:

- Studies of older waste to energy facilities have shown some associations with health effects
- Some studies of waste to energy facilities that are presumed to comply with EU IED or equivalent emission standards found associations with health effects although the evidence is more limited
- All the studies have methodological issues (which are inherent in these types of studies)
- One of the methodological issues common to all of the studies is the presence of other sources of combustion emissions in the area where health effects were investigated which means that none of the studies can identify the emissions from the waste to energy facilities as the sole reason for the identified health effects

Therefore, while a few studies, around plants using modern technologies and complying with EU IED standards or equivalent, have shown associations with some health effects, given the limitations in these types of studies and the many common sources of some of the chemicals emitted from such facilities, it is not possible to be conclusive that the identified health effects were or were not due to these facilities.

The current limitations surrounding the assessment of emissions from waste to energy facilities impede the ability to provide a list of generic chemicals of concern and emission concentrations that are protective of human health for all facilities. The chemicals nominated in the EU IED should be considered, at bare minimum, for all waste to energy facilities. However, there is a need to understand:

- fuel mix at a proposed plant
- size of the plant
- local meteorology
- local topography
- nature of land uses in the area surrounding such a facility

when considering the health implications of emissions from waste to energy facilities.

Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been commissioned by EPA Victoria to undertake a literature review on potential health effects in local communities associated with air emissions from 'Waste-to-Energy' facilities.

Waste to energy is a recognised recovery option in the waste hierarchy and is likely to play an increasingly important role alongside other waste management options in contributing to Victoria's resource recovery targets.

Waste-to-energy facilities have operated throughout the world since the 1980s and approval to develop Waste to Energy facilities in Victoria is being sought from the Victorian Government. By their very nature, these facilities will generate air emissions as does every combustion process (e.g. cars, power stations, woodfires, bushfires), which may include chemicals that can cause short and long term health impacts (i.e. particulates, carcinogens and dioxins). Accordingly, it is important to ensure that any air emissions from new waste-to-energy facilities, which will be facilities designed to meet the European Union's Industrial Emissions Directive (EU IED) or equivalent emissions standards, will not cause adverse human health effects (EU 2010).

1.2 Objectives

The overall objective of this report is to produce a review of the scientific literature on the significance or otherwise of potential short and long-term health risks in local communities associated with air emissions from operational waste to energy facilities designed to meet EU IED or equivalent emissions standards.

More specifically the project aims to:

1. Identify compounds (and compound properties) that are found in the air in the vicinity of operational waste to energy facilities designed to meet EU IED or equivalent emissions standards.
2. Examine the published literature of studies investigating the short and long-term health of residents living near operational waste to energy facilities designed to meet EU IED or equivalent emissions standards and any association with air emissions.
3. Critically review the literature and clearly articulate the potential short and long-term human health risks posed by air emissions arising from operational waste to energy facilities designed to meet EU IED or equivalent emissions standards in a manner that is readily understood by communities and decision-makers.
4. Develop recommendations for monitoring parameters, identification of chemical species to be monitored and monitoring methodology to assist the technical preparation of a scope for future monitoring of waste to energy facilities designed to meet EU IED or equivalent emissions standards to inform the characteristics of any actual risks to human health from such facilities.

This scope of this report is limited to air emissions as they relate to stack emissions from waste to energy facilities involved in thermal degradation of waste feedstock, including combustion, gasification and pyrolysis processes.

1.3 Methodology

1.3.1 Literature review and critical appraisal

The literature review has been undertaken to identify national and international published papers that examine compounds (and compound properties) that are found in the air in the vicinity of operational waste to energy facilities designed to meet EU IED or equivalent emissions standards and / or the short and long-term health of residents living near operational waste to energy facilities designed to meet EU IED or equivalent emissions standards.

This search was undertaken as described in **Sections 3.3** and **4.2**. Critical appraisal of the literature was undertaken in a semi qualitative manner as outlined in **Section 4.2**.

1.3.2 Key Terms

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

Waste to Energy:	'Waste to energy' and 'energy from waste' are terms that can be used interchangeably. 'Waste to energy' is used to describe a number of technologies and treatment processes which extract the calorific value of waste material to generate energy. This process may include an intermediate conversion process as primary sources of energy generated, such as heat, steam or synthetic gas – or can be further transformed into other usable forms of energy such as electricity and fuel. This conversion process also reduces the solid volume of waste feedstock and can generate by-products such as char and ash.
Waste hierarchy:	The waste hierarchy is one of eleven principles of environment protection contained in the Victorian *Environment Protection Act 1970*. The principles provide a framework for EPA's decision making and are intended to benefit the Victorian environment and community. The waste hierarchy is a set of priorities for the efficient use of resources with avoidance being the most preferred option followed by resource recovery and finally disposal.
EU IED	European Union Industrial Emissions Directive (EU IED). A European based directive adopted by EPA Victoria that sets, among other things, emission limit values for selected pollutants for waste incineration and co-incineration plants. These emission limits are based on a previous directive, the EU Waste Incineration Directive (EU WID).

Section 2. Waste to Energy Process

2.1 General

Waste to energy facilities can play an important role in an integrated waste management system for Victoria. Victoria's waste and resource recovery system manages more than 12.7 million tonnes of waste each year, which constitutes a recovery of approximately 67 percent of all waste. It is predicted that by 2046 sixty percent more waste will be generated in the state of Victoria (DELWP 2017). To effectively manage this waste, and protect human health, community amenity and the environment, the Victorian government 'Energy from Waste' guideline outlines how the Victorian Environment Protection Act 1970 and associated statutory policies and regulations are applied to the assessment of proposals that recover energy from waste (EPA Victoria 2013a).

2.2 Waste to energy

Waste to energy is also known as 'energy from waste' and 'energy recovery from waste'. These terms can be used interchangeably to describe a number of treatment processes and technologies used to generate a usable form of energy from waste materials. Examples of usable forms of energy include electricity, heat and transport fuels. Waste to energy technologies fall into two broad types: thermal treatments and the biological processing of organic waste. This report is focused on thermal treatment which can be divided into three different categories; combustion, gasification and pyrolysis, combustion being the most common process. The difference in these three categories is related to the concentration of oxygen in the process, with combustion taking place in an environment with an excess of oxygen (full oxidisation), gasification with partial oxygen (partial oxidisation) and pyrolysis occurring in an absence of oxygen.

The typical waste to energy plant contains a number of segments (**Figure 1**) that include waste receiving and storage, combustion and steam / energy generation, waste gas treatment and residue handling and treatment. More detailed descriptions of the waste to energy process can be found in (EC 2006; WSP 2013)

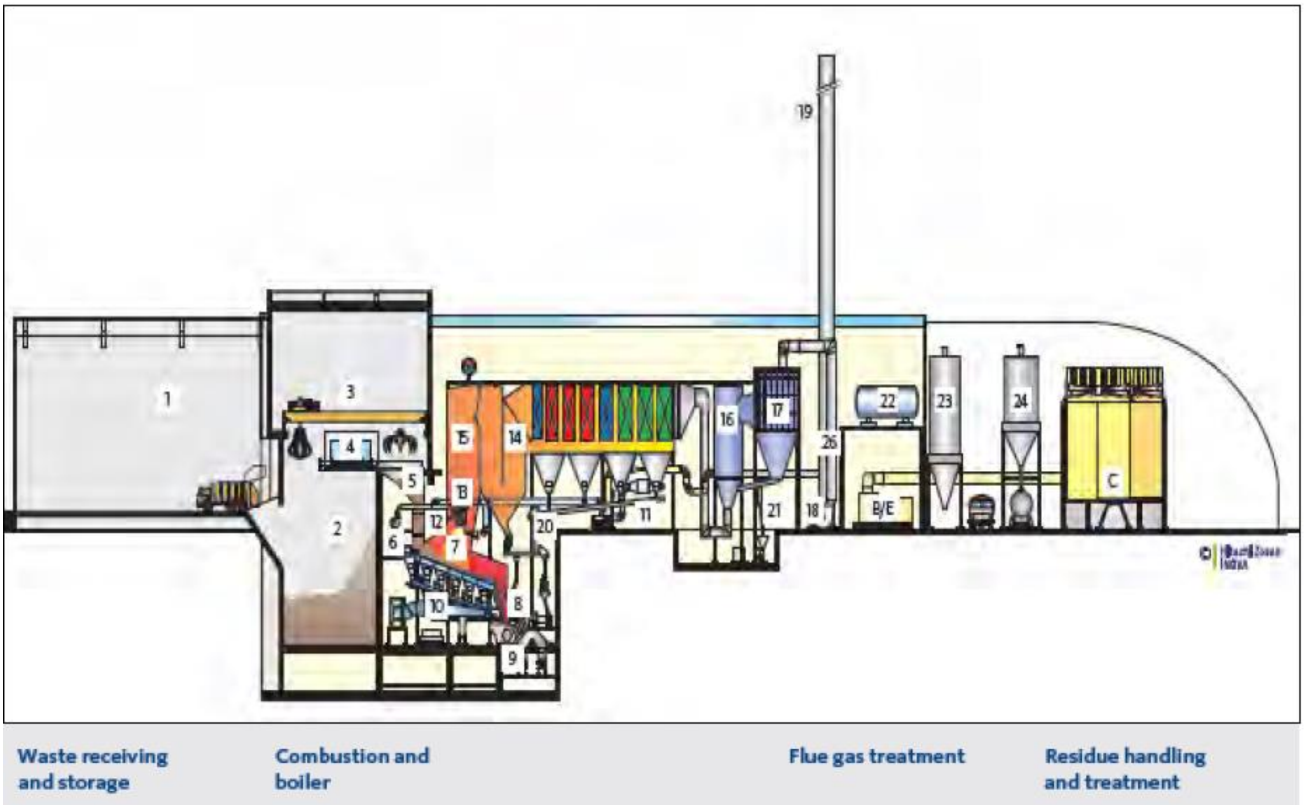

Figure 1: Layout of an energy to waste facility (WSP 2013)

2.3 Victorian waste to energy air emission guidelines

In order to minimise the discharge of pollutants to the environment, and reduce risks to human health and the environment, the Victorian Environment Protection Authority (EPA) requires all proposed waste to energy facilities to comply with best practice for all air emissions. The EPA deem the emission limits set in the European Union Industrial Emissions Directive (EU IED) as values representative of best practice (EPA Victoria 2013a; EU 2010). The EU IED was adopted in the European Union in 2010 and came into force in Europe in 2011. It is noted that the emission restrictions in the EU IED are based on the previous EU Waste Incineration Directive. The EU Waste Incineration Directive was adopted in 2000 and came into force in the United Kingdom for all new municipal waste incinerators in 2002 and existing municipal waste incinerators in 2005 (Font et al. 2015).

Section 3. Review of Air Emissions from Waste to Energy facilities with EU IED or equivalent emission standards

3.1 General

Waste to energy processes can play an important role in the waste hierarchy. The waste hierarchy guides the efficient use of resources and is used in Victoria and around the world to define the order of preference for waste management activities (**Figure 2**).

Figure 2: The waste hierarchy (from – https://www.epa.vic.gov.au/your-environment/waste)

The recovery of energy from waste is a lower order use below avoidance, reuse and recycling, but should be used where higher order recovery options are not practicable, or where higher order recovery options may lead to worse outcomes for the environment or human health (DELWP 2017).

Incineration is a key component of the waste to energy process, where waste is incinerated, and the energy generated from the combustion process is captured for reuse/electricity generation.

The objective of waste incineration is to treat wastes so as to reduce their volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances that are, or may be, released during incineration. Incineration processes can also provide a means to enable recovery of the energy, mineral and/or chemical content from waste.

Basically, waste incineration is the oxidation of the combustible materials contained in the waste. During incineration, flue-gases are created that will contain the majority of the available fuel energy as heat.

In fully oxidative incineration the main constituents of the flue-gas are: water vapour, nitrogen, carbon dioxide and oxygen. Depending on the composition of the material incinerated and on the operating conditions, smaller amounts of carbon monoxide, hydrogen chloride, hydrogen fluoride, hydrogen bromide, hydrogen iodide, oxides of nitrogen, sulfur dioxide, volatile organic compounds, polychlorinated dibenzo-*p*-dioxins and dibenzofurans, polychlorinated biphenyls and heavy metal compounds (among others) are formed or remain (JRC 2018). Depending on the combustion temperatures during the main stages of incineration, volatile heavy metals and inorganic compounds (e.g. salts) are totally or partly evaporated into the flue-gas.

