LIFE CYCLE ASSESSMENT

ArmaPET™ Life Cycle Assessment

In this analysis the environmental impact of ArmaPET foam products has been evaluated by the Life Cycle Assessment (LCA) method. It includes a carbon footprint comparison with competitive materials.

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ArmaPET™

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PLASTIC CIRCULAR ECONOMY

The circular economy involves switching from a linear 'make-take-dispose' economy to a circular one based on 'reduce, reuse and recycle'. An economy in which waste and pollution are designed out, products and materials kept in use longer and natural systems regenerated. The plastics circular economy is a model for a closed system that promotes the reuse of plastic products, generates value from waste and avoids sending recoverable plastics to landfill. Plastic waste is a valuable resource that can be used to produce new plastic raw materials and manufacture plastic parts and products, or to generate energy when recycling is not viable.

Armacell is working towards a circular economy in multiple ways, focusing on converting more waste into recyclates, maximising resource efficiency and reducing greenhouse gas emissions. Our main initiatives towards a plastic circular economy model are:

// RESOURCES RECOVERY

Some of Armacell's manufacturing facilities host solar panels on their roofs. The PET Foams headquarters in Belgium, for example, generate on average 10% of the plant's annual energy requirement.

// CIRCULAR SUPPLIES

The substitution of fossil materials by recycled resources sustains circular production and consumption systems.

// CLOSE THE LOOP PROGRAMME

Reusing internal production scrap is commonplace in our industry. Armacell has gone one step further by collaborating with two of the largest European converters for the return of sorted residual material from their operations. Following reprocessing, this material is reused to limit waste generation along the value chain.

// LEAN MANUFACTURING

Armacell partner in the Operation Clean Sweep® initiative, a global product stewardship programme aiming to drive best practices in plastic material loss management. We continuously improve our worksite setup for plastic pellet prevention with the ultimate goal of achieving zero material loss.

// PRODUCT LIFE EXTENSION

Armacell's unique recycled PET foam technology (rPET) grants plastic bottles a new life through the conversion of single-use PET bottles into long-lifetime, high-value foam cores materials. Instead of a service life of just weeks, Armacell's PET foam products endure several decades.

PET FOAMS IN THE ECO CYCLE

Armacell is a pioneer in the field of polyethylene terephthalate (PET) technology and initiated the breakthrough of PET foams as a structural core material in the composite industry (2005). But our research did not stop there; as a technology leader, Armacell went on to further developed its unique and patented rPET process technology that enables PET foam products to be made entirely from recycled beverage bottles (2010). Today, Armacell offers a diverse product portfolio of environmentally friendly solutions based on 100% recycled PET: structural foam cores, thermoformable flexible sheets and particle foams.

In the post-consumer life cycle of a plastic bottle Armacell's reprocessing technology creates a virtuous eco cycle. After collection, the PET bottles are sorted and crushed into flakes. This is followed by an in-house granulation process and, finally, extrusion foaming.

In this way, single-use plastic bottles are converted into long-lifetime, high-value foam core materials used in a variety of applications, such as 90-metre-long wind turbine blades, the body structure of high-speed trains, surfboards, or even the 24-karat gilded roof of an Orthodox cathedral in Paris.

PUTTING PLASTIC WASTE TO GOOD USE:

1. PET bottles
2. rPET flakes
3. Inhouse granulation
4. Extrusion foaming
5. Use-phase
6. Recyclable PET foams

LIFE CYCLE ASSESSMENT

A life cycle assessment (LCA) is used to systematically investigate the environmental impact of industrial goods. All processes which take place at the subsequent stages of a product's life cycle are addressed: raw material extraction, material transport and processing, product manufacturing, distribution and use, wastes or emissions associated with a product, process, or service as well as end-of-life disposal, reuse, or recycling. In the next step, all this data is then translated into potential human health and environmental impacts and expressed as such factors as global warming potential (based on greenhouse gases emissions), ozone depletion, water quality impacts, human health impacts, and others.

As an LCA provides specific information on an individual manufacturer's products, the results can serve as a valuable benchmark. Foam producers like us can demonstrate how their products show environmental advantages over competitive products. LCAs can also help designers, specifiers and panel manufacturers to select materials with lower environmental impacts during the design phase or for making environmental improvements in existing processes.

