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FAKULTA STAVEBNÍ

Katedra ekonomiky a řízení ve stavebnictví

# Diplomová práce

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Bc. Jakub Stránský

**ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE**
**Fakulta stavební**
Thákurova 7, 166 29 Praha 6

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Na tomto místě bych rád srdečně poděkoval všem, kteří se přímo i nepřímo podíleli na vzniku tohoto dokumentu, zejména:

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# Use of Plastic Waste in the Construction Industry

**Autor diplomové práce:** Bc. Jakub Stránský
**Vedoucí diplomové práce:** Ing. Martin Čásenský, CSc.
**Praha, 2014**

# Abstrakt

Hexabromcyklododekan (HBCDD) se posledních 50 let používá jako zpomalovač hoření v polystyrenových tepelných izolacích (EPS a XPS). Mezinárodně uznávané Stockholmská úmluva o perzistentních organických polutantech zakazuje jeho další produkci, používání a dále recyklaci materiálů, které HBCDD obsahují. Do značné míry také omezuje možnosti nakládání s odpadem obsahující tuto látku. Legislativa Evropské unie (především Nařízení (ES) č 850/2004 a tzv. Směrnice REACH) vytvořila závazný legislativní rámec pro členské státy EU, které jejím prostřednictvím omezuje možnosti nakládání s odpadem obsahujícím HCDBB prakticky pouze na jeho spalování. Táto práce se zabývá jak mezinárodní, tak českou legislativou vztahující se k této problematice a zmiňuje možné provozní a ekonomické dopady na stavební průmysl. V rámci práce byl vytvořen ucelený seznam možností likvidace XPS a EPS a dále specifikace možností ekonomicky výhodného využití těchto materiálů díky jejich vysoké výhřevnosti. Nynější možnosti ekonomicky výhodné likvidace mohou být zejména spoluspalování v cementárnách a spalování za účelem generování tepelné či elektrické energie.



# Klíčová slova

Hexabromcyklododekan, HBCDD, zpomalovač hoření, Stockholmská úmluva, EPS, XPS, polystyren, plastový stavební odpad, spalování odpadu

# Abstract

Hexabromocyclododecane (HBCDD) has been used as a flame retardant in polystyrene thermal insulation (EPS and XPS) for the last 50 years. Now the internationally recognized Stockholm Convention on Persistent Organic Pollutants prohibits future production, use and recycling of materials that contain HBCDD. It also, to a large extent, limits the options of waste management of such materials. European legislation (in particular Regulation (EC) No 850/2004 and the so called REACH Directive) established a binding legal framework for EU Member States which reduces waste management options of material containing HCDBB practically only to incineration. This thesis deals with both the international and the Czech legislation related to this issue. It outlines the possible operational and economic impact on the construction industry. A comprehensive list of options for disposal of XPS and EPS was created as part of the work, and a further assessment of cost-effective use of these materials (due to their high heating value) conducted. At this point, the most economically advantageous options include co-incineration in cement plants and combustion to generate heat or electrical energy.

# Key Words

Hexabromcyclododecane, HBCDD, flame retardants, Stockholm Convention, REACH, EPS, XPS, polystyrene, plastic construction waste, waste incineration

# List of Acronyms

- **Act no. 100/2001 Coll.** – Zákon č. 100/2001 Sb., o posuzování vlivů na životní prostředí a o změně některých souvisejících zákonů (zákon o posuzování vlivů na životní prostředí)
- **Act no. 185/2001 Coll.** - Zákon č.185/2001 Sb., o odpadech a o změně některých dalších zákonů
- **Act no. 201/2012 Coll.** – Zákon č. 201/2012 Sb., o ochraně ovzduší
- **Act no. 695/2004 Coll.** - Zákon č. 695/2004 Sb., o podmínkách obchodování s povolenkami na emise skleníkových plynů a o změně některých zákonů
- **Act no. 76/2002 Coll. –** Zákon č. 76/2002 Sb., o integrované prevenci a o omezování znečištění, o integrovaném registru znečišťování a o změně některých zákonů (zákon o integrované prevenci)
- **BFR** - Brominated flame retardant
- **CZ** – The Czech Republic
- **Decree no. 376/2001 Coll.** - Vyhláška Ministerstva životního prostředí a Ministerstva zdravotnictví č. 376/2001 Sb., o hodnocení nebezpečných vlastností odpadů
- **Decree no. 381/2001 Coll.** Vyhláška Ministerstva životního prostředí č. 381/2001 Sb., kterou se stanoví Katalog odpadů, Seznam nebezpečných odpadů a seznamy odpadů a států pro účely vývozu, dovozu a tranzitu odpadů a postup při udělování souhlasu k vývozu, dovozu a tranzitu odpadů (Katalog odpadů)
- **Decree no. 415/2012 Coll.** – Vyhláška č. 415/2012 Sb., o přípustné úrovni znečišťování a jejím zjišťování a o provedení některých dalších ustanovení zákona o ochraně ovzduší
- **Directive 2008/98/EC** – Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives
- **Directive 2010/73/EU** - Directive 2010/73/EU of the European Parliament and of the Council of 24 November 2010 amending Directives 2003/71/EC on the prospectus to be published when securities are offered to the public or admitted to trading and 2004/109/EC on the harmonisation of transparency requirements in relation to information about issuers whose securities are admitted to trading on a regulated market
- **ECHA** - European Chemicals Agency

- **EPS** – Expanded polystyrene foam
- **ETICS** - External thermal insulation composite system
- **EU** – European Union
- **FR** – Flame retardant
- **Government Resolution no. 1572** – Usnesení vlády České Republiky ze dne: 7. prosince 2005 č. 1572 k Národnímu implementačnímu plánu Stockholmské úmluvy o persistentních organických polutantech
- **Government Resolution no. 810/2012** - Usnesení vlády České Republiky zed ne 8. Listopadu 2012 č. 810/2012 Sb. k aktualizovanému Národnímu implementačnímu plánu Stockholmské úmluvy o perzistentních organických polutantech na léta 2012-2017
- **HBCD, HBCDD** - Hexabromocyclododecane
- **MBT** - Mechanical biological treatment (of waste)
- **PBT** - Persistent, bioaccumulative and toxic substance
- **PCB** - Polychlorinated biphenyl
- **pFR** - Polymeric flame retardant
- **POP** - Persistent Organic Pollutant
- **PS** – Polystyrene
- **REACH** - Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency
- **Regulation (EC) No 1272/2008** - Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006
- **Regulation (EC) No 1907/2006** - Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency
- **Regulation (EC) No 850/2004** - Regulation (EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and

amending Directive 79/117/EEC as amended by Council Regulations (EC) No 1195/2006, 172/2007 and 323/2007

- **Regulation (EU) No 143/2011** - Commission Regulation (EU) No 143/2011 of 17 February 2011 amending Annex XIV to Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals ('REACH')
- **Regulation (EU) No 756/2010 -** Commission Regulation (EU) No 756/2010 of 24 August 2010 amending Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants as regards Annexes IV and V
- **SECURE** - Self-Enforced Control of Use to Reduce Emissions
- **Stockholm Convention -** Stockholm Convention on Persistent Organic Pollutants signed at a Conference of Plenipotentiaries on 22 May 2001 in Stockholm, Sweden
- **VAT** - Value added tax
- **VECAP** - Voluntary Emission Control Action Program
- **vPvB** - Very persistent and very bioaccumulative substance
- **XPS** - Extruded polystyrene foam

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# 1 Introduction and Objectives

## 1.1 Statement of the Problem

Upcoming changes in the European and other internationally binding legislation related to waste and its management will also have significant impact on construction waste. First level of fundamental changes will happen gradually until 2020 starting in 2015. Out of the construction waste, plastic waste (consisting largely of the EPS and XPS polystyrene insulations) will be affected the most significantly.

Among other things, new ratios of landfilled, recycled and incinerated construction waste will be designated by the European Union.

The internationally recognized Stockholm Convention will indirectly affect the possibilities of dealing with EPS and XPS insulation once it becomes waste. Those changes will be stricter than others due to the potentially harmful substances contained in these materials. The resulting differences in the options of managing EPS and XPS waste might affect the total price of reconstruction of facades insulated by polystyrene.

As the lifetime of such facades done in the Czech Republic in the early nineties will come to an end in several years[1], construction companies might soon notice the impact of what they are allowed to do with polystyrene insulation waste.

## 1.2 Objectives

### 1.2.1 General Objective

This work aims to describe the impending changes in the international legislation that affects dealing with plastic construction waste and also mention and assess their economic impact.

[1] PAŠEK, J., The Future of the Polystyrene as Thermal Insulation in Buildings, 2013: 1.

### 1.2.2 Specific Objectives

#### 1.2.2.1 Legislation

The first goal is to list international law that will directly or indirectly affect construction waste management in the near future and determine its consequences and impact on the process related to waste management after the reconstruction or demolition of a building, which is where most of construction waste comes from.

Furthermore, the list and description of related legislation in the Czech Republic should be added along with possible change suggestions in order to be able to use plastic construction waste more efficiently in terms of both ecology and economy.

Related to the Czech and international legislation, the legal possibilities of dealing with EPS and XPS waste from the construction industry shall be specified along with the description of required authorizations and other documents needed for its disposal or other utilization.

#### 1.2.2.2 Possibilities of Disposal of Plastic Construction Waste

The next objective is to create the most comprehensive list of the options where, according to the impact of the legislation and other criteria, the EPS and XPS that becomes waste can be disposed of or otherwise used.

#### 1.2.2.3 Economy and Management of Plastic Construction Waste

Plastics have considerable material potential and the use of plastic waste is possible and advantageous in different ways that don’t have a negative effect on the environment.

As a consequence, the aim is to specify the exact amount of EPS and XPS polystyrene already built-in into structures and estimate the annual amount of EPS and XPS becoming waste. Another aim is to assess whether this amount might be problematic to handle in an economic and ecological way and if so, suggest solutions or preventive actions.

Therefore, another goal of this thesis is to describe ways of dealing with plastic in the most efficient and the most economical way (compliant with all the legislative provisions) from the perspective of the person responsible for the renovation or demolition of a building - the waste generator.

## 1.3 Scope and Languages

Geographically, the scope of this paper is limited to Europe paying close attention to the Czech Republic. However, several legislation changes are relevant even for non-European countries.

The language is limited to English as it is the predominant language in science. The official language of the Czech Republic is Czech and the quoted acts have no official translations, so the citations of Czech law will be kept in original and only **unofficially translated** into English to describe their meaning and main points. Titles of individual acts are always translated into English and are **not official translations either**. Their official names are presented in the list of acronyms in the Czech language. In the chapter Sources are listed official names of the Czech legislative documents.

## 1.4 Methodology

Initial focus before the beginning of this work was on the European and other international legislation and the corresponding the Czech legislation, both publicly available via the internet.

The first step was to consider the impact of such changes on the construction industry. The potential impact was evaluated as significant.

The methodology of the thesis itself consists of the following steps:

- Preliminary research through books, publications and internet search. After this, the gathered material was filtered in order to avoid incomplete, duplicated or inaccurate sources.

- With an accurate set of sources and based on the known legislation changes, preliminary conclusions and statements were set to define the current state of things in relation to the topic and to estimate future changes and their impact that should be taken into consideration.

- Preliminary conclusions were consulted with experts in relevant fields. Mainly the executives and other employees of the companies Holcim (Česko), a.s. (further also as Holcim) and Ecorec Česko s.r.o. (further also as Ecorec), Czech Association of Cement Producers, Czech Waste Management Association and others.

- Based on new facts and knowledge based on experiences from practice, the final conclusion was reached and specific examples made.

# 2 Polystyrene Foam, Its History and Use in Construction Industry

## 2.1 History of Polystyrene as a Thermal Insulation

Polystyrene was discovered by Eduard Simon in 1839. Simon was an apothecary from Berlin. The discovery occurred accidentally when he distilled storax (resin of tree Liquidambar orientalis) and obtained a monomer that he named Styrol. Few days after the distillation he found changes in the styrol structure - it thickened (from oxidation, he assumed) into a jelly-kind material he named Styroloxyd. [2]

Later in 1845 two chemists John Buddle Blyth and August Wilhelm von Hofmann proved, that it was not really an oxidation and the same transformation of Styrol can be observed in the absence of oxygen as well. So they called the substance Metastyrol as they assumed it was not really an oxide.[3] Later analysis showed, that both Metastyrol and Styroloxyd are chemically identical. In 1866 it was proved by Marcelin Berthelot, that the formation of Metastyrol (Styroloxyd) is the so called polymerization process.[4] Eighty years later, a thesis by a German organic chemist Hermann Staudinger made clear that heating of Styrol starts a chain reaction that produces macromolecules.[5] Later on, based on the known facts about the production of such material it obtained its current name - Polystyrene.

The first attempt to commercially utilize Polystyrene (PS) was in 1931 by the company I. G. Farben operating in Ludwigshafen. They tried to substitute die-cast zinc with PS for different purposes.[6] However, it is the production of polystyrene in pellet form using reactor vessel extruding polystyrene through a heated tube and separating to small pieces using a cutter that is considered their biggest success.

In 1941, Dow's Chemical Physics Lab discovered the possibility of making foamed polystyrene and named it Styrofoam.[7] To this day, Styrofoam is a trademarked name

[2] DITCHFIELD, Ch., The Story Behind Plastic, 2012: 29.
[3] MYERS, L. R., The 100 Most Important Chemical Compounds: A Reference Guide, 2000: 266.
[4] WAGNER, J. R. Jr., Multilayer Flexible Packaging, 2009: 4.
[5] MYERS, L. R., The 100 Most Important Chemical Compounds: A Reference Guide, 2000: 266.
[6] MYERS, J. R., The 100 Most Important Chemical Compounds: A Reference Guide, 2000: 125.
[7] LEE, S. T., Chul, B. P., Foam Extrusion: Principles and Practice, Second Edition (Polymeric Foams), 2014: 323.

describing closed-cell extruded polystyrene foam. This type of polystyrene is currently widely utilized as thermal insulation in the construction industry. It is still owned and manufactured by The Dow Chemical Company.

Further important improvement for the construction industry came in 1950, when the chemical engineer Fritz Stastny working in Badische Anilin & Soda-Fabrik (today known as BASF - The Chemical Company) developed pre-expanded PS beads. The product was called Styropor. [8] As explained on the BASF web site:

> *„Styropor EPS is the BASF trade name for expandable polystyrene (EPS) supplied in the form of beads. Containing a blowing agent, it is produced by the polymerization of a styrene monomer in the presence of a peroxide as catalyst, causing the styrene molecules to form long chains.“*

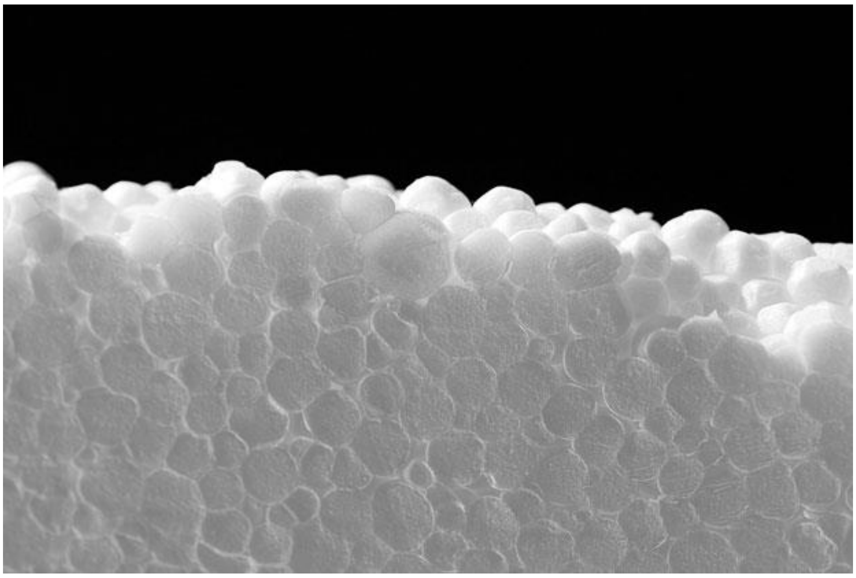

*Figure 1 - Expanded polystyrene*[9]

[8] SCHWEDT, G., Experimente rund um die Kunststoffe des Alltags, 2013: 85.
[9] *The magazine for Europe's plastic processors eppm* [online]. © 2014 Rapid Plastics Media Ltd. [cit. 3.10.2014]. Available from http://www.eppm.com/downloads/279/download/Styron.jpg

These beads are used as the raw material that enables molding larger PS parts or extruding sheets.

