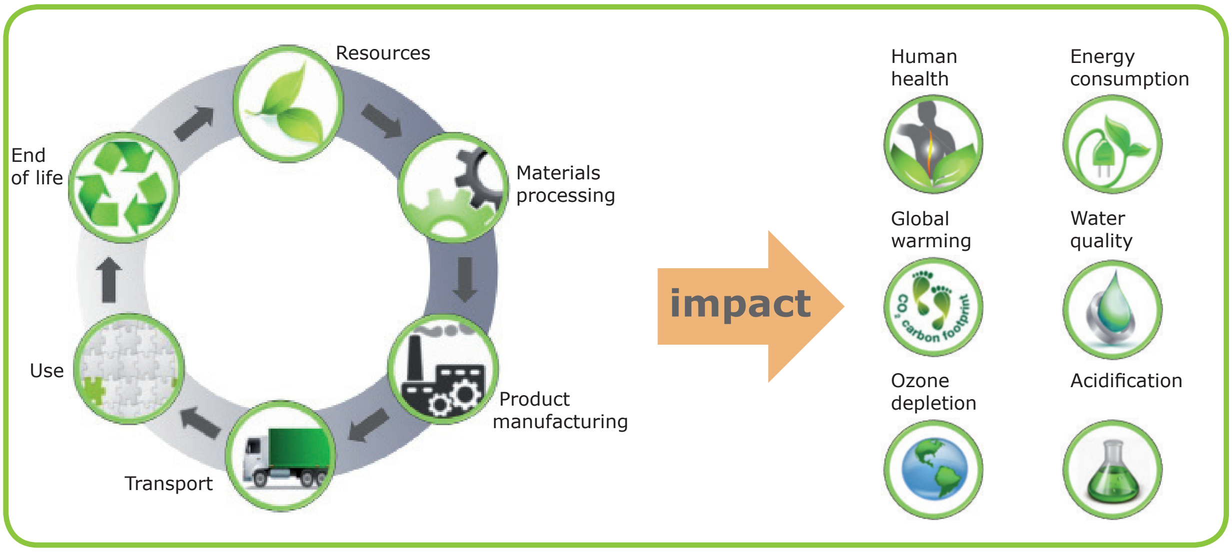
LIFE CYCLE ASSESSMENT ARMAFORM® PET

In this analysis the environmental impact of ArmaFORM® PET has been evaluated by the Life Cycle Assessment (LCA) method. The results prove that the environmental benefits of ArmaFORM® PET GR, which is 100% made of post-consumer PET material, outperform any other foam core currently available on the composite market.

¬ Introduction

A life cycle assessment (LCA) is used to systematically investigate the environmental impact of industrial goods. The complete life cycle of a product is tracked from cradle to grave. All processes which take place at the subsequent stages of product life cycle are addressed, including 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 of these data, represented by Life Cycle Inventory (LCI), are then translated into potential human health and environmental impacts and expressed as such factors as global warming potential (based on greenhouse gases emissions), water quality impacts, human health impacts, or many others.



Picture 1: Product life cycle and potential impacts

¬ Product description ArmaFORM® PET

Armacell is one of the leading manufacturers of highly-developed technical foams and insulation materials. As a pioneer in the field of reactive processing of polyesters, Armacell was the first manufacturer to succeed in foaming high quality, bottle-grade PET on an industrial scale and qualifying PET foams for the composite

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industry. PET foams are used in sandwich constructions for the wind energy sector, building & construction industry, rail & road transportation and marine environments, and the range of applications is still growing. ArmaFORM® PET foams perfectly meet the demanding requirements of today's core materials, providing the ideal combination of strength, stiffness, toughness and flexibility at the same time.

All ArmaFORM® PET foam cores are manufactured in an energy and resource-optimized production process: 100% re-use of material loss and no use of ozone-depleting HFH or CFC blowing agents. In addition, the products are fully recyclable at life cycle's end and thus are considered to be an environmentally sensitive solution in the composite industry. But Armacell did not stop there and has again made a significant contribution to sustainable growth in the composite industry. Scientists from the global R&D Team have spent several years in the development of a technology that enables the production of PET foam boards with consistent, reliable qualities 100% made of post-consumer PET materials, called ArmaFORM® PET GR. This "green" foam core meets not only stringent technical requirements but also provides sustainable development, following the guidelines of circular economy and helping in preservation and enhancement of the human environment. The life cycle of ArmaFORM® PET GR is presented below.

