GREENING OLD INDUSTRIES

The Challenge of Bio-Plastics

Polyethylene terephthalate ("PET") has become the most used plastic for bottles, semi-rigid containers, and fibres. PET, produced from purified terephthalic acid ("PTA") and monoethylene glycol ("MEG"), can be replaced by bio-based alternatives, including polyethylene furanoate ("PEF") which has bio-based constituents. PEF provides superior barrier properties in comparison to PET and a net-zero generation of CO_2 when recycled. The bioplastics industry is challenged by the extensive capital investment required and competition with other industry sectors. This paper sets out the challenges of this industry, whereby increased government regulation or other incentives are required for meeting PEF's full potential.

INTRODUCTION

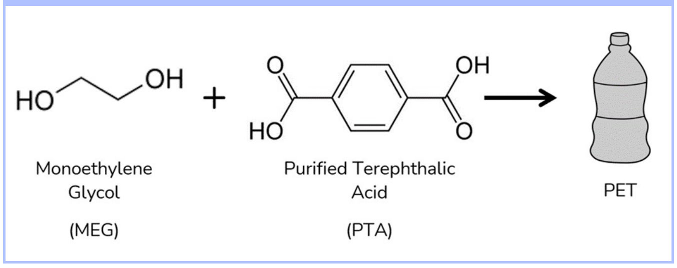
Polyethylene terephthalate ("PET") has become essential to modern life due to the convenience and simplicity of single use plastic. In 2021, over 82 million tonnes of PET were produced annually from oil, and it has become the most used plastic for bottles, semi-rigid containers and fibres. Currently, only 2.2 million tonnes of plastics are derived from renewable resources annually, accounting for less than 1% of the global plastics market. As a result of increasing public awareness of the extent of plastic pollution, as well as fossil fuel consumption attributed to single-use plastic, a bioplastic alternative in the form of polyethylene furanoate ("PEF") has gained momentum. PEF has the potential to rival the staple PET bottle and this article looks more closely at this more environmentally-friendly alternative, its potential benefits and which companies are active in this space.

THE THEORY BEHIND THE SOLUTION

MANUFACTURING PROCESSES: PET

PET bottles are produced from purified terephthalic acid ("PTA") and monoethylene glycol ("MEG"), which undergoes polymerisation to form PET. PET's constituent, PTA, is produced from the oil-derived para-xylene ("PX").

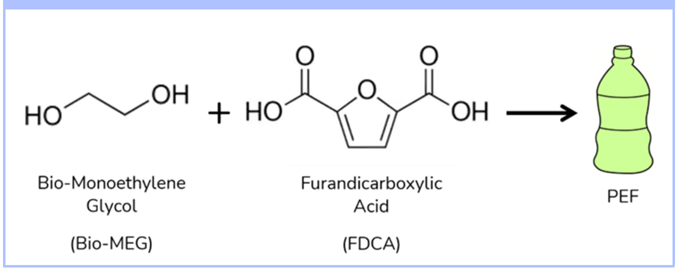
Figure 1. *PET Production Reaction*



MANUFACTURING PROCESSES: PEF

In contrast to PET, PEF is a unique polymer composed of two bio-based molecules. Approximately two thirds is furandicarboxylic acid ("FDCA"), and one third is bio-monoethylene glycol ("Bio-MEG"), both of which can be renewably sourced. FDCA is derived from sugar and, potentially, lignocellulosic feedstock; and Bio-

Figure 2. *PEF Production Reaction*



MEG is made from ethylene derived from the dehydration of bio-ethanol, which is itself derived from sugars. The process for the manufacture of PEF is the condensation polymerisation of Bio-MEG with FDCA (See Page 4 for information on FDCA).

MANUFACTURING OF BIO-PET

Bio-PET is made of fossil-based PTA and plant-based Bio-MEG. This is a 'half-way' approach to sustainable formulation, but as the Bio-MEG is only one third of the overall polymer and the other two thirds is oil-based, this is not as sustainable as PEF.