LIFE CYCLE ASSESSMENT METHODOLOGY

BOUNDARY CONDITIONS

Boundary conditions are used to define what is included in an LCA. The common boundary conditions are cradle-to-gate, cradle-to-site and cradle-to-grave.

Cradle-to-grave is the full life cycle assessment from resource extraction ('cradle') to the use phase and disposal phase ('grave'). **Cradle-to-gate** is an assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (i.e., before it is transported to the consumer). **Cradle-to-site** includes the cradle-to-gate results and the transportation of the material or product to customer site.

In this LCA **we follow the cradle-to-site approach**, the use phase and end-of-life scenario are not included. The analysis of the transport from factory gate to customer site is based on the average figures for worldwide distribution.

Our different PET foam products are used in multiple applications and are always subjected to further processing. Our customers produce multi-layered structures in which our products are thermoformed, thermos-compressed, wet-laminated, infused, combined with skins, reinforcements or prepregs, etc.

All these operations as well as new raw materials used for manufacturing final parts affect the LCA. In the current calculation, we only include processes which are fully controlled by Armacell. This ensures data quality and reliability and indicates which life cycle stages could be improved further as a part of our sustainable development programme.

METHOD OF ANALYSIS

The environmental impact of Armacell's PET foam products is assessed with the use of the **EDP (2018) method** (Environmental Product Declarations), as published on the website of the Swedish Environmental Management Council (SEMC).

Table 1 on the next page shows the impact categories considered in this analysis.

SYSTEM MODEL

The **Consequential System Model** is applied, which uses a constrained supply of products, based on market activity data and on information about technology level, and applies substitution (system expansion) to convert multi-product datasets into single-product datasets.[1)]

// Acidification potential

Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification Potential for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of **acidifying substances**. AP is expressed as kg SO2 equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale.

// Eutrophication potential

Eutrophication (also known as nitrification) includes all impacts due to excessive levels of **macro-nutrients** in the environment caused by emissions of nutrients to air, water and soil. Expressed as kg PO4- equivalents per kg emission. Fate and exposure is not included, time span is eternity, and the geographical scale varies between local and continental scale.

// Global warming potential (climate change)

Climate change can result in adverse effects upon ecosystem health, human health and material welfare, and are related to emissions of **greenhouse gases** to air. The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterization factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is a global scale.

// Photochemical oxidant formation potential (summer smog)

Photo-oxidant formation is the formation of reactive chemical compounds by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health and ecosystems, and may damage crops. Photo-oxidants may be formed in the troposphere under the influence of ultraviolet light, through photochemical oxidation of **Volatile Organic Compounds** (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx). It is expressed as kg NMVOC (non-methane volatile organic compounds).

// Abiotic depletion potential - elements

This impact category is concerned with protection of human welfare, human health and ecosystem health. It relates to extraction of **minerals** due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is a global scale.

// Abiotic depletion potential - fossil fuels

This impact category is concerned with protection of human welfare, human health and ecosystem health. It relates to extraction of **fossil fuels**. The Abiotic Depletion Factor (ADF) is determined for natural energy carriers (e.g. crude oil, hard coal, brown coal and natural gas) and their energy content (net calorific value), and therefore is expressed in MJ. The geographic scope of this indicator is a global scale.

// Water scarcity footprint (WSF)

It quantifies the potential of water deprivation, to either humans or ecosystems, and serves in calculating the impact score of water consumption at midpoint in LCA or to calculate a water scarcity footprint as per ISO 14046. It is based on the available water remaining (AWARE) per unit of surface in a given watershed relative to the world average, after human and aquatic ecosystem demands have been met.

// Ozone-depleting gases

It measures harmful effects resulting from larger fraction of UV-B radiation which reaches the earth surface, due to the reduction of protective ozone layer within the stratosphere caused by emissions of ozone depleting substances (CFCs, HFCs, and halons). It affects human and animal health, terrestrial and aquatic ecosystems, biochemical cycles and materials. The ozone depletion potential of substances is characterized relative to CFC-11, and is expressed in equivalent CFC-11 (kg CFC-11 equivalent/kg emission), for 20 years horizon.

Table 1: Impact Categories

LIFE CYCLE ASSESSMENT RESULTS

The following results are based on the data sources **SimaPro 9.0.0.49 and ecoinvent 3**, using the EPD (2018) method.
SimaPro and ecoinvent 3 provide broad evaluation options for waste treatment – a new treatment and/or disposal datasets have been introduced to provide a better picture of the situation of waste management at regional and global levels, including the informal waste disposal methods of open burning and open dumping, as well as the treatment unsanitary landfill. As the climate of a specific location can affect the emissions from the treatment and disposal (unsanitary landfill and open dump) activities, climatic conditions such as precipitation, temperature and evapotranspiration are now considered in the LCI model.

