WHITE PAPER

BIOPOLYETHYLENE – A CRITICAL ENABLER FOR THE DECARBONISATION OF PLASTICS

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Learn how biopolyethylene can make plastics more sustainable.
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Biopolyethylene (Bio-PE) is a biobased equivalent to conventional fossil-based polyethylene. Bio-PE can substitute for conventional polyethylene in all applications without any modification to processing equipment and while preserving all product properties. Bio-PE delivers a drastic reduction in the carbon footprint of polyethylene products, providing a ready means of decarbonising plastics product and packaging supply chains where few other alternatives are available. Bio-PE has been in use for more than a decade in markets including rigid and flexible packaging, consumer goods, and building and construction. With increasing production capacity announced through two major routes starting from a wide variety of biomass sources, the bio-PE market is poised for strong growth in the years ahead.

BIOPOLYETHYLENE (BIO-PE) REFERS TO POLYETHYLENE THAT IS DERIVED FROM BIOMASS, RATHER THAN FOSSIL OIL OR GAS AS IS THE CASE FOR CONVENTIONAL POLYETHYLENE (PE). ASIDE FROM ITS RENEWABLE ORIGINS, BIO-PE HAS IDENTICAL CHARACTERISTICS TO CONVENTIONAL NON-RENEWABLE PE AND CAN BE DROPPED INTO EXISTING PLASTICS SUPPLY CHAINS AND RECYCLING PROCESSES.

BIOBASED VS BIODEGRADABLE

Bio-PE belongs to the family of bioplastics, which is a broad term and encompasses plastics that are biobased, biodegradable or both (Figure 1).

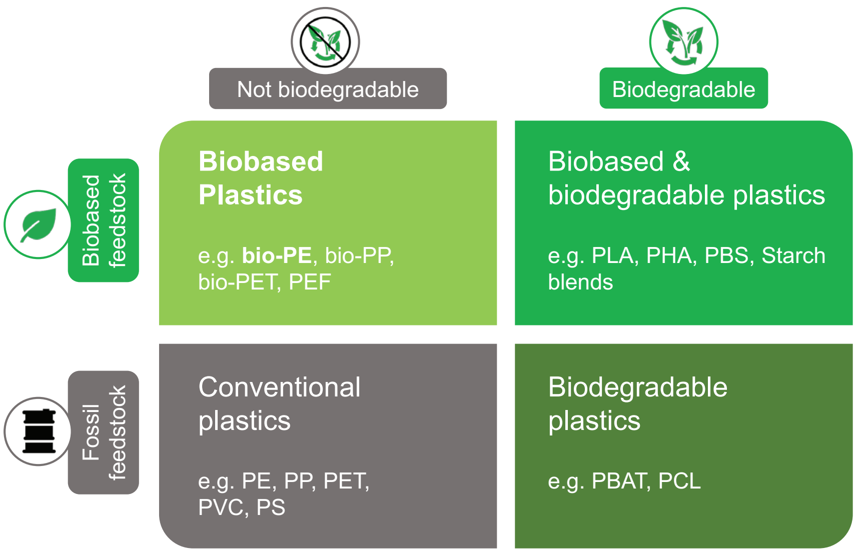

Figure 1. Classification of bioplastics based on feedstock and biodegradability adapted from European Bioplastics (EUBP). Bio-PE is biobased but not biodegradable.

Bio-PE is derived from renewable biomass like corn, sugarcane or vegetable oils. It is biobased but not biodegradable. It has the same structure as fossil-based PE and can therefore be used as a direct substitute in the production of PE products and packaging such as bags, pouches and containers. No modification to downstream processing equipment is required and the resulting products have identical physical and chemical properties.

Bio-PE is also fully compatible with existing mechanical and emerging advanced recycling pathways. This means that rigid packaging produced with bio-PE can be collected via existing kerbside systems, sorted in material recovery facilities (MRFs) and be processed back into recycled products and packaging through mechanical recycling. Pathways based on advanced recycling, also known as chemical recycling, are collecting and recycling PE-based flexible packaging and other formats that are more challenging to recycle using conventional mechanical recycling processes [Wassenaar 2023]. Bio-PE is fully compatible with these circular approaches.

