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

General-Purpose Polystyrene (GPPS) and High-Impact Polystyrene (HIPS)

PlasticsEurope

November 2012

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Environmental Product Declaration

Introduction

This Environmental Product Declaration (EPD) is based upon life cycle inventory (LCI) data from 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 the General Purpose Polystyrene (GPPS) and High Impact Polystyrene (HIPS) polymer from cradle to gate (from crude oil extraction to granules or resin at plant, i.e. polystyrene 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, Product Group Styrenics
LCA Practitioner	PE International AG
Programme Owner	PlasticsEurope aisbl
Programme Manager, Reviewer	DEKRA Consulting GmbH
Number of plants included in data collection	13 (GPPS) 11 (HIPS)
Representativeness	95%
Reference year	2010
Year of data collection and calculation	2012
Expected temporal validity	2022
Cut-offs	No significant cut-offs
Data Quality	Very good
Allocation method	Price allocation

Description of the Product and the Production Process

General Purpose Polystyrene (GPPS) is a hard, transparent material with a high gloss. High Impact Polystyrene (HIPS) is a white, non-shiny and basically opaque, but relatively flexible, rubber-modified polystyrene, that has high impact strength, high stiffness and excellent moldability, but reduced transparency.

Production Process

Polystyrene is produced by polymerisation of styrene monomer, a chain-growth reaction which is induced by any known initiation techniques such as heat, free radical organic initiator, anionic or cationic initiating systems, or coordination-insertion organometallic initiating complexes. Both GPPS and HIPS are produced by continuous-mass radical polymerisation of styrene; in case of HIPS, it is a polymerisation of polybutadiene rubber in a styrene solution. The reference flows, to which all data given in this EPD refer, are 1 kg of GPPS and 1 kg of HIPS pellets, respectively.

Data Sources and Allocation

The main data source was a primary data collection from European producers of GPPS and HIPS, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: six GPPS producers with thirteen plants in nine different European countries; six HIPS producers with eleven plants in eight European countries. This covers 95 % of the European GPPS and HIPS production capacity (EU-27) in 2010, respectively. With the exception of one company which delivered primary data for styrene due to specific technology, the data for the upstream supply chain until the precursors are taken from the database of the software system GaBi 5 [GABI 5 2011]. Two different routes for the production of styrene (EBSM and POSM) were modelled as per the actual supply situation. All relevant background data, such as energy and auxiliary materials, is from the GaBi 5 database, but is also publicly available and documented [GaBi 5 2011]. Price allocation was applied where off-grade GPPS and HIPS was relevant.

Use Phase and End-of-Life Management

GPPS and HIPS are used in many applications such as food and non-food packaging, disposable cups and cutlery, furniture, toys and consumer goods, as well as electronics and appliances. Polystyrene is also easily foamed in order to manufacture insulation boards and lightweight foamed packaging. The packaging market is the main market and accounts for around one half of the European polystyrene market. Extrusion can be in form of plates, sheet, or foam boards. In a secondary process step extruded sheet can be thermoformed, for example into disposables such as trays and containers. Typical injection moulding applications are televisions housing and toys. HIPS is also used to make engineering resin blends with polyphenylene oxide for the automotive industry, electrical appliances, and electronics. Polystyrene can be recycled mechanically several times without deteriorating physical properties; furthermore, energy recovery is also possible.

Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg GPPS and 1 kg of HIPS.

Input Parameters

Indicator	Unit	Value	
		GPPS	HIPS
Non-renewable energy resources[1]	MJ	82.26	86.43
• Fuel energy	MJ	33.96–37.96	38.13–42.13
• Feedstock energy	MJ	44.3–48.3	49.3–48.3
Renewable energy resources (biomass)[1]	MJ	0.52	0.56
• Fuel energy	MJ	0.52	0.56
• Feedstock energy	MJ	–	–
Abiotic Depletion Potential			
• Elements	kg Sb eq	9.21E-07	1.04E-06
• Fossil fuels	MJ	74.70	78.46
Renewable materials (biomass)	kg	–	–
Water use (key foreground process level)	kg		
• for process	kg	0.51	0.78
• for cooling	kg	12.93	11.38
[1] Calculated as upper heating value (UHV)			

Output Parameters

Indicator	Unit	Value	
		GPPS	HIPS
GWP	kg CO_2 eq	2.25	2.43
ODP	g CFC-11 eq	1.63E-05	1,72E-05
AP	g SO_2 eq	5.38	5.65
POCP	g Ethene eq	0.85	0.90
EP	g PO_4 eq	0.48	0.51
Dust/particulate matter[2]	g PM10	0.15	0.15
Total particulate matter[2]	g	0.17	0.18
Waste			
• Radioactive waste	kg	5.50E-04	5.82E-04
• Non-radioactive waste [3]	kg	1.5E-02	1.4E-02
[2] Including secondary PM10			
[3] Non-radioactive wastes include: spoil, tailings, and waste, deposited			

Additional Environmental and Health Information

Polystyrene can be safely used for food packaging applications.

Additional Technical Information

The main properties of polystyrenes are high stiffness, low density, excellent processability and a low heat capacity value leading to process energy reduction. They also exhibit superior thermal and electrical insulation properties. Further, GPPS offers excellent optical clarity, and HIPS good mechanical properties, such as toughness.

Additional Economic Information

Due to high stiffness and low density, all articles made from polystyrene have excellent strength-to-weight ratio, offering many environmental benefits such a reduction of weight, non-renewable resource savings, transportation costs and carbon footprint. Polystyrene foaming can reduce density by a factor of 35 that allows significant savings on resources and cost of packaging. 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

Product Group Styrenics, PlasticsEurope
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B-1160 Brussels, Belgium
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E-mail: info@plasticseurope.org.

Programme Manager & Reviewer

DEKRA Consulting GmbH

This Environmental Product Declaration has been reviewed by DEKRA Consulting GmbH. It was approved according to the Product Category Rules PCR version 2.0 (2011-04) and ISO 14025:2006. Registration number: PlasticsEurope 2012-004, validation expires on 30 November 2015 (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

➢ *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 primary General Purpose Polystyrene (GPPS) granules – or – 1kg of primary High Impact Polystyrene (HIPS) granules, respectively, »at gate« (polystyrene production site output) representing a European industry production average.

Product and Producer Description

Product Description

General Purpose Polystyrene (GPPS) and High Impact Polystyrene (HIPS) are thermoplastic polymers, used in many applications such as food and non-food packaging, disposable cups and cutlery, furniture, toys and consumer goods, as well as electronics and appliances.

