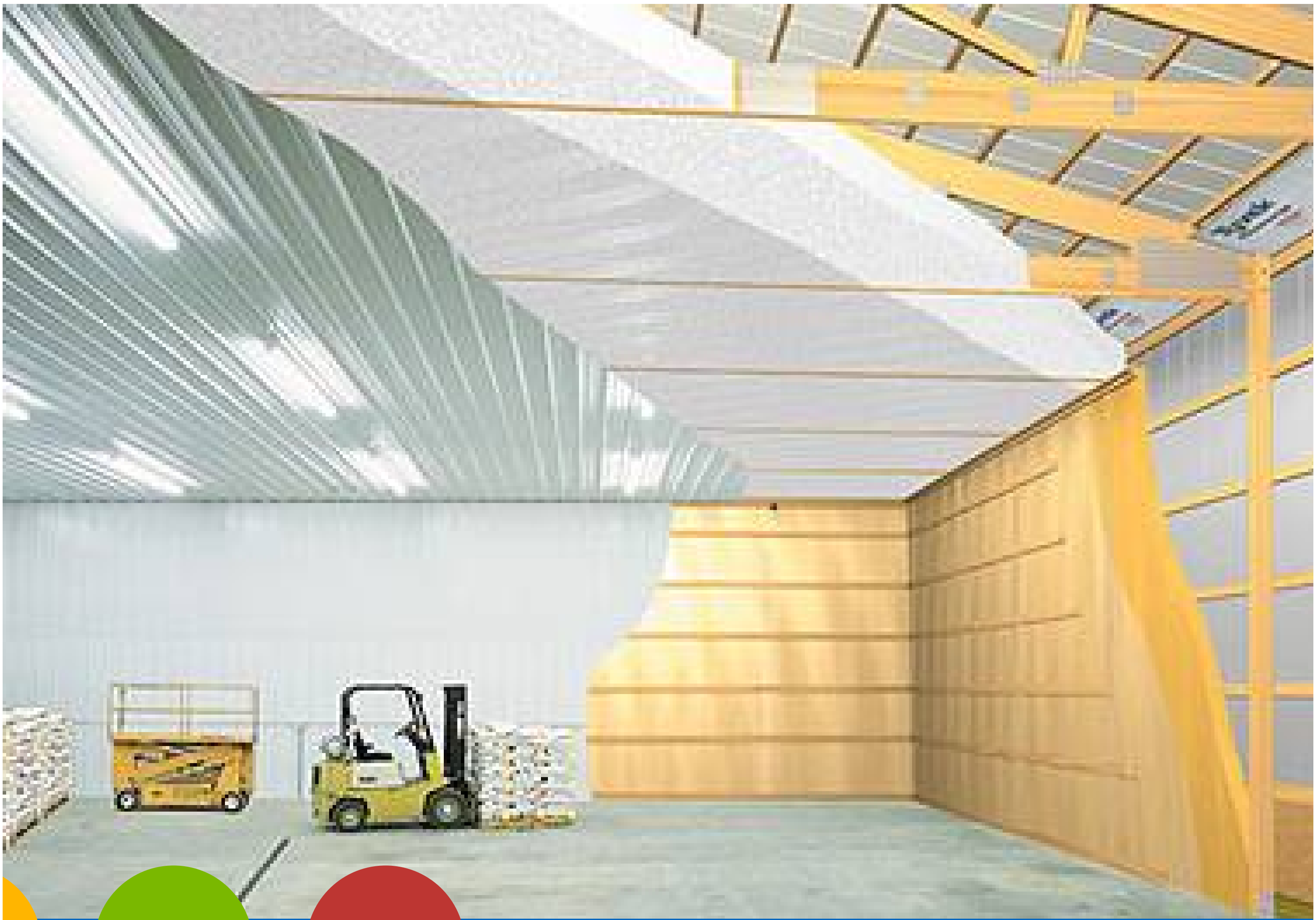

Eco-profiles and Environmental Product Declarations of the European Plastics Manufacturers

Expandable Polystyrene (EPS)
PlasticsEurope
February 2015

PlasticsEurope
Association of Plastics Manufacturers

Table of Content

Environmental Product Declaration

Introduction

This Environmental Product Declaration (EPD) is based upon life cycle inventory (LCI) data from the GaBi database 2013 fulfilling the requirements on PlasticsEurope's Eco-profile programme. It has been prepared according to **PlasticsEurope's Eco-profiles and Environmental Declarations – LCI Methodology and PCR for Uncompounded Polymer Resins and Reactive Polymer Precursors** (PCR version 2.0, April 2011). EPDs provide environmental performance data, but no information on the economic and social aspects which would be necessary for a complete sustainability assessment. EPDs do not imply a value judgment between environmental criteria.

This EPD describes the production of expandable polystyrene from cradle to gate (from crude oil extraction to beads at plant, i.e. EPS production site output). **Please keep in mind that comparisons cannot be made on the level of the polymer material alone**: it is necessary to consider the full life cycle of an application in order to compare the performance of different materials and the effects of relevant life cycle parameters. This EPD is intended to be used by member companies, to support product-orientated environmental management; by users of plastics, as a building block of life cycle assessment (LCA) studies of individual products; and by other interested parties, as a source of life cycle information.

Meta Data

Data Owner	PlasticsEurope aisbl
LCA Practitioner	PE INTERNATIONAL AG
Programme Owner	PlasticsEurope aisbl
Programme Manager, Reviewer	DEKRA Assurance Services GmbH
Number of plants included in data collection	4 for grey material 13 for white material (summed up in 10 sets of data collections)
Representativeness	80%
Reference year	2013
Year of data collection and calculation	2014
Expected temporal validity	2023
Cut-offs	No significant cut-offs
Data Quality	Good
Allocation method	none

Description of the Product and the Production Process

Expandable Polystyrene (EPS) is a polymer produced in the form of beads containing polystyrene, pentane as a blowing agent (up to 7 mass%) and possibly flame retardant.

It exists in two forms: White EPS beads, and grey EPS beads that contain carbon for improved insulation properties. Beads are further processed into expanded polystyrene, a lightweight, rigid, insulating material used to make foam blocks and molded parts.

Production Process

Expandable Polystyrene (EPS) is produced by polymerisation of styrene monomer, a chain-growth reaction which is mostly initiated by free radical organic initiators. EPS beads are produced by suspension polymerisation, extrusion or mass pelletisation.

The reference flow, to which all data given in this EPD refer, is 1 kg of average EPS beads (including white and grey material).

Data Sources and Allocation

The main data source is a primary data collection from European producers of white and grey EPS beads, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: ten white EPS beads producers with thirteen plants in nine different European countries; four grey EPS producers with four plants in four European countries.

This covers more than 80 % of the European white and grey EPS beads production (EU-27) in 2013, respectively.

The data for the upstream supply chain until the precursors (styrene) are taken from the database of the software system GaBi 6 [GaBi 6].

A mix of two different routes for the production of styrene (EBSM and POSM) is modelled. All relevant background data, such as energy and auxiliary materials, is from the GaBi 6 database; the documentation is publicly available [GaBi 6].

