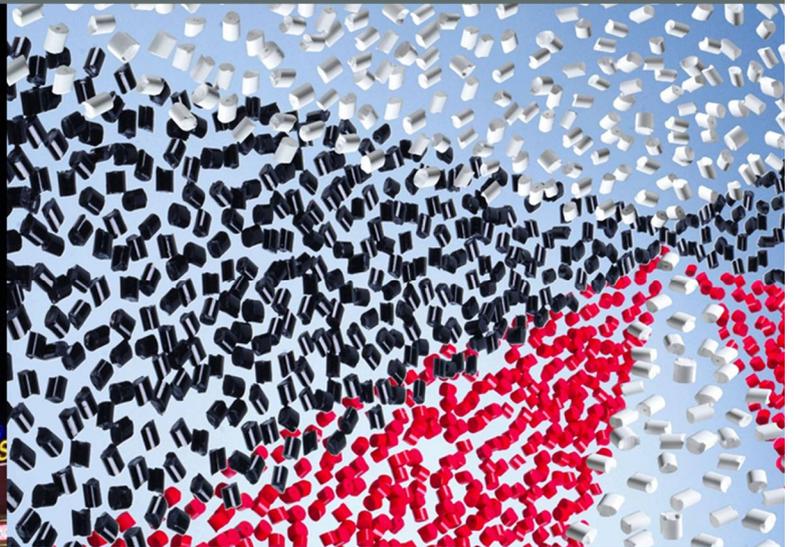


Poly methyl methacrylate (PMMA)

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

January 2015





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. Further, they do not imply a value judgment between environmental criteria.

This EPD describes the production of poly methyl methacrylate (PMMA) from cradle to gate (from crude oil extraction to polymer at plant). **Please keep in mind that comparisons cannot be made on the level of the 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	Cefic, MSG
LCA Practitioner	BIO Intelligence Service
Programme Owner	PlasticsEurope aisbl
Programme Manager, Reviewer	DEKRA Assurance Services GmbH
Number of plants included in data collection	12
Representativeness	European and Israeli production >85%
Reference year	MMA: 2010 – 2011

	PMMA: 2011 – 2013
Year of data collection and calculation	MMA: 2012 – 2013 PMMA: 2013 – 2014
Expected temporal validity	2017
Cut-offs	No significant cut-offs
Data Quality	Good
Allocation method	Price allocation and 50/50 allocation (functional approach) for MMA production No significant allocation made for PMMA production (polymerisation, casting or extrusion process)

Description of the Product and the Production Process

This Eco-profile represents the European and Israeli average production of poly methyl methacrylate (PMMA) from cradle to gate.

PMMA is a thermoplastic with the formula $(C_5H_8O_2)_n$.

3 types of products are studied: PMMA resin, PMMA cast sheets and PMMA extruded sheets. These products correspond to the main PMMA products marketed in Europe.

Production Process

PMMA resin, PMMA cast sheets and PMMA extruded sheets are produced according to a succession of different processes, the first one being the production of MMA.

PMMA resin is then produced via the polymerisation of MMA. Two main processes can be used: the mass process or the suspension process.

The mass process is carried out by adding a soluble initiator to MMA monomers and by heating. As the reaction proceeds the mixture becomes more viscous and a wide range of molecular masses are produced. The polymer is then pelletised into granules.

The suspension process is a heterogeneous radical polymerisation process. MMA is dispersed in water under controlled agitation. After centrifugation and drying, the process gives beads of polymer.

PMMA cast sheets are produced from MMA via a bulk polymerisation process. The process consists of casting liquid monomer in a flat mould (between two sealed glass sheets) and to heat it (in hot water baths or in ovens) in order for the MMA to polymerise. The PMMA sheet is then withdrawn from the mould.

PMMA extruded sheets are produced from PMMA resin, that is to say after a previous step of polymerisation of MMA. PMMA resin is fed into an extruder that melts and pressurises the polymer. The molten polymer then goes through a die and takes the form of a thin and flat planar flow. The polymer is finally cooled with cooling rolls in order to obtain the PMMA sheet.

Data Sources

This Eco-profile is based on 5 individual LCA studies performed independently by the 5 main European and Israeli producers of PMMA: Altuglas, Evonik, Lucite, Plazit Polygal and Polycasa.

The primary data used in these 5 studies and then in this Eco-profile comes from 12 plants located in 9 different countries and is site-specific gate-to-gate production data.

The 5 producers participating in this Eco-profile cover >85% of the European and Israeli PMMA production in 2012.

Regarding MMA production, the company specific LCIs of MMA were used after a harmonisation process covering several aspects such as system boundaries or allocations rules. For PMMA producers which do not produce MMA, the MMA Eco-profile [PLASTICSEUROPE 2014], which is

representative of the European average production of MMA, was used. Regarding background data (such as energy and auxiliary materials), theecoinvent database 2.2 was used.

Allocation

Several co-products are produced at the MMA production step. In order to share the inputs and outputs of the system between the co-products, economic allocation and functional allocation (50/50 split based on the functions fulfilled by an intermediate reagent) were applied.

Regarding the following steps of the production process of PMMA products, no significant allocation rule was applied, as each individual process is mono-functional (i.e. generates only one type of output).

Use Phase and End-of-Life Management

The disposal of waste from production processes is considered within the system boundaries of this Eco-profile. The use phase and end-of-life processes are outside the system boundaries of this cradle-to-gate system.

Environmental Performance

The tables below show the environmental performance indicators associated with the production of 1 kg of each PMMA product.

Input Parameters

Indicator	Unit	PMMA resin	PMMA cast sheet	PMMA extruded sheet
Non-renewable energy resources ¹⁾	MJ	104	130	116
• Fuel energy	MJ	69	95	80
• Feedstock energy	MJ	36	36	36
Renewable energy resources (biomass) ¹⁾	MJ	0,9	1,5	1,4
• Fuel energy	MJ	0,9	1,5	1,4
• Feedstock energy	MJ	-	-	-
Abiotic Depletion Potential				
• Elements	kg Sb eq	2,3E-06	7,0E-06	2,3E-06
• Fossil fuels	MJ	97	119	106
Renewable materials (biomass)	kg	-	-	-
Water use (including cooling water) ²⁾	kg	498	614	506
¹⁾ Calculated as upper heating value (UHV)				
²⁾ Considering available data, it was not possible to calculate the following indicators : Water use without cooling water or Net freshwater consumption				

Output Parameters

Indicator	Unit	PMMA resin	PMMA cast sheet	PMMA extruded sheet
GWP	kg CO ₂ eq	3,75	4,77	4,38
ODP	g CFC-11 eq	4,2E-04	4,6E-04	4,1E-04
AP	g SO ₂ eq	17,4	26,3	18,3
POCP	g Ethene eq	0,94	1,48	0,96
EP	g PO ₄ ³⁻ eq	2,16	2,99	3,04
Dust/particulate matter	g PM10	0,46	0,71	0,55
Waste sent to landfill ¹⁾				
• Non-hazardous	kg	0,16	0,32	0,23
• Hazardous	kg	4,8E-03	4,9E-03	4,4E-03
¹⁾ Considering available data, it was not possible to assess the amount of waste sent to incineration.				

