

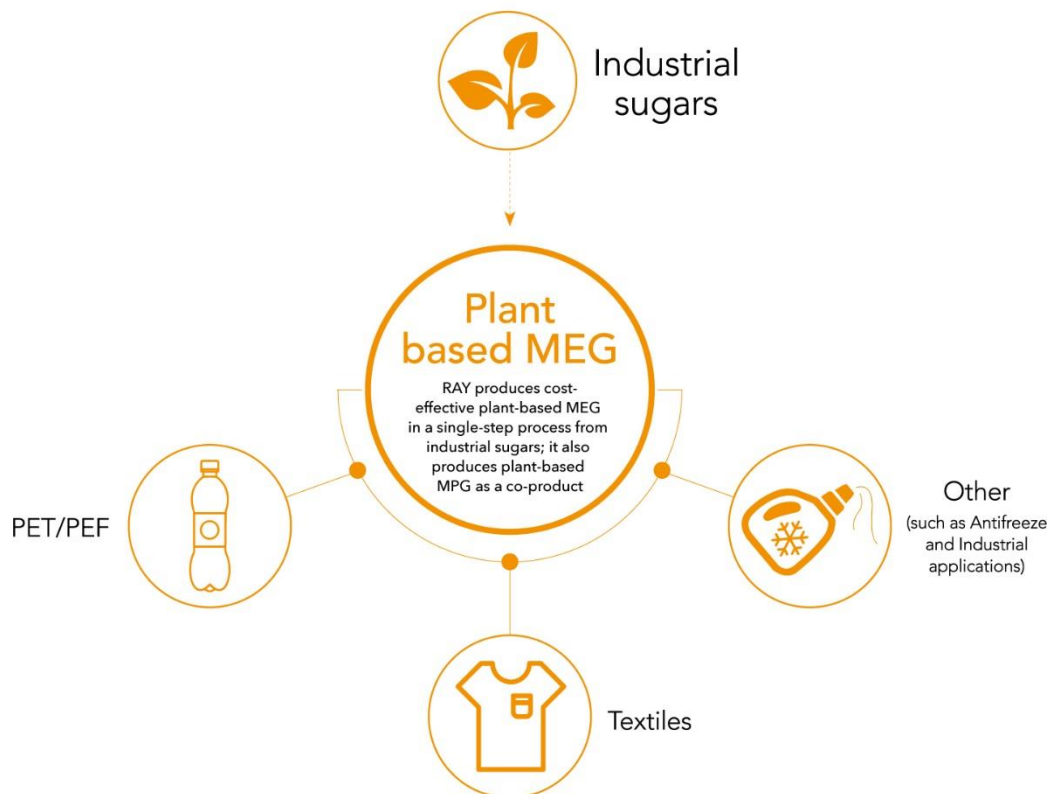
About Ray Technology™ - A Bright Step to the Future

Ray Technology™ is Avantium's plants-to-*glycols* technology producing plant-based *mono-ethylene glycol* (MEG), a fossil-free core component for everyday products such as textiles or plastic materials like PET (polyethylene terephthalate) and *PEF* (polyethylene furanoate) (produced by Avantium's *YXY® Technology*), making it a key ingredient of products such as plastic bottles and clothing.

Today, more than 99% of MEG is produced from petroleum, with a market value of about \$25 billion. Ray Technology™ aims to produce plant-based MEG that is chemically identical to petroleum-based MEG and competitive in terms of cost and quality.

Avantium's Ray Technology™ delivers an environmentally sustainable and cost-effective plant-based alternative for fossil MEG, producing it in a single-step process from plant-based sugars.

RAY Technology™





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How does Ray Technology™ work?

Ray Technology™ is a highly efficient one-step **hydrogenolysis process** to produce MEG from plant-based sugars, with a maximum theoretical yield of 100% and a practical yield of over 70%. This direct pathway from sugars to MEG makes Avantium's plant-based MEG cost-competitive with fossil-based alternatives, while reducing the supply chain's dependence on fossil feedstocks.

