Pollution from Waste Incineration

A Synopsis of Expert Presentations on Health and Air Quality Impacts

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All-Party Parliamentary Group on Air Pollution

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Foreword and summary

With air pollution now claiming 64,000 deaths per year in the UK alone and a global death toll of 8.7 million, it is imperative that we reduce fossil fuel burning, in particular that which has the worst impacts upon human health.

Therefore, the impact of the UK Government giving approval to 50 new plants[1] to double the volume of energy-from-waste incineration by 2030 is naturally of concern with respect to both human health and climate change.

That is why I was pleased to host a series of presentations[2] concerning the health impacts of waste incineration, some fiscal measures to limit its activity, and the latest technical approaches to mitigate its impact.

Of critical importance is that it is the *number* of particulates, as opposed to their combined mass, that is the key determinant for human ill health. The smallest particulates act like a gas and penetrate seamlessly into the blood stream and organs.

The World Health Organization guidelines use the mass of particulates alone, for instance calling for a reduction from 10 to 5 micrograms per cubic metre for PM2.5. While necessary, this step may not be sufficient to protect human health, especially if a lower mass of particulates masks a greater number of ultrafine particulates (which weigh almost nothing).

In this context, Prof. Vyvyan Howard found that if incinerator filters are successful in stopping small particulates like PM2.5 but allow ultrafine particulates into the local environment at scale, then the resulting emissions are very damaging to human health. In other words, urban incinerators can constitute a significant health hazard for nearby populations.

Evidence of the biological impacts of air pollution from waste incineration was presented by Ruggero Ridolfi, MD. He led a study into the prevelance of heavy metals in the toenails of children living near incinerators in Italy, including nickel, which is associated with acute childhood leukemia.

Moreover, Kirsten Bouman's findings of the accumulation of dioxins in chicken eggs – and in grass and moss – up to 10 kilometres from incinerators imply that health risks decrease, but still exist, if waste incineration is further afield from urban populations.

These presentations fundamentally question BEIS's rationale for granting development consent orders that will effectively double incineration by 2030, in particular in poorer neighbourthoods[3] whose residents already suffer worse health outcomes from disproportionately higher levels of air pollution and inequality.

This will be on top of the growth of emissions from wood-burning stoves, which already constitute 38% of urban PM2.5. In other words, the positive switch to electified transport may be more than offset by woodburning and incineration. Therefore, the Government needs to legally enforce and gradually tighten air quality standards and a fiscal and regulatory strategy to deliver them.

Dr Dominic Hogg presented fiscal mechanisms, including putting waste incinerators into the UK Emissions Trading Scheme, plus taxing pollutants emitted or taxing incinerator carbon and pollutants seperately. By countering the imbalance created by the landfill tax, such measures would create a more level playing field to help incentivize local authorities to be more ambitious with their targets for reuse and recycling.

In Wales, current recycling levels are much higher than the targets in England (for example, 64 per cent achieved in Swansea) and the Welsh Government has imposed a moratorium on new large-scale waste incinerators.

This approach should be extended to England to stop the growth of burning and its pollutants. Government action is needed to confront the single-use culture both for plastics and other materials. In addition, chemical and mechanical waste recovery means that the feedstock for waste incineration can be reduced. It is important that investors do not invest in potentially stranded assets.

At the time of these presentations, interest was growing in the proposed new waste incinerator at Edmonton in north London, which is planned to burn 700,000 tonnes of waste a year. I am very grateful to the North London Waste Authority for presenting their plans,[4] which make every effort on the basis of known technology to minimize health and climate impacts from burning waste, for example through selective catalytic reduction to reduce NOx emissions.

If waste must be burnt, then it should be done in a way that minimizes harmful impacts, following mixed-waste sorting up front to ensure only truly non-recyclable waste is incinerated. However, north London's recycling rate is just 30 per cent[5] with a target of 50 per cent. Also effective technologies for carbon capture and storage are yet to materialize and the full picture regarding health harm from ultrafine particulates is still emerging.

