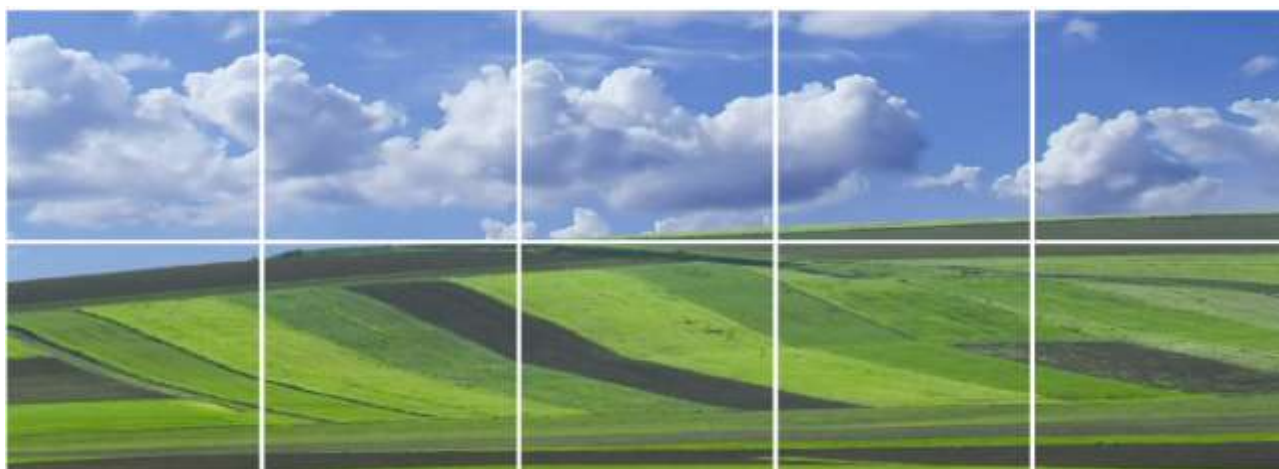


A further update of the UK source inventories for emissions to air, land and water of dioxins, dioxin-like PCBs, PCBs and HCB, incorporating multi-media emission inventories for nine new POPs under the Stockholm Convention



Report for the Department for Environment
Food and Rural Affairs

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Executive Summary

The Stockholm Convention on Persistent Organic Pollutants (POPs) was established under the United Nations Environment Programme. It came into force on 17 May 2004, and was ratified by the UK on 17 January 2005. Under the original text of the convention, 12 substances were to be covered, the majority of which were dispersed within the environment as a consequence of their use or disposal following commercial manufacture; which has since been phased out and not occurred within the UK for considerable time. However the management of emissions from unintentionally produced POPs (U-POPs) is far more difficult to control and for this reason the Convention places a requirement on ratified states to develop release inventories for substances listed within Annex C of the Convention, entitled “Unintentional Production”.

It is intended that these release inventories should help inform the ratified states in the development of action plans (which form part of a national implementation plan (NIP)) for emission reduction and also to map trends across time, which includes reporting requirements to UNEP.

The substances listed in the Stockholm Convention were originally dioxins and furans, PCBs (polychlorinated biphenyls), and HCB (Hexachlorobenzene). In May 2009 an additional nine substances were provisionally added to the annexes of the Convention as listed:

- ▶ Alpha hexachlorocyclohexane (added to Annex A)
- ▶ Beta hexachlorocyclohexane (added to Annex A)
- ▶ Hexabromodiphenyl ether and heptabromodiphenyl ether (added to Annex A)
- ▶ Tetrabromodiphenyl ether and pentabromodiphenyl ether (added to Annex A)
- ▶ Chlordane (added to Annex A)
- ▶ Hexabromobiphenyl (added to Annex A)
- ▶ Lindane (added to Annex A)
- ▶ Pentachlorobenzene (added to Annex A and C)
- ▶ Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (added to Annex B)

The new substances were then fully endorsed from August 2010 placing a requirement on the ratified states to act, both in terms of the development of new release inventories for the additional Annex C substance (pentachlorobenzene) and update of their National Implementation Plan (NIP) by August 2012.

In July 2009, AEA working on behalf of Defra completed a body of work to develop the first full emission inventories by source (based on the NFR – Nomenclature For Reporting source classification scheme) for the original Annex C substances, as well as dioxin-like PCBs, a reporting requirement of the POPs regulation (EC850/2004). These inventories spanned the time-series of emissions for the UK from 1990 to 2006 for air, land (total) and water vectors. The work included communication with industry, regulatory bodies, reviewing of existing data held within the NAEI (National Atmospheric Emissions Inventory) as well as extensive efforts to review academic literature in the development of an emission factor library for development of the inventory.

The report for this first inventory submitted to Defra in July 2009¹ details the mechanics of how the first full multi-vector (termed 'multi-media' in the report) inventory POPs inventory had been compiled with detailed information on key sources and trends. As part of this work recommendations were also made to Defra highlighting the aspects where the uncertainty was particularly high and where further action was required to help further evolve the inventories to reduce uncertainty and better characterise the trends between 1990 – 2006.

From December 2009, AEA undertook a dual focused project which was aimed firstly at improving the aspects of the original release inventories to reduce uncertainty, as well as updating the inventories for the emission years 2007, 2008 and 2009. The second aspect of the project was to address the new additions to the Stockholm Convention, with the aim of developing multi-vector release inventories wherever possible for the nine new POPs that were added to the Convention. This report details that body of work and the findings of the inventory improvement programme as well as the new emission release inventories for the POPs added to the Convention in May of 2009.

Improvement programme

Following the completion of the original POPs multi-vector inventory in July 2009; the inventory as a whole was reviewed and the areas where the uncertainty of the data was highest were identified. This led to a set of recommendations for further work to improve upon the estimates: this further work is the focus of part 1 of this report. The source estimates which have been reviewed and improved are:

- ▶ Dust (Air Pollution Control (APC) Residue) and ash from hazardous and clinical waste incineration
- ▶ Dust (APC residues) from the smelting of non-ferrous metals
- ▶ Working concentrations of HCB within pesticide products
- ▶ Concentrations of the original POPs in sewage sludges
- ▶ Estimate of POPs emissions to controlled water which fall below the reporting threshold for the UK pollution inventories
- ▶ Review of the UK waste burning habits to improve estimates for open burning in households and bonfires.

Dust (APC Residues) and ash – hazardous and clinical Incineration

The estimates made in the original multi-vector inventory were based on assumed 'activity' data for combustion rates in both the hazardous and clinical waste incineration sector, data which was derived from previous reviews of the sector cross referenced to IPPC permits. For PCB emissions an 'ash generation' factor was used to quantify total ash generated as part of the process and literature emission factors used to quantify the concentration of PCB in the final ash created. Dioxin and furan emission estimates were more straightforward with an emission factor applied directly to the activity (combustion) data. This emission factor was derived based on existing literature and the UNEP toolkit. In both cases the assumption was also made that 100% of this material was sent to landfill in the absence of better information. However the authors recognised that within the UK it may be possible to recycle such waste into other industries, principally as aggregate for cement and concrete or road surfacing materials.

The current study has carried out a full industry stakeholder consultation with the operators in both sectors to gain UK operator data and improve estimates. A key component of this process

¹ <http://archive.defra.gov.uk/environment/quality/chemicals/documents/dioxins-report100630.pdf>

has been to investigate not only the quantity of APC residue and granulated slag generated, but also its final destination. Within the hazardous waste incineration sector there are a small number of large scale plants and in all cases the waste materials generated are further processed to reduce hazardous content before recycling into the aggregate industries. The picture for the clinical waste incineration sector is more variable. However the consultation has shown that the original estimates for quantities of waste generated were too high and these estimates have now been revised. Further discussion of the results is given in the main body of the report.

Dust (APC Residues) – non-ferrous metals

The non-ferrous metal sector was identified within the original multi-vector inventory as a potential key source, particularly for emissions from materials sent to landfill. The secondary manufacture of metal from scrap with surface contamination has the potential to generate dioxins and furans. There was also the issue of secondary copper manufacture where the copper element could potentially act as a catalyst for de novo formation of dioxins and furans within the filter dust from air pollution control residues. The original estimates were generated based on quantities of metal manufacture (from industry review and IPPC permits) an ash generation factor and emission factors taken from a 1997 study.² As with the incineration sector, an assumption was made that 100% of this material would be consigned to landfill.

The current study has carried out an industry stakeholder consultation with the operators of the largest plants, as well as the trade associations and communication with local authorities where smaller size plants are located. The local authorities in this case were identified based on the notes submitted by the authorities identifying which industry sector operators are within their area.

The results provided new data while highlighting further issues. The industries within the non-ferrous metal sector, who are dominated by secondary aluminium manufacture and recycling processes, produce smaller quantities of APC residue than originally quoted within the first multi-vector inventory. There are also high levels of recycling of this material into other industries, primarily as aggregate. This means the original estimates for quantities consigned to landfill are significantly too high and will need to be revised.

However the results also show a lack of monitoring data for POPs, particularly dioxins and furans within this material, meaning it is not possible to improve upon the emission factors based on the 1997 data. One possible exception was a study carried out by Lancaster Environment Centre on behalf of the galvanising association,³ which provides new data for the zinc hot dip galvanising, and concentrations of dioxins and furans in APC residue.

The study also found that the available data at local authority level was patchy with IPPC permits commonly only held as hardcopy in reference libraries. The exception to this case was Walsall Metropolitan Borough Council who makes the permits available online. This allowed some indication of the ratio of IPPC A2 and B1 size plants within the borough to be identified, noting that the small scale (IPPC B1 <20 tonnes per day) plants will likely be concentrated in

² Dyke et al. (1997) – A review of dioxin releases to land and water in UK. The Science of the total environment issue 207 pp 119-131

³ Jones et al, 2003 'Report on PCDD/Fs in samples of bag dust collected from galvanising plants in the United Kingdom. Report by Lancaster University to the Galvanizers Association.

larger cities where scrap metal is more readily available. The AQ notes indicate that most of this industry is in the West Midlands.

Working concentrations of HCB within pesticides

Historically the issue of HCB contamination within a small group of chlorine based pesticides; particularly chlorothalonil has been well documented. Research from North America provides an indication of working concentrations, but a lack of UK data exists. The original multi-vector inventory was based on the legal limit for contamination – 40ppm (mg/kg wt/wt) in the absence of UK data.

The current study involved a sampling and analysis regime of UK pesticides taken from farm level and then tested for both the concentration of the active as well as the concentration of HCB. The study was primarily focussed on the key pesticide of concern, chlorothalonil; but also looked to carry out exploratory research into one other potential source of HCB – Chlorpyrifos. The results showed no presence of HCB in chlorpyrifos above the detection limits (0.05 mg/kg). The results of the chlorothalonil found a clear split in results between branded products and non-branded products. The concentrations in branded products showed a small band of variation between 1- 5 ppm, with non-branded products being more variable having concentrations between 0.16 – 38ppm. The study was able to use the results of the testing regime to derive a new weight average of 8ppm (mg/kg wt/wt) which has been used to update the inventory.

Concentrations of the established POPs in sewage sludges

The original POPs multi-vector inventory provides estimates for POPs, particularly PCBs within sewage sludge which are then principally consigned to agricultural land as fertiliser. After the ban on dumping of sludge at sea in 1999 this means of disposal became more important. The emission factors used for the original POPs multi-vector inventory (440 µg/kg of sludge for PCBs) were based on a literature review carried out in 2005,⁴ which in turn quotes a sampling and analysis study carried out in 2000. The results of this study showed that the PCB concentrations in sludge were still a concern even after use of PCBs (primarily in dielectric fluids) in new equipment was banned in 1985, and the removal of equipment containing more than 1kg of PCB from service by 2000.

The current study carried out a sampling and analysis regime for 35 samples based on 'end-of-process' sludges for a range of flow types (industrial, urban and rural) as well as looking at season variation and five additional samples for treated effluents. The results showed a decline in PCB concentrations since the 2000 study with a new recommended emission factor of 42 µg/kg of sludge. The results also provide new data on concentrations for dioxins and furans. HCB was not detected above detection limits in any of the samples analysed.

The results also show higher concentrations for industrial flow compared to urban and rural samples, and some indication of seasonal variation. However the comparison of data between PCBs and dioxins and furans shows a reverse pattern during seasonal change, with highest PCB concentrations in the winter months, and the highest dioxins and furan concentrations in the summer months.

Estimate of POPs emissions to controlled water which fall below the reporting threshold for the UK pollution inventories

⁴ Sweetman, A, 2005 'Polychlorinated Biphenyls: fate and behaviour during the wastewater treatment process'

The hydrophobic nature of POPs means that during the waste water treatment process the presence of dioxins and furans and PCBs will likely partition into the sludge component of the process. Consequently, the disposal of sewage sludge from waste water treatment works is likely to be the key source emission for POPs in that process. However it is possible to find very small concentrations of dioxins and furans and PCBs within treated effluents, mostly likely related to the presence of very fine suspended matter in the final treated effluent. The UK regulatory authorities place a requirement for gathering data on concentrations for reporting to the pollution inventories. The concentration of dioxins and furans and PCBs within treated effluents above a threshold of 0.1g WHO-TEQ/per annum and 1g/per annum per works respectively are reported in the UK pollution inventories.

While the above threshold proportion of the emissions reported within the pollution inventories is likely to represent the most significant share, there was an issue identified with the below threshold proportion. While the below-threshold emissions are smaller than above-threshold emissions; the quantity of activity may mean that the combined total of these emissions is not insignificant.

The current study has reviewed the data in the pollution inventories, results of the sampling and analysis part of the project and looked to derive alternate methods of calculation to estimate total emission and therefore the proportion that is below the reporting threshold. Full details of the approach taken and findings are given within the main body of the report.

Review of the UK waste burning habits to improve estimates for open burning in households and bonfires.

The regulation and control of emissions of POPs from regulated sources has meant that the more diffuse activities have increased in relevance. The original multi-vector inventory identified the uncontrolled combustion of waste as a key source for dioxins and furans. However the nature of burning waste on open fires either in the home or bonfires in gardens and allotments means that the level of uncertainty is high. One possible improvement which was identified was to look at the nature of burning habits within the UK. This would include information on how often people burn such waste, the nature of the waste burnt, the nature of how the waste is burnt – for example, fire place, open bonfire or barrel burning – and also the awareness among the general public of which waste materials should not be burned.

The current study carried out a two tier survey beginning with a qualitative phase using face to face interviews with key identified demographic groups. This helped inform a wider survey of a 1000 people across the UK, which was followed by a final review of the results. The survey phase showed that the occurrence of waste burning was marginally less frequent than originally thought. There was a good level of understanding within the sample group that burning of plastic wastes in particular is not advisable, but less understanding about the issues of burning treated woods, particularly varnished furniture. The survey phase showed particular issues with a small sub-set of society with tradespeople using bonfires as a means of disposal for craft materials such as treated timber and paints. There was also a regional split with an issue identified in Northern Ireland where old car tyres are sometimes burned on open fires.

The results of the survey should be used to better quantify the existing methodology used for calculation of activity data for these activities. Annex II of the main report will provide tables of improvement to show where the results from the current programme of work have been used to update the emission inventories.

New emission release inventories

As stated on the 8th May 2009, at the fourth Conference of the Parties (CoP4) for the Stockholm Convention, it was agreed that nine additional substances would be added to the Annexes of

the Convention. These newly designated substances are primarily pesticides and brominated flame retardants, together with perfluorooctane sulphonate (PFOS) which has been used as a surfactant in a number of products.

The project team at AEA and the Lancaster Environment Centre (LEC) has researched the available information on UK activities that may lead to emissions of the nine new POPs, with the aim of establishing complete source-specific air, land and water emission inventories where possible.

The study consisted of an initial scoping phase, reviewing the available UK and international evaluations of the nine new POPs, to identify the range of activities and sources within the UK that are most likely to lead to environmental releases of the substances. A more detailed literature search and consultation was then carried out, to research the highest priority emission sources and release pathways for the new POPs in the UK. This work included:

- Consultation with national and international POPs experts, including the environmental regulatory agencies in the UK;
- Consultation with industry-specific contacts such as fire-fighting organisations, pesticide experts;
- Literature search of scientific journals and academic papers, via the British Library;
- Review of available UK emission inventory data for the new POPs within existing data reporting mechanisms such as the IPPC/EPR pollution inventories, and the PRTR dataset;
- Review of available UK emission inventory data for related substances, such as dioxins and furans;
- Review of international emission inventory literature sources, such as emission factor studies on PeCB releases from combustion processes;
- Review of industry-specific studies on fate of materials and treatment of waste streams, for sectors such as: waste water treatment and waste wood.

In the case of PFOS, the study team at Lancaster University has conducted a sampling and analysis study of the Calder and Aire river systems, to monitor PFOS emissions from sewage treatment works. This work was extended to further develop the available UK dataset on PFOS releases to watercourses, to test the correlation between urban density and observed PFOS concentrations, and to provide a cross-reference to the model currently used to report emissions of PFOS to the Environment Agency's Pollution Inventory.

Summary of Study Findings

A number of the nine new POPs are already included within existing UK inventories such as the national atmospheric emissions inventory (NAEI), pollutant release and transfer register (PRTR) and the pollution inventories for regulated processes compiled by the regulators. In general, however, the research has highlighted the scarcity of both international and UK-specific data on the source activities and environmental releases of the new POPs. More data was available for pentachlorobenzene than for the other newly designated POPs. This enabled an inventory to be developed for PeCB, whereas it was not possible to develop a source-specific inventory for the other new POPs.

As required for the new Annex C substance, the study team developed a source-specific emission inventory for releases of pentachlorobenzene to air, land and water from 1990 – 2008, using the NFR (Nomenclature For Reporting) classification scheme.

For the remaining POPs which have been recently added to Annex A and Annex B of the Convention, it has not been possible to derive full source-specific inventories; there is currently insufficient scientific data for these substances (nationally and internationally) on emission sources, emission factors, pollutant concentrations in different environmental media and in many cases the underlying activities that lead to environmental releases. However, initial indicative estimates (that are not source-specific) for UK releases to air, land and water of these new POPs have been developed using the best available data. Emission estimates for 2008 are presented in Table ES1 below. The release estimates presented for all of the new POPs are associated with high uncertainty due to the scarcity of source data.

The report also includes a series of recommendations for Defra to consider in order to establish a programme for improving the data quality for these substances. This would contribute to an international research focus on improving scientific understanding of source releases and environmental fate of these new POPs, through new monitoring, analysis and source-specific research.

The key findings for each of the newly designated POPs are summarised below:

Chlordecone

Chlordecone is a fungicide which has been banned in the UK since 1977. It is likely that chlordecone was not used in the UK prior to 1977, and it has been banned in the UK for over 30 years. There is very limited potential for slight residual levels of chlordecone to be present on treated crops imported to the UK. UK releases of chlordecone are therefore expected to be very low, and would be a low priority for further work.

Alpha and beta HCH

Alpha and beta HCH were important components of the pesticide 'technical HCH', which was widely used in the 1940s. Technical HCH was subsequently phased out and replaced by lindane. This is made up mainly of gamma-HCH, with only trace amounts of alpha and beta HCH. However the production process for lindane was inefficient, and resulted in up to 10 tonnes of waste per tonne of lindane manufactured. This waste is likely to have contained alpha and beta HCH, but the quantities involved are not clear. The sale and use of technical HCH was banned in the UK in 1982, and lindane was banned in 2002.

The main release pathway in the UK for these substances is emissions to air from the past production and use of the pesticide lindane. Other release pathways include:

- Emissions to air of HCH from contaminated soils (particularly the case for beta HCH); and
- Emissions to water from sewage treatment works.

UK environmental releases are estimated to be around 7.4 tonnes of alpha HCH to all media in total per year, and 2.7 tonnes of beta HCH to all media in total per year, with an uncertainty of approximately a factor of 3 in each case.

Lindane

Lindane was an insecticidal product used to treat timber and was also used in specialist shampoos used to treat head lice. Lindane had its peak use in the 1970s, after which; its usage declined until its ban in 2002. The estimated global usage in 1990 was 8,400 tonnes. The main release pathways in the UK for lindane are:

- Emissions to air from historic lindane production and usage; and

- Emissions to land from historic lindane application, notably as a legacy of treated stockpiles of wood (e.g. used in construction, fencing etc.) with an estimated lifespan of 50 years.

It is also likely that there will be additional emissions to air from contaminated soils, and releases to land and possibly groundwater from waste materials consigned to landfill. UK environmental releases of lindane are estimated to be around 26 tonnes per year emitted to all media in total, with an uncertainty of approximately a factor of 3.

Tetra and penta brominated diphenyl ether

Tetra and penta brominated diphenyl ether (BDE) are the two main constituents of commercial pentaBDE. Commercial pentaBDE has been used in the past as a flame retardant additive in plastics and soft furnishings. The manufacture of commercial pentaBDE ceased in Europe in 1997, but demand continued until its use was banned in 2003. Emissions of tetraBDE and pentaBDE are likely to be ongoing, from the use and disposal of goods which may have been treated prior to the ban in 2003, such as carpets, textiles, furnishings and other items. These are likely to continue in use and enter the waste stream for some time.

Estimated emissions of polyBDEs to air, land and water were developed during the course of the project. PolyBDEs may be emitted during use, during disposal, and following disposal of goods containing these chemicals, and may also occur in the environment following degradation of substances such as octa-BDE.

Hexa and hepta brominated diphenyl ether

The hexa and hepta brominated diphenyl ether are components of the commercial OctaBDE product. HexaBDE may also be found in low concentrations in commercial PentaBDE. commercial OctaBDE was banned in 2004, and commercial PentaBDE was banned in 2003. These bans apply to goods marketed in the UK, as well as to goods manufactured in the UK. However, low levels of brominated chemicals could continue to be present in unlabelled recycled plastics. Commercial OctaBDE had more limited applications than the PentaBDE, mainly as a flame retardant in plastic housings used for electrical goods. In the UK, the recycling and disposal of these items has been controlled under the Waste Electrical and Electronic Equipment Regulations since January 2007. In recent years, the main release pathways for these substances are thought to be emissions to air and land from the disposal of products manufactured prior to the ban at WEEE waste handling, storage and disposal sites. It is expected that releases from this source will diminish over time as these items are removed from the UK stock of electrical goods. .

Less data is available to allow an inventory of emissions of higher brominated BDEs to be developed.

Hexabromobiphenyl

Hexabromobiphenyl (HBB) has been used in the past as a flame retardant in a number of plastic applications. UK production ceased in 1977, in common with most other European countries and the USA. However, Germany continued production up until the mid 1980s, and France ceased production in 2000. No further production took place in Europe after 2000. During production, the key emissions were to air and water, with further residual emission to air from in-use goods (for example, due to abrasion resulting in dusts containing HBB). Emissions also take place to air, land and/or water during and after final disposal to landfill. Plastic products treated with HBB are expected to have a lifespan ranging from 5 to 10 years, and consequently there was little HBB in use in the UK by 1990. A separate inventory study found that no HBB emissions were expected for Europe in 2007. There remains a low residual risk of

releases from use and disposal of imported plastic goods, and environmental releases of HBB in the UK in recent years are estimated to be very low (50 kg to landfill; 1 kg to air with an uncertainty factor of approximately 5 in each case). Emissions of HBB are a low priority for further research.

PFOS and its salts

PFOS was manufactured by the 3M Company in Europe as a surfactant for a range of applications. However after concerns were raised with regard to potential long term environmental effects, the company voluntarily ceased manufacture in 2001. Some small scale manufacture of PFOS continued outside Europe after 2001. The main applications for PFOS are dominated by the domestic market, particularly in the use of furniture stain repellent products. It has also been used as a surfactant in a number of fire fighting foams. In the UK, the use of foams containing PFOS was phased out around the time that 3M ceased production. The remaining fire brigade stockpiles of PFOS foams were largely consumed at the Buncefield fuel storage terminal fire in December 2005. It is estimated that approximately 0.5 tonnes of PFOS in industrial firefighting foam was used at the Buncefield incident. Other possible sources include metal plating activities, the use of small quantities of PFOS in semiconductor manufacture, and limited applications in the photographic industry.

The main release pathways to environmental media in the UK are thought to be to water. There are concerns about further formation of PFOS within waste water treatment works. However there is a lack of substantiated data to verify current emission estimates. The present study included a limited sampling and analysis programme for the Calder and Aire rivers, which was designed to verify the modelling methods used by the water industry to estimate emissions from sewage works. The UK estimates for annual emissions to water and land have been revised in this study, with new annual estimates of around 300 - 800 kg PFOS to water and 5 kg PFOS to land.

Pentachlorobenzene

Pentachlorobenzene (PeCB) has no current commercial uses. However, in the past pentachlorobenzene has been present in the following applications:

- used as an elastomer in PCB di-electric fluids
- a contaminant of HCE (hexachloroethane) de-gassing agents used in aluminium manufacture
- a contaminant of the pesticide Quintozene
- a contaminant of the pesticide PCP (pentachlorophenol)
- a contaminant of tetrachloroethene (also known as perchloroethylene or PERC) used in dry cleaning
- a by-product of the production of carbon tetrachloride

There are also a number of diffuse sources of pentachlorobenzene:

- uncontrolled combustion of waste
- accidental fires
- incineration of hazardous and clinical wastes
- combustion of solid fuels – principally coal in domestic grates
- trace residues from emissions of waste water treatment works

Emissions of pentachlorobenzene from a wide range of sources have been estimated for the period 1990 to 2008. Emissions in 1990 were dominated by industrial sources and from the legacy of earlier industrial process sources. The significance of these industrial sources has declined since 1990, and the PeCB emission estimates in the years up to 2008 are dominated by diffuse sources.

Estimated PeCB emissions to air have declined significantly (421 kg in 1990 to 66 kg in 2008) as industrial sources have been phased out. Estimated releases to land are primarily from the disposal of contaminated ash, notably from diffuse waste combustion sources. Water emissions are dominated by waste water treatment works and reflect the residue emissions from the food chain.

UK environmental releases of PeCB in 2008 are estimated to be around 66 kg to air, 388 kg to land and 3 kg to water.

Table ES1 – UK Emission Estimates for the newly designated POPs in 2008

POP	Emission to air (2008)	Emission to land (2008)	Emission to water (2008)	Estimated uncertainty
Chlordecone	Negligible	Negligible	Negligible	
Alpha HCH	7.4 tonnes to all media			Factor of 3
Beta HCH	2.7 tonnes to all media			Factor of 3
Lindane	26 tonnes to all media			Factor of 3
Tetra and PentaBDE	2500 kg	2000 kg	700 kg	Factor of 5
Hexa and HeptaBDE	0.77 kg	no data	no data	Factor of 5
HBB	1.8 kg	no data	<1 gram	Factor of 5
PFOS	0 kg	5 kg	600 kg	Land: Factor of 5 Water: $\pm 40\%$
PeCB*	48 kg	388 kg	3 kg	Air: $\pm 25\%$ Land: $\pm 50\%$ Water: $\pm 100\%$

* data for PeCB is 2009

Recommendations for Further Work

The review of the nine new POPs has identified specific areas where additional work would reduce uncertainty and benefit the overall integrity of the estimates, most notably regarding release estimates to land and water, where POPs data are very scarce.

Table ES2 – Summary of recommendations

Ranked Priority	Substance	Aspect	Proposed approach	Priority
1	PeCB and PBDEs	Emissions of PeCB and PBDEs from waste water treatment works	A focused sampling and analysis campaign covering sewage treatment works in different locations	High
2	PBDEs	Limited data on plastics containing flame retardants in WEEE waste	Periodic consultation with WEEE waste handling companies and trade associations to provide data on quantities of plastic within WEEE waste; proportion containing flame	High

Ranked Priority	Substance	Aspect	Proposed approach	Priority
			retardants; means of disposal or export and storage prior to disposal.	
3	All new POPs	Limited data on presence of newly designated POPs in specific industrial waste streams	Targeted sampling and analysis programme for specific waste streams, designed to provide compositional analysis on materials such as: APC residues, boiler ash and bottom ash residues, domestic combustion grate ash, open burning ash residues, industrial slags and skimmings, and industry-specific effluent streams such as textile finishing processes, plastics manufacturing processes and flame retardant application processes	High
4	PeCB	Reporting threshold for PeCB in the E-PRTR is relatively high, making it less useful as a data source	Lobby EEA to reduce reporting threshold for PeCB in the E-PRTR	High
5	All new POPs	Drawing on current research to maintain and improve inventories	Maintain watching brief on UNEP and EU working groups	High
6	PeCB	Review of potential sources not included in the current inventory	Desk-based review of potential for emissions of PeCB from metals processes to establish whether more detailed assessment is needed	High
7	All new POPs	Potential to extend Water Framework Directive procedures to cover new POPs	Lobby EC to co-ordinate WFD requirements with Stockholm Convention obligations	High
8	All new POPs	Potential to extend OSPAR convention procedures to cover new POPs	Lobby OSPAR secretariat to co-ordinate convention requirements with Stockholm Convention obligations	High
9	All new POPs	Unreliable data on past disposal of hazardous wastes potentially containing POPs	Review availability of historical data on disposal of hazardous wastes	High
10	PeCB	Uncertainty in emissions to all media of PeCB from domestic combustion sources	Laboratory studies to improve understanding of emissions from domestic waste combustion (including air and ashes). This should consider a range of fuel types and combustion conditions. Surveys to improve estimates of the amounts of materials burnt	High

Ranked Priority	Substance	Aspect	Proposed approach	Priority
11	PFOS	Improvement of estimates of PFOS from sewage works	Sampling and analysis of effluent and sludges in the water treatment industry to determine PFOS levels.	Medium
12	PBDEs	Limited data on levels of PBDE in plastics	Sampling and analysis of a cross-section of UK electrical goods (domestic production and imported goods) to assess the PBDE content	Medium
13	PBDEs	Potential exposure to PBDEs in the home, workplace and in vehicles	Measurement survey of PBDE congeners within dust samples in a range of environments. Design survey to investigate potential significance of degradation pathways	Medium
14	PeCB	Further analysis of potentially significant sources	Measurement of emissions from accidental fires; industrial coal combustion; waste incineration facilities; residential coal and treated wood combustion; dry cleaning; disposal of WEEE; landfill gas	Medium
15	PeCB, PBDEs	Airborne measurements to support emissions estimates and verify emissions reductions achieved	Extend coverage of existing TOMPs network to include newly designated POPs, focusing as a first priority on PeCB and PBDEs	Medium
16	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from historic disposal of products/materials containing HCH	Measurements of HCH in landfill gas and leachate from a sample of relevant landfill sites	Medium
17	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from historic disposal of manufacturing waste	Measurements of HCH in landfill gas and leachate from a sample of relevant landfill sites	Medium
18	PBDEs	Potential emissions of PBDEs from WEEE processing facilities	Measurement survey of PBDE congeners within dust samples from a range of sources within stored items. Concurrent air and soil sampling at the processing facility.	Medium
19	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from re-use of waste wood	Extend existing waste wood survey to include measurement of HCH content of wood samples and rate of phase-out	Medium
20	Alpha-HCH Beta-HCH Lindane	Unintentional emissions of HCH from metalworking processes	Measurements of HCH in workplace air and emissions to air and water from relevant processes	Medium
21	PeCB	Limited data on waste from dry cleaning sector	Annual request for data from contractors serving dry cleaning industry	Medium
22	All new POPs	Limited data on emissions and wastes generated at Part B/C processes	Development of a scheme for reporting activity and emissions from Part B processes (and Part C processes in Northern Ireland).	Low

Ranked Priority	Substance	Aspect	Proposed approach	Priority
23	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from ongoing use of materials containing HCH	Measurements of HCH in samples of treated materials and in nearby soils and waters	Low
24	PFOS	Potential significance of degradation pathways in determining environmental levels and exposure to PFOS	Environmental monitoring survey, forming part of wider international research initiatives	Low
25	HBB	Verification of emissions of HBB from processing end-of-life vehicles	Measurement survey at a sample of representative end-of-life vehicle processing facilities	Low
26	HBB	Verification of emissions of HBB from landfill sites	Measurement survey of landfill leachate and landfill gas at a sample of representative landfill sites	Low
27	HBB	Verification of emissions of HBB from processing WEEE	Measurement survey at a sample of representative WEEE processing facilities	Low
28	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from past use of HCH in agriculture	Measurements of HCH in soils and ambient air	Low

Part one table of contents

1	Introduction.....	3
2	Dust (Air Pollution Control (APC) Residue) and ash from hazardous and clinical waste incineration.....	5
3	Dust (Air Pollution Control (APC) residues) from the smelting of non-ferrous metals	16
4	Working concentrations of HCB within pesticide products.....	22
4.1	Sampling and analysis regime	23
4.2	Results and inventory update.....	23
5	Emissions from wastewater treatment works.....	27
5.1	Concentrations of the established POPs in sewage sludges.....	27
5.2	Estimate of POPs emissions to controlled water which fall below the reporting threshold for the UK pollution inventories	37
6	Review of Public waste burning habits	44
6.1	Development of survey requirements and target groups	44
6.2	Qualitative interviews	46
6.3	Quantitative Survey	47
6.4	Results of the Qualitative and Quantitative Surveys.....	47
6.5	Summary and Recommendations for inventory update.....	53

ANNEXES

Annex I – References

Annex II – Tables of improvements

Annex III – Waste burning habits questionnaire

Annex IV – Results of the public survey into waste burning habits

Part two table of contents

1	Introduction.....	1
1.1	Policy background	1
1.2	Objectives.....	3
1.3	Report Structure	4
2	Methodology	5
2.1	Review of uses and releases of the nine new POPs	7
2.2	Review of monitored emissions and update of existing emission factors	8
2.3	Establish new emission factors	9
3	Emissions Inventory for newly designated POPs	11
3.1	Introduction.....	11
3.2	Alpha, beta and gamma hexachlorocyclohexane (Lindane)	11
3.3	Pentachlorobenzene	16
3.4	Hexabromobiphenyl.....	39
3.5	Polybrominated diphenyl ethers (PBDEs): Tetra, Penta, Hexa and Hepta Brominated Diphenyl Ether	41
3.6	PFOS and its salts	48
4	POPs data sources and inventory improvement.....	57
4.1	UK POPs inventory data management systems.....	57
4.2	Scope of work for monitoring land and water emissions.....	66
4.3	Summary	69
5	Conclusions	71
5.1	Overview.....	71
5.2	Individual POPs	71
5.3	Emissions inventory summary	74
5.4	Recommendations.....	74

Appendices

Appendix 1: Glossary and Abbreviations

Appendix 2: Summary tables for Pentachlorobenzene

Part One:

Further improvement for Emission inventories to air, land and water for dioxins and furans, polychlorinated biphenyls, dioxin-like polychlorinated biphenyls and Hexachlorobenzene

Part one table of contents

1	Introduction.....	3
2	Dust (Air Pollution Control (APC) Residue) and ash from hazardous and clinical waste incineration.....	5
3	Dust (Air Pollution Control (APC) residues) from the smelting of non-ferrous metals	16
4	Working concentrations of HCB within pesticide products.....	22
4.1	Sampling and analysis regime	23
4.2	Results and inventory update.....	23
5	Emissions from wastewater treatment works.....	27
5.1	Concentrations of the established POPs in sewage sludges.....	27
5.2	Estimate of POPs emissions to controlled water which fall below the reporting threshold for the UK pollution inventories	37
6	Review of Public waste burning habits	44
6.1	Development of survey requirements and target groups	44
6.2	Qualitative interviews	46
6.3	Quantitative Survey	47
6.4	Results of the Qualitative and Quantitative Surveys.....	47
6.5	Summary and Recommendations for inventory update.....	53

ANNEXES

Annex I – References

Annex II – Tables of improvements

Annex III – Waste burning habits questionnaire

Annex IV – Results of the public survey into waste burning habits

1 Introduction

The UNEP Stockholm Convention on Persistent Organic Pollutants (POPs) places a requirement on ratified Member States to derive emission release inventories for the Annex C substances to air, land, residue, water and product. Until the formal addition of nine new POPs to the annexes in August 2010, the Annex C substances included dioxins and furans, hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs). The EU POPs regulation EC850/2004 also places requirements on EU Member States to derive emission release inventories, based on the EU's role as signatory to the Stockholm Convention. This covers the same substances to the same vectors with the key difference being the inclusion of 'dioxin-like' PCBs for the non-ortho and mono-ortho PCB congeners in Regulation EC 850/2004.

The development of such emission release inventories is intended to help the Member States when developing their action plans, which then form part of a larger document called a National Implementation Plan (NIP), used to communicate not only to the Stockholm Convention but the other Member States on how POPs will be managed and emissions reduced within their country.

The development of such emission release inventories are also intended to help track emission trends and development of sources over time, publication of these inventories through the Convention is intended to promote knowledge sharing and understanding between the Member States. The Stockholm Convention gathers the data for emission releases for each year, on a four year cycle. The first submission round for release inventories was in 2006, and the UK submission at that time was based on the data taken from the UK NAEI (National Atmospheric Emissions Inventory) with emissions data to one vector – air.

In the summer of 2007 a program of work began to take the data from the NAEI and expand it to cover other vectors. This program of work was completed in the summer of 2009 after an extensive body of work to look at the existing activity data, emission factors, monitoring, academic research and other inventories. The completed inventory program provided full emission release inventories by source for dioxins and furans, HCB, PCB (total) and dioxin-like PCB for 1990 – 2006 and spanning three vectors, air, land (total) and water. The land vector in this case is assumed to be all releases to land of which the bulk will be assumed to be landfill. Note that the direct release of POPs to land from industry is actually illegal in the UK. This body of work was then used to inform the second round of Stockholm Convention reporting in 2010.

The final stage in completion of the UK POPs multi-vector inventory was a review of all data and sources in order to identify where the uncertainty in the estimates were at their highest. Recommendations were then made on how the inventory could be further improved and evolved to reduce these uncertainties in order to give greater confidence in the inventory and assist in planning for the updated POPs action plan due in August 2012.

From December 2009, the improvement plan was implemented in earnest. This comprised a series of activities including stakeholder communication with industry, surveying of the general public at national level, sampling and analysis for given sectors, and further review of the available emission inventory data in order to update the POPs multi-vector inventory for the inventory years 2007, 2008 and 2009 as well as to improve estimates for the areas with highest uncertainty. This project also included development of emission release inventories wherever possible and appropriate for the nine new POPs added to the Convention annexes in May 2009 (discussed in part 2 of this report).

This report is therefore intended to inform on the work carried out in relation to the improvement program and new emission release inventories for the UK POPs multi-vector inventory. This part of the report focuses on the improvement program, and covers the following activities:

- ▶ Dust (Air Pollution Control (APC) Residues) and ash from hazardous and clinical waste incineration
- ▶ Dust (APC residues) from the smelting of non-ferrous metals
- ▶ Working concentrations of HCB within pesticide products
- ▶ Concentrations of the established POPs in sewage sludges
- ▶ Estimate of POPs emissions to controlled water which fall below the reporting threshold for the UK pollution inventories
- ▶ Review of the UK waste burning habits to improve estimates for open burning in households and bonfires.

A full set of tables for improvement of the emission estimates is given in annex II of this report.

2 Dust (Air Pollution Control (APC) Residue) and ash from hazardous and clinical waste incineration

The multi-vector inventory compiled by AEA on behalf of Defra (2009) recognised that an important issue for emissions to land (largely as landfill) was the generation of ash and dust from sources other than large-scale power production. In particular, incineration of hazardous wastes and clinical waste, which is likely to have a high plastic content and potential for dioxin and furan generation, were identified as potentially key issues.

The original multi-vector inventory was largely based around estimates of dust generation against default emission factors, primarily from the UNEP toolkit for dioxins and furans, and non-UK literature references for PCBs. Therefore, the recommendations made at the end of the original inventory compilation identified a genuine need to update this aspect of the inventory with particular regard to ash and dust generation in order to provide UK data on:

- Quantities of ash produced,
- Processes
- Contamination levels
- Final destination

Typically the plants operated within the incineration sectors fall within environmental permitting category A1 and will therefore be facilities regulated by the UK Environment Agencies. The methodology for the current project therefore centered on communication with the permit officers at the UK Environment Agencies as well as direct communication with the operators themselves with the aim of gathering data from the operator level in order to improve upon the current estimates.

Hazardous waste incineration

Hazardous waste incineration within the terminology used for the NAEI and POPs inventories covers a range of incineration processes used to dispose of hazardous wastes. Only a small number of facilities exist which broadly cover the following operations:

- Commercial incineration facilities – solely dealing with disposal of hazardous wastes
- In-house incineration facilities – used to deal with waste generated on-site from production processes
- Recovery processes – used to retrieve valuable materials (usually metals) from contaminated waste
- Drum reconditioning – used to destroy any surface contamination by residues on the drum materials
- Thermal oxidisers – used to dispose of hazardous liquid or gaseous wastes, and hence unlikely to generate ash
- Specialist operations – dealing with specific waste streams such as radioactive contaminated wastes.

The range of 'sub-sectors' within the hazardous waste incineration sector will behave differently and have different drivers that affect the amount of ash produced. This in turn affects the overall total ash generation for the UK. Within the NAEI, emissions factors are calculated based on the quoted emissions and assumed activity data. The activity data is based on the UK pollution inventories, permitted capacity under the environmental permits and estimates made by AEA for assumed combustion rates where gaps exist in the data.

The POPs inventory for emissions to land has made use of the same approach for activity data to maintain consistency with the approach adopted in the NAEI. The emissions to land as 'landfill' have been based on literature emission factors for dioxins and furans and PCBs. The UNEP toolkit provides default emission factors for dioxins and furans as shown in table 2.1 (this is for fly-ash concentrations only). Alongside this, reviews by Dyke (1997)¹ and LUA (1999)² quote emission factor ranges of between 0.02 – 6.8 µg I-TEQ dioxins and furans/t burned for all residues generated. On this basis the POPs inventory makes use of the tier 3 UNEP³ figure for 1990, and then a derived value of 15 µg I-TEQ/t (half-way between UNEP tier 4 and upper bound of Dyke and LUA) for 2006, assuming a linear regression between 1990 – 2006.

For PCB emissions, the POPs inventory makes use of an ash generation factor from UNEP (assumed to be 3% of pre-combustion weight resulting as fly ash), and an emission factor from BIPRO⁴, which is quoted as 0.1 mg/kg of ash, and used as a static emission factor across all years.

Table 2.1 UNEP default factors for hazardous waste combustion

Tier	Description	µg ITEQ dioxins and furans / tonne of hazardous waste combusted (fly ash only)
Tier 1	Low technology, no APCS (Air Pollution Control System)	9000
Tier 2	Controlled combustion, minimal APCS	900
Tier 3	Controlled combustion good APCS	450
Tier 4	High technology combustion, sophisticated APCS	30

The use of these defaults and assumed capacity as activity highlights the need for the current program of work to refine the estimates and provide a truer picture of the UK industry. The current project has carried out a consultation process with UK industry as well as the Environment Agency officers to retrieve environmental permit data. We have also reviewed data produced by the Environment Agency⁵ which provides details of actual combustion rates for 2006, 2007, 2008 and 2009.

Initially the project began by identifying the previously assumed IPPC category A1 plants within the UK as detailed within table 2.2. However, the industry is dynamic with the potential for company mergers and closures since the time the permit was taken out. Further research was therefore carried out to ascertain which sites were still live and to whom they belonged.

Table 2.2 – Original list of UK IPPC A1 facilities for hazardous waste incineration.

Operator	Location
Dascern Europe Limited	Peterlee
Mountstar Metal Corp.	Machynlleth
BIP Ltd	Oldbury
Degussa Knottingley	Knottingley
Laporte Ltd	Seal Sands
Cleanaway Ltd	Ellesmere Port
Ineos Chlor	Runcorn
Magnox Electric plc	Dungeness A
Veolia Onyx	Hythe
British Energy Gen.	Hartlepool
British Nuclear Fuels	Capenhurst
Solvent Resource Management	Rye
Qinteq Ltd	Southend
Pyros Environmental A	Hardley
Pyros Environmental B	Hardley
Fine Organics	Middlesbrough
Pack2Pack Ltd	Avonmouth

Table 2.3 shows the updated list of facilities together with details of the nature of the operation and tonnage of waste processed based on the Environment Agency data. This notes the removal of two named facilities (the site for Laporte Ltd, Seal Sands has since become Fine Organics (already listed), and the site for Veolia Onyx, Hythe is now owned by Pyros (already listed). These sites were removed to avoid a double count), while a further three plants (JBR recovery, Robinson Brothers, and Solvent Resource Management (BL7302ID)) were added, based on the 2009 Environment Agency data.

In a number of cases the named facilities have closed in recent years. Based on the review carried out, these are as follows:

- Dascern Europe – closed 2008
- BIP Ltd – Closed mid-2008
- Degussa – Closed 2007
- Ineos – Ceased incinerator activity end of 2008
- British Nuclear Fuels – Ceased incinerator activity 2007
- Fine Organics – Operation ceased 2007, but was expected to begin again at end of 2010
- Tradebe (formerly Pyros) HP3835UZ (60,000t capacity) – closed mid-2009

These closures have reduced UK hazardous waste incineration capacity by approximately 90 kt per annum.

Communication was carried out with two hazardous waste incinerator operators which have helped define the typical process and waste generation outputs. One facility was reported as generating approximately 0.1% of the waste input tonnage as hazardous waste. This is re-introduced into the combustion processes along with granulated slag to produce a crystalline slag product for use as aggregate in the cement and concrete industry. This process means that there is no waste stream to landfill from this facility. The slag product was described as being non-hazardous, as the low concentrations of POPs present would be trapped within the cement matrix.

The operator of the second facility indicated that the process generates approximately 17% of the waste input tonnage as slag, and 7% of the waste received as APC residues. Chemical analysis data was provided for these materials.

Communication with two of the drum reconditioning facility operators indicated that no bottom ash was generated from these processes. Some air pollution control (APC) residue was generated: this is likely to have similar concentrations to that seen for fly ash. The nature of the process means that incinerator equipment is used to destroy surface contamination from the drums, but the plant itself does not operate in the sense of a waste disposal outlet. A third drum reconditioning plant operator (British Energy Generation) was not contacted due to the small size of the operation (permit is for 72 tonnes per annum) and lack of data in the Environment Agency list⁵.

Communication with one further specialist incinerator stated that their process was used principally to recover silver and lead from contaminated wastes. The residues generated including fly-ash are returned to the combustion process with granulated slag to produce a crystalline blast furnace slag, which is then consigned to the cement and concrete industry as an aggregate. Environment Agency data quotes the quantity of waste generated as 4721 tonnes in 2008. It is assumed that the quantity quoted is the slag produced which is then used in the cement and concrete industry. No waste was consigned to landfill.

Table 2.3 Details of hazardous waste incineration plants within the UK.

Hazardous Waste Incinerators						
IPPC reference	Company name	Location	Capacity in tonnes (based on IPPC permit)	Tonnage incinerated 2009 (EA data)	Nature of operation	Update
BQ2138IC	Dascern Europe Limited	Peterlee	600	-	Halon gases – disposal	Closed
BL1126ID	Mountstar Metal Corp.	Machynlleth	2500	*	Drum reconditioning	Data received
BT5075IW	BIP Ltd	Oldbury	1575	-	Thermal oxidiser for liquid wastes	Closed
BU70086IV	Degussa Knottingley	Knottingley	3000	-	In-house facility	Closed
BS5193IE	Veolia (formerly Cleanaway Ltd)	Ellesmere Port	100,000	85,000	Commercial Incinerator	Data received
BS5428IP	Ineos Chlor	Runcorn	345	-	In-house facility	Closed
BX6286IT	Magnox Electric plc	Dungeness A	290	-	Radioactive disposal	Not contacted*
BM4295IK	British Energy Gen.	Hartlepool	72	-	Drum reconditioning	Not contacted*
BX2381IR	British Nuclear Fuels	Capenhurst	1018	-	Radioactive disposal	Closed
GP3437PL	Solvent Resource Management	Rye	31,250	827	Thermal oxidiser for liquid wastes (solvents)	No Response – permit only
BL7302ID	Solvent Resource Management	West Brom	15,000	1065	Thermal oxidiser for liquid wastes (solvents)	No Response – permit only

FP3131SF	Qinteq Ltd	Southend	3000	-	Explosives disposal	Not contacted*
HP3835UZ	Tradebe (Formerly Pyros Environmental A)	Hardley	60,000	5105*	Commercial Incinerator	Data received
TP3935UL	Tradebe (Formerly Pyros Environmental B)	Hardley	45,000	26775	Commercial Incinerator	Data received
PP3439GG	Fine Organics	Middlesbrough	23,600	-	In-house facility	Closed
QP3638UP	Pack2Pack Ltd	Avonmouth	8000	6116	Drum reconditioning	Data received
BJ9878IQ	JBR Recovery	West Brom	4800	3573	Metal recovery	Data received
BS4316IV	Robinson Brothers	West Brom	6880	2623	In-house facility	Data received
Total UK Capacity (Kt)			307	131	2008 UK total incineration (kt)	

* Data not required as no ash generated. **From communication with Tradebe

Two further 'specialist' operations have not been contacted within the bounds of the current study. Qineteq operates a specialist incineration facility used to dispose of explosive ordinance materials. The permit provides for a capacity of 3000 tonnes per annum. The combustion rates in this case are likely to vary greatly from year to year and are not expected to reach levels near capacity, based on AEA knowledge of a similar facility run by DSTL which is also used for ordinance disposal. No combustion rate data is given for the Qineteq facility by the Environment Agency for 2006-2009. Secondly, a facility, operated by Magnox is used to dispose of waste which has been contaminated by radioactive materials, again in this case the permit (290 tonnes per annum) is for a small quantity of material and combustion rates are not listed within the EA data.

AEA also contacted Solvent Resource Management which operates two facilities. It was not possible to get monitoring data for these facilities. The IPPC environmental permits indicate that the nature of these operations is essentially the generation of bio-diesels from solvent recovery. The operation handles liquid residues rather than solid materials, and consequently the generation of bottom ash is unlikely. Any solid waste residues created from this operation will more likely be APC residue, which again is likely to have concentrations similar to that of fly ash. The EA data provides details of waste residues generated from both plants operated by Solvent Resource Management.

Recommendations and review of inventory

Activity data

The 2009 NAEI compilation cycle saw a review and adjustment of the incineration sector to update information on IPPC permits and classification of specific operators. 2009 activity data within this cycle for hazardous waste incineration identified total combustion rates of 124 kt hazardous waste, similar to the EA data which quoted 131 kt. As has been noted in this section, the range of sub-sectors under review has different processes which will affect the outputs. Two commercial operators do not generate waste which goes to landfill, and a further four do not generate bottom ash.

Communication with the industry about standard process and approach suggested that typical ash generation rates for hazardous incineration were 4.6% for bottom ash and 2.2% for fly ash. Taking into account these factors, it is estimated that (based on 124kt of incinerated waste) approximately, 5700 tonnes of bottom ash and 2830 tonnes of APC residue (as fly ash) were generated in 2009.

Emission factors

The monitored data gathered covers only dioxins and furans, no data was made available for PCB concentrations in waste residues and ash from the processes under review. Emission factors range from 1.4 – 63 µg I-TEQ dioxins and furans/tonne residue for APC residues and 0.38 – 0.94 µg I-TEQ dioxins and furans /tonne of bottom ash. The factor currently used (15 µg I-TEQ/t) is based on tonnes of material combusted, rather than tonnes of ash generated, so a direct comparison is not possible. However, the factor is applied to all materials combusted, and does not distinguish between dioxins and furans in APC residues and those in bottom ash. The new data confirms that there is likely to be a significant difference between concentrations in APC residues and bottom ash. The different disposal routes for APC residue and bottom ash means this difference in concentrations will likely have a significant effect on the emission estimates

Therefore for 2009, assuming a worst case scenario and using the upper limits of these ranges, UK total concentrations in waste were estimated to be 0.18 g I-TEQ from fly ash and 0.005 g I-TEQ from bottom ash, which would then be consigned to landfill. Using the Dyke/LUA^{1,2} emission factor (15 µg I-TEQ/t of combusted material) on the 2009 EA data

(excluding sites that do not generate waste to landfill) would equate to a total emission of 0.64 g I-TEQ to landfill.

This gives an estimate of emissions to landfill of between 0.18 – 0.64 g I-TEQ from APC residues and bottom ash in the hazardous waste incineration sector for 2009.

Based on the communication with industry and review of data, the recommendations for inventory improvement are:

- Use of EA data (2006-2009) to help improve estimates in earlier inventory years which are based on IPPC permit capacities
- Wherever possible to base estimates on ash and APC residue separately (Bottom ash is produced in greater quantities but with lower concentrations); rather than total quantities combusted
- Make use of ash generation values derived from operator data where appropriate to scale activity values for land emissions
- Tailored approach to emission estimates for land, noting processes which do not generate bottom ash or waste that goes to landfill.

Clinical Waste Incineration

Clinical waste incineration within the context of the NAEI and POPs inventory refers to the destruction of medical waste by incineration. The nature of the waste includes a variety of materials, particularly contaminated plastics and PVC based materials which are potentially a concern for the generation of POPs.

The current NAEI inventory includes estimates for emissions to air from this sector based on the UK pollution inventories, capacities of IPPC permitted facilities, and AEA estimates (where data gaps exist) to derive activity data in a similar fashion to the hazardous waste sector. The POPs inventory uses the same activity data to maintain continuity with the NAEI. The emission factors used are currently based on derived literature values and cross-matched to other sources.

The UNEP toolkit³ quotes default emission factors for dioxins and furans of 920 and 150 µg I-TEQ per tonne combusted, based on total ash (fly ash and bottom ash combined). The emission factor is dependent on the level of abatement at the facility. The current emission factor used is between these values (450 µg I-TEQ/t – equivalent to tier 3 hazardous waste incineration). The factor was chosen in the absence of better data due to a lack of UK information on the quantities of fly ash and bottom ash generated from this sector.

The PCB emission factor was matched to that used for hazardous waste incineration (0.1 mg/kg ash); from the same reference source (BIPRO)⁴ to keep continuity between sectors. This approach was adopted on the basis that the generation of PCB from hazardous waste incineration is likely to be governed by similar processes to the generation of PCBs from clinical waste incineration. This is likely to be linked to the chlorine content of clinical wastes, particularly from PVC based plastics.

A review of other literature carried out during the completion of the original multi-vector emission inventory identified factors by Dyke 1997¹ and LUA 1999², which quote emission factors for bottom ash between 2.25 – 45 µg I-TEQ/ t of ash, and fly ash as 144 – 360 µg I-TEQ / t of ash. This is specific to the clinical waste incineration sector.

The current project has involved direct consultation with the operators within the clinical waste incineration sector. The list of key companies and sites is set out in Table 2.4. One further site, Compact Power, Bristol was omitted early in the project as it closed at the end of

2008. AEA has been successful in obtaining data from three operators on the generation of bottom ash, fly ash and some limited monitoring data of ash from combustion of these wastes. In the case of the clinical waste, the aim had been to secure data from SRCL Ltd who operates approximately 45% of all UK plants, but this has proved not possible. The data quoted within Table 2.4 (taken from the Environment Agency waste data⁵) shows that clinical waste incinerators work more closely to the permit capacity levels than the hazardous waste incineration sector, an observation corroborated by the information from the three operators that supplied data. The activity data within the NAEI and Environment Agency waste list also show good compatibility to data supplied.

Table 2.4 Environmental (IPPC) permitted clinical waste incineration facilities (Environment Agency, 2009)

Operator	Permit number	Location	Capacity (tonnes per year)	Tonnage incinerated in 2009
Defra	AP3039SD	New Haw, Surrey	5200	929
Polka Crest	AP3538SM	Wrexham	6000	5552
Grundon	BT2866IG	Colnbrook	10000	6145
SRCL	EP3530XY	Ipswich	8500	7474
SRCL	FP3634SL	Nottingham	6500	5705
Medical Energy	JP3235SB	Alexandra Hospital,	10000	8650
Clinical Energy	KP3530BU	Hillingdon Hospital	8000	7492
SRCL	KP3738SA	Royal Bournemouth hospital	8000	12381
Ethos	LP3432XX	Bristol	8000	1644
SRCL	NP3630XK	Pontefract	4500	3814
SRCL	RP3538SY	Ashford, Kent	8500	6612
SRCL	RP3938SU	Queen Mary's Hospital, Sidcup	8000	6890
HPA	SP3934SJ	Wiltshire	312	70
Viridor	VP3734SY	Derriford hospital	4270	3342
Cambridgeshire Hospital Trust	WP3935SM	Cambridgeshire Hospital Trust	4500	3371
SRCL	XP3838ST	Knostrop, Leeds	17,000	16,519
Royal Wolverhampton Hospital Trust	YP3634SJ	Royal Wolverhampton Hospital Trust	2500	1368
Peake Ltd	YP3934SM	Pengover, Cornwall	5241	3730
SRCL	ZP3233BD	Bolton	6000	5457
North West Energy	ZP3433BP	Salford	8000	7148
SRCL	ZP3633BM	Oldham	6570	5935
Total			221,000	127,000

The data from three plant operators provides a breakdown for fly ash and bottom ash allowing ash generation factors to be developed. The results are shown in Table 2.5 and provide a variable picture in terms of ash generation rates and the fly ash – bottom ash ratio between sites.

The UNEP toolkit (2005)³ quotes an estimated ash generation rate of 3% wt/wt. Based on the combustion rates from table 2.4 and review of the Pollution Inventory records⁶ for the industry suggests that the ash production between plants is highly variable. Based on 2008 data, this report suggests that an industry average rate for generation of ash is closer to 19% wt/wt ash generation, which would equate to 24,000 tonnes ash generated in 2009. Based

on the average from consultation with three UK plants in table 2.5 is 23% wt/wt, which is broadly in line with the pollution inventory.

The ratio of fly ash to bottom ash also varies. The industry standard data⁶ quotes a roughly 50:50 split between bottom ash and fly ash, which is consistent with the information provided by one of the operators. The data from a second operator more closely reflects the ratios seen in the hazardous waste sector (the data from one hazardous waste operator has been included in table 2.5 as an example of the hazardous waste sector). The average of the three sites indicates a bottom ash: fly ash ratio of 45:55. However in view of the variation between different plants, we recommend adopting a 50:50 ratio where no specific data are available.

Table 2.5 Ash generation values based on submitted data from UK incineration facilities

Operator	Quantity of waste combusted to generate 1 tonne of bottom ash	Quantity of waste combusted to generate 1 tonne of fly ash
Operator 1	11	8
Operator 2	6.5	18
Operator 3	14*	14*
Average of three operators	10.5	13
Hazardous waste (for comparison)	6	15

* Operator 3 data is given as a three year average 2008 - 2010

Based on 127 kt of clinical waste incinerated, this indicates that approximately 12.2 kt of bottom ash, and 12.2 kt of fly ash are generated per year. Two operators stated that all waste goes to landfill. Monitoring of the ash by one of the three operators enabled emission factors to be derived of 74 µg I-TEQ/t of waste burned for dioxins and furans and 21 µg/tonne of waste burned for PCBs

The current estimates for dioxin and furan emissions are based on the UNEP toolkit tier 3 level (hazardous waste incineration)³, which quotes an emission factor of 450 µg I-TEQ/tonne of waste burned. As a review of this, Dyke (1997)¹ and LUA (1999)² quoted emission factors by waste type (bottom ash and fly ash) generated by the clinical waste incineration sector. Tables 2.6 and 2.7 show two alternate methods to estimate dioxin and furan concentrations in the ash generated by the clinical sector based on the Environment Agency 2009 data⁵.

Table 2.6 Method 1 – estimated dioxin and furan emissions for 2009 based on Dyke and LUA data

Parameter	Ash stream	Minimum value	Maximum value
Mass produced	Bottom ash	12.2 kt	
	Fly ash	12.2 kt	
Dioxin and furan level in ash stream	Bottom ash	2.25 µg I-TEQ/t of ash	45 µg I-TEQ/t ash
	Fly ash	144 µg I-TEQ/t ash	360 µg I-TEQ/t ash
Total emission of dioxins and furans	Bottom ash	0.027 g ITEQ	0.55 g ITEQ
	Fly ash	1.75 g ITEQ	4.39 g ITEQ
	Total	1.77 g ITEQ	4.94 g ITEQ

Table 2.7 Method 2 – assumed dioxin and furan emissions for 2009 based on UNEP and operator data

Parameter	Emission factors	Emissions based on 127 kT clinical waste
UNEP – tier 3 emission factor	450 µg I-TEQ/t of waste	57 g I-TEQ
Operator data	74 µg I-TEQ/t of waste	9.4 g I-TEQ

The first method provides an annual emission estimate for the UK of between 1.77 – 4.94 g I-TEQ, and the second method between 9.38 – 57.15 g I-TEQ. Again, the sector shows a high level of variability in the generation of ash and likely concentrations of dioxins and furans found within them. The operator data (total UK emission 9.38 g I-TEQ) represents the most up to date data from monitoring of ash in 2009. Our recommendation is to adopt the emission factor from the current round of monitoring data with the understanding that uncertainty would be high as the sector is variable.

The monitoring data also provides a new emission factor for the PCB emissions to replace the current estimate of 0.1 mg/kg of ash. The monitoring data indicates a new value of 0.003 mg/kg of ash, which would be more representative of a UK plant in 2009. The existing factor for PCB emissions to landfill would be 0.39 kg of PCB, whereas the new data would give a value of 0.01 kg of PCB in waste to landfill.

3 Dust (Air Pollution Control (APC) residues) from the smelting of non-ferrous metals

The non-ferrous metal sector was identified within the original multi-vector inventory as a potential key source, particularly for emissions that ended up in landfill. The secondary manufacture of metal from scrap with surface contamination has the potential to generate dioxins and furans. There was also the issue of secondary copper manufacture where the copper element could act as a catalyst for de novo formation of dioxins and furans within the filter dust from air pollution control residues.

The non-ferrous metal sector is more diverse than incineration, with greater variation in the process operations and also in terms of the size of plants in operation, which will affect the environmental permitting (parts A1, A2 and B respectively), and hence information is held by a number of agencies (Environment Agencies / Local Authority). The current project has aimed at gathering further information on production rates, generation of dust (as air pollution control residue), monitoring of such materials for POPs (principally dioxins and furans) and final destination of the waste.

Initial discussions with the trade associations listed in table 3.1 provided only a study conducted on behalf of the galvanizing association by Lancaster Environment Centre (LEC). The LEC study⁷ into dioxin and furan concentrations in galvanizing waste carried out in 2003 looked to characterise the industry. The study collected and analysed 19 samples of APC (Air Pollution Control – Bag filters) residue from the galvanizing hot-dip facilities, which was then analysed using high resolution gas chromatography. The results show dioxin and furan concentrations ranging between 62 – 13,000 ng I-TEQ/kg with the majority above 1000 ng I-TEQ/kg of APC residue. The study also quotes research in Germany which found concentrations in the order of 2000 – 9600 ng I-TEQ/kg. This suggests that the galvanizing sector should also be included within the POPs inventories for generation of such solid wastes.

Table 3.1 list of trade associations contacted

Trade Association	Sub-sector
ILA – International Lead Association	Lead Manufacture
LSA – Lead Sheet Association	Lead Manufacture
CDA – Copper Development Association	Copper Manufacture
ALFED – Aluminium Federation	Aluminium Manufacture

The inventory compilation for this sector faced two key issues. Firstly, a need for a better means of estimating the generation of dusts and concentration of POPs (likely dioxins and furans) by differing non-ferrous metal industries is needed. Secondly, information on the size and nature of the industry is needed at the smaller part B (environmental permit) end of the scale, where the activities are less well documented. The review of the available data in this case has found that the part B information held by local authorities is largely held as hard-copy within reference stores only available to view in person. Only Walsall Metropolitan Borough Council provided evidence on the numbers of part A2 and part B processes. Emissions from Part A2 processes are also reported to the PRTR database.

Initially the project carried out a consultation process with the largest operators of the A1 size facilities directly in order to gather data for 2009 and 2010 on production rates, waste generation, dioxins and furans concentration and end destination for the waste. This was compared to the data from the IPPC permits (which give an indication of capacity – use for

gauging earlier years), Mineral Yearbook⁸ (provides UK totals on non-ferrous metal production), BREF note for non-ferrous metals⁹ (which details the likely process technology and emission sources) and existing literature used to calculate the inventories.

The discussion of the results is given for each individual sector below.

Aluminium

The Aluminium sector is split into processes that make use of primary aluminium (virgin metal) and secondary aluminium (scrap metal) which will include recycling processes, such as those used for recycling of aluminium drinks cans. Historically both primary and secondary processes had the potential to generate emissions of dioxins and furans. In the primary process emissions originated from anode baking, whereas in the secondary process emissions originate from surface contamination or surface treatments of scrap metals. In modern operations however, the primary aluminium process is no longer a source of dioxins and furans due to changing process design.