- General-purpose polystyrene (GPPS)

  CAS no. 9003-53-6

  Chemical formula (C8H8)n

  Gross calorific value 42.4 MJ/kg

- High-impact polystyrene (HIPS)

  CAS no. 9003-55-8

  Chemical formula (C8H8)x(C4H6)y

  Gross calorific value 42.4 –42.6 MJ/kg (depending on polybutadiene content)

Production Process Description

Both GPPS and HIPS are produced by continuous-mass radical polymerisation of styrene; in case of HIPS, it is a polymerisation of polybutadiene rubber in a styrene solution. The plant setup generally comprises a feed section, a polymerisation section, a devolatilisation and solvent recovery section, and a pelletizing section. Styrene and processing aids are fed into the reactor. In the case of HIPS, polybutadiene rubber is ground and dissolved in styrene to obtain a rubber solution. An antioxidant is usually also added in the dissolving tank. In addition, other chemicals can be added here such as white oil, peroxides, recycled styrene, ethyl benzene or chain transfer agents. Solvents, such as toluene or ethylbenzene, are added to provide better control of the polymerisation rate and the heat release rate, to modify the viscosity of the polymerisation bulk solution melt, and the cross-linking of the rubber phase. The dissolved mixture is then fed continuously to the reactor train where bulk polymerisation takes place. The reactors' temperatures are between 100 and 180 °C. The process flow then goes through a devolatilisation section to separate the polymer from the unreacted monomers and solvent. The

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

melted polymer is then transferred through a die head to obtain strands that are cut (dry or underwater) by pelletisers.

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 data to this Eco-profile and EPD:

- BASF SE

  ZZS/SE - Z007
  D- 67056 Ludwigshafen
  Germany
  http://www.basf.com

- Synthos S.A.

  ul. Chemików 1
  32-600 Oswiecim
  Poland
  http://www.synthosgroup.com

- Styrolution Netherlands B.V.

  Strawinskylaan 411
  1077 XX Amsterdam
  The Netherlands
  http://www.styrolution.com/

- Total S.A.

  2, place Jean Millier
  La Défense 6
  92078 Paris La Défense Cedex
  France
  http://www.total.com

- Styron Europe GmbH

  Zugerstrasse 231
  8810 Horgen
  Switzerland
  http://www.styron.com

- versalis S.p.A.

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

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 for GPPS and Figure 2 for HIPS).

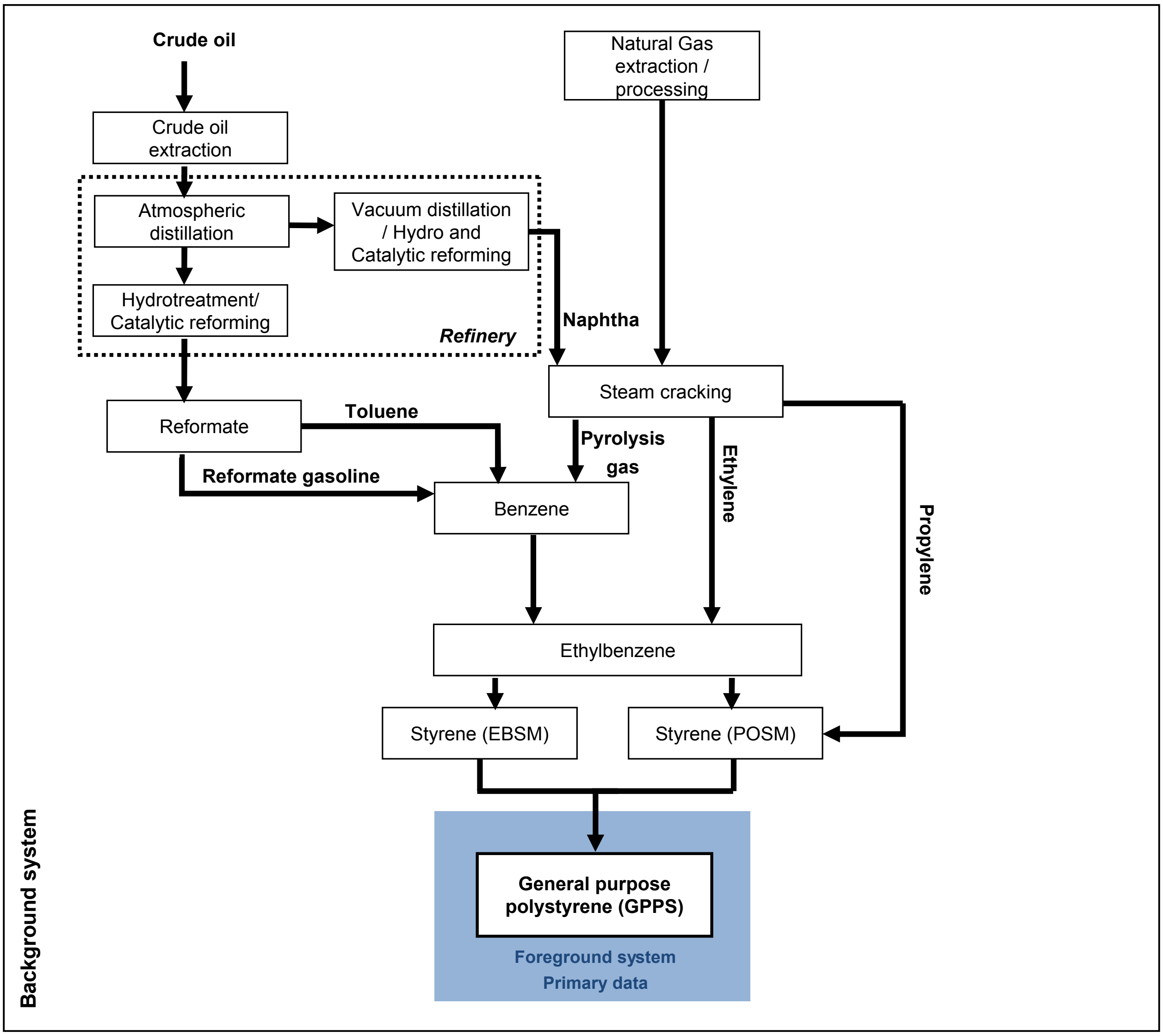


Figure 1: Cradle-to-gate system boundaries (GPPS)

