Eco-profiles of the European Plastics Manufacturers

# Poly methyl methacrylate (PMMA): resin, cast sheets and extruded sheets

PlasticsEurope

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# 1. Summary

This Eco-profile has been prepared according to **the PlasticsEurope Eco-profiles program and methodology** (September 2022). It provides 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 Eco-profile describes the production of the polymethyl methacrylate (PMMA) from cradle to gate (from crude oil extraction to polymer at plant). **Please keep in mind that comparisons <u>cannot</u> 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.

## 1.1. Meta Data

| | |
|---|---|
| Data Owner | Cefic, Methacrylates Sector Group |
| LCA Practitioner | Deloitte Conseil |
| Programme Owner | PlasticsEurope |
| Reviewer | Angela Schindler |
| Number of plants included in data collection | 11 |
| Representativeness | European production (>80%) |
| Reference year | 2021 |
| Year of data collection and calculation | 2022-2023 |
| Expected temporal validity | 5 years |
| Cut-offs | <2% in mass and energy except for the flows with environmental significance - 0%) |
| Data Quality | Good |
| Allocation method | MMA production: System expansion by substitution for ammonium sulphate co-product, and mass allocation for hydrogen gas co-product.<br>PMMA production (polymerisation, casting or extrusion process): no allocation made. |

## 1.2. Description of the Product and the Production Process

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

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

Three 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.

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, 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.

## 1.3. Data Sources

This Eco-profile is based on a collective LCA study performed by the 5 main European and Israeli producers of PMMA: 3A Composites, Mitsubishi Chemicals, Plaskolite, Röhm and Trinseo.

The primary data used in these 5 studies and then in this Eco-profile comes from 11 plants located in 9 different countries and is site-specific gate-to-gate production data.

Based on expert judgement, the 5 producers participating to this Eco-profile cover more than 80 % of the European PMMA production in 2021.

Regarding MMA production, the MMA Eco-profile [PLASTICSEUROPE 2024], developed during the same project, which is representative of the European average production of MMA, was used. Regarding background data ((such as energy and auxiliary materials), the ecoinvent database 3.8 was used.

## 1.4. Allocation

Ammonium sulphate and hydrogen gas are produced at the MMA production step. In order to share the inputs and outputs of the system between the co-products, system expansion by substitution was applied for the ammonium sulphate, and mass allocation was applied for the hydrogen gas.

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

## 1.5. 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.

MMA and PMMA are important solutions providers in EU industrial ecosystems like Automotive, Construction, Health as well as Electronics and appliances. The durability and light weight aspect of MMA and PMMA containing products is one key element to reach EU sustainability and energy efficiency targets.

Due to advantages over other polymers such as durability, transparency and ability to form copolymers, PMMA and MMABP (MMA based polymers) have a wide range of applications, such as in automotive (rear) lights, glazing, aerospace, signs and displays, indoor and outdoor lighting, bathtubs, appliances, LCD screens, surface coatings and niche markets like bone cement, dentures and artificial teeth or intraocular lenses.

With regards to recyclability, mechanical and chemical recycling processes for the different PMMA grades and products are established for post-industrial scrap and post-consumer waste after sorting the waste streams. Unlike most other polymers, PMMA is a unique material. Through a depolymerisation process called molecular recycling, it easily breaks down to its original molecule, MMA. When exposed to high temperature, its polymer chains break and revert to the monomer, MMA. This temperature is far lower than what is typically required for pyrolysis. As a result, PMMA has a very high recovery rate and recycling potential. In addition, PMMA can also be mechanically recycled. Typically, waste from PMMA production is ground down and repelletised, so that it can be fed back into the production process.

## 1.6. 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) | | | | |
| • Fuel energy | MJ | 67 | 86 | 69 |
| • Feedstock energy | MJ | 27 | 27 | 27 |
| Renewable energy resources (biomass)(1) | | | | |
| • Fuel energy | MJ | 3.0 | 4.3 | 4.7 |
| • Feedstock energy | MJ | - | - | - |
| Resource use(2) | | | | |
| • Minerals and metals | kg Sb eq | 2.4E-06 | 2.6E-06 | 2.4E-06 |
| • Energy carriers | MJ | 88 | 106 | 90 |
| Water scarcity(2) | $m^3$ world eq | 0.70 | 0.98 | 0.74 |
| (1) Calculated as upper heating value (UHV)<br>(2) Calculated with EF3.0 characterisation method | | | | |

### Output Parameters

| Indicator | Unit | PMMA resin | PMMA cast sheet | PMMA extruded sheet |
|---|---|---|---|---|
| Climate change, total | kg $CO_2$ eq | 3.9 | 5.1 | 4.1 |
| Ozone depletion | kg CFC-11 eq | 4.3E-07 | 5.9E-07 | 4.5E-07 |
| Acidification | Mole of H+ eq | 8.8E-03 | 1.1E-02 | 1.0E-02 |
| Photochemical ozone formation | kg NMVOC eq | 7.9E-03 | 2.2E-02 | 8.8E-03 |
| Eutrophication. freshwater | kg P eq | 3.5E-05 | 3.8E-05 | 4.1E-05 |
| Particulate matter | Disease incidences | 4.7E-08 | 6.0E-08 | 5.4E-08 |

## 1.7. 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 recyclable. Some grades are approved for food contact and medical use. With 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 classified as non-hazardous waste. Small quantities can therefore be disposed of as household refuse. However, large quantities should be disposed to recycling.