Use Phase and End-of-Life Management

EPS beads are foamed in order to manufacture lightweight industrial and food packaging, insulation boards for construction, safety and sporting equipment, flotation devices, seed trays, geofoam etc. The building and construction sector is the main market and accounts for around 70% of the European EPS market.

Polystyrene, without the flame retardant HBCD, can be reused directly as new packaging, or ground for reuse as soil conditioner or in light concrete blocks; it can also be recycled in new PS-based products; furthermore, energy recovery by incineration is also possible for all types of EPS.

Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg EPS.

Input Parameters

Indicator	Unit	Value
Non-renewable energy resources[1)]	MJ	84.60
• Fuel energy	MJ	41.11
• Feedstock energy	MJ	43.49
Renewable energy resources (biomass)[1)]	MJ	0.99
• Fuel energy	MJ	0.48
• Feedstock energy	MJ	0.51
Abiotic Depletion Potential		
• Elements	kg Sb eq	1.30E-06
• Fossil fuels	MJ	76.59
Renewable materials (biomass)	kg	-
Water use (key foreground process level)	kg	16.72
• for process	kg	na
• for cooling	kg	na
[1)] Calculated as upper heating value (UHV) na= not available – details see table 9		

Output Parameters

Indicator	Unit	Value
GWP	kg CO_2 eq	2.37
ODP	g CFC-11 eq	1.84E-07
AP	g SO_2 eq	6.46
POCP	g Ethene eq	1.21
EP	g PO_4 eq	0.57
Dust/particulate matter[2)]	g PM10	2.90E-04
Total particulate matter[2)]	g	2.28E-01
Waste		
• Radioactive waste	kg	6.06E-04
• Non-radioactive waste [3)]	kg	4.84E-02
[2)] Including secondary PM10 [3)] Non-radioactive wastes include: spoil, tailings, and waste, deposited		

Additional Environmental and Health Information

Non Flame Retardant Expandable Polystyrene can be safely used for food packaging applications.

With the development of the knowledge on the impact on health and environment of chemical substances, it was understood that HBCD, the flame retardant additive used for many years where needed to ensure the fire safety of the end uses of the expanded polystyrene applications, has PBT (Persistent, Bio accumulative and Toxic) properties according to the criteria set by the European law on the classification of chemical substances (REACH). Recently, within the UNEP (UN Environment Programme) Stockholm Convention, it was decided to classify HBCD as a POP (Persistent Organic Pollutant). Both regulatory frameworks target for such kind of chemicals for phase-out.

When the properties of HBCD began to be better understood, the EPS industry, following the Responsible Care principles, jointly began a search for safer and viable alternatives. Such new additives, safe for health and environment, can now replace HBCD.

The switch to the new flame retardant alternatives for HBCD is already initiated and partly realised. The members of the European industry of EPS are fully committed to complete swiftly such change as soon as technically viable considering all the boundaries in place such as product certification, additive availability, such that in some cases the change-over might be feasible and implemented before the phase out date. Industry has a continuous liaising with all relevant authorities to ensure that there will a smooth transition within the regulatory framework.

Additional Technical Information

The outstanding quality of expandable polystyrene lies in its performance (strength, thermal insulation,…) to weight ratio. It is also a versatile and easy to process material. Furthermore, grey EPS offers enhanced insulation properties.

Additional Economic Information

Expandable Polystyrene can be processed to very low densities – once expanded, it actually consists of 98% air and 2% polystyrene, which allows reduction of packaging weight, non-renewable resource savings, reduction of packaged goods transportation costs.

Building insulation using polystyrene foam boards enables energy savings within one year which exceed the energy used to manufacture the insulation products, but which last more than 50 years.

Information

Data Owner

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E-mail: info@plasticseurope.org.

Programme Manager & Reviewer
DEKRA Assurance Services GmbH
This Environmental Product Declaration has been reviewed by DEKRA Assurance Services GmbH. It was approved according to the Product Category Rules PCR version 2.0 (2011-04) and ISO 14025:2006.
Registration number: PlasticsEurope 2015-002, validation expires on 31 December 2017 (date of next revalidation review).

Programme Owner

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E-mail: info@plasticseurope.org.

For copies of this EPD, for the underlying LCI data (Eco-profile); and for additional information, please refer to http://www.plasticseurope.org/.

References

PlasticsEurope: Eco-profiles and environmental declarations – LCI methodology and PCR for uncompounded polymer resins and reactive polymer precursors (version 2.0, April 2011).

Plastics
The Material for the 21st Century

Goal & Scope

Intended Use & Target Audience

Ø Eco-profiles (LCIs) and EPDs from this programme are intended to be used as »cradle-to-gate« building blocks of life cycle assessment (LCA) studies of defined applications or products. LCA studies considering the full life cycle (»cradle-to-grave«) of an application or product allow for comparative assertions to be derived. It is essential to note that comparisons cannot be made at the level of the polymer or its precursors. In order to compare the performance of different materials, the whole life cycle and the effects of relevant life cycle parameters must be considered.

PlasticsEurope Eco-profiles and EPDs represent polymer production systems with a defined output. They can be used as modular building blocks in LCA studies. However, these integrated industrial systems cannot be disaggregated further into single unit processes, such as polymerisation, because this would neglect the interdependence of the elements, e.g. the internal recycling of feedstocks and precursors between different parts of the integrated production sites.

PlasticsEurope Eco-profiles and EPDs are prepared in accordance with the stringent ISO 14040–44 requirements. Since the system boundary is »cradle-to-gate«, however, their respective reference flows are disparate, namely referring to a broad variety of polymers and precursors. This implies that, in accordance with ISO 14040–44, a direct comparison of Eco-profiles is impossible. While ISO 14025, Clause 5.2.2 does allow EPDs to be used in comparison, PlasticsEurope EPDs are derived from Eco-profiles, i.e. with the same »cradle-to-gate« system boundaries.

As a consequence, a direct comparison of Eco-profiles or EPDs makes no sense because 1 kg of different polymers are not functionally equivalent.

Once a full life cycle model for a defined polymer application among several functionally equivalent systems is established, and only then, can comparative assertions be derived. The same goes for EPDs, for instance, of building product where PlasticsEurope EPDs can serve as building blocks.

Eco-profiles and EPDs are intended for use by the following target audiences:

- member companies, to support product-orientated environmental management and continuous improvement of production processes (benchmarking);
- downstream users of plastics, as a building block of life cycle assessment (LCA) studies of plastics applications and products; and
- other interested parties, as a source of life cycle information.

Product Category and Declared Unit

Product Category

The core product category is defined as **uncompounded polymer resins and reactive polymer precursors**. This product category is defined »at gate« of the polymer or precursor production and is thus fully within the scope of PlasticsEurope as a federation. In some cases, it may be necessary to include one or several additives in the Eco-profile to represent the polymer or precursor »at gate«. For instance, some polymers may require a heat stabiliser, or a reactive precursor may require a flame retardant. This special case is distinguished from a subsequent compounding step conducted by a third-party downstream user (outside PlasticsEurope's core scope).