CURRENT PRODUCTION

Industrial scale operations have the ability to create Bio-PET, and can replace some PET in the market place. There are also efforts to make PTA from bio-based PX. In 2021 **Virent** produced Bio-PX using sugar derived from corn for **Coca-Cola's** plant-based bottles. Although the manufacture of 100% PEF bottles is technically feasible, industrial scale production is yet to become economically viable in today's market.

WHY PEF?

PEF offers many benefits when compared to PET including the following:

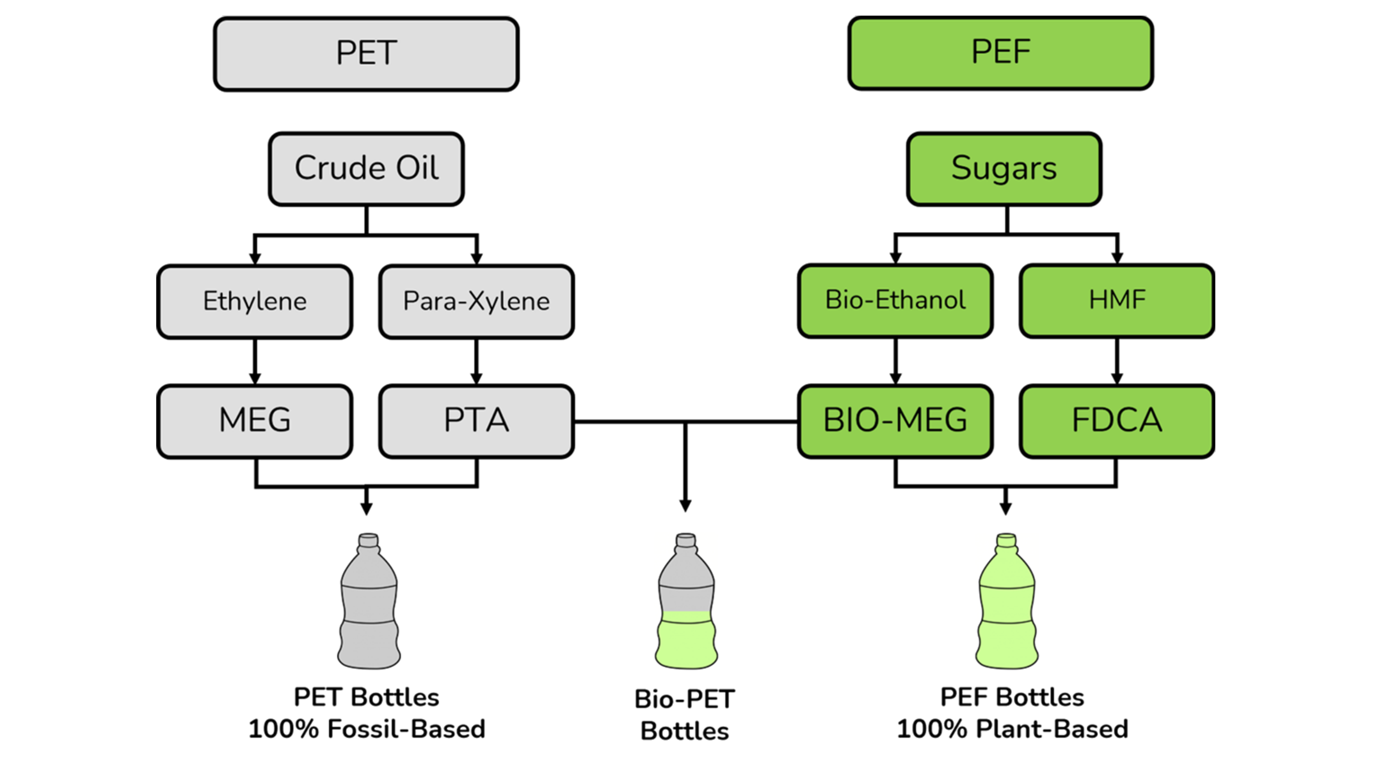
- Higher glass transition temperature (T_g)
- Lower melting point temperature (T_m)
- Reduced greenhouse gas emissions compared to PET for cradle to grave systems (approximately 45% - 55% reduction)
- Cost competitive at industrial scale (predicted)
- Higher mechanical strength

In addition to the characteristics stated above, PEF offers improved barrier properties, which have been seemingly difficult to achieve with other bio-based polymers. These include:

- 6x greater O_2 barrier than PET
- 3x greater CO_2 barrier than PET
- 2x greater H_2O barrier than PET

PEF bottles also require less material, therefore they are lighter and more stable than their PET competitors, with their barrier properties also allowing beverages to last longer.

