Thailand's POPs Inventory Assessment Report

Part 2:
Thailand's 2019
POPs Industrial Chemicals Inventory

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Cover image: "Mountain of PC CRT cases" by N. Ramungul (c) 2019

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List of Acronyms and Abbreviations

ABS	Acrylonitrile butadiene styrene
AFFF	Aqueous film forming foam
AOT	Airport Authority of Thailand
AR-AFFF	Alcohol resistant-aqueous film forming foam
ATR	Attenuated total reflectance
BB	Brominated biphenyls
BDE	Brominated diphenylethers
BEL	Belgium
BFR	Brominated flame retardants
BTBPE	1,2-Bis(2,4,6-tribromophenoxy)ethane
CAS	Chemical Abstracts Service
CHN	China
CI	Confidence interval
CID	Chemical identification
CiP	Chemical in product
CN	Chlorinated napthalenes
COP	Conference of Parties
CRM	Certified reference materials
CRT	Cathode ray tubes
DBDPE	Decabromodiphenyl ethane
DEHP	Bis(2-ethylhexyl) phthalate
DEQP	Department of Environmental Quality Promotion
DEU	Germany
DIW	Department of Industrial Works
DLT	Department of Land Transports
DOA	Department of Agriculture
DOEB	Department of Energy Business, ministry of energy
EBTBP	Ethylene bis(tetrabromophthalimide)
ECHA	European Chemical Agency
ECS	Environmental and chemical safety
EDC	Ethelene dichloride (also known as dichloroethane)
EDXRF	Energy dispersive X-Ray fluorescent spectroscopy
EE	Electrical and electronics
EEE	Electrical and electronic equipment
EFSA	European Food Safety Authority
EOL	End-of-life
EPS	Expanded polystyrene
ERTC	Environmental Research and Training
EU	European Unions
FMVSS	Federal Motor Vehicle Safety Standards
FOSA	Perfluorooctane sulfonamide
FPD	Flat panel displays

FR	Flame retarded, Flame retardant
FTI	The Federation of Thai Industries
GCMS	Gas chromatograph-mass spectrometry
GPPS	General purposes polystyrene
HA	Home appliances
HBB	Hexabromobiphenyl
HBCD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCBD	Hexachlorobutadiene
HFC	Hydrofluorocarbons
HIPS	High impact polystyrene
HS	Hazardous substance
HS-Code	Harmonized system of tariff nomenclature code
HSDB	Hazardous Substances Data Bank
IEC	International Electrotechnical Committee
IEEE	Institute of Electrical and Electronics Engineers
IMDS	International Material Data System
ISO	International Standards Organization
JGPSSI	The Japan Green Procurement Survey Standardization Initiative
JPN	Japan
LCP	Liquid crystal polymer
LF	Landfill
LOI	Limited oxygen index
LTA	Land Transport Act
LTR	Liter
MCCPs	Medium-chain chlorinated paraffins
M-Industry	Ministry of Industry
MNRE	Ministry of Natural Resources and Environment
MOPH	Ministry of Public Health
MTEC	National Metal and Materials Technology Center
NBFR	Novel brominated flame retardants
NSO	National Statistical Office
NSTDA	National Science and Technology Development Agency
OECD	The Organisation for Economic Co-operation and Development
OIE	Office of Industrial Economics
ONEB	Office of National Environment Board
PA	polyamide
PAHs	Polycyclic aromatic hydrocarbons
PBBs	Polybrominated biphenyls
PBDEs	Polybronated diphenylethers
PBT	Polybutylene terephthalate
PC	Polycarbonate
PCA	Principle component analysis
PCBs	Polychlorinated biphenyls
PCD	Pollution Control Department

PCNs	Polychlorinated napthalenes
PCNB	Polychlorinated nitrobenzene (also known as Quintozene)
PCPs	Pentachlorophenols
PFAS	Per- and polyfluorinated alkylated substances
PFCs	Perfluorocarbons
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PIR	Polyisocyanurate
POPs	Persistent organic pollutants
POPRC	Persistent Organic Pollutants Review Committee
PRTR	Pollutant release and transfer register
PS	Polystyrene
PTIT	Petroleum Institute of Thailand
PU, PUR	Polyurethane
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
SC	Stockholm Convention
SCCPs	Short-chain chlorinated paraffins
SVHC	Substances of very high concerns
TAPMA	Thai Auto Parts Manufacturing Association
TBBPA	Tetrabromobisphenol A
TCE	Trichloroethylene
TEA-PFOS	Tetraethylammonium perfluorooctane sulphonate
TEPNET	Thai Electroplating Professional Network
TEQ	Toxic equivalent
THTI	Thailand Textile Institute
TIS	Thai Industrial Standard
TISI	Thai Industrial Standards Institute
TV	Television
UNEP, UN Environment	The United Nations Environment Programme
US	United States of America
VOC	Volatile organic compound
VTM	Vertical thin material
WEEE	Waste of electrical and electronic equipment
WHO	World Health Organization
WWTP	Wastewater treatment plants
XPS	Extruded polystyrene

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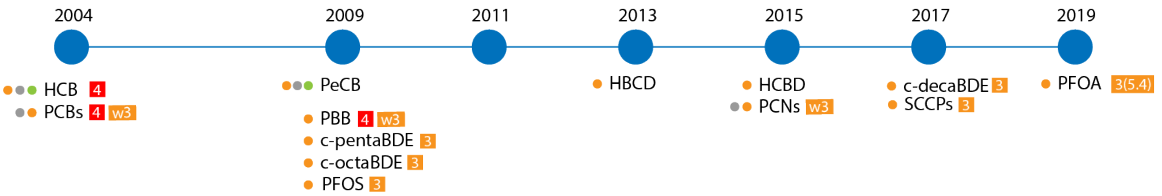

Numbers in square brackets indicate the substances are listed as hazardous substances in Thailand

Summary of assessment results

Thailand ratified the Stockholm Convention (SC) on Persistent Organic Pollutants (POPs) on 31 January 2005. The Convention initially included 12 chemical substances or groups of substances, 2 of which were industrial chemicals listed in Annex A (for elimination). As of 2019, the SC has subsequently added 11 more POPs industrial chemicals; 10 substances to Annex A and 1 substance to Annex B (for restriction).

Thailand has compiled its first industrial POPs inventory in 2006. Based on information gained from the first inventory report, the Thai government had developed and implemented its National Implementation Plan (NIP) to fulfill its obligations under the convention. Since the last study was completed more than 10 years ago, an update of industrial POPs inventories is required to better reflect current situations as well as new knowledge accumulated over the years.

This study is intended to be a preliminary POPs industrial chemicals inventory study, covering relevant activities that took place in Thailand up to 2019. It aims to gather baseline information for the 9 newly listed POPs industrial chemicals up to the year 2017 (not include SCCPs). Due to limitation in both time and resources, this study does not intend to provide precise figures for each POPs nor does it investigate specific chemical substances down to congener level. Instead it aims to provide general idea of the current situation concerning these chemicals to support policy makers in their decisions to mitigate risks and to fulfill Thailand's obligations toward the Stockholm Convention.

Hexabromobiphenyl (HBB)

Hexabromobiphenyl (HBB, CAS No 36355-01-8) can be considered a legacy chemical, with no new production for decades. Thailand never produced this substance and there is no data to suggest that HBB had ever been imported into or used in Thailand. HBB was totally banned as a Category 4 substance under the Thai Hazardous Substance Act (HSA) since 2013. No report of any detection of HBB in food chain or in any of Thailand's environmental media was found. HBB is, therefore, considered irrelevant for Thailand.

Tetrabromodiphenyl ether and pentabromodiphenyl ether (c-pentaBDE)

Tetrabromodiphenyl ether and pentabromodiphenyl ether (or commercial pentabromodiphenyl ether, c-pentaBDE) is also a historical substance with production ceased over 15 years ago. Thailand never produced this substance. There is no record of c-pentaBDE ever been imported into or used in Thailand. C-pentaBDE was listed as Category 3 HS in 2017. At the time of this report, no firm filed any request to process or to handle this substance. Additionally, since worldwide production of c-pentaBDE was ceased more than 15 years ago, stockpile of c-pentaBDE in Thailand is believed to be zero.

Thailand's only involvement with c-pentaBDE is believed to be through imports of transport vehicles that may contain c-pentaBDE (produced before 2005), possibly in their seats and interior fabrics. The cumulative amount of c-pentaBDE imported into Thailand via these vehicles is estimated at **1.5 tonnes**. These contaminated materials are believed to have reached end-of-life and have been replaced with locally produced parts. The removed materials are believed to be discarded as municipal solid waste (MSW); which could be landfilled, incinerated or open-dumped depending on the MSW management system available to the relevant community.

Hexabromodiphenyl ether and heptabromodiphenyl ether (c-octaBDEs)

Polybrominated diphenylethers (PBDEs) were imported into Thailand in the 1990s to produce UL 94 V0 grade acrylonitrile butadiene styrene (ABS) resins. However, due to the lack of supplier data disclosure in the past, the type of these PBDEs could not be confirmed. Since these ABS resins were produced 20-30 years ago (before the widespread uses of computers and database management system to store industrial transactions), information related to the type of the end-use product or the final market destinations were no longer traceable.

C-octaBDE was listed as Category 3 HS in 2017. At the time of this report, no firm filed any request to process or to handle this substance. Since worldwide production of c-octaBDE was ceased more than 15 years ago, stockpile of c-octaBDE in Thailand is believed to be zero.

Due to the lack of historical data, the inventory team developed a predictive model to estimate the levels of octaBDE based on results from a product survey for the type of BFR used in everyday products and the corresponding wastes found at waste management sites. From over 500 parts/devices found positive for brominated flame retardants (BFR), only two samples were found positive for octaBDE; one was ABS casing from a high-end computer monitor, another was polystyrene (PS) casing taken from a CRT TV imported from an Asian country. Both products were produced in the 1990s.

Based on the developed model, the total amount of octaBDE in the affected ABS is estimated at 12 tonnes. Most of these products are believed to have reached end-of-life, leaving about 1,000 monitors, with **about 300 kg of octaBDE remained in hibernation**.

ABS resins extracted from end-of-life (EOL) monitors are shredded and sold as recycled ABS chips, with ABS-V0 grade can command higher price than general grade. Most of the ABS-V0 chips found in Thailand were flame retarded with tetrabromo bisphenol-A (TBBPA), in-line with results for BFRs in house dusts and in e-waste dismantle sites published in the literatures. Nevertheless, ABS-V0 chips with octaBDE may still be found especially those from recycle shops located in the central part of the country.

Decabromodiphenyl ether (c-decaBDE)

Before listing in Annex A of the Stockholm convention, decaBDE used to be a popular flame retardant. Unlike other SC's industrial POPs, worldwide production and sale of decaBDE have not yet ceased. C-decaBDE may have been imported into Thailand in the past but due to the non-unique import classification code, the amount of decaBDE ever imported into the country was unknown. C-decaBDE was recently listed as Category 3 HS in 2019. Though, during 2015 to 2017 DIW received (voluntary) notifications for the intentions to import about 70 tonnes of decaBDE. However, since decaBDE was not a controlled substance at the time, it was uncertain whether or not the notified activities were actually taken place.

Results from questionnaire survey indicated that producers along the electrical and electronic (EEE) supply-chain had phased-out the use of c-decaBDE since 2006, as a result of the enforcement of the EU RoHS directive. This result could imply historical uses. It was not clear whether or not the compounding of the affected resins took place in Thailand. Nevertheless, since the phase-out was commenced more than 10 years ago, stock of decaBDE for these historical uses (if exist) may already be exhausted.

Results from field survey suggested that decaBDE may find other uses in applications that faced lower restriction such as upholstery and drapery textiles, rubbers and silicone parts. Also, the survey found BFR in interior textiles and underhood parts in several passenger cars. It is not known whether these flame retarded materials were imported or locally produced. With limited responses from stakeholders and limited access to material samples, the type of the BFR cannot be confirmed at this time.

The uses of decaBDE were confirmed for polystyrene (PS) housings of CRT TVs produced before 2006. The number of the affected TVs is estimated at 5 million sets. The corresponding amount of PS resins that contained decaBDE is estimated at 10,000 tonnes and the total amount of decaBDE is estimated at 920-1,500 tonnes. About half of this amount is believed to be already disposed of; leaving about **500-820 tonnes** remaining 'in-stock' in the in-use and in-hibernation products.

The affected PS resins are recycled along with other plastic resins that can be extracted from e-waste. The concentrations of decaBDE in the shredded PS chips and, consequently, the recycled PS pellets depend on the feedstock that arrived at the recycle shops. While decaBDE concentrations in most batches tested were low, concentration in black PS-V0 chips can be high. Due to low demands from local compounders, these recycled materials are believed to be exported.

Apart from PS from CRT TVs, this assessment found traces of decaBDE in shredded PS chips from other applications. Unfortunately, the source of these chips cannot be confirmed at this time. This assessment also found TBBPA the most popular BFR for casings of computer's CRT monitors found in Thailand. As for decaBDE in other WEEE components, this study did not yet find decaBDE in other rigid polymeric resins other than PS.

For decaBDE uses in textile applications, the average amount of decaBDE in flame retarded fabrics is estimated at **300 kg per year** and the cumulative amount of decaBDE in impregnated fabrics that are in use-phase is estimated at **3 tonnes**.

DecaBDE can be released from the affected products at any stage throughout products' life-cycle. Results from an emission model suggested that the releases from EEE in form of dust are now shifting from the use-phase to the dismantling and recycling facilities. Moreover, the model indicates residues from EOL management will become an important emission source of decaBDE in the next 10 years.

Plastic resins extracted from casings of e-waste are likely recycled. Due to the relatively high values of the affected resins, most of the decaBDE in polymeric resins are likely recirculated along with these engineering plastics. Half of the relevant amount was believed to have been returned to material cycle while the fate of the remaining half is still unclear.

Hexabromocyclododecane (HBCD)

HBCD is not manufactured in Thailand but imported by expanded polystyrene foams (EPS) beads producers to be used as a flame retardant in self-extinguish grade EPS (SE-grade EPS) to produce EPS-core sandwich panels in applications such as cold storage and cleanroom, etc.

There are two local EPS beads producers, producing about 12,000 tonnes of SE-grade EPS beads per year. Based on local EPS beads production capacity and EPS beads import/export statistic, the total amount of HBCD contaminated SE-grade EPS is estimated at 175,000 tonnes, with the corresponding amount of HBCD of about **1,300 tonnes** [890-1,770 tonnes]. Most of the relevant amounts of HBCD are believed to remain within SE-grade EPS foams which are currently in the use phase.

There is no information related to HBCD uses for other purposes. Local industries have been unable to provide information on their involvement. Samples with HBCD were yet to be found. Furthermore, there is no report of detecting HBCD in environment media. Nevertheless, considering the large scale of the ‘likely’ relevant products, the number of samples explored was still too low to arrive at any conclusion.

HBCD was no longer imported into Thailand after key global manufacturers terminated their productions, though HBCD may still be available from certain area[1]. Local EPS bead producers have ceased to use HBCD and, instead used Polymeric FR (CAS No 1195978-93-8) – a novel substance offered by the same suppliers as a drop-in substitute for HBCD. Because EPS beads have a limited useful life of about 6 months, the affected EPS beads are expected to remain in the market only shortly after the phase-out of HBCD.

At the time of this report, HBCD is not yet a ‘classified’ substance under the HSA. Consequently the low POPs content for HBCD has not been established and, hence, waste containing HBCD is not yet classified as hazardous waste. Nevertheless, HBCD’s inherent hazards meet the requirements for voluntary declaration under DIW’s ‘list 5.6’. In 2016 a local distributor filed an intention to import about 8 tonnes of HBCD for EPS foam application. This is presumed to be the last import.

PS foams may be recycled and re-entered material cycle, possibly as general purpose polystyrene resins (GPPS). As the uses of SE-grade EPS foams are not yet widespread in Thailand and the installed panels are yet to reach end-of-life phase, the level of HBCD affected GPPS is presumed to be low. HBCD in articles made of GPPS was not yet found. Still, it is important to set a low POPs content for HBCD, in line with provisions developed by the Basel convention, to prevent HBCD from re-entering material cycle, as a substance or as a contaminant in PS resins/articles.

Because flame retarded and non-flame retarded EPS foams cannot be distinguished by physical appearance, it is imperative that the affected foams or panels be clearly marked to allow for easy identification, in line with the provisions of Part VII of Annex A of the SC. It is also necessary to identify appropriate disposal routes and develop guidance for the decommissioning and disposal of the affected panels to protect workers from the exposure to HBCD and to prevent further releases to the environment. As Thailand is making a transition toward a more circular economy, proper marking of BFR in products will remain an important

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[1] An online search on March 3rd, 2020 found HBCD (CAS No 3194-55-6) was available for sale at a very cheap price (1$/t).

measure to avoid unnecessary risk of cross-contamination of substances of potential concerns into sensitive products (such as food packaging, buoy, etc.) even after the phase-out of HBCD.

Except for the confirmed uses in EPS foams, information related to sources, releases and environmental fate of HBCD at the national level is lacking. Particularly, the levels of exposure of general population as well as workers to HBCD are currently unknown. It is therefore recommended that research studies should be conducted. Particular attentions should be paid to confirm levels of HBCD in following areas:

- Household dust (results from this study can help confirming the uses of HBCD in textiles and other household items)
- Dust and soil in and around e-waste dismantling sites and plastic shredding facilities (results from this study can help confirming the uses of HBCD in rigid polymeric resins, particularly HIPS)
- HBCD in other products/applications (In case the study of indoor dusts indicates possible uses or concerns)
- The releases of HBCD along pre- and post-consumer SE-grade EPS foams value chain (including sludge from wastewater treatment plants).
- Landfills and dump sites leachates and sediments[2]

Finally, once potential sources are confirmed, a full inventory should be conducted to provide an appropriate baseline data for HBCD for the country.

Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F)

PFOS is a surfactant that may be used in Thailand in textile (possibly mainly for export-oriented products), paper (food packaging), metal plating, and firefighting foams applications.

Information from stakeholder interviews indicated that most export-oriented firms had phased-out PFOS since 2009 as a result of the publication of EU's PFOS Directive [1]. Unfortunately, due to long delay in surveying for relevant data, the exact applications, amount used as well as the users cannot be traced. Information from local chemical distributors indicates that some small plating companies still prefer to use PFOS, but information related to the amount uses and the users is not disclosed to the inventory team.

Nine PFOS, its salts, and PFOS-F were recently listed as Category 3 HSs in 2013 and 2017. Based on PFOS-related substances import statistics, the remaining demand for PFOS for plating applications is estimated at **300-400 kg per year**.

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[2] This study should apply for all POPs industrial chemicals, not limited to HBCD.

PFOS was detected in several products sold in Thailand including textiles, sun screen cream and bottled water. There were also reports of detecting PFOS in effluent of industrial wastewater treatment plants, groundwater, surface water and tap water, with the concentration level appeared to associate with the areas where PFOS may have been used.

Results from the survey of PFOS in firefighting foams found possible stockpile of PFOS containing foams in foams stored in petroleum refineries and oil depots that were imported before 2009. The amount of PFOS relevant foams are not available to the inventory team but, based on the amount firefighting stock required by the law, the amount of PFOS relevant firefighting foams is estimated at **<u>3,700 – 5,500 kg</u>**. Apart from petroleum depots, other facilities such as airports and cities fire control departments also keep stock of AFFF foams. However, based on information gained from relevant stakeholders (AOT, the Department of Airports, and city fire stations), none of these foams contain PFOS.

For firefighting training, which is considered the largest PFOS release source that lead to contamination to groundwater, the survey found most fire trainings in Thailand do not use actual foams, due to the high price of firefighting foams. However, expired foams may be used in firefighting trainings in certain high risk areas, such as petroleum complex and nearby industrial estates. Based on interview with industrial estate officers, effluent water both from firefighting trainings and real fire extinguishing within industrial estate are required to be collected and treated at the source before they are allowed to be released to the industrial estate's central wastewater treatment plant. However, in absence of regulatory limit, the level of PFOS in the effluents has never been confirmed.

PFOS can contaminate surface water and groundwater. PFOS leached from sewage sludge can be accumulated in agricultural plants and animals, where they can transfer to humans through the food chain. Existing treatment plants may not be able to handle (remove or destroy) PFOS contaminated inputs. Depending on the sources of the influents and the treatment technique, some types of PFOS, particularly linear and long-chain congeners, may be captured in organic matter fractions and the rest may remain in aqueous phases. Some of the WWTP sewage sludge is being used as soil conditioner. Without analysis results from water and wastewater treatment plants, it is not possible to trace the fate of PFOS at this time.

Based on the assessments, the inventory team identified following areas that could have PFOS but has not been checked and/or controlled

- Wastewater treatment plants that receive wastewater from factory that uses or used PFOS and/or central WWTP that cannot separate incoming water
- WWTP effluent water, effluent from plating plants, sewage

sludge and landfill leachate

- Areas that receive contaminated biosolids, particularly areas where these biosolids are used as soil conditioners
- Soil and groundwater in the affected areas
- Landfills, particularly industrial waste landfills

Responsible parties also need to develop a plan/measure to handle PFOS containing firefighting foams that will become expired over the next 10 years or so to ensure that these foams are contained (including water runoff during fire extinguishing) and disposed of in an environmentally sound and efficient manner.

Hexachloro-butadiene (HCBD)

There is no information related to production and uses of hexachlorobutadiene (HCBD) in Thailand. Since Thailand has no chlorinated solvent production plant, there is no major source for HCBD.

HCBD is not covered in the Pollutant Release and Transfer Registers (PRTR) pilot project, implemented in Rayong Province in 2013. However, HCBD monitoring data appeared in the state of Thailand's pollution reports published between 2006 and 2009 by the PCD (during the survey of 44 volatile organic compounds (VOC)). The results for Bangkok and Rayong provinces found annual average between 0.14 – 0.22 $\mu g/m^3$.

HCBD is listed in DIW's 2016 soil and groundwater standards. Relevant factories[3] are required by the Ministry of Industry's Ministerial Regulation on the control of contamination within factory into soil and groundwater B.E. 2559 (2016) to periodically monitor and report their soil and groundwater quality. However, the underlying criteria for reporting HCBD are not met. At the time of this report, none of the listed factories is required to monitor and report levels of HCBD contamination in their soil and groundwater.

Finally, a search for information in international journals did not yet find a report on the detection of HCBD in environmental media in Thailand.

Polychlorinated biphenyls (PCBs)

PCBs are included in the initial list of POPs under the SC and, hence, had been addressed in Thailand's first NIP. The PCD had periodically submitted reports to the Secretariat in accordance to its obligation under Article 15 of the convention.

Thailand banned PCBs by listing them as Category 4 substances under the HSA in 2003 and 2004, respectively. The ban covers all activities, including the production, import, export or possess of PCBs. The ban also

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[3] 12 Factory Types: 22, 38, 42, 45, 48, 49, 60, 74, 100, 101, 105 and 106

covers devices that contain PCBs.

In 2004, the DIW designated end-of-life devices, transformers and power capacitors that contain PCBs a chemical waste, classified as Category 3 HS. Any production, import, export, or possess of these devices requires prior approval from DIW.

In 2008, the DIW announced a plan to totally phase-out PCBs by 2012. The announcement obligated device holders to prepare and implement a plan to phase-out and completely dispose of PCBs by 2012. Any movement of the affected devices also needed prior approval from the DIW.

Since PCBs oil was not one of the wastes or discarded materials that were allowed to be treated or disposed of by waste management processors, industrial waste incinerators in Thailand were not allowed by law to incinerate PCBs oils. All PCBs oils, therefore, were collected and exported to the third countries (France, the Netherland, etc.) for final destruction. In particular, as reported in Thailand's National Reporting of the Stockholm Convention (Fourth Reporting Cycle), 761 tonnes of PCBs wastes were exported to France(20 t), the United Kingdom (452 t), Belgium (33 t), and other countries (256 t) for final destruction during 1992-2002. Moreover, in 2012, 110 tonnes of transformers contaminated with PCBs and 100 tonnes of waste containing PCB oils were exported to the Netherlands and France for final disposal.

PCBs has been monitored through several activities as follows:

(1) In 2006-2007, the Department of Environmental Quality Promotion (DEQP) studied PCBs in sediments in Chao Praya River, estuaries and upper gulf of Thailand. The study found highest accumulations in areas around Klong Tuy district (Bangkok) and Amphoe Prapradang (Samut Prakarn Province). The level of PCBs, though, was in pg/g (dw) range. This level of contamination was considered low in comparing to similar areas in other countries. The study found no PCBs accumulation in sediments in central areas from Nonthaburi Province upward.

(2) From 2004 to 2009, Ministry of education in collaboration with the Inter-University Program on Environmental Toxicology, Technology and Management of Chulabhorn Research Institute, Asian Institute of Technology and Mahidol University's Center for Environmental Health, Toxicology and Management of Chemical conducted research under the project "The evaluation of PCBs and dioxin -like PCBs contaminated coast of Thailand by using chemical and biological techniques" to assess the accumulation of PCBs in seafood from eastern coast of Thailand. The study found PCBs contaminations in mussels, oyster, and shrimps ranging between 19-1,100 ng/g (lipid adjusted weight),

and the levels of PCBs in shrimp was higher than that in mussels and oysters.

Polychlorinated naphthalenes (PCNs)

In 2013, the DIW designated wastes, substances and articles containing, consisting of or contaminated with polychlorinated biphenyl (PCBs), polychlorinated terphynyls (PCTs), polychlorinated naphthalenes (PCNs) or polybrominated biphenyls (PBBs), or any other polybrominated analogues of these compounds, at a concentration level of 50 mg/kg or more as chemical wastes which are also classified as Category 3 that require prior approval from the DIW. A search in DIW database found no record that could be linked to PCNs.

Apart from this filing, this assessment study did not find any other data related to PCNs in Thailand.

Hexachlorobenzene (HCB) and Pentachlorobenzene (PeCB)

HCB is included in the initial list of POPs under the SC and, hence, had been addressed in Thailand's first NIP. HCB was banned as a Category 4 substance under the HSA in 2003. Moreover, in 2020 M-Industry announced a low POPs limit of 0.005% w/w for HCB as an impurity in other products.

As for PeCB, this assessment study did not find any data/information related to PeCB in Thailand. PeCB is not yet classified as a hazardous substance under HS Act. There is no record to indicate that PeCB was ever produced in Thailand. Except for small amounts imported for research/laboratory purposes, there is no information to whether PeCB ever been imported into Thailand[4]. A search for published articles also found no reports related to PeCB in Thailand.

There is no data to suggest that PeCB had ever been used as an intermediate chemical to produce other chemical substances in Thailand. However, PeCB may be indirectly imported as impurity in PCNB, 2,4-D products, phthalocyanine dyes, and dioxaxine dyes.

Limitation of the study and recommendation

As mentioned earlier, with limitation in both time and resources, this study is classified as a preliminary inventory study. It has limitations in terms of data quality as well as data coverage to determine high risk areas which will be presented here along with recommendation to reduce risk from POPs on basis of the available data.

Data Gap

This study suffers from the lack of historical records/data, particularly data related to chemicals in products, and the amount and flow of these affected products. Since most relevant products were produced and put on

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[4] HS Code 29039300

market during the period when there was no system in place to control chemicals in products, firms had no obligations to gain knowledge and, hence, unaware of chemicals incorporated in their products.

Consumption data for relevant products as well as markets shared by each player/brand were also lacking. Estimations made in this study were largely based on objective evidences gained from products survey and testing of EOL products that were arrived at waste management sites during the project's survey period.

This assessment only focused on large emission sources (e.g., large part size) that are easily encountered in daily life. Apart from BFR in polymeric resins and EPS foams, this assessment determined and reported relevant products (such as textiles) but made no attempt to confirm the type nor did it quantify the relevant amount. There are also other important products that had not been covered under this study. This data gap should be addressed in the upcoming NIP.

Because there is no regulation in place to obligate relevant parties to monitor possible releases from their activities, this assessment lacks important data related to the emissions from factories and/or monitoring data for relevant POPs in important media such as wastewater, sludge, soil, etc. Nevertheless, Thailand's existing legal framework can be updated to address this short comings as follows:

- Add newly listed POPs to the existing laws and standards (drinking water, surface and groundwater, soil, sludge, wastewater)
- Relevant agencies should have system in place to monitor upcoming (emerging) pollutant that may be included in the SC in the future
- Include monitoring of POPs industrial chemicals in environmental media and food and feed in line with the monitoring of POPs pesticides

Difficult to request data from producers after the product already put on market

Without legal obligation, not only that it is difficult to request data related to chemicals in products from producers, the chance of receiving reliable data is slim if the products were already put on market, especially if delayed for more than 5 years.

In case of export products, especially to the EU, producers must inform the next recipient of article of all substances of very high concerns (SVHC) that are embedded in every part of the products. The concern substances do not need to be a restricted/forbidden substance. Furthermore, producers of EEE under the EU RoHS Directive are obligate to keep information related to CiP for at least 10 years to enable data/material flow tracing, when needed. Producers exporting products to the US (California) also need to inform intended customers of the embedded carcinogen and reproductive toxins in the products.

These material declaration systems will help in the tracing of hazardous substances that are embedded in products/articles and help reducing burdens to both public and private sectors from requesting CiP data along supply chain after product put on market.

Since CiP data declaration is become a new norm in the global market, firms who are producing products to serve global market are already required to have a system to collect and communicate CiP along their supply chain. These CiP data and declaration system are crucial elements for the management of chemical and environmental safety throughout product life-cycle. Therefore, relevant authorities should explore and take advantage from this globally established system.

Up-to-date materials (in/out) flow

Factories are required by law to report of their materials input and product/waste output. This information is fundamentally important for chemical and environmental safety management. Materials and products flowing in and out from factories are valuable data for inventory assessment. It is unfortunate that this inventory assessment study could not benefit from this dataset. Except for the data from waste transfer manifests, the obtained data were fragmented, out-of-date and/or not reflecting the actual products.

As worldwide industry is entering the 'Industry 4.0' era, automated data collection and update of factories' materials input, products and residues output data are becoming feasible and, hence, should be explored. If properly designed and implemented (such as the PRTR system), this industry data should proof to be an invaluable asset not only for fulfilling obligation toward the SC but also for the effective chemical and environmental safety management at the national level.

POPs substances in import products/articles

This study relies on evidence obtained from testing of EOL products. It does not cover newer import products that did not yet show up at waste management sites. When other countries deploy measures to prohibit put-on-market of contaminated products, these products may be diverted to countries without such measures, like Thailand.

All SC POPs industrial chemicals are prohibited substances for export products. Environment and chemical safety (ECS) regulations such as REACH and RoHS are becoming new norm for global supply chain. As an important producer for many of the relevant products, Thailand export products satisfy customers' requirements; including fire safety and ECS regulations in most stringent markets and/or sectors. It is unfortunate that Thailand does not yet introduce such ECS measures. Although most local producers tend to also place similar RoHS/REACH compliance products on domestic market, this study found products with decaBDE begin to emerge in newer EEE products, believed to targeting only for Thai market. Due to limited number of samples and lack of market-share data, this assessment study does not include the estimation of the amount of SC POPs in these newer products.

Contaminated products do not only pose risks to consumers but also put unnecessary burdens to the public for their disposal. Materials contaminated with POPs are difficult to recycle without releasing harmful substances to the environment. Since recycled materials contaminated with prohibited substances are not accepted by mainstream producers, they are diverted to low cost products, undercutting the viability of the recycling industry.

It is, therefore, proposed that Thailand imposes measures to prohibit the uses of certain hazardous substances in domestic products, in-line with ECS measures imposed elsewhere around the world.

Plan for proper management of stockpile in in-uses articles

POPs industrial chemicals differ from POPs pesticides by the fact that they are embedded in products with much longer life-cycle/value chain and they can be recycled into new products. While users of pesticides are mostly know or aware of their actions, except for the actor who actually add the substance into target material, users of industrial POPs contaminated materials do not yet have a viable mean to know/aware of substances embedded within their products.

It is, therefore, important that contaminated products/materials are clearly identified and separately collected for proper disposal/management before they are mingled with other materials, causing wider spread and, consequently, posing higher risks.

For HBCD in SE-grade EPS Foams

- Since they are used in recently built constructions where information/materials specifications are still relatively fresh, it may still be feasible to conduct nationwide survey to locate and provide proper markings for these foam panels/constructions and to the affected buildings.
- It is recommended that appropriate disposal routes be identified and guidances for the decommissioning and disposal of the

affected panels be developed to protect workers from the exposure to HBCD and to prevent further releases of HBCD to the environment.

For brominated flame retardants in polymeric resins

- Identifications of relevant BFR based on chemical testing are costly. The practices in developed countries that rely on XRF and IR technologies to automatically separate contaminated materials (chips) at shredder facilities are considered too costly and, thus, may not be appropriate for Thai recyclers. It will be simpler and cheaper to separate out contaminated parts before mingling. However, to do so, dismantlers need ‘intelligence’ information to help identify contaminated parts. It is, therefore, essential to conduct researches to gather such intelligence information to enable accurate prediction for all relevant products.
- It is also imperative to lay down measures to prohibit mixing (or dilution) of contaminated material with other cleaner material to prevent further spread out of POPs.

For other POPs and upcoming POPs industrial chemicals

This assessment demonstrated the benefit of the new screening test methods. These test methods should be developed further to support the assessment of other SC POPs industrial chemicals, as well as the upcoming POPs, that suffered from limited evidence/data (such as SCCPs and PFOS/PFOA).

□□□

Introduction

Thailand ratified the Stockholm Convention (SC) on Persistent Organic Pollutants (POPs) on 31 January 2005. The Convention initially included 12 substances or groups of substances, 2 of which were industrial chemicals listed in Annex A (for elimination) to the Convention. The SC has subsequently been amended, adding 11 more industrial chemicals to Annexes A and B to the Convention. This inventory assessment report covers 8 of the POPs listed between 2009 and 2015 and decaBDE which was listed after the commencement of this Enabling Activity (EA) project.

Each chemicals entry in the SC Annexes does not always represent a single substance. Some SC POP substances can have many congeners, and different congeners may have different risk profiles. For example, PCBs and PBDEs are families of 209 congeners each. The SC also listed certain chemical entries as groups of substances, for example 'Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F)'. Thus, for those POPs that consisted of multiple congeners or multiple substances, this report treats each of these POPs as a single group rather than as separate congeners/substances, as summarized in Table 2-1.

Table 2-1: The 11 newly listed POPs industrial chemicals to be covered in this report

Item	Chemical as listed in the SC	SC Decision	Annex	To be considered together as	
1	Hexabromodiphenyl ether and heptabromodiphenyl ether (commercial octabromodiphenyl ether: c-octaBDE)	SC-4/14	A*	1	PBBs & PBDEs [Hexabromobiphenyl (HBB) or Polybrominated biphenyl (PBBs) & Polybrominated biphenylethers (PBDEs)]]
2	Tetrabromodiphenyl ether and pentabromodiphenyl ether (commercial pentabromodiphenyl ether: c-pentaBDE)	SC-4/18	A*		
3	Decabromodiphenyl ether (commercial mixture, c-decaBDE)	SC-8/10	A*		
4	Hexabromobiphenyl	SC-4/13	A		
5	Hexabromocyclododecane (HBCD)	SC-6/13	A	2	Hexabromocyclododecane (HBCD)
6	Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F)	SC-4/17	B**	3	PFOS
7	Polychlorinated naphthalenes (PCNs)	SC-7/14	A* and C	4	Chlorinated naphthalenes (CN), Polychlorinated naphthalenes (PCNs)
8	Hexachlorobutadiene (HCBD)	SC-7/12	A	5	Hexachlorobutadiene (HCBD)
9	Pentachlorobenzene (PeCB)	SC-4/16	A and C	6	Pentachlorobenzene (PeCB)
10	Short-chain chlorinated paraffins (SCCPs)	SC-8/11	A*	Not cover	
11	Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds	SC-9/12	A*	Not cover	

Note: (*) with specific exemptions, (**) with acceptable purposes and specific exemptions

From an inventory investigation point of view, chemicals that are intentionally used for industrial purposes can be divided into two classes;

processing chemicals and chemicals that are intended to incorporated in product (‘Chemical in Product: CiP’).

Process chemicals are employed for their specific properties to provide certain benefits to the process. By virtue of their intention, users of process chemicals have some (apparent or perceived) knowledge of the chemicals, and usually are the end-users of the chemicals. PCNs, PeCB, HCBD and PFOS belong to this group.

Situations are different for CiPs. Industry adds certain chemicals into base materials to render special characteristics, such as to retard fires. The CiP added materials are then converted into parts and products. Once CiPs are incorporated, downstream users of the resulted materials and/or end-users of the products rarely have knowledge of the contents of these CiPs. PBDEs and HBCD are examples of chemicals in this group. When used as plasticizers, PCBs, PCNs, and SCCPs also belong to this group.

Based on these different circumstances, different data gathering strategies are needed for each chemical group.

Thailand has long been important producer for electrical and electronic equipment (EEE) and automotive parts. Most of the companies in EEE and automotive industries are parts/components producers and electronic manufacturing service (EMS) providers. Although there are growing number of Thai original design manufacturing (ODM) companies, most brand-name product manufacturers (original equipment manufacturer (OEM)) are joint-ventures, largely with Japanese companies.

‘POPs’ may be an unfamiliar word but the substances listed to the Annexes A and B of SC are not entirely new for Thai industry. Regulations such as EU RoHS[5] directive [2], [3] and REACH[6] regulation [4] had been key drivers that pushed global industry to phase-out concerned substances[7], particularly CiPs, since 2006. Firms who are part of the global supply-chain are forced by customers to provide information of substances of high concerns (SVHC) in their supplied products which include almost all relevant substances listed in Table 2-1, except PCNs, HCBD and PeCB.

Unfortunately, Thailand does not yet to have any system to keep track of CiPs that are embedded in products at the national level. Therefore, it will be challenging to find information for substances that might have been embedded in materials/products more than a decade ago (particularly before 2006).

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[5] Restriction of the use of certain Hazardous Substances

[6] Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

[7] Known to Thai Industry as ‘SOC’ (Substances of Concerns) or ‘SVHC’ (Substances of Very High Concerns)

Purposes of the study

This study is intended to be a preliminary inventory study. It aims to gather baseline information for the 11 newly listed POPs industrial chemicals in Thailand to gain general idea of the current situation concerning these chemicals. It does not aim to provide precise figures for each POPs nor does it investigate specific substances down to the congener level.

This inventory forms a core part for Thailand to make informed policy decisions to mitigate the associated risks and to fulfill its obligations toward the Stockholm Convention.

Methodology

MTEC was assigned by the PCD and endorsed by the National Environment Board's Stockholm Convention Sub-Committee on POPs ("Thai SC-subcommittee") to take charge of this inventory assessment. The inventory team was assisted by 2 national experts on PBDEs and PFOS.

In compiling this inventory study, following steps were taken to ensure quality[8] of the assessment as far as practicable.

1. Establish Working Group

POPs Industrial Chemicals Working Group (WG3) with 11 representatives from relevant public and private organizations was officially established and endorsed by the Thai SC-subcommittee to support the inventory study and to work toward the formulation of the NIPs. The director-general of the Department of Industrial Works (DIW) is appointed as the chair of this WG with the PCD and MTEC serving jointly as the secretary.

The WG3 was presented with relevant pertinent data, accumulated by MTEC's preliminary research, in order to define the scope of the inventory and formulate a practical work plan.

2. Choosing data collection methodologies

The WG was presented with relevant background information associated with each POPs industrial chemical. Methods to be chosen to collect data were discussed along with anticipated constraints before the WG made decision on the scope and the depth of the assessment for each POPs.

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[8] Transparency, Consistency, Comparability, Complete (fit for purpose) and Accuracy

3. Collecting data from key stakeholders

The Inventory team was in charge of collecting and compiling data from identified key stakeholders using the agreed method, with supports from the WG members. The data collection was scheduled for 4 months, during February to June, 2019.

Due to the large number of POPs involved in this study, data collection campaign was preceded by a technical seminar entitled "the Stockholm Convention & REACH/RoHS" held on September 11th, 2018 (seminar presentation and supporting document are available online on MTEC run website www.ThaiRoHS.org) and accompanied by an explanatory document entitled "Thai POPs Inventory and the Stockholm Convention" that highlighted relevant provisions of the SC and summarized the new POPs with a focus on application areas that might have used certain POPs, business sectors/parties that might be involved and possible impact.

With limited time and resources available, the questionnaire survey was conducted through industrial organizations/professional associations. Each organization visited was presented with relevant background information to ensure their members awareness about SC and POPs. The questionnaire was tailored for specific industry sectors to limit number of questions and to avoid overwhelming respondents with too many chemical substances. Every questionnaire was accompanied by a 2-pages summary of relevant chemicals to assist respondents in assessing their involvements. Following are list of industry specific questionnaire that were distributed.

- Chemical and petrochemical Industry
- Plastics parts industry
- Automotive industry
- Automotive parts industry [in Thai and in English]
- Electrical and electronic industry (with separate section only for televisions and monitors manufacturers) [in Thai and in English]

Followings are the list of organizations visited and requested for information

- Electrical, Electronic and Telecommunication Club of the Federation of Thai Industry (FTI)
- Thai Auto Parts Manufacturing Association (TAPMA)
- Petrochemical Industry Club of the FTI
- Thai Plastics Institute
- Thailand Textile Institute
- Thai Electroplating Professional Network (TEPNET)

To ensure adequate data coverage, another set of generic questionnaire entitled "Management practices for controlling Chemical Substances in Products" was formulated for industry in general. The questionnaire dissemination was accomplished through a public seminar entitled “Regulations on Chemicals Substances in Products” held on February 20th, 2019. The seminar was attended by 341 participants from 172 companies. Through this event, the inventory team was able to received 223 questionnaires returned.

4. Collecting data via field survey

For some POPs CiP, such as PBDEs, the global phase-out from certain products has already begun and the risk phase may already have been shifted to the use phase and disposal phase. Most Thai producers produced compliance products to feed global markets. Thailand does not yet have legislation in place to deter contaminated products from entering local market. But, Thailand also does not have requirements that demand extensive uses of flame retardants. The extent in which POPs CiP has penetrated into Thailand’s daily life products and appliances are, therefore, largely uncertain. It is also unlikely that the survey results from local producers alone can adequately fill this information gap.

