Australian
Wine
Research
Institute

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Ms Jennie Fischer
Viticultural Society of the Canberra District
mountnanima@bigpond.com

Subject: Veolia's proposed Woodlawn Advanced Energy Recovery Centre

Query: "We have become aware that the above facility is proposed and plume data indicates that emissions will be possible over the grape growing area of the Canberra district. Is there anyone in AWRI who is familiar with this type of emission and can assist us with determining the possible effects on grapes and subsequent wines."

Dear Jennie,

After reviewing the Environmental Impact Statement (EIS) prepared for Veolia Environmental Services (Australia) Pty Ltd by EMM Consulting Pty Ltd and the peer-reviewed literature on the emissions associated with incinerators such as the type proposed by Veolia, it is considered that the major risk associated with the proposed Advanced Energy Recovery Centre (ARC) is the potential for contamination of grapes and subsequent tainting of wine.

Summary

- Depending on the type of waste, incineration of municipal solid waste (MSW) can yield a variety of compounds including chlorophenols (CPs), bromophenols (BPs) and polycyclic aromatic hydrocarbons (PAHs).
- Many CPs, BPs and PAHs are potent food taint compounds and the AWRI has conducted numerous investigations over several decades where one or more compounds from these three groups have been found to be responsible for taints in grapes and/or wines.
- Various compounds within the three groups of chemicals listed above are extremely potent, causing wine taints at concentrations that might be 1,000 times (or more) lower than the national health and safety criteria exposure limit guidelines.
- The use of ammonia and lime to treat the flue gas, while effective at limiting the formation of polychlorinated dibenzo-*p*-dioxins (PCDDs), may lead to the accumulation of the chlorophenol precursors to PCDDs and the bromophenol precursors to polybrominated dibenzo-*p*-dioxins (PBDDs).
- Using data provided in the Woodlawn ARC EIS, two separate approaches were used to estimate the amount of chlorophenols that could potentially be emitted by the

Woodlawn ARC each year. In both estimations, the amount of CPs that could potentially be emitted was more than double the amount required to taint all the wine produced by Australia in the 2021-22 period.

- Based on the dataset provided in the Air quality impact assessment (Appendix O of the EIS), the prevailing wind alignment at the site of the proposed ARC is to the east and west, with the occurrence of easterly winds highest during the night, when there is a higher percentage of calm winds and hence a lower potential dispersion of air pollutant emissions. The average wind speed was lowest during the summer, when there was a higher occurrence of easterly winds. An easterly wind direction would direct emissions from the ARC straight towards the Canberra District viticultural region. There is likely to be higher occurrence of easterly winds, and lower wind speed, during summer months, when grapes are ripening.
- The dataset provided in the Air quality impact assessment also show that stable atmospheric conditions associated with lower mixing heights and lower potential for the atmospheric dispersion of pollutants prevail during the night-time. These poorer dispersion conditions coincide with the highest occurrence of easterly winds and lower average wind speed, which direct emissions from the ARC towards the Canberra District viticultural region. The data show that stable atmospheric conditions, with associated lower potential for dispersion of pollutants, are likely to occur 48% of the time during summer when grapes are ripening, coinciding with the highest occurrence of easterly winds and lower average wind speed.
- The three groups of compounds listed above are well known environmental pollutants that can accumulate in soil. Some of these compounds have been shown to revolatilise during summer (when grapes are ripening) which, under easterly wind conditions, introduces the possibility of their increased concentration in the air during this period. Any increased concentration of these compounds in the air increases the risk of contamination of grapes.
- Accumulation of 2,4,6-trichlorophenol (TCP), one of the chlorophenols in MSW incinerator flue gas emissions, in vineyard soil introduces the possibility of its biotransformation to one of the most potent food taint compounds known: 2,4,6-trichloroanisole (TCA). Volatilisation of TCA from vineyard soil during summer introduces the risk of aerial contamination of grapes with this compound.
- Given brominated flame retardants are present in numerous consumer products, such as plastics, textiles, electronic equipment and furniture, to enhance their fire resistance, and given the anticipated waste composition profile destined to be incinerated in the ARF as outlined in the Woodlawn ARC EIS, there is a possibility that various BPs will be produced during combustion and emitted in the flue gas, including 2,4,6-tribromophenol.
- If emitted, 2,4,6-tribromophenol (TBP) is likely to accumulate in vineyard soil in the same way as described above for TCP. Therefore, there is the possibility that biotransformation of TBP to 2,4,6-tribromoanisole (TBA) could occur. TBA is another known food taint with similar potency to that of TCA. As with the scenario described above for TCA, volatilisation of TBA from vineyard soil during summer also introduces the risk of aerial contamination of grapes with this potent taint compound.