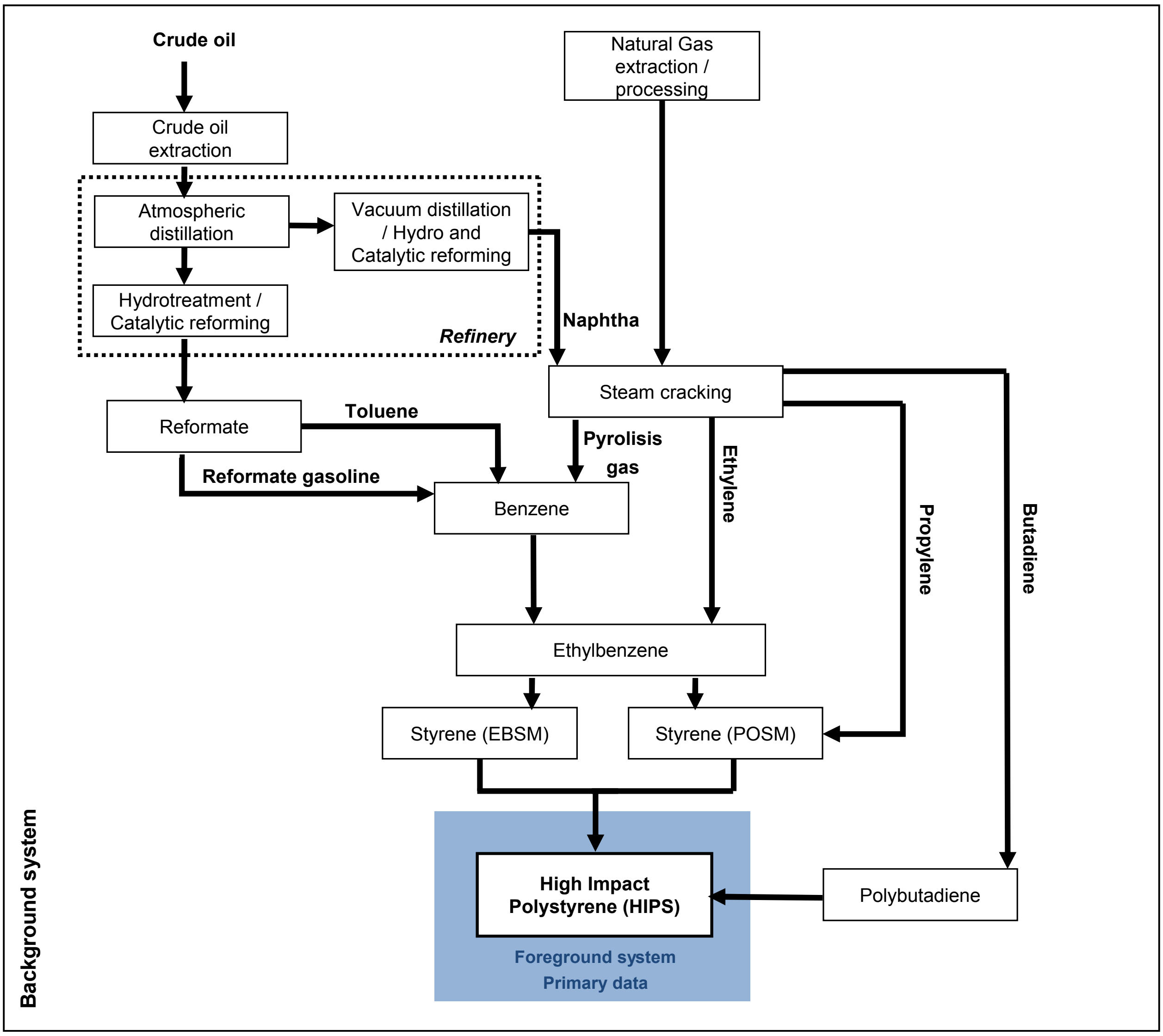


Figure 2: Cradle-to-gate system boundaries (HIPS)

Technological Reference

The production processes were modelled using specific values from primary data collection at site. The main data source was a primary data collection from European producers of GPPS and HIPS, providing site-specific gate-to-gate production data for processes under operational control of the participating companies: six GPPS producers with thirteen plants in nine different European countries; six HIPS producers with eleven plants in eight European countries. This covers 95 % of the European GPPS and HIPS production capacity (EU-27) in 2010, respectively. Primary data were used for all foreground processes (under operational control) complemented with secondary data for background processes (under indirect management control). With the exception of one company which delivered primary data for styrene due to specific technology, the data for the upstream supply chain until the precursors are taken from the database of the software system GaBi 5 [GABI 5 2011].

As shown in Figure 1 and Figure 2, two different routes for the production of styrene (EBSM and POSM) were modelled as per the actual supply situation. 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 was modelled according to site-specific information. For the resulting European mix as represented by this Eco-profile, the styrene production is based on 31–33 % from POSM and 67–69 % from EBSM.

Temporal Reference

The LCI data for production was collected as 12 month averages representing the year 2010, to compensate seasonal influence of data. In 2010 production volumes were close to the nameplate capacity, which confirms the representativeness of the temporal reference used. Background data have reference years between 2010 and 2008 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 2010, with a maximum temporal validity until 2022 for the foreground system.

Geographical Reference

Primary production data for both GPPS and HIPS production are from six different European suppliers each. Whenever applicable (in the majority of the cases), site specific conditions were applied. Only in cases where no further information was available, average European conditions were used for fuel and energy inputs in the system. Therefore, the study results are intended to be applicable within EU boundaries: adjustments might be required if the results were applied to other regions. GPPS and HIPS imported into Europe were not considered in this Eco-profile.

Cut-off Rules

In the foreground processes all relevant flows were considered, trying to avoid any cut-off of material and energy flows. In single cases additives used in the GPPS and/or HIPS unit process (<0.1 % m/m of product output) were neglected. In such cases, it was assured that no hazardous substances or metals were present in this neglected part. According to the GaBi database 2011 [GABI 5 2011], used in the background processes, at least 95 % of mass and energy of the input and output flows were covered and 98 % of their environmental relevance (according to expert judgment) was considered, hence an influence of cut-offs less than 1 % on the total in expected. All transports in the pre-chain contribute less than 0.2 % to the overall environmental burden. Considering the entire system under assessment, the contribution of all transports is expected to be less than 1 %; hence, transports were excluded from this investigation.

Data Quality Requirements

Data Sources

Eco-profile 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). With regard to the most relevant intermediate, styrene, the participating member companies validated the datasets and their quality.

- The EBSM process is based on the catalytic dehydrogenation of ethylbenzene, with styrene as its main product. The documentation is publicly available and accessible at: http://gabi-dataset-documentation.gabi-software.com/xml_data/processes/508c9a84-1019-4cc2-a5e8-c96f83c3a52e_05.00.000.xml

- The POSM process involves the oxidation of ethylbenzene to form ethylbenzene hydroperoxide (EBHP), with styrene as a co-product of propylene oxide. The POSM process is part of the internal GaBi 5 Database and therefore not publicly available. This dataset was modelled based on literature and PE International's engineering know-how. It was cross-checked with other references and reviewed by industry representatives for plausibility and quality.

The data for the upstream supply chain as well as relevant background data such as energy and auxiliary materials were sourced from the life cycle database of the software system GaBi 5 [GaBi 5 2011]. Most of the background datasets used are publicly available and documented. The dominance analysis (Table 39 and Table 40) showed that the contribution of these background datasets, excluding the main intermediates as mentioned above, on impact indicators is around 5 % for GPPS and around 14 % for HIPS – in both cases with the exception of ADP elements. By contrast, the main intermediate styrene monomer contributed to 94–97 % for GPPS and 82–86 % for HIPS.

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 GPPS and HIPS 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 95 % of the European GPPS and HIPS production volume in 2010. 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 5 databases [GaBi 5 2011] were used. While building up the model, cross-checks ensured 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 foreground and background system. In addition to the external review, an internal independent quality check was performed (see 'Internal Independent Quality Assurance Statement')

Reliability

Data of foreground processes provided directly by producers were predominantly measured. Data of relevant background processes were measured at several sites – alternatively, it was 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 GPPS and HIPS covers all related flows in accordance with the above cut-off criteria. In this way all relevant flows were quantified and data is considered complete. The elementary flows covered in the model enable the impact assessment of all selected impact categories. Waste treatment was 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 GaBi5 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 from the project partners and the data providing companies was validated in an iterative process several times. The collected data was 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 has been performed with the LCA software GaBi 5 [GABI 5 2011]. 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 was 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 were calculated (Figure 3).