Therefore, a brief preliminary products survey (for elemental bromine: Br) using a Handheld EDXRF was conducted to assess possible contamination in daily life products and appliances, and to grasp some idea of the situation. Products include in this screening survey were those suspected by relevant UNEP guidances and those suggested by their needs to be flame retarded. [ICT equipment, office appliances, office furniture, building materials, cars interior parts, toys from flea market, etc. (see detail in respective chapter)]

For POPs in products that may already have reached the end-of-life stage, 20 e-waste dismantling shops and plastic waste shredders/recyclers in eight provinces were visits, 20 shop owners were interviewed, more than 2,000 targeted samples were collected back to MTEC for further analysis. (see detail in respective chapters)

Finally for POPs in disposal phase, 9 suspected dump sites/waste treatment plants were visited. Relevant 64 samples (sludge, soils, leachates, waste water, etc.) were collected and submitted to laboratories for further analysis. [analysis data are not available in time for this report]

5. Managing and evaluating the data

Data and information received during data collection period were compiled and analyzed by the inventory team. Apparent inconsistencies and/or ambiguous answers were resolved through follow-up phone call. The findings of the assessment study were summarized and presented to the WG3 for their review/evaluation.

After passing the WG review process, the inventory results were then presented to the public (relevant stakeholders) via the Inventory

Validation Workshop, held on July 31st, 2019. The workshop was attended by 99 participants from 52 organizations. Feedbacks received during the workshop and the one-week comment period were compiled and the inventory was refined as appropriate before the refined version was circulated to WG members for endorsement.

6. Inventory report preparation

The inventory team was in charge of preparing the inventory report. The final (draft) version of the inventory report was reviewed by the Working Group on Project Supervision and Coordination (WG1) prior to being submitted to UNIDO for review by international expert(s).

Data collection methodology

This study adopted the Tier approach to collect data for the inventory. Due to the diverse nature of the substances under investigation, different levels of assessment were taken for different substances as detailed below [see summary in Table 2-34 in the Annex]:

Tier I: Initial (Indicative) assessment

Desk researches were performed for every substance under investigation. Example of information sources for these assessments are as follows:

- Import-Export statistics from Thai Customs
- Industrial products output statistics from Office of Industrial Economics (OIE)
- Information technology and communication statistics from National Statistics Office (NSO)
- Motor vehicles registration statistics from Department of Land Transport (DLT)
- Relevant standards from Thai Industrial Standards Institute (TISI)
- Relevant products from UNEP Guidance document, EU ECHA Substance information system, EU RAPEX[9] system,
- Relevant material (Fire safety) standards and literatures in scientific community (ScienceDirect, IEEE, Springer, ACS, etc.)
- Relevant environmental, chemicals, and product safety (ECS) regulations in the global markets

Note that most available statistics data can only be traced back up to the year 2000.

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[9] the rapid alert system for dangerous non-food products

Tier II: (Preliminary) Inventory

All POPs industrial chemical assessments under this study are classified ‘preliminary inventory’. However, depending on level of stakeholders involvement and perceived risk of the substance, the depth of data assessment varied as follows:

Substance	Depth of data assessment
PBBs, PBDEs	Qualitative method based on questionnaire survey and interview Semi-quantitative method based on in-house predictive model accompanied by a limited number of quantitative analysis
HBCD	Qualitative method based on questionnaire survey and key producers interview Qualitative method based on EDXRF results and a limited number of quantitative analysis by LC-MS/MS
PFOS	Qualitative method based on questionnaire survey, stakeholder interview, and available test data in literature
PCBs, PCNs	Qualitative method based on questionnaire survey and follow-up interview
HCB, PeCB, HCBD	Preliminary assessment based on questionnaire survey and available test data on public domain.

Detail methodology for each substance will be presented in respective chapter.

Organization of this report

This report represents part 2 of the 3-parts national inventory report. It comprises 6 sections detailing information gathered for each POPs industrial chemical. It also provides details on limitations and assumptions made in order to estimate the amount of POPs industrial chemicals in Thailand. Data gaps are described in forms of qualitative uncertainty assessment to indicate limitations of the study. Finally, emissions estimated (as far as data allowed) for each substance are discussed along with a highlight of possible hotspots as well as recommended activities/measures to fill data gaps and to avoid the releases.

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2.1 Hexabromobiphenyl (HBB) and Polybrominated diphenylethers (PBDEs)

2.1.1 Introduction

Hexabromobiphenyl (HBB) (a member of polybromiated biphenyls (PBBs)) and polybrominated diphenylethers (PBDEs) are polymeric compounds known to the industry for their flame retardant (FR) property.

HBB (CAS No. 36355-01-8) was commercially produced during the 70s with production in the US started at around 9.5 metric tons in 1970 to about 2,200 metric tons in 1974 [5]. The production in the US ceased in 1975, with estimated productions from 1970 to 1976 of around 6,000 metric tons, in which HBB constituted around 5,400 metric tons [6]. HBB was the main constituent of flame retardant under tradename FireMaster BP-6 and FireMaster FF-1. According to POPRC review document [6], HBB production was phased-out in 1975 while production of octa- and decaBB continued in the US until 1979. Outside the US, there were minor PBB productions in the UK, Germany and France. By the year 2000, all productions were ceased [6].

PBDEs is a family of 209 congeners of polybrominated diphenylethers, with number of bromine atoms in diphenylether structure ranged from 1 (monoBDE) to 10 (decaBDE). PBDEs are commercially available in 3 mixtures; c-pentaBDE, c-octaBDE and c-decaBDE, with the names reflecting the average number of bromine in the compound as summarized in Table 2-2.

C-pentaBDE was mainly produced in the US with productions in the EU and the US ceased in 1997 and 2004, respectively [7][8], while c-octaBDE was produced in the EU, US, Japan, and Israel with productions ceased around 2004 [7][8]. The UNEP estimated total amount of worldwide pentaBDE and octaBDE productions of about 100,000 metric tons each [7].

C-decaBDE represented about 75-80% of total global PBDEs production [9]. Unlike c-pentaBDE and c-octaBDE where main producers were located in the US, EU, Japan, and Israel, China and India also took parts in the production of c-decaBDE. The UNEP estimated the amount of worldwide c-decaBDE production until 2005 at about 1.1-1.25 million tonnes. While productions of c-decaBDE were phased-out in the EU, Japan and the US [9][10], the production status in other areas are unknown.

Table 2-2: Typical composition of commercial PBDEs mixtures

Commercial PBDEs		Tetra-BDE	Penta-	Hexa-	Hepta-	Octa-	Nona-	Deca-BDE	Estimated Production*
	Congener	40-81	82-127	128-169	170-193	194-205	206-208	209	
	CAS No								
c-pentaBDE	5436-43-1 60348-60-9	24-38%	50-62%	4-12%	Trace				91-105kt
c-octaBDE	68631-49-2 207122-15-4 446255-22-7 207122-16-5		1%	12%	45%	33%	10%	1%	102.7-118.5kt
c-decaBDE	1163-19-5					Trace	0.3-3%	97-98%	1.1-1.25 Mt

Note (*): 1970-2005, Data source: [7], [9], [11], [12]

PBBs and PBDEs in SC List

The Stockholm Convention listed PBBs and PBDEs in 4 entries; namely "hexabromobiphenyl" (Decision SC 4/13), "tetrabromodiphenyl ether and pentabromodiphenyl ether" (Decision SC 4/18), "hexabromodiphenyl ether and heptabromodiphenyl ether" (Decision SC-4/14), and "decabromodiphenyl ether (BDE-209)" (Decision SC-8/10). As seen in Table 2-3, in total of 7 PBDE congeners were listed in Annex A of the SC.

Table 2-3: PBDEs listed in Annex A of the Stockholm Convention.

commercial mixture	SC list	Congener	CAS No
c-hexaBB	hexaBB	PBB-128 ~ PBB-169	36355-01-8
c-pentaBDE	tetraBDE	BDE-47	5436-43-1
	pentaBDE	BDE-99	60348-60-9
	and other tetra- and pentaBDE present in c-pentaBDE		
c-octaBDE	hexaBDE	BDE-153	68631-49-2
		BDE-154	207122-15-4
	heptaBDE	BDE-175	446255-22-7
		BDE-183	207122-16-5
	and other hexa- and hepta-BDE presented in c-octaBDE		
c-decaBDE	decaBDE	BDE-209	1163-19-5

Inventory assessment process

PBBs and PBDEs are known for their flame retardant (FR) property. They had been added to flammable material to improve fire resistance properties. Particularly, for developed countries with stringent fire safety regulation; such as US, EU, and Japan, PBDEs were used in products with high (fire) risks such as EEE, upholstered furniture, automotive parts, construction materials, etc., [9][13]. However, for a country with less stringent fire safety regulation like Thailand, the extents of the uses of PBBs and PBDEs are largely unknown. This information is fundamentally important for the development of a national PBBs/PBDEs inventory.

This PBBs/PBDEs inventory assessment process; therefore, started with the identification of PBBs/PBDEs relevant products/applications.

Information gained from this process should help pointing inventory team toward appropriate stakeholders. This identification process involves 3 stages:

1. Desk study: Following information was studied for identifying PBBs/PBDEs relevant products/applications in Thailand
    - Relevant PBBs/PBDEs usages from UNEP guidances,
    - Flammability of polymers and applications of flammable polymers in ‘high risk’ application
    - Available literatures/published reports on the detection of PBBs/PBDEs in the environment in Thailand (including levels of PBBs/PBDEs in dust and soil at e-waste dismantling sites, plastic recycling plants, and nearby (household) communities
2. Preliminary products survey: A brief preliminary products (analytical) survey to screen for PBDEs relevant applications using handheld EDXRF
3. National surveys consisting of
    - Questionnaire survey for information from potentially relevant stakeholders
    - Products survey using results from MTEC’s 2018-2019 studies on BFR in Thai e-waste and recycled plastic resins (see detail in Annex 8)

Once the target products/applications are identified, further inventory assessment to evaluate the amount of relevant POPs PBB/PBDEs throughout life-cycle of the affected products, disposal practices, and potential contaminated sites etc., as suggested by relevant UNEP guidances [7], [10] was undertaken using both available information from relevant national database and predictive models derived from MTEC studies (see Annex 7).

2.1.2 Identification of relevant products/applications

Thailand’s fire safety regulations are not as demanding as in developed countries, suggesting that there is only marginal demand for fire retarded products. Additionally, there has never been any brominated flame retardants (BFR) production capacity in Thailand.

However, Thailand has long been an important producer for many of the relevant (high risk of PBDEs contamination) products[10]. As with other leading suppliers, Thailand export products satisfy customers’ requirements; including fire safety, environment and chemical safety

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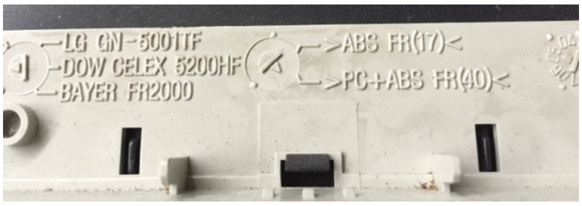
[10] including EEE, automotive parts, upholstered furniture, and interior and exterior construction products

(ECS) regulations in most stringent markets[11]. Unfortunately, no information on the use of flame retardants (particularly PBDE) in export products was found.

Generally, it can be expected that producers would add FR to their products only when necessary since adding FR to polymeric matrix not only incurs extra costs but also reduces materials' engineering performance that usually requires additional efforts to compensate. From producers' perspective, the choices of FR depend on many factors particularly the associated fire safety standards/regulations, the compatibility of the base materials to the FR system, and the availability of other cheaper/simpler alternatives.

Thailand market is a price sensitive market. Although it can be anticipated that export products that meet stringent safety regulations (both fire safety and chemical safety) are more costly than typical 'price-sensitive' products, it is unclear whether or not producers placed products with the same specification/construction on domestic market. An attempt by the inventory team to obtain PBBs/PBDEs related information from key producers has failed, possibly due to following reasons:

- Industry has phased-out the use of PBBs/PBDEs since 2006 to meet the EU RoHS Directive and other RoHS-like regulations that have been enforced in many regions worldwide. Before this 'RoHS era', producers specified/controlled resins either by tradename (see photo) or by fire resistance rating (such as UL V0) and did not have system to control chemical contents in their incoming materials. Therefore, the chemicals content in products (CiP) were unknown to most parties along the supply-chain except the compounders who were responsible for adding the relevant chemicals in the first place.

  Additionally, as it may notice in the above photo, the compounders who provided the relevant resins to Thai industry 10-20 years ago may not be located in Thailand.

- The requested data/information was rather historical data. Producers may already discard old data and knowledgeable staff may already retire or change job position. For most producers, data retention time (according to ISO 9001) was about 5 years and just been updated to 10 years starting from 2012 as a result of

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[11] Including EU RoHS and REACH

the EU RoHS recast version [3].

2.1.2.1 National regulatory context

Fire safety (regulatory) requirements in Thailand are mainly specified through Thai Industrial Standards (TIS) and safety requirements (Notifications) based on specific Acts; such as Land Transport Act (LTA) [14] and Building Control Act (BCA) [15].

TIS standards with specified fire safety requirements are mostly for EEE products. These TIS standards stipulate fire resistance of the parts/products (see relevant standards in Table 2-4) and are mostly in line with international standards. Particularly, TISI published one generic standard in 1993 (TIS 1195-2536) that specifically prescribes resistance to fire for circuit boards and enclosures, particularly for high fire risk parts/products such as CRT TVs. These requirements; equivalent to UL V2 and UL HB for circuit boards and enclosures, respectively, are not as demanding as the requirement for export EEE parts/products which are typically required to meet UL V0 flammability rating (see detail for UL flammability rating in Annex 3).

Table 2-4: Relevant (fire) safety standards for EEE and automotive parts

Products	Thai's Standard	International Standards
Mains operated electronic and related apparatus for household and similar general use (Television Sets, etc.)	TIS 1195-2536 (1993)	IEC/EN 60065
Electronic devices (computers, printers, telephone, copy machine, etc.)	TIS 1195-2536 (1993)	IEC/EN 60950 or UL 1950
Home appliances (HA) (washing machine, refrigerators, hair dryers, rice-cookers, tumbler dryers, electric fryers, instantaneous water heaters, microwave ovens, etc.)	TIS1463-2556 (2013) TIS 2214-2548 (2005) TIS 1985-2549 (2006) TIS 1039-2547 (2004) TIS 1389-2559 (2016) TIS 1509-2547 (2004) TIS 1693-2547 (2004) TIS 1773-2548 (2005)	IEC/EN 60335
Plastic parts & components (in EEE)	Indirectly controlled by TIS 1195-2536*	IEC 60707, 60695-11-10, 60695-11-20, ISO 9772 & 9773
Automotive (interior fittings)	DLT Notification 2557 [16]	ISO 3795, ASTM D635 Federal Motor Vehicle Safety Standards (FMVSS) 302: Flammability of Interior Materials)

Note: * TISI does not have standards to control EEE parts or components. But finished product producers must provide proof of compliance for all relevant parts/components to the authority for approval.

Thailand's LTA- and BCA-related fire safety standards are focused on designs and installations for fire prevention and extinction. It is not until recently that responsible agencies issued notification to limit materials' flame spread rate and smoke development for interior materials for public transport vehicles [16], cinema/theaters [17], and building's interior finish and decorative materials [18].

Thailand's flexible fire safety requirements may suggest only minor PBDEs usages. Nevertheless, PBDEs had been detected in car and house dust [19], dust around e-waste storage facilities [20] and a dismantle facility [21], leachates from a municipal solid waste dump site [22] , and sediments [23][24]. These findings suggested that PBDEs may still be relevant in certain applications, though not as wide spread as in developed countries. More information is needed to clarify the target of the investigation.

2.1.2.2 Preliminary identification of high risk products

Initial guess (High risk products)

Since HBB was only briefly produced in the 70s, used mainly in the US and Canada during the 70s-80s [6][7], and never been detected in food chain or in any of Thailand's environmental media, the inventory team considered it is unlikely that this substance could find any use in Thailand and therefore, considered this substance irrelevant for Thailand.

On the other hand, for PBDEs or HBCD, following materials and corresponding products were initially considered relevant for Thailand:

- Plastics: EEE, automotive parts.
- Textiles: upholstery textiles, carpets.
- Polyurethane (PUR) foams (flexible and rigid): furniture and car seats, insulation for cold storage, refrigerators, and building.

These materials/product groups were selected as initial target for preliminary products (analytical) survey to screen for relevant applications using a handheld EDXRF.

Preliminary (products) survey using HH-EDXRF

In February to April 2018, MTEC conducted a brief preliminary survey for Br in products using a handheld EDXRF spectrometer (Bruker S1 TITAN 800) to assess possible BFR contamination in the initial target products and to grasp rough ideas of BFR usages in everyday offices/household items in Thailand. Products included in this screening survey were those suggested by relevant UNEP guidances [7], [10] and those suggested by their needs to be flame retarded.

Results from this preliminary survey are qualitatively summarized in Table 2-5. At the first glance, it can be confirmed that the initial list of materials and corresponding products are potentially relevant for Thailand. Moreover, the relatively frequent bromine detection in textile products indicates a wider uses of BFR than originally anticipated. Particularly, the positive detection of Br from office and building upholstery fabric samples that were put into uses 15-20 years before the publication of fire safety standards suggested that there were other factors that govern the FR usages in Thailand. However, without BFR type identification, it is not clear at this stage whether these BFRs were PBDEs, HBCD or another BFR.

Table 2-5: Brief summary of results from preliminary survey for bromine in products using HH-EDXRF

Sample Group	Description	Source	Results*
TV & PC CRT monitors	In-situ testing on EOL TV & PC CRT monitors housing	• MTEC WEEE storage • e-waste dismantling shops	Mostly positive TV CRT (44±8%)## PC CRT (73±5%)##
TV & PC flat panel monitors	In-situ testing on EOL TV & PC FPD monitors housing	• MTEC WEEE storage • e-waste dismantling shops	Positive for TV monitors (62±10%)## Negative for PC monitors (2±5%)##
Laptop computers	In-situ testing on housings of EOL laptop computers	MTEC WEEE storage	Mostly negative except for battery packs (76±14%)
Air conditioner	Exterior and internal parts of split-type, indoor (fan coil) unit	MTEC WEEE storage	Mostly negative except for EE control compartment#
Refrigerator	interior parts of EOL refrigerators	• MTEC WEEE storage • e-waste dismantling shops	• Negative for interior shells and components • Negative for PS foam • Negative for PU foam • Positive for certain components (heater terminals, light bulb socket, etc.)
Home EEE appliances (microwave oven, toaster oven, Irons)	Plastic components from EOL home appliances	• MTEC WEEE storage • Staff-donated EOL appliances • e-waste dismantling shops	Positive for certain part (knobs, motor controllers)
Laser printers	In-situ testing of accessible parts of EOL laser printers	MTEC WEEE storage	Rarely found Br positive housings
Toner cartridge	In-situ testing of accessible parts of EOL laser printers toner cartridges	• MTEC WEEE storage • e-waste dismantling shops	Positive (FR(17))
Power bank	In-situ testing of accessible parts of EOL Li-ion power bank	e-waste dismantling shops	Negative
Power stripe (Extension Cords)	In-situ testing of accessible parts of In-use & EOL Power stripe	• MTEC office • MTEC WEEE storage	Positive for high-end products#
EEE parts	Thermoplastics enclosures from parts extracted from	WEEE (selected based on risk of spark ignition)	Positive for 'high energy' parts#

Sample Group	Description	Source	Results*
	WEEE		
Gas (canister) Stove	In-situ testing of accessible parts of Lab Mobile Gas (Canister) Stove (in use)	MTEC labs	Positive for plastic parts$^{\#}$
Passenger Cars (interior compartment)	In-situ testing of accessible parts of passenger cars interior components	MTEC staff's volunteer cars	Positive for textile parts (40±30% of car models)
Passenger cars (underhood compartment)	In-situ testing of accessible parts of passenger cars underhood components		• Positive for underhood parts (Shrink Tubes, flexible cable conduits, battery terminals and fuse box (brand dependent)) (50±30% of car models) • Negative for rubber parts
Buses	In-situ testing of accessible parts of buses seats and curtains	NSTDA service buses	Trace
Office furniture	Chairs, tables, partitions, tablecloth, etc.	• MTEC obsolete equipment storage room (about 15-20 years old EOL products) • NSTDA office furniture	• Positive for textiles (20±5%) • Negative for flexible foams
Building materials	In-situ testing of accessible parts in-use building materials, such as carpets, curtains	NSTDA buildings	Positive for textiles in crowded area (16±11%)
	EPS foam	Off-cuts from a cold storage room construction site	Positive$^{\#}$ (1 sample)
Packing materials	EPS foam	Discarded materials from MTEC office	Negative
Textile	New fabric (for curtain)	Randomly brought from local market (for curtain)	Some positive (high end, imported fabrics) (25±25%)$^{\#}$
Toys	Disassembled cheap toys	NSTDA flea market	Some positive (18±11%) (Some positive for Pb)
Back pack	In-situ testing of accessible parts of everyday back packs	Volunteer MTEC staff	Positive for high-end products$^{\#}$
Dust	Mixed dusts	Mixed dust from e-waste dismantling shop (near dismantling station)	Positive$^{\#}$

(*): Numeric results are shown in percent of Br positive samples ± uncertainty (t*CI at 95% confident level) (bootstrap resampled with 10,000 bootstrap replicates)

(#): Results with limited number of samples

(##): Results are taken from one sample for each product (Brand, model, year, and manufacturer), with no account for market share.

2.1.2.3 Information from questionnaire surveys

Information from official questionnaire survey

Results from preliminary screening were used to identify relevant stakeholders/producers and official questionnaire were sent out to relevant firms through following industrial organizations and professional associations:

- Chemical and petrochemical industry
- Plastics parts industry
- Automotive industry
- Automotive parts industry [Thai and English]
- Electrical and electronic industry (with separate section only for televisions and monitors manufacturers) [Thai and English]

Respondents were given 1 month to return the questionnaire. Unfortunately, this survey received very low return rate (estimated at less than 5%[12]). Only 14 responses were received from EEE (4), plastics (7) and chemical industries (3) by the end of the survey period. The low response rate was attributed to following reasons:

- Firms were uncertain of potential legal/social implications from their answers/collaborations.
- The issues may be too complicated (the questionnaire covers all relevant POPs substances).

Still, qualitatively the received responses provided following useful information:

- Only 'negative' or non-uses responses were returned. From these responses, it can be confirmed that leading EEE producers have phased-out PBDEs since 2006 (because of EU RoHS Directive). Additionally, even without domestic requirements, leading firms produced products with only one (chemical, environmental, and safety) standard –possibly to reduce risk of accidental contamination and/or to minimize procurement/stock management costs.
- All respondents have management system in places to cope with CiP. Upstream firms appeared to have extra-system to communicate substances information along supply chain and they had started communicating SVHC information since 2009-2010.

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[12] Questionnaire files were distributed by the above mentioned industrial associations to their members. These firms were also asked to distribute the questionnaire to their (relevant) suppliers. Therefore, the exact number of questionnaires that were disseminated was unknown. However, it can be roughly estimated at about 300 sets.

Results from a general survey (Feb 20th, 2019)

In addition to the official POPs survey, a general survey was disseminated to participants of a seminar aimed to raise awareness of CiP related regulations among Thai producers on February 20th, 2019 (see questionnaire in Annex 6). This general survey received a high return rate of about 67%; with 223 responses from 110 unique companies, mostly in EEE (81%) and automotive industry (65%).

Results obtained from this general survey are consistent with the previously described official survey. Particularly, as summarized in Table 2-6, firms had put in place systems to cope with CiP, though not yet as popular as ISO 9001 and ISO 14001 management systems.

Table 2-6: Management systems that firms have in place

Management system	Percent of firms
ISO 9001	92%
ISO 14001	74%
CiP Communication system	50%
Occupational Health and Safety	43%
CiP Management system	40%
ISO 16949	36%
ISO 13485	8%

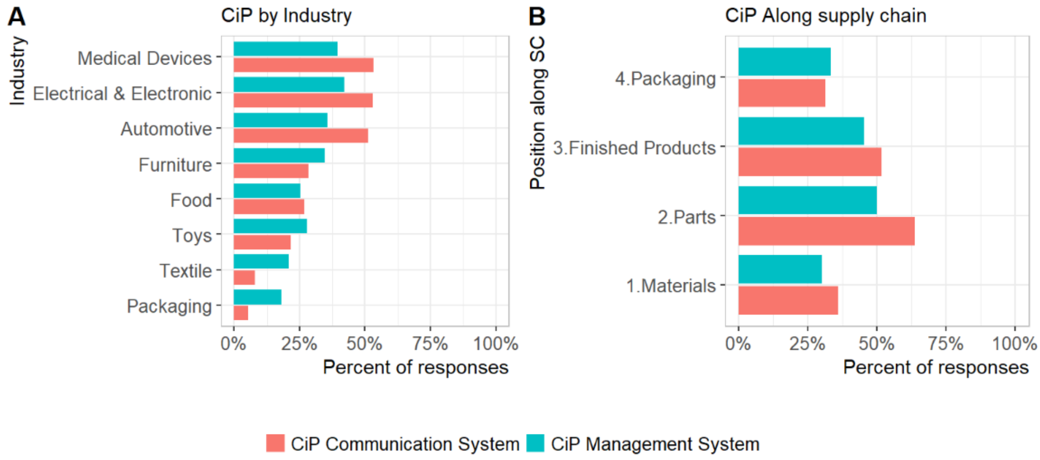

Figure 2-1: Stakeholders' existing system for controls of Chemical in Product (CiP)

Table 2-7: Proportion of respondent in relevant industry who have FR in their products and knows their FR

Industry	With FR in products	Knows their FR
Electrical & Electronics	42%	62%
Automotive	40%	60%
Medical Devices	31%	53%

Table 2-8: Proportion of respondent along supply chain who have FR in their products and knows their FR

Product Type	With FR in products	Knows their FR
Packaging	37%	35%
Finished Products	39%	64%
Parts	23%	56%
Materials	20%	82%

Table 2-9: Key industries' involvement in PBBs/PBDEs

Industry	Number of responses (companies)	Not sure, never survey	Never use	Used in the past BUT already phased-out	Used in the past AND still use in the present
Electrical & Electronics	90	17%	53%	10%	13%
Automotive	72	17%	54%	5%	16%
Medical Devices	22	16%	67%	9%	9%

As shown in Figure 2-1, CiP appeared to be more important for medical devices, electrical and electronics, and automotive industries, particularly for parts producers. Interestingly, as presented in Table 2-7 and Table 2-8, about 30 to 40% of respondents from these industries responded that they use FR in their products and more than 50% of these firms knew the type of FR being used.

Among the chemicals under producers' controls, the 10 restricted substances under the current RoHS Directive[13] and substances listed in Annex XVII of the REACH regulation are the most requested both from respondents' customers and to respondents' suppliers. Other POPs and concern substances; particularly PFOS, TBBPA, and HCBD, have also been requested (>25%) but not as frequent (<50%). These results indicate the influence of EU ECS regulations on global supply-chain's practices.

Finally, for the levels of respondents' involvement in the use of PBDEs in their products, the majority of the responses indicated no involvement (never use – see Table 2-9). Nevertheless, about 10-15% of the respondents (about half of these were trading firms) indicated their continue involvement until present. The provided reasons were mostly to satisfy the remained customer demands. Unfortunately, the nature of the parts/products and the final destinations for these parts are not disclosed to the inventory team.

2.1.2.4 Identification of BFR in polymeric resins

Results from the preliminary survey for Br in products using HH-EDXRF suggested a wider uses of BFR than the inventory team originally anticipated but it was not clear whether the detected BFRs were PBDEs. Results from the 2 questionnaire surveys also suggested possible PBDEs

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[13] Pb, Cd, Hg, Cr(VI), PBB, PBDE, DEHP, BBP, DBP, and DIBP

involvement. Unfortunately, responses from local producers could not help locating relevant products. Lacking data from producers, the only way to check whether or not a product contains PBDEs is through analytical testing, which is costly and time-consuming. Industrial products also contain hundreds of parts. The costs for confirming the presence or absence of PBDEs will be prohibitive.

Markings on plastic parts

ISO has published ISO 1043 standards on plastics symbols and abbreviated terms since 1987. Part 4 of this standard [25] prescribes marking for flame retardants added to plastic materials. Table 2-10 summarizes FR codes that considered relevant to this inventory assessment. If properly implemented, these FR marks can help stakeholders identify (and screen-out) the relevant products.

Interestingly, though resin marking was not a mandatory requirement, a significant portion of plastic parts found in e-waste dismantle shops were with material marking according to ISO 1043; including FR marking per Part 4 of the standard, as shown in Figure 2-2.

Figure 2-2: Resins and FR Markings on e-waste plastic parts

Table 2-10: FR codes relevant to this project

Code	Meaning
FR (15)*	Aliphatic/Alicyclic BFR + ATO
FR (16)	Aromatic BFR [exclude PBB & PBDE]
FR (17)	Aromatic BFR+ATO [exclude PBBs & PBDEs]
FR (18)	PBDEs
FR (19)	PBDEs + ATO
FR (20)	PBBs
FR (21)	PBBs + ATO
FR (40)	Halogen-free organic phosphorus compounds
FR (42)	Brominated organic phosphorus compounds

Note: * ISO1043-4: 2016 designated new FR codes [FR (23) and FR (24)] for HBCD and excluded HBCD from FR (15)

Unfortunately, like the results obtained from official survey in which producers' declarations were available only from the 'non-use' firms (with negative results), parts frequently found with FR markings were either marked with FR (17) or FR (40). From over 500 plastic parts inspected, only 2 samples were marked with FR (19). These samples (produced by the same maker in 2010 and 2011), however, were tested negative for Br contents. These false-positive markings suggested historical use in the same product line (using the same mold while resin had been changed).

The above findings could suggest the possibility of using plastic parts markings for the screening of PBDE-free parts. However, at the time of this study, there was no report elsewhere on the reliability of the FR (17) or other 'non-PBDE' markings. Moreover, parts without FR marking can be ambiguous. According to ISO 1043, only parts with FR exceeding 1% (w/w) have to be marked. However, since FR marking is not a mandatory requirement, parts found without FR marking cannot always be interpreted as FR-free. In fact, most PBDEs positive parts found during the course of this study did not have FR marking.

ML assisted ATR-FTIR for BFR types identification

In 2018-2019, MTEC employed an in-house developed screening test method based on ATR-FTIR measurement and a machine learning (ML) algorithm to study BFR in Thai e-waste and recycled plastic resins (see detail in Annex 8).

This method relies on ATR-FTIR measurement technique to generate distinct responses (spectrum) from additives within polymeric samples and a series of multivariate data analysis techniques to cluster 'similar' samples. By confirming some of the representative samples taken from each cluster using appropriate analytical techniques such as GCMS and HPLC-MS/MS, a semi-supervise machine learning model had been developed. This ML model was employed to predict the BFR types from ATR-FTIR spectrum that were otherwise difficult to distinguish by human eyes. Nevertheless, expert interventions were still needed to confirm the results and to evaluate results that were classified with low level of confidence. Finally, for certain samples that displayed ambiguous results, particularly samples that display some of the PBDEs characteristics, GCMS and/or HPLC-MS/MS were employed for confirmation.

The types of the ML-identifiable BFR are those frequently found in Thai e-waste, including octaBDE, decaBDE, decabromodiphenyl ethane (DBDPE), tetrabromobisphenol A (TBBPA), 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE) and ethylene bis(tetrabromophthalimide) (EBTBP), as summarized in Table 2-11. Although HBCD is detectable by ATR-FTIR, due to the lack of HBCD contaminated samples from the field, it is excluded from the ML assisted BFR classification model.

Table 2-12 presents a brief summary of the results of BFR checked from products/applications previously tested positive for BFR. Although there were many positive products, not many of them were tested positive for PBDEs. The results also showed patterns of the uses of similar BFR for the same resins. Particularly, TBBPA was typically used for ABS while PBDEs and DBDPE were most likely found in PS.

Table 2-11: List of BFRs included in MTEC's ML assisted BFR classification model

Abbreviation	Substance	CAS No	Known Tradename
octaBDE	Octabromodiphenyl ether	32536-52-0	DE79, BDE 203, Saytex 105, FR1208
decaBDE	Decabromodiphenyl ether	1163-19-5	FR 300BA, Saytex 102[E], Bromkal 83, PBDE 209, FR1210
DBDPE	Decabromodiphenyl ethane	84852-53-9	Saytex 8010, FIREMASTER 2100
TBBPA	Tetrabromobisphenol A	79-94-7	Firemaster BP4A, Saytex RB 100PC, FG 2000, FR-1524
BTBPE	1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1	FF680, FM680
EBTBP	Ethylene Bis(Tetrabromophthalimide)	32588-76-4	Saytex BT93

Note:

[1] BFRs other than these 6 frequently encountered BFRs are treated as 'novel BFR'

[2]: HBCD is detectable by ATR-FTIR but excluded from the ML assisted BFR classification model due to the lack of HBCD contaminated samples from the field

Table 2-12: Brief summary of results from preliminary survey for BFR in products using in-house developed ML assisted ATR-FTIR technique

Sample Group	**Description**	**Resin**	**Results***
TV CRT monitors	Plastic housing	PS	Positive for PBDEs (65±11%)## and DBDPE (7±7%)##
PC CRT monitors	Plastic housing	ABS	Negative for PBDEs, positive for TBBPA (84±5%)## and BTBPE & TBBPA mixture (15±5%)##
Flat panel TV monitors	Plastic housing	PS	Positive for DBDPE (16±10%)##
Flat panel PC monitors	Plastic housing	ABS, PC/ABS	Negative for BFRs
Battery pack for laptop computers	Plastic sticker	PC	Positive for TBBPA (88±12%)
Extension cords	Receptacle parts – extracted from high-end products	ABS	Positive for TBBPA# (100% of Br positive ABS samples)
Split type air conditioners	EEE control compartment	PS, ABS	Positive for TBBPA# (100% for Br positive ABS samples) and DBDPE# (33% for Br positive PS samples)
Laser printers toner cartridges	Plastic enclosures	PS, some PC/ABS	Positive for DBDPE (54±8%)
Parts from home appliances	Knobs motor controllers, etc.	various (PBT, nylon, PPS, etc.) - rarely ABS nor PS	Negative for PBDEs and DBDPE
EEE parts 	Thermoplastic enclosures from parts extracted from WEEE (Relays, Connectors, Capacitors)	varies (PBT, nylon, PPS, PVC, etc.) - rarely ABS nor PS	Negative for PBDEs
EEE parts	Box fan	PC, nylon	Negative for PBDEs

Sample Group	Description	Resin	Results*
			

Note: (*): Numeric results are shown in percent of Br positive samples ± uncertainty (t*CI at 95% confident level) (bootstrap resampled with 10,000 bootstrap replicates), (#): Results with limited number of samples, (##): Results are taken from one sample for each unique product (brand, model, year, and country of origin), with no account for market share.

BFRs in PS

With maximum limit of oxygen index (LOI) values of less than 21 (the average amount of oxygen in air), PS and ABS are flammable polymers. These resins must be flame retarded to meet V0 rating if they are to be used in EEE products targeted for global market.

Though without stringent national fire safety requirements, MTEC study indicated BFR uses in housings of domestic EEE products produced with PS resins. DecaBDE and DBDPE were the most popular BFR for PS but other BFRs such as BTBPE and novel BFRs were also found. DecaBDE was most likely found in housings of TV CRT monitors, though there were also other minor uses but not as common.

Interestingly, MTEC study showed clear trend of PBDEs phase-out for Thai market as a result of the EU RoHS Directive [2]. Particularly, before 2006, decaBDE was regularly found in EOL TV housings from 2 leading brands and their BFR use patterns changed only in response to RoHS.

Nevertheless, while leading firms phased-out their uses of decaBDE the survey identified new use in housings of FPD TVs from 2 brands, both produced in Thailand. The inconsistent pattern of FR usages from these 2 brands suggested unintended inclusion, possibly from recycled resins.

Plastic resins extracted from housings of e-waste are important source of income for e-waste dismantlers. Naturally, characteristics of the resulted resins (recyclates) will mirror characteristics of the wastes arriving at the shop. Shredded flame retarded PS chips (aka PS-V0 chips) are available from shredders both in white and in black colors. Black chips are found to be more likely to contain decaBDE than white chips, possibly due to the PBDE's yellowing problem.

BFRs in ABS

Housings for computer monitors are typically made of ABS or PC/ABS resins. Based on MTEC's BFR in Thai e-waste study (see Annex 8), most PC CRT housings found in e-waste dismantle shops were flame retarded, mostly with BFRs. The preferred type of BFR depended on the producer (brand owner), with TBBPA and BTBPE being the two most popular BFRs found in ABS resins. None of the PC CRT monitors from leading-brands[14] were found with PBDEs. Specifically, only two samples out of

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[14] "Leading brands" are defined here as the most found brand in e-waste

316 samples were tested positive for PBDEs; one octaBDE and one decaBDE. These samples were from mini- or mainframe computer's monitors produced in Asia in the 1990s.

Figure 2-3: Helmets and automotive parts at a plastic recycle shop

Apart from CRT monitors, other EEE parts that were made of ABS or PC/ABS resins that found positive for Br included plastic enclosures for air conditioners' electric control compartment and power stripe (extension cords). However, results from BFR type identification did not find either octa- or decaBDE in these applications.

ABS may be found in other parts that require high impact strength such as motorcycle helmets, motorcycle and car parts, as shown in Figure 2-3. These parts were tested negative for Br.

Among the plastic resins extractable from e-waste, ABS can command relatively high prices. Also, according to shops owners, flame retarded ABS-V0 shredded chips can gain as high as 30% higher price than regular ABS chips; hence merit separation efforts. Typical shops identifications method comprise two stages; resin identification by solvent (gasoline) dissolution and the so-call 'V0' identification by burning tests.

Like PS chips, the pattern of BFR contained in ABS chips was found to reflect e-waste that reached the shops at a given time. Specifically, though PBDEs were rarely found in ABS, MTEC reported higher chance to find PBDEs in ABS chips from shops in the central region which confirmed observations on the usages of PBDEs in ABS in high-end monitors.

2.1.2.5 Identification of BFR in textiles

Unlike originally anticipated, a relatively high number of textile samples (used in automotive, office furniture, office building, and household interior fabrics) were tested positive for bromine.

Four and three textile samples extracted from Br-positive chairs and curtain fabric, respectively, were submitted to GCMS and HPLC-MS/MS analysis to identify the associated FR types. Interestingly, all of these suspected fabrics were PET based. Three out of four office chair upholsteries and all of the drapery fabric samples were tested positive for decaBDE, indicating the relevance of decaBDE for Thailand.

Unfortunately, with limited time and resources available as well as limited access to the suspected samples, detail investigation on the uses of

PBDEs in this area is beyond the scope of this preliminary inventory study. Nevertheless, due to its risk proximity and virtually no system in place in the country to cope with contaminated textile at their end-of-life, PBDEs in textile products deserves a more in-depth study in the upcoming NIP.

2.1.3 Inventory Estimation

2.1.3.1 Production, import and export of HBB and PBDE

HBB was banned (Category 4) in 2013 while 7 PBDE congeners (penta-, octa-, deca-BDE) were listed as Category 3 hazardous substance in Thailand in 2017 and 2019 (see detail in Table 2-13)

Since HBB was only briefly produced in the 70s, used mainly in the US and Canada during the 70s-80s [6][7], and never been detected in food chain or in any of Thailand's environmental media, the inventory team considered it is unlikely that this substance could find any use in Thailand and therefore, considered this substance irrelevant for Thailand.

Table 2-13: PBBs and PBDEs Control under Thai Hazardous Substance Act

No	Substance	CAS No	Category	HS Code	Started
1	decaBB	13654-09-6*	4	2903.99.00-008/KGM 2710.91.00-000/LTR 3824.82.00-000/KGM	2013
2	octaBB	27858-07-7*	4	2710.91.00-000/LTR 2903.99.00-990/KGM 3824.82.00-000/KGM	2013
3	hexaBB	36355-01-8	4	2710.91.00-000/LTR 2903.94.00-000/KGM 3824.82.00-000/KGM	2013
4	tetraBDE (BDE-47)	40088-47-9*	3	2909.30.00-008/KGM	2017
5	pentaBDE (BDE-99)	32534-81-9*	3	2909.30.00-010/KGM	2017
6	hexaBDE (BDE-153)	68631-49-2	3	2909.30.00-011/KGM	2017
7	hexaBDE (BDE-154)	207122-15-4	3	2909.30.00-012/KGM	2017
8	heptaBDE (BDE-175)	446255-22-7	3	2909.30.00-013/KGM	2017
9	heptaBDE (BDE-183)	207122-16-5	3	2909.30.00-014/KGM	2017
10	decaBDE (BDE-209)	1163-19-5	3		2019

Note: (*) CAS number differs from those listed in SC Annex A

Thailand never commercially produced any type of PBDEs. Due to the lack of harmonized tariff codes in the past, tracing the amounts of PBDEs that had been imported in the past had been difficult. While customs data indicated some PBBs/PBDEs imports in the past 10 years (8 transactions with import amounts ranges from 1 to 460 kg), these data cannot be reconciled with data from exporting countries. Except for decaBDE that just has been added to SC list, worldwide productions of POPs PBBs and PBDEs were supposed to have ceased [6][7]. Judged from the recorded data from both importing and exporting countries, it is unlikely that these chemicals were actually imported into Thailand.

During 2015-2017, the DIW received 2 notifications for the intentions to import about 70 tonnes of decaBDE (CAS No 1163-19-5) from China and 1 notification for the intention to produce about 1 tonne of a chemical mixture that containing about 150 kg-250 kg of decaBDE. Since these amounts were not reflected in the import statistics, it is not known whether these notified activities were actually taken place.

