The future of plastics

High potential polyesters from biomass and CO_2

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avantium

Universiteit van Amsterdam

NPT Nederlandse Procestechnologen

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

Renewable Polymers (formerly Synvina)

Polyesters

YXY® Technology: FDCA & PEF

Ticker: **AVTX Amsterdam & Brussels**

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

100+ patent families

300

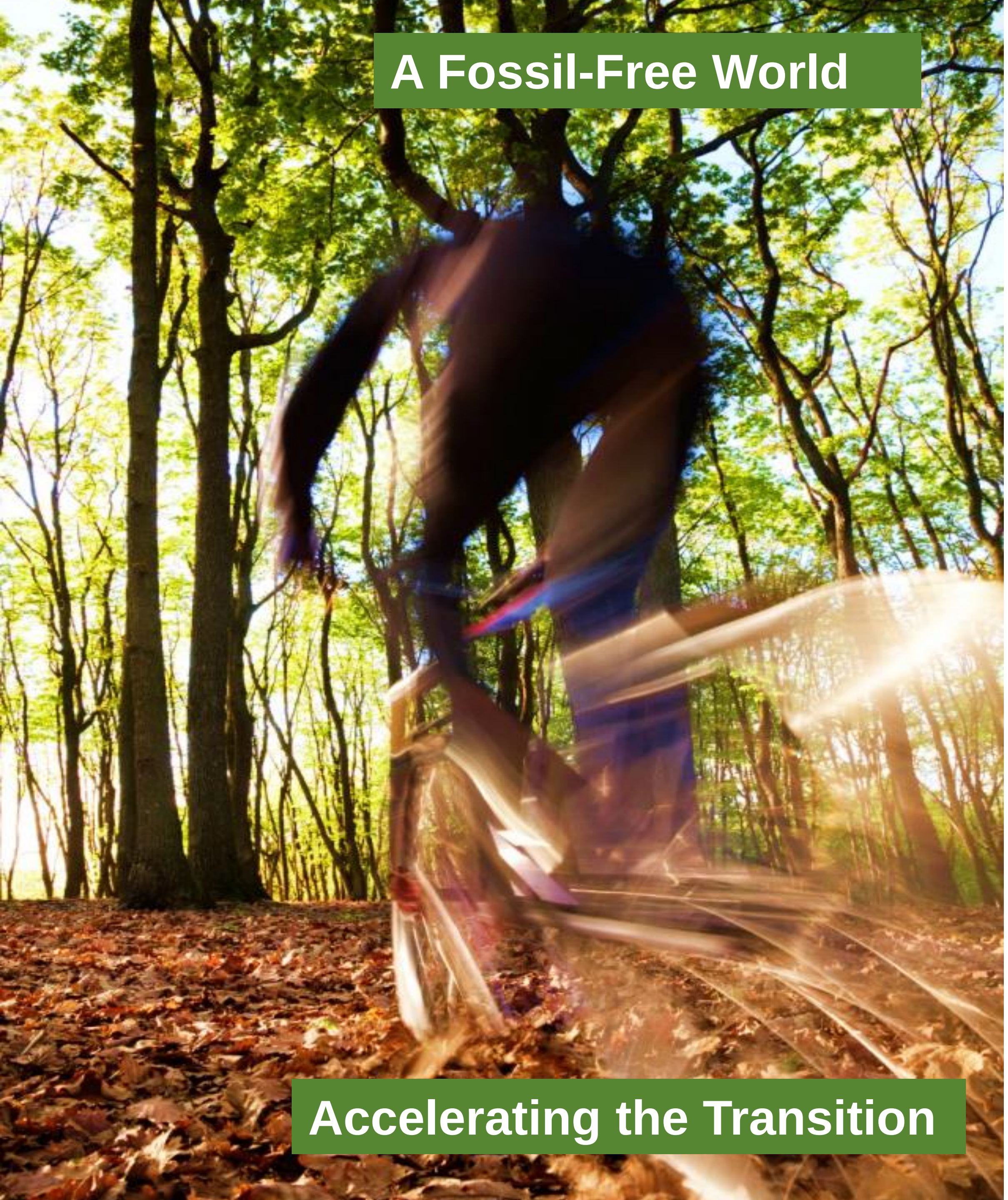
>75% scientists
20+ nationalities
30% female

Avantium Corporate Technology VOLTA & Yukon/DAWN

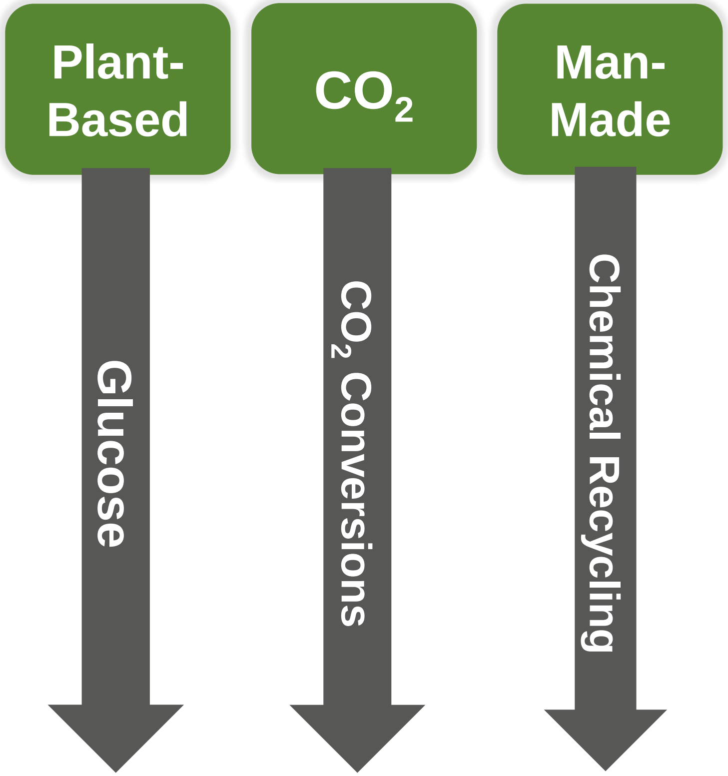
UvA - Industrial Sustainable Chemistry PARANA

University of Amsterdam

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)



