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An overview of policies for managing polybrominated diphenyl ethers (PBDEs) in the Great Lakes basin

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A B S T R A C T

The Great Lakes are an important environmental and economic resource for Canada and the United States. The ecological integrity of the Great Lakes, however, is becoming increasingly threatened by a number of persistent, bio-accumulative and harmful chemicals that enter the Great Lakes ecosystem through fluvial and atmospheric deposition. Polybrominated diphenyl ethers (PBDEs), a class of brominated flame retardant, are among such chemicals, whose concentration in the Great Lakes has greatly increased in recent years. Despite growing concern over the possible health and environmental effects of these compounds, only four of the eight Great Lakes states have enacted regulations to ban/restrict the use of PBDE while the two Canadian Great Lakes provinces are yet to endorse any regulation. Of the three main commercial PBDE mixtures (pentaBDE, octaBDE and decaBDE), penta- and octaBDE are no longer manufactured or imported into the United States and Canada. DecaBDE, however, still finds use in a variety of products.

In the present paper, the authors review the current regulations and policies for managing PBDEs in the Great Lakes jurisdictions and briefly review commercially available non-bromine chemical alternatives to PBDE. As these alternatives are comparatively more expensive than PBDE, future adoption of more eco-friendly flame retardants by the polymer industry will likely depend on stricter legislation regulating the use of PBDE and/or an increased public demand for PBDE-free products.

1. Introduction

The Great Lakes, comprised of Lake Superior, Lake Huron, Lake Michigan, Lake Erie and Lake Ontario (Fig. 1), have a total volume of 23,000 km^3 and a drainage area encompassing 750,000 km^2. Together, these lakes form the largest fresh water surface system on earth, retaining approximately 80% of the total surface water of North America and more than 20% of the world's total freshwater supply (EC and EPA, 1995). The Great Lakes are thus an important environmental and economic resource for Canada and the United States. The basin provides drinking water for millions of people and supports numerous species of terrestrial and aquatic wildlife, including more than 130 globally rare, endangered and at-risk species (USFWS, 2005; COSEWIC, 2007). Economically, the Great Lakes basin sustains more than 50% of Canada's manufacturing output and generates over $330 billion USD annually in Canada–US trade (EC and EPA, 1995; Fields, 2005).

The immediate vicinity surrounding the lakes, however, is one of the most densely populated and highly industrialized areas in North America. Approximately 40 million people live within the boundaries of the Great Lakes basin, accounting for 30% of the total Canadian population and 10% of the US population (EC and EPA, 2003). Associated high levels of urban, agricultural and industrial run-off of toxic contaminants, in addition to atmospheric deposition and fluvial migration of chemicals, are threatening the ecological and economic health of the ecosystem and millions of people living in the Basin. Over 1000 different chemicals have been identified in the Great Lakes, more than 350 of which exist in considerable quantities (EC, 1997; IJC, 2003a). Levels of a few chemicals, such as PCBs, have declined in recent years as a direct result of legislative changes (DeVault et al., 1996; Hickey et al., 2006). However, concerns with respect to the increasing environmental presence of a group of related compounds, Polybrominated diphenyl ethers (PBDE), have recently been raised (Renner, 2000; Darnerud et al., 2001; Rahman et al., 2001; Hites 2004).

PBDEs are a class of brominated flame retardant known to be environmentally persistent and lipophilic that bioaccumulate in animal tissue and biomagnify with increasing trophic distance (De Wit, 2002; Law et al., 2006; Burreau et al., 2006;Voorspoels et al., 2007). Observations that PBDEs have increased exponentially in the Great Lakes in recent years, combined with data indicating adverse effects on human health, suggest that the formulation and implementation of effective policies to rid the Great Lakes basin of these chemicals is urgently needed. In the present paper, the authors have reviewed the current regulations and policies concerning PBDE in the Great Lakes jurisdictions. The efficacy of these policies has been analyzed and prospective legislative and research priorities are

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Fig. 1. The Great Lakes basin.

suggested. In addition, occurrence, geographic and temporal distribution, toxicity, and environmental effects of PBDE are briefly described.