END-OF-LIFE

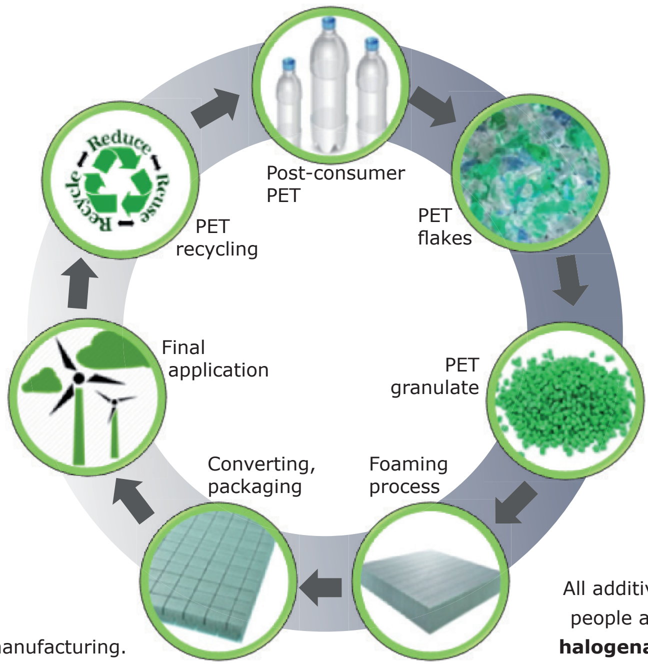
ArmaFORM® PET can be **recycled and reprocessed into full value raw material** if removed properly.

USE-PHASE

In the majority of applications, ArmaFORM® PET core generates even more **environmental savings** (windmills producing green energy, buildings providing thermal insuation...).

CONVERTING, PACKAGING

90% of the internally generated **polyester scrap is returned to the process** and used for foam manufacturing. Ready product is packed on reusable wooden pallets, protected with carton and PET strips, which can also be reused or recycled.



RESOURCES

95% of our raw materials comes from recycling. Partnership with key PET flakes suppliers guarantees the best quality of recycled stream and continuity of supply.

GRANULATION

Fast and energy efficient **granulation process allows us to fully control the quality** and shorten start-up time for foaming operations.

EXTRUSION FOAMING

All additives used in our process are safe for people and environment. We only use **non-halogenated additives**. Our foaming agent has no ozone depletion potential **and very limited global warming potential.**

Picture 2: Life cycle of ArmaFORM® PET GR

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![armacell logo]

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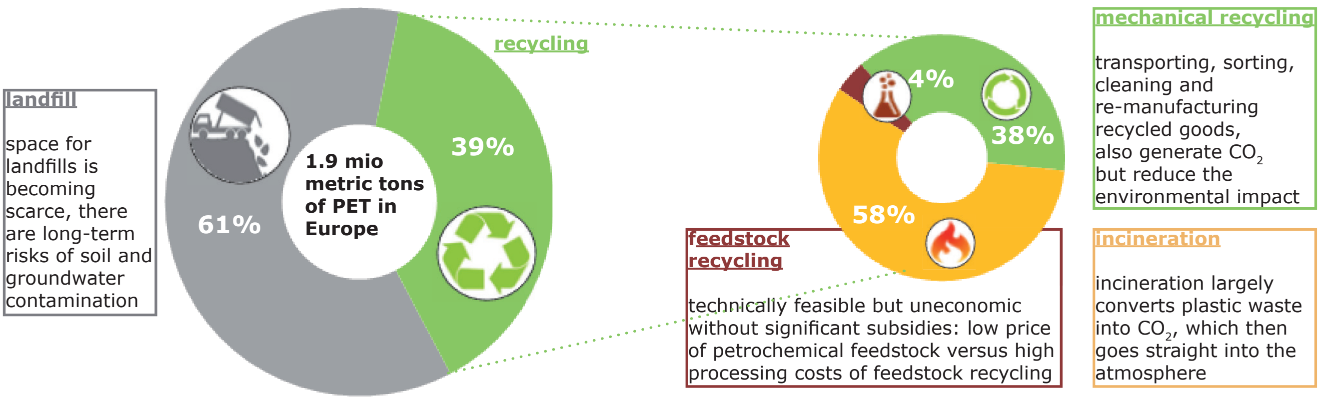
¬ Innovative solutions of Armacell support recycling

