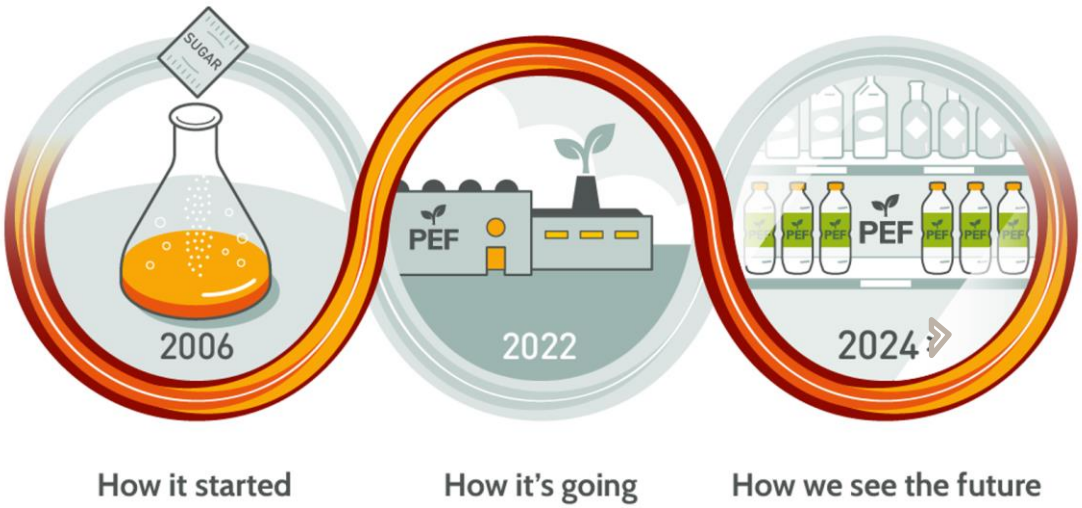
The Journey of Avantium's PEF towards Commercialisation

History, Present and Future



Avantium N.V. 9 December 2021

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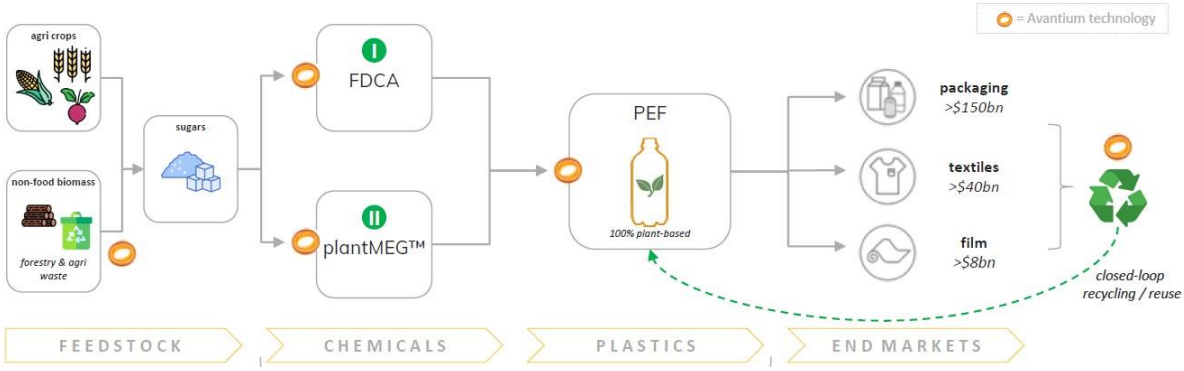
1. Company snapshot

Avantium is an innovation-driven company dedicated to developing and commercialising breakthrough chemical technologies for the production of building blocks (monomers) from renewable sources (plant-based sugars and CO_2) instead of from fossil resources such as petroleum. Avantium also provides advanced catalysis products and services to companies who desire to gain improved efficiency in their catalytic chemical processes. Headquartered in Amsterdam, Avantium currently employs approximately 220 people, and has extensive R&D laboratories and operates three pilot plants in Geleen and Delfzijl, the Netherlands.