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



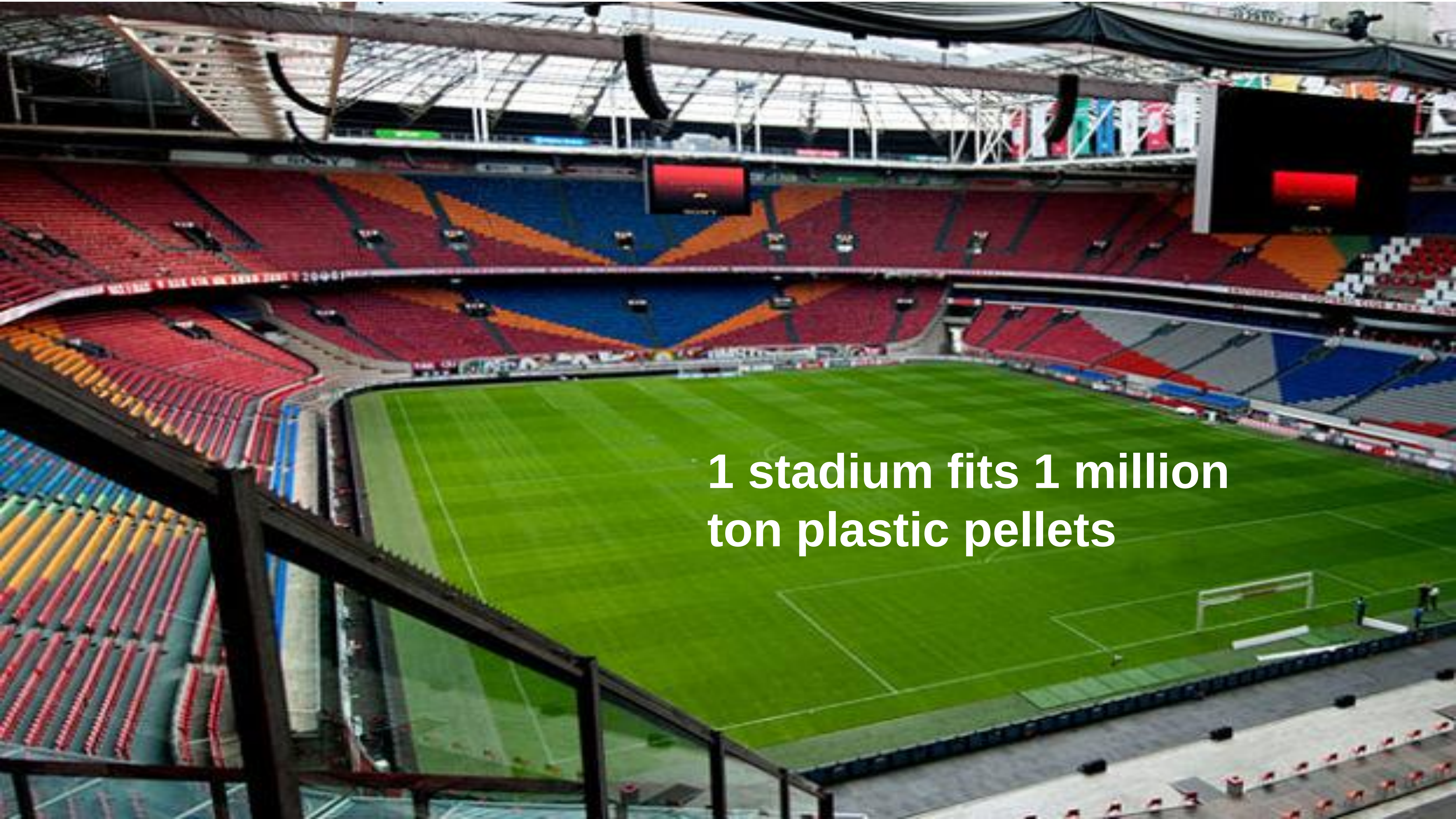
…that enable a circular economy

Where are we today ?

Some plastics facts & figures*

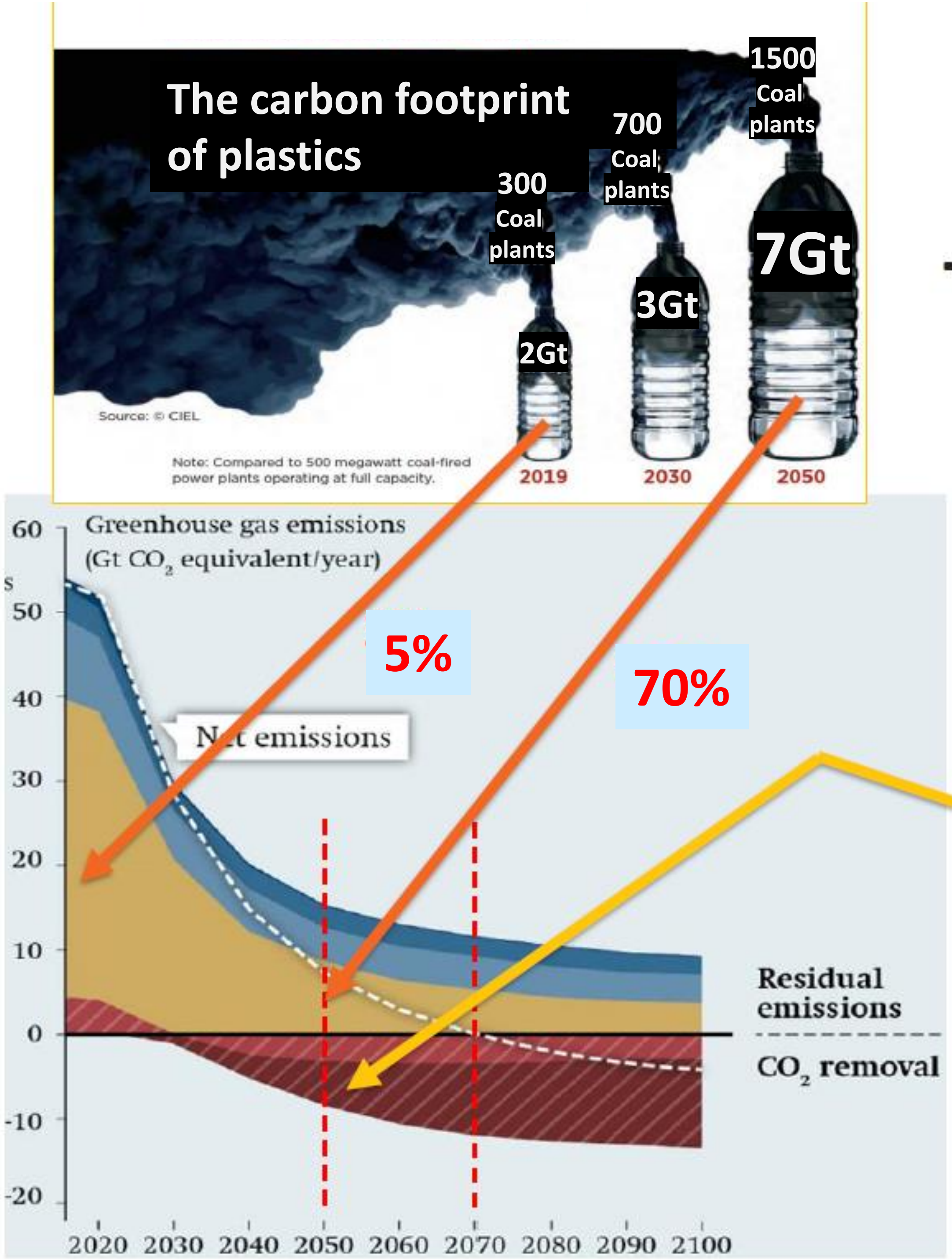
- 2022 global plastics production: 400 Mt
  - Excluding rubber (tyres), fibers (textiles, carpets), thermosets and recyclate
- 5-6% of all oil → plastics
- 2 Mt/yr bio-based (0.5%)
- 8 Mt/year “leakage” of plastic waste into the environment
- 3.5% averge demand growth per year