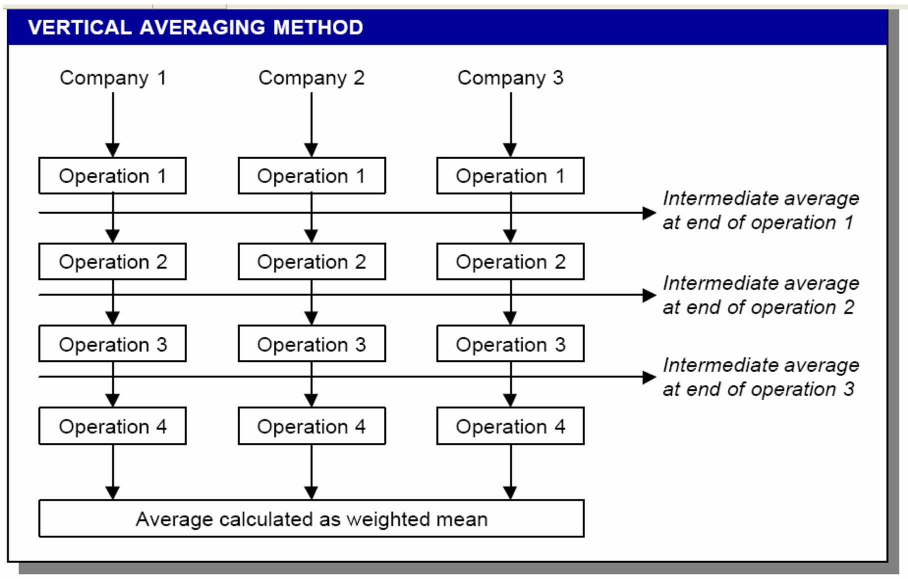


Figure 3: *Vertical Averaging (source: Eco-profile of high volume commodity phthalate esters, ECPI European Council for Plasticisers and Intermediates, 2001)*

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

Where off-grade GPPS and HIPS were relevant, price allocation was applied, because they are marketable co-products. Off-grade GPPS and HIPS had much lower assignments (about 0.1–0.2%) compared to the main product GPPS and HIPS (99.8% in each case). The purpose of the processes is the production of GPPS or HIPS, respectively. A quantified sensitivity analysis showed that if mass allocation were applied, results would differ by about 0.2% for both cases and in all impact categories analysed in this report. No post-consumer waste has been reported as input to the system, therefore no allocation between different life cycles was necessary.

Background system

In the refinery operations, co-production was addressed by applying allocation based on mass and net calorific value [GABI 5 2011]. The chosen allocation in refinery is based on several sensitivity analyses, which was reviewed by petrochemical experts. The relevance and influence of different possible allocation keys in this context is small. In steam cracking, allocation according to net calorific value with regard to the whole product range was applied. The difference compared with mass allocation is below 2 %.

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 GBX file 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 82.78 MJ/kg GPPS and 86.99 MJ/kg HIPS 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 42.4 MJ/kg for GPPS, and 42.4 –42.6 MJ/kg for HIPS (depending on polybutadiene content). The net calorific value (lower heating value, LHV) is 39.9 MJ/kg GPPS and 40.7 MJ/kg HIPS.

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

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	42.40
Process energy (quantified as difference between primary energy demand and energy content of polymer)	40.38
Total primary energy demand	**82.78**

Table 2: Primary energy demand (system boundary level) per 1kg HIPS

Primary Energy Demand	Value [MJ]
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer)	42.40
Process energy (quantified as difference between primary energy demand and energy content of polymer)	44.59
Total primary energy demand	**86.99**

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. Useful energy flows leaving the system boundaries were removed during allocation.

Table 3 and Table 4 show 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 a range.

Table 3: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1kg GPPS

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	0.60	0.02	0.00	0.60
Oil	52.18	1.15	35.60–37.60	14.60–16.60
Natural gas	27.65	0.57	8.70–10.70	17.00–19.00
Lignite	0.48	0.04	0.00	0.48
Nuclear	1.34	2.97E-06	0.00	1.34
Biomass	0.00	0.00	0.00	0.00
Hydro	0.20	0.00	0.00	0.20
Solar	0.17	0.00	0.00	0.17
Geothermics	0.01	0.00	0.00	0.01
Waves	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00
Wind	0.14	0.00	0.00	0.14
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	**0.52**	**0.00**	**0.00**	**0.52**
Sub-total Non-renewable	**82.26**	**1.78**	**44.30–48.30**	**33.96–37.96**
Total	**82.78**	**1.78**	**44.30–48.30**	**34.48–38.48**

Table 4: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per 1kg HIPS

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	0.66	0.02	0.00	0.66
Oil	54.04	1.19	36.00–38.00	16.04–18.04
Natural gas	29.78	0.61	9.00–11.00	18.78–20.78
Lignite	0.52	0.04	0.00	0.52
Nuclear	1.42	3.14E-06	0.00	1.42
Biomass	0.00	0.00	0.00	0.00
Hydro	0.20	0.00	0.00	0.20
Solar	0.19	0.00	0.00	0.19
Geothermics	0.02	0.00	0.00	0.02
Waves	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00
Wind	0.15	0.00	0.00	0.15
Other renewable fuels	0.00	0.00	0.00	0.00
Sub-total renewable	**0.56**	**0.00**	**0.00**	**0.56**
Sub-total Non-renewable	**86.43**	**1.87**	**44.3–48.3**	**38.13–42.13**
Total	**86.99**	**1.87**	**44.3–48.3**	**38.69–42.69**

Table 5 and Table 6 show 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 7 and Table 8 analyse the types of useful energy inputs in the polymerisation process: Electricity has a minor contribution here, whereas the majority is thermal energy (heat). This represents the share of the energy requirement that is under operational control of the polymer producer (Figure 4). Accordingly, Table 9 and Table 10 show that the majority (98 % for both cases) of the primary energy demand is accounted for by upstream processes. Finally, Table 11 and Table 12 provide 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 (»other chemicals«). In order to analyse these upstream operations more closely, please refer to the Eco-profiles 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 GPPS and HIPS system.