Information supporting the above summary is provided below, while information on atmospheric emissions as sources of taint and aerial contamination in the wine industry is provided in the Appendix.

Given the risks described above, it is considered not advisable to build the ARC at the site proposed by Veolia and it is therefore suggested that an alternative site be sought.

Yours sincerely,

Adrian Coulter
Senior Oenologist

Work Health and Safety limits versus tainting levels

The chemicals responsible for taints in wine are frequently very potent, having very low odour and taste thresholds, and so can often be present at exceedingly low concentrations in affected in grapes and wines. Consequently, while the concentration of a compound might be well within national health and safety criteria, it could be far greater than the concentration required to cause a taint in grapes and wine. For example, in one investigation conducted by the AWRI, tasters observed a ‘plastic/mothball-like’ taint in a wine that was determined to contain 5 micrograms per litre (µg/L), or parts per billion (ppb), of naphthalene and 3 µg/L of methylnaphthalene (unpublished data). However, the Safe Work Australia Workplace exposure standards for airborne contaminants indicate an TWA (eight-hour time weighted average) exposure limit for naphthalene in the workplace of 10 milligrams per litre (mg/L), or parts per million (ppm), and an ST (short-term exposure limit: 15 minutes) as 15 ppm (Safe Work Australia 2013). That is, the exposure limit guidelines for naphthalene are approximately 1,000 times higher than the level that would cause a ‘mothball-like’ taint in wine. Hence, whilst a prediction of the ground level concentration of naphthalene might be well within national health and safety criteria, it could be far greater than the concentration required to cause a taint in grapes and wine[1]. Other taint compounds, for example trichloroanisole and tribromoanisole, are so potent they cause taints in wine at levels as low as 1 – 3 nanograms per litre (ng/L), or parts per trillion (ppt).

Potent taint compounds: chlorophenols and bromophenols from incineration of municipal solid waste (MSW)

Chlorophenols (CPs)

Chlorophenols are chlorinated aromatic compounds that have been used for several decades as biocides and in the manufacture of agricultural chemicals, pharmaceuticals and dyes. They are resistant to biodegradation and consequently persistent in the environment to such an extent that they are now general environmental contaminants. Given the potential toxicity of CPs and their persistence in the environment, the US Environmental Protection Agency has classified them as priority pollutants and the European Union has restricted their use (Igbinosa et al. 2013, Olaniran and Igbinosa 2011).

CPs are regularly cited as compounds generated by incineration of MSW, formed as a consequence of the presence of organic and inorganic chlorides in the waste (Kanters et al. 1996, Li et al. 2016, Liu et al 2013, Peng et al 2016, Wang et al. 2017, Yamada et al. 2001, Yamamoto et al. 1990). While some sources of chlorine can be removed from waste

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[1] It should be noted, however, that the relationship between exposure of a vineyard to naphthalene and the resulting concentration of naphthalene in the grapes and wine produced from that vineyard is not known.

before combustion, such as polyvinylchloride (PVC) plastics, organic materials present in MSW provide another source (Kanters et al. 1996). It is noted that table 6.5 in the Woodlawn Advanced Energy Recovery Centre Environmental Impact Statement shows the anticipated organics fraction of the MSW received to be in the order of 40%.

Over the past 40 years, the AWRI has investigated numerous wines and juices that have been affected by 'plastic-like', 'disinfectant- like' or 'chlorine-like' taints that were determined to be due to the presence of one or more of the following CPs: 2-chlorophenol, 4-chlorophenol, 2,4-dichlorophenol, 2,6-dichlorophenol, 2,4,6-trichlorophenol, tetrachlorophenol and pentachlorophenol. While some of the chlorophenols have sensory thresholds in the low µg/L range, others have thresholds in wine in the low ng/L range. For example, the aroma threshold of 2,6-dichlorophenol was determined to be 32 ng/L in wine, while the threshold of 2-chlorophenol was found to be 437 ng/L (Coulter et al. 2008). The CPs are therefore potent taint compounds and their presence at, or above, threshold concentrations in grapes and wine can render them unsaleable.