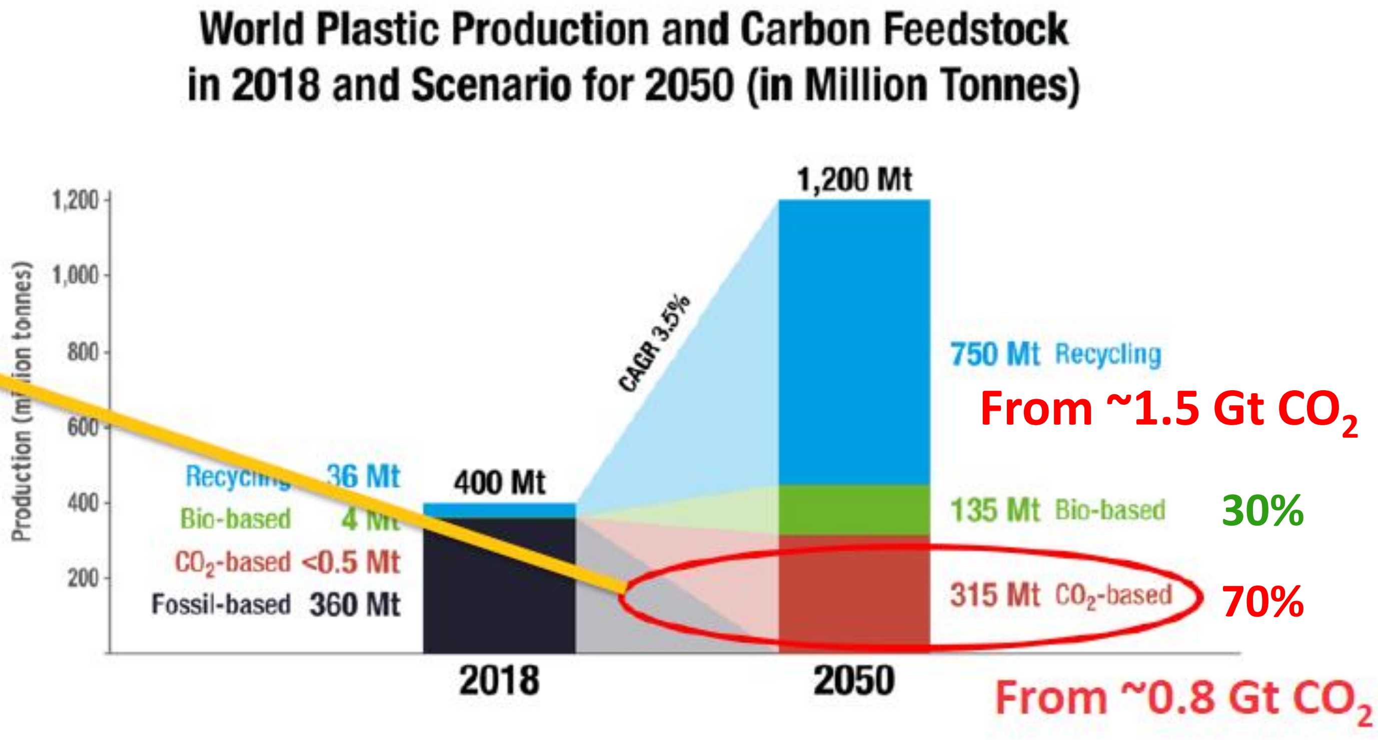
** https://ourworldindata.org/faq-on-plastics#how-much-plastic-and-waste-do-we-produce*


