Environmental Assessment
- Paxymer®

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Abstract

Jegrelius - Institute for Applied Green Chemistry are managing the project Show Rooms for Products of Tomorrow with the aim to support small and medium enterprises to achieve the competitive advantages that environmentally driven markets can offer. One of the elements to achieve this is to assess and verify the environmental performance of the participating companies products. In this report we therefore provide, an assessment of the environmental performance of Paxymer AB's product Paxymer®, an antimony and halogen free flame retardant for polyolefin plastic such as polypropylene and polyethylene.

The environmental assessment is based on three perspectives; a risk assessment of the chemicals, a sustainability analysis and a assessment of the environmental impact during the products life cycle.

In the Paxymer formula there are three inorganic compounds; aluminium trihydroxide, magnesium hydroxide and ammonium polyphosphate based adducts. They are all well tested regarding ecotoxicology and health. All data indicates that the compounds are unproblematic from a toxicological and ecotoxicological point of view. They have been evaluated in several risk assessments and recommended as good alternatives to brominated flame retardants. The three other components in the formula are not as well studied and have not been evaluated as flame retardants in the reviewed risk assessments. Although, based on the available data and literature these compounds are in this assessment evaluated as good alternatives to brominated flame retardants.

The assessed chemicals in the Paxymer® formula are much closer to sustainability compared to the market dominating groups of brominated and organophosphorus flame retardants that both includes a range of persistent, bioaccumulating and CMR compounds. The final polypropylene or polyethylene plastic treated with Paxymer has a good potential to be a part of a sustainable society, if the fossil carbon is kept in a technical loop by material recycling. The impact from Paxymer on the recyclability of polyolefins is not fully known, but nothing indicates that it would deteriorate the recyclability.

The Paxymer® is sold as a master batch product that can be used in a wide range of application and products making it difficult to assess the environmental impact during a life cycle. Although, the production phase shows low environmental impact due do closed loop of process water, the energy consumption is rather low and is based on electricity from renewable sources. The small amount of waste that is produced is possible to recycle in the production process.

Our conclusion is that the product Paxymer® is an environmental sound and recommended substitute to brominated and organophosphorus flame retardants. Paxymer® has a good environmental performance in all three assessed perspectives; chemical, sustainability and during its life cycle.

1 Introduction

1.1 About Jegrelius – Institute of Applied Green Chemistry

Jegrelius - Institute of Applied Green Chemistry is an public non-profit organization that works with consumers, businesses and the public sector to stimulate demand and production of toxic free products. The vision is to contribute to a safer environment in our everyday life. The Jegrelius Institute supervises companies in chemical issues, run projects and support local governments in innovation procurement. The Jegrelius Institute is a part of the Regional Council of Jämtland in Sweden.

1.2 The project: Show Rooms for Products of Tomorrow

The project *Show Rooms for Products of Tomorrow* is managed by Jegrelius - Institute of Applied Green Chemistry. The project was started 1 July 2010 and runs for three years. The project aims to support small and medium enterprises to achieve the competitive advantages that the environmentally driven markets offer.

In the project the Jegrelius Institute makes, as an independent player, an environmental assessment of the participating companies' products in comparison with selected market-dominating competing products.

The project is funded by the European Regional Development Fund, Swedish Agency for Economic and Regional Growth, Jämtland County Administrative Board and the Regional Council of Jämtland.

1.3 Paxymer AB's flame retarding product

The company Paxymer AB manufactures and sells the flame retardant product Paxymer® as a master batch for polyolefin polymers such as polypropylene (PP) and polyethylene (PE). The product Paxymer® is a halogen and antimony free flame retardant and a novel substitute for the brominated flame retardants dominating market today.

Due to confidentiality issues the exact formulation of the product is not exposed in this assessment. Instead, we will make the environmental assessment of a range of possible ingredients, listed in Table 2, based on the compounds mentioned in the company's patent description from 2008[1], a case story in the SUBSPORT database[2], and in a report from the Swedish Contingencies Agency[3].

Some of the compounds mentioned in those references are according to the company Paxymer not a part of the formulation they are using today. These are red phosphorus, calcium/zinc molybdate, expandable graphite and borate salt.

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[1] Patent WO 2008/051120, Flame retardant additive for polymers, free of halogens, antimon oxide and phosphorus-containing substances.

[2] Evaluation of different halogen-free flame retardants in polypropylene formulations as alternatives to flame retardants containing halogens (http://www.subsport.eu/case-stories/072-en)

[3] Evaluation of several halogen-free flame retarded Polypropylene formulations, Swedish Contingencies Agency, Räddningsverket

Table 1: Possible substances in the Paxymer® formula based on patent description and other official reports.

Substance	Cas number
Aluminum trihydroxide (ATH)	21645-51-2
Magnesium hydroxide	1309-42-8
Ammonium polyphosphate based aducts	
Organoclays	
Silicon resins	

1.4 Market dominating flame retardants

In order to meet fire safety standards a wide range of different flame retarding substances are used to day. The flame retardants can be divided up in groups based on their chemical structure. The largest group is the metal hydroxides with over 50 % of the European market (Figure 1). Brominated flame retardants (BFRs) together with non halogen organic phosphorus compounds (PFRs) and chlorinated organic phosphorus compounds makes around 10 % each of the total consumption.