## 1.8. 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.

## 1.9. Information

**Data Owner**

Methacrylates sector Group, a Cefic Sector Group
Rue Belliard 40, Box 15
B-1040 Brussels Belgium
Tel.: +32.475.62.36.81
Email: mvo@cefic.be.

**Reviewer**

Angela Schindler
Tüfinger Str. 12
88682 Salem, Germany
E-mail: angela@schindler-umwelt.de

**Programme Owner**

PlasticsEurope
Rue Belliard 40, Box 16
B-1040 Brussels, Belgium
E-mail: connect@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 program and methodology (version 3.1, September 2022).

# 2. Goal & Scope

Eco-profiles (LCIs) 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 using polymers. It is essential to note that comparisons cannot be made at the level of the polymer or its precursors. Comparisons can only be made through LCAs applied at the level of a product using these different materials as different options on the basis of the same functional unit of this product.

Eco-profiles 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.

## 2.1. 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 industry production average.*

## 2.2. 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 $C_5H_8O_2$.

Three 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.

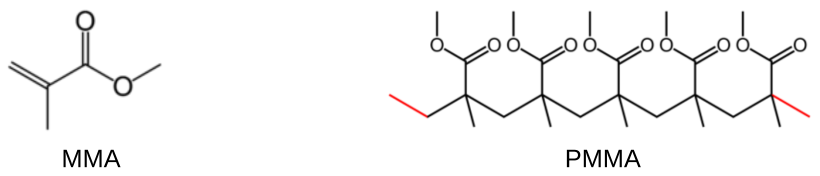


*Figure 1: MMA and PMMA formulas*

- 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 MMA[1])

## 2.3. Manufacturing 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 Andrussow process or the Degussa process.

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

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 sulphate 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 sulphate as a co-product.

For further details on the MMA production, see the MMA Eco-profile [PlasticsEurope 2024].

**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 in 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.

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[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.

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.

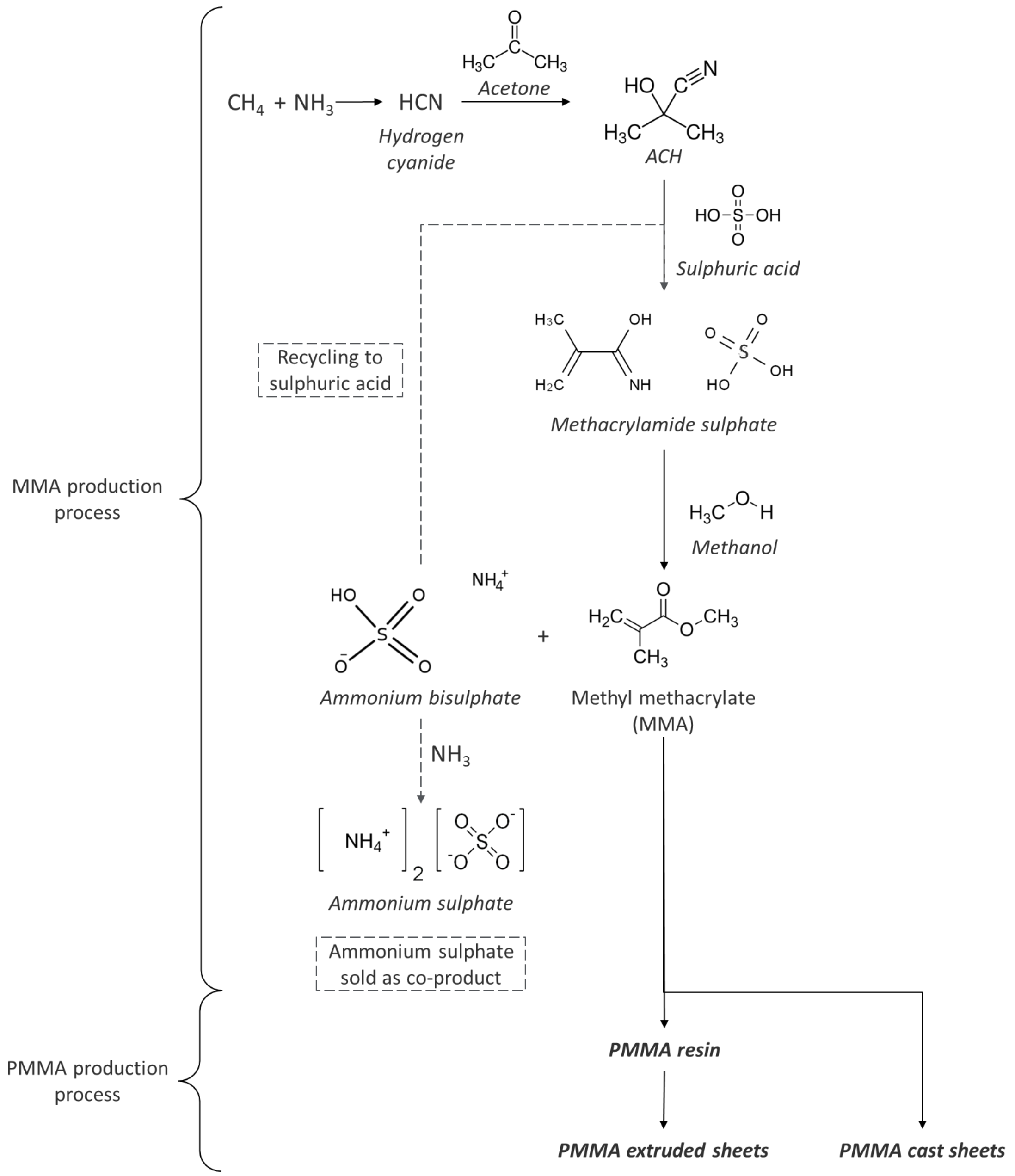


*Figure 2: Production process of PMMA resin, PMMA cast sheets and PMMA extruded sheets*