2.1.3.2 C-pentaBDE in motor vehicles

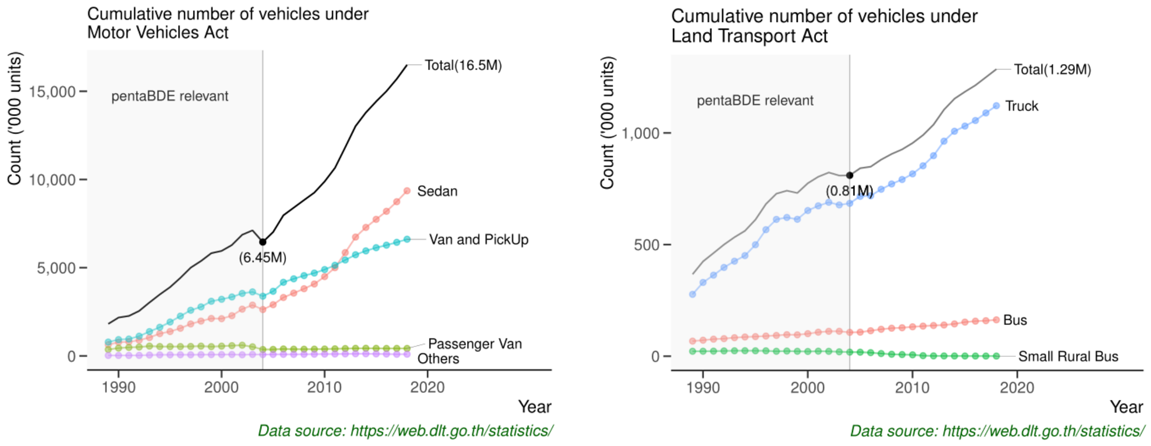
Transport vehicles produced before 2005 may contain c-pentaBDE, possibly in their seats (flexible PUR foams and seat upholstery textile) [7]. The relevant amounts of c-pentaBDE used depend on the type of the vehicle and the country of origin, with cars produced in the US more likely to have c-pentaBDE than cars produced in other areas, as summarized in Table 2-14.

Table 2-14: Suggested emission factor for c-pentaBDE in transport vehicles

Category	UNEP suggested rate	Regional Factor
Passenger Cars	160 g/unit	US=0.5
Truck	160 g/unit	Europe, China, etc. = 0.05
Buses	1 kg/unit	Japan=0

Ref: Adapted from [7].

Noted that decaBDE has been used in vehicles at even higher level compared to c-pentaBDE [26]. However, c-decaBDE in motor vehicles is not considered in this inventory.



Data source: https://web.dlt.go.th/statistics/

Data source: https://web.dlt.go.th/statistics/

a) Passenger Cars

b) Buses and Trucks

Figure 2-4: Cumulative number of motor vehicles in Thailand

Based on registered vehicles statistics from the DLT [27], in 2018 there were about 16.5 million registered passenger cars and about 1.29 million buses and trucks in Thailand. Of these amounts, about 5.4 million cars, 95,000 buses, and 750,000 trucks were registered before 2005 (Figure 2-

4).

The DLT just notified a law in 2017 to limit materials’ flame spread rate and smoke development for interior materials for public transport vehicles [13]. This notification was originally planned to take effect on January 1, 2019 but the enforcement date has been extended for 1 year due to low materials registration.

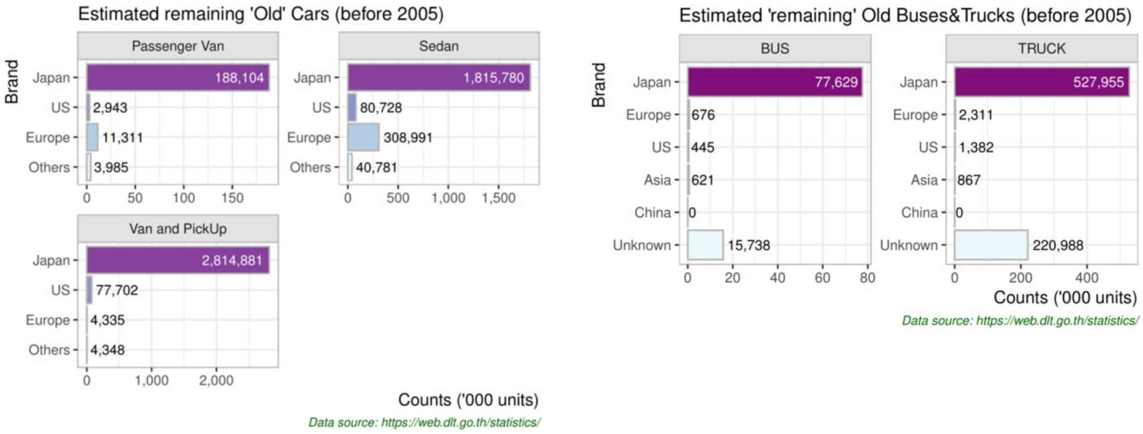
Although with extensive data dated back to 1987 (or older), publicly available database on the registered motor vehicles contained brand name but did not have information about the countries of origin.

Worst case scenario:

Assuming the production of motor vehicles depended on the quality control of the brand owners and not on the country where they were produced or consumed, brand names (brand-origin) can be used as a proxy for country of origin and the remaining ‘old’ vehicles classified by brand-origin can be estimated as shown in Figure 2-5. The corresponding amount of c-pentaBDE contained in these vehicles is estimated at 18.5 metric tons (see Table 2-15). This estimated amount is about 0.02% of all c-pentaBDE ever produced worldwide.

Thailand is a hot and humid country. Car seats in Thailand must endure high humidity, temperature, and UV exposures. Experts estimated service life for car seats in Thailand of less than 10 years. All of the affected seats, therefore, are believed to have reached end of life and have been replaced. There is no information on the disposal of these seats.

Car seats repair shops are common in local communities. It can be assumed that the EOL fabric and cushion foams were removed and discarded as MSW; which could be landfilled, incinerated, or open-dumped depending on the available MSW management system.



a) Passenger cars

b) Buses and trucks

Figure 2-5: Estimated remaining ‘old’ transport vehicles (produced before 2005) classified by brand origins

Table 2-15: Estimated amount of c-pentaBDE (kg) contained in motor vehicles

Category	USA	Europe	Asia & Australia	Unknown	Subtotal
Passenger Van	235	90	-		325
Sedan	6,458	2,472	16		8,946
Van & Pickup	6,216	35	4		6,255
Bus	222	34	-	787	1,043
Truck	111	18	-	1,768	1,897
Total	13,242	2,649	20	2,555	18,466

Conservative case scenario:

According to data from FTI and DLT (see Annex 9), most cars registered in Thailand were locally produced and, therefore, unlikely to contain c-pentaBDE. Moreover, based on interviews with leading polyurethane producers, Thai PU producers never used BFR in their PUR foams. Also, based on hundreds of HH-EDXRF screening tests, Br has never been detected in either flexible or rigid PU foams. It is, therefore, logical to assume that only vehicles directly imported from the US were affected. Note, however, that Br had been detected in interior textiles components of passenger cars, indicating the relevance of BFRs (possibly decaBDE or HBCD) in motor vehicles (see section 2.1.2.5).

Figure 2-6 displays cumulative amount of motor vehicles directly imported from the US during 2001-2005[15]. The numbers of the affected vehicles in this case are estimated at 10,000 units and the amount of c-pentaBDE imported into Thailand via import of these vehicles is estimated at 1.5 metric tons, which is about 0.002% of all c-pentaBDE ever produced worldwide.

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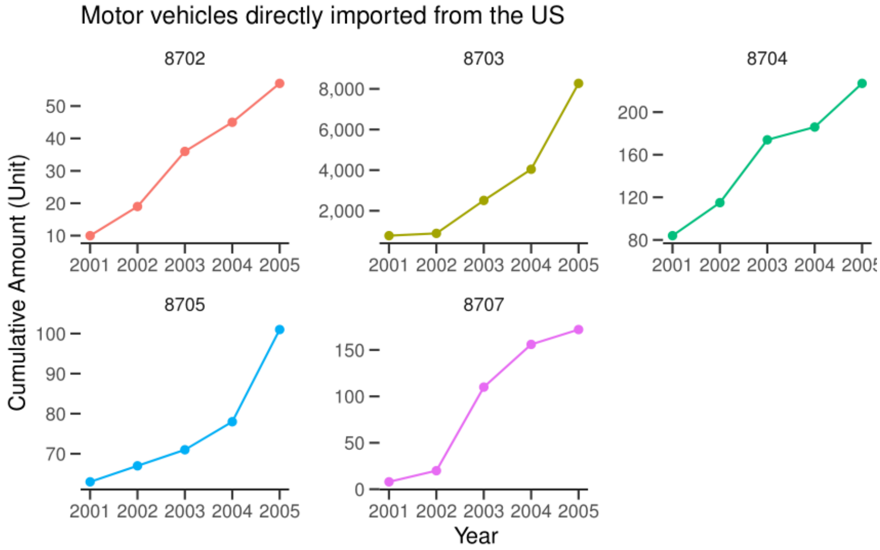
[15] Import/Export statistics are only available to the year 2001



Data source: Thai Customs

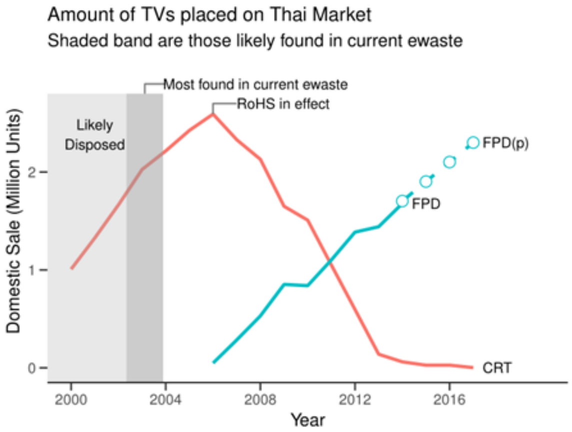
Figure 2-6: Cumulative amounts of motor vehicles (classified by HS Code) directly imported from the US during 2001-2005

2.1.3.3 PBDEs in polystyrene resins

CRT TVs

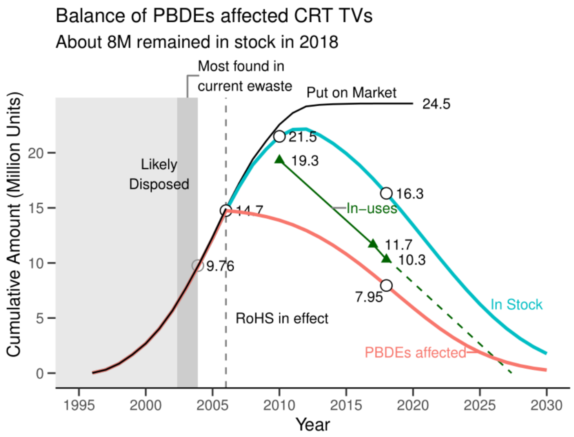
C-decaBDE was used in housing of CRT TVs produced before the year 2006. Particularly, c-decaBDE was regularly found in housings of EOL CRT TVs produced by 2 leading brands. Moreover, c-decaBDE was also found as unintended contaminants in housings of CRT TVs produced by other secondary brands.

National statistics for the amount of TVs locally produced and placed on domestic market are available from the OIE [28]. As shown in Figure 2-7, domestic TV consumption grew from 1 million units per year in 2001 to 2.6 million units per year in 2006 before declined to virtually zero in 2013. Unfortunately, information on the market share for each brand was not available to the inventory team. Moreover, information related to product lifespan and the amount of EOL products that had been disposed of are not available elsewhere. Therefore, the total amounts of the PBDEs affected TV sets as well as the amounts that are still in-use/in-stock are unknown.



Data Source: OIE, MTEC

Figure 2-7: Amount of TVs placed on Thai market since the year 2000



Data Source: NSO, OIE, MTEC

Figure 2-8: Predicted profiles CRT TVs and PBDEs affected CRT TVs in Thailand

In 2018-2019, MTEC conducted 2 surveys to profile EOL TVs found at e-waste dismantle shops in the central region and the northeastern region of Thailand (see Annex 7). The study provided estimated cradle to grave lifespan for TV CRTs in Thailand between 16 and 17.9 years. Additionally, the fitting of this (cradle to grave) lifespan distribution to the Weibull distribution yielded α (shape) value of 3.4 and β (scale) value of 17.8 years.

Using the OIE annual consumption data and the estimated products lifespan model, the balance of CRT TVs and PBDEs affected TVs can be estimated, the results are shown in Figure 2-8.

Out of 24.5 million sets of CRT TVs put on market; about 14.7 million sets were produced before 2006 and, hence, were likely contaminated with decaBDE. Some of these TVs were already disposed of. Particularly, in 2018 NSO reported numbers of in-uses CRT TVs of 10.3 million sets while MTEC's lifespan model indicated numbers of in-stock CRT TVs of about 16.3 million sets (i.e., about 6 million sets were in hibernation). About half of these amounts (7.95 million sets) were PBDEs affected CRT TVs.

Amount of affected PS

Using an average weight of CRT TV housings of 1.65±0.4kg[16], the total amount of PS resin from CRT TV are estimated at 30.6-50.2 kt, about 18.4-30.1 kt were produced before 2006. The chance of finding CRT TVs with PBDEs is roughly calculated (without considering market share) at about 28±7%. The amount of PS resins that contained PBDEs is, therefore, estimated at about 10,000 tonnes.

These affected resins are recycled along with other plastic resins that can be extracted from e-waste. If they are not separated out before recycle into recycled PS chips, the PBDEs affected resins will contaminate other

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[16] Based on weighing of 25 randomly selected CRT TV housings

non-affected resins and the amount of the affected resins will escalate.

Table 2-16: Calculated chances of finding different types of BFR and expected values for decaBDE concentrations in PS from various sources

Sample group	Shop	Color	Grade***	P{LBr}	P{FR17}	P{dBDE}	$E\{dBDE_{Batch}\}$
CRT TV*	All	Black	-	56±8%	15±6%	28±7%	3.1±0.8%
FPD.TV**	All	Mixed	-	38±10%	56±11%	6±6%	0.6±6%
Toner cartridge	All	Black	-	17±9%	83±8%	0%	-
Chips	B	Black	V0	54±10%	8±6%	38±10%	5.2±1.4%
Chips (monitors)	C	Black	V0	9±6%	56±10%	35±9%	4.8±1.3%
Chips	E	Black	G	93±4%	7±5%	0%	-
Chips	G	Black	G	74±8%	13±7%	12±7%	1.6±0.9%
Chips	B	Mixed	G	99±1%	0	1±2%	0.1±0.3%
Chips	A	White	G	98±2%	2±3%	0%	-
Chips	B	White	V0	98±2%	2±3%	0%	-
Chips	D	White	G	98±2%	2±3%	0%	-
Chips	F	White	V0	32±9%	65±9%	3±4%	0.4±0.5%
Chips	G	White	G	96±3%	4±4%	0%	-

Note: P{.}=Probability of finding ±uncertainty (t*CI at 95% confident level)

LBr=samples with low or no Br contents, FR17=samples with BFRs other than PBB and PBDE, dBDE=decaBDE

*: Bootstrap over all unique (brands & year) samples without considering market share for each brand

**: Only limited number of FPDs that reached EOL (as of April 2019)

Grade***: Shredders specified, “V0” = flame retarded grade (not UL certified V0 rating), “G”= general

$E\{dBDE_{Batch}\}$=Expected concentration of decaBDE for the whole batch.

Estimated PBDEs concentration

Plastic resins extracted from housings of e-waste are important source of income for e-waste dismantlers. Naturally, the characteristics of the resulted resins will mirror the characteristics of the wastes arriving at the shop. Flame retarded PS chips are available from shredders both in white and in black colors. Not all of these FR-chips contain decaBDE. Black chips are found to be more likely to contain decaBDE than white chips, possibly due to the PBDE’s yellowing problem. Also, most CRT TV housings are in black color.

Table 2-16 shows estimated chances of finding different types of BFR and expected values for decaBDE concentrations in PS from various sources. For the purpose of this preliminary inventory estimation, the amounts of relevant decaBDE in PS resins are estimated at 5% concentration (average black V0 chips from shops B and C).

Consequently, the total amount of decaBDE in the affected PS is estimated at 920-1,500 tonnes[17]. About half of these amounts are believed to be already disposed of, leaving about 500-820 tonnes left ‘in-stock’ (within products that are in-used or in hibernation).

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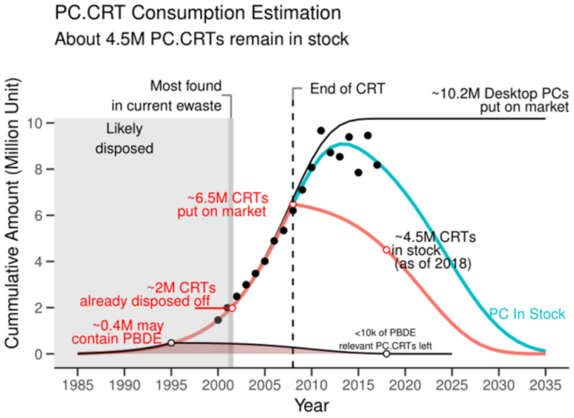
[17] 5% of the amount of PS from TV cases produced before 2006 (18.4-30.1 kt)

Based on results from e-waste and shredded chips, a minor contribution from FPD TVs (found in some models from 2 producers) can be anticipated. However, the amount of EOL FPD TVs is still very limited. FPD TVs waste profile cannot be established at this time.

2.1.3.4 PBDEs in ABS resins



Data Source: NSO
Estimated by MTEC

Figure 2-9: Predicted profiles of PC CRT and PBDEs affected PC CRTs in Thailand

Similar approach was taken to estimate the amount of PBDEs affected PC CRT monitors.

Data from NSO and MTEC's product lifespan model were used to develop a model to predict the amount of PC CRTs consumed in Thailand. The results are shown in Figure 2-9.

Unlike TV CRTs, PBDEs were rarely used in PC CRT housings (see Annex 8) and, hence, the PC CRT production/consumption pattern was not impacted by EU RoHS. Since there was no PC CRT produced after 2008 found anywhere throughout this project, it can be assumed that PC CRT monitors were totally replaced by FPD monitors in 2008. The total number of PC CRT monitors put on Thailand's market from 1985 to 2008 was estimated at 6.5 million units.

MTEC study indicated that high-end mini- and mainframe CRT monitors produced before 1995 could be affected by octaBDE and decaBDE. From Figure 2-9, the amount of computer monitors put on Thailand's market before 1995 was estimated at 400,000 units. However, there is no other information available to the inventory team to estimate the amount of high-end mini- and mainframe CRT monitor. Therefore, all of the 400,000 computer monitors produced before 1995 will be treated as PBDEs relevant.

Most of these monitors, nevertheless, are most likely disposed of. Particularly, MTEC's lifespan model predicted less than 10,000 PBDEs relevant PC CRTs were left in hibernation in 2018.

Assuming 10% of the relevant monitors actually contain PBDEs at an average concentration of 15% and the average ABS weight of 2 kg per monitor, the total amount of PBDEs in the affected ABS is estimated at 12,000 kg. Of which, about 300 kg are believed to be remained in hibernation.

Table 2-17 shows the estimated octaBDE and decaBDE concentration in shredded ABS-V0 chips samples from 4 different recycle shops located in the central and north-eastern regions of the country. (See Figure 2-35 (page 2-159) for BFR type distribution). OctaBDE and decaBDE had been detected in V0 chips sampled from recycle shops located in the central part of Thailand. The average concentration of octa- and decaBDE in the affected batches ranged from low level at 0.1% to a high level at 1.3%. Based on visual inspection, these chips were relatively thick, suggesting that they might have been produced with an old injection molding technology. Nevertheless, due to the limited number of PBDE-positive samples and sampling sites, the (true) sources for these affected chips remain unknown.

Table 2-17: Estimated chances of finding octa- and decaBDE and the associated octa-/decaBDE concentration from ABS-V0 shredded chips from 4 different recycle shops

Shop	Color	Grade	P{LBr}	P{FR17}	P{oBDE}	P{dBDE}	E{oBDE$_{batch}$}	E{dBDE$_{batch}$}
A	Mixed	V0	9±7%	82±8%	1±2%	8±6%	0.2±0.3%	1±0.8%
A	Light	V0	4±4%	92±5%	0%	4±4%	-	0.5±0.6%
B	Mixed	Unknown*	19±8%	76±8%	4±4%	1±2%	0.7±0.8%	0.1±0.2%
B	Cream	Unknown	6±6%	94±5%	0%	0%	-	-
B	Black	V0	4±4%	96±3%	0%	0%	-	-
C	Gray	V0	0±0%	92±4%	8±5%	0%	1.3±1%	-
C	Mixed	V0	0±0%	95±5%	0%	5±10%	-	0.7±1.5%
D	Mixed	V0	2±3%	98±2%	0%	0%	-	-

Note: P{.}=Probability of finding ±uncertainty (t*CI at 95% confident level)

LBr=samples with low or no Br contents, FR17=samples with BFRs other than PBB and PBDE,

oBDE= samples with octaBDE, dBDE= samples with decaBDE

E{o/dBDE$_{Batch}$ }=Expected concentration of octa- or decaBDE for the whole batch.

*: Obsolete stock

2.1.3.5 PBDEs in Textiles

Data Source: Thai Customs

Figure 2-10: Import and export of fire retarded fabrics since 2007

Note: dashed line indicated sharp spike, possibly due to high demands after the 2011 Thailand great floods.

As mentioned previous section, decaBDE has been detected in upholstery and drapery fabrics. Several other textile products were also tested positive for Bromine (see section 2.1.2). However, there is no statistical data for local production and consumption of these FR impregnated fabrics.

Figure 2-10 shows import/export statistics for fire retarded textiles starting from 2007, the year this HS code first appeared. The import amount started from 20 t per year in 2007 to about 400 t per year in the recent years. (The sharp spike in 2011 is believed to be imports for replacing damaged materials due to the 2011 Thailand great floods). The types of FR used in these fabrics as well as the end-uses (particularly the final destination) for these fabrics are unknown.

DecaBDE can be back-coated with latex to render flame retarded properties to fabric. In theory, an effective decaBDE FR system based on a synergistic antimony-halogen (Sb_2Br_3) formation consist of 17 parts of Sb_2O_3, 33 parts of decaBDE and 50 parts of resin [29]. For polyester fabric, the total weight of the whole FR system (i.e., the loading) can be 10-25% of the weight of the fabric [30]. Actual FR loading used by fabric finisher, however, depend on the weight of the fabric [31] and the desired flame retarded performance.

Assuming the FR system with 30% decaBDE on the dry coating weight basis [31] was used at 10% loading, the corresponded bromine concentration on the fabric will be about 2.5%. However, the actual amount of the decaBDE remaining on the fabric also depends on the fixation process.

For the purpose of this preliminary estimation, following assumptions are made:

- About 20% of the imported FR impregnated fabrics contain decaBDE.
- The average decaBDE concentration is 1% by weight of the fabric.
  (Note: typical Br concentrations obtained from MTEC's preliminary survey of about 240 fabric samples using HH-EDXRF for fabrics tested positive for Br are in the hundreds to thousand ppm ranges).
- Except for the year 2010, about 50% of the imported FR fabrics are re-exported as parts of finished products (such as furniture,

automotive, drapery, etc.) and the remaining 50% are consumed within the country.

- Average service life of impregnated textiles of 10 years[18]

The average amount of decaBDE in FR fabrics that were consumed in Thailand is, therefore, estimated at about 300 kg per year and the cumulative amount of decaBDE in impregnated fabrics that are in use-phase is estimated at about 3 metric tons.

Currently, there is no system in place to trace the flow of the contaminated fabrics. However, since these fabrics are used in close proximity to human, including vulnerable groups, it is important to conduct a full survey to evaluate the usages and distribution patterns as well as the associated risks from these impregnated textiles.

Thailand also does not yet have a system to manage the end-of-life textiles. Although a small portion of EOL carpets are collected back by the original producers for recycle, textile recycle in Thailand is still insignificant. It can be assumed that all FR impregnated textiles are disposed of as municipal solid waste (MSW). Since these textiles are likely concentrated only in large municipalities, they are believed to be either incinerated or landfilled at the end-of-life.

2.1.4 Emission of PBDEs

At the time of this report, Thailand does not have a regulation that mandate routine monitoring of PBBs/PBDEs in environmental media, along food chain, and in humans. Nevertheless, several research works had reported detections of PBDEs in indoor dusts (in cars, house [19], office [32], and e-waste dismantle facilities [20], [21]), leachate from a MSW dump site [22], sediments [23], and in the upper Gulf of Thailand [24].

Figure 2-11summarizes ranges of PBDEs in indoor dusts in many countries around the world, including Thailand. The reported level of PBDEs in Thai house dust was in-line with other developing countries. However, levels of PBDEs in recycling facilities were on the high range, possibly contributed from dismantling and shredding of PS from TV CRTs.

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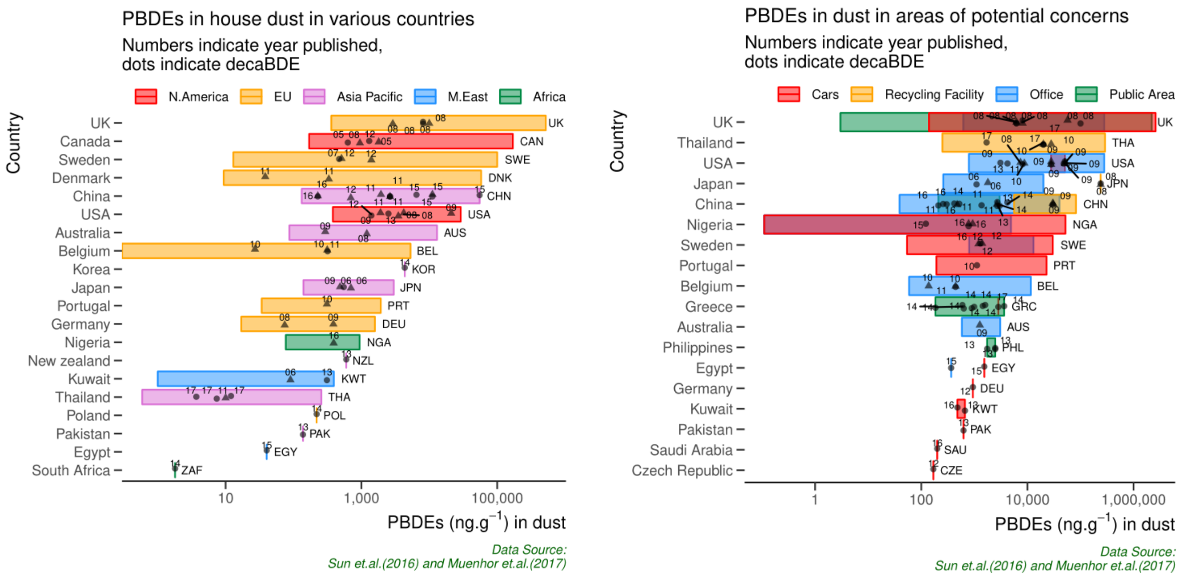
[18] some applications such as draperies might have longer service life

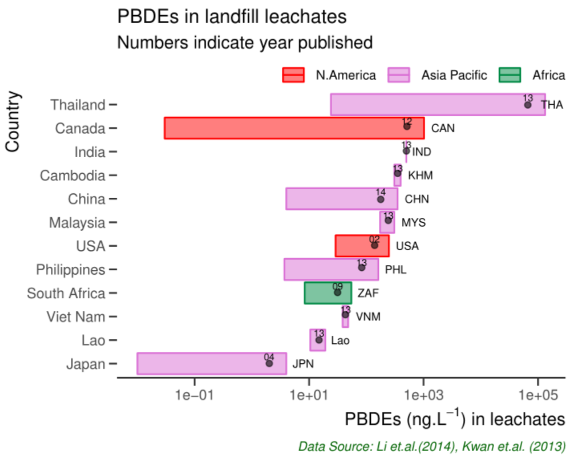


(a) PBDEs in house dust

(b) PBDEs in areas of potential concerns

Reference: Sun et.al. [33], Muenhor et.al. [21]

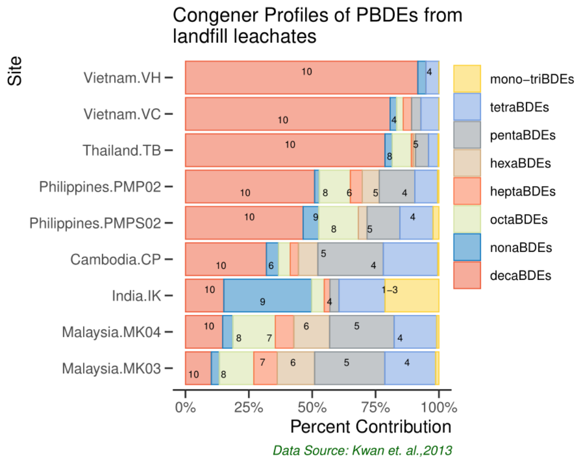
Figure 2-11: Ranges of PBDEs in indoor dusts in various countries



Note: dots locate median values

Reference: Li, et.al. [34], Kwan et.al. [22]

Figure 2-12: Levels of PBDEs in landfill leachates in various countries



Reference: Data from Kwan et.al. [22]

Figure 2-13: Congener profiles of PBDEs from landfill leachates in several Asian countries

Similarly, Figure 2-12 displays ranges of PBDEs in leachates from landfills in countries in North America, Asia Pacific and Africa. The figure clearly shows leachate from Thailand was on the high side. Figure 2-13 further illustrates congener profiles of PBDEs from leachates from this landfill in compared to leachates from other landfills from the same study [22]. The leachate from Thailand was taken from a closed-down, small (6 ha) dump site which was operated for 7 years (during 1993 to 2000). Although this site was expected to accept only MSW from small cities in Pathum Thani Province, the true nature of waste dumped on this site was unknown.

With very limited number of samples, the aforementioned levels of PBDEs in the environment cannot be considered as Thailand national baseline. Unfortunately, to the best of our knowledge, there was no other report for PBDEs in environmental media in Thailand.

2.1.4.1 Predicted emissions of PBDEs from polymeric sources

PBDEs applications that are considered relevant to Thailand can be separated into two paths:

- rigid plastics (particularly PS) in EEE and automotive parts and
- impregnated fabrics

Since Thai polyurethane producers never used BFR in their PUR foams and, so far, there is no analytical result to suggest otherwise, the uses of PBDEs in PUR foam is considered irrelevant to Thailand.

DecaBDE can be released at any stage along the supply chain [31]. Unfortunately, there is no information on the current production of both the BFR compounded resins and the BFR impregnated fabrics in Thailand.

Nevertheless, decaBDE has been detected in housings of CRT TVs that are currently in the use and the disposal phases. With the estimated amount of relevant products put on market and product lifespan model (see section 2.1.3.3), the emission of PBDEs from PS can be estimated as follows.

Emission factors

Since there is no relevant study in Thailand, the emission factors for PBDEs from CRT monitors from the use phase to final disposal as shown in Table 2-18 are used to estimate the PBDEs emissions.

The flow of the TV housings after reaching EOL is assumed to follow simple path as shown in Figure 2-14. The fractions of relevant materials flowing in different paths are time dependent. With the approved Municipal Solid Waste Management Master Plan (2016-2021)[35], the management of e-waste residues is assumed to be improved over time. The assumed fractions of relevant materials flowing into different pathway are summarized in Annex 10.

Table 2-18: Emission factors for the estimations of the releases of PBDEs from polymeric sources in Thailand

Stage	max	min	average	Ref
Use (dust)	1.0×10^{-5}	9.0×10^{-7}	4.3×10^{-6}	[1]
	5.0×10^{-4}	4.0×10^{-8}		[2]
Recycling (dismantle & shredding)	$2.35 \times 10^{-6} \sim 2 \times 10^{-5}$	$8.67 \times 10^{-10} \sim 5.0 \times 10^{-6}$	$3.64 \times 10^{-7} \sim 1.25 \times 10^{-5}$	[1]
	5.0×10^{-6}	8.0×10^{-9}		[2]
Recycling -pellet	5.0×10^{-4}	1.4×10^{-7}	2.5×10^{-4}	[1]
Disposal (simple landfill*)	1.0×10^{-3}	1.0×10^{-6}		[2]
Disposal (incineration)	1.8×10^{-6}			[1]
	2.0×10^{-4}	1.0×10^{-6}		[2]
Disposal (open burning)	1.0×10^{-2}	1.0×10^{-5}		[2]

Ref:

[1] S.Lee, et.al, "Static and dynamic flow analysis of PBDEs in plastics from used and end-of-life TVs and computer monitors by life cycle in Korea", Science of the Total Environment 506-507 (2015) 76-85 [36]

[2] G.Abbasi, et.al, "Global Historical Stocks and Emissions of PBDEs", Environmental Science & Technology, 2019, 53(11), 6330-6340 [37]

Note (*): Abbasi, et.al. [37][38], defined simple landfill as landfills with no control measures on the emission of POPs.

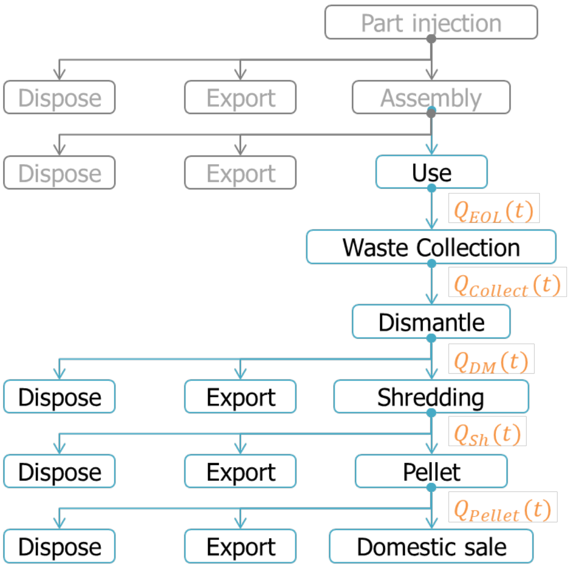
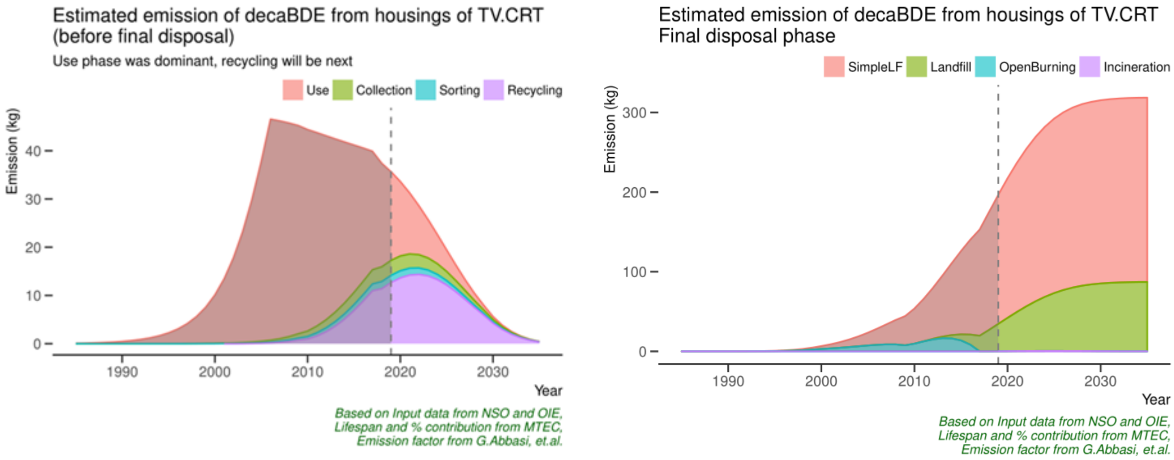


Figure 2-14: Assumed flow of TV CRT housings after reaching EOL

Note: Disposal routes include simple landfill, landfill, open burning, and incineration



Estimated emission of decaBDE from housings of TV.CRT (before final disposal)

Use phase was dominant, recycling will be next

Based on Input data from NSO and OIE, Lifespan and % contribution from MTEC, Emission factor from G.Abbasi, et.al.

Estimated emission of decaBDE from housings of TV.CRT Final disposal phase

Based on Input data from NSO and OIE, Lifespan and % contribution from MTEC, Emission factor from G.Abbasi, et.al.

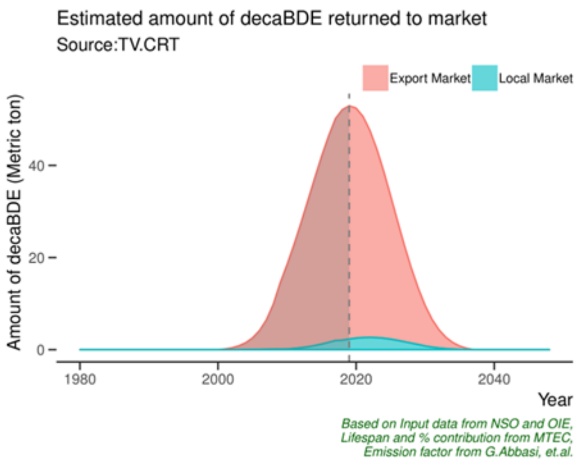
(a) use phase and recycling

(b) final disposal phase

Figure 2-15: Estimated emission of decaBDE from housings of TV CRTs in the use- and disposal phases

Figure 2-15 (a) and (b) summarize the estimated emission of decaBDE (in kg) before and at the final disposal phases, respectively. When most of the relevant TVs were in the use-phase, the emissions in form of dust were dominant. As more TVs are reaching end-of-life, the relative importance is now shifted toward the recycle phase. Unless there is a major change in the recycling technology and/or practices to reduce dust emission in the dismantling and shredding operations, plastic recycling activity will be an important source of decaBDE emissions into living environment for the next 10 years.

Residues generated during EOL management can be disposed of by landfill, open burning or incineration. Assuming that open burnings are no longer practiced after 2018 as a result of the implementation of the national MSW management master plan [35], Figure 2-15 b) shows increasing amount of decaBDE that will be diverted to and stored in landfill in the next 10 years. This PBDEs storage further increases risks over the life cycle of the landfill; particularly from the releases of PBDEs into landfill gas and/or landfill leachate, and the unintended formation and releases of brominated dioxins and furans from incomplete combustion and smoldering during landfill fires.


Estimated amount of decaBDE returned to market
Source:TV.CRT

Based on Input data from NSO and OIE, Lifespan and % contribution from MTEC, Emission factor from G.Abbasi, et.al.

Figure 2-16: Estimated amount of decaBDE that will be returned to market

Shredded chips and plastic pellets obtained from recycling activities will be returned back to the material cycle. As shown in Figure 2-16, about half of the relevant amounts are believed to have been recycled. As noted in previous section, the affected materials are mostly black PS-V0.

Based on the interviews with both the recyclers and the compounders, recycled PS-V0 and ABS-V0 are not attractive to typical Thai converters due to unfavorable price-performance trade-off (price was not low enough to compensate for the hardship due poor and unpredictable feedstock quality). The prospect for domestic uses of these recycled materials to produce cheap products is also very slim due to high competition from cheaper import products. Most of the recovered materials are, therefore, believed to be exported – previously as shredded chips and currently as plastic pellets.

DecaBDE contained in the plastic pellets will be an important issue when the listing of decaBDE under SC becomes effective after 2019. As previously shown in Table 2-16, decaBDE concentrations in certain batches of black PS-V0 chips can be higher than the RoHS and EU’s low POPs limits of 0.1% by weight of homogeneous material.

Although separation of contaminated parts/materials at source is technically feasible, unless there is a clear policy/market mandates to separate out the contaminated resins, it is likely that these contaminated materials be diluted with cleaner resins to make them fit for export/market reentry.

2.1.5 Conclusion and recommendation

Production of PBBs/PBDEs

Thailand never produced any type of PBB/PBDEs. All of the SC listed PBBs/PBDEs are listed under the hazardous substance act. HBB was banned in 2013 while all relevant PBDEs were listed as Category 3 hazardous substances; pentaBDEs and octaBDEs in 2017 and decaBDE in 2019.

Import and Export of PBB/PBDEs

Except for the newly listed decaBDE, only negligible amounts of PBBs and PBDEs were imported into Thailand in the past 10 years.

2.1.5.1 HBB

HBB

There is no information of HBB ever been imported into Thailand. HBB is a Category 4 HS. It is illegal to have HBB in possession. Therefore, stockpile of this substance is assumed to be zero.

There is no data to suggest that HBB had ever been used in Thailand. No report of any detection of HBB in food chain or in any of Thailand's environmental media was found. HBB is, therefore, considered irrelevant for Thailand.

2.1.5.2 C-pentaBDE

Stockpile

There is no record of c-pentaBDE ever been imported into Thailand. C-pentaBDE was listed as Category 3 HS in 2017. At the time of this report, no firm files a request to the authority to process this substance. Moreover, since worldwide production of c-pentaBDE was believed to be ceased almost 20 years ago, stockpile of c-pentaBDE in Thailand is assumed to be zero.

Uses and estimated amount of c-pentaBDE

There is no record of any c-pentaBDE uses in Thailand. According to UNEP [7], transport vehicles produced before 2005 may contain c-pentaBDE, possibly in their seats (flexible PUR foams and seat upholstery textile). Since most vehicles registered in Thailand were locally produced, only imported vehicles were considered relevant. The cumulative amount of c-pentaBDE imported into Thailand via imported vehicles is estimated at **1.5 metric tons**. These seats are believed to have reached end of life and have been replaced with locally produced seats. The removed materials are believed to be discarded as MSW; which could be landfilled, incinerated or open-dumped depending on the MSW management system available to the relevant community.

While there is a report that showed a relatively high concentration of PBDEs in landfill leachates taken from one landfill in Thailand, a detailed investigation found these PBDEs were predominantly decaBDE not pentaBDEs and their lower brominated congers (Figure 2-13). It is unfortunate that Thailand does not yet have a system to monitor the releases of SC POPs from landfills. Therefore, the fate of pentaBDE as well as other relevant POPs cannot be traced at this time.

Alternatives

Until recently, Thailand's Land Transport Act did not demand materials used in transport vehicles to be flame retarded. Based on interviews with leading PU foam producers, flame retarded PU foams in Thailand are mostly with phosphorous-based FR. Thai industry never used BFR in their PU foams. Also, throughout the course of this study, brominated PU foams has never been found. Nevertheless, a brief survey by this inventory team using HH-EDXRF found that BFRs may be used in textiles for interior parts of motor vehicles.

2.1.5.3 C-octaBDE

Stockpile

Based on an interview with a leading compounder, PBDEs were imported into Thailand in the 1990s to produce V0 compounded resins. However, due to the lack of supplier data disclosure in the past, the type of these PBDEs could not be confirmed.

C-octaBDE was listed as Category 3 HS in 2017. At the time of this report, no firm files a request to the authority to process this substance. Since worldwide production of c-octaBDE was believed to have been ceased almost 20 years ago, stockpile of c-octaBDE in Thailand is believed to be zero.