Additional Environmental and Health Information

PMMA products can be easily machined and processed by standard mechanical and thermal techniques. PMMA is insoluble in water and resistant to salty water. Acrylic sheets and their polyethylene protective layers are fully recyclable. Some grades are approved for food contact. Acrylic sheets do not contain any toxic materials or heavy metals, which may cause environmental damage or health risks. When acrylic burns, it does not produce toxic or corrosive gases which is compliant with international standards. Given correct fabrication, PMMA releases no pollutant substances to the environment. At the end of its product life and after careful separation from other materials, PMMA can be used for energy recovery and chemical or mechanical recycling. PMMA scrap is not classed as hazardous waste. Small quantities can therefore be disposed of as household refuse. However, large quantities should be disposed to recycling.

Additional Technical and Economic Information

PMMA is widely used in various applications for its many advantageous properties. Perhaps the most well-known of these properties is light transmission. Typical PMMA grades allow 92% of light to pass through it, which is more than glass or other plastics. This outstanding clarity enables the use of PMMA in many different optical and related applications. Because it is inherently stable to UV-light, PMMA is used for many outdoor applications, in which it maintains its original colour and finishes for many years. PMMA also has excellent scratch resistance and is able to be processed to a very high gloss finish. These properties, combined with PMMA's dimensional stability, enables its use in many different applications where lasting beautiful appearances are important, such as on furniture or kitchen or bath walls or cabinet facades. PMMA can be further modified by incorporating different additives. These modifications are typically performed to improve specific properties of the polymer, usually targeted toward specific

applications. Examples of properties that can be adjusted in this way are impact resistance, chemical resistance, flame retardancy, light diffusion, UV light filtering, or optical effects.

Optical properties: Since cast PMMA is manufactured by cell casting between two sheets of mirror-like glass, it has excellent surface quality. Extruded PMMA is manufactured in a special extrusion process and therefore cannot always match the high optical quality of cast PMMA.

Machining: Cast PMMA offers greater scope for fabrication, which means the machining conditions do not have to be observed with such accuracy. Less scope is available with extruded PMMA, and care must be taken to ensure the correct tools are used in order to obtain clean cuts and drill holes, if necessary using cooling lubricants.

Thermoforming: Extruded PMMA allows more economical solutions during thermoforming because the forming cycles are shorter and contours can be more accurately reproduced.

Information

Data Owner

Cefic, Methylmethacrylates sector Group

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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 2015-01
validation expires on 31 December 2017 (date of next revalidation review).

Programme Owner

PlasticsEurope

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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 www.plasticseurope.org.

References

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

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 monomer or 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 monomers or 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, or 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”. 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 Functional Unit (or Declared Unit) of this Eco-profile is:

1 kg of primary poly methyl methacrylate (PMMA) “at gate” (production site output) representing a European and Israeli industry production average.

Product and Producer Description

Product Description

Poly methyl methacrylate (PMMA) is a thermoplastic with the formula $(C_5H_8O_2)_n$.

PMMA is produced via the polymerisation of methyl methacrylate (MMA), an organic compound with the formula $C_5H_8O_2$.

3 types of PMMA products are studied in this Eco-profile: PMMA resin, PMMA cast sheets and PMMA extruded sheets. These products correspond to the main PMMA products marketed in Europe.

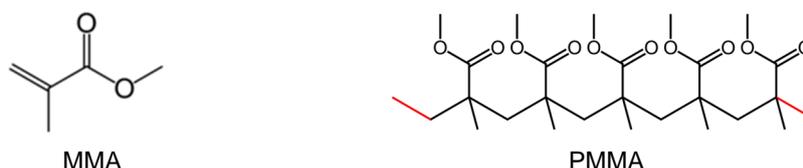


Figure 1: MMA and PMMA formulas

- IUPAC name: Poly(methyl 2-methylpropenoate)
- Molar mass:
 - PMMA resin: 60 – 110 kg/mol,
 - PMMA cast sheet: 1000 – 6000 kg/mol.
 - PMMA extruded sheet: 100 - 150 kg/mol
- CAS no. 9011-14-7
- Chemical formula: $(C_5H_8O_2)_n$
- Gross calorific value: 27.0 MJ/kg (considered equal to the gross calorific value of MMA¹)

Production process Description

PMMA resin, PMMA cast sheets and PMMA extruded sheets are produced according to a succession of different processes, the first one being the production of the monomer MMA.

MMA production process

The main process used in Europe for MMA production is the “acetone Cyanohydrin route”. This process is based on three steps.

The first step is intended to produce hydrogen cyanide (HCN). This intermediate product is usually produced from methane and ammonia according to the Andrussov process or the Degussa process.

In the second step, HCN and acetone are used as reagents for the production of acetone cyanohydrin (ACH).

¹ The polymerisation enthalpy (which is released upon polymerisation) is about 0,55 MJ/kg, which should lead to lower gross calorific value of PMMA compared to MMA. However the gross calorific value of additives and acrylates that are contained in PMMA is considered to compensate this decrease. Therefore the gross caloric value of MMA is considered to be a good approximation.

In the third step, MMA is produced from ACH, sulfuric acid and methanol. Firstly, ACH undergoes sulfuric acid assisted hydrolysis and is converted into a sulfate ester of methacrylamide. Finally, an esterification with methanol gives MMA. During the third step, sulfuric acid is used as an intermediate reagent. After the reactions, the spent sulfuric acid may be recycled and reused for the MMA production or may be neutralised with ammonia, producing ammonium sulfate as a co-product.

For further details on the MMA production, see the MMA Eco-profile [PLASTICSEUROPE 2014].

PMMA resin production process

PMMA resin is produced via the polymerisation of MMA. Two main processes can be used: the mass process or the suspension process.

The mass process is carried out by adding a soluble initiator to MMA monomers and by heating. As the reaction proceeds the mixture becomes more viscous and a wide range of molecular masses are produced. The polymer is then pelletised into granules.

The suspension process is a heterogeneous radical polymerisation process. MMA is dispersed in water under controlled agitation. After centrifugation and drying, the process gives beads of polymer.

PMMA cast sheets production process

PMMA cast sheets are produced from MMA via a bulk polymerisation process. The process consists of casting liquid monomer in a flat mould (between two sealed glass sheets) and to heat it (in hot water baths or in ovens) in order for the MMA to polymerise. The PMMA sheet is then withdrawn from the mould.

PMMA extruded sheets production process:

PMMA extruded sheets are produced from PMMA resin, that is to say after a previous step of polymerisation of MMA.

PMMA resin is fed into an extruder that melts and pressurises the polymer. The molten polymer then goes through a die and takes the form of a thin and flat planar flow. The polymer is finally cooled with cooling rolls in order to obtain the PMMA sheet.

Contrary to the casting process which is a simultaneous polymerisation and shaping process; the extrusion process is only a shaping process.

The figure below presents the different steps of the production process for PMMA resin, PMMA cast sheets and PMMA extruded sheets.