In 1959, the last milestone in the development of PS as thermal insulation was reached when the Koppers Company in Pittsburgh, Pennsylvania, developed the expanded polystyrene (EPS) foam. They chose the name Dylite for their new product.[10]

Since then, EPS became the most commonly used thermal insulation in civil engineering for its thermal and other physical properties, workability and economic reasons. Proponents of PS as thermal insulation were also talking about the possibility of recycling and the use of old insulation as an energy source. Today’s average properties of such materials are:

| | |
|---|---|
| Thermal conductivity [W/(m·k)] | 0.031 – 0.045 |
| Density [kg/m$^3$] | 10 – 35 |
| Compressive strength at 10 % deformation [MPa] | 0.07 – 0.26 |
| Heat capacity [J/(kg·K)] | 1,500 |
| Building material class | E (European classification) |

*Table 1 - Physical properties of EPS[11]*

Another improvement came later with extruding polystyrene that led to the possibility of production of a material today commonly known as XPS boards. This process was invented by Dow´s Chemical Company[12]. Such PS boards offers much better surface roughness and also higher stiffness and last but not least reduce thermal conductivity.

[10] CARRAHER, Ch. E. Jr., Carraher's Polymer Chemistry, Ninth Edition, 2013: 221.
[11] Source: Author. Data: WINTERLING, H., Rigid Polystyrene Foam (EPS, XPS), 2011: 18.
[12] CARRAHER, CH. E. Jr., Carraher's Polymer Chemistry, Ninth Edition, 2013: 221.


*Figure 2 - XPS insulation board*[13]

Extruded polystyrene (XPS) foam is a rigid insulation that's also formed with polystyrene polymer, but manufactured using an extrusion process, and today is often manufactured with a distinctive color to identify product brand.

| | |
|---|---|
| Thermal conductivity [W/(m k)] | 0.035 – 0.045 |
| Density [kg/m3] | 25 – 45 |
| Compressive strength at 10 % deformation [MPa] | 0.15 – 0.70 |
| Heat capacity [J/(kg K)] | 1,500 |
| Building material class | E (European classification) |

*Table 2 - Physical properties of XPS*[14]

[13] *Isover* [online]. © 2014 Divize Isover, Saint-Gobain Construction Products CZ a.s. [cit. 14.12.2014]. Available from http://www.isover.cz/data/imgs/00192l.jpg
[14] Source: Author. Data: WINTERLING, H., Rigid Polystyrene Foam (EPS, XPS), 2011: 18.

### 2.2 Hexabromocyclododecane as a Flame Retardant

#### 2.2.1 Basic Information on Hexabromocyclododecane

Hexabromocyclododecane (HBCDD) can be found in 16 different forms because of 16 different stereo-isomers with different biological activities. The mixture that is being commercially utilized is composed of three main diastereomers denoted as alpha (α-HBCDD), beta (β-HBCDD) and gamma (γ-HBCDD) with traces of others.[15]

For purposes of the construction industry and thermal insulation using polystyrene, requirements to reduce flammability of EPS and XPS came up naturally. In EU, for more than 50 years, the HBCDD flame retardant was used and the same substance is commonly used even today.[16]

*Figure 3 - Hexabromocyclododecane[17]*

[15] SCHECTER, A., Dioxins and Health Including Other Persistent Organic Pollutants and Endocrine Disruptors, Third Edition, 2012: 600.
[16] PAŠEK, J., The Future of the Polystyrene as Thermal Insulation in Buildings, 2013: 1.
[17] *Shouguang zixu chemical* [online]. © 2014 Shouguang zixu chemical Co., Ltd. [cit. 8.10.2014]. Available from http://www.zixuchem.com/en/web/images/UpFile/2013-12/201312111124110.jpg

Already in 1966 the Swedish Chemical Institute KEMI was asked to develop a comprehensive risk report considering the wide use of HBCDD in the production of plastic materials. Ever since, the use of HBCDD has sometimes been called into question and other alternatives considered to substitute its role in the production of plastics. HBCDD (for commercial use it is a white solid substance) is in fact mainly used in civil engineering, which consumes approximately 90 % of its total production in the form of EPS and XPS insulations.[18] In a paper called Hexabromocyclododecane in Industrial and Food Samples the concentrations of HBCDD in polystyrene foam insulations are specified by weight:

> *"Hexabromocyclododecane (HBCD) is brominated flame retardant used primarily in expanded (EPS) and extruded (XPS) polystyrene foams that are used for thermal isolations in the building industry. Typical HBCD levels for EPS foams are 0.67% and 1 – 3% in XPS foams. HBCD as additive flame retardant is not covalently bound to the material, therefore it is released into the environment during the production, processing and storage of waste containing this compound."*[19]

Basic physical properties are presented in the following table:

| Property | Value |
|---|---|
| Physical state at 20 C and 101.3 KPa | White odorless solid |
| Melting / freezing point | Ranges from approximately:<br>172-184 °C to 201-205 °C<br>190 °C , as an average value, was used as input data in the EU risk assessment |
| Boiling point | Decomposes at >190 °C |
| Vapor pressure | 6.3. 10-5 Pa (21 °C) S |

*Table 3 - Physical properties of HBCDD*[20]

[18] VÖRÖS, F., Využití odpadů z pěnového polystyrenu, 2014: 5.
[19] KUC, J., GROCHOWALSKI, A., Hexabromocyclododecane in industrial and food samples, 2014: 526.
[20] Source: Author. Data: PELTOLA-THIES, J., Hexabromocyclododecane as a Possible Global Pop, 2008: 19.

### 2.2.2 Voluntary Efforts to Reduce the Use of HBCDD

In 2004, Voluntary Emission Control Action Program (VECAP) was founded as a tool to control emissions during the handling and use of brominated flame retardants (BFRs). In 2006, producers of HBCDD and polystyrene insulations themselves founded the SECURE programme (Self-Enforced Control of Use to Reduce Emissions). It´s a voluntary program established in order to reduce emissions. It was incorporated into the already running VECAP program. The objective of this program is not only to control but also reduce potential emissions of HBCDD into the environment. It is focusing specifically on the polystyrene foam supply chain and therefore civil engineering.[21] The efforts to reduce emissions caused by use of HCDB as flame retardant were successful. The public report of VECAP activities shows, that in 2008 the total emissions found in soil, water and air were 212 g per tonne of product. In 2012 the number is significantly lower - 19 g per tonne of product in EU. In 2013, expected volume was 48,8 g per tonne of product.[22] The numbers are evaluated based on the total EFRA production. EFRA is assumed to be the leading manufacturer and marketer of flame retardants in Europe.

Although there were published reports refuting HBCDD's negative impact on health, more reports seem to confirm the concerns. The strong argument against HBCDD is the simple fact, that as a substance in the environment, it is very persistent and not easily degradable, its concentrations in the environment are therefore increasing constantly. Another fact is, that HBCDD is listed in the so called R Phrases (short for Risk Phrases) defined in Annex III of European Union Directive 67/548/EEC: Nature of special risks attributed to dangerous substances and preparations. Specifically in phrases R50 - Very toxic to aquatic organisms and R53 - May cause long-term adverse effects in the aquatic environment.

Opinions of experts on exact level of toxicity and noxiousness related to HCDB contained in PS insulations differs.

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[21] *Voluntary emissions reduction programme: VECAP* [online]. BSEF and its members. [cit. 12.10.2014]. Available from http://www.bsef.com/voluntary-emissions-reduction-programme-vecap-and-secure/
[22] *VECAP report 2013* [online]. VECAP, 2013. [cit. 12.10.2014]. Available from: http://www.vecap.info/uploads/VECAP_report_2013_WEB.pdf

Ing. Darina Lanková and Ing. Jana Pulkrabová, Ph.D. from Arnika (Czech non-governmental organization engaged in ecology, environment and the related legislation) states, that HBCDD has been found everywhere in the environment - air, water, wastewater, sludge, office dust, fish and other animals, human blood, adipose tissues and breast milk. It enters the human body mainly as dust particles through contact with the skin or through the consumption of food (in particular fish). Human body then distributes HBCDD to the whole organism. The highest concentrations can be found in the adipose tissues. Tests in laboratory animals have shown its negative effect on the proper development and hormonal balance in the exposed body.[23]

In contrary, from the report by Ing. František Vörös published under the Association of Producers of EPS in CZ follows:

During the 50 year long application of HBCDD in Europe, a number of measurements by independent institutes e.g. German Fraunhofer Institute and the Research Institute for Insulation (FIW) were done. They confirmed that HBCDD in EPS insulation is nonvolatile and is not washed out by water. The same is confirmed by measuring end-of-life hoses insulated with PS containing HBCDD and after many years of Geofoam applications in roads in the extreme northern conditions.[24]

### 2.2.3 Alternatives to HBCDD

Dangerous or not, since 2003 manufacturers of EPS are looking for possible replacements of HCDB in polystyrene insulations. Patented and proven solutions there already exist, invented by the American company Dow and named Polymeric FR. The results were published on 29 March 2011. The substance is a brominated polymer product, which is not persistent and dosage of about 1% meets the requirements for flame retardancy in EPS insulations. As stated by the Dow company:

[23] LANKOVÁ, D., PULKRABOVÁ, J., Hexabromcyklododekan (HBCD) [online]. Arnika [cit 14.10.2014]. Available from http://arnika.org/hbcd-hexabromcyklododekan
[24] VÖRÖS, F., Využití odpadů z pěnového polystyrenu, 2014: 5.

*„The Polymeric FR is expected to be the 'next generation industry standard' flame retardant for use in both extruded polystyrene (XPS) and expanded polystyrene (EPS) foam insulation applications globally. The development of the new Polymeric FR is the result of Dow's continuing search for more sustainable products and in this case for a flame retardant that can replace hexabromocyclododecane (HBCD).“*

In the same report from 29 March 2011, Dow also announced commercial possibilities of such solution:

*„Dow has worked with potential licensees to validate the technology and enable them to start scaling up a commercially viable production process.“*

Further:

*„Today, DGTL also announced the first license agreement with Chemtura Corporation. This first license agreement makes it possible for Great Lakes Solutions, a Chemtura business, to produce and sell the newly developed Polymeric FR for use in XPS and EPS foam. DGTL is currently engaged in advanced licensing discussions with several other interested companies and expects to finalize these agreements by the end of the year. DGTL expects this will enable global supply security, foster market competition and help facilitate a smooth industry conversion to the new technology as EPS and XPS manufacturers adopt Polymeric FR, thereby becoming the new global standard.“*[25]

Other license followed, on 25 January 2012 another official statement announced a license agreement for the use of their Polymeric FR technology by Bromine Compounds Ltd., a company within the ICL Industrial Products. According to the statement, the Dow

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[25] *Dow Announces Development of a New Polymeric Flame Retardant Technology for Polystyrene Foam Building Insulation Products* [online]. The Dow Chemical Company, 2011. [cit. 18.10.2014]. Available from http://www.dow.com/licensing/news/2011/20110329a.htm

Chemical Company is ready for the strict changes in international legislation related to the use of HBCDD that will become effective in the coming years. The statement says:

> *„The second licensing agreement will enhance global supply security and facilitate an industry conversion to the new technology as XPS and EPS manufacturers' transition to Polymeric FR. The Polymeric FR licensees have planned large plant constructions enabling commercial volumes to become available over the coming years. This will allow the global polystyrene foam insulation industry to make a smooth transition as regulations are implemented for hexabromocyclododecane (HBCD) around the world.“*[26]

Dow announced that the third granted license will be also the final one. The last license agreement was signed with Albemarle Corporation. The announcement says:

> *„Albemarle is a global leader in the development and production of flame retardants, and its commitment to this new technology, as the third and final licensee, validates the selection of the Polymeric FR as the new global industry standard flame retardant in the production of extruded polystyrene (XPS) and expanded polystyrene (EPS) foam.“*

Further in the announcement:

[26] *Dow grants second license for new Polymeric Flame Retardant to ICL affiliate* [online]. The Dow Chemical Company, 2012. [cit. 18.10.2014]. Available from http://www.dow.com/news/corporate/2012/20120125a.htm

*„Having three international licensees to produce and market the new Polymeric FR, assures global supply security and facilitates industry conversion to the new technology as XPS and EPS manufacturers' transition to the Polymeric FR. The Polymeric FR licensees have planned large plant constructions enabling commercial volumes to become available over the coming months and years. This enables the global polystyrene foam insulation industry to make a smooth transition to the Polymeric FR.“*[27]

From the aforementioned it is clear, that the producers are prepared to stop using HBCDD and will able to produce polystyrene insulation with an alternative flame retardant in the future. That is a very important fact on account of the upcoming legislation changes described in the following chapter. **The market is prepared for the changes and technological matters will not affect or slow down the legislation changes.**

[27] *Dow grants third and final license for new Polymeric Flame Retardant to Albemarle* [online]. The Dow Chemical Company, 2012. [cit. 18.10.2014]. Available from http://www.dow.com/news/press-releases/article/?id=5651

| | |
|---|---|
| 1839 | Polystyrene was discovered by Eduard Simon and process was assumed to be an oxidation (of resin). |
| 1845 | John Buddle Blyth and August Wilhelm von Hofmann proved, that oxidation is not responsible for transformation. |
| 1866 | It was proved by Marcelin Berthelot, that the formation is so called polymerization process |
| 1931 | First attempts to commercially utilize Polystyrene, I. G. Farben |
| 1941 | Dow's Chemical Physics Lab discovered the possibility of making foamed polystyrene |
| 1950 | Pre-expanded PS beads were developed in Badische Anilin & Soda-Fabrik (BASF) |
| 1959 | EPS was developed by Koppers Company (Pittsburgh) |
| Early in 1960´ | XPS was marketed |
| 1960´ | Flame retardant HBCD was used for purpose of construction industry |
| 1966 | The Swedish Chemical Institute KEMI was asked for a comprehensive risk report considering wide use of HBCD |
| 2004 | VECAP was found as a tool to control emissions during handling and use of brominated flame retardants |
| 2011 | European Commission included HBCD in the amended Annex XIV of REACH |
| 2011 | Polymeric FR was introduced by Dow company as a alternative for HBCD |
| 2013 | HBCD listed in Annex A of Stockholm convention |

*Figure 4 - Timeline of development of polystyrene[28]*

[28] Source: Author.

# 3 International Legislation related to HBCDD

## 3.1 Summary of International Legislation

In 2008 the European Commission adopted Directive 2008/98/EC, which is the main document on waste management in the EU. The directive defines a five-step waste hierarchy. Countries are required to ensure that waste undergoes some degree of recovery (material, energy). The hierarchy is defined as follows:

a. waste prevention - i.e. behave so as to avoid waste,
b. preparing for re-use - returnable packaging, cleaning and adjustments
c. material use - an inability to use the products, emphasis on material use - this principle is recycling waste
d. other uses (e.g. energy) - it is not possible to utilize the material waste and it should be used in other ways - waste incineration is mentioned as recovery rather than disposal / removal.
e. removal - location for permanent storage of waste - landfills.


*Figure 5 - Scheme of EU waste management*[29]

[29] *European Commission* [online]. European Commission, 2014. [cit. 8.10.2014]. Available from http://ec.europa.eu/environment/waste/framework/images/prevention.jpg

The statement of EU for this directive follows:

> *„Directive 2008/98/EC sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. The Directive introduces the "polluter pays principle" and the "extended producer responsibility". It incorporates provisions on hazardous waste and waste oils (old Directives on hazardous waste and waste oils being repealed with the effect from 12 December 2010), and includes two new recycling and recovery targets to be achieved by 2020: 50% preparing for re-use and recycling of certain waste materials from households and other origins similar to households, and 70% preparing for re-use, recycling and other recovery of construction and demolition waste. The Directive requires that Member States adopt waste management plans and waste prevention programs."*[30]

Directives of the EU also distinguish between types of waste in terms of its chemical composition. Despite the effort of the EU for a total prohibition of plastic waste landfilling in the last several years, there are other international regulations which will significantly limit the possibilities of the disposal and recycling of plastic waste. The key documents for the future treatment of plastic waste (mainly XPS and EPS thermal insulations) in the construction industry are the so called Stockholm Convention on Persistent Organic Pollutants and the European chemicals law REACH.

The basic legal framework for dealing with POPs at the level of the European Union member countries is the directly applicable Regulation of the European Parliament and Council Regulation (EC) No 850/2004 on persistent organic pollutants. This regulation is relating to the manufacture, marketing, use of POPs, their unintended releases and waste

[30] *Directive 2008/98/EC on waste (Waste Framework Directive)* [online]. European Commission, 2014. [cit. 20.10.2014]. Available from http://ec.europa.eu/environment/waste/framework/

containing such substances or they are contaminated by them. It is the European Union's legal framework for the fulfillment of obligations following from the Stockholm Convention.

## 3.2 Stockholm Convention on Persistent Organic Pollutants

It is an international environmental treaty signed at a Conference of Plenipotentiaries on 22 May 2001 in Stockholm, Sweden and effective from 17 May 2004. The Czech Republic has signed the Convention on 23 May 2001 and ratification is valid since 6 August 2002. Its main goal is to eliminate or restrict the production and use of persistent organic pollutants.