Uses and estimated amount of c-octaBDE

Two EOL e-waste samples were found positive for octaBDE. The first sample was ABS casing taken from a CRT computer monitor produced before 1995. The second sample was PS casing taken from a CRT TV, produced in 1994 and imported from an Asian country.

Number of computer monitors produced before 1995 is estimated at 400,000 units and the number of monitors that could contain octaBDE is estimated at 40,000 units. Assuming an average c-octaBDE concentration of 15% and the average ABS weight of 2 kg per monitor, the total amount of c-octaBDE in the affected ABS is estimated at 12 metric tons. Most of these monitors are believed to have reached end-of-life, leaving about 1,000 monitors, with about **300 kg of c-octaBDE remaining in hibernation**.

ABS resins extracted from EOL monitors are shredded and sold as recycled ABS chips, with ABS V0 grade commanding higher prices than regular grade. Most of the ABS-V0 chips found in this investigation were flame retarded with TBBPA. Nevertheless, ABS-V0 chips with c-octaBDE may still be found especially those from recycle shops located in the central part of Thailand.

Alternative

Based on product survey results, c-octaBDE was found mainly in ABS resins. However, the chance of finding ABS-V0 with c-octaBDE was very low. For ABS resins, this study found TBBPA followed by BTBPE the two most popular BFRs for ABS. Moreover, as demands for halogen-free products continue to increase in the recent years, ABS/PC blends (marked with FR (40)) are frequently found in modern IT appliances.

2.1.5.4 C-decaBDE

C-decaBDE may have been imported into Thailand in the past but due to the unclear import classification code, the amounts of decaBDE imported into the country were unknown. In 2018, DIW received notifications for the intentions to import about 70 tonnes of decaBDE. However, since decaBDE was not a controlled substance until recently [39], it is not known whether or not these notified activities were actually taken place.

Results from questionnaire surveys indicated that key stakeholders had phased-out the use of c-decaBDE since 2006 as a result of the enforcement of EU RoHS Directive. This result could imply historical uses. However, it was not clear whether or not the compounding of the affected resins took place in Thailand. Nevertheless, since the phase-out was commenced more than 10 years ago, stock of decaBDE for these historical uses are assumed to be exhausted.

Results from a field survey suggested that decaBDE may find new uses in applications that faced lower restriction such as upholstery and drapery textiles, rubbers and silicone parts. It is not known whether these flame retarded materials were imported or locally produced. With limited responses from stakeholders and limited data for CiP, the stockpile of decaBDE for these new applications cannot be estimated at this time.

Uses and estimated amount of decaBDE

Thailand’s flexible fire safety regulations suggested that there is only marginal demand for fire retarded products. Nevertheless, results from preliminary products survey indicated decaBDE had been used in several high risk applications, particularly plastic housings of CRT TVs produced before 2006 and upholstery furniture and draperies textile products. Unfortunately, the sources for these materials could not be identified.

Although several other plastic resins were tested positive for bromine contents, decaBDE were predominantly found in PS resins, particularly in housings of CRT TVs produced before 2006. The number of affected TVs is estimated at 5 million sets. The corresponding amount of PS resins that contained PBDEs is estimated at 10,000 tonnes and the total amount of decaBDE is estimated at 920-1,500 tonnes. About half of these amounts are believed to have been already disposed of; leaving about **500-820 tonnes** left ‘in-stock’ in the in-use and in-hibernation products.

The affected polymeric resins are recycled along with other plastic resins that can be extracted from e-waste. The concentrations of decaBDE in the shredded PS-chips and the recycled plastic pellets depend on the feedstock that arrived at the shop. While decaBDE concentrations in most batches that were sampled were low, concentration in certain batches, particularly black PS-V0 chips, can be high. Due to low demands from local compounders, these recycled materials are believed to be exported.

For decaBDE uses in textile applications, the average amount of decaBDE in flame retarded fabrics is estimated at **300 kg per year** and the cumulative amount of decaBDE in impregnated fabrics that are in use-phase is estimated at **3 tonnes**.

Emissions of decaBDE

DecaBDE can be released from the product at any stage throughout product life-cycle. Results from an emission model suggested the release in form of dust are now shifting from the use-phase to the dismantling and recycling facilities. Moreover, the model indicates that residues from EOL management will become important emission source of decaBDE in the next 10 years.

Plastic resins extracted from housings of e-waste are likely recycled. Due to the relatively high values of the affected resins, most of the decaBDE in polymeric resins are likely recirculated along with these engineering plastics. Half of the relevant amount was believed to be returned to material cycle, possibly via export plastic chips and resins.

The fate of the remaining half of the relevant amount of decaBDE consumed in Thailand is unclear. Unless there is a clear policy/market mandates to separate out the contaminated resins, decaBDE contaminated resins may be diluted with cleaner resins to make them fit for export/market reentry.

Alternative

This study found DBDPE the most popular BFR for PS/HIPS-V0 resins. As with the trend for ABS, other halogen-free blends (FR (40)) were also found in modern IT appliances.

Due to limited information both from the field survey and from relevant stakeholders, the types FR used in textile applications are not clear. However, MTEC's preliminary survey of fire retarded fabrics suggested that fabrics with other BFR and non-BFR system were available in the market.

Limitation of the study

This study suffers from the fact that most stakeholders do not have information/records of PBDEs that were embedded in their products, especially for products put on the market decades ago. Also, historical data both on imported substance and on imports of PBDEs embedded articles were not available. This assessment study, therefore, based mainly on evidences from preliminary surveys of 'suspected' products and end-of-life products that were accessible to the inventory team.

Relevant products:

This study confirmed (with high confidence) historical uses of decaBDE in PS resins used to produce housings of CRT TVs. It also found that TBBPA, not decaBDE, was the BFR of choice for ABS resins for computer monitors in Thailand. Additionally, this study revealed that Thai industry had phased-out the uses of decaBDE in EEE applications, as a result of EU RoHS Directive. However, this study found that decaBDE were also used in other areas, particularly automotive parts and textiles. Due to limited time and resources, the uses of decaBDE in these areas had not been sufficiently explored.

Particularly, screening results indicated that decaBDE are used in FR grade textiles (for automotive and for building applications). However, due to limited data particularly on local production and consumption of FR grade textiles, the estimated amount of decaBDE in textiles in this study considered only imported fire retarded fabrics with HS Code 59070030. This amount did not include imports of impregnated textiles in finished products, such as furniture, draperies, carpets, garments, etc.

Moreover, the uses of decaBDE in automotive parts, particularly underhood rubbers/silicone parts, have not been confirmed.

Identification of hotspots:

Based on the predicted amount of decaBDE in plastic housings of CRT TVs that had been put on market in the past, this inventory team made an attempt to estimate the emission of decaBDE to the environment. This estimation covered only emissions during the use- and EOL management phases. The lack of data on the flow of decaBDE affected materials/parts along supply chain had made it impossible for the inventory team to identify possible contaminated sites along the pre-consumer value chain.

Estimated emission:

At the time of this report, there was no mandate for relevant organizations to monitor PBBs/PBDEs in environmental media, along food chain, and in humans. The estimated emission, therefore, relies on published emission factors and the assumed EOL management scenario. The model covers only decaBDE from housings of CRT TVs which is believed to be the dominant source of decaBDE in Thailand.

However, emissions from other unconfirmed sources, such as plastic compounders and FR textile finishers, are also possible. If these activities exist, emissions from these facilities (particularly residues, WWTP sludge, and effluent water) can be significant as seen in other countries [40][41].

Recommendation

Communication and/or disclosure of concern substances in products

This inventory assessment study has proved it is difficult and costly to trace the uses of chemical substances that were embedded in products, especially for those that were placed on market years ago. Historically, before EU introduced RoHS and REACH, firms had no obligations to gain knowledge and, hence, unaware of chemicals incorporated in their products. This situation has now changed. Declaration and communication of CiP and/or disclosure of concern substances in products have become a new norm for global products. These CiP data and declaration system are crucial elements for the management of chemical and safety throughout product life-cycle. It is, therefore, suggested that Thailand lays down measures to benefit from such system. This declaration should also include appropriate marking and/or labeling on materials to assist EOL management.

Prohibit marketing of PBDEs contaminated products (and waste)

All SC POPs industrial chemicals are prohibited substances for export products. REACH and RoHS are becoming new norm for global supply chain. As an important producer for PBDEs relevant products, Thai products always satisfy customers' requirements. It is unfortunate that Thailand does not yet introduce such measures. When countries deploy measures to prohibit PBDEs in products, contaminated products/wastes (including products from recycled materials) are likely diverted to areas with limited controls of chemical substances in products. Contaminated products do not only pose risks to consumers but also put burdens to public for their disposal. Contaminated products will likely release harmful substances to waste processors and to the environment at EOL.

Although all commercial PBDEs are designated Category 3 HSs, the contents of PBDEs in materials, parts, and/or finished products are beyond the scope of the existing controls. Therefore, following actions should be considered:

- Lay down measures to prohibit marketing of PBDEs contaminated products, in-line with RoHS-like measures put in place elsewhere in the world.
- Publish low POP concentrations for PBDE, in-line with levels agreed upon under the Basel convention [42]. Note that there are currently two low POPs content suggested for PBDEs by Basel Convention; 50 mg/kg for each type of PBDE or 1000 mg/kg as a sum of all PBDEs.
- Lay down plans and supports for proper management of contaminated products, including:
    - Develop methods to identify and separate out contaminated materials/parts before mixing with other materials.
    - Conduct researches to gather intelligence information to enable accurate identification of PBDEs in EOL products
    - Lay down clear policy/measure to prohibit mixing and recycling of contaminated material with other cleaner material to prevent further spread out of PBDEs (in cheap products)
    - Verify and develop a guideline for proper handling and disposal of the contaminated materials

Finally, as Thailand is making a transition toward a more circular economy, it is important that all valuable materials/products are recovered. Researches toward finding better alternative and technology to eliminate the unwanted PBDEs while preserving the valuable base materials should be encouraged.

Notifications of articles in use pursuant to note (ii) of Annex A

Although this study is a preliminary study and the list of products found to be contaminated with decaBDE is not exhaustive, the government should notify articles in use in pursuant to note (ii) of Annex A of the Convention.

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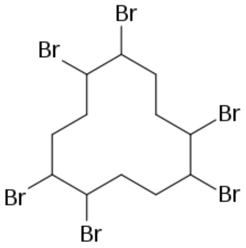
2.2 Hexabromocyclododecane (HBCD)

2.2.1 Introduction



Hexabromocyclododecane (HBCD, CAS No.: 3194-55-6) is a white solid, odorless, cycloaliphatic compound with six bromine atoms. Theoretically, it consists of 16 stereoisomers, while the commercial HBCD is mainly composed of three diastereoisomers: α (10-13%), β (1-12%), and γ (75-89%) [43].

HBCD has extensively been used as additive flame retardant, mainly in expanded polystyrene foams (EPS) and extruded polystyrene foams (XPS) for insulation boards in building and construction applications. HBCD is also used, to a lesser degree, in high impact polystyrene (HIPS) in electrical and electronic parts [44], in the back-coating of textile [45] and of fabrics in vehicles [46].

HBCD has been detected in ice-box foams, food packaging EPS foams [44][47] and EPS buoys [48], [49], despite no fire safety requirements for these products. These findings raised concerns that HBCD may be added or may cross-contaminate (via the use of PS from recycling) to packaging EPS foams [50].

EPS foams are produced by expanding EPS foam beads. There are mainly two types of EPS beads production: the (batch) suspension polymerization of styrene (monomer) in water and the (continuous) melt impregnation of polystyrene. For EPS beads produced via suspension polymerization process, HBCD is added to the styrene polymerization reactor along with the blowing agents (typically pentane) and other reactants during polymerization into the small EPS foam beads [51]. HBCD concentration of about 0.5%-1.0% is required to meet flame retardant standards [52].

For XPS foam, about 0.8 – 2.5% of HBCD [50] is mixed with PS resins, blowing agents and other additives in an extruder. The resulting mixture is melted into a viscous plastic fluid, forced through a die, expanded into foam, and finally cut into final shape.

Similarly for HIPS, about 1-7% of HBCD [53] is mixed with PS pellets and other additives in a masterbatch extruder to produce UL 94-V2 grade flame retarded HIPS resins [54].

Finally, for uses in textile, HBCD dispersed in acrylic or latex dispersions are back coated to textile in the textile finishing industry. Typical HBCD loading is about 10-25% [54].

In 2013 the Stockholm Convention decided to list HBCD in Annex A of the convention (decision SC 6/13 [55]), which obligates member countries to take measures to eliminate the production and use of HBCD; with specific exemptions for production and use of HBCD for EPS and XPS in buildings provided that necessary measures are taken to ensure that EPS/XPS containing HBCD can be easily identified by labelling or other means throughout their life cycles.

Prior to the listing in the SC, the market size for HBCD was about 31,000 t/year with the EU and China each consuming about 40% of the global production [52]. However, for a hot and humid country with less stringent fire safety regulation like Thailand, the extents of the uses of HBCD are largely unknown. This information is fundamentally important for the development of a national HBCD inventory.

Inventory assessment process

This HBCD preliminary inventory assessment comprises a 3 stages process:

1. Desk study:
   The following information was studied for identifying HBCD relevant products/applications and stakeholders in Thailand
   - Relevant HBCD usages from UNEP guidances
   - Available literatures/published reports on the detection of HBCD in environmental media in Thailand
2. Preliminary products survey:
   A brief preliminary products (analytical) survey to screen for HBCD relevant applications using handheld EDXRF and LC-MS/MS (see below)
3. National surveys consisting of:
   - Questionnaire survey for information from potentially relevant stakeholders
   - Interview of key stakeholders

Sample collections and analysis

Information related to HBCD in Thailand was scarce. There was no HBCD specific HS Code to enable tracing of imports[19]. Although HBCD is banned under EU POPs regulation[56], it is not a restricted substance under EU RoHS Directive [2][3]. Local producers have not been requested by global customers for HBCD relevant information. Therefore HBCD was an unfamiliar substance to most firms except for a few firms who actually use it.

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[19] HS Code 29038900-990 (Halogenated derivatives of cyclanic, cyclenic or cycloterpenic hydrocarbons (excluding HCH, lindane, aldrin, chlordane, and heptachlor)) is widely recommended by global suppliers. However, this code was not specific enough to exclude other halogenated organic compounds.

A preliminary products survey was needed to assess the possible relevance of HBCD in following 3 materials in Thailand: EPS, textile, and HIPS. HBCD in XPS foam was excluded from this survey because of the difficulties of finding XPS samples both from household items and from waste management sites. It should be noted that there was no local production capacity for XPS foam at the time of the assessment. According to a PS producer, XPS foam was mainly imported and, hence, not widely used.

Screening tests

MTEC has launched a brief survey for bromine (Br) in targeted products using a handheld EDXRF spectrometer (Bruker S1 TITAN 800, Billerica, MA, USA) during February to April 2018 to assess possible BFR contamination. Samples tested were consumer products, office furniture and devices, automotive interior parts, and e-waste plastic components. EPS foam samples were collected from packaging wastes, ice boxes, off-cuts from a sandwich panel installation, and samples submitted to MTEC by EPS foam producers. In addition, EPS foam beads were sampled from one of the EPS bead producer (see more detail in PBDEs section.)

Samples found positive for Br and EPS foam samples were collected back to MTEC laboratories for further analysis as follows:

- **EPS Foam:**
  Due to its predominant air content, in-situ HH-EDXRF testing of EPS foams normally failed to provide meaningful counts. Therefore EPS foam samples were ground and compressed before being submitted to a more sensitive screening technique using a desktop EDXRF spectrometer (Shimadzu EDX-8000, Shimadzu Corporation, Japan). EPS foams that were found positive for Br were further characterized using Schlummer et.al. solvent dissolution method [57]. The method makes use of the fact that HBCD and EPS are soluble in common solvents (such as acetone) whereas the currently available alternative BFR[20] is not. The positive detection of Br (by desktop EDXRF) in the solvent phase, therefore, further confirms HBCD content. Finally, confirmations and quantifications of several HBCD positive samples were carried out by liquid chromatography-tandem mass spectrometry (LC-MS/MS)
- **Textile:**
  Due to the porous nature of the textile samples and the very thin layer of FR coatings, HH-EDXRF testing of FR impregnated textile samples suffered from low signal counts. Where applicable, samples were folded in-situ to stack thick enough

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[20] Chemtura’s “Emerald Innovation 3000” or “Polymeric FR” also known as PolyFR

material for HH-EDXRF to generate sufficient counts. Moreover, as some textile samples such as seat covers can accumulate BFR during usages (possibly carried over by human or deposited from the surrounding environment), low level of Br (in the order of 10 ppm) in textile samples taken from contaminated area can be anticipated. These results are considered false positive and only samples with Br level higher than 1,000 ppm are considered positive for BFR and, consequently, sent for further confirmation test using ultrasonic extraction followed by either gas chromatography-mass spectrometry (GC-MS) as described by ISO 17881-1 standard [58] or LC-MS/MS (modified from ISO 17881-2 [59]).

- **Rigid HIPS:**
  Rigid plastic samples tested positive for Br by HH-EDXRF were further characterized to identify BFR type by ATR-FTIR. Some inconclusive samples were also sent to LC-MS/MS for HBCD analysis.

2.2.2 Inventory of HBCD in Thailand

2.2.2.1 Relevant uses in Thailand

HBCD in EPS foams

EPS foams are used to produce thermal insulation panels or sandwich panels for cold storage rooms, freezer rooms and cleanrooms in Thailand. Based on information from EPS foam converters, EPS core sandwich panels for industrial and commercial facilities are required to be flame retarded to meet fire safety standards [60] and insurance risk control standards.

Flame retarded EPS foams are produced from 'self-extinguishing' or SE-grade EPS beads that meet fire safety requirements (such as DIN 4102 B1 or B2). Based on information from EPS bead producers, HBCD was historically used and has recently been phased-out; in-line with the global supply cessation. The HBCD loading used was not disclosed, but the upper range of 1% was accepted as a reasonable value. Due to the extra costs of the flame retardant and the required synergists, SE-grade EPS beads are generally about 10-30% more expensive than standard grades.

The majority (~75%) of EPS foam beads produced in Thailand are used in the packaging sector. With increasing number of reports of finding HBCD in ice-boxes, food packaging EPS foams [44][47] and EPS buoys [48], [49], there are concerns that HBCD may be added or may cross-contaminate (via the use of PS from recycling) to packaging EPS foams [50]. Based on information from a major EPS beads producer, recycled PS from post-consumer EPS foams are not yet commercially available in Thailand. Additionally, EPS beads in Thailand are produced using conventional beads suspension polymerization process [61] which is a batch process that converts styrene monomer into expandable polystyrene beads. The process cannot accept polymerized PS feedstock; hence it is considered unlikely that HBCD from contaminated EPS foams was unintentionally introduced into locally produced EPS beads.

Furthermore, according to EPS beads producers, SE-grade EPS beads are distinguishable (by bead sizes and the milky appearances) from general beads. Since SE-grade EPS beads are more expensive than general ones, it is unlikely that the more expensive beads are intentionally used to produce cheaper products.

However, due to the inherent volatility of the blowing agents, EPS beads have limited shelf-life of about 6 months (in cold storage). Nearly expired SE-grade EPS beads from abroad may be offered on sale for competitive prices which might occasionally lead to SE-grade EPS beads being utilized in relatively low-cost products, e.g. packaging, buoys, etc. Nevertheless, according to a bead producer, HBCD synergists within SE-grade beads are incompatible with general beads, making it problematic to mix more than 5% of SE-grade beads to general beads to make packaging grade EPS.

Based on results from MTEC's screening tests of EPS foam samples using Schlummer's solvent extraction followed by EDXRF analysis, the use of HBCD in EPS-core sandwich panels can be confirmed. However, the screening survey did not yet find other EPS samples that were contaminated with HBCD. Nevertheless, due to limited time and resources, the number of samples explored in this survey was too limited to arrive at any conclusion. The relevance of HBCD in other EPS foams, therefore, cannot be confirmed at this time.

HBCD in other applications

Information related to HBCD uses in other applications in Thailand is very limited. Except for the confirmed uses in SE-grade EPS foam as mentioned above, no firm indicated their HBCD involvements in the questionnaire responses (see detail in PBDEs section).

Results from screening tests of targeted samples using handheld EDXRF indicated BFRs were used in a wide range of products, including textile and plastic parts. However, apart from EPS foams, results from more detailed confirmation tests have not yet identified any sample contaminated with HBCD.

Particularly, several textile samples were tested positive for BFR. Some of these samples were confirmed to be contaminated with decaBDE. However, detail analysis using LC-MS/MS did not detect HBCD in any of these samples. Similarly, a large number of rigid polystyrene (PS) parts were tested positive for BFR but more detailed analysis using ATR-FTIR did not yet identify any HBCD contaminated sample.

HBCD in recycled (rigid) PS

EPS foam can be recycled [62], with or without removing inherent contaminants [63]. Simple EPS foam recycling based on thermal process can return rigid-polystyrene (PS) pellets suitable for producing PS parts/products, such as cloth hangers, picture frames, toys and stationery items, etc. If SE-grade foams are recycled without decontamination, HBCD can then be transferred to the next articles.

However, dedicated EPS foam collection system does not yet exist in Thailand. Consequently, EPS recycling is not yet widely available. Nevertheless, a brief check of listed price of recyclable materials that are accepted by a leading post-consumer 'recycle shop' (or scrap shop) [64] found 'clean foams' (in Thai) as an entry on the list, indicating the availability of an outlet for post-consumer EPS foams. Moreover, a search on the internet for information related to "white foam recycling"(in Thai)[21] found a local firm that offers EPS foam collection, transport, and recycling service to convert EPS foam into recycled PS pellets.

Based on interviews with plastic recyclers, post-consumer general purpose polystyrene (GPPS) resins are not attractive to typical Thai converters due to unfavorable price-performance trade-off (price was not low enough to compensate for the difficulties due to poor and unpredictable feedstock quality). The prospect for domestic uses of these recycled materials to produce cheap products is also very slim due to high competition from much cheaper import products.

A brief product screening survey at NSTDA flea market did not find any Br contaminated GPPS products/parts. However, considering the massive scale of cheap import products, the number of samples in this preliminary study is considered too low to arrive at any conclusion.

2.2.2.2 Manufacture and import

HBCD is not manufactured in Thailand. Based on information from stakeholder interviews, HBCD has been imported by EPS bead producers to produce SE-grade EPS beads. According to the DIW factory database, there were two EPS bead producers in Thailand in 2017 [65].

As HBCD is not yet classified as a Category 3 hazardous substance, imports/exports of HBCD do not yet require an authorization. There is currently no specific tariff code for this substance either. However, HBCD's inherent property renders it a Category 1 hazardous substance, which is automatically included in the DIW hazardous substance list known as the "list 5.6" [66]. Firms who produce or import more than 1,000 kg of HBCD per year are encouraged to notify the authority within 60 days [67]. This notification process is not mandatory but firms who voluntarily provide the required information can be exempt from

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[21] Last search January 27, 2020

obligations from 4 other relevant DIW notifications.

In 2016, one firm notified DIW of their intention to import about 8,000 kg of HBCD from China. Since global HBCD producers had previously phased-out HBCD production and China was likely the only place where HBCD was produced around that period [50], this shipment is expected to have been the very last shipment of HBCD.

Based on an interview with a local HBCD distributor, HBCD was no longer imported into Thailand since 2017, when the global manufacturers terminated their production, though HBCD may still be available from certain area[22]. Prior to 2017, this firm imported HBCD at about 10-15 t/year, according to the exact amounts requested by local customers. The shipments were transported from the port directly to the customers, resulting in zero stockpile of HBCD at distributor’s warehouse. This firm currently imports Polymeric FR, aluminum hydroxide ($Al(OH)_3$ or ATH) and zinc borate, which are alternatives and synergists to HBCD. Apart from importing for EPS beads, there was no HBCD import for other uses.

HBCD may be indirectly imported in SE-grade EPS beads. Unfortunately, due to the absence of a unique product tariff code, the import/export amount of SE-grade EPS beads cannot be determined. Furthermore, the number (and locations) of converters who produce SE-grade EPS foams are also unknown as existing factory database does not have specific information about the type, the grade, and the end-use of the foams.

HBCD may also be imported in form of chemical mixtures for textile finishers to produce flame retarded fabrics. Again, the import amounts cannot be estimated due to the absence of a unique tariff code. Moreover, since HBCD impregnated textiles have yet to be found, and since there is no report related to HBCD in the environmental media in Thailand, the relevance of HBCD in textile application cannot be confirmed at this time.

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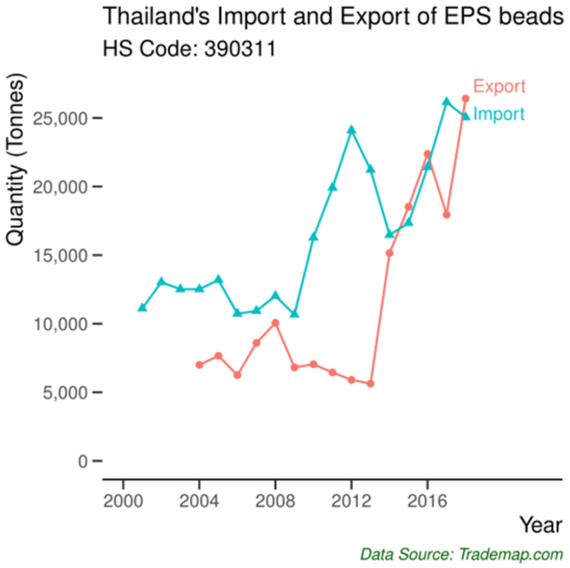
[22] An online search on March 3rd, 2020 found HBCD (CAS No 3194-55-6) was available for sale at a very cheap price (1$/t).

2.2.2.3 Estimation of stock of HBCD in EPS foams

Based on information from PTIT[23] and a major bead producer, Thailand's total EPS beads production capacity increased from 44,000 tonnes per year in the year 2000 to 80,000 tonnes per year in 2018. (Table 2-19). Some of these EPS beads were exported but some EPS demands were also met by imports, as shown in Figure 2-17. These import/export figures also included SE-grade EPS beads. Unfortunately, due to the absence of a unique product tariff code, the import/export amount of SE-grade EPS beads cannot be determined.

According to local EPS beads producers, SE-grade accounted for about 20% of total EPS beads produced in Thailand. HBCD was the only FR these producers ever used until the recent cessation of global HBCD production.



Note: exports in 2001 to 2003 are excluded due to suspected error

Figure 2-17: Thailand's import and export of EPS beads from 2001 to 2018

Table 2-19: Estimated amount of SE-grade EPS production and HBCD consumption rates between 2001 and 2018

Items	Unit	2001-2011	2012-2013	2014-2017	2018	Total
Locally produced EPS beads	t/a	44,000	48,000	60,000	80,000	50,000
Locally produced SE-grade EPS (20%)	t/a	8,800	9,600	12,000	16,000	10,000
Amount of HBCD*	t/a	66[44-88]	72[48-96]	90[60-120]	8***	69[46-92]
Total HBCD imported	t	726 [484-968]	144 [96-192]	360 [240-480]	8	1,238 [828-1,648]
Net Imported EPS beads**	t/a	3,200	9,100#	1,900	-1,400	3,311
Net Imported SE-grade EPS (20%)	t/a	640	1,820	380	0	470
Total amount HBCD embedded in imported SE-grade EPS	t	53[35-70]	27[18-36]	11[8-15]	0	92[61-122]
Net imported HBCD (in all forms)	t	779 [519-1,038]	171 [114-228]	371 [248-495]	8	1,330 [885-1,770]

Note: * assumed 0.75 [0.5-1] % loading rate, ** excluded export data for 2001 to 2003 (suspected error – recorded values were much higher than production capacity) , *** accounted for the last shipment, # exclude sharp import spike in 2012 believed to be results of the 2011 major flood

Assuming, for the purpose of this study, that SE-grade contributed to 20% of total EPS beads and that SE-grade beads contained 0.5-1% (w/w) HBCD, the total amount of HBCD consumed between 2001 and 2018 in Thailand is estimated at 1,330 [885 -1,770] tonnes, as detailed in Table 2-19.

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[23] PTIT insight & analysis: http://www.ptit.org/index.php/Service.Insight/PTIT-Insight-&-Analysis, last access September 2019

SE-grade EPS foams are predominantly used to construct durable products. With a service life for insulation foam of 30 to 50 years or longer, all of the relevant amounts of HBCD are assumed to currently remain in use-phase.

2.2.2.4 Alternatives

Both local EPS bead producers have concurrently ceased to use HBCD, in-line with the global cessation of HBCD production. Since then, Polymeric FR (CAS No 1195978-93-8) or PolyFR has been offered by the same suppliers as a drop-in substitute for HBCD. According to a beads producer, as of 2019 the PolyFR costs about twice as much as HBCD. Additionally, since PolyFR contains lower number of bromine per unit weight [68], higher loading of PolyFR will be required to attain the same amount of bromine.

Alternatively, other material systems with improved flame retardance; such as PIR (Polyisocyanurate) foam, Rock wool, etc., are available in the market. The costs for these options, however, may be higher.

2.2.2.5 Waste management

HBCD is not yet a ‘classified’ substance under the Hazardous Substance Act. Consequently the low POP content for HBCD has not yet been established in Thailand and; hence, waste containing HBCD is not yet classified as hazardous waste. Note that there are currently two low POPs content suggested for HBCD by Basel Convention; 100 mg/kg or 1,000 mg/kg [42].

Industrial waste from bead producers and SE-grade foam converters (generated before 2018) may contain HBCD. A search in DIW waste transfer manifest database [69] found that about 40 tonnes of “foam” related wastes were generated in 2017. Most of them (~90%) were disposed of by incineration with energy recovery. Unfortunately, existing industrial waste manifest system does not allow for the classification of the types of the foams. Nevertheless, it can be deduced that most EPS foam wastes were also incinerated with energy recovery.

There is no information related to the management of post-consumer SE-grade EPS foams. Due to their long service-life, most of the EPS-core sandwich panels are believed to still be in use-phase. Areas where SE-grade sandwich panels were put into uses are likely industrial and commercial areas. Currently, there is no designated system for construction/demolition waste in Thailand. However, since decommissioning activities are mostly performed manually, usable panels may be removed and sold to second hand building materials shops for reuse. Residues mixed with other combustible materials may be sent to incineration with energy recovery and the remaining residues may end up in the municipal waste stream which is likely dispose of in landfill.

2.2.2.6 Release to the environment

Release of HBCD to the environment can be expected in all life-cycle stages. Since the uses in EPS foams had been confirmed, the releases from foam processing, SE-grade EPS-core sandwich panel installation, and demolition are considered relevant. Unfortunately, there is no data related to the detection of HBCD in any environment media in Thailand.

HBCD emissions during the use phase of EPS foam is believed to be low [70]. However, HBCD in indoor dusts have been reported in countries where HBCD uses in household items (other than EPS foams) had been confirmed; particularly in Asian countries such as Japan [71], Korea [72], China [73], [74]. Most of the HBCD released is believed to be from textiles. Again, to the best of our knowledge, there was no study to identify HBCD in indoor dusts in Thailand.

2.2.3 Conclusion and recommendation

Stock of HBCD

HBCD may be added to EPS/XPS, textile and HIPS to impart flame retardant property. Only the uses of HBCD to produce SE-grade EPS foams had been confirmed in this study. The total amount of HBCD contaminated SE-grade EPS foams is estimated at 175,000 tonnes and the corresponding amount of HBCD is estimated at **1,300 tonnes** (between 890-1,770 tonnes). Most of the relevant amounts of HBCD are believed to still be in use-phase.

Emissions of HBCD during EPS foam use phase is believed to be low [70]. However, the emissions are highly likely during the decommissioning and disposal of the constructed panels. Thus, it is imperative that the affected foams or panels be clearly marked to allow for easy identification, in line with the provisions of Part VII of Annex A of the SC. It is also necessary to identify appropriate disposal routes and develop guidance for the decommissioning and disposal of the affected panels to protect workers from the exposure to HBCD and to prevent further releases to the environment.

As Thailand is making a transition toward a more circular economy, proper marking of BFR in products will be an important measure to avoid unnecessary risk of cross-contamination of substance of potential concerns into sensitive products (such as food packaging, buoys, etc.) even after the phase-out of HBCD.

Potential contaminated sites

According to UNEP guidance [50], all sites where the manufacture of products and articles containing HBCD, the use of these products, the recycling and the end-of-life treatment of these products have taken place may be potentially contaminated. Workers can be exposed to HBCD and fine particles resulted from hot wire cutting of EPS boards at production and at construction sites [75]. However, except for the confirmed uses in EPS foams, information related to sources, releases, environmental fate of HBCD at the national level is lacking. Particularly, the levels of exposure of general population as well as workers to HBCD are currently unknown.

It is therefore recommended that research studies should be conducted. Particular attentions should be paid to confirm levels of HBCD in following areas:

- Sites where HBCD was used in production and compounding
- Household dust (results from this study can help confirm the uses of HBCD in textiles and other household items)
- Dust and soil in and around e-waste dismantling sites and plastic shredding facilities
- HBCD in other products/ applications (in case the study of indoor dusts indicates possible uses or concerns)
- The releases of HBCD along pre- and post-consumer SE-grade EPS foams value chain (including sludge from wastewater treatment)
- Landfill and dumpsite leachates and sediments[24]

Finally, once potential sources are confirmed, a full inventory should be conducted to provide an appropriate baseline data for HBCD for the country.

Notifications of articles in use pursuant to note (ii) of Annex A

Although this study is a preliminary study and the list of products found to be contaminated with HBCD is non-exhaustive, the government should notify flame retarded expanded polystyrene (EPS) currently in use in pursuant to note (ii) of Annex A of the Convention.

Limitation of the study

This survey is a preliminary assessment, focusing on large-sized components as suggested by the UNEP guidance. Except for the use of HBCD in SE-grade EPS foams, other possible uses could not be confirmed. Local industries have been unable to provide information on their involvement. Samples with HBCD were yet to be found. Although the inventory team made an attempt to identify HBCD in a number of suspected items, the survey results were not comprehensive enough to arrive at any conclusion.

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[24] This study should apply for all POPs industrial chemicals, not limited to HBCD.

Particularly, due to lack of analytical evidence, the uses of HBCD in textiles and XPS applications cannot be confirmed at this time. Furthermore, the extents of HBCD contamination in imported products produced with GPPS from recycled SE-grade EPS is largely unknown. Unlike EPS foams, these products can release HBCD during use-phase, posing risk to consumers especially the vulnerable groups.

Depending on the findings from the proposed research studies as mentioned above, actions should be taken to limit the releases to the environment. Particularly, following measures should be considered:

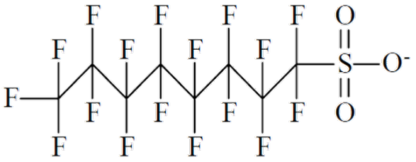
- Establish low POP concentration for HBCD, in line with provisions developed by the Basel Convention [42], and specify waste containing HBCD as hazardous waste
- Limit HBCD concentration in products
- Establish national standard value for HBCD in relevant environmental media so that its releases from potential sources (such as landfill and dumpsite leachates and sediments) can be routinely monitored.

* * *

2.3 Perfluorooctane sulfonate (PFOS)

2.3.1 Introduction

Perfluorooctane sulfonate (PFOS) is a fully fluorinated anion [76] with eight-carbon chain length (C8). PFOS is known for its unique fat and water repellant property along with its high tolerance to heat and chemical attacks – making it a highly useful surfactant for a broad range of applications [77]. Examples of applications known to use PFOS in the past include non-stick products, stain-resistant fabrics and all-weather clothing, water/oil/solvent repellent for paper/leathers/food containers, surfactant in firefighting foam, mist suppressant in metal plating bath, surfactant for etching acid for circuit board, etc.



$CF_3(CF_2)_7SO_3^-$

Figure 2-18: Structural formula of PFOS

PFOS can exist in anionic, acid and salt forms [77]. However, PFOS by itself, as an anion, does not have a specific CAS number but its acid, salts, and other compound forms do.

In 2009 the Stockholm Convention listed perfluorooctane sulphonic acid (PFOS, CAS No. 1763-23-1), its salts, and perfluorooctane sulfonyl fluoride (PFOSF, CAS No. 307-35-7) in Annex B (Restriction) of the Convention [78]. Some examples of PFOS salts are shown in Table 2-20. It should be noted that the number of PFOS-related substances regulated under the Stockholm Convention are much more than those listed in the table.

Since PFOS anion is the most common form found in the environment and in the human body, the Stockholm Convention restricts the use and the production of PFOS and its related substances[77], [79]. The term "PFOS-related substances" is referred to all substances that contain one or more perfluorooctylsulfonyl moiety (defined as $C_8F_{17}SO_2$), which have the potential to transform or degrade to PFOS in the environment. Therefore, the number of PFOS-related substances can be large. In 2007 the Organization for Economic Co-operation (OECD) compiled a comprehensive list consisting of 165 PFOS-related substances [80]. All of these PFOS-related substances are regulated under the Stockholm Convention [77]

Table 2-20: Examples of PFOS salts as demonstrated in Annex B to the SC

CAS No	Short name	Full name
2795-39-3	PFOS potassium (K+) salt	Potassium perfluorooctane sulfonate
29457-72-5	PFOS lithium (Li+) salt	Lithium perfluorooctane sulfonate
29081-56-9	PFOS ammonium (NH_4+) salt	Ammonium perfluorooctane sulfonate
70225-14-8	PFOS diethanolamine (DEA) salt	Diethanolammonium perfluorooctane sulfonate
56773-42-3		Tetraethylammonium perfluorooctane sulfonate
251099-16-8		Didecyldimethylammonium perfluorooctane sulfonate

Source: Adapt from Stockholm Convention Decision SC-4/17 [78]

According to UNEP guidances[77], [79], application areas where PFOS was used can be classified as follows:

- **Surface treatments** for textiles, leather, upholstery, carpet, automobile interiors, etc.
- **Paper protection** for food contact applications (plates, food containers, bags, and wraps) and non-food contact applications (folding cartons, containers, carbonless forms, masking papers)
- **Performance chemicals** such as firefighting foams, mining and oil well surfactants, surfactant/wetting agent and mist suppressants for metal plating, electronic etching baths, photolithography, electronic chemicals, hydraulic fluid additives, alkaline cleaners, floor polishes, photographic film, denture cleaners, shampoos, chemical intermediates, coating additives, carpet spot cleaners, insecticide in bait stations

In developed countries, PFOS was historically used mainly for textiles and carpets protection and paper packaging protection [77]. PFOS was also used, to a lesser extent, as performance chemicals. The uses of PFOS-related chemicals as textiles/carpet surface treatment and paper protection appeared to have phased-out during 2000s, leaving the uses in firefighting and metal plating the major remaining uses for PFOS. Table 2-21 illustrates the yearly consumption of PFOS-related chemicals in EU in 2004 [81].

Table 2-21: OECD estimated uses of PFOS-related chemicals in the EU in 2004

Application	Estimated consumption
Firefighting foams	122 tonnes/year
Metal plating	10 tonnes/year
Photographic industry	1 tonne/year
Aviation industry (hydraulic fluids)	0.73 tonnes/year
Semiconductor industry	0.5 tonnes/year

Data source: OECD 2005 [81]

Perfluorooctanesulfonyl fluoride (PFOSF), a PFOS related chemicals, is also used to produce sulfluramid ($C_{10}H_6F_{17}NO_2S$, CAS No. 4151-50-2), a pesticide that is used in bait boxes to control ants, cockroaches and termites. Sulfluramid is an alternative to Mirex, an initial SC POPs that was banned since 2004. Sulfluramid is the most used active ingredient in formicide baits for leaf-cutting ants [82]. POPRC estimated that the production of sulfluramid in Brazil is about 30 tonnes per annum [76]. The use sulfluramid as an active ingredient for control of leaf-cutting ants from *Atta* spp. and *Acromyrmex* spp. for agricultural use is currently the only remaining “acceptable purpose” in the Stockholm Convention.

As a developing country, the demand for surface treatment for textiles and paper protection in Thailand during the 90s may be limited. However, Thailand has long been an important producer for the relevant products. It is not known whether or not PFOS-related substances were used in the past to produce products for high-end customers. Furthermore, as a global supplier, particularly in the electrical and electronic (EE) and the automotive supply-chain, the uses of PFOS as performance chemicals; such as firefighting foam, surfactant/wetting agent and mist suppressants for metal plating, electronic etching baths, etc., may be relevant for Thailand.

Inventory assessment process

This PFOS preliminary inventory assessment comprises a 2 stages process:

- Desk study: following information was studied to identify PFOS relevant products/applications and stakeholders in Thailand
    - Relevant PFOS applications from UNEP guidances
    - Available literatures/published reports on the detection of PFOS in environmental media in Thailand
- National surveys consisting of:
    - Questionnaire survey for information from potentially relevant stakeholders
    - Interview of key stakeholders

2.3.2 Inventory of PFOS in Thailand

2.3.2.1 Relevant uses

Information from official questionnaire survey

Questionnaire survey forms were sent out to relevant firms through following industrial organizations and professional associations in April 2019:

- Chemical and Petrochemical Industry
- Plastics Parts Industry
- Automotive Industry
- Automotive Parts Industry [Thai and English]

- Electrical and Electronic Industry (with separate section only for Televisions and Monitors Manufacturers) [Thai and English]
- Thai Electroplating Professional Network (TEPNET)

As mentioned in the PBDEs section, the official survey received very low return rate (estimated at less than 5%[25]) and only 'negative' or non-uses responses were returned. Nevertheless, qualitatively the following observations can be made:

- Industries had put in place measures to control chemical substances in products (CiP). However, most of these efforts are directed toward well-known regulations such as RoHS and REACH (Annex XVII). There are only a few firms in chemical industry who also control SC POPs.
- Producers of finished products had audited their chemicals management system, surveyed for the remaining of the contaminated materials/parts and send them out for final destruction.
- Very few firms checked their POPs releases (to wastewater, sludge, and exhaust air) beyond what stated in the regulated emission standard.
- Unlike PBDEs, no firm stated their involvement with PFOS (never (intentionally) used, never received requests from customers, and never checked).

