BOPEF Film

A New Sustainable Solution for Flexible Food Packaging

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Oben BOPET Manager

TERPHANE

Agenda

Avantium

- Avantium Introduction
- PEF (PolyEthylene Furanoate) – Resin Overview

Terphane

- Terphane Introduction
- PEF – Film Overview
- Conversion Process (Printing, lamination, metallization).

Conclusions

Next Steps

Avantium

Zekeringstraat /

Flagship Plant

Pliot Plant (Delfzijl)

Science Park (AMS)

RNP Pilot Plant (Geleen)

Avantium at a glance: a pioneer in renewable chemistry

PEF Resin Overview

avantium

FDCA Pilot Plant (since 2011)

PlantMEG Pilot Plant (since 2019)

Pilot Biorefinery (since 2018)

Technology testing	Demonstrate technology & market testing	Commercial roll-out
R&D research	*Technology demonstration*	*Commercialisation & industrial roll-out via technology licensing*
Develop technology economic feasibility	*Commercial launch*	
Product validation and applications		

Lab scale & Pilot Plants → ✓ Flagship Plant → Industrial

Mission: create & commercialise disruptive technologies & products to accelerate the transition to renewable & circular plastics

From technology development to commercialization

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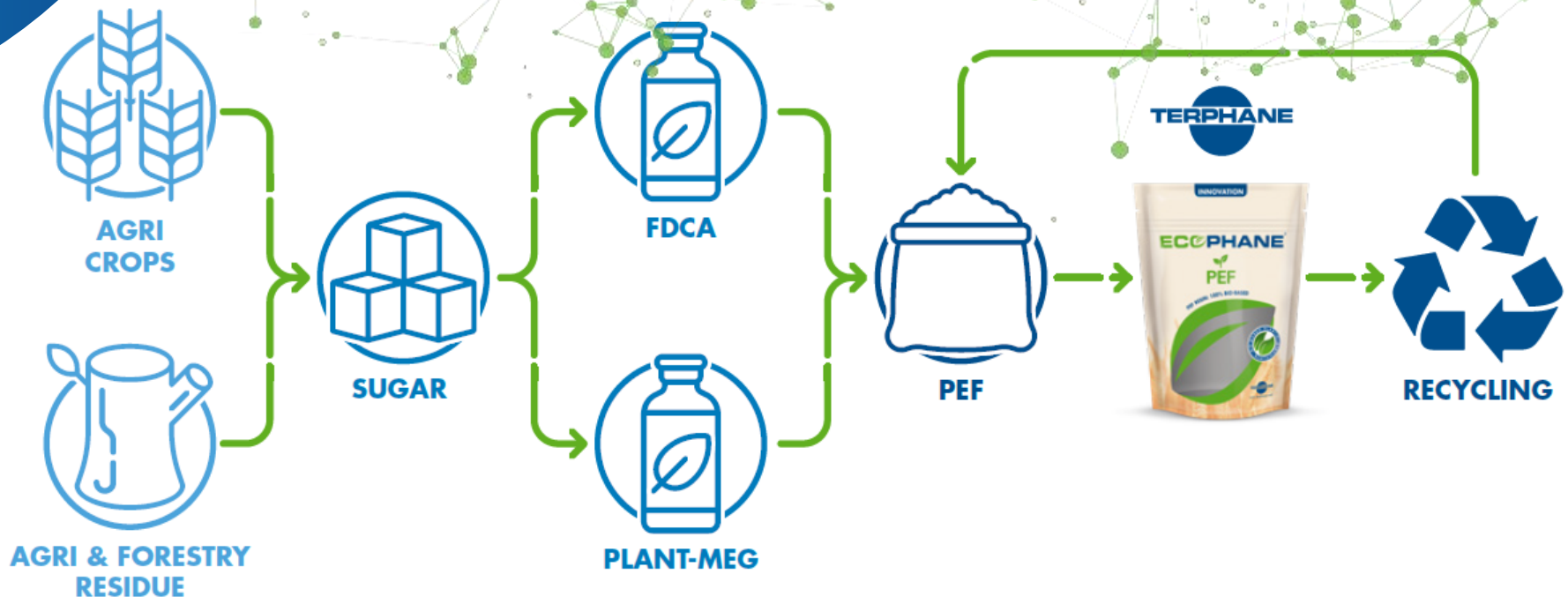
A coherent portfolio of renewable products

