The future of plastics

High potential polyesters from biomass and CO_2

gert-jan.gruter@avantium.com

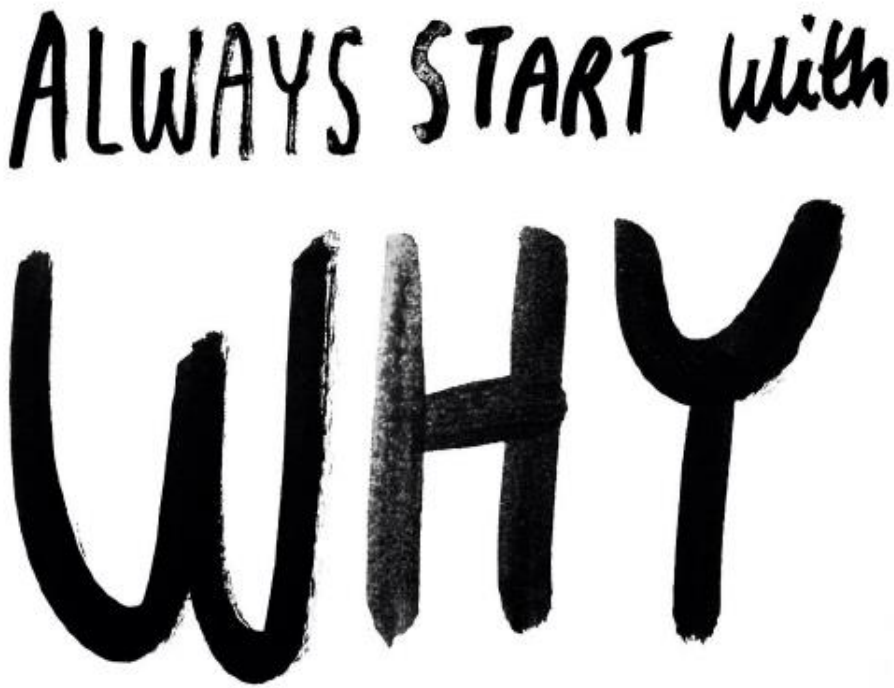
15 January 2024

Gert-Jan Gruter

avantium

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The plastic transition
Why do we need a plastic material transition?



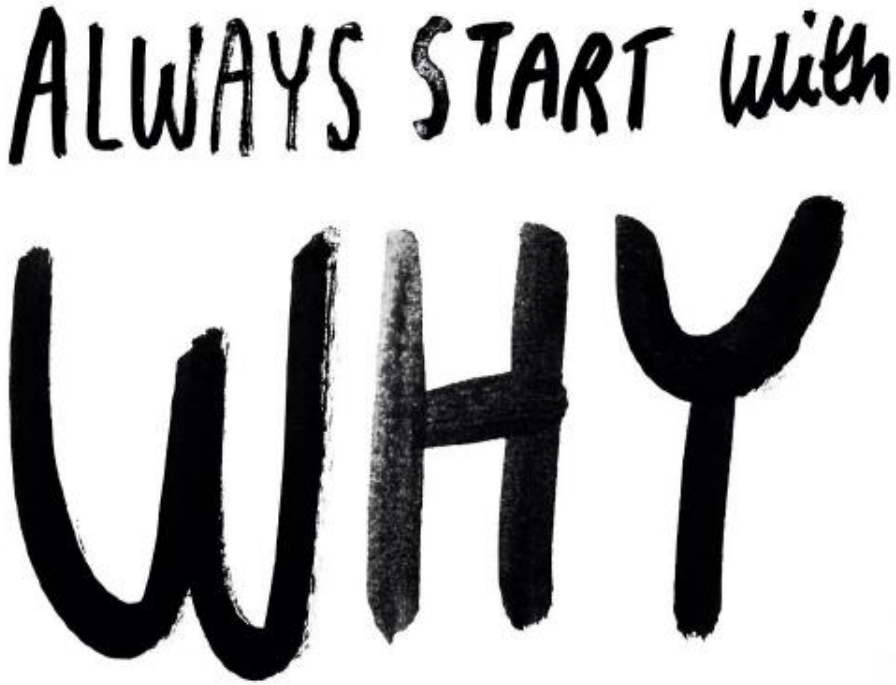
The plastic transition
Why do we need a plastic material transition?



Maria Zwicker
Soc. Psychology
UvA

"Bio-based plastics are biodegradable"

Completely disagree – disagree – not disagree/not agree – agree – completely agree



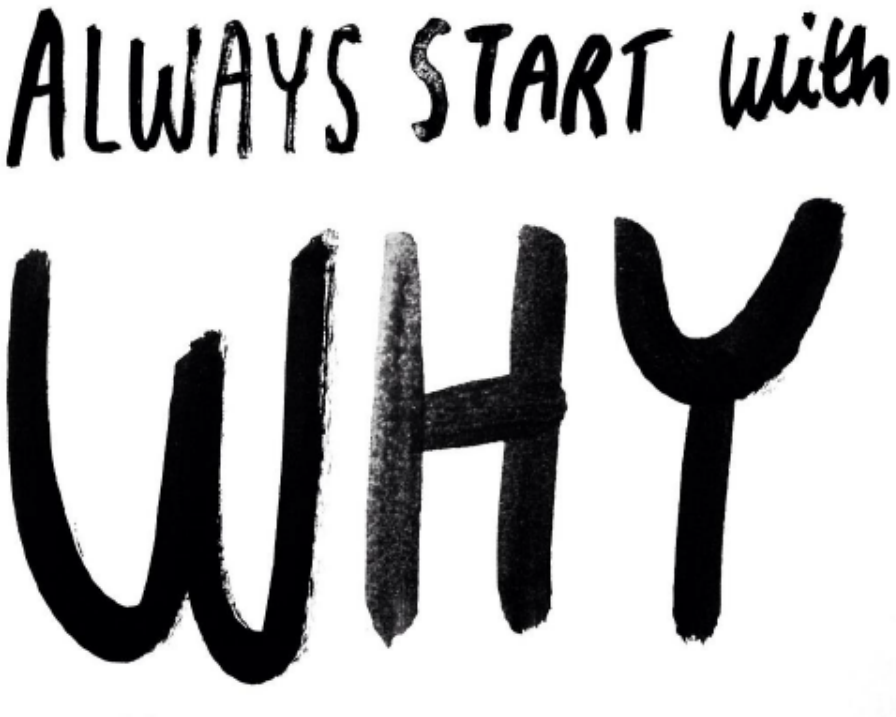
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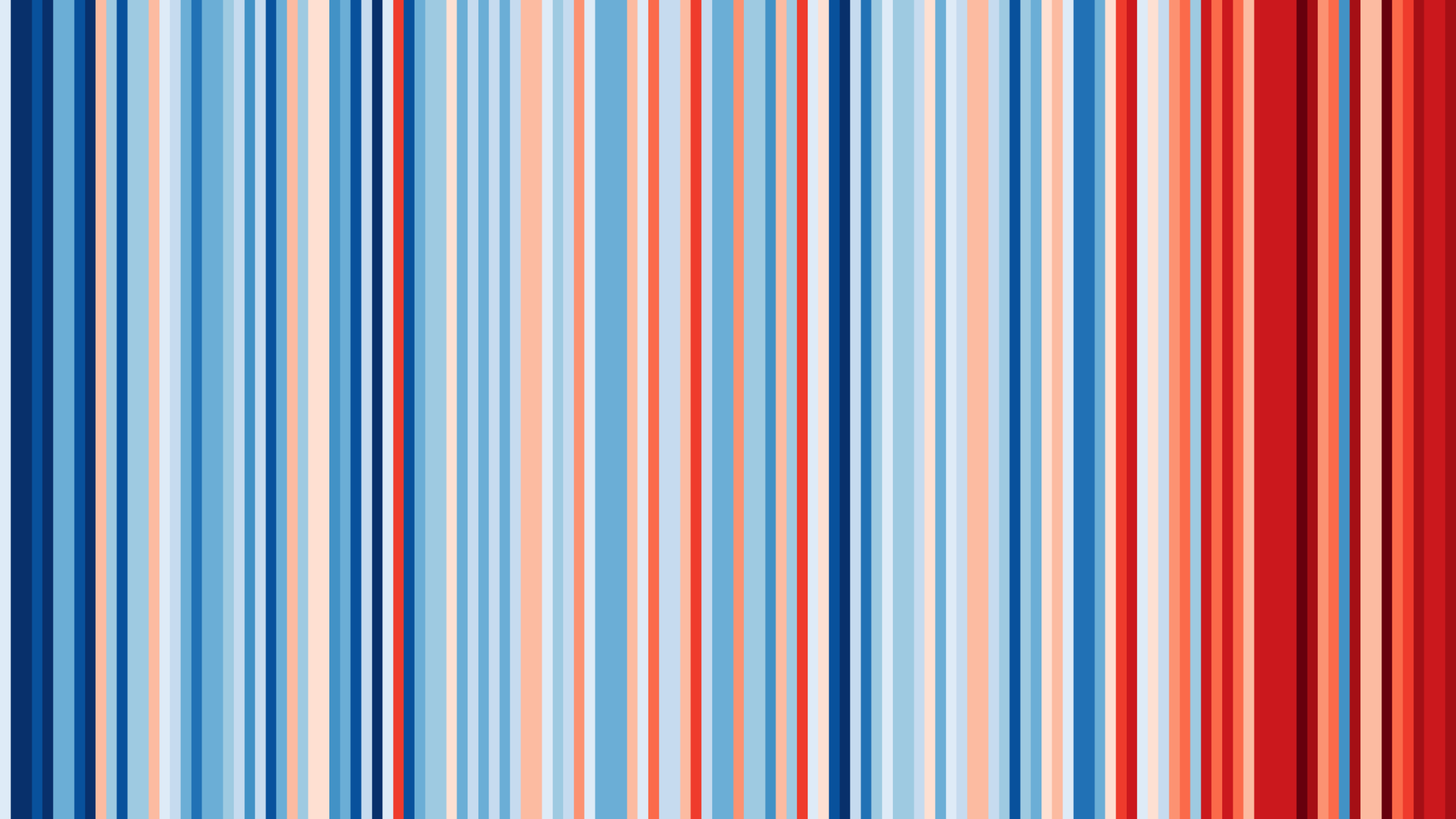
Response frequencies
Bio-based plastics are biodegradable (*N=508*)

	Response Frequency (%)
	Biodegradability
1 Strongly disagree	4 (0.8%)
2	8 (1.6%)
3	7 (1.4%)
4 Neither agree nor disagree	87 (17.1%)
5	100 (19.7%)
6	143 (28.1%)
7 Strongly agree	154 (30.3%)
Total *N*	503 (99%)

80%







The plastic materials transition

sustainability

Sustainability **2021**, *13*, 6819.

MDPI

Article

(Not) Doing the Right Things for the Wrong Reasons: An Investigation of Consumer Attitudes, Perceptions, and Willingness to Pay for Bio-Based Plastics

Maria V. Zwicker [1,*], Cameron Brick [1], Gert-Jan M. Gruter [2,3] and Frenk van Harreveld [1,4]