The secondary manufacture of aluminium is therefore the key area of industry we have reviewed. The assumed production from the NAEI is 630,000 tonnes per year based on IPPC capacity rates. The A1 group of operators comprises the 12 plants listed in table 3.2. The rate of responses from the industry covers five operators with a combined capacity of c.339,200 tonnes per annum (about 54% of the UK capacity).

Table 3.2 List of UK secondary aluminium manufacturers contacted.

Environmental Permit IPPC A1 size secondary aluminium manufacturers	
Hydro Aluminium Deeside	FE Mottram
Mountstar Metals	Aleris Recycling
Norton Aluminium Products	Bridgnorth Aluminium
A Cohen & Co.	Calcast
Bernhard Metals	Montuppet
Novelis Latchford (formerly Alcan)	JBMI group Staffordshire

In contacting the operators, the aim was to evaluate actual production rates against capacity, the quantity of APC residue generated, monitoring of the waste for POPs, which has provided data for dioxins and furans only, and final destination of the material produced.

The current estimates are based on production capacity with an assumed APC residue generation factor of 20.9 kg/tonne of metal (based on a BIPRO reference⁴). We have then used an emission factor from Dyke (1997)¹, which is 10 mg I-TEQ/tonne of APC residue and assumed that 100% of this material is then consigned to landfill. Based on these figures the quantity of APC residue consigned to landfill in 2009 is estimated to be 11,750 tonnes, with a dioxin load of 117 g I-TEQ.

Communication with the operators indicated that the current estimates need revision to bring them back into line with current UK working conditions and waste output. The response from the 14 operators contacted showed dioxin concentrations in APC residue varied from 1.1 – 1.7 mg I-TEQ/ tonne of APC residue. Further review of other research and monitoring of such waste including the BREF note for non-ferrous metals is quoted within table 3.3.

Table 3.3 List of emission factors for dioxins and furans in APC residue in secondary aluminium manufacture

Data source	Assumed emission factor for APC residue
Lexen 1993 ¹⁰	0.48 mg I-TEQ/tonne
TNO – 1994 ¹¹	3 – 4 mg I –TEQ/tonne
C. De Wit 1996 ¹²	3 mg I-TEQ/tonne
BREF note (2001) ⁹	Average 5 mg I-TEQ/tonne (range 3 – 10 mg I-TEQ/tonne)
Byeong-Woon 2006 ¹³	2 mg I-TEQ/tonne
Minghui Zheng 2009 ¹⁴	4.4 mg I-TEQ/tonne
Current POPs factor – based on worst case scenario from Dyke 1997	10 mg I-TEQ/tonne
Response from UK operators 2010	Range 1.1 – 1.7 mg I-TEQ/tonne

The current emission factor used for dioxins and furans in APC residue has been based on the worst case scenario quoted within Dyke³ and matches the upper range from the BREF note⁹. The BREF note does also state that concentrations have fallen by a factor of four – ten over the last 15 years. Other references give a constant factor of 2 – 4 mg I-TEQ/tonne. The data from the UK operators indicates a slightly lower factor of 1.1 – 1.7 mg I-TEQ/tonne. This suggests that a reasonable estimate for the 1990 emission factor is the BREF average of 5 mg I-TEQ/tonne with a gradually decrease to current UK levels at around 1.4 mg I-TEQ/tonne.

The response from the UK operators has also shown that the APC residue rates are lower than the current generation factor of 20.9 kg/tonne of metal. The UK operators APC residues ranged from 2 – 10 kg/tonne which would suggest improvements in process efficiency and handling of scrap metal have also decreased the quantity of residue generated.

In terms of production rates compared against capacity, the five plants that responded have a combined capacity of 339 kt and actual production of 261 kt, or 76% of capacity. The waste generated by these processes is largely recycled into other industries, principally cement and concrete manufacture, and road surfacing. The recycling rates in this case would be greater than 95% of the APC residue created.

Based on the revised data (assuming a new APC residue generation factor of 10 kg/tonne) the quantity of APC consigned to landfill in 2009 (assumed to be 5% wt/wt of the APC residue created) would be c.122 tonnes with a dioxin and furan concentration of 0.17 g I-TEQ. A further 2318 tonnes would be recycled into other industries with a dioxin concentration of 3.23 g I-TEQ.

Lead

Similarly to the aluminium sector, the likely emissions of POPs (as dioxins and furans) will come from handling and processing of secondary metals (scrap metal), and surface contamination during the smelting and production of new metal. The finite nature of mineral ore and inherent value of metal, particularly the case in some of the rarer metals such as lead, means the secondary industry is as important as the primary processing plants for production of lead.

The assumed production of secondary lead from the NAEI is 280,000 tonnes per annum based on IPPC capacity rates. The A1 group of operators includes the 7 plants listed in table 3.4. These plants will include both the smelting of scrap lead into new products, but also plants designed to reclaim lead from batteries, where the waste processing aspect of the operation will differ significantly. This difference needs to be recognized in the review of the

sector. The rate of responses from the industry covers three operators with a combined capacity of c.144,000 tonnes per annum (c.51% of UK capacity).

The current estimates have been based on production capacity with an assumed APC residue generation factor of 20.9 kg/tonne of metal (based on a BIPRO reference)⁴. We have then used an emission factor of 17.7 mg I-TEQ/tonne of APC residue from Dyke's 1997 work¹, and assumed that 100% of this material is then consigned to landfill. Based on these figures, the quantity of APC residue consigned to landfill in 2009 is estimated to be 6310 tonnes, with a dioxin content of 111 g I-TEQ.

Table 3.4 List of UK secondary lead manufacturers contacted.

Environmental Permit IPPC A1 size secondary lead manufacturers	
Royston Lead (scrap metal)	Britannia Refined Metals (battery reclamation)
Calder Industrial (scrap metal)	Midland Lead Manufacturers (scrap lead)
Britannia lead Mills (scrap metal)	Enviro Wales (battery reclamation)
HJ Enthoven and sons (battery reclamation)	

The response from the UK operators covers both scrap metal processing as well as reclamation of batteries, with a large variation in the results and in comparison to the existing estimates. In this case the small number of responses makes it difficult to comment with confidence on the true nature of the market and emissions. However, all three manufacturers agree that the high recycling rates of the APC residue into other industries. The recycling rates in this case range from 80 – 100% of residue produced.

The review of the dioxin and furan concentrations from the operators shows a range between 0.3 – 15 mg I-TEQ/tonne of residue, compared to the current factor at 17.7 mg I-TEQ/tonne. This factor which is quoted by Dyke (1997) is the upper end of the range originally quoted by TNO in 1994¹¹. Table 3.5 shows references as quoted.

Table 3.5 List of emission factors for dioxins and furans in APC residue in secondary lead manufacture

Data source	Assumed emission factor for APC residue
TNO 1994 ¹¹	Range 7.7 – 17.7 mg I-TEQ/tonne
Byeong-Woon 2006 ¹³	0.128 mg I-TEQ/tonne
Current POPs factor – based on worst case scenario from Dyke 1997	17.7 mg I-TEQ/tonne
Response from UK operators 2010	Range 0.3 – 15 mg I-TEQ/tonne

The generation of APC residues currently used within the inventory is based on an aluminium manufacturing value from BIPRO of 20.9 kg/tonne. This was used as a proxy during the original inventory compilation in the absence of any better data. The response from the operators again shows a wide range from 0.1 – 2 kg/tonne, with two out of the three responses quoting the 2 kg value. Again the limited data set makes it extremely difficult to comment with confidence, but suggests that both the APC residue generation factor and the dioxin and furan emission factor are too high.

In the absence of better data it is recommended to reduce the emission factor estimate to 15 mg I-TEQ/tonne of residue (as a worst case), and to reduce the APC generation rate to 2 kg/tonne of metal produced as a total for the quantity of ash produced before recycling/disposal to landfill. This would be adopted as a static emission factor and APC generation factor for all inventory years.

Copper Alloys

The manufacture of copper alloys is seen as a key potential source for the emission of dioxins and furans, due to the potential for de novo synthesis of dioxins and furans⁹. This could potentially occur where copper acts as a catalyst in the presence of particulate matter if the process temperature should drop to levels favourable for de-novo dioxin and furan generation in part of the process. In modern plants the use of sophisticated air abatement systems means that while the emission of dioxins and furans to air is well controlled and monitored, dioxins and furans could potentially be present at significant levels in APC residues.

The assumed production of copper alloys from the NAEI is 160,000 tonnes per annum based on IPPC capacity rates. The A1 group of operators comprises the five plants listed in table 3.6. The rate of responses from the industry covers two operators with a combined capacity of c.85,000 tonnes per annum (c.53% of UK capacity).

Table 3.6 List of UK copper alloy manufacturers contacted.

Environmental Permit IPPC A1 copper alloy manufacturers	
McKechnie Brass (Formerly Boliden MKM)	Park and Paterson (Manchester) Ltd
Brookside Metal company	Bolton Manganese Bronze Ltd
Mueller Europe	

The current estimates are based on production capacity with an assumed APC residue generation factor of 20.9 kg/tonne of metal (based on a BIPRO reference)⁴. An emission factor of 12 mg I-TEQ/tonne of APC residue has been used, taken from Dyke (1997)¹, and it was assumed that 100% of this material is then consigned to landfill. Based on these figures, the quantity of APC residue consigned to landfill in the UK in 2009 would be 2650 tonnes, with a dioxin content of 31 g I-TEQ.

The response from the operators within the copper manufacture industry highlights a data gap with regard to monitoring APC residues for dioxins and furans, although like the aluminium and lead sectors the majority of the APC residue generated is recycled into other industries. Review of emission factors from other research shows highly variable results, the 12 mg I-TEQ/tonne of APC residue used within the current inventory from Dyke 1997 is based on a study by Strandell in 1994¹⁵. Minghui Zheng (2009)¹⁴ quotes an emission factor of 29.5 mg I-TEQ/tonne of residue and Byeong-Woon (2006)¹³ quotes 16.8 mg I-TEQ/tonne of residue.

The lack of emission factor data from UK operation makes it difficult to comment with confidence on concentrations within modern operations. The BREF note for the industry⁹ states that concentrations have fallen by a factor of four – ten over the last 15 years. However this is not substantiated based on the two more recent studies by Minghui Zheng¹⁴ and Byeong-Woon¹³. In the absence of better data it is recommended that the emission factor for copper be retained at the current estimate.

In terms of APC residue generation the current estimates are based on a factor from BIPRO (20.9 kg/tonne⁴) which actually relates to the manufacture of secondary aluminium. This factor was adopted in the original inventory as a proxy factor in the absence of better data. The communication with the industry has provided a significant variability with generation rates ranging between 0.01 – 44 kg/ tonne of metal. It is not possible to comment with further confidence in view of the variability in a small sample size.

The key finding from communication with the operators is that virtually all (>99%) of the APC residue generated is recycled into other industries. Production values for 2009 and 2010

show the sector to be operating at 25% of possible capacity. This is likely to be due to the current economic climate.

Magnesium

The manufacture of magnesium is a process involving the electrolysis of brine with the mineral dolomite ($\text{Ca.Mg}(\text{CO}_3)_2$). The thermal nature of the process and the presence of the chlorine in the brine means that this process is a potential source for the generation of dioxins and furans, hence its inclusion as a potential source in the POPs inventory⁹. The current estimates for the magnesium sector have been based on production rates quoted by the mineral yearbook⁸, a proxy APC residue generation value (20.9 kg/tonne – BIPRO, taken from secondary aluminium processes)⁴ and a proxy emission factor (17.7 mg I-TEQ/tonne – taken from secondary lead processes)¹.

However, further discussion and review of the data indicates that the manufacturing processes which make use of magnesium and magnesium alloys are based on processing of scrap metals which are already in existence. Like the other non-ferrous metal sectors the use of secondary metals with contaminated surfaces has the potential to generate dioxins and furans which would then be captured within the filter dust of the APC control system.

Using the existing estimates for 2009, 220 tonnes of APC residue would have been generated with an estimated concentration of 3.84 g I-TEQ of dioxins and furans. The review of the aluminium and lead sectors indicates that APC residue generation is likely to be approximately 2-4 kg/tonne compared to the current value of 20.9 kg /tonne. Even applying the current proxy emission factor (17.7 mg I TEQ/ tonne), this would reduce the estimated emissions to less than 0.5 g I-TEQ per annum. Current estimated emissions to air for magnesium manufacture in 2009 are 0.14 g I-TEQ.

It is concluded that the estimates for magnesium production are likely to be relatively small and therefore it would be more worthwhile to concentrate on the inclusion of emissions from the zinc hot-dip galvanizing sector where emissions are likely to be more comparable with aluminium and lead. Therefore we recommend that existing estimates for magnesium emissions to air and land should be retained.

4 Working concentrations of HCB within pesticide products

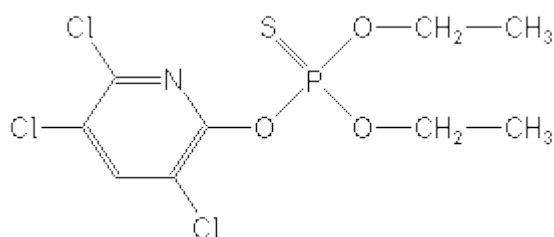
The original POPs multi-vector inventory identified multiple sources of emission for HCB, which historically could be tracked largely to non-ferrous metals, incineration and agricultural product manufacturing and use. Since the year 2000 however, following reductions in other sources, the key sources for emission of HCB to air, land and water have been pesticide usage in the agricultural sector^{16,17}. The use of the pesticide chlorothalonil in particular has been identified as a key source of HCB emissions to all vectors and is still widely used in the UK.

The estimates made for emission of HCB as contamination in chlorothalonil during the compilation phase of the original POPs multi-vector inventory were based on the legal limit (40 ppm equivalent to 40 mg/kg wt/wt chlorothalonil), in the absence of better UK centric data. Existing research from North America by Bailey¹⁸ identified working concentrations as approximately 26 ppm HCB during the mid-1990s and evidence lodged with the EU by the patent holder for chlorothalonil suggested that UK working concentrations could be as low as 10 ppm¹⁹. Therefore a need was identified to carry out research into the true working concentrations of HCB in chlorothalonil for modern use.

The current project involved the collection and analysis of 30 plant protection products for contamination with HCB and active ingredient; with the intention of revising the estimate for emission factors in the POPs multi-vector inventory. Along with chlorothalonil, two further pesticides, chlorthal-dimethyl and quintozone, also carry contamination with HCB and estimates are included within the POPs multi-vector inventory. Quintozone is no longer used and was therefore not considered an issue, but given that chlorthal-dimethyl is still in use, it raised the issue of a testing regime not only for chlorothalonil but also at least one other pesticide to check the market for additional non-chlorothalonil sources of HCB.

Early in the project design a review was carried out using the Defra Pesticide Usage Survey report 224 (2008)²⁰. The review was designed to identify pesticides which could potentially contain significant levels of HCB, based on the presence of chlorine and benzene ring structures within the chemicals used, and also the quantities in use, as other factors being equal, pesticides with a higher mass usage would have a greater impact on the UK estimated emissions.

Chlorthal-dimethyl is documented as being a contributor to HCB formation, but its usage is limited to specialist fruit, vegetables and some amenity turf, with only four products on the market. On this basis, it was reasoned that the impact would likely be relatively small. The pesticide chlorpyrifos ($C_9H_{11}Cl_3NO_3PS$), structure (see figure 4.1, shown below) was identified as a more viable candidate. While chlorpyrifos has fewer chlorine atoms available to form HCB, there remains the potential for HCB to be present, and its usage as an insecticide was more significant.²⁰ Consequently, if HCB should be detected, the impact on total estimated emissions would be more significant.

Figure 4.1 Structure of chlorpyrifos

4.1 Sampling and analysis regime

Thirty samples were taken (23 chlorothalonil based and 7 chlorpyrifos based) during the summer/autumn season of 2010 within the UK. During sampling duplicate samples were also taken from each product bottle to protect against losses or contamination during transport for analysis. Samples were stored within brown glass bottles to protect against photodegradation and stored at 5 degrees Celsius prior to analysis.

The gathered samples were analysed for both concentration of the active ingredient (chlorothalonil/chlorpyrifos) as well as the concentration of HCB at a GLP (Good Laboratory Practice) certified laboratory through our project partner, The Arable Group – Silsoe Spray Unit.

Determination of the concentration of active ingredient within the thirty samples was carried out using high performance liquid chromatography using internal standards for weighting. In the case of chlorpyrifos, 1-4, Dimethylnaphthalene was used as an internal standard as an alternative to 1,4-Dibromonaphthalene due to difficulties sourcing 1-4 Dibromonaphthalene.

Determination of the concentration of HCB was carried out using capillary gas chromatography with mass selective detection (GC/MS) according to the method recommended for the 'determination of hexachlorobenzene and decachlorobiphenyl in technical formulated chlorothalonil', by the Pesticide Management Group of the FAO Plant Protection Service as stated in the FAO specifications for chlorothalonil²¹.

The GC/MS equipment used a 30 m x 0.25 mm x 0.25 µm Zebron ZB-5 capillary column, capable of limits of detection of HCB in at the 0.05 mg/kg (ppm) level and 2.2 mg/kg (ppm) level for HCB in pesticide products based on chlorothalonil and chlorpyrifos respectively. All chlorothalonil based products had HCB content above the limits of detection. However none of the chlorpyrifos based products produced HCB content above the limits of detection. On this basis chlorpyrifos as a source of HCB emissions within the UK has been ruled out at the 2.2 mg/kg level.

4.2 Results and inventory update

Chlorothalonil

In 2005 data was submitted by the patent holder for chlorothalonil (Syngenta) to the EU to highlight the fact that concentrations of HCB in chlorothalonil were much lower than the then FAO Regulation concentrations (300 ppm). On the basis of this evidence the legal limits were lowered to 10 ppm, which then sparked a legal case in the EU from a rival manufacturer, who alleged that the new limit did not take into account concentrations from other manufacturers. The EU commission in 2006 therefore adopted a revised legal limit of 40 ppm¹⁹. During the sample gathering phase of the project we found the brand leading product (manufactured by the patent holding company) had approximately 50% of the market share. Based on market

share the samples collected reflect this market split with seven samples for the branded product and 16 samples for non-branded or other chlorothalonil based products.

The results of this sampling and analysis phase also show a split in the results in terms of the concentrations witnessed between the branded and non-branded products. Table 4.1 displays the results of the testing for the chlorothalonil products in this testing regime. The results are also shown pictorially in figure 4.2. All measured levels of HCB were below the legal limit of 40 ppm as defined by the FAO.

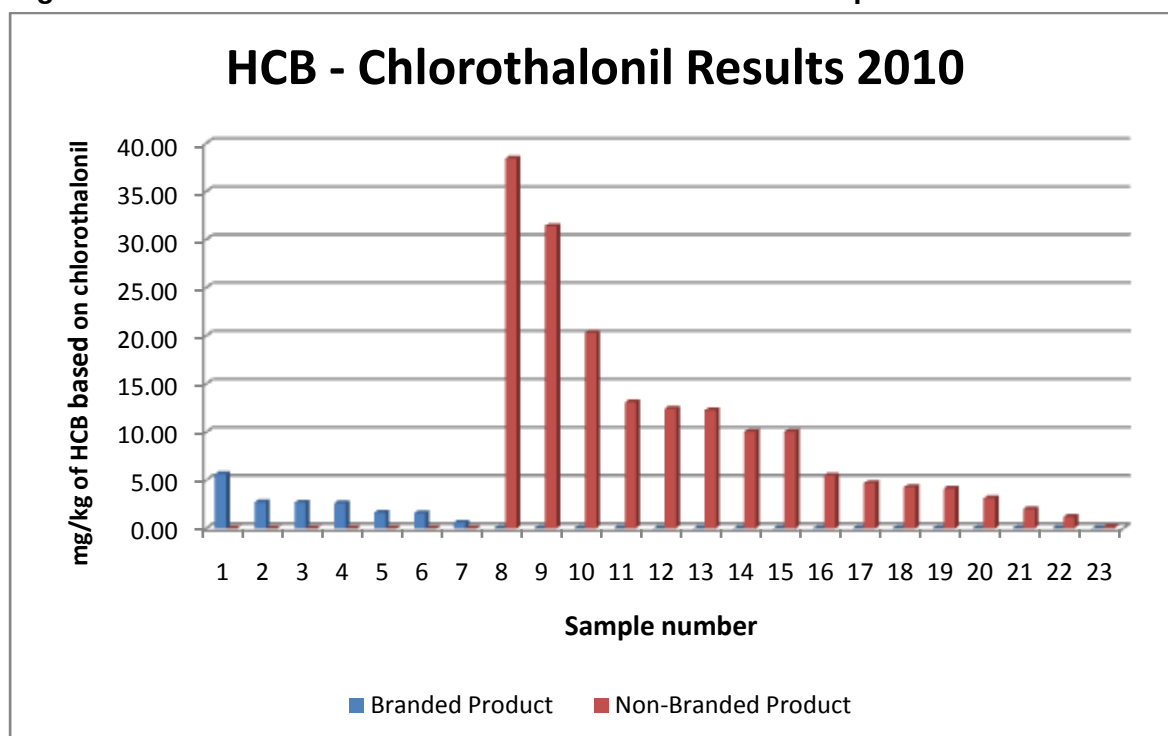
The results showed differences between the datasets. The branded product had HCB levels ranging from 0.61 – 5.63 mg/kg, with an average concentration of 2.50 mg/kg based on seven samples. The non-branded samples showed a greater range of concentrations from 0.16 – 38.41 mg/kg, with an average of 10.8 mg/kg based on 16 samples. However a significant proportion of the concentrations in the non-branded products were still below 10 mg/kg (eight of the 16 samples).

In order to test whether the difference between the branded and non-branded products was statistically significant, we employed the use of a two-tailed t-test. Welch's t-test was used to account for the fact that the two samples were of different sizes and had unequal variances. On this basis with 15 degrees of freedom the critical value for t was 2.131 at the 95% confidence level. The results of the t-test gave a value of 2.98 confirming that the branded and non-branded sample sets were statistically different at a 95% confidence level.

Table 4.1 – Analysis results for chlorothalonil based products

Product	Concentration of chlorothalonil g/l	Concentration of HCB mg/kg (ppm)
Branded Product	500	5.63
Branded Product	500	2.74
Branded Product	500	2.70
Branded Product	500	2.63
Branded Product	500	1.65
Branded Product	500	1.59
Branded Product	500	0.61
Non-Branded Product	200	38.41
Non-Branded Product	500	31.39
Non-Branded Product	500	20.31
Non-Branded Product	530	13.10
Non-Branded Product	500	12.41
Non-Branded Product	500	12.27
Non-Branded Product	500	10.05
Non-Branded Product	500	10.02
Non-Branded Product	510	5.50
Non-Branded Product	375	4.72
Non-Branded Product	500	4.27
Non-Branded Product	500	4.12
Non-Branded Product	100	3.15
Non-Branded Product	500	2.00
Non-Branded Product	375	1.19
Non-Branded Product	375	0.16

Figure 4.2: Measured HCB levels in UK chlorothalonil based products



Chlorpyrifos

Alongside the sampling and analysis regime for the chlorothalonil based products, additional sampling and analysis was carried out for a small number of chlorpyrifos samples. This was intended to act as exploratory measures to test for the presence of HCB in at least one other chlorine based pesticide product.

The seven samples analysed for both concentration of active component and HCB, showed no presence of HCB in any of the samples above the limit of detection of HCB in chlorpyrifos of 2.2 mg/kg (2.2 ppm)

Inventory update

The current testing regime has intended to provide new evidence for the true working concentrations of HCB within plant protection products for the UK. This has been based on the fact that the estimates within the original POPs multi-vector inventory are based on the legal limits for chlorothalonil at 40 ppm (equivalent to mg/kg wt/wt). The results of this testing regime have identified that working concentrations are significantly lower than the legal limit.

The results demonstrate that for the branded products (assumed to have approximately 50% of market share based on communication with field operatives) typical HCB concentrations of 0.61 – 5.63 ppm (mg/kg of chlorothalonil) were found. For other products on the market concentrations were more variable (0.16 – 38 ppm) but still below the legal limit originally used. These results have been used to derive a mean value, with assumed UK working concentration for HCB in chlorothalonil as 8 ppm (mg/kg) for 2009. This update of emission factor has already been adopted into the NAEI at the 2009 compilation year, and will likewise be adopted in the new POPs multi-vector inventory. This factor will be seen as the modern emission rate. For historic emissions, noting that the inventory spans 1990 – 2009, it is necessary to reflect changes in concentration over time. The original legal limit adopted in 1998 was 300 ppm, while Bailey shows working concentrations for the mid 1990s in North America to be closer to 26 ppm¹⁸. On this basis the inventory will look to assume a sensible figure that reflects both these facts. On that basis the current legal limit of 40 ppm will be assumed to act as the emission factor for the years 1990 – 1998 (the time of Bailey's research), after which it will see a linear decline to 8 ppm by 2009 to match the current research.

5 Emissions from wastewater treatment works

The original POPs multi-vector inventory includes estimates for the emission of dioxins and furans, PCBs and HCB from waste water treatment works. This includes emissions both as final stabilized sewage sludge but also treated effluent which is returned to controlled waters. As part of the improvement program for the emission inventories, studies were undertaken to better characterise the concentration of emissions from these sources; which culminated in a sampling and analysis regime for treated sewage sludge and effluent, but also a review of the UK pollution inventories – particularly discharge of treated effluent, which were key to the estimates made in the POPs multi-vector inventory. Section 5.1 sets out the work carried out under the sampling and analysis program, with review of the effluent results and pollution inventories detailed in section 5.2.

5.1 Concentrations of the established POPs in sewage sludges

The key disposal route for sewage sludge within the UK currently is to agriculture, where sludge provides nutrients and bulk to the soil, and helps limit the need for artificial fertilisers. Since dumping at sea was banned in 1999, this option has become increasingly important and therefore this route provides a potentially important source of emissions to land for POPs²². The POPs under review are all lipophilic substances with a strong affinity for organic material; and because of this adsorption ability have the potential to pass through standard waste water treatment works' processes.

As stated, the UK POPs multi-vector inventory has made estimates for the emission of dioxins and furans, PCBs and HCB from waste water treatment works; in the case of sewage sludge the inventory makes use of UK reference data for quantities of sludge generated and consigned to agricultural land. This is then used in line with the reference emission factors quoted in Table 5.1 below. The estimates for treated effluent have been based on reported emissions within the England and Wales Pollution Inventory, and an emission factor derived based on population to allow for full UK populace to be accounted for. Again Table 5.1 quotes the derived factors based on pollution inventory estimates.

Table 5.1 – Emission factors current used within the UK POPs multi-vector inventory.

POP	Sewage Sludge	Treated Effluent	Reference Source
Hexachlorobenzene (HCB)	No estimate	21.95 µg/person/year	Derived from England and Wales Pollution Inventory
Polychlorinated Biphenyls (PCBs)	440 µg/kg (dry weight)	No estimate	Sweetman A. 2005 ²³ , PCBs: fate and behaviour during the wastewater treatment process
Dioxins and Furans	0.1 µg I-TEQ/kg*	420 ng WHO TEQ /person/year**	* UNEP toolkit ³ ** Derived from England and Wales Pollution Inventory

The literature factor for PCBs in sludge is based on the 2005 review by Andy Sweetman at Lancaster University LEC (Lancaster Environment Centre)²³. In this case the quoted factor was based on the maximum concentration (440 µg/kg (dry weight) seen from a survey and

analysis regime of 14 UK sewage sludge samples from works receiving different waste flows (urban / industrial / rural) and as the sum of 37 congeners. The full range of results was between 110 – 440 µg/kg (dry weight), and so the value used may represent an over-estimate by a factor of approximately 2. The dioxins and furans emission factor used is based on a default value quoted within the UNEP toolkit³.

The current project was intended to provide an update to Dr Sweetman's work for PCBs, as well as improved UK data for dioxins and furans and HCB.

Methodology

Sampling regime

The sampling regime was designed to test concentrations across waste flows from a range of flow types; in practice modern waste water treatment works take in a variety of different types of waste covering domestic residences as well as industrial plants. The nature of the flow will however vary depending on the populace and industrial makeup of the local catchment. Broadly this allowed the sampling to be subdivided into three flow types named 'urban' (mostly residential flow with little or limited industrial presence), 'industrial' (a mixture of residential and industrial, where industrial has a significant impact) and 'rural' (where the catchment area is made up of a mixture of farmland and residential properties).

The sample range also included testing for seasonal variation (spring / summer / winter) within the samples taken. Five waste water treatment works were selected, two urban with flows, two with industrial flows and one with rural flows. Five samples of sludge were taken at each works in June/July 2010. Additionally, for one of the domestic sites five sewage sludge samples were taken in March 2010, and another five in November 2010.

The low solubility and potential for sorption to organic matter means that the POPs within a water treatment works would be expected to partition into the sludge portion of the material. However to assess the ratio and apportionment between liquid and solid phases, alongside the sludge sampling five samples of treated effluent were also taken from the urban works site in June/July 2010. This single sampling study was intended to provide context to the partitioning for all works, with 'urban' being most typical of the three categories of waste water treatment works under consideration. This completed a sampling regime for 40 samples which were then analysed for dioxins and furans, PCBs, and HCB.

In all cases the samples were taken from the final stabilised sludge which is at a stage where it is ready for despatch for agricultural use. Samples were taken by an accredited commercial laboratory.

Method of analysis

All samples were collected in pre-washed glass containers at 1 kg per container (with duplicate collections for each sample) and then analysed for HCB, along with the World Health Organisation (WHO) specified congeners for Dioxins and furans (17 congeners) and PCBs (12 congeners) as listed in Table 5.2²⁴. Samples were analysed by an accredited commercial laboratory.

Table 5.2 – List of PCB and dioxin and furan congeners as listed by the World Health Organisation

Dioxin and Furan Congeners	PCB Congeners
Dioxins 2,3,7,8 – Tetrachlorodibenzo-p-dioxin 1,2,3,7,8 Pentachlorodibenzo-p-dioxin 1,2,3,4,7,8 Hexachlorodibenzo-p-dioxin 1,2,3,6,7,8 Hexachlorodibenzo-p-dioxin 1,2,3,7,8,9 Hexachlorodibenzo-p-dioxin 1,2,3,4,6,7,8 Heptachlorodibenzo-p-dioxin Octachlorodibenzo-p-dioxin Furans 2,3,7,8 Tetrachlorodibenzofuran 1,2,3,7,8 Pentachlorodibenzofuran 2,3,4,7,8 Pentachlorodibenzofuran 1,2,3,4,7,8 Hexachlorodibenzofuran 1,2,3,6,7,8 Hexachlorodibenzofuran 1,2,3,7,8,9 Hexachlorodibenzofuran 2,3,4,6,7,8 Hexachlorodibenzofuran 1,2,3,4,6,7,8 Heptachlorodibenzofuran 1,2,3,4,7,8,9 Heptachlorodibenzofuran Octachlorodibenzofuran	Non-ortho substituted PCBs PCB 77 PCB 81 PCB 126 PCB 169 Mono-ortho substituted PCBs PCB 105 PCB 114 PCB 118 PCB 123 PCB 156 PCB 157 PCB 167 PCB 189

The sewage sludge samples were air dried and then ground and spiked with stable isotopically labelled standards (16 standards for dioxins and furans (which covers 17 congeners), and 12 standards for PCB). The samples were then Soxhlet extracted for a minimum of 16 hours with toluene. The extracts were washed with concentrated sulphuric acid and aqueous potassium hydroxide as required, before being dried and concentrated. Impurities were removed as necessary using column chromatography based on silica and alumina columns.

For the dioxins and furans and PCB congeners the resulting extracts were then concentrated and solvent exchanged to give a final volume of 10 µl in nonane and then analysed using high resolution gas chromatography – high resolution mass spectroscopy (HRGC-HRMS) using an isotope dilution method.

For the HCB extracts these were analysed using a low-resolution gas chromatography – mass spectroscopy (GC-MS) method.

Results

Tables 5.3 and 5.4 quote the results of analysis for the PCBs and dioxin and furans analysis. The values presented are the average of five samples per congener per site. For PCBs this gives a range of between 890 – 4067 ng/kg (dry weight) of sludge, and for dioxins and furans a range of between 2.10 – 6.96 ng I-TEQ/ kg (dry weight) of sludge. HCB was not detected above the limits of detection for any of the sludge samples or treated effluent samples during the analysis process. It should be noted that the analysis for HCB concentrations made use of low resolution spectroscopy, which will naturally have higher limits of detection. It is estimated that analytical uncertainty may be of the order of ±25%, which is minor compared to the inter-sample variability indicated by the ranges above.

It was necessary to perform 'clean up' of some samples to remove impurities and concentrate the samples ready for analysis by GC-MS. The clean-up process can also affect

the limits of detection as dirty samples require further dilution in order for the chromatography to be effective. This affects the limits of detection achieved for HCB, shown in Table 5.5. The study results are discussed in the next section.

Table 5.6 provides the results of five treated effluent samples taken during June 2010 for domestic site 1. These were analysed for the WHO PCB and dioxin and furan congeners. In the case of the dioxins and furans, all but two congeners reported results below the limits of detection.

Table 5.3 – PCB congener results

PCB congeners - Average sludge concentration from 5 samples as ng/kg							
	Domestic 1	Domestic 1	Domestic 1	Domestic 2	Industrial 1	Industrial 2	Rural
	March	June	November				
81	4	4	7	10	14	6	11
77	87	86	93	99	350	233	153
123	8	6	10	9	42	21	22
118	568	433	540	815	2038	1539	1524
114	20	17	18	14	83	62	59
105	237	183	226	388	897	583	596
126	3	3	5	5	5	14	12
167	36	30	38	49	127	144	114
156	111	94	108	151	398	462	344
157	23	20	23	22	78	97	76
169	1	1	1	2	4	2	5
189	11	12	11	6	31	55	26
Total	1110	890	1082	1570	4067	3219	2943

Table 5.4 – Dioxin and Furan congener results.

Dioxin and Furan congeners - Average sludge concentration from 5 samples as ng I-TEQ/kg							
	Domestic 1	Domestic 1	Domestic 1	Domestic 2	Industrial 1	Industrial 2	Rural
	March	June	November				
2378 TCDF	0.11	0.19	0.29	0.04	0.17	0.18	0.23
2378 TCDD	0.00	0.00	0.00	0.00	0.40	0.00	0.05
12378 PeCDF	0.05	0.06	0.06	0.02	0.00	0.00	0.04
23478 PeCDF	0.00	0.56	0.90	0.13	0.00	0.87	0.91
12378 PeCDD	0.00	0.49	0.13	0.16	0.00	0.00	0.17
123478 HxCDF	0.19	0.26	0.30	0.17	0.13	0.06	0.34
123678 HxCDF	0.06	0.06	0.12	0.08	0.00	0.04	0.06
234678 HxCDF	0.04	0.31	0.18	0.06	0.12	0.19	0.20
123789 HxCDF	0.00	0.00	0.00	0.07	0.00	0.02	0.00
123478 HxCDD	0.00	0.07	0.02	0.00	0.04	0.02	0.00
123678 HxCDD	0.45	0.99	0.83	0.08	0.46	0.16	0.48
123789 HxCDD	0.25	0.42	0.27	0.00	0.00	0.08	0.20
1234678 HpCDF	0.14	0.11	0.06	0.23	0.42	0.40	0.44
1234789 HpCDF	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1234678 HpCDD	1.29	1.76	1.26	0.46	1.73	0.80	1.71
OCDF	0.04	0.02	0.02	0.04	0.09	0.13	0.05
OCDD	0.73	1.02	0.63	0.55	2.13	0.77	2.05
Total	3.3	6.3	5.1	2.1	5.7	3.7	7.0

Table 5.5 – Limits of detection for HCB determination

Sample	Limits of detection (µg/kg (dw))
Domestic 1 – March	100
Domestic 1 – June	40
Domestic 1 – November	20
Domestic 1 - Effluents	0.02 µg/l
Domestic 2	400
Heavy Industry 1	400
Heavy Industry 2	400
Rural	40

Table 5.6 – PCB concentrations for treated effluent results.

PCB	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
81	0.66	0.96	0.29	0.84	0.75	0.7
77	0.7	9.95	7.43	11.01	10.76	8.0
123	0.29	0.31	0.24	0.26	0.23	0.3
118	15.1	29.35	20.33	25.17	24.52	23
114	0.28	0.29	0.24	0.28	0.24	0.3
105	13.69	12.37	11.1	11.97	11.32	12
126	0.27	0.27	0.23	0.28	0.23	0.3
167	0.17	0.16	0.14	0.14	0.14	0.2
156	4.17	6.3	0.13	6.16	0.13	3.4
157	0.17	0.16	0.13	0.95	0.14	0.3
169	0.15	0.14	0.12	0.11	0.12	0.1
189	0.11	0.09	0.07	0.08	0.07	0.1
					Total as pg/L	48
					Total as ng/L	0.048

Discussion

Polychlorinated Biphenyls (PCBs)

The current project found reportable (above limits of detection) levels PCB for all congeners under review for all of the samples analysed. This has also allowed for review of the trends witnessed between samples sets, based on seasonal variation and also different waste streams entering the works. This section sets out the trends identified, as well as comparison of the results to the previous works, and recommendations for revision of the emission factors used in the POPs multi-vector inventory.

Seasonal variation

Sampling and analysis was carried out at one of the identified 'domestic' works, in the March, June and November of 2010. In each case 5 samples were taken and analysed for the 12

WHO PCB congeners (see table 5.2). The averaged values for each congener plus total concentration are given in table 5.3 (found in the results). The results show a variation in concentrations between the summer and winter months, June = 890 ng/kg (dw) and November = 1082 ng/kg (dw). The concentrations were highest in March (1110 ng/kg (dw)). To test whether the difference in the results was statistically significant, a one-sided t-test at the 99% confidence level was carried out, based on the ratio of paired congeners between June and November, this proved the results to be statistically significant ($t = 4.06$ at 11 degrees of freedom, 99% confidence level = 3.10).

The reason for the observed variation in PCB concentrations between summer and winter months is less clear. A number of possible reasons exist, which could include water temperature entering the wastewater works. This might affect solubility of the PCBs and help further drive the adsorption to sewage sludge. Temperature may also affect microbial action in water treatment at the works, with greater degradation during the warmer summer months. However research exists to illustrate that microbial action has only minimal effect on degradation of PCBs in wastewater treatment works. Previous studies^{22,23} have also highlighted the importance of deposition and run-off in PCB concentrations. It is possible that during the wetter winter months this process is increased, resulting in higher PCB loading at the wastewater works. A study by Blanchard (2004)²⁵ looked at PCB concentrations from inlet flows into waste water treatment works. This study shows concentrations to be higher during the winter and spring seasons when the weather was wetter.

Variation in waste flow

The current project investigated the PCB concentrations in different waste flows from areas which were described as 'domestic', 'heavy industry' and 'rural'. This represents the nature of the main base load into works. Typically there will be some variation outside of the main category and flows will also include run-off from roads.

Levels of PCBs in 'domestic' flows were around 890 – 1570 ng/kg (dry weight) (dw). Levels of PCBs in 'Heavy industry' areas had concentration approximately two and a half times greater than domestic concentrations ranging between 3218 – 4067 ng/kg (dw). A single 'rural' works was also sampled, with an average concentration of 2943 ng/kg (dw). It is reasonable to expect heavy industrial waste flows to have higher levels of PCB concentrations than domestic flows. However, the higher levels at the rural site than the domestic sites were unexpected.

Previous papers^{22,23} have noted the potential impact that local catchment issues, particularly run-off from roads can have on PCB loading of works. The nature of the process used at the site may also have an effect on how PCBs are partitioned and degraded. The process at the rural works involves mesophilic anaerobic digestion, followed by batched 21 day liquid storage then centrifuge dewatering. The secondary storage of the sludge is used to ensure a good pathogen kill rate to meet conventional standards, and is done within a liquid phase (prior to de-watering) to help the process²⁶. This process is likely to generate a limited amount of heat from the digestion process. The other works use thermal and/or chemical processes more directly to aid the pathogen destruction process. This varies between the use of quicklime (reaction generates heat and pH greater than 12) at the domestic works, and steam treatment for one of the heavy industry sites²⁶.

Comparison to previous studies

The POPs multi-vector inventory makes use of activity data provided by Ofwat²⁷ for sludge generated and sent to agriculture combined with literature emission factors based on the work of Sweetman, 2005². The work in this case was based on 14 samples from UK wastewater works, again with different waste flows broadly categorised as 'domestic', 'heavy industry' and 'rural'. The survey work was completed in 2001, and found PCB concentrations that varied between 110 – 440 µg/kg (dw) based on the sum of 37 congeners. Within this the range for the seven congeners listed under the EU wastewater treatment directive²³, was 44

– 180 µg/kg (dw). The results of the current study show concentrations ranging from 0.8 – 4 µg/kg (dw) for the sum of 12 congeners.

Based on the congener profile developed by Sweetman²³ for the 37 congeners, it is possible to scale up the current results to match the sum of 37 congeners (noting that the two studies analysed for six of the same congeners). This would produce a revised estimate of 18 – 83 µg/kg (dw), which is below the minimum levels found in the previous study. PCB emissions have declined steadily since their peak in the late 1960s, and the current results are consistent with this trend.

However it is also necessary to take some care in analysis of the results and test method. Further communication with Dr. Sweetman²⁸ indicated that the samples for the work carried out came from the final settling tank. This represented a good indication of the wastewater treatment process and the concentrations in final sludge. The aim of the current project has been to provide estimates for emission to land through agricultural use. The sampling has therefore been conducted on the final stabilised sludge, which undergoes a further de-watering and air drying process to prepare the goods for despatch. It is possible during this final drying stage that further PCB could be lost through volatilisation to air.

On this basis it may not be appropriate to directly compare the results of the current project to the previous one²³. However, the previous study results can be used as an indicative guide to the likely concentrations in the final settlement stage. The full congener profile developed by Sweetman is useful to gain full benefit from the smaller congener data set in the current study.

Recommendations for emission factor revision

The current study has provided new concentrations for PCBs in a range of different waste flow types across UK waste water treatment plants. This data will be used to help derive a 2009 current emission factor for loss of PCB to land through sludge consigned to agriculture. In order to maintain continuity between the previous emission factors used, which is based on the sum of 37 congeners, the congener profile developed by Sweetman²³ has been used with the current data to scale up the emissions to match the sum of 37 congeners.

The next stage in the process is to derive a weighted average for PCB concentrations in sludge. This should represent the UK network of plants which handle different waste flows. The majority of these are 'domestic' works, which handle waste from urban populations as well as some rural waste and run-off from surfaces. The heavy industry flows are more typical of works that handle waste from industrial areas which will affect the outputs. Rural plants tend to be less common as often waste handled by these plants is part treated and then carried by tanker into towns to be treated alongside domestic waste flows.

On this basis the estimated provisional weighting shown in Table 5.7 has been adopted, to reflect the dominance of domestic flows and smaller contribution from heavy industry and rural works. Using this weighting system and scaled up data based on the congener profile from Stevens, provides an emission factor of 42 µg / kg (dw). The estimated UK 2009 emission of PCB to land from sludge to agriculture would therefore be 64 kg.

Table 5.7 Estimated ratios of sewage treatment work types

Domestic waste flows	Heavy Industry waste flows	Rural waste flows
65%	25%	10%

*AEAT estimate based on knowledge of UK water industry

Dioxins and Furans (PCDD/Fs)

The current project found reportable (above limits of detection) levels of dioxins and furans for most of the congeners under review for all of the samples analysed. This has also

allowed for a closer review of the potential effect of seasonal variation and type of waste flow (domestic/industrial/rural) may have on concentrations within sewage sludge.

Emission trends

The results for the dioxins and furans provide a different picture to that found for PCB concentrations. The PCB results show a clear seasonal variation in concentrations with the highest levels seen during the winter months, and also a clear variation between different types of waste flow, with concentrations from heavy industrial areas approximately 2.5 times greater than domestic flow.

In contrast, the results for the dioxins and furans are less defined with no clear pattern displayed across the data set. The sampling for domestic site 1 in June produced total concentration of 6.33 ng TEQ/kg (dw) which is higher than either of the industrial sites (5.70 and 3.72 ng TEQ/kg respectively). The results for domestic site 2 produced a total concentration of 2.10 ng TEQ/kg (dw) which is the lowest concentration recorded across the entire sampling project. The results show that dioxin and furan concentrations were within a range of 2.10 – 6.96 ng TEQ/kg (dw) across the sampling regime. On this basis the impact of different waste flows is of less significance for dioxins and furans than for PCBs.

The Stevens²² study conducted in 2001 took 14 samples from the final settling tank of UK works with a range of waste flow types (domestic/industrial/rural). This study provided similar results, with no discernible pattern between the measured levels of dioxins and furans and the nature of the flow or size of the receiving works. In the Stevens study, it was suggested that the nature of the treatment process may have a greater bearing on the measured concentrations, with the highest dioxins and furans concentrations coming from wastewater plants that made use of percolating filters as oppose to activated sludge tanks.

The current study shows the highest concentrations of dioxins and furans at the rural sampling site. The rural sampling site also produced PCB concentrations higher than those witnessed at the domestic sites. Stevens notes that the nature of the process at the works as well as local catchment, particularly run-off from roads can have a greater impact on dioxin and furan concentration than the nature of waste treated at the works. The process at the rural works involves mesophilic anaerobic digestion, followed by batched 21 day liquid storage then centrifuge dewatering. The secondary storage of the sludge is used to ensure a good pathogen kill rate to meet conventional standards, and is done within a liquid phase (prior to de-watering) to help the process²⁶.

The process adopted at the rural sampling site may therefore have some bearing on the concentrations witnessed, with the other works making greater use of thermal and chemical treatment processes that may promote the volatilisation of dioxins and furans from the works. The nature of the catchment could potentially also contribute to the levels of dioxins and furans recorded at the rural works.

The current study also investigated the effects that seasonal variation may have on the measured concentrations. The measured PCB concentrations were highest during the winter months. The results for the dioxins and furans show the reverse trend, with the highest concentration reported in the June samples. However, the sample set for dioxins and furans showed a greater level of variance generally. In view of this variability, the study does not give a clear indication of seasonal trends in levels of dioxins and furans in sludge.

Comparison to previous studies

The current study has measured dioxin and furan concentrations seen within final stabilised sludge. This is representative of the sludge 'product' which is then sent for use on agricultural land. In order to assess the results of the current study it is useful to compare the current results against previous studies and the emission factor currently used within the POPs multi-media inventory. This information is provided within Table 5.8 shown below.

Different survey systems and means of analysis were used to derive the values in Table 5.8, as well as differing waste flows, process types and sampling points. However the information within Table 5.8 provides a summary of the typical range in concentrations seen within sludges from wastewater treatment work plants over the last 20 years.

Most studies show typical concentrations ranging from around 20 ng I-TEQ/kg (dw) – 180 ng I-TEQ/kg (dw) and this remains relatively constant across the time series, and location with LUA (Germany)² producing a similar range to Stevens (UK)²². The current results show lower concentrations (2.1 – 6.9 ng I-TEQ/kg (dw)) than other studies. This may reflect the effect of the process and sampling point on measured concentrations. The current study took samples of final stabilised sludge which has undergone air drying to prepare it for agricultural use. It is possible that this process causes loss of dioxins and furans to air.

The current results represent the concentrations of dioxins and furans in sludge consigned to agriculture and therefore can be used to estimate emissions to land.

Table 5.8 review of previous studies for dioxins and furans within sewage sludge

Reference	Year	Range as ng I-TEQ/kg (dw) Sludge
Hagenmaier et al (Germany) ²⁹	1992	20 – 177 (mean 47)
Bremmer et al ³⁰	1994	26
Sewart et al ³¹	1995	19 – 206 (mean 72)
Dyke (AEAT) ¹	1997	20 – 80
LUA (Germany) ²	1997	9 – 144
Jenseit et al ³²	1999	33
Stevens et al ²²	2000	20 – 225 (mean 65)
UNEP tool kit ^{3*}	2005	100 (default for urban environments)
UNEP tool kit ³	2005	10 (default for remote areas or high control systems)
Current study	2010	2.1 – 6.9

*emission factor currently used within the POPs multi-media inventory.

Recommendations for emission factor revision

The current POPs multi-media inventory estimates dioxin and furan emissions on the basis of the quantities of sludge generated from Ofwat statistics²⁷ and a default emission factor taken from the UNEP toolkit³. An emission factor of 100 ng I-TEQ/ kg (dw) of sludge is used, based on the default for urban waste flows. This emission factor was chosen based on a literature review including the LUA study which provides corroborative values for sewage sludges.

The current study suggests that the working concentrations in the final sludge, which then goes to agriculture, are much lower. The measured levels of 2.1 – 6.9 ng I-TEQ/kg (dw) were below the minimum value quoted within the LUA study² of 9 ng I-TEQ/kg (dw), while the UNEP default for the lowest concentration is 10 ng I-TEQ/kg. Stevens²² has suggested that deposition from air and run-off can have an impact on dioxin and furan concentrations loaded into the receiving works.

The results of the current study show no particular trend or pattern between different waste flow types. Consequently, it is not appropriate to use, a weighted average for emissions of dioxins and furans, and an average value is recommended for deriving a new emission factor. The mean concentration of dioxins and furans recorded in this study was 4.74 ng I-TEQ/kg (dw). Historic emissions to land are likely to have been higher, and therefore the recommendation would be to adopt the new emission factor for 2009 onwards, selecting an appropriate factor of scale for the historic trend. Based on the data in Table 5.8, it is recommended that an emission factor of 100 ng I-TEQ/kg (dw) is used for 1990, with a linear regression to a value of 4.7 ng I-TEQ/kg (dw) for 2009.

Hexachlorobenzene (HCB)

Hexachlorobenzene emissions to land from final stabilised sewage sludge are not quoted within the original POPs multi-vector inventory. This was due to a lack of viable data during the compilation phase, but also due to uncertainty on whether waste water treatment works is a true emission source for HCB to sludge and treated effluent. The current study sampled sludges from a variety of different waste flows (urban/industrial/rural) to help fill this knowledge gap. The effluent results are discussed in the next section as part of the overall review for examining the estimates against what is reported in the pollution inventory.

In the current round of testing hexachlorobenzene was not reported above the limits of detection during the course of the current sampling and analysis for HCB within waste water treatment works across all waste flow types (domestic / industrial / rural) and all media (sludge and treated effluent). While HCB is a highly lipophilic substance (the octanol-water partition coefficient, $\text{Log}(K_{ow})$ is 5.73³³) the levels of emission to all vectors are considerably lower than PCB. As comparison of emission ratios the National Atmospheric Emissions Inventory (NAEI⁵) quotes 2009 emissions to air for HCB as 33kg compared to 906 kg for PCBs.

The paper by Sweetman (used in the current POPs multi-vector inventory²³) and another by Stevens²² highlight the importance of wet deposition and run off on concentrations reaching waste water works. We would expect the same to be true for HCB given the key emission source is the use of pesticides in agriculture. On this basis the considerably lower emission rates might well result in smaller concentrations reaching the waste water treatment process. This would therefore have an effect on concentrations and raise the importance for limits of detection.

In view of the absence of measured levels of HCBs in effluent, an alternative approach for estimating emissions was investigated. The current inventory estimates for HCB have been based on the England and Wales Pollution Inventory⁶, which only quotes emissions for treated effluent (1.62 kg for England and Wales in 2009). This reported emission was then used to derive an emission factor based on population which is mapped to the full UK. This gave an estimated emission for 2009 of 1.36 kg). Having noted the lipophilic nature of HCB and potential to survive water works processes it is reasonable to assume that HCB would also be present within the sewage sludge, although at very low concentrations.

Estimates were made of the levels of HCB which would be expected within sewage sludge consigned to agriculture. Blanchard (2004)²⁵ carried out an environmental fate review of PCBs within a French wastewater works. This indicated partitioning of 76% to bio-solids/effluents within the process, although other references quote as high as 90%:10%⁷. The partition coefficient ($\text{Log}(K_{ow})$ for PCB (6.30³²) is greater than for HCB but might lead to similar partitioning levels for HCB as observed for PCBs. On this basis, the pollution inventory estimate combined with the partitioning observed by Blanchard (2004)²⁵ suggests a total emission to sewage sludge of 5.41 kg in 2002, and 5.54 kg in 2009.

In 2009 approximately 1,830,000 tonnes of sewage sludge (dry weight) were generated in the UK of which, 1,530,000 tonnes was consigned to agriculture (based on Ofwat 2009²⁷ report scaled up for UK on population). Based on the assumed total UK emission of 5.54 kg,

this suggests a derived emission factor of 3.0 µg/kg of sludge, and an emission to agricultural land of 4.65 kg in 2009. This estimate is intended to provide a guide to likely concentrations and should be treated as having a high uncertainty. An assumed range for emissions to agricultural land would be estimated to be between 0.5 – 7 kg for 2009.

The estimated emission factor of 3.0 µg/kg sludge represents a relatively low HCB concentration for the UK. This level of HCBs in sludge falls below the limits of detection for this pollutant set out in Table 5.5. The recommendation for the inventory would be that the revised EF be used to calculate emissions for HCB via sewage sludge in-order to provide a complete set of sludge and effluent emissions. This provides a sensible estimate given the lipophilic nature of HCB (potential to bind to biosolids) but should still be treated with a high level of uncertainty.

5.2 Estimate of POPs emissions to controlled water which fall below the reporting threshold for the UK pollution inventories

The POPs multi-vector inventory quotes estimates for the emission of POPs to controlled waters, which has largely been based upon the available data taken from the England and Wales pollution inventory. The pollution inventory in this case places a requirement for waste water treatment works to report on emissions above given thresholds, with data then collated and presented as a single data-set per annum. The use of a threshold means that the most significant concentrations for emission will be captured and reported. While the below threshold emissions will be considered of less concern the likely greater volume of treated effluent that falls into this category means that the total emission for below threshold may not be insignificant. Therefore the current project has looked to make use of the data from the sampling and analysis program, together with a review of the academic literature and data in the pollution inventory to make an assessment about quantities of POPs emissions that fall below the reporting threshold.

Table 5.9 details the current thresholds used by the pollution inventory⁶ for reporting of emissions of dioxins and furans, PCBs and HCB to controlled waters within treated effluents. All emission above threshold will be reported to the pollution inventory. Table 5.10 details the results of this data capture, with details of total emission per pollutant per year. The table also details the number of works who reported and whether the emission quoted was based on measurements, estimates or calculation. In this regard many water treatment works make use of modelling tools to help in the estimation of emissions as a valuable alternative to continuous monitoring.

Table 5.10 reported emissions of POPs to controlled waters within the England and Wales Pollution Inventory

Year	Hexachlorobenzene			Polychlorinated Biphenyls			Dioxins and Furans		
	Release (as kg)	Number of sites	Method of calculation	Release (as kg)	Number of sites	Method of calculation	Release (as g WHO-TEQ)	Number of sites	Method of calculation
2006	0.85	6	5 measured 1 estimated	0.51	3	1 measured 2 calculated	25.62	93	92 calculated 1 measured
2007	1.53	5	4 measured 1 estimated	0.66	4	3 measured 1 calculated	5.92	20	19 calculated 1 measured
2008	0.90	6	5 measured 1 estimated	0.91	6	5 measured 1 calculated	20.53*	20	19 calculated 1 measured
2009	1.62	10	9 measured 1 estimated	0.53	5	4 measured 1 calculated	2.31	12	12 calculated

* One site within the 2008 submission for the pollution inventory quotes an emission of 15.7 g WHO-TEQ (equivalent to 76% of the total emission for England and Wales for that year). If we assume that this reported emission is an error and remove it from the total, the 2008 release to controlled waters are 4.83 g WHO-TEQ. The values for 2006 are correct and reflect a higher number of reporting sites, likely related to use of the estimator tool.

Table 5.9 Reporting thresholds within the England and Wales Pollution Inventory

Pollutant	Reporting threshold for controlled waters as emissions per annum
Hexachlorobenzene	0.01 kg
Polychlorinated Biphenyls	0.001 Kg
Dioxins and Furans	0.1 g WHO-TEQ

Review of hexachlorobenzene

The release emissions of hexachlorobenzene within treated effluent to controlled waters in the POPs multi-vector inventory are based on the reported value within the pollution inventory for 2002 – 1.3 kg. This value was then converted into an emission factor based on population to map the emissions to the time-series for 1990 – 2006. Table 5.10 details the hexachlorobenzene emissions reported to the pollution inventory for 2006 – 2009. This shows a reasonable level of continuity with the 2002 value, with the quoted emissions from a small number of works largely based on true measurements. The works reporting in this case are dominated by plants treating industrial effluents with the key source being Ineos Chlor, with reported releases of 0.82 kg in 2007 and 0.63 kg in 2009.

In terms of estimating the emissions of hexachlorobenzene below reporting threshold, this has proved more challenging with a lack of viable data, and results from the testing regime failing to detect hexachlorobenzene above detection limits. Therefore an alternative approach has been adopted. The testing regime described in chapter 5.1 had limits of detection set at 0.02 µg/L equivalent to 20 ng/L of treated effluent. Further research of academic studies locates work carried out by Robles-Molina (2010)³⁴ who carried out a similar study in Spain to look at a range of waste flows (urban/industrial/agricultural) and treated effluents after 24 hours into the treatment process (post primary filtration and treatment). In this case a mean HCB concentration for urban works (based on 19 samples from three works) is quoted as 24 ng/L, with the lowest concentrations detected as 5.3 ng/L.

Alongside academic reviews we also further examined the reported data in the pollution inventory, which includes one major urban/industrial works – Davyhulme⁶, operated by United Utilities. Davyhulme is one of the largest waste water works in the UK servicing southern Manchester, and having a capacity of 1.2 million population equivalent (700,000 people plus industrial flows)³⁵. The pollution inventory records reported emissions of 0.35kg in 2008 and a further 0.35kg in 2009. Assuming the daily water emissions to works of per capita to be 160 litres (WRc³⁶), it is possible to estimate total wastewater treatment by Davyhulme and derive an emission factor of approximately 5 ng/L. However this is based solely on population equivalent, with industrial flows likely to be more heavily polluted. For example, Mogden works (operated by Thames Water³⁷) which serves 1.4 million people in west London, does not report HCB above threshold for any of the reporting years in the pollution inventory.

Based on the results for PCB in sewage sludge as an example, the concentrations in industrial flows might be approximately double to 2.5 times greater than urban flows. In the case of Davyhulme if it is assumed that the industrial flows (500,000 population equivalents) are twice as polluted as domestic, then the derived emission factor for domestic effluent would be 3.5 ng/L.

Table 5.11 details the emission factors derived along with corresponding total emissions to controlled waters based on total quantities of water treated in the UK taken from OfWat data²⁷ and scaled to full UK level based on population.

In terms of interpreting the results a common sense approach is required, the reporting threshold established by the pollution inventory is set at 0.01 kg of HCB as total emission per annum. In reflection to total emissions in the POPs multi-vector inventory (33 kg to air, 10 kg to land and 2 kg to water 2009) it is probably reasonable to assume that the key point sources are captured within the pollution inventory, as is demonstrated by the industrial waste treatment plants found.

The Robles-Molina emission factor³⁴ is based on sampling and analysis of modern works with a good limit of detection (1ng/L). However, samples taken are based on effluent after 24

hours of treatment, and it is less clear whether final treated effluent would have concentrations as high as those witnessed.

Table 5.11 Derived estimates for below threshold emissions of HCB

Assumed Emission Factor ng/L		Activity data as ML of treated effluent in the UK 2009	Total emission of HCB to controlled waters (kg)	Reported to pollution inventory (kg)	Assumed below threshold (kg)
Detection limits of current study	20	4,075,000	81.5	1.62	79.9
Robles-Molina average	24	4,075,000	97.8	1.62	96.2
Derived factor based on total flow at Davyhulme	5	4,075,000	20.4	1.62	18.7
Revised factor based only on populace at Davyhulme	3.5	4,075,000	14.2	1.62	12.6

The reported values for Davyhulme have been used to represent UK data and the closest match to current UK practice. However, again, care needs to be taken, given that a works of similar size (Mogden) does not report HCB at all. In this case it is possible that the industrial flows into Davyhulme account for the majority of HCB emissions rather than domestic effluent. The revised factor quoted in Table 5.11 takes this into account, but care needs to be taken and the uncertainty in the values quoted should be considered. On this basis we would recommend an uncertainty of -99% to +100% in the below-threshold value, giving a range of 1.75 – 26.8 kg) when estimating the total emission of HCB, including both reported and “below threshold” components.

Review of polychlorinated biphenyl

The release emissions of polychlorinated biphenyls within treated effluents are not quoted within the original POPs multi-vector inventory due to a lack of data at the time of compilation, and the assumption that the lipophilic nature of PCBs would mean that the partitioning within waste water treatment works would favour the sewage sludge component with only trace concentrations in the treated effluent. The POPs multi-vector inventory does make estimates for dumping of sewage sludge at sea prior to the ban in 1999³⁸. The pollution inventory reported emissions, shown in table 5.10, quote emissions of PCB in treated effluent to controlled waters varying between 0.51 – 0.91 kg per annum⁶. These values like the hexachlorobenzene have been based on monitoring at site.

The sites reporting to the pollution inventory are largely industrial companies with onsite treatment works, the exception being two domestic works, Davyhulme and Bromborough, both owned by United Utilities and treating a combination of both domestic and industrial waste, with Davyhulme already previously discussed in the emissions to hexachlorobenzene (see previous section).

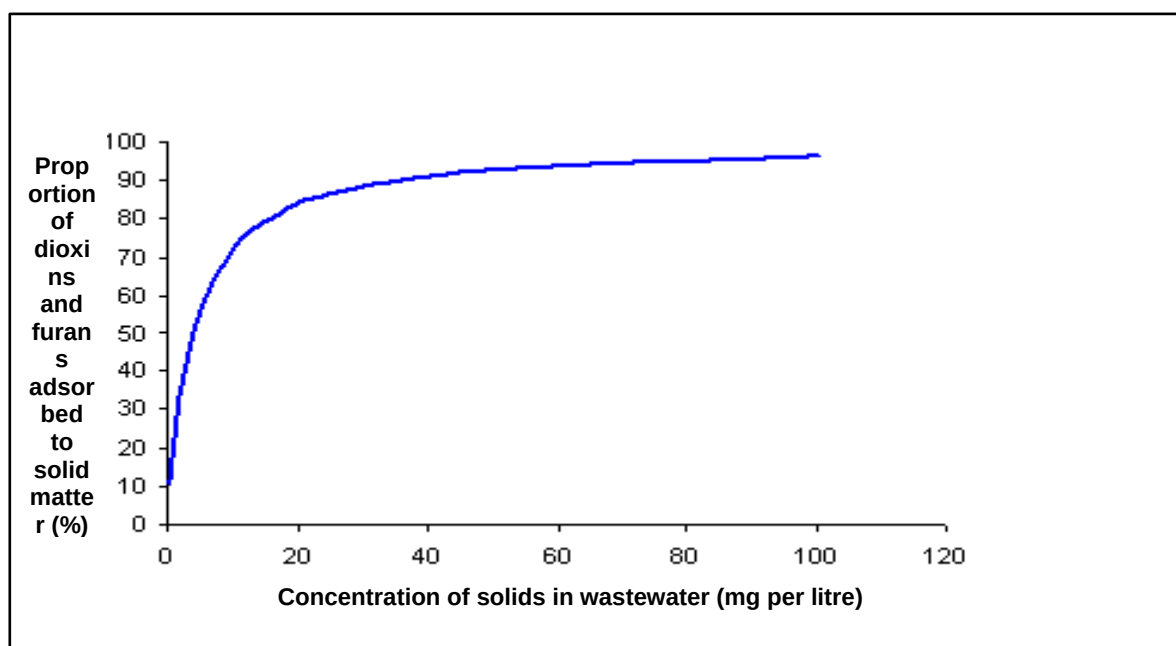
As part of the current project five samples of treated effluent were taken from the Domestic 1 site during June 2010. These measurements were designed to provide data to support a mass balance approach between PCB and dioxin and furan concentrations within final stabilised sewage sludge and treated effluents. The measured levels of PCBs in effluent are given in Table 5.6, with an average concentration of 0.05 ng/l.

In order to develop an updated estimate of partitioning between sludge and effluent, it is necessary to put the data for PCB levels in effluent into the same format as the sludge results (sum of 37 congeners based on the Sweetman profile), and account for the quantities of effluent and sludge produced. Multiplying the concentration of PCBs in effluent to account for the full profile from Sweetman²³ gives a concentration of 0.8 ng/l. The July 2009 Ofwat data indicates that approximately 8550 litres of effluent are produced per 1 kg of sludge (dry weight). This indicates that approximately 7 µg PCBs in effluent are produced per kilogram of sludge (dry weight), compared to the measured concentration of 42 µg/kg (dw) of sludge. The partitioning can therefore be estimated as 86%:14% in favour of the sludge.