Additional information from the general questionnaire survey (Feb 20th, 2019)

General summary of results from the general questionnaire survey held during a public seminar aimed to raise awareness of CiP related regulations among Thai producers on February 20th, 2019 is shown in the PBDEs section (see the questionnaire in Annex 6).

Generally, results are in-line with the official survey. Producers had more awareness of the restricted substances under the RoHS Directive than others. Particularly, among the chemicals under producers' controls, the 10 restricted substances under the current RoHS Directive and the substances listed in Annex XVII of the REACH regulation were the most requested from respondents' customers and to respondents' suppliers. Interestingly, as shown in Table 2-22, PFOS/PFOA ranked first among non-RoHS/REACH substances that were requested along supply-chain.

Note that this survey aimed to capture on-going activities (in general sense) along the supply chain. It was not meant to investigate specific substance. The PFOS/PFOA related questions, therefore, reflected the control of fluorinated surfactants in general. This survey did not

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[25] Questionnaire files were distributed by the above mentioned industrial associations to their members. These firms were also asked to distribute the questionnaire to their (relevant) suppliers. Therefore, the exact number of questionnaires that were disseminated was unknown. However, it can be roughly estimated at about 300 sets.

differentiate PFOS and PFOA. This is also true for the four heavy metals, the four phthalates, and the restricted substances under REACH Annex XVII.

Note also that this survey aimed to capture activities related to the controls of CiP substances that may remain in the manufactured products, particularly those with imposed restrictions on the market. This survey did not cover indirect materials such as firefighting foam. (Firefighting foams are addressed in the next section).

Table 2-22: List of CiP substances frequently enquired along supply chain

	CiP substance enquiries	Substance Group	Frequency of requests (scale 0-3) from customers	to suppliers
1	Four heavy metals (Pb, Cd, Hg, Cr(VI))	RoHS	2.6±0.03	2.5±0.04
2	PBB/PBDE	RoHS (&SC POPs)	2.3±0.05	2.3±0.04
3	Four Phthalates (DEHP, BBP, DBP, DIBP)	RoHS	2.3±0.04	2.2±0.05
4	Restricted substances under REACH Annex XVII	REACH	2.1±0.05	2.0±0.05
5	PFOS/PFOA	SC POPs (&EU POPs)	1.5±0.05	1.3±0.05
6	TBBPA	Candidate for RoHS	1.1±0.05	1.0±0.05
7	HCBD	SC POPs (&EU POPs)	1.0±0.04	1.1±0.04
8	HBCD	SC POPs (&EU POPs)	1.0±0.04	0.9±0.04
9	SCCP	SC POPs (&EU POPs)	0.7±0.04	0.6±0.04
10	Biocides		0.4±0.04	0.3±0.04
11	PCP	SC POPs	0.3±0.04	0.5±0.04
12	MCCP		0.3±0.05	0.3±0.04

Note: Scale 0 to 3: 0=never requested, 1=sometime requested (<25%), 2= half (50%), 3=mostly requested (>75%)

Table 2-23: Respondents levels of PFOS/PFOA involvement

Industry*	Not sure, never survey (%)	Never involve (%)	Used but phased-out (%)	Used and still needed to use (%)	No answer (%)
Electrical and electronics	22	54	3	10	11
Automotive	21	53	3	12	11
Medical devices	20	74	1	5	0

(*): Includes businesses/suppliers along the supply-chain of the specified industries (from raw materials to finished products and packaging)

Based on 110 firms who responded to PFOS/PFOA related questions (Table 2-23), most of them never had any involvement with PFOS/PFOA, a small percentage of them used PFOS/PFOA in the past but already phased-out, and about 10% of the respondents used and still need to continue using PFOS/PFOA. The given reasons for the remaining uses were that i) PFOS/PFOA were unavoidable contaminant in the received parts/materials and ii) customer demands for PFOS/PFOA (chemical formulation) still exist. The details for the relevant parts were not disclosed. However, based on respondents’ affiliations, it is anticipated that the remaining demands are in the plating/mist suppressant applications.

Based on information from questionnaire surveys, PFOS may be used in metal plating and mist suppressant applications. Also, PFOS may have been used in the past (before 2009) in textile and paper protection applications. However, relevant data from stakeholders were not available possibly due to following reasons:

- For export products:
  the prohibition from the EU's 2009 PFOS Directive drove industries to block the presence of PFOS in/on incoming products. Since this measure was enforced more than 10 years ago, current stakeholders only have 'non-use' declaration from their suppliers.
- For domestic products:
  There was no legal requirement to control PFOS on domestic products (including food contact materials). However, PFOS uses in 'high-tech' food packaging in Thailand had been confirmed [83]. Particularly the reported values for PFOS on fried-chicken boxes were higher than the EU PFOS Directive's tolerable limit of 1 $\mu g/m^2$. It is not known whether these boxes (and the chemicals used) were imported or locally produced. Again, due to long delay time, relevant information can no longer be retrieved.

Information from stakeholder interview

Based on knowledge gained from questionnaire surveys, following groups of stakeholder were interviewed for detailed information related to PFOS:

PFOS for firefighting foams:

- Airport authority of Thailand (AOT)
- Department of Airports, ministry of transportation
- Bangkok Aviation Fuel Services Public Company Limited
- Suppliers of firefighting foams
- Cities' fire control department
- Department of Energy Business (DOEB), ministry of energy
- Petroleum refinery companies

PFOS for metal plating:

- Metal plating firms
- Suppliers of metal plating chemicals

PFOS for textiles:

- Thailand Textile Institute (THTI)

PFOS for firefighting foams

Based on information from firefighting foams suppliers, the imports of PFOS containing foams were ceased since around 2009. However, the amount of PFOS-related foams ever imported prior to 2009 was unknown. Assuming an average shelf life of Aqueous Film Forming Foam (AFFF) of about 20-25 years[26], PFOS containing foams imported

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[26] Actual shelf life depend on several factors, including the manufacturer, temperature, and storage conditions

between 1995 and 2009 might still be present (see section 2.3.2.3 for the estimated amount of the remaining foams).

The main users for these foams were petroleum depots, which are mandated by DOEB’s petroleum depots regulation to keep stock of adequate amount of AFFF foams [84]. The petroleum depots regulation does not specify the type of the foam. Nevertheless, existing foams stored in petroleum depots are routinely checked for their fitness to use to ensure they are in compliant to the law. Based on information from safety officers from two petroleum depots, the expired foams were usually used up in firefighting trainings.

According to information gained from a provider of AFFF foams, a firefighting training school, and safety officers from relevant facilities, AFFF foams are rarely used in typical fire trainings due to their high price. For trainings that involve the uses of expired foams, the run-off were collected and treated by the facilities wastewater treatment plants before discharge. Unfortunately, in absent of regulatory limit, no firm and/or industrial estate had ever conducted an analysis to confirm levels of PFOS in their effluent water.

Apart from petroleum depots, other facilities such as airports and cities’ fire control departments also keep stock of AFFF foams. Based on information gained from the AOT and the Department of Airports, the stock of AFFF is estimated at 140,000 liters, and none of them contain PFOS. Similarly, based on information received from 40 fire stations (out of 835 fire stations nationwide), the amount of AFFF foams stock in fire stations is estimated at 170,000 liters, none of them contain PFOS. PFOS-free foams are often with the ‘C6’ quote. However, since the exact material compositions for these foams are unavailable to the inventory team, it is not known whether PFOA containing foams are kept in these facilities.

Metal plating

Based on information from 3 major suppliers of metal plating chemicals, PFOS was used in the past to suppressed acid fume. The specific type of chemical used depends on end uses of the plated parts. For automotive industry, chemicals used in the plating bath are limited to chemicals that have been pre-approved by first tier customers. For parts used in EEE industry, PFOS was banned since 2009. Due to the inclusion of PFOS/PFOA in many major substance declaration lists; such as Global Automotive Declarable Substance List (GADSL) [85] and IEC 62474 database on material declaration [86], most export oriented firms were already moved away from PFOS/PFOA. Although the chemicals cost is an important factor for plating firms, due to its relatively low cost in comparing to other costs such as materials, electricity, equipment and labor, etc., the cost of PFOS (or its alternatives) does not constitute a major concern for these (export oriented) plating firms. Based on information from chemicals suppliers, a small amount of PFOS may still be needed to support small firms who serve domestic market.

Textile

Prior to the publication of the EU PFOS Directive in 2009, chemicals used in the textile finishing industry may contain PFOS, with or without firms' awareness of the inclusion. Based on information from the Thailand Textile Institute (THTI), textile products that required PFOS features (water/oil/dirt repellent) are most likely export products that are required to meet rigorous requirements. After 2009, when the customers' requirements also include the prohibition of the uses of PFOS, the industry added a new PFOS-free requirement for their supply-chain to comply. For products that are required to be PFOS-free, only products proven (via third party test reports) to be without PFOS are allowed. Unfortunately, for products without the needs to control PFOS or for non-compliance products, no PFOS records were available. This action pattern led to the availability of only 'negative' responses (or not include) from the industry.

Since Thailand does not yet have any regulatory control for PFOS in/on products, it is not known whether domestic products also contain PFOS. In 2016, a research team at Mahidol university studied the amount of PFOS and PFOA in 32 locally purchased textile samples [87]. The samples covered 3 important categories; textiles used on human body (diapers, shirts, pants, footwear, towels, uniforms, and bags), textiles used in household items (curtains, upholstery, carpets, blankets, and tablecloths), and textiles used in outdoor items (umbrellas, sunshades, and tents). Interestingly, the team found none of the samples contained PFOS above the EU limit ($1\mu g/m^2$) while 68.75% of the samples (22 samples) were found over limit for PFOA.

While PFOS was banned in 2009, PFOA was not in the EU restriction list until 2017 and the PFOA ban will not be enforced until 2020 (Regulation 2017/1000 [88]). These Mahidol university's findings could illustrate the influence of EU environmental and chemical safety (ECS) regulations over the uses of certain hazardous substances in Thailand that were otherwise unknown to the both producers and the public.

2.3.2.2 Manufacture and import

Thailand never produced PFOS-related substances. Nine PFOS-related substances, as shown in Table 2-24, were recently classified as Category 3 hazardous substances under the HSA [14][89]. Table 2-25 summarizes imports of PFOS-related substances since 2012. It can be seen that imports of the 2 controlled PFOS-related substances (K-PFOS and TEA-PFOS) were gradually decreased. Based on UNEP Guidance [77], these 2 PFOS-related substances are believed to be used as mist suppressants for metal plating baths. PFOS-related substances may be imported before 2012 but import statistic could not be compiled due to lack of substance specific HS Code. As noted earlier, the main uses of PFOS-related substances are believed to have ceased since 2009 except for minor uses in plating application.

According to information from the Thai Food and Drugs Administration (Thai FDA) who is in charge with the authorization of pesticide products for the control of vectors and pests of public health importance, sulfluramid has never been registered in Thailand.

Data from trade statistics showed Thailand imports of about 160 tonnes of perfluorooctane sulphonamides (FOSA under HS-Code 2935.10, 2935.20, 2935.30, 2935.40, 2935.50) since 2017. However, these import amounts cannot be reconciled with the exporting countries.

Table 2-24: PFOS-related substances that were classified as Category 3 hazardous substances in 2013 and 2017

List	Item	Substance Name	CAS No	HS Code
4.1	50	Sulfluramid	4151-50-2	2935.00.00-008/KGM 3808.91.19-569/KGM 3808.91.99-569/KGM 3808.91.20-69/KGM 3808.91.30-569/KGM
5.1	505	Perfluorooctane sulfonic acid	1763-23-1	2904.31.00-000/KGM
5.1	507	Didecyldimethylammonium perfluorooctane sulfonate	251099-16-8	2923.40.00-000/KGM
5.1	508	Diethanolammonium perfluorooctane sulfonate	70225-14-8	2922.16.00-000/KGM
5.1	509	Tetraethylammonium perfluorooctane sulfonate	56773-42-3	2923.30.00-000/KGM
5.1	510	Perfluorooctane sulfonyl fluoride	307-35-7	2904.36.00-000/KGM
5.1	511	Potassium perfluorooctane sulfonate	2795-39-3	2904.34.00-000/KGM
5.1	515	Lithium perfluorooctane sulfonate	29457-72-5	2904.33.00-000/KGM
5.1	517	Ammonium perfluorooctane sulfonate	29081-56-9	2904.32.00-000/KGM

Source: Ministry of Industry's Announcement on List of hazardous substances B.E. 2556 [90] **and B.E. 2560** [89]

Table 2-25: Imports of PFOS-related substances since 2012 (in kg)

HS Code	Substance	2012[3]	2013	2014	2015	2016	2017[6]	2018	2019
2904.90.00.009	K-PFOS[1]			27	150	1			
2904.34.00.000	K-PFOS[1]						42	233	26
2923.90.00.005	TEA-PFOS[2]	6,200	380	1,520	1,520	2,090			
2923.30.00.000	TEA-PFOS[2]						380	23	0
2935.10.00.000	N-Methyl FOSA[5]						10,500	2,021	4,000
2935.20.00.000	N-Ethyl FOSA[5]						0	0	0
2935.30.00.000	N-Ethyl-N-(2-hydroxyethyl) FOSA[5]						0	0	0
2935.40.00.000	N-(2-Hydroxyethyl)-N-methyl FOSA[5]						0	0	0

Note: Data source – Thai Customs
[1]: Potassium perfluorooctane sulphonate
[2]: Tetraethylammonium perfluorooctane sulphonate
[3]: No PFOS specific classification prior to the year 2012
[4]: Sulfluramid (CAS No. 4151-50-2) was listed as a Category 3 substance under HSA in 2013 (under the FDA control)
[5]: FOSA=Perfluorooctane sulphonamide. These are not classified substances under HSA
[6]: 8 Industrial PFOS-related substances listed as Category 3 HS, HS Code for PFOSA specific substances became available

In 2018, DIW received a notification to import 1,008 kg of chemical formulation that contain 3% TEA-PFOS (30 kg) for resell. A follow up phone call in May 2019 found about 126 kg of the chemical (3.7 kg of TEA-PFOS) remained in stock.

Based on PFOS-related substances import statistics (Table 2-25), the remaining demand for PFOS for metal plating applications is estimated at **300-400 kg per year**.

2.3.2.3 Estimation of stock of PFOS in firefighting foams

Petroleum depots are required by the DOEB's petroleum depots regulation to keep stock of firefighting foams in readiness for the fire incident [84]. The amount of the required foam stock depends on the type of the petroleum storage tank, the flammability of the petrol in the tank, the amount of petroleum store in the facility, and whether or not the site is also a refinery. Each facility is only required to keep enough foam for the largest tank. Nevertheless, large depots (over 120 million liters) or refineries' depots are required keep extra amount of foams (at least 3 times extra in addition to the required amount) while the rests are only required to keep 1X extra of the amount dictated by the largest storage tank.

In 2017, there were 6 refineries, about 9 large petroleum depots (with over 120 million liters), and about 171 regular size depots. Unfortunately, there is no inventory of the type and the amount firefighting foams currently stored in each facility. Therefore, for the purpose of this inventory assessment, an estimation had been made based on following assumptions:

1. The average diameter of the largest tank in all depots is 40 meters[27]
2. Each facility kept 225.5 liter of foam solution per square meter of the largest tank's cross sectional area, regardless the tank type and the flammability of the petroleum (see Table 2-46) (or on average about 280,000 liter of foam solution per site)
3. The foam solution contains 3% concentrated foam, giving the total amount of foam concentrates per site of about 8,500 liters.
4. All facilities installed 3 supplementary hose lines that can dispense foam at 189 liter per minute for 30 minutes or 17,010 liter of foam solution per facility or 510 liters of concentrated foams.
5. The total amount of concentrated foams, including those required to fill all hoses and pipes are, therefore, estimated at about 9,100 liters. (8,500 L for basic foam stock, 510 L for supplementary

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[27] This dimension is based on information from an interview with a refinery safety officer. The DOEB officer, who is in charge of inspecting depots' foams, concurred with the proposed dimension.

hose lines, 90 L for the amount to fill hoses and pipes)

6 Out of the 186 facilities operating in 2017, the 15 large depots/refineries kept 3 times extra amount of foams while the remaining 171 depots kept only 1X extra amount. (This bring the total amount of foam concentrates to 3.7 million liters)

7 About 25% of the stocked foam concentrates contain PFOS[28]. With the estimated total amount of foam concentrates at 3.7 million liters, the amount of PFOS relevant foams is estimated at 925,000 liters.

8 The concentration range of PFOS-related substances in these foam concentrates is 0.4-0.6% (w/v). The total amount of PFOS remained in the stocked AFFF foam in Thai petroleum facilities is, therefore, estimated at **3,700 – 5,500 kg**

2.3.2.4 Alternative

Firefighting foams

Based on information from a leading petroleum refinery and 13 depots with combined foam storage of about 260,000 liters (about 7% of the estimated nationwide stock), there are four types of firefighting foams currently kept in their stock; Alcohol Resistant - Aqueous Film Forming Foam (AR-AFFF), Aqueous Film Forming Foam (AFFF), Protein, and Protein-Alcohol Resistant (Protein-AR), each representing about 50%, 28%, 20% and 2% of the overall stock, respectively. Protein foams are mostly over 10 years old. AFFF and AFFF-AR foams stocked after 2009 are with the 'C6' quote. Unfortunately, the exact material compositions for these foams are unavailable to the inventory team.

Similarly, based on responses received from 40 fire stations, AFFF foams kept at cities fire stations are claimed (by their suppliers) to be 'PFOS – free'. However, information related to the alternative foams is lacking. An impromptu visit by the inventory team to a fire station near an industrial estate found a sizable stock of foams labelled with following words - 'environmentally friendly AFFF foam'. Again, material safety data sheet for these foams were not available to the firefighter at the station

Metal plating

Based on information from 3 major providers of plating chemicals in Thailand, PFOS-free formulations are available and most customers had phased away from PFOS since 2009. However, except for the generic 'C6' mentioning, information related to the alternative chemicals is withheld as trade secret.

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[28] Average (based on responses received from two refineries) proportion of (AFFF and AR-AFFF) foams stocked before 2009 to the total amount of foams of all types

Textile

Due to limited time and resources, the inventory team could not reach the relevant stakeholders in the textile industry for more detailed information. Nevertheless, based on information from the previously described study from Mahidol University [87] and data from the study of textile finishing agents in China [91], it is anticipated that PFOA, particularly PFOA precursors like 8:2 telomer and 10:2 telomer, may be chosen as an alternative for PFOS in textile application.

2.3.2.5 Waste management

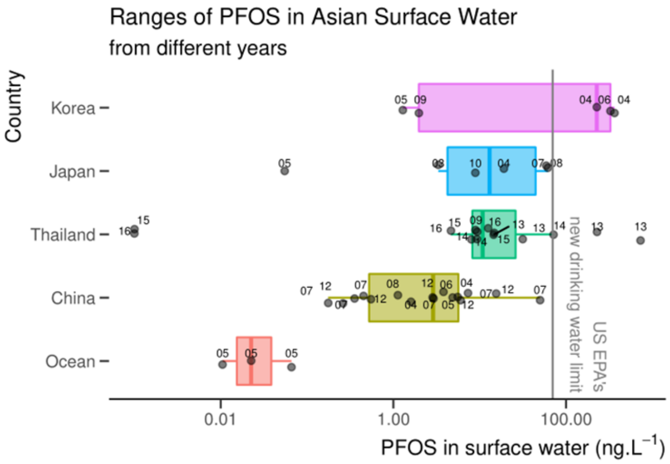
Currently, there is no (environmental) standard value to trigger the monitoring of PFOS in the environment. Releases of effluent water from factories are generally controlled by the newly revised M-Industry notification on industrial wastewater B.E. 2560 (2017)[92]. Moreover, 12 controlled industries; including textile, paper, chemicals, paints, wetting agents, refineries, and metal plating, are required by M-Industry's regulation on contamination to groundwater and soil within factory B.E. 2559 [93], [94]. However, PFOS was not yet a controlled substance (or group of substances) in any of these regulations. Therefore, there is currently no regulatory requirement to monitor and control the release of PFOS from the sources.

Information gained from interviews with representative from 5 major industrial estates in Samut Prakarn, Chon Buri and Rayong provinces, indicated that industrial estates do have some control over the chemicals used and, consequently, the wastes that will be eventually released to the estates' central wastewater treatment plants. However, as a surfactant PFOS is only used at very low concentration. It is not certain if chemicals containing small amount of PFOS will be correctly reported.

Since there is no regulatory requirement to control the release of PFOS from factories, neither firms nor industrial estates had ever measured/analyzed PFOS in their effluent water, WWTP sludge, and residues. Residues from WWTP may be disposed of in landfill or burned in incinerators, depending on the waste characteristics (and factory type). Moreover, upon prior approval from the responsible authority, WWTP residues may be used as biosolids for soil conditioner. Nevertheless, since wastes/residues from metal plating and textile finishing are likely contain other toxic metals/chemicals; they are unlikely to be approved to be used as biosolids. However, the fate of PFOS carried over in effluent water to industrial estates' central WWTP is unknown.

2.3.2.6 Release to the environment

PFOS had been detected in effluent of central industrial wastewater treatment plants of industrial zones [95], groundwater [96], surface water [97]–[100] and tap water [101][99], with the concentration level appeared to associate with the areas where PFOS may have been used [99].



Data Source: T.Wang et.al [102], ERTC 2013 [100], ERTC 2016 [98]

Figure 2-19: Ranges of PFOS in surface water in hotspot areas in Thailand compared to other Asian countries

The Thai Environmental Research and Training (ERTC) of the department of environmental quality promotion, ministry of natural resources and environment (MNRE) had monitored PFOS and PFOA in 4 main rivers and surface waters near major industrial estates in Thailand during wet and dry seasons between 2013 and 2016 [21][19]. The level of PFOS ranged from below detection limit to about 700 ng/L, with a median value of 4.8 ng/L. The researchers also found a decreasing trend for levels of PFOS taken from the same river over the monitoring years.

The levels of PFOS in surface water in Thailand in 2009 to 2016 are plotted alongside the levels found in other Asian countries [23] in Figure 2-19. The median value of all available measurements in Thailand were about an order of magnitude lower than the US EPA’s recently published drinking water health advisories value of 70 ng/L [103][104]. This health advisory level, however, may be considered ‘too high’ when compared to the European Food Safety Authority (EFSA) newly published tolerable weekly intake (TWI) value of 13 ng/kg body weight per week [105].

Nevertheless, readers should be reminded that the values reported in Figure 2-19 are from surface water, not drinking water. The numbers of data points from this monitoring activity are still too low to arrive at any conclusion at the national level at this time.

PFOS leached from sewage sludge can be accumulated in agricultural plants and animals, where they can transfer to humans through the food chain. Existing treatment plants (water and waste water) may not be able to handle (remove or destroy) PFOS contaminated inputs [95], [96], [101], [106].

Depending on the sources of the influents and treatment technique, some types of PFOS, particularly linear and long-chain congeners, may be captured in organic matter fractions and the rest may remain in aqueous fractions [107]–[111]. Some of the WWTP sewage sludge is being used as soil conditioner. Without analysis results from water and wastewater treatment plants, it is not possible to trace the fate of PFOS at this time.

2.3.3 Summary and recommendation

PFOS may be used in Thailand in textile (possibly mainly for export-oriented products), paper (food packaging), metal plating, and firefighting foams applications. PFOS uses as pesticides are considered not relevant to Thailand. According to the Thai FDA, sulfluramid has never been registered in Thailand.

Information from stakeholder interviews indicated that most export oriented firms had phased-out PFOS since 2009 as a result of the publication of the EU's PFOS Directive [1]. Unfortunately, due to long delay in surveying for relevant data, the exact applications, amount used as well as the users cannot be traced. Information from local chemical distributors indicates that some small plating companies still prefer to use PFOS, but information related to the amount uses and the users is not disclosed to the inventory team.

Nine PFOS, its salts, and PFOS-F were recently listed as Category 3 HSs in 2013 and 2017. Based on PFOS-related substances import statistics, the remaining demand for PFOS for plating applications is estimated at **300-400 kg per year**.

PFOS was detected in several products including textiles, sun screen cream and bottled water. There were also reports of detecting PFOS in effluent of industrial wastewater treatment plants, groundwater, surface water and tap water, with the concentration level appeared to associate with the areas where PFOS may have been used.

Results from the survey of PFOS in firefighting foams found possible stockpile of PFOS containing foams in foams stored in petroleum refineries and oil depots that were imported before 2009. The amount of PFOS relevant foams are not available to the inventory team but, based on the amount firefighting stock required by the law, the amount of PFOS relevant firefighting foams is estimated at **3,700 – 5,500 kg**

For firefighting training, which is considered the largest PFOS release source that lead to contamination to groundwater, the survey found most fire trainings in Thailand do not use actual foams, due to the high price of firefighting foams. However, expired foams may be used in firefighting trainings in certain high risk areas, such as petroleum complex and nearby industrial estates. Based on interview with industrial estate officers, effluent water both from firefighting trainings and real fire extinguishing within industrial estate are required to be collected and treated at the source before they are allowed to be released to the industrial estate's central wastewater treatment plant. However, in absent of regulatory limit, no firm and/or industrial estate had ever conducted an analysis to confirm level of PFOS in their effluent water.

PFOS can contaminate surface water and groundwater. PFOS leached from sewage sludge can be accumulated in agricultural plants and animals, where they can transfer to humans through the food chain. Existing treatment plants may not be able to handle (remove or destroy) PFOS contaminated inputs.

Depending on the sources of the influents and treatment technique, some types of PFOS, particularly linear and long-chain congeners, may be captured in organic matter fractions and the rest may remain in aqueous fractions [107]–[111]. Some of the WWTP sewage sludge is being used as soil conditioner.

Based on the assessments, the inventory team identified following areas that could have PFOS but has not been check and/or controls

- Wastewater treatment plants that receive wastewater from factory that uses or used PFOS and/or central WWTP that cannot separate incoming water
- WWTP effluent water, effluent from plating plants, sewage sludge and landfill leachate
- Areas that receive contaminated biosolids, particularly areas where these biosolids are used as soil conditioners
- Soil and groundwater in the affected areas
- Landfills, particularly industrial waste landfills

Responsible parties also need to develop a plan/measure to handle PFOS in firefighting foams that will come to expire over the next 10 years or so.

Registration of Acceptable Purposes

The government should file a register of Acceptable Purposes on PFOS, its salts and PFOSF pursuant to paragraph 1 of part III of Annex B of the Convention for the country's needs for continued use of stockpiles of PFOS containing firefighting foam.

Additionally, the government should decide whether or not to request a specific exemption for metal plating (hard metal plating) only in closed-loop systems.

Limitation of the study

This study suffers from the fact that most stakeholders do not have information/records of PFOS both as a constituent in chemicals and as a chemical in products, especially for chemicals purchased more than 10 years ago. Also, historical data on imported substances were not available. Although tariff codes specific to certain PFOS-related substances are recently available, the large number of possible PFOS-related substances make it impossible to trace them one-by-one.

Identification of hotspots:

Firefighting training areas where (expired) AFFF foams were used are potential contaminated sites. However, due to the lack of data on areas where AFFF foams containing PFOS had been used, all relevant firefighting training areas should be investigated and the level of PFOS contamination should be analyzed to identify hotspots.

Similarly, according to UNEP, areas where PFOS-related chemicals had been used should be considered potential contaminated sites. A list of locations of factories with relevant activities (metal plating, textile finishing, paper finishing, and central wastewater treatment plants in relevant industrial estates) should be developed and levels of PFOS contamination (in residues, effluent water, surface and underground water, etc. as appropriate) should be investigated.

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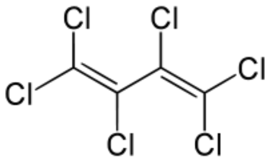
2.4 Hexachlorobutadiene (HCBD)

2.4.1 Introduction



CAS No. 87-68-3

Hexachlorobutadiene (HCBD) (CAS No: 87-68-3) is a chlorinated aliphatic compound, mainly formed as a by-product in the manufacture of chlorinated solvents, especially trichloroethylene (TCE) and tetrachloroethylene or perchloroethylene (PCE) and tetrachloromethane (or carbon tetrachloride, CCl_4) [112]. HCBD is most commonly used as a solvent for other chlorine-containing compounds.

HCBD is liquid at room temperature (melting point and boiling point of $-21°C$ and $215°C$, respectively). With water solubility of $3.2\ mg/L$ at 25°C, some experts may consider HCBD insoluble in water [113] while others considered this value significant enough to cause problems for disposal sites that contain HCBD [114], [115]. HCBD is also denser than water (density of $1.68\ g/cm^3$ at 20°C). With boiling point below $250°C$ at 101.3 kPa and vapor pressure of 20 Pa at 20°C, HCBD is considered a volatile organic compound (VOC) by many regulators/organizations such as the EU (the paint Directive (2004/42/CE) [116] and the solvent Directive (1999/13/EC [117])), US EPA [117] as well as WHO (indoor air quality). HCBD is combustible when exposed to heat or flame and can react vigorously with oxidizing materials [118].

HCBD was produced in high volumes between 1970 and 1980 [113]. According to the UNEP's HCBD guidance [113], HCBD was used in the past in both agriculture and industrial sectors. In agriculture sector, HCBD was used as fumigant, fungicide, pesticide, as well as algaecide. In industrial sector, HCBD was reportedly used in following applications:

- as a chemical and intermediate to produce articles, such as synthetic rubber compounds, aluminum and graphite rods, lubricants, chlorofluorocarbons, and as a solvent for rubber and other elastomers,
- as a gas purification agent, and
- as a heat-transfer liquid (in transformers), hydraulic fluid and liquid in gyroscopes

According to the UNEP guidance [113], in the 1990s major uses of HCBD were stopped in most industrial countries but some uses in countries with chlorinated solvent production may still be present.

In 2015 the Conference of Parties (COPs) to the Stockholm Convention decided to list HCBD in part I of Annex A of the Convention (decision SC 7/12 [119]) without exemption. This decision obligates member countries to take measures to eliminate the production and use of HCBD. In 2017, the COP further decided to list HCBD in Annex C of the

Convention (decision SC 8/12), obligating member parties to take measures to reduce or eliminate releases from unintentional production of HCBD.

Thailand is updating its national implementation plan to include measures to eliminate new POPs that were included in the Annexes of the Convention after 2009. In order to develop effective strategies for the elimination of HCBD and the environmentally sound management of products, stocks and wastes containing HCBD, Thailand needs to develop a sound understanding of their national situation concerning HCBD. This inventory study, therefore, aims to gather relevant information to establish the country's baseline with respect to HCBD production/generation, use, stockpiles and disposal.

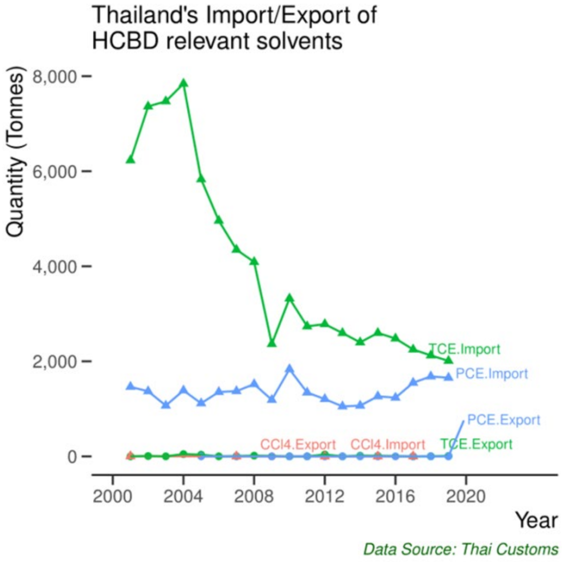
However, due to limitation in both time and resources, this study is intended to be a preliminary study that provides general idea of the current situation concerning HCBD, to inform policy makers in their decisions to mitigate risks and to fulfill Thailand's obligations toward the Stockholm Convention.

2.4.2 Inventory of HCBD in Thailand

2.4.2.1 Past and current production and import/export of HCBD

Based on information from the DIW factory database [65], Thailand never commercially produced trichloroethylene (TCE) and tetrachloroethylene (PCE) and tetrachloromethane (or carbon tetrachloride). As seen in the import and export statistics shown in Figure 2-20, Thailand has been a net importer of the three chlorinated solvents.

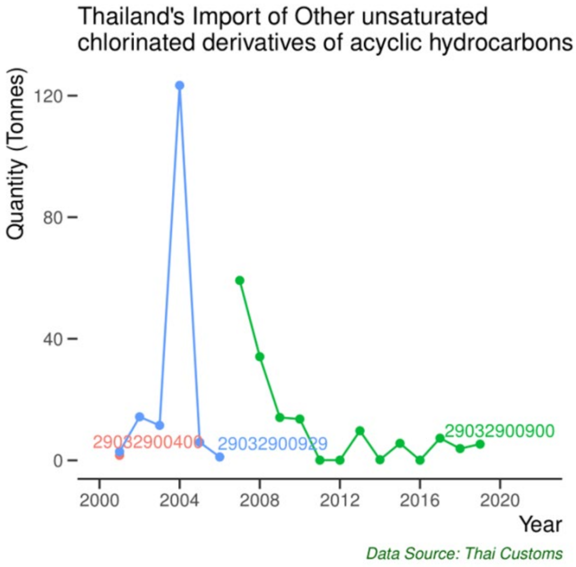
There is no tariff code specifically assigned for HCBD. According to the UNEP guidance, HCBD is traded under the HS code "Other unsaturated chlorinated derivatives of acyclic hydrocarbons" (corresponding to 2903.29xx.xxx). This code was not specific enough for the assessment of HCBD imports, though the level of the un-specificity is decreasing over the years, as seen in Figure 2-21.



Thailand's Import/Export of HCBD relevant solvents

Data Source: Thai Customs

Figure 2-20: Thailand's import and export of HCBD relevant chlorinated solvents since 2001



Thailand's Import of Other unsaturated chlorinated derivatives of acyclic hydrocarbons

Data Source: Thai Customs

Figure 2-21: Thailand's imports of chemicals under the HS code "Other unsaturated chlorinated derivatives of acyclic hydrocarbons"

2.4.2.2 Intentional uses of HCBD

Thailand produced following products that may have used HCBD:

- synthetic rubbers and synthetic rubbers compounds,
- rubbers and elastomers compounds
- lubricants,
- graphite rods,
- transformers

Based on information from the official questionnaire survey and general questionnaire survey (see PBDEs section), no firm indicates any involvement with or awareness of HCBD.

Based on interviews with two major producers of lubricants, HCBD was never intentionally used. However, since HCBD contents in the feedstock was never analyzed and there is no industrial standard to dictate the control of HCBD in products, the level of HCBD contamination in their products is unknown.

Synthetic graphite in Thailand is produced from petroleum coke and coal tar pitch which are by-products from petroleum refinery. There is no data to indicate the production of graphite from HCBD in Thailand.

As for the use of HCBD as heat-transfer fluid in transformers, since the oldest producer of power transformer was established in 1980, it is considered unlikely that Thai transformer producers intentionally used HCBD in their products. Again, since there is no industrial standard to dictate the control of HCBD in products, the level of HCBD contamination in their products is unknown.

2.4.2.3 HCBD in products, stocks and wastes

HCBD used as intermediate chemical (such as rubber vulcanization agent) is not expected to remain within the resultant material.

According to UNEP guidance, the major use of HCBD took place about 30 to 50 years ago. As a volatile organic compound (VOC), if HCBD was used as an additive, it is unlikely that the chemical can remain within products/materials for such long period of time. Furthermore, the mentioned products (rubbers, elastomers, lubricants) are relatively short service-life products. Therefore, except for the uses in long service-life products (such as power transformer, heat exchangers, and hydraulic machinery), HCBD embedded in material/products is believed to be either evaporated out or discarded with the end-of-life products.

To our best knowledge, HCBD in transformer oils and hydraulic fluids in Thailand has never been studied. Therefore, there is no information about HCBD in these oils at this time. However, HCBD's relatively high density ($1.68\ \mathrm{g/cm^3}$) and high chlorine content (81.6%) suggested that HCBD can be screen-tested in a cost-effective manner. Therefore, potentially contaminated oil and fluids should be checked for HCBD in the upcoming NIP.

2.4.2.4 Chemical and thermal processes in which HCBD is unintentionally generated as a by-product and associated releases

HCBD may be unintentionally generated as a by-product of chemical and thermal processes. Relevant processes that could lead to the formation of HCBD and their existence in Thailand are summarized in Table 2-26.

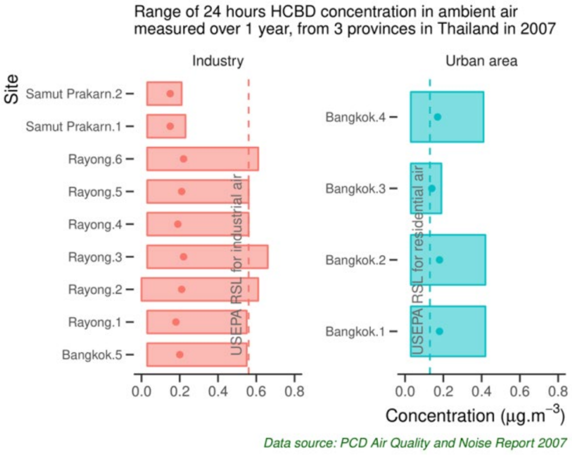
As seen in the table, EDC/VCM, allyl chloride and epichlorhydrin production processes, and municipal waste incinerators may be sources of the unintentionally produced HCBD in Thailand and there is no analytical data for the emissions from these sources. Nevertheless, emissions from incineration from these plants are under regulatory control for PCDD/F emission (with limits of 0.5 ng TEQ/m^3 (7% O_2) for industrial waste incinerator and 0.1 ng TEQ/m^3 (7% O_2) for municipal waste incinerator). With appropriate technology/practices that the industry put in place to control the generation and emission of PCDD/F, the generation and emission of HCBD should simultaneously be minimized.

Table 2-26 Processes with proven or reported potential formation of HCBD

Process	HCBD concentration (mg/kg)	Process exists in Thailand?
Dichloroethane/Vinyl chloride monomer (EDC/VCM)	12,000 mg/kg (in the waste)	Yes but waste are incinerated[1]
Waste incinerator (particularly when incinerating wastes with high chlorine contents)		Yes[1]
Tetrachlomethane (high-pressure chlorolysis or stepwise chlorination)	<1 mg/kg (raw product)	No
Allyl chloride and epichlorhydrin	Suspected but no data	Yes but waste are incinerated[1]
Chloroprene rubber	Suspected but no data	No
Production of chlorine (graphite electrodes)	<10,000 mg/kg in the waste	Yes, but not with graphite electrodes
Magnesium and aluminium production	about 15 to 20g HCBD per 1 tonne Mg	No
Municipal waste incinerators	Suspected but no data	Yes
Secondary copper/metal smelters (Smelter with high copper chloride content)	Suspected but no data	Yes but uncertain for copper chloride

Reference: Adapted from UNEP Guidance [113]

Note: [1] with regulatory control for dioxin emission (limit 0.5 ng TEQ/m^3 (7% O_2)) and facilities are operated according to BAT (see UPOP Part)



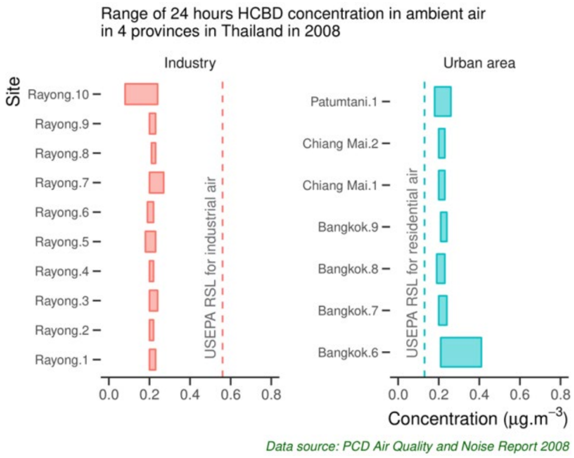
Data source: PCD Air Quality and Noise Report 2007

Note: Measured monthly over 1 year period. Dots indicate one year average value

Reference: PCD Air Quality and Noise Report 2007 [120]

Figure 2-22: Range of HCBD in ambient air in Thailand in 2007

In 2007, PCD conducted a study to evaluate levels of 44 VOCs, including HCBD, in ambient air in Thailand. The ranges of the 24 hours HCBD concentration taken monthly from 13 sites in 3 provinces (Bangkok, Samut Prakarn and Rayong) over 1 year period are shown in Figure 2-22. Although the contamination levels were relatively low, the 1 year average values for air in Bangkok were mostly above USEPA's Regional Screening Level (RSL) for HCBD for residential air ($0.13\ \mu g \cdot m^{-3}$) [120] while the levels for air in industrial areas were below the USEPA's RSL for industrial air ($0.56\ \mu g \cdot m^{-3}$) [120].



Note: Measured over 24 hours period

Reference: PCD Air Quality and Noise Report 2008 [121]

Figure 2-23: Range of HCBD in ambient air in Thailand in 2008

The 24 hours VOCs measurements were repeated in 2008 for 17 sites in 4 provinces (Bangkok, Rayong, Pathum Thani, and Chiang Mai). The results, shown in Figure 2-23, shared similarity to the previous year with HCBD levels above RSL for residential air but below RSL for industrial air.

(Note the narrower ranges in 2008 are due to the fact data from 2008 study were from a single 24 hours measurement while data from 2007 study were from twelve 24 hours measurements.)

In 2007 the Office of National Environment Board (ONEB) published standard values for 9 VOCs[29] in ambient air [122]. The ONEB also adopted 24 hours screening levels for 19 VOCs[30]. Since the levels of HCBD in ambient air in 2007 were relatively low, no standard value was given for HCBD.

In 2004, WHO published a guideline value for HCBD in drinking water of 0.6 µg/L [123]. Although most POPs pesticides are included in most of Thailand’s water quality standards [124]–[129], HCBD was not yet listed as a control substance in any of these standards.

2.4.2.5 Sites potentially contaminated by HCBD

According to the UNEP HCBD guidance [113], areas where residues from EDC/VCM, allyl chloride and epichlorhydrin production processes are incinerated or landfilled can be considered potential HCBD contaminated sites. Since HCBD is not yet a controlled substance or a substance in the Pollutant Release and Transfer Registers (PRTR) pilot project (implemented in Rayong Province in 2013), analytical data for the releases of HCBD from these sites are not available. Nevertheless, when comparing levels of HCBD in ambient air in industrial areas in Thailand (including areas where HCBD may be formed) as shown in Figure 2-24, the level in Thailand is about three orders of magnitude lower than values reported for the areas with PCE production [130].