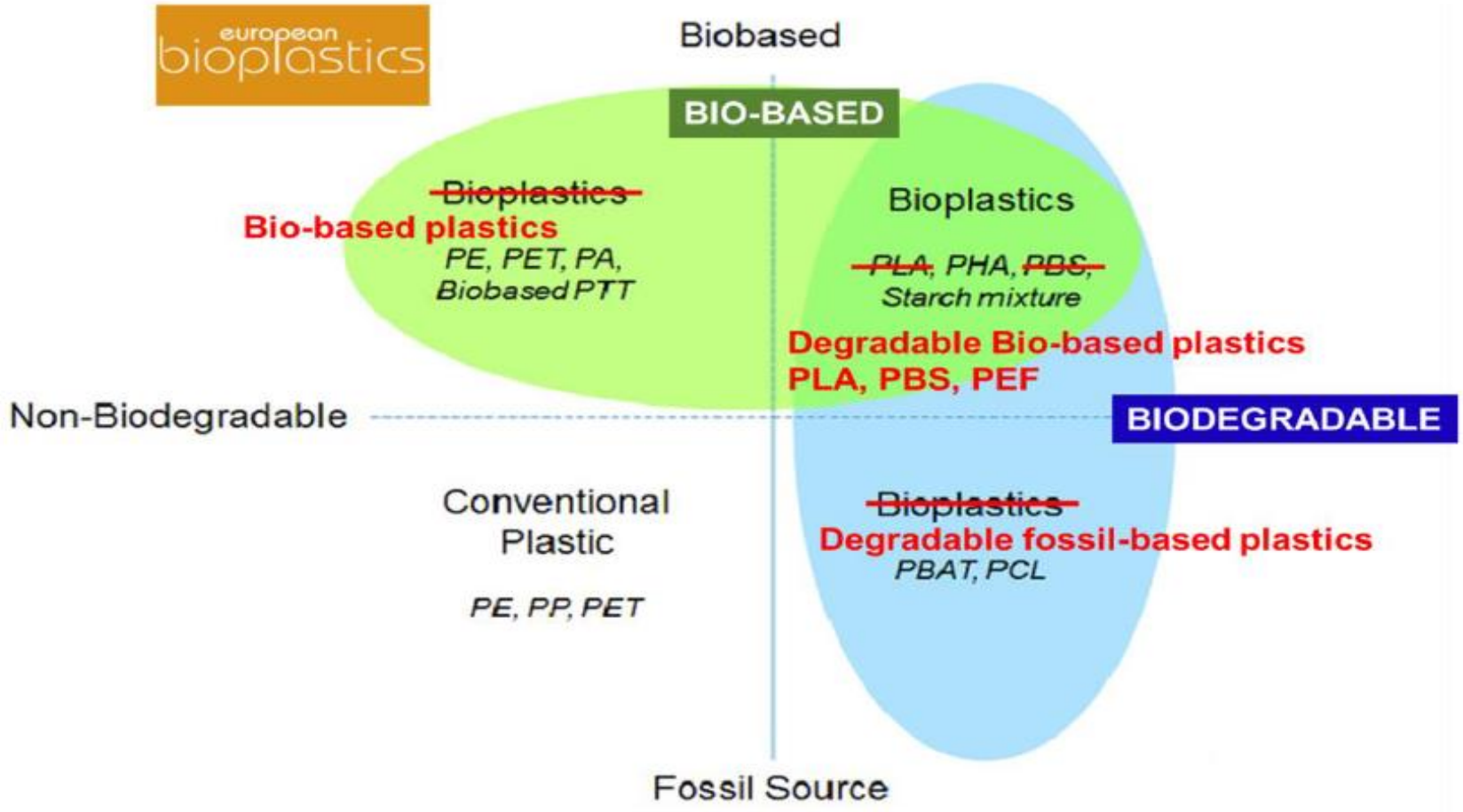
Maria Zwicker
Soc. Psychology
UvA

ALWAYS START WITH WHY

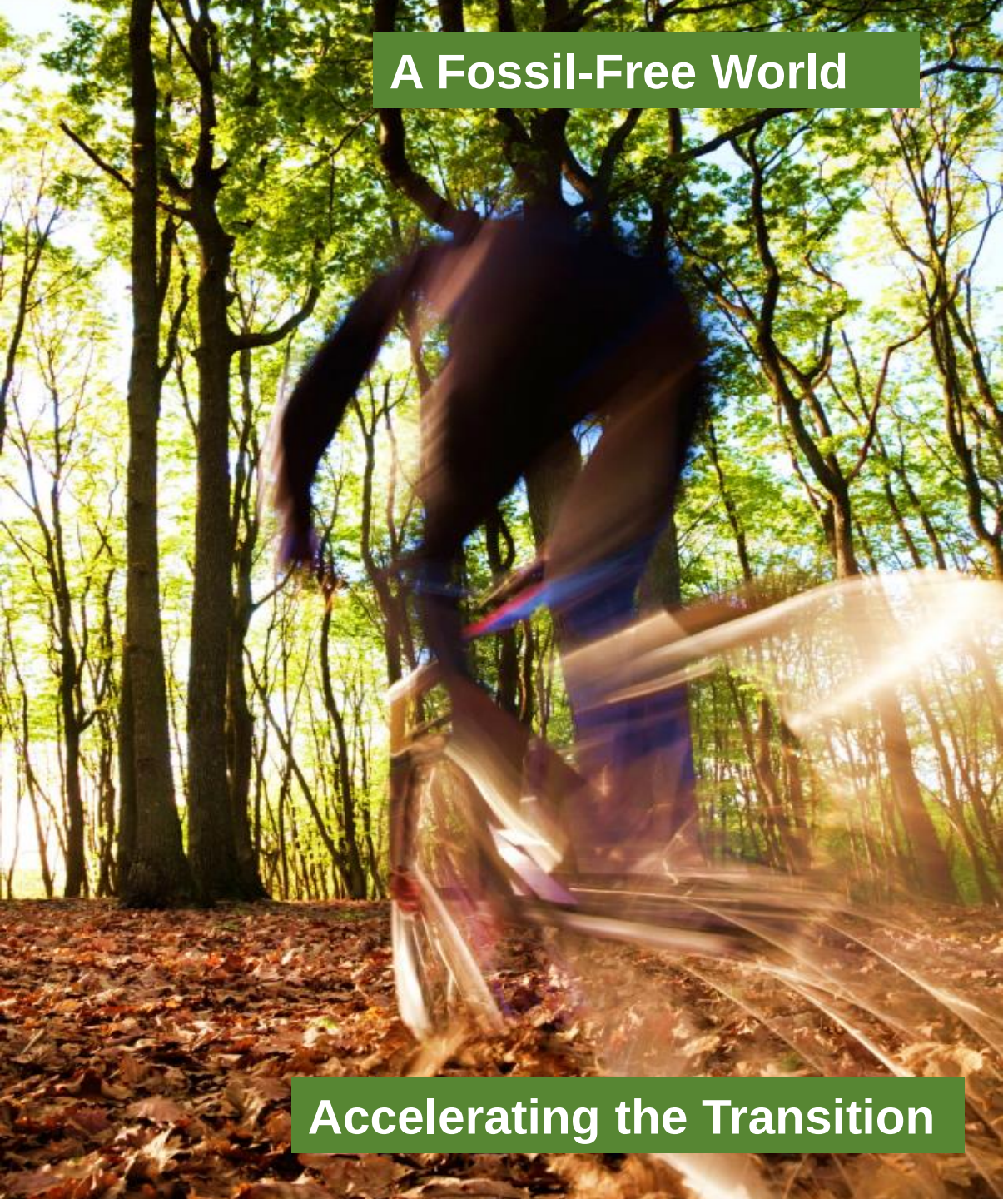
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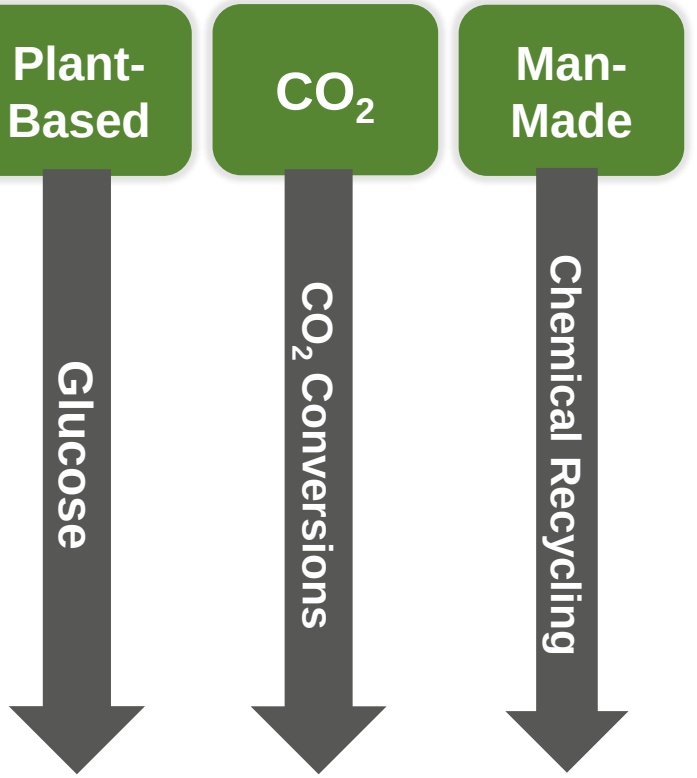
Industry creates huge confusion



IUPAC: The term bioplastic should preferably be avoided as it is a general term that can refer to materials that are either bio-based (related to how the material is sourced — wholly or partly from biomass), biodegradable (related to whether a material can be broken down into carbon dioxide, water, and biomass by the natural action of microorganisms), or both. Because not all bio-based plastics are biodegradable, and some biodegradable plastics are fossil-based (for example, PBAT), the term bioplastic is confusing.



For energy we have many alternatives but there are only three renewable carbon sources available in this world…



…that enable a circular economy

Catalysis

Foundational Technology and Expertise

Leading Systems and Services Provider for Catalyst R&D

Renewable Chemistries

Novel Chemical Technology to Transform carbohydrates into renewable glycols

RAY® Technology: 1 step bio-MEG

Cosun Beet COMPANY

Renewable Polymers (formerly Synvina)

Polyesters
YXY® Technology: FDCA & PEF

avantium

EURONEXT

Ticker: **AVTX**
Amsterdam & Brussels

HQ Amsterdam
Science Park and Prodock Amsterdam (VOLTA)
ChemiePark Delfzijl (DAWN and MEKONG)
Chemelot (YXY)

100+
patent families

300

>75% scientists
20+ nationalities
30% female

UNIVERSITY OF AMSTERDAM

Avantium Corporate Technology
VOLTA & Yukon/DAWN

UvA - Industrial Sustainable Chemistry
PARANA

Applied research with focus on sustainable polyesters, (bio)degradation; Social studies (consumers), (chemical recycling incl e.g. PET/cotton).
With funding from EU, NWO, and Industry (e.g. Avantium, LEGO)

avantium

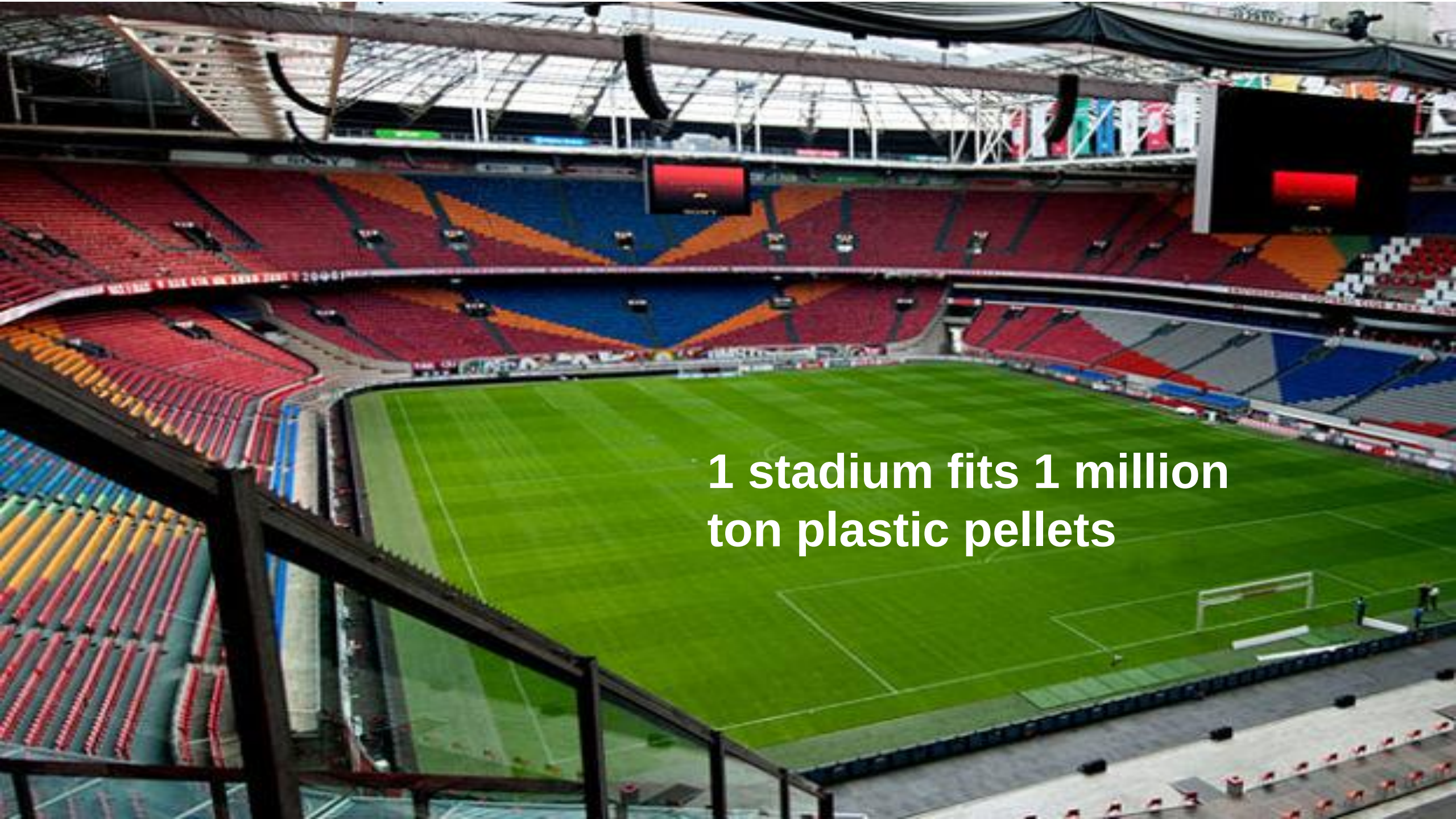
avantium

Where are we today ?

