EPOXY RESINS

ASSESSMENT OF POTENTIAL BPA EMISSIONS – SUMMARY PAPER

The research on the potential emissions of Bisphenol A (BPA) from manufacturing, using and dismissing epoxy resins was conducted by Beratungsgesellschaft für integrierte Problemlösungen (BIPRO) on behalf of the Epoxy Resin Committee (ERC). This document summarises the results of the assessment which covered five key application sectors of epoxy resins in Europe. Individual factsheets are available on www.epoxy-europe.eu. For more information contact info@epoxy-europe.eu.

BACKGROUND

Over the past two years there have been several regulatory developments in Europe affecting Bisphenol A, a key starting material of epoxy resin. As a result of a first evaluation by the European Chemicals Agency (ECHA), German authorities requested further information about skin absorption and environmental exposure to Bisphenol A and its applications.

1. **Manufacturing of liquid and semi-solid epoxy resin**
2. **Manufacturing of the epoxy resin products, e.g. wind blades**
3. **Service life of the epoxy resin products**
4. **End-of-life stage of the epoxy resin products, e.g. disposal ways**

In response to this request, the Epoxy Resin Committee commissioned an independent agency to perform a series of studies on the life cycle of epoxy resins used in water pipes, flooring, marine coatings, automotive and wind rotor blade applications. The analyses encompassed all stages from manufacturing of the resin and applications to service life and disposal. The application sectors were selected according to two criteria: largest consumption of epoxy resin and probable sources of possible BPA losses.

EPOXY RESIN MANUFACTURING

Epoxy resins are created by mixing BPA and epichlorohydrin (ECH), which are then reacted so as to create the basic monomer unit of epoxy resin called BADGE or DGEBA. The properties of the cured epoxy resins are determined by a chemical process called curing or hardening. It involves mixing the resin with (poly)amines, aminoamides, phenolic compounds or other reactive substances. This curing process will determine many properties of the cured epoxy resin, like, its adhesion to other materials, durability, resistance and versatility. The ratios of BPA and ECH also contribute to determine the epoxy's final properties.

Products	Type of epoxy resin
Water pipes	LER
Flooring	LER
Wind rotor blades	LER and SsEr
Marine coating	LER and SsEr
Automotive coating	SsER

Residual BPA content: Epoxy can be used either in solid (SsER) or liquid (LER) form depending on the applications. Thus, the amount of unreacted BPA in final applications would also depend on the type of epoxy resin used. Although lots of factors indicate that the values usually are much lower, according to literature LER can contain a maximum of 10 ppm of residual (unreacted) BPA. For SsER the maximum amount is 65 ppm of BPA. This analysis assumed the highest estimate for both type of epoxy resins; hence the final amount of residual epoxy per step of the life cycle of epoxy resin is likely to be lower in reality. Unreacted BPA could potentially leave the epoxy matrix and enter the environment but there are no available scientific studies specifying in what quantities and how it would be further degraded in the environment.

	Annual epoxy usage
Water pipes	2,873 t
Flooring	45,000 t
Wind rotor blades	24,162 t
Marine coating	51,000 t
Automotive coating	27,600 t
Total	150,635 t
Maximal annual BPA release	572 kg

Potential BPA release: BPA may be released when BADGE is washed during manufacturing of epoxy resin. BPA dissolved in water is assumed to be disposed of via the sewages. ERC Members indicated that between 5 and 19 g of BPA per produced ton of epoxy resin was released after on-site and municipal waste water treatment in the past ten years, with an efficiency BPA removal rate of 80% to 90%. Assuming a highest estimate scenario (highest BPA quantity and lowest removal rate), it has been estimated that a total of 572 kg of BPA per year could leave the wastewater treatment plant in the whole of Europe and enter water bodies, possibly being removed due to bacteria and other biological means or degradation as well as UV-light.

APPLICATION MANUFACTURING

BPA losses during manufacturing of specific applications depend on the process being used. For this reason, each application is assessed separately. BPA residues are usually generated as leftovers of the different production processes. Incineration of such epoxy waste would be the most beneficial way of disposing of BPA, because the latter would be destroyed by extreme heat and leave the life cycle. Otherwise, if epoxy resins are flushed into waste water, BPA residues could leach out into the environment. The analysis assumed the lowest removal rate possible for municipal wastewater, which would result in the highest possible amount of BPA releases.

Water pipes: Leakages of LER into water depend on accidental cases when the defined ratio of LER and hardener is not followed. In these case and also for other residues that could come into contact with water (e.g. cleaning of coating tools) epoxy losses could not be quantified. Metal buckets containing epoxy resins and hardeners would be destroyed during thermal treatment for recycling purposes, thus degrading BPA. It has been estimated that from 80,000 t of epoxy in water pipes in the EU, around 2,873 kg (29 kg annually) of unreacted BPA would be degraded during recycling of the metal buckets.

Flooring: Tools used for the application of epoxy resin mixtures on floors can be washed with water; thus LER with its residual BPA content could enter wastewater. An estimated annual amount of 176 g of BPA could be released into water bodies for the whole of Europe. From 450 t of epoxy resin used annually, about 1% is estimated to remain as leftover in buckets, resulting in an additional 4.5 kg of BPA to be thermally destroyed during metal recycling.