REAL LIFE APPLICATIONS

Bio-PE has been available at commercial scale for more than a decade and has replaced conventional PE in dozens of applications, decreasing fossil resource dependency and lowering greenhouse gas emissions. One of the most recognisable applications was announced by Lego, who utilises bio-PE for numerous shapes of their famous bricks [Barrett 2018]. Moving up in scale, bio-PE has also found application in high volume food packaging applications. Fonterra launched its first plant-based 2L high density polyethylene (HDPE) milk bottle made from 100% bio-PE in New Zealand in 2020 [Fonterra 2020]. FrieslandCampina introduced milk cartons using coating and caps made from bio-PE in The Netherlands back in 2015 [Il Bioeconomista 2015]. Amcor offers bio-PE based flexible packaging for a wide range of applications, including coffee pouches used by Swedish coffee roaster Lofbergs [Amcor 2019]. Interestingly, the 2021 Tokyo Olympic hockey tournament was played on artificial grass made from bio-PE. Artificial grass manufacturer Polytan has been offering bio-PE based artificial grass pitches since 2017.

> **BIO-PE IS A CRITICAL ENABLER FOR THE PLASTICS INDUSTRY AND THE SECTORS OF THE ECONOMY IT SUPPLIES TO ACHIEVE DEEP DECARBONISATION WHERE LIMITED ALTERNATIVE APPROACHES ARE AVAILABLE.**

These examples demonstrate the broad applicability of bio-PE and its ability to be used in the production of any article made from conventional PE. Brand owners have a strong motivation to switch to bio-PE as it drastically reduces greenhouse gas emissions in line with their ESG objectives and offers a supply chain no longer reliant on fossil fuel as its feedstock.

TWO PRODUCTION ROUTES

The principal pathway for the production of bio-PE is through the fermentation of biomass into ethanol, followed by its dehydration to ethylene and the subsequent polymerisation into bio-PE (Figure 2). Sugar cane and corn starch are the preferred feedstocks as they yield the highest volumes of ethanol per hectare of arable land and are therefore the most cost effective. Technology for the production of cellulosic ethanol from non-food sources such as crop residues and wood waste is continuing to advance and may become available at larger scale in the near future [Kramer 2022].

The second route used to produce bio-PE starts with oils such as used cooking oil (UCO), wood-based residue and vegetable oils. A process of hydrotreatment and subsequent hydrocracking transforms these oils into a hydrotreated vegetable oil (HVO) which contains a variety of fractions, including diesel, jet, gasoline and (bio)naphtha. The bionaphtha fraction can be converted into bioethylene through steam cracking and eventually polymerised into bio-PE.