In the round, it is clear from these presentations that the UK Government's strategy needs fundamental change to decrease not increase overall waste incineration, in line with efforts to drive down the production of waste and increase reuse and recycling, towards a sustainable future that fully respects human health and climate change.

In particular, the emerging evidence does not support increases in incineration in London, but rather a need for the Government and investors to pause and reflect and not to allow excess capacity to drive the burning of recyclable waste.

In the aftermath of a disappointing COP26, it is important to promote the improvement of air quality as a central strategy to combat climate change and to improve human health. This means that we should apply the precautionary principle to waste incineration and that Government and local authorities must take time to think again, in particular when considering the health risks of putting plants in urban locations with dense populations.

Geraint Davies MP
Chair, APPG on Air Pollution

Geraint Davies

Waste incineration, air quality & public health
A synopsis of expert presentations

> 'Ultrafine particulates are, because they are so small, it's very difficult to find a filtration process that can capture them all. I think what we need to ensure is that we have a method by which we are able to monitor the presence of substances in the environment. […] When you've got significant point sources of pollution, the further away they are from people, the less people are exposed.'
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> – Dr Bill Parish, Head of Air Quality and Industrial Emissions, Department for Environment, Food and Rural Affairs, 6 July 2021[6]

1. Toxicology of fine particulate matter

Prof. Vyvyan Howard is a medically qualified toxico-pathologist and Emeritus Professor of Bioimaging in the Centre for Molecular Biosciences at the University of Ulster. In 2019, he served as a member of the Particulate Research Group, which found that filter systems of waste incinerators may not be effective at blocking nanoparticles (PM2.5 and smaller), raising concerns about long-term health impacts on communities in the vicinities of such plants. He has investigated the toxicology of nanoparticles, which is of considerable importance to understanding the hazards associated with waste incineration, and co-edited a book entitled *Particulate Matter: Properties and Effects upon Health*. He also appeared in the 2012 film *Trashed*, presented by Jeremy Irons.

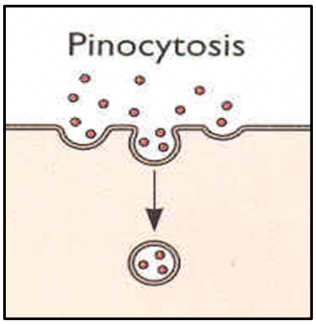
Presentation summary

Weight vs. number. The regulatory metric that is currently used to set standards for particles is based on their weight or mass, which is not a very useful metric. The number of very small particles is much more important as health effects are based on their number rather than their mass. **By far the majority of particles are ultrafine particles** or nanoparticles ($PM_{0.1}$), but they weigh very little.

Particle size and reactive nature. Toxicologists study the interaction of human wet biochemistry with the surface chemistry associated with particles. What particles are made of is of less importance than their size, the latter being the most the critical factor. Very small particles – ones that are less than 100 nanometres (a nanometre is one-millionth of a millimetre) – become very reactive; that is how catalysts are made. In addition, because the formation of the particles has come about through the process of incineration of a heterogenous waste stream, toxic substances, such as dioxins, form on the particles as the gases cool, and the **particles are a major way by which dioxins get out of incinerators**. It is possible to measure the number of ultrafine particles, but all studies published to date cut off at about three nanometres. From a technical perspective, it is more difficult to measure particles below that size.

No safe level of particulate exposure. Scientists cannot detect a safe level of exposure to particles. Any level of exposure has an effect. Science accepts that particles are deleterious to health, and there is no debate about the fact that long-term exposure to very small particles is bad for human health.

Unknown toxicity. The toxicity of effluvia coming out of incinerator chimneys has never been measured, although it could be. Based on what goes into incinerators – radioactive materials, heavy metals, chlorinated plastics – one would predict, a priori, that the effluvia would be more toxic than, say, diesel exhaust, and this has indeed been demonstrated by scientists in China.