Before it is discharged to the environment the flue-gas is ‘cleaned’ via a number of techniques. These include:

- Technologies to reduce acid gases. These technologies can be dry, where an absorbent material like lime or sodium bicarbonate is fed into a reactor to mix with the gases, or partially wet, where water and the absorbent material are mixed with the flue-gas, or finally wet systems where water is injected into the flue gas to wash out the hydrogen chloride and other acid gases.
- Technologies to reduce nitrogen oxides include managing the combustion chamber effectively including preventing the oversupply of air and managing the temperature in the chamber well to minimise local hot spots. Oxides of nitrogen can also be removed during flue-gas treatment using a selective non-catalytic reduction process where ammonia or urea are injected into combustion chamber to reduce the oxides of nitrogen.
- Technologies to reduce mercury include putting in place procedures to ensure mercury does not get into the waste stream or it can be removed, if required, through the addition of sulfurised activated carbon. Most plants have sufficient chlorine to ensure mercury is in ionised form which may mean it is more likely to be present in the particulate phase of the emissions and thus is controlled by the processes used to manage particulates in the emissions.
- Technologies to reduce particles are a critical component in managing the flue-gases as they contain many of the chemicals formed in the combustion of the waste. Techniques for particle capture include:
  - Electrostatic precipitators – the emissions travel between two charged plates – particles that are charged are captured on the plates
  - Scrubbers – can include a precipitator as well as a packed scrubber where the gases are forced through packing which drops out more particles
  - Bag filters – fabric filters are used to capture particles
  - Cyclones – use centrifugal forces to take out particles from the gases

Besides mercury most other metals will be reduced by the technologies used to control particles in the emissions from an incineration plant.

Organic compounds like dioxins can be reduced by managing the combustion chamber temperature to ensure destruction of the molecules that form dioxins and decreasing the temperature of the flue gases after the combustion chamber to prevent reformation. Where necessary additional steps can be included such as the use of oxidising catalysts (such as used to reduce oxides of nitrogen) or absorption processes (e.g. activated carbon).

As with all combustion processes smaller organic compounds are mostly destroyed during combustion at the appropriate temperature however some of these compounds can remain in the emissions. These are compounds that are normally present in urban air as a result of vehicle emissions.

In Victoria every new waste to energy facility must adopt 'Best Available Techniques' meaning they need to employ the most appropriate techniques to reduce emissions as described above.

The technology used in a plant is only one component of determining the types of chemicals people might be exposed to from emissions from waste to energy facilities. The emissions (including chemical concentrations) are dependent on:

- type of waste incinerated (i.e. fuel mix)
- pollution control technology adopted for the plant

The ground level concentrations around the plant will also be dependent on:

- engineering of the stack including height, exit velocity and temperature of emissions at discharge
- local meteorology
- local topography of the area
- distance from stack to relevant receptors – residents or other landuses

3.2 EU IED Emission Limits

In the European Union, the policy to ensure the application of best available techniques to waste incineration involves both identifying the types of technologies for combustion and flue-gas cleaning that are considered best practice and the identification of the key chemicals. For these key chemicals, emission limits (EU IED emission limits) have been set to control emissions. The aim is to achieve a high level of protection of human health and the environment (EU 2010).

The identification of key chemicals serves two functions.

First, these chemicals are a recognised risk from incineration emissions so must be controlled as they are for many combustion processes like coal fired power stations. Limits for these chemicals are also placed on these other types of facilities.

Second, they act as indicators that the emission control systems on the facility are working as predicted, and that in doing so, are also capturing the many other chemicals which are not subject to emission limits. Pollution control technologies are designed to remove all chemicals with a particular characteristic (e.g. baghouse removes all types of particles so will capture the various chemicals that are associated with particles or acid gas scrubber removes all acids not just hydrogen chloride and, if it is a wet scrubber, will capture water soluble chemicals). Having limits for key types of chemicals that indicate that the pollution control technology associated with that characteristic is working correctly is the most effective approach to indicate the plant is working as designed. It is the same approach adopted for many types of facilities with complex mixtures as emissions as it is not possible to measure every single chemical in such mixtures (e.g. sewage treatment plants; car emission standards)

The EU IED emission limits, as listed in Annex VI, Part 3 of the EU Directive, include:

- Half hour and daily average emission limits for:
  - Total dust
  - Gaseous and vaporous organic substances, expressed as total organic carbon (TOC) also known as Volatile Organic Compounds (VOCs)
  - Hydrogen chloride (HCl)
  - Hydrogen fluoride (HF)

  - Sulfur dioxide (SO_2)
  - Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2
- Average emissions limits over a sampling period of a minimum of 30 minutes and a maximum of 8 hours for:
  - Antimony (Sb)
  - Arsenic (As)
  - Cadmium (Cd)
  - Chromium (Cr)
  - Cobalt (Co)
  - Copper (Cu)
  - Lead (Pb)
  - Manganese (Mn)
  - Mercury (Hg)
  - Nickel (Ni)
  - Thallium (Tl)
  - Vanadium (V)
- Average emission limit value for dioxins and furans over a sampling period of a minimum of 6 hours and a maximum of 8 hours
- Carbon Monoxide (CO) (EU 2010).

There are also special limits that are required in addition to these depending on the type of incinerator (EU 2010).

3.3 Studies

3.3.1 General

A search for studies that could meet the aim of identifying compounds (and compound properties) that are found in the air in the vicinity of operational waste to energy facilities designed to meet EU IED or equivalent emissions standards was undertaken. This included a search in Scopus and Web of Science using the search terms “EU” and “IED”, a google scholar search using “EU IED incinerat”, as well studies identified from the health studies search (**Section 4.2**). Studies that identified compounds in the air around waste to energy facilities were of two general types, those that undertook sampling (generally ambient) of the compounds, and those that modelled the ground level concentrations of the compounds from predicted (or measured) stack emissions. Both methods have limitations (**Section 3.4**) a main limitation being ability to only detect what is tested for or predicted.

3.3.2 Studies undertaking ambient measurements around municipal solid waste incinerators operating to meet EU IED standards

Four studies were identified for inclusion in this section.

A study in the United Kingdom examined available stack emissions data for metals from 10 municipal waste incinerators between 2003 to 2010 (Font et al. 2015). Although it is not known if all these 10 municipal waste incinerators were EU IED/ EU WID compliant, the authors noted that any new incinerator in the UK was required to be compliant with EU WID by 2002, and existing incinerators were required to be compliant by 2005. The authors also undertook ambient sampling of metals around a subset (3) of the ten municipal waste incinerators investigated, these three sites being located close to heavily industrialised areas. The waste / fuel stream for the incinerators was identified as “a mix of combustible and non-combustible materials such as paper, plastic, food waste, glass, defunct household appliances and other non-hazardous materials”. Metals reported in stack emissions included - arsenic, cadmium, chromium, copper, lead, manganese, mercury (concentrations not reported), nickel and vanadium. Ambient sampling was only for metals and included arsenic, cadmium, chromium, copper, iron (concentrations not reported), lead, manganese, mercury (concentrations not reported), nickel, platinum (concentrations not reported), vanadium and zinc (concentrations not reported). **Figures 3** & **4** provide the reported ambient concentrations down plume of the waste incinerators. The figures also show the ambient concentrations in the non-plume directions and the reported range of general ambient concentrations of the identified chemicals in the UK. These figures highlight the limited impact of the emissions from these facilities, in particular, it is noted that where increases are seen down plume of the facility similar increases are also seen in the non-plume direction indicating that the increase is unlikely to be due to the emissions but rather to a change in the topography, meteorology or the presence of other sources in the local area. It is, however, important to consider the limited nature of this evidence (**Section 3.4**).

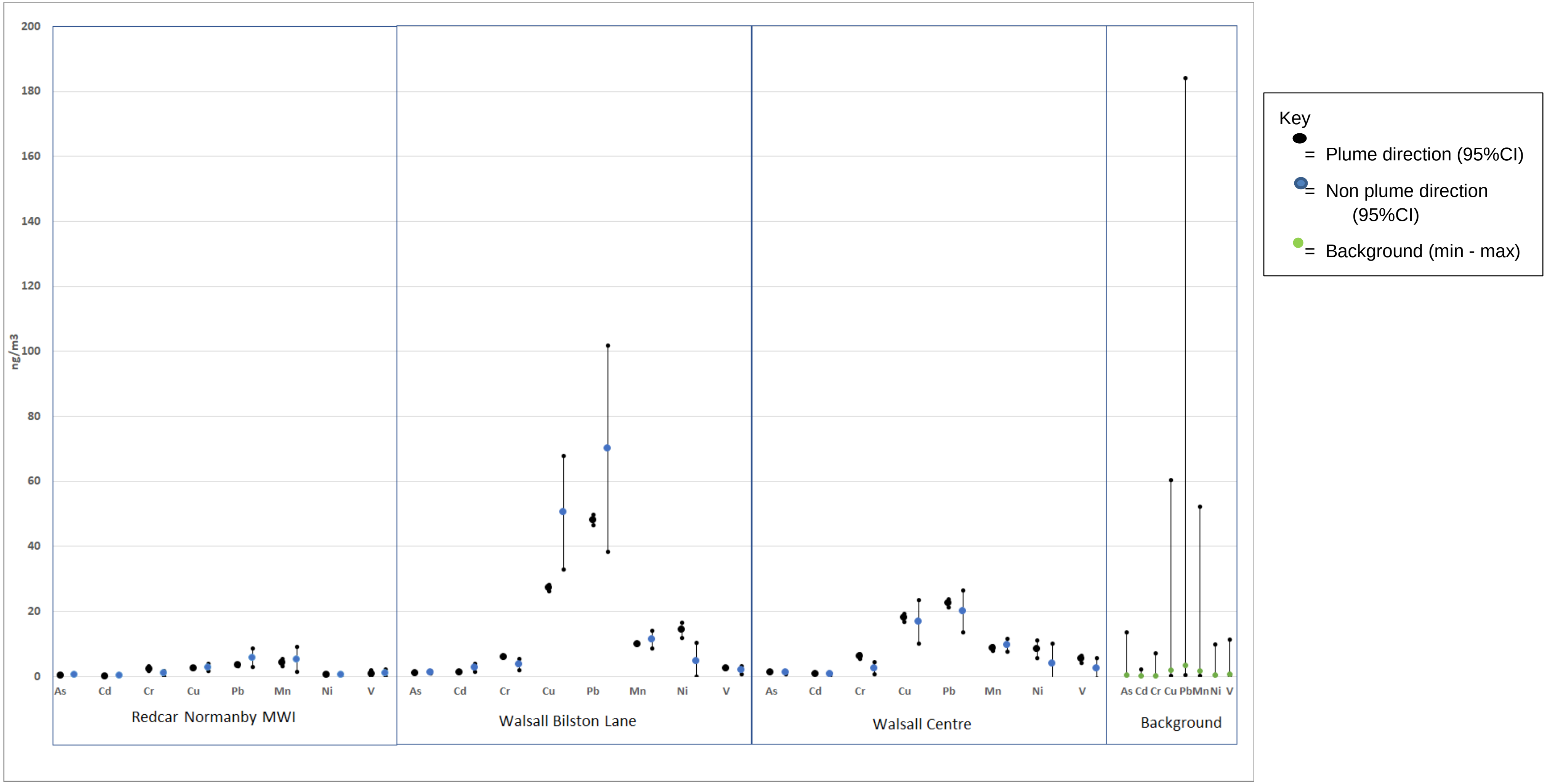

Figure 3: Reported ambient metal concentration at 3 UK waste to energy facilities plus measured background concentrations in the UK