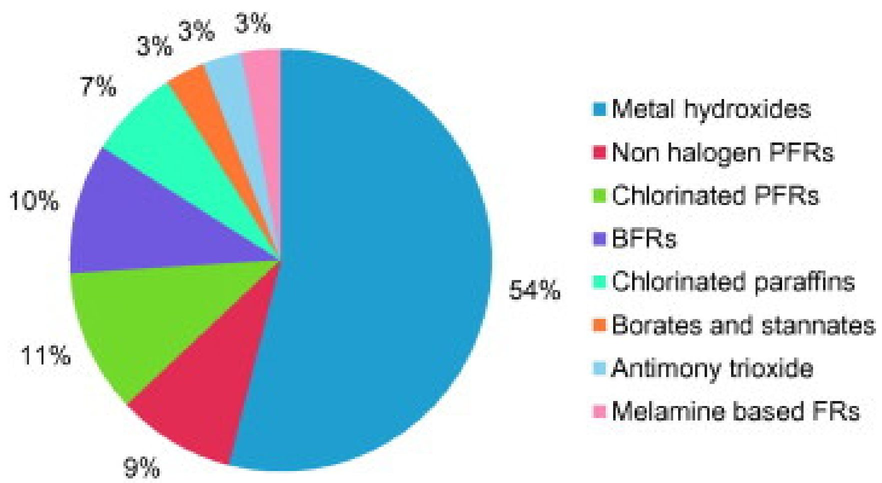

Figure 1: Industry estimate of total consumption of flame retardants in Europe 2006. Total : 465000 tonnes. From van der Veen (2012)[4]

[4] van der Veen & de Boer (2012) Phosphorus flame retardants: Properties, production, environmental occurrence, toxicity and analysis, *Chemosphere 88 (2012) pp 1119-1153*

2 Method

2.1 The Jegrelius Model for Environmental Assessment

In order to perform assessment of the environmental performance, we work according to the Jegrelius Model for Environmental Assessment[5] which defines and describes our values and the methods and tools we use.

A fundamental part of our approach is to base our evaluation on three types of environmental perspectives:

- The products Life Cycle
- Sustainability
- Chemicals

The life cycle approach gives us a good scan of different environmental impacts during a products whole life cycle. Many of the environmental impact parameters are quantitative, such as energy consumption, greenhouse gases, resource depletion etc. The way these impacts are evaluated between each other and what priority they are given are subjective and depend on the method used.

Sustainability Analysis is a suitable way to deal with more dynamic processes from present to a certain time in future and is suitable to handle non quantitative aspects as biodiversity, chemical risks, social justice etc. A Sustainability Analysis is not sensitive for differences in inherent and adjustable problems such as changes in electricity supply and routes for transportation.

In both the life cycle and the Sustainability Analysis, chemicals and chemical use during the products life cycle are assessed. With the Assessment of Chemicals approach we look closer at the individual chemicals included in the final product with a risk for exposure to the users.

2.2 Sustainability Analysis (SA)

During an environmental assessment it is important to ask whether it is a step towards a sustainable society and whether it is a flexible platform for further improvement.

In a sustainable society there are four Basic Principles of Sustainability (System Conditions, SC 1-4) that should be fulfilled[6]:

1. Substances extracted from the earth's crust must not systematically accumulate in the environment.
2. Society-produced substances must not systematically accumulate in the environment
3. The physical conditions for production and diversity within the ecosphere must not become systematically deteriorated
4. The use of resources must be efficient and just with respect to meeting human needs

[5] Jegreliusmodellen – vårt sätt att arbeta med hälso- och miljöbedömningar. Unpublished report Jegrelius 2010
[6] Azar, Holmberg & Lindgren 1996, Socio-ecological indicators for sustainability, Ecological Economics, Vol 18, pp 89-112

2.3 Assessment of Chemicals

When it is possible our aim is to perform a simplified risk assessment based on the hazardousness of the chemical, the specific exposure, how the product is used and the exposed people's vulnerability.

We are also convinced that there are a large number of chemicals that should be phased out from our society. Many of these are included on various lists of priority substances. Examples of some of such lists are: ChemSecs SIN List, ECHAs Candidate List of Substances of Very High Concern and the Swedish Chemicals Inspectorate's database PRIO. For substances with CMR and PBT properties not included on these lists, we base our evaluation on the same criteria.

The Jegrelius institute has the conviction that in many occasions it is essential and in some cases an obligation to use the precautionary principle. Our criteria for substitution can be expressed as: *If there is a scientifically based suspicion of serious negative effect from chemical A, but not from chemical B, then substitution should be made provided that the function is otherwise satisfactory.*

3 Result

3.1 Assessment of the chemicals in Paxymer®

Aluminium Trihydroxide (ATH)

Aluminium trihydroxide is one of the most used flame retardants, only in Europe 136 000 ton/year[7]. ATH is used as secondary additive acting by decomposition in the heat of the flame and releasing water of hydration and it can also act as smoke suppressants.
ATH is not classified according to the EC regulations and are not toxic to aquatic organisms or humans[8].
Aluminium trihydroxide is considered be largely unproblematic from a toxicological and ecotoxicological viewpoint in several risk assessments of flame retardants[31, 33, 7, 9].