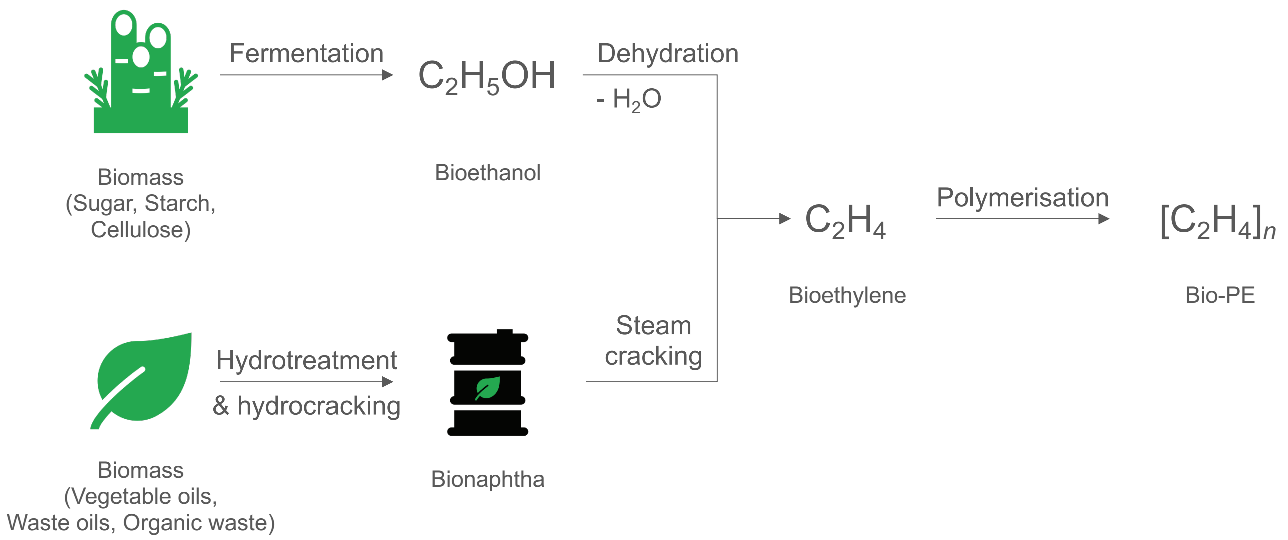

Figure 2. Production routes for bio-PE employed on industrial scale

The bioethanol pathway is the principal means of producing bio-PE and the current annual global capacity is estimated at 200,000 metric tonnes (t), soon to increase to 260,000 t following an expansion announced by producer Braskem [Braskem 2022]. Braskem is also planning a new plant in Thailand in partnership with SCG Chemicals. Additional activity includes Petron Scientech's development of a range of projects to produce bioethylene from ethanol around the world with annual nameplate capacities between 80,000-360,000 t [Petron 2023].

Bionaphtha is typically produced as a by-product of the production of renewable diesel, a fuel that is in high demand driven by the biofuel targets contained in regulations such as the EU's updated Renewable Energy Directive (RED II). Global bionaphtha production volume was estimated at 250,000-500,000 t in 2021 [Dimitriadou 2021]. However, it is difficult to translate this figure into bio-PE volumes as bionaphtha is also blended into gasoline to meet renewable fuel standards and may be used to produce a variety of biobased petrochemicals such as bio-PP, bio-PS and bio-PVC. Nonetheless, with renewable diesel production estimated to grow significantly from 1.8 EJ in 2021 to 6.4 EJ in 2030, it is certain that bio-PE volumes through the bionaphtha route will increase as well [IEA 2022]. Several petrochemical manufacturers including Dow, LyondellBasell, Versalis and TotalEnergies are already marketing bionaphtha based bio-PE products and are establishing ongoing access to bionaphtha as raw material.

DECARBONISATION POTENTIAL

The world is starting to take action to reduce greenhouse gas emissions with the goal of net zero by 2050 and warming of less than 1.5°C above pre-industrial levels. Whilst the transport and household sectors can leverage electrification combined with renewable electricity generation to reduce the carbon footprint, emissions in material supply chains can be harder to abate. Plastic already provides the lowest carbon footprint in a wide range of essential supply chains including packaging, consumer goods and mobility [Feber 2022]. However, the vast majority of plastic is derived from fossil fuel and requires energy intensive processing. It is estimated that plastics are currently responsible for 4.5% of global greenhouse gas emissions and these emissions are projected to double by 2050 based on a business as usual approach as demand for plastic is set to double in this time frame [Stegmann 2022]. A sustainable plastics industry requires both increasing the circularity and a decoupling from finite fossil resources [Bachmann 2023].

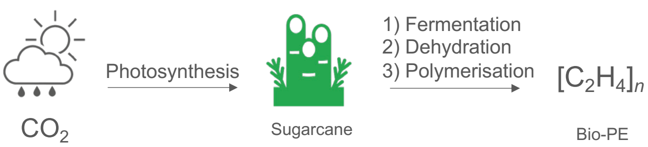

Figure 3. Illustration of CO_2 sequestration into sugarcane biomass and subsequent transformation into bio-PE