Although CPs have been used as biocides and are relatively resistant to biodegradation, a number of soil microorganisms are able to degrade or transform CPs to their corresponding methyl ethers (i.e. chloroanisoles). In the case of 2,4,6-trichlorophenol (TCP), certain moulds and fungi can transform TCP to 2,4,6-trichloroanisole (Simpson and Sefton 2007). Chloroanisoles are even more potent taint compounds than CPs, with the sensory threshold of 2,4,6-trichloroanisole (TCA), for example, reported to be 1.4 ng/L (Duerr 1985), although some sensitive tasters at the AWRI have been able to identify TCA at <1 ng/L. Given the ability of soil microorganisms to transform CPs to chloroanisoles, the accumulation of CPs in vineyard soils introduces the possibility they could be transformed to the more volatile and more potent chloroanisoles, which could volatilise during the summer months when the grapes are ripening and aerially contaminate them. Chloroanisoles impart taints to grape juice and wine that are typically described as 'musty' or 'mouldy'.

Chlorophenol compounds such as 2,6-dichlorophenol and 2,4,6-trichlorophenol, which are typically found downstream of incinerators (Ballschmiter et al. 1988), are the main precursor compounds to polychlorinated dibenzo-*p*-dioxins and dibenzofurans (Altarawneh et al. 2009, Kanters et al. 1996, Luijk et al. 1994, Ma et al. 2021, Wang et al. 2017, Yamamato et al. 1990), hereafter referred to simply as dioxins. Given the highly toxic nature of dioxins and their persistence in the environment, basic compounds such as ammonia and/or lime are often introduced to MSW incinerator processes to suppress their formation. Yamamato et al. (1990) found that introduction of lime supressed post-furnace reaction of the chlorophenol precursor molecules, preventing them from forming dioxins. Liu et al. (2012) indicate that the addition of basic compounds absorb the acidic gas hydrogen chloride (HCl) thought to promote dioxin formation. However, these authors also indicate that it is in fact unclear whether HCl concentration is a control factor in the formation of dioxins, as some studies showed that dioxin concentrations can still be elevated when the HCl concentration is reduced.

The production of the phenoxy radical from a chlorophenol molecule is an important step in the formation of dioxins and involves the loss of hydrogen from the phenol group to form the corresponding phenoxy radical (Altwicker 1967, Altarawneh et al. 2009, Lomnicki and Dellinger 2003). Interestingly, when investigating the oxidative degradation of TCP, Zhang et al. (2021) found that the degradation efficiency of TCP by ferrate (VI) decreased with increasing pH. The pKa of TCP is 6.23 (National Center for Biotechnology Information 2022), indicating TCP would be more dissociated at high pH. It is likely that the TCP phenolate anion is not susceptible to phenoxy radical formation given its phenol group lacks a hydrogen atom. This would explain the why ammonia and lime suppress the reaction of chlorophenol molecules to form dioxins, as indicated by Yamamato et al. (1990). Consistent with this, Li et al. (2016) found that while the analysis of stack gas from six MSW incinerators showed dioxins to be the major contributor to the Toxic Equivalent (TEQ) value, non-dioxin polychlorinated compounds were dominant in terms of mass concentration. It therefore might be possible that when dioxin levels in flue gas are relatively low, chlorophenol levels may be relatively high. Intriguingly, when chlorine reacts with phenol in aqueous solution, optimal formation of mono-, di- and trichlorophenol occurs at pH 8 (i.e. basic conditions) (Simpson and Sefton 2007).

In summary, it appears that the methods introduced to limit the formation of dioxins in MSW incinerators may inadvertently increase the levels of chlorophenol precursors.

Quantity of chlorophenols that might be produced by the ARC

Much of the research into the emissions from incineration of MSW has concentrated on the measurement of dioxins, greenhouse gasses, fine particulate matter (e.g. $PM_{2.5}$), polyaromatic hydrocarbons (PAHs), hydrogen chloride (HCl) and heavy metals. Apart from the data provided by Hsu et al. (2021) and Wang et al. (2017), there is a paucity of data on the concentration of various CPs in the emissions of MSW incinerators. It is noted that the Woodlawn Advanced Energy Recovery Centre EIS does not mention CPs and Neuwahl et al. (2019) mention CPs only once in their document ‘Best available techniques (BAT) reference document for waste incineration’, which references CPs as precursor compounds to dioxins. It is therefore clear that there is a lack of awareness of the fact that CPs are potent food taint compounds, most likely due to the emphasis on the health impacts of emissions from waste incinerators.