Some plastics facts & figures*

- 2022 global plastics production: 400 Mt
  - Excluding rubber (tyres), fibers (textiles, carpets), thermosets and recyclate
- 5-6% of all oil → plastics
- 2 Mt/yr bio-based (0.5%)
- 8 Mt/year “leakage” of plastic waste into the environment
- 3.5% averge demand growth per year

** https://ourworldindata.org/faq-on-plastics#how-much-plastic-and-waste-do-we-produce*

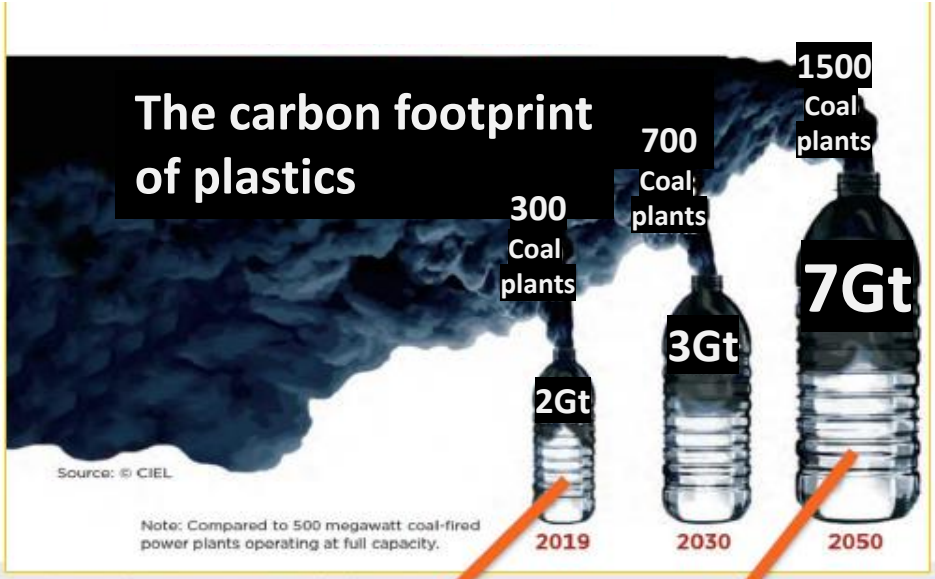

1 stadium fits 1 million
ton plastic pellets

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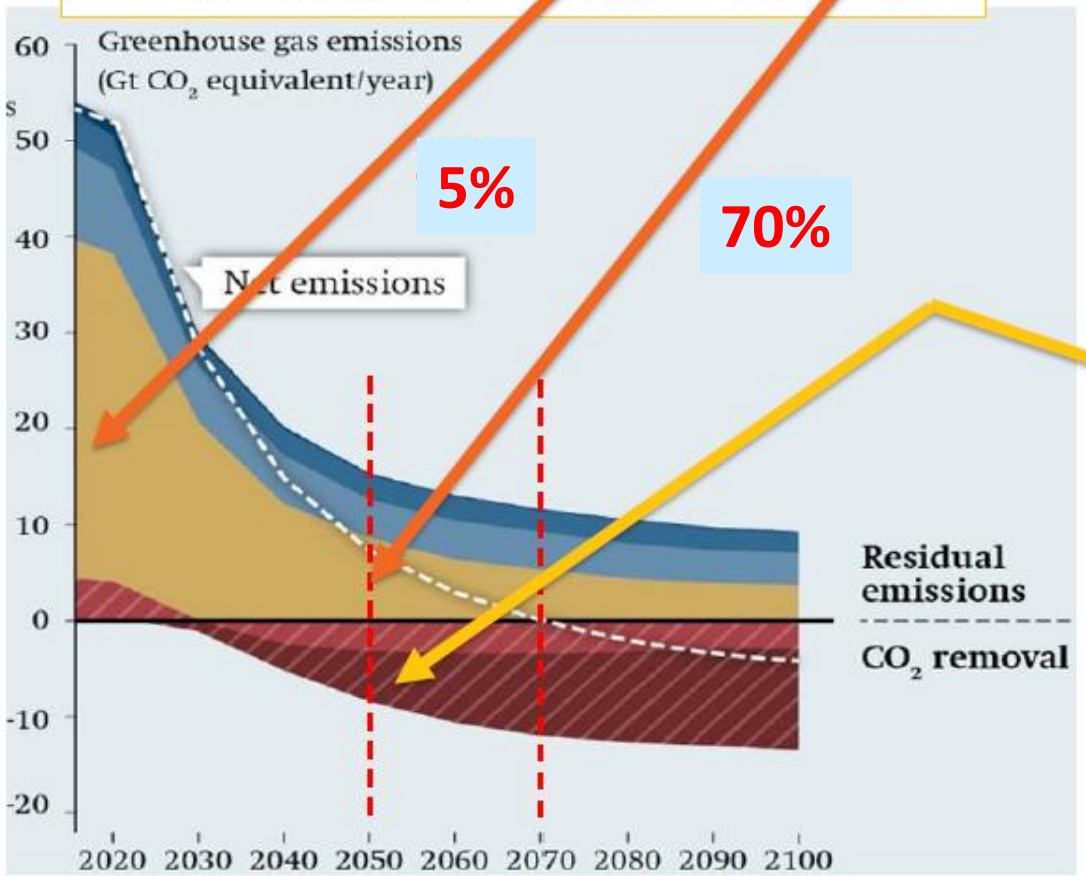


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Avantium | CorpTech

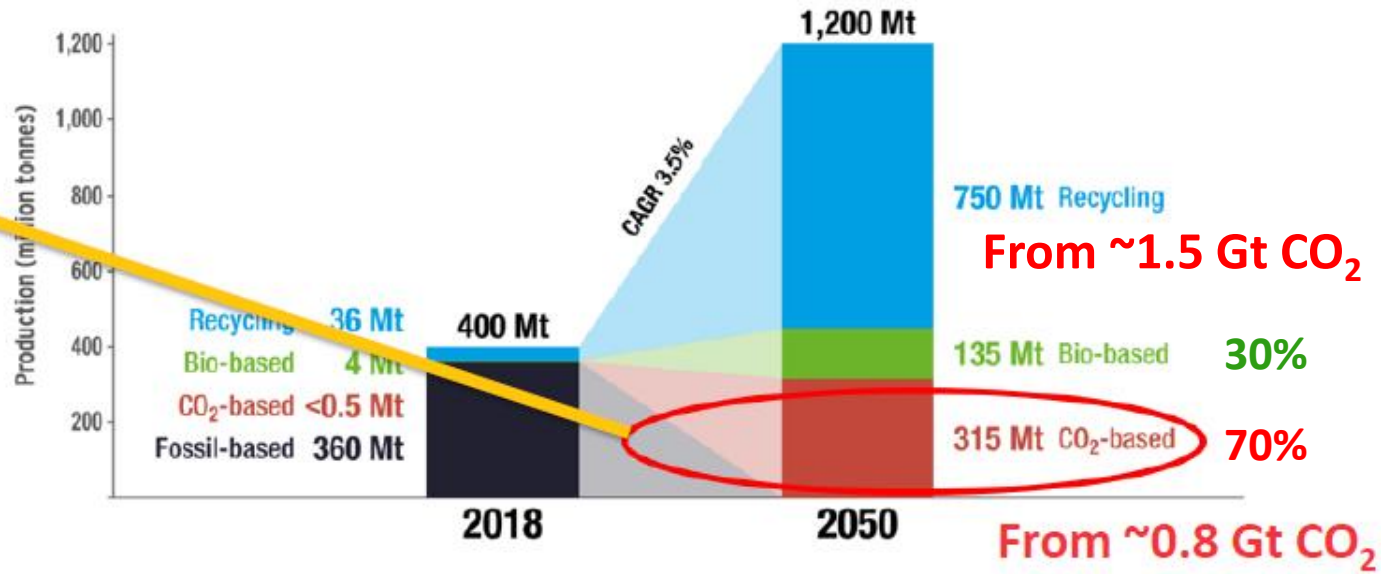
The plastic materials transition



5%

70%

World Plastic Production and Carbon Feedstock in 2018 and Scenario for 2050 (in Million Tonnes)