A lifecycle analysis (LCA) published by Braskem and validated by the Carbon Trust indicates that bio-PE can be carbon negative through the sequestration of CO_2 into sugarcane biomass and locking the carbon into the product (Figure 3) [Braskem 2016]. The study investigated a functional unit of 1 kg of HDPE derived from sugar cane in Brazil and accounted for the electricity produced from the bagasse byproduct. The scope of the study was cradle to gate, which means that environmental impacts are accounted from growing or extracting raw materials up until the point where the HDPE pellet leaves the factory gate. Bio-PE and conventional PE perform equally in the product and at the end-of-life, hence this approach provides a valid comparison. The study concluded that the sequestration of CO_2 that occurs during the growth of the sugarcane and the credits from bioelectricity cogeneration using the bagasse byproduct, more than offset the emissions from the agricultural operations of growing and harvesting as well as the emissions related to the processing into bio-PE (Figure 4). It is important to note that material efficient product design coupled with reuse and recycling loops are critical to keep the carbon locked within the material.

Climate change impact of bio-HDPE made in Brazil

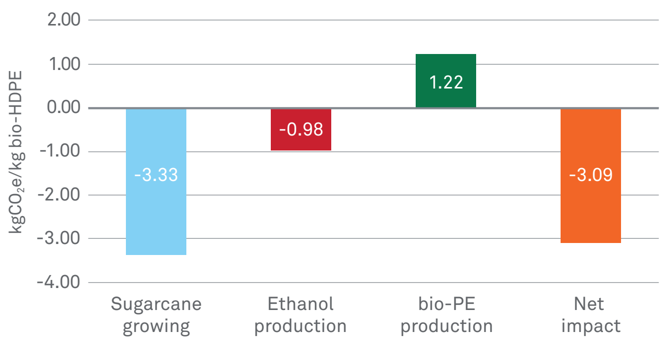

Figure 4. Climate change impact of bio-HDPE from the LCA published by Braskem for I'm green™ biobased PE

The sensitivity of the outcome of LCA studies to the underlying assumptions and feedstocks is illustrated by a second study on bio-PE derived from corn stover (stalks, leaves and cobs that remain after harvest) conducted by the Argonne National Laboratory [Benavides 2020]. Whilst it confirms the overall beneficial climate change impact in line with the Braskem study, the greenhouse gas reduction potential at -1.0 $kgCO_2e/kg$ bio-PE is lower. This difference is accounted for by the choice of a different feedstock and the study's inclusion of the transformation by extrusion or injection moulding which occurs beyond the gate of the resin producer. Care needs to be taken when attempting to generalise conclusions and a specific LCA is essential in underpinning environmental claims.

No detailed publicly available LCA has been uncovered for bio-PE produced via the bionaphtha route. Nonetheless, an LCA has been published for bio-PP produced from liquid hydrocarbons made from 100% renewable waste and residue raw materials, which may be assumed to provide similar climate change impacts to bio-PE [Neste 2021]. The study that included cradle to gate as well as end-of-life impacts concluded that bio-PP offers a more than 80% reduction in greenhouse gas emissions compared to conventional polypropylene.

LAND USE

Concerns have been raised about the land use of biofuels and bioplastics and the perceived competition with food for human and animal consumption. Data published by European Bioplastics (EUBP) indicates that bioplastics (including bio-PE) used about 0.015% of the global agricultural area in 2022 (Figure 5) [EUBP 2022]. To calculate the estimated land use impact for bio-PE, we assume for simplicity that all of it is produced from sugar cane via the ethanol dehydration route. EUBP estimates bio-PE global production capacity at 330,000 t in 2022, which would require about 550,000 t of bioethanol equating to 697 million litres. The Food and Agriculture Organization of the United Nations (FAO) estimates the ethanol yield from sugarcane in Brazil at 5,476 litres per hectare (ha) [FAO 2008]. Dividing the bioethanol requirement for bio-PE production by the yield per hectare results in an estimated agricultural land use of 0.127 million ha, representing about 0.003% of the global agricultural area.