1 stadium fits 1 million
ton plastic pellets

UNIVERSITEIT VAN AMSTERDAM avantium

The plastic materials transition





nova Institute for Ecology and Innovation

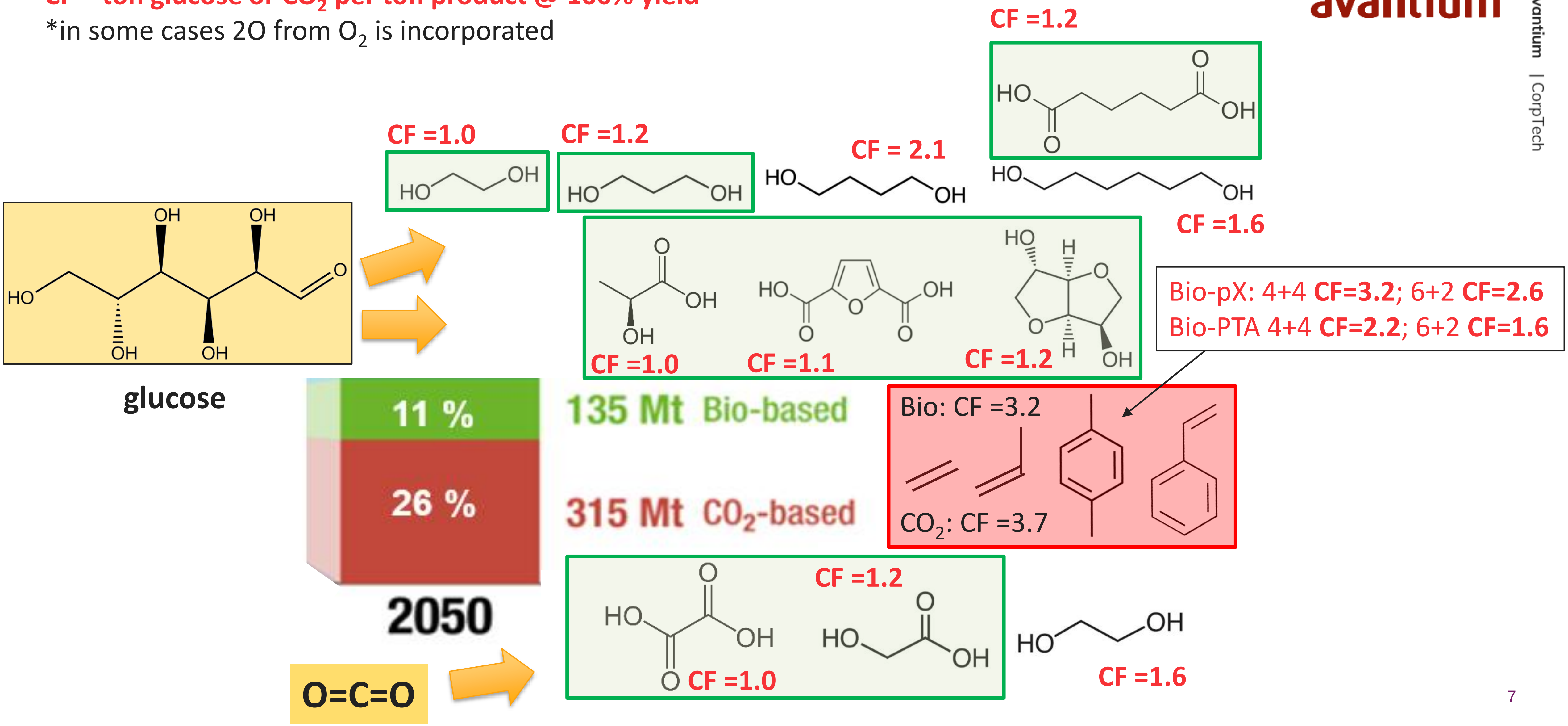
Avantium | CorpTech

Which molecules make (most) sense from Glucose and CO_2

(technologically and economically)

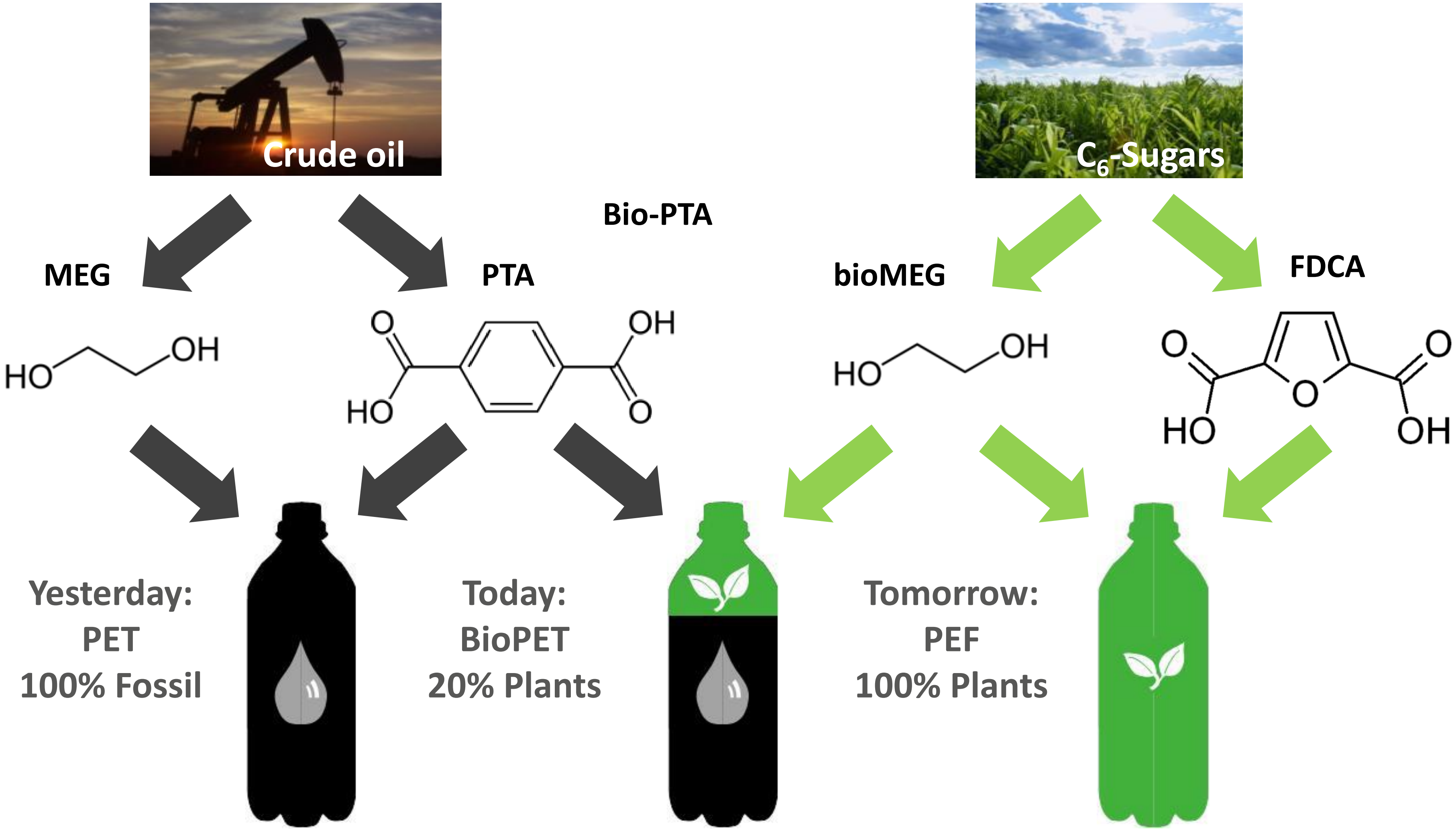
CF = ton glucose or CO_2 per ton product @ 100% yield