From ~1.5 Gt CO_2

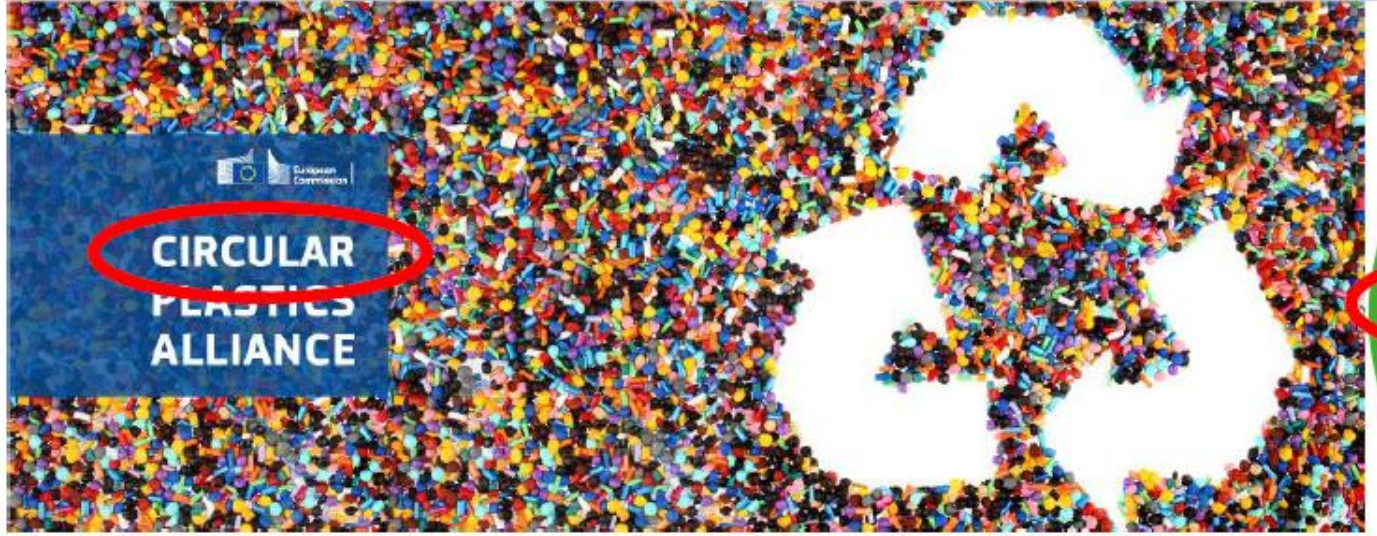
30%

70%

From ~0.8 Gt CO_2

nova Institute for Ecology and Innovation

The global ambition wrt plastics



CIRCULAR
INNOVATIONS IN PLASTICS

RESEARCH PRIORITY AREA SUSTAINABLE CHEMISTRY

EUROPEAN
PLASTICS
PACT

EVOLVING
A CIRCULAR
PLASTICS
ECONOMY

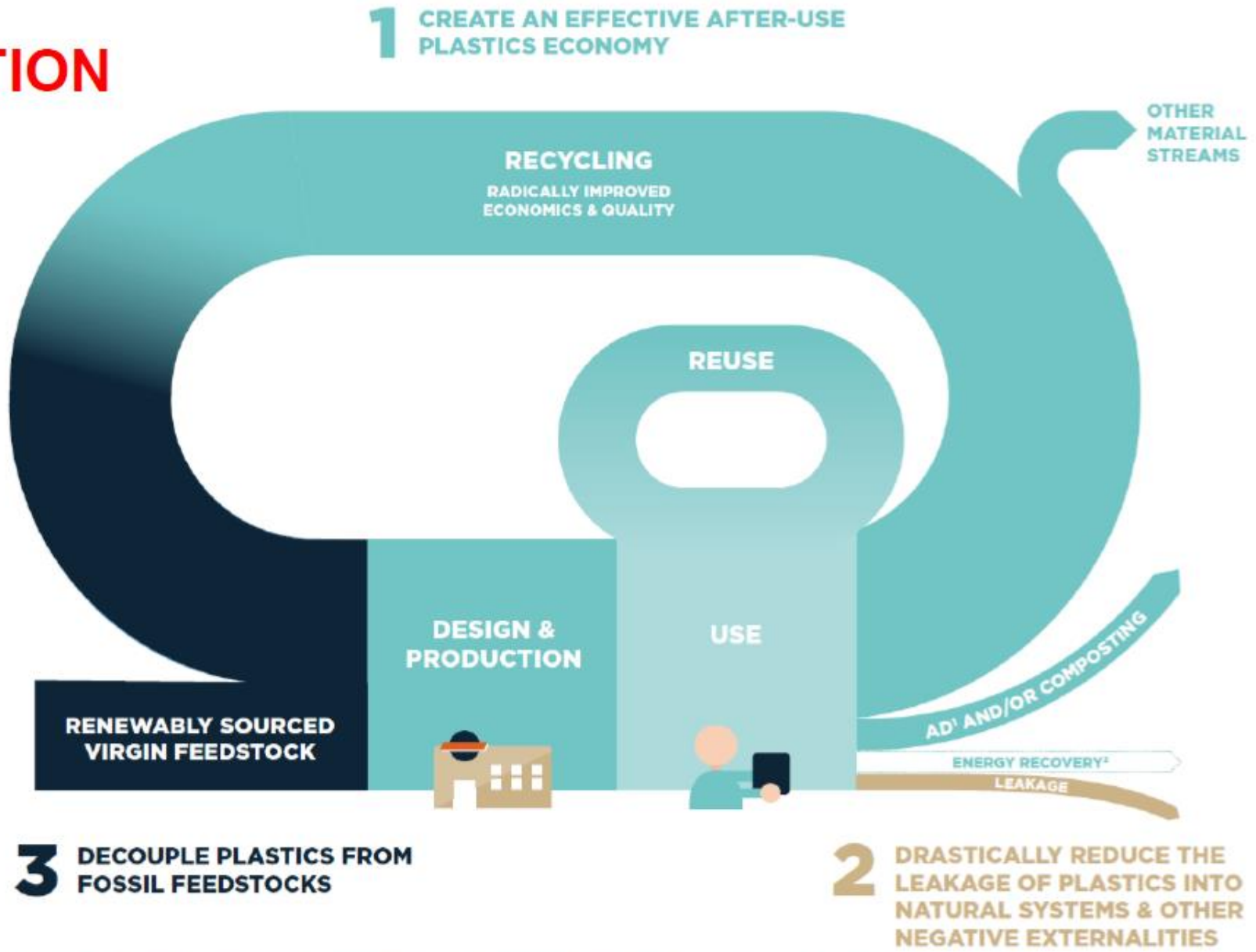


Circular Economy
for Plastics



AMBITION

FIGURE 1: THE NEW PLASTICS ECONOMY AND ITS THREE AMBITIONS

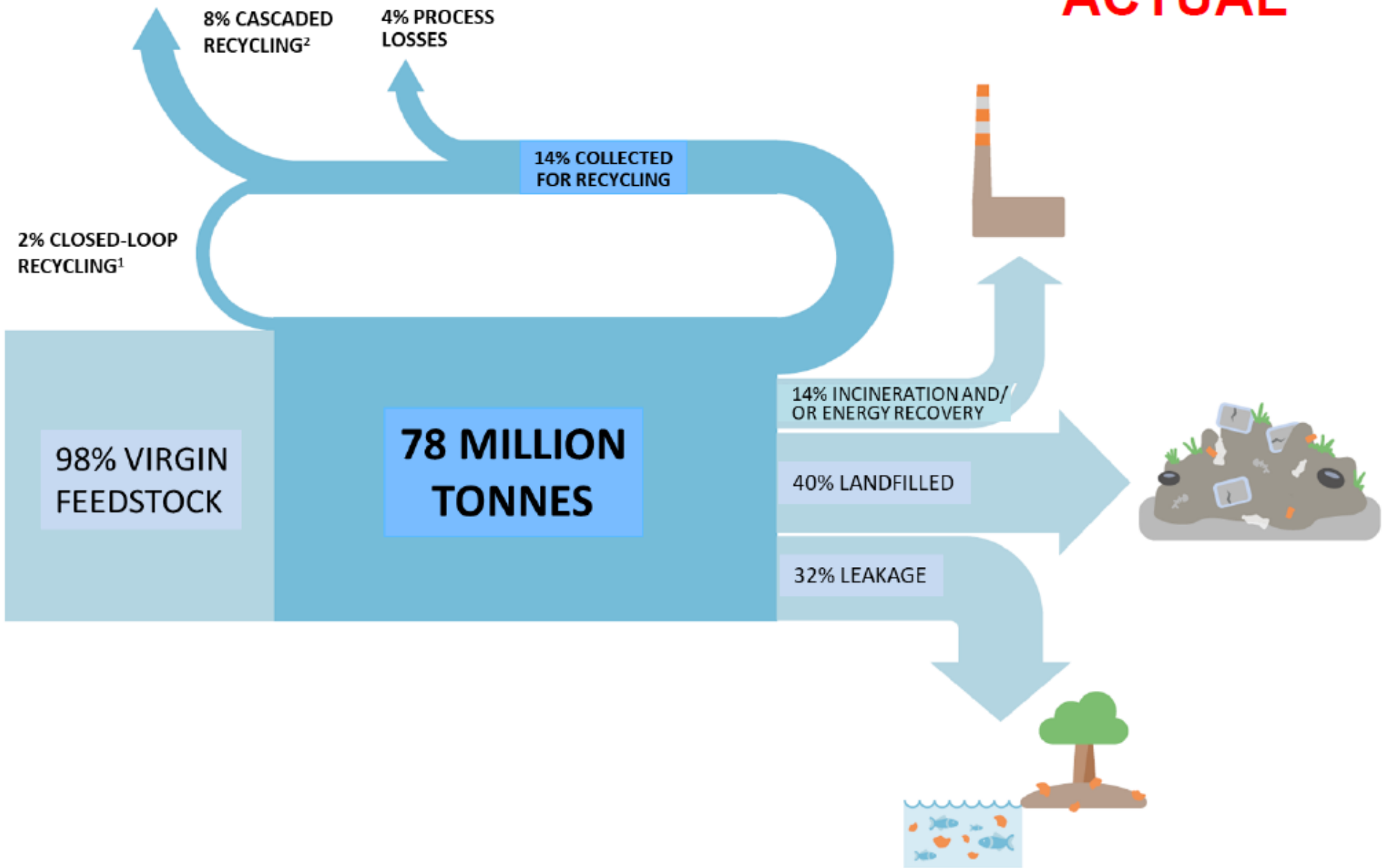


Source: *The New Plastics Economy – Rethinking the future of plastics*

Ellen MacArthur foundation

GLOBAL FLOWS OF PLASTIC PACKAGING MATERIALS IN 2013

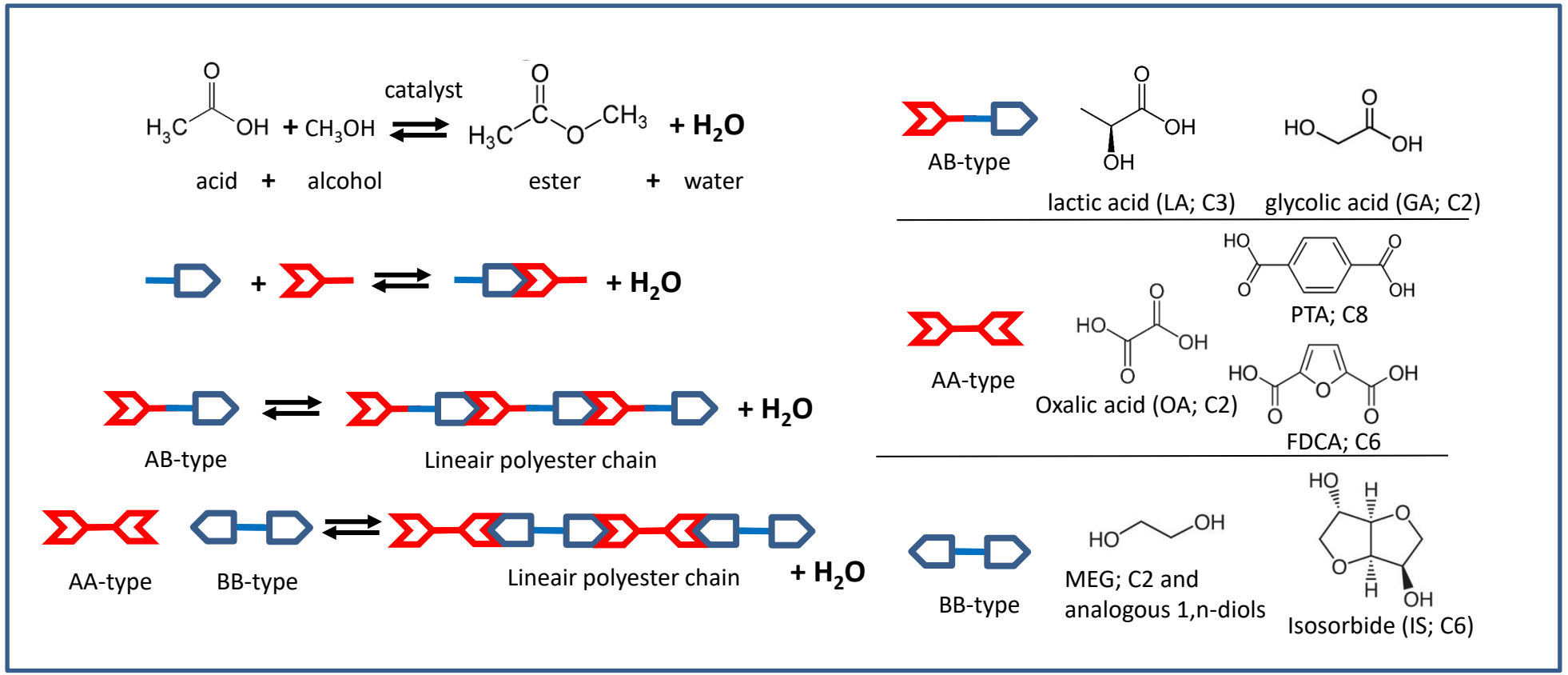
ACTUAL



Source: Ellen MacArthur foundation

For a circular future we need different polymers

- Different feedstock (more oxygen) → oxygenates (diols/ diacids) → polyesters
- Reuse → better (thermal) properties → high Tg polymers
- Much improved (closed-loop) recycling → polyesters

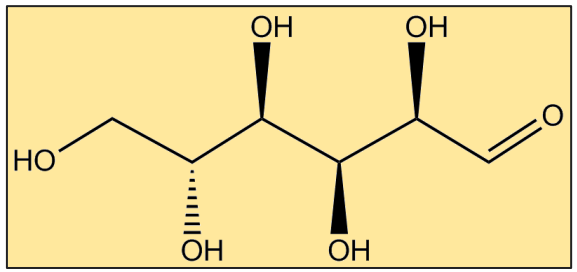


Which molecules make (most) sense from Glucose and CO_2

(technologically and economically)