## 2.4. Producer Description

PlasticsEurope Eco-profiles 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 five following companies, which are the five main producers that put PMMA on the European market, contributed data to this Eco-profile:

- **3A Composites GmbH**

Kiefernweg 10,

49090, Osnabrück,

Germany

https://www.3acomposites.com/

- **Mitsubishi Chemical UK Limited**

Cassel Works, New Road,

Billingham TS23 1LE,

United Kingdom

https://mitsubishichemical.co.uk/

- **Plaskolite (Plazit-Polygal)**

Kibbutz Gazit, 1934000,

Israel

https://plazit-polygal.com/en/

- **Röhm GmbH**

Deutsche-Telekom-Allee 9,

64295 Darmstadt

Germany

https://www.roehm.com/en/

- **Trinseo Europe GmbH**

Gwattstrasse 15,

8808 Pfäffikon,

Switzerland

https://www.trinseo.com/

## 2.5. 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.

Companies that are also MMA producers use their own MMA, whereas companies that do not produce MMA purchase it. All processes for PMMA resin and sheets are assumed to be fed by average MMA-data.

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

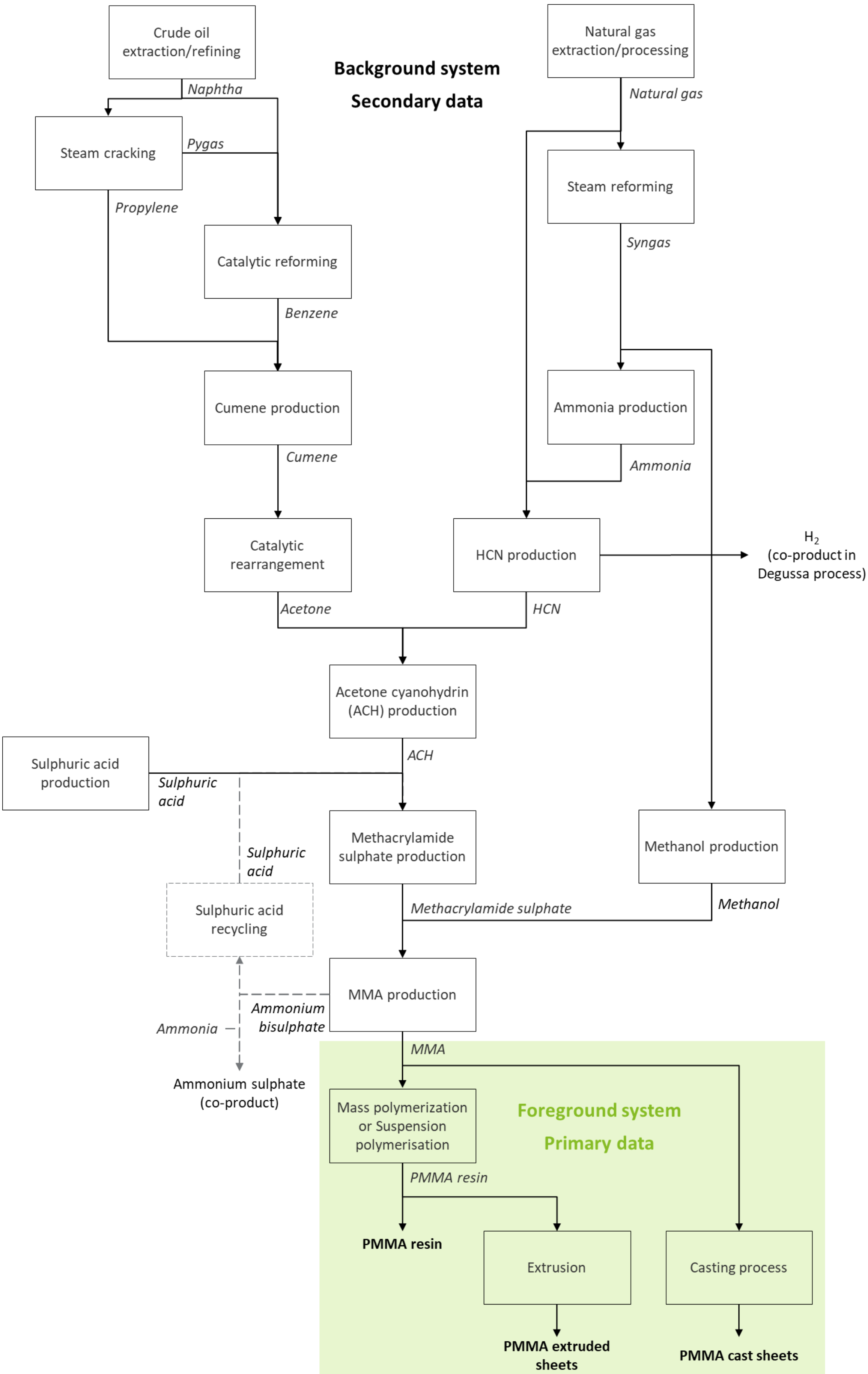


*Figure 3: Cradle-to-gate system boundaries*

## 2.6. Technological reference

This Eco-profile represents the European 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).