*in some cases 2O from O_2 is incorporated



Novel, sustainable polyesters

PET: Meeting the demand – The options



FDCA & PEF Resin


avantium
C-WATCH
Collé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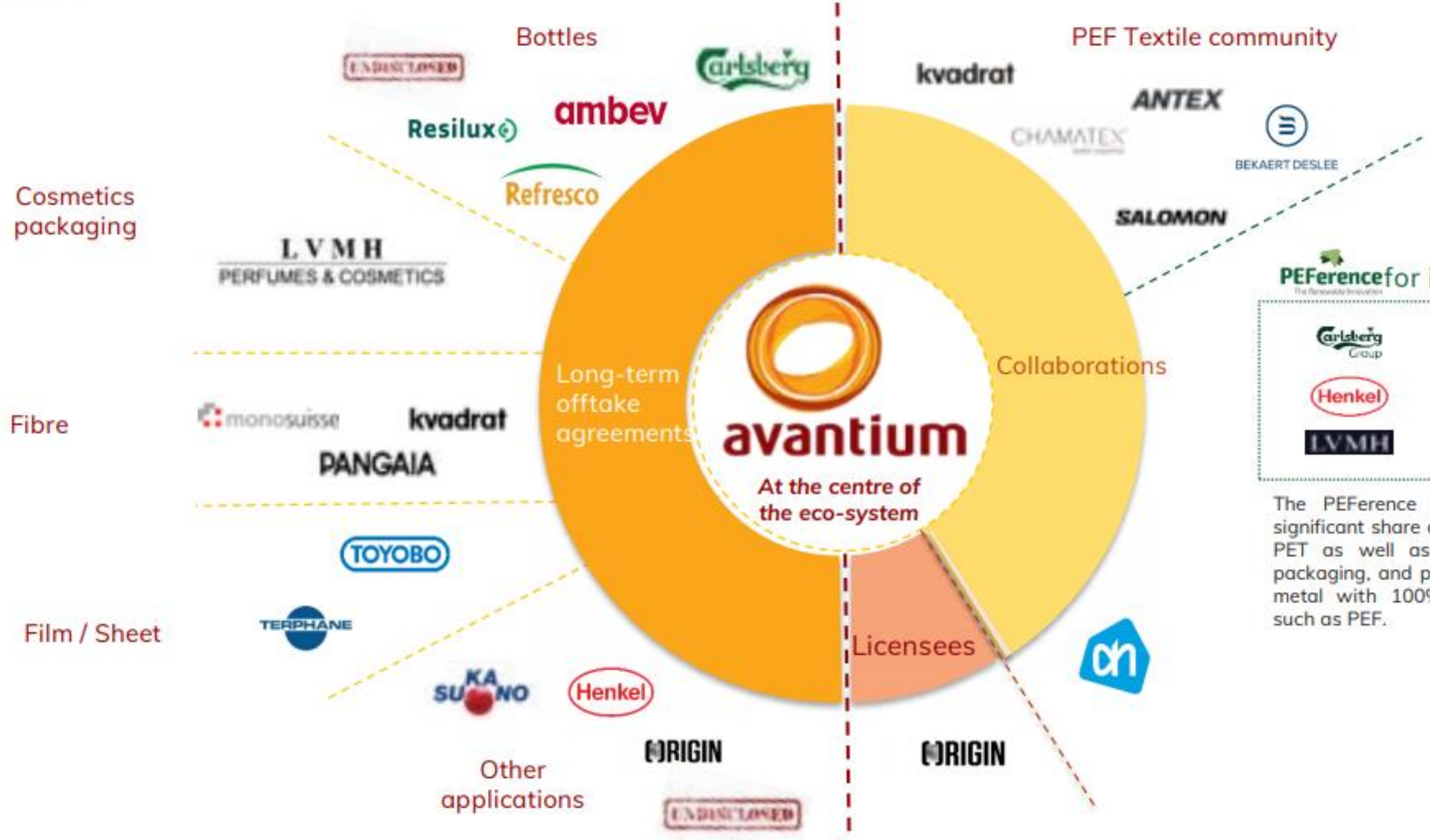
Driving renewable & circular polymers



PEFerence for innovative supply chain

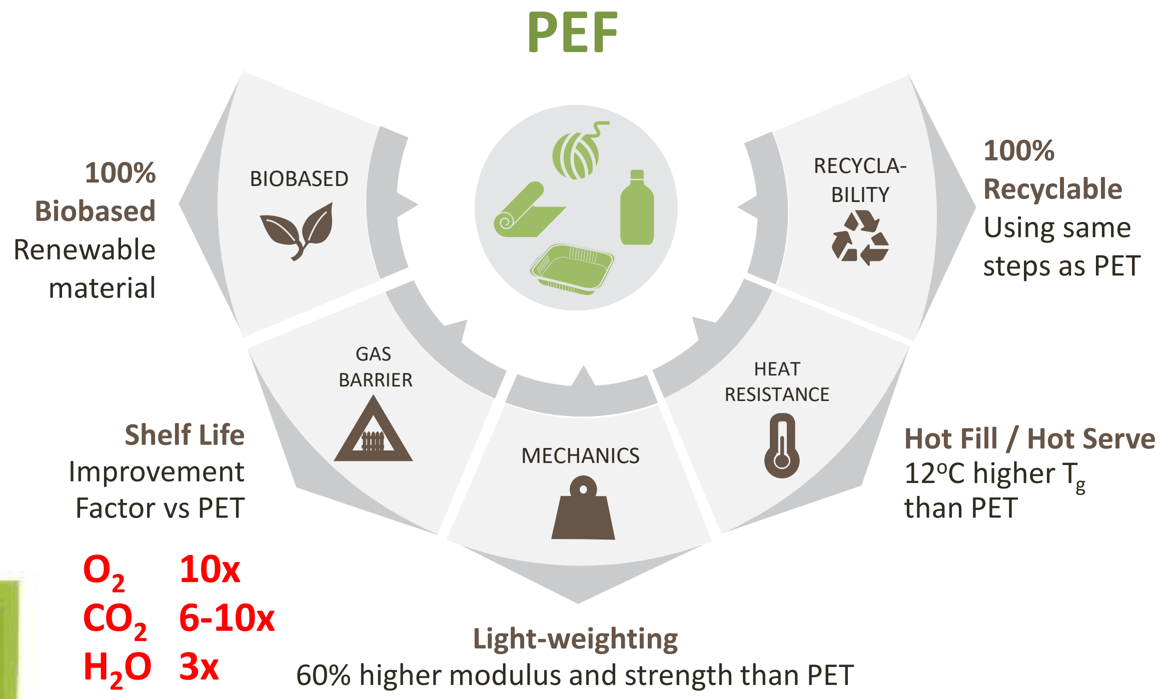
Carlsberg Group, LEGO, Nestlé, Henkel, Tereos, LVMH, kebony, Worley

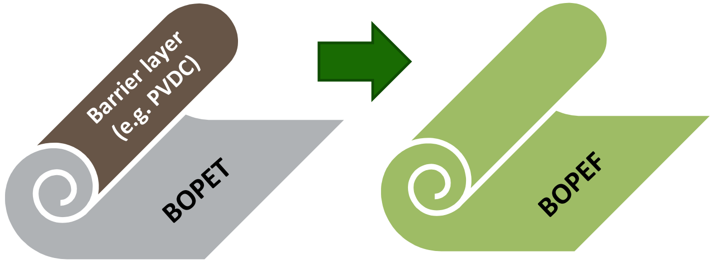
The PEFerence consortium aims to replace a significant share of fossil-based polyesters, such as PET as well as polyamide layers in multilayer packaging, and packaging materials like glass and metal with 100% bio-based polymer materials such as PEF.