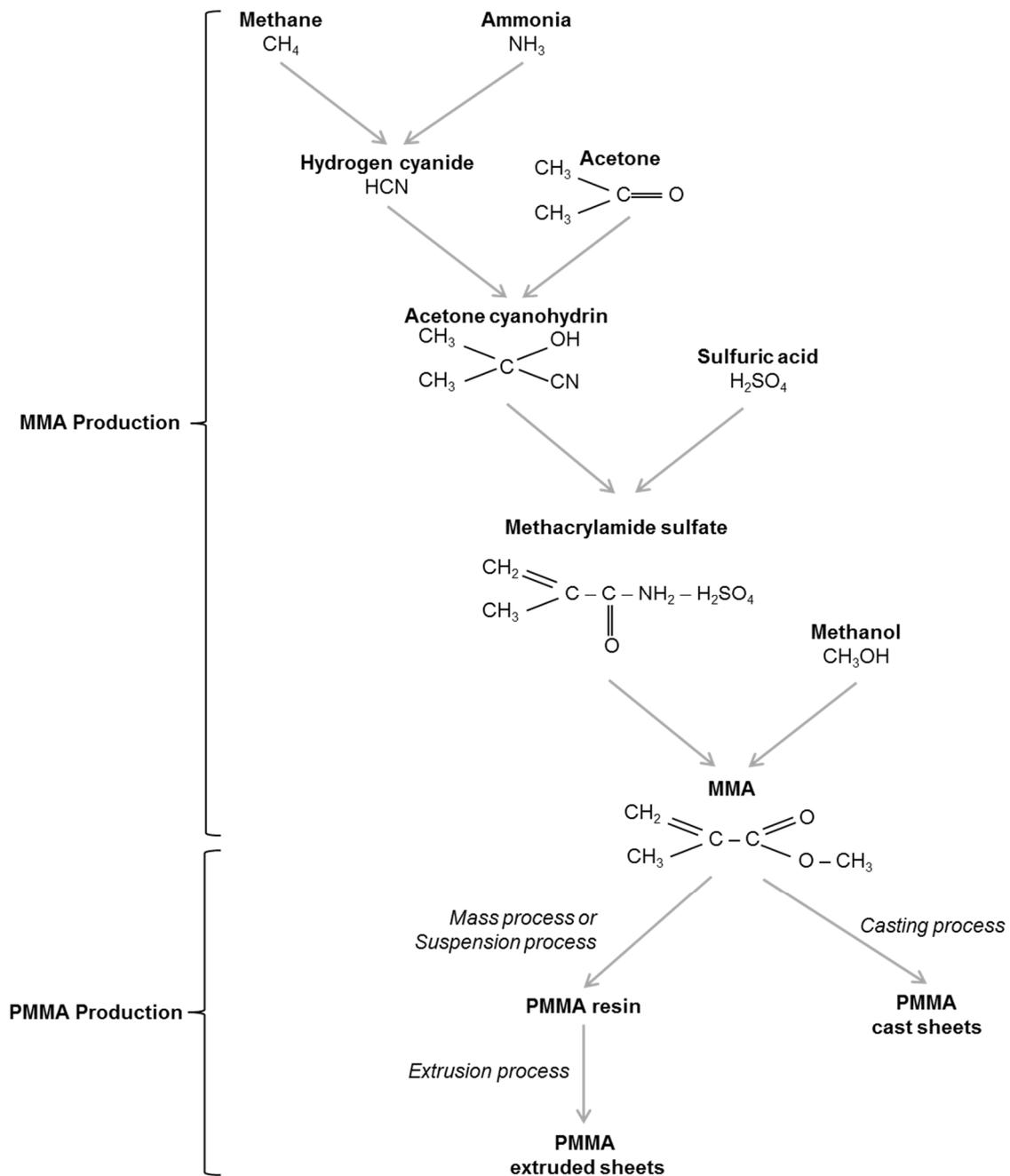


Figure 2: Production process of PMMA resin, PMMA cast sheets and PMMA extruded sheets

Producer Description

PlasticsEurope Eco-profiles and EPDs represent European industry averages within the scope of Cefic and PlasticsEurope as the issuing trade federations. Hence they are not attributed to any single producer, but rather to the European plastics industry as represented by Cefic's membership and the production sites participating in the Eco-profile data collection. The 5 following companies, which are the 5 main producers that put PMMA on the European market, contributed data to this Eco-profile and EPD:

- **Arkema Group (Altuglas International)**
420 rue d'Estienne d'Orves
92705 Colombes Cedex
France
<http://www.arkema.com/>
- **Evonik Industries**
Kirschenallee
64293 Darmstadt
Germany
<http://www.evonik.com/>
- **Lucite International**
Cumberland House
15-17 Cumberland Place
Southampton, SO15 2BG
United Kingdom
<http://www.luciteinternational.com/>
- **Plazit Polygal Group**
1934000 Gazit
Israel
<http://www.plazit-polygal.com/>
- **Polycasa N.V.**
Leukaard 1
2440 Geel
Belgium
<http://www.polycasa.com/>

Eco-profile – Life Cycle Inventory

Special feature of this Eco-profile

This Eco-profile is based on 5 individual LCA studies performed independently by the 5 participating companies. These LCA studies are based on primary data collected separately by each company. Each individual study was externally reviewed, either through a critical review according to ISO 14040-44 standards or through a “sanity check” covering both method and data. Hence, contrary to what is usually done, the data collection process was not carried out during the elaboration of this Eco-profile. The main tasks performed for the elaboration of this Eco-profile were to harmonise the underlying methodology of the 5 studies and to consolidate the results in order to obtain life cycle inventories representative of PMMA resin, cast sheets and extruded sheets produced in Europe and Israel.

System Boundaries

This Eco-profile refers to the production of PMMA resin, PMMA cast sheets and PMMA extruded sheets as a cradle-to-gate system (see Figure 3).

The production covers all life cycle processes from extraction of natural resources, up to the point where the product is ready for transportation to the customer.

The subsequent steps of polymer transformation, use phase and end-of-life management are not included in the system boundaries.

According to PlasticsEurope methodology [PLASTICSEUROPE 2011]:

- Production and transport of the product packaging is not included ;
- Management of production waste in landfill or incinerator and related emissions are included ;
- Waste sent for recycling leave the system without any burden ;
- All relevant transportation processes are included (transportation of landfilled or incinerated waste which is neglected) ;
- Capital goods, i.e. the construction of plant and equipment as well as the maintenance of plants, vehicles and machinery are outside the system boundaries.