Given the incinerator investigated by Hsu et al. (2022) was more like the incinerator proposed by Veolia than the incinerators investigated by Wang et al. (2017), including the air pollution control devices and composition of the feed waste, data provided by these authors was used to calculate the mass of CPs likely to be emitted by the proposed ARC under normal operating conditions over a one-year period. Additionally, a second estimate was made based on the emissions data for HCl provided in the Woodlawn ARC EIS. Kanters et al. (1996) observed that for every gram of wet MSW incinerated in a micromodel reactor system, 2.8 mg of HCl and 113 ng of CPs were generated and that this was consistent with observations for municipal waste incinerators. Put another way, for every mg of HCl generated, 40.36 ng of CPs were generated.

Estimation 1

Hsu et al. (2021) conducted intensive stack sampling in a municipal waste incinerator with a furnace operating at a temperature between 900°C and 1,000°C using a feed of 40% municipal waste and 60% industrial waste, and utilising air pollution control devices including lime slurry injection, activated carbon injection and baghouse filtration. These authors measured 290 ng/Nm^3 of CPs in the stack flue gas and calculated an emission factor of 1572.45 µg/ton of waste. Using this emission factor and the figure of 380,000 tonnes as the anticipated annual amount of waste to be processed by the ARC (as indicated in the Woodlawn ARC EIS), this equates to 5.9753 x 10^8 µg of CPs emitted per year. As Hsu et al. (2021) showed that dichlorophenols represented the largest proportion (~57%) of CPs in the stack flue gas, and given that the sensory threshold of 2,6-dichlorophenol has been determined to be 32 ng/L in wine (Coulter et al. 2008), it does not seem unreasonable to use an ‘average’ chlorophenol sensory threshold of 200 ng/L to calculate an approximate value for the amount of wine 5.9753 x 10^8 μg of CPs might be capable of tainting. If we divide the mass (5.9753 x 10^8 μg) of CPs potentially emitted by the 'average' sensory threshold of 200 ng/L (or 0.2 μg/L), this equates to 3.0 x 10^9 L of wine. The Wine Australia 'Production, sales and inventory report' indicates that Australian wine production in 2021-22 can be estimated as just over 1.3 billion litres (Wine Australia 2022). The figure for the amount of CPs that could potentially be emitted by the Woodlawn ARC under normal operating conditions each year is more than double the amount required to taint all the wine produced by Australia in the 2021-22 period.

Estimation 2

As stated above, Kanters et al. (1996) found that for every 2.8 mg of HCl produced by combustion of MSW, 113 ng of CPs were also produced. Put another way, for every mg of HCl produced, 40.36 ng of CPs would also be expected to be produced, or for every kg of HCl produced, 40.36 mg of CPs would be expected. Using these figures, and the modelled emissions rate figure of 4.80 x 10^{-1} g/s for HCl provided in Table 7.6 in Appendix O (Air quality impact assessment) of the ARC EIS, which is the "expected emissions", the amount of CPs that might be released pre year by the proposed ARC can be calculated.

Using the emissions rate figure of 4.80 x 10^{-1} g/s, this equates to 15,137.3 kg of HCl emitted per year. The amount of CPs expected can be calculated as follows:
15,137.3 kg of HCl x 40.36 mg of CPs per kg of HCl = 610,940 mg of CPs per year, or 610,940 x 10^3 μg/year. If we divide the mass (610,940 x 10^3 μg) of CPs potentially emitted by the 'average' sensory threshold of 0.2 μg/L (as was done above for Estimate 1), this equates to 3.1 x 10^9 L of wine. This value is remarkably similar to the value (3.0 x 10^9 L) obtained in Estimate 1 above and is, again, more than double the amount required to taint all the wine produced by Australia in the 2021-22 period.

Bromophenols (BPs)

Like CPs, BPs are not readily biodegradable and persist in the environment (European Food Safety Authority 2012). BPs, including tribromophenol (TBP), have been widely used on wood as antifungal agents (Chatonnet et al. 2004) and as flame retardants added to polymeric components in numerous consumer products such as plastics, textiles, electronic equipment and furniture, to enhance their fire resistance (Altarawneh et al. 2019). Tetrabromobisphenol A (TBBA) is one of the most common flame retardants used in plastic paints, synthetic textiles, and electrical devices as a substitute for polybrominated diphenyl ethers (Yamauchi 2021). TBBA is also used as an intermediate in the manufacture of polycarbonate unsaturated polyester and epoxy resins, which are often used in communication and electronic equipment and electronic appliances, transportation devices, sports and recreational equipment, and lighting fixtures and signs (Anon 2018).

Altarawneh et al. (2019) noted that articles treated with brominated flame retardants used in the domestic, industrial and commercial sectors are often discarded into regular municipal waste streams at the end of their lifecycles.