Based on Ofwat data for 2009²⁷ scaled up on population to include Scotland and Northern Ireland, total quantity of released treated effluent to controlled waters in 2009 was 4,075,000 million litres. This would give a total PCB release to controlled waters from treated effluent of 3.26 kg, of which 2.73 kg would be below threshold.

As comparison two additional methods have also been used, with the aim of quantifying the total release of PCB to controlled waters from treated effluent. Polychlorinated biphenyls are highly lipophilic substances with the log-octanol-water coefficient varying between 5.7 – 8.26³³, depending on the level of chlorination. During the compilation work carried out for the original POPs multi-vector inventory, a project partner at the time³⁶ carried out a study of the partitioning of dioxins, in particular TCDD which has a log K_{ow} value of 6.3. The partitioning for TCDD showed increasing adsorption to the sludge as the suspended solid quotient of the waste flow increased, as shown in figure 5.1

Figure 5.1 partitioning for dioxins and furans to suspended solids.



Based on this partitioning and assumed suspended solid concentration of 20mg/l of treated effluent, estimates of total emissions to controlled waters were made, based on quantities of water treated. Given that PCB partition coefficients are broadly in line with that of dioxins and furans, and using the new assumed emission factor for PCB concentration in sewage sludge from the previous chapter (see section 5.1) it is possible to make estimates for total PCB emitted to controlled waters based on suspend solid loads in treated effluent.

PCB concentration = 42µg/kg d.w. of sludge.

1 litre of treated effluent contains 20 mg of solid,

Concentration of PCB per litre of treated effluent = 0.042ng/mg x 20mg = 0.84ng.

Concentration in treated effluent is 0.84ng/l of which 0.72 ng/l is present as suspended particles, and 0.12 ng/l is in the liquid phase

This method therefore derives a similar emission factor as that quoted from the existing research when the test results are scaled up to match the sum of 37 congeners in the Sweetman emission profile. Again based on the Ofwat data scaled to UK population this gives a total emission of 3.26 kg, of which 2.73 kg would be below threshold.

As a second alternate to this method, it is possible to repeat the method used for Hexachlorobenzene using Davyhulme as an example works, where the population equivalent of 1.2 million is split between 700,000 people plus industrial flows³⁵. Again based on the work carried out within the sampling regime the industrial flow was assumed to be twice as concentrated as domestic flows.

Davyhulme works did not report a PCB emission for 2009, but the quoted emission in 2008 was 0.27kg per annum. Based on a population equivalent of 1.2 million, of which 0.5 million population equivalent is industrial flow, this gives a per person emission of 0.16 mg/per person/per year. Based on the UK population in 2009 (61.8 million – reference ONS) this would give a total emission to controlled waters from treated domestic effluent of 9.8 kg. Table 5.12 displays the estimates for the emission factors based on these different methods.

Table 5.12 assumed PCB emissions to controlled water

Method	Assumed total emission (2009)	Below threshold emission
England and Wales Pollution inventory	0.53 kg	0 – assume total is PI
Calculation based on current test results	3.26 kg	2.73 kg
Suspended solids method	3.26 kg	2.73 kg
Back-calculation on Davyhulme	9.8 kg	9.27 kg

Two methods (method based on current test results and suspend solids method) provide similar results, although again care should be taken when making use of the data and some guidance provided in terms of the uncertainty. In this case we would assume similar uncertainty ranges as those found with the hexachlorobenzene estimates, and a range in the final estimates of +/- 50% across the range of estimates, equivalent to 1.9 – 14.4 kg based on the results of the current testing.

Review of dioxins and furans

The release emissions of dioxins and furans within treated effluent to controlled waters in the original POPs multi-vector inventory are based on the reported value within the pollution inventory for 2006 – 25.62 g WHO-TEQ. This value was then converted into an emission factor based on population to map the emissions to the time-series for 1990 – 2006. Table 5.10 details the dioxins and furans emissions reported to the pollution inventory for 2006 – 2009⁶. This illustrates a highly variable pattern with emissions of above 20 g WHO-TEQ for 2006 and 2008 and less than 6 g WHO-TEQ for 2007 and 2009. It is also worth noting that

the bulk of reported emissions are based on calculation with the number of reporting sites declining each year from 92 in 2006 down to 12 in 2009. The reported emissions for 2008 show one site quoting an emission of 15.7 g WHO-TEQ (76% of the total emission for that year) which is likely to be an error. If this value is removed from the calculation, total emissions for the year 2008 are 4.83 g WHO-TEQ – more in line with the preceding and succeeding years.

The current study took five treated effluent samples from the domestic site 1 during June. This was intended to provide the basis of a mass-balance study to gauge the likely concentration of dioxins and furans in treated effluent. The results showed only detectable levels of the congener OCDF (octachlorodibenzofuran) in two of the five samples (0.0085 and 0.0058 pg/l⁻¹) analysed. All other congeners sampled and analysed were below the limits of detection. The limits of detection used were congener specific and range between 0.025 and 0.105 pg/l⁻¹.

The lack of test data and reference data makes calculation of total release difficult. One option is to make use of the method quoted previously derived by WRC³⁶. This stated that the quantity of the dioxin TCDD in treated effluent was linked to adsorption rates to suspend solid, based on the lipophilic nature of dioxins and furans, see figure 5.1. On this basis the quantity of dioxins and furans in treated effluent is proportional to the quantity of suspended solids, which is assumed to be 20mg/l in the WRC report.

Using the new emission factor for dioxins and furans in sewage sludge in the current study it is possible using this method to make estimates for total dioxins and furans in treated effluent released to controlled waters.

Dioxins and Furan concentration = 4.7ng I-TEQ/kg d.w. of sludge.

1 litre of treated effluent contains 20 mg of solid,

Concentration of dioxins and furans per litre = 0.0047pg I-TEQ/mg x 20mg = 0.094pg I-TEQ.

Partitioning for sludge at 86% = 0.094pg I-TEQ x 0.86% = 0.081 pg to sludge and 0.013pg I-TEQ to liquid phase

Concentration in treated effluent is 0.013pg I-TEQ/l.

Based on Ofwat data for 2009 scaled up on population to include Scotland and Northern Ireland, total quantity of released treated effluent to controlled waters in 2009 was 4,075,116 ML. This would give a total dioxins and furans release to controlled waters from treated effluent of 0.05 g I-TEQ. This 'total' emission is smaller than the value quoted within the pollution inventory for 2009 (2.31 g WHO-TEQ). There is a discrepancy in units for these values: 'WHO-TEQ' will produce slightly higher emissions than 'I-TEQ'.

The revised method quoted produces an emission factor which falls below the limits of detection in the current round of testing. The test results themselves only show above threshold emissions in two of five samples making it difficult to derive a total emission other than to comment that dioxins and furans are highly lipophilic and that it would be reasonable to assume that the treated effluent concentrations would be significantly lower than that for treated sludges (4.7 ng I-TEQ/kg d.w.). The pollution inventory estimates are based largely on calculation of waste flows with the single monitored site being the chlor-alkali plant at Ineos chlor in Runcorn. In absence of other evidence the current study may suggest that the reported figures in the pollution inventory are an over estimate, but this is extremely difficult to corroborate with confidence based on existing data.

6 Review of Public waste burning habits

The original POPs multi-vector inventory has highlighted the importance of diffuse emissions sources in the current trends. These sources have been increasingly important as industrial sources have been brought under more strict regulatory control between the start of the inventory in 1990 and current year, 2009. The incidence of what is termed 'backyard burning' is of particular significance for dioxins and furans as a key source, but also due to its very nature has high levels of uncertainty in the estimates. This reflects the ad-hoc nature in which material is burned in domestic residences, both in terms of the frequency and quantity of material burned, but also the nature of the material burned and environmental conditions.

It should also be noted that within the POPs multi-vector inventory the term 'backyard burning'³⁷ is a generic term used to define a variety of activities including disposal of garden and household waste on bonfires, recreational fires on open ground (excluding bonfire night), and burning of waste materials on open fireplaces or hearths within the home. After completion of the original POPs multi-vector this source was identified as an area that needed further improvement partly due to the high uncertainty attached, but also due to the fact that the activity estimates and methodology was based on a survey by the Environment Agency in 2003³⁹, meaning that current trends may not reflect the activity data in use.

To overcome this issue the current project has developed and carried out two rounds of surveying of the general public, firstly a qualitative set of face-to-face interviews with identified target groups, and then a broader quantitative survey of 1000 households across the UK. The methodology in this case has therefore consisted of the following steps:

- Establish the data requirements of the survey
- Identify the target groups thought to be of interest to the survey and any appropriate segmentation (e.g. by region or by housing and heating type)
- Develop an appropriate questionnaire
- Run a pilot survey – as qualitative face-to-face interviews.
- Review of results and further tailoring of the survey for quantitative stage.
- Completion of a large-scale baseline survey for 1000 households spread across the UK
- Gather results which will then be interpreted in terms of the quantity of waste materials burnt in the UK in the open and in domestic appliances
- Identify the typical range of materials burnt, together with uncertainty estimates.

6.1 Development of survey requirements and target groups

The first three steps in the proposed method have been to identify the data requirements, develop an appropriate questionnaire and to identify what we would perceive as the key target demographic groups for the qualitative stage.

Establishing data requirements

Extensive desk research has been carried out, looking at published research and reports which investigate the issues surrounding the domestic burning of waste. The aim of this initial research was to develop and gather sufficient information to establish the data requirements for the project and to develop an appropriate questionnaire. Reports and research consulted includes:

- Air Pollution Forecasting Report: Bonfire Night 2007 - Report by AEA for the Defra, Scottish Government, Welsh Assembly Government and the DoE in Northern Ireland, December 2007
- Air Pollution in Northern Ireland 2007 – Report produced by AEA for the Department of Environment in Northern Ireland
- Bonfires – A Report by the Interagency Working Group on Bonfires (Northern Ireland), 2004
- Emissions of Dioxins and Dioxin-Like Polychlorinated Biphenyls from Domestic Sources – Defra 2006 (report by Enviro Consulting Ltd)
- The Nature and Extent of Unauthorised Waste Activity in Ireland - Environmental Protection Agency, 2005
- Household Waste Prevention Evidence Review: L1 m1 – Executive Report. A report for Defra's Waste and Resources Evidence Programme (WR1204) – Resource Recovery Forum, The Social Marketing Practice and Brooklyndhurst, October 2009
- The Open University Household Waste Study: Factsheet No 9. Non-Municipal Waste Disposal Routes, 2008
- Various attitudinal and behavioural waste surveys undertaken for local authority and other clients (eg CA Site surveys)
- Data from a number of local authority environmental health departments on investigations into complaints from the public about smoke from bonfires
- Various information and literature produced by Environmental Protection UK (formerly NSCA)

This information gave insights into the potential extent of the issue, types of combustion activities and materials being burnt by people in domestic settings. It also helped provide information on target groups and audience segmentation which contributed to the next task.

This research also identified some potentially useful sources of information – local authority environmental health departments for example – which have data on complaints made by the public about domestic and commercial 'burning' incidents, usually open bonfires in gardens, allotments, waste ground and commercial premises. However, a full examination of this data will be outside the scope of the current project.

Establish the target groups

The research carried out in the previous task shows that people burning rubbish tend to have the following characteristics:

- Older (35+)
- Have an older property with a garden
- May have one or more of the following:
 - a larger than average sized garden (and more mature than average)
 - an open fire/solid fuel burner for domestic heating
 - an allotment

In terms of audience segmentation main quantitative research (Task 4d) will provide more information but at this stage of the project the following target groups have been identified:

- Householders with gardens (likely to be older (45+) have larger properties with gardens) living in suburban fringe and rural areas

- Also, keen gardeners with larger, mature gardens (likely to be older (45+) have larger properties with gardens) living in suburban fringe and rural areas
- Householders living in rural areas (all ages)
- DIY enthusiasts with large items to dispose of (all householders)
- Allotment holders (can be any age (25+) but predominantly older (45+), living in urban areas and suburban fringes. Also in country towns and villages with community allotments)
- Householders with open fireplaces or solid fuel heating appliances (predominantly householders in rural areas, particularly in Northern England)
- Householders living in areas with poor (eg narrow range of material collected/small containers/restrictions on collections) or hard to access waste collection services (eg HWRC located long distance from property)

Other potential groups identified include:

- All householders (who might have a fire on their property eg garden/celebratory bonfire, BBQ etc)
- Community bonfire organisers eg for Bonfire night or other community based celebrations

The research was weighted towards northern England and Northern Ireland as our preliminary investigations have highlighted historical issues in these areas (due to the predominance of older housing types, generally poorer historical waste management services and cultural issues).

Developing an appropriate questionnaire

To inform the quantitative element of the surveying a pilot question was run in IPSOS MORI's national Capibus survey in February 2010 to show how many suitable people (those who have bonfires or open-fires at home) would be reached using this method for the survey. The results showed that approximately 400 interviews each week could be achieved with respondents who have either had bonfires or used open-fires in their homes. Around 14% of people who answered said they had used an open-fire, aga or wood burning stove in their home in the last 12 months. Around 10% had made use of a bonfire on their property.

This meant that a two week survey on the face to face omnibus would be expected to achieve roughly 800 interviews within mainland England, Wales and Scotland. The survey would also be carried out in Northern Ireland and it was assumed that this would reach a similar proportion of suitable people, resulting in around 120 interviews. This would give a total of around 920 interviews - a large enough sample size to look at the characteristics of people who might be more likely to burn waste, e.g. what social grade they are, where they live, how old they are etc.

Postal surveys among allotment holders were considered but discounted as this approach would be inefficient - response rates to postal questionnaires are often low and targeting allotment holders through their national associations would be both time consuming and slow.

6.2 Qualitative interviews

To inform the development of the questionnaire for the quantitative element of the surveying, and to investigate people's attitudes and behaviours surrounding the burning of domestic waste at home, 10 in-depth interviews (conducted by telephone) were conducted across England (in the North West, North East and South East) to explore in some detail people's behaviour and the underlying reasons for it. The findings from these interviews informed the design of the final quantitative questionnaire.

A copy of the survey used for this qualitative phase is reproduced in annex III of this report.

6.3 Quantitative Survey

The quantitative survey used a 10 minute questionnaire which was run on Mori's face-to-face omnibus, Capibus (this is a method where multiple surveys for different projects are conducted at the same time to given populous). The questionnaire was run on Capibus for two weeks which meant a total of 4,000 people were given the chance to respond to the survey. Further to this, the questionnaire was also run on Nbus, Ipsos MORI's face-to-face omnibus survey in Northern Ireland for one week. This survey contacts 60 people, every week, across the province. In total, 834 interviews were achieved across Great Britain and Northern Ireland so the incidence was slightly higher than anticipated with just over 20% saying they had domestic fires or had / attended bonfires. The results have been weighted to ensure they are nationally representative.

The results from both the qualitative and the quantitative research have been analysed together to identify what people burn on domestic fires or bonfires, why they do this, what issues are felt to arise from doing so and how any later campaign to target such behaviour could be delivered.

6.4 Results of the Qualitative and Quantitative Surveys

This section interprets the key results of the survey in terms of the quantity of waste materials burnt in the UK in the open and in domestic appliances, and identify the typical range of materials burnt, together with uncertainty estimates. The detailed results of the quantitative and qualitative survey that was carried out by MORI can be found in Appendix III.

Ipsos MORI conducted both qualitative and quantitative research to investigate what people burn on different types of fires (domestic open fires, Agas/Rayburns, boilers and bonfires held at home, allotments or within the community), why they do so and what could be done to discourage the burning of materials which produce persistent organic pollutants (POPs). The quantitative research was conducted using Ipsos MORI's face-to-face omnibus survey, Capibus. Capibus is run weekly and interviews 2,000 residents across Great Britain and once completed, the results are then weighted to be nationally representative.

Who has domestic fires and bonfires and how often

The burning of waste materials in the UK in the open and in domestic appliances is a highly dispersed habit performed by a minority of the population (approximately 20%). It is also, in some instances, a secretive pastime and difficult to identify and record – for example, the illegal disposal of trade waste by burning on bonfires at home. The scale and frequency also varies from relatively small regular open domestic and garden fires to less frequent medium sized garden and allotment bonfires to infrequent larger scale community bonfires celebrating events such as Bonfire Night.

Key findings from the quantitative research undertaken as part of this project indicate that:

- around one in five respondents (22%) either used a domestic fire or had a bonfire in the last 12 months;
- those in the North of England were more likely to have bonfires, whereas people living in the South of England tend to have more domestic fires;
- further to this, those living in rural areas were more likely to have bonfires or domestic fires;
- most respondents, who had bonfires at home or attended community bonfires, tended to do so **once a year or less**;

- respondents who had bonfires at allotments did so more often with over half (56%) saying they did so at least twice a year compared to 36% of those who had bonfires at home. The number of people with allotments is however, a relatively small proportion of the population (There are around 300,000 allotments in the UK that are often used by several members of a same family); and
- Only 4% of those who had bonfires said they did so **once a month or more often**

Analysis of 2007 Fire Statistics, published in August 2009 by the Department for Communities and Local Government shows that primary and secondary recorded call-outs to outdoor fires totalled 291,600 in 2007. Of this total, 152,500 (52%) were refuse fires (including bonfires, fires in derelict vehicles and refuse containers), 58,000 (20%) were grassland and heathland fires, 51,000 (17%) were road vehicle fires and 30,000 (10%) were other outdoor structures (including derelict buildings). The data for bonfires is likely to be a small fraction of actual number of bonfires as most bonfires do not trigger fire service call-outs.

A speculative enquiry into smoke related enquiries and complaints to the Environmental Health and Housing Departments at the City and Council of Swansea shows a range of incident types reported from a variety of sources:

Table 6.1: Smoke related complaints reported to City and Council of Swansea

Category	Number of complaints		
	2006	2007	01/01/2010 – 02/03/2010
Domestic burning	82	120	8
Dark Smoke	51	62	6
Smoke Other	32	46	5
Smoke – Industrial/Commercial	38	35	4
Cable burning	6	8	1
Smoke – Domestic Chimney	4	8	1
Industrial Chimney	-	5	-
Total	213	284	25

Source: City and Council of Swansea - Environment & Health and Housing Departments, Smoke complaints

This proved to be a potentially interesting source of information about fires and would be worthy of further, more detailed investigation to find out more about this data from other local authorities.

With regards to trade waste, the quantitative research confirmed that some people burn trade waste at home. Around one in seven (15%) of those who had bonfires said they worked in one of the following occupations or trades - building, joinery, carpentry, plumbing, gardening, farming or working as a general 'handyman'. Of these, around a quarter (26%), said they burn leftover materials at home.

The trade waste materials burnt on bonfires or domestic fires tended to be:

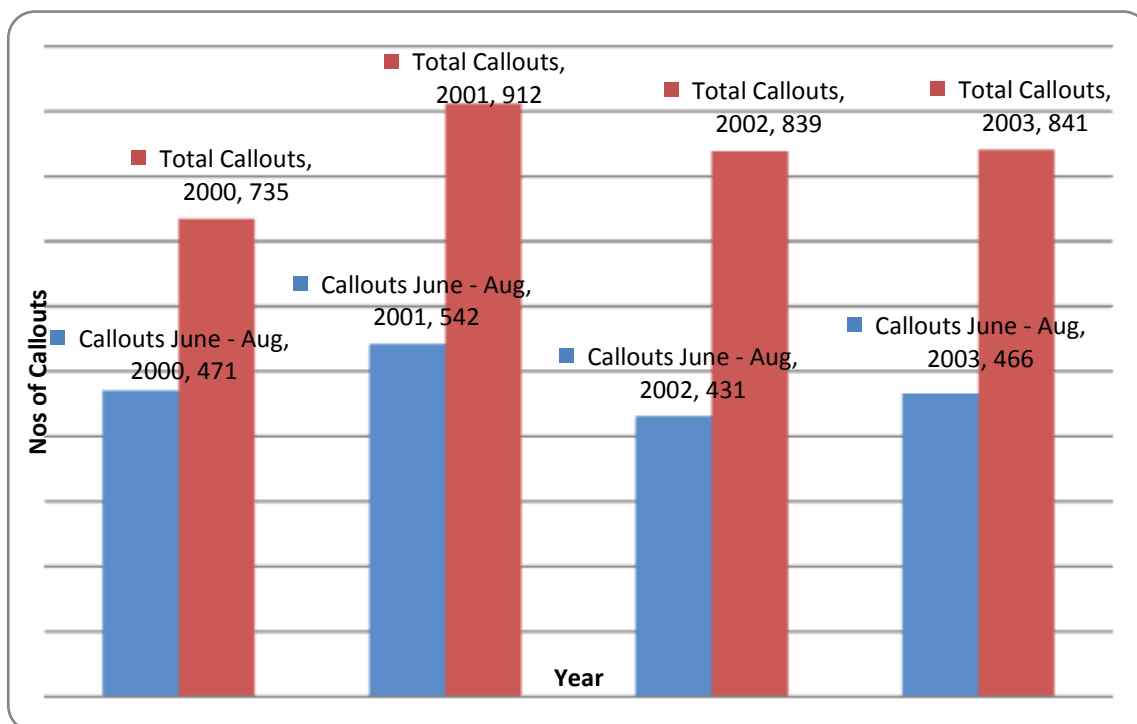
- wood that had not been treated (60%);
- garden waste (44%);
- wooden furniture (15%); and
- cardboard (13%).

Further to this, around half (47%) said they burnt materials such as these at least once a month, however it should be noted that the base sizes for this group were extremely low and so the results should be treated as indicative only. It does indicate a potentially significant niche audience for any campaign attempting to discourage people from burning unsuitable items on bonfires or domestic fires. Within the POPs multi-vector inventory and similarly within the NAEI, 'bonfire' is disaggregated to a separate source from 'backyard burning' due to the scale of the event.

Seasonality issues

Traditionally within the UK there are two distinct peak times of the year for public or community bonfires: November 5th – Bonfire Night for most of the UK*; and in Northern Ireland July 11th to celebrate the Battle of the Boyne and August 9th to mark the anniversary of internment. These periods are mirrored by increases in airborne pollutants. According to research commissioned by Defra (Emissions Of Dioxins And Dioxin-Like Polychlorinated Biphenyls From Domestic Sources, Enviro 2006), around 14% of the year's emissions of dioxins can be linked to Bonfire Night related fires. In Northern Ireland the peak period for Fire Service callouts to bonfires is the three month period between June 1st and August 31st.

Figure 6.1: Bonfires attended by the Northern Ireland Fire Brigade 2000-03



Source: Bonfires, Environment and Heritage Service 2004

Types of materials burnt

The amount of waste used for domestic burning amounts to an estimated 121 kt (due to high uncertainties this could range from 60 kt to 242 kt), what is burnt at bonfires amounts to an estimated 141 kt (again due to uncertainty this could range from 75 kt to 280 kt)⁵.

Analysis of domestic energy consumption indicates 793 kt (thousand tonnes of oil equivalent) of solid fuel was used for space heating, heating water and for cooking in 2008. In addition, some 265,000 homes in Great Britain (or 1%) have solid fuel central heating.

Table 6.2: Types of waste materials used in domestic combustion

Waste material	kt	Uncertainty(kt)
Domestic fires		
Paper & card	75.6	37.8 - 151.2
Plastic	7.6	3.8 - 15.3
Textiles	2.6	1.3 - 5.2
Putrescibles (garden waste & food waste)	25.1	12.6 - 50.3
Treated wood	5.1	2.5 - 10.2
Untreated wood	5.1	2.5 - 10.2
Total	121.2	60.6 - 242.4
Bonfires		

⁵ NAEI data

Waste material	kt	Uncertainty(kt)
Vegetation	126.6	63.3 - 253.1
Plastic (including fertiliser bags etc)	2.8	1.4 - 5.6
Paper & card	2.8	1.4 - 5.6
Textiles	2.8	1.4 - 5.6
Wood (untreated)	2.8	1.4 - 5.6
Wood (treated)	2.8	1.4 - 5.6
Total	126.6	63.3 - 253.1

Source: NAEI

Table 6.3: Domestic energy consumption by end use and fuel 2008

Fuel Type	Energy consumption (Thousand tonnes of oil equivalent)				
	Space heating	Water	Cooking	Lighting and Appliances	Total
Solid fuel	596	155	3	-	753
Gas	21,887	8,357	668	3	30,916
Electricity	1,455	1,501	625	7,236	10,818
Oil	2,305	725	3	-	3,033
Total	26,244	10,738	1,300	7,239	45,521

Source: Department of Energy and Climate Change - Energy Consumption in the UK Domestic data tables 2010 Update (including secondary analysis of data from the Building Research Establishment)

Table 6.4: Ownership of central heating by type in Great Britain 2007 (thousand properties)

Solid fuel	Electric storage	Other electric	Oil	Gas	Other	Total	All housing stock
265	1,060	856	939	19,858	481	23,459	25,360

Source: Department of Energy and Climate Change - Energy Consumption in the UK Domestic data tables 2010 Update - Domestic Energy Fact File and bespoke analysis of data supplied by the Building Research Establishment

In short, as well as domestic solid fuel, anything combustible can and probably is burnt on domestic fires of different types. The research undertaken by MORI indicates that a range of materials is burnt in different settings:

- **Domestic fires:** Paper, DIY waste material and cardboard are the most common items burnt. Of those that have an open fire, one in five said that they put DIY waste materials on their domestic fire once a month or less often, just 10% said they did so once a week
- **Domestic/garden bonfires and at allotments:** Untreated wood, garden waste and paper are the most common items burnt.
- **Community bonfires:** Untreated wood, garden waste and wooden furniture were the most common items burnt. However separate research in Northern Ireland indicated that 71% of material burnt on annual bonfires is trade waste, mainly wooden pallets and tyres (Bonfires, Environment and Heritage Service 2004).

The most frequently burnt items on bonfires were untreated wood (59%) and garden waste (46%), with treated wood such as furniture being mentioned by 25% of respondents. This was true across all types of bonfires that people had or had attended. This is in line with the qualitative research findings where participants felt bonfires were an environmentally friendly way to dispose of large quantities of garden waste.

Residents who held or attended bonfires also reported burning other items:

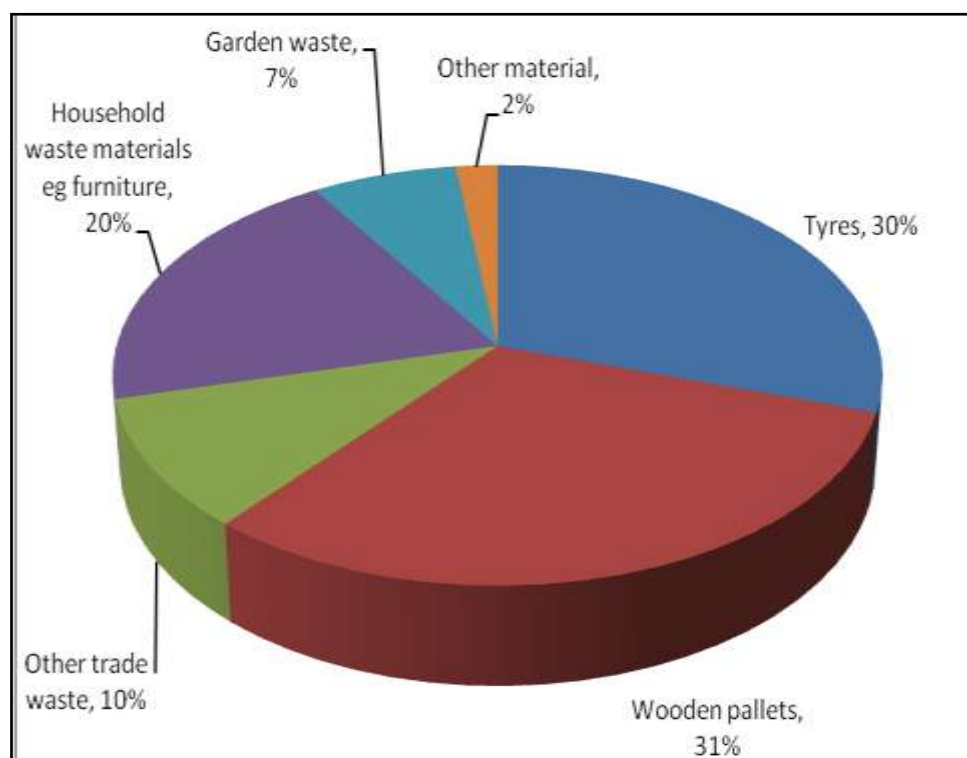
- Around a third (31%) said they had put paper on bonfires.
- Just over a quarter (26%) put wooden furniture on bonfires (treated wood disposed of this way is likely to have an impact on local air emissions).
- The qualitative work indicated that participants deliberately had bonfires in order to burn items of wooden furniture while paper and cardboard were often just added to bonfires.

This research is supported by earlier research from Northern Ireland which indicated a range of materials being burnt on bonfires at the time. One significant difference is a high proportion of tyres (30%) which may have been deliberately chosen because of the thick smoke given off when burning. Other materials burnt included wooden fencing, washing machines and fridges.

From the quantitative and qualitative research there seems to be general awareness that some materials were not suitable for burning indicating a tendency to avoid some materials:

- Respondents mainly identified plastic containers, plastic wrappers and rubber as unsuitable items for burning.
- The release of harmful fumes such as dioxins and a negative impact on air quality were thought to be the main impacts that could arise from burning unsuitable items. This is in line with respondents views around materials they burn on domestic fires. Respondents felt that the most likely impact from domestic fires would be on air quality.
- Nearly nine in ten (89%) of respondents were at least fairly concerned by the impact of dioxins as a result of what they burnt on either bonfires or domestic fires.

Figure 6.2: Main sources of bonfire materials in Northern Ireland:



Source: Bonfires, Environment and Heritage Service 2004

6.5 Summary and Recommendations for inventory update

The existing POPs inventory makes estimates for emissions to air and land make using a calculation model to derive activity data combined with literature emission factors for open burning of waste. The assumed quantity of waste burned per annum on open fires remains static at 299 kt for each year of the time series from 1990 – 2009. This quantity is split between open burning of wastes on fire places, general bonfires (bonfire night is categorized as a separate entry) and open burning of wastes within industry and construction. In order to make use of the current survey results to advise on recommendations for revising the calculation method it is necessary to understand the calculation method first.

Open burning of wastes on fire places

The open burning of waste on fire places accounts for 121 kt of the 299 kt total quoted. This is based on assumed quantities of waste generated and NAEI estimates for quantities of waste which would likely end up being burnt in an open fire place.

Quantities of waste generated per household have been based on a cross-comparison of the DETR's (Department of the Environment and Transport Regions)' municipal waste management review 1998/9 and an Integra review of waste habits in Hampshire around the same time. This provides the data in table 6.5 below:

Table 6.5 – Quantities of waste generation

Material	National Average quantity as kg per household per week	Percentage of total waste
Paper and card	4.7	28%
Plastic	1.9	11%
Textiles	0.65	4%
Miscellaneous (including nappies)	1.3	8%
Glass	0.85	5%
Metals	0.85	5%
finer	0.4	2%
Putrescible waste	6.25	37%
Total	16.9	100

The NAEI estimates assume that 75% of households will have open fires and that a proportion of the household waste generated each week will end up on such a fire together with other conventional fuels. In this case:

20% of the paper and card waste generated will be burnt.

5% of the plastic waste generated will be burnt.

5% of the textile waste will be burnt.

5% of the putrescible waste will be burnt.

Additionally it is assumed that 1% (0.5% treated 0.5% untreated) of household waste will be wood and 75% of this will be burnt. Table 6.6 displays the quantities of household waste burnt together with the emission factors and emission factor references for dioxins and furans and PCBs.

Bonfires

An NAEI review of available documents including the previously stated DETR report and the Environment Agency's waste burning survey from 2003 showed that between 5 – 9% of households had a viable bonfire site. The assumed figure is 7% or 1,730,610 homes based on 1999 UK stats. It is then assumed that these households will have a bonfire approximately 13 times a year, burning 6.25 kg of material (equal to the putrescible figure in table 6.5 above). This equates to 141 kt of material burnt.

This figure is then further sub-divided down into different waste groups in order to apply waste specific emission factors. Table 6.7 shown below provides details of the waste split for the 141 kt of waste quoted, along with the emission factors currently used and the reference source for those emission factors.

Table 6.6 Quantities of waste burnt on domestic open fireplaces and emission factors for air

Material	Quantity of burnt in the UK total	Percentage	Dioxin and furan emission factor	Reference	PCB emission factor	Reference
Paper and Card	75.6 kt	62 %	300 µg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;	1000 mg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;
Plastic	7.6 kt	6 %	300 µg/t		1000 mg/t	
Textiles	2.6 kt	2 %	300 µg/t		1000 mg/t	
Putrescibles	25.1 kt	20%	300 µg/t		1000 mg/t	
Wood (treated)	5 kt	5 %	59.05 µg/t	Derived emission factors based on AEAT/R/ENV/0301	-	
Wood (Untreated)	5 kt	5 %	0.24 µg/t	CPL ltd 2002	1.99 mg/t	

Table 6.7 Quantities of waste burnt on bonfires and emission factors for air

Material	Quantity of burnt in the UK total	Percentage	Dioxin and furan emission factor	Reference	PCB emission factor	Reference
Vegetation	126.5kt	90%	300 µg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;	1000 mg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;
Plastic (including filter bags)	2.8kt	2%	300 µg/t		1000 mg/t	
Paper and card	2.8kt	2%	300 µg/t		1000 mg/t	
Textiles	2.8kt	2%	300 µg/t		1000 mg/t	
Wood (Untreated)	2.8kt	2%	0.24 µg/t	CPL ltd 2002	-	
Wood (Treated)	2.8kt	2%	59.05 µg/t	Derived emission factors based on AEAT/R/ENV/0301	-	

Commercial, Industrial and construction open burning of wastes

The quoted NAEI estimates for quantities of waste burnt in the open for the commercial, industrial and construction industries are 37.2 kt. The activity estimates in this case are based upon the following research work: 'J. R. Bellingham, et al, 'The UK methane emissions inventory: A scoping study on the use of ambient measurements to reduce uncertainties, NPL (National Physical Laboratory), Report No DQM 98, January 1994'. Table 6.8 provides a full breakdown of the estimates with emission factors and emission factor references.

Recommendations.

The calculation method now detailed is used to make estimates of total activity as waste burned within household open fire places and open burning, with disaggregation for waste material and use of suitable emission factors to derive emissions. The activity value in this case (299kt) remains static across all years of the inventory as the act of waste burning will be variable from one year to the next. A static value therefore provides a best estimate of what is occurring out in the real world.

The survey results from the current study are an extremely useful guide to changing levels of activity and public perception of what should and shouldn't be burned. In this regard we would therefore suggest the following amendments to the calculation method to refine and improve current estimates based on the new results:

- Open burning in fire places
 - The current estimates assume that 75% of households have a fireplace and use this as a method to get rid of a proportion of their household waste. This value is likely too high and should be reduced.
 - The current estimates assume that 5% of plastic waste generated is burned on open fires, the current survey shows the general public have a good understanding of the issues surrounding burning of plastics, so again this is likely too high.
- Bonfires
 - The current estimates quote that approximately 7% of households have a viable bonfire site, with 13 events per annum. While the number of sites seems reasonable, the frequency of events seems too high.
 - Quantity of material burnt at each event is 6.75kg; the survey suggests fewer events but potential more waste burnt on each occasion.
 - The results show a potential variation in waste burning habits regionally, with trends in Northern Ireland notably different from other parts of the UK. The recommendation would be to further disaggregate the estimates from UK total to regional level and modify the proportion of waste types accordingly.
- Commercial and Industrial opening burning
 - The survey results have highlighted an issue with burning of 'business waste' by tradesman as a means of disposal. This would likely best reflect the construction industry proportion of the estimates.
 - Recommendations therefore at this stage would be to retain the estimates for these sectors as they are currently.

Table 6.8 Quantities of waste burnt in the open for commercial, industrial and construction with emission factors for air

Material	Quantity of burnt in the UK total	Percent age	Dioxin and furan emission factor	Reference	PCB emission factor	Reference
Commercial sector						
Paper and Card	15.4 kt	74%	300 µg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;	1000 mg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;
Plastics	4.2 kt	20%	300 µg/t		1000 mg/t	
Wood (treated)	0.1 kt	0.5%	59.05 µg/t		-	
Wood (untreated)	1.2 kt	5.5%	59.05 µg/t		-	
Industrial sector						
Paper and Card	4.1 kt	49%	300 µg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;	1000 mg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;
Plastics	2.8 kt	34%	300 µg/t		1000 mg/t	
Wood (treated)	0.4 kt	5%	59.05 µg/t		-	
Wood (untreated)	1	12%	59.05 µg/t		-	

Table 6.8 continued.

Construction and demolition sector						
Paper and Card	2.4 kt	30 %	300 µg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;	1000 mg/t	Coleman P., Conolly, C., Dyke, P. & Watterson, J., Toxic Organic Micropollutant Monitoring 1999 to 2000, AEA Technology, Report No AEAT/R/ENV/0301 Issue 1, March 2001;
Plastics	4 kt	50 %	300 µg/t		1000 mg/t	
Wood (treated)	0.8 kt	10 %	59.05 µg/t			
Wood (untreated)	0.8 kt	10 %	59.05 µg/t			

Annex

Annex I – References

Annex II – Table of improvements

Annex II – Waste burning habits questionnaire

Annex III – Results of the public survey into waste burning habits

Annex I – References

- 1 Dyke P, 'A review of PCDD/F Releases to Land and Water in the UK', AEAT Report for Environment Agency, UK.
- 2 LUA (1999) Releases of Dioxins to Land and Water in Europe
http://ec.europa.eu/environment/dioxin/pdf/stage2/dioxins_to_land_and_water.pdf
- 3 UNEP Toolkit (2005) Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases. This document, which covers dioxin emissions to air, land and water from various sources, was developed to promote more standardisation in national dioxin inventories. www.ipen.org/ipepweb1/library/DioxinToolkit.pdf
- 4 BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)
- 5 Environment Agency, "England and Wales: Incineration Throughput 2008," and Pollution Inventory records for 2008 obtained from www.environment-agency.gov.uk
- 6 England and Wales pollution inventory
<http://www.environment-agency.gov.uk/business/topics/pollution/32254.aspx> and
<http://www.environment-agency.gov.uk/homeandleisure/37793.aspx>
- 7 Jones et al, 2003 'Report on PCDD/Fs in samples of bag dust collected from galvanising plants in the United Kingdom. Report by Lancaster University to the Galvanizers Association.
- 8 <http://www.bgs.ac.uk/mineralsuk/statistics/UKStatistics.html>
- 9 <http://eippcb.jrc.es/reference/>
- 10 Lexen et al, 1993, 'Dioxin and furan levels and patterns in samples from the Swedish industries analysed within the Swedish dioxin survey' Chemosphere col. 27 pp 163 - 170
- 11 Bremmer et al, 1994, Emissions of dioxins in the Netherlands, TNO report
- 12 Cynthia De Wit, 1996, Personal communication to Patrick Dyke at AEA
- 13 Byeong Woon et al, 2005, 'Emissions of dioxins and furans and dioxin like PCBs from metallurgy in South Korea' Chemosphere vol.62 pp494 -501
- 14 Minghui zheng et al, 2009, 'Estimation and Characterization of dioxins and dioxin-like PCBs from secondary copper and aluminium metallurgies in China. Chemosphere vol. 75 pp 1173 - 1178
- 15 Strandell et al, 1994, 'The Swedish dioxin survey: summary of dioxins and furans and coplanar PCBs analysis in source-related samples', Organohalogen chemicals vol.20 pp 363 – 366
- 16 UK NAEI (United Kingdom – National Atmospheric Emissions Inventory) - <http://naei.defra.gov.uk/>
- 17 Hexachlorobenzene – Sources, Environmental fate and risk characterisation, Jones K et al, Eurochlor dossier, 2005
- 18 Bailey RE (2001), "Global hexachlorobenzene emissions," Chemosphere 43 pp 167-182
- 19 EU court rules against Vischim on chlorothalonil', Agrow no 579, November 2009
http://www.agrow.com/multimedia/archive/00084/Agrow_579_84933a.pdf
- 20 Defra Pesticide Usage Survey report 224 (2008)
www.fera.defra.gov.uk/plants/pesticideUsage/.../arable2008.pdf
- 21 "Determination of hexachlorobenzene and decachlorobiphenyl in technical formulated chlorothalonil", by the Pesticide Management Group of the FAO Plant Protection Service as

stated in the FAO specifications for chlorothalonil.

<http://www.fao.org/ag/AGP/AGPP/Pesticid/Specs/docs/Pdf/new/Chlorothalonil07.pdf>

22 Stevens, Joanna et al, 2001, 'Survey of PCDD/Fs and non-ortho PCBs in UK sewage sludges' Chemosphere vol 44 pp 1455-1462

23 Sweetman, Andrew, 2005 'Polychlorinated Biphenyls: fate and behaviour during the wastewater treatment process'. Unpublished paper supplied to AEA.

24 Martin Van den Berg et al, 2006, "The 2005 World Health Organization Re-evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds", Toxicol. Sci. (October 2006) 93 (2): 223-241.

25 Blanchard et al, 2004, 'Polycyclic aromatic hydrocarbons and polychlorinated biphenyls in wastewaters and sewage sludge from the Paris area (France). Environmental Research vol 95 pp 184-197

26 Personal communication with water treatment works, 2010.

27 Ofwat June 2009 return of Water statistics report.

http://www.ofwat.gov.uk/regulating/junereturn/jrhistoricdata/prs_web_jr09

28 Personal communication with Dr. A. Sweetman Lancaster Environment Centre, 2010

29 Hagenmaier, H, 1992, 'Analysis of sewage sludge for polyhalogenated dibenzo-p-dioxins, dibenzofurans and diphenyl ethers', Chemosphere, vol 25 pp 1457-1462

30 Bremmer H J, 1994. 'Emissions of dioxins in the Netherlands. Report No. 770501003, RIVM (Research for Man and the Environment), Bilthoven, Netherlands.A

31 Sewart, A, 1995 ' PCDD/Fs and non-ortho PCBs in digested UK sewages sludges', Chemosphere vol. 30 pp 51-67

32 Jenseit (1999) Personal communication to LUA (see ref 2), on behalf of Eurostat (Maila Puolamaa). Comments on draft report (March 1999) (Received 21 June 1999).

http://ec.europa.eu/environment/dioxin/pdf/stage2/dioxins_to_land_and_water.pdf

33 Hazardous Substances Database - <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB>

34 Robles Molina (2010), 2010 'Determination of organic priority pollutants in sewage treatment plant effluents by gas chromatography high-resolution mass spectroscopy', Talanta volume 82, pp1318 -1324

35 United Utilities – Davyhulme home page. -

<http://www.unitedutilities.com/bioprocessing.aspx>

36 Gardener MJ, 2008, WRc report for AEA, 'Sources and emission of persistent chlorinated pollutants to the water environment'-

37 Thames – Mogden works home page -

<http://www.thameswater.co.uk/cps/rde/xchg/corp/hs.xsl/883.htm>

38 Previous POPs report -

<http://archive.defra.gov.uk/environment/quality/chemicals/documents/dioxins-report100630.pdf>

39 EA survey of waste burning habits from 2003

Annex II – Table of improvements

The table presented below details all of the improvements to activity, and factors made as a result of the current programme of works. This table also sets out the values previously used.

NFR Category	Description	Value type	Old value	New Value	Comment
2C3	Secondary Aluminium Manufacture	Ash generation factor	20.9 kg/t of aluminium	10 kg/t of aluminium	Previous factor was based on literature value. The new factor is based on consultation with UK industry and represents a closer match to current working practices.
2C3	Secondary Aluminium Manufacture	Emission vector.	100% to landfill.	79% (1990) 5% (2010) linear decrease	Previous estimates assumed all waste generated was landfilled, new data from consultation with industry shows waste largely recycled. The estimates have been modified to show the material is now split across two vectors (Land/product)
2C3	Secondary Aluminium Manufacture	Emission factor (dioxins and furans) (land)	10 g I-TEQ/kt of ash	5 g I-TEQ / kt of ash (1990) 1.4 g I-TEQ/kt of ash 2010) linear decrease	Previous Emission Factor was based on literature factors as closest match to industry in lieu of better data. The new factor is based on monitoring at UK plant and represents best match, 1990 value based on BREF note value with assumed process improvement over 20 year span.
2C5a	Copper alloying and semis	Emission vector	100% to landfill	79% (1990) 1% (2010) linear decrease	Previous estimates assumed all waste generated was landfilled, new data from consultation with industry shows waste largely recycled. The estimates have been modified to show the material is now split across two vectors (Land/product)
2C5b	Secondary Lead Manufacture	Ash generation factor	20.9 kg/t of lead	2 kg/t of lead	Previous factor was based on literature value. The new factor is based on consultation with UK industry and represents a closer match to current working practices.
2C5b	Secondary Lead Manufacture	Emission vector	100% to landfill	79% (1990) 5% (2010) linear decrease	Previous estimates assumed all waste generated was landfilled, new data from consultation with industry shows waste largely recycled. The estimates have been modified to show the material

A further update of the UK source inventories for emissions to air, land and water of dioxins, dioxin-like PCBs, PCBs and HCB, incorporating multi-media emission inventories for nine new POPs under the Stockholm Convention

NFR Category	Description	Value type	Old value	New Value	Comment
					is now split across two vectors (Land/product)
2C5b	Secondary Lead Manufacture	Emission factor – (dioxins and furans) (land)	17.7 g I-TEQ/kt of ash	15 g I-TEQ/kt of ash	Previous emission factor was based on default value for metals in lieu of better data. A review of the sector has shown that this value is likely too high and has been revised to a new literature value of '15' g I-TEQ/kt of ash. UK monitoring data unavailable.
2C5e	Hot dip galvanising (new source)	Emission factor – (dioxins and furans) (land)	-	4.6 g I-TEQ/kt of ash	Hot-dip zinc galvanising is a new source identified under the current programme of works. The activity data has been based on one estimated UK out-put against the UK mineral handbook. The emission factor is based on UK monitoring.
4G	Use of pesticide products (chlorothalonil)	Emission factor – (HCB) (all vectors)	40 mg/kg of active	40 mg/kg of active (1990) 8 mg/kg of active (2010) linear decrease	Previous emission factor was based on the UK legal limit for HCB in chlorothalonil. A programme of sampling and analysis has now derived new UK working concentrations.
6A	Disposal of sewage sludge to land	Emission factor – (PCB) (land)	0.44 kg/kt of sludge	0.44 kg/kt of sludge (1990) 0.042 kg/kt of sludge (2010) linear decrease.	Previous emission factor was based on a 2000 sampling and analysis review of sludges. The review from the current programme of work shows a 90% decline in emission factor over 10 years.
6Ca	Clinical waste incineration	Ash generation factor	3% wt/wt	19% wt/wt (9.5% APC residue, 9.5% bottom ash)	Previous estimates for ash generation were based on a survey by the environment agency in 2003. These have been updated (to all years) based on latest round of industry consultation.
6Ca	Clinical waste incineration	Emission factor (dioxins and furans) (land)	450 g I-TEQ/mt of waste burnt* new calculations based on different method	0.07 g I-TEQ / mt of ash.	Previous emission factor was based on the UNEP toolkit against quantity of waste burnt. The current programme of work has looked to better understand quantities of ash (as air pollution control residue) and monitoring data to provide true UK centric estimates.
6Cb	Chemical waste incineration	Ash generation factor	3% wt/wt	6.88% (2.28% fly ash and 4.60% bottom ash)	Previous estimates for ash generation were based on a survey by the environment agency in 2003.

NFR Category	Description	Value type	Old value	New Value	Comment
					These have been updated (to all years) based on latest round of industry consultation.
6Cb	Chemical waste incineration	Emission vector	100% to landfill	79% to landfill (1990) 1% to landfill (2010)	Previous estimates assumed all waste generated was landfilled, new data from consultation with industry shows waste largely recycled. The estimates have been modified to show the material is now split across two vectors (Land/product)
6Cb	Chemical waste incineration	Emission factor (dioxins and furans) (land)	1.88 g I-TEQ/mt of waste burnt* new calculations based on different method	0.02 g I-TEQ/mt of ash	Previous emission factor was based on a literature value against quantity of waste burnt. The current programme of work has looked to better understand quantities of ash (as air pollution control residue and bottom ash) and monitoring data to provide true UK centric estimates.
6Ce	Domestic combustion of waste in the open	Activity Data (affects all vectors)	299 kt	145 kt	The calculation for 'activity' in terms of domestic waste burning is based on a set of parameters including number of households with a viable burning site, frequency of bon fires, quantity of material burnt at each event, nature of material burnt at each event. The previous estimates derived a value of 299 kt per annum. The survey of the UK public suggests that there are less burning events with potential more at each occasion. However the sum of these different variables shows a reduced quantity of waste (145kt). This value has been applied to all years.

Annex III – Waste burning habits questionnaire

Objectives:

The objectives of the interviews are to explore:

- What waste is burnt on bonfires and how much of it and how often.
- Whether people burn waste on fires in their homes
- What potential issues could arise from these activities
- What would make people reduce their waste-burning activities or change what they burn.

Moderator note:

These interviews are with members of the public who participate in bonfires, either building them themselves, in their back garden or at an allotment. Some people will also have open fires in their home.

Key Questions	Purpose	Moderator notes	Approx timing
1. INTRODUCTION			2 mins
▪ Thank participants for agreeing to be interviewed. ▪ Confirm that the interview will last an hour max. ▪ Introduce self, Ipsos MORI – role as independent research organisation, gather all opinions. ▪ Explain that a £30 incentive is a thank you from Ipsos MORI for taking part in the research. ▪ Introduce Defra as the client. ▪ Explain the aim of the discussions: <i>The interview is designed to discuss the use of bonfires and open fires in your neighbourhood or on your allotment – there are no right and wrong answers, we're just interested in finding out about your experiences, views and opinions.</i> ▪ Confidentiality: reassure responses will be anonymous and that information about individuals will not be passed on to anyone. ▪ Demographics	This section will be used to introduce the research to the participant again. Ensuring they understand confidentiality issues and the voluntary nature of the research		
2. General life and neighbourhood			5-10 mins
I'd like you tell me a bit about yourself, what do you do? PROMPT: work, family etc	This section will explore their general life and what they think of their		

Key Questions	Purpose	Moderator notes	Approx timing
I'd like to find out a bit about your local area and what it's like to live here. How long have they lived in the area? What do they like or dislike? Would you say you are active in the community? Do you take part in any community activities PROMPT: Local church, scouts, seasonal events - probe for mentions of bonfires/fireworks displays. What are these like? Do many people go? What do you think of local services generally? PROMPT: Waste disposal. Thinking specifically about waste disposal in this area, can you tell me how it works, i.e. is there a wheelie bin service? How often are the collections? Do they take everything / What do they refuse to take? Are there limitations on waste? Are there charges? How do you dispose of bulkier items, e.g. old furniture, computers? Do you have a collection service for this? How easy is it to dispose of these items? Do you have a recycling service? How does this work? (Are there wheelie bings/bags/boxes) How often are the collections? What can you recycle? How easy do you find it to recycle?	neighbourhood, particularly relating to community and waste.		

Key Questions	Purpose	Moderator notes	Approx timing
What would make it easier? Do you think there are any issues or problems when it comes to waste disposal in this area? Do you see a lot or any fly-tipping?			
3. ALLOTMENT HOLDERS ONLY			5-10 mins
I'd like you to tell me about your allotment. Where is it? How often do you go there? What do you grow? Would you say there is a sense of community with other allotment owners? Do you get together for social events? Do you hold bonfires at the allotments? Who takes part in these? How often do these happen? How big are these bonfires? Why do you have them? What do you mainly burn on these bonfires? PROMPT: Garden waste, wood Do you ever burn or have you ever seen burnt any of the following items? SHOWCARD A <i>Moderator note: If participant says yes to any on the showcard, probe on the following:</i> What was the material?	This section explores the burning activities of allotment holders. What do they burn and how often and why.		

Key Questions	Purpose	Moderator notes	Approx timing
How much was burnt? Why was it burnt? (e.g. old furniture or old containers) Is it hard to dispose of any other way? PROMPT: Poor recycling or waste disposal facilities in the area. Does it happen often when you have these bonfires? How often do you/others burn this type of item?			
4. THOSE WHO HAVE PARTICIPATED IN ANY BONFIRE EITHER IN THEIR OWN GARDEN OR A COMMUNITY BONFIRE (not allotment holders).			5-10 mins
I'd like you tell me about the bonfire you went to / had? When was this bonfire? How big was the bonfire? <i>IF NOT BUILT BY THE PARTICIPANT:</i> Who organised the bonfire? Who built the bonfire How many people attended the bonfire? What was burnt on the bonfire? PROMPT: Wood, furniture, garden waste. Were any of the following burnt on the bonfire? SHOWCARD A <i>Moderator note: If participant says yes to any on the showcard, probe on the following:</i> What was the material? How much was burnt? Why was it burnt? (e.g. old furniture or old containers) Is it hard to dispose of any other way? PROMPT: Poor recycling or waste disposal facilities in the area. <i>GO THROUGH FOR EACH ITEM MENTIONED</i> How often do you/others burn this type of item?	This section explores the burning activities of anyone who has participated in a bonfire, either holding it themselves. What did they burn, how and why.		

Key Questions	Purpose	Moderator notes	Approx timing
5. THOSE WHO HAVE OPEN-FIRES IN THEIR HOME - USE INFORMATION FROM RECRUITMENT FOR WHICH APPLIANCE THEY HAVE			5-10 mins
IF PARTICIPANT HAS AN OPEN-FIRE or WE DO NOT KNOW THE TYPE OF FUEL THEY USE Ask to see the appliance What type of fuel do you mainly use for your open-fire / stove? PROMPT: Wood, coal, chips, gas. How often do you use it? What do you use it for? PROMPT: A main source of heating, additional heating, decorative. Aside from the main fuel you use, do you ever burn anything else on the fire/stove? PROMPT: Kitchen waste, small amounts of rubbish, fire-lighters, newspaper, magazines. Do you ever burn any of the following items on your fire/stove? SHOWCARD B <i>Moderator note: If participant says yes to any on the showcard, probe on the following:</i> What was the material? How often would you say you burn this? DEPENDING ON HOW OFTEN, FRAME THE NEXT QUESTION, E.G. ONCE A WEEK How much would you say you burn? Why did you burn this on the fire/stove? (e.g. convenience, the fire is nearby) Is it easier to put it on the fire/stove than throw away? PROMPT: Poor waste disposal facilities / recycling GO THROUGH FOR EACH ITEM MENTIONED	This section explores the burning activities of those with open fires in their homes - looking at what they burn, how much, how often and why		

Key Questions	Purpose	Moderator notes	Approx timing
6. Issues with burning waste			10-15 mins
Thinking about the bonfires we have talked about have you ever received or heard about any complaints being made related to these bonfires? If yes, what were these complaints about? PROMPT: Smoke / smell / fumes What was your reaction to the complaint? If no, do you think there is anything that people might complain about relating to the bonfires we have talked about? <i>Moderator note: If they have both attended a bonfire and held one themselves please probe for answers on both.</i> Have you ever made a complaint about a bonfire? IF YES; What was the complaint about? How did you make the complaint? Why was that problem an issue for you? Do you think there are any potential issues with bonfires? What do you think these are? PROMPT: Smoke, pollution, health risks If no, why do you think there are no issues? How serious, if at all, do you think these issues are? <i>NB Moderator - PROBE FULLY on which issues they think are most important and why.</i> IF NOT MENTIONED: What does the term ‘dioxins’ mean to you? Where have you heard the term before?	This section will look at people's perceptions of burning waste on bonfires / fires in the home. What they think potential issues are.		

Key Questions	Purpose	Moderator notes	Approx timing
What does it make you think of? Give them the definition: By dioxins we mean XXX I'd now like to discuss with you some of the issues that are associated with bonfires or burning waste on open fires. <i>MODERATOR: Please go through each issue and probe fully on how important these seem to the participant and why.</i> - How important is this issue to you? - Do you think your bonfires would contribute to this? - Is this			
7. Changing behaviour			5-10 mins
Do you think that any of the issues we have talked about would change the way you take part in or hold bonfires? If yes: What would you change? How often you have bonfires? What you burn on bonfires? Why would you make these changes? How easy do you think it would be to make those changes? What would make it easier for you to make these changes? <i>MODERATOR NOTE - Please keep in mind what they thought about waste disposal facilities in their area / were there any issues?</i> PROMPT: Better waste disposal facilities / better recycling	This section will look at the potential ways the issues highlighted in the previous section would change people's behaviours and what would change, how and why.		

Key Questions	Purpose	Moderator notes	Approx timing
What would stop you making these changes? PROMPT: Poor facilities, enjoyable, fun			
8. Campaign			5 mins
If there was to be a campaign to target these issues how do you think this should be delivered? PROMPT: Television, radio, newspapers. IF THEY ARE AN ALLOTMENT HOLDER/TAKE PART IN A COMMUNITY BONFIRE: What about face to face? Do you have a network of allotment holders / community events? Would that be a good way to highlight the campaign to people? <i>MODERATOR NOTE: Probe fully to find out the best channel for this type of campaign, what would make it most effective</i> How do you think these issues could be addressed? Do you think this would make people change the way peoples bonfire activities? What do you think would change? What do you think would make people change? Of all the issues we have discussed, which do you think would be most likely to make people change? What about pollution / potentially harmful fumes? Do you think these are important to people? Why / Why not?	This section explores what participants think of the idea of a campaign to reduce waste burning activities.		

Key Questions	Purpose	Moderator notes	Approx timing
9. Conclusion and thanks			2 mins
Thank you very much for your time today, I have covered everything I need to is there anything else you would like to discuss or add? THANK PARTICIPANTS - SIGN OFF INCENTIVE	Wrap up, gives participants the opportunity to feedback on any thoughts not covered in the discussion so far		

Annex IV – Full Results of the waste burning habits survey

Objectives and approach



Methodology – An overview (1)

- Ipsos MORI conducted both quantitative and qualitative research to investigate what people burn on different types of fires (open fires, agas, boilers and bonfires either held, at home, allotments or within the community) why they do so and what could be done to discourage the burning of unsuitable materials.
- The quantitative research was conducted using Ipsos MORI's face-to-face omnibus survey, Capibus. Capibus is run weekly and interviews 2,000 residents across Great Britain. The questionnaire is delivered using hand-held computers. Once completed, results are then weighted to be nationally representative.
- Ipsos MORI first conducted a pilot survey on Capibus to establish how many people across Great Britain had domestic fires or bonfires in the last 12 months.
- The purpose of the pilot was to establish the feasibility of running a quantitative survey using Capibus. Subsequently we interviewed a nationally representative sample of 1,000 adults as this was more cost-effective.
- One question was asked to determine whether people had open fires, agas, wood burners or other domestic fires and another to determine whether people had bonfires either at their own property, someone else's, at allotments or attended community bonfires.
- The pilot showed, on average, around 18% (360 people) of those contacted would have either a domestic fire or had / attended bonfires.

Methodology – An overview (2)

- After the pilot survey, 10 depth interviews were conducted across England (in the North West, North East and South East) to explore in depth people's behaviour and the reasons behind it. The findings from these interviews informed the design of the quantitative questionnaire.
- Finally, a 10 minute questionnaire was run on our face-to-face omnibus, Capibus. The questionnaire was run on Capibus for two weeks. This meant the survey was asked of a total of 4,000 people.
- Further to this, the questionnaire was also run on Nbus, Ipsos MORI's face-to-face omnibus survey in Northern Ireland for one week. This survey contacts 60 people, every week, across the country.
- Results from both the qualitative and the quantitative research were analysed together to identify what people burn on domestic fires or bonfires, why they do this, what issues are felt to arise from doing so and how any campaign to target such behaviour could be delivered.

Methodology - Qualitative

- 10 depth interviews were conducted in total with 3 in the North West, 3 in the North East and 4 in the South East
- Interviews were achieved with the following people:

Male	6
Female	4
16-34	2
35-54	5
55+	3

Allotment holder	6
Not allotment holder	4
Had bonfire at home	7
Attended community bonfire	1
Had domestic fires	5
Did not have domestic fires	5

Methodology - Quantitative

- We used our face to face omnibus, CAPIbus for this survey, contacting 2,000 respondents each week for 2 weeks across Great Britain.
- The pilot survey showed an incidence of 18% so we expected around 720 residents (across the two weeks) to have had bonfires or have domestic fires.
- We also ran the questionnaire on our face to face omnibus in Northern Ireland, Nbus, contacting 60 respondents.
- In total, 834 interviews were achieved across Great Britain and Northern Ireland so the incidence was slightly higher than anticipated with just over 20% saying they had domestic fires or had / attended bonfires.
- The results have been weighted to ensure they are nationally representative.
- The standard regions were defined as follows:

North	North East, North West, Yorkshire and Humberside, Scotland
South	South East, South West
Midlands	West Midlands, East Midlands, East Anglia, Wales

Objectives (1) – People's behaviour

The following research objectives were set to gain insight into people's behaviour:

- To explore the items people burn on bonfires and domestic fires.
 - What are these items?
 - Which are they most likely to burn?
 - How often do they do this?
- To establish which items people think are suitable/unsuitable to burn.
 - Is the burning of unsuitable items regarded as an issue in their area?
 - Is there a lack of understanding of which items are unsuitable?
- To understand why they do this.
 - What are the key reasons people burn items on bonfires or domestic fires?
- To establish what would discourage them from burning such items.
 - What would prevent people from burning items on bonfires or domestic fires?

Objectives (2) – The Campaign

The following research objectives were set to establish grounds for a campaign and how it could be delivered:

- To establish whether a campaign is needed and how it should be delivered.
 - Do people think burning unsuitable items is a cause for concern?
 - What issues should a campaign address?
 - What would make a campaign most effective?
- To identify any key audiences as a target for a campaign.
 - Are there any types of people who are more likely to burn unsuitable items?
 - Could a campaign easily target certain groups?

Who has domestic fires and bonfires? A SUMMARY



Summary

- Around one in five respondents (22%) either used a domestic fire or had a bonfire in the last 12 months.
- Within the adult group aged 25-64, age is not a factor for determining inclination to have a bonfire.
- Those in the North of England were more likely to have bonfires, whereas people living in the South of England tend to have more domestic fires.
- Further to this, those living in rural areas were more likely to have bonfires or domestic fires.
- Those who attended community bonfires or had bonfires at home tended to do so once a year or less.

Who has domestic fires and bonfires? Profiling respondents



Who has bonfires and domestic fires?

- In total just over one in five (22%) adults across Great Britain and Northern Ireland (aged 15+) said they had either used a domestic fire or had a bonfire in the last 12 months.
 - Around one in ten (11%) adults across Great Britain and Northern Ireland reported they had domestic fires and slightly more had or had attended a bonfire (15%) in the last 12 months.
 - Nearly one in twenty (4%) respondents said they had both a domestic fire and a bonfire.
- This indicates a **small target audience** for any campaign aimed at preventing people burning items on such fires.
 - Further to this only 4% of those who had bonfires said they used these more than once a month. This indicates an even smaller target audience of those who are burning unsuitable items regularly on their domestic fires.
- Older respondents (those aged 65+ yrs) were significantly less likely to have had a bonfire in the last year (9% compared to 15% across the UK adult population).
 - These respondents were also less likely to have a domestic fire, 7% compared to 11% across the UK adult population).
- People who had bonfires or domestic fires were more likely to be in higher social grades, earning more than £25,000 per year and to read broadsheets.

Who has bonfires or domestic fires – Regional analysis

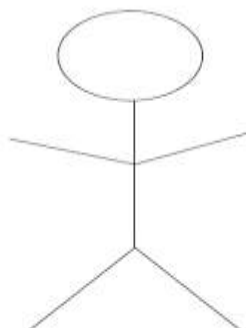
- There was a higher prevalence of domestic fires, especially open-fires in Northern Ireland with around a third (32%) saying they had these.
- Residents in the North of England were significantly more likely to have had a bonfire in the last 12 months (18% compared to 15% across the UK adult population).
- Respondents living in rural areas were significantly more likely to have both bonfires or domestic fires of any kind
 - In particular, those who live in rural areas were more likely to have open-fires (11%), wood burners (5%) or to have attended a community bonfire (10%) in the last 12 months compared to those living in urban areas and the population as a whole.
 - A higher proportion of people living in the South of England live in rural areas compared to the North of England. This could explain why they are more likely to have a domestic fire (16% compared to 11% of the British population). Those in Scotland and London were least likely to have domestic fires (5%).



