Supplementary Information

**A persistent problem: the global challenges to managing PCBs**

1 Faculty of Science, Masaryk University, Kotlarska 2, 611 37 Brno, Czech Republic

2 Department of Earth Sciences, University of Toronto, 22 Ursula Franklin Street, Toronto, Ontario, M5S 3B1, Canada

3 Healthy People & Thriving Communities Program, Natural Resources Defense Council, San Francisco, CA, 94104 USA

4 Science Office, Natural Resources Defense Council, Washington D.C., 20005, USA

5 School of the Environment, University of Toronto, 149 College Street, Toronto, Ontario, M5T 1P5, Canada

+ Current address: Canadian Urban Transit Research and Innovation Consortium (CUTRIC), Toronto, Ontario, Canada.

*Corresponding author: Miriam L. Diamond, miriam.diamond@utoronto.ca
Contents

Supplementary Information ........................................................................................................................ S1
Text S1: Extrapolations of total PCB use from Breivik et al.1 .................................................................... S9
Text S2: Methods used to compile PCB inventory for Ontario, Canada .................................................... S9
Text S3: Uncertainty and Sensitivity Analysis ......................................................................................... S12
References................................................................................................................................................. S17

List of Figures

Figure S1 – Total PCB production by country, 1930-2020 ........................................................................ S3
Figure S2: Timeline of PCB manufacturing and policy actions on a national-scale for USA, Canada, and Czechia, and global scale (Stockholm Convention). ................................................................. S4
Figure S3 – Statistical Distribution of Ontario In-Use, In-Storage Pure PCB Stock (kg) ......................... S13
Figure S4 – Statistical Distribution of Ontario Pure PCB Waste Stock (kg) ............................................. S13
Figure S5 – Colorblind accessible version of manuscript Fig. 2: Global PCB use and management ...... S14
Figure S6 – PCB per capita consumption based on data from Breivik et al.1 extrapolated according to Text S1 .............................................................................................................................................................. S15

List of Tables

Table S1 - Methods for ESM under the Basel Convention Technical Guidelines................................. S5
Table S2 – Summary of major PCB uses................................................................................................... S7
Table S3 – Current data on PCB stocks and progress towards ESM, compiled from Stockholm Convention sources .................................................................................................................................... see excel file
Table S4 – Low and high concentrations used to estimate mass of pure PCBs for Canadian databases.. S10
Table S5 – Concentration assumptions and estimated mass per item used for Czech inventory estimates .................................................................................................................................................................. S10
Table S6 – USA EPA Transformer database ......................................................................................... see excel file
Table S7 – EPA PCB Annual Report Disposal Data 1996-2018 categorized by type of wastes............ S11
Table S8 – EPA PCB Annual Report Disposal Data 1996-2018 total wastes disposed per year .......... S11
Table S9 – Sensitivity analysis of assumptions used to estimate the Ontario federal ePCB (in-use, in-storage) inventory .............................................................................................................................................. S11
Table S10 – Sensitivity analysis of assumptions used to estimate the Ontario MOECC PCB (waste) inventory ................................................................................................................................................... S12
Table S11 – PCB stock estimates for Ontario, USA, and Czechia ........................................................... S15
Figure S1 – Total PCB production by country, 1930-2020. Data from Breivik et al.¹ and estimated from North Korean Stockholm Convention National Implementation Plan.² Production of unknown amounts occurred in Austria, East Germany, and Poland.¹ Today, Czechoslovakia is partitioned to two countries, Czechia and Slovakia.

*The most recent available information (2016) suggests PCB production in North Korea is on-going.³
Figure S2: Timeline of PCB manufacturing and policy actions on a national-scale for USA, Canada, and Czechia, and international scale (OECD and Stockholm Convention).
Table S1 - Methods for ESM under the Basel Convention Technical Guidelines. The Stockholm Convention requires that POP materials are “disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants” or “disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low”. Under the Stockholm Convention, the technical guidance on what constitutes ESM is in cooperation with the Basel Convention (basel.int).