ArmaFORM® PET GR foam is not only green in color, it is a truly sustainable solution. It provides all the known benefits of PET-based structural foams, such as thermal resistance, fatigue behavior, compressive strength, it also brings measurable environmental and socio-economic benefits. PET is the most widely recycled polymeric material in the world. The highest quality material is directly re-used by bottle manufacturers - the average recycled content in PET bottles in Europe is now 10.6%. Some cleaner streams are reused in food contact packaging, strapping bands, fibers, filaments and nonwovens. More contaminated quality streams of lower intrinsic viscosity could be chemically depolymerized into initial monomers, in a process of feedstock recycling. But there is still a huge amount of material which is incinerated with only partial energy recovery or landfilled.



Picture 3: Plastics consumption and recovery in Europe [1)]

The environmental impact of different end of life scenarios for post-consumer PET is shown in the table 1 and contrasted with production of virgin material.

Environmental impact	Unit	1 ton of virgin PET	1 ton of recycled PET	1 ton of incinerated PET	1 ton of landfilled PET
Abiotic depletion	kg Sb eq	38,48	1,92	0,11	0,14
Acidification	kg SO_2 eq	40,00	16,00	0,32	0,07
Eutrophication	kg PO_4^{3-} eq	2,69	1,08	0,42	4,35
Global warming (GWP 100)	kg CO_2 eq	2416	604	2033	76
Human toxicity	kg 1,4-DB eq	186	47	1740	1436

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Fresh water aquatic ecotoxicity	kg 1,4-DB eq	22,15	13,29	2159	3558
Terrestrial ecotoxicity	kg 1,4-DB eq	1,45	0,36	0,17	0,12
Photochemical oxidation	kg C_2H_4	1,71	0,43	0,01	0,02
Data source: SimaPro Database 7.3.0, method: CML 2001, obligatory impact categories with impact >0.		PET bottle grade B250	Recycled PET bottle grade B250	Disposal, PET, 0.2% water, to municipal incineration/CH U	Disposal, PET, 0.2% water, to sanitary landfill/ CH U

Table 1: Comparison of different end of life scenarios for PET

According to the analysis, landfilling bottles in generates a lower carbon footprint than recycling or incineration, but results in much higher human toxicity and ecotoxicity. Incinerating PET bottles generates huge amounts of greenhouse gases, which can be partially reduced by generating power and heat. But even at their best, waste incinerators are inefficient sources of energy and their net contribution is negative, far from environmental impacts of recycling or landfilling. **The above results clearly show that post-consumer PET has a much lower impact on human health and the environment than virgin PET.** ArmaFORM® PET GR 100% produced with post-consumer PET is much more environmentally friendly than any other foam core available on the market. Instead of being landfilled or incinerated the recycled PET returns to the system and thanks to Armacell's patented technology is remanufactured into a full value product.

¬ LCA Methodolgy

Functional Unit: The calculations are based on 100 kg of foam of the average density produced in 2013 (100 kg/m³), i.e. 1 m³ of foam.

System boundary: The data collection refers to the yearly production in 2013. The following life cycle stages are considered

- raw material supply (inventory estimations and approximations: recipes contain specific substances which are only partly available in life cycle inventories build in the software; approximations are used with the consideration of similar supply chain effort or similar elementary composition),
- transport of raw materials to the production facility in Belgium (based on the average figures representing the supply chain),
- granulation of PET flakes (based on internal data),
- foaming process (based on internal data),
- post-operations, including packaging material (based on internal data),

- transport from factory gate to customer site (based on the average figures for the worldwide distribution of ArmaFORM® PET).

Use phase and end-of-life scenario is not included.

The LCA of ArmaFORM® PET GR is applied with restricted boundaries, representing cradle-to-gate approach. Why not cradle-to-*grave*? PET foam cores are used in multiple applications and are always subjected to further processing. Our customers are producting multi-layered structures in which PET foam is thermoformed, thermocompressed, wet-laminated, infused, combined with skins, reinforcements, prepregs, etc. All these operations as well as new raw materials used for manufacturing of final parts affect the Life Cycle Assessment of PET foam core. 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 program.

Cut-off criteria: The assessment, factored in all reported data from the production process, thermal energy consumed, and electric power consumption using the best available LCI datasets. Thus material and energy flows contributing less than 1% of mass or energy are taken into account. No cut-off criteria are applied in the foreground data in this study.
For cut-off criteria in the background system, see the information provided in the modelling principles and specific documentations of SimaPro v7.3 provided by Pre Consultants/ the Netherlands.