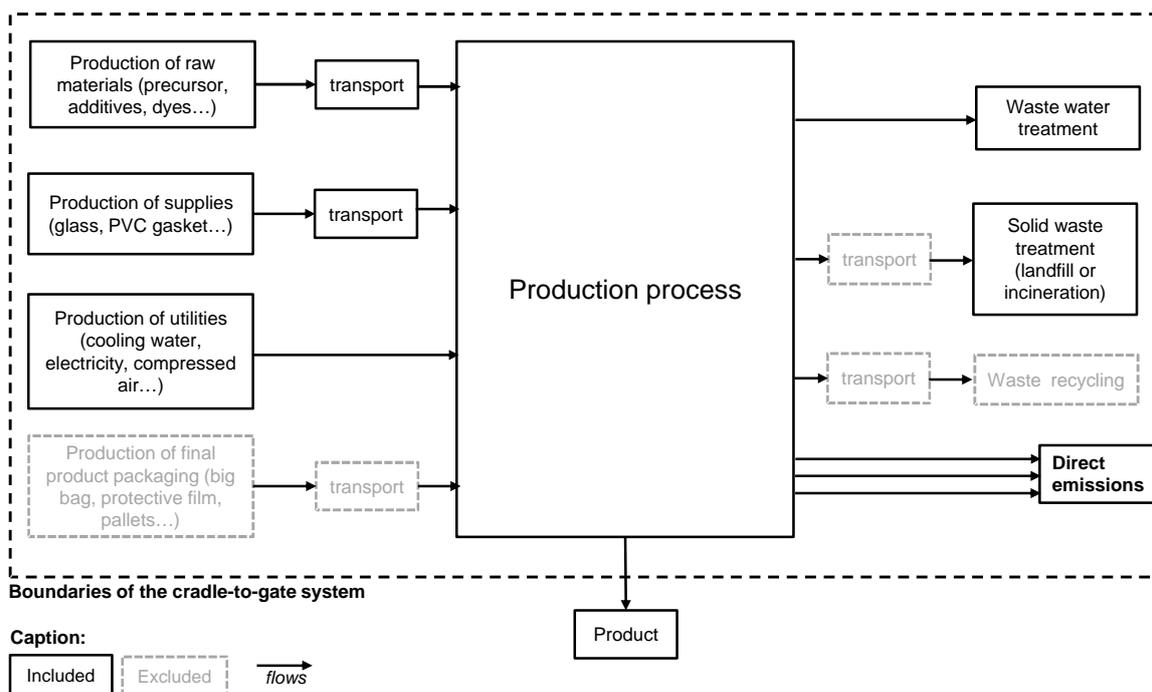


Figure 3: Cradle-to-gate system boundaries

Technological Reference

This Eco-profile represents the European and Israeli average technology for the production of PMMA products (mass process and suspension process for production of PMMA resin, casting process for production of PMMA cast sheets and extrusion process for production of PMMA extruded sheets).

This Eco-profile is based on data coming from the 5 main producers of PMMA in Europe and Israel. These 5 producers cover >85% of the European and Israeli PMMA production in 2012 (based on actual production data from the participating companies and market data from IHS Chemical, 2013). Primary data were used for all foreground processes (under operational control) complemented with secondary data for background processes (under indirect management control).

Consequently, the technological coverage is understood as representative.

Temporal Reference

Primary data used for this Eco-profile is representative of the year 2011, 2012 or 2013 depending on the participating companies. Primary data was collected as 12 month averages to compensate seasonal influence of data. The overall reference year for this Eco-profile is 2011 - 2013 with a maximal temporal validity until 2017.

Geographical Reference

Primary data for PMMA production comes from 12 plants, including 11 plants located in 8 different countries in Europe and 1 plant located in Israel. Fuel and energy inputs in the system reflect site specific conditions. The study results are intended to be representative of the PMMA products produced in Europe and Israel. For other regions, adjustments might be required.

Cut-off Rules

The cut-off rules applied in the 5 individual LCA studies used for this Eco-profile were different. In order to harmonise the scope of the inputs and outputs taken into account, an additional data collection was performed for some specific flows. For example, complementary data such as transportation distances (for key inputs of the production processes), masses of specific auxiliary substances or amount of wastewater were collected in some participating companies. After this harmonisation, one can state that all relevant flows of the foreground process are considered, trying to avoid any cut-off of material or energy flows.

Note that packaging of final product (PMMA resin, cast sheet or extruded sheet) is not considered in the scope of assessment.

Regarding potential cut-off in background data, please refer to the ecoinvent documentation.

Data Quality Requirements

Data Sources

This Eco-profile is based on 5 individual LCA studies performed independently by the 5 main European and Israeli producers of PMMA. The primary data used in these studies and then in this Eco-profile comes from 12 plants located in 9 different countries and is site-specific gate-to-gate production data.

Hence, this Eco-profile is based on average data representative of the respective foreground production processes of the participating companies, both in terms of technology and market share.

Concerning MMA production (upstream supply chain) and background data (such as energy and auxiliary materials), the 5 individual LCA studies used for this Eco-profile were based on datasets coming from different databases. For consistency reasons, datasets used in the 5 studies were harmonised.

Regarding MMA production, the company specific LCIs of MMA were used after a harmonisation process covering several aspects such as system boundaries or allocations rules². For PMMA producers which do not produce MMA, the MMA Eco-profile [PLASTICSEUROPE 2014], which is representative of the European average production of MMA, was used.

Regarding background data, the ecoinvent database 2.2 was used.

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. the collected data reflects the activities of the most important PMMA producers in Europe and Israel.

Representativeness

The considered participants cover >85% of the PMMA European and Israeli production in 2012. The selected background data can be regarded as representative for the intended purpose, as it is average data and not in the focus of the analysis.

Consistency

To ensure consistency, primary data of the same level of detail were used.

While building up the model, cross-checks concerning the plausibility of mass and energy flows were continuously conducted. The methodological framework is consistent throughout the whole model as the same methodological principles are used both in foreground and background system.

Reliability

Regarding foreground processes, data on MMA and PMMA production were directly provided by producers and were predominantly measured. Regarding background processes, data were taken from the ecoinvent 2.2 database. All these data are considered to be reliable.

Completeness

Thanks to primary data collected by the 5 participating companies to perform the 5 individual LCA studies and thanks to additional data collected for the elaboration of this Eco-profile, one may consider that all relevant flows were quantified and data is complete.

Precision and Accuracy

As the relevant foreground data is primary data or modelled based on primary information sources of the owner of the technology, better precision is not reachable within this goal and scope.

² The harmonisation process of the company specific LCIs of MMA is described in the MMA Eco-profile [PlasticsEurope 2014]. The harmonised company specific LCIs of MMA were used for the development of the LCI of the European average MMA production.

Reproducibility

The reproducibility is given for internal use since the owners of the technology provided the data and the models are stored and available in a 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, it may be the case that full reproducibility in any degree of detail will not be available for confidentiality reasons.

Data Validation

The 5 individual LCA studies used for the elaboration of this Eco-profile were third-party reviewed. Four of them were critically reviewed by independent experts according to ISO 14040-44 standards and one of them underwent a "sanity check" covering both method and data.

The background information from the ecoinvent database is updated regularly and validated in principle daily by the various users worldwide.

Life Cycle Model

The study was performed with the LCA Software Simapro and the ecoinvent 2.2 database. This database integrates ISO 14040/44 requirements. The life cycle models of the 5 participating companies were either created in Simapro or integrated in Simapro by using import/export functions of the different softwares used by the companies. In case of Simapro import, a specific check was carried out in order to ensure that the results were consistent with those of the original LCA study. Then, a harmonisation process was applied to each model (e.g. regarding system boundaries) and consolidated datasets representative of PMMA resin, cast sheets and extruded sheets produced in Europe and Israel were elaborated.

Calculation Rules

Averaging

The calculation follows a hybrid approach combining vertical and horizontal averaging method.

- When possible, a vertical averaging method was applied. This method consists in calculating the average after modelling the whole production process of each participating company. This method is recommended by PlasticsEurope [PlasticsEurope 2011] as it is considered to be the most appropriate method in order to represent industrial reality and to reflect the high level of integration within production sites and industrial networks.
- Otherwise, a horizontal averaging method was applied. This method consists in calculating the average after modelling each production step.

In practice, the vertical averaging method was applied when a given company produces both the precursor (MMA or PMMA resin) and the final PMMA product (PMMA resin, PMMA cast sheets or PMMA extruded sheets). In this case, the company-specific LCI of the precursor was used as an input for establishing the LCI of the final PMMA product of this company. Nevertheless, in order to ensure consistency between the different company-specific LCIs of precursors, these LCIs were used after an harmonisation process covering several aspects such as system boundaries or allocations rules³.

³ Regarding the different company specific LCIs of MMA, the harmonisation process is described in the MMA Eco-profile [PlasticsEurope 2014]. These harmonised company specific LCIs of MMA were used for the development of the European average LCI of MMA production.