Avantium will use sugars from various **1st generation feedstock** such as sugar beet, sugar cane, wheat and corn, as well as **2nd generation non-food feedstock** such as forestry or agricultural residues which is converted into sugars by Avantium's **Dawn Technology™**.

Internal calculations show that the process to produce plant-based MEG by Avantium's Ray Technology™ significantly reduces the **CO₂ equivalent** versus traditional processes to produce fossil-based MEG. If you consider the source – plants instead of oil -, internal calculations show that the production of plant-based MEG by Avantium's Ray Technology™ reduces the CO₂ equivalent with around 70% versus traditional production of fossil-based MEG. This equates to taking half a million passenger cars of the road per plant. This internal calculation will be validated by an independent **Life Cycle Analysis (LCA)**.

Why has Avantium developed Ray Technology™?

Avantium is a pioneer in developing unique renewable-chemistry innovations, with a mission to help create a fossil-free world through a **circular economy**. Most of the materials and chemicals used in modern daily life – such as plastics, packaging, furniture, clothing and pharmaceuticals – are derived from oil, coal or natural gas, and are responsible for 11% of the primary global demand for oil as well as for 8% of world demand for natural gas (source: IEA July 2018).

Avantium's innovative chemistry technologies within the polyester value chain enable the production of chemicals and materials that are based on sugars from plants instead of fossil resources. Its YXY® technology pioneered the viable production of PEF plastic. PEF is a fully recyclable novel polymer made from plant-based feedstocks and is in many respects superior to PET. Avantium has successfully demonstrated the YXY Technology at its pilot plant in Geleen, the Netherlands. The second technology is the Dawn Technology™ that converts non-food biomass into industrial sugars and lignin in order to transition the chemicals and materials industries to non-fossil resources. In 2018, Avantium opened the Dawn Technology™ pilot biorefinery in Delfzijl, the Netherlands. The third technology is the Ray Technology™. Avantium's technologies are complementary but not dependent on the other technology programs.

How is Avantium bringing Ray Technology™ to market?

On 7 November 2019 Avantium is opening a demonstration plant in Delfzijl, the Netherlands, with an annual capacity of around 10 tonnes of plant-based MEG. The objective of the demonstration plant is to scale up the technology from lab to demonstration size, to further optimise the technology and to validate applications. Avantium also plans to collect data to execute an environmental **Life Cycle Analysis (LCA)** quantifying the sustainability benefits of our Ray Technology. The end-to-end demonstration plant will cover all process steps from sugars to glycols, which will allow for the

production of MEG and **mono-propylene glycol (MPG)** samples that are representative of the final product produced at subsequent commercial plants. In this way, the demonstration plant can act as a flywheel for commercial developments.

The demonstration plant will also produce several tonnes of plant-based MPG as a co-product. MPG is used in multiple applications in a variety of different industries, such as in unsaturated polyester resins, cosmetics, pharmaceuticals, food flavoring, deicing and antifreeze.

Why do we need plant-based MEG?

Today, 99% of MEG is produced from fossil-based resources, representing a value of approximately \$25 billion. Market demand for MEG is expected to grow from 28 million to 50 million tonnes in the next 20 years; a global CAGR of 3.5%ⁱ. This translates to over a million tonnes of additional MEG per year; for which roughly 60 new commercial plants around the globe will be needed. The combination of the growing MEG demand and its strong dependence on fossil resources, provides a great opportunity for the introduction of plant-based alternatives.

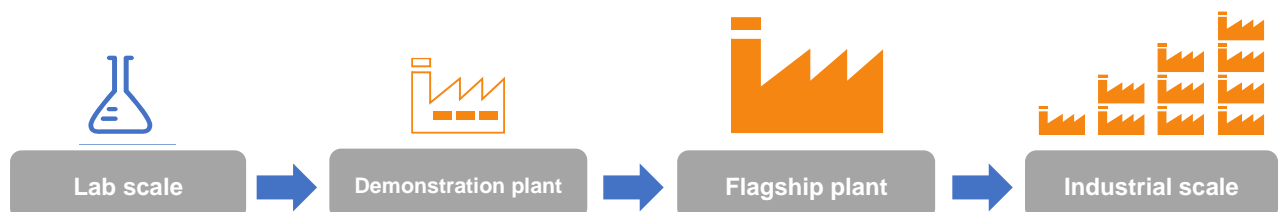
Global demand for MPG is approximately 1.5-2 million tonnes per annum, with year-over-year growth of around 2-3% until 2021.