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.

## 2.7. Temporal coverage

The primary data used for this Eco-profile is representative of the year 2021. Primary data was collected as 12-month averages to compensate seasonal influence of data. The overall reference year for this Eco-profile is 2021 with a maximal temporal validity until 2028.

## 2.8. Geographical coverage

Primary data for PMMA production comes from 11 plants, including 10 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.

## 2.9. Cut-off Rules

All relevant flows of the foreground process are considered, trying to avoid any cut-off of material or energy flows. However, for a few select commodities (input <0.2% in mass of product output), generic datasets have been used.

Note that capital, i.e. the construction of plant and equipment as well as the maintenance of plants, vehicles and machinery is outside the LCI system boundaries of this study and is therefore not included in this Eco-profile.

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

## 2.10. Data Quality Requirements

**Data Sources and Types of Data**

The primary data used in these studies and then in this Eco-profile comes from 11 plants located in 9 different countries and is site-specific gate-to-gate production data.

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

Regarding MMA production, the MMA Eco-profile [PLASTICSEUROPE 2024], developed during the same project, which is representative of the European average production of MMA, was used.

Regarding background data, the ecoinvent database 3.8 was used.

**Relevance and representativeness**

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.

The considered participants covered more than 80% of the PMMA European production in 2021. The selected background data can be regarded as representative for the intended purpose, as it relies on averaged MMA-data collected during the same project.

**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 and uncertainty**

Data reliability ranges from measured to estimated data. 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 3.8 database. All these data are considered to be reliable.

**Completeness**

Thanks to primary data collected by the five participating companies 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.

**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**

All activity data was collected directly from the 11 production sites of the five participating companies. The activity data collected from the project partners and the data providing companies was validated in an iterative process. The collected data was validated using existing data from published sources or expert knowledge. The data itself has been checked with regards to mass, water and elemental balance performing stoichiometric checks. Environmental data is mainly from the ecoinvent v3.8 database. The eco-profile have been verified by an independent expert.

**Life Cycle Model**

The study was performed with the LCA Software SimaPro and the ecoinvent database. This database integrates ISO 14040/44 requirements. Due to confidentiality reasons details on software modelling and methods used cannot be shown here. The calculation follows the vertical calculation methodology as far as possible, i.e. that the averaging is done after modelling the specific processes.

## 2.11. Calculation Rules

### Vertical Averaging aggregated datasets

The calculation follows the vertical calculation methodology, i.e. that the averaging is done after modelling the specific processes of each participating company (Figure 4).

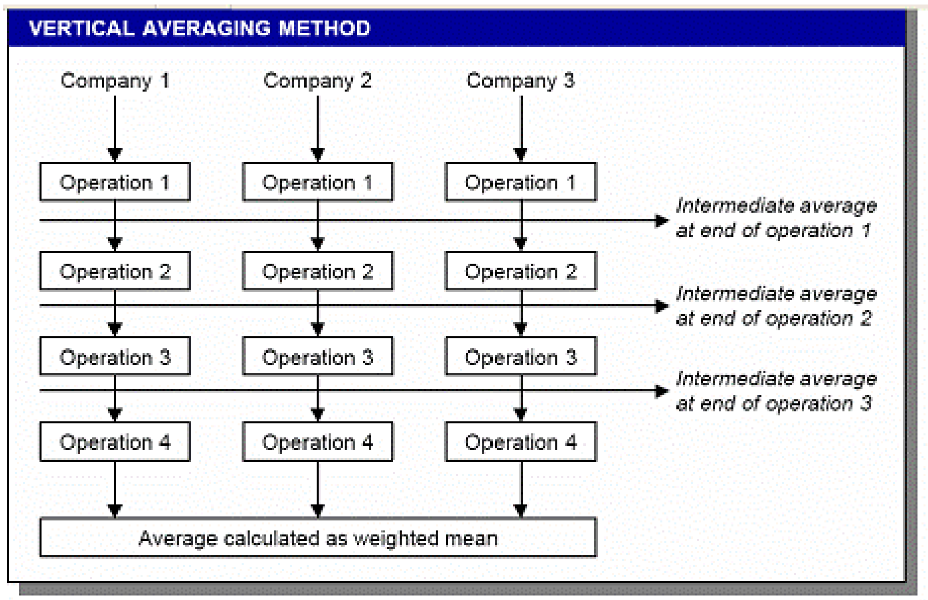


*Figure 4: Vertical Averaging (source: Plastics Europe, 2022)*

### 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. To this aim, a generic process with the same function (product) can be introduced, and the examined system receives credits for the associated burdens avoided elsewhere ("avoidance allocation", avoided burden).

At the MMA production step, ammonium sulphate and a small quantity of hydrogen gas is produced. System expansion by substitution was applied to the quantity of ammonium sulphate produced during the MMA production process, and mass allocation was applied for hydrogen gas. For further details on the allocation rules at the MMA production step, see the MMA Eco-profile [PlasticsEurope 2024].

Regarding the following steps of the production process of PMMA products, no allocation rule was applied, as each individual process is mono-functional (i.e. generates only one type of output). All considered sites had access to detailed data only related to the product of the Eco-profile.