ENVIRONMENTAL IMPACT OF DIFFERENT END-OF-LIFE SCENARIOS

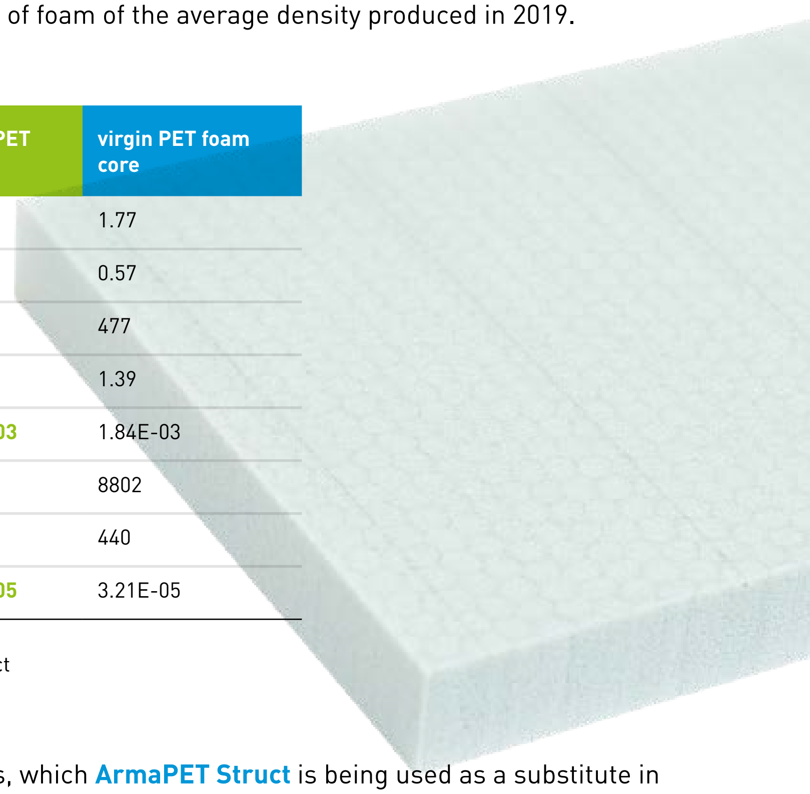
The environmental impact of different end-of-life scenarios for post-consumer PET is shown in table 2 and contrasted with the production of virgin material.

Environmental impact	Unit	1 tonne virgin PET	1 tonne recycled PET	1 tonne incinerated PET	1 tonne landfilled PET
Acidification (fate not incl.)	kg SO_2 eq	12.22	654	0.43	0.09
Eutrophication	kg PO_4- eq	6.82	2.68	0.43	4.35
Global warming (GWP100a)	kg CO_2 eq	3481	1824	2035	87
Photochemical oxidation	kg NMVOC	10.48	6.21	0.64	0.11
Abiotic depletion, elements	kg Sb eq	1.53E-02	8.43E-03	4.02E-05	1.58E-05
Abiotic depletion, fossil fuels	MJ	73327	48541	214	236
Water scarcity	m^3 eq	1762	1173	45.50	1.58
Ozone layer depletion (ODP)	kg CFC-11 eq	1.46E-04	0.00	1.78E-06	2.61E-06

Table 2: Environmental impact of different PET end-of-life scenarios

ENVIRONMENTAL IMPACT OF ARMAPET STRUCT

The environmental impact of **ArmaPET Struct** manufacturing made from recycled PET in comparison to virgin PET is shown in table 3. The calculations are based on 100 kg of foam of the average density produced in 2019.