A profile of those with domestic fires

Most likely to be aged 35-54

Tend to be in higher social grades – ABC1 and earning more than 25k per year.



More likely to live in rural areas

Higher proportion living in Northern Ireland*

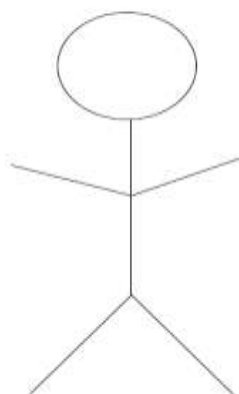
Tend to read broadsheets.

A profile of those who have bonfires

More people living in the North of England are likely to have bonfires than any other region

More likely to live in rural areas

Tend to be in higher social grades – ABC1 and earning more than 25k per year.



Those aged 45-54 are more likely to have bonfires at home

Those aged 25-44 are most likely to attend bonfires held in the community

Tend to read broadsheets.

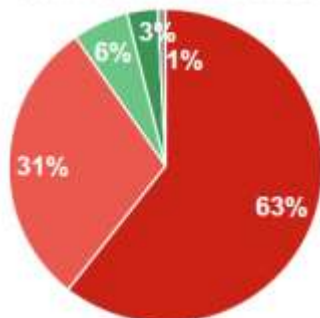
How often do people have bonfires?

- Most respondents who had bonfires at home or attended community bonfires tended to do so once a year or less.
 - This was particularly true for those who attended community bonfires with nearly nine in ten (88%) saying they did so once a year or less.
- Only 4% of those who had bonfires said they did so once a month or more often.
- Respondents who had bonfires at allotments did so more often.
 - Over half (56%) of those who had bonfires at allotments said they did so at least twice a year compared to 36% of those who had bonfires at home.

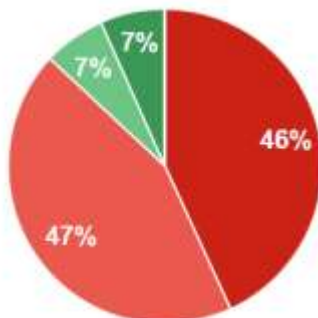
How often do people have bonfires

Q2 Thinking about the last 12 months, on average how often have you....

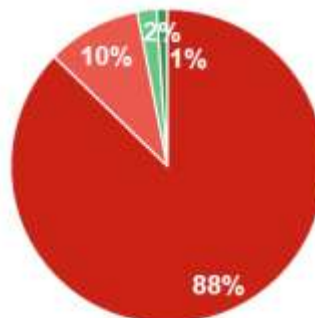
had bonfires at home/someone else's?



had bonfires on your allotment?*



attended a community bonfire?



■ % once a year or less ■ % every 2-3 months – 6 months
■ % once a month ■ % more than once a month ■ % don't know

Ipsos MORI Base: 408 – Those who had bonfires at home or someone else's, 41 – Those who had bonfires at their allotment, 298 – Those who have attended a community bonfire, 7th – 17th June *Indicates low base size

Source: Ipsos MORI



What do people burn? A SUMMARY



Summary

- Paper, DIY waste material and cardboard are the most common items put on domestic fires.
- Untreated wood, garden waste and paper are the most common items put on bonfires at home, at someone else's, and at allotments.
- Whereas on community bonfires, untreated wood, garden waste and wooden furniture were the most common items to be burned.
- 26% of people working in trades such as building, joinery, carpentry, plumbing, gardening, farming or working as general 'handymen', burnt leftover material from work. These results could highlight a potential target audience for any campaign.

What do people burn? DOMESTIC FIRES



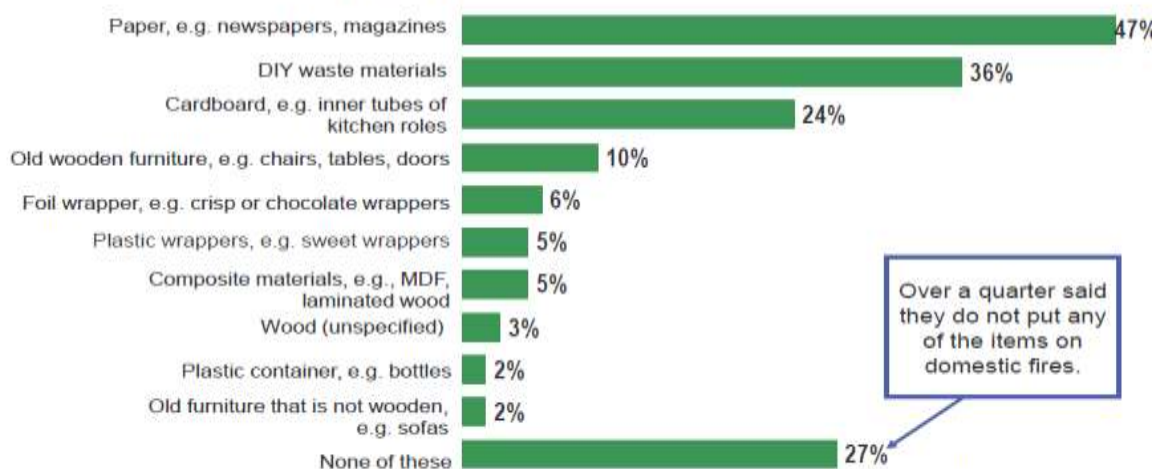
Paper and DIY waste materials are most common items people put on domestic fires

- Paper, DIY waste materials, such as leftover wood, and cardboard are the most common items aside from fuel put on domestic fires (for full show card please see appendix 1 – slide 93).
- This is in line with the qualitative findings where participants said they often used paper or cardboard to help light fires.
- The qualitative work showed people tended to refer to leftover wood when speaking about DIY waste materials. However this was not defined as such in the quantitative survey which could mean other miscellaneous materials may be included in respondent's definition of this.
- Further to this, **over a quarter (27%) of residents with domestic fires said they never put the items listed on fires.**
- There were **no significant differences across the demographics** to show certain people are more likely to burn particular items on domestic fires.



Paper and DIY waste materials are most commonly put on domestic fires

Q6 Which if any of the following items do you ever put on/in your open fireplace/Aga/wood burner/boiler?



Source: Ipsos MORI

Ipsos MORI Base: 384 Those who have open fireplace/aga/burner/boiler, 7th – 17th June 2010

24

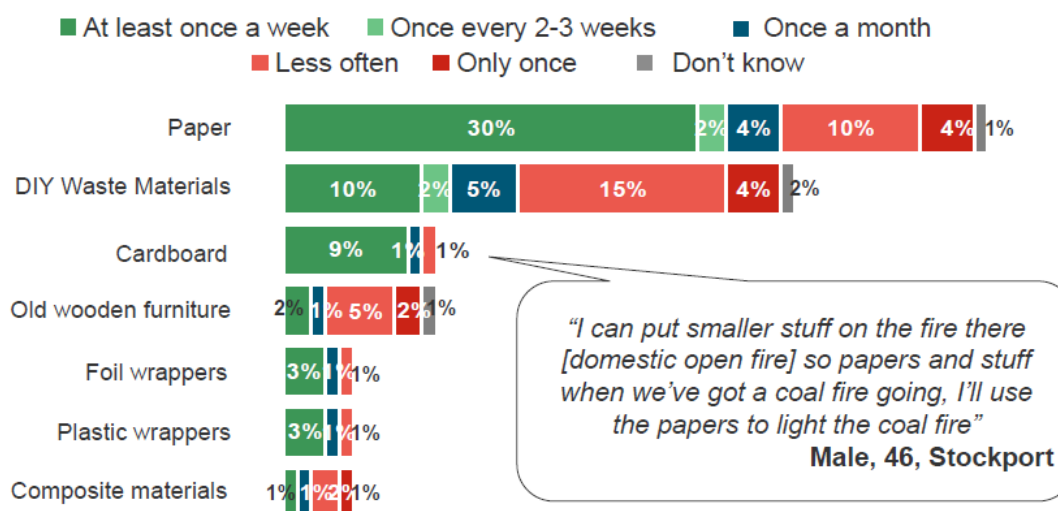
People regularly burn paper on domestic fires

- Certain items were more regularly put on domestic fires, such as paper with 30% of respondents saying they put paper on their fire at least once a week.
 - This drops to around one in ten (10%) of respondents who said they burn DIY waste at least once a week and just under one in ten (9%) who said they burn cardboard this often.
- One in five (20%) said they put DIY waste materials on their domestic fire once a month or less often.
- This means effectively targeting a campaign at those who burn unsuitable items regularly, would be challenging, as the audience is small.



People burn paper most often

Q7 Thinking about the time of year you use your open fireplace/Aga/wood burner/boiler how often do you put the following on it...



Source: Ipsos MORI

Ipsos MORI Base: 296 Those who have put items on domestic fires, 7th – 17th June 2010

Ipsos 26

What do people burn on bonfires?



Garden waste and untreated wood are most commonly burnt on bonfires

- The most frequently burnt items on bonfires were wood that has not been treated (59%) and garden waste (46%). This was true across all types of bonfires that people had or had attended. (please see Appendix 2 – slide 95 - for full show card)
- This is in line with the qualitative work where participants felt it was an environmentally friendly way to **dispose of large quantities** of garden waste.
- The **promotion of composting** as an alternative and environmentally friendly way to dispose of garden waste could be incorporated into a campaign.
- Residents who held or attended bonfires also reported burning other items:
 - Around a third (31%) said they had put paper on bonfires.
 - Just over a quarter (26%) put cardboard or wooden furniture on bonfires.
- The qualitative work showed participants said they often had bonfires simply in order to burn items of wooden furniture while paper and cardboard were often just added to bonfires.



Very few respondents had put plastic or rubber on bonfires

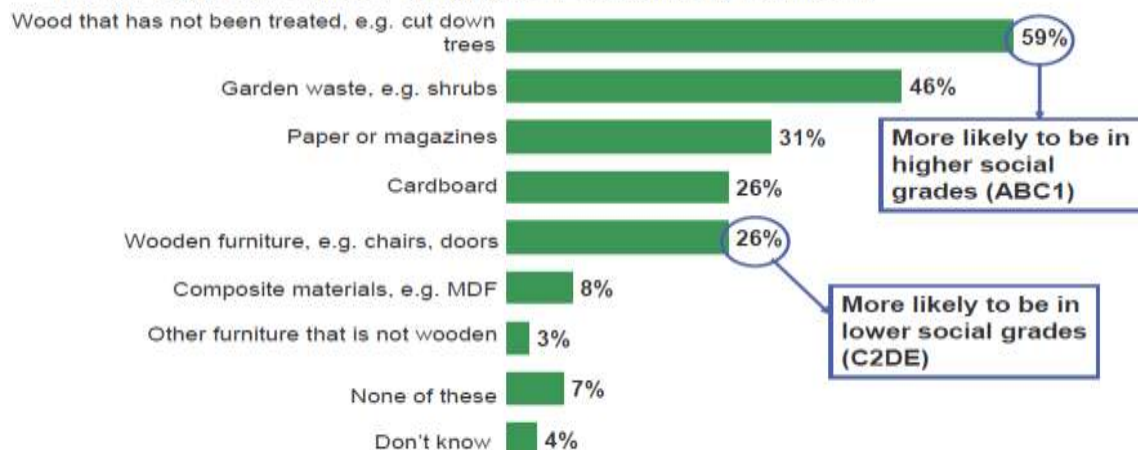


- In line with the qualitative work, a very low proportion of those who had bonfires reported that they had put plastic or rubber on these with just 1% saying they had.
- Similarly, those who would put furniture that was not wooden on bonfires was only 3%.

"I wouldn't put anything with plastic in or rubber that would cause very thick, noxious black smoke. I don't think that's fair. I'm very conscious of that and I suppose most people who have fires around here probably think the same way"
Male, 46, Stockport, not allotment holder

What do people burn on bonfires?

Q6 Which if any of the following items do you ever put on your bonfire at home/ someone else's/ allotments / community bonfires?



Source: Ipsos MORI

Ipsos MORI Base: 583, Those who have or have attended bonfires, 7th – 17th June

Ipsos 30

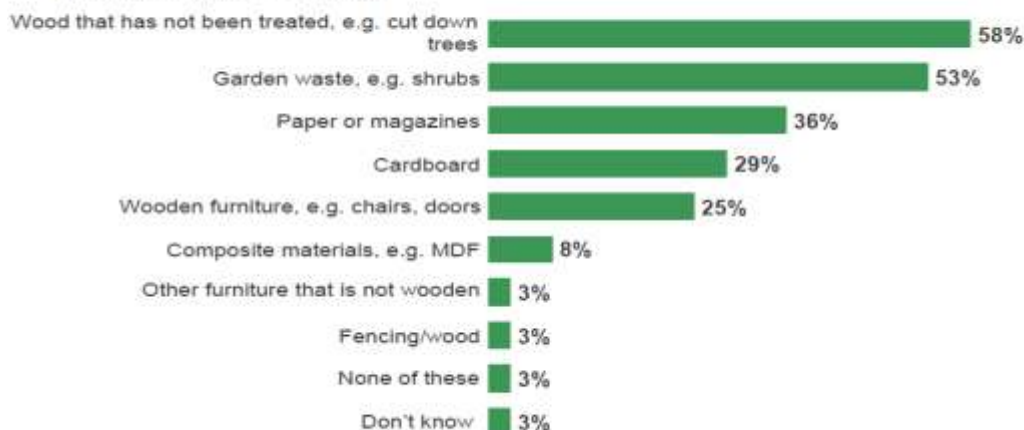
Differences in what people burn on different types of bonfire

- There were very few differences across the different types of bonfires in relation to what people burnt on them.
- **Garden waste was less likely to be put on community bonfires** with just over a third (36%) saying it had been, compared to over half (53%) of those who had bonfires at home and nearly two-thirds of those who had allotment bonfires (65%).
- Around a third (31%) of residents who had bonfires burnt cardboard or paper
- Across all bonfires around one person in every fourteen (7%) said they would not put any of the items on the show card on a bonfire.
- Significantly, more people who attended community bonfires did not know what items had been put on the bonfire; 12% compared to 3% of those who had bonfires at home and 1% of those who had allotment bonfires.
- This could be due to the fact respondents said they only attended these types of bonfires annually so there may be issues with recall.
- However it could also be that these types of bonfires are organised officially and therefore respondents may have had less control regarding what was burnt. **This could indicate a need for a campaign to target those who organise community bonfires.**



What people burn on bonfires at home/ someone else's

Q6 Which if any of the following items do you ever put on your bonfire at home/ someone else's?



Source: Ipsos MORI

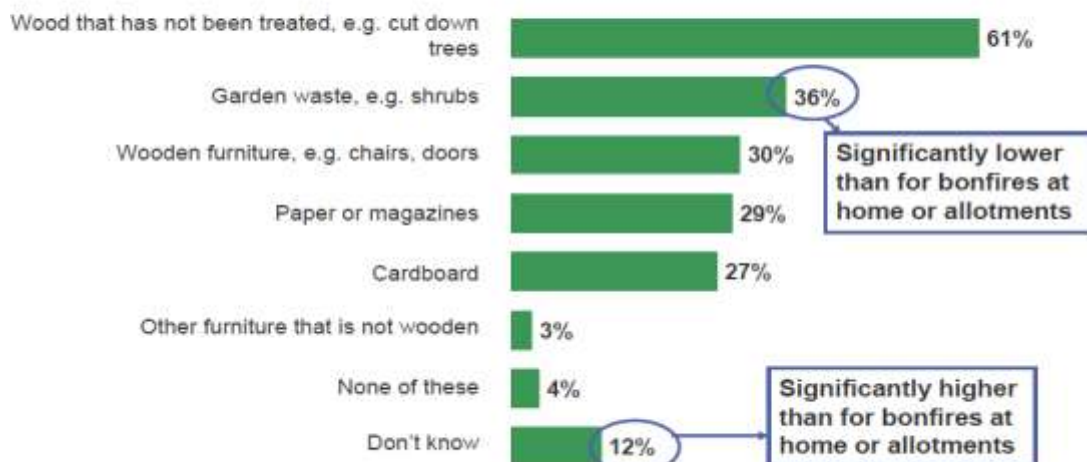
Ipsos MORI Base: 358, Those who have bonfires at home / at someone else's, 7th – 17th June



32

What people burn on community bonfires

Q6 Which if any of the following items do you ever put on your community bonfire?



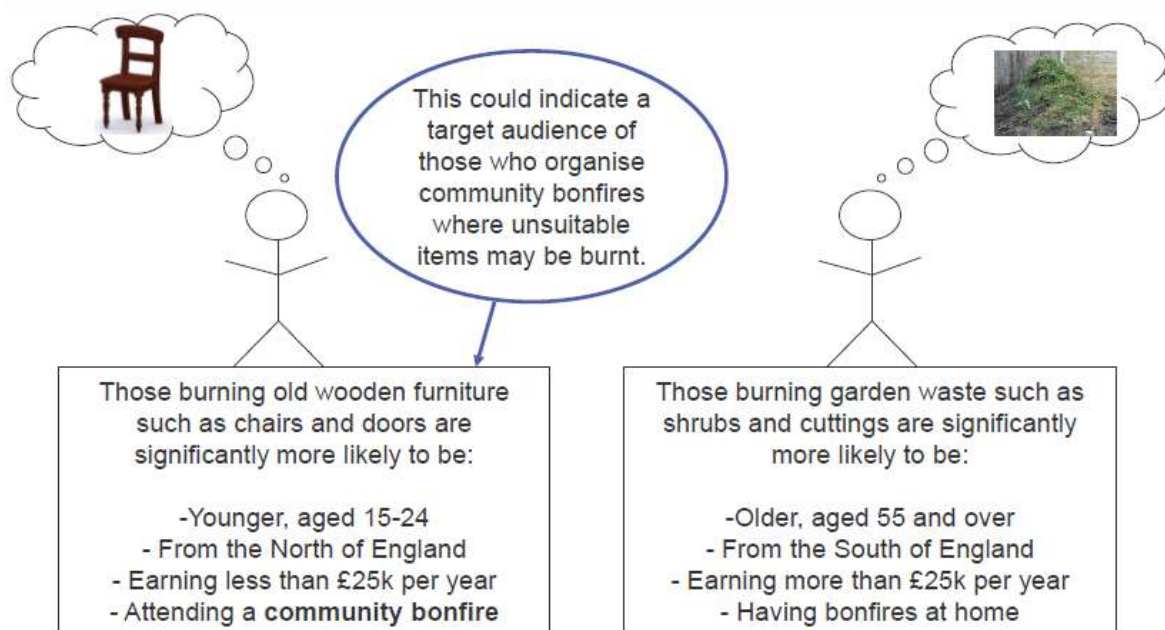
Source: Ipsos MORI

Ipsos MORI Base: 270, Those who have community bonfires, 7th – 17th June 2010



33

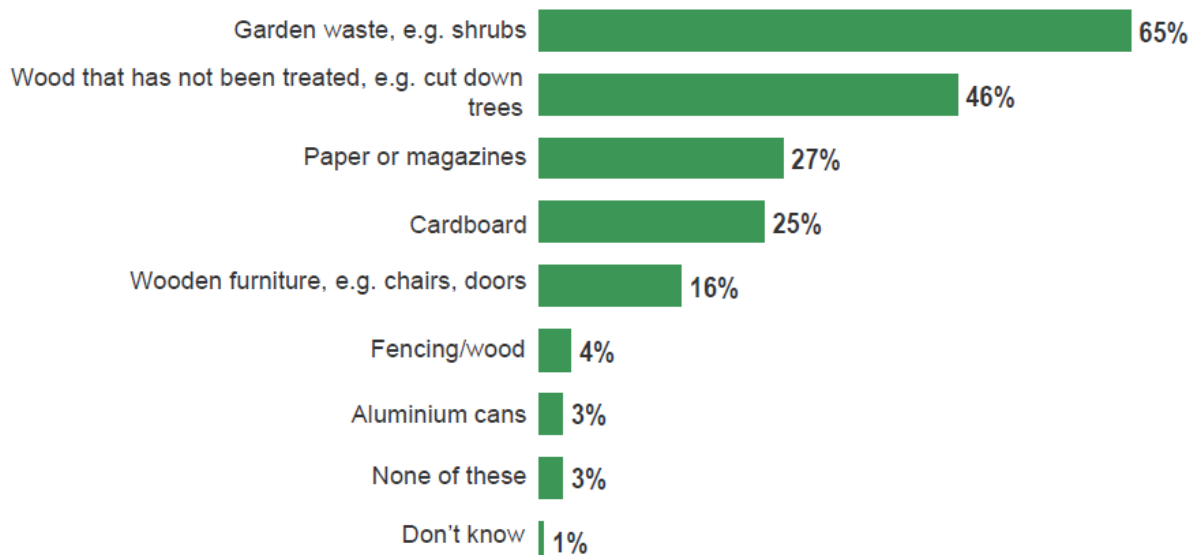
A profile of those who burn wooden furniture and garden waste on bonfires



- There were very few significant differences in demographics across people burning other items on bonfires.

What people burn on bonfires at allotments

Q6 Which if any of the following items do you ever put on your bonfire at your allotment?



Source: Ipsos MORI

Ipsos MORI Base: 41*, Those who have bonfires at allotments, 7th – 17th June 2010 *Indicates a low base size.



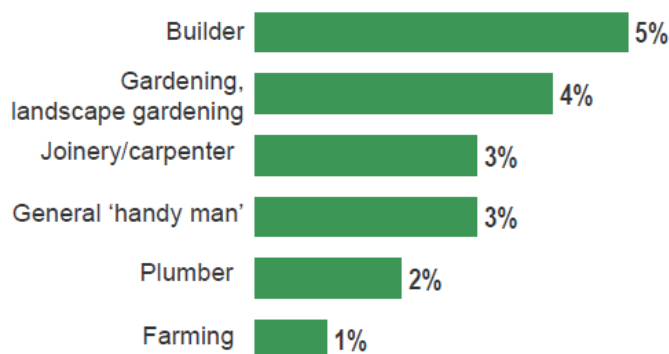
34

Burning trade waste

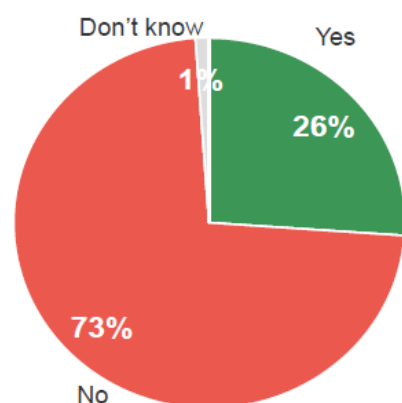
- It was identified in the qualitative research that some **people burn trade waste at home**. Leftover materials from certain occupations, that are unsuitable for burning could be added to bonfires.
- This led to questions being incorporated into the questionnaire to try and establish whether this could be a target audience for a campaign.
- Around one in seven (15%) of those who had bonfires said they worked in one of the listed occupations or trades (building, joinery, carpentry, plumbing, gardening, farming or working as a general 'handyman').
 - Of these, around a quarter (26%) said they burn leftover materials at home.
 - Similar to general responses about what was burnt on bonfires or domestic fires, the items burnt tended to be wood that had not been treated (60%), garden waste (44%), wooden furniture (15%) and cardboard (13%)
 - Further to this **around half (47%) said they burnt materials such as these at least once a month**.
- Base sizes for this group were extremely low so should be treated as indicative only but could highlight a potential target audience for any campaign attempting to discourage people from burning unsuitable items on bonfires or domestic fires.

Burning trade waste

Q13 Do you or does anyone in your household work in the following occupations or industries?

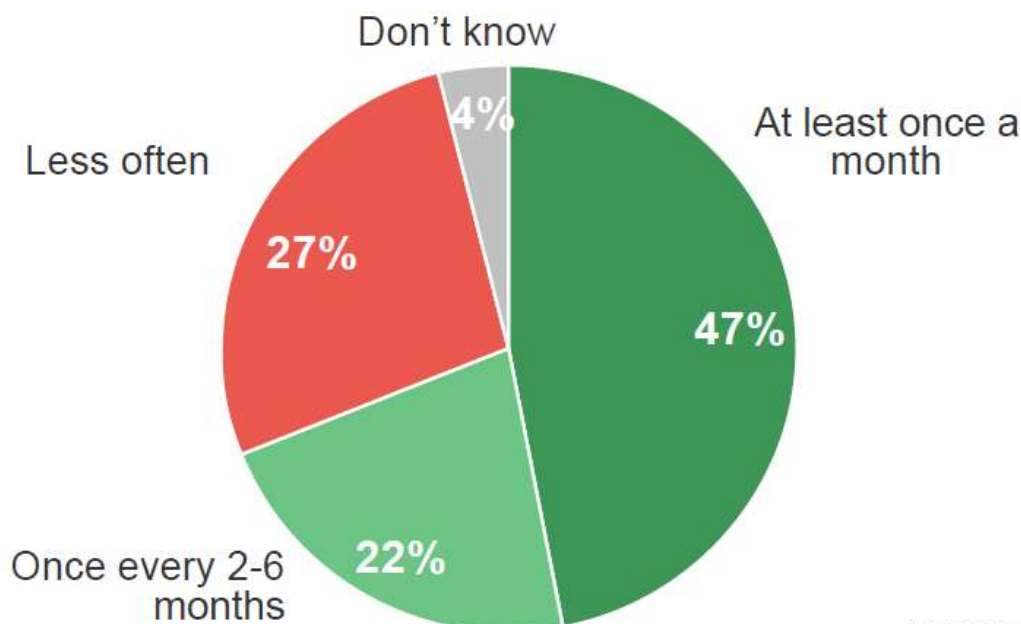


Q14 Do you or they ever burn leftover materials from work on bonfires?



How often do they burn trade waste

Q16 And on average, how often would you say you or members of your household burn leftover work materials on a domestic fire or bonfire?



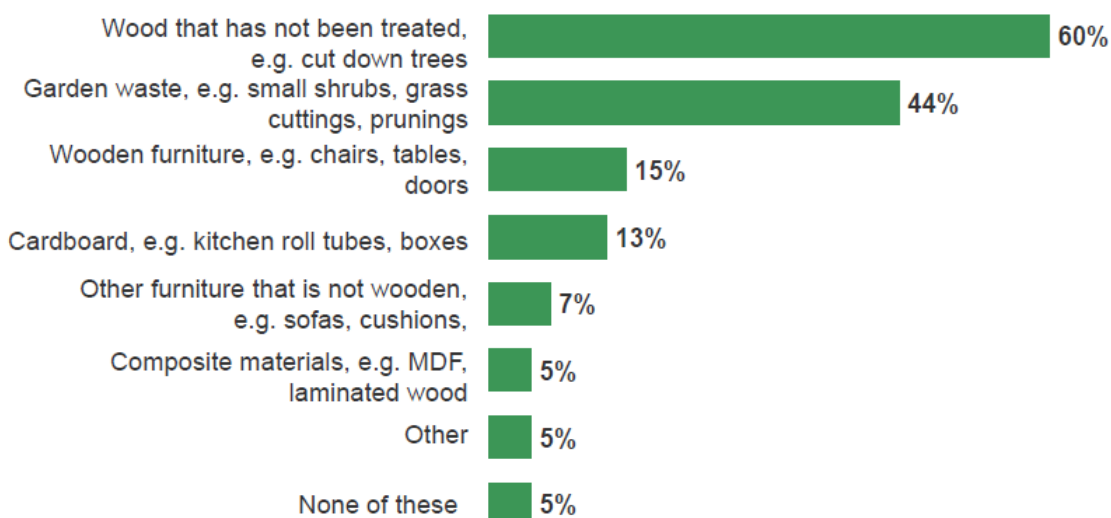
Source: Ipsos MORI

Ipsos MORI Base: 17*, Those who burn trade waste, 7th – 17th June. *Indicates low base size



What leftover materials are burnt

Q15 Which, if any, of the following leftover materials from work, do you or members of your household burn?



Source: Ipsos MORI

Ipsos MORI Base: 17*, Those who burn trade waste, 7th – 17th June 2010, *Indicated low base size



40

What are the concerns about the impacts of the materials being burnt? A SUMMARY



Summary

- **Concern was split across all potential impacts** with around half of those who burn items on either bonfires or domestic fires stating they were at least fairly concerned with all impacts.
- Concern was higher amongst those respondents who said they had not burnt any items on the show card on their domestic fire. This could, in part, be because they were considering impacts of burning any items on the show card including plastic and rubber.
- In comparison, those who were considering the impacts in relation to what they burn might have registered lower concern as the items they burnt were more likely to be garden waste, untreated wood or paper which they may think are safer to burn.
- Harmful fumes generated the highest concern but only those who had domestic fires felt it was the most likely impact to occur. Those who had bonfires thought, that the most likely impact to occur from burning items was bad/foul odours.
- However, a quarter (23%) of those who had domestic fires and a third (35%) of those who had bonfires felt that **none of the impacts were likely to occur** as a result of their behaviour.
- Results show low levels of awareness of the likelihood of the impacts which indicates **low awareness of some items that are unsuitable to burn**.

What are the concerns about the impacts of the materials being burnt? DOMESTIC FIRES

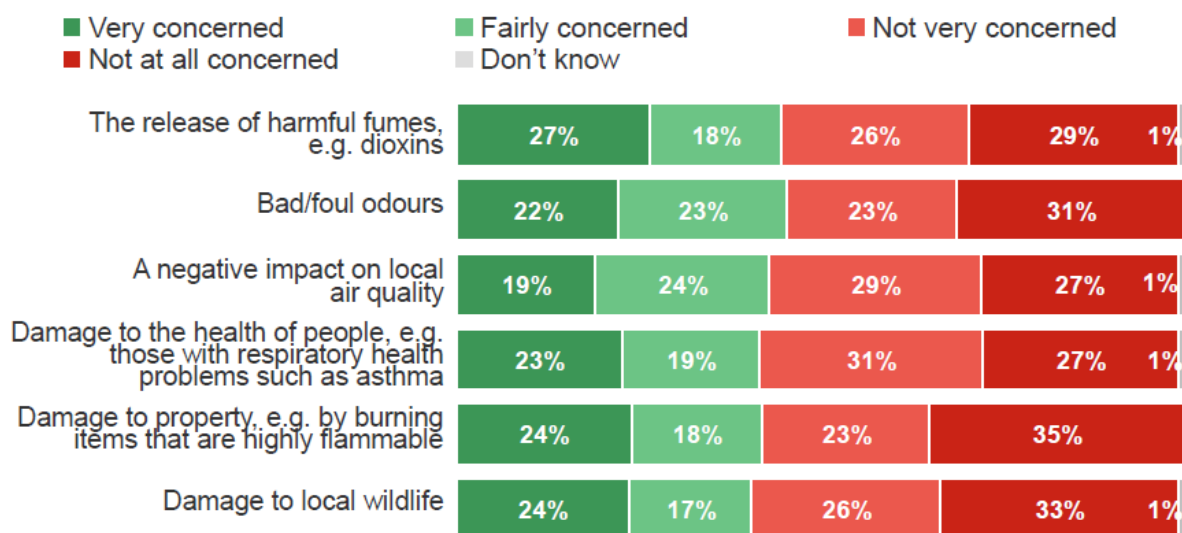


Concern amongst those who burn items on the show card

- Those respondents who said they had put items on the show card on their domestic fires were asked about their levels of concern regarding certain impacts, e.g. bad or foul odours, negative impacts on air quality.
- These respondents were divided over concern across all the issues raised.
 - **Just under half said they were at least fairly concerned by each impact.**
 - However, with a similar proportion of respondents showing a lack of concern, this could suggest there is some ignorance of the potential impacts of burning such items.
- Those who had burnt the items listed tended to be slightly more concerned with the release of harmful fumes compared to other impacts.
 - Residents who were not working were more likely to be concerned regarding the release of harmful fumes such as dioxins - 54% of these respondents said they were at least fairly concerned by this compared to 38% of those who were working full-time.
 - Those respondents who were concerned regarding harmful fumes were more likely to think a campaign was necessary (53% compared to 27% who were not concerned by this impact).
 - This could indicate a **key area of content for a campaign**.

Concerns regarding the items burnt on their domestic fires...

Q8a To what extent are you concerned about the following issues as a result of **what you put on your domestic fire**....



Source: Ipsos MORI

Ipsos MORI Base: 259, All who said they had put at least one of the items on the show card on a domestic fire, 7th – 17th June



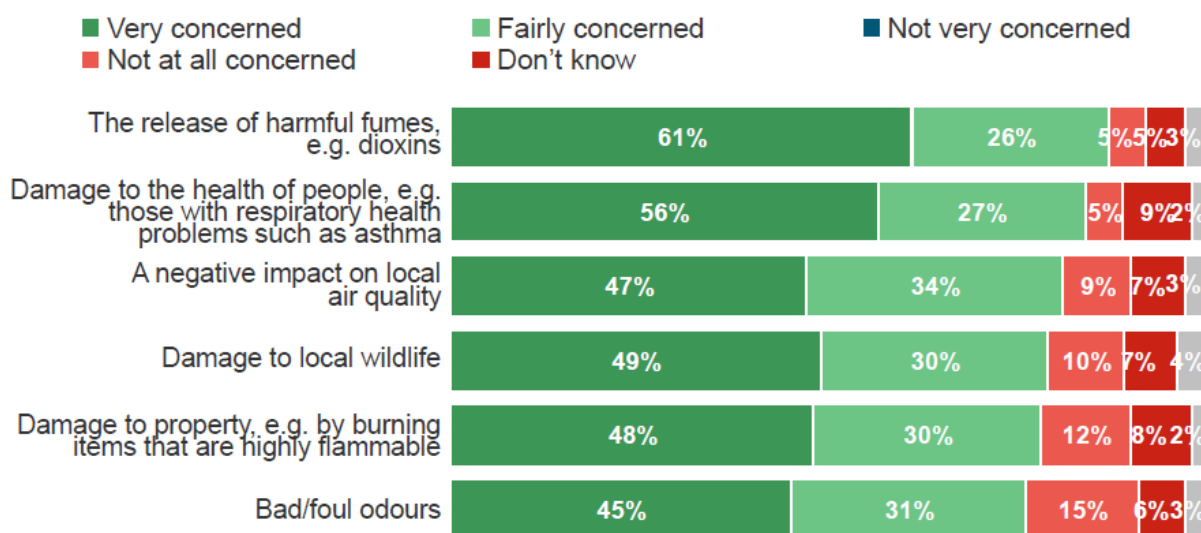
45

Concern amongst those who said they did not burn the items on the show card.

- 27% of respondents said they had not burnt any of the items on the show card on their domestic fire. These respondents were asked about what their level of concern would be with the different impacts from burning any of items on the show card. (please see Appendix 1 – slide 93 - for full show card.)
- Concern** was much higher amongst these respondents across all the impacts.
 - Nearly eight in ten of these respondents said they were at least fairly concerned by each potential impact and concern was slightly higher regarding harmful fumes.
 - It is important to note they were speaking about **concern related to burning any of the items listed**. They might be very concerned with burning items such as plastic and rubber but less so with other items such as paper or wooden furniture.
 - Indeed the qualitative work showed participants were far more concerned with burning items such as plastic and rubber but they also said they would not burn these items and did not think many people would.

Concerns about burning the items on the show card on domestic fires

Q8a To what extent are you concerned about the following issues as a result of **burning the types of items shown on the show card**....



Source: Ipsos MORI

Ipsos MORI Base: 126, All who said they had not put the items on the show card on domestic fires, 7th – 17th June



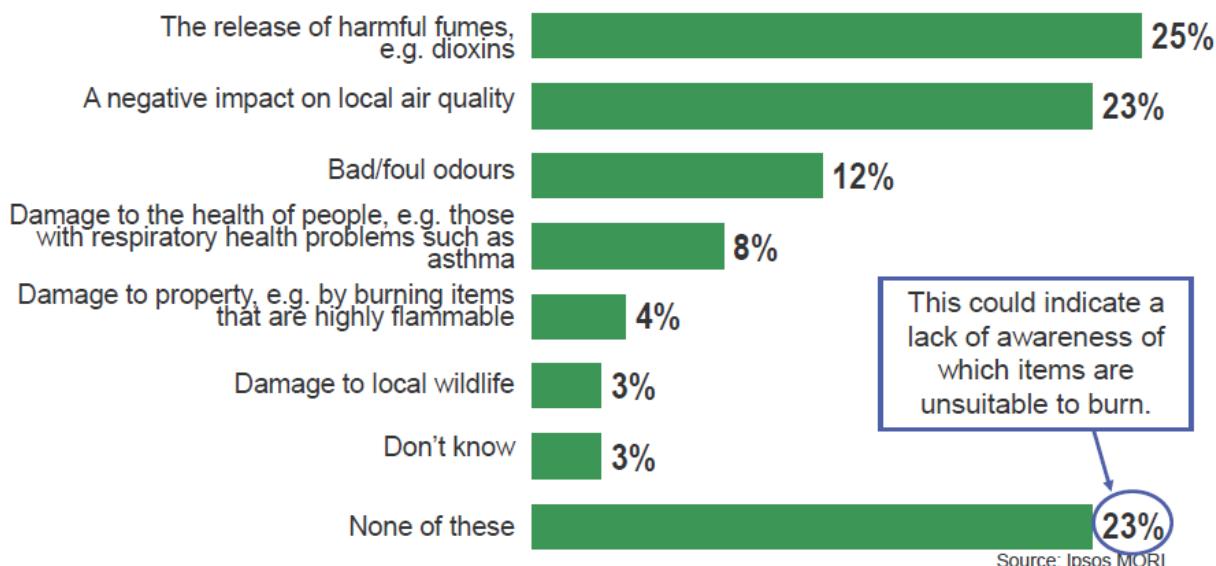
47

Which impact is most likely to occur?

- Respondents who had burnt any items on the show card were asked which impact they felt was most likely to occur as a result of their behaviour. Those respondents who said they hadn't burnt any of the items on the show card were asked which impact they felt was most likely to occur from burning any of the items on the show card. (please see Appendix 1 – slide 93 - for full show card).
- In line with the slightly higher levels of concern, the **release of harmful fumes was felt to be the most likely impact to occur** amongst all respondents who had domestic fires with a quarter (25%) selecting this.
 - Despite high levels of concern regarding potential health impacts, fewer than one in ten (8%) felt this was the most likely impact that would occur.
 - This highlights, again, a lack of awareness as earlier questions indicated a high level of concern surrounding potential issues caused by toxic fumes but these results indicate that fewer respondents thought this was actually likely to occur as a result of what they burn.
- **Just under a quarter (23%) felt that none of the impacts were likely to occur** as a result of what they burn on domestic fires or as a result of burning the items on the show card. This highlights a potential lack of awareness of the possible impacts and therefore a lack of knowledge of which items are unsuitable to burn.

Most likely impact from domestic fires

Q9 And which, if any, of the following impacts do you think is most likely to happen?



Ipsos MORI Base: 384 Those who have domestic fires, 7th - 17th June 2010

49

What are the concerns about the impacts of the materials being burnt? BONFIRES

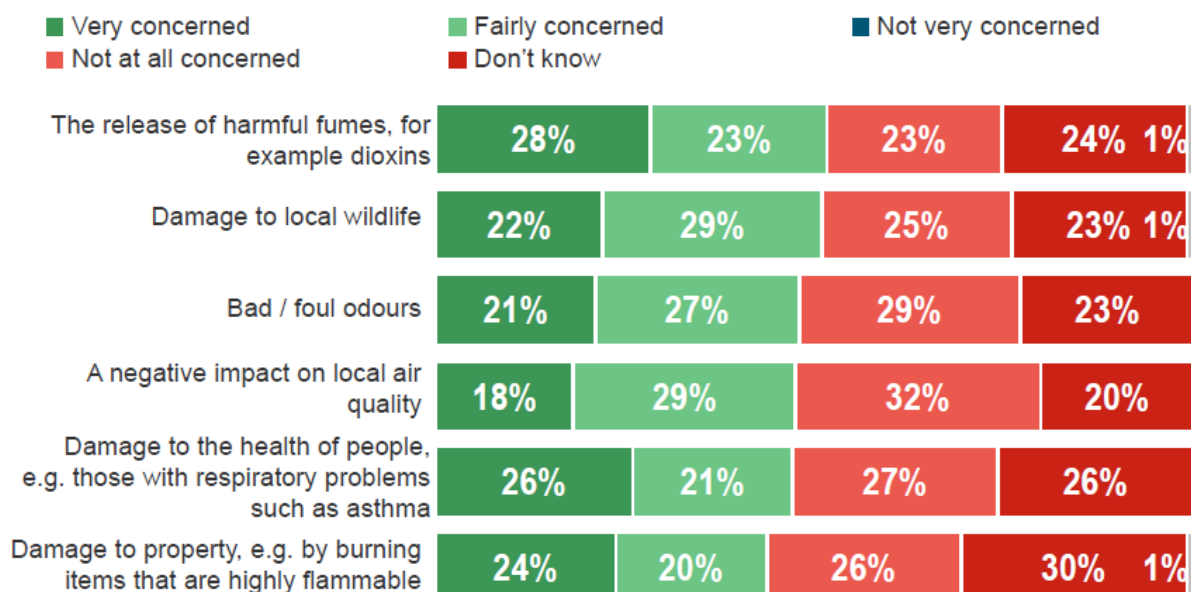


Impacts people were concerned about from burning the items they did on bonfires

- Those respondents who had bonfires were asked about their levels of concern with the impacts identified as a result of what they burn on bonfires. (Please see Appendix 2 – slide 95 - for full show card)
- Similar to results amongst those who had put items on domestic fires, those who had put items listed on bonfires were also fairly split on levels of concern with the potential impacts identified.
 - Around half of respondents who had put any item listed on a bonfire felt at least fairly concerned with each potential impact.
 - In line with the results amongst those who put listed items on domestic fires, those who had done so on bonfires were **most concerned about the release of harmful fumes** as a result of what they burn on bonfires. Just over half (51%) were at least fairly concerned.
 - Those who had put items on bonfires were more concerned about potential damage to wildlife than those who had put items on domestic fires with just over half (51%) at least fairly concerned by this compared to 41%.

Concern about what they are burning on bonfires....

Q11 Thinking about what is burnt on the bonfires you have had/have attended, to what extent are you concerned about the following impacts as a result of this?



Ipsos MORI Base: 516 Those who have burnt the items listed on bonfires, 7th - 17th June 2010

Source: Ipsos MORI

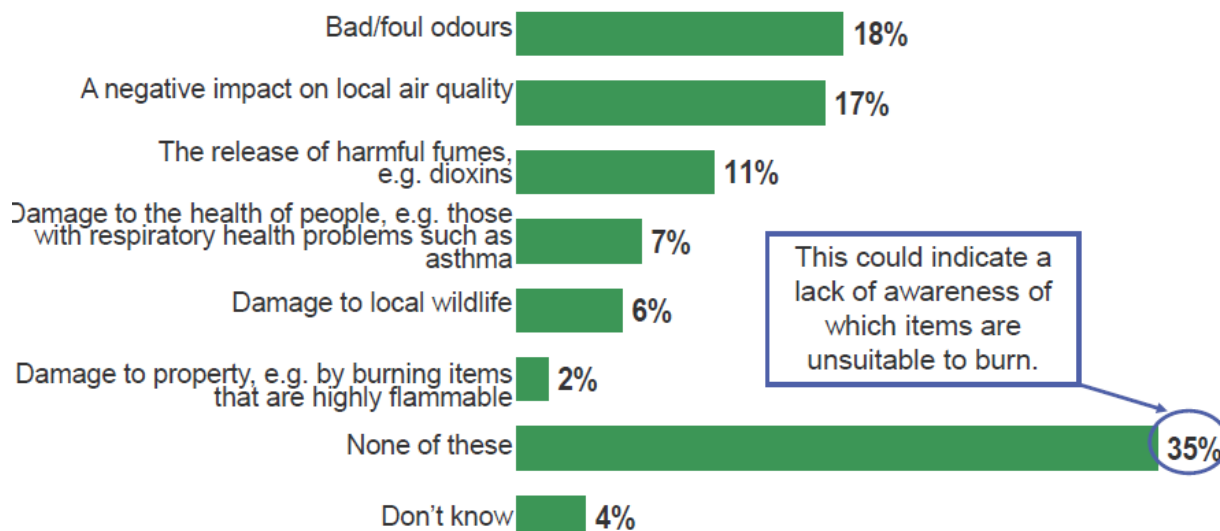
52

Which impact was most likely to occur from what is burnt on bonfires?

- Despite half of respondents who had put items on bonfires being concerned by harmful fumes, only around one in ten (11%) thought this was the most likely impact.
 - These respondents felt bad or foul odours were the most likely impact with around one in five (18%) selecting this.
 - Only around one in twenty (6%) felt damage to wildlife was the most likely impact to occur despite a higher level of concern regarding this impact amongst these respondents who had put items on bonfires.
- Over a third (35%) felt that none of the impacts were likely to occur as a result of what they burn on bonfires.
 - These results indicate many respondents did not see a link between their own behaviour and the potential impacts.
 - This, in turn, highlights a lack of understanding regarding which items are unsuitable to burn.

Most likely impact from bonfires

Q12 And which, if any, of these impacts do you think is most likely to result from the bonfires you had attended/have had?



Source: Ipsos MORI

Ipsos MORI Base: 583 Those who have / have attended bonfires, 7th - 17th June 2010

54

Perceptions of unsuitable items to burn and the potential impacts of doing so A SUMMARY



Summary (1)

- Respondents mainly identified plastic containers, plastic wrappers and rubber as unsuitable items for burning. This does not mean that other items, such as electrical goods, were considered suitable but just that they were not front of mind.
- The release of harmful fumes such as dioxins and a negative impact on air quality were thought to be the main impacts that could arise from burning unsuitable items.
- This is in line with respondents views regarding what they themselves burn on domestic fires where they felt the impact on air quality was the most likely impact.
- However, for those who had bonfires they felt the damage to wildlife was a more likely impact. This indicates respondents were not aware of all the likely impacts that could arise from what they burn. This, in turn, shows a lack of awareness of all items that are unsuitable to burn.
- Both respondents who have bonfires and/or domestic fires, were more likely to mention potential impacts on air quality with regard to burning items they deemed unsuitable compared to the impacts they identified as most likely to result from their own actions.
- This shows, again, a lack of awareness of which items are unsuitable.

Summary (2)

- Once the potential impacts of dioxins on health and the environment were explained, concern with harmful fumes such as these rose, with more than one in eight being fairly concerned.
 - Previously, levels of concern regarding the potential impact of harmful fumes in relation to what respondents' said they burnt on bonfires or domestic fires showed around half were concerned with this.
- This rise in concern, once dioxins were explained, illustrates a need to raise awareness of the potential issues. It also highlights a potentially effective message for a campaign.
- Further to this, it also indicates respondents were less likely to link their own behaviour to this impact as respondents were less concerned with regards to their own behaviour.
 - This, in turn, could highlight a lack of understanding as to which items are unsuitable for burning.
- Another potential indication of a lack of awareness of unsuitable items could be that half of respondents did not think burning unsuitable items was an issue in their area. This perception could change if people were made more aware of the different items that are unsuitable.
- Both the qualitative and the quantitative research show the **issue of health is important and potentially a highly effective angle for a campaign to take.**

Which items do people think are unsuitable to burn?



Which items are unsuitable?

- Results have indicated a potential lack of awareness in several areas. Firstly, regarding which impacts are likely to be linked to respondents' own behaviour. Secondly, as to which items are likely to lead to such impacts occurring and therefore a misunderstanding as to which items are unsuitable to burn.
- Before respondents were asked about their own behaviour and the potential impacts of this they were asked to identify which items they thought were unsuitable.
 - This question was spontaneous and respondents were not provided with a show card from which to pick out unsuitable items.
 - For this reason, lower mentions of certain items do not indicate they think these are suitable to burn but merely that these did not come top of mind.
 - This was echoed in the qualitative research where participants felt there were certain items that were more obviously unsuitable to burn, such as rubber or plastic.

What do people think are unsuitable items to burn?

▪ In line with the qualitative work, **plastic was the most frequently mentioned item** that would be unsuitable to burn with just over half (53%) highlighting plastic containers and just under half (48%) mentioning plastic wrappers.

▪ Further to this, over a third (36%), mentioned rubber and just over a quarter (28%) highlighted aluminium cans.

▪ These items were highlighted in the qualitative work as having more obvious negative impacts so it is unsurprising they were the most mentioned by respondents.

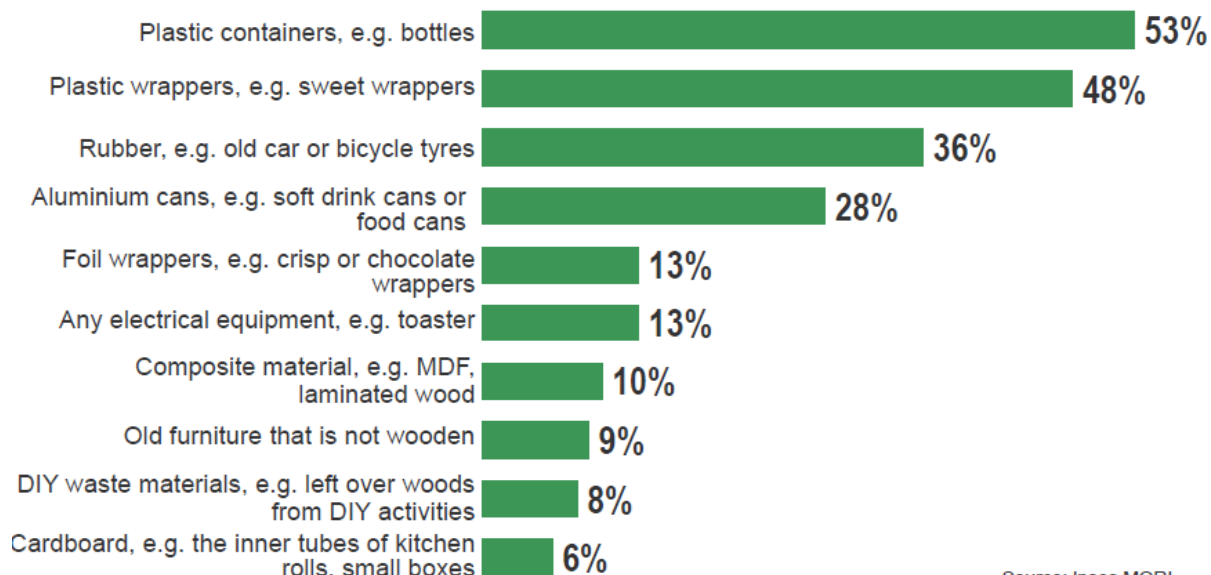
▪ Lower mentions of certain items such as leftover DIY material (8%), cardboard (6%) and old wooden furniture (5%) further indicates a lack of awareness surrounding unsuitable items to burn.

"I wouldn't put anything with plastic in or rubber that would cause very thick, noxious black smoke. I don't think that's fair. I'm very conscious of that and I suppose most people who have fires around here probably think the same way"

Male, 46, Stockport

Materials which are unsuitable to burn

Q3 There are certain materials that are unsuitable to burn on open fireplaces/Agas/wood burners/boilers or bonfires. What materials do you think these might be?



Source: Ipsos MORI

Ipsos MORI Base: 901, Those who have domestic fires or have / have attended bonfires, 7th - 17th June 2010



61

What are the potential impacts of burning unsuitable items?



Questions regarding potential impacts

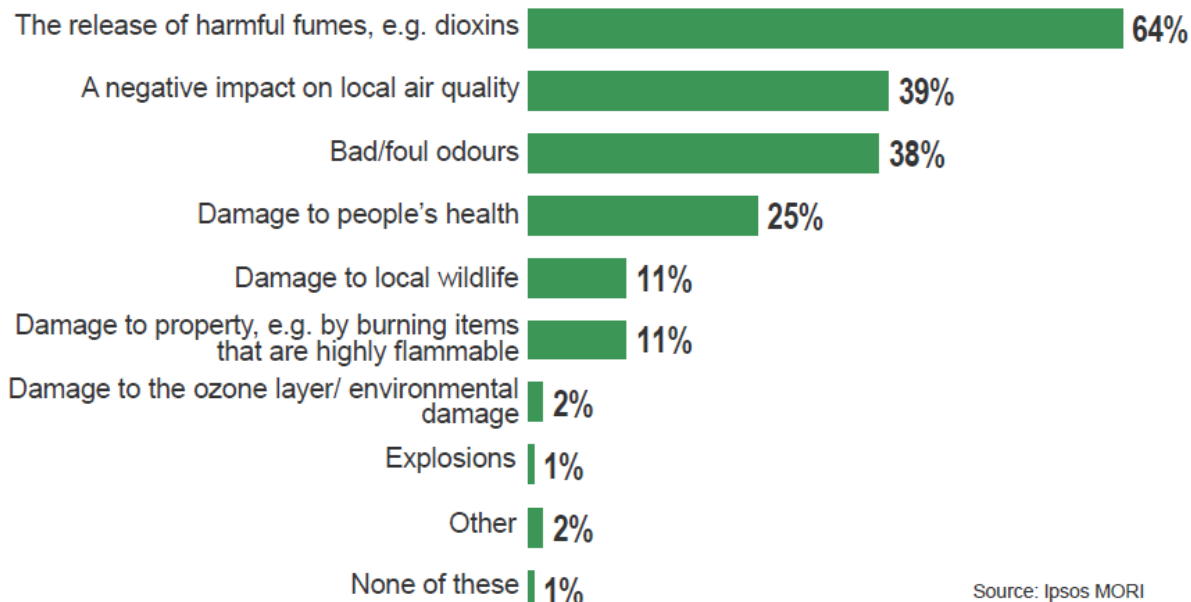
- Respondents were also asked to identify what they thought the potential impacts could be from burning any of the items they identified as unsuitable.
 - Again, this question was not prompted, they were not asked to choose from a list but to give their top of mind responses.
 - Any mentions of impacts on health were queried further to establish exactly what these were thought to be, e.g. damage to respiratory health, burns etc.

What are the potential impacts of burning such items?

- **Harmful fumes was most frequently mentioned** by respondents as a potential impact of burning items they identified as unsuitable, e.g. plastics or rubber.
 - This is in line with the qualitative work where participants spoke of noxious smoke or bad odours resulting from burning items such as those.
- **Over half (53%) mentioned damage caused by toxins.**
- This indicates **fairly high levels of awareness of the potential issues surrounding dioxins** and other chemicals that a campaign could seek to highlight to the public.
 - However, fewer than one in ten (8%) identified leftover DIY materials and only around one in twenty (6%) mentioned cardboard as an unsuitable item to burn.
 - And none mentioned old wooden furniture as an unsuitable item.
 - This could indicate a **lack of awareness as to which items could lead to the impacts they identified and highlights a key area of content for any campaign.**
- Damage to people's health was highlighted by a quarter (25%) of respondents as a potential impact from burning unsuitable items.
 - Eight in ten (80%) of those who felt damage to people's health was a potential impact felt this was likely to be damage to people's respiratory health.

Potential impacts of burning unsuitable materials

Q4 What, if any, do you think are the potential impacts from burning unsuitable items?



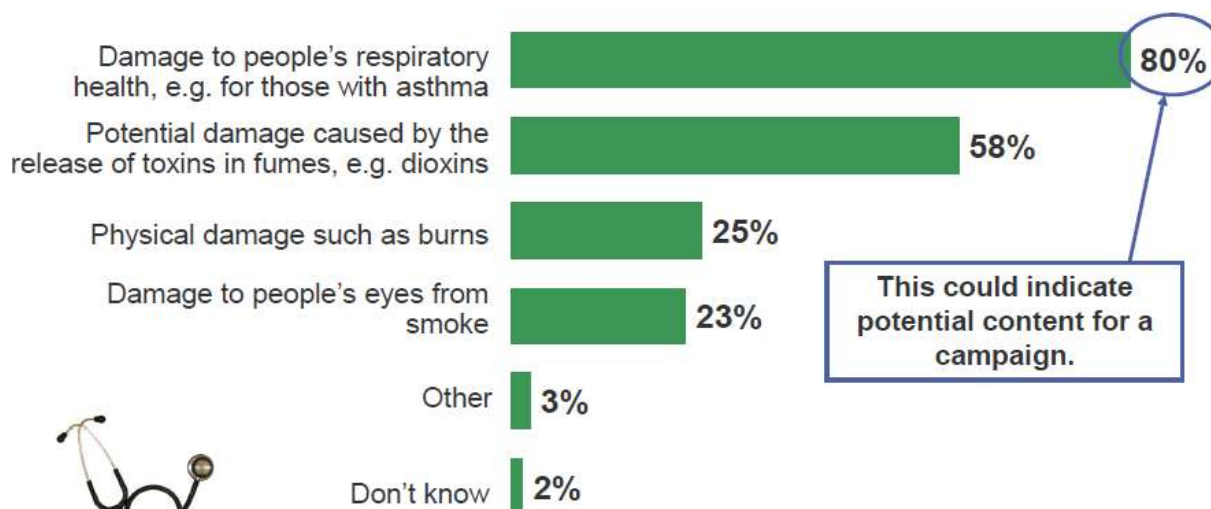
Ipsos MORI Base: 734, Those who mentioned listed items as unsuitable, 7th - 17th June 2010

Source: Ipsos MORI

65

Impact on health

Q5 And thinking about the damage to people's health, what do you think this could be?



Ipsos MORI Base: 186 Those who think there are potential health impacts from burning unsuitable materials, 7th - 17th June 2010

Source: Ipsos MORI

66

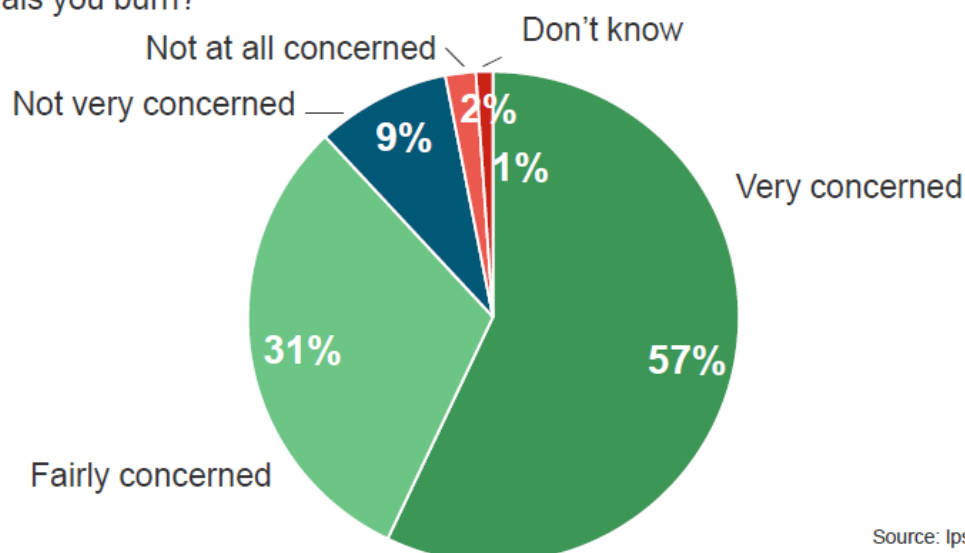
Explanations of the impacts of dioxins led to increased concern

- Once respondents' own behaviour had been explored, the potential impacts of dioxins on health and the environment were then explained to gauge whether this affected their levels of concern.
- Nearly nine in ten (89%) of respondents were at least fairly concerned by the impact of dioxins as a result of what they burnt on either bonfires or domestic fires.
 - This shows a rise in concern regarding harmful fumes such as dioxins compared with the concern respondents felt regarding the items they themselves burnt on bonfires (where around half were fairly concerned by this).
 - This shows that **when awareness of the issues is raised, concern also rises.**
 - This could indicate a potential target for a campaign – to raise awareness of the issues in relation to health.
- The qualitative work also showed participants were most concerned about issues related to health. Further to this, when it was explained that dioxins have been linked to cancer people felt this would be a powerful factor in discouraging the burning of items that gave off these toxins.

Concern about dioxins

Q20 It has been identified that harmful fumes, such as dioxins, can be released when certain materials, such as plastic and treated wood are put on fires. Dioxins are highly toxic and have been linked to cancer and other diseases.

To what extent would you be concerned about the release of dioxins from the materials you burn?



Source: Ipsos MORI

Ipsos MORI Base: 834 Those who have domestic fires and/or bonfires, 7th - 17th June 2010



68

Do people think burning unsuitable items is an issue in their area?



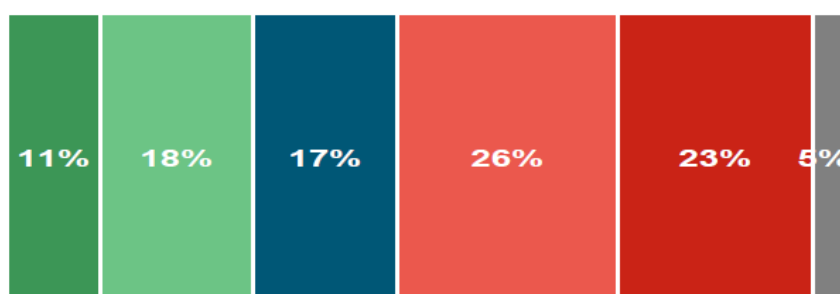
Nearly half do not think burning unsuitable items is an issue in their area

- Respondents were asked a general question to gauge whether they felt other people in their area burnt unsuitable items and therefore whether it was an issue.
- Around a third of respondents (29%) felt people burning unsuitable items was an issue in their area while just under half (49%) disagreed.
 - However, this could be, in part, due to some lack of awareness surrounding which items are unsuitable.
 - This is supported by the qualitative research which showed people felt burning certain items was an environmentally friendly way to dispose of them.
 - As participants tended to mention plastics and rubber, in line with the qualitative research, it is likely they are referring only to these types of items in their answer to this question. This could mean, if people were more aware of potential issues linked to burning other items, this perception might change.

People burning unsuitable items

Q17 To what extent do you agree or disagree that people burning unsuitable items on bonfires, such as plastic, is an issue in your local area?

- | | | |
|--------------------|---------------------|-----------------|
| ■ Strongly agree | ■ Tend to agree | ■ Neither / nor |
| ■ Tend to disagree | ■ Strongly disagree | ■ Don't know |



Strongly agree/tend to agree: 29%

Tend to disagree/strongly disagree: 49%

Source: Ipsos MORI

Ipsos MORI Base: 834 Those who have domestic fires or have / have attended bonfires, 7th - 17th June 2010



71

Why do people burn unsuitable materials?



Convenience and better waste disposal are key reasons people burn unsuitable items.

- The qualitative research showed participants felt convenience was the key reason behind why people burnt the things they do.
- This is echoed in this quantitative survey where respondents mentioned laziness around going to a tip (27%), burning being a method of disposing of waste (17%) and burning being an easy way to dispose of items (6%).

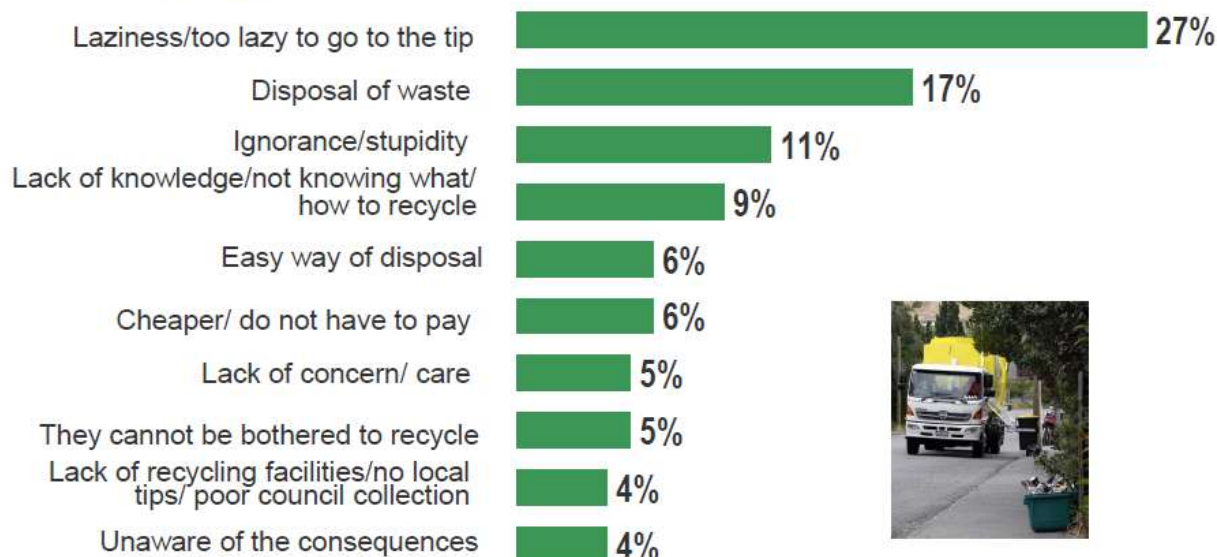
"I'd say the reason why I do burn stuff in the garden is probably because it's either too big to go in the car or it's too mucky or something because it won't go in the recycle stuff."