1.1 Avantium's coherent portfolio of technologies

It is Avantium's goal is to be a world leader in renewable and sustainable chemistry technology solutions and to commercialise them through partnerships and licensing. With a mission to move towards a fossil-free world, Avantium has developed multiple game-changing technologies at various stages of commercialisation, poised to disrupt the plastic packaging material industry and covering the value chain from plant-based feedstock towards multiple end-applications such as packaging, textiles, film and more – everyday items fit for today's world and addressing growing end-markets worth over $200 billion.



Avantium's most advanced technology is the YXY® Technology that catalytically converts plant-based sugars into FDCA (furandicarboxylic acid), the main building block of PEF: a 100% plant-based, fully recyclable plastic material with significant performance benefits and with a significantly lower carbon footprint than fossil-based plastics. Avantium has successfully demonstrated the YXY® Technology at a pilot plant in Geleen, The Netherlands. The second technology is the Ray Technology™ that catalytically converts industrial sugars to glycols, such as plantMEG™ (mono-ethylene glycol), an important monomer for both PEF and PET. Avantium has a demonstration plant to produce plantMEG™ in Delfzijl, the Netherlands. The third technology is Dawn Technology™ and converts non-food biomass into industrial sugars and lignin in order to transition the chemicals and materials industries to non-fossil non-food resources. Avantium runs a DAWN pilot biorefinery in Delfzijl, the Netherlands. In addition to Avantium's technologies using plant-based carbon sources, Avantium aspires to develop materials using carbon dioxide (CO_2) as a feedstock. While for energy we have many renewable options, for materials next to biomass, CO_2 is the only other renewable carbon source. Avantium's Volta Technology, a carbon capture and utilization (CCU) technology, is an electrocatalytic platform that converts CO_2 into chemical building blocks and high-value products. Finally, Avantium is applying its new plant-based and CO_2-based building block opportunities by developing and evaluating novel and improved polymer products for the plastic materials of the future.

1.2 Business model

Avantium has multiple strategic routes for monetising its breakthrough technologies. These include (i) own and operate the technology; (ii) applying the technology in partnerships or joint ventures; (iii) licensing the technology to third parties; or (iv) divesting them to third parties. Avantium has chosen licensing to be the business model for the YXY® Technology: aside from being the most capital-efficient way to commercialise the technology, Avantium strongly believes it is also the fastest way to bring PEF to market. With Avantium's YXY® Technology, brand owners and other companies have the tools to significantly reduce their CO_2 emissions and to get access to a sustainable material with unique performance benefits. For Ray Technology™, Avantium plans to form a joint venture with Cosun Beet Company, with the ambition to jointly construct and operate the first commercial plant for the production of plant-based glycols using Avantium's Ray Technology™. The intent is that the joint venture will acquire a Ray Technology™ license from Avantium. As part of its licensing business model, Avantium will continue to develop and license its Ray Technology™ globally.

1.3 Patent protection

Avantium's technologies are covered by 137 patent families (2020). For its PEF technology, Avantium has a solid protection of its leading technology with 57 patent families representing more than 400 patent rights and covering the full PEF value chain. This is not only required to safeguard Avantium's leading position of the production of FDCA and PEF but also required for the technology to be licensed out. Avantium has patents to produce FDCA precursors and FDCA, as well as to polymerise FDCA to PEF. The company has also patent protected many applications of PEF, such as bottles, fibers and films, as well as (chemical) recycling of PEF. Avantium continuously monitors other companies active in the field of PEF and FDCA, and is active in licensing and opposition discussions. The fact that other companies are also striving to produce FDCA demonstrates that the production of FDCA is a major market opportunity with large market potential in different application fields.