## 2.12. Life Cycle Inventory (LCI) Results

### Delivery and Formats of LCI Dataset

The Eco-profile is provided in two electronic formats:

- As input/output table in Excel®

- As XML document in ILCD format (http://lct.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.

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 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] | 70 | 91 | 74 |
| **Total primary energy demand [MJ]** | **97** | **118** | **101** |

### Water Use and Consumption

- **Cradle-to-gate water consumption**

The cradle-to-gate water consumption is presented in Table 2 for PMMA products.

*Table 2: Cradle-to-gate water consumption per 1kg of PMMA products*

| | **PMMA Resin** | **PMMA Cast sheet** | **PMMA Extruded sheet** |
|---|---|---|---|
| **Cradle-to-gate water consumption [kg]** | **13** | **20** | **15** |

- **Gate-to-gate water use and consumption**

Table 3, Table 4 and Table 5 show the weighted average values for water use of the foreground production process for PMMA products. For each of the typical water applications the water sources are shown.

*Table 3: Water use and source per 1kg of PMMA resin*

| **Source** | **Process water [kg]** | **Cooling water [kg]** | **Steam Water [kg]** | **Water in Raw Materials [kg]** | **Total [kg]** |
|---|---|---|---|---|---|
| From Tap | 6.9E-02 | 0.67 | - | - | 0.74 |
| Deionised | 0.73 | - | - | - | 0.73 |
| From River | 1.8 | 1.0 | 0.12 | - | 3.0 |
| Relooped | - | - | - | - | - |
| **Totals** | **2.6** | **1.7** | **0.12** | **-** | **4.4** |

*Table 4: Water use and source per 1kg of PMMA cast sheet*

| Source | Process water [kg] | Cooling water [kg] | Steam Water [kg] | Water in Raw Materials [kg] | Total [kg] |
|---|---|---|---|---|---|
| From Tap | 5.2 | 4.9E-02 | - | - | 5.3 |
| Deionised | - | - | - | - | - |
| From River | 0.22 | 0.18 | 0.48 | - | 0.88 |
| Relooped | - | - | - | - | - |
| **Totals** | **5.5** | **0.23** | **0.48** | **-** | **6.2** |

*Table 5: Water use and source per 1kg of PMMA extruded sheet*

| Source | Process water [kg] | Cooling water [kg] | Steam Water [kg] | Water in Raw Materials [kg] | Total [kg] |
|---|---|---|---|---|---|
| From Tap | 0.18 | 4.4E-02 | - | - | 0.22 |
| Deionised | - | - | - | - | - |
| From River | 0.12 | 0.12 | 2.1E-02 | - | 0.25 |
| Relooped | - | - | - | - | - |
| **Totals** | **0.30** | **0.16** | **2.1E-02** | **-** | **0.48** |

Table 6, Table 7 and Table 8 show the further handling/processing of the water output of the PMMA resin, cast sheet and extruded sheet production process.

*Table 6: Treatment of Water Output per 1kg of PMMA resin*

| Treatment | Water output [kg] |
|---|---|
| To WWTP | 2.3 |
| To Sea (after WWTP) | - |
| To River (untreated) | 1.7 |
| Reloop to process | - |
| Water Vapour | 0.35 |
| Formed in reaction (to WWTP) | - |
| **Totals** | **4.4** |

*Table 7: Treatment of Water Output per 1kg of PMMA cast sheet*

| Treatment | Water output [kg] |
|---|---|
| To WWTP | 5.5 |
| To Sea (after WWTP) | - |
| To River (untreated) | 0.23 |
| Reloop to process | - |
| Water Vapour | 0.50 |
| Formed in reaction (to WWTP) | - |
| **Totals** | **6.2** |

*Table 8: Treatment of Water Output per 1kg of PMMA extruded sheet*

| Treatment | Water output [kg] |
|---|---|
| To WWTP | 0.28 |
| To Sea (after WWTP) | - |
| To River (untreated) | 0.12 |
| Reloop to process | - |
| Water Vapour | 7.8E-02 |
| Formed in reaction (to WWTP) | - |
| **Totals** | **0.48** |

Based on the water use and output figures above the **water consumption** can be calculated as:

Consumption = (water vapour + water lost to the sea) – (water generated by using containing raw materials + water generated by the reactor). Table 9 presents the gate-to-gate water consumption for PMMA products.

*Table 9: Gate-to-gate water consumption per 1kg of PMMA products*

| | PMMA Resin | PMMA Cast sheet | PMMA Extruded sheet |
|---|---|---|---|
| **Gate-to-gate water consumption [kg]** | **0.35** | **0.50** | **7.8E-02** |

**Dominance Analysis**

Table 10, Table 11 and Table 12 present dominance analysis of impacts of PMMA production process. The analysis shows the dominance of the production of chemicals, and especially of MMA, to the production of PMMA resin and PMMA cast sheet, and the dominance of PMMA resin to the production of PMMA extruded sheet.