Magnesium Hydroxide

Magnesium hydroxide acts the same way as ATH, by decomposition in the heat of the flame and releasing water of hydration but at slightly higher temperatures[9]. Magnesium hydroxide is not classified as dangerous to health and environment[10], but can act as an irritant due to its actions as a base[11].

According to risk assessment by Stockholm Convention on POPs[9] magnesium hydroxide is a recommended alternative to brominated flame retardants and the health and environmental properties are of low concern.

Ammonium polyphosphate based adducts

During thermal decomposition phosphoric acid is released which leads to carbonization of the material. The formed carbon layer impedes further supply of oxygen[31].

Ammonium polyphosphate is not classified as dangerous to health and environment[10] and the acute toxicity is low according to test values as[11] LC_{50} Fisk 96h: 123 mg/l (Oncorhynchus mykiss) and EC_{50} Daphnia 48h: 848 mg/l (Daphnia magna).

Ammonium polyphosphate based adducts is considered be largely unproblematic from a toxicological and ecotoxicological viewpoint in several risk assessments of flame retardants[31, 33, 7].

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[7] Fisk et al. (2003) Prioritisation of Flame Retardants for Environmental Risk Assessment, Environment Agency's Science Group, UK
[8] IUCLID Dataset Aluminium trioxide, European Commission (2000)
[9] Guidance on feasible flame-retardant alternatives to commercial pentabromodiphenyl ether, Stockholm Convention on POPs (2009)
[10] ESIS : European chemical Substances Information System, http://esis.jrc.ec.europa.eu/index.php?PGM=ein /
[11] The database ”Kemiska ämnen Prevent” (2012-10-28)

Organoclays

Organoclays are made from natural or synthetic layered silicate clays such as monmorillonite and bentonite. In order to enhance the solubility in polymer materials the clay is organically modified with an appropriate surfactant. The treatment makes it possible for the inorganic clay to be distributed as silicate layers at a nano-level in the polymer. The final material is therefore called polymer layered silicate nanocomposite or PLS nanocomposite and exhibit enhanced flame retardation, barrier properties and ablation resistance[12, 13, 14].

None of the reviewed risk assessments of flame retardants have assessed the use of organoclays and organoclays are not classified according to EC regulations. There is nothing that indicates that the incorporation of layered silicate into a matrix of polyolefin should cause any negative effects to health or for the environment.

Silicone resins

Silicone or polysiloxanes are a family of organo-silicon inorganic polymers based on a molecular chain of alternate oxygen and silicon atoms with attached organic groups. Based on the chain length and organic groups, the appearance ranges from water thin through oil like fluids to solid resins[15]. They can reduce combustibility in combination with other flame retardants and the main modes of action are proposed to be formation of crosslinked silicaceous surface barrier and reflectivity of radiant heat[26].

None of the reviewed risk assessments of flame retardants have assessed the use of polysiloxanes as flame retardants and they are not classified according to EC regulations. But polysiloxanes do have the common trait of being persistent in nature because of slow biodegradation. Despite a rather high lipophilicity (log Kow >3) they are not substantially bioaccumulated due to the large molecular size. The water solubility is very low, and the soluble fraction have low toxicity to aquatic organisms. The environmental hazard from polysiloxanes is mainly attributed to physical-mechanic effects at very high exposures[16].

The low bioaccumulation potential and low aquatic toxicity indicates that the use of silicone resins as a flame retardant component in polyolefins should not cause any negative effects to health or for the environment.

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[12] Morgan & Wilkie (2007) Flame retardant polymer nanocomposites
[13] Al-Malaika et al. (1999) Chemistry and Technology of Polymer Additives,
[14] Chen & Wang (2010) A review on flame retardant technology in China. Part I: development of flame retardants, *Polym. Adv. Technol*, *2010:21*
[15] Rahimi & Shokrolahi (2001) Application of inorganic polymeric materials I Polysiloxanes, *Int. J. of Inorg. Materials 2001:3*
[16] Nendza (2007) Hazard assessment of silicon oils used in antifouling-/foul-release-products in the marine environment, *Marine Pollution Bulletin 54:2007*

3.2 *Assessment of market dominating flame retardants*

Brominated flame retardants

There are over 70 individual brominated flame retardants (BFRs). They have all high thermal stability due to the bromine content and are active in the gas phase. BFRs are often used in combination with antimony[31].

Brominated flame retardants are members of a large group of halogenated chemicals such as PCB, DDT etc. Many of these chemicals are persistant, bioaccumulative, toxic to the environment and to humans. These general traits have been proven to be true for several of the brominated flame retardants and the use of some of them have been legally restricted and some have been labeled as persistant organic pollutants (POPs) by the parties of the Stockholm Convention.

Many of the other not yet legally restricted BFRs show similar persistant, bioaccumulative and toxic traits, making them appear as POPs with long range transport and bioaccumulation/biomagnifications in arctic biota such as polar bears, seals and birds[17] and in human breast milk as shown in Figure 2. Substantial evidence also exists indicating that brominated flame retardants as a group are potential endocrine disruptors[18].

Our conclusion and stand point from a precautionary perspective is that none of the brominated flame retardants could be used in a sustainable society.