| Destruction transformation methods                              |
|-----------------------------------------------------------------|
| **Alkali metal reduction** - Alkali metals react with chlorine in halogenated waste to produce salts and non-halogenated waste, metallic sodium is the most commonly used reducing agent. Destruction efficiency >99.999% |
| **Base-catalysed decomposition** – wastes are treated with a reagent mixture consisting of hydrogen-donor oil, alkali metal hydroxide and a catalyst. The mixture is heated to produce atomic hydrogen, which reacts to remove toxic constituents. Destruction efficiencies 99.99–99.9999% |
| **Catalytic hydrodechlorination** - treatment of wastes with hydrogen gas and palladium on carbon catalyst in paraffin oil. Hydrogen reacts with chlorine in halogenated waste to produce hydrogen chloride and non-halogenated waste. In the case of PCBs, biphenyl is the main product. Destruction efficiency: 99.98–99.9999% |
| **Cement kiln co-incineration** – incineration of POP wastes at high temperatures (1400-1500°C) in rotating cement kilns, where hazardous wastes can constitute up to 40% of the fuel heat requirement. Destruction efficiency: >99.99998% |
| **Gas-phase chemical reduction** - thermochemical reduction of chlorinated organic compounds to yield primarily methane and hydrogen chloride. Destruction efficiency: 99.9999% |
| **Hazardous-waste incineration** - controlled flame combustion to treat organic contaminants by heating to >850°C or, if the chlorine content is above 1%, to >1,100°C, Destruction efficiency: >99.9999% |
| **Photochemical dechlorination and catalytic dechlorination** - PCBs are mixed with sodium hydroxide and isopropyl alcohol so that the PCB concentration in the IPA should reach several per cent by weight. Subsequently, PCBs are dechlorinated by photochemical and catalytic dichlorination, yielding biphenyl, sodium chloride, acetone and water. Destruction efficiency: 99.99–99.9999% |
| **Plasma arc** - uses a plasma arc with temperatures in excess of 3,000°C to pyrolyse wastes. Destruction efficiency: 99.9999 to 99.999999% |
| **Potassium tert-Butoxide method** - dechlorinated by reaction with potassium tert-butoxide to produce salt and non-chlorinated waste Destruction efficiency: 99.98–99.9999% |
| **Supercritical water oxidation and subcritical water oxidation** - using an oxidant (such as oxygen, hydrogen peroxide, nitrite, nitrate, etc.) in water to produce carbon dioxide, water and inorganic acids or salts. Destruction efficiency: 99.999% |
| Thermal and metallurgical production of metals - destruction of PCBs in metal-containing wastes use certain types of blast or other furnaces, kilns or melting baths operating at high temperatures (>1000°C). |
| --- |
| Waste-to-gas conversion - gasification pre-treatment and treatment technology for the recovery of hydrocarbon-containing waste operating at high temperatures (1300°C–2000°C) and high pressure using steam and pure oxygen in a reducing atmosphere Destruction efficiency: 99.974% |
| Use as a fuel (other than in direct incineration) or other means to generate energy, ensuring that the wastes and releases do not exhibit POP characteristics |
| Specially engineered landfill – has special requirements in terms of location, pre-conditioning of wastes, long-term measures for management and control, particularly to avoid pollution of groundwater by leachate infiltration into the soil. Liquid wastes or materials containing liquids may not be disposed of in landfills. |
| Permanent storage in underground mines and formations – underground storage in geohydrologically isolated salt mines and hard rock formations is an option to separate hazardous wastes from the biosphere for geological periods of time. |
| Other methods, according to national legislations - only for materials with low POP content. For PCBs, wastes with <50 mg/kg PCBs are considered “low POP”. |
Table S2 – Summary of major PCB uses.