Figure 3. *Production Path for PET, Bio-PET and PEF*



Plastics derived from fossil fuels are particularly stable and resistant to enzymatic degradation. These plastics can be mechanically shredded and reused to a limited extent or incinerated, producing CO_2. Since the PEF bottles are made from renewable and bio-based raw materials, recycling by incineration results in a net-zero generation of CO_2 into the atmosphere. Whilst more exploration is needed into PEF's long-term ability to degrade in the environment, PEF can be recycled mechanically using the same technology that is now used for PET. PET recycling is challenged by the ability to reuse post-consumer waste in certain applications.

CONTRIBUTION TO CIRCULAR ECONOMY

Currently, the plastics industry is mostly linear, whereby products are produced, used and disposed of in an unsustainable manner. A circular economy aims to close the loop on the lifecycle of plastics whilst using renewable feedstock. Currently, only 30% of PET plastic is productively recycled each year in the US.

Figure 4. *The Circular Economy*

The UK has enacted new regulations with the goal of cracking down on corporations not committed to supporting a circular economy. Companies are required to manufacture plastics with at least 30% recycled content by 2030 or risk a fine of up to £210/tonne. The scheme is known as the Plastic Packaging Tax ("PPT"). The EU follows the Packaging and Packaging Waste Directive whereby a call rate of €0.80 per kilogram is applied to the weight of plastic packaging that is not recycled. However, more investment is required to fulfil a circular economy.

OPPORTUNITIES

Renewable – *one step closer to being carbon neutral*

Cost – *growth of the required feedstocks can be inexpensive compared to current PET technology*

Support – *government subsidies available to help a bioeconomy*

CHALLENGES

Throughput – *lots of biomass is needed to make products, competing with the growth of food*

Landmass – *land use needed and the organisms required take time to grow, unlike synthetic chemicals*

Diversity – *the ability for different locations around the globe to grow biomass in large quantities (feedstock variability)*

Resources – *growth of biomass requires lots of natural resources including water and feedstocks*

Availability – *the commercial production of the FDCA and Bio-MEG monomers*

CHALLENGES & OPPORTUNITIES

Although the use of bioplastics has many upsides, as with any new technology, there are limitations in the current infrastructure.

The commercial production of PEF faces limitations due to the availability of its key components. **India Glycol**, a prominent player in the industry, produces Bio-MEG at a small-scale commercial plant. **Avantium** is looking to commercialise the FDCA production, with its flagship plant for FDCA due to be in operation by the end of 2023. This facility is projected to have an annual throughput of 5,000 metric tonnes, incurring a substantial capital expenditure ("CAPEX") of €115m (Avantium Investor Presentation Feb'22). In 2020, **Intesa Sanpaolo** and **Novamont** announced the signing of a €20m loan agreement to finance two innovative circular economy projects, one of which is to produce FDCA.

Feedstock for Avantium's Flagship Plant will be supplied by **Tereos**, who produce high fructose syrup from wheat. Avantium is in advanced negotiations with several global brands, with offtake agreements already in place with **LVMH Group**, **Sukano**, **Carlsberg**, **Henkel**, **Monosuisse**, **Origin Materials**, **Refresco**, **Resilux** and **AmBev** for the PEF and FDCA products.

For comparison, China's **Yisheng Petrochemical** has recently announced the addition of 6.6 million tonnes per annum of PTA across two production sites, with a total annual capacity of close to 20 million tonnes.

These figures emphasise the niche nature of the PEF market, as its production remains relatively small-scale compared to that of other plastics. Considering the costings mentioned, it becomes evident that scaling up PEF to replace the 82 million tonne PET market would be economically challenging with today's infrastructure and requires extensive capital investment from industries and governments.