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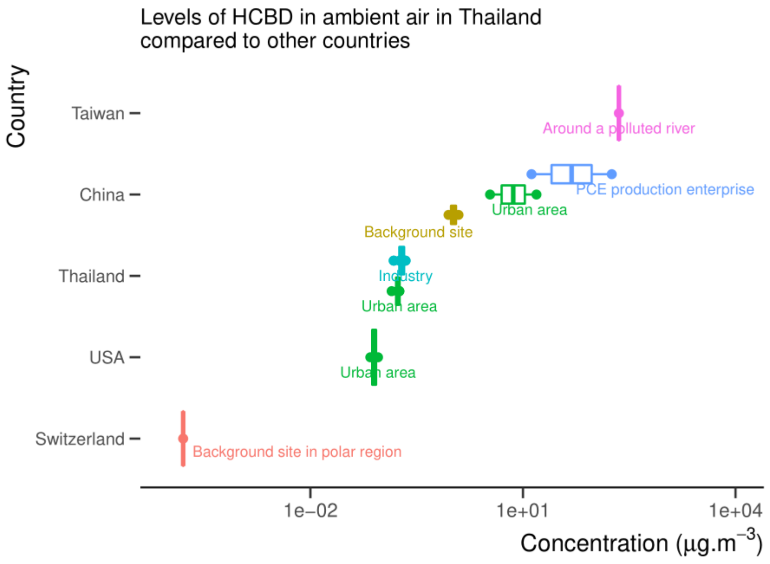
[29] benzene, vinyl chloride, 1,2-dichloroethane, trichloroethane, dichloromethane, 1,2-dichloropropane, tetrachloroethelene, chloroform, and 1,3-butadiene

[30] Acetaldehyde, acrolein, acrylonitrile, benzene, benzyl chloride, 1,3-butadiene, bromomethane, carbon tetrachloride, chloroform, 1,2-dibromoethane, 1,4-dichlorobenzene, 1,2-dichloroethane, dichloromethane, 1,2-dichloropropane, 1,4-dioxane, tetrachloroethylene, 1,1,2,2-tetrachloroethane, trichloroethylene, vinyl chloride

In addition to the release into air, HCBD may be released to surface water, soil, and groundwater. HCBD is listed in DIW's 2016 soil and underground water standards [94]. Relevant factories[31] are required by the Ministry of Industry's Ministerial Regulation on the control of contamination within factory into soil and underground water B.E. 2559 (2016) [93] to periodically monitor and report their soil and underground water quality. Unfortunately data related to HCBD in these media are still lacking. The underlying criteria for the listed factories to report HCBD are not met. Hence, none of these factories is required to monitor levels of HCBD contamination in their soil and groundwater.



Data Source: PCD Air Quality and Noise Report 2007, 2008, Lei Wang, et.al., 2018

Reference: PCD Air Quality and Noise Report 2007 [120], PCD Air Quality and Noise Report 2008 [121], Lei Wang, et.al., [130]

Figure 2-24: Levels of HCBD in ambient air in Thailand compared to values reported from other countries

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[31] 12 Factory Types: 22, 38, 42, 45, 48, 49, 60, 74, 100, 101, 105 and 106

2.4.3 Conclusion and recommendation

There is no information related to production and uses of HCBD in Thailand. Since Thailand has no chlorinated solvent production plant, there is no major source for HCBD.

HCBD is not covered in the Pollutant Release and Transfer Registers (PRTR) pilot project, implemented in Rayong Province in 2013. However, HCBD monitoring data appeared in the state of Thailand's pollution reports published between 2006 and 2009 by the PCD. The results for Bangkok and Rayong found annual average between $0.14 - 0.22\ \mu g/m^3$.

HCBD is listed in DIW's 2016 soil and underground water standards. Relevant factories are required by the Ministry of Industry's Ministerial Regulation on the control of contamination within factory into soil and underground water B.E. 2559 (2016) to periodically monitor and report their soil and underground water quality. However, the underlying criteria for reporting HCBD are not met. At the time of this report, none of the listed factories is required to monitor and report levels of HCBD contamination in their soil and groundwater.

Finally, a search for information in international journals did not yet find a report on the detection of HCBD in environmental media in Thailand.

Limitation of the study

This study suffers from the lacking of analytical data and/or information about HCBD in Thailand. There is no standard to mandate the control of HCBD in products. Until very recently, there was also no regulatory requirement to monitor the release of HCBD from generation sources to the environment. Therefore, most relevant parties did not have information/record about this substance.

The PCD had studied levels of HCBD in ambient air and the results indicated that HCBD posed low concern in comparing to other more problematic VOCs (such as dichloroethane and benzene). The study led to the publication of standard air quality for VOCs in ambient air as well as screening level for stack releases. However, this study was conducted more than 10 years ago. Since then, the knowledge about the risk of HCBD had been improved. As illustrated in Figure 2-22 and Figure 2-23, level of HCBD in ambient air in residential areas may be of a concern when reference to the newly published screening level.

Moreover, with water solubility of 3.2 mg/L, HCBD contamination into aqueous effluents, soil, and underground water can be anticipated. A search for information in international journals did not yet find a report on the detection of HCBD in any of the environmental media in Thailand. Therefore, to ensure public safety, relevant standards particularly drinking water standards should be updated and current level of HCBD in environmental media as well as in biota in Thailand should be reviewed against the newly published standards/guideline values.

Moreover, with essentially no new uses for HCBD for a relatively long period of time, the risk phase of HCBD is believed to have shifted to the unintentional formation during waste disposal. Therefore, it is recommended that emissions of HCBD from waste incinerators, landfills and dump sites into all relevant environmental media (air, soil, water) are monitored.

□□□

2.5 Polychlorinatedbiphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are mixtures of 209 chlorinated compounds congeners. PCBs were included in the initial list of POPs under the SC and, hence, had been addressed in Thailand's first NIP. The PCD had periodically submitted reports to the Secretariat in accordance to its obligation under Article 15 of the convention.

Thailand banned PCBs by listing them as Category 4 substances under the HSA in 2003 and 2004, respectively. The ban covers all activities, including the production, import, export or possess of PCBs. The ban also covers devices that contain PCBs.

In 2004, the DIW designated end-of-life devices, transformers and power capacitors that contain PCBs a chemical waste, classified as Category 3 HS. Any production, import, export, or possess of these devices requires prior approval from DIW.

In 2008, the DIW announced a plan to totally phase-out PCBs by 2012. The announcement obligated device holders to prepare and implement a plan to phase-out and completely dispose of PCBs by 2012. Any movement of the affected devices also needed prior approval from the DIW.

Since PCBs oil was not one of the wastes or discarded materials that were allowed to be treated or disposed of by waste management processors, industrial waste incinerators in Thailand were not allowed by law to incinerate PCBs oils. All PCBs oils, therefore, were collected and exported to the third countries (France, the Netherland, etc.) for final destruction.

Particularly, data from Thailand's National Reporting of the Stockholm Convention (fourth reporting cycle) [131] indicated that 761 tonnes of PCBs wastes, mostly in the form of PCBs-containing transformers, were exported to France(20 t), the United Kingdom (452 t), Belgium (33 t), and other countries (256 t) for final destruction during 1992-2002.

Moreover, Thailand's National Reporting of the Basel Convention for the year 2012 reported 110 tonnes of electric transformer and packaging contaminated with PCBs and 100 tonnes of waste containing PCB oil and packaging were exported to the Netherlands and France for final disposal.

In terms of the awareness of the environmentally sound management of PCBs, the Ministry of Industry by the DIW had published document related to the legal obligations and the guidance on the management of PCBs. The Ministry of Natural Resources and Environment by the PCD had published PCBs management handbooks [132], guideline for the management of PCBs contaminated devices [133], monograph [134], as well as general document [135] to raise awareness about PCBs and their environmental and health impacts.

PCBs had been monitored through several activities as follows:

(1) In 2006-2007, the DEQP studied PCBs in sediments in Chao Praya River, estuaries and the upper gulf of Thailand. The study found highest accumulations in areas around Klong Tuy district (Bangkok) and Amphoe Prapradang (Samut Prakarn Province). The level of PCBs, though, was in the pg/g (dw) range. This level of contamination was considered low in comparing to similar areas in other countries. The study found no PCBs accumulation in sediments in central areas from Nontaburi Province upward.

(2) From 2004 to 2009, the Ministry of Education in collaboration with the Inter-University Program on Environmental Toxicology, Technology and Management of Chulabhorn Research Institute, Asian Institute of Technology and Mahidol University's Center for Environmental Health, Toxicology and Management of Chemical conducted a study under the project "The evaluation of PCBs and dioxin -like PCBs contaminated coast of Thailand by using chemical and biological techniques" to assess the accumulation of PCBs in seafood from eastern coast of Thailand. The study found PCBs contaminations in mussels, oyster, and shrimps ranging between 19-1,100 ng/g (lipid adjusted weight), with the levels of PCBs in shrimp higher than that in mussels and oysters, respectively.

Table 2-27: Estimated annual releases of unintentionally produced PCBs in 2017

Group	**Source Groups**	**Annual Releases (g TEQ/a)**					
		Air	Water	Land	Product	Residue	Subtotal
1	Waste Incineration						**0**
2	Ferrous and Non-Ferrous Metal Production	2.50				4.02	**7**
3	Heat and Power Generation	9,349.12					**9,349**
4	Production of Mineral Products						
5	Transportation	642.77					**643**
6	Open Burning Processes						**0**
7	Production of Chemicals and Consumer Goods				4,950,000		**4,950,000**
	Total	**9,994**			**4,950,000**	**4**	**4,959,998**

Note: Figures in this table have been rounded to increase their legibility. Some totals may not correspond with the sum of the separate figures

Table 2-28: Estimated annual releases of unintentionally produced dioxin-like PCBs in 2017

Group	**Source Groups**	**Annual Releases (g TEQ/a)**					
		Air	Water	Land	Product	Residue	**Subtotal**
1	Waste Incineration						
2	Ferrous and Non-Ferrous Metal Production						
3	Heat and Power Generation	0.93				0.01	**0.94**
4	Production of Mineral Products	0.01			0.01		**0.01**
5	Transportation						
6	Open Burning Processes	20.73		2.25			**22.98**
7	Production of Chemicals and Consumer Goods				0.04		**0.04**
	Total	**21.67**	**0.00**	**2.25**	**0.05**	**0.01**	**23.99**

Note: Figures in this table have been rounded to increase their legibility. Some totals may not correspond with the sum of the separate figures

PCBs are also listed in Annex C of the Convention. Using emission factors given in the UNEP 2013 Toolkit for identification and quantification of releases of dioxins, furans and other unintentional POPs [136], the annual releases of unintentionally produced PCBs and dioxin-like PCBs in Thailand in 2017 can be estimated, and the results are summarized in Table 2-27 to Table 2-28, respectively. (see detail in Part 3 of this report)

The unintentionally produced PCBs in 2017 is estimated at 5 tonnes, with the production of chlorinated paraffins (CPs) being the main contributor, responsible for about 99.8% of the total releases.

It should be noted that this estimation is based on available emission factors, given in the UNEP Toolkit 2013. Emissions from several important sources, such as waste incinerations and open burnings, have not been accounted for due to lack of data.

Identification of hotspots

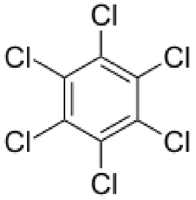
Since PCBs are highly persistent, areas where PCBs containing transformers and capacitors were installed, repaired and/or reconditioned, stored, and decommissioned may be contaminated with PCBs. According to the PCD, PCBs containing devices were decommissioned and all PCBs oils were reportedly disposed of according to the UNEP's POPs wastes guidance [137]. While monitoring data showed relatively low levels of PCBs contaminations in sediments in Chao Praya river, estuaries and the upper gulf of Thailand, data related to the assessment of levels PCBs contaminations in and/or surrounding these (historical) potentially contaminated sites are missing. It is, therefore, recommended that these areas are assessed and levels PCBs contaminations are appropriately evaluated and documented.

□□□

2.6 POPs legacy chemicals (HCB, PeCB, and PCNs)

Three POPs industrial substances; hexachlorobenzene (HCB, CAS No 118-74-1), pentachlorobenzene (PeCB, CAS No. 608-93-5), and polychlorinated napthalene (PCNs, CAS No. 70776-03-3), are considered here as "legacy chemicals" due to the fact that there were no new production and industrial application for these substances for very long time. There is no data to suggest that these substances were ever produced or intentionally used by industrial producers in Thailand. Nevertheless, these substances may be indirectly imported within devices and/or materials imported decades ago. Some, if not most, of the devices/materials may have already reached end-of-life and disposed. Moreover, since all of these substances can be unintentionally produced by incomplete combustion processes and industrial processes involving chlorine and hydrocarbons, they are also listed in Annex C of the Convention.

2.6.1 Hexachlorobenzene (HCB)



HCB is included in the initial list of POPs under the SC and, hence, had been addressed in Thailand's first NIP. HCB was banned as a Category 4 hazardous substance under the HSA in 2003. Moreover, in 2020 M-Industry announced a low POPs limit of 0.005% w/w for HCB [39] as an impurity in other products.

Table 2-29: Estimated annual releases of unintentionally produced HCB in 2017

Group	**Source Groups**			**Annual Releases (g TEQ/a)**			
		Air	Water	Land	Product	Residue	**Subtotal**
1	Waste Incineration						**0**
2	Ferrous and Non-Ferrous Metal Production	20,200.17					**20,200**
3	Heat and Power Generation	934.91				26.80	**961.71**
4	Production of Mineral Products	320,000.00			200,000	1,000	**521,000**
5	Transportation	163.62					**164**
6	Open Burning Processes						**0**
7	Production of Chemicals and Consumer Goods				377,550		**377,550**
	Total	**341,298.70**	**0**	**0**	**577,550**	**1,026.8**	**919,875**

Note: Figures in this table have been rounded to increase their legibility. Some totals may not correspond with the sum of the separate figures

HCB is also listed in Annex C of the Convention. Using emission factors given in the UNEP 2013 Toolkit for identification and quantification of releases of dioxins, furans and other unintentional POPs [136], the annual releases of unintentionally produced HCB in Thailand in 2017 can be estimated, and the results are summarized in Table 2-29 (see detail in Part 3).

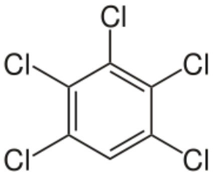
The unintentionally produced HCB in 2017 is estimated at approximately 920 kg, with the production of bricks, chlorinated paraffins (CPs) and phthalocyanine dyes and pigments being the main contributors, responsible of about 57%, 25%, and 12% of the total releases, respectively.

It should be noted that this estimation is based on available emission factors, given in the UNEP Toolkit 2013. Emissions from several important sources, such as waste incinerations and open burnings, have not been accounted for due to lack of data.

Identification of hotspots

As a Category 4 hazardous substance, the use of HCB is prohibited. However, as seen in Table 2-29, HCB may be unintentionally produced particularly during the production of bricks, chlorinated paraffins (CPs). Therefore, bricks and CPs production plants and nearby environment should be assessed for possible contamination of HCB (see Part 3, Source Group 10, for more detail).

2.6.2 Pentachlorobenzene (PeCB)



Pentachlorobenzene (PeCB, CAS No. 608-93-5) is a chlorinated aromatic hydrocarbon with molecular formula C_6HCl_5. PeCB is solid, colorless-to-white crystals with characteristic odor at room temperature. Table 2-30 summarizes selected physio-chemical properties of PeCB.

Table 2-30: Selected physio-chemical properties of PeCB

Property	Value [a)]
Molecular mass	250.34
Melting point (°C)	84.6
Boiling point (°C)	277
Density of solid (g/cm^3)	(1.8342)
Log octanol/water partition coefficient at 25°C	4.88-6.12 (5.19)
Water solubility at 25°C (mg/L)	0.135-3.46 (0.68)

a) Values outside of brackets were from POPRC risk profile on PeCB 2007 [138]; values in brackets were from Bailey 2007 [139]

According to International Programme on Chemical Safety (WHO-IPCS) [140], PeCB is very toxic to aquatic organisms. It can be bio-accumulated in fish, milk, plants and mammals. PeCB may be hazardous to the environment. Particularly, it may cause long-term effects in the aquatic environment. It is persistent in soil and can be adsorbed into sediments.

PeCB was formerly used to produce pesticides, particularly the fungicide pentachloronitrobenzene (PCNB, also known as Quintozene) but quintozene is now produced by chlorination of nitrobenzene [141]. PeCB was found to be an impurity in several pesticides including quintozene, endosulfan, chlorpyrifos-methyl, atrazine, and clopyrilid [142].

PeCB was a component of a mixture of chlorobenzenes, a chemical that was added to products containing polychlorinated biphenyls in order to reduce viscosity [143]. PeCB was reportedly used as a flame retardant in the 90s [144] although it was not clear to which material and/or end-use applications. Nevertheless, it is believed that large scale uses of PeCB have ceased for more than 10 years [143][145].

PeCB can be unintentionally produced by incomplete combustion processes and industrial processes involving chlorine and hydrocarbons. Moreover, pentachloronitrobenzene (PCNB or quintozene) in soil can be biologically degraded to PeCB, with reported yield of approximately 3% [143].

These unintentionally produced PeCBs may be released into air, (pesticides) products, or adsorbed into soil and sediments [145]. Unfortunately, the current version of UNEP UPOPs toolkit [136] does not yet include emission factors for PeCB.

In Thailand, PeCB is not yet classified as a hazardous substance under HS Act. There is no record to suggest that PeCB was ever produced in Thailand. Except for small amounts imported for research/laboratory purposes in 2018, there is no information to whether PeCB had ever been imported into Thailand[32]. PeCB may be indirectly imported in the past as an impurity in PCBs oils. However, since PCBs oils as well as PCBs containing devices were required by the DIW's 2008 notification to be properly disposed by 2012 [146], PeCB from this source is presumed to be zero.

There is no data to suggest that PeCB had ever been used as an intermediate chemical to produce other chemical substances in Thailand. However, PeCB may be indirectly imported as impurity in PCNB, 2,4-D products, phthalocyanine dyes, and dioxazine dyes [145],[147].

Pentachloronitrobenzene (PCNB):

PCNB (Quintozene) is a Category 3 hazardous substance under the DOA since 1995 [148]. A search in DOA's registered substances [149] found one registered formula with 24% quintozene. The recent DOA report (2017) indicated that quintozene was imported from the USA [150].

2,4-Dichlorophenoxyacetic Acid (2,4D) and Derivatives:

Similarly, almost all types of 2,4-D and derivatives are Category 3 hazardous substances under the DOA. A search in DOA's registered substances found 168 import licenses for fifteen 2,4-D formulations. DOA reported total import of 12,550 tons of 2,4-D related chemicals from China, Indian, Poland, Malaysia, and Indonesia, in descending order.

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[32] HS Code 29039300

Phthalocyanine dyes and pigments:

Phthalocyanine (Pc) is an important class of colorant, with phthalocyanine copper (CAS no. 147-14-8) as the single largest-volume colorant sold [151].

Phthalocyanine copper is allowed for use in cosmetic products under the MOPH’s Notification on the list of substances that may be used in cosmetics B.E. 2559 (2016)[152] but forbidden for uses in hair-dyes by MOPH’s Notification on the list of substances forbidden for uses in cosmetics B.E. 2559 (2016)[153]. No other information about these dyes can be extracted from the government database.

For the preliminary assessment purpose, a rough figure of 1,000 tonnes was allocated to each phthalocyanine pigment.

Dioxazine dyes and pigments:
UNEP Toolkit identifies 3 potential PCDD/Fs contaminated dioxazine dyes; Blue 106, Blue 108 and Violet 23.

Violet 23 (CAS 6358-30-11) has been forbidden for use in cosmetics[153] except for rinse-off application[152].

There was very limited data available about the activity rates for dioxazine pigments. However, for the preliminary assessment purpose, a rough figure of 100 tonnes was allocated to each of the 3 dioxazine pigments. (see detail in Part 3)

There is no information about the level of PeCB contamination in these imports. However, Gong et.al [145] had recently compiled $EF_{Product}$ for PeCB in relevant chlorinated aromatic chemicals. Using these EFs, the amount of PeCB indirectly imported within chlorinated aromatic chemicals into Thailand in 2017 is estimated at **2.8 kg**, as detailed in Table 2-31.

Identification of hotspots

Since quintozene and 2,4-D and derivatives may be contaminated with and/or biologically degraded to PeCB, areas where these substances were applied in large quantities may be contaminated with PeCB. Moreover, with very large EF in to products, areas where phthalocyanine dyes and pigments were heavily used (textiles and leather finishers) are potentially contaminated with PeCB.

These areas should be investigated in more details in the upcoming NIP.

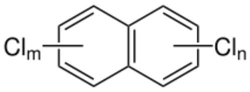
Table 2-31: Estimated amount of PeCB indirectly imported within chlorinated aromatic chemicals in 2017

	Class	Source categories	EF$_{Product}$ a) (µg/t product)	Amount Imported (t)	PeCB indirectly imported (g)
df		**Pentachloronitrobenzene (PCNB)**		**28**	**0.008**
	1	Low-End Technologies	No data	0	0
	2	Mid-Range Technologies	300	28	0.008
	3	High-End Technologies	50	0	0
dg		**2,4-D and derivatives**		**12,550**	**753**
	2	Mid-Range Technologies	60,000	12,550	753
	3	High-End Technologies	500	0	0
di		**P-Chloranil**		**0**	**0**
	3	Chlorination of hydroquinone with moderate purification	30,000	0	0
dj		**Phthalocyanine dyes and pigments**		**2,000**	**2,000**
	1	Phthalocyanine copper	1,000,000	1,000	1,000
	2	Phthalocyanine green	1,000,000	1,000	1,000
dk		**Dioxazine dyes and pigments**		**300**	**0.9**
	1	Blue 106	3,000	100	0.3
	2	Blue 108	3,000	100	0.3
	3	Violet 23	3,000	100	0.3
		Total			**2,753.9**

a) From W. Gong et.al, 2017 [145]

Note: Figures in this table have been rounded to increase their legibility. Some totals may not correspond with the sum of the separate figures

2.6.3 Polychlorinated naphthalenes (PCNs)



Polychlorinated naphthalenes (PCNs) is a group substances with molecular formula $C_{10}H_{8-n}Cl_n$, where n=1 to 8. PCNs have 8 homologue groups, 7 of them were listed in Annex A and C of the Stockholm Convention, as summarized in Table 2-32. According to the UNEP guidance [154], PCNs were produced for technical use during the first decade of the 20th century. While the production declined after the World War II, PCNs remained high volume chemicals until 1970s. The former uses of PCNs in closed and open applications and the likelihood that the products were put into use in Thailand (based on the inventory team's judgement) are summarized in Table 2-33.

PCNs were not controlled under EU RoHS Directive and REACH regulation. Therefore, PCNs were not among the controlled substances typically requested among parties along supply chain. Also, emissions of PCNs are not yet regulated. Unlike PCBs, there is no environmental standard value for PCNs in any environmental medium in Thailand.

Consequently, PCNs have not been checked. No company indicated any involvement with or awareness of PCNs in their products/processes in the questionnaire surveys (see detail about questionnaire survey in PBDEs section). Relevant stakeholders (such as Electricity Authority, the Department of Highways, and the State Railways of Thailand) did not have any information about PCNs in products/materials that they used. Also, during the period when PCNs were used there was no system to check and/or control chemical contents in the purchased products. Therefore, it is not known whether PCNs (as chemical substances) had ever been imported into Thailand. Moreover, a search for published articles also found no reports related to PCNs in Thailand.

Table 2-32: Names, CAS numbers and selected physical properties of PCNs homologue groups

PCNs name	homologue group	CAS number	Molecular formula	Solubility (µg/L)[a]	Melting point (℃)	Boiling point (℃)
(Monochloronaphthalene)#		25586-43-0	$C_{10}H_7Cl$			
Dichloronaphthalene	Di-CNs	28699-88-9	$C_{10}H_6Cl_2$	137–862 (2713)	37–138	287–298
Trichloronaphthalene	Tri-CNs	1321-65-9	$C_{10}H_5Cl_3$	16.7–65 (709)	68–133	274*
Tetrachloronaphthalene	Tetra-CNs	1335-88-2	$C_{10}H_4Cl_4$	3.7–8.3 (177)	111–198	Unknown
Pentachloronaphthalene	Penta-CNs	1321-64-8	$C_{10}H_3Cl_5$	7.30 (44)	147–171	313*
Hexachloronaphthalene	Hexa-CNs	1335-87-1	$C_{10}H_2Cl_6$	0.11* (11)	194	331*
Heptachloronaphthalene	Hepta-CNs	32241-08-0	$C_{10}HCl_7$	0.04* (2.60)	194	348*
Octachloronaphthalene	Octa-CNs	2234-13-1	$C_{10}Cl_8$	0.08 (0.63)	198	365*

Not listed in Annex A to the Stockholm Convention

*Estimated value, using methodologies laid out in Lyman et al. (1982)

a) Values outside brackets were experimentally determined by aqueous saturation method for the solid congeners; values in brackets are predicted using WSKOWWIN 2000

Source: Adapted from UNEP PCN Guidance 2019 [154]

In 2003, DIW designated wastes, substances and articles containing, consisting of or contaminated with polychlorinated biphenyls (PCBs), polychlorinated terphynyls (PCTs), polychlorinated naphthalenes (PCNs) or polybrominated biphenyls (PBBs), or any other polybrominated analogues of these compounds, at a concentration level of 50 mg/kg or more as chemical wastes which are also classified as Category 3 hazardous substance under the HSA that require prior approval from the DIW [155]. A search in the DIW waste manifest database found no record that could be linked to PCNs. Apart from this DIW filing; this inventory assessment study did not find any other data related to PCNs in Thailand.

Table 2-33: Former PCNs uses in closed and open applications and their possible uses in Thailand

Application	Likely to be used in Thailand?	Likely to find the contaminated products?
Batteries: Separator in storage batteries produced before 1970	Uncertain	No, relevant products are most likely reached end-of-life
Plastics and cables:		
Cable covering compositions (for cables produced during 1920s to 1960s)	Unlikely – considering the fact that electricity was not widely accessible in Thailand in the period mentioned.	No, relevant products are most likely reached end-of-life
Additive in plastic, intermediate for polymers and as flame-retardants in plastics	Yes, for soft polymeric parts that also required to be flame retarded such as electric cables	No, relevant products are most likely reached end-of-life
Rubbers:		
Additive in neoprene and possibly other chloroprene with use in printer belts until around 2000	Yes, but only as rubber products. Thailand did not have a chloroprene rubbers production plant	May be. Some, if not most, relevant products (rubber belts, rubber belts for printers and shock absorbing materials) are most likely reaching end-of-life
Sealants:		
Water proof sealants/ caulks and putty (polysulfide, polyurethane, acrylic and butyl sealants) until around 2000	Uncertain	Uncertain
Paints, lacquers, dyes/dye carrying agents:		
In anti-corrosion/underwater paints and lacquers, Raw material/feedstock dye carriers	Uncertain	Possibly (for paints on durable products such as transformer, machinery, metal bridges)
Wood preservative/fungicide:		
Impregnation of wood	No (PCNs was not listed in the DOA/FDA approved wood preservative/fungicide)	-
Textile and paper industry:		
• Coating/impregnation of paper and textiles for water proofing • Binders in paper coating and impregnation	Yes	No, relevant products are most likely reached end-of-life
Oil additives and lubricants:		
• Additives in oils for lubrication in gear and machinery • Oils in mining sector • Cutting oils • Engine oil additive • Refracting index testing oils	Uncertain	Uncertain
Military use: • Fogg ammunition; smoke grenades. • Inert artillery and mortar projectiles • Paper filter for gas masks in WW1 • Paints for ships and possibly other metal surfaces of military vehicles/equipment.	No information	No information

Recommendation

PCNs in closed applications:

Since former uses of PCNs in closed applications are identical to the uses of PCBs, measures taken to address PCBs in closed applications should also cover PCNs. Also, since the methods recommended to electricity authorities to identify PCBs containing transformers and capacitors (year of manufacturing, the word "Non-inflammable Oil", the density, the chlorine contents, etc.) are not specific to PCBs, devices with PCNs should also be collected and submitted to final destruction as PCBs.

However, unlike PCBs devices, PCNs are not yet (officially) controlled. It is therefore recommended that the government conducted a nationwide survey for PCNs in transformers, power capacitors and coupling capacitors, produced before 1990 and manage them in a similar approach as previously done for PCBs.

Moreover, since PCNs have been used in hydraulic fluids in the mining sector until 1989, it is recommended that an inventory of PCNs in hydraulic oils should also be developed.

PCNs in open applications:

Since the major use of PCNs was almost 100 years ago, products that might have PCNs are most likely reached end-of-life. Unlike the situation in developed countries, the mass production and consumption of electricity and electric machines/equipment in Thailand did not start until after the World War II [156]. It is unlikely to find houses with electric cables produced during 1920s to 1960s.

On the other hand, corrosion protection paints for metal constructions such as bridges, towers, ships, pressure pipes, etc. may contain PCNs. The UNEP guidance suggested that metal construction built before 1980 should be compiled. Information on anti-corrosion paints should be documented, including whether the construction has been (partly) sand blasted to remove paints [154].

Note that former uses of PCNs are also identical to the uses of short-chain chlorinated paraffins (SCCPs) and PCBs. The inventory assessment study for PCNs (as well as PCBs uses in open applications) can be conducted together with the study for SCCPs.

PCNs in environmental media:

Products, parts and materials that may contain PCNs (such as neoprene rubbers, cutting oils, oils for lubrication in gear and machinery) are most likely reached end-of-life. The risk phase of PCNs, therefore, is believed to have shifted to the disposal phase. It is therefore important to monitor the emission of PCNs from relevant locations such as e-waste processing sites, landfills, dump sites and incineration sites. It is also important to study the level of PCNs in environmental media to assess the risk of

PCNs in Thailand.

It should be noted that PCNs is also listed in Annex C of the Convention. It is therefore recommended that unintentional releases of PCNs from chemical and thermal processes be assessed and the environmental quality standard be reviewed accordingly.

Identification of hotspots

Since former uses of PCNs in closed applications are identical to the uses of PCBs, areas identified as hotspots for PCBs are also potential contaminated sites for PCNs. While assessing historical sites for potential contaminations with PCBs, PCNs should also be included in the evaluation.

Similarly since former uses of PCNs in open applications are identical to the use of SCCPs, PCNs should be included when assessing potential contaminated sites for SCCPs.

□□□

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Annex 1. Work Plan

Table 2-34: Work plan for the inventory assessment of industrial POPs

Group	Substances	Factors considered	Scope	Depth of data assessment
Br-Based Chemicals in Products	PBBs, PBDEs (penta-, octa-, decaBDE) HBCD	▪ Inter-relationship between consumers, domestic (fire) regulation and producers ▪ Influence from international regulation, such as RoHS, REACH, on Thai products ▪ Costs and compatibility of the substances and base polymers ▪ Results from preliminary survey	▪ Plastic parts in electrical and electronic (EEE) and automotive products ▪ Textiles in automotive, construction, and furniture applications EPS foam in construction application	Qualitative and semi-quantitative method, using in-house predictive model
Cl-Based Chemical in Product	PCBs, PCNs (SCCPs)	▪ Physical properties of the substances ▪ Current and historical applications ▪ Potential users (and key stakeholders)	Cutting fluids Soft PVC and rubbers Hydraulic oil Paints, sealants and gaskets Fat liquor Recycled oils	Qualitative and semi-quantitative method, with primary focus on SCCPs
Cl-Based chemicals (chemical products)	HCB, PeCB, HCBD	▪ Physical properties of the substances ▪ By-products from production of chlorinated solvents	Chlorinated organic compounds value chain	Preliminary assessment
F-Based chemicals (chemical products)	PFOS, (PFOA)	▪ Physical properties of the substances ▪ Current and historical applications ▪ Potential users (and key stakeholders)	Fire-fighting foams Metal plating and lithography: chemicals suppliers Other surfactants	Preliminary assessment

Note: SCCPs and PFOA are beyond the scope of this study.

Annex 2. Summary of ISO 1043 FR Codes

Table 2-35: Summary of ISO 1043 Part 4 FR codes

FR Group	Meaning
10-25	Halogenated compounds
30	Nitrogen compounds
40	Organic phosphorus compounds
50	Inorganic phosphorus compounds
60	Metal oxides, metal hydroxides, metal salts
70	Boron, Zinc, Silica Compounds

Annex 3. UL flammability rating and group of polymers based on maximum LOI values

Table 2-36: UL 94 flammability rating

Rating	Characteristics	Requirements
HB	Slow burn, horizontal burn	burning rate < 76 mm/min for thickness < 3 mm or burning stops before 100 mm (within 3 second)
V-2	Self-extinguish, vertical burn	burning stops within 30 seconds, drips allowed
V-1	Self-extinguish, vertical burn	burning stops within 30 seconds, No flaming drips allowed
V-0	Self-extinguish, vertical burn	burning stops within 10 seconds, No flaming drips allowed
5VB	Surface burn	burning stops within 60 seconds, burn-through hole allowed
5VA	Surface burn	burning stops within 60 seconds, No burn-through hole
HF-1, HF-2, HBF	Horizontal burning foamed material	burning stops within 30 seconds
VTM-0, VTM-1, VTM-2	Vertical thin material	burning stops within 50, 250 seconds, respectively

Source: UL International TTC, https://www.ulttc.com/en/solutions/test-methods/combustion-fire.html, last accessed September 5, 2019

Table 2-37: Group of Polymers based on maximum LOI values

Max LOI	Polymer Type
Less than 21 (Flammable)	ABS, ASA, ASA/PC, EVA, HDPE, HIPS, LDPE, LLDPE, PE, PMMA, PMP, POM, PP, PS, SAN, XLPE PA-GF, PE-GF, PET-GF, PMP-GF, PP-GF, SAN-GF
Between 21 and 30 (Slow burning)	ABS-FR, ETFE, HIPS-FR, PA, PARA, PBT, PET, PETG, PPE ABS/PC-GF, PA-GF PARA-GF, PET-GF, PPE-GF
More than 30 (Self-extinguishing)	ABS/PC, FEP, LCP, PAI, PC, PCTFE, PEEK, PEI, PEKK, PESU, PFA, PI, PMP, PPE-FR, PPS, PPSU, PSU, PTFE, PVC, PVDF, SRP, TPI, TPI-PEEK LCP-GF, PC-GF, PC-GF-FR, PEEK-GF, PEI-GF, P ESU-GF, PPS-GF, PSU-GF, PTFE-GF, PVC-GF

Note: FR=Flame retarded, GF=Glass Fiber reinforced/filled

Annex 4. Screening of BFR in polymeric materials with handheld EDXRF analyzer

Instrument

Bruker S1 TITAN 800 Handheld XRF spectrometer (Bruker, Billerica, MA, USA) with 5 mm collimator and large area CUBE$^{(TM)}$ SDD detector.

Excitation conditions

Spectrum	kV	Filter	Time (s)*	Analytes
1	50	Cu/Ti/Al	10	Br, Sb (Cl, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Sn, Ba, Hg, Pb)

Note: (*) Optimized for high throughput

Sample preparation

- In-situ measurement, large rigid samples: clean surface to remove dust, dirt, and other surface contaminants
- Plastic chips: clean and rinse well with tap water, natural air dry
- Plastic pellets: pack in 32mm double open-ended sample holder cup, covered with 6.35µm (0.25mil) thick Mylar films

Calibration

Repeatability tests were performed to determine the achievable precision for the 10 s total counting time. The statistical summary of ten measurements of 5 samples is presented in Table 2-38.

Table 2-38: Measurement precision

Sample	Bromine (Br)	Antimony (Sb)
	Average ± 1-sigma	Average ± 1-sigma
A (CRM)	284±5	
B (CRM)	833±21	
C (CRM)	255±12	
D (RM)	114,219±2,182	4,320±34
E (Sample)	104,060±3,042	7,853±33

Note:
RM: In-house produced Reference Material
CRM: Certified Reference Material

Annex 5. POPs Questionnaire (for EEE producer)

MTEC
a member of NSTDA

Management of Chemicals in Products (CIP) Survey
Group: Electrical and Electronic Equipment (EEE) producers
April 2019

(Please print or fill in the blank and/or mark ☑ in appropriate boxes)

Part 1: Company information

1.	**Company Name**	Zip Code	
2	**Contact person**	Phone Number	
3.	**Year established**		

4.	**Number of employees**	☐ 1-100 ☐ 1,001-3,000	☐ 101-500 ☐ 3,001-5,000	☐ 501-1,000 ☐ Over 5,000
5.	**Products**	☐ Refrigerators/Cold appliances	☐ Air Conditioners	☐ Electric Fans
		☐ Washing Machines/Cloth Dryers	☐ Vacuum Cleaners	☐ Irons
		☐ Ovens	☐ Microwave Ovens	☐ Electric Stoves
		☐ Printers	☐ Telephones/Fax Machines	☐ Photocopiers
		☐ Televisions	☐ Computer Monitors	☐ Computers
		☐ Others (Please specify) …………………..		

6. **Brand (Please specify)**

7. **Markets** Domestics (Approx.) …………….. % Export (Approx.) …………….. %

8. **Management system in place** (Select all that apply)
☐ ISO 9001 ☐ ISO 14001 ☐ Chemicals in products (CIP) management system
☐ System for the communication of chemicals in products (JGPSSI, IMDS, chemSHERPA, IPC-1752, etc.)
☐ Occupational, health and safety management system
☐ Others (Please specify) …………………..