Environmental impact	Unit (100 kg of foam)	ArmaPET Struct	virgin PET foam core
Acidification (fate not incl.)	kg SO_2 eq	**1.01**	1.77
Eutrophication	kg PO_4- eq	**0.45**	0.57
Global warming (GWP100a)	kg CO_2 eq	**300**	477
Photochemical oxidation	kg NMVOC	**0.90**	1.39
Abiotic depletion, elements	kg Sb eq	**1.13E-03**	1.84E-03
Abiotic depletion, fossil fuels	MJ	**6694**	8802
Water scarcity	m^3 eq	**413**	440
Ozone layer depletion (ODP)	kg CFC-11 eq	**2.01E-05**	3.21E-05

Table 3: Environmental impact of using recycled PET in ArmaPET Struct manufacturing in comparison to virgin PET

We apply she same analysis to other foam core materials, which **ArmaPET Struct** is being used as a substitute in more and more applications:

Environmental impact	Unit (100 kg of foam)	ArmaPET Struct	PVC	SAN	PUR	XPS
Acidification (fate not incl.)	kg SO_2 eq	**1.01**	1.48	0.71	2.60	1.32
Eutrophication	kg PO_4- eq	**0.45**	0.271	0.160	1.388	0.307
Global warming (GWP100a)	kg CO_2 eq	**300**	481	437	635	601
Photochemical oxidation	kg NMVOC	**0.90**	2.37	1.17	2.49	1.25
Abiotic depletion, elements	kg Sb eq	**1.13E-03**	2.60E-04	8,81E-05	4.32E-03	5.98E-04
Abiotic depletion, fossil fuels	MJ	**6694**	9944	7915	10460	8187
Water scarcity	m^3 eq	**413**	4683	2929	513	341
Ozone layer depletion (ODP)	kg CFC-11 eq	**2.01E-05**	8.34E-05	5.72E-05	9.38E-05	1.31E-05

Table 4: Environmental impact of ArmaPET Struct in comparison to other foam cores

ENVIRONMENTAL IMPACT OF ARMAPET ECO

For **ArmaPET Eco** the following assumptions have been taken: one line operating with the average throughput of the current two production lines running at Armacell S.C.S in Belgium, at the same energy and natural resources consumption.

The recipe is based on current formulations with an average density of 50 kg/m^3. The same transportation conditions of raw materials and final products are applied.

Environmental impact	Unit (100 kg of foam)	ArmaPET Eco
Acidification (fate not incl.)	kg SO_2 eq	0.8
Eutrophication	kg PO_4- eq	0.4
Global warming (GWP100a)	kg CO_2 eq	240
Photochemical oxidation	kg NMVOC	0.7
Abiotic depletion, elements	kg Sb eq	9.60E-04
Abiotic depletion, fossil fuels	MJ	5527
Water scarcity	m^3 eq	363
Ozone layer depletion (ODP)	kg CFC-11 eq	1.25E-05

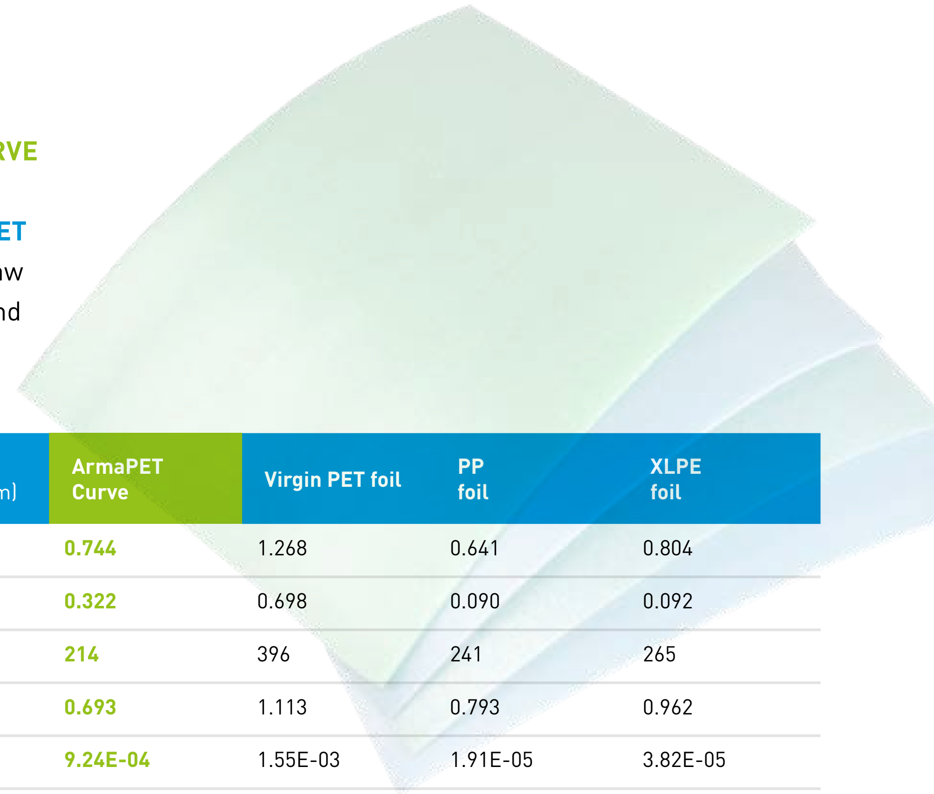
Table 5: Environmental impact of ArmaPET Eco