Table 5: Primary energy demand by renewability per 1kg GPPS

Fuel/energy input type	Value [MJ]	%
Renewable energy resources	0.52	1%
Non-renewable energy resources	82.26	99%
Total	**82.78**	**100%**

Table 6: Primary energy demand by renewability per 1kg HIPS

Fuel/energy input type	Value [MJ]	%
Renewable energy resources	0.56	1%
Non-renewable energy resources	86.43	99%
Total	**86.99**	**100%**

Table 7: Analysis by type of useful energy (GPPS production – unit process level) per 1kg GPPS

Type of useful energy in process input	Value [MJ]
Electricity	0.30
Heat, thermal energy	0.62
Other types of useful energy (relevant contributions to be specified)	0.00
Total (for selected key process)	**0.92**

Table 8: Analysis by type of useful energy (HIPS production – unit process level) per 1kg HIPS

Type of useful energy in process input	Value [MJ]
Electricity	0.33
Heat, thermal energy	0.58
Other types of useful energy (relevant contributions to be specified)	0.00
Total (for selected key process)	**0.91**

Table 9: Contribution to primary energy demand (dominance analysis) per 1kg GPPS

Contribution to Primary Energy per segment	Value [MJ]	%
GPPS Production (electricity, steam, unit process, utilities, waste treatment)	1.76	2%
Pre-chain	81.02	98%
Total	**82.78**	**100%**

Table 10: Contribution to primary energy demand (dominance analysis) per 1kg HIPS

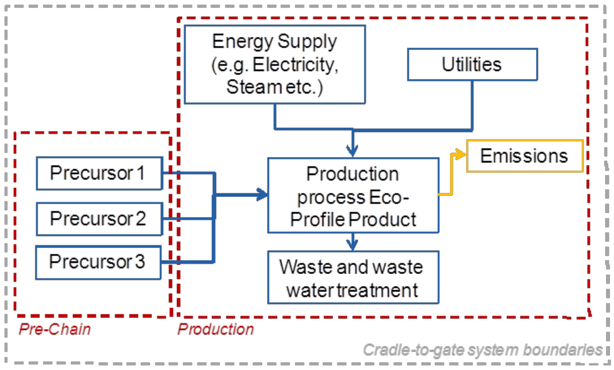
Contribution to Primary Energy per segment	Value [MJ]	%
HIPS Production (electricity, steam, unit process, utilities, waste treatment)	1.94	2%
Pre-chain	85.05	98%
Total	**86.99**	**100%**

Table 11: Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1kg GPPS, see Figure 4

Total Primary Energy [MJ]	Styrene and GPPS Process	Other Chemicals	Utilities	Electricity	Thermal Energy	Process Waste Treatment
Coal	0.46	0.01	0.02	0.10	0.00	2.49E-03
Oil	50.96	1.08	0.01	0.03	0.09	2.12E-03
Natural gas	26.44	0.20	0.03	0.26	0.74	-2.94E-03
Lignite	0.42	0.01	0.02	0.03	0.00	1.61E-03
Nuclear	0.99	0.02	0.03	0.30	0.00	1.31E-03
Biomass	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.15	3.64E-03	0.01	0.04	6.21E-04	1.21E-04
Solar	0.12	0.03	0.00	0.02	3.08E-04	3.31E-04
Geothermics	7.94E-03	1.67E-04	2.61E-04	1.80E-03	3.11E-05	-5.38E-07
Waves	0.00	0.00	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.12	2.20E-03	4.08E-03	0.02	2.79E-04	3.13E-04
Other renewable fuels	0.00	0.00	0.00	0.00	0.00	0.00
Total	**79.66**	**1.35**	**0.12**	**0.80**	**0.83**	**0.01**

Table 12: Contribution of life cycle stages to total primary energy demand (gross calorific values) per 1kg HIPS, see Figure 4

Total Primary Energy [MJ]	Styrene and HIPS Process	Other Chemicals	Utilities	Electricity	Thermal Energy	Process Waste Treatment
Coal	0.43	0.11	0.01	0.11	1.76E-03	3.09E-03
Oil	48.25	5.63	5.00E-03	0.06	0.09	1.97E-03
Natural gas	24.37	4.29	0.01	0.39	0.74	-2.28E-03
Lignite	0.37	0.07	3.85E-03	0.07	7.63E-04	1.98E-03
Nuclear	0.85	0.20	0.01	0.36	3.18E-03	1.65E-03
Biomass	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.14	0.02	1.07E-03	0.03	5.28E-04	1.61E-04
Solar	0.10	0.06	1.03E-03	0.03	3.33E-04	4.12E-04
Geothermics	0.01	1.08E-03	1.61E-04	3.55E-03	5.00E-05	-1.31E-07
Waves	0.00	0.00	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.10	0.02	9.59E-04	0.02	2.76E-04	3.89E-04
Other renewable fuels	0.00	0.00	0.00	0.00	0.00	0.00
Total	**74.64**	**10.41**	**0.03**	**1.07**	**0.83**	**0.01**



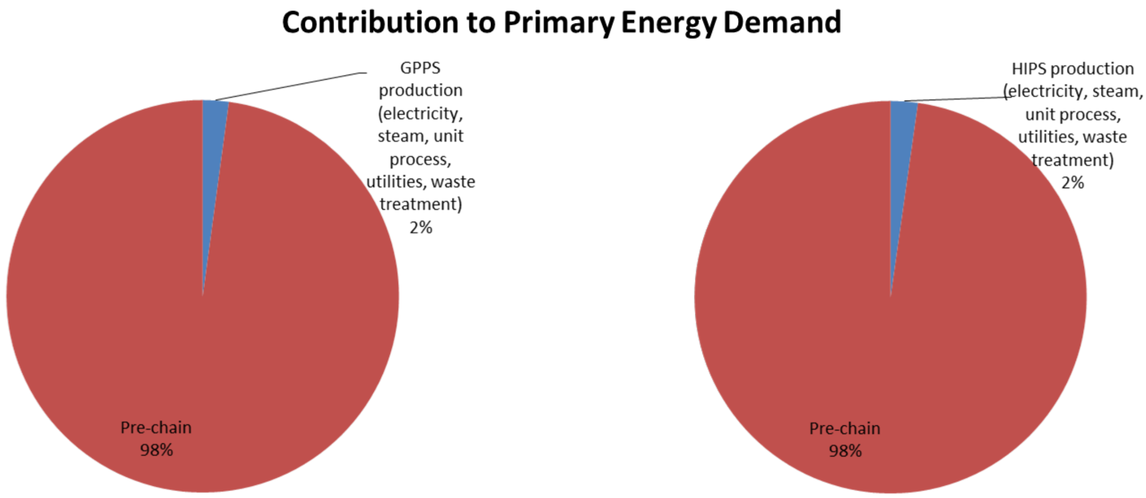


Figure 4: *Contribution to primary energy demand per segment*

Water Consumption

Table 13 and Table 14 show 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 13: *Water use (fresh- and seawater; blue- and greenwater) table per 1kg GPPS (cradle-to-gate)*

Input	Value [kg]
Water (ground water)	12.91
Water (lake water)	33.09
Water (rain water)	0.87
Water (river water)	660.14
Water (sea water)	1.36
Water (fossil groundwater)	0.00
Overall water use [kg]	**708.37**

Table 14: Water use (fresh- and seawater; blue- and greenwater) table per 1kg HIPS (cradle-to-gate)

Input	Value [kg]
Water (ground water)	13.81
Water (lake water)	31.20
Water (rain water)	1.21
Water (river water)	704.15
Water (sea water)	1.37
Water (fossil groundwater)	0.00
Overall water use [kg]	**751.74**

Table 15 and Table 16 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 15: Freshwater (blue water not including rain water) use table per 1kg GPPS (cradle-to-gate), see Figure 5