Otherwise, when a company does not produce the precursor and only produces the final PMMA product, the horizontal averaging method was applied. In that case, the average LCI of the precursor was used as an input for establishing the LCI of the final PMMA product of this company.

The figure below presents an overview of the averaging method applied. In this illustration, companies 1, 2 and 3 produce both precursor and final product. Company 4 only produces final product.

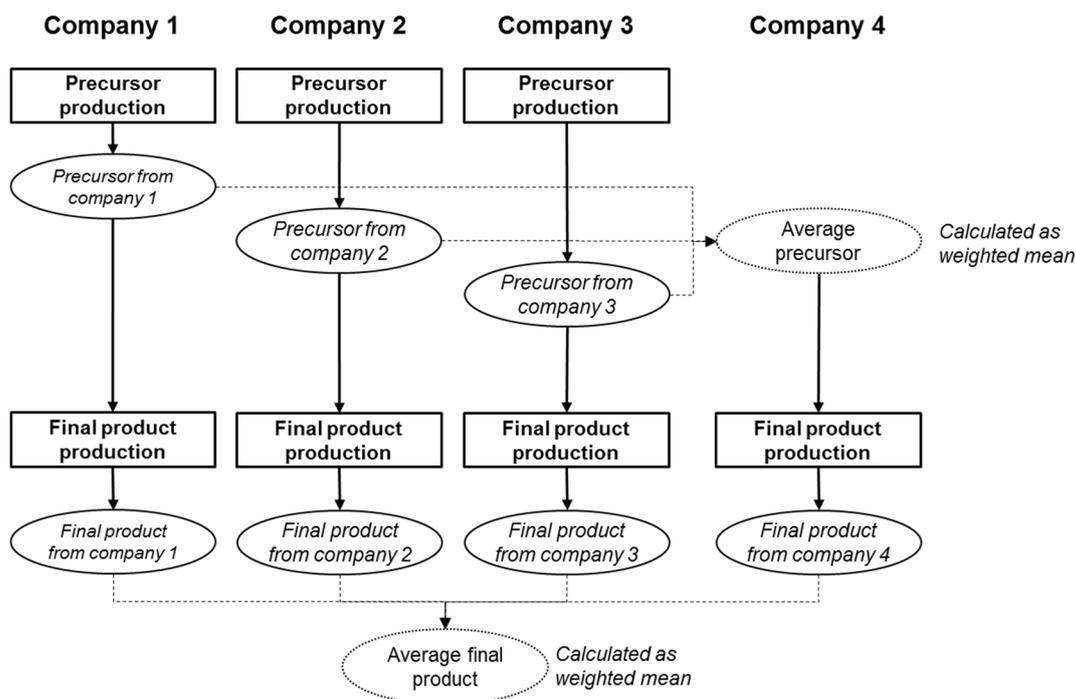


Figure 4: Averaging method (hybrid approach combining vertical and horizontal averaging method)

A sensitivity analysis comparing the vertical and the horizontal approach was carried out in order to evaluate result differences for both approaches. For details please refer to the Chapter 'Consistency Check'.

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 in reality or 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.

Regarding PMMA products, several co-products are produced at the MMA production step. In order to share the inputs and outputs of the system between the co-products, economic allocation and functional allocation (50/50 split based on the functions fulfilled by an intermediate reagent) were applied. For further details on the allocation rules at the MMA production step, see the MMA Eco-profile [PLASTICSEUROPE 2014].

Regarding the following steps of the production process of PMMA products, no significant allocation rule was applied, as each individual process is mono-functional (i.e. generates only one type of output). One can notice that an economic allocation was applied in the model of 1 of the 12 plants studied since different qualities of sheets were produced in this plant. However, this allocation rule has a very low influence on the results.

Life Cycle Inventory (LCI) Results

Formats of LCI Dataset

The Eco-profile is provided in three electronic formats:

- As input/output table in Excel®
- As XML document in EcoSpold format (www.ecoinvent.org)
- As XML document in ILCD format (eplca.jrc.ec.europa.eu)

Key results are summarised below.

Energy Demand

As a key indicator on the inventory level, the **primary energy demand** (system input) 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 27.0 MJ/kg.

Table 1: Primary energy demand (system boundary level) per 1kg of PMMA products

Primary Energy Demand	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Energy content in polymer (energy recovery potential, quantified as gross calorific value of polymer) [MJ]	27	27	27
Process energy (quantified as difference between primary energy demand and energy content of polymer) [MJ]	78	105	90
Total primary energy demand [MJ]	105	132	117

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, Table 3 and Table 4 show how the total energy input (primary energy demand) is used as fuel or feedstock, for each type of PMMA product. 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 monomer (measurable as its gross calorific value). Considering the uncertainty of the exact division of the process energy as originating from either fuels or feedstock, as well as the use of average data (secondary data) in the modelling with different country-specific grades of crude oil and natural gas, there are uncertainties on the feedstock energy and fuel energy results presented in the 3 following tables.

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

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	7,4	0,2		7,4
Oil	35,8	0,8	19,2	16,5
Natural gas	55,5	1,1	16,3	39,2
Lignite	2,2	0,14		2,2
Nuclear	3,3	5,9E-06		3,3
Biomass	0,16			0,16
Hydro	0,44			0,44
Solar	0,22			0,22
Geothermics				
Waves				
Wood				
Wind	0,09			0,09
Other renewable fuels				
Sub-total renewable	0,9	0	0	0,9
Sub-total Non-renewable	104	2,2	35,6	68,5
Total	105	2,2	35,6	69,4

Table 3: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per kg of PMMA cast sheet

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	10,1	0,3		10,1
Oil	38,3	0,8	19,2	19,1
Natural gas	71,9	1,4	16,3	55,6
Lignite	2,5	0,17		2,5
Nuclear	7,5	1,3E-05		7,5
Biomass	0,34			0,34
Hydro	0,73			0,73
Solar	0,27			0,27
Geothermics				
Waves				
Wood				
Wind	0,18			0,18
Other renewable fuels				
Sub-total renewable	1,5	0	0	1,5
Sub-total Non-renewable	130	2,7	35,6	94,7
Total	132	2,7	35,6	96,2

Table 4: Analysis by primary energy resources (system boundary level), expressed as energy and/or mass (as applicable) per kg of PMMA extruded sheet

Primary energy resource input	Total Energy Input [MJ]	Total Mass Input [kg]	Feedstock Energy Input [MJ]	Fuel Energy Input [MJ]
Coal	13,6	0,42		13,6
Oil	37,6	0,82	19,2	18,4
Natural gas	55,9	1,1	16,3	39,6
Lignite	3,5	0,23		3,5
Nuclear	5,1	9,1E-06		5,1
Biomass	0,19			0,19
Hydro	0,53			0,53
Solar	0,62			0,62
Geothermics				
Waves				
Wood				
Wind	0,11			0,11
Other renewable fuels				
Sub-total renewable	1,4	0	0	1,4
Sub-total Non-renewable	116	2,6	35,6	80,2
Total	117	2,6	35,6	81,6

Table 5 shows that nearly all of the primary energy demand is from non-renewable resources.

Table 5: Primary energy demand by renewability per kg of PMMA products

Fuel/energy input type	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Renewable energy resources [%]	0,9%	1,2%	1,2%
Non-renewable energy resources [%]	99,1%	98,8%	98,8%
Total [%]	100%	100%	100%

Table 6 and Table 7 analyse the types of useful energy inputs in the production process. This represents the share of the energy requirement that is under operational control of the producers, regarding PMMA production related processes only (Table 6) or regarding both MMA and PMMA production related processes (Table 7).