CF = ton glucose or CO_2 per ton product @ 100% yield

*in some cases 2O from O_2 is incorporated

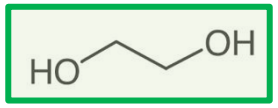


glucose

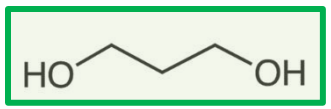


O=C=O

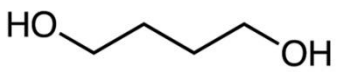
CF =1.0



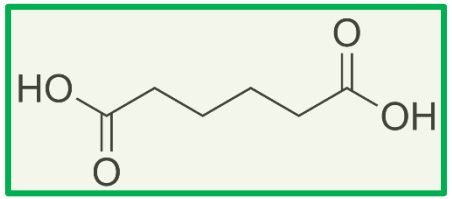
CF =1.2

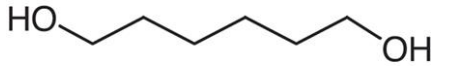


CF = 2.1

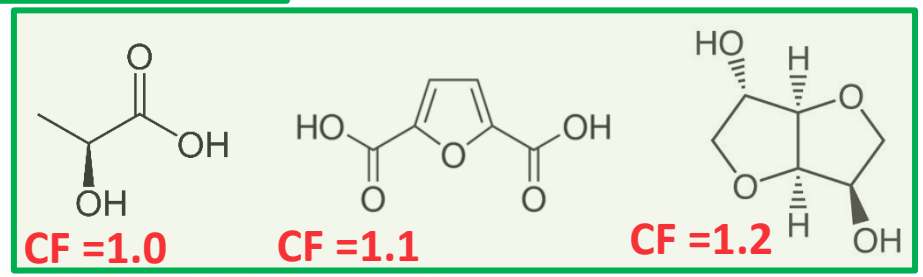


CF =1.2





CF =1.6

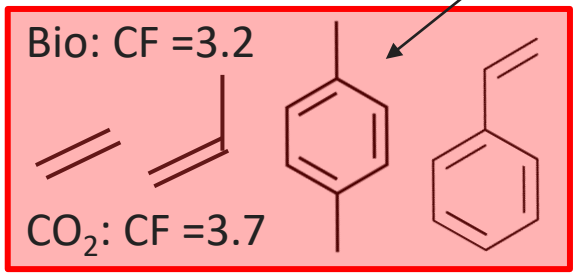


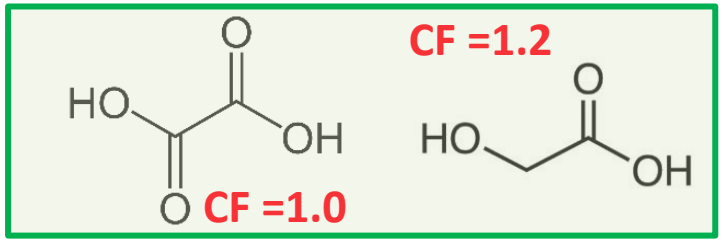
Bio-pX: 4+4 **CF=3.2**; 6+2 **CF=2.6**

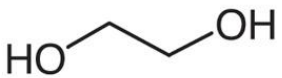
Bio-PTA 4+4 **CF=2.2**; 6+2 **CF=1.6**

135 Mt Bio-based

315 Mt CO_2-based







CF =1.6

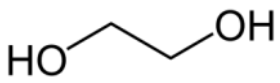

Novel, sustainable polyesters

PET: Meeting the demand – The options



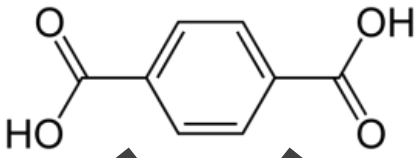


MEG

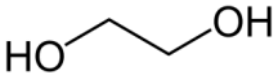


PTA

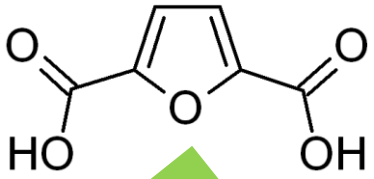
Bio-PTA



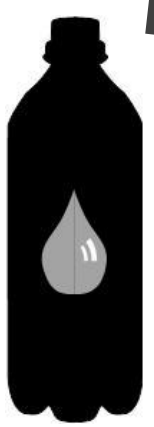
bioMEG



FDCA



Yesterday:
PET
100% Fossil



Today:
BioPET
20% Plants



Tomorrow:
PEF
100% Plants



avantium



FDCA & PEF Resin

Maintaining Leadership

Upscaling our technology into world scale production

LAB-SCALE	PILOT PLANT SCALE	COMMERCIAL SCALE	INDUSTRIAL SCALE
2008	**2011 - now**	**H1 2024**	**>2024**
Amsterdam	**Geleen**	**Delfzijl (Groningen, NL)**	**Licensee Site**
Kg’s	Tons	5000 Tons	100,000 Tons
Innovative research	Technology development	Commercial launch of FDCA & PEF	Roll-out of FDCA & PEF at larger scale
			Licensing



1 | Commercial plant for proof of concept & market development

2 | Licensing to rapidly expand market

FDCA Pilot Plant – Chemelot Geleen (NL)

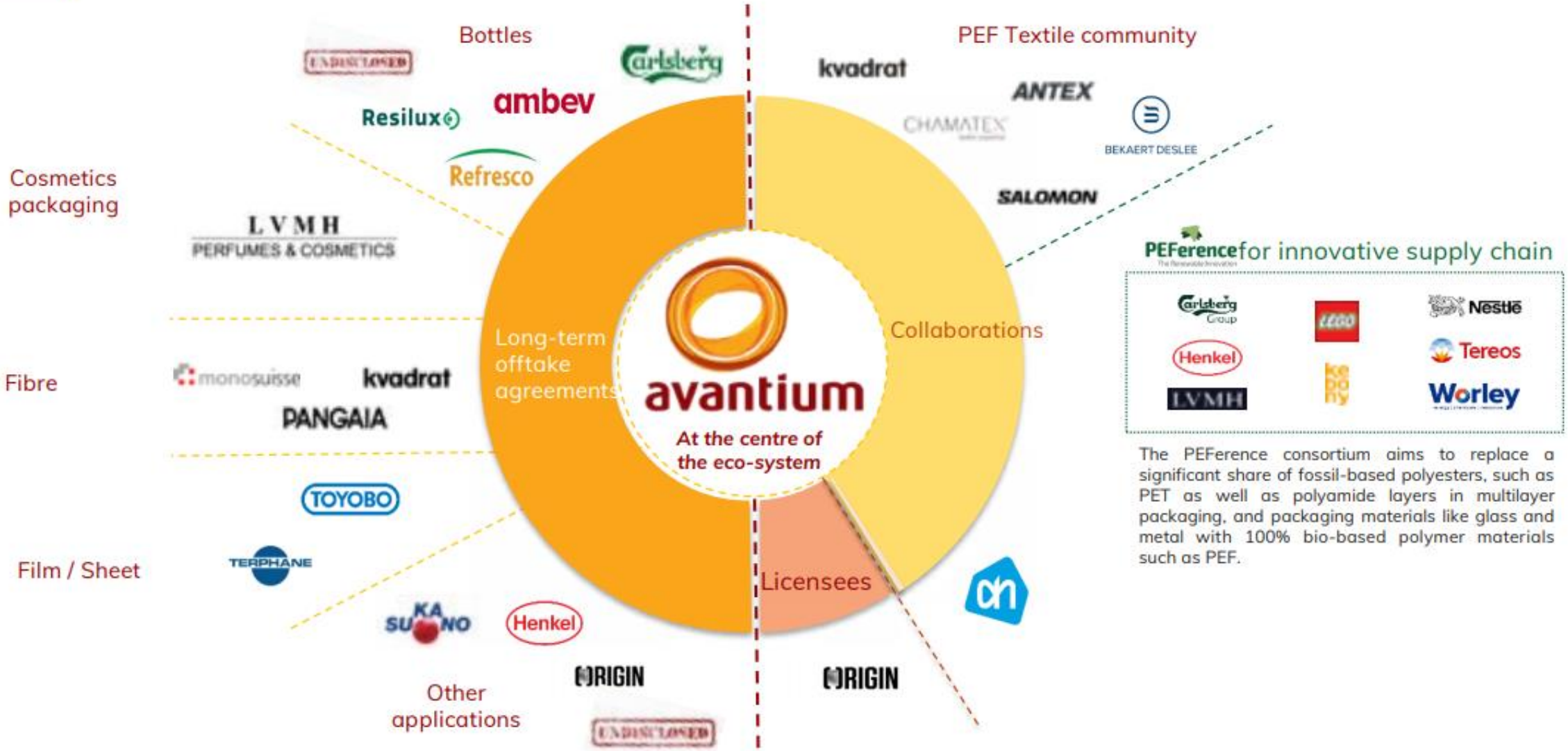


“Prove the process” & “Prove the products” (application development)


avantium
C-WATCH
Collé

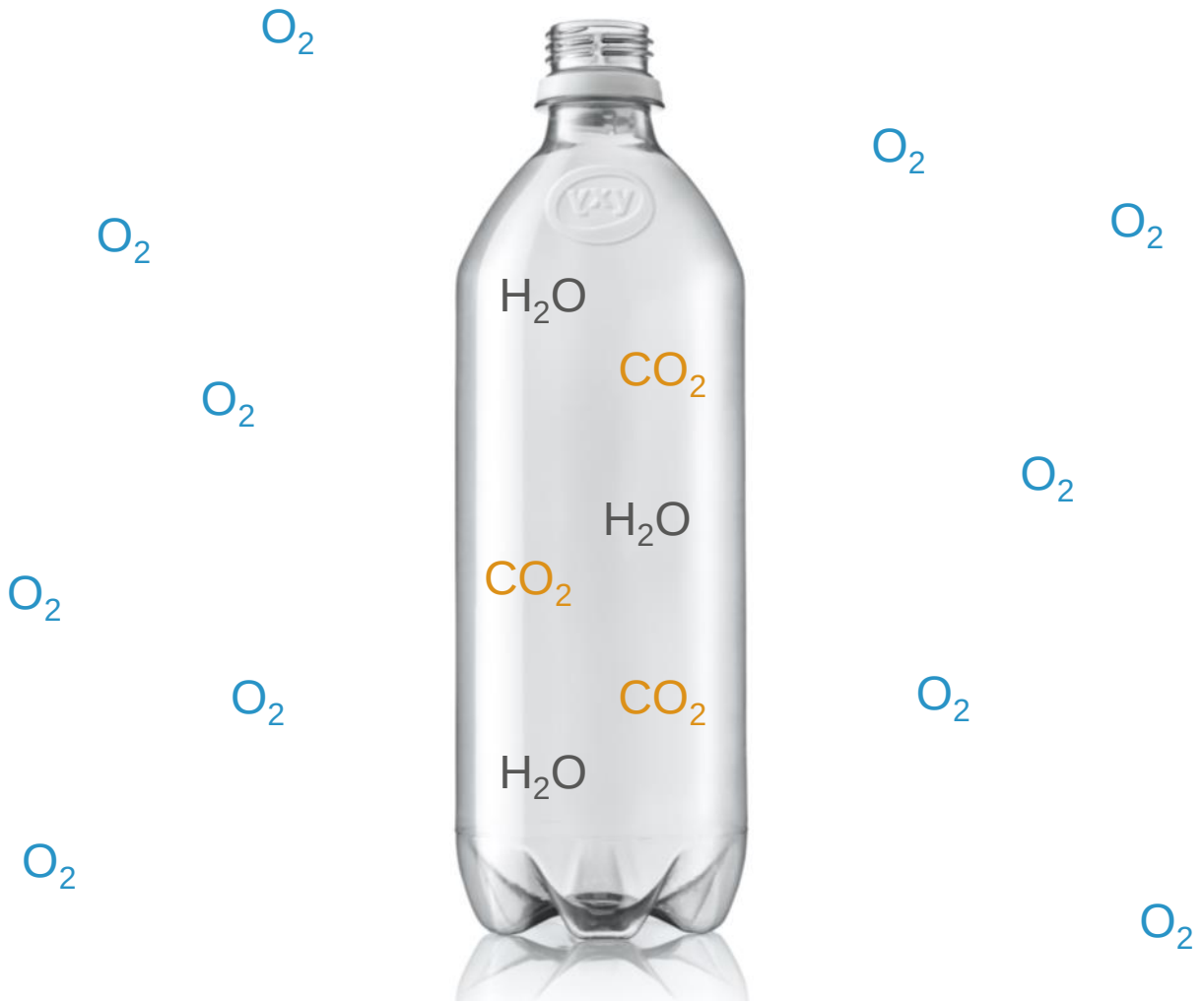

avantium

Driving renewable & circular polymers



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 polymer materials such as PEF.

PEF has barrier !



Why PEF?

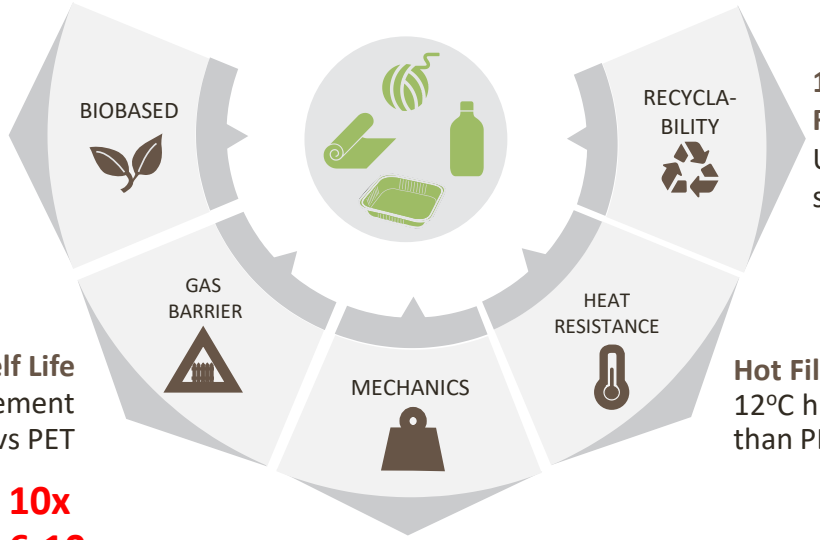
Trends in packaging:

- **Sustainability**
- **Smaller servings**
- **Healthier drinks**
- **Cost reduction**





PEF



100% Biobased
Renewable material

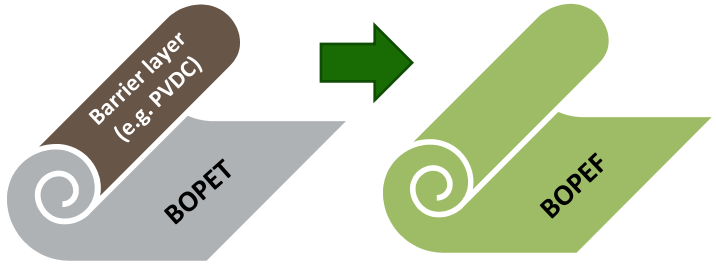
100% Recyclable
Using same steps as PET

Shelf Life
Improvement Factor vs PET

O_2 **10x**
CO_2 **6-10x**
H_2O **3x**

Hot Fill / Hot Serve
12°C higher T_g than PET

Light-weighting
60% higher modulus and strength than PET



PEF as barrier layer in Carlsberg's paper bottle

Making use of PEF barrier; Paper and PEF liner can both be recycled (no glue…);
First commercial product launched @ events.