Functional Unit and Declared Unit

The default Functional Unit and Declared Unit of PlasticsEurope Eco-profiles and EPDs are (unless otherwise specified[1]):

1 kg of Expandable Polystyrene beads – based on average white and grey material, respectively, »at gate« (production site output) representing a European industry production average.

Product and Producer Description

Product Description

Expandable Polystyrene is a thermoplastic polymer, used after expansion in many applications such as lightweight industrial and food packaging, disposable cups, insulation boards for construction, safety and sporting equipment, flotation devices, seed trays, geofoam…

White Expandable Polystyrene
CAS no. 9003-53-6
Chemical formula (C8H8)n
Gross calorific value ca. 42.4 MJ/kg

Grey Expandable Polystyrene
CAS no. 9003-53-6
Chemical formula (C8H8)n x C
Gross calorific value 41.9 – 42.4 MJ/kg (depending on carbon content)

Production Process Description

Expandable Polystyrene (EPS) is most commonly made using a suspension polymerisation process. Styrene charged with organic peroxide initiators is added to an aqueous phase and forms a suspension upon stirring. Flame retardant and elemental carbon, as well as auxiliaries such as suspension stabilisers, chain transfer agents, expanding aids, nucleating agents and plasticisers can also be added.

[1] Exceptions can occur when reporting Eco-profiles of, for instance, process energy, such as on-site steam, or conversion processes, such as extrusion.

The styrene droplets polymerise to polystyrene during heating of the reactor between 80 and 150°C. Blowing agent, typically pentane, is added to the reactor during polymerisation and dissolves in the polymer, producing the Expandable Polystyrene bead.
After the reactor is cooled, the polymer is separated from the water phase using a centrifuge. The EPS beads are dried and sieved into the required size fractions before being coated with additive, which aids the conversion process and final foam properties.
The EPS beads may also be produced by applying a melt process. In a first step styrene is polymerised to polystyrene. Afterwards pentane and other additives are mixed into the polystyrene melt; the final product is formed to beads in a pelletisation equipment. A variation of this type of technology is called mass pelletisation: polystyrene from suspension polymerisation is re-melted in an extrusion process, further auxiliaries are added; the beads are produced with special pelletisation nozzles.

Producer Description

PlasticsEurope Eco-profiles and EPDs represent European industry averages within the scope of PlasticsEurope as the issuing trade federation. Hence they are not attributed to any single producer, but rather to the European plastics industry as represented by PlasticsEurope's membership and the production sites participating in the Eco-profile data collection. The following companies contributed to provide data to this Eco-profile and EPD:

- BASF SE

  Carl Bosch Str 38
  D-67056 Ludwigshafen
  Germany
  http://www.basf.com

- STYROCHEM FINLAND OY

  PO Box 360
  FI-06101 Porvoo
  Finland
  http://www.styrochem.fi

- GABRIEL TECHNOLOGIE S.A

  1, Rue de Roseaux
  7331 Baudour
  Belgium
  http://www.knauf.fr

- SUNPOR KUNSTSTOFF GmbH

  Tiroler Straße 14
  3105 St. Poelten
  Austria
  http://www.sunpor.at

- INEOS STYRENICS INTERNATIONAL SA

  Avenue des Uttins 3
  1180 Rolle
  Switzerland
  http://www.ineos.com

- SYNBRA TECHNOLOGY B.V.

  Zeedijk 25
  4871 NM Etten–Leur
  The Netherlands
  http://www.synbratechnology.nl

- JACKON GmbH

  Tonnenhofstrasse 16
  23970 Wismar
  Germany
  http://www.jackon.de

- VERSALIS S.p.A.

  Piazza Boldrini, 1
  20097 San Donato Milanese (MI)
  Italy
  http://www.versalis.eni.com

- RAVAGO SA

  Rue Notre-Dame 16
  2240 Luxembourg
  Luxembourg
  http://www.ravagoeps.com

- UNIPOL HOLLAND BV

  Rijnstraat 15-A
  5347 KL Oss
  The Netherlands
  http://www.unipol.nl

Eco-profile – Life Cycle Inventory

System Boundaries

PlasticsEurope Eco-profiles and EPDs refer to the production of polymers as a cradle-to-gate system (see Figure 1).

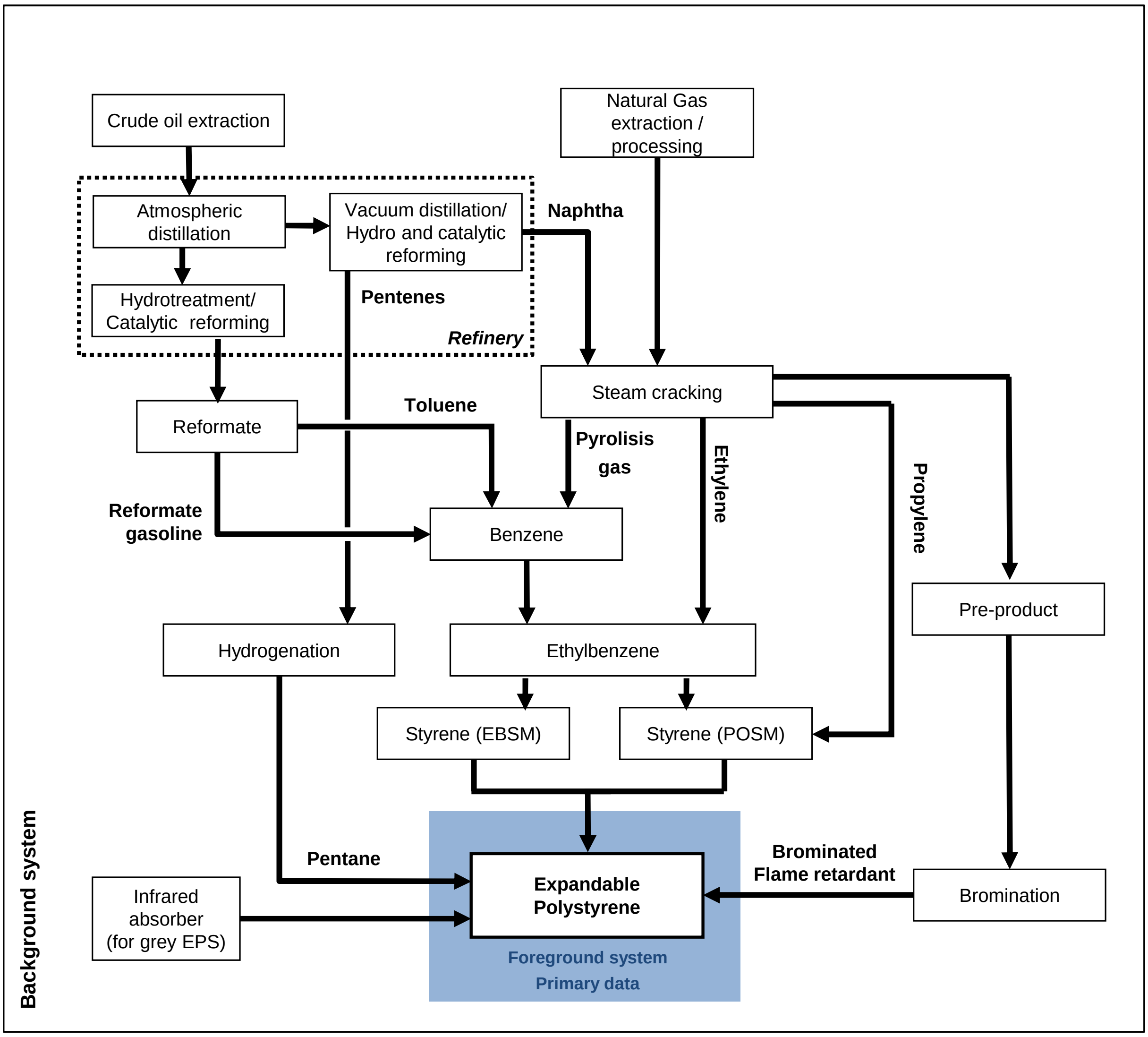


Figure 1: Cradle-to-gate system boundaries (EPS)