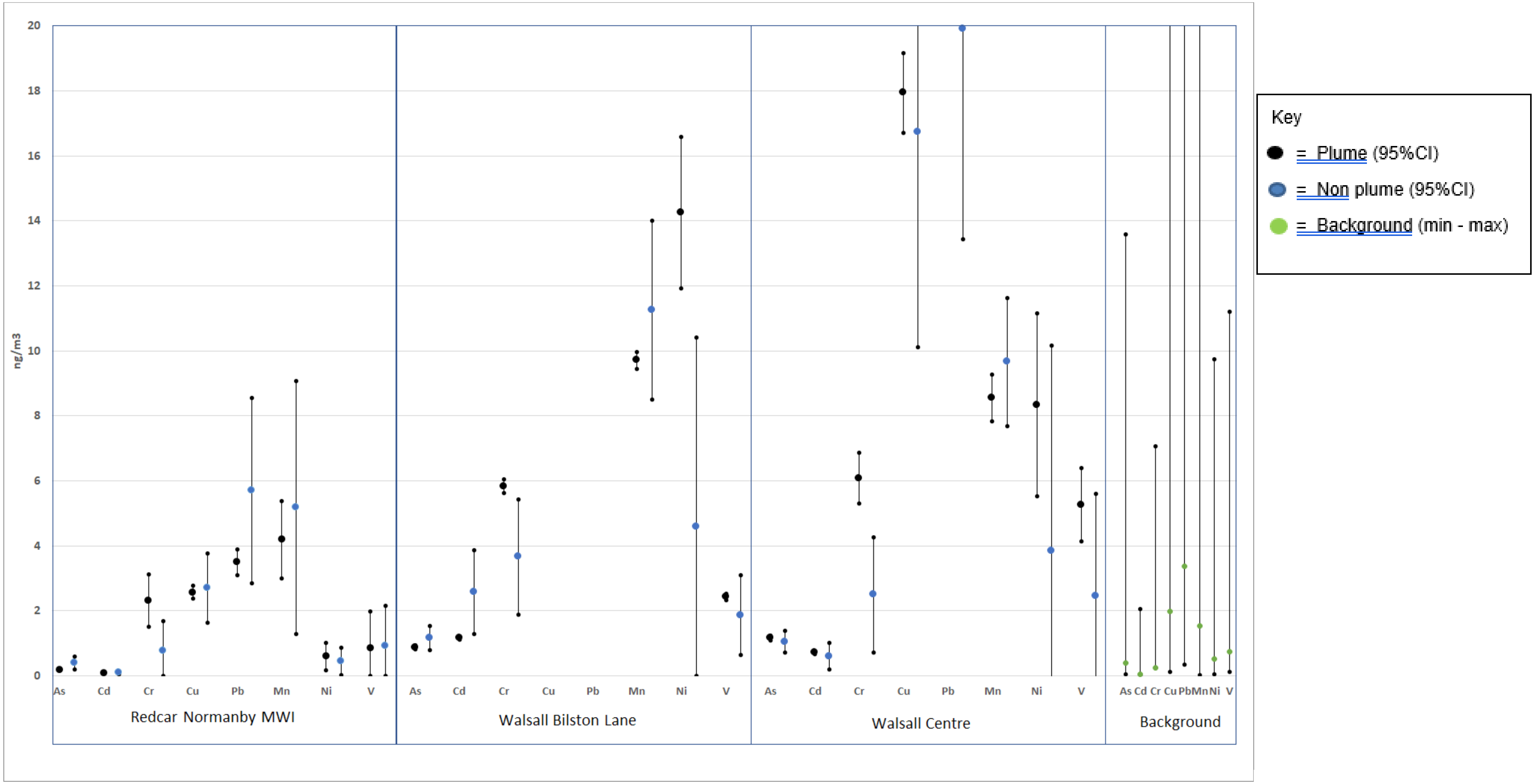

Figure 4: Magnified subsection of Figure 3 to a scale of 20 ng/m^3

Two separate studies were undertaken around a municipal solid waste incinerator in Tarragona, Spain (Vilavert et al. 2014; Vilavert et al. 2015). Neither study identified if the facility was EU IED compliant at the time of the study, nor the specific waste / fuel stream, however, given it is a municipal waste incinerator operating at a time when such facilities were required to be EU IED compliant, it is assumed to be compliant and accepting municipal waste only. The first study involved air sampling of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs) and polychlorinated naphthalenes (PCNs) by means of passive air sampling (Vilavert et al. 2014). Polyurethane foam disk samplers were deployed at 8 sampling points in the vicinity of the municipal waste incinerator for approximately 3 months. Four campaigns were carried out sampling twice a year for 2 consecutive years (March–June and September–December, in 2010 and 2011). The second study undertook air sampling of metals and PCDD/Fs in May and June 2013, although other time periods of sampling are also reported (Vilavert et al. 2015). Eight air samples were collected for analysis of metals which included antimony, arsenic, beryllium, cadmium, cobalt, chromium, copper, lead, manganese, mercury, nickel, thallium and vanadium. Eight air samples were collected for PCDD/F analyses in this second study.

Another study was undertaken around a municipal solid waste incinerator in Barcelona, Spain (Domingo et al. 2015). The facility was EU IED compliant at the time of the study, with a waste / fuel stream identified as municipal solid waste. It consumes approximately 350 000 tonnes per year of waste for energy recovery. In May to June 2014, the authors sampled the ambient air in the vicinity of the waste incinerator for polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs) and metals. Sampling locations were determined from air dispersion modelling which identified the areas likely to be most impacted. Sampled metals included antimony, arsenic, beryllium, cadmium, cobalt, chromium, copper, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, thallium, tin, vanadium and zinc.

Considering all four of the studies discussed above, the following chemicals were identified as likely to be present in the emissions of a waste to energy combustion facility:

- Metals
    - Antimony
    - Arsenic
    - Beryllium
    - Cadmium
    - Cobalt
    - Chromium
    - Copper
    - Lead
    - Manganese
    - Mercury
    - Molybdenum
    - Nickel
    - Selenium
    - Strontium
    - Thallium
    - Tin

    - Vanadium
    - Zinc
- Polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs)
- Polychlorinated biphenyls (PCBs)
- Polychlorinated naphthalenes (PCNs)

The ambient concentrations of the chemicals found in the above four studies are shown in **Figures 5 to 7**. It is important to remember that many of these chemicals are ubiquitous in the environment, so the ambient concentrations reported may not reflect the impact of the incinerator but rather the many potential sources in a particular location.

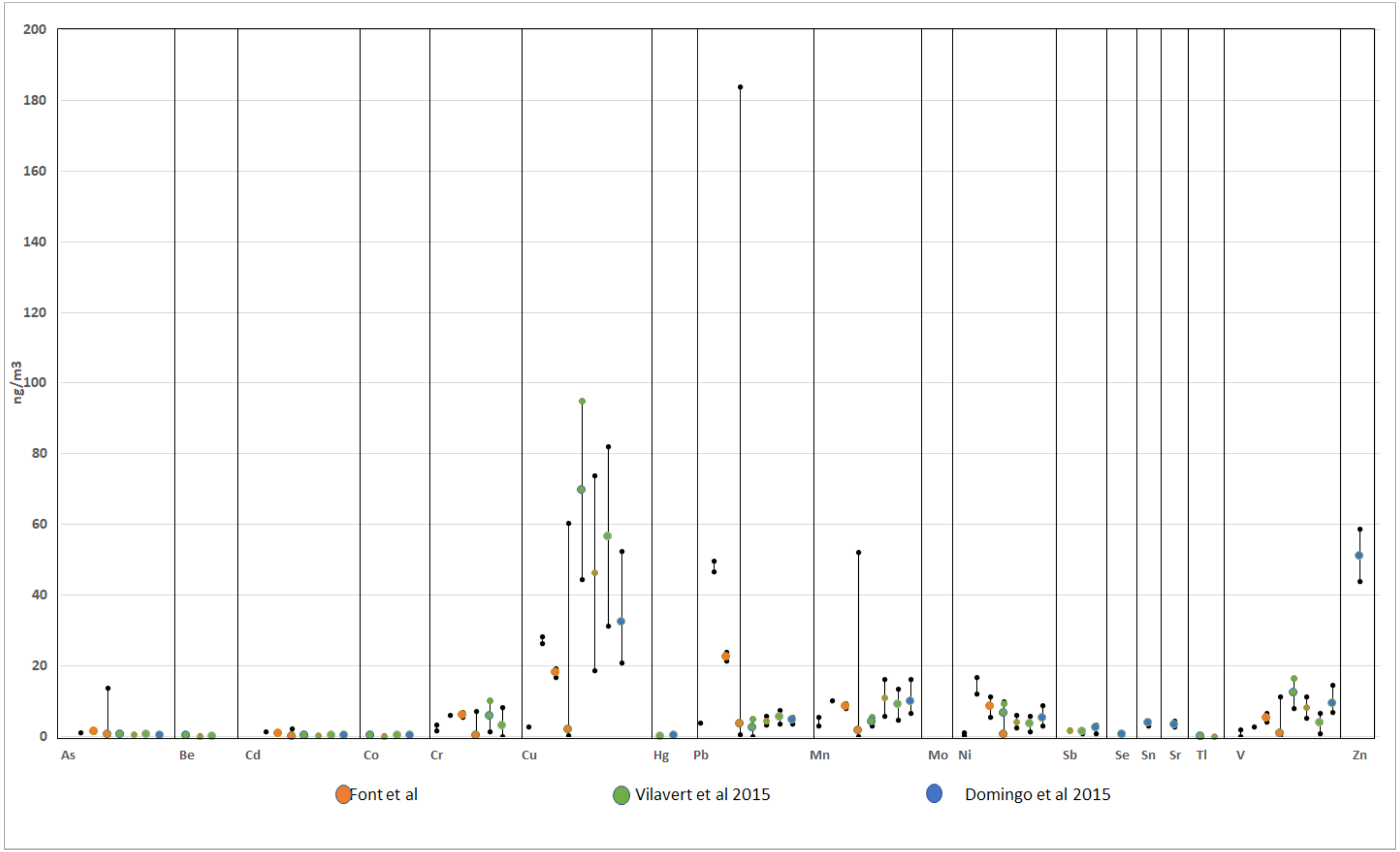

Figure 5: Reported ambient concentration of metals identified in the above four studies