Persistent Organic Pollutants (POPs) are organic chemical substances. That means, that they are carbon-based. They also possess a specific combination of physical and chemical properties which makes them persistent and polluting. Some of these properties, once released into the environment, cause the substance to:

- remain intact for exceptionally long periods of time (many years);
- become widely distributed throughout the environment as a result of natural processes involving soil, water and, most notably, air;
- accumulate in the fatty tissue of living organisms including humans, and are found at higher concentrations at higher levels in the food chain;
- be toxic to both humans and wildlife.[31]

For the purpose of this thesis, the most important statement in the Convention is to be found in Article 6. Once POPs become waste, Parties to the Stockholm Convention are among other required to:

- Manage stockpiles or wastes in a safe, efficient and environmentally sound manner;

[31] *What are POPs?* [online]. Stockholm Convention, 2008. [cit. 20.10.2014]. Available from http://chm.pops.int/TheConvention/ThePOPs/tabid/673/Default.aspx

- Dispose of such waste in a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that it does not exhibit the characteristics of a persistent organic pollutant anymore;
- Not permit any disposal operations of waste contaminated with POPs that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of POPs;
- Not transport waste contaminated with POPs across international boundaries without taking into account relevant international rules, standards and guidelines;
- Identify contaminated sites and perform remediation in an environmentally sound manner.

The above mentioned implies, that not only future production but disposal options of any existing and used material containing any of POPs is strongly limited. Until 2013, the in construction industry widely used XPS and EPS insulations were not influenced by the Convention. However, at the sixth meeting of the Parties to the Convention, which was held in Geneva from 28 April to 10 May 2013, the decision to list also the chemical hexabromocyclododecane (HBCDD) in the Annex A of the Convention was adopted.

In relation to list HBCDD to the Convention, its definition in part III of Annex A is described as follows:

"Hexabromocyclododecane" means hexabromocyclododecane (CAS No: 25637-99-4), 1,2,5,6,9,10-hexabromocyclododecane (CAS No: 3194-55-6) and its main diastereoisomers: alpha- hexabromocyclododecane (CAS No: 134237-50-6); beta-hexabromocyclododecane (CAS No: 134237-51-7); and gamma-hexabromocyclododecane (CAS No: 134237-52-8).

Annex A supported by Article 4 of the Convention admits authorization of specific exemptions for the production or use of POPs. Special rules are applied to the group of PCBs (PCBs are chemically stable, heat-resistant, adhesive and non-flammable. Comprising a total of 209 congeners (related substances) bound with at least 4 chlorine atoms. HBCDD is not counted into PCBs). The import and export of chemicals listed in Annex A might be allowed when satisfying some specific conditions, as set out in paragraph 2 of Article 3.

Such exemptions were accepted by the Parties for use in Civil Engineering, as explained in the text by the United Nations issued on 13 May 2013 in the magazine Chemical and Engineering News (C&EN):

> *„Parties to the treaty gave HBCD a reprieve before the global ban takes effect. Under the agreement, HBCD can continue to be used in expanded or extruded polystyrene insulation for buildings until 2019, a UN spokesman tells C&EN. The industry forum says this exemption "will provide downstream users with the time that they need to ensure a smooth transition to alternatives."*
>
> *Treaty members also created labeling requirements for new building insulation products that contain HBCD, says Joseph DiGangi, senior science adviser for the network of advocacy groups. Labels will provide information to purchasers of insulation products and will also help ensure proper disposal of HBCD-containing materials when buildings are renovated or torn down, he says."*[32]

So the newly produced materials using HBCDD would have to be marked. This requirement, however, won't have any significant impact (depending on customers and their interest in chemical composition of thermal insulation) on production until 2019.

### 3.3 European Union Legislation

REACH means Registration, Evaluation, Authorization and Restriction of Chemicals. It is a European Union Regulation (EC) No 1907/2006 serving as a legislative tool covering the production and use of chemical substances and their potential impacts on human health and the environment. Its beginnings are dated 18 December 2006 and entered into force in 1 June 2007.

[32] HOGUE, CH., Global Ban for Flame Retardant, 2013: 6.

It addresses the overall chemicals policy, which also contributes to the restriction of movement and inputs of POPs into the environment. However, REACH does not use the term “POP” itself. It refers to so called PBT (persistent, bioaccumulative and toxic) and vPvB (very persistent and very bioaccumulative) substances, which are subject to certain obligations with respect to safety data sheets, registration and objects. Or they may eventually be banned completely in accordance with Annex XIV of REACH.

The full name is the Regulation of the European Parliament and Council Regulation (EC) No 1907/2006 on the registration, evaluation, authorization and restriction of chemicals, establishment of the European Chemicals Agency and amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94, Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105 / EC and 2000/21/EC. On 20 January 2009 the Regulation of the European Parliament and Council Regulation (EC) No 1272/2008 on classification, labeling and packaging of substances and mixtures entered into force. It aligns existing EU legislation to the United Nations Globally Harmonised System (GHS) and amending Regulation (EC) No 1907/2006.

As the law consequently affected chemical industries from all corners of the world, European Chemicals Agency (ECHA) was established in order to properly manage complicated scientific and technical aspects of such regulations.

ECHA added HBCDD to the list of candidate SVHC (substances of very high concern) because of its properties as a persistent, bio accumulative and toxic substance (PBT) in June 2008. Since 2009, the ECHA classified HBCDD as very toxic to aquatic organisms with possible long-term negative effects in the aquatic environment (R50 and R53). In December 2010, ECHA proposed to classify HCBD in accordance with EU Directive 67/548/EEC as substance causing reproductive toxicity with possible effects on the unborn child (R63) and possible effects on infants (R64). ECHA defines HCDB as follows:

| | |
|---|---|
| Chemical Name: | Hexabromocyclododecane and 1,2,5,6,9,10-hexabromocyclododecane |
| EC Number: | 247-148-4; 221-695-9a |
| CAS Number: | 25637-99-4b ; 3194-55-6a |
| IUPAC Name: | Hexabromocyclododecane |
| Molecular Formula: | C12H18Br6 |
| Structural Formula: | for 1,2,5,6,9,10-HBCDD, i.e., CAS no 3194-55-6a |

*Table 4 - ECHA brief definition of HBCDD*[33]

The European Commission included HBCDD in the amended Annex XIV to Regulation (EC) No 1907/2006, which was published as the Commission Regulation (EU) No 143/2011 amending Annex XIV to Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals on 17 February 2011.

According to the mentioned Annex XIV, sunset date for HBCDD is 21 August 2015. After this date use of materials containing HBCDD will be allowed in Europe only with valid authorization. Annex XIV states, that applications for such authorization should be submitted to ECHA by 21 February 2014.

Major producers of EPS materials used this option. They are seeking authorization for longer use of HBCDD as explained in their joint application. As mentioned in the application, those eight companies represent in total over 50% of the EU EPS market. Submitting members are: INEOS Styrenics Netherlands BV, INEOS Styrenics Ribecourt SAS, INEOS Styrenics Wingles SAS, Synthos Dwory 7 spółka z ograniczoną odpowiedzialnością spółka komandytowo-akcyjna, Synthos Kralupy a.s., StyroChem Finland Oy, Monotez SA, RP Compounds GmbH, Synbra Technology bv, Sunpor

[33] Source: Author. Data: European Chemical Agency. Member State Committee Support Document for Identification of Hexabromcyclododecane and All Major Diastereoisomers Identified as a Substance of Very High Concern [online]. European Chemical Agency. [cit 21.10.2014]. Available from http://echa.europa.eu/documents/10162/13638/svhc_supdoc_hbccd_publication_en.pdf

Kunststoff GmbH, Dunastyr Polystyrene Manufacturing C. Co. Ltd, Versalis SpA, Unipol Holland bv. Through the application it is sought for:

1. Use 1: “Formulation of FR EPS to solid unexpanded pellets using HBCDD as the flame retardant additive (for onward use in building applications)”; and

2. Use 2: “Manufacture of FR EPS articles for use in building applications”.

The applicants are committed to completely switching from HBCDD to an alternative polymeric flame retardant (pFR) as soon as possible over the period 2015-2019.[34]

The application mainly asks for a four year period ongoing until 2019 and aligning REACH with the Stockholm Convention on Persistent Organic Pollutants. The applicants in their 162 pages long Socio-economic Analysis explain, that this period is necessary for complete substitution of HBCDD with an alternative solution. The use of HBCDD will be banned since 21 August 2015 unless the application is granted.

As a result, until 21 August 2015 there will be both solutions available on the market. The variant with Polymeric FR and also with HBCDD which will be offered under specific exemption and have to be marked as such. After 21 August 2015, placing HBCDD on the market or using it will be prohibited unless an authorization is granted to a particular person for a particular use.

There is another key document for dealing with POPs, which is not part of so called REACH Regulation. It is the Regulation of the European Parliament and Council (EC) No 850/2004 on Persistent Organic Pollutants. **It was already mentioned as legal framework for implementation of Stockholm Convention in Europe.** Regulation No 850/2004 entered into force on 19 May 2004 and is directly applicable and binding in its entirety. It also specifies the limits determining whether the material has to be treated as containing POP or not:

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[34] Peter Fisk Associates Limited, Economics for the Environment Consultancy. Socio-economic Analysis [online]. European Chemical Agency. [cit 27.10.2014]. Available from http://echa.europa.eu/documents/10162/0ed074ab-00e9-42d8-aaea-60a08568551c

> *“Waste containing or contaminated by any substance listed in Annex IV may be otherwise disposed of or recovered in accordance with the relevant Community legislation, provided that the content of the listed substances in the waste is below the concentration limits to be specified in Annex IV.”*

In other words, this regulation concerns the protection of the environment and human health against POP substances by prohibiting, and as soon as possible ending and restricting the production and use of substances covered by the Stockholm Convention on POPs, defining what POPs specifically are and issuing regulations related to waste which contains any of these substances or are contaminated by them.

The POPs are specified in Annex IV. Last regulation of Annex IV was Regulation (EU) No 756/2010 of 24 August 2010. HCDB is not yet listed. Also the limit value for HBCDD was not specified. Its addition to the Annex IV along with the limit value is expected in the very near future.

However, the highest permissible value which appeared in Annex IV is 50 mg/kg. That represents concentration 0.0001% by weight. Concentration in polystyrene insulations starts at 0.5% by weight. The possibility of the new Regulation (EC) No 850/2004 listing such a benevolent limit for POP is practically non-existent.

## 3.4 Legislation of the Czech Republic Related to the International Law

Those international regulations are also followed by the legislation of the Czech Republic. In order to support the proper implementation of the Convention at the national level, the National Centre for Persistent Organic Pollutants was established. The headquarters of the National POPs Centre is a Research Centre for Environmental Chemistry and Ecotoxicology, Masaryk University in Brno. In 2013, the center was renamed to National Center for Toxic Substances.[35]

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[35] *Stockholmská úmluva o persistentních organických polutantech (2001)* [online]. The Ministry of Environment of the Czech Republic. [cit. 24.10.2014]. Available from http://www.mzp.cz/cz/stockholmska_umluva_polutanty

An important document for adopting international law is the National Implementation Plan of the Stockholm Convention on Persistent Organic Pollutants. The National Implementation Plan is subject to regular updating, that is tied to the inclusion of substances in the Annexes to the Stockholm Convention. The text of the first implementation plan was approved by Government Resolution no. 1572 of 7 December 2005. Updated National Implementation Plan was prepared from 2010 to 2012. The government approved it by Government Resolution no. 810/2012 of 8 November 2012.[36] For the purpose of long-term tasks within the plan were included some activities related also to the candidate substances, that time HBCDD. As stated in the Implementation Plan, Handling wastes containing POPs is regulated by Act no. 185/2001 Coll., on waste and amending certain other laws. This Act is in case of dealing with POPs, in fact, only referring to Regulation (EC) No 850/2004 on Persistent Organic Pollutants.

Annex V of Regulation (EC) No 850/2004 **specifies the options for the disposal of materials contaminated with POPs in accordance with Annex IIA and IIB of Directive 75/442/EEC as follows:**

- D9 - Physico-chemical treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D 12 (e.g. evaporation, drying, calcination, etc.);
- D10 - Incineration on land;
- R1 - Use as a fuel or other means to generate energy excluding waste containing PCBs.

[36] *Národní implementační plán Stockholmské úmluvy o perzistentních organických polutantech* [online]. Research Centre for Toxic Compounds in the Environment. [cit 17.10. 2014]. Available from http://www.recetox.muni.cz/index-en.php

# 4 Legislation of the Czech Republic Related to the Disposal of Waste Containing HBCDD

## 4.1 List of Laws Influencing Incineration and Co-incineration of EPS and XPS

The options are limited by the law of the Czech Republic in order to control the disposal of waste and mainly hazardous waste and to prevent any adverse side effects caused by inappropriate handling of waste of any kind.

Waste itself could be defined as any movable thing one is getting rid of, or has the intention or obligation to discard and belongs to one of the groups defined under Act no. 185/2001 Coll. on waste and amending certain other laws

The basic Czech legal regulations related to dealing with waste containing hexabromcyclododecane (and also many other waste types) are:

- Act no. 100/2001 Coll., on the assessment of environmental impacts
- Act no. 185/2001 Coll., on waste and amending certain other laws
- Act no. 201/2012 Coll., on the protection of the air
- Act no. 695/2004 Coll., on conditions for trading with allowances to greenhouse gas emission
- Act no. 76/2002 Coll., on the integrated prevention
- Decree no. 376/2001 Coll., on classification of hazardous waste properties
- Decree no. 381/2001 Coll., waste catalogue
- Decree no. 415/2012 Coll., on the permissible level of pollution

XPS and EPS containing HBCDD that became waste have to be treated in compliance with these (and other) laws of the Czech Republic.

## 4.2 Classification of Waste

The originator of waste and the beneficiary are obliged to classify waste category. The category of hazardous waste should be included if they fall into one of three cases:

- is mentioned in the list of hazardous waste specified in the Waste Catalogue. (Appendix 2 of Decree no. 381/2001)
- is mixed with or contaminated by any of the ingredients listed in a list of ingredients that make waste hazardous (listed in Annex no. 5 of Act no. 185/2001 Coll., on waste and amending certain other laws)
- is mixed or contaminated by any of the waste listed in the list of hazardous waste
- has one or more hazardous characteristics listed in Annex no. 2 Act no. 185/2001 Coll., on waste and amending certain other laws, the originator or an authorized person managing the waste is required to classify such waste as hazardous and dispose of it as hazardous, even if it does not meet the above conditions

Mixed municipal waste is not included in the category of dangerous. Perpetrators and beneficiaries of mixed municipal waste are not obliged to dispose of it as hazardous, even if it satisfies the conditions set out in the preceding paragraphs.

According to mentioned laws, there might be an obligation to classify the POP-containing substance as hazardous (or special) waste. This will place additional requirements on how the substance might be stored, transported or the possibilities of how to dispose of it to those stated by already mentioned Regulation of the European Parliament and Council (EC) No 850/2004 on Persistent Organic Pollutants.

The classification of substances containing POP might be problematic. Currently the legislations on chemicals that become waste considerably differ from the legislations on other materials that become waste. Substances are classified solely according to Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures and waste still under the original above mentioned guidelines. As a consequence, POPs themselves are classified as hazardous waste[37], however, no condition specified by the Czech law (condition according to Annex 2 to the Act no. 185/2001 Coll., on waste or occurrence in Waste Catalogue) was proven for XPS and EPS insulations. In consequence, XPS and EPS that became waste are generally not

[37] *Nebezpečné odpady* [online]. The Ministry of Environment of the Czech Republic. [cit. 2.11.2014]. Available from http://www.mzp.cz/cz/nebezpecne_odpady

considered hazardous waste and therefore they might be added into the mixture of waste used as fuel without any impact on emission limits and related measurements. Also, most of the waste is not considered dangerous, unless it passes the assessment of hazardous properties in accordance with Decree no. 376/2001 Coll. Under this decree the waste either is or is not stated as hazardous.

## 4.3 Authorization for Incineration and Co-incineration of Waste

**Any facility has to have an authorization in order to incinerate waste. Therefore EPS and XPS definitely cannot be used as fuel without limitation.** In other words, it is not legal to receive polystyrene waste and incinerate it even for obtaining and subsequent utilization of energy without valid authorization.