Male, 46, Stockport, not allotment holder

- A lack of awareness of the issues was also highlighted as a potential reason behind people burning items.
 - This lack of awareness around which items are unsuitable also appears when people were asked to identify such items. This indicates a campaign could seek to raise awareness of the issues, as a means to discourage this behaviour.

Why do people burn unsuitable items?

Q18 Why do you think people burn unsuitable items on bonfires or fires in their home?



Ipsos MORI Base: 834, Those who have domestic fires and/or bonfires, 7th - 17th June 2010



74

Enjoyment was still a factor

- The qualitative work highlighted that, for some participants, they liked to have bonfires because they enjoyed the activity.
 - They would participate in community bonfires and liked to have their own in summer.
- One participant worked for the girl guides and helped out with the annual bonfire every year.
- However, enjoyment and convenience were closely linked, one was usually a bonus of the other.

"Every year, we have a bonfire for the girls and everyone can come. We build it ourselves, just with wood, nothing else because we have to think about safety. It's great fun!"

Female, 43, Leeds, not allotment holder

What would help prevent people burning unsuitable items? A SUMMARY



Summary

- The potential of harmful fumes being released and the smell of the smoke from what is burned, would be issues likely to put people off burning unsuitable items.
- Furthermore, a greater understanding of the consequences of burning such items upon human health, would potentially help dissuade people from burning those unsuitable items.
- The lack of awareness of which items are unsuitable to burn could mean simply that raising awareness of this might lead to fewer people burning such items.
- Respondents felt that easier ways of disposing large items would also help to prevent people from burning items as convenience was a key reason behind why people burnt such items in the first place.

What are the factors that discourage people from burning unsuitable items?

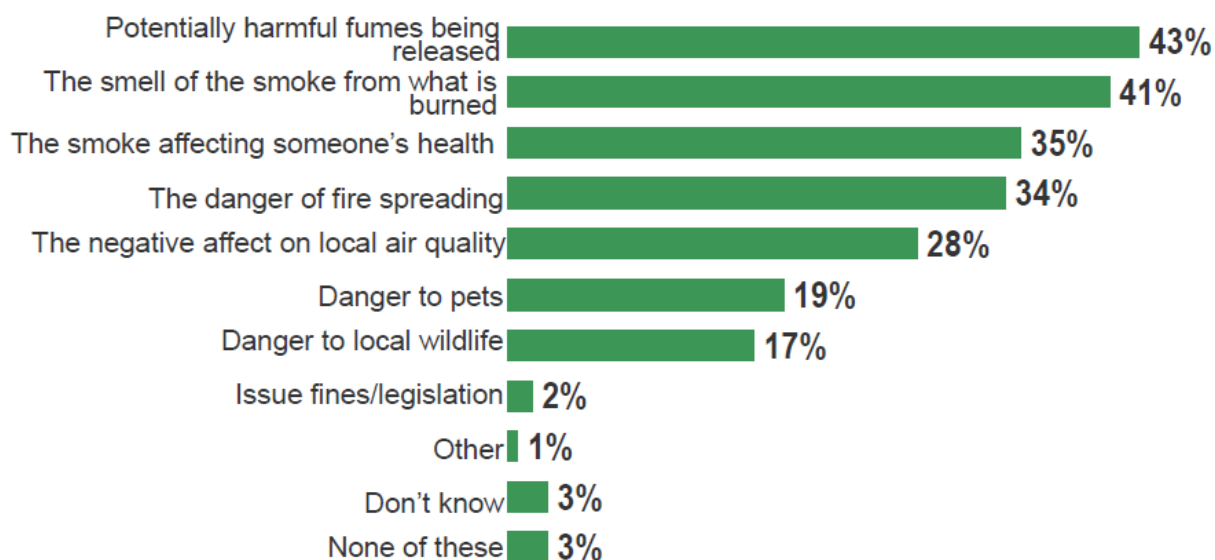


What would discourage people?

- Around two in five (43%) respondents mentioned harmful fumes as a key factor for discouraging people from burning unsuitable items.
 - In the qualitative research most participants felt the health impacts of smoke and pollutants such as dioxins would be most likely to discourage people from burning items on bonfires.
 - This is also evident in the quantitative survey where concern regarding dioxins increased once the issues surrounding these toxins was explained.
 - In addition to this, over a third (35%) felt the impact on people's health was a discouraging factor.
- In the qualitative work it became clear that tangible and obvious impacts were most likely to discourage people from burning certain items on bonfires. Similarly in the quantitative research, 41% of respondents felt the smell of the smoke was a key discouraging factor.
 - Participants in the qualitative research felt these impacts were particularly relevant with regards to burning plastic and rubber which meant people would not burn these materials. This is supported by the quantitative research where respondents were least likely to put items such as these on bonfires or domestic fires.

What are the discouraging factors?

Q19 Which, if any, of the following issues do you think would be most likely to discourage people from putting unsuitable items on bonfires or domestic fires?



Source: Ipsos MORI

Ipsos MORI Base: 834, Those who have domestic fires and/or bonfires, 7th - 17th June 2010

80

The convenience factor needs to be addressed...

- **Raising awareness is key** to preventing people from burning unsuitable materials.
 - Around half of respondents thought it was important to increase understanding of the issues related to human health (47%) and to increase understanding of the issues related to the environment (45%).

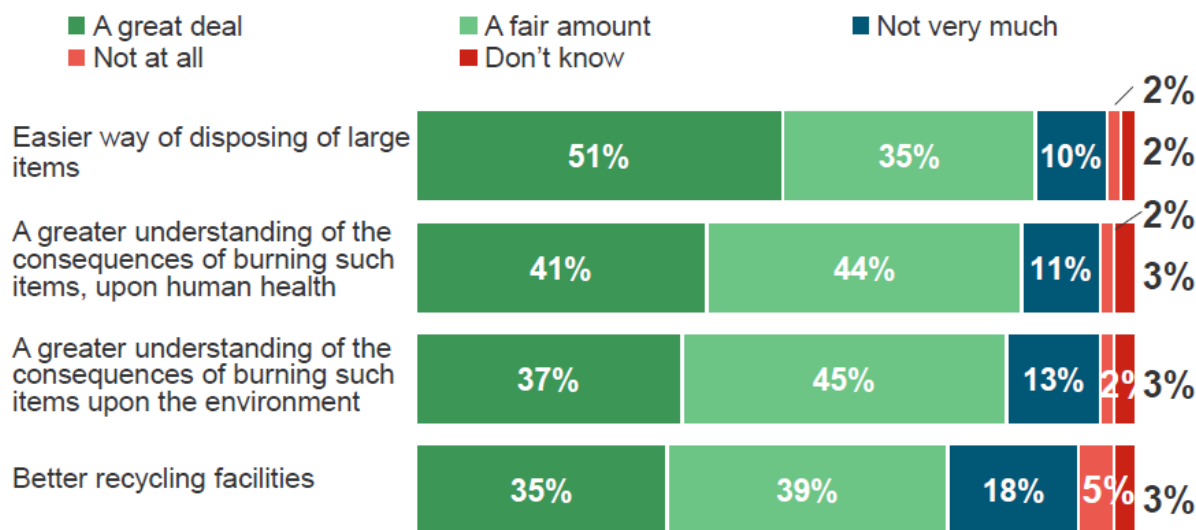
"Yeah we would burn old furniture or DIY stuff, not really thought about the varnish and things, I guess that might be bad for the environment. I wouldn't know."

Female, 18, Leeds, not allotment holder

- Alongside raising awareness respondents also felt there was a **need to make disposing of waste more convenient**.
 - In particular this was true for larger items of furniture where nearly half (47%) felt there should be easier ways to dispose of these items.
 - In the qualitative research, most participants said that since household recycling had been introduced they were less likely to have bonfires at home as it was more convenient just to put items such as garden waste or cardboard in the relevant bin for collection.

What would prevent people burning unsuitable items?

Q22 To what extent would each of the following prevent people in your community from burning unsuitable items on bonfires or domestic appliances?



Source: Ipsos MORI

Ipsos MORI Base: 834 Those who have domestic fires and/or bonfires, 7th - 17th June 2010

82

Conclusions and Recommendations



Conclusions (1)

- People tend to only **burn items that do not “seem” harmful**, e.g. cardboard, old wooden furniture.
 - The findings from the qualitative research showed people feel this way because burning these items does not have any obvious negative impacts such as thick smoke.
 - The quantitative research showed that respondents did recognise that certain impacts such as harmful fumes were a possible outcome of burning unsuitable items. However they did not link this to their own behaviour.
 - This indicates a **lack of clarity around which items are and aren’t suitable to burn**.
- **Convenience** is a key reason behind any burning activity; it is done simply to get rid of items that are not easy to dispose of.
 - There is some element of enjoyment, with people having bonfires around Bonfire Night but **convenience and enjoyment tend to go hand in hand**.
 - Many felt they did not burn items that could be harmful to the environment or their health, indicated by lower levels of respondents thinking these would be the most likely impacts from their behaviour.

Conclusions (2)

- The **associated health risks** with burning certain items would strongly discourage people from doing so. A campaign could raise awareness of the potential issues related to dioxins as respondents reported higher levels of concerns once the impacts of these toxins were explained.
 - In addition to this, the **risk to the environment** could also play a part but it needs to be made to feel relevant, e.g. the effect on local air quality.
- The campaign would **need to feel relevant** and this could be achieved through local delivery, timing and clear evidence of the impacts.
 - Using local newspapers or poster campaigns.
 - Putting the campaign out at relevant times of year e.g. bonfire night.
 - Using visuals to show the impacts such as dangers to wildlife.
- Respondents in the quantitative research felt convenience of waste disposal was a key reason behind why people burn items that are not suitable. Further to this the findings of the qualitative work showed participants felt any campaign would need to be **run alongside better waste disposal services, or raising awareness of those services/facilities that are available**.

Appendix 1 – Items put on domestic fires show card



Show card for items burnt on bonfires



Wood that has not been treated, for example, cut down trees or pallets



Garden waste, for example, small shrubs, grass cuttings or prunings



Plastic, for example, bottles, old containers, wrappers



Cardboard, for example, kitchen roll tubes, boxes



Wooden furniture, for example, chairs, tables, doors



Other furnishings that are not wooden, for example, sofas, cushions, curtains



Any electrical equipment, for example, toasters



Paper or magazines, for example, old newspapers, telephone directories



Rubber, for example, old car or bicycle tires



Composite materials, e.g. MDF, Fibreboard, laminated wood



96

Appendix 2 – Items put on bonfires show card



Show card for items burnt on domestic fires



Cardboard, e.g. the inner tubes of kitchen rolls, small cardboard boxes



Plastic wrappers, e.g. sweet wrappers



Foil wrappers, e.g. crisp or chocolate wrappers



Aluminium cans, e.g. soft drink cans or food cans



Plastic containers, e.g. bottles



Old wooden furniture e.g. chairs, tables, doors



Old furniture, e.g. sofas, carpets



DIY waste materials, e.g. left over wood or other materials from DIY activities



Paper, e.g. newspapers, magazines, wrapping paper



Composite materials, e.g. MDF, Fibreboard, laminated wood

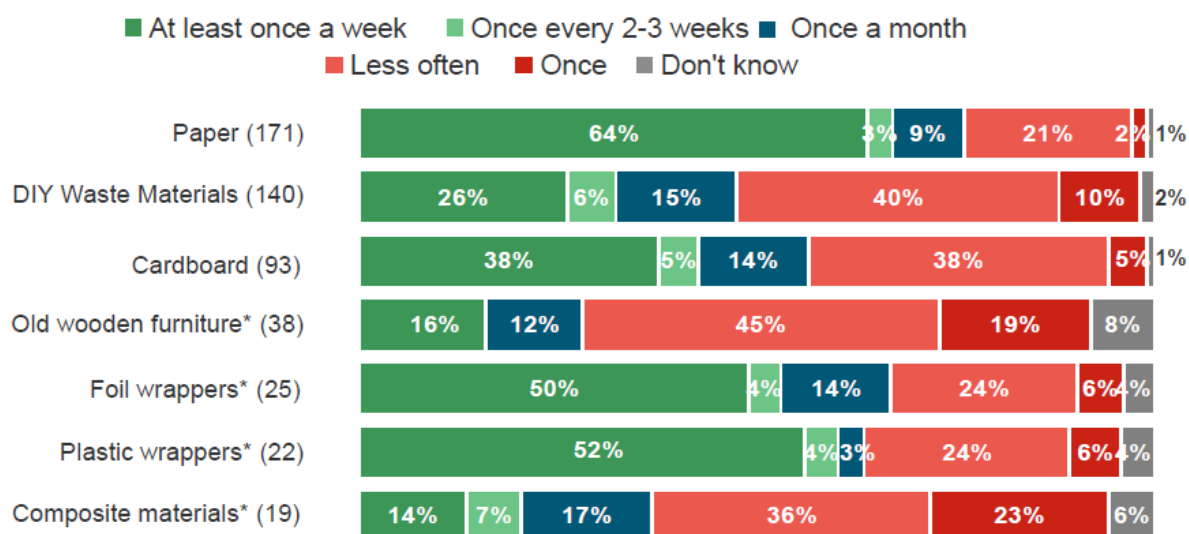


Appendix 3 – How often participants burn items on their domestic fire based on just those who burn those items.



People burn paper most often

Q7 Thinking about the time of year you use your open fireplace/Aga/wood burner/boiler how often do you put the following on it...



Source: Ipsos MORI

Ipsos MORI

Base: 259 Those who put the materials mentioned on their domestic fires, 7th – 17th June 2010

*Indicates a low base size



98

Part Two:

Emission inventories to air, land and water for nine new Persistent Organic Pollutants

Part two table of contents

1	Introduction	1
1.1	Policy background.....	1
1.2	Objectives	3
1.3	Report Structure.....	4
2	Methodology	5
2.1	Review of uses and releases of the nine new POPs	7
2.2	Review of monitored emissions and update of existing emission factors.....	8
2.3	Establish new emission factors	9
3	Emissions Inventory for newly designated POPs	11
3.1	Introduction	11
3.2	Alpha, beta and gamma hexachlorocyclohexane (Lindane)	11
3.3	Pentachlorobenzene	16
3.4	Hexabromobiphenyl	39
3.5	Polybrominated diphenyl ethers (PBDEs): Tetra, Penta, Hexa and Hepta Brominated Diphenyl Ether.....	41
3.6	PFOS and its salts	48
4	POPs data sources and inventory improvement	57
4.1	UK POPs inventory data management systems	57
4.2	Scope of work for monitoring land and water emissions	66
4.3	Summary	69
5	Conclusions.....	71
5.1	Overview	71
5.2	Individual POPs	71
5.3	Emissions inventory summary.....	74
5.4	Recommendations	74

Appendices

Appendix 1: Glossary and Abbreviations

Appendix 2: Summary tables for Pentachlorobenzene

1 Introduction

1.1 Policy background

There is considerable concern over the potential effects on public health and the environment of persistent organic pollutants (POPs). These are defined in the Stockholm Convention as substances that have the following properties:

- (a) Persistence:
 - (i) A half-life in water greater than two months, or a half-life in soil or sediment greater than six months; or
 - (ii) Sufficient persistence to justify its consideration within the Convention;
- (b) Bio-accumulation:
 - (i) A bio-concentration factor or bio-accumulation factor in aquatic species greater than 5,000 or, in the absence of such data, a log Kow value greater than 5; or
 - (ii) Other reasons for concern, such as high bio-accumulation in other species, high toxicity or ecotoxicity; or
 - (iii) Monitoring data in biota indicating sufficient bio-accumulation potential to justify its consideration within the Convention;
- (c) Potential for long-range environmental transport:
 - (i) Measured levels of the chemical in locations distant from the sources of its release that are of potential concern; or
 - (ii) Monitoring data showing that long-range environmental transport of the chemical, with the potential for transfer to a receiving environment, may have occurred via air, water or migratory species; or
 - (iii) Environmental fate properties and/or model results that demonstrate that the chemical has a potential for long-range environmental transport through air, water or migratory species, with the potential for transfer to a receiving environment; and
- (d) Adverse effects:
 - (i) Adverse effects to human health or to the environment that justifies consideration of the chemical within the Convention; or
 - (ii) Toxic or ecotoxic properties that indicate the potential for damage to human health or to the environment.

Concern over these substances has led to the establishment of a number of international treaties and regulations to help identify, monitor and reduce the emissions of such substances. The UK is a signatory to these treaties in its own right, and also as a European Union member state. This means that the UK is required to act to minimise such emissions by the following international agreements:

- The United Nations Stockholm Convention on Persistent Organic Pollutants which came into force on 17 May 2004 and was ratified by the UK on the 17 January 2005. This requires the UK to reduce or eliminate environmental emissions of a number of POPs. It also requires parties to develop multi-media release inventories for a number of POPs.

- The United Nations Economic Commission for Europe's Convention on Long Range Transboundary Air Pollution. This is a long standing international agreement on air pollution, which in 1998 added a Protocol on POPs. This came into force on 23 October 2003 and was ratified by the UK on 2nd September 2005. This requires the UK to develop atmospheric emission inventories for POPs.
- The European Union has published Regulation (EC) 850/2004 on Persistent Organic Pollutants. This requires Member States to develop release inventories for POPs and review them every three years. This also covered material stockpiles, and required the POP content of waste to be destroyed or irreversibly transformed.

The Stockholm convention established in May 2004 originally identified 12 POPs which required further action. Based on the letter of the convention the 12 substances were listed in annexes labeled A to C to control and reduce their environmental emissions.

- Annex A: Banned from commercial sale
- Annex B: Restricted from commercial sale
- Annex C: Unintentional releases requiring minimization

For this study, Annex C compounds pose the greatest challenge. These substances, often known as U-POPs (Unintentional Persistent Organic Pollutants) are of greatest concern due to their unintentional releases, often from diffuse sources which are difficult to quantify. The U-POPs, dioxins and furans, PCBs (polychlorinated biphenyls) and HCB (hexachlorobenzene) have been the subject of a continued body of research work and form part of the UK National Implementation Plan (NIP), as required by the Stockholm Convention, to provide strategies to reduce emissions of these substances.

The Stockholm Convention Review Committee (POPRC) through continuous communication with the ratified nations identified a further nine substances for addition to the convention in May 2009. These nine substances are outlined in Table 1.1. The substances are largely associated with pesticides and flame retardants, and a number are already covered by the UNECE convention on long range transboundary air pollution. As set out in Table 1, the majority of these substances fall within annexes A and B, with one new Annex B substance (PFOS and its salts and PFOS-F) for inclusion within the category of U-POPs.

The nine new POPs were officially adopted into the annexes of the convention in August 2010, a year after agreement was reached, to allow ratified nations to voice opinions on the substances listed. Now that the new POPs have officially been adopted and have become part of the convention text, ratified nations have up to a maximum of two years to update their NIP, and are also required to establish a full air, land and water emission inventory for the new Annex C substance.

The current study has been commissioned by Defra in the light of these developments to the Stockholm Protocol. Ultimately this will result in an amended NIP and emission inventories for the new POPs listed under the Stockholm Protocol. The objectives of the study are discussed in more detail in the next section.

Table 1.1 – Nine new POPs added to the Stockholm Convention

Substance	Usage within the UK	Banned in the UK	Stockholm Convention
Lindane (gamma Hexachlorocyclohexane)	Pesticide	2002* exemptions	A* with exemptions
Alpha HCH (Hexachlorocyclohexane)	Pesticide	1981 (Directive 79/117/EC)	A

Beta HCH (Hexachlorocyclohexane)	Pesticide	1981 (Directive 79/117/EC)	A
PeCB (Pentachlorobenzene)	Pesticide and chemical intermediate; unintentional releases from combustion processes and as contaminant in chemical products	*legal contamination limits set for use in Quintozene	A and C
HBB (Hexabromobiphenyl)	Flame retardant	1998 Banned under the Convention for Long Range – Transboundary Air Pollution (CLR-TAP)	A
TetraBDE and PentaBDE (brominated diphenyl ether)	Flame retardant	2004 (Directive EC 2003/11)	A
HexaBDE and HeptaBDE (brominated diphenyl ether)	Flame retardant	2004 (Directive EC 2003/11)	A
PFOS (Perfluorooctane sulfonic acid) and its salts, and PFOS-F (Perfluorooctane sulfonyl fluoride)	Multiple uses, primarily fire fighting foams, solvents and coatings	Foams containing PFOS no longer used in fire-fighting	B
Chlordecone	Pesticide	1977	A

1.2 Objectives

The aim of Work Package 2 is to support Defra in establishing air, land and water emissions inventories for the UK for the nine new POPs that were formally added to the Stockholm Convention in August 2010. The project objectives were defined in the light of Defra's responsibilities under the Stockholm Convention, as follows:

Objective 1 A comprehensive review of the nine new POPs to develop a dossier of uses and emission sources for the UK.

Objective 2 A comprehensive review of the existing research literature for the nine new POPs to develop a bank of emission factors, to include a critical review of data gaps and uncertainties.

Objective 3 To develop multi-media (air, land and water) emission inventories for the nine new POPs, providing annual estimates of POPs releases to the UK environment during 1990-2008. For Annex C substances, the UK will be required to report source-specific emission inventory estimates. For Annex A and Annex B POPs, supporting data on sources of environmental releases are required to enable development of UK action plans and updates to the NIP.

Objective 4 A review of the existing UK emission inventories to provide a summary for the potential for synergies in data gathering, and future inventory development.

Objective 5 To develop an outline scope of how additional monitoring of releases to land and water might benefit the existing UK emission inventory infrastructure.

1.3 Report Structure

The report aims to fulfil the objectives of the study outlined within Section 1.2, namely the review and development of source inventories for emissions to air, land and water of the nine new POPs within the UK. In order to address the objectives the report has been broken down into the following chapters:

- Chapter 1: Introduction
- Chapter 2: Methodology (Objectives 1 and 2)
- Chapter 3: Review of the nine new POPs. (Objectives 1, 2 and 3)
- Chapter 4: Review of existing UK emission inventories and scope for further research and monitoring. (Objectives 4 and 5)
- Chapter 5: Conclusions and recommendations

The report annexes provide a summary of activity and emission factors used in inventory compilation, together with their original reference sources.

2 Methodology

As described in Chapter 1, the aim of Work Package 2 is to support Defra in establishing air, land and water emissions inventories for the UK for the nine newly designated POPs. This overall aim is broken down into a set of discrete objectives (detailed in section 1.2) which are designed to enable a critical appraisal of the UK position to be developed, along with a review and evaluation of available data on emissions of the nine new POPs to all media. This report is intended to provide Defra with the available information on UK emissions of the nine newly designated POPs, in order to support Defra in developing policy in this area, fulfilling its obligations under the Stockholm Convention, and setting priorities for further research in this important area.

This chapter sets out the approach taken by the project team to achieve the objectives listed within section 1.2. The research findings, including emission inventory estimates, are presented in chapter 3.

The project team at AEA and the Lancaster Environment Centre (LEC) has researched the available information on UK activities that may lead to emissions of the nine newly designated POPs, with the aim of establishing complete source-specific air, land and water emission inventories where possible.

The study has comprised an initial scoping phase, reviewing the available international documents (including Stockholm Convention risk assessments) of the nine new POPs, to identify the range of activities and sources within the UK that are most likely to lead to environmental releases of the substances. The team has subsequently conducted a more detailed literature search and consultation, to research the highest priority emission sources and release pathways for the new POPs in the UK.

The development of inventory information included a series of sub-tasks, outlined below:

Table 2.1 POPs Inventory Research Sub-Tasks

Sub-task	Aim	Information sources
Part 1a – Review commercial uses	The majority of the nine new POPs no longer have commercial use. However for those which are used commercially it is important to identify the key uses, manufacturers and users to help derive accurate activity data.	Communications with relevant industry stakeholders, POPs experts and manufacturers Review of relevant industry studies Review of POPs guidance documents, notably Stockholm Convention risk assessments and POPs dossiers
Part 1b - Review emission sources and releases to environmental media	Alongside commercial use and unintentional emissions, it is necessary to derive a list of emission sources and media, to enable total emissions and key source/s to be identified for the nine new POPs where possible	Review of existing emission inventories both within the UK and internationally. Review of inventories for similar pollutants Review of scientific journal papers
Part 2a - Emissions data from existing monitoring and reporting mechanisms	For several emission sources (primarily regulated industrial processes) there are existing emission estimates based on monitoring programmes. These resources are useful for inventory compilation, although data quality	Review of existing UK inventories covered by UK legislation such as the pollution inventories, and the PRTR (Pollutant Release and Transfer Register) IPPC permits for relevant industry processes

Sub-task	Aim	Information sources
	needs to be closely reviewed to consider monitoring and reporting methods and data uncertainty.	Communication with environmental regulators
Part 2b - Emission factor research / data	Where monitored emission data is not available, especially for diffuse emission sources, inventory estimates are calculated using activity data in conjunction with emission factor data which may be available from national or international research. Data quality and applicability to UK circumstances are key considerations in the application of these data.	Review of existing emission factor libraries and research papers Review of scientific journal articles and relevant academic literature Consultation with international POPs and inventory experts including UNEP Working Group leaders, USEPA dioxin inventory compilers, the Environment Canada POPs research team, and several EU-based POPs experts and industry contacts. New sampling and analysis programmes to generate a new dataset for specific POPs sources and emissions, such as that implemented for PFOS in river water from waste water treatment.
Part 2c – Activity data research		Because of commonality with the existing inventories for dioxins and furans, PCBs and HCH, activity data was adapted from the existing inventory datasets
Part 2d – Source-specific data	Where emissions factors were not available, source-specific estimates were made. This enabled preliminary estimates of environmental emissions from materials during use and in the waste stream to be made.	Parameters such as levels of POPs in relevant items; stock disposal / replacement rates for POPs-containing items, congener breakdown; and partitioning between environmental media were taken from published research and stakeholder consultation.
Part 3 - cross-comparison and checking	Identify suitable data / proxies to enable some sense-checking of inventory estimates, e.g. cross-comparison against other pollutants or benchmarking emissions against production / activity indicators over the time-series.	Review UK data against other international like-for-like inventories. Cross comparison against inventories of related pollutants from specific sources. Given the scarcity of new POPs activity and emissions data, in some cases benchmarking against estimates from other countries, and/or extrapolating a limited dataset to generate an initial national estimate has been used in this study.

Once this analysis was carried out, and emissions estimates made, it was possible to complete the work programme by carrying out additional sampling and analysis to support the emissions estimates. Finally, recommendations were made for further work which would be most useful in reducing uncertainty in the emissions inventory.

2.1 Review of uses and releases of the nine new POPs

The initial step in the inventory compilation process was to develop a dossier for each of the nine POPs detailing the key emission sources and vectors (objective 1). As this work was designed to map emission trends and provide data as a time series (1990 – 2008), it took into account emission sources that were no longer current but may have a bearing on historic emissions.

This part of the work began with a full review of the UK legislation which affects the use of solvents and pesticides for some of the new POPs. We also reviewed relevant guidance documents from the Stockholm Convention including the risk assessment documents and survey returns under annex E. We then carried out a stakeholder consultation process with national stakeholders (Environment Agency, Devolved Administrations, UK POPs network, Defra officers, and industry trade associations) and international bodies (UNEP, US EPA, Environment Canada and international trade associations). This process was designed to guide the team to the key information needed to generate dossiers.

The project team developed a detailed knowledge of the applications which use these substances and of the products in which they are incorporated and the lifecycle of the product and its components. A degree of commonality was identified between the flame retardant chemicals as to the usage and fate of the products. Consultation was carried out with the chemical industry and other stakeholders to establish the technical process details for incorporation of flame retardants into product matrices, with the aim of understanding any implications for release routes of each substance to the environment.

Describing release routes of pesticides was found to be more straightforward in that - over the timescale of the inventory from 1990 onwards - they have been licensed for specific uses. The use of Chlordecone has been banned in the UK since 1977. Chlordecone was principally used as a fungicide for treatment of tobacco and banana crops which are not grown in the UK. Consequently, no significant usage is likely to have occurred within the UK. The absence of production or use of Chlordecone on crops imported into the UK for over 30 years means that any trace residues are likely to be negligible. Therefore releases of Chlordecone from the UK are highly likely to be insignificant in the global context.

Regulations to require that Lindane contain at least 99% gamma - hexachlorocyclohexane have been in place since 1979. Production of lindane is not thought to have taken place in the UK since before 1990. This means that fresh lindane in use since then, until its approval was revoked in January 2003, will contain only small quantities of alpha and beta isomers. However, there is a considerable stock of timber in use, which may have been treated with technical grade hexachlorocyclohexane in which alpha and beta hexachlorocyclohexane will be present in small quantities.

A dossier of major usage and manufacture of the POPs was compiled to identify key point sources and industries likely to be important to each substance. This was found to vary in relevance and reliability between substances, and over time. For example, the key manufacturer of PFOS was 3M, until manufacture ceased around 2001. Activity data was therefore sourced from both historic sales data, and wider industry usage rates. The UK reserves of PFOS in fire fighting foams were substantially exhausted in 2005, in dealing with the Buncefield explosion. This means that residual sources of PFOS are progressively harder to identify, but also likely to be of relatively low significance compared to the quantities that may have been released in the past.

2.2 Review of monitored emissions and update of existing emission factors

Building on the approach in part 1, the next step involved two processes:

- A review of the available monitored emissions reported within the UK
- A full review and assessment of the available emission factors quoted within scientific media.

The project team reviewed the available emission data reported through the UK inventories, namely: the NAEI (national atmospheric emissions inventory), UK Pollution Inventories, UK PRTR (pollutant release and transfer register), communication with the TOMPs network (Toxic Organic Micro Pollutants) and review of the Environment Agency waste interrogator databases for 2007 and 2008. A full discussion of the UK emission inventories infrastructure and synergies that exist between them is given in chapter 4. In summary, the critical review of the available reported emissions showed that reported emissions were mainly based on calculation rather than monitoring. The greatest abundance of data was related to emissions for air, with less data available for emissions to water and land.

The NAEI provides estimates of emissions to air for lindane, chlordecone and PBDEs. As discussed in Section 2.1, chlordecone releases are estimated in the NAEI and in the present study as zero since 1990, as a result of the use of the substance having been banned since 1977. The estimated lindane releases given in the NAEI are dominated by releases from the large stock of historically treated timber. However, the estimation technique used for this is currently subject to significant uncertainty, since there is poor information on both the quantity of wood which has been treated and the volatilisation rate of the HCH isomers from the aged treated wood.

Agricultural and pharmaceutical lindane use has been controlled in the UK since the 1990s and no longer occurs. A literature review was carried out, with the aim of improving the current emission estimates to air, and on linking these to releases to land. Water release routes were evaluated, but these were found to be limited to historic agricultural and pharmaceutical uses.

The NAEI emission estimates for the brominated diphenyl ethers are currently based on a per capita estimate of EU usage and emission factors from the Existing Substances Risk Assessment.⁶ These were considered likely to be conservative, because they were designed for risk assessment rather than inventory purposes.

The National Atmospheric Emission Inventory does not currently contain estimates for the other new POPs added to the Stockholm Convention.

The second process within this step was to carry out a full review of the available emission factor data within the existing scientific media. This process was designed to allow for the development of emission factor libraries, which are a useful tool to gauge the variation in quoted emission factors, leading to an estimate of the uncertainties within the emission factors.

This process began through a review of key guidance documents produced by the Stockholm Convention and guidance through communication with key national and international experts. A review of the scientific journals was then commissioned in combination with the British Library.

The literature search was carried out by searching Chemical Abstracts and Pollution Abstracts for CAS registry numbers for the substances under consideration together with any of the following terms

⁶ European Chemicals Bureau (2002), "European Union Risk Assessment Report bis(pentabromophenyl)ether," Ref. EUR 20402 EN

- Emission(s) factor(s) / Emission(s) Inventory
- Environmental release / Environmental emission / Environmental fate / Environmental sink / Environmental concentration
- Aqueous emission(s) / Aqueous release / Aqueous transport / Aqueous measurement
- Atmospheric emission(s) / Atmospheric release / Atmospheric transport / Atmospheric measurement

The search was limited to references published from 1990 onwards.

The British Library search produced 148 viable documents, which on further review was reduced to 34 key documents. The results of the search of published scientific journals found the greatest abundance of research papers in relation to PBDEs, followed by hexachlorohexanes (including lindane) and pentachlorobenzene. There was only limited research data available for PFOS and there were no papers identified for hexabromobiphenyl and chlordecone within the search results. In the case of chlordecone this may reflect the fact that the key emissions occur before 1990.

Further research was carried out by the University of Lancaster in relation to polybrominated diphenyl ethers and PFOS. Relevant research was shared between the project team members to ensure full access to data.

The results of the library search in combination with the review of existing inventories were compared with the results of release dossiers, to help establish preliminary inventories, and more importantly to help establish where data gaps existed. This additional process was carried out by the full project team which included AEA and The University of Lancaster (responsible for managing the TOMP network on behalf of Defra). The findings of this review are given in Chapter 3.

2.3 Establish new emission factors

Initially preliminary emission inventories were established using the release dossiers along with the gathered emission factor data and reported emission data. This was done to help identify where data gaps existed within the inventories, and allow for the development of new methodologies to close those gaps.

The review of these inventories highlighted specific issues which required further action. In particular these relate to the emission of PFOS and to a secondary degree pentachlorobenzene. It was established early within the project that the key emission vector for PFOS would be surface water based on its historic commercial use in household goods. In this regard the emission to surface waters from waste water treatment works represents the key emission source for this pollutant. However the emissions quoted within the UK pollution inventories are based on a theoretical model which is likely to reflect a conservatively high estimate for emissions. Given that this source in particular was of high importance, a further study was devised by Lancaster University to cross reference the quoted emissions within the pollution inventory against a sampling and analysis regime in two fresh-water rivers downstream of such works. Further discussion of this analysis is given in chapter 3.

The preliminary pentachlorobenzene inventory identified several gaps within the data, particularly in regard to emissions for land. This is because the most significant sources of pentachlorobenzene emissions to land result from diffuse combustion processes, particularly backyard burning and bonfires. In this case there is a lack of data in terms of quantities of contaminated ash and air pollution control residues generated from combustion processes. Ash generation factors based on key literature sources were used to gauge the emission of

contaminated ash for several sources. The inventory was also checked through comparison to existing pentachlorobenzene inventories produced by Environment Canada and a Eurochlor global inventory. This allowed some of the data gaps to be evaluated against these inventories, and also to be checked against existing inventories for hexachlorobenzene and dioxins and furans where appropriate.

3 Emissions Inventory for newly designated POPs

3.1 Introduction

This chapter summarises the study findings for each of the newly designated POPs added to the Stockholm Convention in August 2010. A complete source-based inventory has been derived for Pentachlorobenzene, whilst non-source-specific national estimates of releases to air, land and water have been compiled for the other newly designated POPs.

The scoping phase of the project identified that emissions of chlordecone in the UK are expected to be negligible, and hence no further research effort has been directed towards chlordecone and no emission estimates are presented here. This reflects the fact that there appear to be no policy issues for Defra to consider with regard to chlordecone, unless additional information on potential sources of chlordecone comes to light.

3.2 Alpha, beta and gamma hexachlorocyclohexane (Lindane)

3.2.1 Sources

Lindane is an insecticide comprising over 99% gamma-hexachlorocyclohexane (HCH). The production of lindane has been banned in the UK since 2002. However, lindane production continues in some countries – currently believed to comprise only India.⁷ Alpha and Beta-HCH have been banned in the UK since 1982, and are not intentionally produced or marketed. However, they do form minor constituents of lindane.

Technical HCH was manufactured and used from the 1940s on a large scale as an alternative to DDT, due to its effectiveness as an insecticide. It was found that gamma-HCH was the most effective isomer for insect control, and consequently, technical grade HCH was gradually replaced by lindane, which consists of more than 99% gamma-HCH. Lindane was produced from the 1940s through to the 1990s. The process for manufacture of lindane is inefficient, and produces 6 to 10 tonnes of by-products including alpha and beta-HCH for each tonne of lindane produced. This has resulted in disposal of large quantities of by-products during past production of lindane. In some cases, landfilled by-product material from past production of lindane could constitute a significant environmental source of alpha- and/or beta-HCH.

IHPA (2006) estimated that a global total of approximately 1.9 to 4.8 million tons of waste HCH residuals require disposal, based on global lindane production of approximately 600,000 tonnes. It is estimated that about 10 million tons of technical HCH were released into the environment between 1948 and 1997 (Li et al., 1999), mainly as an insecticide. Breivik et al. (1999) estimated technical HCH usage at approximately 400 000 tons in Europe between 1970 and 1996. HCH (including lindane) was not extensively used in the UK, and its use has now been banned almost universally worldwide. . However, use of stockpiled material or limited public health applications may still continue in some parts of the world.^{7,8,9}

⁷ United Nations Environment Programme, Report of the Persistent Organic Pollutants Review Committee on the work of its second meeting, Addendum: Risk profile on lindane," Ref. UNEP/POPS/POPRC.2/17/Add.4, November 2006

⁸ United Nations Environment Programme, Report of the Persistent Organic Pollutants Review Committee on the work of its third meeting, Addendum: Risk profile on alpha hexachlorocyclohexane," Ref. UNEP/POPS/POPRC.3/20/Add.8 January 2008

HCH and lindane were largely used as agricultural pesticides, but there have also been minor uses for treatment of scabies and head lice in humans.

1.3.1 Environmental release pathways

In the past, HCH was released into the environment during the manufacture of technical HCH and lindane, and also through the use of these substances as pesticides. The manufacture and use of HCH in the UK has now ceased, since the ban in 2002.

Releases of alpha-HCH into the environment from legacy sources remain possible. These include hazardous waste sites, stockpiles and residues of lindane production. Contaminated sites could contribute to the environmental burden of alpha-HCH by release into groundwater, surface water or the atmosphere.

The HCH enantiomers have relatively long lifetimes in the environment (up to or longer than 1 year). However, an environmental lifetime of up to 1 year¹⁰ indicates that any residual HCH in the environment from past uses is likely to have substantially ceased. The only release routes of potential concern for the UK would be from imported products containing HCH, or from legacy sources such as stockpiled or landfilled industrial wastes. Because of the bioaccumulative properties of HCH, one potential exposure route could be increased levels of HCH in food products brought into the UK.

3.2.1.1 Alpha HCH

The main sources of alpha-HCH are as follows:

1. Current manufacturing (None in the UK)
2. Stockpiles (None in the UK)
3. Historic waste disposal
4. Current use in timber treatment, agriculture (None in the UK)
5. Current medical use (None in the UK)
6. Historical use in timber treatment, agriculture
7. Unintentional release from metal working

3.2.1.2 Beta-HCH

The main sources of beta-HCH are as follows:

1. Current manufacturing (None in the UK)
2. Stockpiles (None in the UK)
3. Historic waste disposal
4. Current use in timber treatment, agriculture (None in the UK)
5. Current medical use (None in the UK)
6. Historical use in timber treatment, agriculture
7. Unintentional release from metal working

⁹ United Nations Environment Programme, "Report of the Persistent Organic Pollutants Review Committee on the work of its second meeting, Addendum: Risk profile on beta hexachlorocyclohexane," Ref. UNEP/POPS/POPRC.3/20/Add.9 December 2007

¹⁰ Philip H. Howard, Robert S. Boethling, William F. Jarvis, W. Meylan (1991). "Handbook of Environmental Degradation Rates," CRC Press

3.2.1.3 Gamma HCH (Lindane)

The main sources of gamma-HCH are as follows:

1. Current manufacturing (None in the UK)
2. Stockpiles (None in the UK)
3. Historic waste disposal
4. Current use in timber treatment, agriculture
5. Current medical use (None in the UK)
6. Historical use in timber treatment, agriculture
7. Unintentional release from metal working

3.2.2 Emission factors

Few emission factors were identified for HCH. It was possible to identify emissions factors for landfill sources only. Assmuth (1996)¹¹ reported concentrations of alpha-HCH and lindane in landfill leachate at 52 sites in Finland. The landfill sites were described as *“uncontrolled landfills of low technical standard, implying lack of base compaction, of waste pretreatment and compartmentalization, of top sealing, and of treatment of gas and leachate.”* The reported concentrations were:

- Alpha-HCH: Mean concentration: 0.096 µg/litre
Median concentration: 0.021 µg/litre
- Lindane: Mean concentration: 0.41 µg/litre
Median concentration: 0.025 µg/litre

Research carried out for Defra indicates that approximately 0.15 m³ of leachate is discharged per tonne of waste landfilled¹², although this estimate is subject to considerable uncertainty and variability from site to site. However, taking this at face value, and using the mean concentration values from reported by Assmuth,¹¹ this gives the following emission factors:

- Alpha-HCH: 14 µg/tonne of waste landfilled
- Lindane: 62 µg/tonne of waste landfilled

In view of the lack of emissions factors for the HCH enantiomers from potentially significant sources such as current and historical use in timber treatment, the literature review was extended to investigate whether a preliminary UK inventory could be developed from other data sources. The preliminary inventory obtained in this way is set out in Section 3.2.4 below.

3.2.3 Emission inventory

3.2.3.1 All HCH isomers

As lindane is no longer used or manufactured in the UK, any current releases would result from hazardous waste sites, old manufacturing sites, or past use of lindane. *(A release of HCH is identified in the Pollutant Release and Transfer Register for 2008. The site in question was contacted to query this data point, and we have confirmed that the data is a mis-report by the operator within the PRTR.)*

¹¹ Assmuth, TW, “Comparative risk analysis of waste site toxicants by indices based on concentration distributions, fluxes, environmental fate and critical effects”, Journal of Hazardous Materials, 48, p121, 1996.

¹² Defra, 2004, “Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes,” Enviro Consulting Ltd and University of Birmingham, Report Ref. PB9052A

Van den Gon et al. (2005)¹³ estimated emissions of HCH from the UK to be 30,300 kg per year in 2000, made up of 24,000 kg from solvent and production use, and 6,300 kg from agriculture. This is likely to have declined significantly from 2000, because materials containing HCH will have been progressively removed from use and disposed of by incineration or landfill (production in the UK had already ceased by 2000).

3.2.3.2 Alpha-HCH

Li and Macdonald estimated that a global total of 6 million tonnes of alpha-HCH were released to the environment during the manufacture and use of HCH as a pesticide.¹⁴ Of this release, 4.3 million tonnes was released to the atmosphere, and would degrade relatively quickly. This gives a balance of approximately 1.7 million tonnes present on land, in water or in landfill worldwide.

The UK was a minor user and manufacturer of HCH, and so the UK is expected to have a relatively low proportion of global disposal. A preliminary estimate of current lindane emissions from the UK was therefore obtained assuming that emissions were in proportion to the UK proportion of world Gross Domestic Product, multiplied by a factor of 10% to account for relatively low UK manufacture and use. The UK GDP is 4.4% of the global GDP.¹⁵ Assuming that 0.1% of the remaining alpha-HCH is released to the environment per year, this gives an estimated annual release to all media in the UK of 7.4 tonnes alpha-HCH per year. This is comparable with the estimate of van den Gon of 30 tonnes total HCH emissions in the UK in 2000. The UK release estimate for alpha-HCH has high associated uncertainty due to the scarcity of UK-specific source data. The uncertainty in the emissions estimate is estimated to be approximately a factor of 3 (1 Standard Deviation) or a factor of 10 (2 Standard Deviations). Recommendations for studies to reduce this uncertainty are given in Section 3.2.4.

3.2.3.3 Beta-HCH

Li et al.¹⁶ estimated that a global total of 850,000 tonnes of beta-HCH was released to the environment during the manufacture and use of HCH as a pesticide.¹⁴ Of this release, 230,000 tonnes was released to the atmosphere, and would degrade relatively quickly. This gives a balance of approximately 620,000 tonnes present on land, in water or in landfill worldwide.

Again, as the UK was a minor user and manufacturer of HCH, a preliminary estimate of current beta-HCH emissions from the UK was obtained by assuming that emissions were in proportion to the UK proportion of world Gross Domestic Product, multiplied by a factor of 10%. Assuming that 0.1% of the remaining alpha-HCH is released to the environment per year, this gives an estimated annual release to all media in the UK of 2.7 tonnes beta-HCH per year. This is about one tenth of the estimate of van den Gon of 30 tonnes total HCH emissions per year in the UK in 2000. The uncertainty in this estimate is estimated to be approximately a factor of 3 (1 Standard Deviation) or a factor of 10 (2 Standard Deviations). Recommendations for studies to reduce this uncertainty are given in Section 3.2.4.

As a cross-check, Li et al.¹⁶ estimated that 66 tonnes of beta-HCH were emitted from soils globally in 2000. As a preliminary assumption, emissions from soil residues could be estimated to be approximately in proportion to GDP, multiplied by a factor of 10% to account for relatively low UK manufacture and use. On this basis, a preliminary estimate of UK emissions of beta-HCH from soils is 0.29 tonnes per year, compared with the estimate from the global manufactured inventory of 2.7 tonnes beta-HCH per year.

¹³ H Denier van der Gon, M van het Bolscher, A Visschedijk, P Zandveld (2005), "Study to the effectiveness of the UNECE Persistent Organic Pollutants Protocol and cost of possible additional measures," TNO Report Ref. 36663

¹⁴ Li, YF., Macdonald, RW., "Sources and pathways of selected organochlorine pesticides to the Arctic and the effect to pathway divergence on HCH trends in biota: a review. *The Science of the Total Environment*" 342, 2005, p. 87-106.

¹⁵ World Bank World Development Indicators (accessed via www.google.co.uk 2010)

¹⁶ Li YF., Scholtz MT., and van Heyst BJ., "Global Gridded Emission Inventories of Beta-Hexachlorocyclohexane." *Environmental Science & Technology* 37 (16), 2003, p. 3493-3498.

These emission estimates for the UK are associated with high uncertainty, due to the scarcity of UK-specific source data. This is highlighted by the range of estimated UK emissions, which cover two orders of magnitude. The best estimate of emissions is approximately 3 tonnes beta-HCH per year, with an uncertainty estimate of –90% to +1000%. , That is, emissions from the UK are estimated to be in the range 0.3 to 30 tonnes beta-HCH per year. Recommendations for improving this estimate are made in Section 3.2.4 below.

1.3.1.1 Lindane

The UNEP POPs Review Report estimated that a total of 600,000 tonnes of Lindane was used globally between 1950 and 2000.⁷ As a worst case, it could be assumed that all this material was released to land, to landfill, and to water.

The UK was a minor user and manufacturer of lindane, and so the UK is expected to have a relatively low proportion of global disposal. However, most lindane was produced in Europe. A preliminary estimate of current lindane emissions from the UK was therefore obtained assuming that emissions were in proportion to the UK proportion of world Gross Domestic Product (4.4%), multiplied by a factor of 10% to account for relatively low UK manufacture and use. Assuming that 0.1% of the total manufactured quantity of lindane is released to the environment per year, this gives an estimated annual release to all media in the UK of 26 tonnes lindane per year. The uncertainty in this value is estimated to be approximately a factor of 3 (1 Standard Deviation) or a factor of 10 (2 Standard Deviations). Recommendations for studies to reduce this uncertainty are give in Section 3.2.4.

This is about one tenth of the estimate of van den Gon et al. of 30 tonnes total HCH emissions per year in the UK in 2000. The estimate of van den Gon is for total HCH, rather than for lindane alone. Emissions from soils are likely to be dominated by lindane, which was the main species used as an insecticide during the later years of its usage. However, emissions from manufacturing residues are more likely to be dominated by alpha-HCH, as this was produced in larger quantities from the manufacturing process. This will depend on the details of the disposal and environmental release pathways for the HCH isomers (see recommendations in the following section).

3.2.4 Recommendations for further research

Little UK-specific data on lindane and its related HCH enantiomers was identified in the study. However, from the broad estimates derived from limited global and European data, it is clear that there is potential for emissions of lindane into the UK environment from a range of sources, primarily legacies of earlier production and contamination. There may also be some scope for imported emissions of lindane on materials from areas where it is still used, perhaps on textile raw materials from overseas that are subsequently washed, processed and used in UK manufacturing processes.

The uncertainties in the UK estimates are high and the levels of the emission estimates are quite significant. This could potentially be a significant issue for Defra policy in regard to its obligations under the Stockholm Convention, and hence further research to improve the emission estimates for lindane and HCH enantiomers is considered to be a high priority.

Improvements to the data quality should be prioritized for the main potential emission sources of alpha, beta and gamma hexachlorohexane. These are:

- Historic disposal of waste containing HCH from manufacturing
This could be carried out by taking measurements of HCH in landfill gas and leachate from relevant landfill sites. It may be possible to use regulatory measures to implement this recommendation

- Historic and current disposal of materials containing HCH
This could be carried out by taking measurements of HCH in landfill gas and leachate from relevant landfill sites and/or waste incineration facilities. It may be possible to use regulatory measures to implement this recommendation
- Ongoing use of materials containing HCH
This could be carried out by taking measurements of HCH in treated materials and in nearby soils and waters
- Historical use of HCH in agriculture
This could be carried out by taking measurements of HCH in soils
- Unintentional release of HCH from metal working processes
This could be carried out by taking measurements of HCH in workplace air and emissions to air and water from relevant processes. It may be possible to use regulatory measures to implement this recommendation

These studies could be carried out on a similar scale to the survey conducted within this programme for sludge compositional analysis in order to provide a relatively low-cost option for extending the data set and assist in scoping out the potential emission sources from different industries, processes and waste streams.

The estimates of UK soil emissions are based on data from around 2000. There is likely to have been a reduction in emissions from these sources, as the reservoir of HCH held in soils is reduced. Hence, attention could also be focused on investigating the likely reduction in emissions of HCH enantiomers since 2000. This could involve a study of HCH enantiomers in soils and air.

The addition of these substances to the Convention will prompt more global research into sources and emissions, and hence a close watching brief on UNEP and EU-level working group activities is recommended.

3.3 Pentachlorobenzene

3.3.1 Background

Pentachlorobenzene, CAS 608-93-5, is a poly-chlorinated aromatic compound from the same family of chemicals as hexachlorobenzene, which has been the subject of extensive study.¹⁷ Under review by the Stockholm Convention it has been found to meet the requirements to be classed as a 'POP' (persistent; bio-accumulative; potential for causing harm through toxicity/eco-toxicity; and capable of long range transport). It was the only new substance to be added to Annex A and C of the convention in 2010. This was due to concerns over unintentional emissions.¹⁸

Pentachlorobenzene is also covered by the E-PRTR (European Pollutant Release and Transfer Register).¹⁹ This is due to its inclusion under the water framework directive (2000/60/EC) as one of a set of 16 priority substances for concern regarding release to surface waters.²⁰ Its inclusion within the set of 16 is likely to be linked to the use of the pesticide Quintozene, which contained pentachlorobenzene as a contaminant of the production process.

¹⁷ Bailey R., 2007, 'Pentachlorobenzene – Sources, environmental fate and risk characterization', Eurochlor science dossier.

¹⁸ Stockholm Convention new substance additions to annexes: <http://chm.pops.int/Programmes/New%20POPs/Overview/tabid/667/language/en-GB/Default.aspx>

¹⁹ European Pollutant Release and Transfer Register (E-PRTR) <http://prtr.ec.europa.eu/>

²⁰ Amendment to the Water framework directive – priority list of substances for surface water emissions: http://ec.europa.eu/environment/water/water-dangersub/pri_substances.htm

Pentachlorobenzene is no longer used commercially^{17,21}, but historically has had a wide array of applications. It is also produced unintentionally during combustion processes such as domestic use of coal and firewood, and the incineration of municipal waste.^{17,21,22} This combination of legacy issues from commercial use and unintentional emissions means that over the 1990 – 2009 timeframe pentachlorobenzene has a wide range of sources.

3.3.1.1 Studies of Pentachlorobenzene emissions

Inventory compilation for Pentachlorobenzene began with a review of the existing inventories and literature to help identify a complete list of sources and their relevance to the UK perspective. The main reference sources reviewed were:

- Environment Canada, 2005, Pentachlorobenzene and tetrachlorobenzene, proposed risk management strategy.²²
- Bailey, R and Eurochlor, 2007, Pentachlorobenzene – sources, environmental fate and risk characterization – Science dossier.¹⁷
- Hogendoorn et al, 2009, Inventory emission factors for Pentachlorobenzene, RIVM report²¹
- Stockholm Convention, 2008, Annex E survey for submitting pursuant to article 8 of the Stockholm Convention. Member states feedback^{7,23}
- Persistent Organic Pollutants Review Committee, 2008, Draft risk management evaluation for Pentachlorobenzene, Stockholm Convention working group.²⁴
- Bailey, R et al, 2009, 'Sources and Prevalence of Pentachlorobenzene in the environment', Chemosphere issue 75, pp 555-564²⁵
- Robles-Molina, J et al, 2010, 'Determination of organic priority pollutants in sewage treatment plant effluents by gas chromatography high-resolution mass spectrometry', Talanta issue 82 pp 1318-1324.²⁶

3.3.1.2 Comparison of UK inventory against Canadian and Eurochlor inventories

The review of emission inventories found two key references:

- The Environment Canada review from 2005.²² This was largely based on monitoring data as well as theoretical equations based on the physical properties of the compound.
- A dossier from 2007¹⁷ which was compiled by an independent consultant Dr Robert Bailey on behalf of Eurochlor, a body representing the European Chlor-Alkali industry. Dr Bailey also completed a global review of hexachlorobenzene emissions in 2000.²⁷ The 2007 dossier draws upon the Canadian 2005 inventory as well as building in new data from the US EPA and the chlorine industry to provide global estimates of emissions.

These two inventories in combination with the other key reference sources have provided a useful reference point for comparison against the UK results, in particular to sense-check the magnitude of emission estimates to different media. Table 3.1 below provides a summary of all three inventories.

²¹ Hogendoorn et al, 2009, 'Inventory emission factors for pentachlorobenzene', RIVM report

²² Environment Canada, 2005, 'Pentachlorobenzene and tetrachlorobenzene – proposed risk management strategy'

²³ Stockholm Convention, 2008, Annex E survey for submitting pursuant to article 8 of the Stockholm Convention. Member states feedback

²⁴ Persistent Organic Pollutants Review Committee, 2008, Draft risk management evaluation for Pentachlorobenzene, Stockholm Convention working group

²⁵ Bailey, R et al, 2009, 'Sources and Prevalence of Pentachlorobenzene in the environment', Chemosphere issue 75, pp 555-564

²⁶ Robles-Molina J, et al, 2010, 'Determination of organic priority pollutants in sewage treatment plant effluents by gas chromatography high-resolution mass spectrometry', Talanta vol 82 pp 1318 - 1324

²⁷ Bailey, R, 2000 'Global Hexachlorobenzene emissions', Chemosphere, vol 43 pp 167-182

The key emission vector is identified as emissions to land. Source emission estimates for PeCB in the UK show that the current and future emissions of Pentachlorobenzene are predominantly from combustion activities, particularly uncontrolled combustion such as backyard burning of waste and accidental fires. The residual PeCB within combustion ash is one of the main components of the UK inventory estimates, as outlined below in section 3.3.2.

Table 3.1 Comparison and review of UK inventory with other inventories

Medium	UK inventory 2009	Eurochlor global inventory 2007	Canadian inventory 2003
Emission to air	48 kg (11%)	11050 kg (13%)	8 kg (19%)
Emission to land	388 kg (88%)	71400 kg (84%)	33 kg (79%)
Emission to water	3 kg (1%)	2120 kg (3%)	0.8 kg (2%)
Total	439 kg	85000 kg	41.8 kg
Source	AEA Technology	Ref. 17	Ref. 22

3.3.2 Environmental release pathways

The potential sources of pentachlorobenzene in the UK are listed as the following:

- Contaminant in current pesticide use No longer used in UK
- Contaminant in historical pesticide use or stockpiles Likely to be minor
- Contaminant in HCE use for aluminium industry No longer used in UK
- Byproduct of solvent processes (manufacture of carbon tetrachloride) No longer used in UK
- Component of PCB mixes Potential release pathway (to air/waste disposal)
- Current use as fire retardant No longer used in the UK
- Current use within dry cleaning chemicals Likely to be minor
- Historical use as fire retardant Likely to be minor
- MSW incineration Potential release pathway (to air)
- Hazardous and clinical waste incineration Potential release pathway (to air)
- Open waste burning Potential release pathway (to air/land/water)
- Biomass burning Potential release pathway (to air/land/water)
- Accidental fires – buildings and vehicles Potential release pathway (to air/land/water)
- Waste water treatment works Potential release pathway (to water)

The emission pathways over the period 1990 – 2009 are linked to former commercial uses, and legacy thereof, as well as unintentional sources. Historically, the presence of pentachlorobenzene has been linked primarily with the following products:

- An elastomer used alongside PCB (Polychlorinated Biphenyls) in di-electric fluids.
- A contaminant of the pesticide Quintozene (pentachloronitrobenzene CAS 82-68-8) resulting from its use as an intermediate in the production process. The UK limit is 10g PeCB / kg of Quintozene.
- A contaminant of hexachloroethane (HCE), a degassing agent used in secondary aluminium manufacture.
- A trace contaminant in the pesticide pentachlorophenol (PCP)
- A trace contaminant in tetrachloroethylene (PERC), used primarily in dry cleaning
- A trace contaminant in carbon tetrachloride, a solvent and chemical reagent with multiple applications.

All of these uses have since either been banned except for the use of PERC which is subject to strict control with phase out expected in the near future. The use of PCB within di-electric equipment was banned in 1977 and has been subject to a phase out programme since that time. This includes the removal of di-electric equipment assumed to contain more than 5kg of PCB from service by 2000.²⁸ Similarly the use of HCE for degassing in aluminium smelters was banned in 2000 over environmental concerns regarding the emissions of hexachlorobenzene.²⁸

The pesticide licence for use of Quintozene was allowed to lapse in 2002, meaning it can no longer be used legally. However restrictions on the level of HCB and pentachlorobenzene were imposed in the early 1990s, and this marked a change in production process which significantly reduced the contamination levels. The legal limit prior to cessation from the market was 10g/kg of Quintozene (or 1% wt/wt).²⁹ Pentachlorobenzene is also found as a trace contaminant in PCP,³⁰ a wood fungicide which has also been phased out, although some legacy issues do exist regarding stockpiles of treated wood on the market.

Carbon tetrachloride historically had multiple applications including production of CFC refrigerants, aerosol propellants, foam blowing agents, grain fumigants and as a metal degreaser. It was banned in 2002 over concerns on its effect to the O-zone layer.³¹ PERC is controlled under the solvent emissions directive (1999/13/EC) and as a known carcinogen is subject to strict controls on use of the product in the dry cleaning sector.³² The use of PERC has declined significantly since 1990 and is expected to continue to decline as its use is phased out. However, it remains an ongoing source of pentachlorobenzene emissions.

Emissions arising from unintentional sources are more difficult to control, and emissions estimates are typically subject to higher uncertainty. Bailey, 2000,²⁷ notes the potential emission of chlorobenzenes from solid fossil fuel combustion. This is particularly true where the combustion process is less efficient, such as small-scale combustion in domestic grates, rather than within power stations, for example. The generation of PeCB within domestic grates (and also from backyard waste burning activities) also provides a direct exposure pathway due to the likely risks of inhalation and skin contact during ash handling and disposal.

²⁸ Whiting R et al, 2009, 'Review and update of the UK source inventories of dioxins, dioxin-like PCBs, PCBs and HCB for emissions to air, water and land', AEA report on behalf of Defra

²⁹ Health and Safety Executive, <http://www.pesticides.gov.uk/approvals.asp?id=55>

³⁰ Borysiewicz, 2008, 'Preliminary risk profile for pentachlorophenol', Institute of Environmental Protection, Poland.

³¹ HPA (Health Protection Agency) guidance document on carbon tetrachloride ban 2002: http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1235032868074

³² Guidance document on use of PERC and solvent emissions directive in dry cleaning. <http://drycleanersconsultants.com/solvent-emissions-directive.php>

3.3.3 Pentachlorobenzene emissions to air

This section sets out a review of the available emission factors from the key literature sources. It then documents the emission inventory to air, with discussion of the key sources and trends across the 1990 – 2009 timeframe.