Given the similar chemical properties of chlorine and bromine, it would be expected that bromine would behave in a similar way to chlorine on combustion. In fact, the combustion of waste containing bromine results in the formation of brominated dioxins and furans (Neuwahl et al. 2019, Ortuño et al. 2014). Ortuño et al (2014) found the oxidative thermal decomposition of TBBA at 600°C produced mono-, di- and tribromophenols, as well as toluene, *o*-, *m*- and *p*- xylenes and naphthalene, while Yu et al. (2013) demonstrated that

BPs were the predominant precursors or key intermediates in essentially all proposed pathways for the formation of polybrominated dibenzodioxins and furans.

Given the prevalence of brominated fire retardants, it is likely that brominated phenols would be produced and emitted by the ARC proposed by Veolia. In addition, similar to the situation with chlorine, it is probable that the methods introduced to limit the formation of dioxins in MSW incinerators may also inadvertently increase the levels of the brominated precursors, such as mono-, di- and tribromophenol.

Like CPs, BPs are also potent taint compounds. However, BPs generally have lower sensory threshold values than CPs and therefore have much higher tainting potential (Wells 2007). While the AWRI has not yet encountered wines or juices tainted with BPs, taints due to 2,4,6-tribromoanisol (TBA), which is the microbial degradation product of 2,4,6-tribromophenol (TBP), have been encountered on numerous occasions. The sensory threshold of TBA in wine has been reported to be 3 ng/L (Boutou and Chatonnet 2007), and imparts a 'musty', 'mouldy' aroma to wines containing concentrations at, or above, this concentration.

In one investigation conducted by the AWRI, all the wines and equipment within a small winery became tainted with TBA due to the accumulation of TBA vapors within the winery (Anon 2008). Similarly, Chatonnet et al. (2004) investigated a large number of cases of wines polluted during storage in facilities where the atmosphere was contaminated with TBA. In some cases, even though the original source of TBA had been removed, residual pollution adsorbed on walls was considered to be sufficient to cause ongoing tainting. These examples exemplify the risk associated with the accumulation of BPs in the environment, the microbial conversion to bromoanisoles, the possible aerial contamination of grapes that might be in that environment, and subsequent tainting of wine made from those grapes.

Atmospheric modelling

There are approximately 140 vineyards in the Canberra District wine region, ranging from approximately 18 – 50 km from the proposed Woodlawn ARC. The diurnal wind roses shown in the Air quality impact assessment (AQIA) (Appendix O of the EIS) prepared for Veolia by EMM Consulting Pty Ltd indicate a prevailing wind alignment to the east and west, with the occurrence of easterly winds highest during the night when there is a higher percentage of calm winds and hence a lower potential dispersion of air pollutant emissions. The average wind speed was lowest during the summer, when there was also a higher occurrence of easterly winds. An easterly wind direction would direct emissions from the ARC straight towards the Canberra District viticultural region. There is likely to be higher occurrence of easterly winds, and lower wind speed, during summer months, when the grapes are ripening.

The dataset provided in the Air quality impact assessment also show that stable atmospheric conditions associated with lower mixing heights and lower potential for the atmospheric dispersion of pollutants prevail during the night-time. These poorer dispersion conditions coincide with the highest occurrence of easterly winds and lower average wind speed, which direct emissions from the ARC towards the Canberra District viticultural region. The data show that stable atmospheric conditions, with associated lower potential for dispersion of pollutants, are likely to occur 61% of the time during winter and 48% of the time during summer when grapes are ripening, coinciding with the highest occurrence of easterly winds and lower average wind speed.

The EIS states that “introduction of the project will not significantly change air quality impacts currently associated with the Eco Precinct”. However, establishment of an incinerator introduces the production and emission of chlorophenol (and most likely bromophenol) compounds which are not produced, and therefore not emitted, under the current Eco Precinct operating conditions. This is because the chloro- and bromophenol compounds of concern require the conditions created by the incinerator to be produced from the waste.

The EIS also states that “relative to ambient background concentrations, air quality impacts associated with the Eco Precinct are minor at surrounding sensitive assessment locations”. However, the EIS does not consider the impact of the chlorophenol (and most likely also bromophenol) compounds that are known to be produced and emitted by the combustion of MSW. As is evident from the information provided above, CPs and BPs are potent taint compounds that can taint grapes and wine at levels one thousand (or more) times lower than prescribed health and safety guidelines. Additionally, accumulation of CPs and BPs in vineyard soil, as is known to occur, introduces the possibility of their conversion to more volatile chloro- and bromoanisole taint compounds which could volatilise during summer and aerially contaminate grapes as they ripen.

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