The decision to authorize the operation with waste for waste incineration plants is since the 1 January 2003 issued by the Regional Authorities on the basis of the administrative proceedings. Since 1 September 2012 the authorization is subjected to § 11 and 12 of Act no. 201/2012 Coll., on the protection of the air, repealing the Act no. 86/2002 Coll. The important statements of the law are listed below both in the Czech language as an official language of the legislative document and below translated into English:

*„Pro účely tohoto zákona se rozumí*

*§ 2*

*p) spalovnou odpadu stacionární zdroj určený k tepelnému zpracování odpadu, jehož hlavním účelem není výroba energie ani jiných produktů, a jakýkoliv stacionární zdroj, ve kterém více než 40 % tepla vzniká tepelným zpracováním nebezpečného odpadu nebo ve kterém se tepelně zpracovává neupravený směsný komunální odpad.*

*Stanoviska, závazná stanoviska a rozhodnutí orgánu ochrany ovzduší*

*§ 11*

*(2) Krajský úřad vydává*

*d) povolení provozu stacionárního zdroje uvedeného v příloze č. 2 k tomuto zákonu (dále jen „povolení provozu“).*

*§ 12*

*(4) Povolení provozu obsahuje závazné podmínky pro provoz stacionárního zdroje, kterými jsou*

*i) v případě tepelného zpracování odpadu stanovení množství odpadu a určení kategorií odpadu, které lze spalovat, specifikaci minimálních a maximálních hmotnostních toků nebezpečných odpadů, jejich minimální a maximální spalné teplo a jejich maximální obsah znečišťujících látek v nebezpečných odpadech, zejména polychlorovaných bifenylů, pentachlorfenolu, chloridů, fluoridů, síry a těžkých kovů,*

*(7) Povolení provozu může krajský úřad vydat na dobu časově omezenou, přičemž vychází z obvyklé doby životnosti stacionárního zdroje. Má-li být ve stacionárním zdroji tepelně zpracován odpad, lze povolení provozu vydat nejdéle na dobu 25 let a krajský úřad toto povolení a jeho případné změny zašle bez zbytečného odkladu ministerstvu na vědomí. Ministerstvo vede údaje ze všech povolení provozu jako součást informačního systému kvality ovzduší podle § 7. “*

Unofficial translation of law follows:

For the purposes of this Act:

§ 2

p) waste incinerators, stationary power source for the thermal treatment of waste, which main purpose is not the generation of energy or other products and any stationary source, in which more than 40 % of the heat is generated by the heat treatment of hazardous waste or in which untreated mixed municipal waste is heat treated.

Opinions, binding opinions and rulings of air protection

§ 11

(2) The Regional Authority issues

d) permission to the operation of stationary sources listed in Annex no. 2 to this Act (hereinafter referred to as "operating license").

§ 12

(4) Permit contains binding conditions for the operation of stationary sources, which are

i) in the case of thermal treatment of the waste determination of the amount of the waste and determination of categories of waste which may be treated, specify the minimum and maximum mass flows of hazardous wastes, their lowest and maximum heating values and maximum contents of pollutants in hazardous waste, particularly polychlorinated biphenyls, pentachlorophenol, chloride, fluoride, sulfur and heavy metals.

(7) The Regional Authority may issue operating license for a limited time, based on the standard lifetime of a stationary source. If the waste in a stationary source shall be heat treated, the operating license can be issued at maximum for period of 25 years and the Regional Authority will give notice of such license and any amendments, without undue delay, to the Ministry. The Ministry keeps the data from all operating licenses as a part of the Air Quality Information System pursuant to § 7.

From above mentioned it follows that waste incinerators are for example cement plant co-incinerating waste. Therefore **any such facility has to have the complex and valid permit, otherwise the co-incineration would be an illegal process. Conditions are specified differently for co-incinerating of the hazardous waste and are dependent on the amount.**

In Appendix 2 to this Act, stationary sources are sorted also with listed required assessments for each source. Those requirements could be:

- dispersion study according to § 11 para. 9
- compensatory actions in accordance with § 11 para. 5
- operating procedure as part of the operating permit pursuant to § 11 para. 2 point. d)

Waste incinerator has to have not only the authorization itself. For pollution measurements, there have to be present authorized person according to § 32. In other words, any waste incinerator with authorization have to choose a person suitable for authorization for pollution measurement according to § 32.

Further, compliance with emission limits under Annex no. 4 to the Decree no. 415/2012 Coll. is required. This decree also sets specific conditions for emission measurements for materials containing persistent organic compounds.

Last requirement is the so called Integrated Authorization. Act no. 76/2002 Coll. (the Integrated Prevention Act), requires operators of industrial facilities, in accordance with Annex no. 1 of this Act, to have such Authorization issued in order to be able to operate equipment.

Integrated Authorization basically lays down binding conditions for the operation of facilities, opinions, statements and consents issued pursuant to special legislation in the field of environmental protection, protection of the public health and agriculture, if applicable. Integrated Authorization thus provides binding conditions of technological equipment (defined exhaustively in Annex no. 1 of Act no. 76/2002 Coll., on integrated prevention) and replaces multiple individual permits, approvals and the relevant authorities (in the area of water, air, nature and landscape, waste management, etc.) that would otherwise have to get the facility operator.

In accordance with § 33 point. a) and b) of Act no. 76/2002 Coll., the locally competent Regional Authority performs the following activities:

- decision on the application for an Integrated Authorization
- revision of the binding conditions of the Integrated Authorization

The Ministry of Environment according to § 29 letter. b) e) of the Act. no. 76/2002 Coll. then decide on an application for the Integrated Authorization for the operation which may significantly affect the environment of the State concerned, and reviews the binding conditions of operation devices with a significant negative trans boundary impact. The Ministry of Environment also decide on appeals against decisions of the Regional Authority, Czech Environmental Inspection (CEI) and performs state supervision over all devices.[38]

According to the list of Integrated Authorizations, which is publicly available on the web pages of the Ministry of Environment and the database of the Czech Hydrometeorological Institute, it was possible to put together **the complete list of incineration of hazardous and municipal waste and pollution sources co-incinerating waste, which are currently in operation in the Czech Republic.** According to named sources, only facilities currently incinerating or co-incinerating waste are cement plants and waste incinerators (some are producing heat and electrical energy).

**Any other facility willing to utilize the energetic potential of polystyrene (or any other) waste would have to arrange the necessary permits first.**

## 4.4 Other Impacts of the Czech Legislation

The Czech legislation is influencing co-incineration of waste also in economic manner. Definition of equipment listed in Annex no. 1 to Act no. 695/2004 Coll. defines which kind of incinerator needs the allowances to greenhouse gas emission. According to this Annex, specifically incineration plants (except for the incineration of hazardous or municipal waste) with a rated thermal input exceeding 20 MW doesn´t need the emission allowance.

**Significant help for energetic use of combustible waste would be a single legislative classification of wastes as fuels with $CO_2$ neutral effect, similarly as in the case of biomass.** If the material that could be co-incinerated as a fuel ends up in an

[38] *Integrovaná povolení* [online]. The Ministry of Industry and Trade of the Czech Republic. [cit 4.11.2014]. Available from http://www.ippc.cz/obsah/integrovana-povoleni/

incinerator or a landfill of municipal waste, allowances to greenhouse gas emission is not required to buy. The same principle should be suitable also for co-incineration in cement plants.[39]

[39] GEMRICH, J., SCHLATTAUER, P., JUNGMANN, J., Identifikace možností spoluspalování odpadů, zejména z MBÚ v cementárnách ČR, 2009: 5.

# 5 Current State of Construction Waste Containing HBCDD in the Czech Republic

## 5.1 Overview of Usage of Polystyrene in Construction Industry

For the purpose of this thesis, the most important numbers are the **mass of used polystyrene containing HBCDD in construction industry** through years since the beginning of its use. Contamination of other construction plastic waste by HBCDD is negligible. Relevant number is therefore considered to be equal to the mass of polystyrene insulations used so far in the buildings.

> *„Construction industry in the EU consumes approximately 1,800,000 tons of EPS (almost 80 % is in ETICS) and 400,000 tons of XPS per year, and produces 140,000 tons of polystyrene waste. From its volume, 52 % has been used energetically, 8 % recycled, and 40 % has been stored on waste disposal sites so far. Approximately 150,000,000 m2 of facade areas have been insulated with system ETICS in Europe during last years.*
>
> *In the CR more than 50,000 tons of polystyrene is being used every year for construction application, where about 60 % of that is incorporated into ETICS. On the other hand, little less than 3,000 tons of waste polystyrene (circa 1,200 tons of construction and 1,500 tons of demolition waste) is generated, of which about 31 % is used energetically, 8 % recycled mechanically, and 61 % stored on waste disposal sites."* [40]

[40] PAŠEK, J., The Future of the Polystyrene as Thermal Insulation in Buildings, 2013: 1.

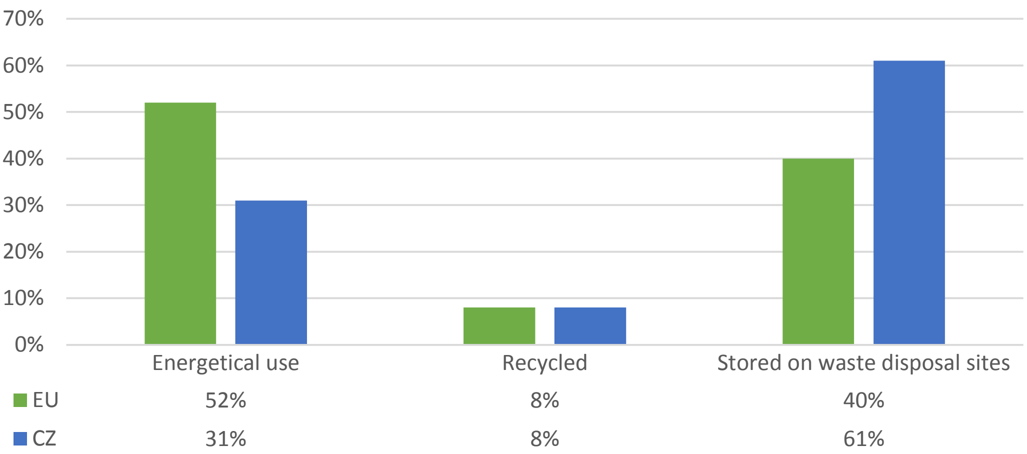



*Figure 6 - Waste management operations in CZ and EU*[41]

## 5.2 Usage of XPS and EPS in the Czech Republic

The usage of polystyrene as a thermal insulation was constantly growing until 2007. Further development was clearly influenced by the upcoming financial crisis. Illustration of the development of usage of PS as thermal insulation is showing following graph:

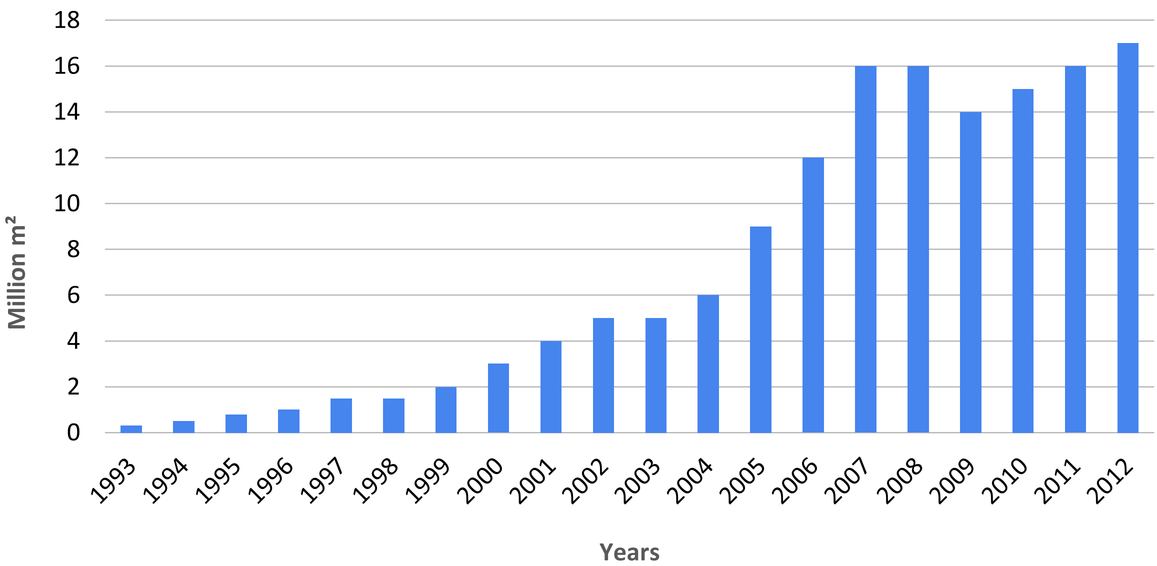
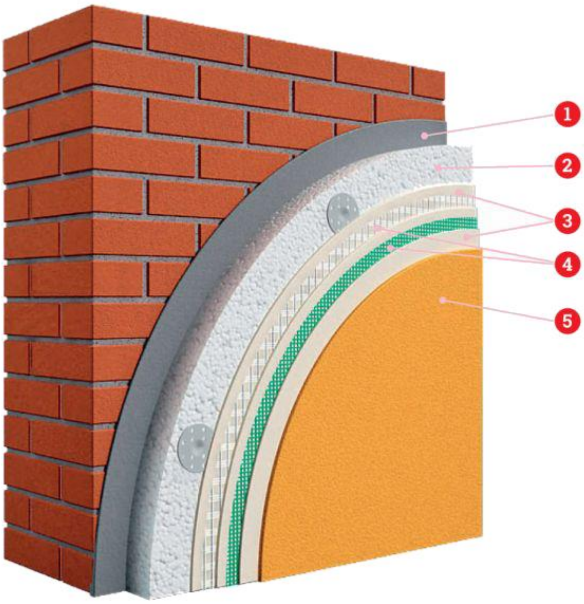



*Figure 7 - Amount of ETICS made in the Czech Republic*[42]

[41] Source: Author. Data: PAŠEK, J., The Future of the Polystyrene as Thermal Insulation in Buildings, 2013: 1.
[42] Source: Author. Data obtained from ČAOH, www.caoh.cz, 2014.

Amount of ETICS made in CZ is a great indicator of increasing tendency of usage of foam polystyrene in civil engineering.




1. Adhesive mortar
2. Thermal insulation boards
3. Reinforcing layer
4. Reinforcing grids
5. Plaster

*Figure 8 - ETICS System with description* [43]

It is important to determine also mass of foam polystyrene used in construction industry through years. Those are shown in following table:

[43] *Odborný stavebný portal* [online]. © 2014 JAGA GROUP, s. r. o. [cit. 4.11.2014]. Available from http://www.asb.sk/sprava-budov/zateplovanie/velky-prehlad-tepelnoizolacnych-systemov-etics

| Year: | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|
| Tons: | 7 058 | 7 268 | 6 641 | 7 708 | 7 141 | 9 141 | 11 551 | 13 664 |

| Year: | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|
| Tons: | 17 096 | 18 651 | 20 443 | 22 664 | 27 728 | 31 029 | 33 632 | 40 000 |

| Year: | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| Tons: | 48 400 | 55 100 | 50 000 | 56 900 | 62 000 | 56 400 | 61 050 | cca 60 000 |

*Table 5 - Amount of built-in EPS in tons[44]*

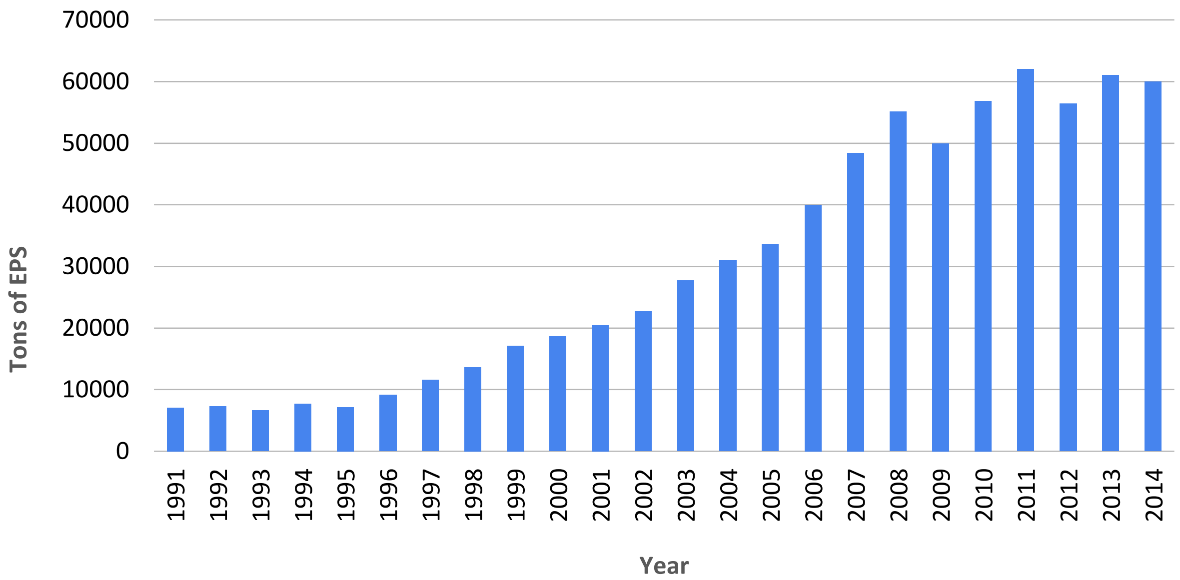



*Figure 9 - Tons of EPS insulation used in the Czech Republic[45]*

To obtain more relevant numbers, also amount of built-in XPS have to be included. From already mentioned data, the amount could be estimated as 22 % of the total EPS consumption. In the Czech Republic, the total amount is assumed to be 15 % of EPS production after the comparism of differencies in pricing of European markets. Estimated amounts of used XPS is presented in following table:

[44] Source: Author. Data obtained from ČAOH, www.caoh.cz, 2014.
[45] Source: Author.

| Year: | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|
| **Tons:** | 1 059 | 1 090 | 996 | 1 156 | 1 071 | 1 371 | 1 733 | 2 050 |

| Year: | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|
| **Tons:** | 2 564 | 2 798 | 3 066 | 3 400 | 4 159 | 4 654 | 5 045 | 6 000 |

| Year: | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| **Tons:** | 7 260 | 8 265 | 7 500 | 8 535 | 9 300 | 8 460 | 9 158 | 9 000 |

*Table 6 - Amount of built-in XPS in tons*[46]

As the life-time of contact insulation systems done with the use of EPS in ninetieth years of 20th century is generally assumed to be approximately 25 years[47], the volume of polystyrene becoming the waste will therefore increase in the next years, as lot of insulated facades are before the renovation process. According to volumes of polystyrene used in early 1990´, it could be the order of 10 000 tons of polystyrene waste per year during the next decade. Expectation of further growth of total amount of plastic waste produced by construction industry each year is reasonable.