3.3.3.1 Review of air emission factors

Table 3.2: Emission factors for Pentachlorobenzene – Air

Source	Emission factor	Comment	Reference
Coal-fired power station < 50 MW	2.5 mg / tonne fuel	Empirical calculation for emission of PeCB from a coal burner, based on ratio of monitored emissions of HCB from coal combustion by Oberg and Bergstrom, 1985. As reported in Bailey 2007.	Bailey 2007 ¹⁷ Hogendoorn et al 2009 ²¹
Combustion of biomass (assumed to be wood and straw)	0.6 mg/tonne fuel 1.2 mg / tonne of carbon in fuel	Original reference (Zimmerman) is based on a ratio of dioxins to PeCB from a domestic wood burner. Calculation based on carbon content of fuel. Bailey 2007 reference provides an assumed emission factor for wood as tonnes of fuel.	Hogendoorn et al 2009; ²¹ Bailey 2007 ¹⁷ Zimmerman et al 2001 ³³
Incineration of municipal solid waste	6.4 mg/tonne 161 mg/tonne 84 mg/tonne 175 mg/tonne	All references quoted within Bailey 2007 as part of a review of incinerator technology. The quoted figures are for fluidised bed based processes. The emissions likely represent older plants prior to improved control and abatement following the implementation of more recent legislative requirements.	Bailey 2007 ¹⁷ Wikstrom et al. 1999 ³⁴ ; Fangmark 1994 ³⁵ ; Akimoto et al. 1997 ³⁶
Incineration of municipal solid waste	273 mg/tonne 7 mg/tonne 2.9 mg/tonne 0.1mg/tonne	All references quoted within Bailey 2007 as part of the review of incinerator technology. Technology not specified, but quoted as being from city incinerators. The value from Kat and Urano (2001) of 7 mg/tonne would likely be the best UK estimate. Following the introduction of the waste incineration directive, it was assumed that abatement improvement is similar to that for dioxins and furans – 90% reduction. The emission factor for HCB in the NAEI (National Atmospheric Emissions Inventory) is 0.5 mg/tonne, suggesting that 0.7 mg PeCB/tonne is likely to be reasonable.	Bailey 2007 ¹⁷ Tiernan et al 1983 ³⁷ ; Kato and Urano 2001 ³⁸ ; Jay & Stieglitz 1995 ³⁹ ; Chandler 2004 ⁴⁰
PVC Combustion	65 µg per kg PVC	Experimental Muffle furnace 600°C	Hogendoorn et al 2009; ²¹

³³ Zimmerman et al, 2001, 'Emission of nonchlorinated and chlorinated aromatics in the flue gas of incineration plants during and after transient disturbances of combustion conditions: Delayed emission effects' Environmental Science and Technology vol 35 pp 1019-1030

³⁴ Wikstrom et al, 1999, 'Influence of variation in combustion conditions on the primary formation of chlorinated organic micropollutants during municipal solid waste combustion' Environmental Science and Technology Vol 33 pp 4263 - 4269

³⁵ Fangmark et al, 1994, 'Influence of postcombustion temperature profiles on the formation of PCDDs, PCDFs, PCBzs and PCBs in a pilot incinerator', Environmental Science and Technology vol 27 pp 1602 - 1610

³⁶ Akimoto et al, 1997, 'Comparative study on formations of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and related compounds in a fluidized bed solid waste incinerator using long term used sand and fresh sand', Chemosphere vol 34, pp 791 - 799

³⁷ Tiernan et al, 1983, 'Chlorodibenzodioxins, chlorodibenzofurans and related compounds in the effluents from combustion processes', Chemosphere vol 12, pp 595-606

³⁸ Kato and Urano, 2001, 'Convenient substitute indices to toxic equivalent quantity for controlling and monitoring dioxins in stack gas from waste incineration facilities', Waste Management vol 21 pp 55-62

³⁹ Jay and Stieglitz, 1995, 'Identification and quantification of volatile organic components in emissions of waste incineration plants', Chemosphere vol 30 pp 1249 - 1260

⁴⁰ Chandler, 2004, 'Assessment of the potential for emissions of tetrachlorobenzenes and pentachlorobenzenes from the incineration of municipal solid waste', Environment Canada, National Office of Pollution Prevention

Source	Emission factor	Comment	Reference
	4700 µg per kg PVC		Kim et al 2004 ⁴¹
Controlled PVC incineration	300 µg per kg PVC 970 µg per kg PVC	Pilot plant burner	Hogendoorn et al 2009; ²¹ Bailey 2007 ¹⁷ Ahling et al 1978 ⁴² ; Kim et al 2004 ⁴¹
Incineration of hazardous waste	14 mg/tonne 14.4 mg/tonne	Technology not specified. Original reference is likely to be the Oberg and Bergstrom (1985) paper. It is unclear whether the Chandler value is quoted from Oberg and Bergstrom. The RIVM report (2009) states the Chandler reference is based on an empirical equation from incomplete combustion.	Bailey 2007 ¹⁷ Oberg and Bergstrom 1985 ⁴³ ; Hogendoorn et al 2009; ²¹ Chandler 2004 ⁴⁰
Household waste burning	80 mg/tonne 76 mg/tonne 53 mg/tonne 4.5 mg/tonne	Open barrel method	Hogendoorn et al 2009 ²¹ ; EPA, 2002 ⁴⁴ ; Bailey 2007 ¹⁷ EPA, 1998 ⁴⁵ ; Chandler 2004 ⁴⁰
Household waste burning	70 mg/tonne	Uncontrolled pit burners and conical burners	Hogendoorn et al 2009 ²¹ ; Chandler 2004 ⁴⁰
Production and use of Quintozene	10 g / kg of Quintozene* *Assumed UK limit not working concentration	Legal limit for PeCB contamination of Quintozene. Production process also changed around the early 1990s reducing the level of contamination. http://www.pesticides.gov.uk/approvals.asp?id=55	HSE ²⁹ –UK limit
Production of carbon tetrachloride	5 mg / tonne of carbon tetrachloride	Emission factor is based on monitored concentrations of PeCB from imported carbon tetrachloride within the Environment Canada inventory.	Environment Canada, 2005 ²²
Use of HCE for secondary aluminium manufacture	310 g / tonne of HCE	Emission rate quoted from monitored emissions in Westberg et al 1997 and repeated in the Eurochlor dossier 2007	Westberg et al 1997 ⁴⁶ ; Bailey 2007 ¹⁷
Contaminant within PCP	5 g / tonne of PCP	Preliminary report from Royal Haskoning, Netherlands on sources of PCP	Borysiewicz, 2008 ³⁰
Contaminant	5 mg / tonne	Emission factor is based on monitored	Environment

⁴¹ Kim et al, 2004, 'Emission characteristics of PCDD/Fs, PCBs, chlorobenzenes, chlorophenols and pahs from polyvinylchloride combustion at various temperatures', Journal of Air Waste Management Association vol 54 pp 555-562

⁴² Ahling et al, 1978, 'Formation of chlorinated hydrocarbons during combustion of polyvinyl chloride', Chemosphere vol 10 pp 799-806

⁴³ Oberg and Bergstrom, 1985, 'Hexachlorobenzene as an indicator of dioxin production from combustion', Chemosphere vol 14 pp 1081-1086

⁴⁴ USA EPA, 2002

⁴⁵ USA EPA, 1998

⁴⁶ Westberg, 1997, 'Emissions of some organochlorine compounds in experimental aluminium degassing with hexachloroethane', Applied occupational environmental hygiene vol 40 pp 943-957

Source	Emission factor	Comment	Reference
within tetra chloroethylene (PERC)	of PERC	concentrations of PeCB from imported carbon tetrachloride within the Environment Canada inventory.	Canada, 2005 ²²
Di-electric fluids – leak of PCB	0.00933 kg/kg of PCB in di-electric fluid	Extrapolation based on quoted emissions and activity data in the Canada inventory against the UK NAEI (National Atmospheric Emissions Inventory)	Cleghorn and Davies 2001 ⁴⁷ ; Environment Canada, 2005 ²²
Combustion of landfill gas	3.2 µg/tonne waste	2.375 ng/m ³ . Assuming 200 m ³ landfill gas per tonne MSW, and 6 m ³ flue gas per m ³ landfill gas	Cianciarelli, 2005 ⁴⁸

3.3.3.2 Inventory of emissions to air

Figure 3.1 below presents the UK inventory emission estimates of Pentachlorobenzene to air based on the NFR (Nomenclature For Reporting) classification system. The total emissions to air decline from 399 kg in 1990 to 48 kg in 2009. This decline in emissions represents changes in practice and policy which have largely removed the industrial emissions of Pentachlorobenzene to air, notably from reductions in the secondary aluminium industry. Current emissions are dominated by the more diffuse unintentional emissions, such as backyard burning and accidental fires. The key sources within the inventory are discussed in greater detail below.

HCE (Hexachloroethane) has historically been used within the UK as a degassing agent (to remove dissolved hydrogen from molten aluminium) in the manufacture of aluminium¹. The manufacturing process for the production of HCE means that it contains contamination with chlorobenzenes, including hexachlorobenzene and pentachlorobenzene. In 1990 approximately 560 tonnes of HCE was used within the aluminium industry⁴⁹ resulting in emissions of 2400 kg of HCB to air (main UK source of air emissions for HCB) and 180 kg of pentachlorobenzene. The use of HCE continued to increase during the 1990s reaching a peak use in 1998 of approximately 1000 tonnes,⁵⁰ with estimated emissions of HCB and Pentachlorobenzene of 4300 kg and 310 kg respectively. The concern over the emission of HCB from this application led to a full ban for the use of HCE within the aluminium industry in 2000. It is assumed that this ban has been fully implemented and emissions from this source dropped to zero after 2000.

Quintozone (pentachloro nitrobenzene) was used commercially within the UK as a pesticide, particularly as a preventative treatment for fungal attack on wood. The original manufacturing process involved using Pentachlorobenzene as an intermediate in the manufacture of the final product^{17,21}, and as such Quintozone contains contamination by Pentachlorobenzene. Concern over the contamination of a range of pesticides by chlorobenzenes (primarily HCB and PeCB) lead to maximum concentration limits for the finished product, in the case of Quintozone, this is 1% wt/wt or 10g / kg in the commercial product.²⁹ However the production process changed in the early 1990s⁵⁰ and it is likely that working concentrations were significantly lower than the legal limit. However in the absence of further data the legal limit was adopted for the current inventory. In terms of activity trends, pesticides tend to fluctuate depending on market and environmental conditions. The

⁴⁷ Cleghorn and Davies, 2001, 'Inventory and technical study on Pentachlorobenzene and tetrachlorobenzene', report for Environment Canada

⁴⁸ Cianciarelli, 2005, 'Characterization of Emissions from a 26 kWe Micro Turbine Fired with Landfill Gas - Shepard Landfill Calgary, Alberta', ERMD report

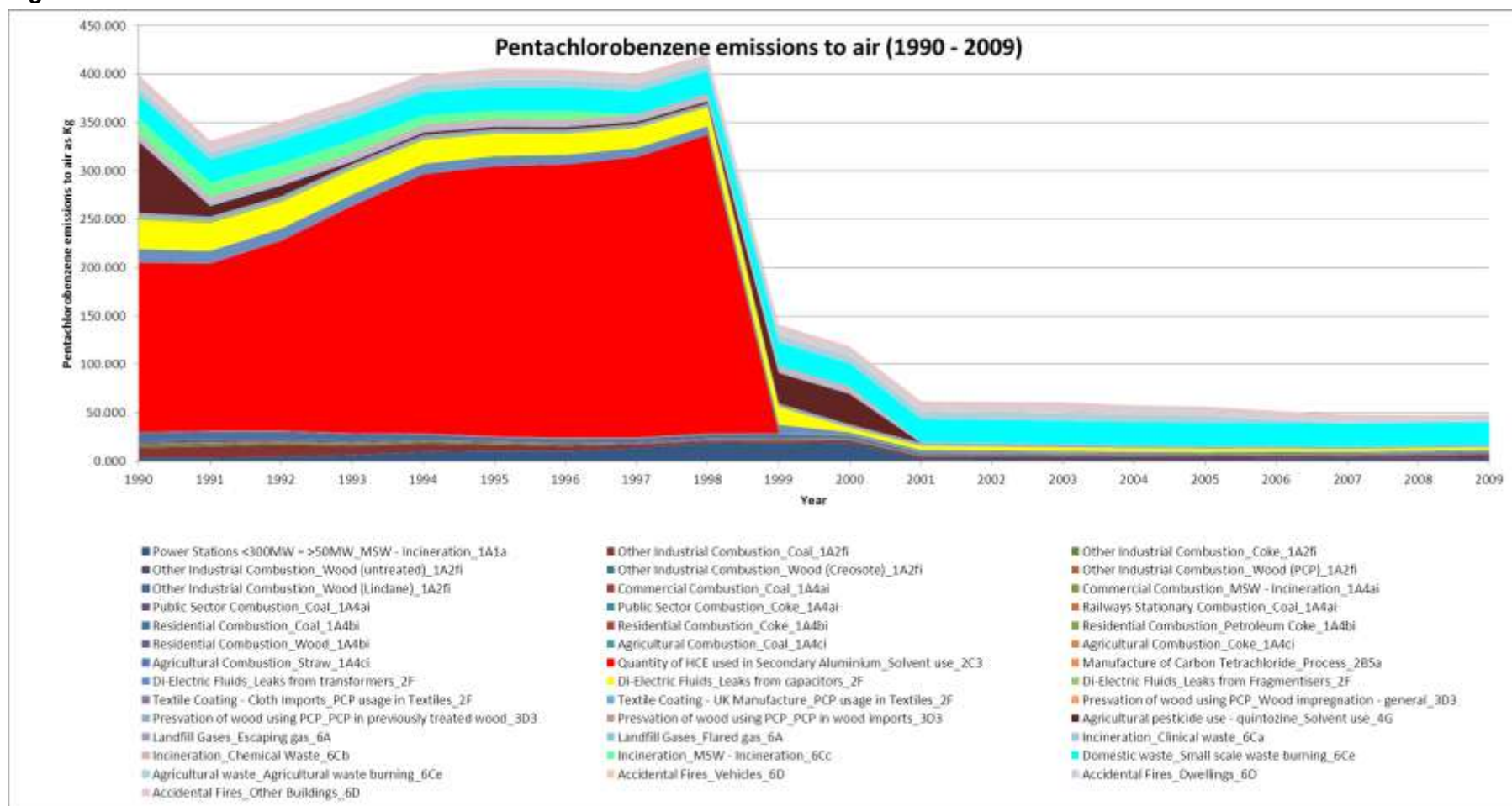
⁴⁹ UK NAEI (National Atmospheric Emissions Inventory)

⁵⁰ CLRTAP Task Force, 2007, 'Exploration of management options for pentachlorobenzene', 6th meeting of the UNECE CLRTAP task force on persistent organic pollutants

sale of Quintozene in the UK has fluctuated between 0.24 tonnes and 7.34 tonnes (weight of Quintozene as active) per annum until 2002 when its licence expired. No further commercial sale occurred after this point although there may be a lag in continued usage dependant on stockpiles. Pentachlorobenzene emissions from this source fluctuated in line with usage of Quintozene between 2.4kg and 73kg per annum.

PCBs (polychlorinated biphenyls) have been used historically as heat transfer fluids within di-electric equipment. However PCBs have not been made in the UK since 1977 and were banned (within the EU) from new equipment since 1985, with US stocks still containing PCB up to around the mid 1990s.²⁸ Service life of equipment is predicted to be between 10 – 40 years, depending on the size and nature of the equipment.²⁸ This means that in terms of stockpiles and in-use equipment there are likely to be ongoing issues of emissions from leaking equipment. Pentachlorobenzene was used alongside PCBs as an elastomer to improve the physical performance of the commercial product. Typically these fluids are oil based with a set concentration of PCB and Pentachlorobenzene which is then emitted to the environment when equipment leaks either through volatilisation to air or absorption onto soil particles. It is extremely difficult to gauge the quantity of equipment still in use although the trend will show a continued decline in emissions as equipment reaches end of service life. Pentachlorobenzene emissions to air from this source have been estimated to be 48 kg in 1990 declining to 4 kg by 2009.

Figure 3.1: Pentachlorobenzene emissions to air



Domestic waste burning encompasses a variety of activities and by its nature is diffuse. This means that it is extremely difficult to gauge the prevalence of activity and in kind emissions. Typically domestic waste burning includes the combustion of garden wastes, household waste such as paper, cardboard, wood, plastic, and other materials. It also includes the open burning of waste on domestic grates such as fire places. The presence of chlorine from plastics, treated woods and to a lesser extent untreated wood, plus the variable and uncontrolled combustion efficiency means that emissions of pentachlorobenzene can be generated. The uncertainty attached to this source is large, and the source itself is also likely to be key (as seen in other such inventories), with increased importance as the legacy issues of commercial use decline. As the activity is highly variable between individuals, locations and time of the year, it has not been possible to apply a trend to this emission. The emission from domestic waste burning has been estimated to account for 23kg of Pentachlorobenzene to air per year for the whole timeframe.

Accidental Fires, like domestic waste burning, comprise a diffuse source, whereby carbon and chlorine (plastic and treated wood) based materials are combusted in an uncontrolled fashion. This has been a key source for other POPs such as dioxins and furans and as such is also of importance for Pentachlorobenzene. In terms of trends, the number of fires per annum fluctuate, but with the advent of equipment such as smoke detectors, sprinkler systems and improved response rates, the overall trend should decline. The estimates within the current inventory have been based on UK fire statistics and AEA's estimates for the scale of a fire (1 room, 2 room, a whole house). AEA also makes estimates for quantity of material consumed in vehicle fires. The emissions to air in 1990 are estimated to be 12.65 kg declining to 7.48 kg by 2009.

Incineration processes – MSW, Hazardous and Clinical. Historically the incineration sector has proved to be a key source for emission of POPs, particularly dioxins and furans²⁸. As of 2000 the waste incineration directive (2000/76/EC) placed requirements on the UK incineration sector to improve abatement measures,⁵¹ resulting in a number of older more polluting plants closing and construction of new plants with improved abatement. This sees a marked decline in estimated emissions of Pentachlorobenzene from 24.3 kg in 1990 to 3 kg in 2009. It is also worth noting the change seen within the municipal incineration of waste to what are now known as energy from waste plants (where municipal solid waste is used as a fuel). The energy from waste sector is expected to grow significantly in the coming years as the UK looks to meet its requirements on reducing the quantity of waste sent to landfill. This in turn may result in an increase in emissions from this source.

3.3.4 Pentachlorobenzene emissions to land

The Pentachlorobenzene emissions to land comprise two main sources. Firstly, combustion products result in the production of ash, which can be either lost directly to land or placed within a controlled landfill. Secondly, direct PeCB emissions may occur, for example from fluid leaks from di-electric equipment during service or from filling or disposal operations. As many of the key sources are diffuse in nature, there is very little data on quantities of ash generated and the fate of that ash (i.e. disposed direct to land or within controlled landfills). As a result, the current inventory does not seek to disaggregate between accidental lost or contaminated materials sent to landfill from diffuse sources, and further work is needed to improve this aspect of the inventory as it is significant for the understanding of human exposure risks.

This means that the inventory has made use of ash generation factors based on combustion source measurement surveys as detailed in table 3.3.

⁵¹ Waste Incineration Directive (WID): http://europa.eu/legislation_summaries/environment/waste_management/l28072_en.htm

3.3.4.1 Review of land emission factors

Table 3.3: Ash generation factors for combustion sources

Source	Emission factor	Comment	Reference
Wood combustion	17 kg of ash per tonne of fuel	Assumed to be ash generation from domestic wood grates	BIPRO ⁵²
Coal combustion	0.08 kg / tonne or 8% wt/wt	Assumed to be ash generation from large scale plants	BIPRO ⁵²
Hazardous and clinical waste incineration	0.03 kg/kg or 3% wt/wt	Assumed to be all as fly ash / air pollution control residue	UNEP toolkit ⁵³ , 2005
MSW incineration	0.28 kg/kg or 28% wt/wt total ash; 0.03 kg/kg or 3% fly ash; 0.25 kg/kg or 25% wt/wt bottom ash	EA report provides splits for total ash, bottom ash and fly ash for modern plants. In the case of Pentachlorobenzene the fly ash will be the key element	EA waste report, ⁵⁴ 2002
Small-scale domestic and agricultural waste burning	0.28 kg/kg or 28% wt/wt total ash		EA waste report, ⁵⁴ 2002
Dust generation from non-ferrous metal smelting (aluminium)	20.9 kg / tonne of aluminium	This factor relates to generation of filter dust from the smelting of secondary aluminium goods.	BIPRO ⁵²
PCB di-electric	Assumed ratios 12% wt/wt to air, and 88% wt/wt to land	This is based on the physical properties of PCBs and likely partitioning between air and land	Dyke, 1997 ⁵⁵

Table 3.4: Emission factors for Pentachlorobenzene - Land

Source	Emission factor	Comment	Reference
Di-electric fluids – leak of PCB	0.00933 kg/kg of PCB in di-electric fluid	Extrapolation based on quoted emissions and activity data in the Canada inventory against the UK NAEI (National Atmospheric Emissions Inventory)	Cleghorn and Davies 2001; ⁴⁷ Environment Canada, 2005 ²²
Ash from combustion of coal	20 µg / tonne of ash	This emission factor relates to contamination of ash with Pentachlorobenzene from domestic grates. Primarily looks at coal and charcoal briquettes. For the inventory it is assumed that this factor will be relevant	Grochowalski, 2009 ⁵⁶

⁵² BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)

⁵³ UNEP (2005) Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases

⁵⁴ Environment Agency (2002) Solid Residues from municipal waste incinerators in England Wales Published by the Environment Agency (UK)

⁵⁵ Dyke (1997) – Releases of PCBs to the UK environment. Report to ETSU on behalf of DETR – AEAT – 2731

⁵⁶ Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting, Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.

Source	Emission factor	Comment	Reference
		for coal, coke and petroleum coke fuels. Anthracite and solid smokeless fuels are assumed not to produce PeCB.	
Ash from MSW incineration	31 mg / tonne of fly ash	Technology source is unknown. Reference reported by Italy in the Annex E survey of ratified nations under the Stockholm Convention 2007	Korenkova et al, 2006 ⁵⁷
Dry cleaning – solid wastes	5 mg / tonne of PERC	Emission factor is based on monitored concentrations of PeCB from imported carbon tetrachloride within the Environment Canada inventory.	Environment Canada, 2005 ²²
Backyard burning and accidental fires	11.09 kg emitted to land per kg emitted to air	Extrapolation of Environment Canada inventory based on ratio of air to land emissions quoted within the inventory	Environment Canada, 2005 ²²

3.3.4.2 Review of PeCB Emission Inventory to Land

Figure 3.2 below presents the UK inventory emission estimates of Pentachlorobenzene to land based on the NFR (Nomenclature For Reporting) classification system.

The total emissions of Pentachlorobenzene to land are estimated to have declined over the timeframe (1990 – 2009) largely due to the decrease in emissions from di-electric leaks (as equipment is removed from service), and a ban on agricultural waste burning. Total estimated emissions have declined from 875 kg in 1990 to 388 kg in 2009. In all cases the emissions are dominated by diffuse unintentional sources, which are likely to fluctuate year on year making a clear trend less likely. The key sources are discussed in more detail below.

Domestic waste burning as previously stated is a diffuse source which is difficult to accurately gauge. Based on the available activity data from the Environment Agency waste survey (2003) and national survey on waste burning habits from the current body of work (2010),⁵⁸ it is assumed 299 kt of waste are burned per annum. In lieu of better data the ash generation factor used was taken from the 2000 Environment Agency survey of MSW incinerators. This quotes ash generation as 0.28 kg/kg (or 28%) ash generated for fuel burnt. On this basis 299kt of domestic waste burning results in the production of 83 kt of ash, and a direct emission to land of 265 kg of Pentachlorobenzene per annum across the whole timeframe. This will represent the single largest emission source to land.

Agricultural waste burning, similarly to domestic waste burning, is a diffuse source. Historically the burning of agricultural wastes has proved an efficient method for the agricultural community to dispose of certain types of waste. Typically this will include items such as silage wrap, bale twine and other plastic wastes, which therefore have the potential to generate a number of types of POP, notably dioxins and furans. These materials have in the past been primarily made of PVC based compounds and therefore the associated emissions were particularly of concern for dioxins and furans and PCBs. During the 1990's the industry began to move away from PVC based products towards ethylene and polyethylene based products which produce lower emissions of POPs.²⁸ This has further

⁵⁷ Korenkova et al, 2006, 'Application of large volume injection GC-MS to analysis of organic compounds in the extracts and leachates of municipal solid waste incineration fly ash', Waste Management Vol 9 pp 1005 - 1016

⁵⁸ Morton G, 2010, 'Recommendations for a public campaign to educate the public on the impacts of burning domestic waste' AEA report for Defra

been reduced with a ban on agricultural burning which was phased in from 2006.⁵⁹ Pentachlorobenzene emissions from this source have been estimated as 86 kg in 1990 declining to 36 kg in 2006 at the time of the ban. Given the remote nature of farm holdings and diffuse nature of the activity it is likely that some waste burning will continue since the ban came into effect. However this is likely to be a minor activity: in the NAEI, it is assumed that the post-ban activity is 2% of the pre-ban activity.

PCBs in di-electric fluid have already been discussed under the air emissions. However with di-electric fluid leaks we would expect to see a partitioning of the emissions between losses to air and losses to land. Both PCBs and Pentachlorobenzene have a low solubility and high capability of combining to organic material within soil. Dyke, 1997,⁵⁵ carried out a full UK review of PCB emissions, estimating a partitioning of 12% to air and 88% to land. Based on the estimated ratio of Pentachlorobenzene to PCB in di-electric fluid, the estimated emissions decline from 174 kg in 1990 to 16kg in 2009. This decline reflects the existing stock of equipment reaching end of life.

Accidental fires within the inventory have been disaggregated further to fires associated with domestic properties, other buildings and vehicle fires. As stated previously within the commentary for air, emissions will fluctuate from year to year, but overall the number and extent of fires within buildings is expected to decline as equipment such as smoke detectors, sprinkler systems and improved call out times mean fires are tackled more quickly. A full breakdown of the estimated emissions from this source is given in the table below:

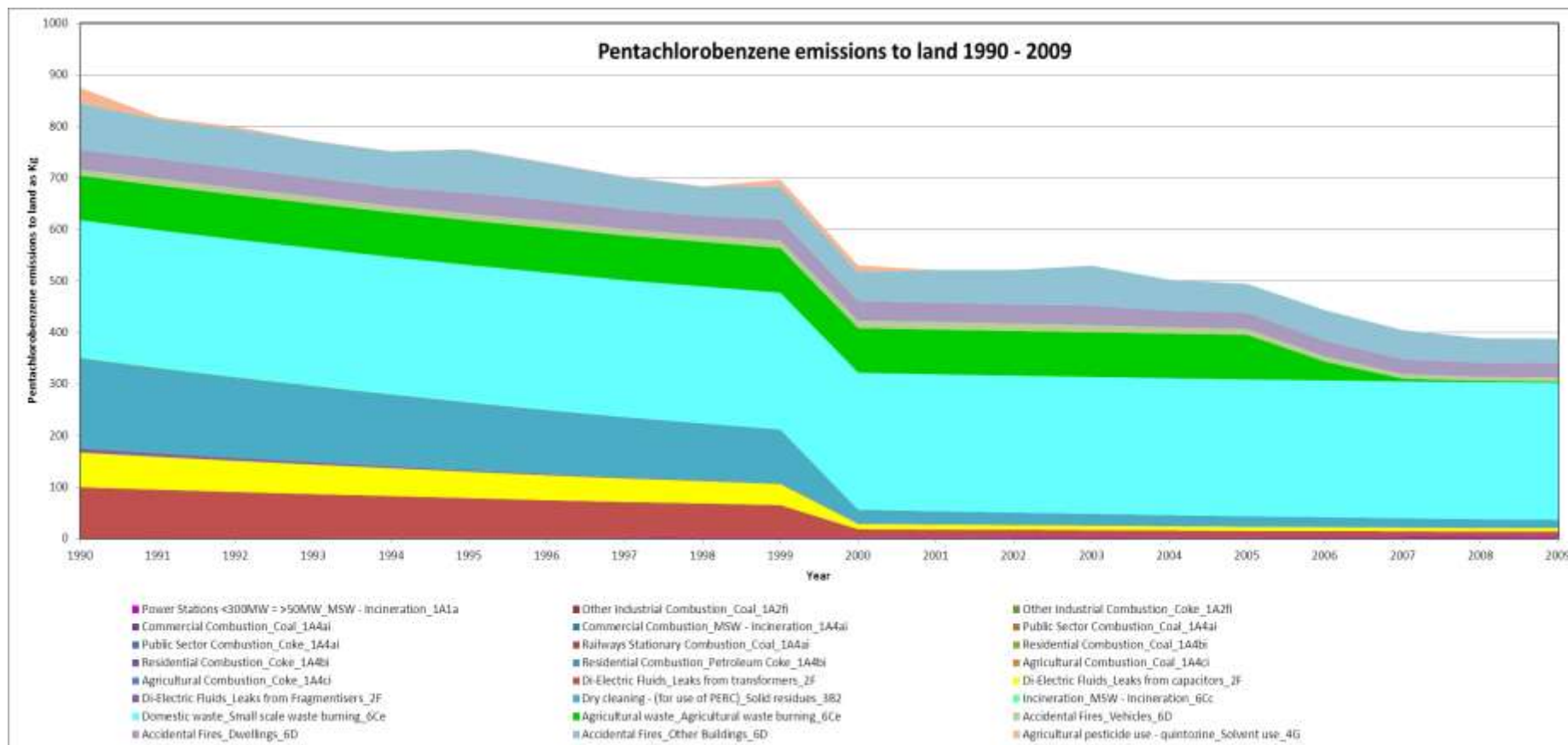
Table 3.5: Emissions of Pentachlorobenzene to land due to accidental fires

Pentachlorobenzene emissions to land 1990	Pentachlorobenzene emissions to land 2009 (kg)
Domestic dwellings – 39 kg	Domestic dwellings – 28 kg
Other buildings – 90 kg	Other buildings – 47 kg
Vehicle fires – 11 kg	Vehicle fires - 8 kg
Total: 140 kg	Total: 83 kg

The estimates provided in table 3.5 are based on the quantity of material burnt multiplied by an ‘ash generation factor.’ This is then multiplied by a suitable emission factor to derive the final estimate. In all cases the activity data has been based on UK fire statistics together with the established NAEI methodology to estimate the scale of domestic fires and hence develop estimates for quantity of material in the fire. In all cases the ash generation factor used was taken from the Environment Agency survey of MSW Incinerators with an ash generation rate of 0.28 kg/kg (or 28%). The emission factor used in all cases was extrapolated from the Canadian pentachlorobenzene risk management strategy (2005). The derived emission factor was 3 kg of pentachlorobenzene per tonne of ash generated.

⁵⁹ Defra guidance document on agricultural waste regulations, 2006, <http://www.defra.gov.uk/environment/waste/topics/farm/documents/agwaste-faq.pdf>

Figure 3.2 Pentachlorobenzene emissions to land



3.3.5 Pentachlorobenzene emissions to water

The key emission source for releases of pentachlorobenzene to water will come from the discharge of treated effluent at waste water treatment works. However the available data on emissions and monitoring for this source is scant, particularly in the earlier part of the timeframe under review. This makes it difficult to produce emission estimates and trends.

One current study that has looked at the emission of pentachlorobenzene as part of a suite of pollutants as a measure of diffuse emissions from waste water treatment works has come from a study by Robles-Molina (2010)²⁶. The study looked to develop analytical methods for monitoring of emissions for all 16 of the surface water priority substances being emitted from waste water treatment works. This research also included a review of different waste streams within its country of origin, Spain, looking at comparison between treated effluents from urban, industrial and rural/coastal works. The reported pentachlorobenzene emission concentrations range from 0.53 – 1.10 ng L⁻¹, with an overall average figure of 0.71 ng L⁻¹. Ofwat provides data on an annual basis for waste water treatment works in England and Wales, and this has been used to derive a per capita quantity of treated effluent emitted in England and Wales for 2009, scaled up to account for total UK effluent discharges, estimated to be approximately 4 billion cubic metres. Based on the available activity data and the Robles-Molina emission factor this would give an estimate of about 3 kg of pentachlorobenzene emitted to water per annum. As a means of further comparison the estimated emissions to surface water of hexachlorobenzene from waste water treatment works (quoted in the POPs air, land and water emission inventory) is quoted as 1.35 kg in 2009.²⁷ This is broadly half the estimated emissions of pentachlorobenzene. This may reflect the partitioning of pentachlorobenzene between organic sludge and treated effluent within the sewage works.

3.3.6 Uncertainty Estimates

Emission inventories are compiled based on the best available monitoring data and in combination with estimates based on activity data vs emission factors where necessary. This process is used to provide credible inventories to gauge the key emission sources and trends across a time-series.

It is also important to recognise however that any estimate is open to a level of uncertainty, based on the reliability of the data used and complexity/variety of emissions within a given source. For example when trying to make estimates of air emissions from backyard burning, in practice the composition of the material burnt and conditions during burning can vary hugely from location to location. This aspect would increase the uncertainty in the estimates for that source.

Uncertainty estimates provide a gauge for where issues may exist within an inventory and can also help other inventory compilers with further inventory development. In the case of the pentachlorobenzene inventory it is necessary to assess the issue in terms of the availability of data and nature of the sources witnessed. The greatest abundance of data is within the air vector, with data for land and water being more scarce.

The compilation for water emissions within the current inventory has used a recent literature emission factor in combination with UK water statistics. A basic comparison has been made to the most comparable pollutant, hexachlorobenzene with emissions in broadly the same order of magnitude. This has been a useful guide to gauge the potential emissions. However uncertainty will remain high as the impact of diffuse emissions is more difficult to gauge, and it is unclear how relevant the Spanish emission factors may be, given that the key historic source has been the use of a given fungicide.

Emissions to land will also have relatively high uncertainty attached to the quoted emissions, due to the fact that this vector is dominated by the backyard burning and accidental fire

sources. The nature of these sources means that it is extremely difficult to accurately gauge the true levels of activity (particularly backyard burning) and take account for the variance in the nature of the material burnt and combustion conditions.

Table 3.6 shown below provides estimates for the minimum and maximum emission to each vector for 2009, together with the estimated uncertainty as a percentage of the quoted value. This reflects as quoted the levels of uncertainty within air, land and water with decreasing availability of data, and particular issues with certain aspects of the sources in given vectors.

Table 3.6 Uncertainty estimates for the pentachlorobenzene inventory

Vector	Estimated emissions for 2009	Minimum emission value	Maximum emission value	Uncertainty range
Air	48 kg	36 kg	60 kg	+/- 25%
Land	388 kg	194 kg	582 kg	+/- 50%
Water	3 kg	1.5 kg	6kg	- 50% + 100%

3.3.7 Recommendations for further research

The current body of work has established a first UK air, land and water emission inventory for pentachlorobenzene; this has also included identification of areas which require further review and research to allow continuous improvement of the established inventory. This section provides a brief commentary of where further work can benefit the overall inventory and help reduce uncertainty. It is recommended that Defra maintains a watching brief on developments from UNEP and EU-level working groups to develop estimation methods, emission factor resources and estimation models for different point and areas sources of PeCB. The commitment on ratified nations to deliver PeCB emission inventories is likely to prompt further research into PeCB emission source estimates globally.

Domestic waste burning has already been identified as an area of the inventory where there are high levels of uncertainty. This source itself will prove to be key for current and future emissions. Part of the reason why the uncertainty for this source is high is due to the diffuse nature of the activity and difficulty in accurately gauging how much waste is burnt per annum. The uncertainty is increased by the complex mixture of waste that are burnt, and combustion / environmental conditions. The recommendation in this case is that further research is required to develop a more extensive dataset of emission factors for this source, possibly extending to the combustion of materials on domestic fires. To achieve this aim would require field and laboratory studies to sample and analyse activities, through air emissions monitoring and ash compositional analysis from processes / units that are representative of UK practices. To develop a larger dataset from such studies (similar to those conducted by Environment Canada and other leading POPs research organizations) would help reduce inventory uncertainties for the most significant potential emission sources. This will assist Defra to identify and target specific types of waste which are undesirable for combustion, and thereby can be used to inform Defra policy development and public information campaigns.

Emissions from waste water treatment works have been identified as a key area for further review. This is particularly true to help accurately gauge the environmental fate of pentachlorobenzene within the waste water treatment works process. Similarly studies to review the environmental fate of PCBs⁶⁰ within waste water treatment works have proved extremely beneficial in gauging the ability of such works to deal with these kinds of

⁶⁰ Sweetman, A, 2005, 'Polychlorinated Biphenyls: fate and behaviour during the wastewater treatment process, paper by Lancaster Environment Centre

pollutants. In terms of the Stockholm Convention Annex C substances, pentachlorobenzene is noted as being the most volatile, based on its solubility and vapour pressure. It is unclear whether volatilisation to air means that expected concentrations in treated effluent and sewage sludge would be lower than corresponding concentrations of hexachlorobenzene and PCBs.

As in the sampling work carried out for this project, a focused sampling and analysis campaign covering sewage treatment works activities in different locations (urban, rural, industrial) would be beneficial in order to improve the source dataset on PeCB sources. It may also be beneficial to commission research to analyse PeCB content of waste water emissions from specific industrial processes and from specific sites, e.g, where PeCB is known to be used within specialist fluids and machinery, and/or where unintentional production of PeCB is expected, such as within the non-ferrous metal sector.

A further review of potential sources not included within the current inventory should also be considered as source of inventory improvement. The Environment Canada inventory identified pentachlorobenzene emissions from the metal sector as potentially significant, in particular the alloying of magnesium. Research from a Norsk Hydro plant based in Norway⁶¹ showed that a switch in abatement in the early 1990s reduced emissions to surface water from 150 kg/week down to 0.1 kg/week. As the UK magnesium alloying industry is relatively small, this potential source may not warrant detailed review or investigation, especially if similar abatement levels are achieved at UK plant. The Eurochlor dossier¹⁷ also notes potential emissions from iron and steel sintering. The UK industry has addressed issues with emissions of dioxins and furans from sintering processes, and has developed novel abatement approaches for this issue, which would also likely reduce the emission of pentachlorobenzene. Further research would be required to identify whether this was a significant source.

3.3.8 Summary

Figures 3.1 and 3.2 summarize the estimated emissions to air and land in 2009. In both cases the emissions are dominated by diffuse sources with the remaining emissions related to legacy issues and combustion of fuels. A full breakdown of the emissions year by year for air and land are given in Tables 3.7 to 3.8. Emissions to water have been assumed to decline from 3.9 kg in 1990 to 2.9 kg in 2009, with the key source based on emissions from waste water treatment works.

⁶¹ Moore JF et al, 2000, 'An inert metal anode for magnesium electrowinning', University of Chicago paper

Table 3.7 UK sources of pentachlorobenzene emissions to air, 2009

Source Name	Activity Name	NFR Reference	2009	Units
Domestic waste	Small scale waste burning	6Ce	23.9344	Kg
Accidental Fires	Other Buildings	6D	4.271574	Kg
Other Industrial Combustion	Coal	1A2fi	3.50835	Kg
Power Stations <300MW = >50MW	MSW - Incineration	1A1a	3.063724	Kg
Di-Electric Fluids	Leaks from capacitors	2F	2.823499	Kg
Accidental Fires	Dwellings	6D	2.489952	Kg
Presvation of wood using PCP	CP in previously treated wood	3D3	1.813223	Kg
Di-Electric Fluids	Leaks from transformers	2F	1.34454	Kg
Residential Combustion	Coal	1A4bi	1.16955	Kg
Accidental Fires	Vehicles	6D	0.717639	Kg
Residential Combustion	Wood	1A4bi	0.678	Kg
Public Sector Combustion	Coal	1A4ai	0.384054	Kg
Residential Combustion	Petroleum Coke	1A4bi	0.275	Kg
Other Industrial Combustion	Wood (untreated)	1A2fi	0.271604	Kg
Agricultural waste	Agricultural waste burning	6Ce	0.23472	Kg
Agricultural Combustion	Straw	1A4ci	0.224479	Kg
Incineration	Clinical waste	6Ca	0.183932	Kg
Incineration	Chemical Waste	6Cb	0.174333	Kg
Commercial Combustion	Coal	1A4ai	0.132307	Kg
Commercial Combustion	MSW - Incineration	1A4ai	0.096561	Kg
Di-Electric Fluids	Leaks from Fragmentisers	2F	0.063028	Kg
Residential Combustion	Coke	1A4bi	0.02575	Kg
Other Industrial Combustion	Wood (Lindane)	1A2fi	0.015089	Kg
Other Industrial Combustion	Wood (Creosote)	1A2fi	0.007545	Kg
Other Industrial Combustion	Wood (PCP)	1A2fi	0.007545	Kg
Other Industrial Combustion	Coke	1A2fi	0.007171	Kg
Landfill Gases	Escaping gas	6A	0.003054	Kg
Landfill Gases	Flared gas	6A	0.000702	Kg

Table 3.8 UK sources of pentachlorobenzene emissions to land, 2009

Source Name	Activity Name	NFR Reference	2009	Units
Domestic waste	Small scale waste burning	6Ce	265.43	Kg
Accidental Fires	Other Buildings	6D	47.37	Kg
Accidental Fires	Dwellings	6D	27.61	Kg
Dry cleaning - (for use of PERC)	Solid residues	3B2	16.285	Kg
Di-Electric Fluids	Leaks from transformers	2F	9.86	Kg
Accidental Fires	Vehicles	6D	7.96	Kg
Di-Electric Fluids	Leaks from capacitors	2F	6.28	Kg
Power Stations <300MW = >50MW	MSW - Incineration	1A1a	4.07	Kg
Agricultural waste	Agricultural waste burning	6Ce	2.60	Kg
Di-Electric Fluids	Leaks from Fragmentisers	2F	0.14	Kg
Commercial Combustion	MSW - Incineration	1A4ai	0.13	Kg
Other Industrial Combustion	Coal	1A2fi	0.0022	Kg
Residential Combustion	Coal	1A4bi	0.0007	Kg
Public Sector Combustion	Coal	1A4ai	0.0002	Kg
Residential Combustion	Petroleum Coke	1A4bi	0.00018	Kg
Commercial Combustion	Coal	1A4ai	0.00008	Kg
Residential Combustion	Coke	1A4bi	0.00002	Kg

Table 3.9 UK Pentachlorobenzene emissions to air (1990 – 2009)

PentaChlorobenzene emissions to air													
Source Name	Activity Name	NFR Ref	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Power Stations <300MW = >50MW	MSW - Incineration	1A1a	Kg	3.42	3.45	4.20	6.03	9.47	10.36	10.05	13.08	18.47	17.87
Other Industrial Combustion	Coal	1A2fi	Kg	9.92	11.46	12.42	9.32	8.08	6.15	5.21	3.48	2.29	2.79
Other Industrial Combustion	Coke	1A2fi	Kg	2.11	1.73	1.58	1.28	0.91	0.78	0.72	0.35	0.52	0.48
Other Industrial Combustion	Wood (untreated)	1A2fi	Kg	0.391	0.391	0.391	0.391	0.751	0.822	0.834	0.835	0.721	0.607
Other Industrial Combustion	Wood (Creosote)	1A2fi	Kg	0.011	0.011	0.011	0.011	0.021	0.023	0.023	0.023	0.020	0.017
Other Industrial Combustion	Wood (PCP)	1A2fi	Kg	0.011	0.011	0.011	0.011	0.021	0.023	0.023	0.023	0.020	0.017
Other Industrial Combustion	Wood (Lindane)	1A2fi	Kg	0.022	0.022	0.022	0.022	0.042	0.046	0.046	0.046	0.040	0.034
Commercial Combustion	Coal	1A4ai	Kg	0.79	0.71	0.47	0.50	0.48	0.40	0.43	0.47	0.23	0.08
Commercial Combustion	MSW - Incineration	1A4ai	Kg	1.52	1.64	1.51	1.38	1.44	1.50	0.98	0.28	0.47	0.62
Public Sector Combustion	Coal	1A4ai	Kg	2.18	2.09	1.86	1.52	1.28	0.87	0.97	1.14	0.78	0.93
Public Sector Combustion	Coke	1A4ai	Kg	0.48	0.39	0.33	0.28	0.00	0.00	0.00	0.00	0.00	0.00
Residential Combustion	Coal	1A4bi	Kg	7.54	7.79	7.06	6.69	4.70	3.02	3.26	3.21	3.48	4.01
Residential Combustion	Coke	1A4bi	Kg	0.95	0.78	0.66	0.55	0.46	0.44	0.45	0.21	0.30	0.30
Residential Combustion	Petroleum Coke	1A4bi	Kg	0.06	0.13	0.19	0.25	0.42	0.53	0.58	0.63	0.60	0.56
Residential Combustion	Wood	1A4bi	Kg	0.315	0.315	0.369	0.369	0.369	0.369	0.369	0.369	0.369	0.369
Agricultural Combustion	Coal	1A4ci	Kg	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
Agricultural Combustion	Straw	1A4ci	Kg	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.121	0.121
Quantity of HCE used in Secondary Aluminium	Solvent use	2C3	Kg	175.13	172.86	196.45	234.82	267.54	279.12	282.29	289.73	308.64	0.00
Manufacture of Carbon Tetrachloride	Process	2B5a	Kg	0.23	0.23	0.23	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Di-Electric Fluids	Leaks from transformers	2F	Kg	13.52	12.87	12.25	11.66	11.07	10.51	9.98	9.48	9.00	8.54
Di-Electric Fluids	Leaks from capacitors	2F	Kg	30.14	28.56	27.07	25.66	24.24	22.91	21.65	20.45	19.33	18.26
Di-Electric Fluids	Leaks from Fragmentisers	2F	Kg	3.87	3.22	2.69	2.24	1.79	1.43	1.15	0.92	0.73	0.59
Textile Coating - Cloth Imports	PCP usage in Textiles	2F	Kg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Textile Coating - UK Manufacture	PCP usage in Textiles	2F	Kg	0.015	0.015	0.015	0.015	0	0	0	0	0	0
Presvation of wood using PCP	Wood impregnation - general	3D3	Kg	0.05	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Presvation of wood using PCP	PCP in previously treated wood	3D3	Kg	3.42	3.43	3.43	3.43	3.40	3.36	3.30	3.22	3.14	3.04
Presvation of wood using PCP	PCP in wood imports	3D3	Kg	0.25	0.25	0.25	0.25	0.25	0.225	0.2	0.175	0.15	0.125
Agricultural pesticide use - quitozine	Solvent use	4G	Kg	73.35	10.99	10.99	2.56	2.56	2.41	2.41	2.41	2.41	31.55
Landfill Gases	Escaping gas	6A	Kg	0.0076	0.0075	0.0073	0.0071	0.0069	0.0067	0.0065	0.0060	0.0056	0.0051
Landfill Gases	Flared gas	6A	Kg	0.0017	0.0017	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0013	0.0012
Incineration	Clinical waste	6Ca	Kg	4.90	4.90	4.62	4.34	4.06	3.78	3.50	3.22	3.30	3.39
Incineration	Chemical Waste	6Cb	Kg	4.06	4.06	4.06	4.06	4.05	4.04	4.03	4.02	4.01	4.00
Incineration	MSW - Incineration	6Cc	Kg	15.36	15.21	14.58	12.89	9.38	8.56	9.38	0.00	0.00	0.00
Domestic waste	Small scale waste burning	6Ce	Kg	23.93	23.93	23.93	23.93	23.93	23.93	23.93	23.93	23.93	23.93
Agricultural waste	Agricultural waste burning	6Ce	Kg	7.82	7.82	7.82	7.82	7.82	7.82	7.82	7.82	7.82	7.82
Accidental Fires	Vehicles	6D	Kg	1.02	1.18	1.18	1.19	1.10	1.15	1.20	1.13	1.12	1.32
Accidental Fires	Dwellings	6D	Kg	3.50	3.49	3.46	3.33	3.30	3.66	3.66	3.50	3.40	3.72
Accidental Fires	Other Buildings	6D	Kg	8.13	6.91	6.84	6.36	6.21	7.57	6.52	5.66	5.10	5.75
			Kg	398.59	331.07	351.14	373.45	399.34	405.98	405.13	399.96	420.57	140.88

Table 3.9 (cont.) UK Pentachlorobenzene emissions to air, 1990 – 2009

PentaChlorobenzene emissions to air													
Source Name	Activity Name	NFR Ref	Units	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Power Stations <300MW = >50MW	MSW - Incineration	1A1a	Kg	18.61	2.02	2.18	2.22	2.14	2.12	2.38	2.42	2.52	3.06
Other Industrial Combustion	Coal	1A2fi	Kg	2.54	2.45	2.67	2.69	2.55	2.77	2.87	2.43	3.01	3.51
Other Industrial Combustion	Coke	1A2fi	Kg	0.50	0.45	0.36	0.07	0.07	0.00	0.03	0.02	0.04	0.01
Other Industrial Combustion	Wood (untreated)	1A2fi	Kg	0.419	0.372	0.372	0.372	0.372	0.154	0.160	0.167	0.268	0.272
Other Industrial Combustion	Wood (Creosote)	1A2fi	Kg	0.012	0.010	0.010	0.010	0.010	0.004	0.004	0.005	0.007	0.008
Other Industrial Combustion	Wood (PCP)	1A2fi	Kg	0.012	0.010	0.010	0.010	0.010	0.004	0.004	0.005	0.007	0.008
Other Industrial Combustion	Wood (Lindane)	1A2fi	Kg	0.023	0.021	0.021	0.021	0.021	0.009	0.009	0.009	0.015	0.015
Commercial Combustion	Coal	1A4ai	Kg	0.03	0.03	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.13
Commercial Combustion	MSW - Incineration	1A4ai	Kg	0.76	0.08	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Public Sector Combustion	Coal	1A4ai	Kg	0.69	0.67	0.43	0.38	0.36	0.42	0.37	0.36	0.36	0.38
Public Sector Combustion	Coke	1A4ai	Kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residential Combustion	Coal	1A4bi	Kg	2.39	1.89	1.19	1.05	0.93	0.73	0.86	1.15	1.29	1.17
Residential Combustion	Coke	1A4bi	Kg	0.36	0.17	0.45	0.32	0.13	0.09	0.06	0.04	0.03	0.03
Residential Combustion	Petroleum Coke	1A4bi	Kg	0.53	0.49	0.45	0.41	0.38	0.35	0.33	0.30	0.31	0.28
Residential Combustion	Wood	1A4bi	Kg	0.369	0.369	0.369	0.372	0.420	0.480	0.540	0.600	0.648	0.678
Agricultural Combustion	Coal	1A4ci	Kg	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.00
Agricultural Combustion	Straw	1A4ci	Kg	0.121	0.121	0.120	0.120	0.120	0.132	0.147	0.140	0.222	0.224
Quantity of HCE used in Secondary Aluminium	Solvent use	2C3	Kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manufacture of Carbon Tetrachloride	Process	2B5a	Kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-Electric Fluids	Leaks from transformers	2F	Kg	2.14	2.03	1.93	1.83	1.74	1.65	1.57	1.49	1.42	1.34
Di-Electric Fluids	Leaks from capacitors	2F	Kg	4.57	4.31	4.09	3.88	3.68	3.49	3.31	3.14	2.98	2.82
Di-Electric Fluids	Leaks from Fragmentisers	2F	Kg	0.47	0.38	0.30	0.24	0.19	0.15	0.12	0.10	0.08	0.06
Textile Coating - Cloth Imports	PCP usage in Textiles	2F	Kg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00000187	0.00000187	0.00000187
Textile Coating - UK Manufacture	PCP usage in Textiles	2F	Kg	0	0	0	0	0	0	0	0	0	0
Presvation of wood using PCP	Wood impregnation - general	3D3	Kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Presvation of wood using PCP	PCP in previously treated wood	3D3	Kg	2.92	2.80	2.65	2.51	2.38	2.25	2.13	2.02	1.91	1.81
Presvation of wood using PCP	PCP in wood imports	3D3	Kg	0.1	0.075	0.05	0.025	0	0	0	0	0.0	0.0
Agricultural pesticide use - quinoxaline	Solvent use	4G	Kg	31.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Landfill Gases	Escaping gas	6A	Kg	0.0048	0.0042	0.0038	0.0034	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
Landfill Gases	Flared gas	6A	Kg	0.0011	0.0010	0.0009	0.0008	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Incineration	Clinical waste	6Ca	Kg	3.47	0.36	0.36	0.31	0.26	0.21	0.16	0.17	0.18	0.18
Incineration	Chemical Waste	6Cb	Kg	3.99	0.40	0.40	0.36	0.32	0.29	0.25	0.23	0.19	0.17
Incineration	MSW - Incineration	6Cc	Kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Domestic waste	Small scale waste burning	6Ce	Kg	23.93	23.93	23.93	23.93	23.93	23.93	23.93	23.93	23.93	23.93
Agricultural waste	Agricultural waste burning	6Ce	Kg	7.82	7.82	7.82	7.82	7.82	7.82	3.28	0.49	0.23	0.23
Accidental Fires	Vehicles	6D	Kg	1.28	1.37	1.30	1.27	1.08	1.00	0.92	0.82	0.72	0.72
Accidental Fires	Dwellings	6D	Kg	3.49	3.36	3.34	3.41	2.96	2.86	2.74	2.61	2.49	2.49
Accidental Fires	Other Buildings	6D	Kg	5.03	5.73	6.02	6.98	5.35	5.04	5.35	5.06	4.27	4.27
			Kg	118.19	61.72	60.96	60.77	57.37	56.11	51.68	47.84	47.29	47.92

Table 3.10 UK Pentachlorobenzene emissions to land, 1990 – 2009

PentaChlorobenzene to land													
Source Name	Activity Name	NFR Reference	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Power Stations <300MW = >50MW	MSW - Incineration	1A1a	Kg	0.45	0.46	0.56	0.80	1.26	1.38	1.34	1.74	2.45	2.37
Other Industrial Combustion	Coal	1A2fi	Kg	0.0064	0.0073	0.0079	0.0060	0.0052	0.0039	0.0033	0.0022	0.0015	0.0018
Other Industrial Combustion	Coke	1A2fi	Kg	0.0014	0.0011	0.0010	0.0008	0.0006	0.0005	0.0005	0.0002	0.0003	0.0003
Commercial Combustion	Coal	1A4ai	Kg	0.00050	0.00046	0.00030	0.00032	0.00031	0.00025	0.00027	0.00030	0.00015	0.00005
Commercial Combustion	MSW - Incineration	1A4ai	Kg	0.20	0.22	0.20	0.18	0.19	0.20	0.13	0.04	0.06	0.08
Public Sector Combustion	Coal	1A4ai	Kg	0.0014	0.0013	0.0012	0.0010	0.0008	0.0006	0.0006	0.0007	0.0005	0.0006
Public Sector Combustion	Coke	1A4ai	Kg	0.00030	0.00025	0.00021	0.00018	0.0	0.0	0.0	0.0	0.0	0.0
Railways Stationary Combustion	Coal	1A4ai	Kg	4.8E-06	0	0	0	0	0	0	0	0	0
Residential Combustion	Coal	1A4bi	Kg	0.0048	0.0050	0.0045	0.0043	0.0030	0.0019	0.0021	0.0021	0.0022	0.0026
Residential Combustion	Coke	1A4bi	Kg	0.00061	0.00050	0.00042	0.00035	0.00030	0.00028	0.00029	0.00013	0.00019	0.00019
Residential Combustion	Petroleum Coke	1A4bi	Kg	0.00004	0.00008	0.00012	0.00016	0.00027	0.00034	0.00037	0.00040	0.00038	0.00036
Agricultural Combustion	Coal	1A4ci	Kg	0.000032	3.04E-05	1.92E-05	2.08E-05	2.08E-05	2.08E-05	2.08E-05	1.12E-05	1.44E-05	1.12E-05
Agricultural Combustion	Coke	1A4ci	Kg	0	0	0	0	0	0	0	0	0	0
Di-Electric Fluids	Leaks from transformers	2F	Kg	99.16	94.39	89.85	85.53	81.20	77.10	73.20	69.50	65.98	62.65
Di-Electric Fluids	Leaks from capacitors	2F	Kg	67.08	63.58	60.26	57.11	53.96	50.99	48.18	45.52	43.02	40.65
Di-Electric Fluids	Leaks from Fragmentisers	2F	Kg	8.61	7.18	5.98	4.98	3.99	3.19	2.55	2.04	1.63	1.31
Dry cleaning - (for use of PERC)	Solid residues	3B2	Kg	174.855	165.144	156.085	147.618	139.150	131.274	123.928	117.062	110.632	104.599
Agricultural pesticide use - quinto	Solvent use	4G	Kg	30.093	4.507	4.507	1.051	1.051	0.991	0.991	0.991	0.991	12.946
Incineration	MSW - Incineration	6Cc	Kg	2.04	2.02	1.94	1.71	1.25	1.14	1.25	0.00	0.00	0.00
Domestic waste	Small scale waste burning	6Ce	Kg	265.43	265.43	265.43	265.43	265.43	265.43	265.43	265.43	265.43	265.43
Agricultural waste	Agricultural waste burning	6Ce	Kg	86.77	86.77	86.77	86.77	86.77	86.77	86.77	86.77	86.77	86.77
Accidental Fires	Vehicles	6D	Kg	11.36	13.12	13.13	13.23	12.24	12.75	13.26	12.52	12.38	14.59
Accidental Fires	Dwellings	6D	Kg	38.82	38.68	38.42	36.96	36.60	40.60	40.55	38.85	37.71	41.29
Accidental Fires	Other Buildings	6D	Kg	90.15	76.58	75.85	70.48	68.84	83.97	72.28	62.76	56.60	63.76
			Kg	875.05	818.09	798.99	771.86	751.94	755.77	729.87	703.23	683.67	696.44

Table 3.10 (cont.) UK Pentachlorobenzene emissions to land, 1990 – 2009

PentaChlorobenzene to land													
Source Name	Activity Name	NFR Reference	Units	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Power Stations <300MW = >50M	MSW - Incineration	1A1a	Kg	2.47	2.68	2.89	2.95	2.84	2.82	3.17	3.22	3.35	4.07
Other Industrial Combustion	Coal	1A2fi	Kg	0.0016	0.0016	0.0017	0.0017	0.0016	0.0018	0.0018	0.0016	0.0019	0.0022
Other Industrial Combustion	Coke	1A2fi	Kg	0.0003	0.0003	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Commercial Combustion	Coal	1A4ai	Kg	0.00002	0.00002	0.00001	0.00001	0.00001	0.00001	0.00002	0.00001	0.00002	0.00008
Commercial Combustion	MSW - Incineration	1A4ai	Kg	0.10	0.11	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13
Public Sector Combustion	Coal	1A4ai	Kg	0.0004	0.0004	0.0003	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002
Public Sector Combustion	Coke	1A4ai	Kg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Railways Stationary Combustion	Coal	1A4ai	Kg	0	0	0	0	0	0	0	0	0	0
Residential Combustion	Coal	1A4bi	Kg	0.0015	0.0012	0.0008	0.0007	0.0006	0.0005	0.0005	0.0007	0.0008	0.0007
Residential Combustion	Coke	1A4bi	Kg	0.00023	0.00011	0.00028	0.00021	0.00008	0.00006	0.00004	0.00002	0.00002	0.00002
Residential Combustion	Petroleum Coke	1A4bi	Kg	0.00034	0.00031	0.00029	0.00026	0.00024	0.00022	0.00021	0.00019	0.00020	0.00018
Agricultural Combustion	Coal	1A4ci	Kg	1.12E-05	0.000008	9.6E-06	9.6E-06	1.3E-05	1.44E-05	0.000008	6.4E-06	0.000016	0
Agricultural Combustion	Coke	1A4ci	Kg	0	0	0	0	0	0	0	0	0	0
Di-Electric Fluids	Leaks from transformers	2F	Kg	15.66	14.87	14.13	13.42	12.75	12.11	11.50	10.93	10.38	9.86
Di-Electric Fluids	Leaks from capacitors	2F	Kg	10.16	9.60	9.11	8.64	8.19	7.77	7.37	6.99	6.63	6.28
Di-Electric Fluids	Leaks from Fragmentisers	2F	Kg	1.05	0.84	0.67	0.54	0.43	0.34	0.27	0.22	0.18	0.14
Dry cleaning - (for use of PERC)	Solid residues	3B2	Kg	26.868	25.308	23.901	22.590	21.365	20.219	19.144	18.133	17.181	16.285
Agricultural pesticide use - quinto	Solvent use	4G	Kg	12.957	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Incineration	MSW - Incineration	6Cc	Kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Domestic waste	Small scale waste burning	6Ce	Kg	265.43	265.43	265.43	265.43	265.43	265.43	265.43	265.43	265.43	265.43
Agricultural waste	Agricultural waste burning	6Ce	Kg	86.77	86.77	86.77	86.77	86.77	86.77	36.34	5.40	2.60	2.60
Accidental Fires	Vehicles	6D	Kg	14.16	15.15	14.40	14.04	11.98	11.07	10.24	9.10	7.96	7.96
Accidental Fires	Dwellings	6D	Kg	38.69	37.23	37.08	37.79	32.87	31.75	30.35	28.95	27.61	27.61
Accidental Fires	Other Buildings	6D	Kg	55.73	63.52	66.76	77.43	59.38	55.84	59.34	56.12	47.37	47.37
			Kg	530.06	521.50	521.28	529.73	502.15	494.27	443.30	404.62	388.82	387.75

1.4 Hexabromobiphenyl

1.4.1 Background

Hexabromo biphenyl (HBB) consists of a biphenyl molecule with six hydrogen atoms substituted with bromine atoms. HBB congeners exist as 42 possible isomeric forms

Technical grade polybrominated biphenyls (PBBs) contain a number of PBB compounds. Hexabromobiphenyl is one of the main components of technical grade PBBs. For example, FireMaster(R) BP-6 consists of 60% - 80% HBB.

Polybrominated biphenyls were manufactured by the bromination of biphenyl. The commercial production of PBBs began in 1970. Approximately 6,000 tonnes of PBBs were produced in the United States from 1970 to 1976, of which hexabromobiphenyl constituted about 5,400 tonnes (88%).⁶² It is estimated that 11,000 tonnes of PBBs were produced worldwide.⁶³ Production of hexabromobiphenyl ceased in the US in 1975, with other PBB compounds produced up to 1979. The production of PBBs in the UK was discontinued in 1977. Manufacture of PBBs continued in Germany until the mid-1980s and in France until 2000. Production could possibly continue in developing countries or in countries with economies in transition.

1.4.2 Environmental release pathways

In the United States and Canada, hexabromobiphenyl was used as a fire retardant in thermoplastics for business machine housings, industrial products and electrical products; as a fire retardant additive in coatings and lacquers, and in polyurethane foam for car upholstery.⁶² For example, in the US in 1974, most of the estimated 2,200 tonnes produced was used in the manufacture of plastic products and cable coatings. A relatively small amount was used in car upholstery.

HBB was released during manufacture, principally to landfill but with emissions also taking place to air and water.

The estimated product lifetime of goods produced which contained HBB is 5–10 years. Consequently, almost all the products containing HBB are expected to have been disposed of by landfill or incineration, with only a small residual quantity of HBB remaining in products with unusually long lifetimes. Because of the high stability of HBB, a significant proportion of HBB may ultimately be released into the environment.

1.4.3 Emission factors

The UNEP Risk Profile⁶² includes the following emission factors for HBB.

- Releases to air during manufacture: 1.1 kg HBB per tonne product
- Releases to waste water during manufacture: 4.6×10^{-6} kg HBB per tonne product
- Releases to landfill during manufacture: 50 kg HBB per tonne product
- Total environmental releases during manufacture: 51 kg HBB per tonne product

⁶² United Nations Environment Programme, "Report of the Persistent Organic Pollutants Review Committee on the work of its second meeting, Addendum: Risk profile on hexabromobiphenyl," Ref. UNEP/POPS/POPRC.2/17/Add.3, November 2006

⁶³ United Nations Environment Programme, "Draft technical guidelines on the environmentally sound management of PCB, PCT and PBB," Ref. UNEP/CHW/OEWG/2/INF/12, September 2003

3.3.9 Emission inventory

Van den Gon et al. (2007)¹³ stated that HBB is “thought to be no longer emitted in Europe” since production and use is banned and/or scheduled for elimination under UNECE POP protocol (UNECE, 1998). The UNEP risk profile indicates that production in the UK stopped in 1977.⁶²

Losses during manufacture were estimated to be approximately 51 kg per 1000 kg production, of which 98% was to landfill and 2% to air.

Use of HBB in the UK was estimated from the US estimates by scaling relative to the GDP for the UK and the US. This indicated that approximately 1,000 tonnes of HBB may have been used in the UK during the period 1970 to 1977.

An estimate of HBB emissions to the environment from product use and disposal in the UK was made using the following assumptions.

- The UNEP estimated that 90% of goods containing HBB would be removed from use over a 10 year period. This corresponds to a removal rate of approximately 21% per year.
- It was estimated that 80% of waste materials containing HBB would be disposed of to landfill. Emissions to air and water were assumed to be in the same proportion relative to landfill as for the manufacturing losses – i.e. 1.8% of HBB in waste materials released to air, and 0.0000074% of HBB in waste materials released to water.
- The calculation was carried out using the simplifying assumption that all HBB products were introduced in 1974, approximately the mid-point of use in the UK. The spread of HBB use across the period 1970 – 1977 would not significantly affect the estimated quantities of HBB discharged to the environment today.

On this basis, it is estimated that approximately 250 kg of HBB remains in use in the UK in 2010, with approximately 50 kg of products discharged to landfill, 1.1 kg to air, and 4.8×10^{-6} kg discharged to waste water. The uncertainty in the emissions estimates is estimated to be approximately as follows:

- Air: a factor of 4 (1 Standard Deviation); or a factor of 15 (2 Standard Deviations)
- Land: a factor of 5 (1 Standard Deviation); or a factor of 25 (2 Standard Deviations)
- Water: a factor of 5 (1 Standard Deviation); or a factor of 25 (2 Standard Deviations)

However, in view of the relatively low quantities of materials and absence of ongoing uses, it is considered that HBB is a relatively low priority substance.

3.3.10 Recommendations for further research

It is recommended that consideration should be given to an evaluation of the potential for ongoing releases of HBB from the following sources:

- Processing, handling, recycling and disposal of WEEE waste materials potentially containing HBB
- Processing, handling, recycling and disposal of end-of-life vehicles potentially containing HBB
- The presence of HBB in landfill leachate and/or landfill gas

The aim of this evaluation would be to provide data to verify the uncertain estimates of HBB emissions set out in Section 3.4.4 above.

3.4 Polybrominated diphenyl ethers (PBDEs): Tetra, Penta, Hexa and Hepta Brominated Diphenyl Ether

PBDEs have been widely used as additive flame retardants in products such as furniture, cars, textiles, paints, electronic equipment and plastics to reduce fire risk. They are referred to as 'additive' flame retardants, because they are simply blended with the product, as opposed to 'reactive' flame retardants that are covalently bound into plastics. This makes them more prone to volatilise into the atmosphere during the product lifetime. The global demand for PBDEs has been very substantial with a peak estimation of 70,000 tonnes for the year 2003 (Hites et al., 2004)⁶⁴.

There are three main technical mixtures of PBDEs, the compositions and usage patterns of which have been reviewed by de Wit (de Wit, 2002)⁶⁵. Typical congener profiles of the three commercial technical mixtures are contained in Table 3.11. It is important to point out the distinction of the nomenclature of the commercial mixtures, i.e. tetra-BDE, penta-BDE, hexa-BDE and hepta-BDE, and individual congeners, for example, BDE-47 is a tetra-BDE whilst BDE-99 is a penta- congener. Congeners BDE-47 and BDE-99 account for approximately 72% of the composition of the penta commercial mixture (pentaBDE). Of these technical mixtures, the commercial pentabromodiphenyl ether (PeBDE) and commercial octabromodiphenyl ether (OctaBDE) mixtures have been banned in the EU and Japan and are currently being phased out in the rest of the world (after being banned in some states of the USA). In the UK there has been previously high use of PeBDE as a result of particularly stringent fire retardancy regulations for furniture. PBDEs can also be formed from the degradation of higher brominated BDEs, as discussed in Section 3.4.4.

The first detection of PBDEs in the aquatic environment was in fish from Sweden (Andersson and Blomkvist 1981)⁶⁶, and since then they have been reported globally in a wide range of biota. There are numerous reports of PBDEs being found in both bird tissues and bird eggs across Europe (reviewed in Law et al., 2006)⁶⁷. A study of three (PeBDE-related) PBDEs in Baltic guillemot eggs showed concentrations peaking around the mid-late 1980s (Sellström et al., 2003)⁶⁸. However, evidence suggests that there is a difference in PBDE congener exposure dependent on foodchain - terrestrial birds appear to be more exposed to heavier PBDEs than aquatic birds, and there are regional differences which can probably attributed to differences in prey availability (Law et al., 2002³; Lindberg et al., 2004⁶⁹). Samples from the CEH Predatory Bird Monitoring Scheme⁷⁰ analysed for PBDEs have shown a marked difference in PBDE patterns and concentrations between terrestrial and aquatic birds with generally lower concentrations of PBDEs found in the UK than in Scandinavian birds.