*Table 10: Dominance analysis of impacts per 1kg of PMMA resin*

| | **Total Primary Energy** | **Resource use, minerals and metals** | **Resource use, fossil** | **Climate change, total** | **Acidification** | **Eutrophication, freshwater** |
|---|---|---|---|---|---|---|
| **MMA** | **92%** | **92%** | **93%** | **91%** | **87%** | **63%** |
| Methyl Acrylate | 1% | 1% | 1% | 1% | 1% | 2% |
| Other chemicals | 3% | 7% | 3% | 3% | 5% | 8% |
| Utilities | 0% | 0% | 0% | 0% | 0% | 0% |
| Emissions in the air | 0% | 0% | 0% | 0% | 0% | 0% |
| Emissions in the water | 0% | 0% | 0% | 0% | 0% | 0% |
| Energy | 4% | 0% | 3% | 4% | 5% | 12% |
| Transport | 0% | 0% | 0% | 1% | 1% | 0% |
| Process Waste Treatment | 0% | 0% | 0% | 1% | 1% | 15% |
| Water | 0% | 0% | 0% | 0% | 0% | 0% |
| **Total** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** |

*Table 11: Dominance analysis of impacts per 1kg of PMMA cast sheet*

| | **Total Primary Energy** | **Resource use, minerals and metals** | **Resource use, fossil** | **Climate change, total** | **Acidification** | **Eutrophication, freshwater** |
|---|---|---|---|---|---|---|
| **MMA** | **81%** | **92%** | **83%** | **76%** | **77%** | **63%** |
| Other chemicals | 1% | 6% | 1% | 1% | 4% | 6% |
| Utilities | 1% | 2% | 1% | 1% | 3% | 5% |
| Emissions in the air | 0% | 0% | 0% | 5% | 0% | 0% |
| Emissions in the water | 0% | 0% | 0% | 0% | 0% | 0% |
| **Energy** | **16%** | 0% | 14% | **15%** | 12% | 12% |
| Transport | 1% | 0% | 1% | 1% | 2% | 0% |
| Process Waste Treatment | 0% | 0% | 0% | 1% | 0% | 14% |
| Water | 0% | 0% | 0% | 0% | 0% | 0% |
| **Total** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** |

*Table 12: Dominance analysis of impacts per 1kg of PMMA extruded sheet*

| | Total Primary Energy | Resource use, minerals and metals | Resource use, fossil | Climate change, total | Acidification | Eutrophication, freshwater |
|---|---|---|---|---|---|---|
| **PMMA resin** | **92%** | **98%** | **93%** | **92%** | **83%** | **81%** |
| Other chemicals | 2% | 2% | 2% | 2% | 3% | 4% |
| Utilities | 0% | 0% | 0% | 0% | 0% | 0% |
| Emissions in the air | 0% | 0% | 0% | 0% | 0% | 0% |
| Emissions in the water | 0% | 0% | 0% | 0% | 0% | 0% |
| Energy | 5% | 0% | 3% | 4% | 4% | 14% |
| Transport | 1% | 0% | 1% | 2% | 10% | 0% |
| Process Waste Treatment | 0% | 0% | 0% | 0% | 0% | 1% |
| Water | 0% | 0% | 0% | 0% | 0% | 0% |
| **Total** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** |

**Comparison of the present Eco-profile with its previous version**

*Table 13: Comparison of the present Eco-profile with its previous version for 1 kg of PMMA resin*

| Environmental Impact Categories (CML 2013) | Eco-profile PMMA resin (2015) | Eco-profile PMMA resin (2024) | Difference (%) |
|---|---|---|---|
| Abiotic depletion (elements) [kg Sb eq.] | 2.3E-06 | 2.5E-06 | 7% |
| Abiotic Depletion Potential (ADP). fossil fuels [MJ] | 97 | 84 | -13% |
| Global Warming Potential (GWP) [kg CO2 eq.] | 3.8 | 3.8 | 0% |
| Acidification Potential (AP) [kg SO2 eq.] | 1.7E-02 | 4.1E-03 | -77% |
| Eutrophication Potential (EP) [kg PO43- eq.] | 2.2E-03 | 5.0E-02 | 2234% |
| Ozone layer depletion (ODP) [kg CFC-11 eq.] | 4.2E-07 | 3.7E-07 | -11% |
| Photochemical Ozone Creation Potential [kg Ethene eq.] | 9.4E-04 | 7.1E-04 | -25% |

*Table 14: Comparison of the present Eco-profile with its previous version for 1 kg of PMMA cast sheet*

| **Environmental Impact Categories (CML 2013)** | **Eco-profile PMMA cast sheet (2015)** | **Eco-profile PMMA cast sheet (2024)** | **Difference (%)** |
|---|---|---|---|
| Abiotic depletion (elements) [kg Sb eq.] | 7.0E-06 | 2.7E-06 | -62% |
| Abiotic Depletion Potential (ADP). fossil fuels [MJ] | 119 | 101 | -16% |
| Global Warming Potential (GWP) [kg CO2 eq.] | 4.8 | 4.7 | -2% |
| Acidification Potential (AP) [kg SO2 eq.] | 2.6E-02 | 5.3E-03 | -80% |
| Eutrophication Potential (EP) [kg PO43- eq.] | 3.0E-03 | 5.4E-02 | 1713% |
| Ozone layer depletion (ODP) [kg CFC-11 eq.] | 4.6E-07 | 5.1E-07 | 11% |
| Photochemical Ozone Creation Potential [kg Ethene eq.] | 1.5E-03 | 8.1E-04 | -45% |

*Table 15: Comparison of the present Eco-profile with its previous version for 1 kg of PMMA extruded sheet*

| **Environmental Impact Categories (CML 2013)** | **Eco-profile PMMA extruded sheet (2015)** | **Eco-profile PMMA extruded sheet (2024)** | **Difference (%)** |
|---|---|---|---|
| Abiotic depletion (elements) [kg Sb eq.] | 2.3E-06 | 2.4E-06 | 5% |
| Abiotic Depletion Potential (ADP). fossil fuels [MJ] | 106 | 86 | -19% |
| Global Warming Potential (GWP) [kg CO2 eq.] | 4.4 | 3.9 | -11% |
| Acidification Potential (AP) [kg SO2 eq.] | 1.8E-02 | 5.3E-03 | -71% |
| Eutrophication Potential (EP) [kg PO43- eq.] | 3.0E-03 | 4.9E-02 | 1496% |
| Ozone layer depletion (ODP) [kg CFC-11 eq.] | 4.1E-07 | 3.9E-07 | -5% |
| Photochemical Ozone Creation Potential [kg Ethene eq.] | 9.6E-04 | 7.5E-04 | -22% |

Please note: The results as presented in table above have been calculated with CML 2013 impact methodology and are therefore not to be compared with any other result table in this report.