Particles in the human body. Nanoparticles spread throughout the human body – the brain, the heart, the kidneys – but how do they make their way there? When a person breathes in nanoparticles, they go down into the upper airways – the trachea and the bronchi. Then they go down into the lower airways. If they land on what is known as the mucociliary carpet, they are removed, but if they get down beyond it, then they enter the alveolar air space. Nanoparticles preferentially get right the way down to the bottom of the lung. When they get to what are called alveolar epithelial cells, they have reached a junction to the blood, as those surface membranes are only 200 nanometres thick. Through a continuous process of invagination called pinocytosis (see the image), the membrane takes in the particles, which can then get into the blood and get distributed around the body. This is one way that viruses, which are of a very similar size, get around in the body. Thus, **we are wide open to nanoparticles**.

Penetration of waste incinerator filters. The protection of people's health is totally reliant upon an engineering fix, predominantly through bag filters. The mesh in bag filters is designed to let gas through and to stop particles. Really small particles are the most energetic and damaging to biological systems; they are the ones that most easily get into people's bodies. These particles act like gas molecules, meaning that the claim that they get stopped by bag filters defies the laws of physics. **They get through, virtually unabated**, and an aerosol of very fine nanoparticles emerges from these point sources. People's protection in the local community is totally dependent on an engineering solution working flawlessly, to the extent that it can provide protection. Even if a waste incinerator is equipped with an electrostatic precipitator, efficiency drops for the particles with the smallest mass. A scrubbing apparatus does not address de novo synthesis. After the gases have left that smokestack, de novo synthesis of particles can take place in the cooling gases.

High-quality scientific studies. Prof. Howard cited relevant research findings (see the endnote).[7]

2. Biomonitoring of dioxins in chicken eggs, grass, and moss near incinerators

Kirsten Bouman works on biomonitoring projects for ToxicoWatch, an independent non-profit organization dedicated to raising awareness of toxic hazards, providing evidence-based policy advice to governments and industry actors, and establishing the precautionary principle as a guideline for decision-makers. The biomonitoring research is focused on tracing the sources of persistent organic pollutants (POPs), such as dioxins, in waste, flue gas, and biomarkers (such as chicken eggs and human mothers' milk), particularly in the vicinity of waste incinerators.

Presentation summary

Biomonitoring as a tool for tracking incinerator toxins. Since 2013, ToxicoWatch has been conducting biomonitoring research on persistent organic pollutants (POPs) emitted through waste incineration, such as dioxins (PCDD/F) and dioxin-like PCBs and PFAS.[8] Some of these very toxic compounds are known as 'forever chemicals'. By burning everyday household waste, incinerators produce thousands of tonnes of bottom ash and fly ash. Bottom ash, which can be loaded with hazardous compounds, finds its way into concrete and road constructions materials. Semi-continuous measurements taken in an incinerator smokestack can be compared with biomonitoring analysis results to provide evidence that dioxin and POP emissions are released by a waste incinerator.

Visible plume as indicator of inadequate combustion. In 2013, ToxicoWatch began biomonitoring research on POPs in the vicinity of a waste incinerator in the Dutch city of Harlingen. The incinerator was touted as a state-of-the-art municipal waste-to-energy (WtE) incinerator with a special system of dry scrubbers to clean the flue gas. This incinerator is located on the shores of the Wadden Sea, a UNESCO World Heritage site, and therefore the local council demanded that no visible plume be released from the very short smokestack. Since it became operational in 2011, however, dark plumes have regularly been seen (and photographed) coming out of the stack, indicating that combustion processes might not be performed as they should be. Dark dust plumes have also been observed during operational failures and start-ups.