| Use                                | Fraction of total PCBs used | Typical PCB content                  | Notes                                                                                                                                                                                                 |
|------------------------------------|-----------------------------|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Askarel transformer oil            | 48% of PCBs produced were used as transformer oil | 40-80% pure PCBs in fluid and ~900 L of fluid per transformer | - Most significant use of PCBs due to high concentrations and volumes used in transformers  
   - “Askarel” is generic name for chlorinated hydrocarbon-containing dielectric fluid  
   - PCB askarel transformers were significantly more costly than conventional mineral oil transformers, so in US they only constituted about 5-10% of the market in 1950s-1970s, however they were required by fire safety regulations for indoor transformers that were not encased in a fireproof concrete vault. |
| Mineral oil transformers           | No intentional uses        | 50-500 mg/kg PCBs in mineral oil fluid | - Do not have PCB intentionally added to dielectric fluid, but dielectric fluid may be contaminated with PCBs if the transformer previously held askarel fluid |
| Capacitor dielectric fluid         | 21% of PCBs produced used in capacitors | Pure PCB dielectric fluid | - Small capacitors (<1.5 kg of dielectric) are used in electrical equipment (fluorescent lights, TVs, small motors), while larger capacitors were independent units in electricity distribution systems.  
   - In USA, about 95% of the capacitors produced during the 1960s and 1970s contained PCBs  
   - in 1979 it was estimated that there were 9.5 million pieces of equipment in USA containing PCB capacitors |
| Other electrical equipment with dielectric fluid | N/A                         | Variable, up to 100% PCBs           | - Other electrical equipment (including light ballasts, switches, circuit breakers, voltage regulators, chokes, electromagnets, mining electric motors and submersible well pump motors) can also contain PCB dielectric fluid |
| Other industrial systems | 10-20% of total PCB use$^{10}$ | - hydraulic systems, such as those used in steel manufacturing and die casting, used PCBs as a fire safety element  
- Heat transfer systems used PCB fluids, and natural gas pipelines used PCBs as a working fluid in compressors.$^7$  
- These systems have significant potential for release and spills due to high pressures, moving elements and flushing of the systems.$^7$

| Open applications | between 5-30% of uses in different regions.$^8,^{10}$ | - Open applications include waxes and resins;$^{11}$ carbonless copy paper; construction sealants, caulking, and coatings,$^{12,13}$ including windshield sealants on vehicles; lubricants, exterior paints;$^{14,15}$ cable insulation;$^{16}$, gaskets and roofing materials.$^7,8$  
- this is typically the most poorly documented type of PCB use, despite clear evidence of environmental release.$^{17–19}$ |
Text S1: Extrapolations of total PCB use from Breivik et al.¹

Total national amounts of PCBs from Breivik et al.¹ are given for a set of 22 congeners (PCBs 5, 8, 18, 28, 31, 52, 70, 90, 101, 105, 110, 118, 123, 132, 138, 149, 153, 158, 160, 180, 194, and 199). To allow comparisons with remaining national stocks of pure PCBs, which cover all congeners, we have recalculated the national totals from Breivik et al. to reflect the sum of all PCB congeners. This involved multiplying all national totals by a factor of 2. This value is based on the contribution of the 22 congeners selected by Breivik to the technical mixtures of Aroclor, Delor, Clophen, Kanechlor and Sovol, representing the major technical PCB mixtures used globally, which range from 37-60%.

The congener composition of Delor mixtures was taken from Taniyasu et al.²⁰, and the Σ22PCBs of Breivik et al. represented 42, 43, 57, and 61% of the ΣPCBs in Delor 103, 104, 105, and 106, respectively. The congener composition of Aroclor mixtures was taken from Frame et al. ²¹, and the Σ22PCBs of Breivik represented 42, 40, 38, 55, and 48% of Aroclor 1016, 1242, 1248, 1254, and 1260, respectively. The congener composition of Clophen mixtures was taken from Takasuga et al. ²², and the Σ22PCBs of Breivik et al. represented 45, 37, 54, and 54% of Clophen A-30, A-40, A-50, and A-60, respectively. The congener composition of Kanechlor mixtures was taken from Takasuga et al. and the Σ22PCBs of Breivik et al. represented 41, 38, 57, and 57% of KC-300, KC-400, KC-500, KC-600, and KC-1000, respectively. The congener composition of Sovol was taken from Wyrzykowska et al. ²³ and the Σ22PCBs of Breivik et al. represented 53% of Sovol mixture.

Text S2: Methods used to compile PCB inventory for Ontario, Canada

Canadian Federal PCB Database. The federal “ePCB” reporting system, launched in 2015 by Environment and Climate Change Canada (ECCC), lists the sites of PCB holdings/records in-use and in-storage from materials containing PCBs in concentrations >50 mg/kg. Data reported under Subsections 33(1), 33(3), 33(4), 37 and 38 of the PCB regulations (SOR/2008-273) were used to identify closed sources that were in-use and in-storage as of December 31, 2016. Materials under sections 33, 37 and 38 contain insulating fluids such as PCB-containing Askarel fluid and mineral oil. Data reported under section 35 (colouring pigments) was not used in this investigation as the quantity of pigments was not reported and open sources are not otherwise included in our estimates.