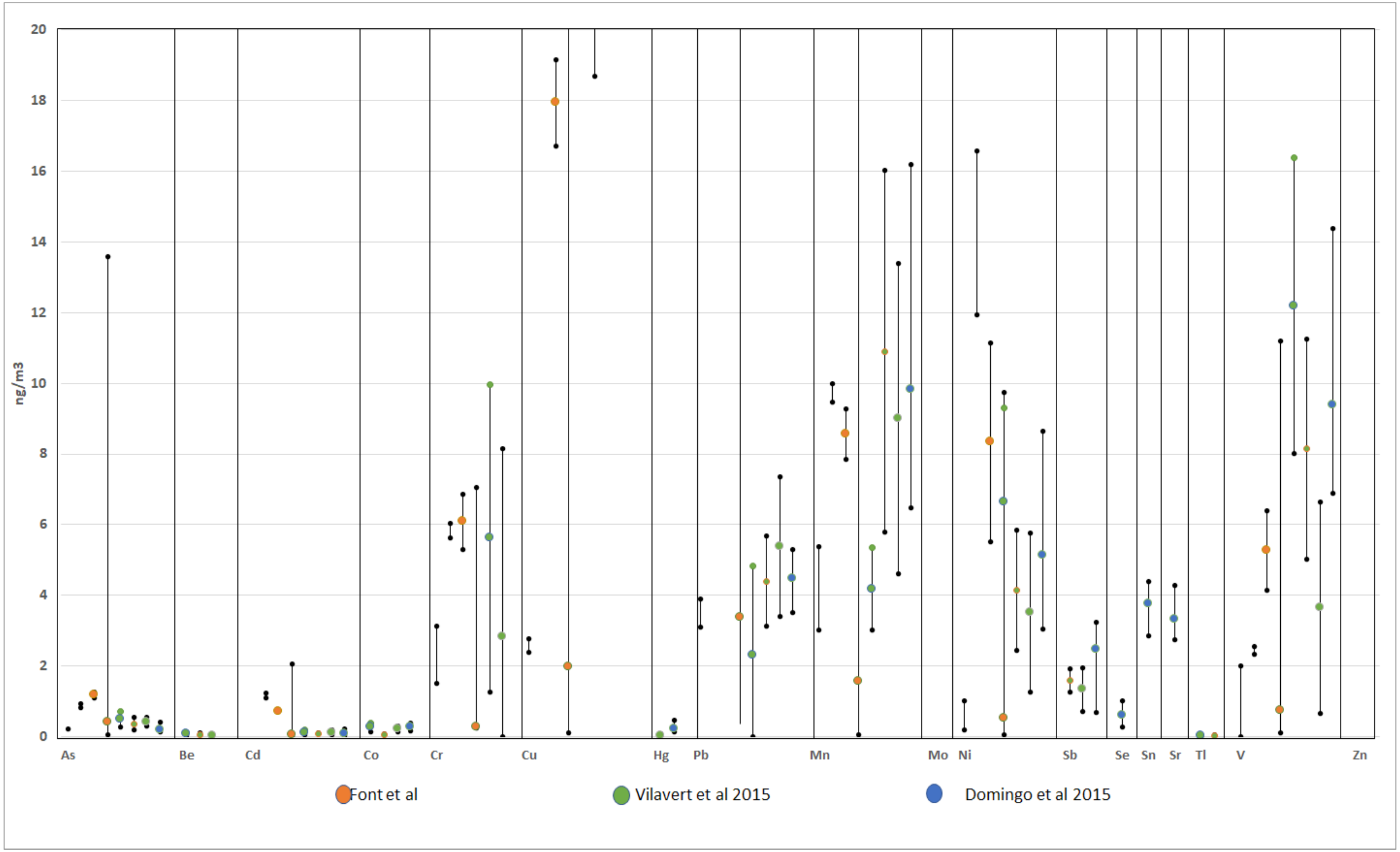

Figure 6: Magnified subsection of Figure 5 to a scale of 20 ng/m^3

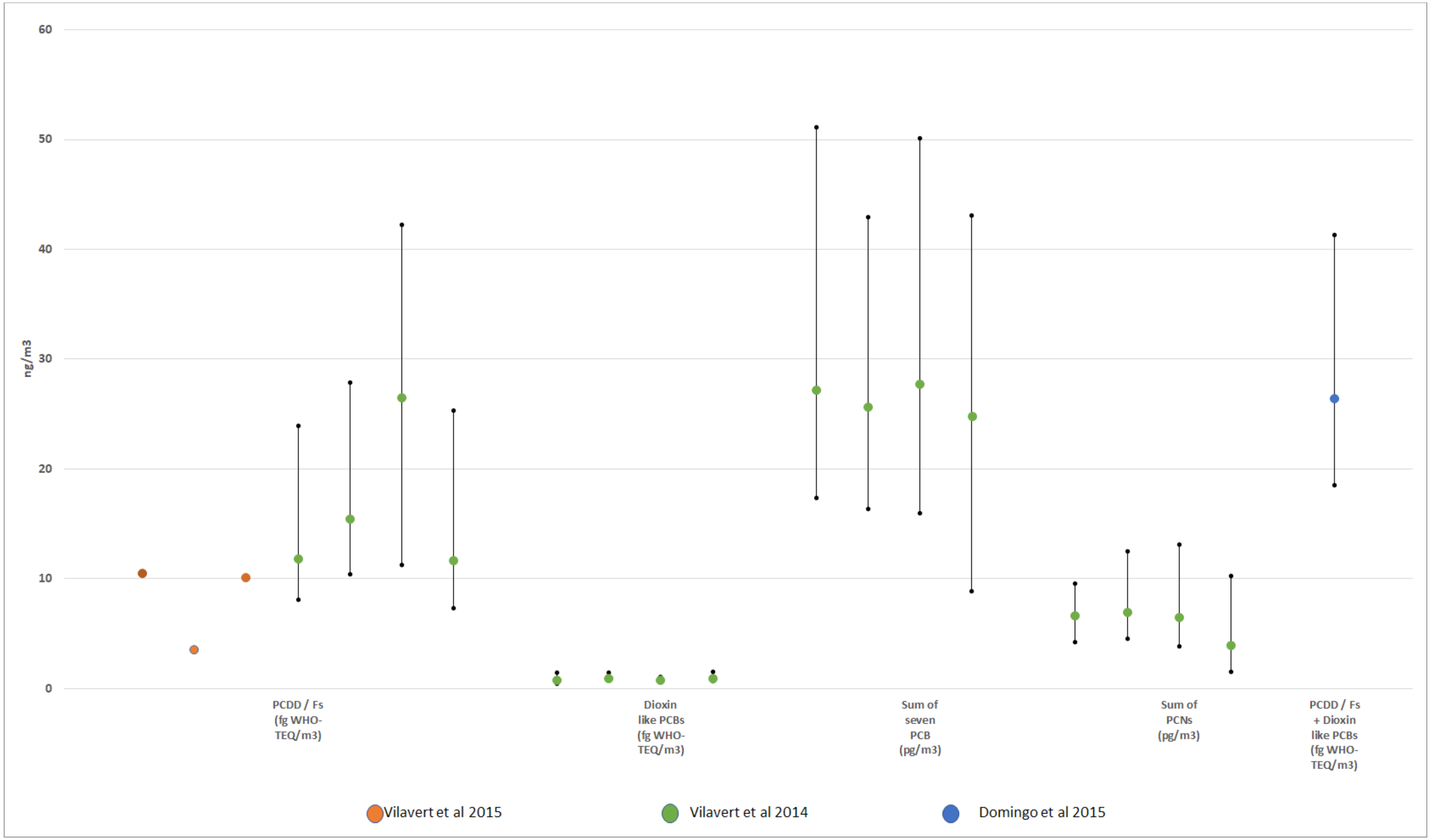

Figure 7: Reported ambient concentration of chlorinated polycyclic aromatics identified in the above four studies

3.3.3 Studies that have modelled impacts from estimated/measured stack emissions

A study in the United Kingdom undertook dispersion modelling to estimate incremental annual mean PM_{10} concentrations from 22 municipal waste incinerators in the United Kingdom between 2003 – 2010 (Douglas et al. 2017). Modelling was undertaken using the Atmospheric Dispersion Modelling System Urban (ADMS-Urban) with a 10 kilometre radius established around each municipal waste incinerator to be modelled. The authors acknowledge that some of the incinerators were not compliant with EU IED for the whole study period, and that a change point in PM_{10} emissions (lower) could be identified for some of these incinerators when they were upgraded to EU IED standards. Annual mean PM_{10} was calculated based on daily average modelled PM_{10} concentrations. The authors acknowledged that

> “Composition of combustion emissions depends on feedstock mix but potentially comprises particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NOx), hydrogen chloride (HCl), carbon monoxide (CO), Volatile Organic Compounds (VOCs), Persistent Organic Pollutants (POPs) such as polychlorinated dibenzo-*p*-dioxins/ furans (PCDD/Fs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals.”

A study from Canada describes a risk assessment undertaken for a proposed energy from waste facility in Ontario (Ollson et al. 2014). The proposal was for the facility to accept only municipal solid waste from typical Ontario kerbside waste collection (i.e. household waste excluding separated recyclable materials and organics) and burn 140,000 tonnes per year. To identify chemicals of concern in the proposed facility emissions, the authors reviewed the provincial Ontario guidelines for municipal incinerators, the Canadian National Pollutant Release Inventory for waste incinerators, and the results of stack testing of an existing waste incinerator in nearby Brampton, Ontario. Out of this review, a list consisting of 87 chemicals was developed. These were:

- Ammonia
- Carbon Monoxide
- Hydrogen Chloride
- Hydrogen Fluoride
- Nitrogen Dioxide
- Particulate Matter (PM_{10})
- Particulate Matter ($PM_{2.5}$)
- Total Particulate Matter (TSP)
- Sulfur Dioxide
- Chlorinated Polycyclic Aromatics:
  - Dioxins and Furans as Toxic Equivalents (TEQ)
  - Total PCBs (as Aroclor 1254)
- Metals:
  - Antimony
  - Arsenic
  - Barium
  - Beryllium
  - Boron

  - Cadmium
  - Chromium (hexavalent)
  - Total Chromium (and compounds)
  - Cobalt
  - Lead
  - Mercury
  - Nickel
  - Phosphorus
  - Silver
  - Selenium
  - Thallium
  - Tin
  - Vanadium
  - Zinc
- Chlorinated Monocyclic Aromatics:
  - 1,2-Dichlorobenzene
  - 1,2,4,5-Tetrachlorobenzene
  - 1,2,4–Trichlorobenzene
  - Pentachlorophenol
  - Hexachlorobenzene
  - Pentachlorobenzene
  - 2,3,4,6-Tetrachlorophenol
  - 2,4,6-Trichlorophenol
  - 2,4-Dichlorophenol
- Poly Aromatic Hydrocarbons:
  - Acenaphthylene
  - Acenaphthene
  - Anthracene
  - Benzo(a)anthracene
  - Benzo(b)fluoranthene
  - Benzo(k)fluoranthene
  - Benzo(a)fluorene
  - Benzo(b)fluorene
  - Benzo(ghi)perylene
  - Benzo(a)pyrene TEQ
  - Benzo(e)pyrene
  - Chrysene
  - Dibenzo(a,c)anthracene
  - Dibenzo(a,h)anthracene
  - Fluoranthene
  - Fluorene
  - Indeno(1,2,3–cd)pyrene
  - Perylene
  - Phenanthrene
  - Pyrene
  - 1–methylnaphthalene

    - 2–methylnaphthalene
    - Naphthalene
- Volatile Organic Compounds:
    - Acetaldehyde
    - Benzene
    - Biphenyl
    - Bromodichloromethane
    - Bromomethane
    - Dichlorodifluoromethane
    - Dichloroethene
    - 1,1-Ethylbenzene
    - Ethylene Dibromide (1,2-dibromoethane)
    - Formaldehyde
    - Tetrachloroethylene
    - Toluene
    - 1,1,2-Trichloroethylene
    - Vinyl chloride (chloroethene)
    - Xylenes, m-, p- and o-
    - Bromoform (tribromomethane)
    - Carbon tetrachloride
    - Chloroform
    - Dichloromethane
    - O-terphenyl
    - Trichloroethane
    - 1,1,1–Trichlorofluoromethane (Freon 11)

Of these chemicals and using Canadian risk assessment methods, the study found that the following chemicals were the key drivers of the health risk[1].

- Concentration Ratio ≥ 0.01
    - Hydrogen Chloride (1 hour and 24 hour exposure time periods)
    - Hydrogen Fluoride (1 hour)
    - Nitrogen Dioxide (1 hour and 24 hour)
    - Particulate Matter (PM_{10}) (has not been assessed so automatically included)
    - Particulate Matter ($PM_{2.5}$) (has not been assessed so automatically included)
    - Total Particulate Matter (TSP) (has not been assessed so automatically included)
    - Sulfur Dioxide (1 hour)
    - Metals (1 hour and 24 hour)
- Hazard Quotient ≥ 0.01
    - Dioxins and Furans as Toxic Equivalents (TEQ)

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[1] A key driver was determined if it had a Hazard Quotient or Concentration Ratio ≥ 0.01, based on “project alone” or “process upset” predictions of ground level chemical concentrations for the “resident” and “farmer” scenarios presented in the paper OR an incremental lifetime cancer risk of ≥ 1 x10 $^{-7}$ as documented in the original risk assessment

    - Thallium
- Incremental lifetime cancer risk of ≥ 1 x10 $^{-7}$
    - Cadmium

The paper was a summary of a comprehensive human health risk assessment that was undertaken for the proposed energy from waste facility in Ontario. The paper only reports the results for the plant operating at a fuel usage rate of 140,000 tonnes per year. However, the original risk assessment also included a 400,000 tonne per year scenario (the maximum capacity of the plant). Reviewing the results presented in the human health risk assessment for the facility at full capacity (Jacques Whitford 2009), the following key chemical drivers were identified[2]:

- Concentration Ratio ≥ 0.01
    - Ammonia (24 hour)
    - Carbon Monoxide (1 hour)
    - Hydrogen Chloride (1 hour and 24 hour)
    - Hydrogen Fluoride (1 hour)
    - Nitrogen Dioxide (1 hour and 24 hour)
    - Particulate Matter (PM_{10}) (24 hour)
    - Particulate Matter ($PM_{2.5}$) (24 hour)
    - Total Particulate Matter (TSP) (24 hour)
    - Sulfur Dioxide (1 hour and 24 hour)
- Hazard Quotient ≥ 0.01
    - Dioxins and Furans as Toxic Equivalents (TEQ)
    - Total PCBs (as Aroclor 1254)
    - Cadmium
    - Inorganic Mercury
    - Lead
    - Thallium
- Incremental lifetime cancer risk of ≥ 1 x10 $^{-7}$
    - Cadmium

It should be noted that while this analysis provides insights into potential chemicals of concern from energy to waste facilities, this data is still limited (**Section 3.4**) and is based on Canadian health risk methods that can differ from Australian methods. This difference can change the estimate of risk of the chemicals.

Glorennec et al undertook a risk assessment of modelled emissions from a municipal solid waste incineration plant in France, following its upgrade to EU IED standards (Glorennec et al. 2005). The incinerator processes approximately 100,000 tonnes of fuel a year and is surrounded by a densely populated zone along with an agricultural zone and market gardens. The authors acknowledged the many pollutants that have been measured in the municipal solid waste incinerator stack but settled

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[2] A key driver was determined if it had a Concentration Ratio ≥ 0.01 using the maximum 1 hour, 24 hour and chronic (annual) project only ground level concentrations OR Hazard Quotient ≥ 0.01, based on the “resident” and “farmer” scenarios OR an incremental lifetime cancer risk of ≥ 1 x10 $^{-7}$

on 7 pollutants: sulfur dioxide (SO_2), hydrogen chlorine (HCl), particulate matter, cadmium, lead, mercury and dioxins, based on the following criteria:

- quantity emitted (a criterion that supported the study of sulfur dioxide, hydrogen chlorine, particulate matter, cadmium, lead, mercury and chromium),
- specificity of incinerator emissions relative to urban background (cadmium and mercury),
- known health effects and available human toxicity values,
- social concern (dioxins and lead).

Although identified, the authors did not select chromium because they could not determine its speciation justifying that “other studies indicate that its toxic forms account for only a small fraction of total chromium emissions”.