Is Ray Technology™ the only plant-based MEG option available?

No. Plant-based MEG alternatives are already available; indeed consumer brands like Coca-Cola use current plant-based MEG in their 'plant bottles'. However, current processes to produce MEG from **biomass** are complex and uneconomical compared to fossil-based alternatives. This has held up mass-market adoption of plant-based materials.

Ray Technology™ removes many of the steps involved in creating plant-based MEG. This in turn reduces cost, making plant-based MEG comparable in cost and performance to existing fossil-based alternatives.

How does Avantium commercially Scale Up?



Assuming successful results from the demonstration plant, Avantium aims to open a commercial flagship plant in 2024. Additionally, Avantium will commercialize Ray Technology™ by licensing it to manufacturers and brands wishing to produce and use plant-based MEG.



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Avantium has signed several agreements to explore partnership opportunities in bringing its Ray Technology™ to full-scale commercialization globally. The Delfzijl plant-based MEG plant will serve as a demonstration facility for these potential partners.

Avantium is progressing well in developing partnership opportunities throughout the value chain in order to bring the technology to full-scale global commercialization. Potential partners around the world have already expressed interest in Ray Technology™ for deployment. This varies from feedstock providers who wish to diversify their markets, chemical companies who seek to enter a significant growth market and transition to a bio-based economy and consumer brands who are looking for plant-based solutions for their textiles and packaging

How is the demonstration plant for Plant-Based MEG financed?

Avantium has funded the demonstration plant from proceeds of its IPO in March 2017 where it allocated €15-20 million investment in our most advanced technologies. Approximately half of these proceeds are being used for Ray Technology™.

Alongside this important investment decision by Avantium, in 2018 the European Innovation Council awarded Avantium's Ray Technology™ an approximately €2 million grant in order to accelerate the scale-up and commercialization of innovative business opportunities.

In March 2019, Avantium received an additional €2 million grant towards constructing the Ray Technology™ demonstration plant from the European Regional Development Fund. This is facilitated by Partnership Northern Netherlands (Samenwerkingsverband, Noord-Nederland). The grant is intended to accelerate innovation in the quest for a low-carbon economy.

In June 2019, Avantium announced that it has been awarded €1.3 million for both Ray Technology™ and Dawn Technology™ from the Bio Based Industries Joint Undertaking (BBI JU) under the European Union's Horizon 2020 Research and Innovation Program. This commits Avantium to participate in the VEHICLE consortium whose members aim to widen the business and market opportunities of existing and future biorefineries by demonstrating the applicability of their sugar streams in several downstream options.

In August 2019, Avantium was awarded €6 million as part of a SPIRE grant to accelerate its Dawn Technology™ and Ray Technology™ in addition to utilizing its expertise in Catalysis. SPIRE, part of Horizon2020, is the European subsidy programme to facilitate the region's Sustainable Process Industry. Avantium participates in a 4-year research programme entitled IMPRESS, which aims to demonstrate a new biorefinery concept based on integrating novel processes such as Avantium's Dawn and Ray Technologies for the first time.

Glossary of terms

1st Generation feedstock

Carbohydrate rich plants such as sugar beet, sugar cane, corn and wheat that can also be used as food are called food crops or 1st generation feedstock. Currently, 1st generation feedstock is the most efficient feedstock for the production of plant-based chemicals and plastics. All regional feedstock is an excellent plant-based source for renewable glycols.

2nd Generation feedstock

This refers to feedstock not suitable for food, such as forestry or agricultural residues.

Bio-based economy

A bio-based economy exists when predominantly plant-based materials, i.e. biomass rather than fossil-based raw materials like petroleum are used as a feedstock for making chemicals, materials and products we consume.