In the Canadian databases, some PCB fluids were reported in litres. The densities of Askarel and mineral oil used to convert volume of PCB-material to mass, were based on data from Diamond et al. 2010 (Table S2). Records identified as having concentrations over 500 mg/kg were assumed to be askarel-containing equipment, and converted from volume to mass using 1.5 kg/L. Records identified as having concentrations between 50-500 mg/kg were assumed to contain mineral oil, and were converted using 0.9 kg/L. Items identified as bushings all had known concentrations, and although the reported concentrations for the bushings were greater than 500 mg/kg, the density conversion for mineral oil was used based on the reported literature identifying that bushings are typically surrounded by mineral oil ²⁴,²⁵.

MOECP PCB Database. In Ontario, the Ontario Ministry of the Environment, Conservation and Parks manages the PCB waste database under the Environmental Protection Act R.R.O. 1990, Regulation 362: Waste Management- PCBs. The most recent inventory includes PCB waste storage sites reported as of 2013. Waste is reported under four categories: liquids drained from electrical equipment, mass of electrical equipment, soil/gravel, and other waste. However, 22% of the database had incomplete entries. To evaluate
the potential importance of these missing entries, we substituted the mean reported weight of materials in the database for each category, assuming a normal distribution. Based on this calculation, the sum of the missing estimates accounted for only 0.15% of the total stock. Therefore, we did not pursue these missing PCB stocks further.

*Estimates of pure PCB concentrations* The available data from both the federal and provincial databases were combined to give total estimate of the in-use, stored, and waste stock of PCB materials in Ontario. Amounts of pure PCBs contained in the materials were estimated based on the assumptions in Table S5.

Table S4 – Low and high concentrations used to estimate mass of pure PCBs for Canadian databases

| PCB material category | Low bound | Mid | High |
|-----------------------|-----------|-----|------|
| Transformer – high level → assumed to indicate askarel transformer | 400000 | 600000 | 800000 |
| Transformer – low level → assumed to be mineral oil transformer | 50 | 300 | 500 |
| Capacitor | Assumed to be 100% PCBs |
| Bushings | All items have known concentration reported |
| Other materials – high level | 500 | 5000 | 10000 |
| Other materials – low level | 50 | 250 | 500 |

Table S5 – Concentration assumptions and estimated mass per item used for Czech inventory estimates

| Category | Number of items | Mass of PCB liquid/solid (kg) | Assumed mass/item | Assumed concentration range | Lower bound conc. | Mid-point conc. | Upper bound conc. |
|----------|-----------------|-------------------------------|-------------------|-----------------------------|------------------|----------------|------------------|
| Transformers | 80           | 91101                         |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Capacitors | 648            | 10871                          |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Chokes | 2                  | 400                             |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Switches | 2                | 1200                            |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| VTI | 7                | 593                             |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| CTI | 10               | 700                             |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Combined transformer | 6           | 600                             |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Circuit breaker | 55          | 3502                            |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Other electrical | 28         | 4637                            |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Machinery | 1                | 600                             |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Other equipment | 11          | 2170                            |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Barrel of liquid | 1            | 200                             |                   | 50-500 ppm according to EU report or 50-10000 ppm according to CENIA | 50 | 500 | 10000 |
| Equipment 50-500 ppm | 3470 | 1011822                       | Stated range 50-500 ppm | 50 | 250 | 500 |
| Small equipment | 2254 | 14355                         | Assumed many are small capacitors, so could be up to 100% PCB content | 50 | 10000 | 100000 |
### Table S7 – EPA PCB Annual Report Disposal Data 1996-2018 categorized by type of wastes

| Year   | Capacitors | Circuit transformer | Combined transformer | Transformers | Total |
|--------|------------|---------------------|----------------------|--------------|-------|
| 2018   | 1,051,879  | 49,697,310          | 785,317              | 3,045,420    | 1,016,530,244 |
| 2017   | 1,260,467  | 2,214,768           | 380,678              | 46,541       | 1,343,395,538 |
| 2016   | 2,015,879  | 1,318,643           | 402,243              | 7,792        | 2,616,171,501 |
| 2015   | 3,535,912  | 2,232,960           | 406,052              | 12,018       | 5,041,376,097 |
| 2014   | 25,972,274 | 49,697,310          | 1,065,703,360        | 30,304       | 26,972,274,244 |