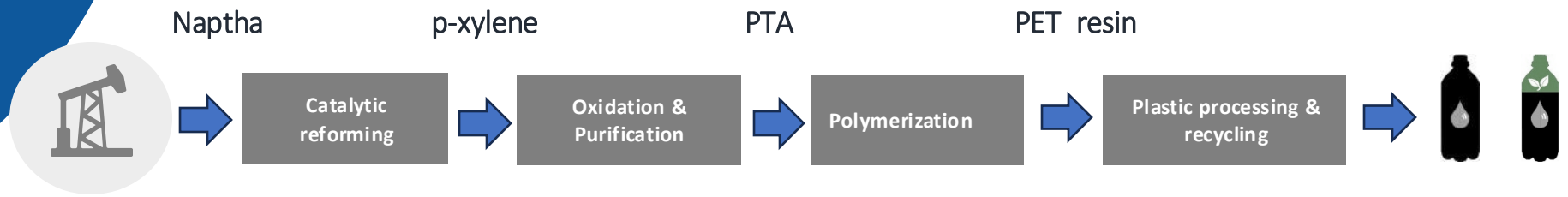


FEEDSTOCK FLEXIBLE → UNIQUE TECHNOLOGICAL PLATFORM CENTERED AROUND CATALYSIS PROCESS → BROAD RANGE OF APPLICATIONS

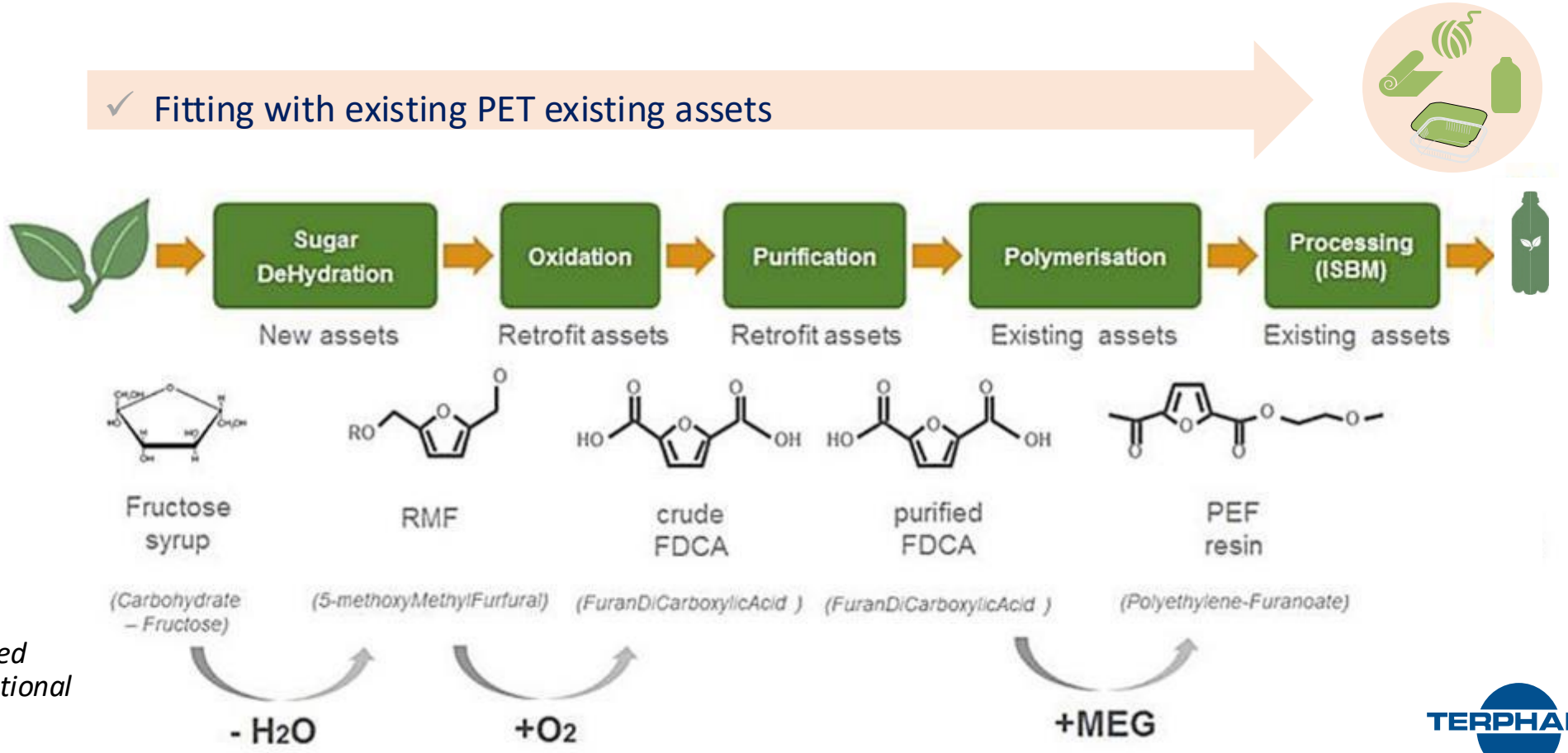
In addition, Avantium is developing a process to produce monomers and polymers from CO_2 using electro-chemistry

*Feedstock for our Flagship Plant is a by-product of wheat

FDCA and PEF Renewing existing Value chain



✓ Fitting with existing PET existing assets



- *With renewable and bio-based material with enhanced functional properties*

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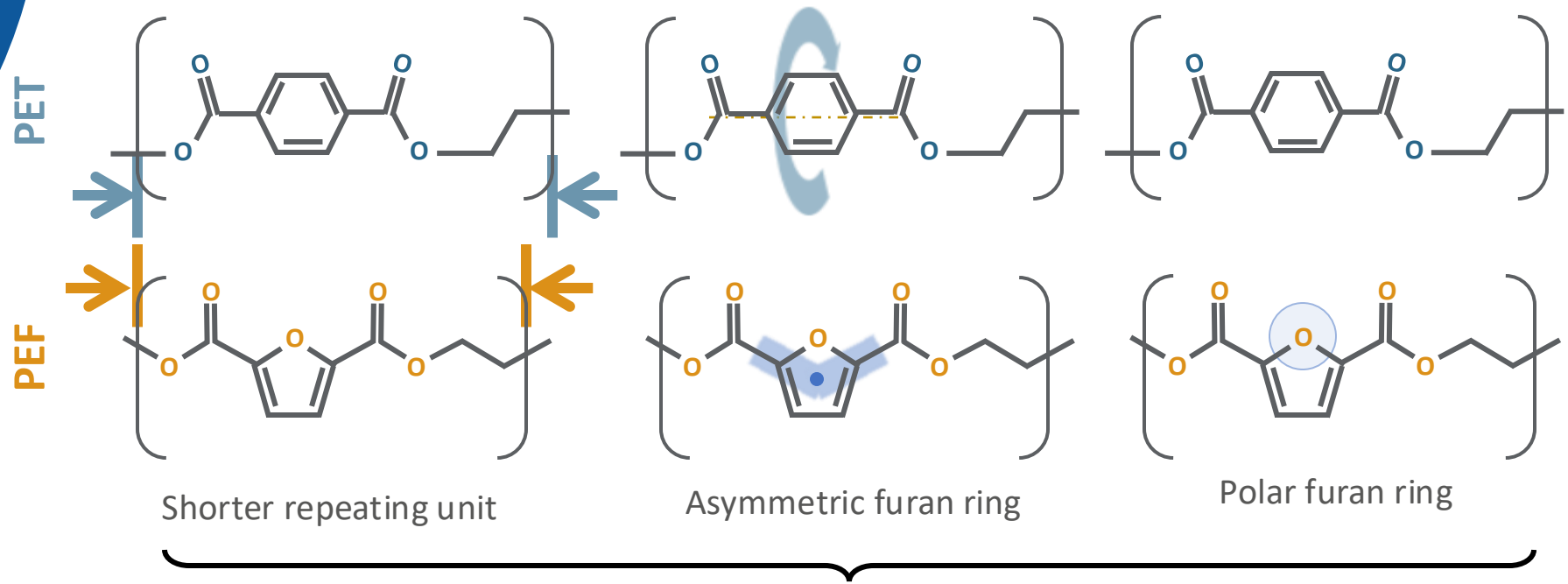
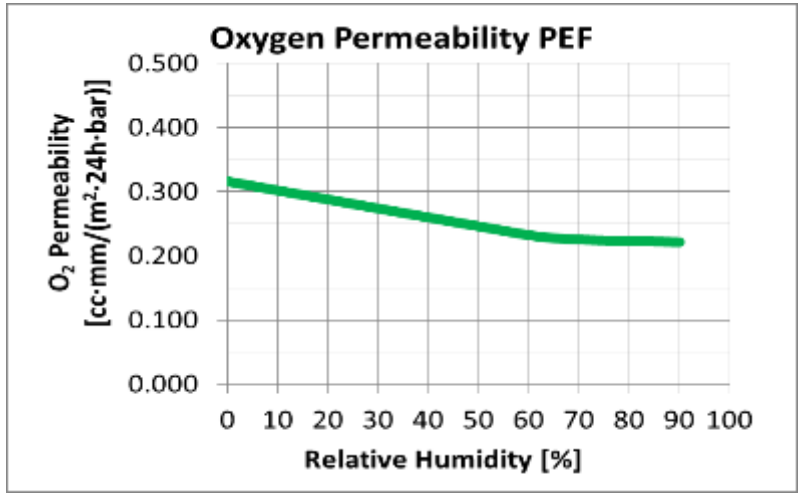
Structure and molecular interaction



Larger interference between ring and carbonyl oxygen groups



- ✓ PEF is a polyester, same chemical family as PET, but with much better barrier performance which show little dependency on ambient conditions (i.e. relative humidity)