Technological Reference

The production processes are modelled using specific values from primary data collection at site. The main data source is a primary data collection from European producers of EPS, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: ten white EPS beads producers with thirteen plants in nine different European countries; four grey EPS producers with four plants in four European countries.

In a first step white and grey material has been assessed separately. Visible differences in the results of the considered impact categories are not due to input materials, but due to differences in data of single companies and less statistic compensation for grey material. Thus, average data as combination for white and grey material are declared.

The data cover 80% of the European EPS production (EU-27) in 2013. Primary data are used for all foreground processes (under operational control) complemented with secondary data for background processes (under indirect management control). The data for the upstream supply chain until the precursors are taken from the database of the software system GaBi 6 [GaBi 6].

As shown in Figure 1, two different routes for the production of styrene (EBSM and POSM) are modelled. The ethylbenzene styrene monomer (EBSM) process is based on the catalytic dehydrogenation of ethylbenzene and renders styrene as its main product and minor quantity of toluene as co-product. The propylene oxide styrene monomer (POSM) process involves the co-production of propylene oxide and styrene: in this case, ethylbenzene is oxidized to form ethylbenzene hydroperoxide (EBHP). The use of one or a mixture of both technologies is modelled according to site-specific information or as an assumption of a 50/50 mix as far as information is available.

Temporal Reference

The LCI data for production is collected as 12 month averages representing the year 2013, to compensate seasonal influence of data. Background data have reference years 2012 and 2010 for electricity and thermal energy processes. The dataset is considered to be valid until substantial technological changes in the production chain occur. In view of the latest technology development, the overall reference year for this Eco-profile is 2013, with a maximum temporal validity until 2023 for the foreground system.

Geographical Reference

Primary production data for EPS production are from ten different European suppliers. The inventories for the precursors and the energy supply are adapted according to site specific (i.e. national) conditions. Inventories for the group of “Other chemicals”, used in smaller amounts, refer to European conditions or geographical conditions as the datasets are available. Therefore, the study results are intended to be applicable within EU boundaries: adjustments might be required if the results are applied to other regions. EPS imported into Europe is not considered in this Eco-profile.

Cut-off Rules

In the foreground processes all relevant flows are considered, trying to avoid any cut-off of material and energy flows. In single cases additives used in the EPS foreground unit process (<0.1% m/m of product output) are neglected. In such cases, it is assured that no hazardous substances or metals are present in this neglected part. According to the GaBi database [GaBi 6], used in the background processes, at least 95% of mass and energy of the input and output flows are covered and 98% of their environmental relevance (according to expert judgment) are considered, hence an influence of cut-offs less than 1% on the total is expected. Transports for the main input materials (styrene) contribute less than 5% to the overall environmental burden. The contribution of transport of small material proportions is expected to be less than 1%; hence the transports for minor input amounts are excluded.

Data Quality Requirements

Data Sources

Eco-profiles and EPDs developed by PlasticsEurope use average data representative of the respective foreground production process, both in terms of technology and market share. The primary data are derived

from site specific information for processes under operational control supplied by the participating member companies of PlasticsEurope (see Producer Description).
The data for the upstream supply chain are taken form the life cycle database of the software system GaBi [GaBi 6]. Most of the background data used is publicly available and public documentation exists.

Styrene as the relevant intermediate originates from two different technology routes.
EBSM (ethyl benzene styrene monomer) is based on catalytic dehydrogenation of ethylbenzene, with styrene as its main product. The process for POSM (propylene oxide-styrene monomer) involves the oxidation of ethylbenzene; the process delivers styrene and propylene oxide.[2]
The environmental impacts of these two styrene production routes show differences of about 10%; this is in the range of common uncertainty conducting an LCA.
Both production routes are mainly based on benzene as a precursor for ethylbenzene. Benzene again is a product of different technology routes, which influences significantly the environmental burden in the supply chain. The applied data refer to the European mix based on current data on market availability of benzene by Petrochemicals Europe (Association of petrochemical producers): major benzene supply originates from pyrolysis gas (about 55%), about one third is produced via reformate production; the leftover proportion of 15% is produced via coal based production and toluene derivates.
The propylene inventory used in the POSM-route reflects the main production route from steam cracking.

Relevance

With regard to the goal and scope of this Eco-profile, the collected primary data of foreground processes are of high relevance, i.e. data was sourced from the most important EPS producers in Europe in order to generate a European production average. The environmental contributions of each process to the overall LCI results are included in the Chapter ‘Life Cycle Impact Assessment’.

Representativeness

The participating companies represent 80% of the European EPS production volume in 2013. This figure refers to an educated estimate of PlasticsEurope and the participating parties of this study. The selected background data can be regarded as representative for the intended purpose.

Consistency

To ensure consistency, only primary data of the same level of detail and background data from the GaBi 6 databases [GaBi 6] are used. While building up the model, cross-checks ensure the plausibility of mass and energy flows. The methodological framework is consistent throughout the whole model as the same methodological principles are used both in the foreground and background systems. In addition to the external review, an internal independent quality check was performed (see ‘Internal Independent Quality Assurance Statement’).

[2] More details on EBSM-POSM technology can be found in the Eco-profile “General-Purpose Polystyrene (GPPS) and High-Impact Polystyrene (HIPS), Registration number: PlasticsEurope 2012-004

Reliability

Data of foreground processes provided directly by producers are predominantly measured. Data of relevant background processes are measured at several sites – alternatively, they are determined from literature data, or estimated for some flows, which usually have been reviewed and quality checked.

Completeness

Primary data used for the gate-to-gate production of EPS covers all related flows in accordance with the above cut-off criteria. In this way all relevant flows are quantified and data is considered complete. The elementary flows covered in the model enable the impact assessment of all selected impact categories. Waste treatment is included in the model, so that only elementary flows cross the system boundaries.

Precision and Accuracy

As the relevant foreground data is primary data, or modelled based on primary information sources of the owners of the technologies, precision is deemed appropriate to the goal and scope.

Reproducibility

Reproducibility is given for internal use since the owners of the technologies provided the data under confidentiality agreements. Key information is documented in this report, and data and models are stored in the GaBi 6 software database. Sub-systems are modelled by ´state of art´ technology using data from a publicly available and internationally used database. It is worth noting that for external audiences, full and detailed reproducibility will not be possible for confidentiality reasons. However, experienced practitioners could reproduce suitable parts of the system as well as key indicators in a certain confidence range.