Wind rotor blades: A total of 1,015 t of epoxy resins waste is produced annually from blade manufacturing, which can include about 30 kg of unreacted BPA. The majority of this waste is incinerated, as is the case of some tools and auxiliaries such as vacuum foil, meshes and resin channels transporting LER into the moulds. However disposal on landfills could not be excluded depending on national regulations and practices. Some epoxy resin particles destined to glue wind blades could be collected through local ventilation and blown out in the air. A precise estimation of BPA release in the latter case is not possible.

Marine coatings: Up to 20% of the epoxy-based marine coatings could be lost during paint application (e.g. dripping) or paint wastage (e.g. unused paint after coating process). Lost paint during application could be washed away with water and enter the sewages. It could also be incinerated for metal recovery or hazardous waste, as mandated by EU legislation. Considering 51,000 t of epoxy used annually for marine coatings in Europe, about 398 kg of residual BPA could be thermally degraded, while about 96 kg could be eventually released into water bodies.

Automotive coatings: During the cathodic electrodeposition (CED) coating process, a multi-stage rinsing zone with ultra filtration recovery is installed at the dipping bath to enable almost full recovery of the primer paint after coating. Potential sources for epoxy losses could be primer residues accruing as sludge in the tank, clogged filters, particle exhausts in the drying oven. Sludge would be the main source for epoxy waste, accounting for 788 t of wasted epoxy resin and 51 kg of residual BPA annually. Sludge is likely to be incinerated, although landfilling could not be excluded.

SERVICE LIFE

Epoxy resins were developed to increase the performance of specific products. When properly installed and maintained, the risk of releasing BPA into the environment is almost non-existant. In most epoxy applications, except automotive coating, it was not possible to develop a reliable estimate of losses during service life. There are no reliable data on how BPA could leach out of the epoxy matrix and in what quantities. Moreover, BPA could be degraded once it has entered the environment, thus complicating estimations even further.

Water pipes: Epoxy losses depend on the technique used during installation. Water pipes rehabilitated via liner technique would not have direct contact with water. Pipes rehabilited via direct coating (and a minority of new pipes originally coated with epoxy resin since) would be exposed to liquids of various compositions (acids, bases, salts, microbes) at various temperatures. The latter is not a concern for cured epoxy resins, which can resist high temperatures. In any case, BPA has been detected in water running through epoxy pipes, possibly due to improper curing of the epoxy or old pipes. The analysis assumed that professional coating techniques would ensure that coated pipes do not release BPA, thus determining overall BPA release at this stage was not possible.

Marine coatings: Epoxy-based marine coatings are applied on multiple parts of ships, including the hull, ballast tanks, cargo tanks/holds, decks and topsides/superstructures. Most of such coated parts could be exposed to various scenarios that might deteriorate the coatings. However European ships undergo full surveys and a dry-dock inspection every 2.5-3 years. Ship coatings are examined and repaired, thus keeping BPA losses at a minimum. The biggest risk would stem from decks coated with epoxy-based topcoats, susceptible to UV radiation degradation and subsequent chalking. Chalked parts of the coatings are likely to be washed off deck, potentially releasing BPA in water. However it was not possible to quantify the number of ships in the EU with epoxy-coated decks.

Flooring: Proper cleaning and maintenance methods decrease the likelihood of BPA release during service life. Epoxy resins are not resistant to concentrated acid and lyes, acetone and specific organic solvents, which may cause BPA releases; otherwise no significant BPA releases loss are expected under normal conditions. No estimates were possible because the area of floors in Europe treated with the aforementioned chemicals is unknown.

Wind rotor blades: The surface of wind blades is protected with non-epoxy based coatings, hence direct weathering exposure of the underlying resin is not likely. Damage to the outer layer can result in epoxy resin losses and the consequent release of epoxy particles in the environment. According to industry information, only micro particles of cured resin would be released, so potential BPA losses are estimated to remain negligible.

Automotive coatings: During the service life of a vehicle the paintwork of the body shell is exposed to weathering conditions (UV rays) but also mechanical and chemical stress. It was estimated that on average up to 1% of the original epoxy coating is lost during a car's service life. Taking into account the number of registered cars in 2013 (11.9 million cars), it was assumed that around 225 t of epoxy resins are can be lost every year, which would amount to 15 kg of BPA potentially reaching our environment.

END-OF-LIFE

The waste stage bears the highest number of uncertainties to determine the potential release of BPA. This is because waste practices differ significantly across EU countries and recycling, landfilling and incineration quotas vary greatly . A quantification of BPA release into the environment during waste stage was not possible in most cases.

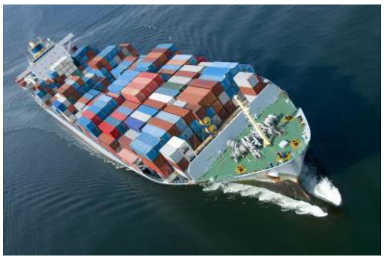
In principle, discarded epoxy resins in landfills or epoxy resin particles released into the environment are likely to experience weathering such as solar radiation, ozone, fluctuations in temperature and moisture. Any residual BPA would be degraded due to photo-oxidation. In case of landfills, BPA may leak into waste water treatment, which would degrade it further. Ultimately, if and in what measure BPA would be released from the epoxy depends significantly on the conditions of the landfills (e.g. opened or covered waste sites).