The information on environmental impacts is expressed with the impact category parameters of LCIA using characterization factors. The characterization factors selected (CML 2001) meet the requirements of EN 15804.

LCA Tool: The analysis is carried out based on ISO 14040-44, the international standard for an ISO-compliant ecobalance. The impact is assessed using CML 2001 in the following categories:

Depletion of abiotic resources protection of human welfare, human health and ecosystem health, related to extraction of minerals and fossil fuels due to inputs in the system	**Climate change (global warming)** addresses adverse effects upon eco-system health, human health and material welfare, related to emissions of greenhouse gases to air
Stratospheric ozone depletion addresses harmful effects on human health, animal health, terrestrial and aquatic eco-systems, biochemical cycles and materials resulting from the larger fraction of UV-B radiation which reaches the earth surface	**Photochemical oxidation (summer smog)** addresses formation of reactive substances (mainly O3) which are harmful to human health and ecosystems and may also damage crops

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Fresh-water aquatic eco-toxicity addresses the impact on fresh water eco-systems, as a result of emissions of substances which are toxic to air, water and soil	**Human toxicity** concerns the effects of toxic substances on the human environment
Marine ecotoxicity addresses impacts of toxic sub-stances on marine ecosystems	**Terrestrial ecotoxicity** addresses the impacts of toxic substances on terrestrial ecosystems
Acidification addresses impacts of acidifying substances on soil, groundwater, surface water, organisms, eco-systems and materials (buildings)	**Eutrophication (nitrification)** addresses the excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water and soil

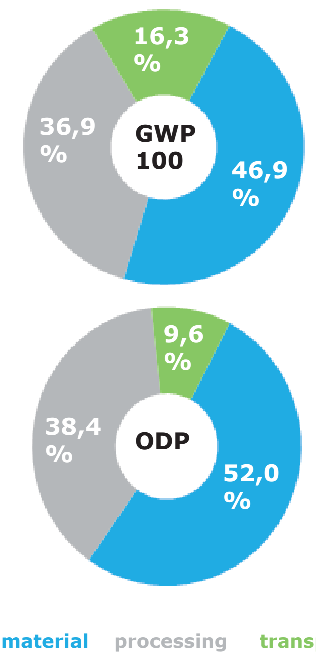
Table 2: CML 2001 impact categories

¬ LCA results for ArmaFORM® PET GR ...

Environmental impact	Unit	100 kg of ArmaFORM® PET GR
Global warming (GWP 100)	kg CO_2 eq	226
Ozone layer depletion (ODP)	kg CFC-11 eq	0,000078
Abiotic depletion	kg SB eq	2,33
Human toxicity	kg 1,4-DB eq	65
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	10,3
Marine aquatic ecotoxicity	kg 1,4-DB eq	213 728
Terrestrial ecotoxicity	kg 1,4-DB eq	0,617
Photochemical oxidation	kg C_2H_4	0,073
Acidification	kg SO_2 eq	1,64
Eutrophication	kg PO_4^{3-} eq	0,099
Data source: SimaPro Database 7.3.0, method: CML 2001, obligatory impact categories with impact >0.		

Table 3: Environmental impact of ArmaFORM® PET GR

... and contribution of life cycle stages to main impact categotries



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Raw materials and processing have the highest contribution to all impact categories of the cradle-to-gate analysis for ArmaFORM® PET GR. The most important environmental indicator, **global warming (GWP 100)**, also known as the "carbon footprint", **is mostly affected by raw materials**, so every further improvement in supply chain of raw materials could further improve the product's sustainability. The high impact processing has on human toxicity is linked to electrical and thermal energy used for extrusion and post-processing operations (converting and others).

¬ Results of LCA for ArmaFORM® PET GR in comparison to other foamed core materials

Similar cradle-to-gate methodology was applied in life cycle assessment of the main core foam materials present on the market.