Table 6: Analysis by type of energy consumed during process per kg of PMMA products (in the foreground system, for PMMA production related processes only)

Type of useful energy in process input	PMMA Resin (polymerisation)	PMMA Cast sheet (casting)	PMMA Extruded sheet (extrusion)
Electricity [MJ]	1,3	2,5	2,6
Heat, thermal energy [MJ]	1,3	5,9	0,26
Total (for selected key process) [MJ]	2,6	8,3	2,8

Table 7: Analysis by type of energy consumed during process per kg of PMMA products (in the foreground system, for MMA and PMMA production related processes)

Type of useful energy in process input	PMMA Resin (MMA production +polymerisation)	PMMA Cast sheet (MMA production +casting)	PMMA Extruded sheet (MMA production +polymerisation extrusion)
Electricity [MJ]	3,3	6,5	4,3
Heat, thermal energy [MJ]	10,2	12,9	9,6
Total (for selected key process) [MJ]	13,5	19,4	13,9

Finally, Table 8, Table 9 and Table 10 present the contribution of the raw materials and the other inputs of the process to primary energy demand and present the type of energy resources used.

Raw materials refer to precursors or necessary chemicals for the production of MMA and its transformation into PMMA: ammonia and methane used for hydrogen cyanide production, acetone used for acetone cyanohydrin production and sulfuric acid and methanol used for MMA production, as well as additives included for PMMA production.

Others refer for example to catalysts, electricity, heat or other utilities (compressed air, nitrogen, water...).

These tables highlight the predominant contribution of the raw materials. In order to analyse the upstream operations more closely, please refer to the Eco-profiles or datasets on the respective chemicals.

Table 8: Contribution of the raw materials to total primary energy demand (gross calorific values) per kg of PMMA resin

Total Primary Energy	Raw materials (MMA precursors and PMMA additives)	Others (catalysts, electricity, heat...)	Total
Coal [MJ]	1,8	5,6	7,4
Oil [MJ]	34,1	1,6	35,8
Natural gas [MJ]	41,6	13,9	55,5
Lignite [MJ]	1,3	0,83	2,2
Nuclear [MJ]	2,1	1,2	3,3
Biomass [MJ]	0,10	0,07	0,16
Hydro [MJ]	0,28	0,17	0,44
Solar [MJ]	0,038	0,18	0,22
Geothermics [MJ]			
Waves [MJ]			
Wood [MJ]			
Wind [MJ]	0,061	0,026	0,086
Other renewable fuels [MJ]			
Total [MJ]	81,4	23,7	105

Table 9: Contribution of the raw materials to total primary energy demand (gross calorific values) per kg of PMMA cast sheet

Total Primary Energy	Raw materials (MMA precursors and PMMA additives)	Others (catalysts, electricity, heat...)	Total
Coal [MJ]	1,8	8,3	10,1
Oil [MJ]	34,4	4,0	38,3
Natural gas [MJ]	50,7	21,2	71,9
Lignite [MJ]	1,2	1,3	2,5
Nuclear [MJ]	1,9	5,5	7,5
Biomass [MJ]	0,07	0,27	0,34
Hydro [MJ]	0,32	0,41	0,74
Solar [MJ]	0,09	0,19	0,27
Geothermics [MJ]			
Waves [MJ]			
Wood [MJ]			
Wind [MJ]	0,10	0,08	0,18
Other renewable fuels [MJ]			
Total [MJ]	90,5	41,3	132

Table 10: Contribution of the raw materials to total primary energy demand (gross calorific values) per kg of PMMA extruded sheet

Total Primary Energy	Raw materials (MMA precursors and PMMA additives)	Others (catalysts, electricity, heat...)	Total
Coal [MJ]	1,9	11,7	13,6
Oil [MJ]	35,0	2,6	37,6
Natural gas [MJ]	40,5	15,4	56,0
Lignite [MJ]	1,4	2,1	3,5
Nuclear [MJ]	2,2	2,9	5,1
Biomass [MJ]	0,10	0,09	0,19
Hydro [MJ]	0,28	0,26	0,54
Solar [MJ]	0,03	0,59	0,62
Geothermics [MJ]			
Waves [MJ]			
Wood [MJ]			
Wind [MJ]	0,05	0,05	0,11
Other renewable fuels [MJ]			
Total [MJ]	81,5	35,7	117

Water Consumption

Table 11 shows the gross water resources used at cradle-to-gate level. It should be noticed that cooling water is taken into account. Considering available data, it was neither possible to calculate the water use without cooling water nor the net freshwater consumption.

Table 11: Gross water resources use per kg of PMMA products (including cooling water)

Source	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
River/canal/lake [kg]	436	486	436
Sea [kg]	3,2	35	2,8
Unspecified [kg]	37	79	43
Well [kg]	22	15	24
Total [kg]	498	614	506

Air Emission Data

Table 12 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 LCIs table in the annex of this report.

Table 12: Selected air emissions per kg of PMMA products

Air emissions	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Carbon dioxide, fossil (CO ₂ , fossil) [kg]	3,47	4,45	4,05
Carbon monoxide (CO) [kg]	8,9E-04	1,9E-03	1,0E-03
Sulfur dioxide (SO ₂) [kg]	1,2E-02	1,9E-02	1,2E-02
Nitrogen oxides (NO _x) [kg]	5,4E-03	7,1E-03	6,4E-03
Particulate matter • 10 µm (PM 10) [kg]	4,6E-04	7,1E-04	5,5E-04

Wastewater Emissions

Table 13 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 13: Selected water emissions per kg of PMMA products

Water emissions	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Biological oxygen demand after 5 days (BOD 5) [kg]	4,3E-03	4,5E-03	4,7E-03
Chemical oxygen demand (COD) [kg]	5,4E-03	6,0E-03	5,9E-03
Total organic carbon (TOC) [kg]	1,8E-03	1,9E-03	1,9E-03

Solid Waste

Table 14 shows the solid waste generation at cradle-to-gate level. Only the amounts of waste which are sent to landfill are reported here because the available data did not allow the calculation of another indicator.

Table 14: Solid waste generation per kg of PMMA products (Waste sent to landfill)

Waste sent to landfill	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Non-hazardous [kg]	1,6E-01	3,2E-01	2,3E-01
Hazardous [kg]	4,8E-03	4,9E-03	4,4E-03
Total [kg]	1,6E-01	3,3E-01	2,3E-01

Life Cycle Impact Assessment

Input

Natural Resources

The Abiotic Depletion Potential (ADP) measures the extraction of natural resources such as iron ore, scarce minerals, and fossil fuels such as crude oil. This indicator is based on ultimate reserves and extraction rates. It is distinguished into the two subcategories 'ADP, elements' and 'ADP, fossil fuels'. For 'ADP, elements' Antimony (Sb) is used as a reference for the depletion of minerals and metal ores and for 'ADP, fossil fuels' the lower heating value (LHV) of extracted fossil fuels is considered. It is calculated according to [OERS2002] with updated characterisation factors of CML (CML 2001, April 2013, version 4.2).