PEF Textile Community with the five reputable global companies Antex, BekaertDeslee, Chamatex, Kvadrat and Salomon







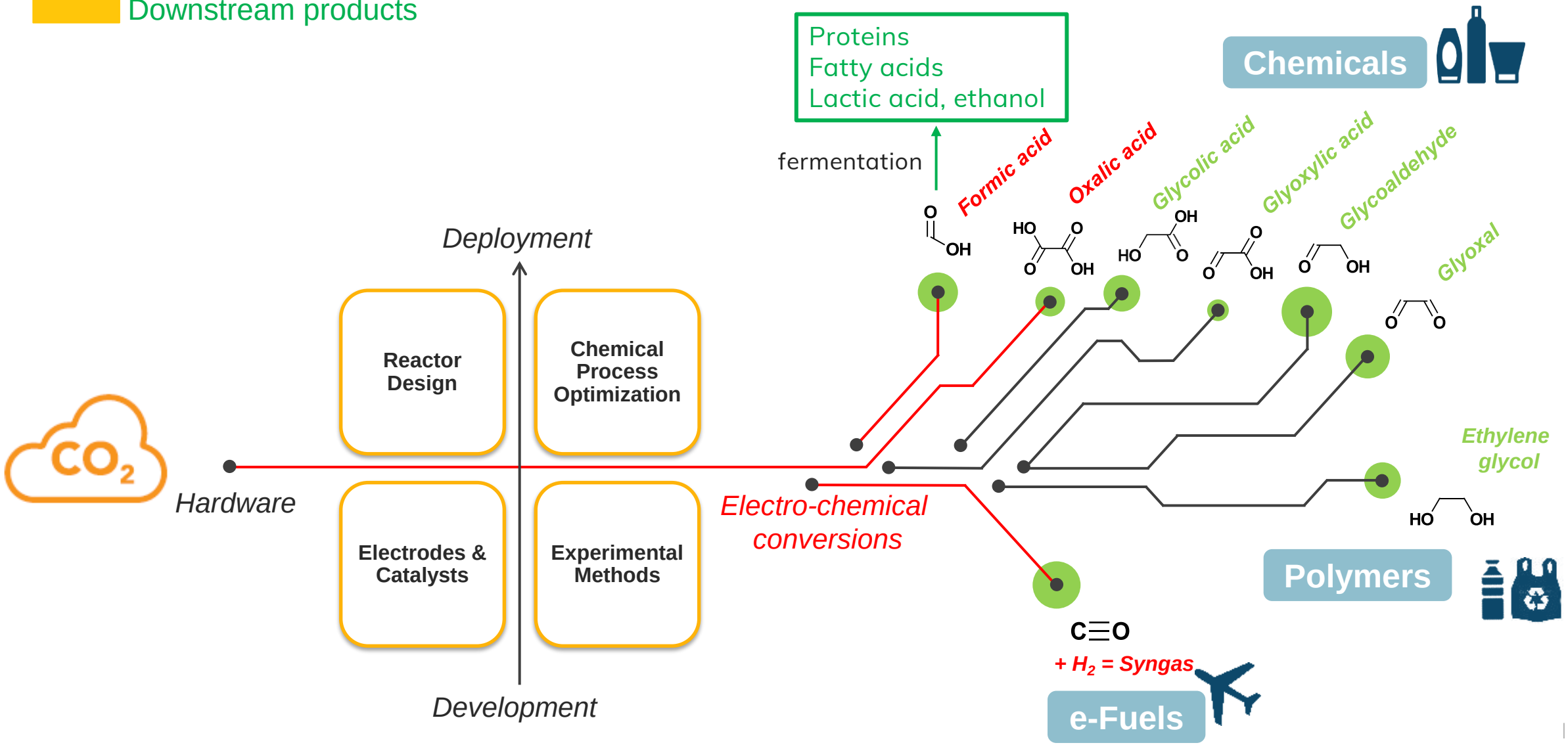

Feedstock – CO_2

Avantium Volta Technology

Combining cutting-edge technology with versatility

3 electrochemical development lines: CO_2 to CO, formic acid, oxalic acid

Downstream products



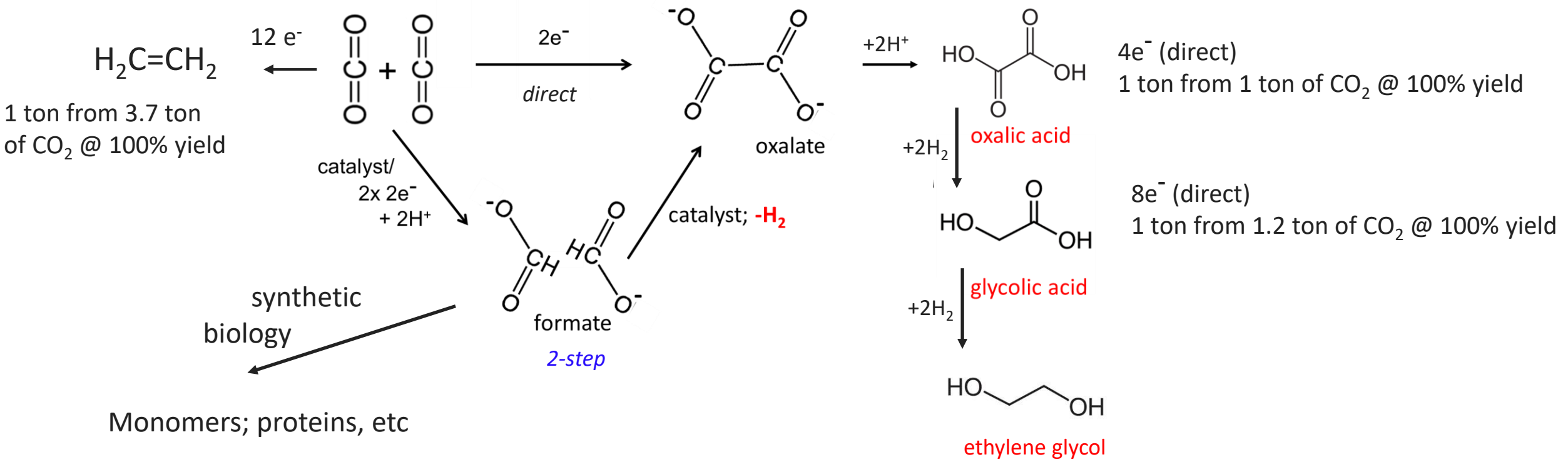
Benefits of CO_2 Reduction

Defined	• CO_2 is well defined vs biomass feed stock
Agnostic	• Multiple sources are possible- Biogenic and DAC are preferred for the long term
Competitive	• No competition with food/land use/deforestation
Clean	• Electrons as a reagent; very high selectivity
Flexible	• Technology allows “peak-shaving”
Valuable	• One of the few technologies to turn CO_2 into valuable products with the potential to enable carbon negative materials
De-risked	• Scaling out electrochemical cell stacks dramatically reduces the risk of scale-up
Potential	• Ability to address large markets (proteins, ethanol, chemicals, polymers and fuels)

Which monomers from CO_2 will be winning ?

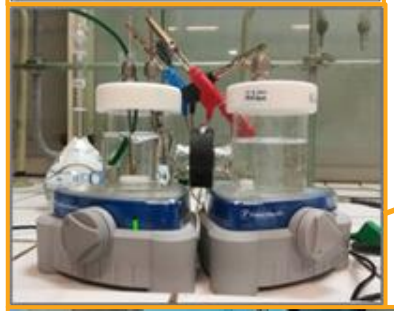
- ✓ CO_2 to oxalic acid [HOOC-COOH]: **4 MWh/ ton oxalic acid.** (**€180/ton;** electricity @ €0.05/kWh & 3V)
- ✓ CO_2 to glycolic acid (w. green H_2): [HOOC-CH_2OH]: **9.5 MWh/ ton glycolic acid** (**€470/ton;** electricity @ €0.05/kWh & 3V)
- ✓ CO_2 to ethylene [C_2H_4]: **38 MWh/ ton ethylene.** (**€1720/ton;** electricity @ €0.05/kWh & 3V)

(producing 1 ton of H_2 requires ~80MWh)



Volta Technology - Scaling







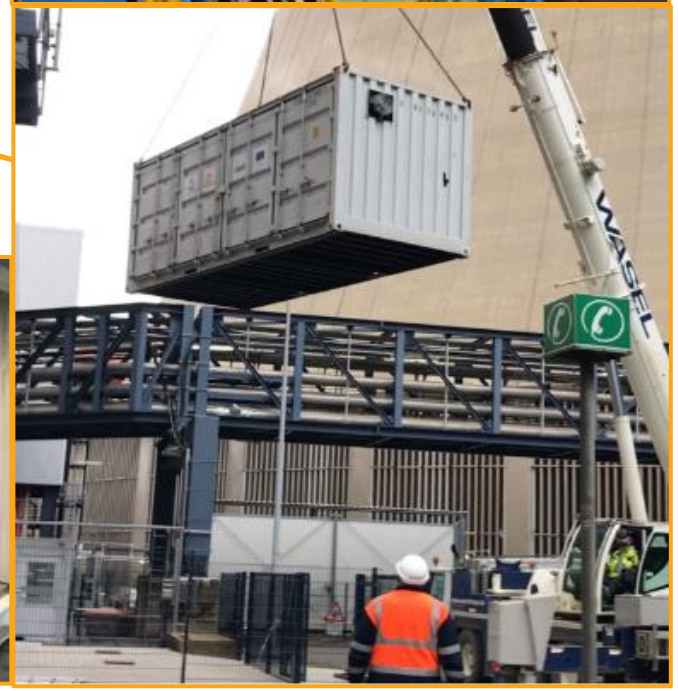




Tonnes/year Ktonnes/year

TRL		1	2	3	4	5	6	7	8	9
(Innovation) Phase	Basic research									
		Applied research								
					Development					
								Deployment		