- *PEF vs PET: a stiffer chain with more chain interaction*

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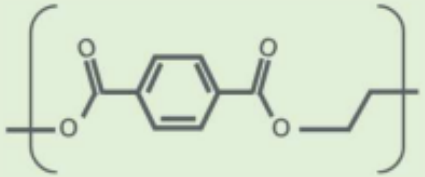
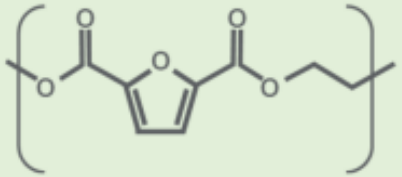
Comparison of the major characteristics of PET and PEF

Property	PET (Amorphous)	PEF (Amorphous)
Molecule		
Density (amorphous)	1.36 g/cm^3	1.434 g/cm^3
Density (crystalline, calculated)	1.455 g/cm^3	1.565 g/cm^3
Melting temperature (T_m)	250–270 °C	210–230 °C
Glass transition temperature (T_g)	~76 °C	~88 °C
Crystallization time	2–3 min	20–30 min
E-modulus (ISO 527/1A, 1 mm/min)	2.1–2.2 GPa	3.6 GPa
Yield strength (ISO 527/1A, 10 mm/min)	50–60 MPa	90–100 MPa
O_2 permeability * (@23 °C, 65% RH)	2.5 cm^3·mm/(m^2·24 h·bar)	0.23 cm^3·mm/(m^2·24 h·bar)
CO_2 permeability * (@23 °C, 0% RH)	23.6 cm^3·mm/(m^2·24 h·bar)	1.6 cm^3·mm/(m^2·24 h·bar)
H_2O permeability * (@38 °C, 90% RH)	0.9 g·mm/(m^2·24 h)	0.36 g·mm/(m^2·24 h)

Ref: de Jong, et al. *Polymers* **2022**, *14,* 943.

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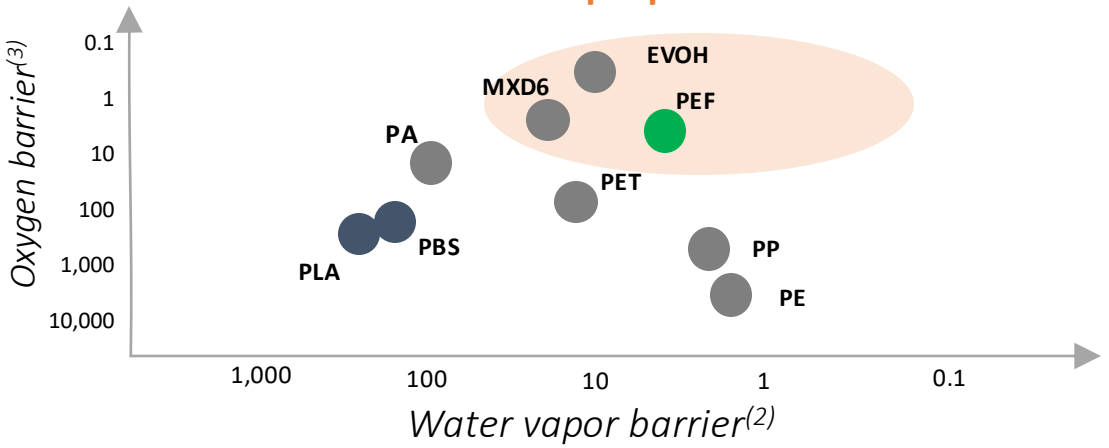
PEF enhanced product performance

Barrier properties(1)



Notes:
(1) Barrier properties for 50 µm film
(2) Water vapor barrier: WVTR at (39 ˚C 85 %RH) [g/(m²·day)]
(3) Oxygen barrier: OTR (23°C, 0%RH) [mL/(m²·day·atm)]

Sources: European Bioplastics; Company Assessment based on: Markus Schmidt et al, Properties of Whey-Protein-Coated Films and Laminates as Novel Recyclable Food Packaging Materials with Excellent Barrier Properties (International Journal of Polymer Science, Volume 2012), https://www.mgc.co.jp/eng/products/ac/nmxd6/barrier.html, http://asuka-platech.com/wp/wp-content/uploads/2013/12/BIOPBS.pdf

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PEF for flexible packaging
Improved barrier to CO_2, O_2 and water vapor.
Better metal adhesion
PEF for CSD
16 — 20x better CO_2 barrier
PEF for rigid packaging
Light weighting potential
(60% higher modulus & strength)
PEF for textiles and fibers
Bio-based with PET-like
mechanical properties
PEF for oxygen sensitive drinks
10x better O_2 barrier
PEF resin
Higher T_g (by about 10 °C)
Lower T_m (by about 30- 40 °C
General
PEF can be processed in
existing PET lines
INOVAÇÃO
ECOPHANE
PEF
PEF extending the polyester portfolio to renewable
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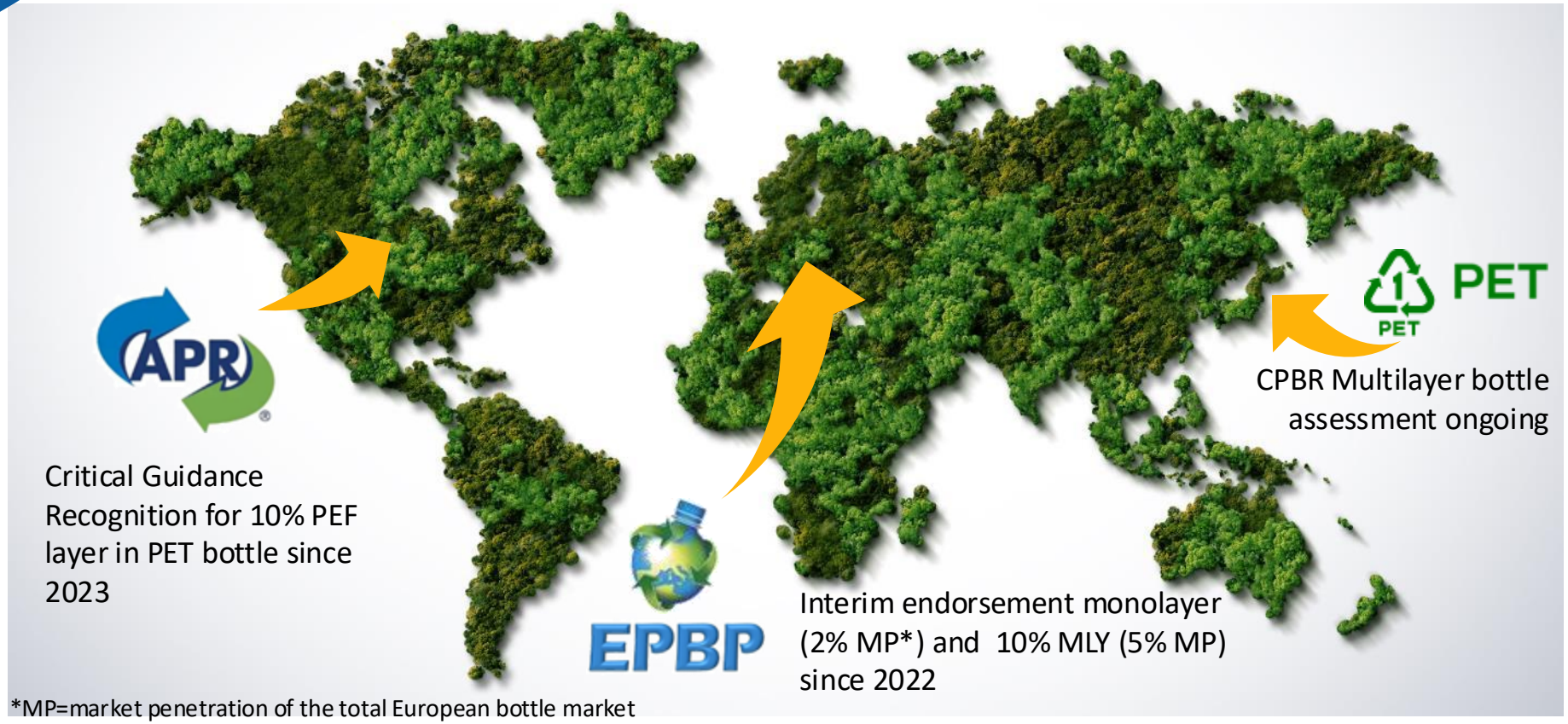
Word-wide recycling recognitions of PEF based containers