Table 15: Abiotic Depletion Potential per kg of PMMA products

Natural resources	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Abiotic Depletion Potential (ADP). elements [kg Sb eq]	2,3E-06	7,0E-06	2,3E-06
Abiotic Depletion Potential (ADP). fossil fuels [MJ]	97	119	106

Output

Climate Change

The impact category climate change is represented by the Global Warming Potential (GWP) with a time horizon of 100 years. The applied characterisation factors come from the last report of the Intergovernmental Panel on Climate Change [IPCC 2007].

Table 16: Global Warming Potential (100 years) per kg of PMMA products

Climate change	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Global Warming Potential (GWP) [kg CO ₂ eq.]	3,75	4,77	4,38

Acidification

The Acidification Potential (AP) is quantified according to [HUIJBREGTS1999] (model including fate) with updated characterisation factors of CML (CML 2001, April 2013, version 4.2).

Table 17: Acidification Potential per kg of PMMA products

Acidification of soils and water bodies	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Acidification Potential (AP) [g SO ₂ eq.]	17,4	26,3	18,3

Eutrophication

The Eutrophication Potential (EP) is calculated according to [HEIJUNGS1992] with updated characterisation factors of CML (CML 2001, April 2013, version 4.2).

It can be noticed that the impact of 1kg of PMMA extruded sheet is higher than the impact of 1kg of PMMA cast sheet for Eutrophication Potential whereas the impact of extruded sheet is lower for all the other studied indicators. This specific result for Eutrophication Potential is partly due to the geographical location of the plants of the participating companies producing extruded sheets or cast sheets, as:

- the electricity consumption is a significant contributor to the Eutrophication Potential,
- and the electricity mix used in a given country has a great influence on the impact of electricity and therefore on eutrophication.

Table 18: Eutrophication Potential per kg of PMMA products

Eutrophication of soils and water bodies	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Eutrophication Potential (EP), total [g PO ₄ ³⁻ eq.]	2,16	2,99	3,04

Ozone Depletion

The Ozone Depletion Potential (ODP) is calculated according to [WMO 2003] (ODP steady state) with updated characterisation factors of CML (CML 2001, April 2013, version 4.2).

Table 19: Ozone Depletion Potential per kg of PMMA products

Ozone depletion	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Ozone Depletion Potential (ODP) [g CFC-11 eq.]	4,2E-04	4,6E-04	4,1E-04

Summer Smog

The Photochemical Ozone Creation Potential (POCP) is quantified according to [JENKIN1999] and [DERWENT1998] with updated characterisation factors of CML (CML 2001, April 2013, version 4.2).

Table 20: Photochemical Ozone Creation Potential per kg of PMMA products

Photochemical Ozone Creation Potential	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Photochemical Ozone Creation Potential [g Ethene eq.]	0,94	1,48	0,96

Dust & Particulate Matter

Dust and particulate matter are reported as PM10 (particulate ≤ 10 µm).

Table 21: PM10 emissions per kg of PMMA products

Particulate matter	PMMA Resin	PMMA Cast sheet	PMMA Extruded sheet
Particulate matter • 10 µm. Total [g PM10 eq.]	0,46	0,71	0,55

Consistency check

Consistency check between MMA and PMMA products

A check was carried out in order to ensure the consistency of results between MMA and PMMA products. When comparing the MMA Eco-profile [PLASTICSEUROPE 2014] and the present Eco-profile, some results may appear counterintuitive:

- For Abiotic Depletion Potential – Elements, Acidification Potential and Photochemical Ozone Creation Potential, the impact of 1kg of PMMA resin and 1 kg of PMMA extruded sheet are lower than the impact of 1kg of MMA.
- For water consumption, the impact of 1kg of PMMA resin is slightly lower than the impact of 1kg of MMA.

Besides, when comparing the results between the different PMMA products, a result may also appear counterintuitive:

- For Ozone Depletion Potential, the impact of 1kg of PMMA resin is higher than the impact of 1kg of PMMA extruded sheet.

Rationale for counterintuitive results

Two main reasons explain these counterintuitive results.

The major part of the explanation lies in the fact that a vertical averaging method was used in priority in this Eco-profile as recommended by the PlasticsEurope methodology [PlasticsEurope 2011]. Consequently, when possible, the company-specific LCI of a precursor was used as an input for establishing the LCI of the final PMMA product of this company. Then, the averaging was done after modelling the whole production process of each company. However, the following elements have to be noticed:

- There are significant differences between the company specific LCIs of precursors, which can lead to significant differences for some environmental impact indicators,
- The contributions of these company specific LCIs of precursors in the final results are very variable as the production shares of the different participating companies are very different for MMA, PMMA resin, PMMA cast sheet and PMMA extruded sheet.

Given that, it turns out that the impacts of an European average PMMA product calculated with a vertical averaging method⁴ may be lower than the impacts of the European average precursor (MMA in the case of PMMA resin and PMMA cast sheets / PMMA resin in the case of PMMA extruded sheets).

Another part of the explanation lies in the fact that in some cases, less than 1kg of precursor is required to produce 1kg of PMMA product, as PMMA products also contain additives. If the environmental impacts of additives are much lower than those of the precursor, this can also lead to counterintuitive results, but to a lesser extent than the averaging method.

Sensitivity analysis regarding averaging method

Given the results obtained, a sensitivity analysis was carried out in order to assess the influence of the averaging method. To this aim, the hybrid approach combining vertical and horizontal averaging methods used in this Eco-profile was compared with a pure horizontal averaging method (systematic use of average LCI of precursors for establishing LCI of final PMMA products). This analysis provided the following insights:

- As expected, counterintuitive results do not appear any more when using a pure horizontal averaging method.

⁴ Or with a hybrid approach combining vertical and horizontal averaging methods as in this Eco-profile

- For a given PMMA product (resin, cast sheet or extruded sheet), the choice of averaging method does not have a significant influence on most environmental indicators.
- The indicators for which the gaps are the highest are the ones, for which the impacts of MMA of the different companies have the highest variability.

Finally, it should be underlined that the discussed result differences are small and are within an uncertainty range that is typical for LCA studies.

This is why, despite these few counteractive results, the hybrid approach giving preference to vertical averaging method was kept in this Eco-profile. Indeed, according to PlasticsEurope [2011], vertical averaging is the most appropriate method in order to represent industrial reality and to reflect the high level of integration within production sites and industrial networks.

Dominance Analysis

Table 22, Table 23 and Table 24 present the contribution of the raw materials and the other inputs and outputs of the process to the results presented above, for each type of PMMA product.

As for Table 8, Table 9 and Table 10, raw materials refer to precursors or necessary chemicals for the production of MMA and its transformation into PMMA: ammonia and methane used for hydrogen cyanide production, acetone used for acetone cyanohydrin production, sulfuric acid, methanol as well as additives included for PMMA production. Others refer for example to catalysts, electricity, heat or other utilities (compressed air, nitrogen, water...).

For most of the analysed environmental impact indicators, raw materials have a higher contribution to the results than the other inputs and outputs of the production process.

Within the impacts of raw materials, acetone used during the MMA production step is a significant contributor. Within the other inputs and outputs, energy consumptions (electricity and heat consumption) are the main contributors. As indicated in Table 6 and Table 7, the energy consumptions mainly occur during the MMA production step but the consumptions during transformation into PMMA product also contribute. For PMMA resin and extruded sheets, the consumptions are relatively low, whereas for cast sheets, the consumptions are almost equal to the consumptions during MMA production.

Besides, it should be noted that the management of the sulfuric acid used in the MMA production process has a notable influence on the results. Indeed, companies which recycle sulfuric acid use less raw materials but more process energy (included in "Others"). To the contrary, companies which do not recycle sulfuric acid have higher contributions in the "Raw materials" category and lower contributions in the "Others" category.