~8 Tonnes/year

Demonstration at TRL5/6

RWE Power

ocean

TITAN

RECODE

CO_2 → Formate

Oxalic acid → Glyoxylic acid

- 20 ft containers
- 0.25 – 0.5 kg/h
- Cell size 0.2 m^2





RWE Power Niederaußem



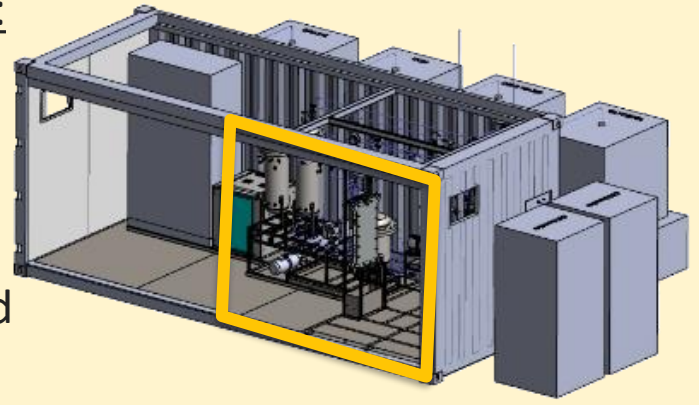
Titan Cement Greece

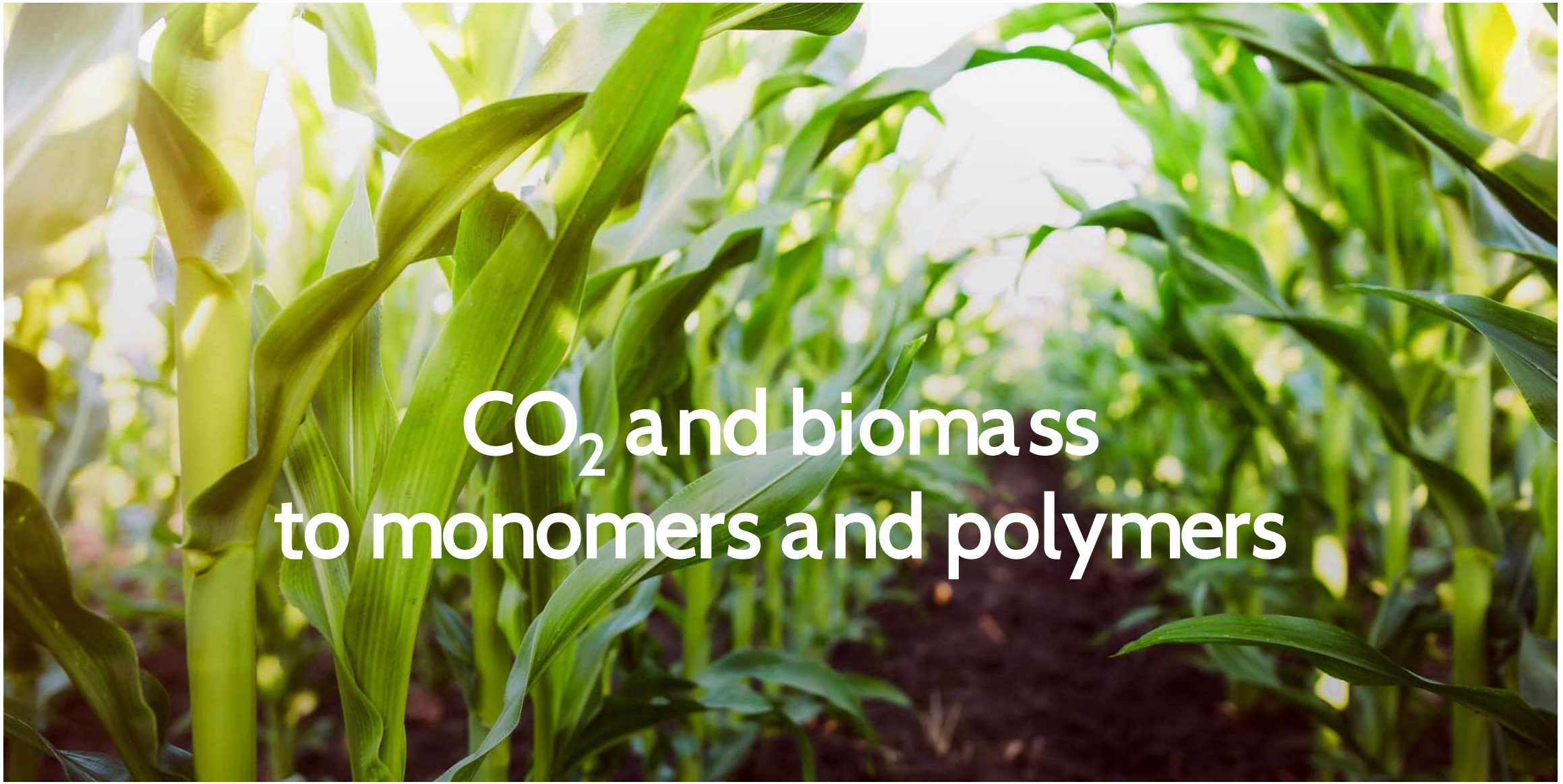
<u>Ocean testing campaign 2022:</u>

>1000 hours of operation at TRL6

First of a kind 1m high GDE electrochemical cell

34.6 kg of CO_2 were converted




CO_2 and biomass
to monomers and polymers

Bio-based polyesters

PLGA with high GA

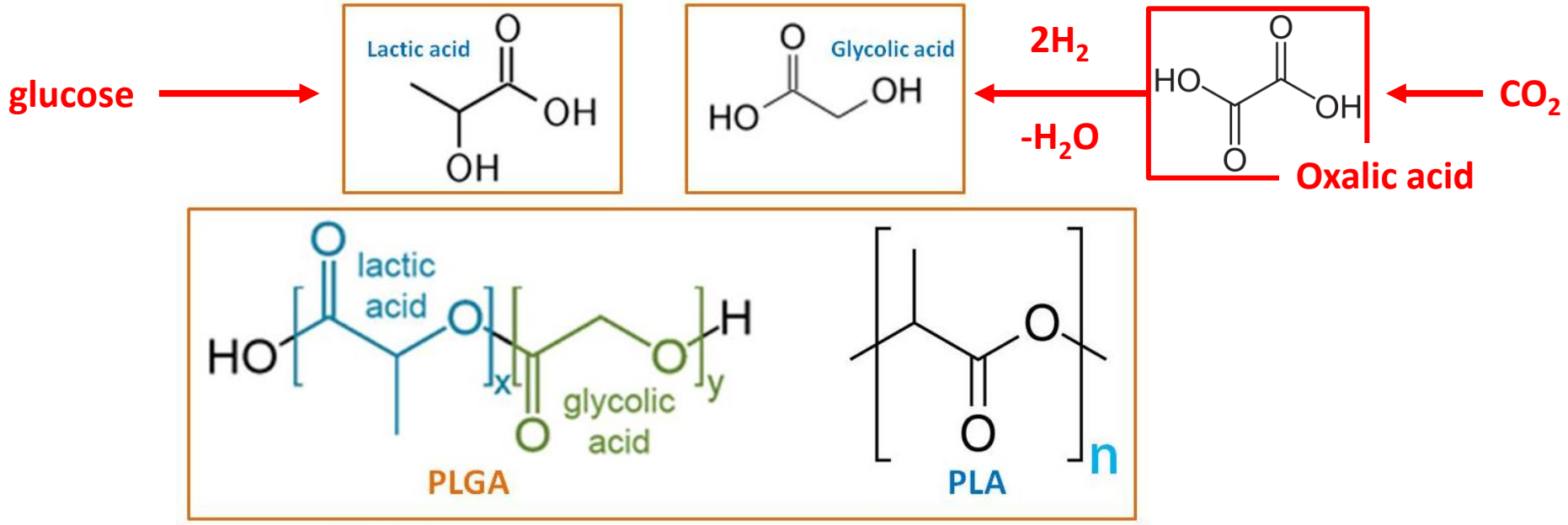
ACS APPLIED POLYMER MATERIALS

ACS Appl. Polym. Mater. 2020, 2, 2706−2718

pubs.acs.org/acsapm Article

PLGA Barrier Materials from CO_2. The influence of Lactide Co-monomer on Glycolic Acid Polyesters

Maria A. Murcia Valderrama, Robert-Jan van Putten, and Gert-Jan M. Gruter*





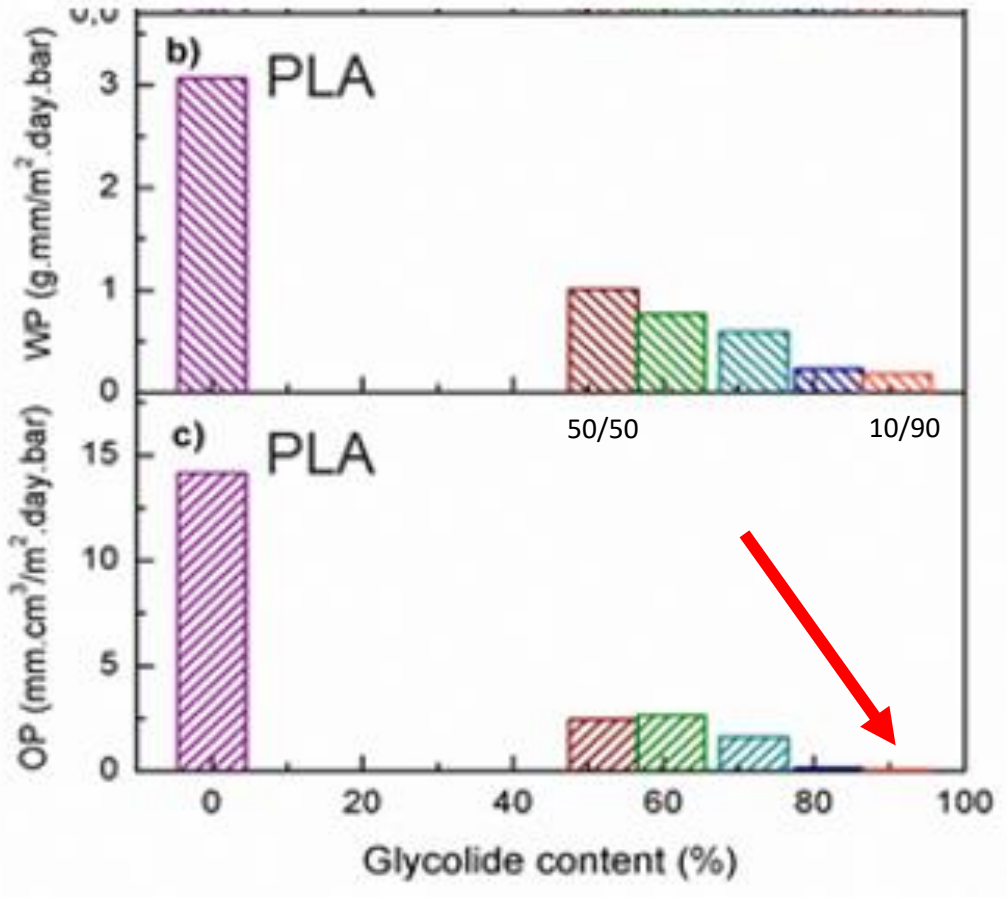
Maria A. Murcia Valderrama

Oxygen permeability (OP) and Water permeability (WP) for PLGA copolymers at 70% RH and 30 °C

Murcia Valderrama, M.A. et al.
ACS Appl. Polym. Mater **2020**, *2*, 2707-2718.

Film thickness = 0.17 mm;

Increased barrier to O_2 and water vapor with increasing GA content (50, 60, 70, 80, 90%)