Backyard chicken eggs and grass as biomarkers. If chickens live in environments that are contaminated by airborne deposits of hazardous substances such as dioxins, they wind up ingesting them by eating grain, grass, soil, and earthworms. Dioxins bioaccumulate in chicken body fat and are passed on to the fatty yolk of eggs. Chicken eggs thus serve as ideal biomarkers, revealing **a clear pattern of dioxin emissions from incinerators**. ToxicoWatch's biomonitoring research shows that the dioxin levels in eggs laid close to the incinerator in Harlingen exceeded the limits for safe consumption (2.5 picogram TEQ per gram of fat). Eggs that were farther away from the incinerator (more than 10 km) were safe for consumption. The fact that contaminated eggs were more prevalent towards the incinerator serves as a strong indication that the incinerator was the source of the dioxins. This conclusion was supported by the results of dioxin analysis of grass around the same incinerator.

Sheep wool as a biomarker. ToxicoWatch started a pilot study with the hypothesis that sheep wool would be as useful as a biomarker thanks to fatty lanolin compounds, which could serve as bioindicators of dioxins and other POPs, such as PAH (polyaromatic hydrocarbons), in the environment. The analysis shows that POPs can indeed be monitored in sheep wool.

Moss as a biomarker. ToxicoWatch conducted long-term, crowdfunded biomonitoring of dioxins in moss near a new WtE incinerator close to San Sebastián, in the Spanish Basque country. The results revealed elevated levels of the dioxin PCDD/F and dioxin-like PCBs only after the facility had become operational, in 2020. ToxicoWatch has also started long-term biomonitoring PFAS in moss in the region and in other European countries, in association with Zero Waste Europe.

Dioxin monitoring requirements. For waste incinerators, the law currently requires only two 6-hour periods of dioxin emission measurements per year. Measurements are taken under pre-enhanced, ideal conditions, not under other-than-normal operating conditions (OTNOC), which are typically associated with much higher outcomes of dioxin emissions. **More than a year's load of dioxins can be emitted in one OTNOC situation, such as a start-up.** ToxicoWatch's research shows that air pollution control devices such as bag filters are bypassed during start-ups. Semi-continuous monitoring undertaken from 2015 to 2017 revealed that the bag filters of the state-of-the-art incinerator in Harlingen were bypassed during start-ups. Moreover, only chlorinated dioxins are measured; monitoring of dioxin-like PCBs and other hazardous compounds is not required. To obtain more reliable and more realistic results, ToxicoWatch recommends:

- semi-continuous measurements in the incinerator smokestack, including during OTNOC: start-ups, shutdowns, failures, and air pollution control device fallouts;
- samplings of four weeks of emissions, not just a few hours;
- measurements of dioxins as well as dioxin-like PCBs and brominated dioxins and PFAS; and
- continuous use of air pollution control devices, including during start-ups, to allow for accurate readings.

Post-combustion zones. The EU requires municipal waste incinerators to ensure a residence time of 2 seconds at 850°C in the post-combustion zone, yet ToxicoWatch research reveals many drops below that required temperature.

3. Biomonitoring of heavy metals in toenails of children who live near incinerators

Ruggero Ridolfi, MD, is an oncologist with more than 40 years of clinical experience. He was the manager and one of the authors of a 2020 study of the accumulation of metals in the toenails of children who live near waste incinerators: 'Biomonitoring of Metals in Children Living in an Urban Area and Close to Waste Incinerators', published in the *International Journal of Environmental Research and Public Health*.[9] He runs the Forlì–Cesena (Italy) section of the International Society of Doctors for the Environment (ISDE), has coordinated the Environment and Cancer Project of the Italian Association of Medical Oncology (AIOM), and is the author of more than 170 scientific publications and a reviewer for 12 international indexed journals.

Presentation summary

Biomonitoring children near incinerators. In 2017, Dr Ruggero Ridolfi of ISDE (International Society of Doctors for the Environment) conducted a crowdfunded biomonitoring study that focused on **heavy metals accumulated in the toenails of children** living in Forlì, Italy, including in the area where two waste incinerators are operating. The concentration of heavy metals in toenails correlates with their presence in the environment. Biomonitoring allows for pollution monitoring in living organisms, as a way of evaluating the status of the exposed subjects. It also helps to raise awareness on this issue of concern.