### Table S6 – USA EPA Transformer database – see excel file included with Supplementary Information

### Table S8 – EPA PCB Annual Report Disposal Data 1996-2018 total wastes disposed per year

| Year | in kg | in # of items |
|------|-------|---------------|
| 1996 | 800,061,833 | 127,061       |
| 1997 | 547,331,834 | 118,371       |
| 1998 | 619,605,094 | 100,719       |
| 1999 | 688,569,711 | 112,830       |
| 2000 | 760,907,286 | 84,597        |
| 2001 | 296,162,978 | 88,445        |
| 2002 | 363,343,541 | 68,650        |
| 2003 | 363,935,140 | 105,647       |
| 2004 | 439,608,227 | 52,858        |
Oracle Crystal Ball v11.1 was used to apply a Monte Carlo analysis to estimate the likely range of the inventory given the uncertainties in the calculations for the federal ePCB and provincial MOECC PCB databases (Tables S9, S10). Distribution assumptions for concentration and density were rectangular, except for the density of bushings. Bushings are more likely to be surrounded by mineral oil, therefore the distribution was triangular, weighted more heavily on the lower range (Jonsson & Johansson, 2009; Harlow, 2011). After 10,000,000 trials, the mean and 95% confidence interval (CI) were recorded. The distribution output of trials is shown in Figures S3 and S4. The results from the sensitivity analysis are shown in Table S9 and S10.

Table S9 – Sensitivity analysis of assumptions used to estimate the Ontario federal ePCB (in-use, in-storage) inventory

| Assumptions                        | Distribution | Sensitivity |
|-----------------------------------|--------------|-------------|
| Concentration Range 500-1000 mg/kg | Rectangular  | 0.00        |
| Concentration Range 500-32,000 mg/kg | Rectangular  | 0.19        |
| Concentration Range 500-800,000 mg/kg | Rectangular  | 0.98        |
| Concentration Range 50-500 mg/kg   | Rectangular  | 0.03        |
| Density conversion 0.9-1.5 kg/L    | Rectangular  | 0.03        |
| Density conversion (Bushings) 0.9-1.5 kg/L | Triangular  | 0.02        |

Table S10 – Sensitivity analysis of assumptions used to estimate the Ontario MOECC PCB (waste) inventory

| Assumptions                        | Distribution | Sensitivity |
|-----------------------------------|--------------|-------------|
| Concentration Range 10,000- 800,000 mg/kg | Rectangular  | 0.41        |
| Concentration Range 10,000-32,000 mg/kg | Rectangular  | 0.00        |
| Concentration Range 50-10,000 mg/kg   | Rectangular  | 0.90        |
| Density Conversion                 | Rectangular  | 0.08        |
Figure S3 – Statistical Distribution of Ontario In-Use, In-Storage Pure PCB Stock (kg)

Figure S4 – Statistical Distribution of Ontario Pure PCB Waste Stock (kg)
Figure S5 – Colorblind accessible version of manuscript Fig. 2: Global PCB use and management. Fig. S5A shows the total PCB consumption by country over the duration of the period 1930-2000 based on data from Breivik et al.11 extrapolated to total PCBs according to Text S1. Figure S6 presents the same data presented as per capita consumption. Fig. S5B shows the current status of PCB management according to the latest reported status for each country, compiled from Stockholm Convention reporting and other sources. Sources used are given in Table S3. NIP indicates Stockholm Convention National Implementation Plan.
Table S11 – PCB stock estimates for Ontario, USA, and Czechia