[46] Source: Author. Data obtained from ČAOH, www.caoh.cz, 2014.
[47] PAŠEK, J., The Future of the Polystyrene as Thermal Insulation in Buildings, 2013: 1.

# 6 Polystyrene as a Fuel

## 6.1 Incineration as the Only Possibility of Disposal

As already mentioned, Annex V of Regulation (EC) No 850/2004 limits the possibilities of disposal of materials containing POPs. From this regulation follows that waste containing POP is to be destroyed or irreversibly transform with use of methods harmless to the environment in any case.

**The only legal and also technologically, ecologically and economically relevant alternative for disposal of EPS and XPS insulation containing HBCDD is incineration of contaminated material.** To make the most of the situation, it is desirable to utilize energy generated by such process. Test of possibility of burning related to environmental needs given by legislation have already been performed:

> *„The results of laboratory experiments showed that at combustion temperatures 840 – 900 °C the total decomposition of HBCDD happens in more than 99.9999 %. Results combustion EPS and XPS containing HBCDD on real municipal waste incineration plant in 2013 in Wurzburg, Germany, showed that the combustion process is safe and the flue gas does not contain higher than permitted levels of pollutants like PCBs and furans. This waste therefore doesn't have to be considered as hazardous as no hazardous emissions originate during its combustion.“*[48]

Thanks to its chemical composition, EPS and XPS insulations have a relatively large heating value reaching up to 38 MJ/kg.[49] This value puts a different light to EPS and XPS waste and opens several possibilities of post-consumer use. Such heating value available is even slightly higher than of coal by weight. It is reasonable to search for economical solution.

[48] PAŠEK, J., The Future of the Polystyrene as Thermal Insulation in Buildings, 2013: 4.
[49] VÖRÖS, F., Využití odpadů z pěnového polystyrenu, 2014: 6.

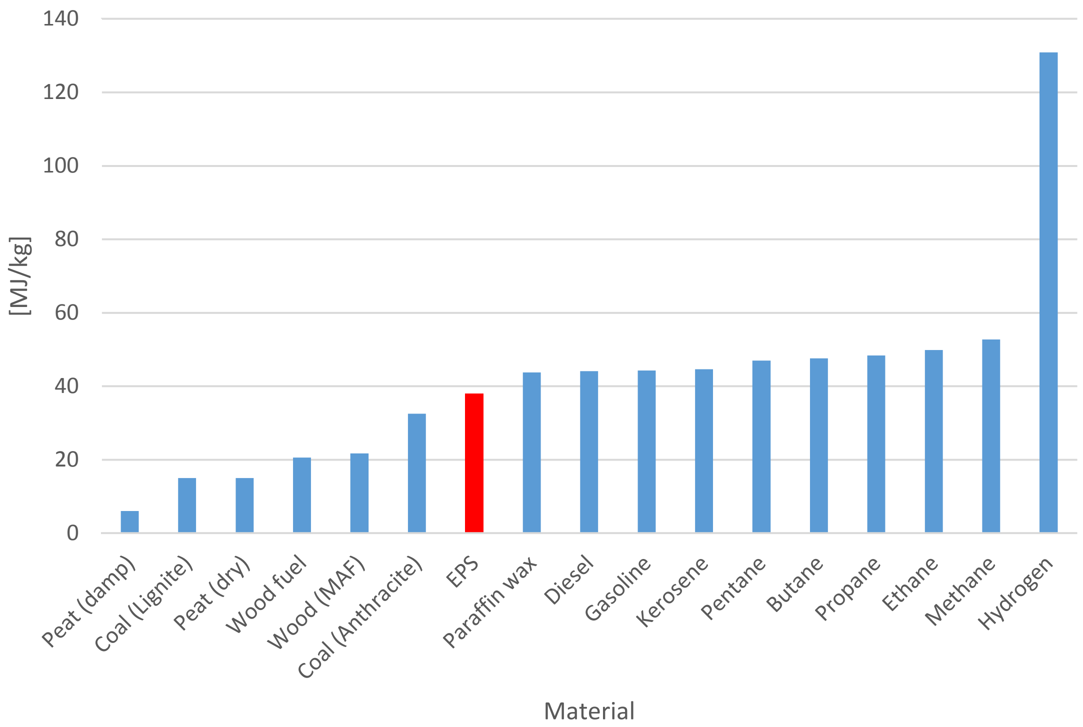



*Figure 10 – Heating value of common fuels in MJ/kg*[50]

Facilities suitable for ecologic but also economic disposal of such contaminated material will have to be able to either substitute solid fossil fuels by previously sorted out EPS and XPS insulations, or incinerate it and generate energy. Temperature of incineration has to exceed 900 °C. The energy gained can be used for local heating or generation of electricity. **Such facilities might be modern municipal waste incinerators, cement plants and heating plants producing heat along with electrical energy.**

## 6.2 Waste as a Fuel in General

Heating value of municipal waste mixture ranges usually between 7,5 and 10,5 MJ/kg. **Mixed municipal waste is a heterogeneous mixture of various components of waste produced by citizens. To the same category is listed similar waste, which has similar characteristics, but is created by companies or industry.**

[50] Source: Author. Data: DEMIREL, Y., Energy: Production, Conversion, Storage, Conservation, and Coupling, 2012. Data: *NIST WebBook Chemie* [online]. National Institute for Standards and Technologies. [cit 9.11.2014]. Available http://webbook.nist.gov/chemistry/

Considering heating value of lignite to be 13 MJ/kg, incineration of one tone of municipal waste would save approximately 0.6 tons of lignite. Municipal waste is indeed quite calorific mixture, but its elemental composition, water content and overall structure is varying. The composition (and also the heating values) varies depending on the origin of waste and even if the origin is known, it also depends on the season.

Composition of the waste is also influenced by the legislation, mainly by the already mentioned Directive 2008/98/EC. The goal of this directive is to prioritize recycling over landfilling and incineration. It sets out the target to recycle 50% of the municipal waste and 70% of construction waste by 2020. Following graph implies, that for the Czech Republic it might be problematic to reach such numbers. Current numbers representing trends in waste management are presented in graph bellow.

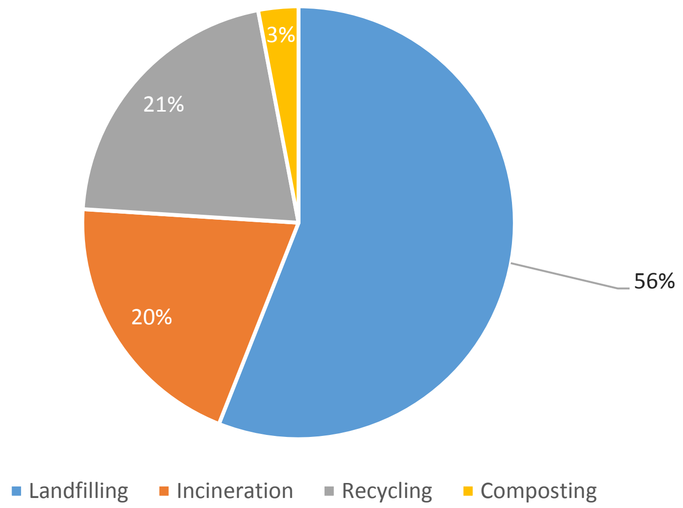



*Figure 11 - Waste management operations in the Czech Republic*[51]

Situation in other countries varies. Almost no landfilling of waste could be currently observed in Sweden, Germany or Nederland. On the other hand in Bulgaria or Romania almost all waste is landfilled. To compare the situation of the Czech Republic with the rest of Europe in terms of waste management, following graph is presented:

[51] Source: Author. Data: BALÁŠ, M., SKÁLA, Z., LISTÝ, M. Spalovny odpadu – odpad jako palivo [online]. *Topinfo s.r.o.* [cit. 11.11. 2014]. Available from http://energetika.tzb-info.cz/energie-z-odpadu/11897-spalovny-odpadu-odpad-jako-palivo

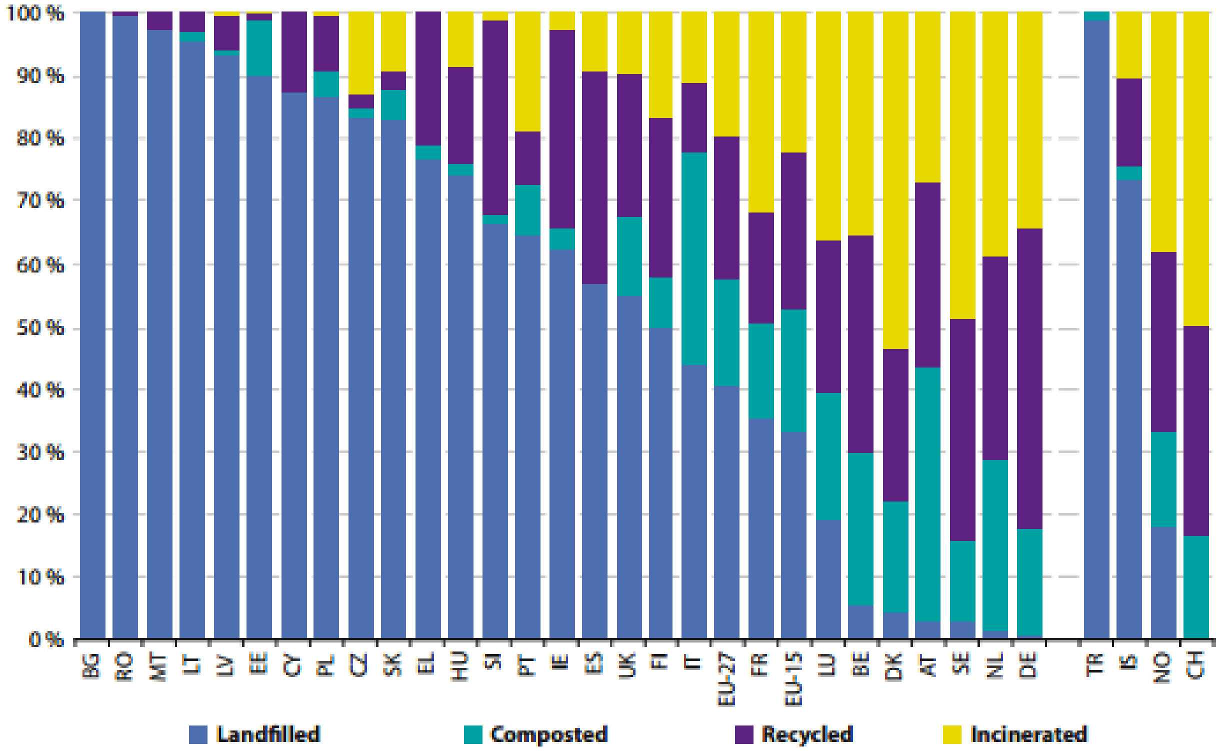



*Figure 12 - Waste management operations in European countries*[52]

The Czech Republic produces approximately 25 M tons of waste per year, which can be divided according to its origin, as presented in following table:

[52] BALÁŠ, M., SKÁLA, Z., LISTÝ, M. Spalovny odpadu – odpad jako palivo [online]. *Topinfo s.r.o.* [cit. 11.11. 2014]. Available from http://energetika.tzb-info.cz/energie-z-odpadu/11897-spalovny-odpadu-odpad-jako-palivo

| | | Total | Hazardous | Non-hazardous |
|---|---|---|---|---|
| **Waste generation** | | **23 435 996** | **1 488 345** | **21 947 651** |
| ***Waste generated by enterprises*** | CZ-NACE | **19 938 705** | **1 474 481** | **18 464 225** |
| *Waste similar to municipal waste* | | 944 759 | 1 706 | 943 053 |
| *Agriculture, forestry and fishing* | 01-03 | 196 065 | 4 383 | 191 681 |
| *Mining and quarrying* | 05-09 | 167 420 | 10 329 | 157 091 |
| *Manufacturing* | 10-33 | 4 376 398 | 493 698 | 3 882 699 |
| *Electricity, gas, steam and air conditioning supply* | 35 | 1 062 880 | 23 037 | 1 039 843 |
| *Water supply; sewerage, waste management and remediation activities* | 37-39 | 2 799 850 | 581 332 | 2 218 518 |
| *Construction* | 41-43 | 8 592 895 | 266 684 | 8 326 211 |
| *Transport and storage* | 49-53 | 231 961 | 17 218 | 214 743 |
| **Waste generated by municipalities** | | **3 497 291** | **13 864** | **3 483 426** |

*Table 7 - Production of waste in 2012*[53]

[53] Source: Author. Data obtained from the Czech Statistical Office, 2014, www.czso.cz.

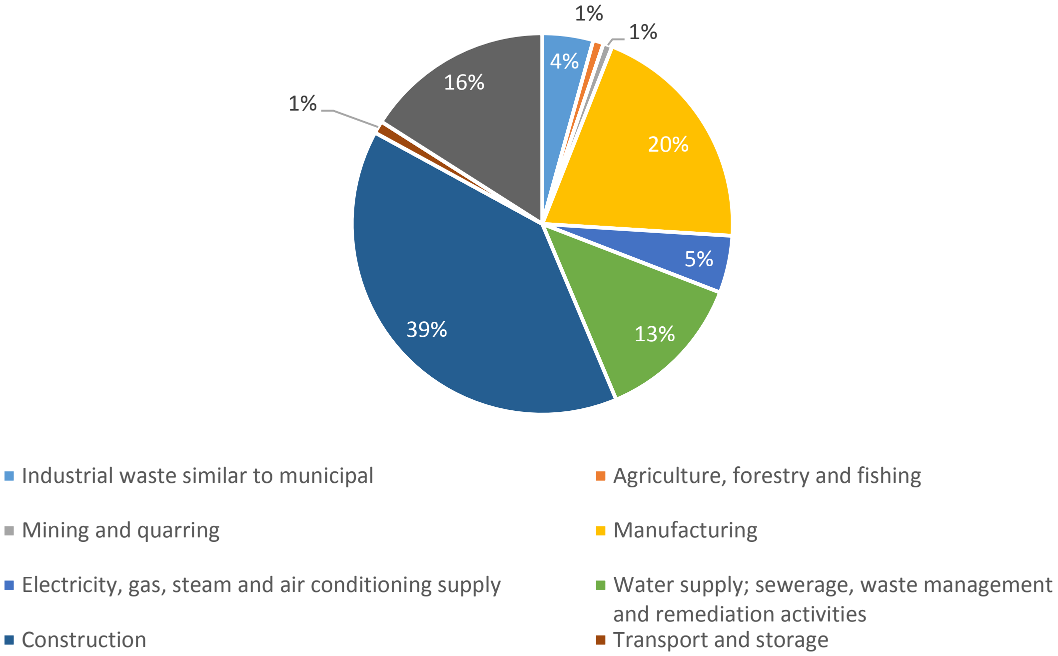



*Figure 13 - Waste according to source*[54]

When the Czech Republic would further improve the system of sorting and recycling of the waste, as required by the EU, it will logically lead to decrease of heating value of the waste (because the energy components such as paper, plastics or biological waste will be sorted out of the municipal waste). Some municipal waste incinerators in Germany are already dealing with such problem[55], where the larger quantities of waste (compared to the Czech Republic) are sorted and recycled already. In consequence, the important fact is that the **European Parliament wants to prohibit the incineration of recyclable and biodegradable compostable waste and instead utilize their material potential after 2020.** The European Union has already anchored such stance to its legislature's resolution, that adoption of prohibition of incineration recyclable waste (paper, plastic, etc.), biodegradable and compostable waste is required until 2020. This is specifically stated in the European Parliament resolution of 24 May 2012. Following tables provide further information on heating value of paper, plastics and biomass and their content in the total mixture.