We apply the same analysis to other insulating foam materials currently on the market, which **ArmaPET Eco** is being used as a substitute in more and more applications:

Environmental impact	Unit (100 kg of foam)	Foam Glass	Glass Wool	Rockwool	Polystyrene	Urea-formaldehyde
Acidification (fate not incl.)	kg SO_2 eq	0.8	1.6	25.5	1.4	1.3
Eutrophication	kg PO_4- eq	0.4	0.7	7.8	0.4	0.5
Global warming (GWP100a)	kg CO_2 eq	288	340	2942	415	320
Photochemical oxidation	kg NMVOC	0.6	1.1	10.2	2.2	1.0
Abiotic depletion, elements	kg Sb eq	8.50E-04	7.57E-04	0.381	5.21E-05	1.71E-03
Abiotic depletion, fossil fuels	MJ	3791	4664	30154	8335	6428
Water scarcity	m^3 eq	68	157	610	269	505
Ozone layer depletion (ODP)	kg CFC-11 eq	2.46E-05	3.13E-05	1.49E-04	1.16E-05	4.83E-05

Table 6: Environmental impact of ArmaPET Eco in comparison to other insulating foam materials

ENVIRONMENTAL IMPACT OF ARMAPET CURVE



All values are calculated based on the **ArmaPET Curve** extrusion model, with adjustment for raw materials used in manufacturing processes and typical foamed foil density.

Environmental impact	Unit (100 kg of foam)	ArmaPET Curve	Virgin PET foil	PP foil	XLPE foil
Acidification (fate not incl.)	kg SO_2 eq	0.744	1.268	0.641	0.804
Eutrophication	kg PO_4- eq	0.322	0.698	0.090	0.092
Global warming (GWP100a)	kg CO_2 eq	214	396	241	265
Photochemical oxidation	kg NMVOC	0.693	1.113	0.793	0.962
Abiotic depletion, elements	kg Sb eq	9.24E-04	1.55E-03	1.91E-05	3.82E-05
Abiotic depletion, fossil fuels	MJ	5361	7611	6205	6233
Water scarcity	m^3 eq	345	398	280	288
Ozone layer depletion (ODP)	kg CFC-11 eq	8.35E-06	1.88E-05	5.71E-06	4.24E-04

Table 7: Environmental impact of ArmaPET Curve in comparison to other thermoplastic foil materials

ENVIRONMENTAL IMPACT OF ARMAPET SHAPE

The environmental impact of **ArmaPET Shape** particle foam manufacturing in comparison to competitive materials is shown in table 8:

Environmental impact	Unit (100 kg of foam)	ArmaPET Shape	EPS particle foam	PMI particle foam
Acidification (fate not incl.)	kg SO_2 eq	0.76	1.11	3.84
Eutrophication	kg PO_4- eq	0.311	0.138	0.384
Global warming (GWP100a)	kg CO_2 eq	218	361	744
Photochemical oxidation	kg NMVOC	0.71	1.17	3.02
Abiotic depletion, elements	kg Sb eq	9.29E-04	4.22E-05	6.56E-04
Abiotic depletion, fossil fuels	MJ	5540	8032	11162
Water scarcity	m^3 eq	253	276	118
Ozone layer depletion (ODP)	kg CFC-11 eq	8.29E-06	6.99E-06	1.42E-06

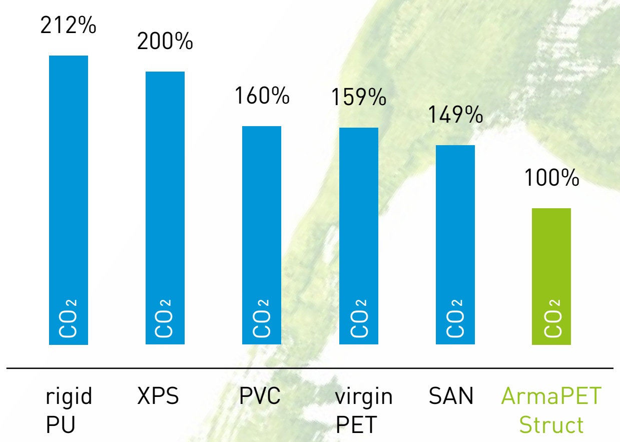
Table 8: Environmental impact of ArmaPET Shape in comparison to other particle foams