Input	Value [kg]
Water (ground water)	12.91
Water (lake water)	33.09
Water (river water)	660.14
Water (fossil groundwater)	0.00
Total fresh water use [kg]	**706.14**

Output	Value [kg]
Water (river water from technosphere, cooling water)	14.47
Water (river water from technosphere, turbined)	676.09
Water (river water from technosphere, waste water)	4.55
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]	**695.11**
Total fresh water consumption (blue water)	**11.03**

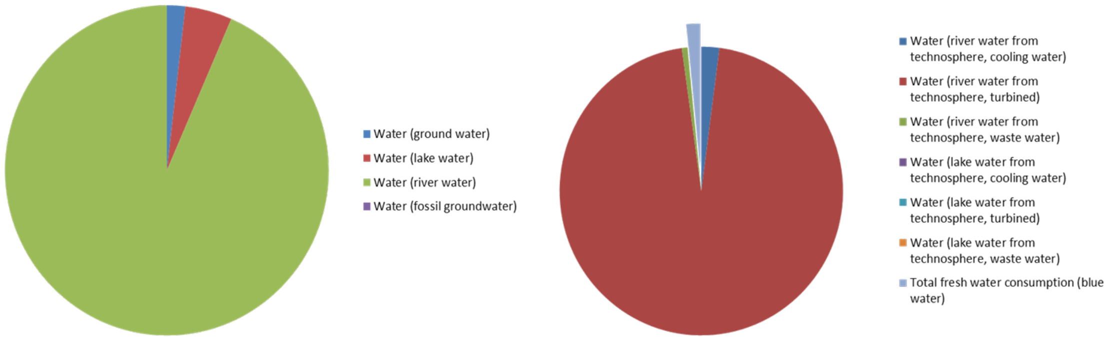


Figure 5: Total fresh water consumption (blue water) GPPS

Table 16: Freshwater (blue water not including rain water) use table per 1kg HIPS (cradle-to-gate), see Figure 6

Input	**Value [kg]**
Water (ground water)	13.81
Water (lake water)	31.20
Water (river water)	704.15
Water (fossil groundwater)	0.00
Total fresh water use [kg]	**749.16**

Output	**Value [kg]**
Water (river water from technosphere, cooling water)	13.20
Water (river water from technosphere, turbined)	719.29
Water (river water from technosphere, waste water)	4.95
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]	**737.44**
Total fresh water consumption (blue water)	**11.72**

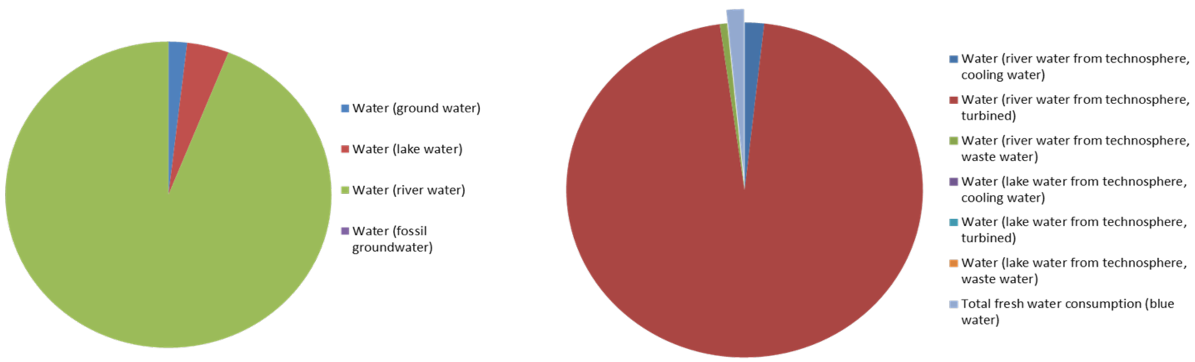


Figure 6: Total fresh water consumption (blue water) HIPS

Table 17 and Table 18 show the water balance at unit process level.

Table 17: Water balance table per 1kg GPPS (unit process level)

Input	Value [kg]
Water (cooling water)	12.93
Water (process water)	0.51
Water (deionised)	0.16
Output	**Value [kg]**
Water vapour	0.20
Water (waste water, untreated) to WWTP	0.96
Water direct released to the environment without WWTP	
Water (river water from technosphere, cooling water)	12.20
Water (river water from technosphere, turbined)	0.00
Water (river water from technosphere, waste water)	0.26
Water (sea water from technosphere, cooling water)	0.00
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

Table 18: Water balance table per 1kg HIPS (unit process level)

Input	Value [kg]
Water (cooling water)	11.38
Water (process water)	0.78
Water (deionised)	0.09
Output	**Value [kg]**
Water vapour	0.07
Water (waste water, untreated) to WWTP	0.98
Water direct released to the environment without WWTP	
Water (river water from technosphere, cooling water)	10.63
Water (river water from technosphere, turbined)	0.00
Water (river water from technosphere, waste water)	0.59
Water (sea water from technosphere, cooling water)	0.00
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

Air Emission Data

Table 19 and Table 20 show 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 19: Selected air emissions per 1kg GPPS

Air emissions	kg
Carbon dioxide, fossil (CO_2, fossil)	2.06
Carbon monoxide (CO)	1.10E-03
Sulphur dioxide (SO_2)	3.08E-03
Nitrogen oxides (NO_x)	3.20E-03
Particulate matter ≤ 10 µm (PM 10)	1.47E-04

Table 20: Selected air emissions per 1kg HIPS

Air emissions	kg
Carbon dioxide, fossil (CO_2, fossil)	2.23
Carbon monoxide (CO)	1.71E-03
Sulphur dioxide (SO_2)	3.23E-03
Nitrogen oxides (NO_x)	3.36E-03
Particulate matter ≤ 10 µm (PM 10)	1.52E-04

Wastewater Emissions

Table 21 and Table 22 show 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 21: Selected water emissions per 1kg GPPS

Water emissions	kg
Biological oxygen demand after 5 days (BOD 5)	2.79E-05
Chemical oxygen demand (COD)	2.39E-04
Total organic carbon (TOC)	2.64E-05

Table 22: Selected water emissions per 1kg HIPS

Water emissions	kg
Biological oxygen demand after 5 days (BOD 5)	3.28E-05
Chemical oxygen demand (COD)	2.45E-04
Total organic carbon (TOC)	2.97E-05

Solid Waste

Table 23: Solid waste generation per 1kg GPPS (key foreground process level)

Waste for –	Incineration kg	Landfill kg	Recovery kg	Unspecified kg	Total kg
Non-hazardous	3.32E-04	6.83E-06	0.00	0.00	3.39E-04
Hazardous	4.57E-04	0.00	0.00	0.00	4.57E-04
Unspecified	0.00	0.00	0.00	0.00	0.00
Total	7.89E-04	6.83E-06	0.00	0.00	7.96E-04

Table 24: Solid waste generation per 1kg HIPS (key foreground process level)