Data collection. The study team collected 236 toenail samples from 6–9-year-old children between 4 March to 8 April 2017. All samples were anonymized and combined with a questionnaire and a written informed consent. Due to the high number of samples, the research took on the form of a true observational study and consent was obtained from the ethics committee of Romagna.

Lab results. A lab in Turin searched for the presence of 23 heavy metals in 221 evaluable toenail samples, divided into the four macro-areas of Forlì. The results show that in the samples taken in the north-eastern areas, which contain the city's industrial zone and both waste incinerators, the concentration of metals in the toenails was 60% higher than in other areas of Forlì. The data also revealed statistically significant **high values for aluminium, copper, and manganese in samples from one area close to the incinerators**, as compared to the other three areas.

Data comparison. The same data were also used to compare the concentration of metals in 62 children residing within 3 km of the incinerators (the 'exposed' children) to the concentration in the other 158 children (the 'control' group). A significantly higher percentage of the exposed children had detectable metal concentrations for aluminium, barium, manganese, copper, and vanadium. The concentrations of **barium, nickel, copper, and manganese in the exposed children indicate a common source of emission**.

Effects of heavy metal exposure on human health:

- **Manganese.** Excessive exposure to manganese can cause **neurotoxic effects with cognitive and behavioural deficits in children**. Manganese is the metal with the highest concentration in the soil and the second-highest concentration in the area around Forlì's solid waste incinerator.

- **Copper.** A high concentration of copper is related to an increase of oxidative stress and the generation of reactive oxygen free radicals, which favour **DNA damage and the occurrence of cancer**.

- **Nickel.** Many studies report a large amount of nickel in air and soil samples around municipal solid waste incinerators. Nickel conveyed by PM10 leads to worsening of lung function. The concentration of this metal in the hair of pregnant women and in the foetal placenta are connected with an increase in **congenital heart defects in children**. Nickel is in carcinogen group 1 of the International Agency for Research on Cancer. A high level of this metal in urine correlates with acute childhood leukemia.

The two waste incinerators of Forlì. One incinerator has a capacity of 120,000 tonnes and treats municipal waste; the other facility treats hospital waste from different areas of northern Italy and has a capacity of 35,000 tonnes. Since the introduction of door-to-door collection of separated waste about two years ago in Forlì, the amount of waste going to the municipal waste incinerator has dropped by 80%. There are still further possibilities for improvement, including the potential decommissioning of the plant in 2025.

4. Fiscal and regulatory strategies to manage the impacts of incineration

> 'One of the lessons I've learnt from my experience doing this type of analysis over the last 20 years is that there's a sort of unwritten law that things are usually worse than we thought they were going to be. […] And look, in most cases, these [incinerator] pollutants turn out to be worse than we thought.'
>
> — Dr Dominic Hogg

Dr Dominic Hogg founded the environmental consultancy Eunomia, where he worked for 20 years. He has undertaken a number of reviews and assessments of the climate change and air quality impacts of waste treatment facilities. He has a degree in physics, a Master's in development economics, and a PhD in economics. He recently began work as an independent environmental consultant through a new company, Equanimator.

Presentation summary

Energy-from-waste incineration no longer justifiable. Around the year 2000, the notion of generating energy from waste seduced policymakers, who generally assumed that incineration would reduce the need for coal-fired power, a source of particulate matter, oxides of sulphur, and NOx. If that was at all true 20 years ago, it is definitely not true anymore. The issue around incineration comes into much sharper focus as we start to consider alternative forms of energy, particularly the electricity that is generated for the grid today. Materials embody energy – they embody climate change emissions, which is why it is a good idea to keep them in use for as long as possible, to keep them moving through a circular economy.

