IMPACT OF PBDD/DFS IN LIFE CYCLE ASSESSMENTS ON RECYCLING OF TV CABINET BACK COVERS

Hirai Yasuhiro, Sato Shunichi, Sakai Shinichi
Environment Preservation Center, Kyoto University, Yoshidahon-machi, Sankyo, Kyoto, 606-8501 Japan

Introduction

Facilities for the recycling of home electronics generate waste plastic containing brominated flame retardants. This waste plastic is disposed of by a variety of methods. Environmental emissions of flame retardants and other substances must be considered when evaluating waste treatment methods. In our previous research[1], we presented life cycle assessments (LCA) on TV cabinet back covers, with a focus on waste plastic containing decabromodiphenylehter (DecaBDE). The research assessed the impact from the exposure to DecaBDE but exposure to other related compounds, such as lower brominated diphenylethers and polybrominated dibenzo-*p*-dioxins and dibenzofurans (PBDD/DFs) were not considered. In this paper, we present LCA results including exposure to lower brominated diphenylethers and PBDD/DFs.

Method

Goal and scope definition: The functional unit, system boundaries and scenarios of this LCA are the same as those of our previous research[1]. We performed a lifecycle impact assessment based on the impact categories of global warming, human health impacts due to brominated compunds exposure, and landfill consumption. The inventory items were landfill mass, emissions of CO_2, DecaBDE, octabromodiphenyethers (OctaBDEs), pentabromodiphenyethers (PentaBDEs) and PBDD/DFs. The weighting was performed by damage cost method.

Inventory analysis: Inventory data for CO_2 emissions were obtained from previous studies on plastic waste recycling.[2, 3] Inventory data for PBDEs and PBDD/DFs emissions were calculated by multiplying activity data by the corresponding emission factors[4, 5].

Characterization method: We distinguished between emissions into atmosphere and indoor air. The characterization factor used to calculate exposure for each type of emission was the intake fraction (iF) for that emission. The following assumptions were made to estimate the iFs of DecaBDE for atmospheric emission and indoor air emission: 1) Exposure pathways are limited to food and to indoor air (dust). 2) The DecaBDE in food comes from atmospheric emission and water emission. 3) The DecaBDE in dust comes from indoor air emission. 4) The iF for air emission is equal to the iF for water emission. In addition to the above assumptions, iFs of DecaBDE were used for iFs of OctaBDEs, PentaBDEs and PBDD/DFs

Intake fractions: The iF for atmospheric emission was derived by dividing the annual intake of DecaBDE from food by the emission of DecaBDE to atmosphere and water. The annual intake of DecaBDE from food was 1.8 kg/year (= 38 ng/person/day × 365 × 128 million).[5] We used a previous estimate of DecaBDE emission to atmosphere (1.7 ton/year).[6] The figure for emission of DecaBDE to water (6 ton/year) was obtained from Pollutant Release and Transfer Register of Japan.[7] The iF for atmospheric emission, based on these figures, was 2.3×10^{-4}. The iF for indoor air emission was 1.3×10^{-2}, which we calculated on the basis of the exposure scenario presented in Table 1.

Table 1: Indoor air exposure scenario

Room size	3.6 m × 3.6 m × 2.5 m
No. of inhabitants	1
Inhalation rate	15 m^3/day
Usage duration	8 h/day
Air exchange rate	0.5 h/day

Weighting: Weighting factors obtained by the damage cost method are as follows: For CO_2 emissions and landfill, the damage costs given in LIME were used.[8] For DecaBDE, OctaBDEs and PentaBDEs, DALY (disability adjusted life years) values due to liver tumors caused by PBDEs exposure were calculated and then converted to a damage cost. It was assumed that liver tumors occur at an exposure of 1120 mg DecaBDE/kg/day, 0.77 mg OctaBDEs/kg/day, 0.1 mg PentaBDEs/kg/day. For PBDD/DFs, DALY values due to cancer were calculated. It was assumed that TEF values for PBDD/DFs are the same as for the corresponding PCDD/DFs and the cancer slope factor were 1.0×10^{-4} $[\text{pg-TEQ/kg/day}]^{-1}$.

Results and Discussion

As to DecaBDE emission, DecaBDE production and uncontrolled combustion were the most important contributors (Figure 1(a)). On the other hand, as to OctaBDEs, PentaBDEs and PBDD/DFs emission, uncontrolled combustion was the single most important contributor (Figure 1 (b)).

As to DecaBDE exposure, TV use and the use of recycled plastic were the most important contributors (Figure 2(a)). As to OctaBDEs, PentaBDEs and PBDD/DFs exposure, uncontrolled combustion was the single most important contributor (Figure 2(b)).