2. Polybrominated diphenyl ethers (PBDE)

Brominated flame retardants (BFRs) are chemical compounds that inhibit the combustion of organic materials by scavenging free radicals that would otherwise encourage the spread of flames (D'Silva et al., 2004; Hites, 2006). These compounds are found in a wide variety of materials including paints, plastics, textiles, furniture and electronics and may be either covalently bonded to the polymer, or additively mixed into the final product. Mounting evidence, however, suggests that the non-reactive BFRs can easily leach into the environment and pose significant environmental and health concerns (Hites, 2006). Despite this, brominated flame retardants are routinely included in the manufacture of household goods and an increasing consumer demand for such products has been reflected in the global BFR production patterns over the past several years (Alaee et al., 2003).

The use of PBDE gained prominence after the manufacture of polybrominated biphenyls (PBB) was stopped in the United States and Canada in the late seventies (Hites, 2006). PBDEs are a class of additive brominated flame retardants made up of 209 possible congeners containing between 1 and 10 bromine atoms (Alaee et al., 2003). Of these, 23 congeners are of environmental significance, the details of which are given in a review by D'Silva et al. (2004). Until early 2005, three commercial PBDE mixtures were widely distributed for use in North America: Penta-bromodiphenyl ether (pentaBDE), Octa-bromodiphenyl ether (octaBDE) and Deca-bromodiphenyl ether (decaBDE) (Table 1). Worldwide, more than 70,000 metric tons of PBDE have been produced annually, half of which have been used in the US and Canada, including almost all of the pentaBDE manufactured (Renner, 2000; Hites 2006).

Globally, high levels of PBDE have been detected in a variety of environmental media including soil and sediment (Song et al., 2005a, b; Zhu and Hites, 2005), air (Wilford et al., 2004; Hoh and Hites, 2005), house dust (Jones-Otazo et al., 2005; Stapleton et al., 2005) and biological samples (Alaee et al., 1999; Ikonomou et al., 2000; Zhu and Hites, 2006). In a recent meta-analysis of global concentration data, Hites (2004) determined that human PBDE levels had increased by a factor of 100 over the past three decades, with concentration loads doubling every 5 years. North Americans have the highest global body burdens, averaging contaminant levels 20 times that of Europeans.

The potential health hazards of PBDEs are significant. Pregnant women and developing fetuses may be particularly susceptible to their effects (reviewed in McDonald, 2002). DecaBDE has been designated as a possible human carcinogen by EPA on the basis of evidence of cancer for animals (ATSDR, 2004). Animal studies have shown that PBDEs delay hatching, depress rates of swimming and feeding in fish (Timme-Laragy et al., 2006) and induce neural defects and cardiac arrhythmia (Lema et al., 2007). Laboratory experiments using rodents found that neo-natal exposure to PBDEs could impair motor skills, learning and memory (Eriksson et al., 2002; Branchi et al., 2003; Viberg et al., 2007), induce immuno-toxicity (Thuvander and Darnerud, 1999; Martin et al., 2007), disrupt endocrine functioning (Hallgren et al., 2001; Hallgren and Darnerud, 2002) and impair reproductive development (Lichtensteiger et al., 2003; Stoker et al., 2004; Kuriyama et al., 2005). Comparable studies investigating the toxicological effects of PBDEs on humans are extremely few, but recent evidence suggesting that PBDEs have an adverse effect on human health and reproduction has emerged. In particular, the developmental aberrations found in the animal studies discussed above indicate that children may be especially at risk of adverse health effects due to PBDE exposure (Eriksson et al., 2001a; Siddiqi et al., 2003). Transfer of PBDE contamination from maternal to fetal tissue during gestation has been documented (Mazdai et al., 2003; Schecter et al., 2007) and young children may be exposed to additional early PBDE contamination through nursing and house dust (Zuurbier et al., 2006).

The consumption of contaminated food is thought to be a major pathway to human exposure (Watanabe and Sakai, 2003; D'Silva et al., 2004). PBDEs have been detected in a wide variety of meat, fish and dairy products in both North America and Europe (Bocio et al., 2003; Schecter et al., 2004, 2006) and the application of PBDE-laden biosolids to agricultural areas is a potential vector to food contamination (Hale et al., 2001; Sjodin et al., 2003). Correlational 'market basket'