2. How it started: an experiment on a late Friday afternoon

2.1 Unlocking the potential of a "Sleeping Giant"

Avantium was founded in 2000, with the objective to accelerate and exploit the application of high-throughput catalysis research. But the discovery of Avantium's lead product FDCA, the building block for PEF, goes back to a Friday afternoon in 2006. One year earlier, Avantium made the strategic decision to leverage its expertise in high-throughput catalysis R&D by initiating its own proprietary development programmes focused on biobased chemicals, materials and fuels. To this end, Chief Technology Officer Gert-Jan Gruter did a small experiment on a Friday afternoon in 2006 with some sugar from the company restaurant. Instead of using water as a solvent, he mixed the sugar with alcohol and some acid in order to dehydrate the sugar. The result of this effort was a beautiful furanic molecule: MMF, the key precursor for the plant-based monomer FDCA. Gert-Jan Gruter immediately realised that this could be a breakthrough invention, due to the large potential of FDCA based polyesters such as PEF.

FDCA was listed already in 2004 by the US Department of Energy as the #2 in top-12 priority chemicals for establishing the "green" chemistry industry of the future.[1] Given the huge potential of FDCA, industrial production of this building block was pursued and researched for over 100 years, without success. As such, FDCA has been called a "sleeping giant"[2]; "sleeping" because no one had ever succeeded in producing FDCA in an economic fashion, and "giant" because of its enormous market potential. Gert-Jan Gruter figured out why no one was able to make this chemistry work: everyone used water as a solvent for the first sugar dehydration step. He came up with the simple but revolutionary idea to run the process in alcohol. The rest is history: this "Eureka! moment" by Gert-Jan Gruter was the beginning of Avantium's most advanced technology, the plant-to-plastics YXY® Technology.

Gert-Jan Gruter working in Avantium's laboratory

[1] www.nrel.gov/docs/fy04osti/35523.pdf
[2] www.mdpi.com/2078-1547/3/2/212/pdf

2.2 Flywheel for commercial developments

Since this discovery, Avantium has developed into a world-leader in FDCA and PEF. Avantium believes it was the first in 2009 to test PEF in a wide range of applications, such as bottles, fibers and films. In 2011, Avantium was the first company to construct and operate an FDCA pilot plant. The objective of a pilot plant is to scale-up the technology from lab to demonstration size, to further optimise the technology and to validate applications, serving as a flywheel for commercial developments. The FDCA pilot plant has enabled Avantium to produce many tonnes of FDCA and PEF samples that are representative of the final product from subsequent commercial plants. Furthermore, the pilot plant enabled Avantium to test PEF in various applications both in-house and through its partners. In 2015, FDCA was adopted by the European Food Safety Authority (EFSA). In August 2016, FDCA was included in the Plastics Regulation as a food contact material. And in 2021, Avantium released PEF food contact grade, RP90Nx, that complies with the required regulations of food contact materials, which would allow the use of the PEF resin in direct contact with acetic foods and alcoholic drinks with an alcoholic strength less than 20% as well as with clear and cloudy drinks in the European Union and the UK. Moreover, in 2017, Avantium received interim approval from the European PET Bottle Platform for the integration of PEF through existing recovery and recycling systems for bottles made from PEF resin.

YXY® Technology Pilot plant in Geleen, The Netherlands

2.3 Revised scale-up and market launch strategy

In 2016, Avantium established the 49:51 joint venture Synvina with BASF to commercialise the YXY® Technology. Apart from technological progress, the Synvina joint venture did not result in the successful collaboration that was envisioned at its start. Due to differing views on the commercialisation of FDCA and PEF, BASF and Avantium decided to dissolve the Synvina joint venture in January 2019. When dissolving Synvina, Avantium bought back the joint venture shares from BASF and acquired 100% ownership of the YXY® Technology. After taking full ownership, Avantium explored different scenarios with potential partners and customers to redefine the commercialisation strategy of PEF to meet both market and capital requirements. This led to a revised scale-up and market launch strategy presented by Avantium in June 2019. Avantium announced its intent to construct and operate a 5.000 tonnes per annum FDCA Flagship Plant. This now becomes reality: Avantium is on the brink of commercialising its most mature technology, with the goal to unlock the large potential of the FDCA and PEF, exactly as envisioned by Gert-Jan Gruter on a late Friday afternoon back in 2006.