Costing damage from waste disposal. In the early 1990s, the government began to consider waste disposal-related externalities – the monetized damages associated with landfill and incineration. A 1993 study set the externalities at a small number of pounds (£) per tonne. Virtually all of the externalities for both landfill and incineration were associated with transport, and the main reason why landfill looked worse than incineration at the time was because of the assumption that waste would typically travel greater distances to reach an incinerator than a landfill. Nowadays, unlike then, waste goes to incineration across borders, and fuel duties and other policies seek to account for the environmental costs of transport.

Determining damage costs and levels. In 1993, externalities for NOx (oxides of nitrogen) and other pollutants were given low values. These values have since gone up quite significantly for most of these pollutants: for particulate matter and NOx, they are ten times what they were in 1993, at the central level. Defra assesses low, central, and high air quality damage cost values for use in the appraisal of policies. Each level reflects the inclusion of different effects of these pollutants. The central case for NOx is relatively cautious, valuing only chronic mortality effects and asthma in children, yet not attributing any value at all to hospital admissions due to associated respiratory complaints, asthma in adults, diabetes, or lung cancer, for example. Similarly, for particulate matter, the values include some impacts and exclude others, and there are issues associated with the way in which particles of different sizes are treated. Experience indicates that today's high value will probably be tomorrow's central value, as there is an unwritten law of environmental policy that things are usually worse than anticipated, and so the government is always playing catch-up. In most cases, **incinerator pollutants turn out to be worse than expected**.

Unassessed incinerator pollutants. **Hundreds of different pollutants come out of an incinerator when it burns waste**. We barely know what is in waste most of the time and we do not always know what is coming out of the stack.

Calculating the NOx-related health impact. In the UK, waste incinerators are permitted to emit just below 200 mg of NOx per m^3. Incinerators typically emit around 5,500 m^3 of exhaust gases per tonne of combusted waste. Multiplying 5,500 by just under 200 mg per m^3 yields roughly 1 kg of NOx that comes out of an incinerator per tonne of waste burnt. A 700,000-tonne incinerator pumps out something like 700 tonnes of NOx per year. The damage cost associated with the health impact of those emissions, at the high value, is around £26 per tonne of waste; at the central value, it is about £7 per tonne.

The financial case for NOx abatement. Available abatement techniques make it possible to slash current NOx emissions from incineration, which would effectively bring down the damage cost by around £5–£5.50 per tonne of waste treated, at the central level. The cost of that abatement is relatively low – about £2 per tonne – meaning that the financial benefit of abating NOx clearly outweighs its cost. But if pollutants are more deleterious to health than previously assumed, and the externalities that are excluded at the central level actually should be included, NOx impacts would increase to about £23 per tonne. In that case, the low-NOx version would save about £18 per tonne of impact for an investment of about £2. Yet that approach is not taken and, instead, **existing incinerators are being allowed to pollute at high levels relative to the potential for abatement**.

Concerns:

- Incinerators are regulated and need to obtain permits, but the **regulated pollutants are a relatively narrow list**. Directives focus on chlorinated dioxins, not the brominated ones that are emitted by incinerators that burn flame retardants, for example.

- The pollutant limit values were set back in 2000, and the **NOx emissions are incredibly permissive relative to abatement potential**. In the UK, the limit value for NOx is 200 mg per m^3, yet some other countries set their own limit values around 50. That means there is no incentive for an incinerator in the UK to improve its abatement performance to below committed emissions.

- **Waste incinerators are not covered by the Emissions Trading Scheme (ETS) for their climate change emissions**. Under climate change inventories, incinerators that generate energy are treated as power stations, not waste installations. But all the other power stations are included under the UK (and EU) ETS, and they do not receive any free CO_2 emission allowances.

- Landfills are taxed at £96.7 per tonne but **incinerators are not subject to any economic instrument to encourage abatement** beyond permitted levels. And they face **no economic instruments to pay for climate change**.

What's to be done?