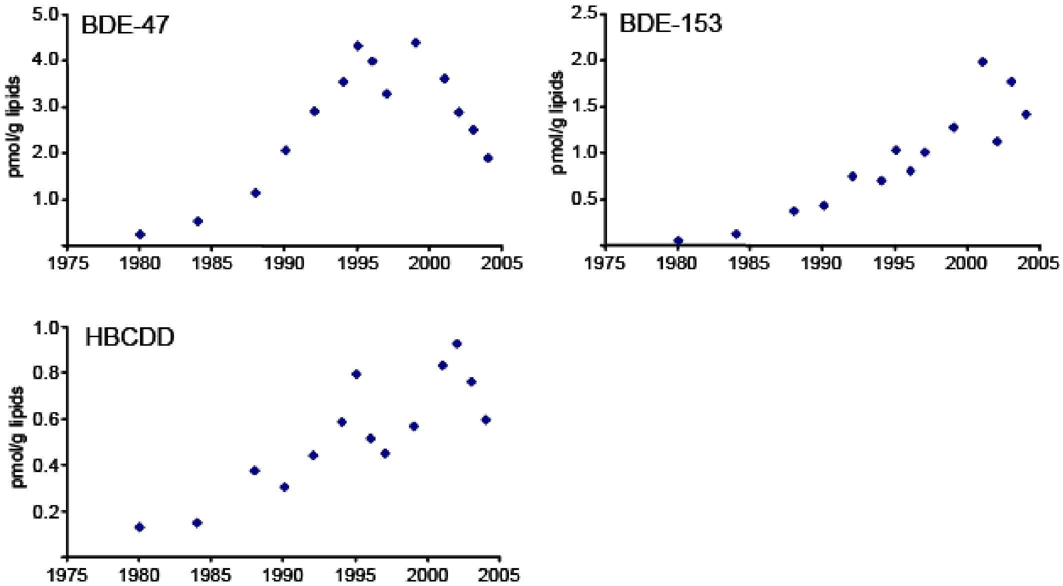

Figure 2: Brominated flame retardants [pmol/g lipids] in human breast milk in Stockholm 1980-2004. (Fängström et al. 2005)[19]

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[17] de Wit et al. (2006) Levels and trends of brominated flame retardants in the Arctic, *Chemosphere 64 (2006) 2009-233*

[18] Legler & Brouwer (2003) Are brominated flame retardants endocrine disruptors? *Environment International 29 (2003) 879-885*

[19] Fängström et al (2005) Analys av polybromerade difenyletrar (PBDE) och hexabromcyklododekan (HBCDD) i human mjölk från Stockholm – en tidstrends studie.

Polymeric brominated flame retardants

There is a rather novel group of brominated flame retardants called polymeric brominated flame retardants. The flame retarding mechanisms are similar to other brominated flame retardants, but the retardants are based on a polymeric structure with a molecular weight larger than 1000 g/mol[20].

This group of polymeric brominated flame retardants is often market as eco friendly with the arguments that the brominated flame retardant do not leach from the matrix[21] and that the polymeric structure makes it not bioavailable[22].

None of the reviewed risk assessments of flame retardants have assessed the use of brominated polymeric substances and no environmental studies have been found in the scientific literature.

The polymeric structure makes most certainly the polymeric flame retardant less bioavailable. But there is always a risk of degeneration of the material during use, ageing and at waste sites, that can generate smaller brominated molecules with similar environmental and health problems as the large group of BFRs. During waste burning and fires there is also a potential risk of brominated dioxin formation.

Despite a probably lower environmental risk than other BFRs, our conclusion and stand point from a precautionary perspective is that with the little knowledge we have today, polymeric brominated flame retardants should not be used in a sustainable society.

Organophosphate flame retardants

Organophosphate flame retardants is a large group of phosphorus containing organic substances both halogenated and non halogenated. During thermal decomposition phosphoric acid is released which leads to carbonization of the material. The formed carbon layer impedes further supply of oxygen[31].

Examples of halogenated organophosphates are TCPP (tris-chloropropyl-phosphate), TCEP (tris-chloroethyl-phosphate) and TDCP (tris-dichloropropyl phosphate). Non halogenated organophosphates can have linear, branched or phenyl groups such as trialkylphosphates, triarylphosphates and bisphenol-A-diphenyl phosphate.

[20] US EPA criteria for low risk polymer, US Federal Register notice 40 CFR 723.250
[21] Flame retardants for polyamides – new developments and processing concerns, *Plastics Additives & Compounding,* March/April 2005
[22] Emerald Innovation 1000, Great Lakes Solutions, a Chemtura Business (http://www.chemtura.com)