| Type of equipment | Stock (Years of latest inventories) | Ontario, Canada (2013-2016) | USA (2020) | Czechia (2016-2017) |
|-------------------|-----------------------------------|-----------------------------|-------------|---------------------|
| Transformers      | Total number of items             | 384                         | 11577       | 17127               |
|                   | Bulk mass (tonnes)                | 58.5                        | 13800       | 5700                |
|                   | Estimated mass of pure PCBs (tonnes) (estimated range) | 25 (17-34) | 776 (517-1040) | 2.59 (0.28-47.3) |
| Capacitors        | Total number of items             | 392                         | NA          | 2902                |
|                   | Bulk mass (tonnes)                | 4.0                         | NA          | 25.23               |
|                   | Estimated mass of pure PCBs (t) (estimated range) | 4.0 | NA | 0.15 (0.001-14) |
| Other equipment   | Total number of items             | 257                         | NA          | 1275                |
|                   | Bulk mass (tonnes)                | 65.6                        | NA          | 36.7                |
|                   | Estimated mass of pure PCBs (t) (estimated range) | 0.015 (0.004-0.03) | NA | 0.018 (0.002-0.37) |
| Other stored materials | Total number of locations | 310                         | NA          | 2                    |
|                   | Bulk mass (tonnes)                | 387                         | NA          | 338                 |
|                   | Estimated mass of pure PCBs (t) (estimated range) | 0.327 (0.041-0.655) | NA | 0.084 (0.017-0.17) |
|                      | Soil/gravel | Total |
|----------------------|-------------|-------|
| Total number of locations | 276         | NA    |
| Bulk mass (tonnes)    | 11800       | NA    |
| Estimated mass of pure PCBs (t) (estimated range) | 2.960 (0.589-5.910) | NA    |
|                      |             |       |
| Total number of items | 1619        | 11577 | 21306 |
| Bulk mass (tonnes)    | 12300       | 13800 | 6092  |
| Estimated mass of pure PCBs (t) (estimated range) | 32.4 (21.4-44.1) | 776 (517-1040) | 2.85 (0.30-62.3) |
| Bulk mass/capita (kg) | 0.91         | 0.041229 | 0.577 |
| Estimated pure PCBs/capita (g) | 2.45       | 2.324704 | 0.27  |
References

(1) Breivik, K.; Sweetman, A. J.; Pacyna, J. M.; Jones, K. C. Towards a Global Historical Emission Inventory for Selected PCB Congeners—a Mass Balance Approach. 1. Global Production and Consumption. Sci. Total Environ. 2002, 290 (1–3), 181–198.

(2) Democratic People’s Republic of Korea. National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants; Pyongyang, 2008.

(3) UNEP. Consolidated Assessment of Efforts Made Towards the Elimination of Polychlorinated Biphenyls
https://wedocs.unep.org/bitstream/handle/20.500.11822/31249/PCBAs.pdf?sequence=1&isAllowed=y.

(4) Secretariat of the Stockholm Convention. Stockholm Convention on Persistent Organic Pollutants - Text and Annexes; 2020.

(5) UNEP. Listing of the Basel Convention Technical Guidelines for Environmentally Sound Management (ESM) of Persistent Organic Pollutants (POPs) Wastes. 2005.

(6) Wagner, U. K. Inventories of PCBs: An Expert’s Point of View. PEN Mag. 2010, No. 1.

(7) US EPA. PCB Inspection Manual; Washington D.C., 2004.

(8) Erickson, M. D.; Kaley, R. G. Applications of Polychlorinated Biphenyls. Environ. Sci. Pollut. Res. 2011, 18 (2), 135–151.

(9) Canadian Council of Ministers of the Environment. PCB Transformer Decontamination. CCME EPC-HW-105E: Ottawa 1995, p 35.

(10) UNEP. Guidelines for the Identification of PCBs and Materials Containing PCBs. United Nations Environ. Program. 1999, No. August, 40.

(11) Rudel, R. A.; Seryak, L. M.; Brody, J. G. PCB-Containing Wood Floor Finish Is a Likely Source of Elevated PCBs in Residents’ Blood, Household Air and Dust: A Case Study of Exposure. Environ. Heal. 2008, 7, 2.

(12) Persson, N. J.; Pettersen, H.; Ishaq, R.; Axelman, J.; Bandh, C.; Bromman, D.; Zebüh, Y.; Hammar, T. Polychlorinated Biphenyls in Polysulfide Sealants—Occurrence and Emission from a Landfill Station. Environ. Pollut. 2005, 138 (1), 18–27. https://doi.org/10.1016/j.envpol.2005.02.021.