Biomass

Biomass is organic feedstock especially of plant origin. These feedstocks are renewable and originally found in nature in the form of agricultural and forestry products like corn, wheat, sugar beet, sugar cane, rapeseed and woody plants. The residues of these products also contain starch, carbohydrates, fats and proteins.

Circular Economy

A circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

CO₂ Equivalent

CO₂ equivalent, or carbon dioxide equivalent, is a standard unit for measuring carbon footprints. The idea is to express the impact of each different greenhouse gas in terms of the amount of CO₂ that would create the same amount of warming.

Dawn Technology™

Dawn Technology™ is the brand name of Avantium's biorefinery technology, which converts non-food plant-based feedstock into industrial sugars and lignin. These sugars, such as **glucose**, are an excellent raw material for chemistry and fermentation processes used to produce a broad range of products.

Glucose

Glucose is a sugar consisting of six carbon atoms (C₆). It is a core building block for the transition to a bio-based economy. Glucose serves as a feedstock for the production of a broad range of chemicals and materials produced via chemistry or fermentation processes. The resulting products can be existing and new plant-based chemicals, such as plant-based mono-ethylene glycol, mono-propylene glycol, FDCA (furanedicarboxylic acid) and PEF (polyethylene furanoate, a 100% plant-based recyclable polymer).

Glycols

Glycol is any of a class of organic compounds belonging to the alcohol family. The term is often applied to the simplest member of the class: ***mono-ethylene glycol***, a colourless, oily liquid.

Hydrogenolysis process

Hydrogenolysis is a chemical reaction whereby a carbon–carbon or carbon–heteroatom single bond is cleaved or undergoes breakdown by hydrogen. Avantium’s plant-based MEG is produced from ethylene via hydrating ethylene oxide by a catalytic production process.

Life Cycle Analysis (LCA)

A LCA is the compilation and evaluation of the input, output and the potential environmental impact of a product system throughout its life cycle.

Mono-ethylene glycol (MEG)

Mono-ethylene glycol - or MEG - is a vital ingredient for the production of polyester textiles and film, polyethylene terephthalate (PET) and polyethylene furanoate (PEF) resins and engine coolants. End uses for plant-based MEG range from clothing and other textiles, through packaging to kitchenware, non-toxic coolants (eg. antifreeze) and solvents (eg. paint and coatings).

Mono-propylene glycol (MPG)

Mono-propylene Glycol (MPG) is a valuable intermediate and is used in a wide variety of applications, including unsaturated polyester resins, industrial uses and food, feed and pharma. Unsaturated polyester resins represent 41% of MPG offtake, and are mainly used in fibreglass reinforced plastics for construction marine and transportation industries. Technical application such as functional fluids and solvents account for 30% of MPG offtake. Food, feed and pharma applications make up the remaining 29% of MPG offtake.

PEF

Polyethylene Furanoate, a polyester made from mono-ethylene glycol (MEG) and FDCA (furandicarboxylic acid). PEF produced by Avantium’s YXY Technology is a 100% plant-based and recyclable polymer that can be applied to an enormous range of applications, including packaging of soft drinks, water, alcoholic beverages and fruit juices. PEF’s barrier and thermal properties are superior to conventional PET. In combination with a significantly reduced carbon footprint, the added functionality gives PEF all the attributes to become the next-generation polyester.

PET

Polyethylene terephthalate, transparent polyester used for bottles and film. The polyester is made from mono-ethylene glycol and (fossil-based) terephthalic acid.

Ray Technology™

Ray Technology™ is the brand name of Avantium’s technology to produce plant-based mono-ethylene glycol, developed under the project name Mekong. Internally, Avantium uses river names for its projects and upon commercialization, the company adopts a brand name.



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Renewable resources

Agricultural or forestry raw materials, which are not used as food or feed, but as raw material for industrial products. The use of renewable resources by industry saves fossil resources and reduces the amount of greenhouse gas emissions.

YXY® Technology

Avantium's YXY technology helps to produce a wide range of novel 100% plants-based materials and products by converting plant-based sugars (fructose) into plant-based chemicals and plastics, such as polyethylene furanoate (PEF).

ⁱ Source: Nexant Report 2017

For more information:

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