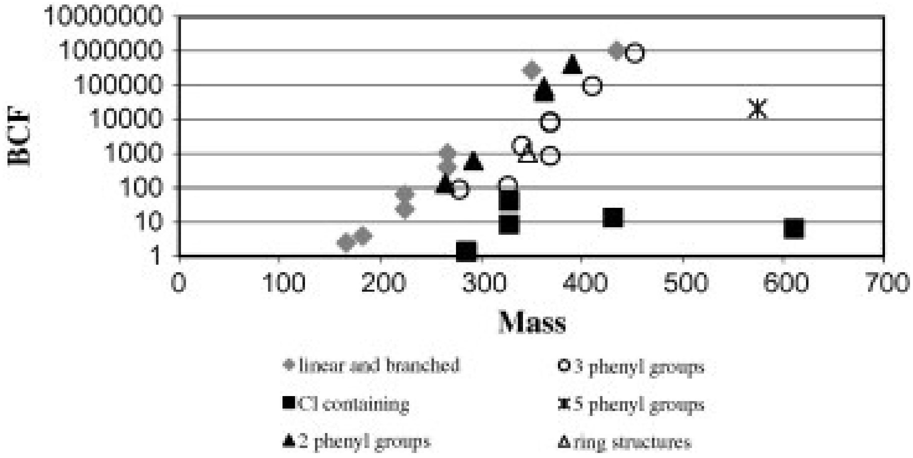

Figure 3: Bioconcentration factor (BCF) versus molecular mass for some non halogenated with linear, branched or phenyl groups and some halogenated chlorine containing organophosphates. (From van der Veen, 2012)[4]

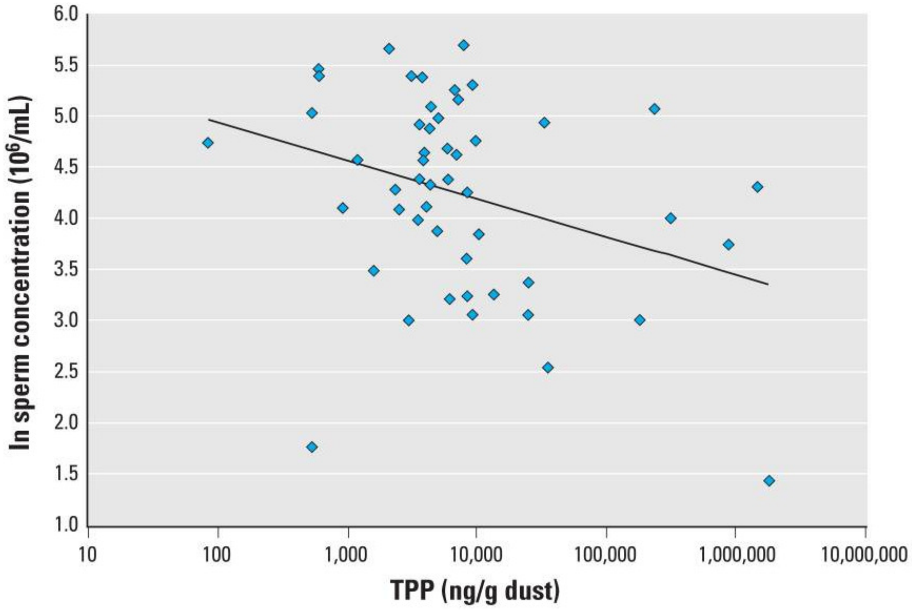

Figure 4: Scatterplot of TPP in house dust and sperm concentration (*n* = 50, *r* =0.33, *p* = 0,02). (From Meeker & Stapleton, 2012)[25]

Both halogenated and non halogenated organophosphates shows bioaccumulating traits (Figure 3),and are detected in house dust[23], in marine and fresh water biota and in human milk[24]. Some non halogenated with phenyl groups and some chlorinated organophosphates shows reproductive and developmental toxicity or are carcinogenic[4]. The relation between the concentration of the chlorinated TDCPP and triphenyl phosphate (TPP) in house dust and hormone levels and semen quality has been explored[25]. They found positive relationships between both TDCPP and TPP with prolactin, a hormone with functions involving reproduction and metabolisms. They also observed that an increase in house dust TPP concentration was associated with a decline in sperm concentration, as shown in Figure 4.

Many of the reviewed risk assessments of flame retardants identify several organophosphate compounds that should be phased out or avoided in the use as flame retardants[7, 9, 31] based on the substances both human toxicological and ecotoxicological properties. In a literature review on phosphorus flame retardants properties, environmental occurrence and toxicity4 the authors concludes that of all the assessed organophosphorus compounds only three may be considered as suitable substitutes for brominated flame retardants.

Our conclusion and stand point from a precautionary perspective is that none of the organophosphorus flame retardants could be used in a sustainable society!

Calcium/Zinc Molybdate

Molybdates are used as additives for low smoke formation and early char formation[26].

Nor calcium or zink molybdate is classified according to the EC regulations and very little data has been found. Both zinc and calcium are essential nutrients for humans. Molybdenum in different oxidation states is also biologically important to humans as an essential trace element in different enzymes[27]. Molybdenum is widely used in different alloys such as stainless steel alloys. In a study by the Danish EPA[28] molybdenum and molybdenum compounds are not to be classified as dangerous for aquatic organisms and the molybdenum concentrations found in sewage sludge was not expected to give negative effects on farmlands.

Of the reviewed risk assessments of flame retardants only one[27] assessed the use of calcium/zinc molybdate. In that study, they assessed the human toxicological risk from flame retardant chemicals in residential upholstered furniture. A hazard index was calculated based on the relation between an estimated worst-case exposure scenario and a calculated reference concentration (RfC) believed to inflict no harm. They found a high hazard index for the critical effect of elevated serum ceruloplasmin and increased urinary copper excretion. Based on this hazard index their conclusion was that dermal absorption of calcium and zinc molybdates should be further investigated together with the potential of these chemicals to be released as particles from the fabric.