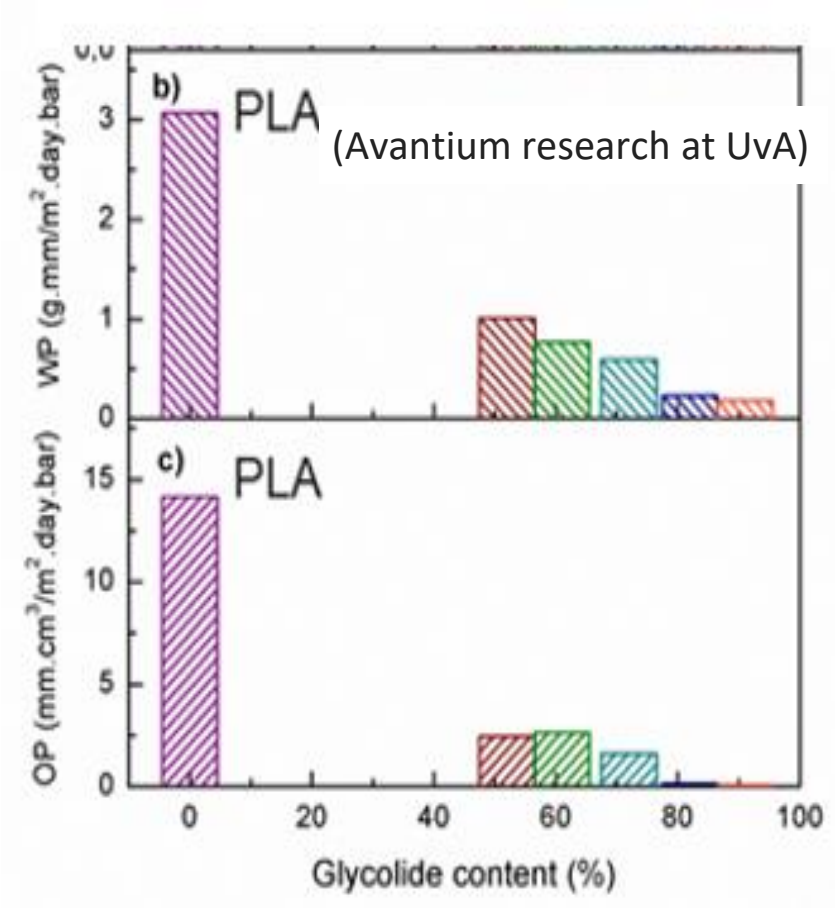


50% GA + 50% LA



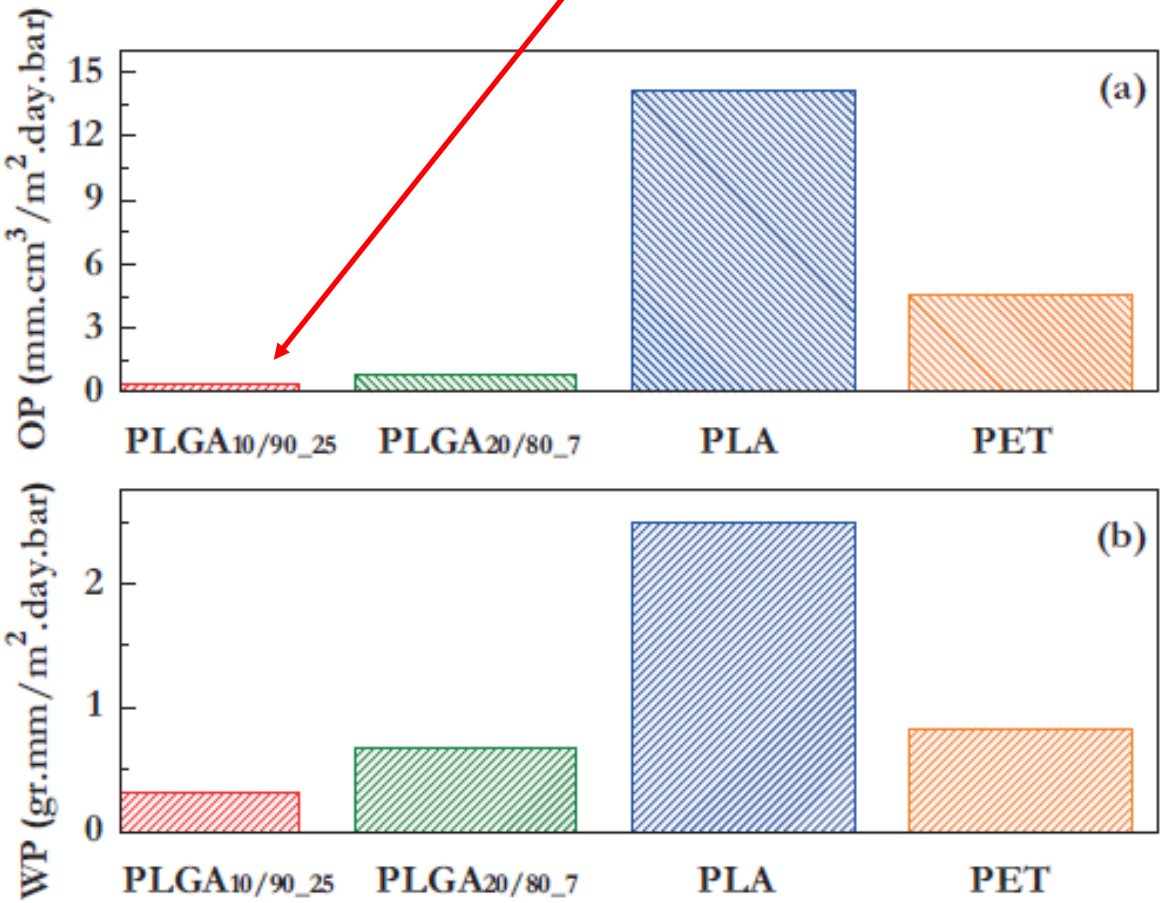
90% GA potentially 90% CO_2-based

PLGA: Barrier Properties



Oxygen barrier PLGA 10/90

- 150x better than PLA
- 50x better than PET;
- 5x better than PEF



Oxygen (a) and water (b) permeability for 2 PLGA's
Measured at 30°C and 70% RH.

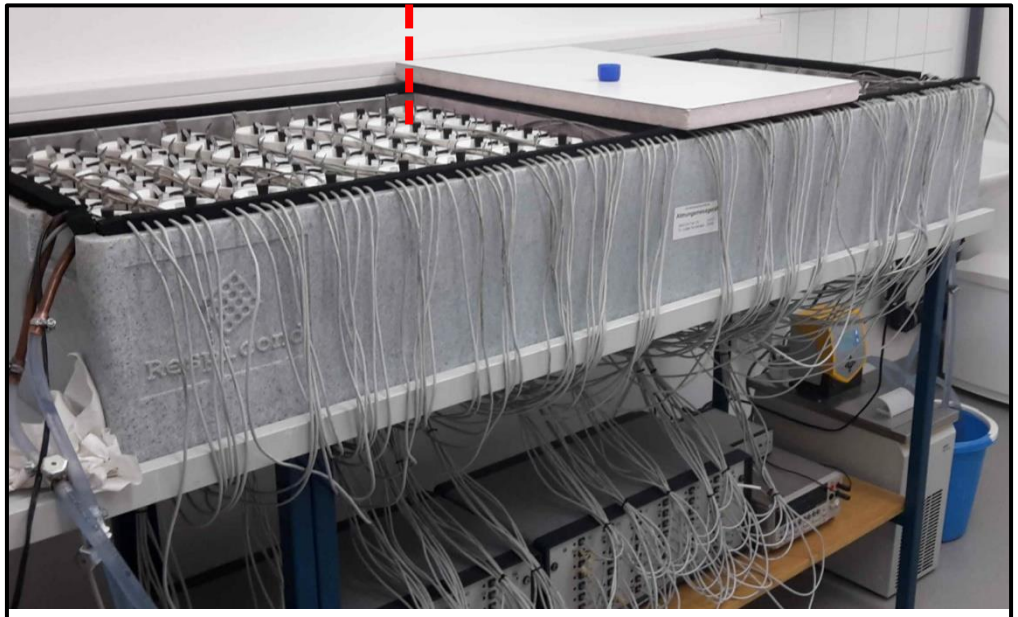


Yue Wang

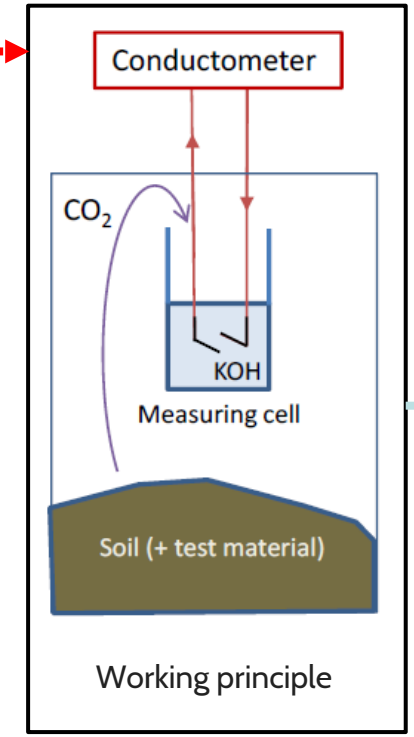
avantium

Biodegradability of PLGA

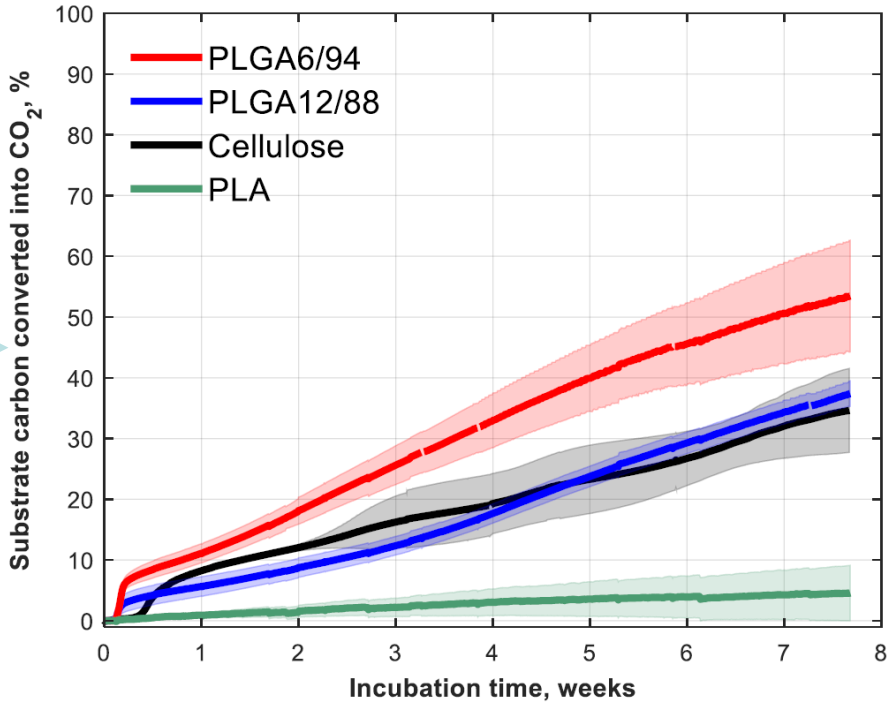
PLGA biodegradability in soil was determined under ambient conditions (25 °C)



Unit for high throughput biodegradability studies



Working principle

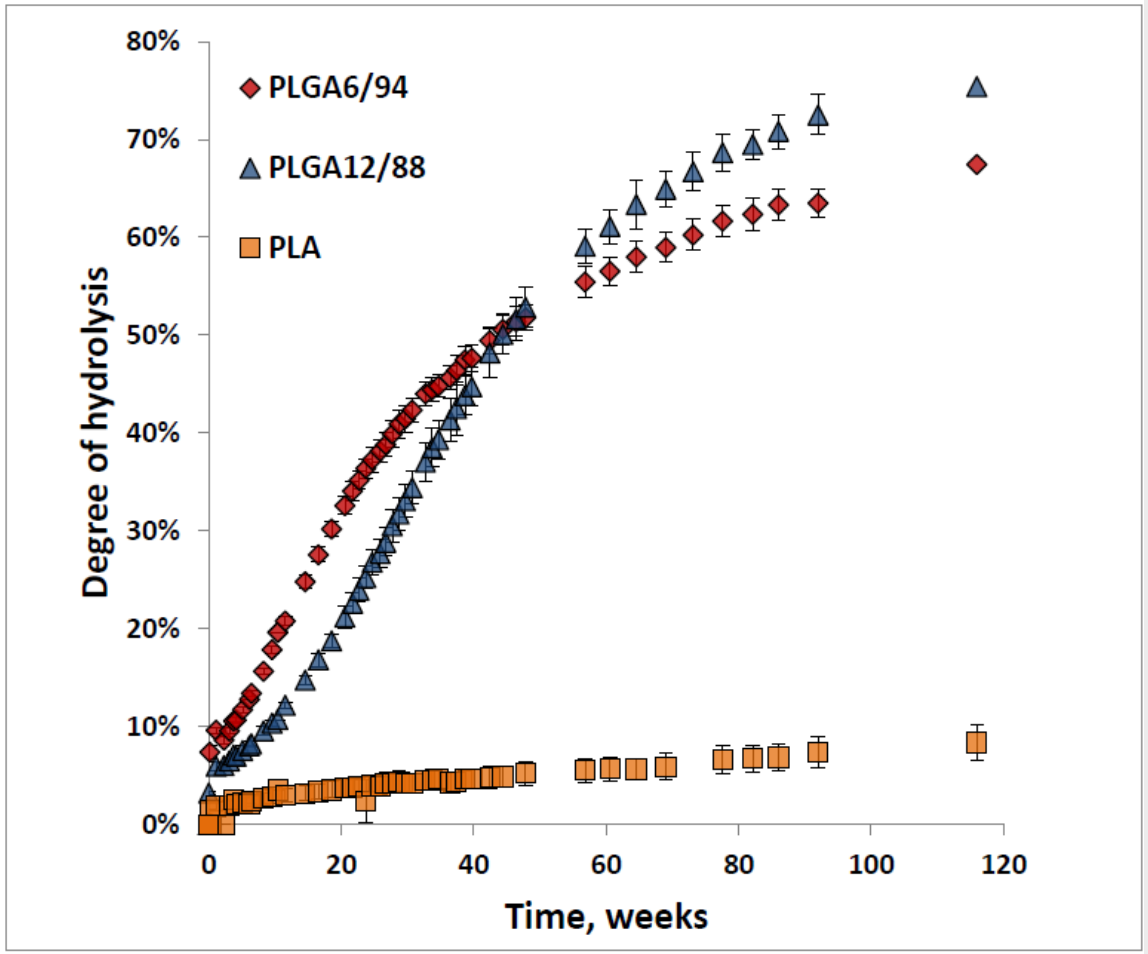


Y. Wang *et al.*, *Polymers* **2022, 14**, 15

avantium

Hydrolytic degradation of PLGA

Non-enzymatic hydrolysis of PLGA was determined with ^{1}H NMR



Y. Wang *et al., Polymers* **2022, 14**, 15

PLGA Market Potential

Applications



- Packaging Film (barrier) – PE replacement (single-use)
- (paper) coating; replacing (multi-layer) PE film – with fantastic moisture/O_2/odor barrier the PLGA layer can be very thin, (much) thinner than PE layer, ~0.15 mm
- Pill (barrier) bottles (discussions with Pfizer). Oxygen and moisture barrier critical. High prices can more easily be absorbed in high end drug packaging. Plastic use is becoming major concern for pharmaceutical companies.
- Scrubs (biodegradability required)
- 3D printing
- Agro foils (biodegradability required)
- Disposable apparel
- Medical textiles (single use, discussion w. AMC)
- ….