Waste for –	**Incineration kg**	**Landfill kg**	**Recovery kg**	**Unspecified kg**	**Total kg**
Non-hazardous	7.55E-04	2.36E-05	7.41E-04	0.00	1.52E-03
Hazardous	7.88E-04	0.00	0.00	0.00	7.88E-04
Unspecified	0.00	0.00	0.00	0.00	0.00
Total	1.54E-03	2.36E-05	7.41E-04	0.00	2.31E-03

Life Cycle Impact Assessment

Input

Natural Resources

Table 25: Abiotic Depletion Potential per 1kg GPPS

Natural resources	Value
Abiotic Depletion Potential (ADP), elements [kg Sb eq]	9.21E-07
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	74.70

Table 26: Abiotic Depletion Potential per 1kg HIPS

Natural resources	Value
Abiotic Depletion Potential (ADP), elements [kg Sb eq]	1.04E-06
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	78.46

Output

Climate Change

Table 27: Global Warming Potential (100 years) per 1kg GPPS

Climate change	kg CO_2 eq.
Global Warming Potential (GWP)	2.25

Table 28: Global Warming Potential (100 years) per 1kg HIPS

Climate change	kg CO_2 eq.
Global Warming Potential (GWP)	2.43

Acidification

Table 29: Acidification Potential per 1kg GPPS

Acidification of soils and water bodies	g SO_2 eq.
Acidification Potential (AP)	5.38

Table 30: Acidification Potential per 1kg HIPS

Acidification of soils and water bodies	g SO_2 eq.
Acidification Potential (AP)	5.65

Eutrophication

Table 31: Eutrophication Potential per 1kg GPPS

Eutrophication of soils and water bodies	g PO_4^{3-} eq.
Eutrophication Potential (EP), total	0.48

Table 32: Eutrophication Potential per 1kg HIPS

Eutrophication of soils and water bodies	g PO_4^{3-} eq.
Eutrophication Potential (EP), total	0.51

Ozone Depletion

Table 33: Ozone Depletion Potential per 1kg GPPS

	g CFC-11 eq.
Ozone Depletion Potential (ODP)	1.63E-05

Table 34: Ozone Depletion Potential per 1kg HIPS

	g CFC-11 eq.
Ozone Depletion Potential (ODP)	1.72E-05

Summer Smog

Table 35: Photochemical Ozone Creation Potential per 1kg GPPS

	g Ethene eq.
Photochemical Ozone Creation Potential	0.85

Table 36: Photochemical Ozone Creation Potential per 1kg HIPS

	g Ethene eq.
Photochemical Ozone Creation Potential	0.90

Dust & Particulate Matter

Table 37: PM10 emissions per 1kg GPPS

Particulate matter	g PM10 eq.
Particulate matter ≤ 10 µm. total	0.15
Particulate matter ≤ 10 µm (direct emissions)	0.00
Particulate matter ≤ 10 µm. secondary	0.15

Table 38: PM10 emissions per 1kg HIPS

Particulate matter	**g PM10 eq.**
Particulate matter ≤ 10 µm. total	0.15
Particulate matter ≤ 10 µm (direct emissions)	0.00
Particulate matter ≤ 10 µm. secondary	0.15

Dominance Analysis

Table 39 and Table 40 show the main contributions to the results presented above. A weighted average of the different technologies represented by the participating producers is used. Regarding GPPS, in all analysed environmental impact categories, intermediates contribute with about 96 % or more of the total impact, with styrene dominating all cases. Regarding HIPS, in all analysed environmental impact categories, intermediates contribute with about 95 % or more of the total impact, with styrene dominating at about 82 % or more (the only exception being the indicator ADP Elements). In the case of ADP Elements, the different distribution results mainly from the use of stabilisers or catalysts with a metal content in production or along the supply chain. Hence the use of high quality data especially for styrene is the decisive influence on this Eco-profile.

Table 39: Dominance analysis of impacts per 1kg GPPS

	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.]**
Styrene and GPPS	96.2%	68.6%	96.8%	95.4%	94.6%	93.8%	96.1%
Other chemicals	1.6%	28.7%	1.6%	1.1%	2.7%	2.2%	2.2%
Utilities	0.2%	1.7%	0.1%	0.3%	0.4%	0.4%	0.2%
Electricity	1.0%	0.3%	0.5%	1.3%	1.4%	1.0%	0.7%
Thermal Energy	1.0%	0.1%	1.0%	1.8%	0.9%	1.1%	0.8%
Process waste treatment	0.0%	0.5%	0.0%	0.2%	0.1%	1.5%	0.0%
Total	100%	100%	100%	100%	100%	100%	100%

Table 40: Dominance analysis of impacts per 1kg HIPS

	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.]**
Styrene and HIPS	85.8%	53.59%	86.43%	83.7%	84.8%	82.4%	83.9%
Other chemicals	12.0%	44.17%	11.85%	12.5%	12.2%	13.3%	14.2%
Utilities	0.0%	1.10%	0.03%	0.1%	0.1%	0.1%	0.0%
Electricity	1.2%	0.34%	0.73%	1.8%	1.9%	1.5%	1.0%
Thermal Energy	1.0%	0.15%	0.96%	1.7%	0.9%	1.1%	0.8%
Process waste treatment	0.0%	0.64%	0.01%	0.2%	0.1%	1.5%	0.1%
Total	100%	100%	100%	100%	100%	100%	100%

Comparison of the Present Eco-profile with its Previous Version (2002/2012)

Table 41 and Table 42 compare the present results with the previous version of the Eco-profiles of GPPS and HIPS.

Table 41: Comparison of the present Eco-profile of GPPS with its previous version (2002/2012)

Environmental Impact Categories	Eco-profile GPPS (2002)[2]	Eco-profile GPPS (2012)	Difference
Gross primary energy from resources [MJ]	89.19	82.26	-7.8%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	4.14E-07	9.21E-07	122.3%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	80.27	74.70	-6.9%
Global Warming Potential (GWP) [kg CO_2 eq.]	3.50	2.25	-35.7%
Acidification Potential (AP) [g SO_2 eq.]	11.48	5.38	-53.1%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	0.72	0.48	-33.2%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	0.00	1.63E-05	
Photochemical Ozone Creation Potential [g Ethene eq.]	1.28	0.85	-33.77%

Table 42: Comparison of the present Eco-profile of HIPS with its previous version (2002/2012)

Environmental Impact Categories	Eco-profile HIPS (2002)[3]	Eco-profile HIPS (2012)	Difference
Gross primary energy from resources [MJ]	89.64	86.43	-3.6%
Abiotic Depletion Potential (ADP), elements [kg Sb eq.]	4.02E-07	1.04E-06	159.5%
Abiotic Depletion Potential (ADP), fossil fuels [MJ]	80.67	78.46	-2.7%
Global Warming Potential (GWP) [kg CO_2 eq.]	3.49	2.43	-30.2%
Acidification Potential (AP) [g SO_2 eq.]	12.25	5.65	-53.9%
Eutrophication Potential (EP) [g PO_4^{3-} eq.]	0.76	0.51	-33.3%
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	0.00	1.72E-05	
Photochemical Ozone Creation Potential [g Ethene eq.]	1.32	0.90	-32.11%

Table 41 and Table 42 show a significant improvement for both GPPS and HIPS 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. As mentioned previously, the dominance analysis shows that styrene data is of critical importance for the Eco-profiles of polystyrenes. Therefore, improvements in the performance of the styrene processes will be reflected here.