Data Validation

The data on production collected by the project partners and the data providing companies are validated in an iterative process several times. The collected data are validated using existing data from published sources or expert knowledge. The background information from the GaBi database is updated regularly and continuously validated.

Life Cycle Model

The study is performed with the LCA software GaBi 6 [GABI 6]. The associated database integrates ISO 14040/44 requirements. Due to confidentiality reasons details on software modelling and methods used cannot be shown here. However, provided that appropriate confidentiality agreements are in place, the model can be reviewed in detail; an external independent review has been conducted to this aim. The calculation follows the vertical calculation methodology (see below).

Calculation Rules

Vertical Averaging

When modelling and calculating average Eco-profiles from the collected individual LCI datasets, vertical averages are calculated (Figure 2).

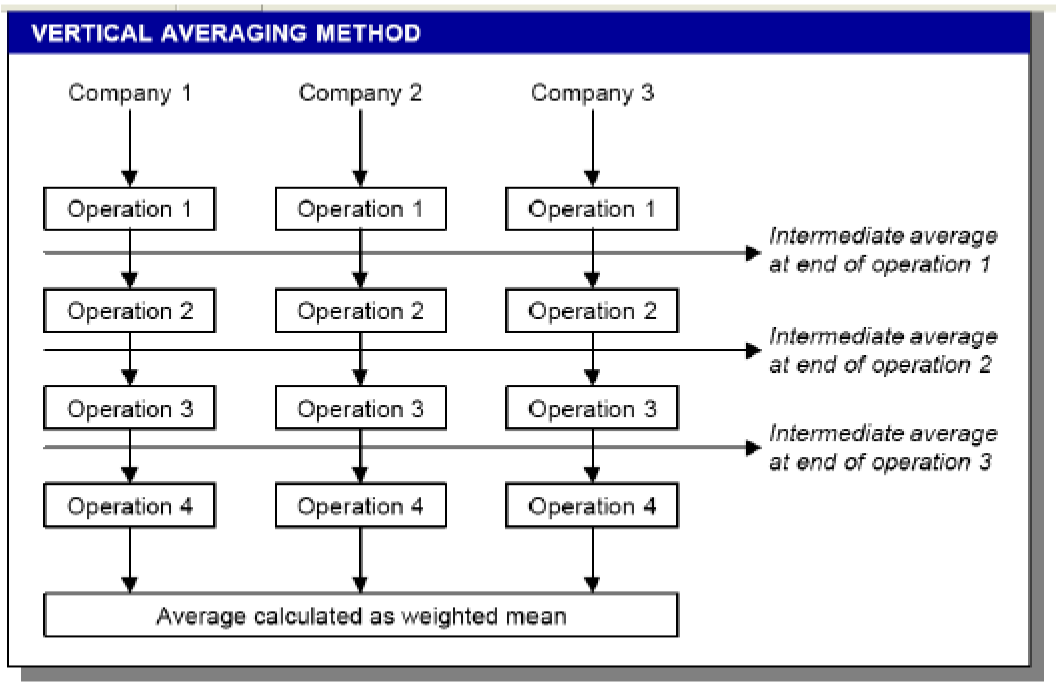


Figure 2: *Vertical Averaging (source: Eco-profile of high volume commodity phthalate esters, ECPI (European Council for Plasticisers and Intermediates, 2001)*

Allocation Rules

Production processes in chemical and plastics industry are usually multi-functional systems, i.e. they have not one, but several valuable product and co-product outputs. Wherever possible, allocation should be avoided by expanding the system to include the additional functions related to the co-products. Often, however, avoiding allocation is not feasible in technical reality, as alternative stand-alone processes do not exist or even alternative technologies show completely different technical performance and product quality output. In such cases, the aim of allocation is to find a suitable partitioning parameter so that the inputs and outputs of the system can be assigned to the specific product sub-system under consideration.

Foreground system

In some companies' information, output material with deviations from the required specification is reported. If these materials show only slight differences and are sold at comparable price-level, they are assumed as product output (< 2% of total production); in case of material declared as off-grade sent to recovery, neither further environmental burden nor credits are given to the modelled system (< 2% of total production).
No post-consumer waste is reported as input to the system, therefore no allocation between different life cycles is necessary.

Background system

In the refinery operations, co-production is addressed by applying allocation based on mass and net calorific value [GaBi 6]. The chosen allocation in downstream petrochemicals is based on several sensitivity analyses, which were reviewed by petrochemical experts. Materials and chemicals needed are modelled using the allocation rule most suitable for the respective product (mass, energy, exergy, economic). For further information on specific product see documentation.gabi-software.com.

Life Cycle Inventory (LCI) Results

Formats of LCI Dataset

The Eco-profile is provided in four electronic formats:

- § As input/output table in Excel®
- § As XML document in EcoSpold format (www.ecoinvent.org)
- § As XML document in ILCD format (http://lct.jrc.ec.europa.eu)
- § As LCI in GaBi format (www.gabi-software.com)

Key results are summarised below.

Energy Demand

As a key indicator on the inventory level, the **primary energy demand** (system input) of 85.59 MJ/kg indicates the cumulative energy requirements at the resource level, accrued along the entire process chain (system boundaries), quantified as gross calorific value (upper heating value, UHV).

As a measure of the share of primary energy incorporated in the product, and hence indicating a recovery potential, the **energy content in the polymer** (system output), quantified as the gross calorific value (UHV), is about 40 MJ/kg for EPS.

Table 1: Primary energy demand (system boundary level) per 1 kg EPS

Primary Energy Demand	**Value [MJ]**
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	40.00
Process energy (quantified as difference between primary energy demand and energy content of polymer)	45.59
Total primary energy demand	**85.59**

Consequently, the difference (Δ) between primary energy input and energy content in polymer output is a measure of **process energy** which may be either dissipated as waste heat or recovered for use within the system boundaries.

Table 2 shows how the total energy input (primary energy demand) is used as fuel or feedstock. Fuel use means generating process energy, whereas feedstock use means incorporating hydrocarbon resources into the polymer. Note that some feedstock input may still be valorised as energy; furthermore, process energy requirements may also be affected by exothermal or endothermal reactions of intermediate products. Hence, there is a difference between the feedstock energy input and the energy content of the polymer (measurable as its gross calorific value). Considering this uncertainty of the exact division of the process energy as originating from either fuels or feedstocks, as well as the use of average data (secondary data) in the modelling with different country-specific grades of crude oil and natural gas, the feedstock energy is presented as approximate data.