*MP=market penetration of the total European bottle market

Tomorrow's solutions have to facilitate the transition today

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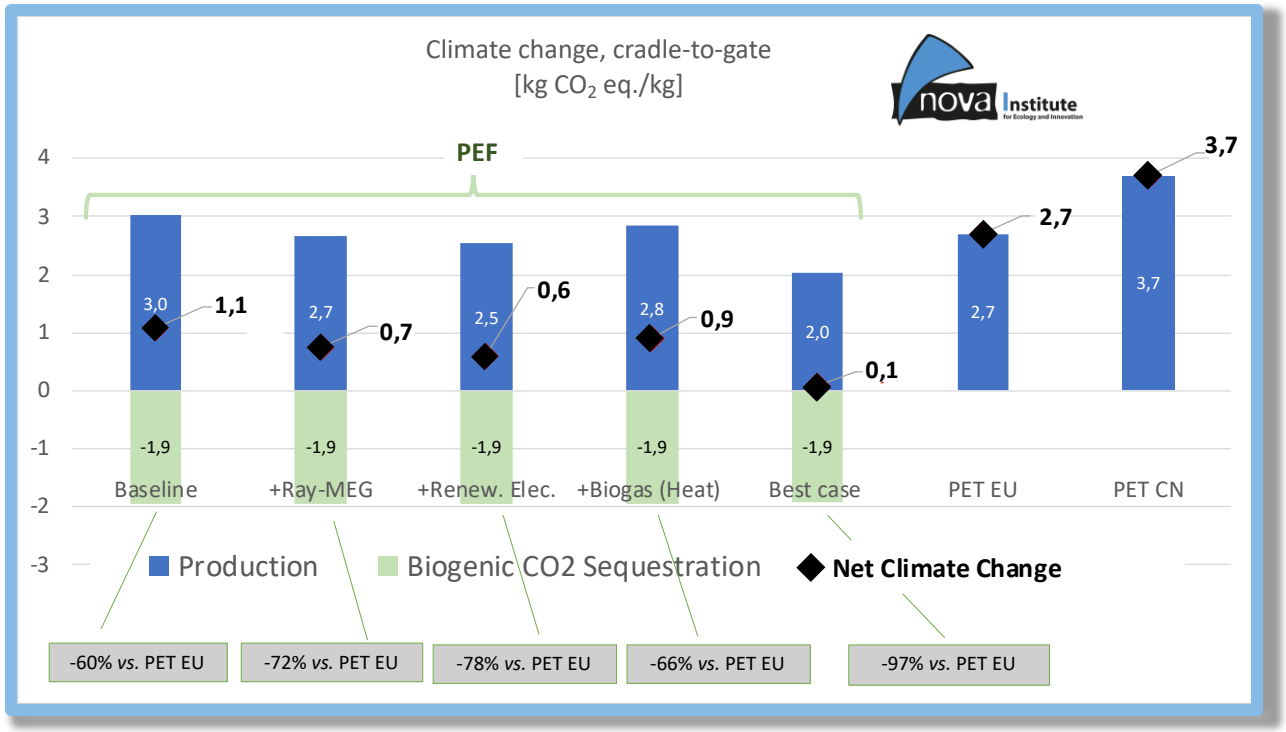
PEF allows for at least 60% carbon footprint reduction vs PET



- ✓ The baseline already shows a carbon footprint **reduction of 60%** versus PET produced in Europe
- ✓ Despite the small scale and young process technology, PEF resin can compete with highly commoditized PET
- ✓ **Further reduction** on Carbon Footprint is seen on application basis, where PEF properties enable improved performance and light weighting
- ✓ 30% additional GHG reductions expected by switching to **2G feedstocks**

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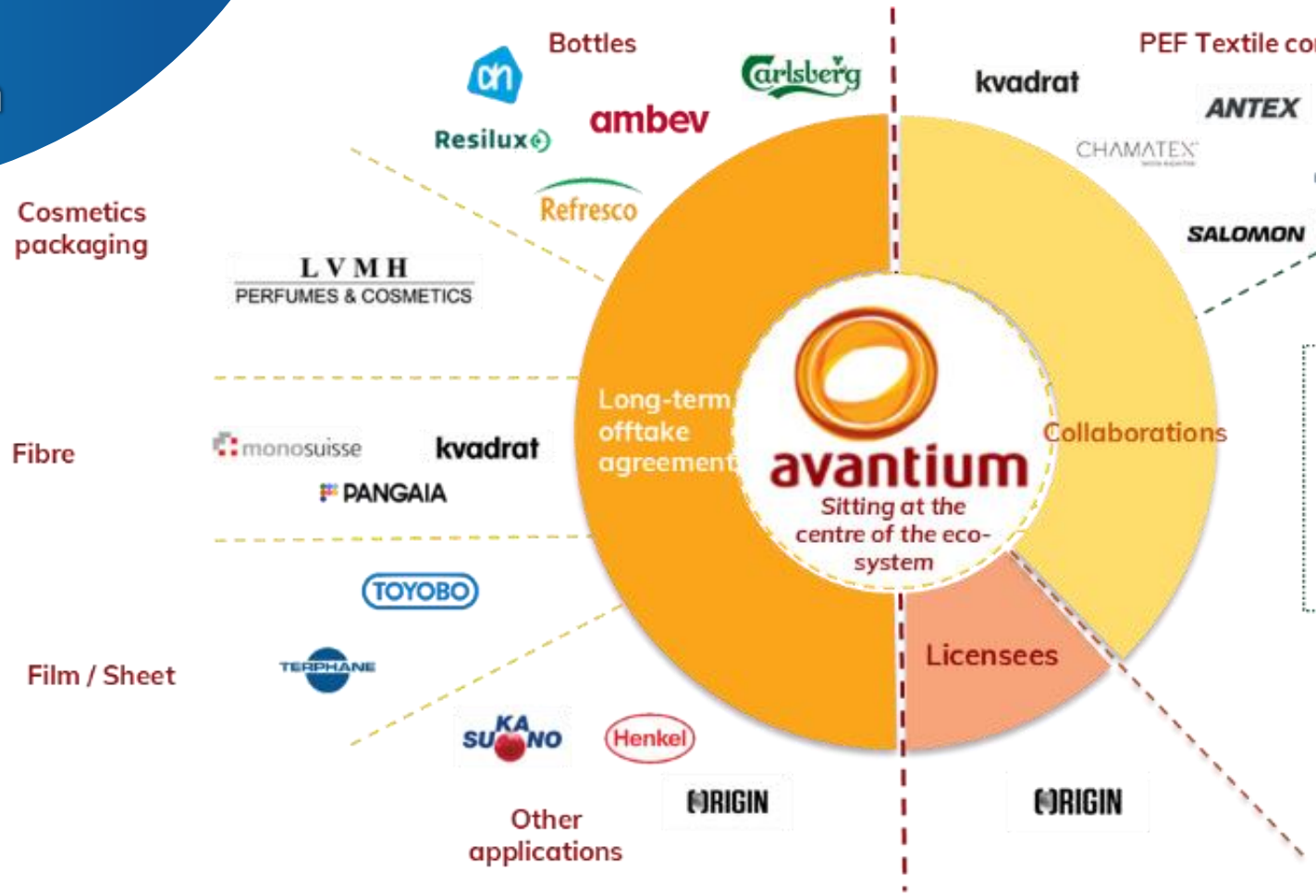
Partners that have joined the sustainable polymers revolution