---

[54] Source: Author. Data obtained from the Czech Statistical Office, 2014, www.czso.cz.
[55] *ČAOH prosazuje co nejširší možnosti nakládání s odpady* [online]. The Czech Waste Management Association (ČAOH), 2013. [cit. 20.11.2014]. Available from http://www.caoh.cz/odborne-clanky-a-aktuality/caoh-prosazuje-co-nejsirsi-moznosti-nakladani-s-odpady.html

| Type of waste | The proportion of the total volume of municipal waste in percent | |
|---|---|---|
| | Housing development of large cities | Mixed development of cities |
| Paper, cardboard | 25,7 | 22,58 |
| Plastics | 16,8 | 17,58 |
| Biomass | 11,2 | 7,82 |

*Table 8 - The proportion of selected waste constituents in percent in 2009*[56]

| Material or mixture | Average heating value in MJ/kg |
|---|---|
| Mixture of papers | 17,6 |
| Newspaper | 19,7 |
| Cardboard | 27,1 |
| Mixture of plastics | 33,4 |
| polyethylene | 43,4 |
| Polystyrene | 38,1 |
| Polyurethane | 26 |
| PVC | 22,5 |
| Biomass | 13,9 |
| Fats | 38,2 |
| Fruits | 18,6 |
| Meat | 28,9 |

*Table 9 - Average heating value of selected constituents of municipal waste*[57]

[56] Source: Author. Data: BENEŠOVÁ, L., KOTOULOVÁ, Z. *Skladba komunálního odpadu v ČR* [online]. ZERA, o.s. [cit. 17. 11. 2014]. Available from http://www.zeraagency.eu/dokumenty/008005001/1_a1benesova.pdf

[57] Source: Author. Data: SKÁLA, Z. *Současný stav spalování tuhých odpadů* [online]. Průmyslová keramika s.r.o. [cit. 17. 11. 2014]. Available from prumyslova-keramika.cz/data/File/pdf/clanky-pps-pdf/05.pps

Plastic plays indeed an important role in a mixture of municipal waste in terms of its heating value. If the incineration is prohibited, there will be a need to find a replacement to increase the heating value of the mixture. **Addition of the polystyrene (containing flame retardant HBCDD) lead to reaching the required values easily.** Both the possibility of incineration polystyrene containing HBCDD and the further development of mixture of municipal waste will depend mainly on legislation.

## 6.3 Economical Comparison of Conventional Fuels and Waste

### 6.3.1 Introduction to the Economical Criterions

Basic economic criterion **is how much money would incineration of polystyrene save if it substitutes any traditional fuel**. Such comparison could be done in terms of heating value. Other factors influencing the overall cost or revenues from incinerating waste are the bulk density and in consequence the volume of the material and the transportation and other logistic costs. Storage possibilities have to be also considered. Also related administrative expanse have to be included. Finally, it is important to include also **demand for polystyrene waste and consider the possibility of substituting it by other waste materials**, such as used tires.

Demand for specific types of waste is very important factor which in the past led to the buyout of wastes such paper or used oils. On the other hand, typical case for the most types of wastes is that the person disposing the waste get paid for taking the waste. Following table presents approximate costs of waste commonly used as fuels.

| Material | Cost<br>Kč per tonne | Relative cost<br>Kč/GJ |
|---|---|---|
| Truck tires | -500 | -20,83 |
| Car tires | -300 | -11,54 |
| Solid waste fuels up to 25 mm | 250 | 9,62 |
| Solid waste fuels up to 90 mm | -370 | -20,56 |
| Meat and bone meal | 250 | 13,16 |
| Distillation residues | -800 | -33,3 |
| Oils, tars | 2500 | 69,4 |

*Table 10 - Approximate prices for purchaser of selected wastes*[58]

### 6.3.2 Buyout of Waste

#### 6.3.2.1 Experience with the Purchase of Waste

**The possibility for waste to be bought out clearly exists. As an example might serve used oils, which are usually bought out for further processing and widely used as secondary raw material in spite of its already reduced quality.**

In 2006 the EU consumed roughly 5.8 million tons of waste oil.[59] Used oil is a valuable industrial material. Its application is possible as substitution for petroleum products (in the construction industry to substitute petroleum lubricants and in the timber industry for a similar purpose.) Important is also use of this material as one of the ingredients for the production of organic fuels or additives into fuels or direct utilization as fuel. It is also suitable for chemical industry (polyurethanes), etc.

Such oils could be used for example in production of lime. Production of lime is energetically intensive process where the cost of energy is usually up to 60% of total

[58] Source: Author. Data: GEMRICH, J., SCHLATTAUER, P., JUNGMANN, J., Identifikace možností spoluspalování odpadů, zejména z MBÚ v cementárnách ČR, 2009: 70.
[59] *Waste Oils* [online]. European Commission. [cit. 18. 10. 2014]. Available from http://ec.europa.eu/environment/waste/oil_index.htm

production costs. In furnaces are mostly used gaseous fuels (e.g. natural gas or coke oven gas). Used oil can be a great substitution of some of the traditional, currently relatively expensive, fuels. Mentioned lead to the buyout of waste oils by third party companies and its further processing and successive resale.[60] **This happened despite the fact that the used oil is considered to be a hazardous waste.** Further information on connected legislation can be found on the official web of the EU:

> *„Waste oils are hazardous waste as they display some hazardous properties. Waste oils that are found in rivers, lakes and streams threaten aquatic life. Indeed, a liter of waste oil can contaminate a million liters of water. Furthermore, severe soil contamination can result from waste oils being left on the ground.*
>
> *Waste oils are governed by the Waste Framework Directive 2008/98/EC, especially by Article 21, which stipulates that Member States shall take the necessary measures to ensure that*
>
> *(a) waste oils are collected separately, where this is technically feasible;*
>
> *(b) waste oils are treated in accordance with Articles 4 (waste hierarchy) and 13 (protection of the environment and human health);*
>
> *(c) where this is technically feasible and economically viable, waste oils of different characteristics are not mixed and waste oils are not mixed with other kinds of waste or substances, if such mixing impedes their treatment."*[61]

In current practice, several companies for example address basic schools with the offer of the collection and buyout of vegetable oil similarly as well-known collection of paper (e.g. Viking group, s.r.o cooperates with several local partners, current offer for schools is buyout of vegetable oil at minimum price 3 Kč for 1 kg of oil).[62]

[60] *Průmyslová odvětví výroby cementu, vápna a oxidu hořečnatého* [online]. Svaz výrobců cementu ČR. [cit. 22. 10. 2014]. Available from http://www.svcement.cz/images/stories/bref/bref-cz.pdf
[61] *Waste Oils* [online]. European Commission. [cit. 18. 10. 2014]. Available from http://ec.europa.eu/environment/waste/oil_index.htm
[62] *Tabulka odběru ekologického oleje v roce 2014* [online]. IS Křivoklát. [cit. 3. 11. 2014]. Available from http://www.is-krivoklat.cz/sber-rostlinneho-oleje/

#### 6.3.2.2 Comparison of Used Oil and Polystyrene Waste

It is not expected that it would be necessary to buyout polystyrene waste similarly to used oil in order to increase the heating value of the waste mixture in the near future.[63] Considering the current situation on the market with waste, it seems reasonable. However, situation can change if the heating value of municipal waste would not be high enough to be used as a substitution of coal in cement plants. Such process will be affected more by the legislation than the overall waste production itself. Therefore it is almost impossible to predict any specific data. However, waste polystyrene containing **HBCDD is a waste with the high heating value and only possibility of its disposal is incineration. Used tires or other plastics might not be allowed for incineration in near future. In consequence, EPS and XPS waste shall be a valuable additive of any waste mixture thought for incineration in order to gain energy.** The similarity with buyout of used oil is not excluded, but not before 2020, when the changes of legislation should be applied.

### 6.3.3 Comparison of Polystyrene Waste with Coal

Basic data for comparison are connected to the physical properties of both materials. Short summary of such data is presented below:

- Heating value of lignite ranges usually between 11 and 20 MJ/kg. Many sources states average value as 13 MJ/kg, what is equal to 3.6 kWh of electricity, or 13 MJ of heat.
- Heating value of anthracite ranges usually between 25 and 35 MJ/kg. Average value is considered to be 27 MJ/kg, what is equal to 7.5 kWh of electricity, or 27 MJ of heat.
- Heating value of EPS polystyrene is 38 MJ/kg. That means that from one kilogram of EPS arises approximately 10.6 kWh of electricity or 38 MJ of heat energy. **In other words, incineration of one tone of EPS would save approximately 1,4 tons of anthracite or almost 3 tons of lignite.**[64]

[63] SEDLÁČEK, M., Ecorec Česko, s.r.o., 18 November 2014, personal communication.
[64] PETCHERS, N., Combined Heating, Cooling & Power Handbook: Technologies & Applications : An Integrated Approach to Energy Conservation, 2003: 58.

Relevant comparison of all mentioned materials is presented in following table and graph:

| **Material** | **Heating value**<br><br>**MJ/kg** | **Density of particulate material**<br><br>**kg/m³** | **Volume of 1 tone**<br><br>**m³** |
|---|---|---|---|
| Lignite | 13 | 720 | 1,4 |
| Anthracite | 27 | 720 | 1,4 |
| EPS | 38 | 15 - 30 | 44,4 |

*Table 11 - Basic physical properties of lignite, anthracite and EPS polystyrene*[65]

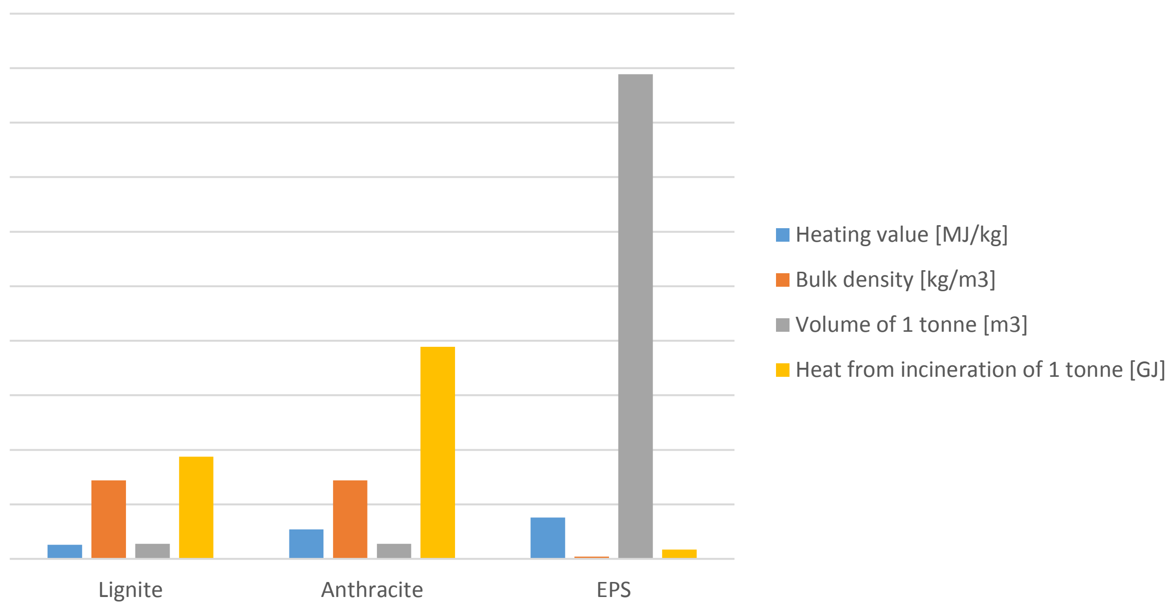



*Figure 14 - Relative ratios between important fuel properties*[66]

From the given data it follows, despite the fact that EPS has far the highest heating value, that EPS has big disadvantages as a fuel when compared to coal. It´s relatively low bulk density causes **the volume of incinerated EPS (needed to arise the same amount of heat as from incineration of coal) would be considerably big.** Utilization of polystyrene waste as a substitution for traditional fossil fuels might be difficult due to the

[65] Source: Author.
[66] Source: Author.

large volume of material which needs to be stored compared to coal. However, that doesn´t reduce it´s potential as an additive to waste mixtures.

# 7 Possibilities of Disposal

## 7.1 Disposal by Co-incineration in Cement Plants

Naturally, the co-incineration is dependent on legislation and also on technological possibilities. One of the ways that technology allows incineration of polystyrene while utilizing its properties is production of cement clinker, where the temperature in the flame reaches 2100°C. The residence time in the flame of burning fuel is at normal gas flow in the rotary kiln for about 2 - 5 seconds at a temperature of flowing air mass above 1200°C. The temperature of the flame together with the fuel residence time in the flame allows perfect destruction and burnout of all organic substances including PCBs and chlorinated hydrocarbons.

Cement plants has years of experience in using wide ranges of waste types as a fuel. Also both the European and the Czech legislation already set the specific conditions for such use. From an economic perspective it can be considered as beneficial to cement plants to co-incinerate fuel of heating value exceeding 17 MJ/kg. Lower heating value results in a lower level of compensation of standard fuel without positive economic effect. Energetically less valuable high-energy fraction of municipal solid waste by MBT[67] process can be enriched for example by higher content of plastics with low chlorine content.[68] By EPS and XPS polystyrene, such criterions are meat.

Generally it cannot be counted with a variant that the cement plants only benefits from the cost savings from co-incinerating waste instead of fossil fuel. Regulatory compliance for incineration of waste requires going beyond standard production expanses by increased operating costs and a significantly larger amount of administrative work. However, operation of rotary kiln by incinerating only the basic fossil fuels is, mainly for economic reasons, disadvantageous. **Manufacturers are therefore looking for either a so-called waste-derived fuels, one type waste or long known waste alternatives. In such cases, the importance of co-incineration of clean plastic materials plus the**

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[67] MBT is a system of mechanical biological treatment of waste that combines a sorting facility with a biological treatment as composting or anaerobic digestion. MBT plants might process municipal waste as well as commercial and industrial wastes.

[68] GEMRICH, J., SCHLATTAUER, P., JUNGMANN, J., Identifikace možností spoluspalování odpadů, zejména z MBÚ v cementárnách ČR, 2009: 4.

**additions of technologically needed inorganic oxides has precedence over mix of the fuel with varying composition.** Also, the need for further analysis of unknown materials with low heating value makes (even high-graded component) of MBT waste less attractive fuel.

From technological reasons, EPS or XPS cannot be used as a fuel alone, but only as an additive to the waste mixture in order to increase the total heating value. **So the main advantage would be obviously its high heating value but also low demands on storage spaces in terms of weathering and the pure fact that it is already the waste needed to be incinerated.**[69]

The main disadvantage is again closely connected with the volume of polystyrene. The volume increases the expanses on transport and any other logistic process.

### 7.1.1 Overview of Legislation for Cement Plants

Cement plants currently fall under the European Directive IED (Industrial Emission Directive) 2010/73, which is implemented in the Czech Republic two laws:

The administrative part is introduced by the Act no. 76/2002 Coll. The emission part is introduced by the Act no. 201/2012 Coll. and Decree no. 415/2012 Sb.

Cement plant that co-incinerate non-hazardous waste, which means conventional fuels (coal, fuel oil, natural gas) are used together with non-hazardous waste, has a fundamental emission limits for cement plants.

Cement plant, incinerating hazardous waste to receive up to 40% of its energy compensation, has a special regime described in the IED and the Czech legislation (Decree no. 415/2012, annex no. 4, Operating conditions for stationary sources of heat treating waste - specific emission limits for cement kilns treating waste along with other fuels.) **Cement plant, which exceeds this value has to reach the same limits as**

[69] HOLAS, V., Holcim (Česko), a.s., 18 November 2014, personal communication.