Why PEF?

Trends in packaging:

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





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.



Feedstock - biorefining

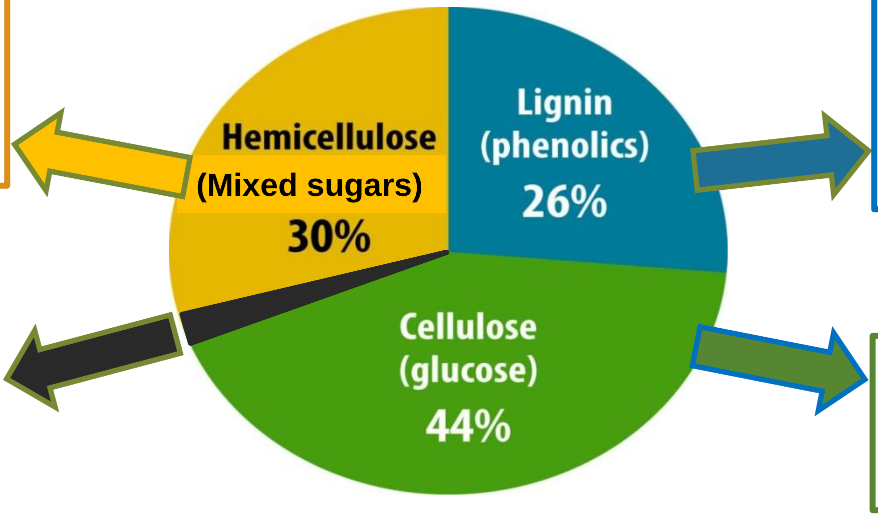
Biomass – Food, Materials & Energy

Pure Glucose is key starting point for most future monomers/polymers (>1Bnt/y)

Wood lignocellulose (LC):

330 kg mixed sugars per ton LC

50-70 kg extractables



250 kg dry lignin per ton LC

480 kg glucose per ton LC

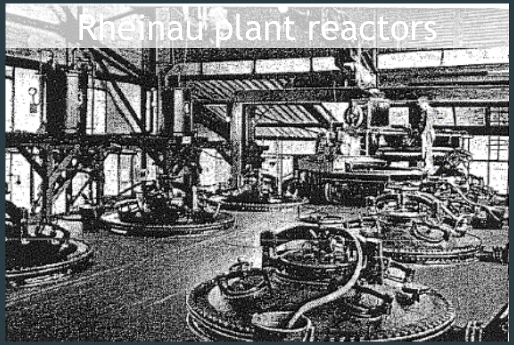
Bergius HCl – Leveraging 100 years of development

1900

Leveraging technology development

Commence Bergius Development
Technology needed in critical times


Regensburg plant


Rheinau plant reactors

- **1916**
  Began development of industrial process of saccharification; **Bergius process**

- **1948-'59**
  Modified **Rheinau process** (with sugar fractionation) (12,000 ton/yr)

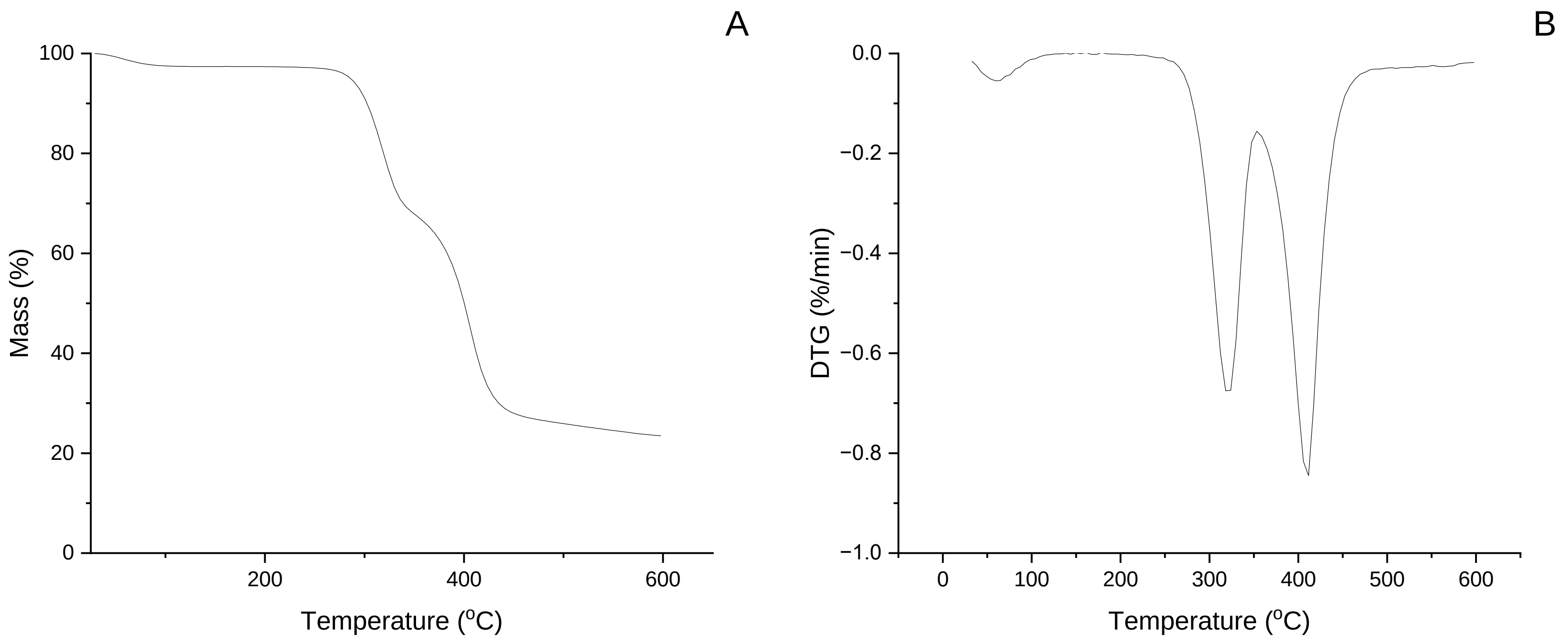
Modern Deployment

Current critical times need modern technology deployment

- **2013-today**
  Avantium develops Dawn Technology™, and opens pilot biorefinery in the Netherlands (2018)