PEFerence for innovative supply chain

Carlsberg Group · LEGO · Nestlé · Henkel · nova · Tereos · LVMH · keboni · EMBV · Worley · SPINVERSE

The PEFerence consortium aims to replace a significant share of fossil-based polyesters, such as PET as well as polyamide layers in multilayer packaging, and packaging materials like glass and metal **with 100 % bio-based furanics polyesters such as PEF.**

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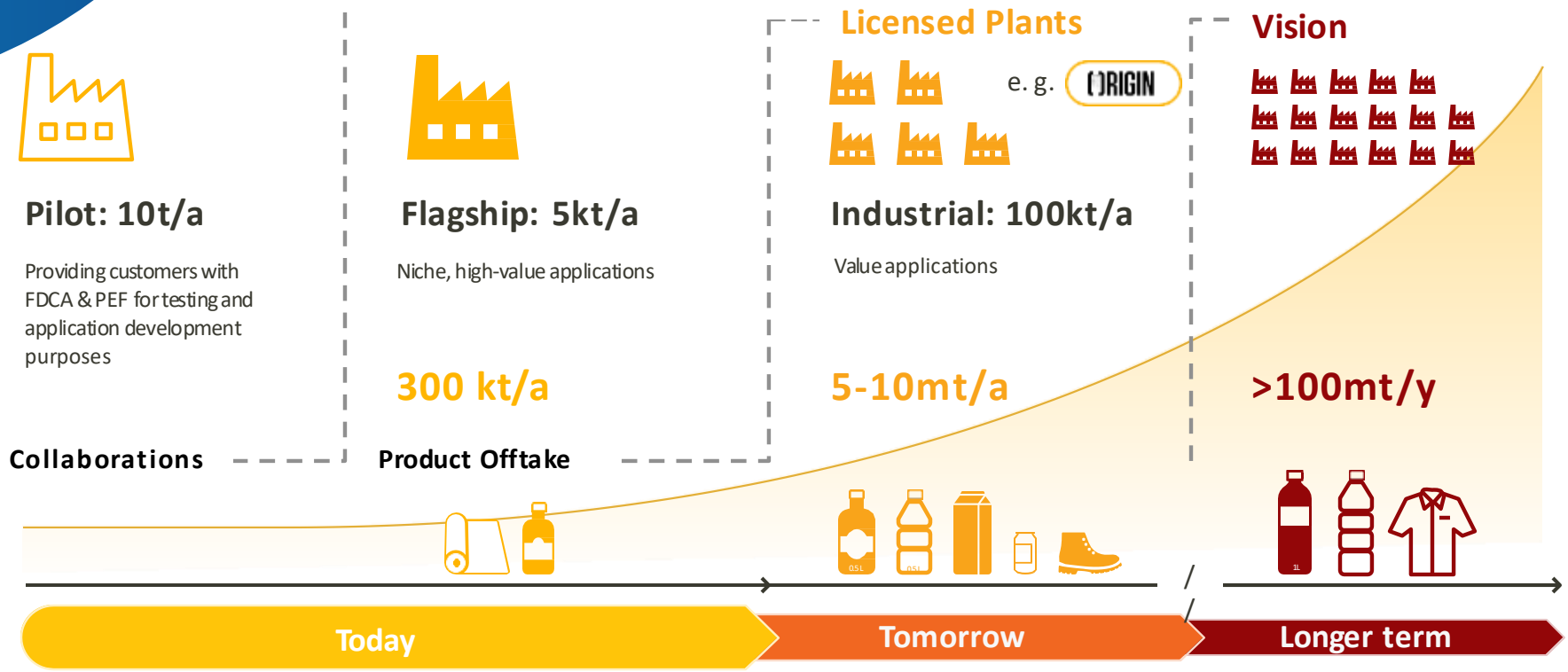
FDCA and PEF commercialization roadmap

Industrial availability of affordable FDCA and PEF comes into view



Sources: Report Global Multilayer PET bottles Industry 2019-2020; The Future of High Barrier Packaging Films to 2024; Soft drink database 2015; Packaging master database 2015