The different technologies for styrene production, POSM and EBSM, present quite similar environmental performance. This can be explained because the different energy requirements of the two technologies are balanced by different yields of styrene. Although POSM has lower energy consumption, the yield of styrene is also lower.

The reason for the substantial improvement in GWP in relation to fairly stable performance in terms of Primary Energy and ADP Fossil Fuels is largely due to the benzene data: as the precursor of ethylbenzene and styrene, benzene can be produced either as a co-product of the naphtha cracker and subsequent aromatics separation, or more directly through catalytic reformation. Whereas the cracker route is assessed to contribute with only one third, the reformer-based benzene contributes around two thirds, and has a lower burden of greenhouse gases. As a result, benzene data from 2002 compared with 2011 differ only by about 3% for Primary Energy, but 20% for GWP. Consequently, the results for GPPS and HIPS are sensitive to the benzene mix.

[2] Slight differences to the report from 2002 might be due to the update of characterisation factors of the environmental impact methods, or different heating values of resources in case of Primary Energy. The impact method used here is CML 2001 – Nov. 2010 (Version 3.9)

[3] See previous footnote.

Further, as previously noted the indicator APD Elements is mainly due to the use of metals (such as catalysts), but the previous version did not offer sufficient detail to make a meaningful comparison. The percentage change should be treated with great caution.

Other factors that have an influence on the current results in reference to the previous study can be qualitatively summarised as follows. Since for the 2002 version, detailed model information is no longer available and in view of the complexity of the changes, quantitative statements about the relevance of each of these factors cannot be derived.

- Changes in the foreground system:
  - Polystyrene manufacturers that have provided data for this Eco-profile have indicated that due to consolidation in the industry, smaller and less efficient plants were closed. Further, energy use has been continuously improved within the existing plants, for instance through better energy integration within the processes. This resulted in an overall lower energy consumption of the polystyrene manufacturing process, leading to improvements in all impact categories.
  - Changes in the energy carrier mix used in the processes of both styrene and polystyrene towards more environmental friendly energy carriers led to improvements in all impact categories, especially for AP.
  - Stricter pollution and emissions control, such as exhaust air purification, led to improvements most notably for POCP.
- Changes in the background system:
  - Changes in the electricity grid mix, in particular electricity from renewables becoming relevant, caused improvements in all impact categories.
  - Stricter pollution and emissions control, especially regarding Eastern European production, led to improvements in all impact categories, but especially for AP.
  - Improvements in the process technology of precursors, such as styrene monomer, gave rise to improvements in all impact categories.
- Methodological changes:
  - Compared with the 2002 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. The resulting quality assurance statement is reproduced in Figure 7.

Internal Independent Quality Assurance Statement

On behalf of PE INTERNATIONAL AG and its subsidiaries

Document prepared by	Dr.-Ing. Cecilia Makishi Colodel
Title	Project Manager
Signature	Cecilia Colodel
Date	6. 9. 2012

Quality assurance by	Dr.-Ing. Thilo Kupfer
Title	Quality Manager Europe
Signature	Thilo Kupfer
Date	6. 9. 2012

Approved by	Jürgen Stichling
Title	VP of Service Delivery
Signature	
Date	2012-11-28

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Figure 7: Internal independent quality assurance statement by PE International

External Independent Review Summary

As part of the PlasticsEurope programme management and quality assurance, *DEKRA Consulting GmbH* conducted an external independent critical review of this work. This included soliciting a co-review from an independent expert, Mr. Aafko Schanssema, Director of the Dutch Plastics Packaging Association (*Vereniging Kunststofverpakkingen Nederland, VMK* under the umbrella of *Federatie Nederlandse Rubber- en Kunststofindustrie, NRK*). The outcome of the critical review is reproduced below.

The subject of this critical review was the development of the Eco-profile for European polystyrene (PS) production. The project included regular milestone meetings with representatives of all participating producers and PlasticsEurope as system operator. The chairman of the review panel participated in these meetings. In addition, a review meeting between the LCA practitioner and the reviewers was held, including a model and database review, and spot checks of data and calculations. The final Eco-profile report was also reviewed by the second co-reviewer, industry expert Aafko Schanssema (VMK). All questions and recommendations were discussed with the LCA practitioner, and the report was adapted and revised accordingly.

Prior to data collection, a dominance analysis was conducted to identify sensitive data requirements. Original industry data were collected for all foreground processes, while background process data were sourced from the GaBi database. Primary industry data was collected from a total of 24 sites (13 for GPPS, 11 for HIPS) which leads to an overall representativeness of 95% of the European PS production.

The environmental impacts for polystyrene are dominated by the styrene production and this, in turn, by benzene. Consequently, the respective datasets for the EBSM and POSM production routes are of great importance, as is the assumed benzene mix. While industry data was used for modelling the EBSM route, the POSM route was modelled based on literature data and the LCA practitioner's expertise, then cross-checked with industry data. It is recommended to further validate the benzene and styrene data with updated information on benzene mix (reformer vs. cracker) and primary data for the POSM route. It is noteworthy that, contrary to some initial expectations the two routes are quite similar in performance: while the POSM route needs less process energy, it renders lower styrene yields. At the moment, the resulting styrene dataset is considered best available data and good quality with respect to the goal and scope, because it reflects the actual supply situation of each PS producer. The LCA practitioner has demonstrated very good competence and experience, with a track record of LCA projects in the chemical and plastics industry.

The Eco-profile report also includes a comparison with the 2002 version of this Eco-profiles, prepared by Dr. Ian Boustead. For some indicators, while there are significant differences, they cannot be interpreted due to the lack of documentation of the previous dataset. Methodological changes are, however, of minor importance: for instance, waste treatment is now modelled within the system boundary, following ILCD requirements; also, characterisation factors were updated. A noteworthy change is the considerable decrease of the climate indicator GWP by 30–35 %, whereas the Primary Energy Demand was shown to be stable: this is largely due to the influence of the benzene mix noted above (reformer benzene with a lower greenhouse gas burden). Finally, consolidation and energy efficiency in industry caused some improvements.

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 PS production in Europe.

Names and affiliations of reviewers:

- Chair: Dr.-Ing. Ivo Mersiowsky – Business Line Manager, Sustainability Leadership, *DEKRA Consulting GmbH*, Stuttgart, Germany
- Co-reviewer: Matthias Schulz – Senior Consultant, Product Sustainability, *DEKRA Consulting GmbH*, Stuttgart, Germany
- Co-reviewer: Aafko Schanssema – Director, Dutch Plastics Packaging Association (*Vereniging Kunststofverpakkingen Nederland, VMK* under the umbrella of *Federatie Nederlandse Rubber- en Kunststofindustrie, NRK*), Leidschendam, The Netherlands.

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