Table 2: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1 kg EPS

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	1.58	0.06		1.58
Oil	49.09	1.09	26.78	22.31
Natural gas	31.58	0.65	17.22	14.35
Lignite	0.81	0.06		0.81
Nuclear	1.53	3.39E-06		1.53
Biomass	0.00			0.00
Hydro	3.02E-01			0.30
Solar	4.68E-01			0.47
Geothermics	1.22E-02			0.01
Waves	2.20E-13			0.00
Wood	2.03E-11			0.00
Wind	2.13E-01			0.21
Other renewable fuels	0.00			0.00
Sub-total renewable	**0.99**	**0.00**	**0.00**	**0.99**
Sub-total Non-renewable	**84.60**	**1.85**	**44.00**	**40.60**
Total	**85.59**	**1.85**	**44.00**	**41.59**

Table 3 shows that nearly all of the primary energy demand is from non-renewable resources. Since the focus scope of PlasticsEurope and their member companies is the polymer production, Table 4 analyses the types of useful energy inputs in the polymerisation process: electricity has a minor contribution compared to thermal energy (heat). This represents the share of the energy requirement that is under operational control of the polymer producer (Figure 3). Accordingly, Table 5 shows that the majority (96%) of the primary energy demand is accounted for by upstream (pre-chain) processes. Finally, Table 6 provides a more detailed overview of the key processes along the production system, their contribution to primary energy demand and how this is sourced from the respective energy resources. This puts the predominant contribution of the production into perspective with the precursors (»pre-cursors«). In order to analyse these upstream operations more closely, please refer to the Eco-profiles and GaBi documentations of the respective precursors. It should be noted, however, that the LCI tables in the annex account for the entire cradle-to-gate primary energy demand of the EPS system.

Table 3: Primary energy demand by renewability per 1 kg EPS

Fuel/energy input type	Value [MJ]	%
Renewable energy resources	0.99	1%
Non-renewable energy resources	84.60	99%
Total	**85.59**	**100%**

Table 4: Analysis by type of useful energy (production – key foreground process level) per 1 kg EPS

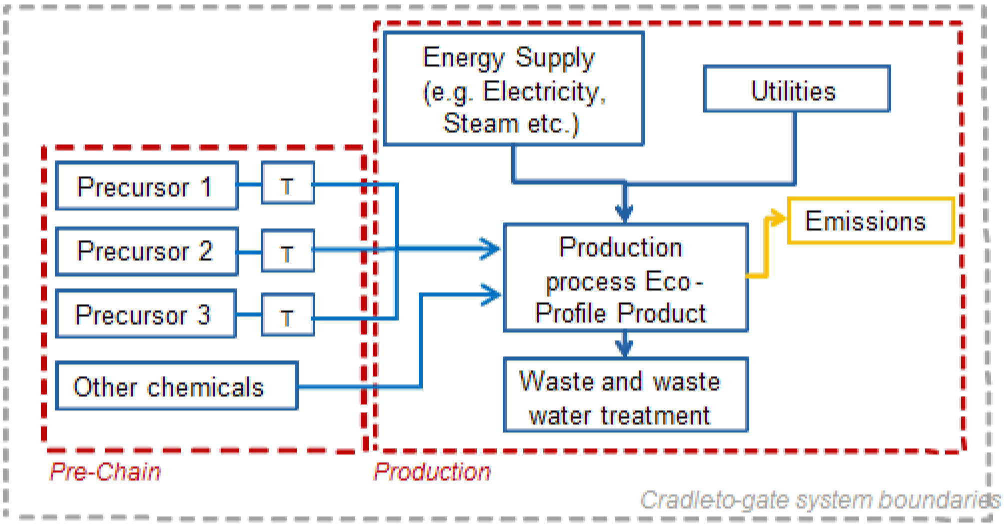
Type of useful energy in process input	**Value [MJ]**
Electricity	0.59
Heat, thermal energy	1.29
Other types of useful energy (relevant contributions to be specified)	0.00
Total (for selected key unit process)	1.88

Table 5: Contribution to primary energy demand (dominance analysis) per 1 kg EPS

Contribution to Primary Energy per segment	**Value [MJ]**	**%**
Production (electricity, steam, unit process, utilities, waste treatment)	3.58	4%
Pre-chain	82.01	96%
Total	**85.59**	**100%**

Table 6: Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1 kg EPS, see Figure 3

Total Primary Energy [MJ]	**Precursors**	**Other Chemicals**	**Utilities**	**Electricity**	**Thermal Energy**	**Transport**	**Process Waste Treatment**
Coal	1.30	0.07	0.06	0.16	0.00	0.01	1.19E-03
Oil	48.41	0.43	0.06	0.05	0.00	0.13	4.47E-03
Natural gas	29.17	0.20	0.10	0.59	1.55	0.02	-0.04
Lignite	0.61	0.03	0.05	0.11	0.00	0.01	-3.44E-04
Nuclear	1.04	0.05	0.07	0.36	0.00	0.01	-3.62E-03
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.16	7.41E-03	1.05E-02	0.12	7.72E-04	2.46E-03	-8.47E-04
Solar	0.26	0.12	1.93E-02	7.17E-02	7.58E-04	3.26E-03	-3.19E-04
Geothermics	8.40E-03	5.16E-04	3.19E-04	2.84E-03	7.31E-05	1.07E-04	-4.60E-05
Waves	1.70E-13	6.25E-15	1.47E-14	2.75E-14	3.39E-16	1.21E-15	-5.38E-17
Wood	1.57E-11	5.75E-13	1.35E-12	2.54E-12	3.38E-14	1.12E-13	-5.06E-15
Wind	0.16	6.92E-03	1.24E-02	3.67E-02	3.93E-04	1.80E-03	-4.19E-04
Other renewable fuels	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**81.10**	**0.90**	**0.39**	**1.50**	**1.56**	**0.18**	**-0.04**



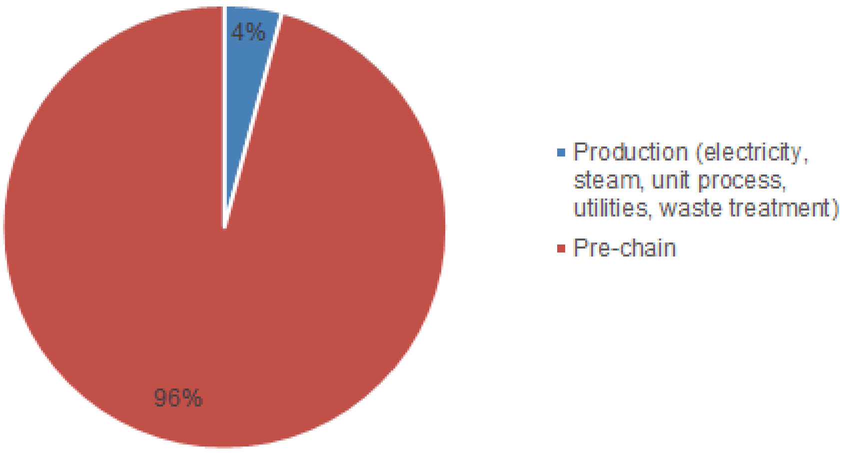


Figure 3: Contribution to primary energy demand per segment

Water Consumption

Table 7 shows the water use at cradle-to-gate level. Water use (incl. fresh- and seawater; blue- and green water) equals the measured water input into a product system or process. Water use is determined by total water withdrawal (water abstraction).