If bio-PE were to replace 100% of the global PE demand estimated at 117 million t in 2022 [CMA 2022], this would require about 192 million t (244 billion litres) of bioethanol. When applying the same yield per hectare of sugarcane this translates into a land use of 45 million ha, representing about 1% of global agricultural area. However, as this number exceeds current estimates for global sugar cane production, the feedstock would need to be sourced from a variety of globally grown crops including corn, sugar beet, cassava and rice, some of which offer lower efficiencies around 2,000 litres per ha [FAO 2008]. Therefore, a land use of ca. 100 million ha or 2% of global agricultural area is more realistic for the scenario where all PE were derived from crop land, noting that some of it would also be derived from waste and residues that requires no additional land. This land use would remain well below the current land use of biofuels and may be drastically reduced through expanding the share of cellulosic ethanol that is derived from crop residues and waste as well as overall reduction of PE demand through increased circularity.

TRACEABILITY

A robust chain of custody process for biobased material is essential to ensure the integrity of environmental claims and avoid unintended social or environmental outcomes. Such an audited and certified process will provide traceability of material throughout the entire supply chain from point of origin (e.g. a farm) to the entity placing the final product on the market (e.g. a brand owner). This ensures that claims can only be made on a material that is grown sustainably in compliance with environmental, human, labour and land rights. A variety of schemes for biobased materials is being offered by independent third-party certification organisations such as ISCC Plus and Bonsucro.

A physically segregated chain of custody approach is possible in processes where the mixing of certified and non-certified material does not occur. For bio-PE this can occur through the bioethanol route if bioethylene and conventional ethylene are not mixed in the polymerisation step. It is also theoretically possible that this can happen through the bionaphtha route but in practice the mixing with conventional naphtha is likely due to the need to leverage economies of scale.

If mixing of the bio- and conventional feedstocks is unavoidable, there are two approaches that can be applied to attribute the renewable content to the end product. Biogenic carbon from plant sources has a $^{12}C/^{14}C$ isotope distribution that is different from that of fossil-based carbon. It is possible to measure the biogenic carbon content in the resulting product [ASTM 2022] and attribute the renewable provenance accordingly. This approach can also be applied as a confirmation where bio and conventional sources have been fully segregated. It should be noted that the use of additives and comonomers in bio-PE manufacture may result in a biogenic carbon content of somewhat less than 100%.

The alternative is to use the mass balance approach in which certified input is attributed to certified output on a bookkeeping basis, accounting for process losses through a conversion factor. Mass balance is already widely used in certified supply chains including fair trade chocolate, forestry products and biofuels.

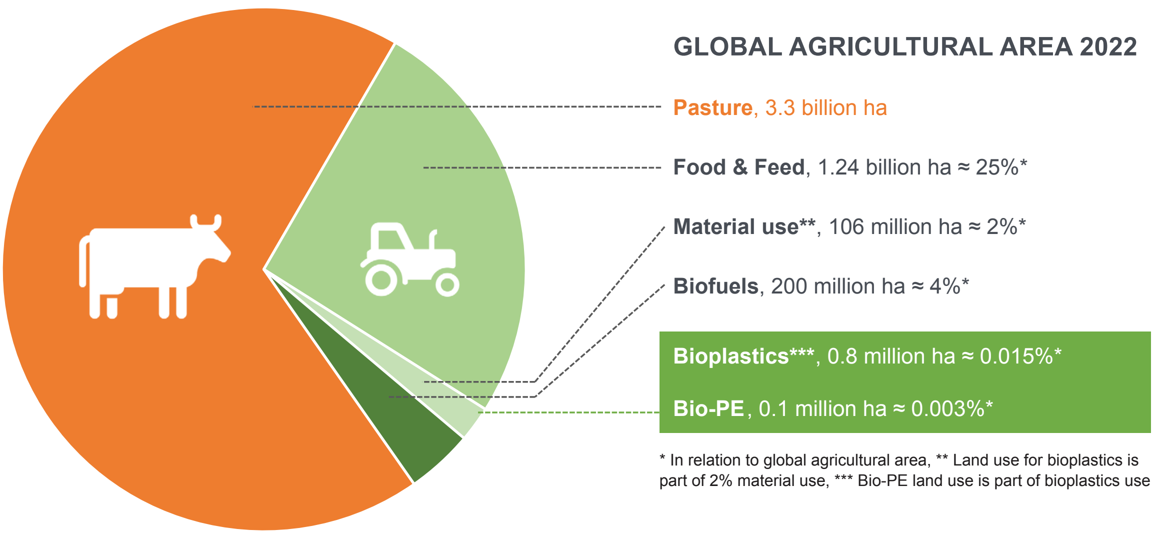

Figure 5. Land use impact of bioplastics and bio-PE in relation to total global agricultural area adapted from European Bioplastics (EUBP)