3. How it's going: PEF has the potential to revolutionise the plastic packaging industry

Through the many years of extensive research & development and rigorous testing in the pilot phase, Avantium has demonstrated PEF to be superior in performance and environmental benefits when compared to conventional fossil-based plastics. Avantium's PEF offers a unique solution to address the global need to reduce plastic waste, help tackle climate change and transition into a circular, sustainable biobased economy.

3.1 The need to keep fossil resources in the ground – and only use carbon sourced above the ground

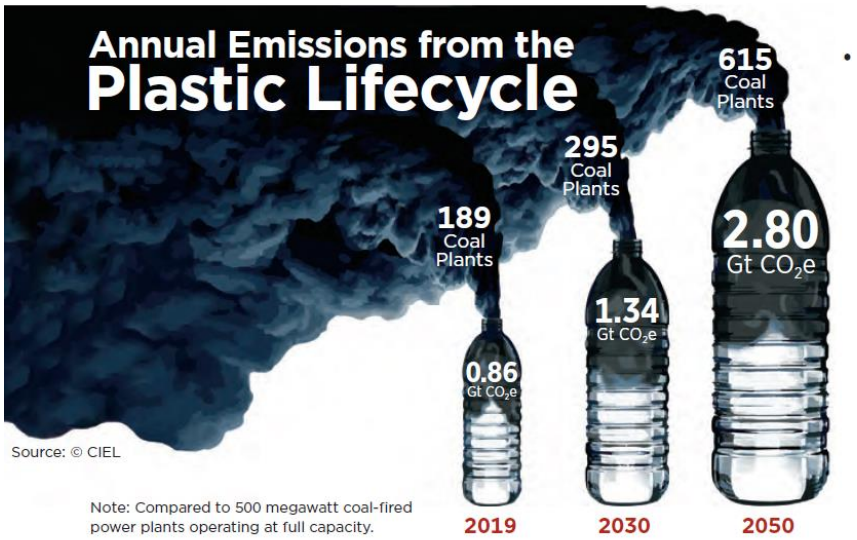
The climate crisis and plastic waste pollution provide a sobering but relevant background for Avantium's work and strategy to bring PEF to market. Climate change is one of the most pressing issues of our generation. In 2015, 196 heads of state and climate experts agreed under the United Nations Paris Agreement to limit global heating to 1.5°C, compared to pre-industrial levels. Beyond a 1.5°C change there will be so much heat globally to push many of the planet's natural systems out of balance; a balance that could not be regained. This was recently reaffirmed under the 2021 Glasgow Climate Pact.

The 2021 report from the Intergovernmental Panel on Climate Change (IPCC) revealed that CO_2 emissions were still higher than at any time in over the last two million years. It is therefore unequivocal that human-caused emissions are a significant factor in climate change.[3] The global climate breakdown demands an entirely new way of doing business, moving the world from its dependence on fossil-based resources towards a sustainable future with renewable energy and materials at its basis.

In recent years, public concern has grown around the damaging levels of CO_2 emissions from plastic production and the large quantities of plastic waste polluting our oceans. In 2019 the carbon footprint of plastics was 860 million tonnes (0.86 Gt). With the growing plastic demand (3.5% average volume growth per year), the carbon footprint will grow to 1.34 Gt in 2030 and 2.8 Gt in 2050 if we continue to use fossil feedstock for our plastics.[4] At the

[3] https://www.ipcc.ch/report/ar6/wg1/
[4] CIEL report "*Plastic & Climate: The Hidden Costs of a Plastic Planet*" *www.ciel.org/plasticandclimate*

same time we have agreed to reduce the global fossil based CO_2 emissions from 36.8 Gt in 2018 with 90% to 3.7 Gt in 2050. It is clear from the above numbers that without a plastics materials transition in which we transition to use carbon above the ground (biomass, CO_2 and recycle) for producing our plastics, we will not make the 2050 CO_2 emission targets.