**incinerator for hazardous waste. This is why it is important to exclude EPS and XPS as being a hazardous waste.**

### 7.1.2 Fuels Used in Cement Production

Cement plants might effectively replace up to 60% of coal by waste mixtures. Heating value for such mixture varies and in average it exceeds 18 MJ/kg. Different technologies in cement production might require different heating value of mixture up to 25 MJ/kg. It is clear, that such mixture have to be adjusted for the needs of cement plants by additives with high heating value as plastics. EPS is suitable for mixture needed in cement plants. Another important information is that **for technology used in cement production it is suitable for co-incineration EPS or XPS polystyrene also even with plaster.**[70]

Composition of fuel in cement plants had changed during time. It is dependent on economical and legislative factors. The development of composition of fuel is described in following table and graphs:

| **Fuel** | **1990** | **2000** | **2012** |
|---|---|---|---|
| Natural gas | 69,6% | 0,2% | 0,8% |
| Heavy fuel oil | 12,0% | 23,1% | 0,6% |
| Coal | 16,4% | 61,7% | 43,9% |
| Used tires | 2,0% | 3,0% | 7,6% |
| Alternative liquid fuels | | 9,3% | 3,9% |
| Alternative solid fuels | | 2,7% | 22,6% |
| Biomass | | | 20,6% |

*Table 12 - Fuels used in cement production*[71]

[70] HOLAS, V., Holcim (Česko), a.s., 18 November 2014, personal communication.
[71] Source: Author. Data: GEMRICH, J., JUNGMANN, J., Výroba cementu a vápna [online]. *Svaz výrobců cementu ČR* [cit. 14. 11. 2014]. Available from http://www.svcement.cz/includes/dokumenty/pdf/vyroba-cementu-a-vapna.pdf

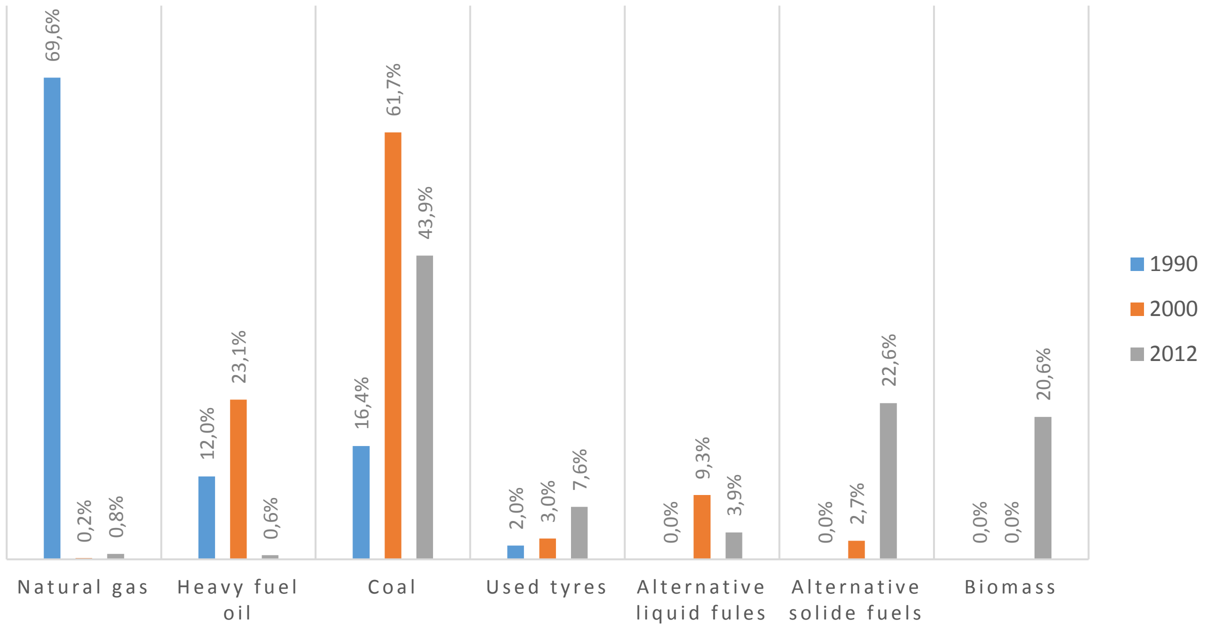


*Figure 15 - Development of composition of fuel in cement plants*[72]

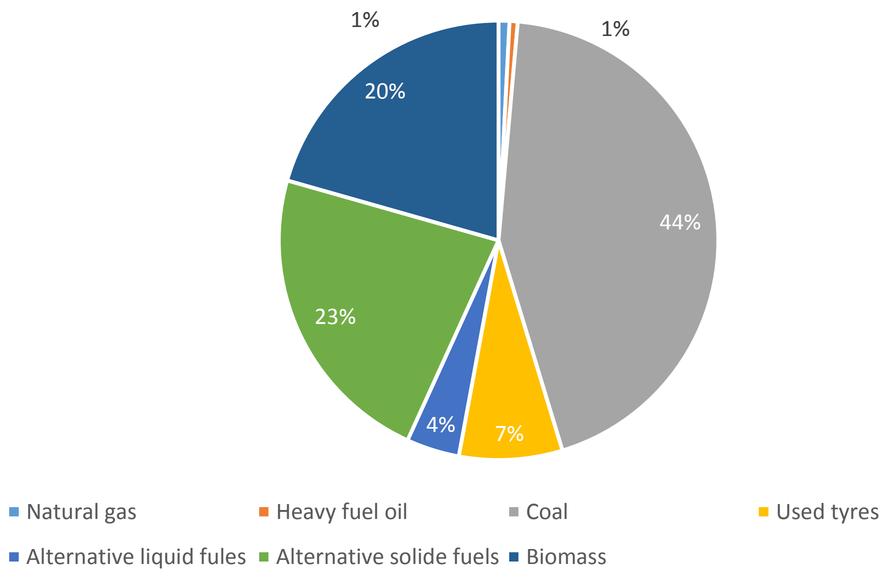


*Figure 16 - Composition of fuel in cement plants in 2012*[73]

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72 Source: Author.
73 Source: Author.

| Fuel | The annual consumption in thousands of tones | | |
|---|---|---|---|
| | **2006** | **2008** | **2010** |
| Plastics | 27,5 | 35,2 | 41,8 |
| TAP (RDF, SRF) from industrial waste | 39,1 | 65,8 | 81,6 |
| Tires, rubber | 41 | 39,7 | 42,3 |
| Industrial sludge | 10,2 | 5,1 | 7,3 |
| Sludge from sewage treatment plants | 0 | 3,4 | 2,9 |
| Meat and bone meal and fat | 25,6 | 19,9 | 14,2 |
| By-products from coal mining | 7,6 | 7,3 | 6,9 |
| Solvents and similar fuels | 9,5 | 4,1 | 4 |
| Waste oils | 24,2 | 5,8 | 2,2 |

*Table 13 - The annual consumption of alternative fuels in tones*[74]

When considering needed heating value of alternative waste fuels exceeding 17 MJ / kg and already mentioned effort of EU to prohibit the incineration of recyclable and biodegradable compostable waste in near future, **this might lead to the high demand for the materials with high heating value, materials which could be co-incinerated in terms of legislation and still cheaper than the standard fuels (as coal). Polystyrene containing HBCDD would meet all this conditions and in consequence might be bought out in the same way as the used oil already is.** This will be strongly dependent on the future legislation changes.

A general improvement of the situation would be mutual agreement between the manufacturer and the customer to produce precisely defined mixtures of waste, especially for cement plants. The mixture must exhibit a range of moisture content, heating value (e.g. adding other materials with higher energy values) and meet the quality parameters

[74] Source: Author. Data: GEMRICH, J., JUNGMANN, J., Výroba cementu a vápna [online]. *Svaz výrobců cementu ČR* [cit. 14. 11. 2014]. Available from http://www.svcement.cz/includes/dokumenty/pdf/vyroba-cementu-a-vapna.pdf

of alternative fuels for cement and maintain the content of substances adversely affecting the quality of the clinker under the agreed limits.

### 7.1.3 Cement Plant and Their Capacities in Terms of Co-incineration of Waste

There are five cement plants in the Czech Republic and all of them hold following authorizations relevant for co-incineration of waste:

1) Authorization subjected to § 11 and 12 of Act no. 201/2012 Coll., on the protection of the air
2) Compliance with emission limits under Annex no. 4 to Decree no. 415/2012 Coll.
3) Integrated Authorization pursuant to § 13 para. 3 of the Act no. 76/2002 Coll., on integrated prevention

All cement plants are listed in following table along with the amount of co-incinerated waste, information about current operations, its locations and other information:

| Sources of pollution authorized for waste co-incineration | | | | | | |
|---|---|---|---|---|---|---|
| **County** | **Operator** | **Address of Facility** | **Amount of Waste Incinerated (t / 2010)** | **Amount of Waste Incinerated (t / 2011)** | **Amount of Waste Incinerated (t / 2012)** | **About Current State** |
| PHA | Českomoravský cement, a.s. | 153 02 Praha 16 - Radotín | 0 | 0 | 0 | In September 2014 the technology was in normal operation. Waste was only used in the 2007 for emission measurements |
| UNL | Lafarge Cement, a.s. | Čížkovice 27, 411 12 Čížkovice | 40 217 | 41 573 | 67 799 | Rotary kiln was in September 2014 under operation with one of the planned shutdown period from 7 to 9 September and one short turnaround on 29 September due to equipment failure. |
| PAR | Holcim (Česko) a.s., člen koncernu | Tovární 296, 538 04 Prachovice | 52 369 | 55 255 | 53 653 | The equipment was through September 2014 operated in normal mode. |
| JM | Českomoravský cement, a.s. | Mokrá 359, 664 04 Mokrá-Horákov | 52 210 | 57 082 | 59 474 | In September 2014, only operated rotary kiln was kiln no 2. |
| OLOM | Cement Hranice, a. s. | Bělotínská 288, 753 39 Hranice | 23 184 | 24 887 | 25 297 | The technology has been in regular operation until 27 September when the kiln line was disabled due to unplanned repairs. Heated was launched on 3 October. |

*Table 14 - List of cement plants in the Czech Republic*[75]

[75] Source: Author. Data obtained from the Czech Hydrometeorological Institute, www.chmi.cz, 2014.

From the given date it follows, that expected annual **amount of polystyrene waste containing HBCDD is not problematic to manage** and the most or all of the annual amount of polystyrene waste in civil engineering in the near future could be possibly co-incinerated only in cement plants. However, distances of the waste transport could be problematic.

## 7.2 Disposal in Waste Incinerators

There are currently operated three municipal waste incinerators In the Czech Republic. All are now equipped for the cogeneration of heat and electricity.

Also waste incinerators producing heat or electrical energy might feel the problems with decreasing heating value of municipal waste and polystyrene might be welcomed additive. Waste incinerators serving only for disposal of waste without any further energetic benefit might also liquidate polystyrene waste, however such variant is neither economic nor ecologic, therefore no economic benefits for person producing the waste would occur.

In the table below all sources with valid authorizations for incineration of waste are listed (table is continued over several pages).

| County | Operator | Address of Facility | Capacity tons per year | Amount of Waste Incinerated (tons in 2013) | Note |
|---|---|---|---|---|---|
| **Equipment for the thermal treatment of municipal waste** | | | | | |
| PHA | Pražské služby, a.s. | Průmyslová 615/32, 108 00 Praha 10 | 310 000 | 304 166 | To incinerator is pulling waste exclusively from the City of Prague |
| LIB | TERMIZO a.s. | Dr. Milady Horákové 571/56, 460 06 Liberec 7 | 96 000 | 95 817 | The incinerator incinerated waste from the city of Liberec, Jablonec nad Nisou and its surroundings. |
| JM | Spalovna a komunální odpady Brno, akciová společnost (SAKO Brno, a.s.) | Jedovnická 2, 628 00 Brno | 248 000 | 237 643 | In incinerator is processed SKO from the city of Brno and the South Moravian Region |
| **Equipment for the thermal treatment of industrial and medical waste** | | | | | |
| **Capital City of Prague** | | | | | |
| PHA | Fakultní nemocnice v Motole | V Úvalu 84, 150 06 Praha 5 - Motol | 2 940 | 2 030 | |
| **Central Bohemian Region** | | | | | |
| STC | AVE Kralupy s.r.o. | O. Wichterleho 810, 278 01 Kralupy nad Vltavou | 10 000 | 9 644 | |
| STC | Purum s.r.o. | Ovčárecká 314, 280 02 Kolín | 3 500 | 2 418 | |
| STC | Nemocnice Rudolfa a Stefanie Benešov, a.s., nemocnice Středočeského kraje | Máchova 400, 256 46 Benešov | 1 000 | 868 | |
| **South Bohemian Region** | | | | | |
| JC | RUMPOLD s.r.o. | Heydukova 1111, 386 01 Strakonice | 1 500 | 1 491 | |
| **Pilsen Region** | | | | | |
| PLZ | SITA CZ a.s. | Skladová 488/10, 326 00 Plzeň | 2 500 | 2 380 | |

| | | | | | |
|---|---|---|---|---|---|
| **Ústí nad Labem Region** | | | | | |
| UNL | SITA CZ a.s. | Na Rovném 865, 400 04 Trmice | 16 000 | 14 190 | |
| UNL | CHS Epi, a.s. | Revoluční 1930/86, 400 32 Ústí nad Labem | 5 000 | 2 224 | Incineration of own waste only |
| **Liberec Region** | | | | | |
| LIB | SPL Jablonec nad Nisou, s.r.o. | Belgická 4613/ 1A, 466 05 Jablonec nad Nisou | 2200 | 1 755 | |
| LIB | NELI servis, s.r.o. | Kristiánova, 460 01 Liberec 1 | 400 | 447 | |
| **Hradec Králové Region** | | | | | |
| HK | Fakultní nemocnice Hradec Králové | Sokolská 581, 500 05 Hradec Králové | 1 000 | 934 | |
| HK | Oblastní nemocnice Trutnov, a. s. | Maxima Gorkého 77, 541 21 Trutnov | 1 000 | 117 | |
| **Pardubice Region** | | | | | |
| PAR | Hamzova odborná léčebna pro děti a dospělé | Košumberk 80, 538 54 Luže | 750 | 502 | |
| PAR | Pardubická krajská nemocnice, a.s. | Kyjevská 44, 532 03 Pardubice | 750 | 945 | On 7 May 2014 the operator was initiated administrative proceedings to impose fines for exceeding the observed half-hour mass concentration of TOC and CO in terms of compliance with emission limits specified in Annex no. 4 of the Decree no. 415/2012 Sb. |

| | | | | | |
|---|---|---|---|---|---|
| **Vysočina Region** | | | | | |
| VYS | SPORTEN, a.s. | U Pohledce 1347, 592 31 Nové Město na Moravě | 864 | 301 | |
| VYS | RUMPOLD s.r.o. | Humpolecká 5, 587 22 Jihlava | 1 900 | 1 472 | |
| VYS | Envir s.r.o. | Pod Kaplí 179, 588 32 Brtnice | 400 | 612 | |
| **South Moravian Region** | | | | | |
| JM | E K O T E R M E X, a.s. | Pustiměřské Prusy 268, 683 21 Pustiměř | 3 240 | 2 998 | |
| JM | Nemocnice Znojmo, příspěvková organizace | MUDr. Jana Janského 11, 669 02 Znojmo | 780 | 609 | |
| **Olomouc Region** | | | | | |
| OLOM | MEGAWASTE - EKOTERM, s.r.o. | U spalovny 4225/6, 796 01 Prostějov | 4 000 | 3 279 | |
| OLOM | SITA CZ a.s. | I. P. Pavlova 185/6, 775 20 Olomouc | 950 | 913 | |
| **Zlín Region** | | | | | |
| ZL | DEZA, a.s. | Masarykova 753, 757 28 Valašské Mezříčí | 10 000 | 8 025 | |
| ZL | SITA CZ a.s. | Třída 3.května 1180, 763 02 Zlín - Malenovice | 4 730 | 4 955 | |
| ZL | Uherskohradišťská nemocnice a.s. | J. E. Purkyně 365, 686 68 Uherské Hradiště | 350 | 341 | |
| **Moravian-Silesian Region** | | | | | |
| MSL | SITA CZ a.s. | Slovenská 2071 709 00 Ostrava - Mariánské Hory | 21 200 | 18 226 | |

*Table 15 - Waste incinerators in the Czech Republic*[76]

Some of those facilities might not be able to incinerate polystyrene with other construction waste (plasters etc.). For example, according to the statement of employees of Sita CZ,

[76] Source: Author. Data obtained from the Czech Hydrometeorological Institute, www.chmi.cz, 2014.

a.s., the technology they use processes only pure polystyrene packaging without additives. Polystyrene demolition waste contains large amounts of dirt and polystyrene processing technology of Sita CZ, a.s. is not designed for such process. For other, especially smaller incinerators or incinerators focused on hospital waste, might be economically or technologically disadvantageous to add polystyrene into waste mixture.

It will depend on the waste producer or company responsible for the collection of waste which incinerator or source will be selected for the final disposal of EPS and XPS waste considering the complexity of logistics solutions and economic factors.

Three main incinerators (SAKO Brno, a.s., Pražské služby, a.s. and TERMIZO a.s.) are able to incinerate great amount of such waste. All use waste as source of energy. But they are focused on the locally produced waste, as noted in the table above. At the same time, it might be financially demanding to transport waste on long distances and for these reasons **it may be preferable to deal with the smaller but geographically closer incinerator.**

New municipal waste incinerator with significant capacity and the most modern technologies are expected to be finished by 2016[77], namely ZEVO Chotíkov operated by the company Plzeňská teplárenská, a.s.