Table 7: Water use (fresh- and seawater; blue- and greenwater) table per 1 kg EPS (cradle-to-gate)

Input	**Value [kg]**
Water (ground water)	16.09
Water (lake water)	39.64
Water (rain water)	4.13
Water (river water)	1300.88
Water (sea water)	11.23
Water (fossil groundwater)	0.00
Overall water use [kg]	**1371.98**

Table 8 provide the corresponding freshwater part in the water balance. Freshwater is naturally occurring water on the Earth's surface in ponds, lakes, rivers and streams, as ice, and underground as groundwater in aquifers and underground streams. The term specifically excludes seawater and brackish water. Blue water refers to surface and groundwater used.

Table 8: Freshwater (blue water not including rain water) use table per 1 kg EPS (cradle-to-gate)

Input	**Value [kg]**
Water (ground water)	16.09
Water (lake water)	39.64
Water (river water)	1300.88
Water (fossil groundwater)	0.00
Total fresh water use [kg]	**1356.62**

Output	**Value [kg]**
Water (river water from technosphere, cooling water)	24.51
Water (river water from technosphere, turbined)	1314.08
Water (river water from technosphere, waste water)	6.09
Water (lake water from technosphere, cooling water)	0.00
Water (lake water from technosphere, turbined)	0.00
Water (lake water from technosphere, waste water)	0.00
Total fresh water release from technosphere (degradative use) [kg]	**1344.69**
Total fresh water consumption (blue water)	**11.93**

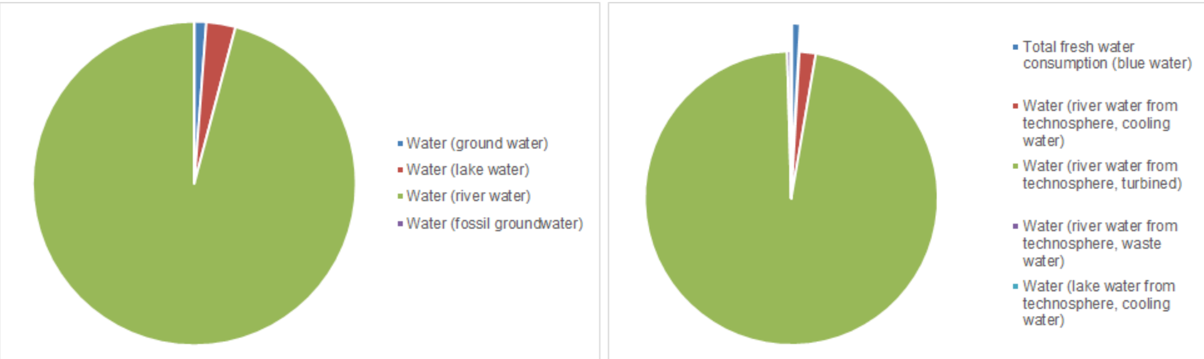


Figure 4: Total fresh water use (input) / water release (output) and water consumption (EPS)

Table 9 shows the water balance at key foreground process level.

Table 9: Water balance table per 1 kg EPS (key foreground process level)

Input	Value [kg]
Water (cooling water)[3]	0.00
Water (process water)	0.06
Water (deionised)	4.22
Water (tap water)	0.77
Water (ground water)	0.53
Water (river water)	4.72
Water (sea water)	6.41
Total water input	**16.72**
Output	**Value [kg]**
Water vapour	2.91
Water (waste water, untreated) to WWTP	2.91
Water direct released to the environment without WWTP	
Water (river water from technosphere, cooling water)	4.86
Water (river water from technosphere, turbined)	0.00
Water (river water from technosphere, waste water)	0.00
Water (sea water from technosphere, cooling water)	6.41
Water (sea water from technosphere, turbined)	0.00
Water (sea water from technosphere, waste water)	0.00
Water (lake water from technosphere, cooling water)	0.00
Water (lake water from technosphere, turbined)	0.00
Total water output	**17.10**

Air Emission Data

Table 10 shows a few selected air emissions which are commonly reported and used as key performance indicators; for a full inventory of air emissions, please refer to the complete LCI table in the annex of this report.

Table 10: Selected air emissions per 1 kg EPS

Air emissions	kg
Carbon dioxide, fossil (CO_2, fossil)	2.14
Carbon monoxide (CO)	1.24E-03
Methane (CH_4)	8.13E-03
Sulphur dioxide (SO_2)	3.84E-03
Nitrogen oxides (NO_x)	3.39E-03
Particulate matter • 10 µm (PM 10)	2.90E-07

[3] Cooling water can be processed (softened), deionised, tap, ground, river or sea water, dependent on the location, applied technology and necessary temperature level and site specific frame conditions. Data for differentiation of water amounts used for cooling and processing due to lack of specific meters only partly available.

Wastewater Emissions

Table 11 shows a few selected wastewater emissions which are commonly reported and used as key performance indicators; for a full inventory of wastewater emissions, please refer to the complete LCI table in the annex of this report.

Table 11: Selected water emissions per 1 kg EPS

Water emissions	kg
Biological oxygen demand after 5 days (BOD 5)	5.03E-05
Chemical oxygen demand (COD)	6.63E-04
Total organic carbon (TOC)	3.44E-05

Solid Waste

Table 12: Solid waste generation per 1 kg EPS (key foreground process level)

Waste for –	Incineration kg	Landfill kg	Recovery kg	Unspecified kg	Total kg
Non-hazardous	0.00	0.00	0.00	0.00	0.00
Hazardous	0.00	0.00	0.00	0.00	0.00
Unspecified	1.89E-03	0.00	1.41E-03	0.00	3.30E-03
Total	1.89E-03	0.00	1.41E-03	0.00	3.30E-03

The End-of-life scenarios for different waste fractions is considered in partial stream calculations; i.e. the resource depletion and emissions referring to incineration and landfilling and the respective credits for energy gain depend on calorific value and actual elementary composition, which is relevant for the life cycle assessment. This is independent from the official attribution into hazardous/non-hazardous categories not consistently provided in the data collection.

Life Cycle Impact Assessment

The results for the impact assessment are calculated applying characterisation factors according CML 2001, latest update April 2013.

Input

Natural Resources

Table 13: Abiotic Depletion Potential per 1 kg EPS

Natural resources	Value
Abiotic Depletion Potential (ADP), elements [kg Sb eq]	1.30E-06
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	76.59

Output

Climate Change

Table 14: Global Warming Potential (100 years) per 1 kg EPS

Climate change	kg CO_2 eq.
Global Warming Potential (GWP)	2.37

Acidification

Table 15: Acidification Potential per 1 kg EPS

Acidification of soils and water bodies	g SO_2 eq.
Acidification Potential (AP)	6.46

Eutrophication

Table 16: Eutrophication Potential per 1 kg EPS

Eutrophication of soils and water bodies	g PO_4^{3-} eq.
Eutrophication Potential (EP), total	0.57

Ozone Depletion

Table 17: Ozone Depletion Potential per 1 kg EPS

	g CFC-11 eq.
Ozone Depletion Potential (ODP)	1.84E-07

Summer Smog

Table 18: Photochemical Ozone Creation Potential per 1 kg EPS

	g Ethene eq.
Photochemical Ozone Creation Potential	1.21

Dust & Particulate Matter

Table 19: PM10 emissions per 1 kg EPS

Particulate matter	g PM10 eq.
Particulate matter ≤ 2.5 µm	7.44E-02
Particulate matter 2.5-10 µm	1.11E-01
Particulate matter ≤ 10 µm	2.90E-04
Particulate matter > 10 µm	4.19E-02
Particulate matter total	2.28E-01

Dominance Analysis

Table 20 shows the main contributions to the results presented above. A weighted average of the participating producers is used. In all analysed environmental impact categories, the precursors contributes to more than 80% of the overall impact. The grouping “Pre-cursors and Process” cover the environmental burden of the supply chain for styrene, pentane and flame retardant. The direct emissions of the polymerisation step are also included here. The production of deionised water, included in the group “Utilities” requires salt, which influences the impact category ADP elements significantly. The group “Other chemicals” covers additives, which also show significant influence to the category ADP elements and EP.