CARBON FOOTPRINT

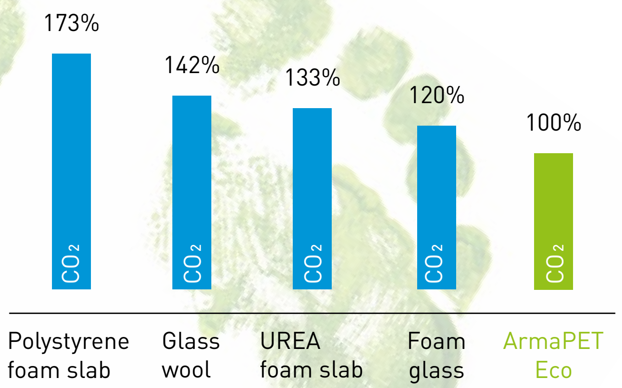
The most important environmental indicator, global warming (GWP100a), is commonly known as the **carbon footprint**.
A carbon footprint is the amount of greenhouse gases — primarily carbon dioxide — released into the atmosphere by a particular human activity (such as a product's manufacture and transport). It is usually **measured as tonnes of CO_2** and is the assessment of the **product´s global warming potential**.

In the following you find the CO_2 emissions caused by the manufacturing of the different ArmaPET products compared to its main competitive materials currently on the market.