Environmental impact	Unit	100 kg PET GR foam	100 kg virgin PET foam	100 kg PVC foam	100 kg PU foam	100 kg SAN foam	100 kg XPS foam
Global warming (GWP 100)	kg CO_2 eq	226	337	472	589	419	404
Ozone layer depletion (ODP)	kg CFC-11 eq	0,000078	0,000119	0,000081	0,000049	0,000054	0,000166
Human toxicity	kg 1,4-DB eq	65	74	65	110	55	338
Abiotic depletion	kg SB eq	2,33	3,76	4,90	5,36	4,20	4,23
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	10,3	11,37	8,05	31,95	66,26	11,72
Marine aquatic ecotoxicity	kg 1,4-DB eq	213'728	228'450	178'326	219'992	185'752	201'882
Terrestrial ecotoxicity	kg 1,4-DB eq	0,617	0,687	0,687	0,583	0,632	0,699
Photochemical oxidation	kg C_2H_4	0,073	0,150	0,128	0,171	0,079	0,086
Acidification	kg SO_2 eq	1,64	3,42	3,55	5,34	1,78	2,21
Eutrophication	kg PO_4^{3-} eq	0,099	0,220	0,271	0,516	0,159	0,174
Data source: SimaPro Database 7.3.0, method: CML 2001, obligatory impact categories with impact >0.							

Table 4: Comparison of environmental impact of various foam cores

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¬ Conclusion

ArmaFORM® PET GR is the absolute best in its class in terms of global warming potential - its carbon footprint is significantly reduced compared to the main competitive foams. Similarly positive trends are observed for the other impact categories – post-consumer PET foam contributes less to abiotic depletion, acidification, eutrophication and summer smog. It is in line with the other foam core materials in the other human and environmental impact categories. Based on these results, one may conclude that **ArmaFORM® PET GR contributes to a more sustainable future and supports the guidelines of circular economy, in which being environmentally and socially responsible goes hand in hand with running a profitable business.**

¬ ArmaFORM® PET GR in wind turbine application

One of the biggest markets for ArmaFORM® PET is the wind energy market, where it is used in sandwich constructions for rotor blades, nacelles and spinners. Today, ArmaFORM® PET is used in >30.000 rotor blades throughout the world. While ArmaFORM® PET based on virgin PET resin was used in the past, more and more wind turbine manufacturers are recently switching to the even more sustainable ArmaFORM® PET GR grade.

The average size of onshore wind turbines being manufactured today is around 2.5-3 MW, with blades of about 50 meters long. Depending on the blade design and the density of the foam used, nearly 1.725 kg of ArmaFORM® PET GR are used in such a wind turbine. Based on the results of above cradle-to-gate analysis, this amounts to 3.9 tons/CO_2 emission.
In comparison, one person flying back and forth from Berlin, Germany to New York, USA in economy class releases the same amount (3.87 tons). A Mercedes Benz C220 CDI Blue Efficiency produces 58.5 tons CO_2 after driving 50.000 km.[2)]

The lifetime $C0_2$ savings provided by such a 3 MW onshore turbine is approximately 83.520 tons[3)]. [4)]

There is no doubt that foam core based on virgin PET resin offers a sustainable solution, and it was Armacell who paved the way when it supplied the first PET foam to the wind turbine industry in 2007. But Armacell did not stop there and is now offering ArmaFORM PET® GR for the blade manufacturing. **Using ArmaFORM® PET GR instead of standard PET foam core (based on virgin PET resin) in the "same" rotor blade reduces the CO_2 emission by -33% or better 1.9 tons.** The improvement is even greater in comparison with other foam core such as PVC. The "same" blades made of PVC core instead would result in approximately 6.1 tons, which is 56% more than with ArmaFORM® PET GR.

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¬ References

[1] Association of Plastic Manufacturers (2004) "An analysis of plastics consumption and recovery in Europe", Brussels, Belgium; PCI PET Packaging, Resin & Recycling Ltd (2015) "PET in Transition: A Global Perspective for 2015", Lyon, France

[2] http://thecompensators.org/de/compensate/examples-of-emissions/

[3] For every kWh of wind energy produced, approximately 696 g of CO2 will be prevented (source: http://www.ewea.org/uploads/pics/EWEA_Wind_energy_factsheet.png). Wind turbines will be running continuously for as much as 120.000 kWh over their lifetime (source: http://www.ewea.org/wind-energy-basics/faq/).

[4] Wind turbines produce no greenhouse gas emissions during their operation. It takes a turbine just three to six months to produce the amount of energy that goes into its manufacture, installation, operation, maintenance and decommissioning after its 20-25 year lifetime. During its lifetime a wind turbine delivers up to 80 times more energy than is used in its production, maintenance and scrapping. Wind energy has the lowest 'lifecycle emissions' of all energy production technologies (source: http://www.ewea.org/wind-energy-basics/faq/).

¬ Version: September 2015