9. **Your company**

☐ has	☐ does not have,	Policy for management of CIPs that cover RoHS
☐ has	☐ does not have,	Policy for management of CIPs that cover REACH restricted substances (Annex XVII)
☐ has	☐ does not have,	Policy for management of CIPs that cover Persistent Organic Pollutants (POPs) substances under the Stockholm Convention
☐ has	☐ does not have,	Internal audits that cover the management of CIPs
☐ does	☐ does not,	Conduct surveys for remaining stock of parts/materials that may contain RoHS, REACH, or POPs restricted substances
☐ does	☐ does not,	Conduct tests for possible POPs contamination within factory (dusts, air, etc.)
☐ does	☐ does not,	Conduct tests for possible releases of POPs from factory (in wastewater, exhaust air, sludge, etc.)
☐ does	☐ does not,	Send out RoHS, REACH, or POPs contaminated parts/materials for proper destruction

10. Your company started producing RoHS compliant products since Year ……………………………….
Your company took approximately ……………. years to adjust your products to meet RoHS requirements

11. Your company started to place RoHS compliant products on Thai market since Year …………………….

12. Your company started to acquire information on REACH (SVHC) substances in your products since Year …………………

Part 2: Parts/Materials Information

1. Technical specifications for parts/materials used in your products

1.1 Are parts/materials in the products that you placed on Thai market **required to be flame retarded**?
(**If YES** – do you know the type of **flame retardants** used? ☐ Yes ☐ No ☐ Not sure)

☐ YES
☐ Not required ☐ Not sure

1.2 Do your products have soft parts/materials that **require plasticizers (e.g., soft plastics, rubbers, glues, paints, gaskets)**?
(**If YES** – do you know the type of **plasticizers** used? ☐ Yes ☐ No ☐ Not sure)

☐ YES
☐ No soft parts ☐ Have soft parts **but without** plasticizers ☐ Not sure

1.3 Do you have a process that requires surfactant? (such as surface tension reducers, fume or suds suppressants, oils/moisture/dust repellants)
(**If YES** – do you know the type of **chemicals** used? ☐ Yes ☐ No ☐ Not sure)

☐ YES
☐ NO ☐ Not sure

2 Fire safety standards

Products placed on Thai market that are required to comply with fire safety standards (Please specify)

	Group of products with the same standard	Applicable fire safety standards (Please specify) (Eg., UL-V0, UL-V1, IEC/EN 60335 etc.)
1		
2		
3		
4		
5		

3. Does your company have any involvement with the following substances? (Mark ✓ in all that apply)

Group of hazardous substances*	Never involved	Not sure, never checked	Used previously but no longer (Since when?)	Used and still currently needed
1. Four toxic metals (Pb, Cd, Hg, Cr(VI))				
2. PBDEs (Flame retardant)				
3. TBBPA (Flame retardant)				
4. HBCD (Flame retardant for EPS/XPS foams, and textiles)				
5. SCCPs (Plasticizers in soft plastics, rubbers, gaskets, sealants; additive in cutting fluids, rust resistant primers, etc.)				
6. Four Phthalates (DEHP, BBP, DBP, DIBP)				
7. PFOS/PFOA (Surfactant, lithography, plating chemicals)				
8. HCBD (Contaminant in ink, paints, and solvents)				
9. PCP (Biocides for textiles, papers, leathers, and woods)				

Note: (*) For more information on these substances please see page 2-139

Part 3: The uses of POPs substances in products

1. Your involvement with Persistent Organic Pollutants (POPs) (Mark ✓ in all that apply)

Name	Used since (Year)	Nature of uses		Will you be affected if the substance is restricted in Thailand?				
						Affected because		
		As chemicals	Contained in parts/ material	Not sure	Not affected	High cost of alternative	Still no alternative available	Still have large remaining stock
PBDEs								
HBCDD								
SCCPs								
PFOS								
PFOA								
PCP								
HCBD								

2. The uses of PBDEs, SCCPs or PFOS in certain applications can still be exempted. Does your company still need to use these substances and, hence, need exemption for your applications? (Mark ✓ where apply)

Name	Not Sure	Not Needed	Still needed in following applications (Please specify)
PBDEs			
PFOS			
SCCPs			

Part 4: Market and production cost of CIP compliant products

1. Fraction **by sales value** of your products that customers require or request to be compliant with applicable chemicals in products (CIP) regulation
☐ Rare ☐ About 25% ☐ About 50% ☐ About 75% ☐ All (100%)

2. Trend **in the number of customers** who require or request CIP compliant products in the past 3 years
☐ drastic decline ☐ slight decline ☐ stable ☐ slight increase ☐ drastic increase

3. Trend **in the degree of complexity** in keeping up-to-date on the growing CIP regulations in the past 3 years
☐ drastic decline ☐ slight decline ☐ stable ☐ slight increase ☐ drastic increase

4. Trend **in the degree of challenges** in improving products to meet the growing CIP regulations in the past 3 years
☐ drastic decline ☐ slight decline ☐ stable ☐ slight increase ☐ drastic increase

5. The costs for producing "Hazardous substance (HS) free products", compared to products made without HS control.
The costs for HS-free products are ☐ higher ☐ lower by about ....%

6. The prices for HS-free products that customers are willing to pay compared to products made without HS control.
Customers are willing to pay ☐ similar ☐ higher prices by about ....%

7. **List of standards/chemicals (in products) that you or your customers requested**

Group of standards/chemicals	Required by customers			You request from suppliers		
	Not required	Sometimes	Must comply	Not required	Sometimes	Must comply
1. ISO 14001						
2. Four toxic metals (Pb, Cd, Hg, Cr(VI))						
3. PBDEs (Flame retardant)						
4. TBBPA (Flame retardant)						
5. HBCD (Flame retardant for EPS/XPS foams, and textiles)						
6. SCCPs (Plasticizers in soft plastics, rubbers, gaskets, sealants; additive in cutting fluids, rust resistant primers, etc.)						
7. Four Phthalates (DEHP, BBP, DBP, DIBP)						
8. PFOS/PFOA (Surfactant, lithography, plating chemicals)						
9. HCBD (Contaminant in ink, paints, and solvents)						
10. PCP (Biocides for textiles, papers, leathers, and woods)						
11. Other Biocides						
12. REACH Restricted Substances (Annex XVII)						

8. Your company use the following methods to guarantee your Hazardous Substance (HS)-free products (Mark all that apply)

☐ Test Report ☐ Declaration of Conformity
☐ Self-declaration based on CIP management system
☐ Third-Party Certification ☐ Sale Contracts
☐ Random testing of incoming materials
☐ Not relevant (No claim for HS-free products)

9. Does your company have any means to confirm the conformity of incoming materials before accepting them?

☐ YES ☐ NO

If YES – Which <u>substances</u> are tested for? (Mark ✓ all that apply)
☐ 4 Metals (Pb, Cd, Hg, Cr(VI)) ☐ Brominated flame retardants (PBDEs, TBBPA, HBCDD)
☐ 4 Phthalates (DEHP, BBP, DBP, DIBP) ☐ SCCPs ☐ PCP
☐ PFOS/PFOA ☐ Other (please specify)…………………………………………..
If YES – Which <u>technique</u> do you use? (Mark ✓ all that apply)
☐ EDXRF ☐ FTIR ☐ UV-VIS ☐ GC-MS ☐ HPLC, LCMS
☐ Other (please specify)…………………………………………..
If YES – Have you ever found non-compliances in incoming materials?
☐ Yes ☐ Never

10. **Key barriers in producing CIP compliant products** (Select **<u>3 most</u>** relevant choices)

☐ CIP regulation/requirements are complex and fast-growing
☐ High switching costs
☐ HS-free materials are more expensive
☐ Cost-Price structures do not encourage the switching
☐ Thai regulations still do not encourage the marketing of HS-free products
☐ High product testing/certification costs
☐ Suppliers are not ready
☐ Lack of personnel with CIP knowledge
☐ Alternative substances are not yet reliable enc
☐ Lack of financial supports

Part 5: Only for Television set and Computer monitors

1.CRT-TVs & CRT-monitors		
Product Information	**When did you start placing CRTs on Thai market?**	Since YEAR …………………………….
	When did you start producing RoHS compliant CRTs?	Since YEAR …………………………….
	When did you stop placing CRTs on Thai market?	Since YEAR ……………………………..
	Number of CRTs sold annually in Thai market:	Approximately …………………………units/year
	Your market share in Thailand for this product:	Approximately …………….. %
	Size of CRTs sold	☐ < 10” ☐ 10- 15” ☐ 16- 20” ☐ 21- 25” ☐ > 25”
	Your best-selling CRT's size is ....…inch, with ……………………………… units sold per year	
	Applicable standards for CRTs sold in Thailand (Please specify)	
	Source of your CRTs sold in Thailand Produced in Thailand (Approx.) ……………………..% Imported into Thailand (Approx.) ………………%	
Fire safety standards	**Fire rating for CRTs placed on Thai market** ☐ UL V0 or equivalent ☐ UL V1 or equivalent ☐ UL HB or equivalent ☐ Other standard (please specify) ______________________	
Production of CRT enclosures (Front and back panels)	**Front panel (only for the best-selling model)** **Average weight: About** kg	
	Production site	☐ Produced in Thailand ☐ Imported into Thailand
	Type of Flame Retardant (FR)	☐ **PBDE** ☐ **TBBPA** ☐ Other **Brominated** FRs ☐ Other **Non-Brominated** FRs ☐ No FR ☐ Not Sure
	Back panel (only for the best-selling model) **Average weight: About** .... kg	
	Production site	☐ Produced in Thailand ☐ Imported into Thailand
	Type of Flame Retardant (FR)	☐ **PBDE** ☐ **TBBPA** ☐ Other **Brominated** FRs ☐ Other **Non-Brominated** FRs ☐ No FR ☐ Not Sure
Resins for CRT enclosures	**Resin used:**	**Front** ☐ ABS ☐ ABS/PC ☐ HIPS ☐ Other (specify) …………….. **Back** ☐ ABS ☐ ABS/PC ☐ HIPS ☐ Other (specify) ……………..
	Resin source	☐ Compounded in Thailand ☐ Imported resins ☐ Imported finished parts
	Any recycled resins used?	☐ Yes ☐ No ☐ Not sure

2. Plasma Television

Product Information

When did you start placing Plasma TVs on Thai market? Since YEAR ……………………………..

When did you start placing Plasma TVs on Thai market? Since YEAR ……………………………..

When did you start producing RoHS compliant Plasma TVs? Since YEAR ……………………………

When did you stop placing Plasma TVs on Thai market? Since YEAR ……………………………..

Number of Plasma TVs sold annually in Thai market: Approximately …………………..units/year

Your market share in Thailand for this product: Approximately …………….. %

Size of Plasma TVs sold (Please specify)

Your best-selling size is .... inch, with ………………………….. units sold per year

Applicable standards for Plasma TVs sold in Thailand (Please specify)

Source of your Plasma TVs sold in Thailand

Produced in Thailand (Approx.) …………….% Imported into Thailand (Approx.) ………………….%

Fire safety standards

Fire rating for Plasma TVs placed on Thai market

☐ UL V0 or equivalent ☐ UL V1 or equivalent
☐ UL HB or equivalent ☐ Other standard (please specify) ______________________

Information about the production of Plasma TVs enclosure (Front and back panels)

Front panel (only for the best-selling model)

Average weight: About kg

Production site ☐ Produced in Thailand ☐ Imported into Thailand

Type of Flame Retardant (FR) ☐ **PBDE** ☐ **TBBPA** ☐ Other **Brominated** FRs
☐ Other **Non-Brominated** FRs
☐ No FR ☐ Not Sure

Back panel (only for the best-selling model)

Average weight: About .... kg

Production site ☐ Produced in Thailand ☐ Imported into Thailand

Type of Flame Retardant (FR) ☐ **PBDE** ☐ **TBBPA** ☐ Other **Brominated** FRs
☐ Other **Non-Brominated** FRs
☐ No FR ☐ Not Sure

Resins for Plasma TVs enclosure

Resin used:
Front ☐ ABS ☐ ABS/PC ☐ HIPS ☐ Other (specify) ………………
Back ☐ ABS ☐ ABS/PC ☐ HIPS ☐ Other (specify) ………………

Resin source ☐ Compounded in Thailand ☐ Imported resins
☐ Imported finished parts

Any recycled resins used? ☐ Yes ☐ No ☐ Not sure

3. Flat panel display (FPD) TVs and Computer monitors (LED, LCD, OLED, …)

Product information

When did you start placing FPDs on Thai market? Since YEAR ……………………………..

When did you start producing RoHS compliant FPDs? Since YEAR ……………………………..

When did you stop placing FPDs on Thai market? Since YEAR ……………………………..

Number of FPDs sold annually in Thai market: Approximately …………………………..units/year

Your market share in Thailand for this product: Approximately ……………..%

Size of FPDs sold (Please specify)

Your best-selling size is ....inch, with ……………………………….. units sold per year

Applicable standards for FPDs sold in Thailand (Please specify)

Source of your FPDs sold in Thailand
Produced in Thailand (Approx.) …………………….% Imported into Thailand (Approx.) …………………….%

Fire safety standards

Fire rating for FPDs placed on Thai market
☐ UL V0 or equivalent ☐ UL V1 or equivalent
☐ UL HB or equivalent ☐ Other standard (please specify) ________________________

Information about the production of FPDs enclosures (Front and back panels)

Front panel (only for the best-selling model)
Average weight: About kg

Production site ☐ Produced in Thailand ☐ Imported into Thailand

Type of Flame Retardant (FR) ☐ **PBDE** ☐ **TBBPA** ☐ Other **Brominated** FRs
☐ Other **Non-Brominated** FRs
☐ No FR ☐ Not Sure

Back panel (only for the best-selling model)
Average weight: About kg

Production site ☐ Produced in Thailand ☐ Imported into Thailand

Type of Flame Retardant (FR) ☐ **PBDE** ☐ **TBBPA** ☐ Other **Brominated** FRs
☐ Other **Non-Brominated** FRs
☐ No FR ☐ Not Sure

Resins for FPD enclosures

Resin used:
Front ☐ ABS ☐ ABS/PC ☐ HIPS ☐ Other (specify) ………………
Back ☐ ABS ☐ ABS/PC ☐ HIPS ☐ Other (specify) ………………

Resin source: ☐ Compounded in Thailand ☐ Imported resins
☐ Imported finished parts

Any recycled resins used? ☐ Yes ☐ No ☐ Not sure

Names and Detail of substances in this survey

Name and CAS No.	Detail	Known uses	Remark
PBDEs (Polybrominated Biphenyl Ether) PentaBDE: 5436-43-1 OctaBDE: 60348-60-9 68631-49-2 207122-15-4 446255-22-7 207122-16-5 DecaBDE: 1163-19-5	PBDEs are a group of Brominated Flame Retardants (BFR) used as additives for plastic resins to adjust their flammability to meet fire safety standards such as UL94-V0. • PBDE can withstand relatively high temperature making it a good choice for parts that require high processing temperature (~ 200-300°C)	• Parts made of PS, HIPS, ABS, PC, ABS/PC • Textiles, synthetic fibers, carpets • Flexible PU foam for cushions in car seats and furniture • Rigid PU foam for construction and cold storage rooms	• All PBDEs are restricted under EU RoHS directive since 2006 • Penta-BDE and octa-BDE are restricted under EU POPs regulation • Penta-BDE and octa-BDE are Category-3 substances under Thai's Hazardous Substance Act. • decaBDE is a restricted substance under REACH regulation • All PBDE are restricted under the Stockholm Convention
TBBPA (Tetrabromo-bisphenol A) 79-94-7	TBBPA is also a BFR. Like PBDE, it is a plastic additive. In addition, TBBPA is used as a reactive FR in thermosetting plastics, wherein the molecular structure will have changed after proper curing.	• Plastic parts and textile products, similar to PBDE • As reactive FR, TBBPA is mixed into epoxy to render flame retardancy for products such as printed circuit boards, ICs. (As a reactive flame retardant, once properly cured, there should be no free TBBPA molecule left behind)	• TBBPA is under investigation for possible restriction under EU's RoHS2 directive
HBCDD (Hexabromocyclo-dodecane) 25637-99-4 3194-55-6	HBCD is another type of BFR mainly used in EPS/XPS foams. To a lesser extent, HBCD can be coated on textiles to improve their fire ratings.	• EPS and XPS foams for insulations and construction works • Textile/carpets back-coatings (e.g., Carpets, upholstery fabrics)	• HBCD is in REACH SVHC list since 2010 • HBCD is listed in EU POPs regulation • HBCD is a restricted substance under the Stockholm Convention
SCCPs (Short chain chlorinated paraffins) 85535-84-8	SCCPs are paraffins oil that contains chlorine. SCCPs can be added to metals cutting fluids to help forming a lubricated film that help extending cutting tools life. In addition, SCCPs are used as plasticizers that can withstand relatively high temperature and, at the same time, serve as an FR.	• Cutting fluids for metal working (Lubricant & Coolants) • Soft plastics and rubbers (e.g., as soft PVC parts, hoses, gaskets, conveyor belts) • Paints, glues, sealants • Use as fat liquors for leather works	• SCCPs are in REACH SVHC list since 2010 • SCCPs are listed in EU POPs regulation • SCCPs are a restricted substance under the Stockholm Convention
4 Phthalates (DEHP, BBP, DBP, DIBP)	These 4 Phthalates are medium molecular weight plasticizers. They are added to plastic resins to increase their plasticity, making them soft or less viscous.	• Soft plastics and rubbers (e.g., as soft PVC parts, hoses, gaskets, conveyor belts) • Paints, glues, sealants	• DEHP, BBP, DBP, DIBP are restricted substances under EU RoHS2 Directive • DEHP, BBP, DBP, DIBP are restricted substances under EU REACH regulation – effective July 2020
PFOS (Perfluorooctane sulfonate) Eg., CAS No 1763-23-1 2795-39-3 70225-14-8	PFOS (and its salts and derivatives) are a class of high performance surfactants. They are insoluble in neither water nor oil. They are highly resistant to chemicals, heat, and UV light.	• Electroplating chemicals (Fume suppressants) • Ni electro-less plating chemicals • Plastic etchants (Pre-treatment for electroplating of metals onto plastic) • Print circuit board – photoresist, etchants and	• All PFOS are restricted under EU POPs regulation and the Stockholm Convention • PFOS are Category-3 substances under Thailand's Hazardous Substances Act.

Name and CAS No.	Detail	Known uses	Remark
29081-56-9 29457-72-5		other lithography chemicals • Textiles (Water, oil, dust repellants) • Textile and paper (Barrier layers for water and oil protection)	
Hexachlorobutadiene, HCBD: 87-68-3	HCBD is a by-product (and a contaminant) from chlorinated hydrocarbons production processes • It can be unintentionally produced from the production or uses of chlorinated hydrocarbons and chlorinated solvents (e.g., TCE, TCA, Carbon Tetrachloride) • It can present as impurity in chlorine containing material	• Impurity in chlorinated hydrocarbons and chlorinated solvents • Solvent for Neoprene Elastomer and lubricants • Could be used or present as contaminant in HFC refrigerant • Contamination in sludge and residues from EDC production process	• HCBDs are restricted under EU POPs regulation and the Stockholm Convention
PCP (Pentachlorophenol) CAS No. 87-86-5, 131-52-2, 27735-64-4, 3772-94-9, 1825-21-4	PCP is an Organo-chlorine biocide • Used as a fungicide in textile/leather industry. • Used as a preservative for paints, glues, sealants	• Fungicide for natural textiles, papers, woods, ropes, jute sacks and canvas • Preservative for paints, glues, sealants • Preservative for timber for railway sleepers and utility poles	• PCP is restricted under EU POPs regulation and the Stockholm Convention • PCP is a Category-4 restricted substance under Thailand's Hazardous Substance Act.
PCNs (Polychlorinated Naphthalenes) CAS 70776-03-3	PCNs are oil with good electrical insulation property. It is non-flammable and can withstand relatively high temperature.	• Transformer and power capacitor (insulation) oils • Hydraulic oils • Paints and sealants for high temperature and/or corrosive applications	• Both PCBs and PCNs are restricted substances under EU POPs regulation and the Stockholm Convention • PCBs are Category-4 restricted substance under Thailand's Hazardous Substance Act.
PCBs (Polychlorinated biphenyls) CAS No. 1336-36-3	PCBs share similar properties with PCNs. They were produced to replace PCNs.		

Annex 6. General Questionnaire (for CiP seminar participants)

แบบสำรวจ
การจัดการผลิตเพื่อรองรับกฎระเบียบสารเคมีในผลิตภัณฑ์
กุมภาพันธ์ 2562

(กรุณาพิมพ์ หรือเขียนตัวบรรจงลงในช่องว่าง และ/หรือ ทำเครื่องหมาย ☑ ในช่องที่เกี่ยวข้อง)

ส่วนที่ 1: ข้อมูลบริษัท

1.	**ชื่อบริษัท**		รหัสไปรษณีย์	
2	**ชื่อผู้ติดต่อ**		หมายเลขโทรศัพท์	
3.	**ปี (พศ.) ที่ก่อตั้ง**			
4.	**ลักษณะการประกอบกิจการ**	☐ กิจการในครอบครัว ☐ บริษัทมหาชน	☐ กิจการร่วมทุนในกลุ่มคนไทย ☐ อื่นๆ (โปรดระบุ)	☐ กิจการร่วมทุนกับต่างชาติ
5.	**จำนวนพนักงาน**	☐1-100 คน ☐ 501-1,000 คน	☐ 101-200 คน ☐ 1,001-3,000 คน	☐ 201-500 คน ☐ เกิน 3,000 คน
6.	**สินค้าของบริษัท (โปรดระบุ)**			
7.	**ประเภทสินค้า (ทำเครื่องหมายทุกข้อที่ตรง)**	☐ เคมีภัณฑ์ ☐ ผลิตภัณฑ์สำเร็จรูป ☐ วัสดุรีไซเคิลและรับจัดการวัสดุเหลือใช้ ☐ อื่นๆ (โปรดระบุ)	☐ วัตถุดิบ ☐ บรรจุภัณฑ์	☐ ชิ้นส่วน/ส่วนประกอบ/โมดูล ☐ บริการชุบ-เคลือบผิว ☐ บริการทดสอบ/ให้การรับรอง
8	**ลักษณะของสินค้าที่ผลิต**	☐ สินค้าภายใต้เครื่องหมายการค้าของตนเอง (Design ของบริษัท) ☐ ผลิตให้กับบริษัทแม่ บริษัทในเครือ หรือผลิตตามคำสั่งลูกค้าที่มีสัญญาระยะยาว ☐ รับจ้างผลิตตามสั่ง ตาม Design ของลูกค้า ไม่มีลูกค้าที่แน่นอน ☐ ตัวแทนจำหน่าย/ Trader ☐ อื่นๆ (โปรดระบุ)		
9.	**กลุ่มลูกค้า (ตลาด) (ทำเครื่องหมายทุกข้อที่ตรง)**	☐ ไฟฟ้าและอิเล็กทรอนิกส์ ☐ สิ่งทอและเครื่องนุ่งห่ม ☐ อุปกรณ์การแพทย์ ☐ อื่นๆ (โปรดระบุ)	☐ ยานยนต์และชิ้นส่วน ☐ บรรจุภัณฑ์ ☐ เกษตรและอาหาร	☐ ของเล่นและผลิตภัณฑ์สำหรับเด็ก ☐ เฟอร์นิเจอร์และของตกแต่งบ้าน
10.	**ตลาดสินค้า (โดยประมาณ)**	ตลาดในประเทศ (ประมาณรอ้ ยละ) .... ส่งออกโดยตรง (ประมาณร้อยละ) .... ส่งออกโดยอ้อม (ประมาณรอยละ)		
11.	**ระบบบริหาร จัดการที่มี (ทำเครื่องหมายทุกข้อที่ตรง)**	☐ ISO 9001 ☐ ระบบจัดการสารเคมีในผลิตภัณฑ์ ☐ ระบบสื่อสารข้อมูลสารเคมีในผลิตภัณฑ์ (JGPSSI, IMDS, chemSHERPA, IPC-1752 เป็นต้น) ☐ ระบบจัดการอาชีวอนามัยและความปลอดภัย ☐ อื่นๆ (โปรดระบุ)	☐ ISO 14001	☐ ISO/TS 16949 ☐ ISO 13485

ส่วนที่ 2: ข้อมูลชิ้นส่วน/วัสดุ

1. ลักษณะทางเทคนิค ของชิ้นส่วน/วัสดุภายในตัวผลิตภัณฑ์

1.1 สินค้าที่ท่านส่งมอบให้กับลูกค้า มีชิ้นส่วน/วัสดุ ที่ต้อง**หน่วงการติดไฟ**หรือไม่

☐ มี (**ถ้ามี** – ท่านทราบหรือไม่ว่า ท่านใช้**สารหน่วงการติดไฟ**ชนิดใด? ☐ ทราบ ☐ ไม่ทราบ ☐ ไม่แน่ใจ)

☐ ไม่มีชิ้นส่วน/วัสดุที่ต้องหน่วงไฟ ☐ ไม่แน่ใจ

1.2 สินค้าที่ท่านส่งมอบให้กับลูกค้า **มีชิ้นส่วน/วัสดุ เนื้อนิ่ม** ที่ต้องใช้ **พลาสติกไซเซอร์** หรือไม่ [เช่น พลาสติก ยาง กาว สี ปะเก็น]

☐ มี (**ถ้ามี** – ท่านทราบหรือไม่ว่า ท่านใช้**สารพลาสติกไซเซอร์**ชนิดใด? ☐ ทราบ ☐ ไม่ทราบ ☐ ไม่แน่ใจ)

☐ ไม่มีวัสดุ เนื้อนิ่ม ☐ มีวัสดุเนื้อนิ่ม แต่ไม่ต้องใช้สารพลาสติกไซเซอร์ ☐ ไม่แน่ใจ

1.3 สินค้าที่ท่านส่งมอบให้กับลูกค้า มีชิ้นส่วน/วัสดุ ที่ต้องมีสารฆ่าเชื้อ (เชื้อรา แบคทีเรีย กันบูด กันเมือก กันปลวก ฯลฯ) หรือไม่

☐ มี (**ถ้ามี** – ท่านทราบหรือไม่ว่า ท่านใช้**สารเคมี**ชนิดใด? ☐ ทราบ ☐ ไม่ทราบ ☐ ไม่แน่ใจ)

☐ ไม่มี ☐ ไม่แน่ใจ

1.4 สินค้าที่ท่านส่งมอบให้กับลูกค้า มีขั้นตอนการผลิตที่ต้องใช้ สารปรับสภาพพื้นผิว หรือไม่

[เช่นสารลดแรงตึงผิว สารกดหมอก สารลดการเกิดฟอง สารเคลือบผิวเพื่อกันน้ำ/ไขมัน/สิ่งสกปรก]

☐ มี (**ถ้ามี** – ท่านทราบหรือไม่ว่า ท่านใช้**สารเคมี**ชนิดใด? ☐ ทราบ ☐ ไม่ทราบ ☐ ไม่แน่ใจ)

☐ ไม่มี ☐ ไม่แน่ใจ

2. วัตถุดิบหลัก (โดยประมาณ)

จำนวนรายการ วัตถุดิบ/ชิ้นส่วนที่ต้องบริหารจัดการ	☐ 1-50 รายการ ☐ 500-1000 รายการ	☐ 50-100 รายการ ☐ เกิน 1000 รายการ	☐ 100-500 รายการ
จำนวน Supplier ที่บริษัทติดต่อ/ทำธุรกิจด้วยอย่างต่อเนื่อง (ประมาณ)	☐ 1-20 ราย ☐ 100-500 ราย	☐ 20-50 ราย ☐ เกิน 500 ราย	☐ 50-100 ราย
สัดส่วนจำนวน Supplier ในประเทศต่อจำนวน Supplier ทั้งหมด	มี Supplier ในประเทศ (ประมาณ).................................% ของ Supplier ทั้งหมด		

3 **บริษัท** ☐ เคย ☐ **ไม่เคย** ได้รับการร้องขอข้อมูล สารเคมีในผลิตภัณฑ์ จากลูกค้า

บริษัท ☐ เคย ☐ **ไม่เคย** ร้องขอข้อมูล สารเคมีในผลิตภัณฑ์จาก Supplier

บริษัท ☐ **มี** ☐ **ไม่มี** ระบบจัดการ และ/หรือ นโยบายที่ชัดเจน ในเรื่องการจัดการสารเคมีในผลิตภัณฑ์

บริษัท ☐ **มี** ☐ **ไม่มี** Approved Vendor List ที่มีเกณฑ์ด้าน สารเคมีในผลิตภัณฑ์

บริษัท ☐ เคย ☐ **ไม่เคย** ตรวจประเมิน (Audit) ภายใน ที่ครอบคลุมการจัดการสารเคมีในผลิตภัณฑ์

บริษัท ☐ เคย ☐ **ไม่เคย** ☐ **ไม่ทราบ** ถูกลูกค้าปฏิเสธสินค้า ด้วยเหตุผล ด้านสารเคมีในผลิตภัณฑ์

บริษัท ☐ เคย ☐ **ไม่เคย** ☐ **ไม่ทราบ** จัดระดับความเสี่ยง ของชิ้นส่วน/วัสดุที่ใช้ ตามการใช้สารเคมีในผลิตภัณฑ์

บริษัท ☐ เคย ☐ **ไม่เคย** ☐ **ไม่ทราบ** สำรวจปริมาณ วัสดุ/ชิ้นส่วน ที่อาจมีสารต้องห้าม (RoHS, REACH, POPs) ที่ยังคงค้างใน Stock

บริษัท ☐ เคย ☐ **ไม่เคย** ☐ **ไม่ทราบ** ตรวจวัดปริมาณสารมลพิษคงทน ภายในบริเวณโรงงาน (ในฝุ่น ในอากาศ ฯลฯ)

บริษัท ☐ เคย ☐ **ไม่เคย** ☐ **ไม่ทราบ** ตรวจวัดปริมาณสารมลพิษคงทน ที่ปลดปล่อยออกจากโรงงาน (ในน้ำทิ้ง, ในฝุ่น/ไอเสีย, กากตะกอน ฯลฯ)

บริษัท ☐ เคย ☐ **ไม่เคย** ☐ **ไม่ทราบ** ส่ง วัสดุ/ชิ้นส่วน ที่อาจมีสารต้องห้าม (RoHS, REACH, POPs) ไปทำลาย

บริษัท ☐ เคย ☐ **ไม่เคย** ☐ **ไม่ทราบ** จัดกิจกรรมพัฒนา Green Supply Chain เพื่อพัฒนา Supplier

ส่วนที่ 3: ข้อกำหนดของลูกค้า

1. รายการสารเคมีในผลิตภัณฑ์ ที่เคยมีลูกค้าร้องขอ

กลุ่ม/รายการสารอันตราย ที่ลูกค้าร้องขอจากท่าน	ไม่แน่ใจ	ไม่เคยขอ (0%)	เคยมีขอ (<25%)	ครึ่งครึ่ง (~50%)	ส่วนใหญ่ขอ (>75%)
1. ธาตุโลหะ 4 ชนิด (Pb, Cd, Hg, Cr(VI))					
2. PBB/PBDE (สารหน่วงการติดไฟ)					
3. TBBPA (สารหน่วงการติดไฟ)					
4. HBCD (สารหน่วงการติดไฟในโฟมขาว และงานสิ่งทอ)					
5. SCCP (พลาสติกไซเซอร์,ยาง, น้ำมัน Cutting fluids, ผสมในสีกันสนิม, สีน้ำมัน ฯลฯ)					
6. MCCP (สารทดแทน SCCP)					
7. พธาเลท 4 ชนิด (DEHP, BBP, DBP, DIBP)					
8. PFOS/PFOA (Surfactant,งานกดลายวงจร,น้ำยาชุบ ฯลฯ)					
9. HCBD (ปนเปื้อนในหมึก สี และ Solvents)					
10.PCP (ยาฆ่าเชื้อในสิ่งทอ กระดาษ เครื่องหนัง และไม้)					
11.ยาฆ่าเชื้อ (Biocides) ชนิดอื่น					
12.สารต้องห้ามภายใต้ REACH (Annex XVII)					

2. รายการสารเคมีในผลิตภัณฑ์ ที่ท่านเคยร้องขอจาก Supplier

กลุ่ม/รายการสารอันตราย ที่ท่านร้องขอจาก Supplier	ไม่แน่ใจ	ไม่เคยขอ (0%)	เคยมีขอ (<25%)	ครึ่งครึ่ง (~50%)	ส่วนใหญ่ขอ (>75%)
1. ธาตุโลหะ 4 ชนิด (Pb, Cd, Hg, Cr(VI))					
2. PBB/PBDE (สารหน่วงการติดไฟ)					
3. TBBPA (สารหน่วงการติดไฟ)					
4. HBCD (สารหน่วงการติดไฟในโฟมขาว และงานสิ่งทอ)					
5. SCCP (พลาสติกไซเซอร์,ยาง, น้ำมัน Cutting fluids, ผสมในสีกันสนิม, สีน้ำมัน ฯลฯ)					
6. MCCP (สารทดแทน SCCP)					
7. พธาเลท 4 ชนิด (DEHP, BBP, DBP, DIBP)					
8. PFOS/PFOA (Surfactant,งานกดลายวงจร,น้ำยาชุบ ฯลฯ)					
9. HCBD (ปนเปื้อนในหมึก สี และ Solvents)					
10.PCP (ยาฆ่าเชื้อในสิ่งทอ กระดาษ เครื่องหนัง และไม้)					
11.ยาฆ่าเชื้อ (Biocides) ชนิดอื่น					
12.สารต้องห้ามภายใต้ REACH (Annex XVII)					

3. บริษัทใช้เครื่องมือต่อไปนี้ ในการรับรองสินค้าปลอดสารต้องห้าม ต่อลูกค้า (โปรดทำเครื่องหมายทุกข้อที่ใช่)	☐ Test Report ☐ การสำแดงตนเอง (Declaration of Conformity) ☐ การรับรองตนเองโดยใช้ระบบจัดการที่ลูกค้ายอมรับ ☐ การรับรองโดย Third Party ☐ สัญญาซื้อ-ขาย
4.บริษัทใช้เครื่องมือต่อไปนี้ ในการ สื่อสารข้อมูลไปยังลูกค้า (โปรดทำเครื่องหมายทุกข้อที่ใช่)	☐ IMDS (GADSL) ☐ JAMP/chemSHERPA ☐ IPC 1752 ☐ BOMCheck ☐ ระบบอื่น (โปรดระบุ) ....

ส่วนที่ 4: ความพร้อม รองรับการจัดการสาร POPs และสารอันตรายอื่นที่ต้องจับตา

1.บริษัทของท่าน มีส่วนเกี่ยวข้องกับสารเคมีต่อไปนี้หรือไม่? (โปรดทำเครื่องหมาย ✓ ในช่องที่ใช่)

กลุ่ม/รายการสารอันตราย	ไม่เคย เกี่ยวข้อง	ไม่แน่ใจ ไม่เคยสำรวจ	เคยใช้และ เลิกใช้ แล้ว (ตั้งแต่ปี)	เคยใช้ และยัง จำเป็นต้องใช้อยู่
1. ธาตุโลหะ 4 ชนิด (Pb, Cd, Hg, Cr(VI))				
2. PBB/PBDE (สารหน่วงการติดไฟ)				
3. TBBPA (สารหน่วงการติดไฟ)				
4. HBCD (สารหน่วงการติดไฟในโฟมขาว และงานสิ่งทอ)				
5. SCCP (พลาสติกไซเซอร์, ยาง, น้ำมัน Cutting fluids, ผสมใน สีกันสนิม, สีน้ำมัน ฯลฯ)				
6. MCCP (สารทดแทน SCCP)				
7. พธาเลท 4 ชนิด (DEHP, BBP, DBP, DIBP)				
8. PFOS/PFOA (Surfactant, งานกัดลายวงจร,น้ำยาชุบ ฯลฯ)				
9. HCBD (ปนเปื้อนในหมึก สี และ Solvents)				
10. PCP (ยาฆ่าเชื้อใน สิ่งทอ กระดาษ เครื่องหนัง และไม้)				
11. PAH (เปื้อนมาใน Carbon Black, Extender Oil)				

2.เฉพาะผู้ที่เกี่ยวข้องกับสาร POPs
(โปรดทำเครื่องหมาย ✓ ในช่องที่ใช่)

ชื่อสาร	เริ่มใช้ ประมาณ ปี พ.ศ.	ลักษณะการใช้		หากกำหนดเป็นสารต้องห้าม				
		สารเคมี	ติดมากับ วัตถุดิบ/ ชิ้นส่วน	ไม่แน่ใจ	ไม่เดือดร้อน	เดือดร้อนเพราะ		
						ลูกค้ายัง ต้องการใช้	ยังหาสาร ทดแทนไม่ได้	ยังมีของค้าง ในสต๊อก
PBDE								
HBCDD								
SCCP								
PFOS								
PFOA								
PCP								
HCBD								

3. บริษัทของท่านหรือกลุ่มอุตสาหกรรมที่ท่านทำธุรกิจด้วย จำเป็นต้องขอรับการยกเว้นการใช้สาร POPs ในงานบางงานหรือไม่

☐ ไม่จำเป็น ☐ จำเป็น เพราะ (โปรดระบุ) ....

4. หากท่านยังมีสาร POPs ในครอบครอง หรือมีผลิตภัณฑ์ที่มีสาร POPs ในสต๊อก และสารเหล่านี้ถูกประกาศห้ามใช้ ท่านต้องการขอรับความช่วยเหลือในการจัดการหรือไม่

☐ ไม่มี ☐ ไม่ต้องการ ☐ ต้องการ ประมาณ..ตัน

Annex 7. Estimations of Lifespans of TV CRTs and PC CRTs in Thailand

In 2018-2019, MTEC conducted 2 surveys to profile EOL TV and PC monitors found at e-waste dismantle shops in the central region and the northeastern region of Thailand.

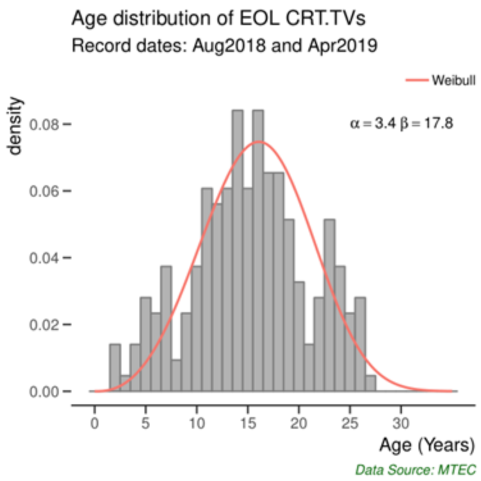
The shops were selected based on following conditions:

- Located in the two designated regions
- Engaged in e-waste dismantle operations on a ‘professional’ basis
- Have sizable stock of relevant monitors at the time of the visits
- Shop owners granted the study team access to the samples

Data collections were kept brief and non-invasive to minimize interference with the shops’ on-going operations. Depending on the conditions at the shops, data were either taken from the complete devices (await disassembly) or from the disassembled housings. Relevant data including brand name, model, country of origin, and year of manufacturing were recorded. When data from disassembled housings were recorded, additional information such as resins and FR codes were noted. For devices produced in the 90s, some information such as country of origin and year of manufacturing data may be missing. When the data were taken from the disassembled housings, the year of manufacturing may be found from the (mold) marking on inside of the housing. This information, though, reflected the time the part was injected which can be assumed to be the same year the product was put on the market.

TV.CRT monitors

The total numbers of EOL TV CRT monitors recorded during the surveys were 305 samples; 209 samples from the central region and 96 samples from the northeastern region, respectively. For about 30% of these monitors information on the year of manufacturing was missing. Judging from their appearances and other pertinent information (such as brand and models) these monitors were believed to be produced in the 1990s. However, since the exact manufacturing years were unknown, these samples were excluded from age profile.


Age distribution of EOL CRT.TVs
Record dates: Aug2018 and Apr2019

Data Source: MTEC

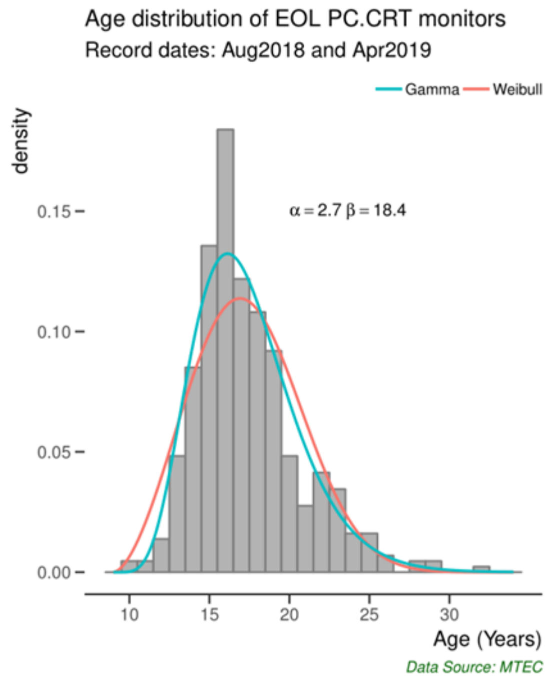
Figure 2-25: Age distribution of CRT TVs found in e-waste dismantling sites

Figure 2-25 shows age distribution of TV.CRT monitors found in e-waste dismantle shops during the two surveys. The bootstrapped-average age of these TV was between 16 and 17.9 years. The fitting of the distribution to the Weibull distribution yielded α (shape) of 3.4 and β (scale) of 17.8 years.

Assuming the EOL samples were shredded within 1 week after data collection, this ‘age’ data represents the craddle to grave period which is longer than the average service lifespan.
(As a reference, the average service lifespan for TVs in the European countries[33] is about 12.6 years (α = 2, β =12.6 years [157][158].)

PC CRT monitors

Similar approach was taken for PC CRT monitors. The total numbers of EOL PC CRT monitors recorded during the surveys were 467 samples; 107 samples from the central region and 360 samples from the northeastern region, respectively. Unlike TV monitors, only 7% of PC CRT monitors were without year of manufacturing marking. These samples were excluded from age profile.


Age distribution of EOL PC.CRT monitors
Record dates: Aug2018 and Apr2019

Data Source: MTEC

Figure 2-26: Age distribution of PC CRTs found in e-waste dismantling sites

The age distribution for the PC CRT monitors collected in this project is shown in Figure 2-26. The bootstrapped-average age of these CRTs was between 17.9 and 18.7 years. The fitting of the distribution to the Weibull distribution yielded α (shape) of 2.7 and β (scale) of 18.4 years, about 1 year longer than the estimated lifespan for TV CRT monitors.

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[33] Netherlands, France and Belgium

Annex 8. ML assisted ATR-FTIR for the identification of BFR in polymeric resins

Developed by: National Metal and Materials Technology Center (MTEC)

Existing analytical methods to identify the type of BFR rely on substances separation by gas or liquid chromatographic techniques [159]. Though capable of identifying organic substances down to congener level, these techniques are slow and costly. They also require sophisticated sample preparation technique to transform samples (typically rigid plastics) into appropriate forms (typically liquid solution). These difficulties translate to the very limited number of test results which is, usually, not enough to represent the uses of BFR in the broad range of products/articles in a country.

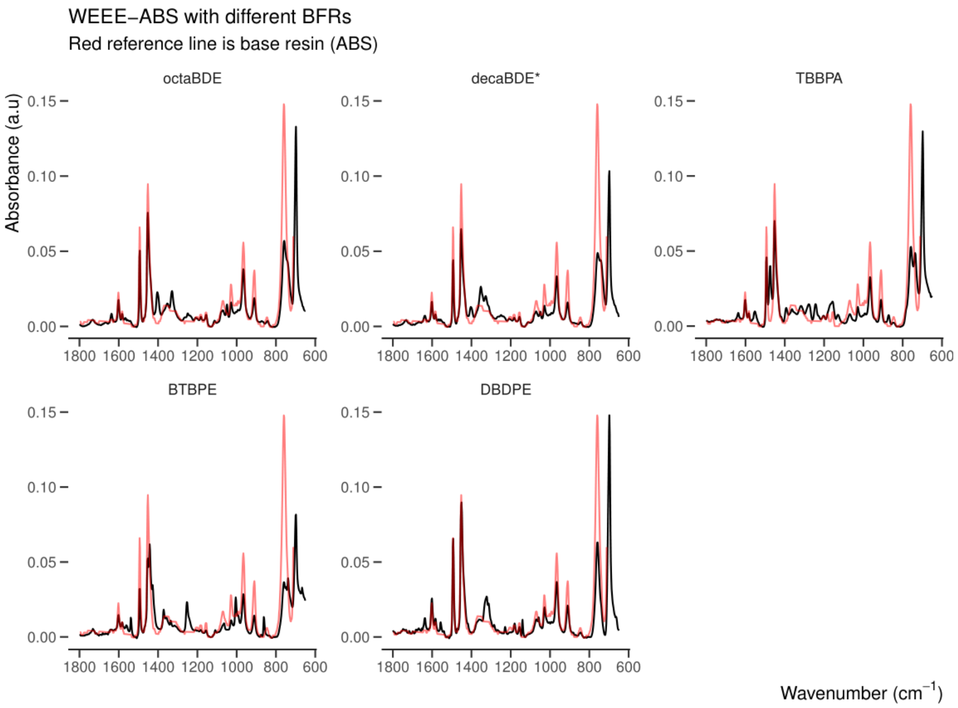

Figure 2-27: Distinct features of popular brominated FR detectable by ATR FT-IR

Test method based on Attenuated Total Reflectance (ATR) Fourier Transform Infrared spectroscopy (FT-IR), on the other hand, is a promising method for solid polymeric samples. Comparing to GC-MS and HPLC-MS/MS, this method is faster and much cheaper. Figure 2-27 illustrates the distinct features of popular BFRs that can be revealed by ATR-FTIR. Unfortunately, real polymeric samples also contain several other additives which make it difficult to distinguish by human eyes. Nevertheless, with appropriate training dataset, these features can be computationally distinguished using a machine learning (ML) classification algorithm.