In 2015 an application was lodged with the NSW government to develop an energy from waste facility in Sydney’s western suburbs (Pacific Environment 2017). The proposal included a plant that would burn up to 1,105,000 tonnes of waste from commercial / industrial and construction / demolition waste in Sydney. The proposal modelled ground level concentrations of the following identified chemicals of concern, as required for any such proposal in most states of Australia:

- EU IED identified emissions
  - Particulate matter (PM), assumed to be emitted as PM_{10} and $PM_{2.5}$
  - Hydrogen Chloride
  - Hydrogen Fluoride
  - Carbon Monoxide
  - Sulfur Dioxide
  - Oxides of nitrogen expressed as Nitrogen Dioxide
  - Heavy Metals
    - Mercury
    - Cadmium
    - Thallium
    - Antimony
    - Arsenic
    - Chromium (Cr (III) and Cr (VI))
    - Lead
    - Cobalt
    - Copper
    - Manganese
    - Nickel
    - Vanadium
  - Gaseous and vaporous organic substances (expressed as total organic carbon (TVOC))
  - Dioxins and furans (PCCD/Fs).
- Additional emissions identified
  - Benzoic Acid
  - Hexa-decanoic Acid
  - Ethyl Benzoic Acid
  - Toluene
  - Phthalate

- Dichloromethane
- Acetone (propanone)
- Tetra-decanoic Acid
- Benzene
- Acetonitrile
- Xylene
- Trichloro-phenol
- Methylhexane
- Trichloro-ethylene
- Heptane
- Hydrogen sulfide
- Ammonia
- Metals
    - Beryllium
    - Molybdenum
    - Selenium
    - Silver
    - Tin
    - Zinc
- Polychlorinated biphenyls
- Hexachlorobenzene
- Polycyclic aromatic hydrocarbons
- Phenol
- Hexane
- Hydrogen bromide
- Brominated flame retardants
- Total brominated dioxins

After a number of revisions to the project including a reduction in size to less than half of the original proposal the project was refused consent. It was found not to comply with the NSW Energy from Waste Policy Statement. One of the issues was the unknown impact on air emissions of the use of novel waste streams that are not included in fuel mixes in similar facilities in Europe. Therefore, this report has not undertaken any further screening of the identified chemicals of concern.

Table 1 collates the chemicals identified from the studies identified in **Sections 3.2** and **3.3**.

Table 1: Chemicals identified in reviewed studies

Chemical	STUDY								
	Font et al 2015	Vilavert et al 2014	Vilavert et al 2015	Domingo et al 2015	Douglas et al 2017	Ollson et al 2014	Ollson et al 2014 (key chemical drivers)	Glorennec et al 2005	Pacific Environment 2017
Ammonia						✓	✓		✓
Carbon Monoxide						✓	✓		✓
Hydrogen Chloride						✓	✓	✓	✓
Hydrogen Fluoride						✓	✓		✓
Hydrogen Sulfide									✓
Nitrogen Dioxide						✓	✓		✓
Particulate Matter (PM10)					✓	✓	✓		✓
Particulate Matter (PM2.5)						✓	✓		✓
Total Particulate Matter (TSP)						✓	✓	✓	
Sulfur Dioxide						✓	✓	✓	✓
Total Organic Carbon									✓
Halogenated Polycyclic Aromatics									
Brominated flame retardants									✓
Total brominated dioxins									✓
Dioxins and Furans as Toxic Equivalents (TEQ)#		✓	✓	✓		✓	✓	✓	✓
PCBs		✓		✓					✓
PCNs		✓							
Total PCBs (as Aroclor 1254)						✓	✓		
Metals									
Antimony			✓	✓		✓			✓
Arsenic	✓		✓	✓		✓			✓
Barium						✓			
Beryllium			✓	✓		✓			✓

Chemical	STUDY								
	Font et al 2015	Vilavert et al 2014	Vilavert et al 2015	Domingo et al 2015	Douglas et al 2017	Ollson et al 2014	Ollson et al 2014 (key chemical drivers)	Glorennec et al 2005	Pacific Environment 2017
Boron						✓			
Cadmium	✓		✓	✓		✓	✓	✓	✓
Chromium (hexavalent)						✓			✓
Chromium (III)									✓
Total Chromium (and compounds)	✓		✓	✓		✓			
Cobalt			✓	✓		✓			✓
Copper	✓		✓	✓					✓
Lead	✓		✓	✓		✓	✓	✓	✓
Manganese	✓		✓	✓					✓
Mercury	✓		✓	✓		✓	✓	✓	✓
Molybdenum				✓					✓
Nickel	✓		✓	✓		✓			✓
Phosphorus						✓			
Platinum	✓								
Silver						✓			✓
Selenium				✓		✓			✓
Strontium				✓					
Thallium			✓	✓		✓	✓		✓
Tin				✓		✓			✓
Vanadium	✓		✓	✓		✓			✓
Zinc	✓			✓		✓			✓
Chlorinated Monocyclic Aromatics									
1,2-Dichlorobenzene						✓			
1,2,4,5-Tetrachlorobenzene						✓			
1,2,4 – Trichlorobenzene						✓			

Chemical	STUDY								
	Font et al 2015	Vilavert et al 2014	Vilavert et al 2015	Domingo et al 2015	Douglas et al 2017	Ollson et al 2014	Ollson et al 2014 (key chemical drivers)	Glorennec et al 2005	Pacific Environment 2017
Pentachlorophenol						✓			
Hexachlorobenzene						✓			
Pentachlorobenzene						✓			
2,3,4,6-Tetrachlorophenol						✓			
2,4,6-Trichlorophenol						✓			
2,4-Dichlorophenol						✓			
Polyaromatic Hydrocarbons									
Acenaphthylene						✓			
Acenaphthene						✓			
Anthracene						✓			
Benzo(a)anthracene						✓			
Benzo(b)fluoranthene						✓			
Benzo(k)fluoranthene						✓			
Benzo(a)fluorene						✓			
Benzo(b)fluorene						✓			
Benzo(ghi)perylene						✓			
Benzo(a)pyrene TEQ						✓			
Benzo(e)pyrene						✓			
Chrysene						✓			
Dibenzo(a,c)anthracene						✓			
Dibenzo(a,h)anthracene						✓			
Fluoranthene						✓			
Fluorene						✓			
Indeno(1,2,3 – cd)pyrene						✓			
Perylene						✓			
Phenanthrene						✓			

Chemical	STUDY								
	Font et al 2015	Vilavert et al 2014	Vilavert et al 2015	Domingo et al 2015	Douglas et al 2017	Ollson et al 2014	Ollson et al 2014 (key chemical drivers)	Glorennec et al 2005	Pacific Environment 2017
Pyrene						✓			
1 – methylnaphthalene						✓			
2 – methylnaphthalene						✓			
Naphthalene						✓			
Volatile Organic Compounds									
Acetaldehyde						✓			
Benzene						✓			✓
Biphenyl						✓			
Bromodichloromethane						✓			
Bromomethane						✓			
Dichlorodifluoromethane						✓			
Dichloroethene						✓			
1,1 - Ethylbenzene						✓			
Ethylene Dibromide (1,2-dibromoethane)						✓			
Formaldehyde						✓			
Heptane									✓
Hexane									✓
Tetrachloroethylene						✓			
Toluene						✓			✓
Trichloroethylene, 1,1,2						✓			
Vinyl chloride (chloroethene)						✓			
Xylenes, m-, p- and o-						✓			✓
Bromoform (tribromomethane)						✓			
Carbon tetrachloride						✓			
Chloroform						✓			

Chemical	STUDY								
	Font et al 2015	Vilavert et al 2014	Vilavert et al 2015	Domingo et al 2015	Douglas et al 2017	Ollson et al 2014	Ollson et al 2014 (key chemical drivers)	Glorennec et al 2005	Pacific Environment 2017
Dichloromethane						✓			✓
O-terphenyl						✓			
Trichloroethane						✓			
1,1,1 -Trichlorofluoromethane						✓			

* Additional chemicals identified in the Pacific Environment report were Benzoic Acid, Hexa-decanoic Acid, Ethyl Benzoic Acid, Phthalate, Acetone (propanone), Tetra-decanoic Acid, Acetonitrile, Trichloro-phenol, Methyl-hexane, Trichloro-ethylene, Hexachlorobenzene, Phenol, Hydrogen bromide however these chemicals could not be verified.

Further information on Dioxins can be found at http://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health and http://www.environment.gov.au/protection/chemicals-management/dioxins

3.4 Limitations

When reviewing data, as outlined in **Sections 3.2** and **3.3**, particularly when inferring outcomes that may be applicable to Victorian waste to energy facilities, it is important to consider the following:

Identification bias

All studies that undertake sampling can only identify what they look for. Therefore, reported detections of chemicals in studies, especially of the type reviewed in **Section 3.2** are limited by this premise. Without appropriate justification for the selection of chemicals, caution should be given before eliminating any other chemicals not detected or identified.

Nature of the waste

The nature of the waste that is used in the incinerator will affect the nature and concentration of chemicals that may be generated in the emissions. Insufficient data is currently available to determine the likely concentrations of chemicals that will be emitted from burning all the different waste streams. While limited, the most common waste stream used for fuel is municipal waste. It is expected that the municipal waste streams in the United Kingdom, some other European countries and North America may present similarities to that of Australia. Other waste streams may (or may not) exhibit significant differences between Australia and other jurisdictions due to differences in how wastes are classified and in how reuse/recycling is undertaken.

Some waste streams have been classified as posing a low risk of harm to human health and the environment due to their origin, composition and consistency. The New South Wales Environment Protection Authority has classified the following as low risk waste streams in that regard (NSW EPA 2015):

- biomass from agriculture
- forestry and sawmilling residues
- uncontaminated wood waste
- recovered waste oil
- organic residues from virgin paper pulp activities
- landfill gas and biogas
- source-separated green waste (used only in processes to produce char)
- tyres (used only in approved cement kilns).

Energy from waste facility design

The age and design of the waste to energy facility will affect the type and concentration of gases that may be emitted to ambient air. While all Victorian waste to energy facilities must meet EU IED emission limits, the size, technology and engineering of the plant requires consideration to ensure other pollutants will be captured appropriately. Further, physical design characteristics such as incinerator stack height will influence the ground level concentrations of emissions.

Climate and topography

The climate and topography of an area will affect how emissions are dispersed and, therefore, their ground level concentrations. The data presented is collected or modelled in countries that are colder and wetter than Victoria (such as in the UK) or warmer (such as in Spain) and/or likely to have differing topography.

Distance to relevant receptors

The distance to relevant receptors around any new facility is likely to vary. The combination of the meteorology, topography and the distance to where people might be impacted by a particular facility will affect the chemicals likely to be present in areas where people might be exposed and to how much they will be exposed.

Measurement of ambient air

The measurement of chemicals in ambient air will report all the concentration of an individual chemical in the sample, regardless of the source. Some of the ambient air measurements from the studies in **Section 3.2** are dominated by other industrial emissions. There are numerous other sources of combustion emissions in ambient air including industrial emissions (including power stations, cement kilns, combustion engines etc), emissions from vehicles and household combustion (heating and cooking). When reviewing ambient air data, it is not possible to distinguish emissions from a waste to energy facility from other industrial/urban air sources. The studies included in this review have collected ambient air data close to the emission source and in locations noted to be either upwind or downwind of the plant at the time of sampling. This assists in reviewing the data but does not exclude that the measured levels may be from the waste to energy facility being studied or they could be from a myriad of other sources.

Lower concentration but higher toxicity

Currently, a case is made in pollution control circles for the control of surrogate or indicator chemicals. Surrogates can be used to indicate that pollution control technologies are working correctly/appropriately. The argument centres around if a surrogate or indicator chemical is controlled, other chemicals that have similar physico-chemical properties will also be controlled. Surrogates can also be used to consider potential health impacts where one particular chemical is known to be more toxic than the chemicals of its type. When surrogates are used for the former purpose only (i.e. to indicate pollution control technology is working correctly), it may mean that chemicals with higher toxicity may be present without being measured. A low concentration of a highly toxic chemical may still present a risk. If a surrogate is chosen to fulfil both of the purposes listed, missing a chemical with higher toxicity is unlikely to occur.

3.5 Conclusion

The current limitations surrounding the assessment of emissions from waste to energy facilities impede the ability to provide a list of generic chemicals of concern and emission concentrations that will always be relevant for the protection of human health. The chemicals nominated in the EU IED should be considered, at bare minimum, for all waste to energy facilities. However, there is a need to understand:

- fuel mix at a proposed plant
- size of the plant
- local meteorology
- local topography
- nature of land uses in the area surrounding such a facility (i.e. distance to and type of relevant receptors).

Section 4. Health Effects Associated with Living near a Waste to Energy facility

4.1 General

Studies investigating the short and long-term health of residents living near operational Waste-to-Energy facilities designed to meet EU IED or equivalent emissions standards are undertaken as epidemiological studies. When considering environmental health issues, these studies examine associations between an exposure variable (from a specific source or event) and a health outcome in a population, e.g. respiratory effects.