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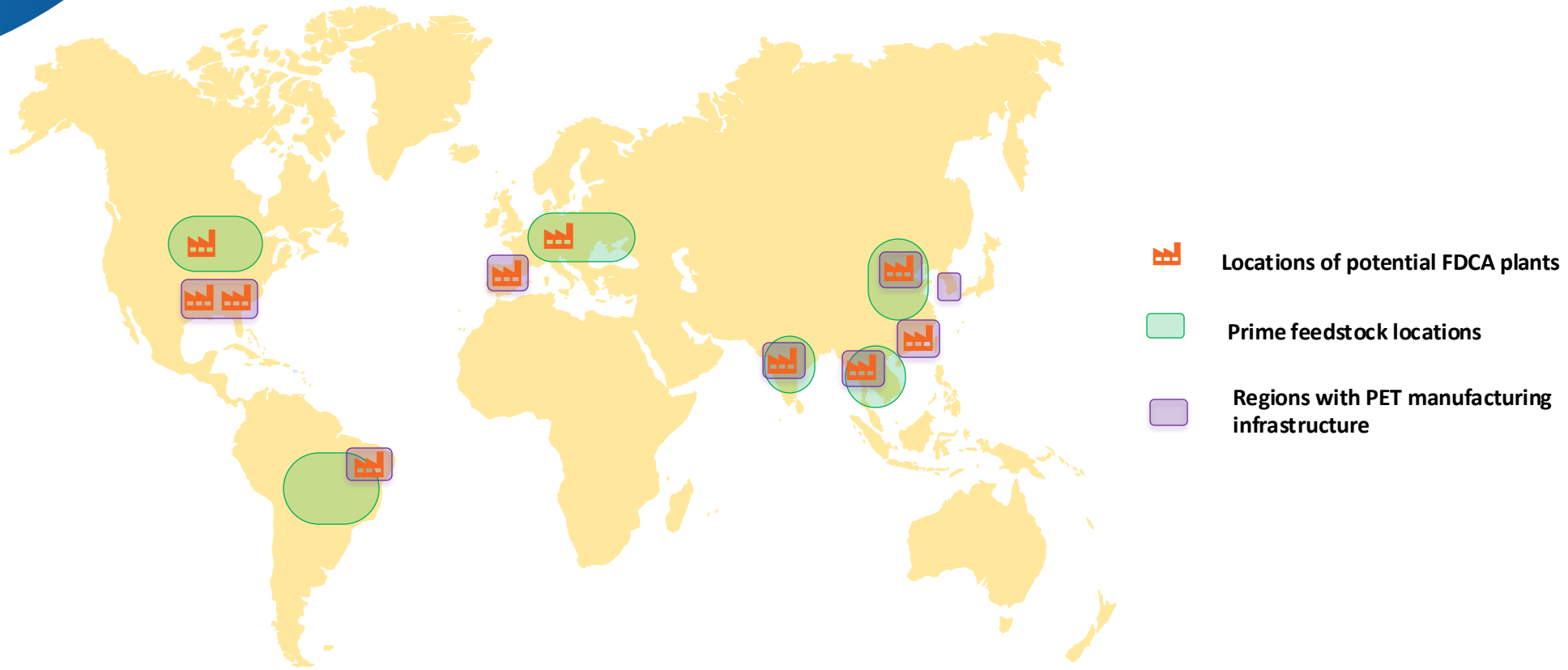
Global FDCA and PEF licensing opportunities for further scale



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Avantium's first-of-a-kind FDCA plant on stream in 2024

Prove Technology at **5 kt/a scale**

Selling PEF & FDCA **at commercial scale**

Further **accelerate licensing deployment**

Progress

- **15** offtake agreements **signed**
- First **commissioning activities** have started in **Q1 2024**
- **FDCA production** expected on stream in **2025**

NETHERLANDS

Chemie Park Delfzijl

Offices:
HQ: Netherlands (Amsterdam)
Asia (Japan) and America (Atlanta)

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Group


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COMPANY OVERVIEW

About us

KEY HIGHLIGHTS

GLOBAL FOOTPRINT

17 plants in
11 countries

MULTICULTURAL TEAM

+2,850
employees

WORLDWIDE PARTNER

Sales to
+40 countries

LARGEST PORTFOLIO OF SOLUTIONS FOR FLEXIBLE PACKAGING

9 business units
BOPP | CAST | BOPET | BOPA
BOPE | PET SHRINK | COATING
THERMOFORMING | PET STRAPS

BIGGEST FILM MANUFACTURER IN THE AMERICAS & EUROPE

+1 MILLION tons
capacity

oben Group

BOPEF Film Overview

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BOPEF VS BOPET

Physical Properties*	BOPET	BOPEF
Thickness (µm)	12	12
Strength (MPa)	230-240	260-310
Elongation at break (%)	90-100	40-50
Impact strength (J)	0.8	1.2
OTR ($cm^3/m^2.day$)	120	11
WVTR ($g/m^2.day$)	50	15

*Avantium

After Metallization*:

BOPET-met	BOPEF-met
< 2.0	< 0.2
<2.0	< 1.0

*Avantium

- ✓ BOPEF has similar mechanical properties as BOPET.
- ✓ BOPEF has impact strength 50% higher → better for lidding applications, possibility to downgauge.
- ✓ BOPEF has ~10x oxygen barrier and ~3x water vapor barrier than BOPET.
- ✓ BOPEF-met ~10x oxygen barrier and ~2x water vapor barrier than BOPET-met.
- ✓ Reduce need for barrier layers, as EVOH and PVdC and Al foil.

PEF - biobased high barrier substrate

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Market & Applications

- ✓ **PEF - Sustainability:**
  - ✓ Renewable content
  - ✓ PEF can be recycled together with PET
  - ✓ High barrier property → Monomaterial structure → recycle ready

PE-EVOH-PE/PET

↓

hs-PEF

Lidding applications - protein, refrigerated

PET/PVDC

↓

PEF

SUP with window (clear barrier)

PE/Al Foil/PET

↓

PE/Met-PEF/PET

SUP – dried products, oxidation protection.

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PEF Converting Processes

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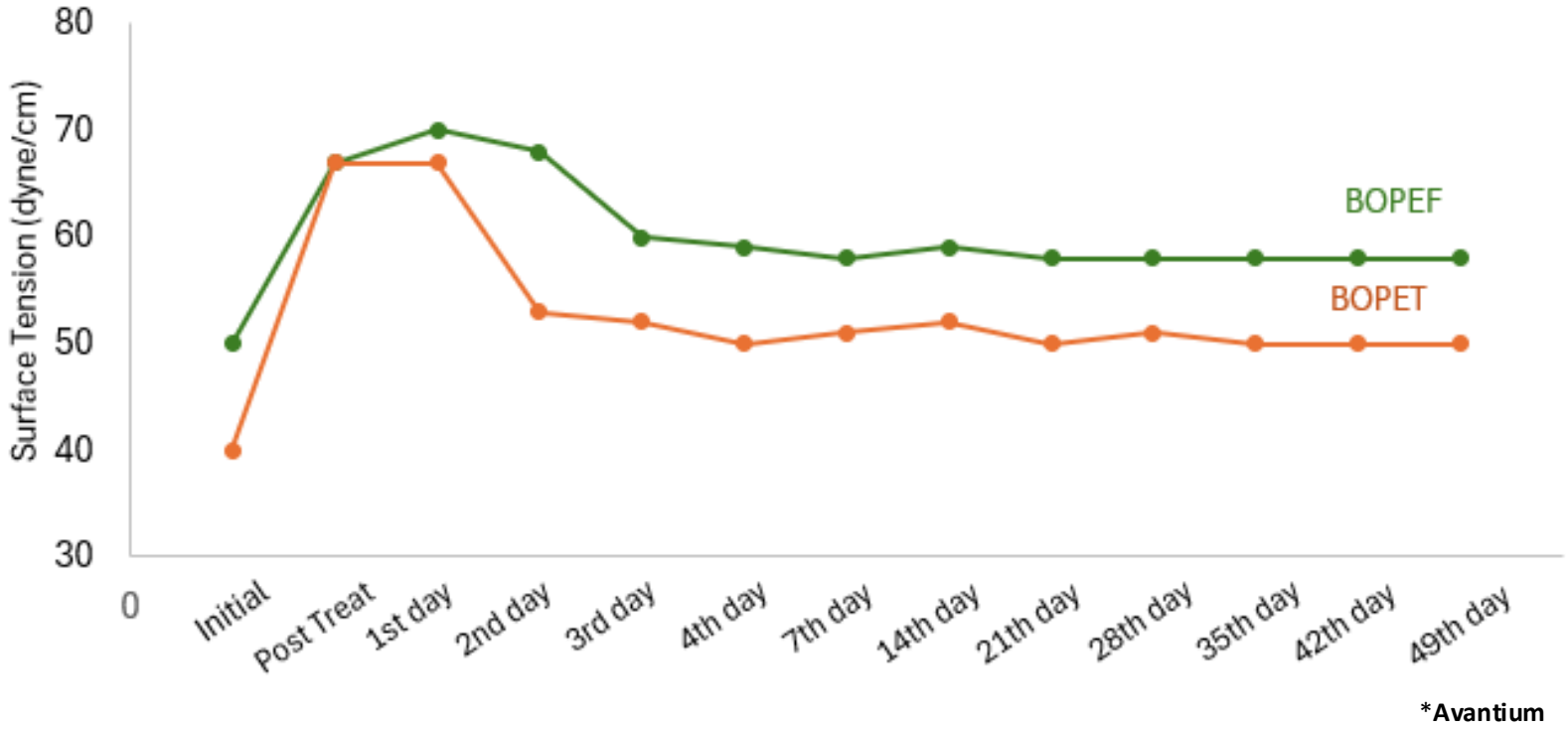
BOPEF – Corona Treatment