(13) Robson, M.; Melymuk, L.; Csiszar, S. A.; Giang, A.; Diamond, M. L.; Helm, P. A. Continuing Sources of PCBs: The Significance of Building Sealants. Environ. Int. 2010, 36 (6), 506–513. https://doi.org/10.1016/j.envint.2010.03.009.

(14) Gill, C. G.; Kuipers, B.; Simpson, C. D.; Lai, V. W. M.; Reimer, K. J.; Cullen, W. R. PCBs from Old Paint? Environ. Sci. Technol. 1997, 31 (8), 1997.

(15) ELSA. PCB in Der Elbe, Eigenschaften, Vorkommen Und Trends Sowie Ursachen Und Folgen Der Erhöhten Freisetzung Im Jahr 2015. 2016, No. September.

(16) Cleghorn, H. P.; Caton, R. B.; Groskopf, N. W.; Pilger, C. W. Production of Dibenzofuran Fumes during Splicing of PCB Contaminated Electrical Cable. Chemosphere 1990, 20 (10), 1517–1524. https://doi.org/https://doi.org/10.1016/0045-6535(90)90306-E.

(17) Marek, R. F.; Thorne, P. S.; Herkert, N. J.; Awad, A. M.; Hornbuckle, K. C. Airborne PCBs and OH-PCBs Inside and Outside Urban and Rural U.S. Schools. Environ. Sci. Technol. 2017, 51 (14),
(18) Kohler, M.; Tremp, J.; Zennegg, M.; Seiler, C.; Minder-Kohler, S.; Beck, M.; Lienemann, P.; Wegmann, L.; Schmid, P. Joint Sealants: An Overlooked Diffuse Source of Polychlorinated Biphenyls in Buildings. *Environ. Sci. Technol.* **2005**, *39* (7), 1967–1973.

(19) Frederiksen, M.; Meyer, H. W.; Ebbehøj, N. E.; Gunnarsen, L. Polychlorinated Biphenyls (PCBs) in Indoor Air Originating from Sealants in Contaminated and Uncontaminated Apartments within the Same Housing Estate. *Chemosphere* **2012**, *89* (4), 473–479.

(20) Taniyasu, S.; Kannan, K.; Holoubek, I.; Ansorgova, A.; Horii, Y.; Hanari, N.; Yamashita, N.; Aldous, K. M. Isomer-Specific Analysis of Chlorinated Biphenyls, Naphthalenes and Dibenzofurans in Delor: Polychlorinated Biphenyl Preparations from the Former Czechoslovakia. *Environ. Pollut.* **2003**, *126* (2), 169–178.

(21) Frame, G. M.; Cochran, J. W.; Bøwadt, S. S. Complete PCB Congener Distributions for 17 Aroclor Mixtures Determined by 3 HRGC Systems Optimized for Comprehensive, Quantitative, Congener-Specific Analysis. *J. High Resolut. Chromatogr.* **1996**, *19* (12), 657–668.

(22) Takasuga, T.; Senthilkumar, K.; Matsumura, T.; Shiozaki, K.; Sakai, S. I. Isotope Dilution Analysis of Polychlorinated Biphenyls (PCBs) in Transformer Oil and Global Commercial PCB Formulations by High Resolution Gas Chromatography-High Resolution Mass Spectrometry. *Chemosphere* **2006**, *62* (3), 469–484. https://doi.org/10.1016/j.chemosphere.2005.04.034.

(23) Wyrzykowska, B.; Bochentin, I.; Hanari, N.; Orlikowska, A.; Falandysz, J.; Yuichi, H.; Yamashita, N. Source Determination of Highly Chlorinated Biphenyl Isomers in Pine Needles - Comparison to Several PCB Preparations. *Environ. Pollut.* **2006**, *143* (1), 46–59. https://doi.org/10.1016/j.envpol.2005.11.018.

(24) Jonsson, L.; Johansson, R. *High-Voltage Bushings: 100 Years of Technical Advancement*; 2009.

(25) Harlow, J. H. *Electric Power Transformer Engineering, Third Edition*; CRC Press: Boca Ruton, Florida, 2011.

(26) Shu-Yin, A.; Diamond, M. L.; Melymuk, L.; Spak, S. N. *PCB Inventory in the Great Lakes Region*; Toronto, Canada, 2018.