The difference in the contribution of DecaBDE sources between the emission and exposure was due to the large difference between iFs for atmospheric emission and indoor air emission. The iF for indoor air emission is higher than the iF for atmospheric emission, thus in terms of exposure the processes with indoor exposure (TV use and the use of recycled plastic) become more important than other processes. In case of OctaBDEs, PentaBDEs and PBDD/DFs, the emission from uncontrolled combustion is so large that this process is dominant in both emission and exposure in spite of the lower iFs applied to the uncontrolled combustion.

The damage costs of human health impacts caused by the exposure to PBDEs and PBDD/DFs are shown in Table 2. Among the five scenarios the highest damage cost was estimated in “landfilling and open fire”, followed by “mechanical recycling” and “feedstock recycling”. Among the four compounds, the highest human health impact was caused by PBDD/DFs followed by PentaBDEs and OctaBDE. The health impacts caused by PBDD/DFs were about 1,000 to 100,000 times higher than those by DecaBDE. The health impacts caused by PentaBDEs were about 20 to 60 times higher than those by DecaBDE.

In this study, we assumed that the TV cabinet back covers are treated with commercial DecaBDE. Thus the exposures to OctaBDEs, PentaBDEs and PBDD/DFs in this study are caused by impurities or thermal breakdown compounds of commercial DecaBDE. Table 2 suggests that in order to evaluate the human health impacts from commercial DecaBDE it is important to consider the impacts caused by PentaBDEs and PBDD/DFs, even if the concentrations of PentaBDEs and PBDD/DFs in commercial DecaBDE are small.

The results of weighting are shown in Figure 3. The best scenario in terms of total damage cost was “feedstock recycling” followed by “mechanical recycling” and “landfilling”. If the inventory items for human health impact were limited to DecaBDE (Figure 3(a)), the total damage cost of “landfilling and open fire” is smaller than that of “thermal recovery”. However, if the inventory items for human health impact were extended to PBDD/DFs, PentaBDEs and OctaBDEs in addition to DecaBDE (Figure 3(b)), the total damage cost of “landfilling and open fire” become larger than that of “thermal recovery”. These results suggest the importance of PBDD/DFs and lower brominated diphenylethers in the life cycle impact assessment of commercial DecaBDE products.

Acknowledgements

This research was funded by Ministry of Environment, Waste Management Research Grant (K1953, K2062).

References

1. Hirai Y., Sato S. and Sakai S. *Organohalogen Compounds* 2007; 69:
2. Inaba R., Hashimoto S. and Moriguchi Y. *Journal of the Japan Society of Waste Management Experts* 2005; 16: 467 (in Japanese)
3. JLCA-LCA database 2004 2nd edition.
4. Sakai S., Hirai Y., Aizawa H., Ota S. and Muroishi Y. *Journal of Material Cycles and Waste Management* 2006; 8: 56

5. Ministry of Environment Japan (2004–2006): Results of PBDDs/DFs study in Japan. http://www.env.go.jp/chemi/report/h18-11/index.html
6. Hirai Y. and Sakai S. *Organohalogen Compounds* 2004; 66: 3712
7. Ministry of Environment Japan 2007 Pollutant Release and Transfer Register.
8. Itsubo N. and Inaba A. *Proceedings of the 6th International Conference on Ecobalance* 2004; 87

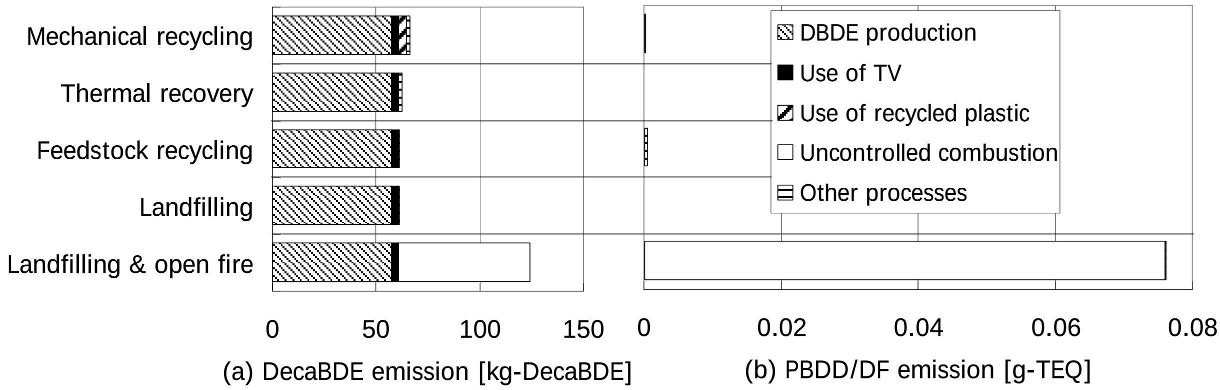

Figure 1: Inventory results for (a) DecaBDE and (b) PBDD/DFs emission by scenarios and processes