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[23] Stapleton et al. (2009) Detection of organophosphate flame retardants in furniture foam and U.S. House dust, *Environ. Sci. Technol. 2009 43 7490-7495*

[24] Sundkvist et al. (2010) Organophosphorus flame retardants and plasticizers in marine and fresh water biota and in human milk, *Journal of Environmental Monitoring 2010 12 943-951*

[25] Meeker & Stapleton (2012) House dust concentration of organophosphate flame retardants in relation to hormone levels and semen quality parameters, *Environmental Health Perspectives, 2010 118 (3) 318-323*

[26] Weil et al. (2009) Flame Retardants for Plastics and Textiles – Practical Applications, Hanser Verlag

[27] Toxicological Risks of Selected Flame-Retardant Chemicals (2000), National Academy of Science

[28] The Elements in the Second Rank – an Environmental Problem Now or in the Future (2003) Danish Ministry of the Environment Project No 770

Borates and boric acids

Borates are active mainly in the solid phase by carbonization and release of chemically bound water.

Boric acid and some borates are since some few years back classified as toxic for reproduction[29] and are on EUs candidate list[30] as a substance of very high concern (SVHC). Due to the rather new classification as a reproduction toxin all the reviewed risk assessments are presenting borates as a rather good substitute to brominated flame retardants. Our conclusion is that the use of borate as a flame retardant is not recommended.

Red phosphorus

Red phosphorus is used as an additive flame retardant and acts by solid phase mechanism. It forms a rigid, glassy carbonized layer of polyphosphoric acid, which prevents the re-supply of flammable material in the gas phase[31]. Oxygen is required for the process, so in oxygen-free material such as polyolefins some synergists are required.

According to EG labeling red phosphorus is classified with the risk phrase R52/53: Harmful to aquatic organisms and may cause long-term adverse effects in the aquatic environment[10]. That classification is due to a high bioconcentration factor (BCF) and a harmful aquatic toxicity[32].

According to a German EPA assessment[31] the release of red phosphorus from polymers into the aquatic environment is expected to be rather low. After slow reaction with water and oxidation in air the formation of phosphoric oxides and phosphoric acids is expected. Compared to occurrence of phosphorus from other activities in the society the possible part from phosphorus flame retarded material is negligible. The effect of phosphorus oxides and acids released in a fire, however, should on the other hand not be ignored.

Red phosphorus is according to organization Clean Production Action[33] a very good substitute for brominated flame retardants and the use is in their ranking system classified as *not problematic.*

Expandable graphite

Expandable graphite is graphite in which sulfuric acid has been introduced between the layers of the graphite. The acid does not leach out, but upon strong heating the graphite can expand quickly to over 100 times its volume and form a heat and mass transfer barrier. Expandable graphite is used in combination with other flame retardants[26].

None of the reviewed risk assessments of flame retardants have assessed the use of expandable graphite. It is only presented as a novel and promising alternative flame retardant. Expandable graphite is not classified according to EC regulations and no data about effects on

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[29] Commission Regulation (EC) No 790/2009

[30] http://echa.europa.eu/chem_data/authorisation_process/candidate_list_table_en.asp

[31] German Federal Ministry for the Emvironment (2000) Substituting Environmentally Relevant Flame Retardants: Assessment Fundamentals

[32] IUCLID Dataset Red Phosphorus, European Commission (2000)

[33] Clean Production Action (2004) Brominated Flame Retardants in Dust on Computers: The case for safer chemicals and better computer design

health and environment have been found in the literature. The raw material graphite is not classified according to EC regulations. Data about health aspects indicates risks of physical effects such as dust bronchitis in workers engaged in graphite industry[34]. Sulfuric acid is a strong acid and can cause severe burns when used in a concentrated form.

None of this sparse data indicates any negative health and environmental effects from the use of expandable graphite as a flame retardant component in polyolefin plastics.

Antimony trioxide

Antimony trioxide is not a flame retardant, but it is an often used flame retardant synergist used together with bromine and chlorine containing flame retardants. Antimony increases the effectiveness of halogenated flame retardants and lowers thereby the use.

According to EG labeling antimony is classified as Carcinogenic Cat. 3, with the risk phrase R40: Limited evidence of a carcinogenic effect[10].

One of the reviewed risk assessments of flame retardants gives the recommendation of reduced use of antimony trioxide due to the bioaccumulative, reproductive toxicity and carcinogenic properties[33]. Another assessment comes to the conclusion that antimony trioxide does not cause any toxicologically relevant concentrations for humans and ecosystem during normal use[31]. One thorough risk assessments come to the conclusion that further investigation of inhalation exposure from antimony treated fabric is recommended due to a potential cancer risk[27].

[34] Toxnet, Hazardous Substance Data Bank (http://toxnet.nlm.nih.gov/index.html)

3.3 Sustainability Analysis

The Paxymer-product is the formulation of flame retarding chemicals in a master batch form, that is adapted to be incorporated into polyolefin plastic. But from a sustainability perspective, the flame retardant chemical formulation is during its use a part of a plastic product that are handled and used in the society. In order to be part of a sustainable society, both the Paxymer chemicals and the plastic product must fulfill the four basic principles of sustainability.