Electrical and thermal energy of the considered foreground production process contributes significantly.

Table 20: Dominance analysis of impacts per 1 kg EPS

	Total Primary Energy [MJ]	**ADP Elements [kg Sb eq.]**	**ADP Fossil [MJ]**	**GWP [kg CO_2 eq.]**	**AP [g SO_2 eq.]**	**EP [g PO_4^{3-} eq]**	**POCP [g Ethene eq.]**
Pre-cursors and Process	94.76%	79.29%	95.73%	90.47%	88.74%	79.93%	95.32%
Other chemicals	1.05%	5.96%	0.87%	1.17%	2.63%	5.99%	1.22%
Utilities	0.45%	13.24%	0.33%	0.89%	0.93%	1.67%	0.39%
Electricity	1.76%	0.80%	1.09%	2.73%	2.43%	2.37%	0.98%
Thermal Energy	1.82%	0.30%	1.83%	3.61%	1.12%	1.69%	1.00%
Transport	0.21%	0.04%	0.19%	0.50%	3.99%	4.74%	1.05%
Process waste treatment	-0.05%	0.38%	-0.04%	0.63%	0.16%	3.62%	0.03%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Comparison of the Present Eco-profile with its Previous Version (2003/2006)

Table 21 compares the present results with the previous version of the Eco-profiles of EPS.

Table 21: Comparison of the present Eco-profile of EPS with its previous version (2003/2006)

Environmental Impact Categories	**Eco-profile EPS (2003/2006)**	**Eco-profile EPS (2014)**	**Difference**
Gross primary energy from resources [MJ]	92.01	84.60	-8.1%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	3.54E-07	1.30E-06	266.1%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	82.29	76.59	-6.9%
Global Warming Potential (GWP) [kg CO_2 eq.]	3.38	2.37	-29.9%
Acidification Potential (AP) [g SO_2 eq.]	1.12E-02	6.46E-03	-42.5%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	9.30E-04	5.74E-04	-38.3%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	-	1.84E-07	
Photochemical Ozone Creation Potential [g Ethene eq.]	1.53E-03	1.21E-03	-21.0%

Table 21 shows a significant reduction of the environmental impact of EPS between the two versions. Since the previous model is unavailable for review, interpretations and explanations are based on the current results and PE INTERNATIONAL's experience.

The dominance analysis above shows that both precursors' data and the energy data are significant for the Eco-profiles. Therefore, improvements in the performance of the supply chain processes as well as reduction of the consumed energy are reflected here.

The higher difference in percentage variation regarding ADP elements should be treated with great caution. The absolute values are very small figures, hence the values are still displaying the same order of magnitude.

Other factors that have an influence on the current results in reference to the previous study can be qualitatively summarised as follows.

- Changes in the foreground and background system:

- Higher efficiency due to plants with higher production capacities
- Improvements in energy management in the supply chain and the processing itself
- Changes in the energy carrier mix used in the overall process chain
- Stricter pollution and emissions control, such as exhaust air purification (POCP)
- Changes in the electricity grid mix, in particular electricity from renewables becoming relevant, caused improvements in all impact categories.

- Methodological changes:
  - Compared with the 2006 version, the system boundaries now include the waste treatment of all wastes occurring in the process, so that only elementary flows cross the system boundary: this causes small changes in all impact categories. Please note that for the sake of comparability, waste arising is also reported on a foreground unit process level.
  - More detailed data collection, e.g. so far unspecified VOC data is now replaced by data for specific emissions or at least NMVOC and methane emissions, leading to higher burdens in POCP results.

Reviews

Internal Independent Quality Assurance Statement

As part of the overall quality assurance during the preparation of this Eco-profile, *PE INTERNATIONAL AG* conducted an internal review of this work.

Internal Independent Quality Assurance Statement

On behalf of PE INTERNATIONAL AG and its subsidiaries

Document prepared by	Angela Schindler
Title	Project Manager
Signature	
Date	16.10.2014
Quality assurance by	Thilo Kupfer
Title	Quality Manager Central Europe
Signature	
Date	20.10.2014
Approved by	Hannes Partl
Title	Regional Director Central Europe, Service
Signature	
Date	22.10.2014

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If you have any suggestions, complaints, or any other feedback, please contact PE at servicequality@pe-international.com.

External Independent Review Summary

The subject of this critical review is the development of the Eco-profile for Expandable Polystyrene (EPS) including white and grey material.

The review process included various meetings/web-conferences between the LCA practitioner and the reviewer, which encompassed a model and database review and spot checks of data and calculations. Furthermore, the final Eco-profile report was reviewed by the reviewer as well as industry participants involved in this project. All questions and recommendations were discussed with the LCA practitioner, and the report was adapted and revised accordingly.

Primary industry data were collected for the foreground processes comprising the production of white and grey EPS and taking into account the specific production processes of the participating companies. Background data representing the main precursor, i.e. styrene as well as all other material and energy inputs were taken from the GaBi database. Primary industry data was collected from 10 white EPS producers with 13 plants in 9 different European countries and 4 grey EPS producers with 4 plants in 4 different European countries, which lead to an estimated overall representativeness of >80% of the installed European EPS production capacity.

The potential environmental impacts for EPS are dominated (≥80%) by the precursor product styrene across all impact categories. Electricity and thermal energy needed for EPS production also have a significant impact (about 6% for GWP). The results for ADP elements are also influenced by the use of deionised water which requires salt and other additives.

The Eco-profile report also includes a comparison of the results with the previous version of the EPS Eco-profile. However, due to reasons outlined in the main report, a detailed analysis of the reasons for the differences is difficult and should be treated with great caution.

The LCA practitioners have demonstrated very good competence and experience, with a track record of LCA projects in the chemical and plastics industry. The critical review confirms that this Eco-profile adheres to the rules set forth in the PlasticsEurope's Eco-profiles and Environmental Declarations – LCI Methodology and PCR for Uncompounded Polymer Resins and Reactive Polymer Precursors (PCR version 2.0, April 2011). As a result, this dataset is assessed to be a reliable and high quality representation of EPS produced in Europe.

Name and affiliation of reviewer:

Reviewer: Matthias Schulz – Product Line Manager, Product Sustainability, *DEKRA Assurance Services GmbH*, Stuttgart, Germany

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