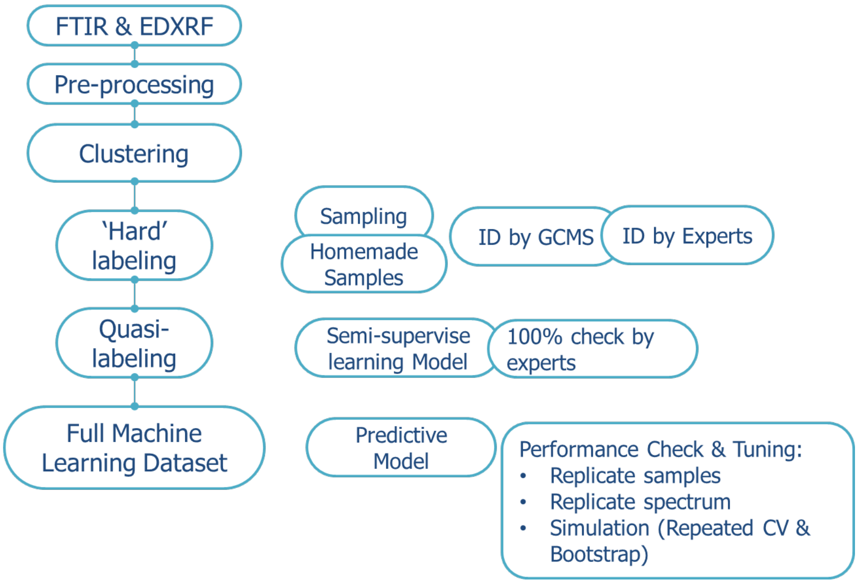

Figure 2-28: Sequence used to develop ML models to identify BFR types from EDXRF and ATR-FTIR spectrum taken from WEEE-ABS and PS resins

The sequence used to develop ML models to identify BFR Types from EDXRF and ATR-FTIR spectrum taken from WEEE-ABS and PS resins is shown in Figure 2-28.

ATR-FTIR spectrums were acquired using a Shimadzu Prestige-21 FTIR spectrophotometer (Shimadzu, Japan) equipped with a MIRacle$^{(TM)}$ single-reflection ATR attachment (PIKE Technologies, USA) with a high-pressure clamp and a diamond-coated ZnSe ATR crystal. Spectrums were recorded with following parameters: 32 scans per spectrum at a resolution of 4 cm^{-1} in the region from 4,500 cm^{-1} to 600 cm^{-1} and using Happ-Ganzel apodization function.

Model training ATR-FTIR spectrums were taken from real WEEE samples and plastic shredded chips taken from e-waste shredders. After performing spectrum pre-processing to reduce unwanted variance, ATR-FTIR spectrums were clustered using partitioning around medoids (PAM) algorithm [160]. Representative samples from each cluster were examined using appropriate analytical techniques such as GC-MS and HPLC-MS/MS. Thirty real WEEE samples (13 PS samples and 17 ABS samples) were submitted to GC-MS to identify/confirm BFR types. FTIR spectrums from each cluster were also evaluated by comparing to existing flame retardants FTIR spectrums database (see, for example, Figure 2-27). Information obtained from GC-MS analysis and expert evaluations were used to (hard) label initial training dataset for the construction of a semi-supervised model for distinguishing BFR clusters. The BFR classification was performed using k-nearest neighbor (knn) algorithm. Particularly, information from the hard labeled spectrums was used to gradually propagate their labels to nearest unlabeled spectrums until all training spectrums were (quasi) labelled. Finally, all labelled spectrums were used to construct a final ML model for predicting BFR types from

ATR-FTIR spectrums.

Due to very low number of PBDEs found in ABS samples, 32 spectrums taken from 12 home-made PBDE-ABS samples, with decaBDE contents ranged from 1% to 15% and 1% antimony trioxide (Sb_2O_3 – ATO), were added to the ABS ML training dataset. Moreover, 41 spectrum from 15 home-made TBBPA-ABS samples, with TBBPA contents ranged from 1% to 18% and 1% ATO), were also add to the ABS ML training dataset to increase number of known samples. The PBDEs positive samples were also resampled to generate enough 'independent' spectrums to balance the training dataset.

All FTIR spectroscopic multivariate data analysis were done using R (version 3.6.2) [161].[34]

After the EU restricted the use of PBDEs in EEE products, many 'novel BFRs' began to emerge. Products with these novel BFRs started to reach their end-of-life and showed up in e-waste. Since there were many novel BFRs each found in only limited number of samples, there were not enough samples to train the ML model. This model, therefore, focused on classification of the 6 frequently encountered BFRs as listed in Table 2-39 and treated the rest of the BFRs as 'novel BFR'. Although HBCD is detectable by ATR-FTIR, due to the lack of HBCD contaminated samples, it is excluded from the ML assisted BFR classification model.

Table 2-39: List of BFRs included in the classification model

Abbreviation	Substance	CAS No	Known Tradename
octaBDE	Octabromodiphenyl ether	32536-52-0	DE79, BDE 203, Saytex 105, FR1208
decaBDE	Decabromodiphenyl ether	1163-19-5	FR 300BA, Saytex 102[E], Bromkal 83, PBDE 209, FR1210
DBDPE	Decabromodiphenyl ethane	84852-53-9	Saytex 8010, FIREMASTER 2100
TBBPA	Tetrabromobisphenol A	79-94-7	Firemaster BP4A, Saytex RB 100PC, FG 2000, FR-1524
BTBPE	1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1	FF680, FM680
EBTBP	Ethylene Bis(Tetrabromophthalimide)	32588-76-4	Saytex BT93

Note:

[1] BFRs other than these 6 frequently encountered BFRs are treated as 'novel BFR'

[2]:HBCD is detectable by ATR-FTIR but excluded from the ML assisted BFR classification model due to the lack of HBCD contaminated samples

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[34] Principal component analysis (PCA) was implemented using the function "prcomp" from the "stats" R package [161], clustering of the spectrums was implemented using the function "pam" from the "clusters" R package [163], and machine learning model was implemented using the function "knn3" from the "caret" P package [164].

The developed ML model could help predicting the BFR types from ATR-FTIR spectrums that were otherwise difficult to distinguish by human eyes. Nevertheless, expert interventions were still needed to confirm the results and to judge results that were classified with low level of confidence. Moreover, for certain samples that displayed ambiguous results (usually from samples with more than one BFR, possibly from recycled materials) particularly samples that display some of the PBDEs features, GCMS and/or HPLC-MS/MS were employed for confirmation.

The ML assisted ATR-FTIR technique was used to identify BFR type from the Br positive products and the results are shown in Table 2-40.

Although there were many products/applications previously tested positive for BFR, not many of these product were tested positive for PBDE. The results also showed the pattern of the uses of similar BFR for certain resins. Particularly, TBBPA was typically used for ABS resins while PBDEs and DBDPE were most likely found in PS resins.

Moreover, due to the resins’ inherent slow burning and/or self-extinguishing property, parts made with high LOI polymers such as PC or PC/ABS blends typically do not need to be flame retarded except when they are thin – as seen in plastic sticker found on battery pack for laptop computers.

Table 2-40: Brief summary of results from preliminary survey for BFR in products using in-house developed ML assisted ATR-FTIR technique

Sample Group	Description	Resin	Results*
TV CRT monitors	Plastic housing	PS	Positive for PBDE (65±11%)[##] and DBDPE (7±7%)[##]
PC CRT monitors	Plastic housing	ABS	Negative for PBDE, positive for TBBPA (84±5%)[##] and BTBPE+ TBBPA mixture (15±5%)[##]
Flat panel TV monitors	Plastic housing	PS	Positive for DBDPE (16±10%)[##]
Flat panel PC monitors	Plastic housing	ABS, PC/ABS	Negative for BFRs
Battery pack for laptop computers	Plastic Sticker	PC	Positive for TBBPA (88±12%)
Extension cords	Receptacle parts – extracted from high-end products	ABS	Positive for TBBPA[#] (100% of Br positive ABS samples)
Split type air conditioners	EEE control compartment	PS, ABS	Positive for TBBPA[#] (100% for Br positive ABS samples) and DBDPE[#] (33% for Br positive PS samples)
Laser printers toner cartridges	Plastic enclosures	PS, some PC/ABS	Positive for DBDPE (54±8%)
Parts from home appliances	knobs motor controllers, etc.	varies (PBT, nylon, PPS, etc.) - rarely ABS nor PS	Negative for PBDE and DBDPE
EEE parts	Thermoplastic enclosures from parts	varies (PBT, nylon, PPS, PVC,	Negative for PBDE

Sample Group	Description	Resin	Results*
	extracted from WEEE (Relays, Connectors, Capacitors)	etc.) - rarely ABS nor PS	
EEE parts	Box fan	PC, Nylon	Negative for PBDE

Note:

(*): Numeric results are shown in percent of Br positive samples ± uncertainty (t*CI at 95% confident level) (bootstrap resampled with 10,000 bootstrap replicates)

(#): Results with limited number of samples

(##): Results are taken from one sample for each unique product (brand, model, year, and country of origin), with no account for market share.

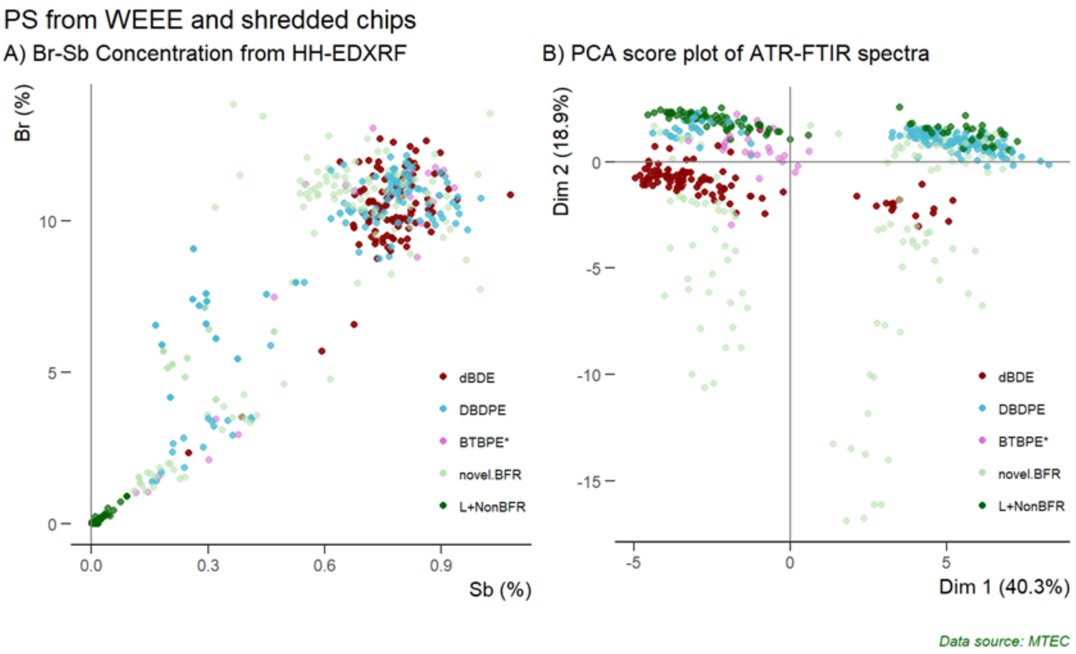
BFRs in Polystyrene

More than 500 polystyrene samples were taken from housings of e-waste (TV, Toner cartridges, etc.) and shredded chips procured from plastic recyclers in the central and the north-eastern regions of the country. The scatter plot of elemental Br-Sb concentrations obtained from HH-EDXRF measurements and a PCA score plot of ATR-FTIR spectra with ML-assisted BFR identification for these samples are shown in Figure 2-29 A) and B), respectively.

As seen in Figure 2-29 A), BFRs are typically added along with antimony trioxide (Sb_2O_3) but Br-Sb relationship alone is not a good indicator for PBDEs in PS. Other BFRs, particularly DBDPE, BTBPE and other novel BFR are also frequently found. It is interesting to note that the types of BFR in this study are in line with BFR in dusts reported in literatures [162][20]. PCA score plot of ATR-FTIR spectra, as shown in Figure 2-29 B, also exhibited interesting patterns showing separations both along Dim 1 and along Dim 2. The distinction along Dim 2 was attributed to the type of BFR and had been used for BFR type classification. The separation along Dim 1, on the other hand, was associated with type of products and is believed to be contributed from impact modifier used in modern plastic parts. Particularly, the plots on the left-hand side were all from TV CRTs while those on the right-hand side were from other applications, including toner cartridges and flat-panel TV monitors.

From these results, following conclusions can be made:

- Even without stringent fire-safety regulations, BFRs have been used in domestic products
- C-decaBDE was most likely found in housings of TV CRT monitors (black PS-V0 resins).
- There were other minor uses of c-decaBDE but not as popular. One of the new applications was FPD TV from two brands.

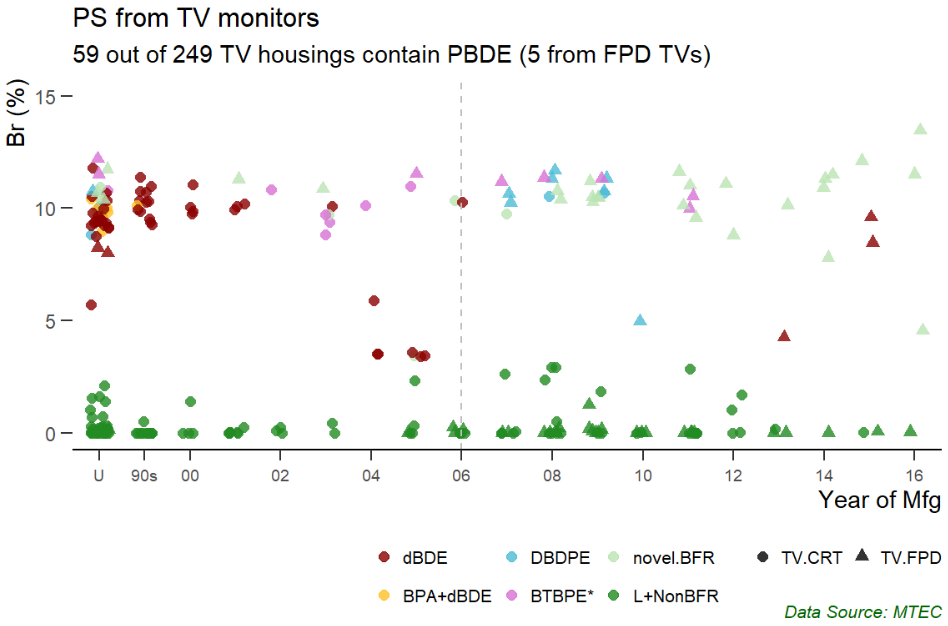


Note: dBDE = decaBDE, BTBPE* = BTBPE+TBBPA mixture ,
novel BFR includes EBTBP and other BFR (exclude PBDE, DBDPE, TBBPA, BTBPE)
L+NonBFR = samples with low or no Br contents

Figure 2-29: A) Br concentration and B) PCA scores scatter plot of ATR-FTIR spectra in the 1,800–650 cm^{-1} region of PS from WEEE and shredded chips with ML-assisted BFR identification

PBDEs in plastic housing of TV monitors

In 2003, the EU published RoHS directive [2] that prohibited placing on EU market of EEE products that contain any type of PBDEs, starting from July 2006. Although the RoHS directive is enforceable only in the EU, Figure 2-30 and Figure 2-31 show clear trend of PBDEs phase-out for Thai market as well. Particularly, decaBDE was regularly found in EOL TV housings produced before 2006 by 2 leading brands (brands A and B). Their uses of BFRs appeared to be consistent and their BFR use patterns changed only in response to EU RoHS directive. On the other hand, brands C and D's BFR usages did not appear to be by intention but rather as contamination (concentrations were too low to be effective) or as provided by suppliers which resulted in mixture of decaBDE and other FRs in the same sample. Brand E, on the other hand, never used any BFR until recently that they started using novel BFR for their FPD TVs.



Data Source: MTEC

Note:

Results are taken from one sample for each product (brand, model, year, and country of origin), with no account for market share

Abbreviation:

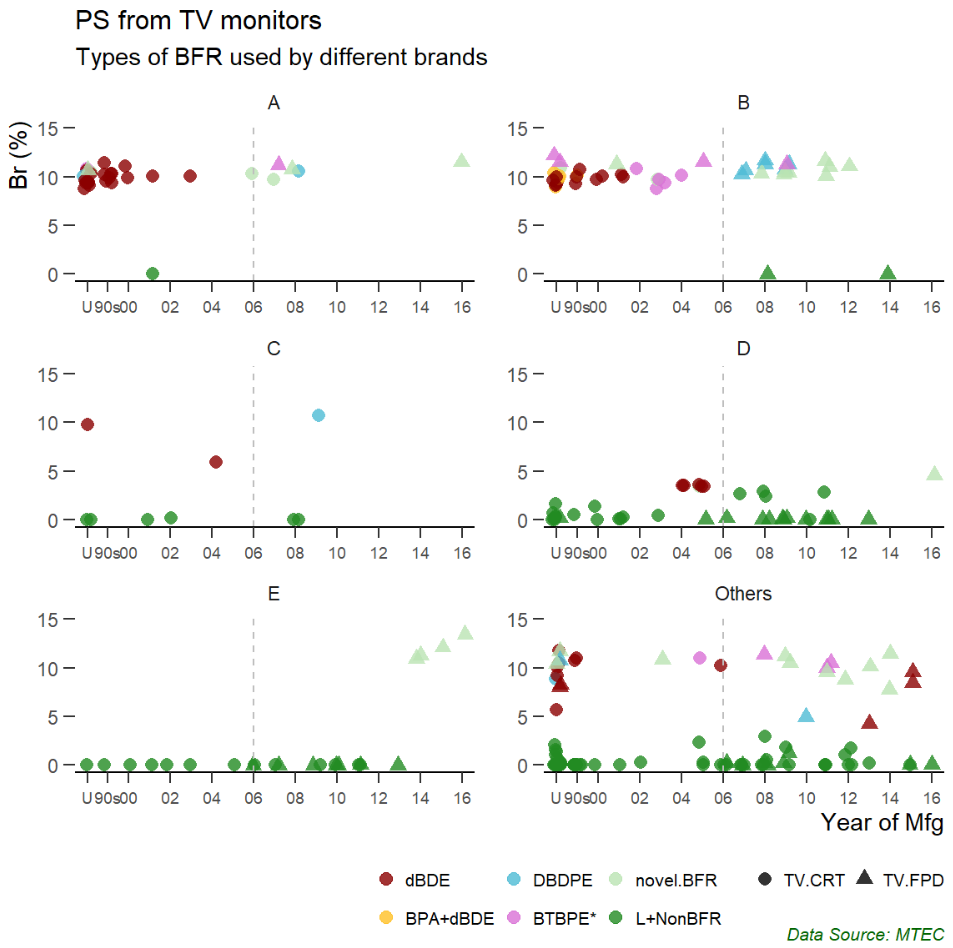
U=Unknown year of manufacturing, 90s = produced before the year 2000

dBDE = decaBDE, BPA+dBDE=decaBDE+TBBPA mixture, BTBPE* = BTBPE+TBBPA mixture ,

novel BFR includes EBTBP and other BFR (exclude PBDE, DBDPE, TBBPA, BTBPE)

L+NonBFR = samples with low or no Br contents

Figure 2-30: The uses of BFRs in TV housings before and after 2006



Note:

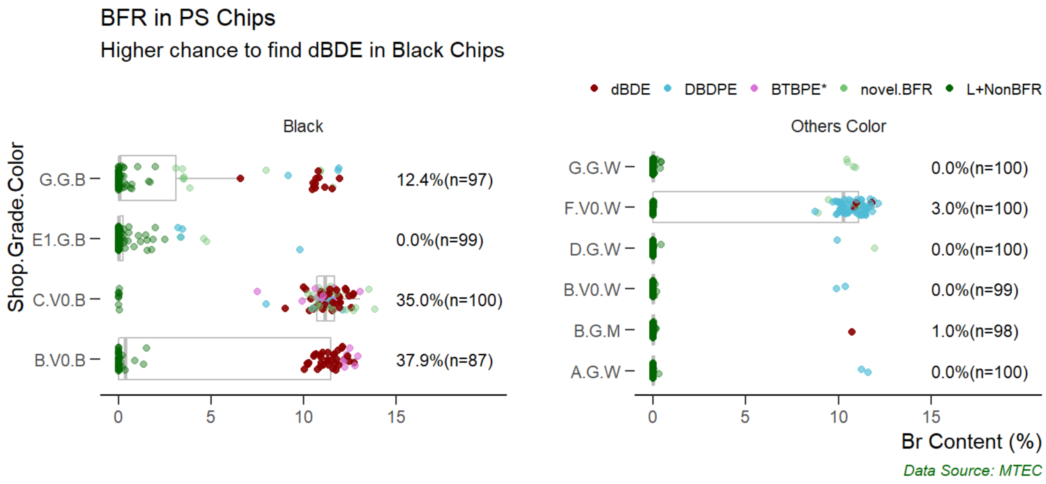
- Results are taken from one sample for each product (Brand, model, year, and country of origin), with no account for market share
- Others include 30 unique brands as well as other fainted labels (unable to identify)

Abbreviation:

U=Unknown year of manufacturing, 90s = produced before the year 2000
dBDE = decaBDE, BPA+dBDE=decaBDE+TBBPA mixture, BTBPE* = BTBPE+TBBPA mixture ,
novel BFR includes EBTBP and other BFR (exclude PBDE, DBDPE, TBBPA, BTBPE)
L+NonBFR = samples with low or no Br contents

Figure 2-31: The type of BFRs used by different TV brands

Additionally, after 2006, most leading brands switched to flat-panel displays but supplies of CRT TVs were continued by new producers until 2015. No BFR was detected from these CRT TVs. Nevertheless, this survey found FPD TVs from 2 brands contained decaBDE, both produced in Thailand. (These samples were confirmed by GCMS.) Since both brands decline to provide more information, the reasons for these inclusions are unknown at this time.



Note: oBDE=octaBDE, dBDE = decaBDE, BTBPE* = BTBPE+TBBPA mixtures, L+NonBFR = Low or no BFR Grade: G=General grade, V0=Flame retarded grade; Color: W=White, B=Black, M=Mixed
The sample size (n) was originally 100 pieces for all samples but the number of usable samples was reduced due to shops' wrong resin classification.

Figure 2-32: BFRs in PS Chips acquired from different shredders

Table 2-41: Calculated chances of finding decaBDE and expected concentration from PS from various sources

Group	Shop	Color	Grade	P{LBr}	P{FR17}	P{dBDE}	E{dBDE$_{Batch}$}
CRT TV*	All	Black	-	56±8%	15±6%	28±7%	3.1±0.8%
FPD.TV**	All	Mixed		38±10%	56±11%	6±6%	0.6±6%
Toner Cartridge	All	Black	-	17±9%	83±8%	0%	-
Chips	B	Black	V0	54±10%	8±6%	38±10%	5.2±1.4%
Chips (monitors)	C	Black	V0	9±6%	56±10%	35±9%	4.8±1.3%
Chips	E1	Black	G	93±4%	7±5%	0%	-
Chips	G	Black	G	74±8%	13±7%	12±7%	1.6±0.9%
Chips	B	Mixed	G	99±1%	0	1±2%	0.1±0.3%
Chips	A	White	G	98±2%	2±3%	0%	-
Chips	B	White	V0	98±2%	2±3%	0%	-
Chips	D	White	G	98±2%	2±3%	0%	-
Chips	F	White	V0	32±9%	65±9%	3±4%	0.4±0.5%
Chips	G	White	G	96±3%	4±4%	0%	-

Note: P{.}=Probability of finding ±uncertainty (t*CI at 95% confident level)
*: Bootstrap over different brands, model, and year (without considering market share)
**: Only limited number of FPDs that reached EOL (as of April 2019)
E{dBDE$_{Batch}$ }=Expected concentration of decaBDE for the whole batch.

Plastic resins extracted from housings of e-waste are important source of income for e-waste dismantlers. Naturally, the characteristics of the resulted resins will mirror the characteristics of the wastes arriving at the shop. Flame retarded PS chips are available from shredders both in white and in black colors. However, black chips are found to be more likely to contain decaBDE than white chips, possibly due to the PBDE's yellowing problem.

Figure 2-32 displays BFRs in shredded PS chips acquired from 7 shops. Depending on the shop's competency, black chips with decaBDE contents may be mixed with other non FR chips (such as in sample “G.G.B”).

The chance for finding decaBDE and the corresponding decaBDE concentration for each batch have been estimated using a bootstrap resampling method and the results are summarized in Table 2-16. Available results for television sets may not represent actual distribution because the study counted products from the same brand and year only once (without considering market share). Results from black PS V0 chips, on the other hand, are considered more representative as these chips can be reasonably assumed that they were extracted from randomly selected TV housings that were arrived at e-waste dismantling shops[35].

BFRs in ABS

Housings for computer monitors, on the other hand, are typically made of ABS or PC/ABS resins. As shown in Figure 2-33, most of the PC CRT housings found in Thailand are flame retarded, mostly with BFRs. Particularly, as shown in Figure 2-34, two types of BFR, TBBPA and BTBPE, were most frequently found. Producers’ BFR choice appeared to be very consistent over long period of time. None of the products from leading brand PC monitors were found with PBDEs.

Specifically, only two samples out of 316 samples contained PBDEs, one octaBDE and one decaBDE. These samples were extracted from mini- or mainframe computer’s monitors produced in the 90s. The results from 16 samples were confirmed by GC-MS analysis.

ABS resins are valuable resources for e-waste dismantle shops. According to shops’ owners, flame retarded ABS-V0 shredded chips can command as high as 30% higher price than regular ABS chips; hence merit separation efforts. Typical shops identifications comprise two stages; resin identification by solvent (gasoline) dissolution and ‘V0’ identification by burning tests.

Figure 2-35 shows the type of BFR in shredded ABS chips sampled from 4 ‘recyclers’ in the central and north-eastern regions of the country. The pattern of BFR found in these chips appeared to reflect e-waste that reached the shops. Specifically, though relatively rare in ABS, the chance of finding PBDEs in ABS chips from shops in the central region appeared to be higher than shops in the rural regions. This further confirms the observations on the usages of PBDEs in ABS in high-end computers.

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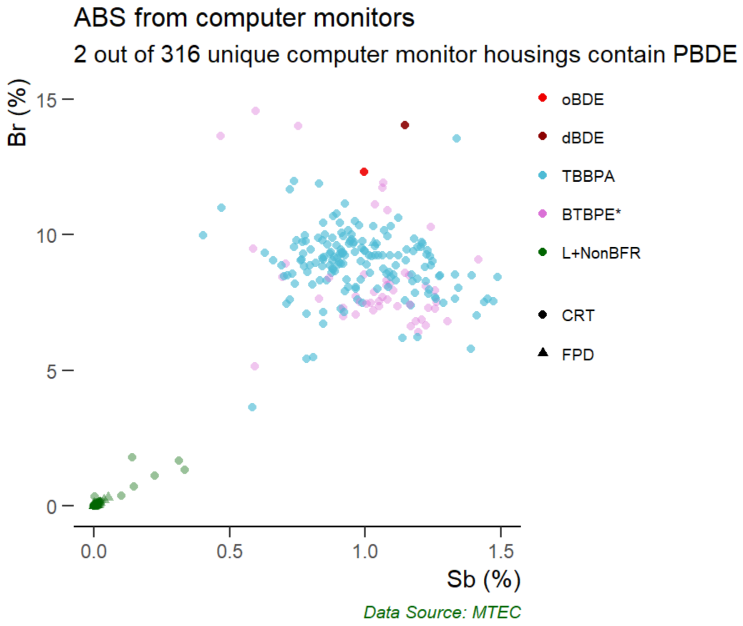
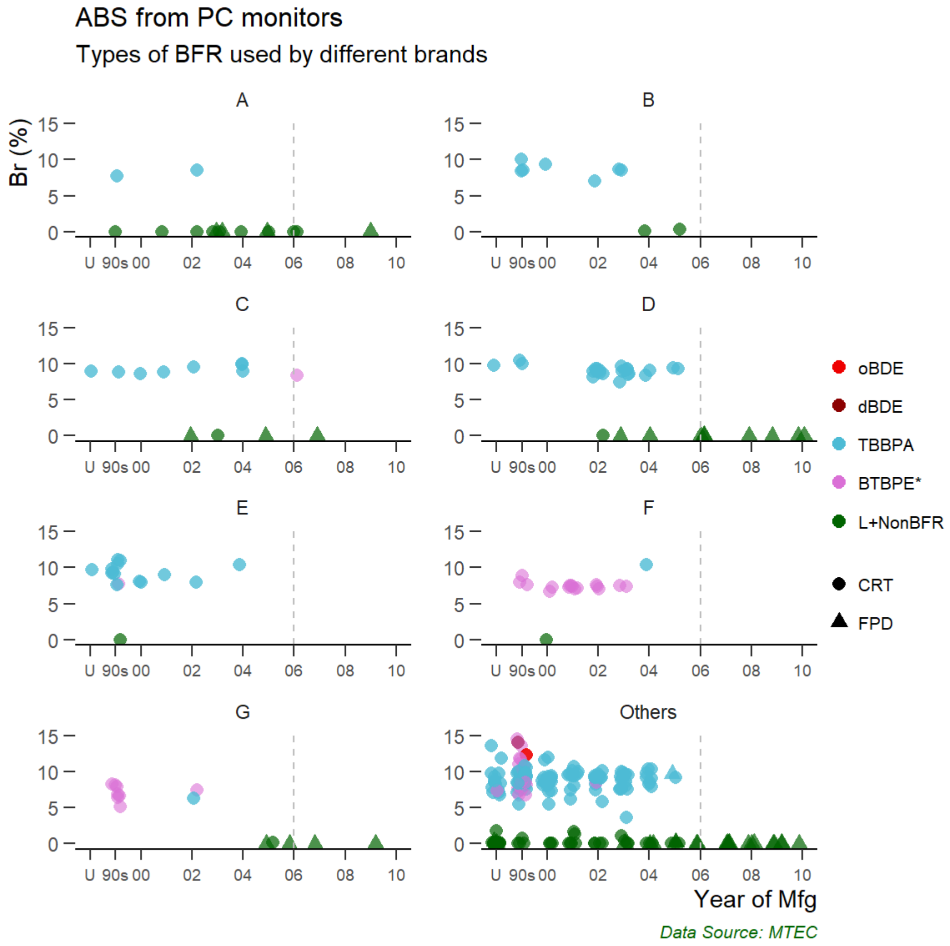
[35] likely biased as there were also TV from other leading brands that did not use V0 resins



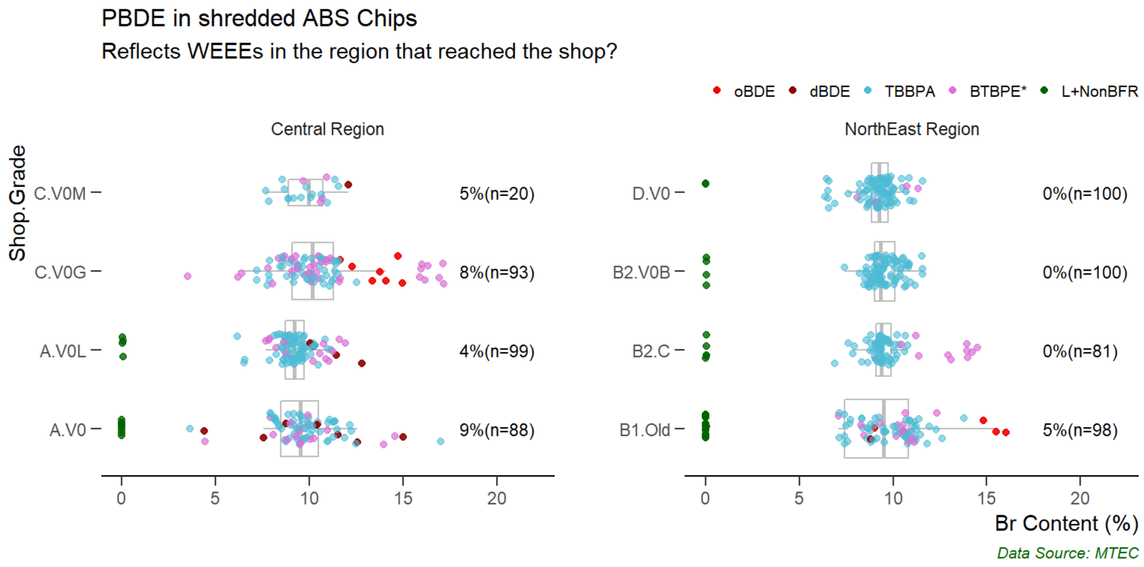
Note: oBDE=octaBDE, dBDE = decaBDE, BTBPE* = BTBPE+TBBPA mixtures, L+NonBFR = Low or no BFR

Figure 2-33: Br-Sb concentrations measured from PC monitor housings (ABS) using HH-EDXRF (with ML-assisted BFR identification)



Note: Others included 55 unique brands as well as other fainted labels (unable to identify)
U=Unknown year of manufacturing, 90s = produced before the year 2000
oBDE=octaBDE, dBDE = decaBDE, BTBPE* = BTBPE + TBBPA mixtures, L+NonBFR = Low or no BFR

Figure 2-34: The type of BFRs used different PC monitors brands



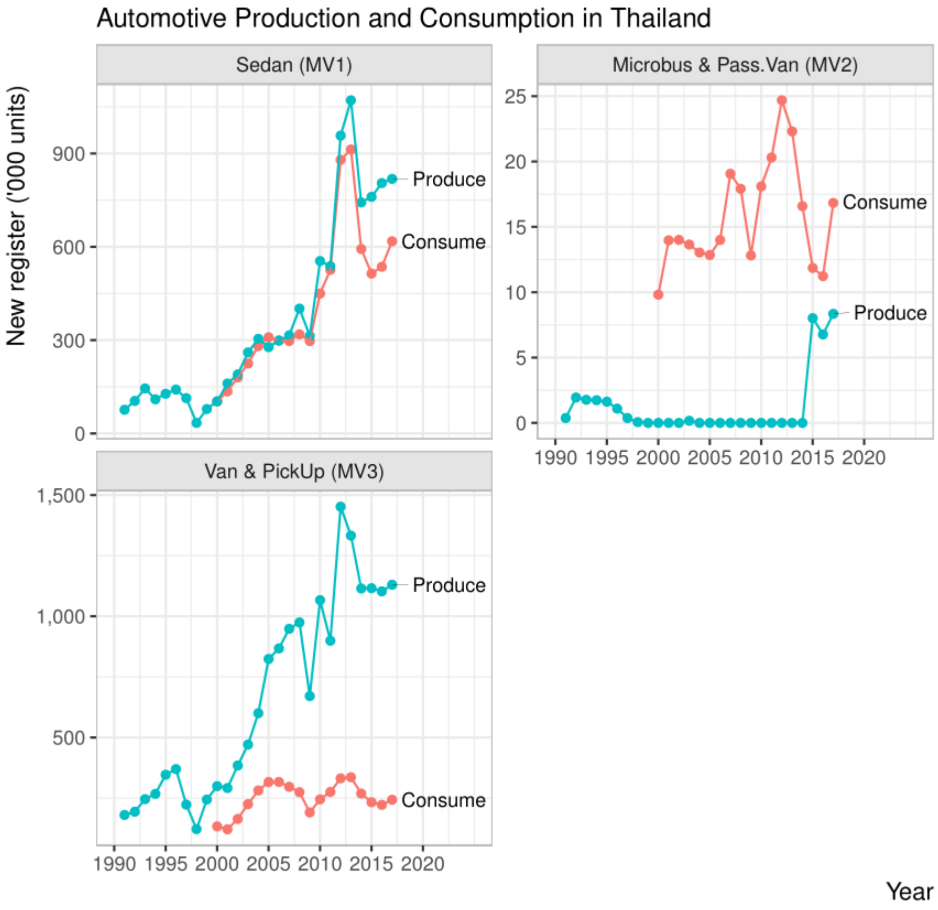
Note: M=mixed color, G=Grey, L=light, B=Black, C=colored, Old=obsolete stock

oBDE=octaBDE, dBDE = decaBDE, BTBPE* = BTBPE + TBBPA mixtures, L+NonBFR = Low or no BFR

The sample size (n) was originally 100 pieces for all samples (except for C.V0M) but the number of usable samples was reduced due to shops' wrong resin classification.

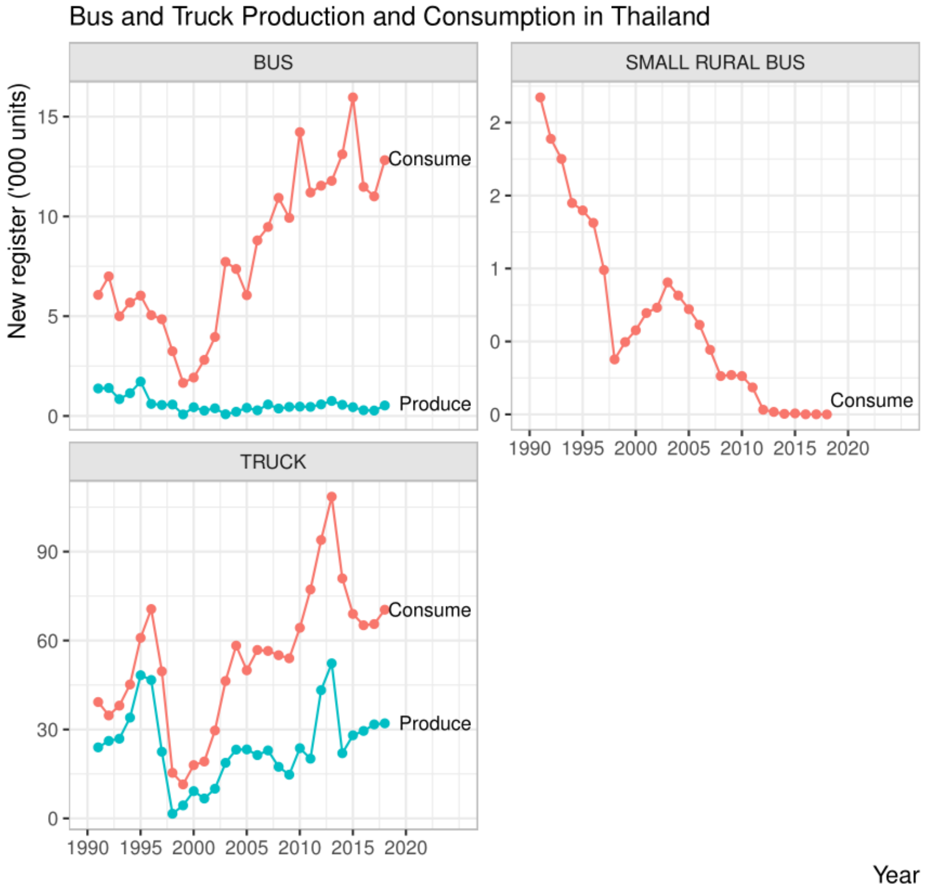
Figure 2-35: PBDEs in shredded ABS chips

Annex 9. Thailand’s motor vehicles production and consumption



Data sources: FTI and DLT

Figure 2-36: Statistic of motor vehicles production and consumption in Thailand since 1991



Data sources: FTI and DLT

Figure 2-37: Buses and trucks production and consumption in Thailand since 1991

Annex 10. Scenario for estimation of PBDEs emissions from TV-CRT housings

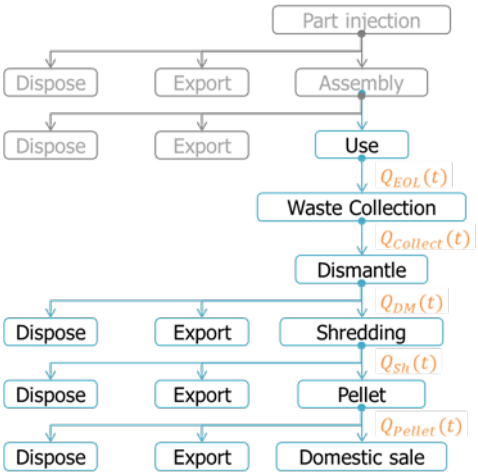


Figure 2-38: Assumed flow of TV CRT housings

Note: Disposal routes include simple landfill, landfill, open burning, and incineration

Table 2-42: Assumed time dependent outputs from waste collection activity

Period	Dismantle
1980-1999	1
2000-2009	1
2010-2017	1
2018-2020	1
2030-2050	1

Table 2-43: Assumed time dependent outputs from dismantle activity

Period	Export	Shredder	Simple Landfill	Landfill	Open Burning	Incineration
1980-1999	0	0	0.8	0	0.2	0
2000-2009	0.5	`0.3	0.2	0	0	0
2010-2017	0.2	0.7	0.1	0	0	0
2018-2020	0.1	0.8	0.01	0.04	0	0.05
2030-2050	0	0.95	0	0	0	0.05

Table 2-44: Assumed time dependent outputs from TV housings shredders

Period	Export	Pellet	Simple Landfill	Landfill	Open Burning	Incineration
1980-1999	0.5	0	0.4	0	0.1	0
2000-2009	0.5	0.2	0.2	0	0.1	0
2010-2017	0.4	0.4	0.1	0.1	0	0
2018-2020	0.1	0.8	0.04	0.04	0	0.02
2030-2050	0.1	0.8	0.04	0.04	0	0.02

Table 2-45: Assumed time dependent outputs from pellet makers

Period	Export	Domestic Sale	Simple Landfill	Landfill	Open Burning	Incineration
1980-1999	0	0.6	0.3	0	0.1	0
2000-2009	0.5	0.1	0.3	0	0.1	0
2010-2017	0.7	0.1	0.1	0.1	0	0
2018-2020	0.8	0.1	0.04	0.04	0	0.02
2030-2050	0.8	0.1	0.04	0.04	0	0.02

Annex 11. Requirements for foam stock for petroleum depots

Table 2-46: The required amount of concentrated foams for different storage tanks

Type of storage tank	Petroleum type	Concentrate foam consumption (liter per minute per square meter) (1)	Area to be used for calculation (square meter)	Require time (minute) (2)	Required foam (liter per square meter) (1)x(2)
Fixed roof	highly flammable	4.1	Tank cross sectional area	55	225.5
	low or moderately flammable			30	123
(external) Floating roof	All types	12.2	cross sectional area between foam barrier on the tank roof to tank wall	20	244
Internal floating roof	highly flammable	4.1	Tank cross sectional area	55	225.5
	low or moderately flammable			30	123
	All types	12.2	cross sectional area between foam barrier on the tank roof to tank wall – in case the internal floating roof is made of steel	20	244

Source: Adapt from Ministry of Energy’s Regulation on “Petroleum Depots” of 2556 B.E.[84]

Table 2-47: Storage tank and number of foam dispenser

Tank diameter (meter)	minimum number of foam discharge outlets (point)
less than 19.50	1
between 19.50 – 36	2
above 36	3

Table 2-48: Storage tank and foam dispensing duration

Tank diameter (meter)	minimum foam discharge time (minute)
less than 10.50	10
between 10.50 – 28.50	20
above 28.50	30