⁶⁴ Hites, R. A. (2004) Polybrominated Diphenyl Ethers in the Environment and in People: A Meta-Analysis of Concentrations Environ. Sci. Technol. 2004, 38, 945-956

⁶⁵ de Wit CA. 2002. An overview of brominated flame retardants in the environment. Chemosphere 46:583-624

⁶⁶ Andersson Ö, Blomkvist G. 1981. Polybrominated aromatic pollutants found in fish in Sweden. Chemosphere 10(9):1051-1060.

⁶⁷ Law RJ, Allchin CR, Bennett ME, Morris S, Rogan E. 2002. Polybrominated diphenyl ethers in two species of marine top predators from England and Wales. Chemosphere 46:673-681.

⁶⁸ Sellström U, Bignert A, Kierkegaard A, Hågberg L, de Wit CA, Mats Olsson, et al. 2003. Temporal trend studies on tetra- and pentabrominated diphenyl ethers and hexabromocyclododecane in guillemot egg from the Baltic Sea. Environ Sci Technol 37:5496-5501.

⁶⁹ Lindberg P, Sellström U, Hågberg L, de Wit CA. 2004. Higher brominated diphenyl ethers and hexabromocyclododecane found in eggs of Peregrine Falcons (*Falco peregrinus*) breeding in Sweden. Environ Sci Technol 38:93-96.

⁷⁰ <http://pbms.ceh.ac.uk/>

Table 3.11 – Typical congener concentration compositions for three technical PBDE mixtures (adapted from La Guardia *et al.* 2006⁷¹ and Sjodin *et al.* (1998)⁷²)

		Penta-brominated technical mixtures		Octa-brominated technical mixtures		Deca-brominated technical mixtures	
		DE-71	Bromkal	DE-79	Bromkal	Saytex	Bromkal
Congener	IUPAC		70-5DE		79-8DE	102E	82-ODE
BDE47/74	tetra	38.2	39.9				
BDE100	penta	13.1	7.31				
BDE99	penta	48.6	39.9				
BDE85	penta	2.96	1.88				
BDE154	hexa	4.54	2.59	1.07			
BDE153	hexa	5.44	4.61	8.66			
BDE175/183	hepta			42	12.6		
BDE180	hepta			1.81			
BDE197	octa			22.2	10.5		
BDE203	octa			4.4	8.14		
BDE196	octa			10.5	3.12		
BDE207	nona			11.5	11.2		4.1
BDE206	nona			1.38	7.66	2.19	5.13
BDE209	deca			1.31	49.6	96.8	91.6

Note: Data for Bromkal 70-5DE mean of La Guardia *et al.* 2006 and Sjodin *et al.* 1998

The less brominated PBDEs (generally originating from the PeBDE and OctaBDE commercial products, but potentially including debromination products of DecaBDE) have a range of proven or potential toxicological endpoints including hepatotoxicity (Darnerud *et al.* 2001)⁷³, neurodevelopmental effects (Muir 2004)⁷⁴, endocrine (particularly thyroid hormone) disrupting effects (Hall *et al.* 2003⁷⁵; Hallgren and Darnerud 2002⁷⁶; Zhou *et al.* 2001⁷⁷; Zhou *et al.* 2002⁷⁸) and cancer (McDonald 2002)⁷⁹.

In order to estimate the UK's emissions of tetra, penta, hexa and heptaBDE during the period 1990 to 2008 to air, water and land the study team has used a combination of direct and indirect methodologies.

3.4.1 Environmental release pathways

New estimates of the UK's PeBDE (penta-BDE) emissions to air, water and soil based on the European Risk Assessment emission factors and usage figures have been produced. PeBDE was not produced in the EU after 1997, however we have conservatively assumed that the amount of PeBDE imported in articles remained static at 1100 tonnes per year until 2003 when the EU banned PeBDE. Application losses are therefore not relevant within the

⁷¹ La Guardia, M.J., Hale, R.C. and Harvey, E. (2006) Detailed Polybrominated Diphenyl Ether (PBDE) Congener Composition of the Widely Used Penta-, Octa-, and Deca-PBDE Technical Flame-retardant Mixtures. *Environmental Science and Technology*, 40, 6247-6254

⁷² A. Sjödin, E. Jakobsson, A. Kierkegaard, G. Marsh, U. Sellström (1998) Gas chromatographic identification and quantification of polybrominated diphenyl ethers in a commercial product, Bromkal 70-5DE. *Journal of Chromatography A*, 822, 83-89

⁷³ Darnerud PO, Eriksen GS, Jóhannesson T, Larsen PB, Viluksela M. 2001. Polybrominated diphenyl ethers: Occurrence, dietary exposure and toxicology. *Environ Health Persp* 109:49-67.

⁷⁴ Muir T. 2004. Is there a relationship between the rise in thyroid and neurodevelopmental health effects in North America and the rise in concentrations of PBDEs in the environment? - An update. *Organohalogen Compounds* 66:3951-3958.

⁷⁵ Hall AJ, Kalantzi OI, Thomas GO. 2003. Polybrominated diphenyl ethers (PBDEs) in grey seals during their first year of life - are they thyroid hormone endocrine disruptors? *Environmental Pollution* 126(1):29-37.

⁷⁶ Hallgren S, Darnerud PO. 2002. Polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs) and chlorinated paraffins (CPs) in rats - testing interactions and mechanisms for thyroid hormone effects. *Toxicology* 177:227-243.

⁷⁷ Zhou T, Ross DG, De Vito MJ, Crofton KM. 2001. Effects of short-term in vivo exposure to polybrominated diphenyl ethers on thyroid hormones and hepatic enzyme activities in weanling rats. *Toxicological Sciences* 61:76-82.

⁷⁸ Zhou T, Taylor MM, DeVito MJ, Crofton KA. 2002. Developmental exposure to brominated diphenyl ethers results in thyroid hormone disruption. *Toxicological Sciences* 66 (1):105-116

⁷⁹ McDonald TA. 2002. A perspective on the potential health risks of PBDEs. *Chemosphere*, 46, 745-755.

inventory estimates, and only emissions arising from use and disposal are considered. All figures are taken from the EU PeBDE risk assessment report (RAR), see Table 3.12⁸⁰. No other estimates were available to allow the application of EU data to the UK as set out below to be cross-checked.

In order to estimate European atmospheric emissions of PeBDE from product use the EU RAR uses a volatilisation emission factor of 3.9% (or 0.39% per year over the 10 year life of the foam). Using this emission factor suggests that 43 tonnes were emitted from the EU15 in 2003 leaving 1057 tonnes remaining in articles, from which a further 2% is volatilised (21 tonnes) during disposal, leaving 1036 tonnes per year disposed of to landfill. Emissions from waste can also be divided up using emission factors derived from the plasticiser DEHP EU risk assessment, whereby 75% binds to soil, 0.1% volatilises and 24.9% migrates to water (Table 3.13). These emission factors are commonly used for non-reactive polymer additives.

Using these data, EU15 per capita emissions of 0.13g/per person/yr were derived based on a population of 325 million, which can be extrapolated to provide an estimated annual volatilisation emission from the UK of 8.2 tonnes in 2003 (based on a population of 62 million). A similar exercise is repeated for the 2003 end of life product wastes, whereby 3 tonnes remains in the soil, 1 tonne is emitted to water and there is negligible volatilisation (Table 3.13).

Table 3.12: Emissions from the EU15 in 2003 (from PeBDE EU RAR (2000))

Parameter	Value	Units
Total amount of PeBDE present in Articles	1100	Tonnes
Volatilisation losses during use	43	Tonnes
Total amount remaining in articles	1057	Tonnes
Amount lost to Environment during disposal	2%	
Emission at disposal (released into the environment)	21	Tonnes
Amount remaining in disposed articles	1036	Tonnes
EU15 Environmental releases (2003) (breakdown from disposal of 21 tonnes)		
To soil	75%	15.86 tonnes
To air	0.1%	0.02 tonnes
To water	24.9%	5.26 tonnes

Table 3.13: EU15 emissions adjusted for the UK

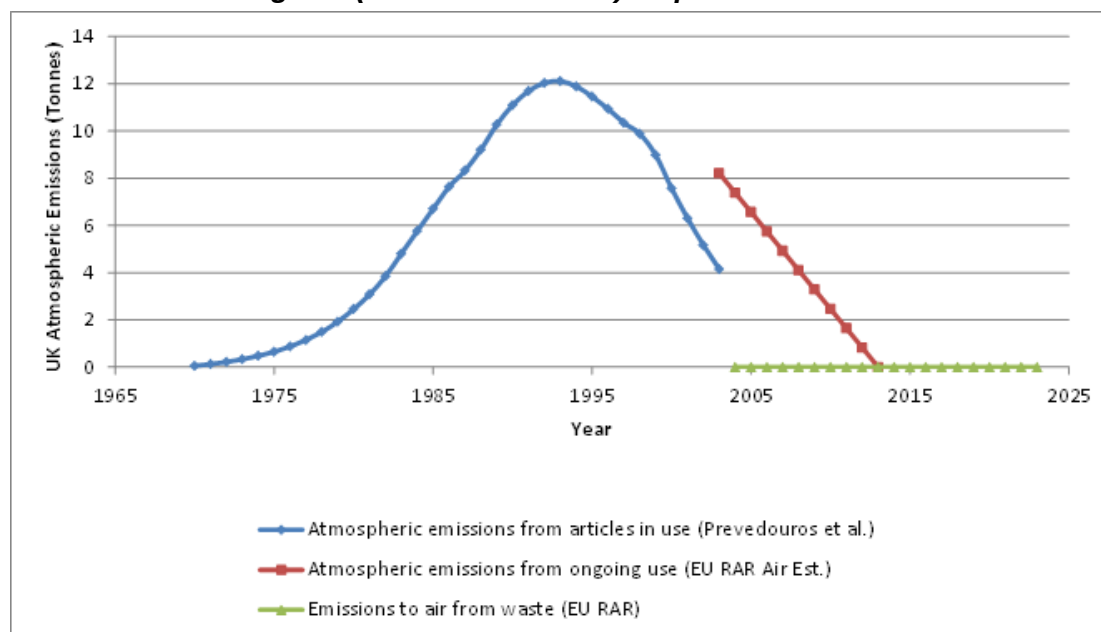
Year	2003	2010
UK losses to air during use (tonnes) from 10 year product life span	8.2	2.5
UK losses during disposal (tonnes) 21 year 'life' span (loss)		
Losses Soil after disposal	3.02	2.0
Losses to Air during disposal	0.004	0.002
Losses to Water after disposal	1.00	0.7
Total	4.03	2.62
Grand Total (air, water and soil; during/after use and disposal)	12.2	5.1

⁸⁰ European Union Risk Assessment Report: Diphenyl ether, pentabromo derivative (pentabromodiphenyl ether). 2000. ISBN 92-894-0479-5

3.4.2 Emissions to air

The UK's historical emissions of tetra, penta, hexa and heptaBDE to air, water and land between the years 1970 and 2013 have been calculated using a combination of methodologies based on TNO estimates (Denier van der Gon, 2007),¹³ European Risk Assessment Reports (RARs) and peer reviewed publications by Prevedouros *et al.* (2004a⁸¹,b⁸²). Firstly, the assessment of PBDE production provided by Prevedouros *et al.* (2004a), has been updated in order to provide a PeBDE production estimate between 1970-2003 and a corresponding atmospheric emissions estimate over the same period. From these calculations, the UK's total production and use of PeBDE has been estimated to be ~2900 tonnes resulting in an estimated atmospheric emission from articles of 203 tonnes between 1970 and 2003, with a maximum of 12 tonnes per year (blue line, Figure 3.3). Using data provided by the EU PeBDE Risk Assessment Report, atmospheric emissions from products in use has been calculated to be a further ~37 tonnes between 2004-2013 with a maximum of 8 tonnes per year (red line). Lastly, emissions from wastes have been calculated using emission factors derived from the plasticizer DEHP which suggests that 75% of emissions binds to soil, 0.1% volatilises and 24.9% migrates to water (Table 3.12). Using this method, the total UK PBDE emissions from wastes have been estimated to be 42 tonnes between 2003 - 2023 (soil 31.8t, air 50kg (green line) and water 10.5t). The difference between the two methods is evident during the year 2003, and highlights the uncertainties involved in calculating retrospective emissions.

Figure 3.3: Projected atmospheric emission trends of PeBDE for the UK arising from volatilisation during use (blue and red lines) disposal



1.4.4 Congener specific emissions from the PentaBDE product

There are limited data on the production and use of individual PBDE congeners, however, some information is available on component composition of commercial mixtures. La Guardia *et al.* 2006 and Sjodin *et al.* (1998)⁷² reported a breakdown of PeBDE mixture Bromkal 70-5DE, which has been manufactured in Europe and so these data have been used to calculate congener emission estimates. Using the year 2003 as a reference year, congener specific emissions associated with product use have been calculated and the results

⁸¹ K. Prevedouros, K. C. Jones, and A. J. Sweetman (2004a) Estimation of the Production, Consumption, and Atmospheric Emissions of Pentabrominated Diphenyl Ether in Europe between 1970 and 2000. *Environ. Sci. Technol.*, 38, 3224–3231

⁸² K. Prevedouros, K. C. Jones, and A. J. Sweetman (2004b) European-Scale Modeling of Concentrations and Distribution of Polybrominated Diphenyl Ethers in the Pentabromodiphenyl Ether Product. *Environ. Sci. Technol.*, 38, 5993–6001

contained in Table 3.14. Historical emission between 2003 and 2023 have also been estimated. These calculations suggest that of the total atmospheric emission of 240 tonnes to air during the period 1970 to 2013, tetra congeners contributed 89 tonnes, penta congeners contributed 104 tonnes, hexa congeners contributed 10 tonnes and hepta congeners contributed 6 tonnes. The emissions from these congeners contribute 88% (210 tonnes) of the total estimated UK PBDE atmospheric releases. Emissions are likely to be biased towards the more volatile, less brominated, congeners. The methodology employed in the EU RAR utilises an emission factor (EF) based on volatilisation of the plasticiser DEHP as a surrogate. DEHP exhibits a similar volatility as BDE-47 (a tetra congener), and although the EFs could be modified to take into account differences in volatility, an established methodology is not currently available and this would only add to the overall uncertainty.

As is evident from Table 3.14, the majority of emissions from the PeBDE mixture are made up of Tetra and Penta congeners, accounting for ~70% of the commercial mixture.

Table 3.14: Total estimated atmospheric UK emissions of PentaBDE by congener in 2003 and between 2003-2023

Congener		Tonnes emitted from UK (2003)	Tonnes emitted from UK (Total)
Tribromo BDE (BDE17-28)			
BDE-17	0.00022%	0.003	0.053
BDE-28	0.0011%	0.01	0.26
Tetra (BDE42-74)			
BDE-47	0.37%	4.5	89
BDE-66	0.0022%	0.03	0.53
Penta (BDE85-119)			
BDE-85	0.016%	0.20	3.8
BDE-99	0.35%	4.3	84
BDE-100	0.068%	0.83	16.3
Hexa (BDE138-156)			
BDE-138	0.0041%	0.05	0.98
BDE-153	0.039%	0.48	9.4
Hepta (BDE173-191)			
BDE-154	0.025%	0.31	6
Total of these congeners	0.88%	10.7	210.1
UK total PentaBDE		12.2	240

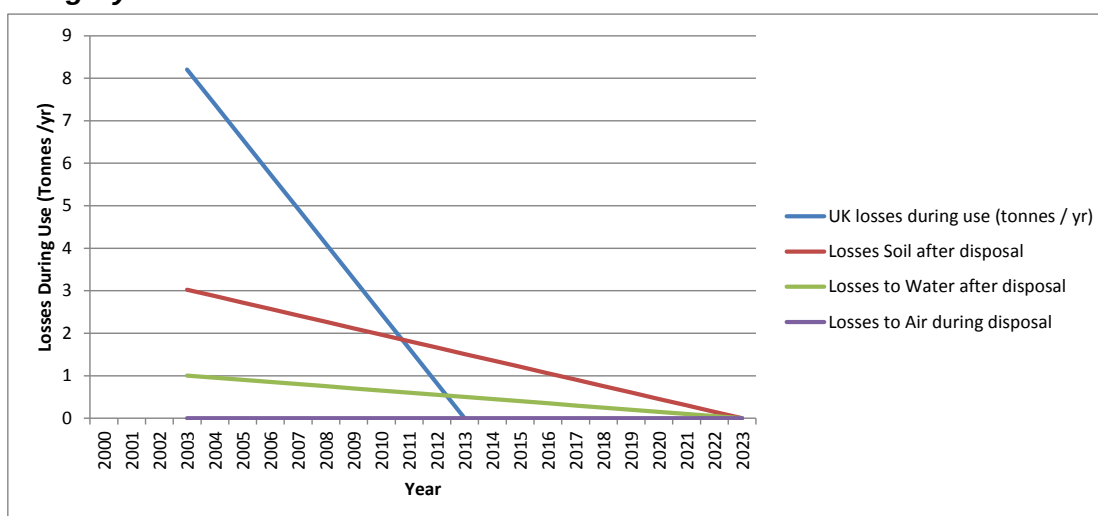
3.4.3 Additional historical PeBDE emissions from product disposal

Emissions to water, soil and air from wastes after disposal were calculated using the same method as the EU PentaBDE RAR, whereby wastes can be divided up using emission factors derived from the plasticiser DEHP EU risk assessment - 75% binds to soil, 0.1% volatilises and 24.9% migrates to water. Total historical UK PBDE emissions from wastes have been estimated to be 42.3 tonnes by 2023. These data are contained in Table 3.15 and shown Figure 3.4.

Table 3.15: UK Emissions of PentaBDE from Waste 2004-2023

	Tonnes
Losses to Soil after disposal	31.8
Losses to Air during disposal	0.05
Losses to Water after disposal	10.5
Total	42.3

Figure 3.4: Breakdown of UK PentaBDE emissions during use and from wastes by category

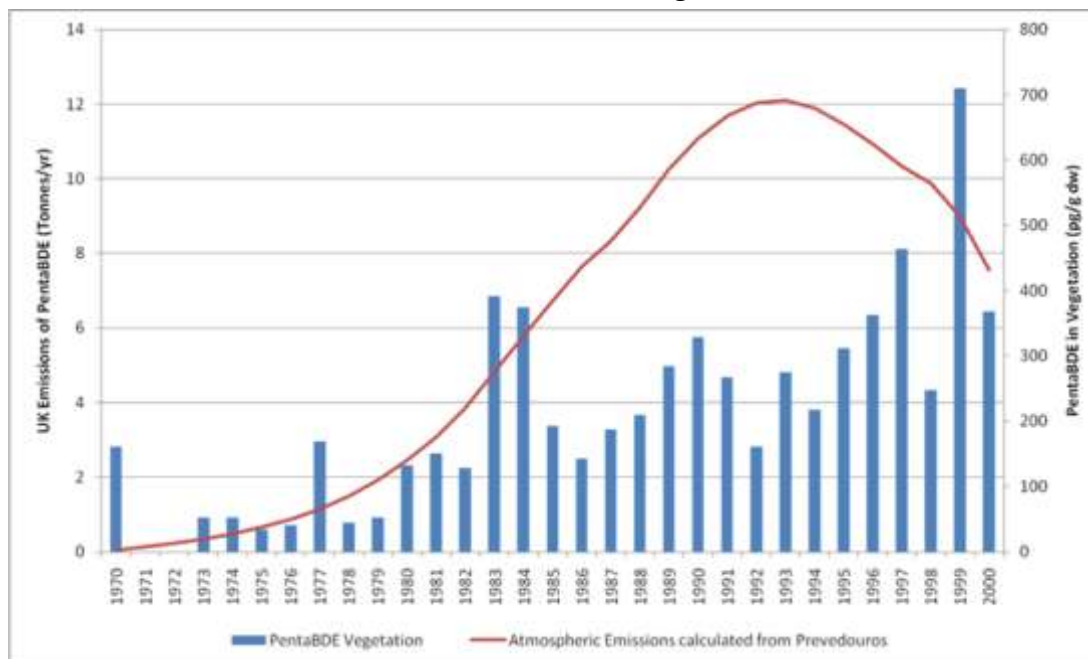


3.4.4 Historical trends of PBDEs in the UK ambient environment

The only UK historical trend measurement dataset available for comparison with these emission estimates comes from a study of vegetation samples taken from the Rothamsted Experimental Station sample archive. More recent measurements have been taken in media such as UK lakes and dusts found in workplaces, homes and vehicles, but this does not provide a historical trend perspective. Aerial portions of vegetation receive the bulk of their burden of POPs, such as PBDEs, from the atmosphere. Vegetation can therefore be a useful indicator of changing atmospheric burdens resulting from changes in emission patterns. Hassanin *et al.* (2005)⁸³ analysed samples of archived pasture, collected from Rothamsted Experimental Station in the United Kingdom between 1930 and 2004, were analyzed for a range of PBDE congeners. PBDEs were not be routinely detected in the pre- 1970 samples, but thereafter, the dominant congeners BDE 28, 47, 49, 99, 100, 153, 154, and 183 were frequently detected. The general trend, shown in Figure 3, was an increase in concentration through the 1970s and with values remaining high through the late 1980s and into the 1990s. This trend, although showing some variation within the data, is consistent with the emission trends reported here. The authors also reported that congener profiles of technical PBDE mixtures, U.K. air, soil, and pasture were compared and shown to be broadly similar.

⁸³ Hassanin, A., Johnston, A.E., Thomas, G.O. and Jones, K.C. (2005) Time Trends of Atmospheric PBDEs Inferred from Archived U.K. Herbage. *Environ. Sci. Technol.*, 39 (8), 2436–2441

Figure 3.5: Historical UK PentaBDE emission trend data from this study, compared with measurement data from the Rothamsted vegetation archive



Potential contribution of OctaBDE to PentaBDE in the environment

Until 1994, OctaBDE was manufactured containing up to 12% PeBDE, although the majority of the commercial mixture was made up of heptaBDE. In 1994 the formulation was changed reducing the concentration of peBDE to <1.5%. Using the same methodology as above, emissions from use between 1970 and 2003 are shown in Table 3.16. Emissions from waste have not been calculated. OctaBDE appears to only be a small source of PeBDE congeners (3.6 tonnes) compared to foams treated directly with PeBDE and emission factors from this source are subject to greater uncertainty.

Table 3.16: UK Emissions of PentaBDE congeners during product use, 1970-2003

Emission by congener group from octa-BDE	Tonnes
Penta	3.6
Hexa	5.4
Hepta	20.4

3.4.5 Summary

The UK's total atmospheric emissions arising from production and use of PentaBDE was estimated to be 240 tonnes between 1970 and 2023 (see Figure 3.3) using a combination of data from Prevedouros *et al.* (2004) and the EU RAR. During the disposal process, the majority of PentaBDEs are directed to solid or liquid waste (Figure 3.4). Emission from these wastes have been calculated to be 27 tonnes to air, 20 tonnes to soil and 6.6 tonnes to water, over the same period. Additional sources include octaBDE, as the commercial mixture contained up to 12% penta and hexa congeners. Over the time period 1970-2003 the octaBDE mixture has been estimated contributed an additional 3.6 tonnes of PentaBDE to the UK's environmental burden although emission factors are subject to greater uncertainty. Table 3.17 contains a summary of the estimated emission data.

Table 3.17: Summary of UK Emissions of PentaBDE commercial mixture congeners during product use and disposal, 1970-2010

Pathway	Tonnes	Period
Losses to Air during use (based on Prevedorous et al 2004)	203 t	Up to 2003
Losses to Air based on EU RAR (from remaining products in use)	34 t	From 2003 to 2010
Losses from wastes to Air (based on EU RAR)	27 t	From 2003 to 2010
Losses from wastes to Soil (based on EU RAR)	20 t	From 2003 to 2010
Losses from wastes to Water (based on EU RAR)	6.6 t	From 2003 to 2010

No data prior to 2003

3.4.6 Recommendations

In view of the potential significance of PBDEs, it is recommended that ongoing research is focused on understanding release pathways and environmental transformations. This is likely to require ongoing monitoring work in relation to discharges to sewage treatment processes; removal during sewage treatment; and discharge in effluent, sludge or to air.

It is also important to understand the potential significance of exposure via airborne dusts in indoor environments and in vehicles. These recommendations are set out in more detail in Chapter 4.

3.5 PFOS and its salts

Perfluorinated organic chemicals (PFCs) have been industrially manufactured for over 50 years. The total historical worldwide production of perfluorooctane sulfonyl fluoride (POSF) has been estimated to be 96,500 tonnes (Paul et al. 2008)⁸⁴. These substances have recently created interest as some perfluorinated chemicals have been widely reported in human blood and in wildlife in remote areas (Giesy and Kannan, 2001)⁸⁵. The largest focus has been on the surfactant perfluorooctane sulphonate (PFOS).

PFOS and its derivatives were produced commercially and used for textile/carpet surface treatments, paper protection and some performance chemicals, e.g. insecticides and fire-fighting foam. In addition to its presence in various perfluorinated products, PFOS is also thought to be a stable degradation product/metabolite of other PFCs. PFOS has recently emerged as a priority environmental pollutant due to its widespread detection in biota (including both Arctic and Antarctic species), and its persistent and bioaccumulative nature. As a result, the main producer of PFOS derived chemicals (3M Company) announced in 2000 that they would phase out the production of perfluorooctane-based compounds.

In June 2000, the USEPA also indicated that it was expanding its investigation of PFOS to encompass other fluorochemicals, including perfluorooctanoic acid (PFOA), in order to determine whether other fluorochemicals might present concerns similar to those found with PFOS. PFOA is used primarily to produce its salts, which are used as essential processing aids in the production of fluoropolymers and fluoroelastomers. The major fluoropolymers manufactured using PFOA salts are polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF).

⁸⁴ Paul, A.G., K.C. Jones, and A.J. Sweetman, A First Global Production, Emission, And Environmental Inventory For Perfluorooctane Sulfonate. Environ. Sci. & Technol., 2008. 43(2): p. 386-392.

⁸⁵ Giesy J.P., Kannan K. (2001) Environ. Sci. Technol. 35, 1339-1342.

In recent years, PFOS and perfluorinated carboxylic acids (PFCAs), of which PFOA is just one, have been detected in a large variety of environmental samples, including high-trophic biota from as remote places as the Canadian and Norwegian Arctic (Smithwick *et al.*, 2005)⁸⁶. These compounds are ionic and possess very low volatility. A question has arisen how they have been transported from densely populated application areas to remote regions such as the Arctic. Ellis *et al.* (2004)⁸⁷ proposed that neutral and volatile precursor compounds could undergo atmospheric long-range transport and finally be degraded to persistent products in remote locations.

Possible precursor compounds for PFCAs and PFOS are fluorotelomer alcohols (FTOHs) and fluorooctane sulfonamides/sulfonamido ethanols (FOSAs/FOSEs), respectively. However, a more recently proposed hypothesis suggests that the acids and sulphonates remain in solution and can be transported by sea currents, and/or because of their surface active character may accumulate at the sea/lake surfaces and become airborne through spray (Prevedouros *et al.*, 2004)⁸⁸. Sweden prepared and submitted a dossier in 2004 to nominate PFOS and 96 PFOS-related substances to the UN/ECE LRTAP Protocol and the Stockholm Convention. In addition, the USEPA has recently declared that PFOA is a 'likely human carcinogen'.

3.5.1 Environmental release pathways

3M's voluntary phase out of PFOS has led to a large reduction in global consumption of both PFOS substances and polymers. At the time of the phase-out, 3M had a greater production capacity than all other manufacturers combined. PFOS was manufactured as a salt, derivative (PFOS substances) or as polymers. PFOS or PFOS containing substances (that may degrade to PFOS in the environment) have historically been used in the following applications:

- Carpets
- Leather / Apparel
- Textiles / Upholstery
- Paper and Packaging
- Coatings and Coating Additives
- Industrial and Household Cleaning Products
- Pesticides and Insecticides

A consultation document prepared by BRE (2004)⁸⁹ for Defra confirmed that the above applications are no longer in use in the UK. PFOS has been reported to have been used in medical applications, mining / oil surfactants, flame retardants and adhesives, although no evidence of recent use in the UK has been found (BRE, 2004). BRE confirmed the five following ongoing industrial and professional uses in their 2004 report:

- Metal Plating
- PFOS based Fire Fighting Foams
- Photographic Industry
- Semiconductors and Photolithography
- Hydraulic Fluids for the Aviation Industry

⁸⁶ Smithwick M., Mabury S.A., Solomon K.R., Sonne C., Martin J.W., Born E.W., Dietz R., Derocher A.E., Letcher R.J., Evans T.J., Gabrielsen G.W., Nagy J., Stirling I., Taylor M.K., Muir D.C.G. (2005) Environ. Sci. Technol. 39, 5517-5523.

⁸⁷ Ellis D.A., Martin J.W., De Silva A.O., Mabury S.A., Hurley M.D., Sulbaek Andersen M.P., Wallington T.J. (2004) Environ. Sci. Technol. 38, 3316-3321.

⁸⁸ Prevedouros K.; Cousins I.T.; Koreniowski S.H.; Buck R.C. (2005) Environ. Sci. Technol., in press.

⁸⁹ Brooke, D., Footitt, A. and Nwaogu, T.A. (2004) Environmental risk evaluation report: perfluorooctanesulphonate (PFOS) Building Research Establishment Ltd Risk and Policy Analysts Ltd on behalf of the Environment Agency

However, these uses have also been recently phased out in the UK and therefore it is uncertain as to how important they are as on-going sources. For example, in 2008 380 kg of PFOS was sold within UK for use in the electroplating industry and in July 2008 approximately 150 kg was reported to have been used as mist suppressants (Industry Association data). For comparison, the estimate provided in the environmental risk evaluation report for the Environment Agency for the EU in 2003 was between 8.6 - 10 tonnes for metal (Chromium) plating.

PFOS based aqueous fire fighting foams (AFFF) are potentially still in use, although being phased out by 2011. These foams have not been produced since 3M's phase-out. Historically PFOS has been used in the UK within fire fighting foams (as part of the AFFF range), and made up approximately 6.5 percent (3M based AFFF) of the UK provision in 1994⁹⁰. The main manufacturer of PFOS, 3M, quotes the usage of PFOS in fire fighting foams as 3% of its market (circa 151 tonnes globally in 2000⁹¹), and the AFFF foams themselves contained approximately between 1 and 2.5% PFOS wt/wt as a surfactant⁹². The use of AFFF foams in the UK historically had two key applications; principally it was used as precautionary stock at COMAH sites, but secondarily was used by the active fire service, mainly at training sites. The RPA report quotes stocks in 2004 as 23.7 tonnes at COMAH sites and 0.76 tonnes for active service (quantity of PFOS).

The 3M company voluntarily ceased production of PFOS by the end of 2002 (phase out began in 2000) after long term environmental issues were discovered.⁸⁹ The UK fire service began a phase out programme shortly after this time (circa 2002/3)⁹³. However phase out at COMAH sites would be expected to be slower. The AFFF foams had a service life of approximately 12 – 15 years;⁹⁷ therefore it would be reasonable to assume a partial replacement of stock year on year at these sites due to usage, training etc. Any expired stock would likely be disposed of through incineration.

Emissions of PFOS from use as an industrial firefighting foam were estimated from information derived for the chemicals and fuel refinery industries. Usage of firefighting foam at oil refineries was estimated from information obtained from consultation with an industry process operator. Usage of foam in the chemicals industry was estimated from consultation with the fire service operator for the Wilton, Billingham and Seal Sands sites in the north-east of England. It was estimated that the Chemicals industry used foams containing PFOS up to approximately 2000, and then phased out linearly to 2006. The refinery industry appears to have phased out the use of foams containing PFOS at an earlier stage. It was estimated that approximately 40% of firefighting foams used in the refinery industry contained PFOS in 1990, declining linearly to 0% in 2000. These estimates are subject to considerable uncertainty (assumed to be -100% / +150% of quoted value).

In December 2005, the Buncefield oil refinery suffered the worst petroleum fire within the UK for some decades. During the incident large quantities of fire fighting foam were required to put the fires out. Due to the nature of the incident detailed records of where foam was sourced from are less clear. From consultation with the chemicals industry, it was estimated that approximately 25% of the national reserves of firefighting foam containing PFOS available in 2005 were used at Buncefield. After the Buncefield the Environment Agency set up an amnesty to gather in all remaining stocks of PFOS containing AFFF for destruction (incineration). Communication with the Environment Agency⁹⁴ suggests that these quantities are expected to be near negligible, consistent with our estimates of declining use up to 2006.

⁹⁰ WRc plc. On behalf of the NRA (National Rivers Authority), 1994, A Review of Fire Fighting Foams to Identify Priorities for EQS Development.

⁹¹ Dorian Carloni for Unido, 2009, Perfluorooctane Sulfonate (PFOS) production and use: past and current evidence.

⁹² Risk & Policy Analysts Limited (RPA) in association with BRE Environment, 2004, Perfluorooctane Sulphonate – Risk reduction strategy and analysis of advantages and drawbacks, for Defra.

⁹³ Denis Ricketts, Fire Service Inspectorate, 2006, Guidance on the phasing out of PFOS based foams for Class B fires. Fire Service circular

⁹⁴ R. Hawkins, Environment Agency, 2010, Personal Communication.

Table 3.18: Estimated emissions of PFOS from use of industrial firefighting foams

Year	Estimated emission (tonnnes per year) from			
	Oil refineries	Chemicals industry	Buncefield	Total
1990	0.76	1.10		1.86
1991	0.67	1.10		1.77
1992	0.61	1.10		1.71
1993	0.58	1.10		1.68
1994	0.63	1.10		1.73
1995	0.53	1.10		1.63
1996	0.43	1.10		1.53
1997	0.32	1.10		1.42
1998	0.22	1.10		1.32
1999	0.11	1.10		1.21
2000	0.00	1.10		1.10
2001	0.00	0.92		0.92
2002	0.00	0.73		0.73
2003	0.00	0.55		0.55
2004	0.00	0.37		0.37
2005	0.00	0.18	0.54	0.73
2006	0.00	0.00		0.00
2007	0.00	0.00		0.00
2008	0.00	0.00		0.00

The assessment set out above indicates that approximately 50 tonnes of foam containing PFOS was used to deal with the Buncefield incident, resulting in the discharge of approximately 0.54 tonnes of PFOS. This foam was collected as a contaminant of a large volume of water. It was stored at two nearby sewage works before being treated and disposed of.

Prior to Buncefield the use and replacement of fire fighting foams is estimated to account for approximately 1 – 2 tonnes of PFOS per annum, declining to 0.37 tonnes per year in 2004. A proportion of theses quantities could be due to partial replacement of stock at COMAH sites, which would likely be incinerated. Foam discharged in active use would likely be sent to waste water treatment works, with a minor quantity lost to open surface waters.

3.5.2 Emission inventory compilation

As a result of the difficulty of estimating emissions directly from on-going sources an indirect approach has been taken. Estimates of UK emissions of PFOS and its salts to air, land and water between 1990-2008 have been derived by using a modified global PFOS-F production and use inventory by Paul *et al.* (2008), the EA Pollution Inventory data and a small scale UK based sampling campaign and corresponding emission modelling exercise carried out on the Rivers Aire and Calder in North Yorkshire.

A recent EU-wide survey of polar organic pollutants (Loos *et al.* 2009)⁹⁵ highlighted the aquatic environment as being the primary recipient of PFOS emissions and hence of greatest concern. This study supports the hypothesis that rivers and oceans are the primary transport

⁹⁵ Loos, R., et al., EU-wide survey of polar organic persistent pollutants in European river waters. *Environmental Pollution*, 2009. 157(2): p. 561-568.

mechanism for PFOS dispersion in the environment. As mentioned previously, PFOS is essentially non-volatile, non-degradable and water soluble (although some precursors are volatile) and therefore exhibits long residence times in surface waters. Loos *et al.* (2009) suggested that the primary source of PFOS to rivers occurs via discharge from sewage treatment works (STWs). The fate of PFOS in the STW process has been studied, for example, a mass balance exercise carried out by Becker *et al.* (2008)⁹⁶ reported a 3 fold increase in PFOS levels in STWs during treatment due to precursor degradation, resulting in higher levels of PFOS in the effluent than the influent. However, up to 45% of the PFOS was found to be retained by the dewatered, deactivated sewage sludge, highlighting that emissions to land or landfill arising from sludge disposal may also comprise a significant environmental release pathway. A recent study by Busch *et al.* (2010)⁹⁷ suggested that landfills may also be a small, but significant source of PFCs to the aquatic environment. However, there remains uncertainties in the PFOS removal efficiencies by STWs and subsequent binding to sediments in rivers after effluent discharge (Becker *et al.* 2008⁹⁸, Yu *et al.* 2009⁹⁹)

As mentioned, major uses of PFOS-related substances have included; treatment of carpets to impart stain and dirt repellence, in apparel to provide water repellence, in paper and packaging to afford oil and grease repellence, in performance chemicals such as hydraulic fluids for aviation, and in aqueous fire fighting foams (AFFFs). Data from 3M, the major manufacturer of PFOS related substances, stated that 85% of environmental emissions occur as a result of consumer use which would occur over a lifetime of the particular product/usage (i.e., it would differ between carpets and paper and packaging). Paul *et al.* (2008)⁵ calculated that historical direct global emissions of PFOS ranged between 450 and 2700 tonnes into wastewater streams, primarily through losses from stain repellent treated carpets, waterproof apparel, and use of AFFFs.

A European-wide study into PFOS emissions by Pistocchi and Loos (2009)¹⁰⁰ demonstrated a statistical link between PFOS releases to European rivers and nearby population density ($R^2=0.66$). They estimated that contemporary European PFOS emissions are in the order of 3.2 tonnes per annum. The Environment Agency Pollution Inventory, covering England and Wales suggests that ~2000kg of PFOS per year has been emitted from regulated sources between 2006-2008 to controlled waters. These estimates equate to an average of 100µg per capita per day which is significantly higher than the European average Pistocchi and Loos (2009)¹¹ estimate of 27 µg per capita per day, and further estimates of 40µg per capita per day in Bayreuth, Germany (Becker *et al.* 2008)⁷, 57µg per capita per day in Switzerland (Huset *et al.* 2008)¹⁰¹ and 42 µg per capita per day calculated for 10 wastewater treatment plants in the U.S. (Schultz *et al.* 2005)¹⁰². The contractor responsible for the estimator tool used to calculate the Environment Agency PI data has suggested that the EA PI is likely to be an overestimation (by up to 100 fold) and consequently a large reduction is predicted for the 2009 figures.

A recent survey of PFOS levels in the Aire and Calder rivers in West Yorkshire, carried out by Paul *et al.* (2010)¹⁰³, has been used to provide emission estimates based on data for

⁹⁶ Becker, A.M., S. Gerstmann, and H. Frank, Perfluorooctane surfactants in waste waters, the major source of river pollution. *Chemosphere*, 2008. 72(1): p. 115-121.

⁹⁷ Busch, J., Ahrens, L., Sturm, R. and Ebinghaus, R. (2010) Polyfluoroalkyl compounds in landfill leachates. *Environmental Pollution*. 158(5): p. 1467-1471.

⁹⁸ Becker, A.M., S. Gerstmann, and H. Frank, Perfluorooctanoic acid and perfluorooctane sulfonate in the sediment of the Roter Main river, Bayreuth, Germany. *Environ.Poll.*, 2008. 156(3): p. 818-820.

⁹⁹ Yu, Q., *et al.*, Sorption of perfluorooctane sulfonate and perfluorooctanoate on activated carbons and resin: Kinetic and isotherm study. *Water Research*, 2009. 43(4): p. 1150-1158.

¹⁰⁰ Pistocchi, A. and Loos, R. (2009) A Map of European Emissions and Concentrations of PFOS and PFOA. *Environmental Science & Technology*, 43, 9237–9244

¹⁰¹ Huset, C.A., *et al.*, Occurrence and Mass Flows of Fluorochemicals in the Glatt Valley Watershed, Switzerland. *Environmental Science & Technology*, 2008. 42(17): p. 6369-6377.

¹⁰² Schultz, M.M., D.F. Barofsky, and J.A. Field, Quantitative Determination of Fluorinated Alkyl Substances by Large-Volume-Injection Liquid Chromatography Tandem Mass Spectrometry Characterization of Municipal Wastewaters. *Environmental Science & Technology*, 2005. 40(1): p. 289-295.

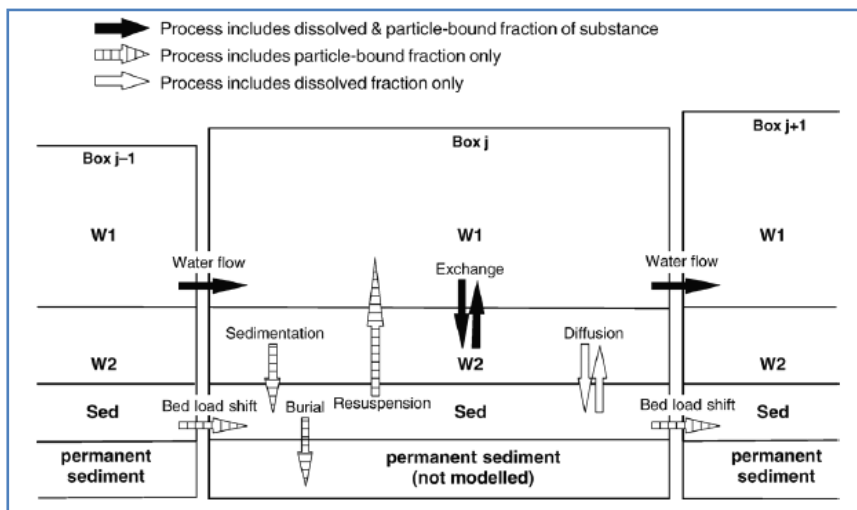
¹⁰³ Paul, A., Earnshaw, M., Jones, K.C. and Sweetman, A.J. (2010) Modeling the environmental fate of PFOS in a UK river catchment. Submitted to *Environmental Science and Technology*.

individual STWs using a knowledge of population served and mass flow downstream of the works, in the respective rivers. The estimate for the river Calder provided a mean value of 38µg per capita per day, and for the Aire 16µg per capita per day. Assuming these data to be representative and a UK population of 62 million with a 95% STW connection rate, this equates to an emission of between 345 and 820 kg per year (2010 data). An assessment of historical PFOS sources, based on data provided by Paul *et al.* (2009), suggests that peak emissions occurred during the late 1990s (170µg per capita per day, equivalent to 3700 kg per annum) but have been steadily declining over the last 10 years.

3.5.3 Rivers Aire and Calder Modelling Study

In order to test the hypothesis proposed by Pistocchi and Loos (2009)¹⁰⁴, that population density is directly linked to PFOS levels seen in the aquatic environment, and that PFOS behaves essentially like a conservative tracer, a multi-segment river model previously used by Blaser *et al.* (2008)¹⁰⁵ to model nano-silver in the river Rhine was re-parameterised to represent the Aire and Calder rivers. Full advective and reactive processes are included within the model, as shown in Figure 3.6.

Figure 3.6: Processes simulated in the Aire and Calder river models.



W1 is the moving water, W2 the stagnant water and Sed represents the top layer of the sediment.

Emission data for each segment of the model was calculated using the EU average emission rate of 27µg per capita per day, as provided by Pistocchi and Loos (2009), and the population density per river segment (derived from EUROSTAT population maps using GIS software). A comparison of the model predictions and measurement data are shown in Figures 3.7 and 3.8, for the Aire and Calder, respectively. The results suggest that the river model, population density and an EU average emission rate can be used to predict environmental trends and concentrations, generally within a factor of 3 to 4, although the predicted environmental concentrations (PECs) for the Calder were a closer fit to the measurement data than for those for the Aire. The authors postulate that this may reflect different removal efficiencies of STWs on the two rivers, or the influence of the spatially averaged population data in comparison to the known population served STW data. On-going industrial sources of PFOS are also possible although not thought likely.

¹⁰⁴ Pistocchi, A. and Loos, R. (2009) A Map of European Emissions and Concentrations of PFOS and PFOA. *Environmental Science & Technology*, 43, 9237–9244

¹⁰⁵ Blaser, S., Scheringer, M., MacLeod, M. and Hungerbühler, K. (2008) Estimation of cumulative aquatic exposure and risk due to silver: Contribution of nano-functionalized plastics and textiles. *Sci of the Total Env.*, 390, 396–409

Figure 3.6: Predicted PFOS environmental concentrations vs. measured river water concentrations in the River Aire

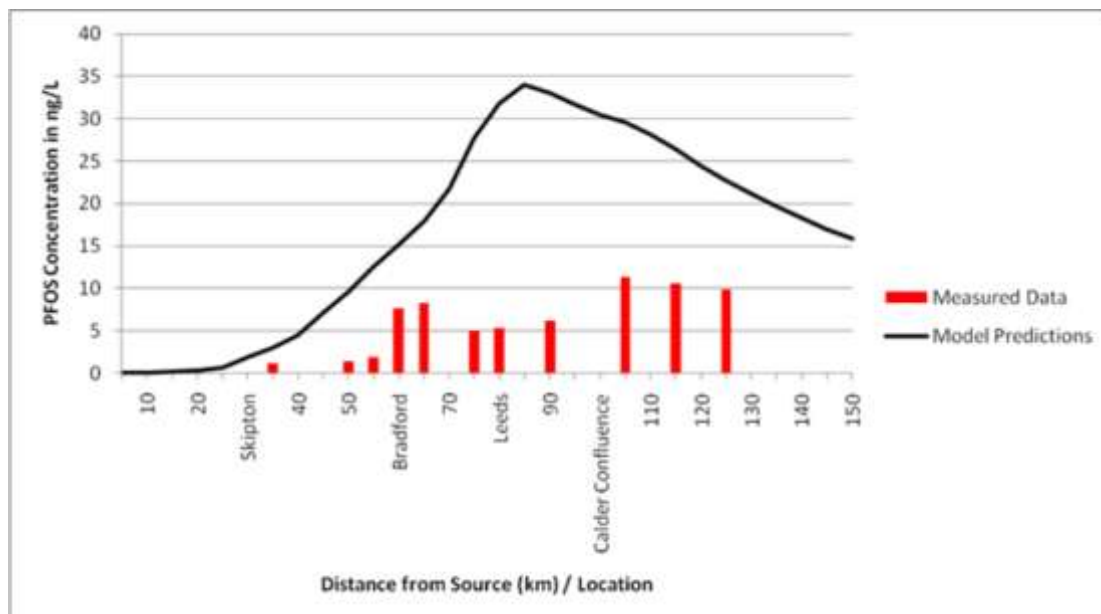
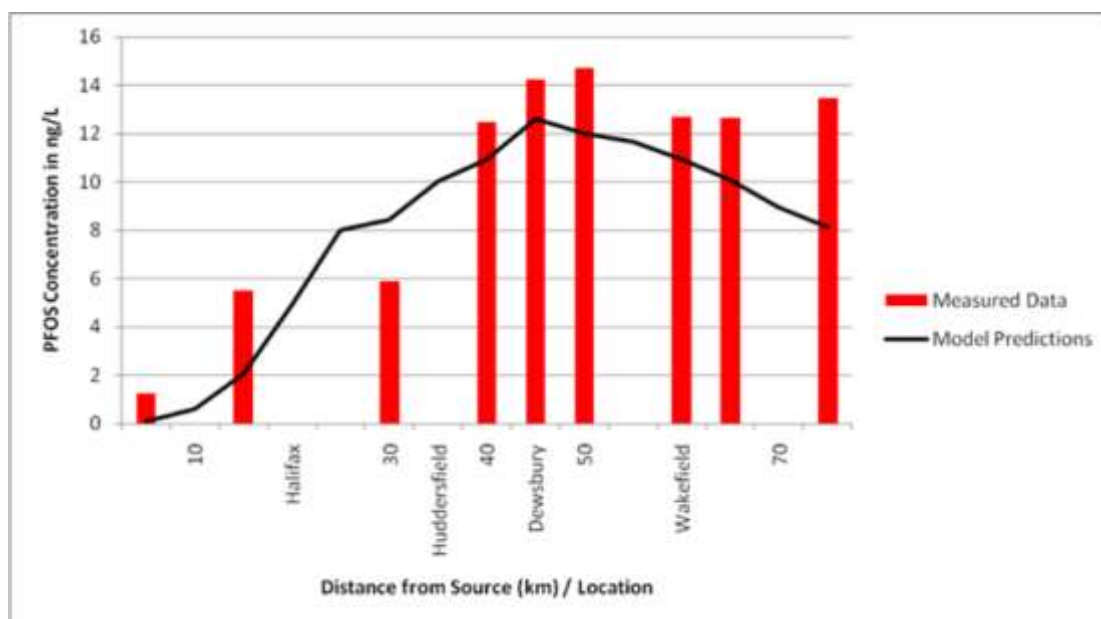


Figure 3.8: Predicted PFOS environmental concentrations vs. measured river water concentrations in the River Calder



3.5.4 PFOS emissions to land via the use of sewage sludge as fertilizer

The partitioning of PFOS to sewage sludge and its subsequent use as an agricultural fertilizer represents a potential emission pathway to land. A detailed mass balance study carried out by Schultz *et al.* (2006)¹⁰⁶ showed that for an STW that treated 26.7 million litres of effluent per day from a population of 50000, an equivalent of 1 kg PFOS was measured in the digested sludge for every 57 kg emitted in the treated effluent. Assuming these data are typical of a wide range of treatment plants, the mass balance data has been applied to the STWs sited along the Aire and Calder sampled during the river water study. These calculations show that for the STWs along the river Aire the average per capita emission to sludge per year was 86 µg and for the STWs connected to the river Calder 157 µg.

¹⁰⁶ Schultz *et al.*, 2006, Fluorochemical Mass Flows in a Municipal Wastewater Treatment Facility. Environ. Sci. Technol., 40, 7350-7357.

Assuming these data to be representative, and a UK population of 62 million with a 95% STW connection rate, this equates to an emission of approximately 5 to 9 kg per year to sludge. As approximately 60% of sewage sludge produced in the UK is used as an agricultural fertiliser, between 3 to 5kg would be emitted to soil per year. These calculations are tentative and may represent an underestimate of this emission route.

3.5.5 PFOS and related fluorinated substances in ambient air

Lancaster University in collaboration the Norwegian Institute for Air Research (NILU) in Tromsø, Norway, have carried out a limited air sampling campaign in North West England for both volatile 'precursor' PFAs by GC-MS (Gas-Chromatography Mass Spectrometry), and the less volatile PFCAs and sulphonates by LC-TOF (Liquid-Chromatography Time of Flight Mass Spectrometry). Analysis of air samples taken at Hazelrigg (Lancaster University field station) and Manchester between February and March 2005 represented the first information on levels of these PFAs in the UK (and in Europe). A number of perfluorinated chemicals were detected in the UK atmosphere. The highest concentrated volatile compound was the fluorotelomer alcohol 8:2 FTOH with up to 330 pgm^{-3} air in a Manchester sample and 200 pgm^{-3} at Hazelrigg. Fluorotelomer alcohols are volatile precursors to the perfluorinated carboxylic acids. Among the ionic compounds present in the particle phase, PFOA was highest concentrated with levels up to 830 pgm^{-3} with PFOS present at 50 pgm^{-3} . However, it remains uncertain as to how important atmospheric sources and subsequent transport is for these substances, particularly for Long-Range Atmospheric Transport (LRAT). It is also unclear as to the identity of such atmospheric sources.

3.5.6 Potential unaccounted sources of PFOS to the environment

The global source inventory provided by Paul *et al.* (2008) provided estimates of direct emission of PFOS to the environment. These estimates suggested that direct historical emissions from POSF-derived products are/were the major source to the environment resulting in releases of 450 – 2,700 t PFOS (total 1970 to 2002) into wastewater streams, primarily through losses from stain repellent treated carpets, waterproof apparel and aqueous fire fighting foams (AFFFs). However, the authors point out that large uncertainties surround indirect sources which have not yet been estimated due to limited information on environmental degradation, although it can be assumed that some POSF-derived chemicals will degrade to PFOS over time. The properties of PFOS (high water solubility, negligible vapour pressure and limited sorption to particles) imply it will reside in surface waters, predominantly in oceans. Measured oceanic data suggests ca 235 – 1,770 t of PFOS currently reside in ocean surface waters, which is similar to the estimated PFOS releases. Since POSF production was stopped by 3M in 2002, a reduction in some compartments has been observed, although current and future exposure is dependent on emission routes, subsequent transport and degradation. However, the formation of PFOS from the degradation of POSF-derived substances could potentially lead to future increases in environmental concentrations. This is a key data gap.

3.5.7 Recommendations

Recommendation for further sampling and analysis for PFOS from wastewater treatment facilities are set out in Chapter 4.

It is also recommended that further analysis is carried out to evaluate environmental degradation pathways involving PFOS.

3.5.8 Summary of estimated PFOS emissions

Table 3.19. Estimated PFOS emissions to surface waters

Estimate	Value (tonnes)
Global emission 1970 to 2002 (Paul et al (2008)) ⁸⁴	450 t to 2700 t
European emission (Pistocchi and Loos (2009)) ¹⁰⁴	3.2 t
UK emission: Environment Agency Pollution Inventory (2008)	2000 kg
UK emission: This study	345 to 820 kg
UK emission: contribution from industrial firefighting foams	
1990	1,900 kg
2000	1,100 kg
2008	0 kg

4 POPs data sources and inventory improvement

This chapter summarises the current system in the UK of source data availability and inventory compilation, and outlines recommendations to improve the POPs inventory systems in the UK, comprising systematic / management options as well as targeted technical studies to further reduce the level of uncertainty in the UK POPs inventories.

4.1 UK POPs inventory data management systems

4.1.1 POPs data reporting systems in the UK

There are a range of different data management and reporting mechanisms that exist in the UK which currently include some element of POPs data reporting. These resources are useful in varying degrees in the compilation of emission estimates to air, land and water, to help meet Defra's commitments under the Stockholm Convention to data reporting and POPs-specific action plan development.

The different data reporting systems have evolved to meet a range of specific environmental reporting obligations, some by site operators, others by regulatory agencies and Government Departments, many for the purpose of reporting to meet international obligations of UK Government and to assist policy development. The scope and reporting detail / format for these systems varies according to the specific role that it has been designed to meet. For example, the scope and reporting thresholds for pollutants varies between systems; there is some duplication in reporting, but data are not always directly comparable between systems due to different scopes and thresholds which can inhibit data transparency and usefulness in inventory compilation.

Several of the existing UK systems are designed for installation-specific or activity-specific reporting (often to regulate against Emission Limit Values for licensed processes), whereas others provide an overall analysis of point and area source emissions and/or pollutant concentrations within environmental media that are not aligned with specific emission inputs but are designed to assess the overall environmental load of specific pollutants. Data on environmental pollutant concentrations in different media are not typically of great use within inventory compilation, other than as a verification step (e.g. sense-checking reported emission inventory trends through comparison against historic ambient pollutant concentration data) and/or within the calibration of emission estimations models (such as that employed to estimate PFOS emissions from waste water treatment works, for example).

In all cases there are data quality issues to consider, and a key part of the inventory compiler's job is to exercise expert judgment as regards source data quality (e.g. are the data based on field measurements and if so, what is the uncertainty in the monitoring method?) and in instances where reported data may be missing or are evidently inconsistent across a time series, e.g. from non-reporting or apparent mis-reporting by stakeholders.

The main systems of use in the development of POPs release inventories are summarised here.

The **National Atmospheric Emissions Inventory (NAEI)** provides data on the UK emissions to air from all anthropogenic sources for a wide range of pollutants including "classic" POPs (dioxins and furans, PCBs, PAHs and HCB) as part of the UK Government's commitments to reporting to the UNECE under CLRTAP. The emission estimates are compiled and reported annually in February each year to the UNECE, providing annual emission estimates for all pollutants across a timeseries from 1990 onwards. The data submitted in February 2011 will

include emission estimates up to and including 2009. . Data are presented using the NFR (Nomenclature For Reporting) classification for emission sources, which includes some industry-specific data (e.g. separate estimates for the power generation sector, refinery sector, iron and steel sector) as well as broader categories such as overall emissions from different modes of transport (rail, road, aviation and shipping), and from “area” sources such as emissions from domestic or agricultural sources.

The scope of the NAEI is intended to be a complete estimate for all anthropogenic emissions; the NAEI has an annual programme of quality assurance and improvement, and is subject to annual reviews by UNECE expert reviewers to ensure that the UK dataset meets the reporting requirements, is complete and therefore delivered in a manner that is transparent, complete, accurate and consistent with all other national inventory data. The NAEI national inventory totals for a given pollutant therefore include an assessment of emissions from point sources (e.g. industrial sites), area sources (e.g. domestic boilers), and line sources (e.g. motorways).

In order to compile these estimates, the NAEI team draws upon datasets from many hundreds of UK organisations, integrating activity data and available emissions and emission factor data. Key data sources include: DUKES (national energy statistics, published by DECC), transport statistics (DfT, DVLA, CAA, ATOC), ONS data on economic activity and population / housing, pollution inventories from environmental regulators, numerous trade associations and individual companies.

The NAEI data contains some useful activity data and information on POPs that are in some cases linked to the sources of newly designated POPs. For example, the unintentional sources of PeCB to some extent coincide with sources of dioxins and furans, although there is a much smaller international body of data on PeCB monitoring and emission factors compared to that evident for dioxins and furans. Therefore, whilst the NAEI may provide some underlying activity data to assist in the compilation of air emission inventories for the newly designated POPs, there is additional research needed to develop emission factor data, cover other sources of new POPs to air; the NAEI includes no data on emissions to water or land.

Pollution Inventories for reporting by IPPC/EPR regulated installations are compiled and reported to Defra by the UK’s environmental regulatory authorities. These inventories comprise the Environment Agency’s Pollution Inventory for England and Wales, the Scottish Pollutant Release Inventory (SPRI) managed by the Scottish Environment Protection Agency and the Northern Ireland Inventory of Sources and Releases (ISR) managed by the Northern Ireland Environment Agency. These pollution inventories are compiled from annual emission returns from all industrial and commercial installations within the UK that are regulated under permits to operate within the Integrated Pollution Prevention and Control (IPPC) and Environmental Permitting Regulations (EPR, gradually superseding IPPC) systems. The inventories are used to publicise the emissions from industrial processes, and to enable environmental regulatory agencies to monitor and track emission performance by industrial sites across a time series.

The inventory data include estimates of emissions of a wide range of pollutants, where sites emit above an agreed threshold of mass emissions per year, and according to the suite of pollutants that are defined within the site’s permit to operate. Estimates are provided as a total release from the regulated site, i.e. not broken down by sub-process / source; where the site estimates that its annual mass emissions of a substance are above the reporting threshold, then it must submit one number to cover the estimates of ALL emissions of that substance from on-site processes (i.e. including emissions from stacks, stockpiles, fugitive releases, emissions from normal and abnormal operating phases including accidental releases).

The inventories have been developed since the mid-1990s (for England and Wales, later in Scotland and Northern Ireland) and the available data across the timeseries varies in scope and quality, reflecting the evolution of environmental regulations, focus on specific pollutants (and hence periodic changes to reporting thresholds) and capability of plant operators to estimate the annual mass emissions either through emission monitoring or other calculation

methods (e.g. mass balance). The inventories initially focused on air emissions, but have been developed to incorporate reporting of emissions to water and land over time. The regulators also provide technical guidance notes and a series of monitoring and reporting protocols have been developed to ensure that plant operators deliver data on a consistent basis. The inventories are also governed by a quality assurance system whereby data are not made publicly available until the data have been checked and authorized by the Site Inspector for the installation.

The pollution inventory data are therefore useful for POPs inventory compilation for industrial and commercial installations that fall under the IPPC/EPR regulations by virtue of the scale and type of activity that they perform. In the case of England and Wales this covers the larger IPPC Part A1 operators (IPPC A2 operators are covered by the local authorities in England and Wales). The SPRI includes data from IPPC part A1 and A2 operators, whereas the Northern Ireland ISR includes data from IPPC Part A, B and C plant. The inventories do not therefore provide comprehensive data for the many smaller industrial and commercial sites that fall below the IPPC/EPR regulation thresholds, or for other area sources such as transport, small-scale combustion, waste burning etc which are thought to be very high contributors to the overall national emissions of u-POPs.

The current scope of POPs data reporting under IPPC/EPR includes dioxins and furans, PCBs, PAHs, and for the newly designated POPs there are data on PFOS emissions from waste water treatment works from 2007 onwards. In some cases, the usefulness of the data for POPs estimates within source inventories is limited due to the lack of transparency of the source of the emissions, for example where several processes within one installation may lead to emissions of POPs, but no breakdown of emissions is provided. This limits the use of the data in understanding the relative significance of different sub-processes, and the ability to derive source-specific emission factors that may be applied to other similar (perhaps non-IPPC-regulated) activities.

The UK PRTR (Pollutant Release and Transfer Register), is a publicly available register of emissions sources within the UK, which began in 2007 and is updated annually. These data are used to fulfill the UK's obligations to the EU to report to the E-PRTR (European Pollutant Release and Transfer Register). The inventory provides details of reported emissions to air, land, water and waste transfer for a variety of activities, based on the PRTR classification scheme for sources, and using the NACE ('Nomenclature générale des activités Économiques dans les Communautés Européennes') codes for facilities. The inventory data in this case is provided by industry operators for the larger scale (IPPC Part A1) operations, and through local authorities (in England) for IPPC Part A2 operators. This data is again based on a range of monitored, calculated and estimated emissions for a wide range of sectors, and in many cases there is a high degree of cross-over between the PRTR data and the IPPC/EPR pollution inventory data outlined above; the PRTR system has different reporting thresholds for some pollutants (compared to the IPPC/EPR system) and also is applied to a far wider range of sites in the UK.

The PRTR reporting system is a relatively new innovation, and the data management processes are to some degree still evolving to address teething problems (notably regarding the data reported by smaller-scale sites that are less experienced in this type of emission estimation and reporting). The usefulness of the PRTR data within the POPs inventories is therefore expected to develop in the coming years, and there is a strong likelihood that more PRTR guidance notes and materials will be published as the scope of the PRTR develops, e.g. to ensure consistency of approach by nations to deriving estimates for area sources. For those sites that operate under IPPC/EPR, the PRTR provides little new information of use to POPs inventory compilers, whereas the data from local authority-regulated sites may in time provide new data. The review of current PRTR data in this study, however, has indicated that there are data quality and reporting consistency issues that limit the usefulness of this dataset currently.

The Environment Agency Hazardous waste database is an annual publication based on the regulatory system of hazardous waste consignment notes used to move hazardous waste from point of production to final destination. This system details the quantities of hazardous waste produced by individual processes based on European Waste Catalogue (EWC) codes. The database does not provide specific details regarding individual pollutant release rates or concentrations, and it would not be practicable to extend this system to include records of contaminants such as the established or new POPs. The database also does not include extensive historical records to enable past waste-related activities to be evaluated.

However, the database provides useful reference data on the quantities of hazardous waste produced by industrial sectors, and the routes for recovery or disposal. This data is important in providing a description of current activity in the waste management sector.

Table 4.1 provides an overview of the scope of POPs information that are available from the above data reporting mechanisms, including data for the newly designated POPs under the Stockholm Convention

Table 4.1 – Summary of UK POPs emission inventory infrastructure

Substance	NAEI	IPPC/EPR Pollution Inventories	UK PRTR
Chlordecone			
Dioxins and furans			
Hexabromobiphenyl (HBB)			
Hexachlorobenzene (HCB)			
α- and β- Hexachlorocyclohexane (HCH)			
Lindane			
Polycyclic Aromatic Hydrocarbons (PAHs)			
Polybrominated diphenylethers (PBDEs)			
Polychlorinated biphenyls (PCBs)			
Pentachlorobenzene (PeCB)			
Perfluoro octane sulphonates (PFOS)			
MEDIA			
Air			
Land			
Water			
Waste transfer			
SOURCE TYPES			
Point source			
Diffuse Source			
Inventory start date	1990	1995	2007

Cells coloured green indicate where specific pollutants are included in the given inventory headings.