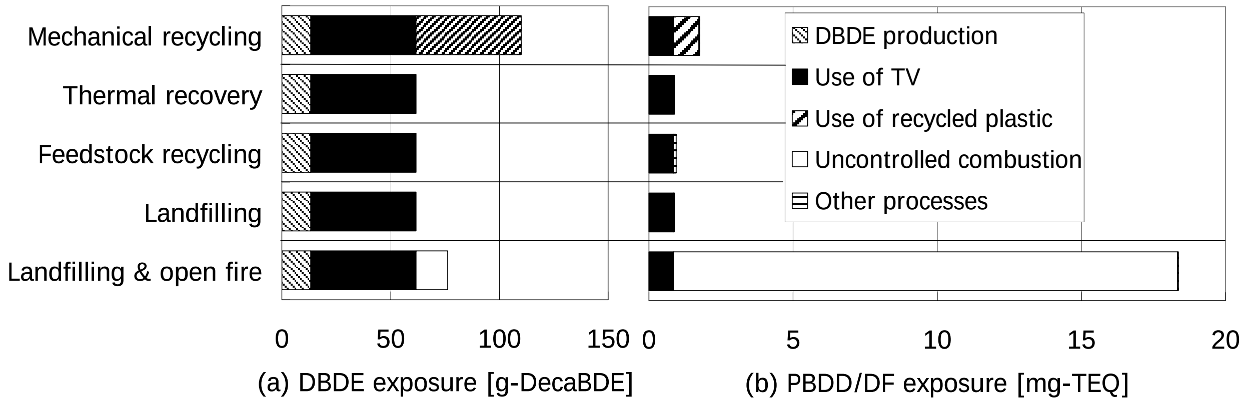

Figure 2: Results of (a) DecaBDE and (b) PBDD/DFs exposure by scenarios and processes

Table 2: Characterization results for human health impact by scenarios and chemicals. Unit: Yen

	Mechanical recycling	Thermal recovery	Feedstock recycling	Landfilling	Landfilling & open fire
PentaBDEs	1,400,000	5,100	0	0	6,200,000
OctaBDEs	45,000	770	0	0	1,700,000
DecaBDE	4,800	27	1.1	0	1,400
PBDD/DFs	7,400,000	0	690,000	0	150,000,000
Total	8,900,000	5,800	690,000	0	160,000,000

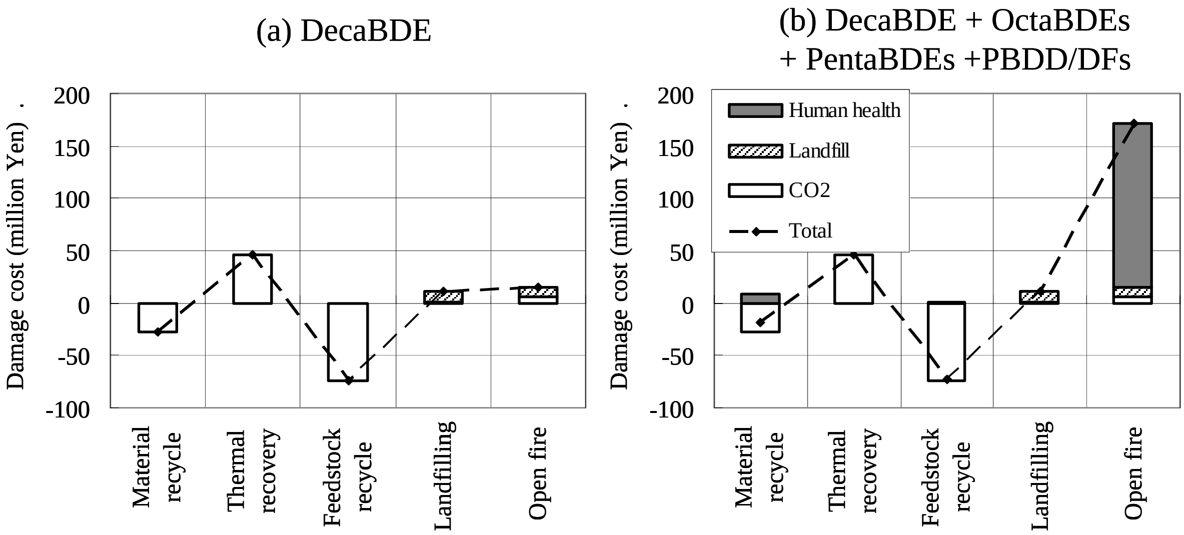

Figure 3: Weighting results according to damage assessment method