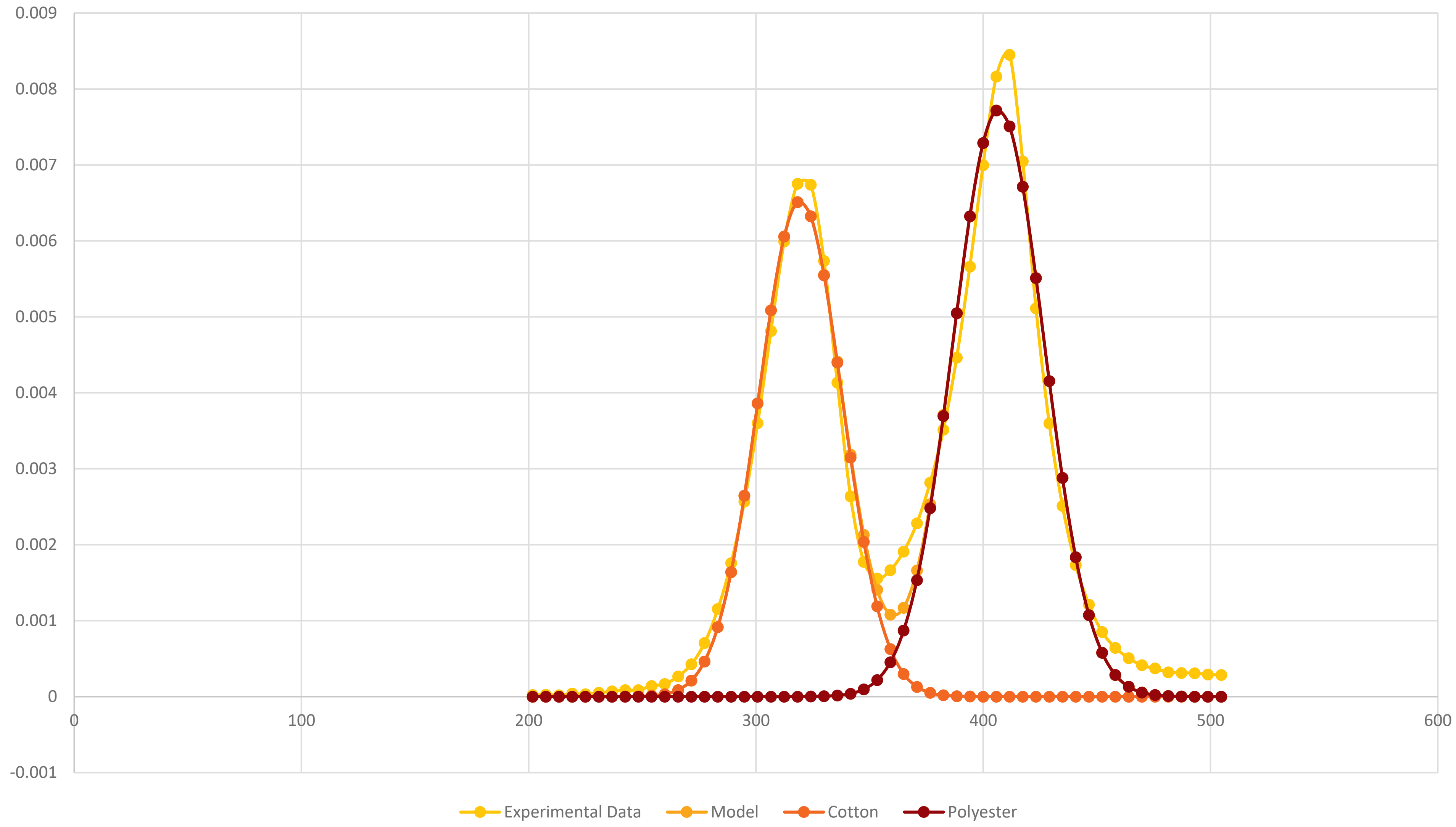
Cotton is also cellulose !
Can we recycle cotton or cotton/polyester blends ?