4.1.2 POPs monitoring systems in the UK

The **PAH (Poly Aromatic Hydrocarbon) and TOMPs (Toxic Organic Micro-Pollutant) network**, is a network of monitoring stations used to provide Defra with information on concentrations of a number of POPs in ambient air. Dioxins/furans and PCBs are measured at six sites, and PAHs are measured at 37 sites, including the six TOMPs sites. This work is carried for Defra's Air and Environment Quality division. The network produces data on three-monthly mean ambient air concentrations of dioxins and furans, PCBs and PAHs. This information is reported on a quarterly or annual basis. The data relates to environmental concentrations and can help provide a useful check on the trends in emissions calculated within air emission inventories and provide further insight to environmental fate and spatial distribution of POPs emissions to air.

The **Water Framework Directive (2000/60/EC)** requires member states to develop 'River Basin Management Plans' within nine years of the directive entering into force. This plan includes critical assessment of surface and groundwater for human impact and release of specific pollutants, including monitoring programmes. Further to this the Environmental Quality Standards directive (2008/105/EC) requires the establishment of emission inventories for both point and diffuse sources to water for those substances previously listed in 2000/60/EC, together with a set of priority pollutants (Annex I and X of the directive). This includes PBDEs, HCH and pentachlorobenzene. The emission inventories are to be incorporated into the River Basin Management plans, which are to be updated and reported to the EC Commission every six years. It is recommended that Defra should consider whether the Water Framework Directive could form a useful basis for establishing Europe-wide procedures and obligations for monitoring point and diffuse emissions to water.

Under the **OSPAR convention**, the UK contributes to a programme of monitoring of inputs to the north-east Atlantic. This programme includes measurement of deposition and riverine/estuarine inputs to the Atlantic, as well as monitoring of the state of the marine environment. Measurements are carried out of a number of metals, together with lindane, nitrogen and phosphorus species and suspended particulate matter. The Convention recommends voluntary monitoring of PAHs, mineral oil, PCBs and other organohalogenes.

It is recommended that the monitoring procedures under the OSPAR convention could provide a useful basis for international co-operation to measure the nine newly designated POPs in rivers discharging to the marine environment.

4.1.3 Inventory cycle for NAEI and PRTR.

This section sets out the nature of the inventory cycle for these inventories. This can be adapted to allow for the annual update of the bulk of the emissions within the new POPs inventories. There are however gaps within the established inventories, which are also discussed here with recommendations for measures to close data gaps.

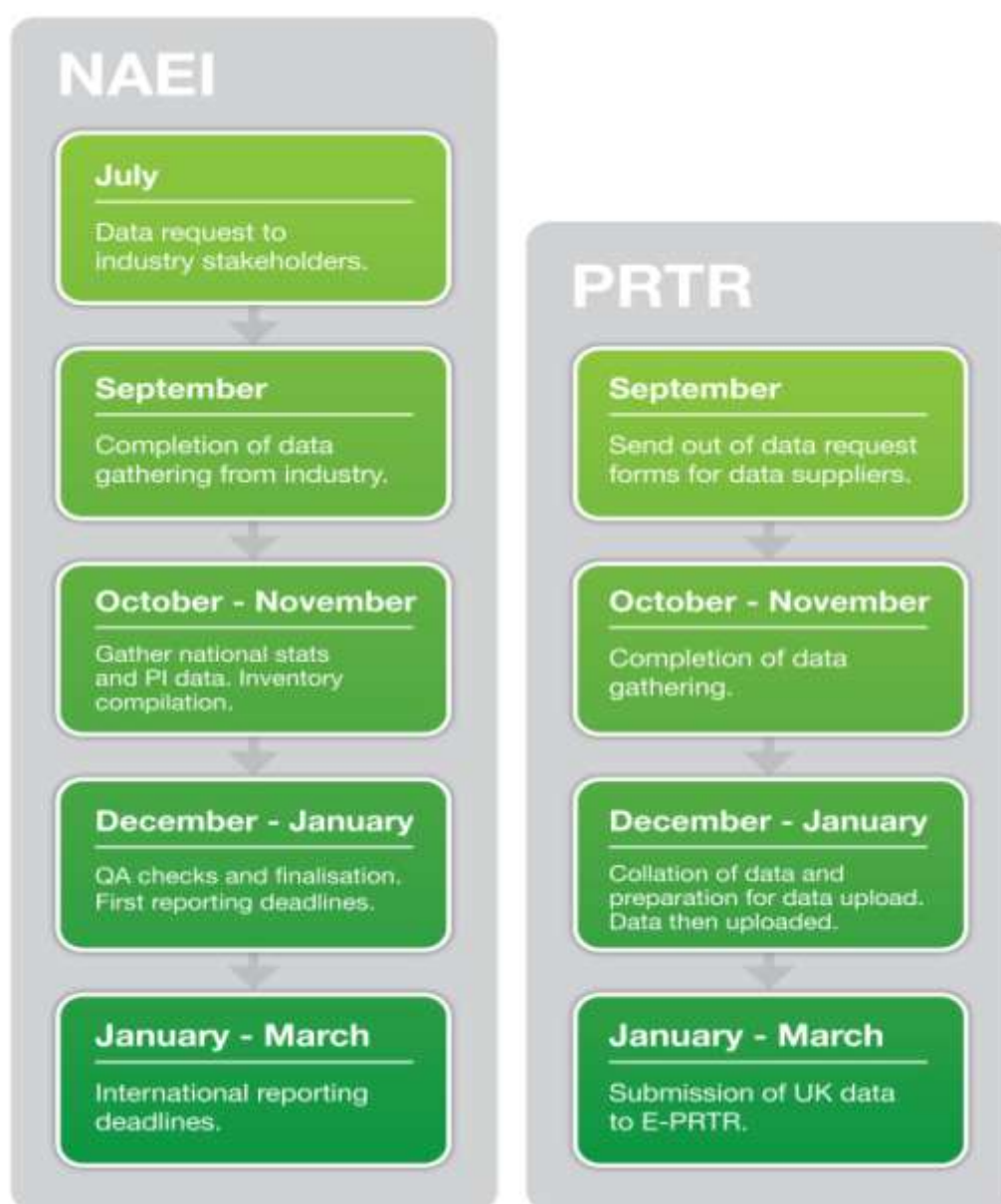
The Inventory cycles for the NAEI and UK PRTR take place at similar times of the year, and involve similar steps. Figure 7 indicates how the two cycles compare.

The NAEI data requests are sent out to all key data providers (Government departments, trade associations, regulatory agencies, statistical agencies and so on) during July, with the main inventory compilation period then running on until November, when pre-submission reviews with Government stakeholders begin. Note that the one of the main data inputs to the NAEI estimates from industrial sources are the regulatory agency IPPC/EPR inventories, which are provided to the NAEI team in the autumn.

NAEI final quality checking, formatting and data reporting is conducted during December to January, with the Informative Inventory Report (for air quality pollutants) and National Inventory Report (for GHGs) submitted to the UNECE and UNFCCC during February and March.

The PRTR works to a slightly tighter schedule. The submission forms for data gathering are sent out to operators and local authorities in September with completed forms due to be returned by the end of November allowing 8 weeks for the forms to be completed and submitted. This data is then collated to extract the information from the forms and place it into a format ready for data upload. This allows for the data to be uploaded and tested before being made available around January. Full submission of the UK data to Europe for inclusion in the E-PRTR takes place during the first quarter of the year, with a final deadline of 31 March.

Figure 7 NAEI and PRTR Annual Compilation and Reporting Cycles



The annual cycles of data compilation and reporting are determined largely by the timescales of source data availability and the international reporting deadlines for the outputs from the NAEI and the PRTR.

The use of NAEI data (such as common activity data for emissions of dioxins / furans and PeCB from combustion sources) and IPPC/EPR inventory data provide a useful framework for emission estimates for the new POPs. There are several sources where common activity data are used to underpin the estimates to air, land and water for the new POPs. Consequently, the development of emission factors to land and water, linked to the activity data used for air emission estimates, remains a priority for the new POPs, and research to improve these factors should not be constrained by the annual programme but should be considered a year-round activity. However, it may be beneficial to seek to influence the timetables of working groups in the UK, EU and globally to release any new sources of information in good time for consideration within inventory compilation during the autumn.

Compilation and improvement of an emissions inventory for the newly designated POPs does not need to be constrained by the existing inventory timetables. Instead, compilation of the emissions inventory for all media should ideally be carried out on an ongoing basis, as soon as relevant data become available. In practice, this may mean compilation of inventories to all media during the autumn period, as activity data to support the NAEI become available.

4.1.4 Recommendations for Technical Programmes to Develop UK POPs Data Sources

This current study has had to employ scoping-study and top-down assumptions and extrapolations in order to generate preliminary inventory estimates for all the newly designated POPs except PeCB. A larger (ideally UK-specific) “bottom-up” dataset would be helpful to test, refine and calibrate these initial estimates, as uncertainties are high for the majority of the new POPs estimates.

A range of technical studies could be considered by Defra as part of an ongoing programme of research to improve the accuracy of the current POPs inventory data. The study team has summarized below those items that are regarded as the highest priority for early consideration by Defra, to address potentially significant emission sources where UK data are scarce.

Of the new POPs, only PeCB is added to Annex C and therefore global efforts to improve inventory estimates are likely to focus on that substance as the highest priority. It is unlikely that the development of source-based inventories for the other newly designated POPs will be achievable in the near future, but it remains a priority for research to seek out new information to identify the key emission sources and onward cycling of the new POPs within the environment, to support the development of policy to fulfil obligations under the Stockholm Convention with regard to the other newly designated POPs.

The potentially high contribution to overall levels of POPs in the environment from legacy contamination cannot be retrospectively accounted through new studies on mass emissions, except where lifecycle analysis models and proxy data on national stock of materials and their fate can be constructed. Therefore, the development of information on POPs within land, landfills and exchanges into groundwater and surface water are likely to rely to a large extent on ambient monitoring observations, together with more scientific analysis to assess the most likely sources and pathways that could explain the observed pollutant concentrations.

Looking ahead to the development of policy, the use of product lifecycle analysis to assess the options for ultimate fate of POPs-containing materials is regarded as a key tool for Government decision-makers to employ, but there is a need to conduct more initial research to generate a better dataset of the current UK “baseline” of POPs sources and reservoirs, in order to help prioritise Government action.

4.1.4.1 Waste Management Data

The UK PRTR uses annual data on quantities of waste as waste transfers, disaggregated to hazardous and non-hazardous waste against a set of source sectors. This is further

supplemented by the Environment Agency's hazardous waste database, which also provides data disaggregated by EWC codes for different source sectors.

However, although good quality current waste activity data are available, a common theme across POPs inventories is that the estimates of emissions to land and landfill are highly uncertain due to a lack of monitoring and mass emission data. There is no practicable way of retrospectively analyzing the composition of historically landfilled materials, although the recent timeseries of hazardous waste disposal records may provide a framework for deriving estimates from specific waste streams for the recent past. As regards future policy priorities, though, this is likely to be low on the agenda, but a higher priority is to assess the risk of POPs emissions from any leaching into groundwater (especially for older landfills that were not as closely regulated, as rigorously engineered and therefore as closely contained from groundwater).

4.1.4.2 Residual Waste / Ash / Effluent POPs Composition Data

Whilst the data sources above will provide data on quantities of waste from given sectors, they do not provide information on which pollutants are present in the waste, or generated during its disposal. There is no information on the POPs concentrations or release rates from industrial processes and waste effluent streams. The waste sector activity data can provide a useful input to the inventory process, but care is required in how the data is used. This is a particular issue if high concentration POPs waste is mixed with other hazardous wastes for disposal. For example within metal industries it might be the case that air pollution control residues (likely to contain dioxins and furans) are disposed along with larger quantities of slag and skimmings. These materials are likely to be contaminated with metals and are therefore hazardous, but are less likely to contain dioxins and furans.

It is recommended that a targeted sampling and analysis programme for specific waste streams is developed. This would be designed to provide compositional analysis on materials such as: APC residues, boiler ash and bottom ash residues, domestic combustion grate ash, open burning ash residues, industrial slags and skimmings, and industry-specific effluent streams such as from textile finishing processes, plastics manufacturing processes and flame retardant application processes.

4.1.4.3 Data Reporting Systems at Local Authority Level

The UK PRTR has provided an extremely useful tool in providing data from both large and medium size operators across the country, combining emissions data from sites regulated by the environmental regulatory agencies (EA, SEPA, NIEA) with data from smaller sites regulated by local authorities. However, the data from LA-regulated sites is only available for a limited time series, and the historic data is typically held in hard copy format within LA offices. Furthermore the data quality of the LA sub-section of the PRTR is uncertain. While the small size operators are likely to generate smaller quantities of waste and emissions, there may be a greater number of them. Additionally, small-scale combustion and waste disposal processes are likely to make a disproportionately high contribution to the overall emissions of u-POPs, due to the less controlled nature of the combustion processes in smaller units.

For England and Wales the hazardous waste generated from these operations should appear in the hazardous waste database, however, this is presented at a higher level of aggregation, making it difficult to gauge the number of smaller operators and quantities of waste generated by operations regulated by local authorities.

It is therefore recommended that Defra give consideration to the development of an extended scheme for reporting activity and emissions from Part B processes (and Part C processes in Northern Ireland). This would be useful in improving estimated emissions of the newly designated POPs, and would also be of much wider value in improving the quality of the NAEI and other environmental databases and tools.

4.1.4.4 PBDEs in waste electrical goods

PBDEs (polybrominated diphenyl ethers) have been used as brominated flame retardants for a number of years, principally with foam based products and plastics used for electrical goods. POPs emissions arise during product use and at the point of product disposal, with disposal becoming an increasingly important source as commercial products containing penta-BDE and octa-BDE reach the end of their life cycle. The current study has made estimates for emissions of the PBDE congeners to air and also land, which in the case of waste electrical goods relates to contaminated dusts, and landfill for foams. Following the implementation of the Waste Electrical and Electronic Equipment (WEEE) Directive and the WEEE regulations (SI 2006 No. 3289 as amended) in the UK, waste electrical goods are handled separately from general municipal waste streams.

To improve inventory estimates, it is recommended that WEEE waste handling companies and trade associations should periodically be consulted to provide data on quantities of plastic within WEEE waste, means of disposal or export and storage options prior to disposal. This data would be used to help re-calibrate and update the current model of product lifecycle and disposal trends that have been used within the current study to generate both historic and projected emissions from this source. If this reveals that significant quantities of plastics containing PBDEs are being disposed of to landfill, it may be worth considering a landfill waste compositional analysis to provide data to support a more detailed evaluation of current landfill as a potential source of PBDEs.

In addition, to generate more information on the PBDE content of plastics in the UK stock, it is recommended that a sampling and analysis programme be considered, to obtain plastic samples from a cross-section of UK electrical goods (covering a range of goods from a cross-section of global producers) and to conduct compositional analysis to assess the PBDE content of the materials.

4.1.4.5 Emissions of PFOS from waste water treatment works

PFOS releases to surface waters from waste water treatment works appear to be the primary point within the cycling of PFOS in the environment that can be used to identify potentially significant emission sources. While PFOS is not currently covered by the IPPC/EPR pollution inventories, work has previously been carried out by the Environment Agency to model emissions, which have been further reviewed and updated by a new study within the current project. PFOS has now been recognised as a POP under the Stockholm Convention and is under review within the Water Framework Directive to be included as one of the priority substances for emission to urban surface waters.

We recommend therefore that Defra considers implementing a sampling and analysis programme in the water industry, either as an extension to the current scope of reporting under both the WFD and the IPPC/EPR pollution inventories or as a stand-alone project. This could be designed to focus on a representative sample of treatment works, in order to avoid excessive cost to the water industry. Periodic consultation between the environmental regulatory agencies, PRTR team, water regulator (OfWAT), water companies/UKWIR and the Defra POPs team is also recommended to ensure that data provision and model development is co-ordinated and communicated between stakeholders to ensure delivery of improved PFOS emission estimates.

4.1.4.6 Emissions of pentachlorobenzene from dry cleaning operators

Pentachlorobenzene exists as a trace contaminant of tetrachloroethene (known as "perchloroethylene" or PERC). PERC is used as a solvent in the dry cleaning industry, and pentachlorobenzene is therefore present within the solvent wastes from this sector. The use of PERC within the dry cleaning industry is controlled through the Solvent Emissions Directive and the associated UK regulations (Solvent Emissions (England and Wales) Regulations 2004; Solvent Emissions Regulations (Northern Ireland) 2004; and the Solvent Emissions (Scotland) Regulations 2004). These regulations also cover the disposal of

wastes from this sector, requiring disposal of still bottoms by a licensed contractor. Communication with the regulator and trade association for dry cleaners indicates that data is not currently collected on quantities of waste generated from this sector. It is therefore recommended that this data be requested annually from the waste contractors that service the industry.

4.1.4.7 Extend TOMPs network to include measurements of POPs

At present, the TOMPs network covers dioxins and furans, polychlorinated biphenyls and polycyclic aromatic hydrocarbons. Following the implementation of the Stockholm Convention, further information on airborne levels of the nine newly designated POPs will be useful in two ways. Firstly, additional measurement data may assist in estimating emissions sources – e.g. measurements in rural areas may assist in estimating the rate of fugitive emissions from soils. Secondly, as a time series of measurements becomes available, this may provide useful evidence to substantiate the benefits in emissions resulting from the implementation of control measures.

It is therefore recommended that consideration is given to extending the range of substances measured as part of the TOMPs network to include some or all of the nine newly designated POPs. Priority may need to be given to substances which are more likely to be present in the airborne phase (e.g. pentachlorobenzene; tetra/penta bromo diphenylether), and those for which policy measures may be effective in reducing emissions.

4.1.4.8 Monitoring land and water emissions

This is an important area for future development, and was a specific objective of Work Package 2. It is therefore addressed in detail in Section 4.2 below.

4.2 Scope of work for monitoring land and water emissions

The fifth objective of Work Package 2 is to provide details of how monitoring schemes for land and water may further benefit the newly developed emission inventories. Typically in the case of POPs inventories the greatest abundance of data relates to air emissions, with less data available for land and water. This has also been the case within the current review of the nine new POPs. For pentachlorobenzene, where there was less available data for emissions, it was necessary to derive indirect emission estimates in order to provide a complete dataset. For other POPs, an overall UK emission budget was estimated, but it was not possible to allocate emissions to individual sources or source category/activity combinations.

The current review has therefore identified a number of cases where additional monitoring would help to revise the current emission estimates, and therefore reduce uncertainty. In specific cases the additional monitoring work could have significant impact for policy planning and therefore requires further discussion. This section details those sources of greatest significance, along with details of how further monitoring could be carried out and likely benefits of such work. Table 4.3 at the end of the chapter summarises all of the options and presents the study team's recommendations for the highest priority actions.

4.2.1 Monitoring of emissions from waste water treatment works

The UK network of waste water treatment works provides a useful framework for establishing new monitoring and reporting mechanisms to monitor POPs concentrations within effluent outputs to surface waters, as they effectively act as a funnel for waste water effluent and are in effect a secondary source of emissions to controlled waters and also to land (via sewage sludge disposal). Waste water treatment works appear to play a key role in the emission pathways for both pentachlorobenzene and PFOS, and possibly also for lindane / HCH.

Two recommendations are made in respect of emissions from waste water treatment works.

4.2.1.1 Emissions of pentachlorobenzene from wastewater treatment works

Pentachlorobenzene is one of the priority sixteen substances listed in the urban surface water directive (which is a daughter directive to the water framework directive); and therefore a better understanding of the environmental fate of pentachlorobenzene through waste water treatment works is of benefit to a number of parties. The current inventory has looked at data based on the UK PRTR which provides modeled emissions to air and water for a small number of works. These estimates are thought to be conservative.

As an alternate method, we have also made estimates for water emissions based on emission factors (derived through a monitoring study) and UK throughput at water treatment plants. This showed estimates to be broadly in agreement (UK PRTR – 13.6 kg per annum, alternate method – 11kg per annum). Despite this consistency in estimates from two estimation approaches, the emission estimates are regarded as uncertain, and further monitoring is required to accurately gauge the fate of this substance within the works and corresponding emission to controlled waters.

Furthermore, previous studies have shown that sewage sludge is a key emission route for other POPs (PCBs and HCB). While pentachlorobenzene is likely to be partitioned more towards airborne release pathways, it remains important to improve understanding of the potential significance of sewage sludge as a potential release pathway. This may be of particular interest if HCB de-chlorinates to form pentachlorobenzene during sludge treatment, digestion and land application.

Therefore it is recommended that a monitoring study be carried out to better define the environmental fate of pentachlorobenzene within UK waste water treatment works. This should include sampling and monitoring of waste flows as they enter the plant, the final treated effluent, the final treated sludge and also background monitoring in the receiving catchment waters. The monitoring program should look to carry out these studies for a number of representative sewage treatment works. It should also include background monitoring for at least one upstream location as a control sample to determine background PeCB levels. This could be implemented as an extension to the current sampling and analysis regime carried out in relation to the Water Framework Directive.

The benefit of carrying out this work will be to provide additional insight into how related POPs behave during the waste water treatment works process. It will also allow a more accurate estimate to be made of UK emissions to surface waters, to meet policy reporting obligations against environmental standards.

4.2.1.2 PFOS in sludge from sewage works

PFOS has in the past primarily been used for stain protection systems within domestic properties. The current study has identified that the key emission route for PFOS is to surface waters in discharges from waste water treatment works. The current study has investigated the estimates previously made by the Environment Agency by carrying out a further monitoring and sampling study of two rivers within in the UK. This has helped revise the original estimates and reduce uncertainty. However additional studies are required to further develop the work carried out in the current project.

In a similar vein to pentachlorobenzene, there may be an issue of PFOS lost to the environment through the use of sewage sludge in agriculture. The current study has made tentative estimates for the emission to land of PFOS in sludge, but further work is required to more accurately estimate the quantities of PFOS committed to land. Given the increasing use of sewage sludge in agriculture the benefits of gauging these emissions may be significant.

One approach would be to carry out a similar scale of monitoring for PFOS to the survey of dioxins and furans, PCBs and HCB reported under Work Package 4 of this project. This involved the sampling and analysis of 40 samples, (35 samples of final treated sludge and 5

samples of final treated effluent sample) across five different works with different waste streams, and during different seasons of the year. This could be implemented as an extension to the current sampling and analysis regime carried out in relation to the Water Framework Directive.

The results from this study would be used create a UK estimate for PFOS in sludge and total emission based on UK activity statistics for sludge used.

4.2.2 Development of emission factors for pentachlorobenzene in backyard burning and small combustion plants

Emission inventory estimate for PeCB in recent years are dominated by diffuse sources, notably backyard burning, the emission estimates for which are highly uncertain due to a limited dataset of monitoring and emission factors. This issue is further complicated by the complex nature of material burnt and (typically incomplete) combustion conditions in smaller, uncontrolled combustion units. The estimates within the current inventory have been based on the best available activity data taken from the NAEI and emission factor data from the Environment Canada (2005) inventory for land and the Hogendoorn et al. (2009) review.

The current UK POPs research project has included a survey of waste burning behaviour as part of the fourth work package. Certain types of waste (such as plastic or treated wood) are expected to generate higher POPs emissions than other kinds of waste (such as paper and cardboard). The literature emission factors for pentachlorobenzene from waste burning show very large variations, with a lack of measurements of activities typical of those carried out in the UK, and high variation in factors from wastes burnt on open fires and within barrels.

As the single key largest emission for pentachlorobenzene to air and land, it is recommended that a laboratory study of pentachlorobenzene emissions from different wastes and combustion conditions should be carried out. This could be usefully combined with studies of a wider range of POPs to evaluate potential emissions from UK practices for waste burning. It is recommended that the monitoring programme includes analysis of emissions to air and also to land from contaminated ash, as well as covering a range of combustion processes (e.g. outdoor bonfire, barrel burning, open fire place, and controlled burners) and a range of typical combusted waste materials.

The results of this testing would then be used to derive emission factors to help review and revise the current estimates. While the uncertainty within this source is likely to always remain high due to its intrinsically variable nature, the use of better derived emission factors will help reduce uncertainty significantly. This has been identified as a priority area for research over a number of years, and new data on emissions of other POPs such as dioxins and furans would be useful to improve other POPs inventory data also. A review of emission factors for POPs emitted from domestic waste burning will aid Defra's future policy decisions in this area.

4.2.3 Monitoring of lindane emissions from treated woods

Lindane has been used historically to treat timber. The use of lindane for this purpose has been banned in the UK since 2002; however, there remains the potential for ongoing releases of lindane from the legacy of previously treated wood products that have not yet been disposed. The current study has made estimates for the stockpiles of treated wood that remained after the ban and then estimates for volatilisation to air, which then leaves the remaining emission to land, as wood containing lindane decomposes in place.

The uncertainty in gauging the size of the stockpiles and quantities of lindane used is likely to be high. The estimates for release to air and land are based on theoretical calculation, partially calibrated by cross comparison to other reference sources. In view of this, an up to date review of the waste wood market could well provide significant clarification in gauging the current size of the lindane treated wood stocks.

Defra currently runs a review program, which gauges the size and nature of the waste wood market through the assessment for environmental impact of management options for waste wood. It is therefore recommended that Defra could make use of this project to gauge the issue of lindane stockpiles by sampling waste wood from different sources. The survey results could be used to investigate how much of the market is affected, the rate of phase-out of treated woods, and typical lindane concentrations in previously treated wood.

The benefit of this monitoring scheme would be to help more accurately quantify the size of the lindane wood stockpiles, and the rate of phase out and ultimate fate of the stock of lindane treated wood. Currently it is assumed that wood will have a lifespan of fifty years, and wood treated with lindane at the time of the ban could potentially be in place and producing low level emissions to air and land up until 2052.

4.2.4 Monitoring of emissions to land of PBDEs at WEEE waste handling sites.

PBDEs have been used as brominated flame retardants in soft furnishings and plastic housing for electrical equipment for a number of years. The WEEE (Waste electrical and electronic equipment) directive means that waste electrical goods are treated separately from the municipal waste stream. In the case of the UK, WEEE waste is commonly stockpiled prior to its treatment or in many cases export to other countries. Previous studies have illustrated that where WEEE waste is stored prior to treatment there is potential for the emission of PBDEs both to air and land within contaminated dusts.

The current study has made estimates for this emission to land based on assumed quantities of PBDE within the finished product, and ratio of emissions to air and land. While the methodology in this case is robust and provides useful data for end of life equipment, in view of the expected increase in quantities of PBDE electrical waste in the next few years as goods containing PBDEs reach the end of their operational life, additional monitoring would prove beneficial.

In terms of inventory compilation it is useful to assign emission rates or factors to given quantity of plastic. This can be difficult to gauge as the plastic housing is only one component of the equipment. Instead it may prove more useful to derive emission factors for given items of equipment by weight, in terms of dust generation and contamination of that dust.

It is recommended that Defra should work in co-ordination with WEEE contractors to take samples of dust from a range of sources within stored items which can then be analysed for a range of PBDE congeners. This should be carried out in tandem with air monitoring and soil sampling at the site of storage.

The benefit from carrying out this monitoring would be to provide ratification to the emission ratios currently used, and also a gauge on how much of the PBDE is emitted prior to its disposal or export. This will help further refine the estimates and help gauge how significant storage sites are in terms of hot-spot sources.

4.2.5 PBDEs in dusts

It is recommended that further consideration is given to the potential for emissions of PBDEs in dusts generated in household, workplace and vehicle environments. Recent research suggests that dust in these environments could potentially result in significant exposure to PBDEs. It is not clear to what extent this reflects abrasion of plastics containing PBDEs; degradation of higher brominated PBDEs; and/or other sources of PBDEs.

4.3 Summary

The monitoring schemes that have been outlined in sections 4.2.1 to 4.2.4 above represent the best monitoring options for further improvement of the established inventories. It is recognised that within these options some prioritisation is likely to be needed.

In order to address this, a prioritised table of recommendations has been provided in Chapter 5. When developing such a priority list, it is necessary to strike a balance between the areas which require the most urgent attention and the cost of the work, and chances of success. The table in chapter 5 has been developed based on a combination of variables, including the areas of highest uncertainty, potentially significant sources, key pollutants (noting the additional reporting requirements for some pollutants), likely cost and effort required, and chances of success. In reviewing the recommendations it is advisable that a similar approach should be adopted. This means drawing up a list based on cost and chances of success, and a second list based on reporting requirements and importance of the knowledge gaps/uncertainty. Comparison of the overlaps between list one and two, should assist the reviewer to identify where additional work is most urgently needed.

5 Conclusions

5.1 Overview

The current study has conducted a review of the sources and releases for the nine new POPs that were added to the Stockholm Convention in May 2009. This work has included a review of existing available inventories for emissions to air, land and water, a periodical review of scientific journals for emission factor data, communication with key national and international experts and industry as well as a further research study to help bridge a data gap within the existing available data.

The nine new POPs are made up of pesticides and brominated flame retardants with the exception of PFOS, which has had multiple applications as a surfactant. In many cases the new substances added to the Stockholm Convention have already been banned within the UK for several years and are also captured under other reporting protocols, in particular the UNECE's convention on long range transboundary air pollution (CLR-TAP). However even though this is the case the current study has found that available data is scarce, particularly for emissions to land and water.

The research highlighted the scarcity of both international and UK-specific data on the source activities and environmental releases of the new POPs. More data was available for Pentachlorobenzene than for the other newly designated POPs. The current study has provided a full emission inventory to air, land and water (based on the NFR classification scheme) from 1990 – 2008 for pentachlorobenzene. Preliminary indicative emission estimates were provided for a further seven of the newly designated POPs (chlordecone is not used or released in the UK). The new inventory is designed to satisfy the reporting requirements of the Stockholm Convention while providing the necessary information to help Defra with development of a new Annex C action plan.

The release estimates presented for all of the new POPs are associated with high uncertainty due to the scarcity of source data.

5.2 Individual POPs

5.2.1 Chlordecone

Chlordecone is a fungicide which has been banned in the UK since 1977. International risk assessments indicate that chlordecone may still be used in some regions to protect tobacco and banana crops, i.e. commercial goods which are not grown in the UK. Global production and consumption data for chlordecone have not been found within the literature.

The use of chlordecone in the UK is unlikely prior to 1977, and the substance has been banned in the UK for over 30 years. There is only a very limited potential for residual concentrations to be present on treated crops imported to the UK. UK releases of chlordecone are expected to be very low and highly uncertain, and hence emission estimates have not been made by the project team and the source is regarded as a low priority for further work.

5.2.2 Alpha and beta HCH

Alpha and beta HCH were previously important components of the pesticide 'technical HCH', which was most widely used in the 1940s, and subsequently phased out to be replaced by the use of lindane (99% by weight gamma HCH), which only contains trace amounts of alpha and beta HCH. However the production process for lindane resulted in significant waste

quantities which may have contained alpha and beta HCH isomers. The sale and use of technical HCH was banned in the UK in 1982, and lindane was banned in 2002.

The main release pathways in the UK for these substances are:

- Emissions to air from the historic production and usage of lindane
- Emissions to air of HCH from contaminated soils (particularly for beta HCH); and
- Emissions to water from sewage treatment works, as reported in the PRTR.

UK environmental releases are estimated to be around 7.4 tonnes of alpha HCH to all media in total per year, and 2.7 tonnes of beta HCH to all media in total per year.

Lindane

Lindane was an insecticidal product used to treat timber and to lesser degree had an application as a component of specialist shampoos used to treat head lice. Lindane had its peak use in the 1970s, after which its usage declined up until its ban in 2002. The main release pathways in the UK for lindane are:

- Emissions to air from lindane production and usage; and
- Emissions to land from lindane application, notably as a legacy of treated stockpiles of wood (e.g. used in construction, fencing etc.) with an estimated typical lifespan of 50 years.
- Emissions to air from contaminated soils
- Possible releases to land or groundwater from waste materials consigned to landfill.

UK environmental releases of lindane are estimated to be around 26 tonnes per year to all media.

Tetra and penta brominated diphenyl ether

Tetra and penta brominated diphenyl ether (BDE) are the two main polyBDE congeners found within the commercial pentaBDE product. Historically commercial pentaBDE has been used as an additive flame retardant in a number of plastic applications as well as being widely used for flame retardancy in soft furnishings. The manufacture of commercial pentaBDE ceased in Europe in 1997, but demand remained high up until a ban in 2003. Emissions from in-use items and disposal are considered to be potentially significant. Materials such as carpets, textiles, furnishings and other items which may have been treated with penta-BDE prior to 2003 are likely to continue in use and to enter the waste stream for some time.

A range of estimates for emissions to air, land and water were developed during the course of the project. PBDEs may be emitted during manufacture, during use, during disposal, and following disposal of goods containing these chemicals, and may also occur as a degradation product of substances such as octa-BDE.

Hexa and hepta brominated diphenyl ether

The hexa and hepta brominated diphenyl ether are congeners found within the commercial OctaBDE product, whilst the hexaBDE congener may also be found in low concentrations within the commercial PentaBDE product. Commercial OctaBDE was banned in 2004, whilst the commercial PentaBDE was banned in 2003. Commercial OctaBDE had more limited applications than the PentaBDE, as it was primarily used as an additive flame retardant in plastic housings used for electrical goods. In the UK, the waste stream for these items has been controlled under the Waste Electrical and Electronic Equipment Regulations since January 2007. In recent years, therefore, the main release pathways for these substances are thought to be emissions to air and land as contaminated dusts at WEEE waste handling and storage sites, from the disposal of products manufactured prior to the ban. It is expected

that the risk of releases from this source will diminish over time as these items are removed from the UK stock of electrical goods. .

Less data is available to allow an inventory of emissions of higher brominated BDEs to be developed.

Hexabromobiphenyl

Hexabromobiphenyl (HBB) has been used historically as a flame retardant within a number of plastic applications. UK production ceased in 1977, although manufacture continued in Germany up until the mid 1980s, and in France until 2000. During production the key emissions would have been to air and water, with further residual emission to air from in-use goods (e.g. due to abrasion during use resulting in dusts containing HBB). Emissions could then take place to air, land and/or water during and after final disposal to landfill. Plastic products treated with HBB are expected to have a lifespan ranging from 5 to 10 years, meaning that there is likely to be little or no 'in-use' stock at the start of the inventory compilation time series in 1990. Environmental releases of HBB in the UK in recent years are estimated to be at a low level, and emissions of HBB are regarded as a low priority for further research.

PFOS and its salts

PFOS was manufactured in Europe as a surfactant for a range of applications. However after concerns were raised with long term environmental effects, manufacture ceased manufacture in 2001. The main applications for PFOS are dominated by the domestic market, particularly in the use of furniture stain repellent. It has also been used as a surfactant in a number of fire fighting foams. In the UK, the use of foams containing PFOS was phased out around the time that production ceased, and the remaining fire brigade stockpiles of PFOS foams are thought to have been largely consumed at the Buncefield fuel storage terminal fire in December 2005. It is estimated that approximately 0.5 tonnes of PFOS in industrial firefighting foam was used at the Buncefield incident. Other possible release sources include from metal plating activities in the chrome industry, the use of small quantities of PFOS in semi-conductor manufacture and limited applications in the photographic industry.

The main release pathways to environmental media in the UK are thought to be to water, where concerns have been raised about further de novo formation of PFOS within waste water treatment works. This study has included a limited sampling and analysis programme designed to verify the currently available emissions modelling methods. Annual emissions of PFOS are estimated to be around 820 kg PFOS to water and 5 kg PFOS to land.

Pentachlorobenzene

Pentachlorobenzene (PCB) has no current commercial uses. However in the past it has been used for specific applications and was present as a contaminant in others. Historically, pentachlorobenzene was present in the following applications:

- an elastomer in PCB di-electric fluids
- a contaminant of HCE (hexachloroethane) de-gassing agents used in aluminium manufacture
- a contaminant of the pesticide Quintozene
- a contaminant of the pesticide PCP (pentachlorophenol)
- a contaminant of PERC used in dry cleaning
- a by-product of the production of carbon tetrachloride

It also has a number of diffuse sources:

- uncontrolled combustion of waste

- accidental fires
- incineration of hazardous and clinical wastes
- combustion of solid fuels – principally coal in domestic grates
- trace residues from emissions of waste water treatment works

Pentachlorobenzene emission estimates have been made for a wide range of emission sources. Emissions to air in 1990 were estimated to be 399 kg per year, dominated by industrial sources and from the legacy of earlier industrial process sources. PeCB air emission estimates in 2008 reduced to 48 kg, and were dominated by diffuse sources. Emissions in 2009 to land were estimated to be 388 kg, and 3 kg to water.

5.3 Emissions inventory summary

Emissions estimates are summarised in Table 5.1.

Table 5.1 – UK Emission Estimates for the newly designated POPs in 2008

POP	Emission to air (2008)	Emission to land (2008)	Emission to water (2008)
Chlordecone	(Assumed to be zero emissions to all media)		
Alpha HCH	7.4 tonnes to all media		
Beta HCH	2.7 tonnes to all media		
Lindane	26 tonnes to all media		
Tetra and PentaBDE	2500 kg	2000 kg	700 kg
Hexa and HeptaBDE	0.77 kg	no data	no data
HBB	1.8 kg	no data	<1 gram
PFOS	0 kg	5 kg	820 kg
PeCB	48 kg*	388 kg	3 kg*

* data for PeCB is 2009

5.4 Recommendations

A range of recommendations have been set out in this report. It is recognised that some prioritisation is likely to be needed in assisting Defra in implementing these recommendations.

In order to address this, table 5.2 sets out a prioritised set of recommendations for ongoing work. This takes account of the potential significance of the issue under consideration; the likelihood of securing useful data; and the potential cost associated with implementing the proposed measure.

Table 5.2: Summary of recommendations

Ranked Priority	Substance	Aspect	Proposed approach	Significance	Likelihood of success	Cost	Priority
1	PeCB and PBDEs	Emissions of PeCB and PBDEs from waste water treatment works	A focused sampling and analysis campaign covering sewage treatment works in different locations (urban, rural, industrial). Include sampling and monitoring of flows entering the plant, final treated effluent, final treated sludge and background monitoring in the receiving waters. Could be combined with analysis of PeCB and PBDE content of waste water emissions from specific industrial processes. Consultation with the environmental regulatory agencies, PRTR team, OfWAT and water industry will be important. This could be carried out as an extension to the current scope of reporting under WFD or EPR, or as a stand-alone project	High	Medium	Medium	High
2	All new POPs	Limited data on presence of newly designated POPs in specific industrial waste streams	Targeted sampling and analysis programme for specific waste streams, designed to provide compositional analysis on materials such as: APC residues, boiler ash and bottom ash residues, domestic combustion grate ash, open burning ash residues, industrial slags and skimmings, and industry-specific effluent streams such as textile finishing processes, plastics manufacturing processes and flame retardant application processes	High	High	High	High
3	PBDEs	Limited data on plastics containing flame retardants in WEEE waste	Periodic consultation with WEEE waste handling companies and trade associations to provide data on quantities of plastic within WEEE waste; proportion containing flame retardants; means of	Medium	Medium	Low	High

Ranked Priority	Substance	Aspect	Proposed approach	Significance	Likelihood of success	Cost	Priority
			disposal or export and storage prior to disposal.				
4	PeCB	Reporting threshold for PeCB in the E-PRTR is relatively high, making it less useful as a data source	Lobby EEA to reduce reporting threshold for PeCB in the E-PRTR	Medium	Medium	Low	High
5	All new POPs	Drawing on current research to maintain and improve inventories	Maintain watching brief on UNEP and EU working groups	Medium	High	Low	High
6	PeCB	Review of potential sources not included in the current inventory	Desk-based review of potential for emissions of PeCB from metals processes to establish whether more detailed assessment is needed	Low	High	Low	High
7	All new POPs	Potential to extend Water Framework Directive procedures to cover new POPs	Lobby EC to co-ordinate WFD requirements with Stockholm Convention obligations	Medium	Medium	Low	High
8	All new POPs	Potential to extend OSPAR convention procedures to cover new POPs	Lobby OSPAR secretariat to co-ordinate convention requirements with Stockholm Convention obligations	Medium	Medium	Low	High
9	All new POPs	Unreliable data on past disposal of hazardous wastes potentially containing POPs	Review availability of historical data on disposal of hazardous wastes	High	Low	Low	High

Ranked Priority	Substance	Aspect	Proposed approach	Significance	Likelihood of success	Cost	Priority
10	PeCB	Uncertainty in emissions to all media of PeCB from domestic combustion sources	Laboratory studies to improve understanding of emissions from domestic waste combustion (including air and ashes). This should consider a range of fuel types and combustion conditions. Surveys to improve estimates of the amounts of materials burnt	High	High	High	High
11	PFOS	Improvement of estimates of PFOS from sewage works	Sampling and analysis of effluent and sludges in the water treatment industry to determine PFOS levels. Include sampling and monitoring of flows entering the plant, final treated effluent, final treated sludge and background monitoring in the receiving waters. Consultation with the environmental regulatory agencies, PRTR team, OfWAT and water industry will be important. This could be carried out as an extension to the current scope of reporting under WFD or EPR, or as a stand-alone project	High	Medium	High	Medium
12	PBDEs	Limited data on levels of PBDE in plastics	Sampling and analysis of a cross-section of UK electrical goods (domestic production and imported goods) to assess the PBDE content	Medium	Medium	Medium	Medium
13	PBDEs	Potential exposure to PBDEs in the home, workplace and in vehicles	Measurement survey of PBDE congeners within dust samples in a range of environments. Design survey to investigate potential significance of degradation pathways	Medium	Low	Medium	Medium
14	PeCB	Further analysis of potentially significant sources	Measurement of emissions from accidental fires; industrial coal combustion; waste incineration facilities; residential coal and treated wood combustion; dry cleaning; disposal of WEEE; landfill gas	Medium	Medium	High	Medium
15	PeCB,	Airborne	Extend coverage of existing TOMPs network to	Medium	Medium	Medium	Medium

Ranked Priority	Substance	Aspect	Proposed approach	Significance	Likelihood of success	Cost	Priority
	PBDEs	measurements to support emissions estimates and verify emissions reductions achieved	include newly designated POPs, focusing as a first priority on PeCB and PBDEs				
16	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from historic disposal of products/materials containing HCH	Measurements of HCH in landfill gas and leachate from a sample of relevant landfill sites, potentially using regulatory measures to implement	Medium	Medium	Medium	Medium
17	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from historic disposal of manufacturing waste	Measurements of HCH in landfill gas and leachate from a sample of relevant landfill sites, potentially using regulatory measures to implement	Medium	Medium	Medium	Medium
18	PBDEs	Potential emissions of PBDEs from WEEE processing facilities	Measurement survey of PBDE congeners within dust samples from a range of sources within stored items. Concurrent air and soil sampling at the processing facility. Could potentially using regulatory measures to implement	Medium	Low	Medium	Medium
19	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from re-use of waste wood	Extend existing waste wood survey to include measurement of HCH content of wood samples and rate of phase-out	Low	Medium	Medium	Medium
20	Alpha-HCH Beta-HCH Lindane	Unintentional emissions of HCH from metalworking processes	Measurements of HCH in workplace air and emissions to air and water from relevant processes, potentially using regulatory measures to implement	Low	High	Medium	Medium
21	PeCB	Limited data on waste from dry cleaning sector	Annual request for data from contractors serving dry cleaning industry	Low	Medium	Low	Medium
22	All new POPs	Limited data on emissions and wastes	Development of a scheme for reporting activity and emissions from Part B processes (and Part C	Medium	Low	High	Low

Ranked Priority	Substance	Aspect	Proposed approach	Significance	Likelihood of success	Cost	Priority
		generated at Part B/C processes	processes in Northern Ireland).				
23	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from ongoing use of materials containing HCH	Measurements of HCH in samples of treated materials and in nearby soils and waters	Medium	Low	High	Low
24	PFOS	Potential significance of degradation pathways in determining environmental levels and exposure to PFOS	Environmental monitoring survey, forming part of wider international research initiatives	Medium	Low	High	Low
25	HBB	Verification of emissions of HBB from processing end-of-life vehicles	Measurement survey at a sample of representative end-of-life vehicle processing facilities	Low	Low	Medium	Low
26	HBB	Verification of emissions of HBB from landfill sites	Measurement survey of landfill leachate and landfill gas at a sample of representative landfill sites	Low	Low	Medium	Low
27	HBB	Verification of emissions of HBB from processing WEEE	Measurement survey at a sample of representative WEEE processing facilities	Low	Low	Medium	Low
28	Alpha-HCH Beta-HCH Lindane	Emissions of HCH from past use of HCH in agriculture	Measurements of HCH in soils and ambient air	Low	Low	High	Low

Appendices

Appendix 1: Glossary and Abbreviations

Appendix 2: Summary tables for Pentachlorobenzene

Appendix 1 – Glossary and Abbreviations

Activity Data	Emission estimates are derived by multiplying ‘activity data’ against a known ‘emission factor’ to create an emission estimate. In this equation ‘activity data’ describes a process or activity that may generate emissions. For example tonnes of coal burnt, tonnes of steel manufactured, or millions of vehicle kilometres driven.
AFFF	Aqueous Fire Fighting Foams
BDE 47	Brominated diphenyl ether congener associated with tetraBDE
BDE 99	Brominated diphenyl ether congener associated with pentaBDE
Commercial DecaBDE	Commercial mixture for decabrominated diphenyl ether, principally comprised of the deca and nona families
Commercial OctaBDE	Commercial mixture of octabrominated diphenyl ether, principally comprised of the Octa, hepta and hexa families
Commercial PentaBDE	Commercial mixture of pentabrominated diphenyl ether, principally comprised of the tetra, penta, and hexa families
DEFRA	Department for Environment, Food and Rural Affairs
DEHP	Di(2-ethylhexyl)phthalate. Used as a plasticizer within plastic products
DUKES	Digest of UK Energy Statistics
Emission Estimate	An emission estimate is the quantification of emissions from a recognised source such as road transport. Typically these estimates will be provided at national level.
Emission Factor	Emission estimates are derived by multiplying ‘activity data’ by an ‘emission factor’ to create an emission estimate. In this equation an ‘emission factor’ identifies the quantity of substance emitted per unit of activity. For example air monitoring at an incinerator may detect a quantity of dioxins and furans, by knowing how much material was burnt or how much gas has passed through the chimney, we can convert the measured data to an emission factor of $x \mu\text{g I-TEQ dioxins and furans/tonne of waste burnt}$. The adopted emission factor can be multiplied by national level ‘activity data’, to provide a full UK estimate.
E-PRTR	European Pollutant Release and Transfer Register
EU	European Union
EWG Codes	European Waste Catalogue. Six digit classification scheme for hazardous waste
FOSA	Fluoro Octane Sulfon Amide
FOSE	Fluoro Octane Sulfonamido Ethanol
FTOH	Fluoro Telomer Alcohols
GC-MS	Gas Chromatography Mass Spectroscopy
GDP	Gross Domestic Product

HBB	Hexa Bromo Biphenyl
HCB	Hexa Chloro Benzene
HCE	Hexa Chloro Ethane
HCH	HexaChlorocyclo Hexane
HeptaBDE	HeptaBrominated Diphenyl Ether
HexaBDE	HexaBrominated Diphenyl Ether
IPPC	Integrated Pollution Prevention Control. EU directive for air pollution.
I-TEQ	'International – Toxic Equivalent'. I-TEQ is the Nato (1989) based system of toxic equivalents used to present a quantity of dioxin and furan congeners as a single value based on the relative toxicity of all congeners to the most harmful congener – TCDD.
LC-TOF	Liquid Chromatography Time Of Flight mass spectroscopy
Lindane	Commercial pesticide comprising 99% by weight gamma HCH and not more than 1% by weight (combined) alpha and beta HCH
LRAT	Long Range Air Transport
LRTAP	Convention on Long Range Transboundary Air Pollution
NACE Codes	'Nomenclature générale des activités Économiques dans les Communautés européennes. Classification system for pollutant sources based on process activities.
NAEI	UK's National Atmospheric Emissions Inventory
NFR	Nomenclature For Reporting. Classification system for pollutant sources to air, based on the nature of the source.
NI-ISR	Northern Ireland Inventory of Sources and Releases
NIP	National Implementation Plan. Stockholm Convention requirement of a national action plan for ratified states, to address the issue of POPs emissions
PAHs	Poly Aromatic Hydrocarbons
PBB	PolyBrominated Biphenyls
PBDE	PolyBrominated Diphenyl Ether
PCBs	PolyChlorinated Biphenyls
PeCB	PentachloroBenzene
PECs	Predicted Environmental Concentrations
PentaBDE	PentaBrominated Diphenyl Ether
PERC	Tetrachloroethylene.
PFCAs	PerFluorinated Carboxylic Acids
PFCs	PerFluoroCarbons
PFOA	PerFluoroOctanoic Acid
PFOS	PerFluoroOctane Sulphonate

PFOS-F	PerFluoroOctane Sulfonyl Fluoride. Also known as POSF
POPRC	Stockholm Convention, POPs Review Committee
POPs	Persistent Organic Pollutants
POSF	PerFluoroOctane Sulfonyl Fluoride. Also known as PFOS-F
PTFE	PolyTetra FluoroEthylene
PVDF	PolyVinylidene Fluoride
RAR	Risk Assessment Report
SEPA	Scottish Environmental Protection Agency
SNAP	Standardized Nomenclature for Air Pollution. Classification system for pollutant sources to air, based on the nature of the source.
SPRI	Scottish Pollutant Release Inventory
STWs	Sewage Treatment Works
TCDD	Tetrachloro dibenzo para dioxin
TCDF	Tetrachloro dibenzo furan
Technical HCH	Commercial pesticide product made up of HCH isomers. Typically concentration of alpha and beta HCH will be higher than in Lindane.
TetraBDE	TetraBrominated Diphenyl Ether
TOMPs Network	Monitoring network for ambient concentrations of Toxic Organic MicroPollutants, typically dioxins and furans, PCBs, and PAHs
UK-PRTR	UK's Pollutant Release and Transfer Register
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
U-POPs	Unintentionally released POPs
US EPA	United States of America Environmental Protection Agency
WEEE	EU directive on Waste Electrical and Electronic Equipment
WHO-TEQ	World Health Organisation – Toxic Equivalent factors. WHO-TEQ is the WHO (2005 version) based system of toxic equivalents used to present dioxins and furans as a single value based on relative toxicity of all congeners to the most harmful congener – TCDD.
WWTWs	Waste Water Treatment Works

Appendix 2 - Summary tables for Pentachlorobenzene

Pentachlorobenzene	Activity		Emission factor
Vector: Air	Name	reference	Reference
MSW	Power stations > 300 MW = <50 MW	Digest of UK Energy Statistics (DUKES)	Kat and Urano, 2001, 'Convenient substitute indices to toxic equivalent quantity for controlling and monitoring dioxins in stack gas from waste incineration facilities, Waste Management 21, pp 55-62.
Coal	Other Industrial combustion	AEA estimates based on Coal data from DUKES	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Coke	Other Industrial combustion	AEA estimates based on DUKES and sector data for Lime industry.	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Wood (untreated)	Other Industrial combustion	AEA Estimates based on industry.	Zimmerman et al. 'Emission of nonchlorinated and chlorinated aromatics in the flue gas of incineration plants during and after transient disturbances of combustion conditions', 2001, Quoted in the 2007 Eurochlor dossier.
Wood (Creosote)	Other Industrial combustion	AEA Estimates based on industry.	Zimmerman et al. 'Emission of nonchlorinated and chlorinated aromatics in the flue gas of incineration plants during and after transient disturbances of combustion conditions', 2001, Quoted in the 2007 Eurochlor dossier.
Wood (PCP)	Other Industrial combustion	AEA Estimates based on industry.	Zimmerman et al. 'Emission of nonchlorinated and chlorinated aromatics in the flue gas of incineration plants during and after transient disturbances of combustion conditions', 2001, Quoted in the 2007 Eurochlor dossier.
Wood (Lindane)	Other Industrial combustion	AEA Estimates based on industry.	Zimmerman et al. 'Emission of nonchlorinated and chlorinated aromatics in the flue gas of incineration plants during and after transient disturbances of combustion conditions', 2001, Quoted in the 2007 Eurochlor dossier.
Coal	Commercial Combustion	AEA estimates based on Coal data from DUKES	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
MSW	Commercial Combustion	Digest of UK Energy Statistics (DUKES)	Prior to 1998 - will be Fangmark, 'influence of postcombustion temperature profiles on formation of PCDD/F, PCBs and PCBs in pilot incinerator', 1994, Environ Sci. Technol vol 28 pp 624-629. Quoted in Eurochlor dossier, and post 1998 will be Kat and Urano see MSW for power stations
Coal	Public Sector Combustion	AEA estimates based on Coal data from DUKES	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.

Pentachlorobenzene	Activity		Emission factor
Vector: Air	Name	reference	Reference
Coke	Public Sector Combustion	Historic data in DUKES, however No longer found in DUKES for recent editions. Assume data has merged with other sectors.	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Coal	Railways Stationary Combustion	AEA estimates based on Coal data from DUKES	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Coal	Residential Combustion	AEA estimates based on Coal data from DUKES	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Coke	Residential Combustion	Digest of UK Energy Statistics (DUKES)	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Petroleum Coke	Residential Combustion	AEA estimates based on Coal data from DUKES	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Wood	Residential Combustion	Digest of UK Energy Statistics (DUKES)	Zimmerman et al. 'Emission of nonchlorinated and chlorinated aromatics in the flue gas of incineration plants during and after transient disturbances of combustion conditions', 2001, Quoted in the 2007 Eurochlor dossier.
Coal	Stationary Agricultural Combustion	AEA estimates based on Coal data from DUKES	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Coke	Stationary Agricultural Combustion	Historic data in DUKES, however No longer found in DUKES for recent editions. Assume data has merged with other sectors.	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report.
Straw	Stationary Agricultural Combustion	Digest of UK Energy Statistics (DUKES)	Zimmerman et al. 'Emission of nonchlorinated and chlorinated aromatics in the flue gas of incineration plants during and after transient disturbances of combustion conditions', 2001, Quoted in the 2007 Eurochlor dossier.
HCE	Quantity of HCE used in de-gassing for aluminium manufacture	AEA extrapolation of HCE usage based on Van der Most 1992 and Bailey 2000, who give HCB emissions based on tonnes of metal produced, and grams of HCE respectively.	Robert Bailey 'Pentachlorobenzene - sources, environmental fate and risk characterization', 2007, - Eurochlor dossier.
Carbon Tetrachloride	Process emission for manufacture of carbon tetrachloride	AEA estimate on industry data. Single UK plant closed in 1994.	Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.

Pentachlorobenzene	Activity		Emission factor
Vector: Air	Name	reference	Reference
Di-electric leak	Leaks from transformers	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Extrapolation of EF based on Canadian PeCB inventory reported in the risk management strategy (PE29)
Di-electric leak	Leaks from capacitors	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Extrapolation of EF based on Canadian PeCB inventory reported in the risk management strategy (PE29)
Di-electric leak	Leaks from fragmentisers	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Extrapolation of EF based on Canadian PeCB inventory reported in the risk management strategy (PE29)
PCP	Textile coatings from imported goods	Smith, C, (Textile Finishers Association), Personal Communication, 10/11/95	Assumed PCP contamination for PeCB based on reported HCB contamination - 'Preliminary risk profile for pentachlorophenol', Mieczysław Borysiewicz, Institute of Environmental Protection, Poland.
PCP	Textile coatings from UK manufacture	Smith, C, (Textile Finishers Association), Personal Communication, 10/11/95	Assumed PCP contamination for PeCB based on reported HCB contamination - 'Preliminary risk profile for pentachlorophenol', Mieczysław Borysiewicz, Institute of Environmental Protection, Poland.
PCP	Preservation of wood	Based on data supplied by Brooks (Protim), 1994 with NaPCP usage assumed to fall to zero by 1998 as a result of imposed limitations on use.	Assumed PCP contamination for PeCB based on reported HCB contamination - 'Preliminary risk profile for pentachlorophenol', Mieczysław Borysiewicz, Institute of Environmental Protection, Poland.
PCP	Imported pre-treated timber for PCP	Figures for 1990-1994 based on an estimate for 1991 given by Wild & Harrad, 1992 and usage by 1999 is assumed to have halved due to restrictions on use in many countries - Wild & Harrad, Pentachlorophenol in the UK Environment 1: A Budget and Source Inventory, Chemosphere, 24, No 7, 833-845, 1992	Assumed PCP contamination for PeCB based on reported HCB contamination - 'Preliminary risk profile for pentachlorophenol', Mieczysław Borysiewicz, Institute of Environmental Protection, Poland.

Pentachlorobenzene	Activity		Emission factor
Vector: Air	Name	reference	Reference
PCP	emissions linked to previously treated timber for PCP	AEA Estimates based on industry.	Assumed PCP contamination for PeCB based on reported HCB contamination - 'Preliminary risk profile for pentachlorophenol', Mieczyslaw Borysiewicz, Institute of Environmental Protection, Poland.
Quintozine	Pesticide usage for Quintozine	updated from pesticide usage survey website; whole new data series for chlorothalonil, 2003 and 2004 numbers for chlorthal-dimethyl and quintozene and data provided by Dr Miles Thomas (CSL) personal communication	Legal limit for PeCB in Quintozene - taken from CSD - http://www.pesticides.gov.uk/approvals.asp?id=55
Landfill Gas	Flaring of landfill gas	Extrapolated from escaping methane figures using figures for escaped landfill gas and flared landfill gas given by HMIP, 1995 - HMIP, A Review of Dioxin Emissions in the UK, Report No HMIP/CPR2/41/1/38, October 1995	Conversion of EF quoted in Cianciarelli, 2005, 'Characterization of Emissions from a 26 kWe Micro Turbine Fired with Landfill Gas Shepard Landfill Calgary, Alberta', ERMD report
Landfill Gas	Escaping gas from landfill	Land Quality Management Ltd, Methane Emissions from Landfill Sites in the UK, Reference No LQM Report 443/1, January 2003	Conversion of EF quoted in Cianciarelli, 2005, 'Characterization of Emissions from a 26 kWe Micro Turbine Fired with Landfill Gas Shepard Landfill Calgary, Alberta', ERMD report
WWTW	process emissions from waste water treatment works	Activity = 1 = Emission Factor	Reported emissions from the UK PRTR
Clinical Waste	Incineration of Clinical Wastes	Time series based around estimates for 1991, 1997 and 2002 from RCEP, 1993, Wenborn <i>et al.</i> , 1998 & Entec, 2003 - RCEP (Royal Commission on Environmental Protection, 17th Report - Incineration of Waste, 1993; Wenborn, M.J., Coleman, P.J., Passant, N.R., Salway, A.G. &	Oberg and Bergstrom, 1985 'HCB as an indicator of PCDD/F production from combustion' Chemosphere Vol 14(8) pp 1081-1086. Quoted in Eurochlor dossier.
Chemical Waste	Incineration of chemical waste - hazardous	Based on estimates of chemical waste incinerated in 1993 (HMIP, 1995) and 2002 (Entec, 2003) with extrapolation/interpolation to give estimates for other years.	Oberg and Bergstrom, 1985 'HCB as an indicator of PCDD/F production from combustion' Chemosphere Vol 14(8) pp 1081-1086. Quoted in Eurochlor dossier.

Pentachlorobenzene	Activity		Emission factor
Vector: Air	Name	reference	Reference
MSW	Incineration of MSW	Difference between AEA estimates of total MSW burnt and MSW burnt for heat or electricity given by DTI, 2009	Fangmark, 'influence of postcombustion temperature profiles on formation of PCDD/F, PCBzs and PCBs in pilot incinerator', 1994, Environ Sci. Technol vol 28 pp 624-629. Quoted in Eurochlor dossier.
MSW	Backyard burning of waste	AEA Estimates.	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report. - Quotation based on data from the US-EPA Toxicological Release Inventory
MSW	Agricultural waste burning	Environment Agency, 2003 + Factoring down for ban on agri.waste burning in 2006. - Environment Agency, Agricultural Waste Survey: A study of the management of non-natural agricultural waste on farms, 2003	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report. - Quotation based on data from the US-EPA Toxicological Release Inventory
Accidental Fires	Accidental vehicle fires	AEA estimate based on fire statistics published by ODMP.	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report. - Quotation based on data from the US-EPA Toxicological Release Inventory
Accidental Fires	Accidental fires in dwellings	AEA estimate based on fire statistics published by ODMP.	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report. - Quotation based on data from the US-EPA Toxicological Release Inventory
Accidental Fires	Accidental fires in other buildings	AEA estimate based on fire statistics published by ODMP.	Hogendoorn et al, 'Inventory emission factors for Pentachlorobenzene', 2009, RIVM report. - Quotation based on data from the US-EPA Toxicological Release Inventory

A further update of the UK source inventories for emissions to air, land and water of dioxins, dioxin-like PCBs, PCBs and HCB, incorporating multi-media emission inventories for nine new POPs under the Stockholm Convention

Pentachlorobenzene	Activity		Emission factor
Vector: Land	Name	reference	Reference
MSW	Power stations > 300 MW = <50 MW	Ash generation factor from: Environment Agency (2002) Solid Residues from municipal waste incinerators in England Wales Published by the Environment Agency (UK)	Stockholm Convention surveys pursuant to Annex E - Response from Italy. Details PeCB EF for fly ash in MSWI
Coal	Other Industrial combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Coke	Other Industrial combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.

Pentachlorobenzene	Activity		Emission factor
Vector: Land	Name	reference	Reference
Coal	Commercial Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
MSW	Commercial Combustion	Ash generation factor from: Environment Agency (2002) Solid Residues from municipal waste incinerators in England Wales Published by the Environment Agency (UK)	Stockholm Convention surveys pursuant to Annex E - Response from Italy. Details PeCB EF for fly ash in MSWI
Coal	Public Sector Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Coke	Public Sector Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Coal	Railways Stationary Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Coal	Residential Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Coke	Residential Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Petroleum Coke	Residential Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Coal	Stationary Agricultural Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Coke	Stationary Agricultural Combustion	Ash generation factor from: BIPRO (2005) Study to facilitate the implementation of certain waste related provisions of the regulation on Persistent Organic Pollutants (POPs)	Grochowalski, 2009, 'UNEP - 4-th Toolkit Expert Meeting. Preliminary report from the determination of PCDDs/PCDFs, PCBs and HCB/PeCB and HBCDD from combustion of coal and biomass', Krakow University of Technology.
Di-electric leak	Leaks from transformers	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Extrapolation of EF based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.

Pentachlorobenzene	Activity		Emission factor
Vector: Land	Name	reference	Reference
Di-electric leak	Leaks from capacitors	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Extrapolation of EF based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.
Di-electric leak	Leaks from fragmentisers	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Extrapolation of EF based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.
PERC	Solid residues from dry cleaning	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Robert Bailey 'Pentachlorobenzene - sources, environmental fate and risk characterization', 2007, - Eurochlor dossier.
MSW	Incineration of MSW	Ash generation factor from: Environment Agency (2002) Solid Residues from municipal waste incinerators in England Wales Published by the Environment Agency (UK)	Stockholm Convention surveys pursuant to Annex E - Response from Italy. Details PeCB EF for fly ash in MSWI
MSW	Backyard burning of waste	Activity = 1 = emission factor	Extrapolation of Emission based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.
MSW	Agricultural waste burning	Activity = 1 = emission factor	Extrapolation of Emission based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.
Accidental Fires	Accidental vehicle fires	Activity = 1 = emission factor	Extrapolation of Emission based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.
Accidental Fires	Accidental fires in dwellings	Activity = 1 = emission factor	Extrapolation of Emission based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.
Accidental Fires	Accidental fires in other buildings	Activity = 1 = emission factor	Extrapolation of Emission based on 'Pentachlorobenzene and tetrachlorobenzenes - proposed risk management strategy', 2005, compiled by the Environmental Protection Service, Canada.

A further update of the UK source inventories for emissions to air, land and water of dioxins, dioxin-like PCBs, PCBs and HCB, incorporating multi-media emission inventories for nine new POPs under the Stockholm Convention

Pentachlorobenzene	Activity		Emission factor
Vector: Water	Name	reference	Reference
PERC	waste effluent from dry cleaning industry	AEA estimates based on Dyke 1997 - Dyke, P et al, Releases of PCBs to the UK Environment, Report to ETSU on Behalf of the DETR. 1997. Report no AEAT-2731	Robert Bailey 'Pentachlorobenzene - sources, environmental fate and risk characterization', 2007, - Eurochlor dossier.
WWTW	Process emission from waste water treatment works	Activity = 1 = Emission Factor	Reported emissions from the UK PRTR
Alternate method for calculating emissions to surface water from waste water treatment works.			
WWTW	Process emission from waste water treatment works	Extrapolation of OfWat data for England and Wales waste water treatment works in 2009, scaled up by population to represent UK levels	Robles-Molina et al, 2010, 'Determination of organic priority pollutants in sewage treatment plant effluents by Gas Chromatography High Resolution Mass Spectroscopy', Talanta, 2010 pp 1318 - 1324



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