The production of PEF is also limited by the availability of bio-based raw materials. The raw material needed to produce PEF needs to evolve from the use of primary sugars (in competition with the food industry) to secondary sugars from waste biomass in order to become cheaper. Producing FDCA, combined with the availability of the required intermediate species, 5-hydroxymethylfurfural ("HMF"), makes the production of PEF economically challenging.

MARKET OUTLOOK FOR BIOPLASTICS

The adoption of PEF is a potential high-growth area that players within the packaging industry are looking to target. However, there is hesitation in the industry around the expense of manufacturing PEF; it is currently estimated PEF will cost roughly €8-10/kg (Avantium Annual Results 2022) compared to €1/kg for PET. The longer-term strategy for the commercialisation of PEF bottles is to expand production to an industrial scale, whereby the cost per kilogram can be reduced to become comparable to existing PET bottle prices.

FDCA and other intermediate furanic chemicals have been termed 'sleeping giants' due to their enormous market potential. Although there is a large market potential, the rate of growth will depend on how quickly producers can expand their operations to meet future global demands.

It is unlikely that PEF will completely replace PET in the near future due to competition with existing PET infrastructure. Theoretically, another potential solution is the repurposing of existing PET infrastructure to produce the required PEF, with only small adjustments to equipment needed. Alternative building blocks in the production of PEF are also being explored, for example replacing FDCA with furandicarboxylic methyl ester ("FDME"). FDME is derived from corn fructose and can reduce the associated costs as it is not required to be as pure as the currently used FDCA. Other solutions proposed include the use of polyhydroxyalkanoate ("PHA") made from sugars which are grown from algae, and polylactic acid ("PLA") made from sugars found in sugarcane.

CUSTOMER INTEREST

Commitments from key players within the industry set important milestones within their pledged sustainability strategies. **Coca-Cola** and partners aim to eliminate fossil-based PET from all bottles by 2030. In late 2021, their commitment to plant-based packaging saw a partnership with **Tech Partners** to create a 100% plant-based bottle prototype with 900 bottles produced. This follows the introduction of the original PlantBottleTM in 2009, made from 30% plant -based raw material as Bio-MEG became available, the world's first recyclable bottle at the time.

Additionally, **Carlsberg** made their bio-based bottle available to consumers in 2022. The corporation trialled 8,000 bottles across 8 Western European markets which employed a plant-based PEF polymer lining developed by their partners, Avantium. Little progress has been made since to roll-out bioplastic bottles.

CONCLUSION

This comparison between PET and PEF illustrates the challenges and opportunities in the development of sustainable materials. As discussed above, bio-based PEF exhibits superior characteristics in terms of barrier properties and mechanical strength, as well as offering a lower environmental impact by reducing the carbon footprint and dependence on fossil fuels. The bio-plastic's ability to be recycled efficiently with net zero generation of CO_2 positively contributes towards the world-wide goal of achieving a circular economy.

Bio-PET and PEF have the potential to become significant parts of the plastics market which is currently occupied by PET. Pressure from consumers for a more sustainable plastics industry underpins long term PEF and Bio-PET demand growth, but use is currently limited by high prices, with PEF costing some 8 to 10 times the PET alternative. The second issue is that the existing PET supply chain infrastructure is well established. For PEF bottles to replace existing PET, major capital investment is needed, but, in the near term, use of Bio-PET bottles looks to be a promising compromise. There needs to be increased government regulation or taxation to compensate for the environmental impact, and other incentives such as subsidies, for this replacement to be fully effective.

ABOUT NATRIUM CAPITAL

Natrium Capital Limited is an independent Chemicals M&A boutique set up by Alasdair Nisbet in 2012. Natrium Capital provides high level strategic and M&A advice primarily focused on the chemical, personal care, adhesive, engineering materials, paints, inks and coatings, biotechnology and clean technology industries. Headquartered in London, Natrium Capital and team advise on complex global cross-border transactions and have advised on over $100bn transaction value in the sector.

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on the merger of Connell, its Asian Speciality Chemical Distribution business with	in the acquisition of Performance Polyamide Business in Europe from	in the sale of its Amphoteric Surfactant Business in N. America & Europe to	in the acquisition of	in the merger of its chlor and vinyl additives business with Georgia Gulf to form
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