When interpreting the results, it should be kept in mind that the previous results have been calculated using the Ecoinvent v2.2 database and use different allocation rules between co-products for MMA production, which adds further uncertainty into the conclusions of a direct result comparison. Besides, the previous Eco-profile was constructed from separate LCAs, the consistency of the methodological approaches was therefore not guaranteed.

# 3. EF 3.0 Indicator results

Table 16 show the LCA results for 1 kg of considered PMMA products when applying the EF 3.0 impact assessment methodology.

*Table 16: LCA results for 1kg of PMMA products applying EF 3.0 impact assessment methodology*

| Indicator | Unit | PMMA resin | PMMA cast sheet | PMMA extruded sheets |
|---|---|---|---|---|
| Climate change, total | kg CO2 eq. | 3.9 | 5.1 | 4.1 |
| Climate Change, biogenic | kg CO2 eq. | 1.0E-02 | 1.1E-02 | 1.1E-02 |
| Climate Change, fossil | kg CO2 eq. | 3.92 | 5.1 | 4.1 |
| Climate Change, land use and land use change | kg CO2 eq. | 3.3E-03 | 1.8E-03 | 4.6E-03 |
| Ozone depletion | kg CFC-11 eq. | 4.3E-07 | 5.9E-07 | 4.5E-07 |
| Acidification | Mole of H+ eq | 8.8E-03 | 1.1E-02 | 1.0E-02 |
| Photochemical ozone formation | kg NMVOC eq | 7.9E-03 | 2.2E-02 | 8.8E-03 |
| Eutrophication, freshwater | kg P eq | 3.5E-05 | 3.8E-05 | 4.1E-05 |
| Eutrophication, marine | kg N eq. | 3.1E-04 | 6.0E-04 | 6.5E-04 |
| Eutrophication, terrestrial | Mole of N eq. | 1.3E-02 | 1.7E-02 | 1.6E-02 |
| Particulate matter | Disease incidences | 4.7E-08 | 6.0E-08 | 5.4E-08 |
| Ionising radiation, human health | kBq U235 eq. | 8.4E-02 | 0.12 | 0.10 |
| Human toxicity, cancer – total | CTUh | 7.1E-10 | 8.2E-10 | 7.7E-10 |
| Human toxicity, cancer inorganics | CTUh | 1.7E-20 | 1.8E-20 | 1.7E-20 |
| Human toxicity, cancer metals | CTUh | 5.0E-10 | 5.9E-10 | 5.0E-10 |
| Human toxicity, cancer organics | CTUh | 2.1E-10 | 2.3E-10 | 2.7E-10 |
| Human toxicity, noncancer – total | CTUh | 2.7E-08 | 3.4E-08 | 2.7E-08 |
| Human toxicity, noncancer inorganics | CTUh | 5.5E-09 | 6.7E-09 | 5.7E-09 |
| Human toxicity, noncancer metals | CTUh | 2.1E-08 | 2.3E-08 | 2.1E-08 |
| Human toxicity, noncancer organics | CTUh | 1.3E-09 | 4.6E-09 | 1.3E-09 |
| Ecotoxicity, freshwater – total | CTUe | -44 | -46 | -41 |
| Ecotoxicity, freshwater inorganics | CTUe | -61 | -65 | -58 |
| Ecotoxicity, freshwater metals | CTUe | 15 | 18 | 15 |
| Ecotoxicity, freshwater organics | CTUe | 1.7 | 1.0 | 1.8 |
| Land Use | Pt | 1.9 | 5.3 | 2.1 |
| Resource use, energy carriers | MJ | 88 | 106 | 90 |
| Resource use, minerals and metals | kg Sb eq. | 2.4E-06 | 2.6E-06 | 2.4E-06 |
| Water scarcity | $m^3$ world equiv. | 0.70 | 0.98 | 0.74 |

# 4. Review

The following pages present the review statement.

Critical Review Statement

# *Eco-profile for Poly methyl methacrylate (PMMA): resin, cast sheets and extruded sheets*

DEKRA Alles im grünen Bereich

| | |
|---|---|
| Commissioned by: | Cefic, Methacrylates Sector Group |
| Version: | Eco-profile, February 2024 |
| Prepared by: | Deloitte Conseil |
| Reviewed by: | Angela Schindler<br>Accredited partner of DEKRA Assurance Services GmbH |

References:

- ISO 14071 (2016): Environmental management – Life cycle assessment – Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006
- ISO 14040 (2006): Environmental Management – Life Cycle Assessment – Principles and Framework
- ISO 14044 (2006): Environmental Management – Life Cycle Assessment – Requirements and Guidelines
- Eco-profiles program and methodology – PlasticsEurope, v.3.1, Sept. 2022

## EXTERNAL INDEPENDENT REVIEW

The reviewer was tasked with assessing whether:

- the methods and inventory modelling used to carry out the Life Cycle Assessment are scientifically and technically valid and conform with ISO 14044:2006 and the methodological protocol of PlasticsEurope,
- the data and model results used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The critical review was performed at the end of the LCA study according to paragraph 4.3.3 of ISO 14071 and 6.2 of ISO 14044 by one independent external expert. This critical review statement is only valid for the specific report in its final version dated February 2024.