CONCLUSION

More than a decade after the first commercial scale production of bio-PE it is fair to conclude that its commercial viability has been proven. The material is a critical enabler for the plastics industry and the sectors of the economy it supplies to achieve deep decarbonisation where limited alternative approaches are available. Demand for bio-PE is accelerating and outstripping supply. Dozens of new projects are in execution or planning globally based on the two principal pathways covered in this paper. The bright future for bio-PE is underpinned by political will as demonstrated by the Biden administration's ambition to deploy biobased recyclable polymers to replace >90% of today's plastics [White House 2023].

REFERENCES

Amcor, *The simple, more sustainable switch to bio-based packaging*, Blog, July 2019

ASTM International, *ASTM D6866-22 Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis*, Standard, 2022

M. Bachmann, C. Zibunas, J. Hartmann et al., *Towards circular plastics within planetary boundaries,* Nature Sustainability, 2023, https://doi.org/10.1038/s41893-022-01054-9

B. Barrett, *Lego Builds a Sustainable Future, One Brick at a Time*, Gear, March 2018

P. T. Benavides, U. Lee, O. Zarè-Mehrjerdi, *Life cycle greenhouse gas emissions and energy use of polylactic acid, bio-derived polyethylene, and fossil-derived polyethylene*, Journal of Cleaner Production, Vol. 277, 2020, 124010

Braskem, *Braskem invests in capacity expansion and partnerships for the production of biobased plastics*, Press release, October 2022

Braskem, *I'm green™ bio-based PE Life Cycle Assessment*, 2017, https://www.braskem.com.br/portal/imgreen/arquivos/LCA%20PE%20I%27m%20green%20bio-based_FINAL%20EN.pdf

Chemical Market Analytics (CMA), *Polyethylene World Analysis edition 2023*, December 2022

E. Dimitriadou, *Regulation, consumer demand drive bionaphtha use in fuels, petchems,* S&P Global Platts Insight, August 2021

European Bioplastics, *Bioplastics facts and figures*, December 2022, https://docs.european-bioplastics.org/publications/EUBP_Facts_and_figures.pdf

D. Feber, S. Helmcke, T. Hundertmark et al., *Climate impact of plastics*, McKinsey & Company white paper, July 2022

Food and agriculture organization of the United Nations (FAO), *The state of food and agriculture – Biofuels: prospects, risks and opportunities*, 2008

Fonterra, *New Zealand's first plant-based milk bottle*, Press release, October 2020

IEA, *Biofuels*, International Energy Agency, https://www.iea.org/reports/biofuels, September 2022

Il Bioeconomista, *FrieslandCampina plans to introduce a new bio-based beverage carton over the next 1.5 years*, Blog, May 2015

D. Kramer, *Whatever happened to cellulosic ethanol?*, Physics Today, 2022, https://doi.org/10.1063/PT.3.5036

Neste, *Combating climate crisis*, Company website, June 2021, https://www.neste.com/products/all-products/plastics/combating-climate-crisis#d992828f

Petron Scientech, *Ethanol to Green – Ethylene Projects*, Company website, May 2023, https://www.petronscientech.com/PSI-Exp.html

P. Stegmann, V. Daioglou, M. Londo et al., *Plastic futures and their CO_2 emissions*, Nature, Vol. 612, 2022, 272-276

J. Wassenaar, *Circular polyolefin capacity set to reach 1 million tonnes globally in 2025*, Qenos white paper, March 2023

The White House, *Bold Goals for U.S. Biotechnology And Biomanufacturing,* Executive order, March 2023, https://www.whitehouse.gov/wp-content/uploads/2023/03/Bold-Goals-for-U.S.-Biotechnology-and-Biomanufacturing-Harnessing-Research-and-Development-To-Further-Societal-Goals-FINAL.pdf

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