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 wrong selection or inaccurate measurement) and
- confounding factors (other factors that are independently related to the exposure and outcome and so may distort the effect).

The most common, and more difficult factors to address in environmental epidemiological studies of this type are measurement bias (for example, estimating exposure rather than having actual values) and confounding factors (for example, socioeconomic status).

4.2 Study selection

A literature search was performed in the MEDLINE database through the Ovid interface with no date limitation (1946 to June Week 5 2018) and written in English. The search strategy used to identify epidemiological studies examining the association between Waste-to-Energy facilities designed to meet EU IED or equivalent emissions standards and health effects is shown in **Figure 8**. Given the lack of identified papers, the search terms were expanded to include incinerator and incineration. Searches were conducted using both keywords and MEDLINE medical subject heading (MESH) terms. The following key words and MESH terms[3] were used: ‘waste to energy’, ‘energy from waste’, ‘waste’, ‘energy’, ‘*incineration*’, ‘ incinerator’, ‘EU IED’, ‘emissions’, ‘exposure’, ‘community’, ‘*residence characteristics*’, ‘*health*’, ‘health effects’, ‘health impacts’, ‘study’, ‘public’, ‘*environmental exposure*’, ‘*survey and questionnaires*’, ‘*refuse disposal*’, ‘*public health*’, ‘*population health*’, ‘waste incineration’, ‘cancer’ and ‘respiratory’.

Papers identified through the searches were first screened for relevance based on title, and abstract if the title was ambiguous. Surviving papers were collated and duplicates removed. Papers published prior to 2000 were removed since the precursor regulations to EU IED were introduced in 2000. Abstracts of the remaining articles were fully reviewed and epidemiological studies examining health outcomes were kept.

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[3] The MESH terms used are italicised

The quality of the identified studies was assessed based on three broad categories – health outcome, exposure and confounding, reflecting similar methods used in other reviews (See Ashworth et al 2014 and Porta et al 2009). The misclassification of health outcome or exposure along with the lack of adjustment for confounding are three major issues that distort the strength of the relationship between the exposure and health outcome. **Table 2** highlights the scoring criteria that was used to subjectively score the studies. Each study was rated for outcome, exposure and confounding. The maximum score that can be assigned to a study is 12 (i.e. 4 for quality of outcome measure, 4 for quality of exposure measure and 4 ability to adjust for confounding). A quality score of 12 highlights a study with few limitations[4], while a quality score of 0 signifies a severely limited study.

Table 2: Quality criteria used for the identified studies

Quality (score)	Outcome	Exposure	Confounding
High (3-4)	Individual medical records	Personal monitoring / exposure for study period adjusted for other exposures during critical period of exposure	Adjusted for relevant confounders measured at an individual level
Medium (1-2)	Self-reported data	Modelled exposure, adjusted for other exposures, during critical period of exposure	Adjusted for some relevant confounders. May have used population level data or residual confounding may still exist
Low (0)	Population level data	Distance from the source	No adjustment for confounding

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[4] Study power has not been considered in these limitations

(waste to energy) AND (incineration OR refuse disposal OR EU IED OR emissions OR exposure OR community OR residence characteristics OR health effects OR public health OR environmental exposure OR health impacts OR survey and questionnaires OR study OR public)	(energy from waste) AND (incineration OR refuse disposal OR EU IED OR emissions OR exposure OR community OR residence characteristics OR health effects OR public health OR environmental exposure OR health impacts OR survey and questionnaires OR study OR public)	(waste incineration) AND (health effects OR public OR public health OR respiratory)	(incineration OR incinerator) AND cancer	(incineration OR incinerator OR refuse disposal) AND (population health OR public health OR health)
330 papers	112 papers	73 papers	110 papers	2111 papers
8 kept	2 kept	16 kept	18 kept	63 kept

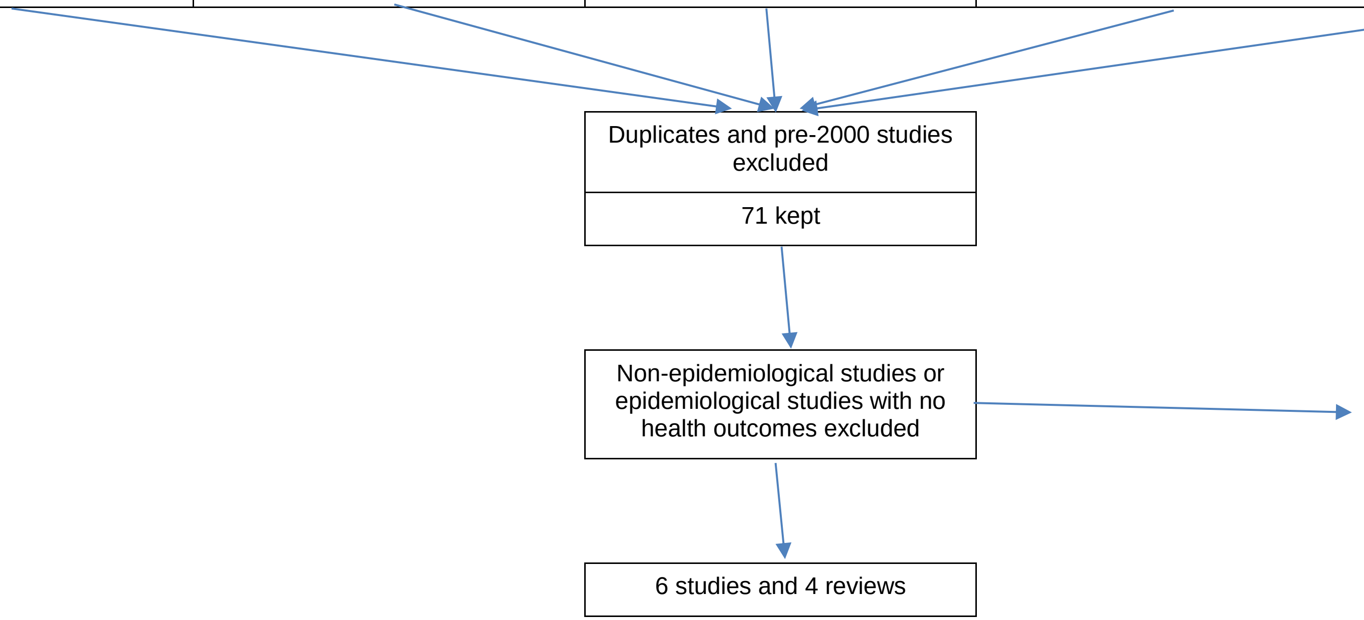

Figure 8: Selection method for identified studies

4.3 Health outcomes studies

4.3.1 Individual studies (Critical appraisal)

Santoro et al undertook a study of 3069 newborn children born between 2001 – 2010 from the municipalities of Azrezzo and Civitella Val di Chiana, Italy, examining adverse reproductive outcomes (preterm birth, small gestational age, low birth weight or sex ratio) (Santoro et al. 2016). Exposure was determined by the mother's residency during pregnancy, and was based on 2007 modelled PM_{10} pollution emissions from the municipal solid waste incinerator. Mothers place of residence was classified as either low, medium or high exposure to PM_{10}. The study attempted to adjust for maternal age, mother's education level, pregnancy order, country of origin, newborn sex, socioeconomic status and exposure to other pollutant sources. The study did not find any association between predicted PM_{10} concentrations and any health outcomes evaluated including preterm birth, small gestational age, low birth weight or sex ratio for all births, even after adjusting for birth order. The authors did, however, stratify by birth order (i.e. separately assess the subset of data for each of first time mothers, second time mothers etc) and reported that when considering newborns of first time mothers only, a statistically significant difference was found between those classified in the high exposure compared to low exposure, and trending across the exposure categories. The authors do not provide a reason for this stratification and it is unclear whether this result is due to chance or residual confounding. The study is limited by potential exposure misclassification and adjustment of population level socioeconomic status.

Quality = 5

Candela et al undertook a study examining all childbearing mothers (aged 15 – 49) within 4 kilometres of seven incinerator plants in Italy (Candela, S. et al. 2015). Women were considered eligible if they resided in the area for the first months of pregnancy and data on birth outcome was matched to each woman. Exposure was assigned through dispersion modelling of PM_{10} within 5 levels. Adjustments for exposure to other sources, maternal age nationality, socioeconomic status and location was undertaken. The risk of miscarriage[5] was calculated and compared across pollutant levels, while adjusting for other confounders. A significant trend across the pollutant levels was found but not between the reference and other levels of PM_{10}. When stratifying by previous spontaneous miscarriage (i.e. noting which mothers had previously had miscarriages), the authors found a significant trend between miscarriage and increase in PM_{10} exposure levels, for those mothers who had not had any previous miscarriages only. The authors conclude that the "study results raises the suggestion of a slight effect of incinerator pollution, even at a low level, on this reproductive event". The study has limitations including potential measurement error through differing hospital reporting and exposure misclassification. Although the study took place between 2001 to 2006 it cannot be determined if all incinerators were emitting to meet the EU IED standards. Despite this, others suggest they were (Douglas et al. 2017).

Quality = 5

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[5] In this paper, the authors used the term 'simplified true abortion risk'. In Australia, it is more common to refer to spontaneous early loss of pregnancy as a miscarriage and an abortion as a loss of pregnancy due to a medical intervention. The terminology used in this review has been adjusted to use the more commonly understood terms to minimise potential confusion.

Lung et al used the Taiwan Birth Cohort study to examine the relationship between living within three kilometres of an incinerator and parental reported health outcomes (gross motor development, fine motor development, language, social and mild or moderate uneven / delayed developmental disability) over a 36-month period (Lung et al. 2013). Significant results were reported for living near an incinerator and gross motor development at 36 months as well as mild and moderate developmental disability at 18 months. The study has several limitations including the self-reported nature of the outcomes and potential exposure misclassification (the arbitrary nature of exposure assignment, lack of adjustment for other confounding polluters and lack of data on total residency of parent and child). Most of the significant results presented do not adjust for any confounders, and there are contradictions between the results presented in the paper and conclusions made regarding the health outcomes. Lastly, there is no information on the discharge standards of the incinerators, with the authors noting “there are no unified clean air standards for waste incinerators in Taiwan”.

Quality = 2

Candela et al undertook a study examining birth outcomes on women who gave birth between 2003 and 2010 and who resided within 4 kilometres of eight incinerators operating in a region of Italy. Maternal exposure was estimated via modelled PM_{10} emissions from the plants and geocoded to the maternal place of residence (Candela, Silvia et al. 2013). Modelled emissions were categorised into 5 concentration tiers, with maternal exposure estimated over 9 months of pregnancy and assigned to one of the 5 tiers. Hospital records on birth outcomes (sex, multiple birth, preterm birth, small for gestational age) were linked to the identified mothers. Adjustments for potential confounding included other pollutant sources, maternal age, education level and country of origin, newborn birth order, sex, and previous maternal hospitalisations. No associations were found between increased estimated exposure to particles from incinerator emissions and sex ratio, multiple births or frequency of small for gestational age births. A significant trend between increased emissions and preterm births was found. This significance was also found when comparing the lowest concentration tier of predicted emissions with the second highest as well as the highest concentration tier of emissions. The study although well designed is limited by potential exposure misclassification and possible measurement bias. It is noted that significant difference was found between those mothers who could be linked to the hospital records and exposure levels meaning potential selection bias may also have resulted in this study. The study does not identify whether the incinerators complied with EU IED standards during the study period, however, it is noted that the study identified most of the incinerators as having been upgraded during the study period (2003, 2006, 2008, 2008, 2008, 2008). Douglas et al suggest they were operating to EU IED standards (Douglas et al. 2017).

Quality = 6 - 7

Cordier et al undertook a case control study where 304 infants in a region of France with urinary tract birth defects. The infants were age, sex and district of birth matched to 226 population controls. Waste incinerator emissions exposure to the mothers were estimated using modelling of predicted atmospheric dioxin, dioxin deposition and deposition of metals from 21 municipal waste incinerators (Cordier et al. 2010). A mother was considered exposed if they lived in an area which was estimated to have greater than the median concentration predicted for all 21 municipal waste incinerators based on air dispersion modelling. The authors attempted to adjust for other pollutant sources, population density and deprivation score (socioeconomic status). The authors found a significant association between dioxin exposure (both atmospheric and deposition) and urinary tract birth defects. However, this result was not significant for any mothers exposed to dioxins from municipal waste incinerators that met the EU IED standard. Also, the results need to be interpreted with caution as there was also a strong correlation between dioxin exposure and both population density and deprivation score. Given this high correlation between these matters, it is possible that the population density and / or deprivation score may be responsible for the significant result (i.e. increase in urinary tract birth defects) rather than the level of exposure to dioxins. The correlation indicates that people who are exposed to higher levels of dioxin are also likely to live in areas of high population density and/or have a high deprivation score (and this is difficult to adjust for). As a result, it is not possible to determine which is responsible for the birth defects – it could be any of the 3 correlated matters or some combination of them. The paper highlights further limitations including possible measurement error from exposure misclassification.