✓ Corona Treatment dosage = 30.4 W.min/m², air*.



*Avantium

✓ BOPEF has higher surface energy than BOPET.

✓ BOPEF also maintain the surface energy level with time.

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Conversion Process
Printing
PET and PEF

Company	Test	Ink	Conclusion
Avantium Flexo	Dot Size	Wickoff WB Actega WB (cyan, black, magenta)	Both substrates had similar dot size.
	Ink Rub Test 250 rubs	Wickoff WB Actega WB (cyan)	After 24hr: same performance PEF and PET.
Terphane Lab Coater	Ink Adhesion Tape 3M600, pull 45°	Sun Chemical SB (white, blue, yellow, red)	No ink removal at both substrates.

Dot size:
magenta and cyan colors

Ink adhesion
White color

Ink Rub Test
250 rubs, after 24hrs.

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Conversion Process
Printing
PET vs PEF

Company	Method	Test	Ink	Conclusion
Terphane*	Ink adhesion, Tape 3M610, fast pull	Rotogravure: K-Proofer 180 lines screen plate	SFP (blue) / PV77 HOKO (white)	No removal at both substrates.
			PV 77 HOKO (white)	No removal at both substrates.
			SFP (blue)/ UR 45 (white)	PET: 50% removal. PEF: no removal.
		Flexo: 360/5.0 hand proofer	NC 503 LINE G/S (blue)	No removal at both substrates.
			NC 503 LINE G/S (blue) / UR 48-1 (white)	No removal at both substrates.
			NC 501-4 (blue)	No removal at both substrates.
			NC 501-4 (blue)/ UR 45 (white)	No removal at both substrates.
			UR 48-1 (white)	PET: 10% removal. PEF film: no removal.
			UR 45 (white)	PET: 70% removal. PEF film: 50% removal.

*Siegwerk. Des Moines, IA.

- ✓ Fast pull: more indicative of performance tested off-press.
- ✓ Similar performance, with PEF ink adhesion better than PET when compared results using inks UR 48-1 and UR-45.

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Conversion Process Lamination PET vs PEF

Company	Ink	Lamination Result PET film	Lamination Result PEF Film
Terphane*	SFP (blue) / PV77 (white)	Tear	339 gf/in
	SFP (blue)/ UR 45 (white)	365 gf/in	154 gf/in
	PV 77 HOKO (white)	Tear	-
	NC 503 LINE G/S (blue)	Tear	Tear
	NC 503 LINE G/S (blue) / UR 48-1 (white)	Tear	Tear
	UR 48-1 (white)	Tear	Tear
	NC 501-4 FLEXO LINE, blue	610 gf/in	Tear
	NC 501-4 FLEXO LINE (blue)/ UR 45 (white)	173 gf/in	229 gf/in
	UR 45 (white)	Tear	166 gf/in

*Siegwerk. Des Moines, IA.

- ✓ Samples: Siegwerk printing tests.
- ✓ Substrate: foil/CPP laminate film.
- ✓ Adhesive: HB Fuller 4245/2282 at 3.6 g/m².
- ✓ Laminations dried at oven at 30°C,1 week.
- ✓ Conclusion: PEF and PET films had similar performance

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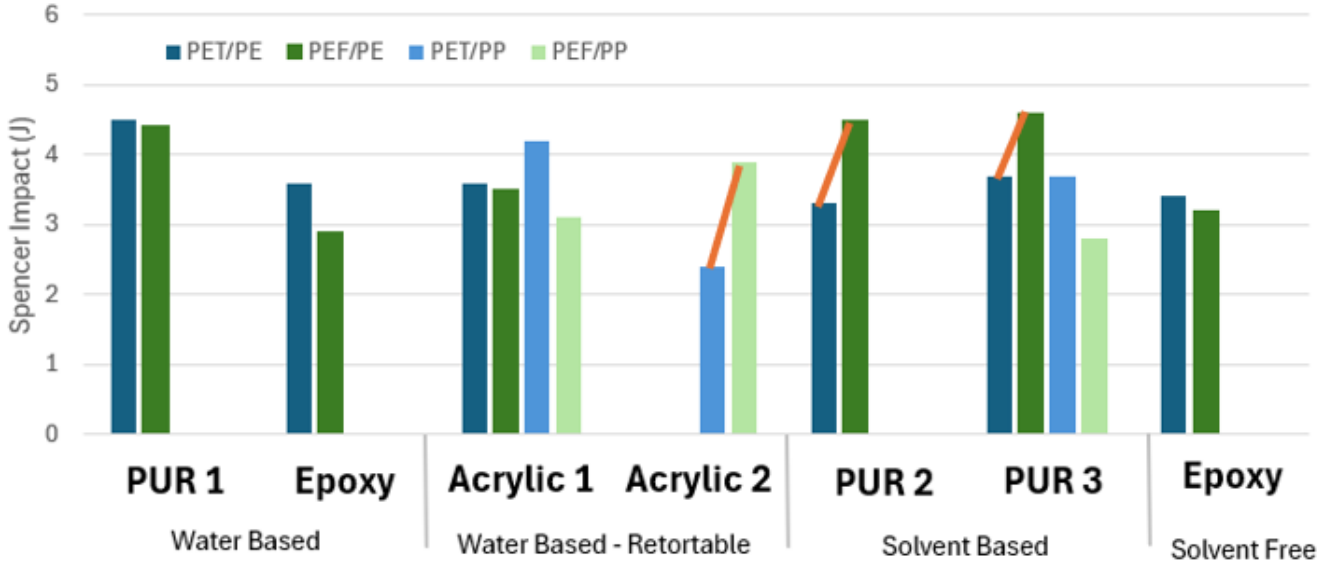
Conversion Process Spencer Impact (after lamination)

✓ Laminated samples at 3-4 g/m² were submitted to Spencer Impact testing*.



*Avantium

✓ PET and PEF: similar spencer impact performance:

- ✓ PEF laminated structures with solvent-based adhesives had better results than PET.
- ✓ When laminated with PP and Acrylic 2 water-based, PEF structures also had better spencer impact performance than PET which could be dependent on the strength of the energy absorption by adhesion debonding during the impact.