Water pipes: It is unclear how many water pipes are collected as waste annually. In theory, end-of-life pipes would become construction and demolition waste. But the fate of the epoxy resin used for rehabilitation of water pipes after service life is likely to be closely linked to the material of the pipes. It has been estimated that if 575 t of epoxy resins in metal pipes would be recycled every year via thermal treatment 6 kg of BPA would be degraded, thus existing the life cycle. Concrete pipes may be recycled and reused for road construction (without thermal treatment) or simply landfilled without any material separation. Some pipes may be simply left in the ground which could result in potential BPA degradation. Thus, the fate of the 2,298 t of epoxy in concrete underground pipes containing 23 kg of unreacted BPA remains unclear.

Flooring: Similar to end-of-life water pipes, epoxy-coated floors would end up as construction and demolition waste. However no quantification was possible because it was unclear whether floorings are torn out from a building before demolition. Practices are changing from country to country. Furthermore, epoxy flooring may be classified either as hazardous or non-hazardous waste. This choice would determine whether epoxy would be thermally degraded or landfilled. Assuming that all epoxy resin flooring is to become waste at some point in the future, the fate of 45,000 t and 450 kg of BPA remains to be properly assessed.

Wind rotor blades: Experience in blade disposal has been scarce due to the low number of wind energy plants dismantled so far. The majority of epoxy is expected to be incinerated as hazardous waste, thus destroying BPA residues. Other disposal methods such as landfilling or material recovery cannot be excluded. Some epoxy particles could be used as additives/fillers in cement or asphalt construction materials. At the same time, some energy plants are dismantled and reassembled outside of Europe and it is not clear in which amounts. With these considerations in mind, it is not clear at this stage what would result of the 24,162 t of waste epoxy resin and the consequent 707 kg of residual BPA.

Marine coatings: The waste handling of end-of-life ships would pose the highest possibility of BPA release for marine coatings. Up to 95% of European ships are dismantled in Asian countries, and it is unclear how the epoxy-coatings would be handled locally. Some ships might be simply abandoned and left at sea to sink. With regard to ships dismantled in Europe, the European Commission regulation about handling end-of-life ships will not be completely enforced until 2020. It will apply to ships with EU flags only, thus some ships may change flagship and avoid the new requirements. In total, 8,000 t of epoxy resins in marine coatings in the existing 350 European ships (as of 2013) could lead to 388 kg of residual BPA released in the environment.



Automotive coatings: Epoxy resin particles could be released during storage and dismantling of end-of-life cars. The car body would be shredded and epoxy resin would end up in the shredder light fraction (SLF) and be subject to various treatment processes depending on the country's waste legislation. The SLF could be used as filling material in closed mines, landfilled or disposed in other ways. Hence BPA release could not be excluded. However, if coated metal pieces from the bodywork of cars would be resmelted according to the End of Life Vehicles Directive, from 2015 onwards epoxy resins could be subject to thermal decomposition. Yet at the moment the fate of 13,230 t of epoxy resin ending up in scrap yards and corresponding 860 kg of BPA remains unclear.

CONCLUSIONS & RECOMMENDATIONS

A precise quantification of the potential BPA releases was only possible at the production stage of the epoxy resin for each application. This is because measurement data were made available from the manufacturers. For other life cycle stages, assumptions had to be made. In most cases the number of uncertainties was too high, hence no estimates were calculated and the fate of epoxy resin losses and respective potential BPA releases into the environment were described qualitatively.

	Annual BPA releases into environment					Annual epoxy usage
	Production	**Application**	**Service life**	**Waste**	**Total**	
Water pipes	max 11 kg	not determinable	not determinable	not determinable	> 11 kg	2,873 t
Flooring	max 171 kg	max 0.2 kg	not determinable	not determinable	> 171 kg	45,000 t
Wind rotor blades	92 kg	not determinable	negligible	not determinable	> 92 kg	24,162 t
Marine coating	max 194 kg	max 96 kg	not determinable	not determinable	> 290 kg	51,000 t
Automotive coating	max 105 kg	max 51 kg	max 15 kg	not determinable	> 171 kg	27,600 t

Following the analysis, the following recommendations were issued:

- Resin manufacturing: conduct additional measurements or make available existing measurement reports to eliminate the uncertainties regarding overall unreacted BPA values in epoxy resin after manufacturing.
- Application manufacturing: perform laboratory tests simulating the curing process of different epoxy formulations so as to determine BPA content in the cured epoxy matrix; suppliers of epoxy applications could conduct workshops and trainings for national professionals.
- Service life: manufacturers may provide protocols for maintenance, similar to the instructions provided for the application stage; legislating and regulating maintenance duties would help minimise BPA losses.
- Waste stage: stricter centralised legislation would harmonise waste handling methods across the EU.