Quality = 5

Vinceti et al examined the rates of miscarriage[6] and prevalence at birth of congenital anomalies in women residing or working near a municipal solid waste incinerator in Italy from 2003 to 2006 (Vinceti et al. 2008). No significant results were found although the study had limited power for some analyses along with the potential for exposure misclassification. Further, it did not adjust for potential confounding. The study noted that the area had an incinerator ‘equipped with advanced pollution control technology’.

Quality = 4

4.3.2 Reviews

Ashworth et al undertook a systematic review of epidemiological studies to evaluate the relationship between waste incineration and the risk of adverse birth and neonatal outcomes up to 2013 (Ashworth et al. 2014). The review identified 14 studies and concluded that the evidence base was inconclusive and often limited by problems of exposure assessment, possible residual confounding, lack of statistical power and variability in study design and outcomes. The review did, however, identify a number of studies reporting significant positive relationships with a broad group of congenital anomalies, that warranted further investigation. Of the 14 studies identified only two had a study period after 2000 ((Cordier et al. 2010; Vinceti et al. 2008)), which have been discussed above in **Section 4.3.1**. Ashworth et al note that the Cordier et al paper found “a two to three fold excess risk of urinary tract defects among mothers exposed to dioxins at the beginning of pregnancy.. (but)…. this related to older generation municipal solid waste incinerators. Since then, the newer generation of municipal solid waste incinerators is more strictly regulated with dioxin emission limits required to be one tenth of previous standards”.

Mattiello et al undertook a systematic review of epidemiological studies that examined the health effects on populations living in close proximity to landfills and / or incinerators (Mattiello et al. 2013). With regard to incinerators, Mattiello et al concluded that while incinerators with older (and thus poorer) emissions standards consistently report a detectable risk of health effects in populations

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[6] In this paper, the authors used the term spontaneous abortion. In Australia, it is more common to refer to spontaneous early loss of pregnancy as a miscarriage and an abortion as a loss of pregnancy due to a medical intervention. The terminology used in this review has been adjusted to use the more commonly understood terms to minimise potential confusion.

living nearby, the evidence for incinerators with modern day standards was more reassuring, that being the studies were not producing a consistency of evidence for health effects in communities surrounding incinerators with modern day standards. All studies were found to suffer from some form of methodological issue, be that lack of statistical power, exposure classification, or confounding.

Porta et al undertook a systematic review of epidemiological studies on populations in the vicinity of landfills and incinerators to derive excess risk estimates for health impact assessment (Porta et al. 2009). In most cases, they found the evidence was inadequate to establish a relationship between a specific waste process and health effects. However, for populations living within three kilometres of old incinerators, they concluded there was limited evidence of increased risk of cancer. The study period deriving this limited evidence being prior to the year 2000. The authors also found inconsistent evidence for birth defects, rating the evidence as limited, and the evidence for respiratory and skin diseases as inadequate. The authors highlight that most studies suffered from limitations related to poor exposure assessment, study design and confounding.

Franchini et al 2004 undertook a review of epidemiological studies published from 1987 to 2003 that examined health effects in populations living in the neighbourhood of waste incinerators (Franchini et al. 2004). The authors acknowledge that the majority of the studies identified refer to “old rather than modern incinerators”. They conclude that several studies found positive associations between health outcomes (cancer, congenital malformations) and residence near an incinerator, but that the studies contain methodological issues such as bias and confounding that limit the ability to interpret the findings.

Another study reviewed published research on the health effects of Energy from Waste facilities for users in the UK (Broomfield 2012). This review identified the following as key issues for such facilities that had been identified in the literature:

- Process emissions
    - Nanoparticles/ultrafine particles
    - Dioxins/furans
    - Emissions during abnormal operating conditions
- Health outcomes
    - Infant mortality
    - Infant development
    - Carcinogens/cancer risk
    - Respiratory disease (Broomfield 2012)

The review then noted that emissions of nanoparticles/ultrafine particles from these types of facilities is likely to be very small compared to other sources such as road traffic, wood heating in homes and electricity generation. For the UK, road traffic is estimated to contribute 29% of the total for these types of particles, wood heating in homes is estimated to contribute 14% and electricity generation is estimated to contribute 5%. Using information from 2009 in the UK and just focusing on municipal waste incineration (not just the subset of such facilities likely to be recovering energy), the contribution of these particles to the UK total is less than 0.1% (Broomfield 2012).

For dioxins and furans, significant improvements in preventing formation or removing these chemicals from such emissions have occurred between 1990 and 2009. The emissions have reduced by 99% from these types of facilities. It is now estimated that only 2.5% of emissions to air of these chemicals in the UK come from such facilities (Broomfield 2012).

This review also noted that a study by the UK environmental regulator showed that, while emissions were slightly elevated during startup and shutdown for such facilities, it was not much different from the load emitted during normal operations (Broomfield 2012).

In regard to health outcomes, the review reported the conclusions of the UK Committee on Carcinogenicity report on such facilities from 2000 and reviews by the Health Protection Agency in 2010 and Health Protection Scotland in 2009. These reviews all noted that, while health effects may have been indicated by association in older studies, that such effects are now unlikely given the improvements in pollution control technology (Broomfield 2012).

Concluding statements such as:

“ any potential cancer risk due to residency (for periods in excess of 10 years) near to municipal solid waste incinerators was exceedingly low and probably not measureable by the most modern techniques. ”

OR

“ Modern, well managed incinerators make only a small contribution to local concentrations of air pollutants. It is possible that such small additions could have an impact on health but such effects, if they exist, are likely to be very small and not detectable.”

were reported (Broomfield 2012).

The UK Health Protection Agency and the UK Committee on Carcinogenicity have also undertaken reviews of the health outcome literature for these types of facilities.

The UK Health Protection Agency review in 2010 concluded:

The Health Protection Agency has reviewed research undertaken to examine the suggested links between emissions from municipal waste incinerators and effects on health. While it is not possible to rule out adverse health effects from modern, well regulated municipal waste incinerators with complete certainty, any potential damage to the health of those living close-by is likely to be very small, if detectable. This view is based on detailed assessments of the effects of air pollutants on health and on the fact that modern and well managed municipal waste incinerators make only a very small contribution to local concentrations of air pollutants. The Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment has reviewed recent data and has concluded that there is no need to change its previous advice, namely that any potential risk of cancer due to residency near to municipal waste incinerators is exceedingly low and probably not measurable by the most modern techniques. Since any possible health effects are likely to be very small, if detectable, studies of public health around modern, well managed municipal waste incinerators are not recommended (UK Health Protection Agency 2010).

The UK Committee on Carcinogenicity undertook a review of the literature in support of the review by the UK Health Protection Agency (UK Committee on Carcinogenicity 2009). A short description of this review is provided in the Annual Report for 2009. The short summary notes that six epidemiological papers were available since their previous review on this subject from 2000. Three of those papers focused on a single facility in France. The committee determined that there were a range of methodological issues with these studies that meant they could not be relied upon. These included:

- not accounting for the other sources of the chemicals emitted from such facilities in analysing the data
- not appropriately dealing with confounding factors
- investigation of a facility (the one in France) with emissions that were much higher than current regulations at the time of the review

These problems are the same as noted in many of the other investigations/reviews discussed above.

Consequently, the committee made the same conclusion as they had in 2000 – that, while effects cannot be ruled out, they are highly unlikely to be sufficient to be detectable (UK Committee on Carcinogenicity 2009).

4.3.3 Conclusion

There is limited evidence regarding whether incinerators emitting to EU IED standards are associated with health effects. The studies reviewed in **Section 4.3.1** have found an association between health effects such as birth outcomes and incinerator emissions, however, these studies are subject to methodological issues such as bias and residual confounding that limit the ability to determine if the effect is real. Further, the health studies reviewed do not identify whether the incinerators in the study were emitting to EU IED standards. It is likely that some of the subject incinerators may have been emitting to EU IED standards while many others were emitting to older and less stringent standards. Since most of the studies involve multiple incinerators it is difficult to draw out whether any identified health impacts are related to the incinerators emitting to EU IED standards or to the older standards. The exception is the work of Cordiner et al 2010 who concluded that incinerators emitting to EU IED standards were not identified as being associated with the investigated health outcome. It is likely that any associations between incinerator emissions and health impacts identified in the reviewed studies have been driven by the higher pollutant concentrations created by incinerators using older technologies. Future investigations that identify incinerators using EU IED standards will be able to resolve this issue.

Section 4.3.2 highlighted reviews undertaken after 2000 that examine emissions from incinerators and health outcomes in populations surrounding them. These reviews identify studies with positive associations between incinerator emissions and health outcomes, although all the studies contained methodological issues. Many of the reviews associated health outcomes with older incinerators making it likely that the health outcomes were based on incinerators using older and higher standards and not EU IED standards. A point highlighted by Mattiello et al "evidence for incinerators with modern day standards was more reassuring, that being the studies were not producing a consistency of evidence for health effects in communities surrounding incinerators with modern day standards".

The methodological issues in the studies used to examine the association between incinerator emissions and health outcomes are a limitation of the study designs. These limitations and resulting outcomes were summarised in a 2000 review of waste incineration and public health by the US National Research Council which concluded

> '*Few epidemiologic studies have attempted to assess whether adverse health effects have actually occurred near individual incinerators, and most of them have been unable to detect any effects. The studies of which the committee is aware that did report finding health effects had shortcomings and failed to provide convincing evidence. That result is not surprising given the small populations typically available for study and the fact that such effects, if any, might occur only infrequently or take many years to appear. Also, factors such as emissions from other pollution sources and variations in human activity patterns often decrease the likelihood of determining a relationship between small contributions of pollutants from incinerators and observed health effects. Lack of evidence of such relationships might mean that adverse health effects did not occur, but it could also mean that such relationships might not be detectable*' (National Research Council 2000)

While it is acknowledged that studies since 2000 have used multisite investigations to increase the study power, the issues raised by the US National Research Council are still valid. So, while health effects associated with incinerator emissions cannot be fully discounted, based on the epidemiological limitations, there is no causal evidence that health effects from incinerators emitting to EU IED standards occur.

Section 5. Monitoring of Waste to Energy facility emissions

The waste to energy industry is a relatively new industry in Australia and there is currently limited information on the relationship between emission limits and their impact on public health in the Australian setting. While current indications suggest the EU IED emission limits protect public health, these limits do not take into account the site-specific factors related to emission discharge from a particular facility. These specific factors include the feedstock, facility stack height and velocity along with surrounding topography and meteorology and the location of relevant receptors.

In Victoria new or modified sources of emissions to the air (including those from waste to energy facilities) may be assessed in accordance with the State Environment Protection Policy (Air Quality Management) (SEPP) (Victorian Government 2001). The SEPP establishes a framework for managing emissions and sets out a program for action to protect the air environment and achieve the regional air quality objectives. Schedule C of the SEPP sets out the minimum requirements for modelling emissions to air and includes specification of the currently approved regulatory model, while Part III documents the role of risk assessment in developing air quality objectives, design criteria and assessment of environmental and health impacts of air pollution (Victorian Government 2001).

For the assessment of air impacts from waste to energy facilities in Victoria, it is recommended that air emission impacts are assessed following the provisions set out in the SEPP and appropriate guidance notes set out by EPA Victoria. These notes include *Guidance notes for using the regulatory air pollution model AERMOD in Victoria (EPA Victoria 2013b)*. Chemical emissions as listed in the EU IED should be assessed at a minimum. These are:

- Total dust
- Volatile Organic Compounds (VOCs)
- Hydrogen chloride (HCl)
- Hydrogen fluoride (HF)
- Sulfur dioxide (SO_2)
- Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2
- Antimony (Sb)
- Arsenic (As)
- Cadmium (Cd)
- Chromium (Cr)
- Cobalt (Co)
- Copper (Cu)
- Lead (Pb)
- Manganese (Mn)
- Mercury (Hg)
- Nickel (Ni)
- Thallium (Tl)
- Vanadium (V)
- Dioxins and Furans
- Carbon Monoxide (CO) (EU 2010).

Further chemicals of concern should be identified on a project and site specific basis taking into consideration the fuel and plant design, along with the local topography and meteorology.

The modelling and risk assessment, as specified in the SEPP, of the identified chemicals of concern can provide stack emission concentrations that are protective of health (Victorian Government 2001). These identified stack emission concentrations (or the generic EU IED emission concentrations whichever is lower) may be used to define site specific stack emission limits for the waste to energy facility, which may then be used to develop an ongoing monitoring program for the facility (EU 2010).