In the past, there were scheduled projects in the Czech Republic related to direct energetic utilization of municipal waste in the heating plant with the participation of municipalities. Projects were based on acquiring subsidies from the EU Operational Program Environment. However, the Ministry of Environment sent on 24 November 2014 to Brussels definite plan, how subsidies should be received from the Operational Program Environment (OPE) between 2014 and 2020. **After repeated criticism of the European Commission the program does not allow financing municipal waste incinerators.** Energetic utilization of waste shall be supported by European funds only if the device

[77] *ZEVO Chotíkov* [online]. Plzeňská teplárenská, a.s. [cit. 24. 11. 2014]. Available from http://www.spalovna.info/#zakladni-udaje

process waste which can no longer be adequately used. Future of planned waste incinerators is uncertain.[78]

## 7.3 Other Possibilities of Managing EPS and XPS Waste

Regulation (EC) No 850/2004 concedes limited possibilities of pre-treatment of the waste containing POP:

> *“Pre-treatment operation prior to destruction or irreversible transformation pursuant to this Part of this Annex may be performed, provided that a substance listed in Annex IV that is isolated from the waste during the pre-treatment is subsequently disposed of in accordance with this Part of this Annex. In addition, repackaging and temporary storage operations may be performed prior to such pre-treatment or prior to destruction or irreversible transformation pursuant to this part of this Annex.”*

Well culled EPS waste can be compressed to 600-800 kg/m3 and then crushed. This activity is carried out for example in the company Remiva Group. Such product has verified and consistent quality and could be eventually used as a fuel for different technologies. **It could be the subject of further research to find economically and technologically reasonable utilization of such product.**

[78] *Nový operační program ŽP: Žádné spalovny, ale recyklace dál pod evropským průměrem* [online]. Hnutí DUHA [cit. 22. 11. 2014]. Available from http://www.hnutiduha.cz/aktualne/novy-operacni-program-zp-zadne-spalovny-ale-recyklace-dal-pod-evropskym-prumerem

# 8 Basic Schemes of EPS and XPS Waste Management Options

## 8.1 Typical Scheme for Managing Waste

Typical circumstances are such that the waste generator would pay for the drop-off of his waste and related services to the logistics company, which consequently deals with the waste. During the next steps the logistics company pays the landfill, waste incinerator, the cement plant or other waste processor for taking over the waste and the disposal, storage, processing or landfilling follows.

The process is also typically influenced by the fee stated in § 46 of the Act no., 185/2001 Coll., on waste and amending certain other laws or can be defined according to the Act no. 565/1990 Coll., on local Fees. Fee is currently paid for the processes connected to landfilling of the waste. The fees serve to finance waste management itself and also have a regulatory function, which makes landfilling disadvantageous. Therefore **it will not affect the process of disposal of EPS and XPS waste containing HBCDD, where landfilling is excluded by the law.**

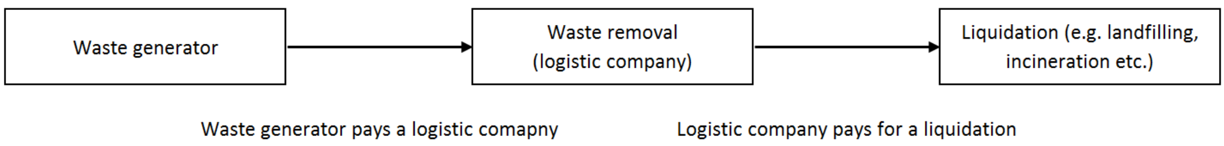


*Figure 17 - Typical scheme of waste management*[79]

## 8.2 Typical Scheme Related to Polystyrene Waste and Upcoming Legislation Changes

Under typical circumstances described above, the **only important price for the waste generator is the price paid to the logistic company for the rental of containers and**

[79] Source: Author.

**drop-off of the waste.** Such prices differ according to the amount of waste, but generally are exceeding 2500 CZK without VAT for all needed services related to the disposal of 6m$^3$ of construction waste in the Prague region. The price might change with the fact that it will not be possible to landfill polystyrene waste and the logistic company would have to find an alternative solution for the disposal of such waste.

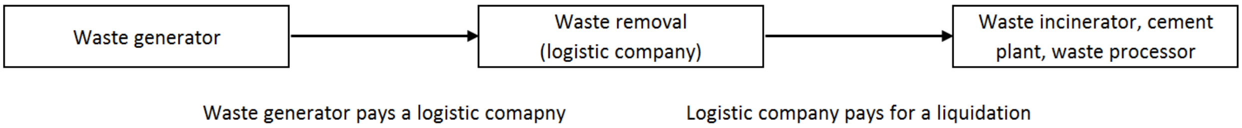


*Figure 18 - Typical scheme of waste management related to the polystyrene waste*[80]

**Mutual Agreement between Waste Generator, Logistic Company and Waste Processor**

It could be the initiative of the waste generator to enter into an agreement with the waste processor (person responsible for disposal of waste, preparing waste fuel mixtures etc.) and use the logistic company as the third party responsible for transportation, but not for agreement and pricing with the waste processor.

**This scheme requires more preparations and would be suitable mainly for companies often dealing with the reconstructions or demolition of insulated facades.**

[80] Source: Author.

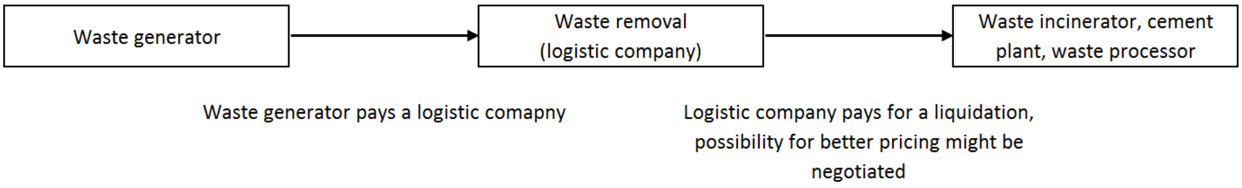


*Figure 19 - Scheme of polystyrene waste management under mutual agreement of all parties*[81]

## 8.3 Supplying the Cement Plant or Other Facility Directly

Under these circumstances, the waste generator has to have his own (or rented) logistics solution. Waste processors such as the company Ecorec, s.r.o. benefiting from waste may offer better prices, mainly for wastes adding heating value to their final products, which are waste fuel mixtures. EPS and XPS insulation, which can be used for the needs of cement plants delivered also with plasters are such waste without a doubt.

The total benefit of such a solution depends on the price of the logistic solution and is mainly suitable for companies already having one. The transport distance is an important factor here. Another factor is the pricing agreement between the waste generator and the person receiving the waste. That would be **dependent on the total amount and quality of waste and also the duration of such supply.**

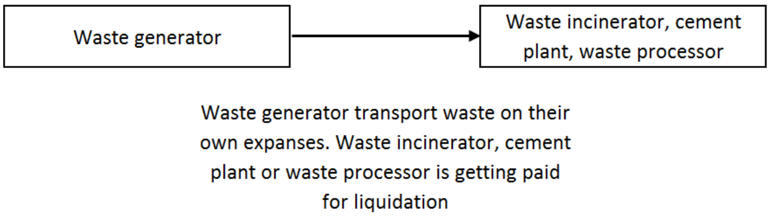


*Figure 20 - Supplying cement plant or other facility directly*[82]

[81] Source: Author.
[82] Source: Author.

## 8.4 Scheme Related to the Possible Buyout of Polystyrene Waste

As already mentioned, this will be dependent on the legislation and the situation on the market with waste mixtures. Such situation is not expected until 2020.

However, this situation would be the most advantageous for waste generators, in this case the person responsible for the reconstruction or demolition of the structure**.**

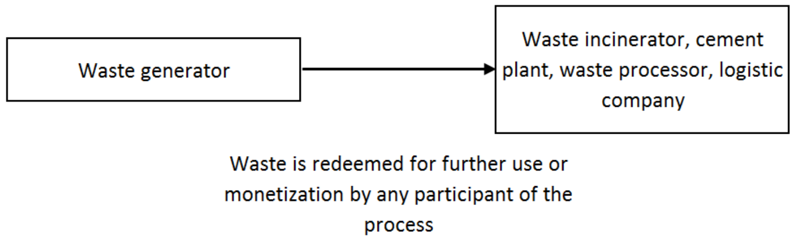


*Figure 21 - Scheme related to the possible buyout of polystyrene waste*[83]

[83] Source: Author.

# 9 Conclusions

## 9.1 Legislation

### 9.1.1 International Legislation

The key document governing waste management related to handling XPS and EPS waste is the Stockholm Convention. The Czech Republic has signed the Convention on 23 May 2001 and the ratification has been valid since 6 August 2002. At the sixth meeting of Parties to the Convention, which was held in Geneva from 28 April to 10 May 2013, was adopted the decision to list also the chemical hexabromocyclododecane (used as flame retardant in EPS and XPS thermal insulations) in the Annex A of the Convention. Annex A supported by Article 4 of the Convention admits authorization of a specific exemptions for the production or use of POPs. Such exemption was accepted by the Parties for use and production for purposes of Civil Engineering until 2019.

Legal framework for adaptation of the Stockholm Convention for the countries in the European Union is the European Parliament and Council Regulation (EC) No 850/2004 on persistent organic pollutants, which entered into force on 19 May 2004 and is directly applicable and binding in its entirety. This regulation **limits possibilities of disposal of materials contaminated with POPs in relation to Annex IIA and IIB of Directive 75/442/EEC as follows:**

- D9 - Physico-chemical treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D 12 (e.g. evaporation, drying, calcination, etc.);
- D10 - Incineration on land;
- R1 - Use as a fuel or other means to generate energy excluding waste containing PCBs.

POPs are specified in Annex IV of Regulation (EC) No 850/2004. Last regulation of Annex IV was Regulation (EU) No 756/2010 of 24 August 2010. **HCDB is not yet listed, as the related changes in the Stockholm Convention took place in the recent past. Also**

**the limit value for HBCDD was not specified. Addition of both the substance itself along with the limit value will take place in the near future.**

Last internationally binding document with significant impact on EPS and XPS waste is the Regulation of the European Parliament and Council Regulation (EC) No 1907/2006 on the registration, evaluation, authorization and restriction of chemicals (the so called REACH regulation).

The European Commission included HBCDD in the amended Annex XIV of the REACH, by publishing the Commission Regulation (EU) No 143/2011 amending Annex XIV to the Regulation (EC) No 1907/2006 on 17 February 2011.

According to the mentioned Annex XIV, the sunset date for HBCDD is 21 August 2015. After this date the use of materials containing HBCDD will be allowed in Europe only with a valid authorization. Annex XIV states, that applications for such authorization should be submitted to ECHA by 21 February 2014.

Eight major producers of EPS materials used this option. They are seeking authorization for longer use (until 2019) of HBCDD as explained in their joint application. **The use of HBCDD in European Union will be generally banned since 21 August 2015 unless the application is granted.**

### 9.1.2 Legislation of the Czech Republic

A key document for adopting international law is the National Implementation Plan of the Stockholm Convention on Persistent Organic Pollutants. National Implementation Plan is subject to regular updating, that is tied to the inclusion of substances in the Annexes to the Stockholm Convention. The text of the first implementation plan approved by Government Resolution no. 1572 of 7 December 2005. Updated National Implementation Plan was prepared from 2010 to 2012.

As stated in the Implementation Plan, Handling wastes containing POPs is regulated by Act no. 185/2001 Coll., on waste and amending certain other laws. This Act is in the case of dealing with POPs, in fact, only referring to Regulation (EC) No 850/2004 on Persistent Organic Pollutants. **In consequence, the Czech law again only allows the limit possibilities of disposal of EPS and XPS materials, which are its physico-chemical treatment, incineration and incineration as an alternative fuel.**

**Any facility wanting to incinerate or co-incinerate waste has to demonstrate the valid permission to such activity.** Since 1 September 2012 authorizing is subjected to § 11 and 12 of Act no. 201/2012 Coll., on the protection of the air. According to the § 32 of mentioned Act, any waste incinerator with authorization also has to choose a person suitable for authorization for pollution measurement. Further, **compliance with emission limits under Annex no. 4 to Decree no. 415/2012 Coll. is required.** This decree also sets specific conditions for emission measurements for materials containing persistent organic compounds. **Last requirement is the so called Integrated Authorization.** Act no. 76/2002 Coll., on integrated pollution prevention and control, integrated pollution register and amending some other laws.

The originator of waste and the beneficiary are obliged to classify waste category. The classification of XPS and EPS might be problematic. POPs are classified as hazardous waste, however, no property listed in Annex 2 to the Act no. 185/2001 Coll., on waste was proven for XPS and EPS insulations. In consequence, XPS and EPS that became waste are generally not considered hazardous waste and therefore might be added into the mixture of waste used as fuel without any impact on emission limits and related measurements. **However, extensive legislative assessment of this issue is advisable as well as a stronger stance of the Czech legislation on waste containing POPs and their subsequent disposal.**

**Significant help for energetic use of combustible waste would be a single legislative classification of wastes as fuels with $CO_2$ neutral effect, similarly as in the case of biomass. Ecological assessment would be necessary, however,** if the same material that could be co-incinerated as fuel ends up in an incinerator or a landfill of municipal waste, it is not required by law to buy allowances to greenhouse gas emission. The same principle should be suitable for co-incineration in cement plants as well.

Further, the principle of sanctions for infringements related to the issue of waste containing POP should be specified in a clear way in the Czech legislation similar too penalties for violations of regulations on hazardous waste management.

## 9.2 Possibilities of Disposal

Naturally, incineration of any alternative fuel including EPS and XPS elsewhere than in waste incineration plants is dependent on technological possibilities but also on the legislation. According to the currently granted permissions to waste incineration and co-incineration, **the only possibilities are waste incinerators and also the five cement plants in the Czech Republic**, however, only four of them currently co-incinerate waste. All potential possibilities are listed in Table 14 and Table 15. Out of those, mainly 4 cement plants and 3 municipal waste incinerators will gain significant energetic benefit from incineration of polystyrene waste. By 2016 new municipal waste incinerator (ZEVO Chotíkov operated by the company Plzeňská teplárenská, a.s.) should start operation.

Legislative permits also possibilities of pre-treatment of the waste containing POP. Such process might be for instance sortorder, cleaning and compressing polystyrene waste up to 600 kg/m$^3$. Such product has verified and consistent quality and physical properties and could be eventually used as a fuel for different technologies. **It could be the subject of further research to find economically and technologically reasonable utilization of such product.**

## 9.3 Economy and Impact of Upcoming Changes

The total annual amount of EPS and XPS waste could be expected in the thousands tons in next 5 years and in tens of thousands after 2019. **It will not be problematic to energetically utilize such amount of polystyrene waste using current possibilities. Physical properties, mainly the heating value, and described legislation changes may lead to increased demand for such material.**

Typical circumstances when handling waste are such that the waste generator would pay for the drop-off of his waste and related services to the logistics company, which consequently deals with the waste. During the next steps the logistics company pays the landfill, waste incinerator, the cement plant or other waste processor for taking over the waste and the disposal, storage, processing or landfilling follows.

The past has shown that under certain market conditions, it is possible to break this chain when valuable application for a specific type of waste material is found and it is reasonable to pay for such waste at the same time. Examples are waste oils and paper.

Related to the decreasing heating value of the municipal waste and the effort of the EU to ban incineration of any material that could be recycled (among others plastics and paper, both materials with high heating value) by 2020, the EPS and XPS waste might become valuable additive for reaching needed energetic value of waste mixtures in order to reach economically reasonable energetic compensation by incinerating or co-incinerating waste. This problem became apparent in a municipal waste incinerator in Germany, where the larger quantities of waste (compared to the Czech Republic) are sorted and recycled already. **The possibility of repurchase of polystyrene waste is therefore strongly dependent on future legislation changes and cannot be excluded.**

In the future, as well as today, it will be up to the waste generators to monitor market development and negotiate advantageous conditions with any possible user of polystyrene waste**. It is not reasonable to expect repurchase of polystyrene in near future, however, material potential of polystyrene could have a positive impact on demand in several years, the latest with changes in legislation which will come by 2020.**

**Especially smaller construction companies specializing in insulation work and reconstruction of facades should follow the development of the problem with waste management.** In the future, specific position of EPS and XPS containing flame retardant HBCDD on the market with wastes may favorably affect the total expenses on demolition of buildings or renovation of facades.

Significant difficulty for the person responsible for disposal of waste might be the **transportation expenses considering the availability of incinerators compared to common previous solution – landfilling.**

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## 10.2 Legislative Documents

### 10.2.1 International Legislative Documents

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Commission Regulation (EU) No 756/2010 of 24 August 2010 amending Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants as regards Annexes IV and V

Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

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Stockholm Convention on Persistent Organic Pollutants

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