Table 22: Dominance analysis of impacts per kg of PMMA resin

	Total Primary Energy	ADP Elements	ADP Fossil	GWP	AP	EP	POCP
	[MJ]	[kg Sb eq.]	[MJ]	[kg CO₂ eq.]	[g SO₂ eq.]	[g PO₄³⁻ eq.]	[g Ethene eq.]
Raw materials (MMA precursors and PMMA additives)	78%	58%	78%	58%	55%	59%	59%
Others (catalysts, electricity, heat...)	22%	42%	22%	42%	45%	41%	41%
Total	100%	100%	100%	100%	100%	100%	100%

Table 23: Dominance analysis of impacts per kg of PMMA cast sheet

	Total Primary Energy	ADP Elements	ADP Fossil	GWP	AP	EP	POCP
	[MJ]	[kg Sb eq.]	[MJ]	[kg CO ₂ eq.]	[g SO ₂ eq.]	[g PO ₄ ³⁻ eq]	[g Ethene eq.]
Raw materials (MMA precursors and PMMA additives)	69%	61%	72%	49%	46%	42%	46%
Others (catalysts, electricity, heat...)	31%	39%	28%	51%	54%	58%	54%
Total	100%	100%	100%	100%	100%	100%	100%

Table 24: Dominance analysis of impacts per kg of PMMA extruded sheet

	Total Primary Energy	ADP Elements	ADP Fossil	GWP	AP	EP	POCP
	[MJ]	[kg Sb eq.]	[MJ]	[kg CO ₂ eq.]	[g SO ₂ eq.]	[g PO ₄ ³⁻ eq]	[g Ethene eq.]
Raw materials (MMA precursors and PMMA additives)	70%	56%	72%	51%	49%	44%	54%
Others (catalysts, electricity, heat...)	30%	44%	28%	49%	51%	56%	46%
Total	100%	100%	100%	100%	100%	100%	100%

Comparison of the present Eco-profile with its previous version (2005)

Table 25 compares the present results with the previous version of the Eco-profile for PMMA resin [BOUSTEAD 2005]. Among the common indicators studied in the 2 Eco-profiles, only the 2 more robust indicators are compared: Global Warming Potential and Primary Energy Demand.

Table 25: Comparison of the present Eco-profile for PMMA resin with its previous version (2005) regarding Global Warming Potential and Primary Energy demand per kg of PMMA resin

Environmental Impact Category	Eco-profile PMMA (2005)	Eco-profile PMMA (2014)	Difference
Global Warming Potential (GWP) [kg CO ₂ eq.]	7,0	3,8	-46%
Primary Energy demand [MJ]	116	105	-10%

Regarding Global Warming Potential, one can notice that the impact assessed in the 2014 Eco-profile is nearly half of the impact assessed in the 2005 Eco-profile. Regarding the Primary Energy Demand, the reduction between 2005 and 2014 is around 10%.

However, care has to be taken when deriving interpretation of this comparison. Indeed, two main factors may explain these differences:

- Changes in production process ;
- Changes in LCA methodology.

Regarding the production process, participating companies have implemented several changes that have led to environmental impact reductions such as process yield improvements, energy efficiency progresses and changes in energy mixes. For example, during the last years, participating companies mentioned an average decrease of 1% per year of energy consumption in their plants.

Regarding LCA methodology, various changes were able to intervene regarding aspects such as:

- The level of detail of data collection (According to participating companies, the information collected for this Eco-profile is far greater than for the previous Eco-profile.) ;
- The scope of assessment (For example, the waste treatment of all wastes occurring during the process is included in the system boundaries of this Eco-profile. In contrast, the wastes were only quantified as flows in the 2005 Eco-profile and the environmental impacts due to their treatment were out of scope of the assessment.) ;
- The databases used for the upstream supply chain and all background processes ;
- The allocation rules between co-products considered for MMA production ;
- The methods used to quantify the environmental impact indicators (For example, the characterisation factor of Methane used for the calculation of the Global Warming Potential has changed between the two versions of the Eco-profile.)

However, the 2005 Eco-profile does not provide detailed and transparent information regarding methodological aspects. This lack of information does not allow identifying and quantifying the importance of methodological changes in the overall environmental impact reduction.

As a consequence, it is not possible to assess the share of environmental impact reduction of PMMA production due to real production process improvements and the share due to LCA methodological changes. Besides, one can mention that the methodological aspects of the 2014 Eco-profile have been deeply analysed and discussed with all the stakeholders involved in order to define the most suitable approaches in a concerted manner. They are transparently reported in this Eco-profile in order to allow an easier monitoring of PMMA production environmental impacts in the future.

Review

Review Summary

As part of the CEFIC / Product Group MSG programme management and quality assurance, DEKRA Assurance Services GmbH conducted an external independent critical review of this work. The outcome of the critical review is reproduced below.

The subject of this critical review was the development of the Eco-profile for three Poly methyl methacrylate (PMMA) products: PMMA resin, PMMA cast sheets and PMMA extruded sheets. In contrast to many other Eco-profile projects, the basis for this European average PMMA Eco-profile were five individual LCA studies which had been performed by the five participating PMMA producers. Consequently, the main challenges in this project included the adoption of a harmonised method, the respective adaptations to the individual studies and the consolidation into one life cycle model.

The project included milestone meetings with representatives of participating producers, the LCA practitioner and the reviewer. In addition, various review meetings between the LCA practitioner and the reviewer were held, which featured discussions regarding the methodological harmonisation of five individual LCA studies and the consolidation (i.e. averaging) into average European Eco-profiles for the three PMMA products. The final Eco-profile report was also made available for comment to representatives of the participating organisations. All questions and recommendations were discussed with the LCA practitioner and the reviewer, and the report was adapted and revised accordingly.

The individual LCA studies are based on primary data collected separately by each company and were each independently critically reviewed according to ISO 14040-44 standards. In order to consolidate the five individual studies into one PMMA Eco-profile, the individual studies were analysed and methodological differences identified. The PMMA Eco-profile builds upon the Eco-profile for MMA, for which best-practice methodological choices were applied. Please compare with the MMA Eco-profile for further details. For the three PMMA products described in this Eco-profile, a hybrid averaging approach was applied according to which vertical averaging was carried out where possible (fully integrated producer) and horizontal averaging was applied for participating companies solely producing PMMA products. This approach aligns with 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). This approach was also discussed with participating industry representatives involved in this project and considered to be highly appropriate. See further reasoning for the chosen approach, explanations for Eco-profile results and results from a sensitivity analysis in the main report.

As a result, both the data quality and methodological consistency can be rated to be very high. In addition and in contrast to the previous version of the PMMA Eco-profile (2005), all methodological and consolidation choices taken are transparently documented in this report.

The five producers participating in this Eco-profile cover >85% of the European and Israeli PMMA production capacity in 2012. Data for the upstream supply chain until the precursors and all relevant background data (such as energy and auxiliary materials) are taken from the ecoinvent 2.2 database. Further details on data quality indicators are available in the accompanying ILCD entry-level template.

The LCA practitioner has demonstrated very good competence and great project management skills. 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) which is based on the ISO 14040/44 Standards. As a result, this dataset is assessed to be a reliable and high quality representation of PMMA produced in Europe and Israel.

Reviewers Names and Institution

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