For the purposes of monitoring the impact that air emissions from a waste to energy facility may have on the local environment, stack emission monitoring is recommended, based on emission concentrations determined as outlined above. Unlike ambient monitoring in the community, stack emission monitoring allows the air pollutant to be assigned to the waste to energy facility. Further, it is the point where the pollutant from the waste to energy facility can be controlled. It will generally be difficult to determine the impact of emissions from the waste to energy facility through ambient monitoring in the community as the results will also contain contributions from:

- Vehicles (cars, trucks, motorcycles)
- Woodfire heating
- Other industry (power stations, cement kilns)
- Generators
- Bushfires

that emit many of the same pollutants. If, however a chemical not commonly found in the environment is identified as being emitted from the waste to energy facility, ambient air monitoring may be appropriate in such a circumstance.

Section 6. Conclusions

Introduction

Environmental Risk Sciences Pty Ltd (enRiskS) has been commissioned by EPA Victoria to undertake a literature review on potential health effects in local communities associated with air emissions from ‘Waste-to-Energy’ facilities.

The literature review has been undertaken to identify national and international published papers that examine compounds (and compound properties) that are found in the air in the vicinity of operational waste to energy facilities designed to meet EU IED or equivalent emissions standards have been reviewed. In addition, the literature has been reviewed to identify papers that describe studies investigating potential short and long-term health impacts on residents living near operational waste to energy facilities designed to meet EU IED or equivalent emissions standards.

Conclusions

This review has found:

- Studies of older waste to energy facilities have shown some associations with health effects
- Some studies of waste to energy facilities that are presumed to comply with EU IED or equivalent emission standards found associations with health effects although the evidence is more limited
- All the studies have methodological issues (which are inherent in these types of studies)
- One of the methodological issues common to all of the studies is the presence of other sources of combustion emissions in the area where health effects were investigated which means that none of the studies can identify the emissions from the waste to energy facilities as the sole reason for the identified health effects

Therefore, while a few studies, around plants using modern technologies and complying with EU IED standards or equivalent, have shown associations with some health effects, given the limitations in these types of studies and the many common sources of some of the chemicals emitted from such facilities, it is not possible to be conclusive that the identified health effects were or were not due to these facilities.

The current limitations surrounding the assessment of emissions from waste to energy facilities impede the ability to provide a list of generic chemicals of concern and emission concentrations that are protective of human health for all facilities. The chemicals nominated in the EU IED should be considered, at bare minimum, for all waste to energy facilities. However, there is a need to understand:

- fuel mix at a proposed plant
- size of the plant
- local meteorology
- local topography
- nature of land uses in the area surrounding such a facility

when considering the health implications of emissions from waste to energy facilities.

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Peer Review: EnRiskS draft reports[a,b] on:

A review of the scientific literature on potential health effects in local communities associated with air emissions from Waste to Energy facilities

[a]EV/18/WtER001; dated 4 September 2018
[b]EV/18/WtER001; dated 8 October 2018

Brian G. Priestly M.Pharm, PhD, FACTRA[1]

12 September 2018
Updated 9 October 2018

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[1] The relevant experience brought to this task by the author includes:

- Fifteen years of leadership of the Australian Centre for Human Health Risk Assessment at Monash University (part time since 2009)
- Experience in regulatory toxicology in former leadership appointments to the Commonwealth Department of Health in areas of toxicological assessment of agricultural & veterinary chemicals, regulation of medicines, and assessment of chemicals for poisons scheduling
- More than 45 years experience with government expert committees and panels assessing chemical toxicity and chemicals risk management, including issues of air quality assessment
- Peer-reviewed recognition as a Fellow of the Australasian College of Toxicology & Risk Assessment (ACTRA), a professional organisation that I helped to found and for which I served as its inaugural President.

The opinions set out in this report are my own, and do not reflect views of any current (Monash University) or previous employers.

The purpose of this peer review report is primarily to consider the approach taken by EnRiskS in its task, commissioned by EPA Victoria, to review of relevant literature relating to air emissions from Waste-to-Energy facilities. These facilities are designed to burn various types of waste with the objective to provide usable energy. The EnRiskS report notes that these types of energy recovery operations have been in wide use since the 1980s, and that the controls over air emissions in Victoria are generally driven by conditions imposed under European Union regulations, specifically the EU Industrial Emissions Directive (EU IED) promulgated in 2010.

The draft EnRiskS report to which my 12 September 2018 peer review relates was dated 4 September 2008. My peer review was provided to EnRiskS, who have responded with a revised report dated 8 October 21018. After reviewing this revised report, I have added further comments dated 9 October 2018.

Comments dated 12 September 2018

In summary, I find the EnRiskS draft report to be a thorough and well-presented review of the relevant available literature. Most importantly, the review of those few published studies that address potential health effects in people living near such facilities is appropriately critical and well balanced.

The Executive Summary is a concise and easily readable summary of the main findings of the review. The fact that it simply repeats the total text from Section 6 of the report (Conclusions) and transfers it to the beginning of the report as an Executive Summary, does not detract from the structure of the report because the other sections include the details of the reviewed literature, from which these conclusions were drawn.

The main body of the document includes sections that separately discuss:

1. An introduction to the issues and a statement on the methodologies used for the literature search.
2. A brief description of the Waste-to-Energy process, and a brief discussion of the relevant Victorian guidelines relating to air emissions.
3. A review of studies that report air emission from Waste-to-Energy facilities that meet EU IED standards.
4. A review of studies that report adverse health effects in people living near Waste-to-Energy facilities – with the caveat that not all such facilities were necessarily compliant with EU IED
5. Some advice on approaches to monitoring air emissions from such facilities; and
6. A discussion of the methodological uncertainties inherent in the reviewed literature, limitations on any conclusions that may be drawn about health effects, and attribution of these health effects to any particular patterns of air emissions (repeated as the Executive Summary, as noted above).

A useful feature of the way the published literature has been summarised has been the use of tables and diagrams, particularly Figures 3 to 7, that visually depict the range and types of air emissions reported in some key studies, and Table 1 that lists some 100 individual chemicals that have been reported in studies of air emissions and identifies the source studies. Table 3 outlines the quality criteria for the studies reviewed in section 4.3 and assists with understanding the quality ratings that have been applied to the reviewed studies. The flow chart in Fig 8 greatly assists an understanding of how the published papers were selected and included in the final review. It is noted that the literature search strategy limited the selection of papers to those that specifically addressed EU IED-compliant waste incinerators, presumably omitting the potentially larger number of papers that deal with health effects of emissions from municipal waste incinerators in general.

Compliance with RFQ specifications

EPA Victoria required that the EnRiskS report provide specific information on:

1. *Identification of compounds and their properties (i.e. toxicity, volatility, solubility, odour threshold) produced in Waste-to-Energy facilities and found in the air in the vicinity of these facilities.*
2. *Examine and critically evaluate the literature of studies investigating the short and long-term health of residents living in the vicinity of operational Waste-to-Energy facilities designed to meet EU IED or equivalent emissions standards. This will involve an evaluation of the appropriateness of methodologies in individual publications, the reliability of the results and comment on the overall weight of evidence supported by these studies.*
3. *The review will also consider and clearly articulate the significance or otherwise of potential short and long-term human health risks posed by air emissions arising from Waste-to-Energy facilities and in a manner readily understood by communities and decision-makers.*
4. *The Supplier will also assist in the technical preparation of a scope (i.e. recommendations for monitoring parameters, identification of chemical species to be monitored and monitoring methodology) for future monitoring of Waste-to-Energy facilities to inform the characteristics of any actual risks to human health from such facilities.*

In my view, the EnRiskS report has adequately addressed each of these requirements, although perhaps not to the extent required by EPA Victoria.

- The chemicals potentially emitted from Waste-to-Energy facilities have been listed (mainly in Section 3) based on literature reports and the inventory specified in the EU IED regulations. However, characteristics such as toxicity, volatility, solubility and odour threshold have not been listed. It is not clear how this information, that should be readily available if needed to inform a risk assessment project, would materially improve the main outcome of the review, that aims to critically evaluate the available literature on the health effects of such emissions.

- As noted above, the evaluation of the literature relating to the health effects of airborne emissions from Waste-to-Energy facilities (in Section 4) is a critical summary, with weightings given to the reliability of the evidence. The report did not specifically separate short-term and chronic health impacts, but simply reviewed what was reported in each of the relevant papers. The scope of the adverse health effects noted in the available literature was heavily weighted towards reproductive outcomes, although some of the reviews of epidemiological studies had a broader scope and the Glorennec and Ollson HHRA studies were more comprehensive. A further caveat was that it could not always be concluded that the studies on health effects were relevant to facilities compliant with EU IED regulations.

In addressing the last two specifications, the EnRiskS report has been cautious, outlining (in Section 3.4) the limitations of any conclusions that can been drawn from its report.

- Essentially, I agree with the point made, that the range of chemicals potentially eliminated from Waste-to-Energy facilities will depend on the waste streams used as the fuel mix. This means that any proposed air monitoring programs will need to be relatively site-specific. There is the additional caveat that some of the chemicals are likely to be present in ambient air as ‘background’ from sources other than specific Waste-to-Energy facilities. The advice offered by EnRiskS is that the EU IED list be used as a starting point for developing monitoring programs and that extension of this list be informed by more specific information on the nature of the waste streams.

- I also agree with comments made about how and where to monitor potentially emitted chemicals. Conventional human health risk assessment procedures will need to consider local topography, meteorology and spatial distribution of human ‘receptors’ and this is likely to be better informed by monitoring of stack emissions, coupled with air dispersion modelling, as opposed to ambient ground level monitoring at selected locations around the facility. The papers reviewed in Section 3 of the EnRiskS report were a mix of those that employed ambient air measurements and air dispersion modelling techniques.

- The EnRiskS report falls short of making specific recommendations about monitoring methodologies or the way such monitoring activities should be shared with local communities. Nor does it specify which chemicals should be monitored, mainly because of the caveats mentioned above. It does note the possibility that surrogate, or indicator chemicals might be chosen to monitor the performance of emission controls measures, but it stops short of nominating a specific indicator, while noting the need to balance between high toxicity and air dispersion characteristics of the chosen surrogate.

Comments that EnRiskS could consider in finalising its report

- It would have been helpful if the key EU IED and Victorian SEPP guidelines had been appropriately cited in the Reference Section. I eventually found these documents through a search of my own, but given their importance in framing the legislation under which Waste-to-Energy facilities operate, a specific reference to the source of these documents would assist the reader.

- The source of Fig 2 (a diagram of the waste hierarchy) should be cited (unless it is an EnRiskS original diagram).

- Section 3.2 summarises to key emission limits imposed in the EU IED. The EU IED Directive is quite a large document. It would have been helpful to identify the relevant part of the EU IED Directive where these values were listed, to facilitate checking the accuracy of these citations. I eventually found and verified these citations.

- Not sure why it was missed by the search strategy used, but a 2012 review (Bloomfield) of the health effects of Waste-to-Energy facilities is relevant and should be cited. See http://www.energyanswers.com/pdf/scientific/2012.UK%20EfW_Health_Review.pdf

  This review places greater emphasis on the health effects of dioxins and furans, as well as ultrafine particulates and studies on cancer incidence. More importantly, its reference list includes some 30 papers that allegedly address health effects around Waste-to-Energy facilities, but only 2 of these were included in the EnRiskS reference list. It may be that some of these papers did not meet inclusion criteria and were eliminated from consideration by the processes outlined in Fig 8, although there were none published pre-2000. EnRiskS should be encouraged to check the reference list of the Bloomfield review to ensure that references not cited in their report have not been inadvertently discarded.

Comments dated 9 October 2018

The EnRiskS report dated 4 October 2018 has been revised in relation to the following points:

- Citation of the EU IED and Victorian SEPP documents.
- Sourcing Fig 2.
- Discussion of the Bloomfield (2012), UK Health Protection Agency (2010) and UK Committee on Carcinogenicity (2009) reviews

These revisions address most of the points raised in my 12 September 2018 peer review. However, while I note the discussion of the three reviews in dot point 3 adds useful information to Section 4.3.2, none of the 28 papers cited in the Bloomfield (2012) review have been added to Section 4.3.1, nor critically assessed in the same way that the six papers originally cited were evaluated. No explanation has been offered as to whether these 28 papers met, or did not meet, the inclusion criteria outlined in Section 4.2 and Fig 8.

I also note that the revised report does not address points made about not meeting some of the specific issues raised by EPA Victoria in the RFQ specifications. In my view, this is primarily a matter for EPA Victoria, because I made it clear in my 12 September 2018 peer review comments that I felt EnRiskS went as far as possible with the approach taken and that the conclusions drawn were appropriately nuanced and conservative.