The verification of the LCI model and individual background datasets is outside the scope of this review.

## 1. REVIEW PROCESS

The review process was performed in accordance with ISO/TS 14071 and coordinated between Cefic/Deloitte and the reviewer. A first draft of the Eco-profile was submitted on 24.11.2023. The reviewer provided comments to Deloitte/Cefic on 06.12.2023, which were discussed to avoid any misunderstandings in a webmeeting on 18.12.2023. The webmeeting also served to show detailed and confidential background information on the data collection and the LCA calculations by the LCA practitioner Deloitte to the reviewer.

A thoroughly revised version was provided by Deloitte on 18.01.2024. Minor questions were clarified in a webmeeting on 08.02.2024. The reviewer checked the full implementation of the issues in the last and final version and agreed to conclude the critical review process on 12.02.2024.

## 2. GENERAL EVALUATION

The present Eco-profile is an update of the previous Eco-profile for Polymethyl methacrylate (PMMA) from 2015.

The compliance of the document was reviewed according to the current requirements of the Eco-profile program and methodology, version 3.1 (Sept. 2022) of PlasticsEurope and the accompanying template for Eco-profile reports.

Main producers have taken part in this study. Thus, the Eco-profile can be seen as representative for the European market.

The LCA practitioners checked the plausibility of input data, the variance of materials and energy of comparable applied technologies and the variance of the results' data.

Minor data gaps of input flows could be closed by using approximated generic inventory data; direct emissions of the plants were reported and included in the calculation. Participants using green electricity were requested to deposit respective evidence on electricity certificates (guarantees of origin) with the LCA practitioners. The participants delivered sufficient information on waste treatment processes, which were also included in the LCA modelling.

The applied system expansion for the co-product ammonium sulphate in the MMA production is traceable. The justification has been discussed in the review process and is described in the MMA Eco-profile. Further sensitivity analysis supports the argumentation.

Some participants have implemented a recycling process for sulphuric acid, which requires energy and reduces the amount of the produced ammonium sulphate. These different technological approaches require different methodological implementations in the calculation model, which have effects on the final results. By averaging the result values, the Eco-profile fulfils the aim to display an average environmental profile, including different technologies applied in Europe for this product. The Eco-profile's objective is to declare the environmental indicators without assessing the impacts of different technologies.

Due to the change of assessment indicators, the Eco-profile is supplemented also by an evaluation applying the impact categories of the preliminary Eco-profile. This principally allows a relative comparison of the results. Both background data and foreground data are updated and previous confidential foreground data are not available to the LCA-practitioner. This enables only a limited statement of the actual improvement in respect to sustainable development.

All related questions were solved in the course of this critical review:

- The LCA practitioner and the sector group delivered information on the declared representativity of the study.
- The indicators for primary energy were checked and adapted following the requirements of the methodological protocol and the template for Eco-profiles.
- The figures displaying the process chain and the description of foreground and background system were optimized for clear understanding.
- All editorial recommendations and initiated re-phrasings for unambiguous understanding were implemented by the practitioners.

The reviewer confirms the presented values and argumentations.

## 3. CONCLUSION

The software model applied has undergone a Deloitte internal quality check to avoid mistakes of data transfer. Overall, the project is carried out very thoroughly.

The structure and description of the Eco-profile is clear and transparent, thus displaying a reliable source of information. Furthermore, the underlying data, the life cycle model, the assumptions and calculations are appropriate and valid and lead to plausible results.

Eco-profiles are often used as background data for construction products. So far, Eco-profiles do not have the requirement to be conform with EN 15804+A2. With the methodological approach of the system expansion for the MMA production calculation, the resulting inventory displays a slight deviation from these rules. The sensitivity analysis still justifies this approach, especially in comparison to economic allocation. Thus, the application of this Eco-profile also for projects following EN 15804+A2 is recommended.

Despite all necessary due diligence performed during the critical review process by the reviewer, the commissioner of the LCA study remains liable for the underlying information and data.

Salem, 12.02.2024

Angela Schindler
Accredited partner of DEKRA Assurance Services GmbH, Stuttgart, Germany

# 5. References


| | |
|---|---|
| ISO 14040: 2006 | ISO 14040 Environmental Management – Life Cycle Assessment – Principles and Framework. Geneva, 2006 |
| ISO 14044: 2006 | ISO 14044 Environmental management -- Life cycle assessment -- Requirements and guidelines. Geneva, 2006ilc |
| PLASTICSEUROPE 2024 | Methyl methacrylate (MMA) Eco-profile of the European Plastics Manufacturers, January 2024 |
| PLASTICSEUROPE 2022 | Eco-profiles program and methodology. Version 3.1, September 2022. |

**PlasticsEurope**

Rue Belliard 40, Box 16

1040 Brussels - Belgium

Phone +32 (0)2 792 30 99

connect@plasticseurope.org
www.plasticseurope.org