Two options regarding existing waste incinerators:

- **include waste incinerators in the UK Emissions Trading Scheme** and, separately, **tax emissions of all the pollutants they are emitting**, and preferably do that as part of a wider tax, covering other stationary combustion installations, such as cement kilns; or

- if waste incinerators are not to be included in the UK Emissions Trading Scheme, then **tax incineration**, just like you tax landfill, and do so in relation to the carbon content of the feedstock and the emissions of NOx, SOx, particulate matter, and other pollutants. Corresponding revenue could be used to compensate local communities that are dealing with harm caused by existing facilities.

For potential incinerators:

- **We need a moratorium on additional incineration capacity.** Capacity is expanding too quickly.

- Some proponents defend expansion by arguing that future incinerators will be equipped with carbon **capture and storage technology** for their CO_2 emissions. But that technology **would have no impact on non-climate-related pollutants** – particulate matter, NOx, SOx, etc.

The past decade in England has seen a flatlining of recycling, an increase in incineration, and a reduction in landfill. These proposals are key to supporting a shift to a more circular economy and adherence to a less-than-1.5°C trajectory for the planet.

Notes

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[1] See https://resource.co/article/incineration-proposals-incompatible-uk-net-zero-and-recycling-targets.
[2] See https://www.youtube.com/watch?v=KRFcXbbScAo.
[3] See https://www.theguardian.com/environment/2020/jul/31/uk-waste-incinerators-three-times-more-likely-to-be-in-deprived-areas and https://unearthed.greenpeace.org/2020/07/31/waste-incinerators-deprivation-map-recycling/.
[4] See https://appgaq.files.wordpress.com/2021/12/nlwa-presentation-to-the-appg-on-air-pollution-final.pdf.
[5] See https://www.nlwa.gov.uk/news/700-mattresses-extracted-waste-stream-each-week-north-london-recycling-trial.
[6] Statement made in response to Geraint Davies' questions about waste incineration emissions during a hearing of the Environment, Food and Rural Affairs Committee meeting on 6 July 2021, https://www.parliamentlive.tv/Event/Index/4ce44852-38d6-4bed-b270-f81dd270ccc4.
[7] Prof. Howard cited studies including the following:

- A study that used X-ray microscopy to demonstrate that up to 30% of particles in the Swedish town of Boras were coming from a local incinerator (Aboh et al., 2007, *X-Ray Spectrom*., 36: 104–110).
- The first multi-author book to address the effects of ultrafine particles (Howard and Maynard, eds., 1999, *Particulate Matter*: *Properties and Effects on Health*, Garland Science).
- A six-city study (Pope and Dockery, 2006, *Air and Waste Mgmt Assoc Annual Critical Rev*, 56: 709–742).
- A study on the effect of European levels of particles on health (Künzli et al., 2000, *Lancet*, 356: 795–801).
- A paper that shows that small particles contain zinc, lead, and copper, and that they are actually carrying heavy metals (Chang et al., 2000, *J. Hazardous Materials*, A79: 229–239).
- A paper that reaffirms that the inhalation of fine and ultrafine particles is a major route of exposure to other pollutants in the gas stream (Cormier et al., 2006, *EHP*, 114: 810–817).
- A paper that shows that particles of less than two microns, PM2.5, had 80% of the toxic equivalent of dioxins (Chao et al., 2003, *Atmospheric Environment*, 37: 4945–4954). This is particularly pertinent with respect to bromides, flame retardants, forming brominated dioxin. Only chlorinated species of dioxins are measured, but there are more than 4,500 brominated and chlorobrominated congeners that are not considered. Particles are a major way by which these dioxins get out of incinerators.

[8] ToxicoWatch performs analyses with bioassay of CALUX, which is faster, easier, and more affordable than the standard chemical analysis by GC-MS (gas chromatography–mass spectrometry). Regulations are based on GC-MS analysis, while bioassay is applied as a robust screening method. The results of the bioassay of CALUX are expressed in bioanalytic equivalent (BEQ), while chemical analysis uses toxic equivalent (TEQ). The bioassay of CALUX detects not only chlorinated dioxins, but also brominated and mixed chlorobromo POPs, which can be formed due incomplete combustion.
[9] See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7143875/.