The flame retarding chemicals

According to the definition of sustainability, there are certain unsustainable substances that should be phased-out. Such substances correspond well to the criteria for SVHC (Substances with Very High Consern) according to REACH. The characteristics of such substances are that they are considered PBT (persistent, bioaccumulative and toxic), vPvB (very persistent and very bioaccumulative) or have CMR (Carcinogenic, Mutagenic, or toxic to Reproduction) properties.

The chemical assessment performed in this report shows that the Paxymer formulation does not include any substances with PBT, vPvB or CMR characteristics.

Some of the chemicals in the formulation like phosphorus, aluminum, magnesium etc. are substances extracted from the earth's crust and can thereby influence the sustainability negatively if the resources are extracted to extensively or ending up accumulating in the environment. But in relation to the dominating brominated flame retardant chemicals that the Paxymer product aims to substitute, it is clear that the use of the Paxymer product is a big step closer to a sustainable society.

The flame retarded polyolefin plastic

The sustainability of polyolefin plastic such as polypropylene (PP) and polyethylene (PE) treated with the Paxymer formulation is here assessed and compared to other polymer materials. Because of some physical/quality traits of Paxymer-polyolefins claimed by the company, it makes it possible to use polypropylene in some applications instead of polycarbonate (PC) and ABS-plastics. As a consequence of that, the sustainability of polycarbonate and ABS-plastic is also assessed.

The following sustainability assessment is based on a compilation of plastic ranking and sustainability analysis of plastic materials performed by Hedenmark Ecoprofits[35] on the behalf of Jegrelius, and integrated in this environmental assessment.

In order to assess the sustainability of different plastic materials a range of both quantitative and non quantitative aspects must be viewed and evaluated. In the literature there are some examples and different attempts to summarize and rank plastic material against each other.

[35] Hedenmark Ecoprofits (http://ecoprofits.se/)

One ranking of different polymers and their environmental impact issues is made by Lars Pedersen (1999)[36]. The method used is a kind of a qualitative LCA, followed by an environmental classification considering mainly content of health or environmental hazardous substances, energy consumption and waste treatment. With his methodology both polypropylene and polyethylene are categorized in the first category, ABS in the second best category and polycarbonate in the second worst category (Table 2).

Table 2: Ranking of plastic according to Pedersen (1999)[36]. The least problematic polymer are categorized as Cat. 1 and the ones poses greatest risk to the health and environment are categorized as Cat. 4.

Cat.	Description	Polymer
1	Substances added or generated during the life cycle do not require any special precautions or result in significant health or environmental impact. Energy consumption is relatively low while the energy generated by incineration is high	**Polypropylene – PP** **Polyethylene – PE** Cellulose acetate – CA Poly (isobutylene) – PIB Ethylene vinyl acetate – EVA
2	Contain health or environmental hazardous substances crucial for the manufacturing or for the properties. Use or disposal phases might have health or environmental impacts. Category 1 polymers but with large energy consumption and/or relatively low levels of energy upon incineration.	Polyamide – PA or Nylon Polyethylene terephthalate – PET Phenolformaldehyd – PF Polystyrene – PS Silicone **Styrene co-polymer and ter-polymer – SAN and ABS**
3	Contain particularly health or environmentally hazardous substances. Some substances added or generated in the production may require special end-of-pipe precautions or protective equipment.	Polyvinyl chloride not plasticized with DEHP – PVC (soft) Polyvinyl chloride – PVC (hard) Polyurethane foam – PUR foam **Polycarbonat – PC** Epoxy – EP
4	The polymer materials regarded as particularly hazardous to health and environment. Category 1-3 polymers which contain additives considered as hazardous to health and environment.	Polyvinyl chloride plasticized with DEHP – PVC(soft) **Halogenated additives** Additives with heavy metals **Fire-retardant based on bisphenols or diphenyl**

[36] Pedersen, L.B. (1999). *Plast og Miljø*. Teknisk Forlag.

Greenpeace has developed a guidance tool to assist people making material selection as shown in Figure 5. The guidance focuses on the toxic characteristics of materials. It provides a qualitative ranking based on environmental and health problems of polymers, addressing the production, additives, and emissions during use, disposal and recycling.

Due to differences in recycling possibilities both ABS and polycarbonate are placed in the second worst group and polypropylene and polyethylene in the second best group to a great extent due to high recycling rates.

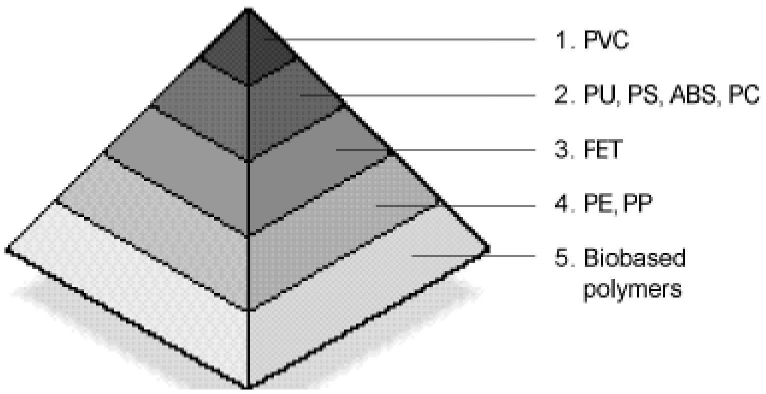

Figure 5: Ranking of plastic according to Greenpeace. The most problematic polymer are placed at the top of the pyramid and the least polluting in the pyramid's base. PVC = Polyvinyl chloride and other halogenated plastics, PU = Polyurethane, PS = Polystyrene, ABS = Acrylonitrile-butadiene-styrene, PC = Polycarbonate, PET = Polyethylene-terephthalate and PE and PP = Polyolefins.