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Conversion Process

Metallization

Company	Film Sample	OD	Metal Adhesion Force (gf/in)		OTR		WVTR	
					cm^3/m^2. day	$cc/100in^2$. 24hrs	g/m^2. day	$g/100in^2$. 24hrs
Avantium*	PET-met	3.0	1140	-	**1.1**	0.07	**1.3**	0.08
	PEF-met	3.0	> 2000	-	**≤0.2**	≤0.01	**0.9**	0.06
Terphane	PET-met	3.0	-	600	**0.5**	0.03	**0.5**	0.03
	PEF-met	3.0	-	900	**<0.1**	<0.01	**0.1**	0.01
		2.2	-	900	**0.3**	0.02	**0.3**	0.02

*Celplast. Ontario, Canada.

- ✓ Flat sheet samples.
- ✓ Terphane metallization with Bobst Metallizer K5000 Expert using same process parameters as for the PET-met
- ✓ OTR at 25°C (77 °F), 1atm, 85% RH at MOCON Oxtran 2/22.
- ✓ WVTR at 38 °C (100 °F), 1atm, 90% RH at MOCON Permatran 3/34.
- ✓ Celplast and Terphane use different metal adhesion methods.
- ✓ Conclusion: Terphane PEF-met could be a replacement for Al foil.

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Conversion Process Lamination after Metallization

- ✓ Sample: metallized PEF sample.
- ✓ Structure: PE/adh/met-PEF/adh/PET-ink

Company	OTR		WVTR		Lamination Bond	Hot Fill Pouch	Boiling Test
	cm^3/m^2. day	$cc/100in^2$. 24hrs	g/m^2. day	$g/100in^2$. day			
Converter 1	0.3	0.018	0.3	0.018	All samples tear.	No delamination	No delamination
Converter 2	0.1	0.006	0.2	0.012	Delamination Force = 117 gf/in PET.... ink/adh/met-PEF/adh/PE	-	-

- ✓ Hot fill:
  - ✓ Made a pouch with laminated sample and filled with 50ml of water.
  - ✓ Immersed in water at 90°C (194°F) for 30 min.
  - ✓ Followed for immersion pouch in water at 25°C (77°F) for 5 min.
- ✓ Boiling test -Pasteurization: cut 10cm*x*10cm specimen and immersed in water at 95°C (203°F) for 30 min.

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Conclusions

PEF resin

- Biobased, recyclable, high barrier, commercially available 2025.

BOPET vs BOPEF

- BOPEF has ~10x oxygen barrier and ~3x water vapor barrier than BOPET, so BOPEF can substitute PVDC and EVOH.
- When metallized, met-BOPEF has 10x higher oxygen barrier and 2x higher moisture barrier than a met-BOPET, so it can substitute Al foil.

Corona Treatment

- PEF films have higher surface energy than PET films.
- PEF films also maintain the surface energy with time.

Printing & Lamination

- PEF and PET have similar performance.

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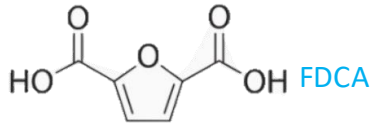
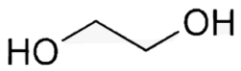
Next Steps

Further evaluations: Flex-cracking of laminated metallized structure, continue to run more PEF and PEF-met trials.

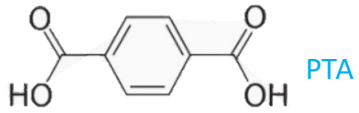
- ✓ **Explore copolymers and co-extrusion process**
  - ✓ **Copolymers**



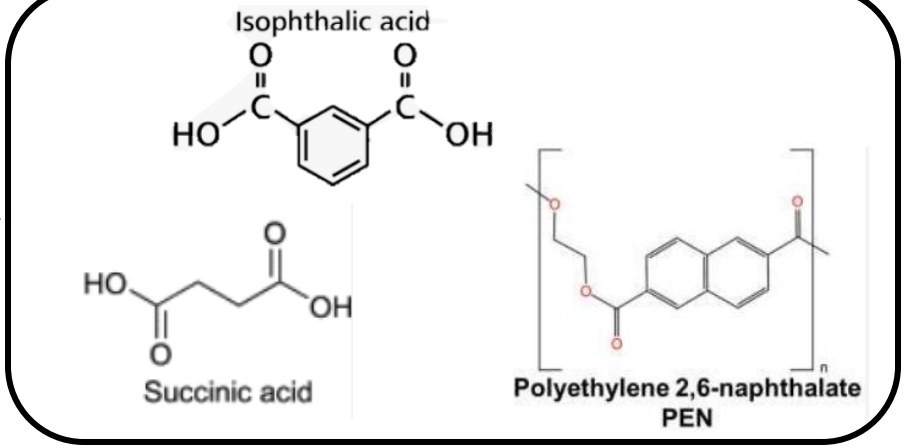
FDCA



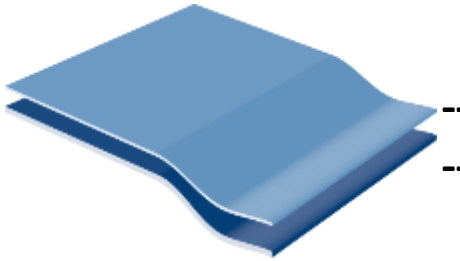
MEG



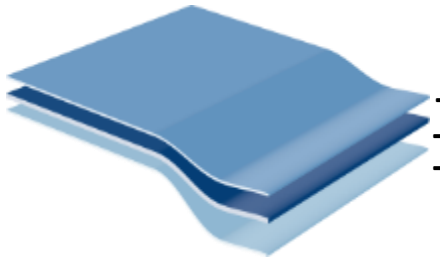
PTA

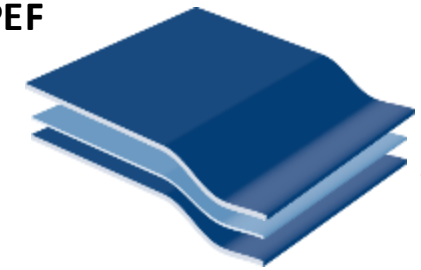


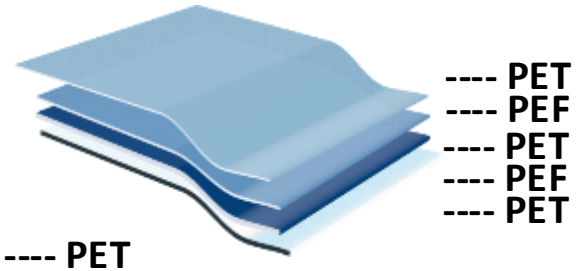
- ✓ **Co-Extrusion**
  - ✓ **PEF Skin Layer**



- ✓ **Multiple PET/PEF layers**







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Next Steps

Explore possibilities for lidding applications and flexible packaging applications:

RESEALPHANE

+ PEF = Resealable film high barrier

SEALPHANE

+ PEF = Easy peel with high barrier

Lidding

ECOPHANE

Sustainability

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avantium

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