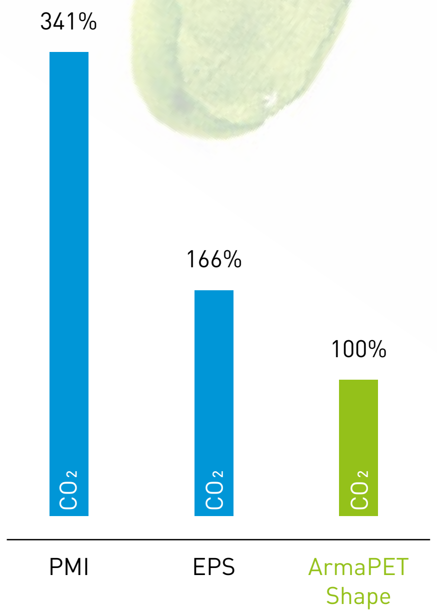
ARMAPET STRUCT



ARMAPET ECO



ARMAPET SHAPE



ARMAPET CURVE

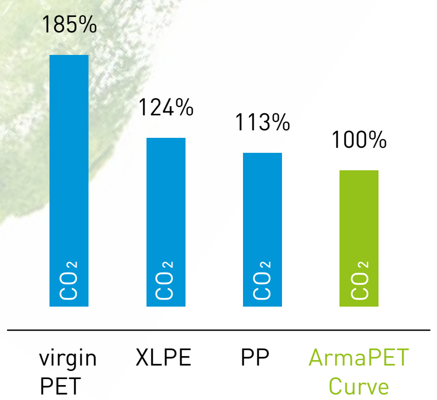
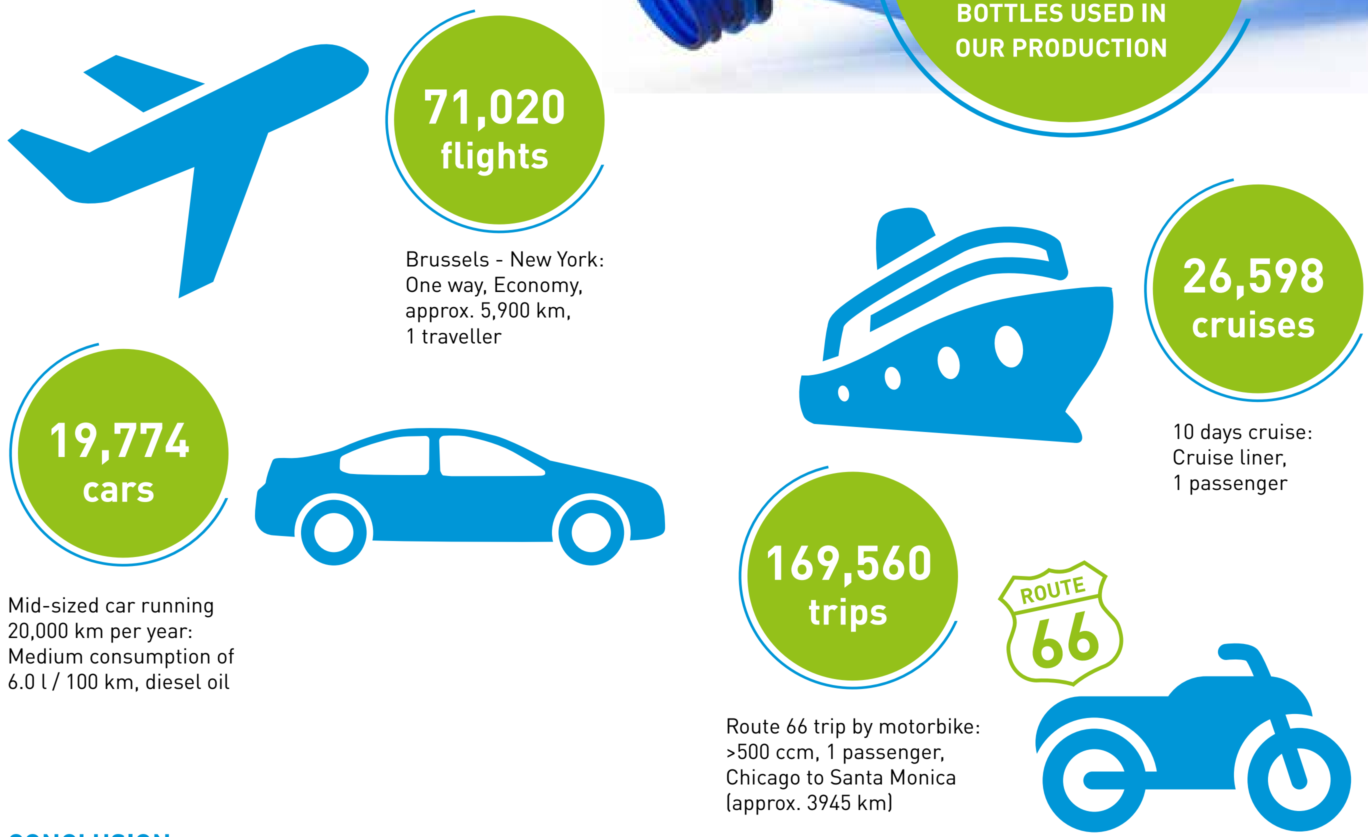


Table 9: CO_2 emissions of ArmaPET products in comparison to competitive materials. ArmaPET = 100% reference.

Over the past decade, Armacell's rPET facilities have reused over 1,500,000,000 PET bottles and **saved more than 67,000 metric tonnes of CO_2 emissions in the process**. That is equivalent to the emissions of ...



CONCLUSION

In this analysis the environmental impact of the ArmaPET product portfolio has been evaluated using the Life Cycle Assessment (LCA) method. A CO_2-balance or Carbon Footprint is part of the LCA of a product and is an assessment of the product´s global warming potential.
The results prove that the environmental benefits of ArmaPET products, all made with Armacell's pioneering rPET process technology, outperform any other comparable foam currently available on the market. For all the different product groups it can be said that the carbon footprint is significantly reduced compared to the main competitive materials.
By giving plastic bottles a new life, through the conversion of waste material into a high-quality resource and feeding it back into the production cycle, Armacell is helping to make a sustainable difference around the world.

REFERENCES

[1] https://www.ecoinvent.org/database/system-models-in-ecoinvent-3/system-models-in-ecoinvent-3.html
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ABOUT ARMACELL

As the inventors of flexible foam for equipment insulation and a leading provider of engineered foams, Armacell develops innovative and safe thermal, acoustic and mechanical solutions that create sustainable value for its customers. Armacell's products significantly contribute to global energy efficiency making a difference around the world every day. With 3,135 employees and 24 production plants in 16 countries, the company operates two main businesses, Advanced Insulation and Engineered Foams. Armacell focuses on insulation materials for technical equipment, high-performance foams for high-tech and lightweight applications and next generation aerogel blanket technology.

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