Another hazard ranking model for plastic polymer types has been developed by Lithner *et al.* (2011)[37]. The hazard ranking is based on the hazard classification of the monomers that the polymer is made of. This can be motivated from risk point of view, since monomers always will be exposed to the environment, either via residues in the product (up to 4%) or via emission from production. In the study, over 40 polymers were ranked and ABS- plastic with a very high hazard score was ranked as the 10th most hazardous plastic, polycarbonate were ranked as number 19 and both polypropylene and polyethylene is found in the bottom of the list as the most toxic benign polymers (Table 3).

[37] D. Lithner et al. (2011) Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition, Science of the Total Environment, 409:3309-3324

Table 3: Ranking of plastic polymer types based on hazard classification of monomers. The most hazardous polymer are ranked with a low number.
(Lithner *et al.*, 2011)[37]

Rank	Polymer	Monomer
1	Polyurethane (PUR)	Propylene oxide (58%) Carc. 1B, Muta. 1B Ethylene oxide (7%) Carc. 1B, Muta. 1B Toulene-diisocyanate (29%) Acute Tox. 2, Resp. Sens. 1, Carc. 2
5	Polyvinyl chloride (PVC), soft	Vinyl chloride (50%) Carc. 1A BBP (50%) Repr. 1B, Aq. Chronic 1
6	Polyvinyl chloride (PVC), rigid	Vinyl chloride (100%) Carc. 1A
10	**Acrylomitrile-butadien-styrene (ABS)**	**Styrene (58%), Acute tox. 4, Acrylonitrile (22%) Carc. 1B, Skin Sens. 1,3.butadiene (20%) Carc. 1A, Muta. 1B**
15	High-impact polystyrene (HIPS)	Styrene (92%), Acute tox. 4 1,3-butadiene (8%), Carc. 1A, Muta. 1B
19	**Polycarbonate (PC)**	**Bisphenol A (70%) Skin Sens 1, Repr. 2 Phosgene (30%) Acute Tox. 2**
36	**Polyethylene (PE)**	**Ethylene (100%) Flam. Gas 1**
>37	**Polypropylene (PP)**	**Propylene (100%) Flam. Gas 1**
> 37	Polylactic acid (PLA)	Lactide (100%) Not classified

Conclusion Sustainability

There is no doubt that the chemical formulation of Paxymer is much closer to be a part of a sustainable society, than brominated flame retardants and organophosphate flame retardants. The plastic materials polypropylene and polyethylene are from a sustainability point of view one of the best polymeric materials only beaten by bioplastics from renewable sources. From a sustainability point of view it is positive to use polypropylene and polyethylene instead of polycarbonate and ABS-plastic when it is technically possible.

3.4 Environmental impact during the life cycle

The Paxymer® is sold as a master batch product that can be used in a wide range of polyolefin plastic. The wide range of possible products and applications makes it difficult to describe and assess the environmental impact during the usage phase. Therefore we will here only briefly describe and assess the manufacturing phase and the possible end of life of the flame retarded polyolefin plastic. In this assessment it has not been possible to compare Paxymer® life cycle data with manufacturing data from competing flame retardants such as brominated flame retardants.

The Paxymer® master batch is a polyolefin plastic with high concentration of the flame retardant chemicals. The master batch material is processed by extrusion and in the process around 3% pure polyolefin plastic waste is generated. With a larger production volume the company is expecting to lower the spill level down to 1-2 %. With a suitable grinder it is possible to recycle the spill in the production. The production process requires electricity at a level of 0.3 kWh/ton material and the process is cooled with a closed loop of process water. The used electricity is based on water and wind power production.

According to the company Paxymer AB, their internal tests of degradation and thermal stability show that the flame retarded polyolefin plastic has similar durability during recycling as the pure polyolefin plastic. This indicates that products containing plastic treated with Paxymer® does not deteriorate the recyclability of the plastic, but we have not been able to verify this claim.

4 Summary of the assessments and Conclusion

The performed chemical assessment shows that the Paxymer® formula does not include any substances that could generate any risks for the environmental or for the human health. The product consists only of rather unproblematic substances. Compared to the assessed competing and market dominating flame retardant chemicals it is clear that Paxymer® is a very good alternative especially compared to brominated and organophosphate flame retardants.

From a sustainability point of view the Paxymer® chemicals are much closer to be a part in a sustainable society than brominated and organophosphate retardants. The final polyolefin product treated with the Paxymer® formula is also closer to sustainability compared to polycarbonate and ABS plastic. As long as the carbon in the polyolefin plastic is from a fossil source material recycling is required to keep the fossil carbon in a closed technical loop.

The environmental impact from the production phase is rather low due do closed loop of process water, low energy consumption based on green electricity and the small amounts of waste that could be recycle in the production process.

Our conclusion is that the Paxymer® flame retarding formula is from a chemical, sustainability and life cycle perspective a very good alternative to the dominating flame retardants of today.

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