Most plastic has a useful but very short life and creates significant and long-lasting harm for our planet, both during manufacture and after disposal. As a society, we therefore need to radically and urgently transform the way we produce, (use and discard plastics. In essence we have to move from today's linear model to a circular business. The chemical and plastics industry need to employ more sustainable practices and create products and materials that feed into the circular economy. This will in turn reduce plastic pollution and overall carbon footprint. And the world needs to embrace a business where we use renewable sources of carbon, emitting no fossil carbon into the atmosphere.

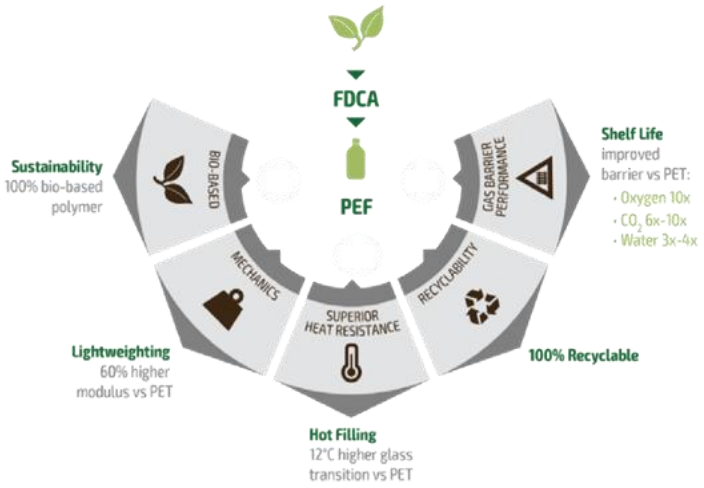
There is a general global consensus on the need to move to a 100% renewable – and decarbonised – energy sector, for example by using solar, wind or hydropower sources. However, there is not yet an equivalent strategy for the materials sector, where carbon is essential. This is especially true for the chemical and plastic industries, where progress away from fossil carbon sources towards above-ground carbon sources has been slow. Under a renewable carbon strategy for the chemical industry, manufacturers would need to stop using fossil (geosphere) sources and instead use the renewable carbon, such as glucose or sucrose from plants or the carbon found in CO_2. Solutions such as PEF will be crucial for the chemical and plastics industry to wean away from fossil-based resources and embrace sustainable, circular technologies to enable a circular, greener future.

3.2 PEF helps tackle climate change and addresses the global need to reduce plastic waste

The 100% plant-based, fully recyclable PEF is designed to improve the circularity of plastics. PEF is 100% made from the sugars generated by plants. The sugars (fructose syrup) used today to make FDCA can be produced from agricultural crops, such as wheat, corn and sugar beet. When commercially available, PEF can also be produced from cellulosic sugars, which are abundant in non-edible biomass, such as agricultural and forestry residue streams.

PEF is designed for recycling and reuse, and therefore it fits well in the circular economy. It has proven fit-for-purpose with existing sorting and recycling facilities. PEF can be recycled mechanically and chemically in the same way PET is recycled. In addition, PEF can easily be distinguished and sorted from PET and other plastics. Currently, many multilayer PET bottles include polyamides (PA) such as MXD6 for improved gas barrier properties required for small volume beer, wine and carbonated softdrink PET bottles. However, a common issue for incumbent barrier materials such as PA is their poor recyclability in combination with PET. PEF can substitute polyamides as barrier material in multilayer PET bottles, enabling the recycling process of these packaging solutions in combination with PET. PEF can also be used as a single layer in small bottles for soft drinks, beer and juices, replacing glass bottles, aluminum cans and multilayer bottles.

Another feature of PEF is that it degrades much faster than conventional plastics when exposed to fungi and bacteria in industrial composting conditions (250-400 days with air / oxygen @ 58°C in soil). Furthermore, initial studies suggest that PEF degrades in the natural environment many times faster than PET - it starts to break down in natural conditions within a single year instead of hundreds of years. Slow degradation in the environment is important as it will avoid the endless accumulation of waste plastic over many decades or even centuries which is the case with non-degradable materials such as PET.



3.3 Superior functionality

The many trials with partners over the past years have also resulted in much better insights in the performance of PEF. Avantium and its partners found out that PEF has high performing gas barrier properties for carbon dioxide (CO_2) and oxygen (O_2) compared to conventional plastics, leading to a longer shelf life of packaged products. This makes it possible to fully enjoy products such as food, drinks and cosmetics -even if stored for a long time - avoiding unnecessary food and product waste. This is an important feature, as food waste is a widely known global problem. Plastics – if used, produced and discarded responsibly – can help combat this problem. PEF offers even better barrier properties than conventional plastics, and is therefore a highly sustainable option for shelf life extension.

PEF also offers higher mechanical strength. In combination with the higher barrier properties, this higher mechanical strength allows thinner applications and reducing weight by more than 20% in line with European legislation.

In terms of thermal properties, PEF has excellent ability to withstand heat and can be processed at lower temperatures. PEF's beneficial barrier and mechanical properties, as well

as its high weakening temperature, makes it potentially a good fit for re-usable applications, which are currently under development. PEF has enhanced mechanical stiffness and allows for increasing shaping possibilities.

In combination with the plant-based feedstock, that added functionality gives PEF all the attributes required to become the next-generation plastic material.

3.4 Disruptive technologies need trailblazers

Disruptive technologies such as the YXY® Technology need trailblazers – those who embrace new, sustainable solutions and pave the way for broader adoption. Not everyone wants to take that first step, but Avantium is. Avantium's YXY® Technology truly is the first of its kind. However, development and deployment are neither quick nor easy processes. Aside from years of R&D, we need to prove the concept, assess its ability to scale, attract the right partners, conduct pilots, and deliver the foundations for large-scale manufacturing – all while testing at every stage to ensure we are meeting the appropriate safety and sustainability standards.

Over the years, PEF has attracted the enthusiasm and support of many partners – varying from offtake partners, governments, and financial partners. With the support of those important partners within the PEF value chain, Avantium is now ready to build and operate the world's first FDCA Flagship Plant, meeting the growing global demand across a range of end-product markets.

4. How we see the future: on the cusp of commercialising PEF

Avantium has taken the Final Investment Decision to build and operate the world's first FDCA Flagship Plant, to be built in Delfzijl (the Netherlands), with construction planned to be completed by the end of 2023 and to be operational in 2024. This commercial facility is set to produce 5000 tonnes of FDCA per annum (5 kta), the key building block for the 100% plant-based and recyclable polymer PEF. The main focus for the FDCA produced by the Flagship Plant will be on high-value applications which can benefit from PEF's powerful combination of sustainability and performance features. In addition to being a profit centre in its own right, the role of the Flagship Plant will be : a) to prove the process technology, and b) to demonstrate the commercial applications of PEF. The business model of the FDCA Flagship Plant is based on sales of FDCA and PEF to offtake partners. In addition, we intend to sell technology licenses to industrial collaborators who are expected to build production capacities of >100kta based on the knowledge and experience derived from our operation of the 5 kta Flagship Plant. The Company will, in parallel, continue to work to further optimise the YXY® Technology to preserve its technological advantages.

Rendered image of the Flagship Plant design Greenfield plot @ Chemie Park Delfzijl

We are ready to accelerate PEF's journey towards commercial reality. Our goal is to launch this technology onto the market, paving the way for global adaptation of this new polymer, and in doing so help to bring novel, sustainable packaging solutions to your supermarket and refrigerator. We believe the commercialisation of PEF will create long-term value for our shareholders, and will also mark a significant step towards a more sustainable and circular world.

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