waste cotton/polyester police uniform polo’s



TGA (A) and DTG (b) of blue postconsumer polycotton textile

Starting material analysis- TGA



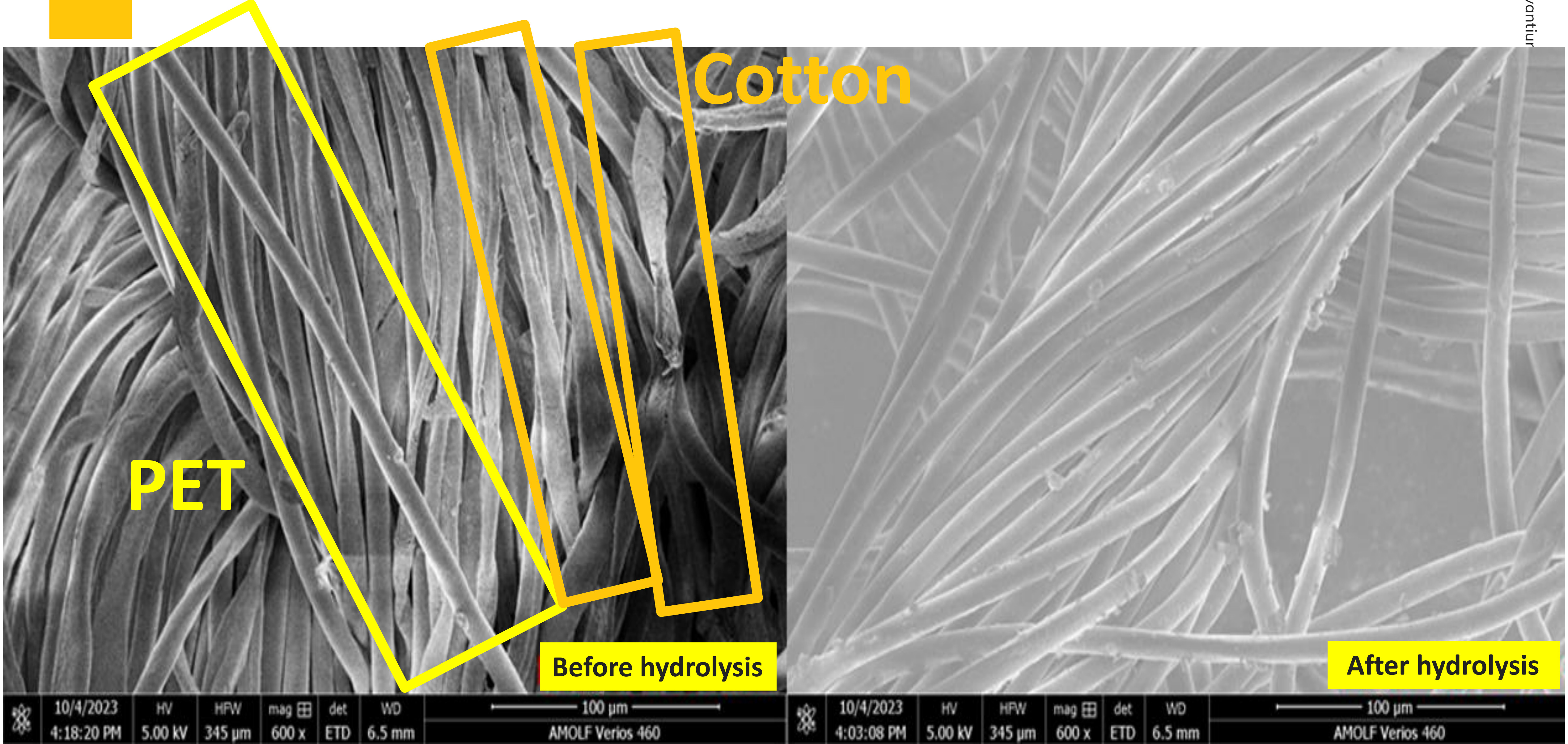
Cotton/polyester

Label
63/38

NREL method
44/56

TGA
44/56

TEM of polyester/cotton blends before and after cotton hydrolysis



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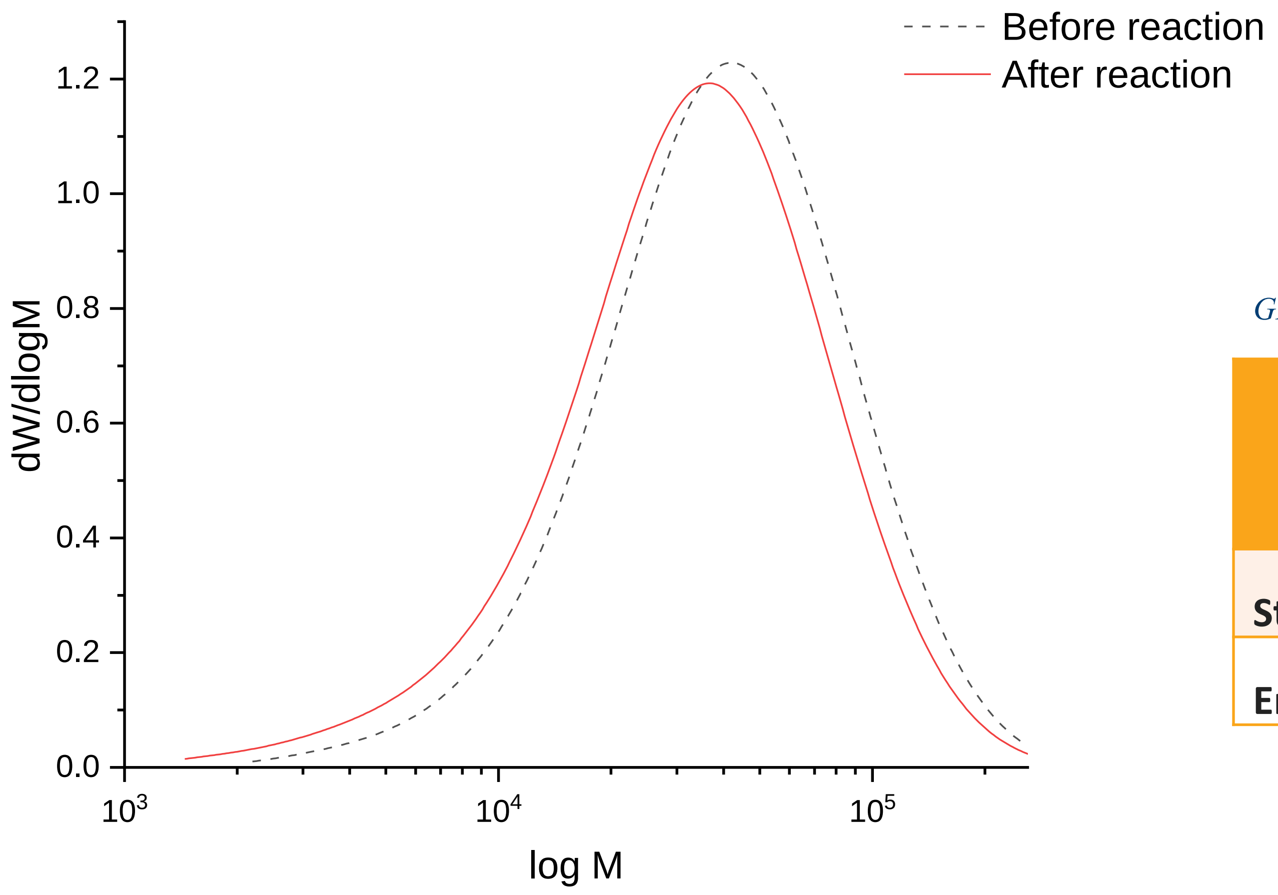
Characterization PET after cotton hydrolysis



Differential molar mass distribution of PET fibers before and after acid hydrolysis.

GPC of PET from waste textile.

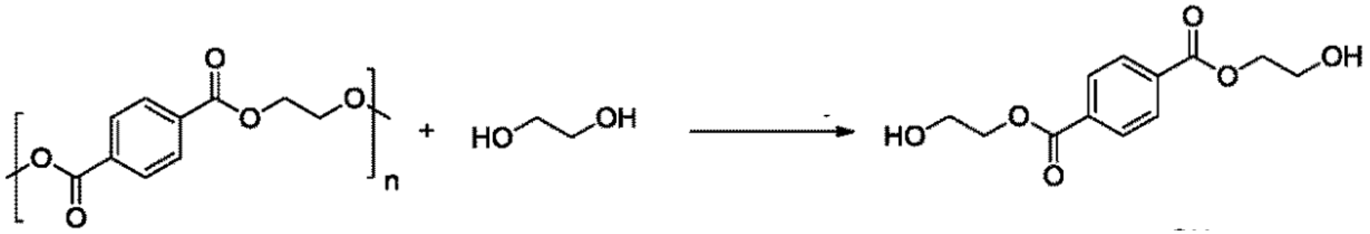
	M_n (kDa)	Mw (kDa)	PDI
Starting material	28.9	48.3	1.7
End material	22.3	41.7	1.9

- GPC: Minimal degradation of polyester after acid hydrolysis

Recycling PET to BHET

Glycolysis:

- catalyst
- 200°C, 4h



After hydrolysis, before glycolysis
(PET)

After glycolysis
(BHET)

Textile hydrolysis in Pilot Plant !

10mL → 1L (lab) → 200L (PP)

[Textile reactor filling.mp4]

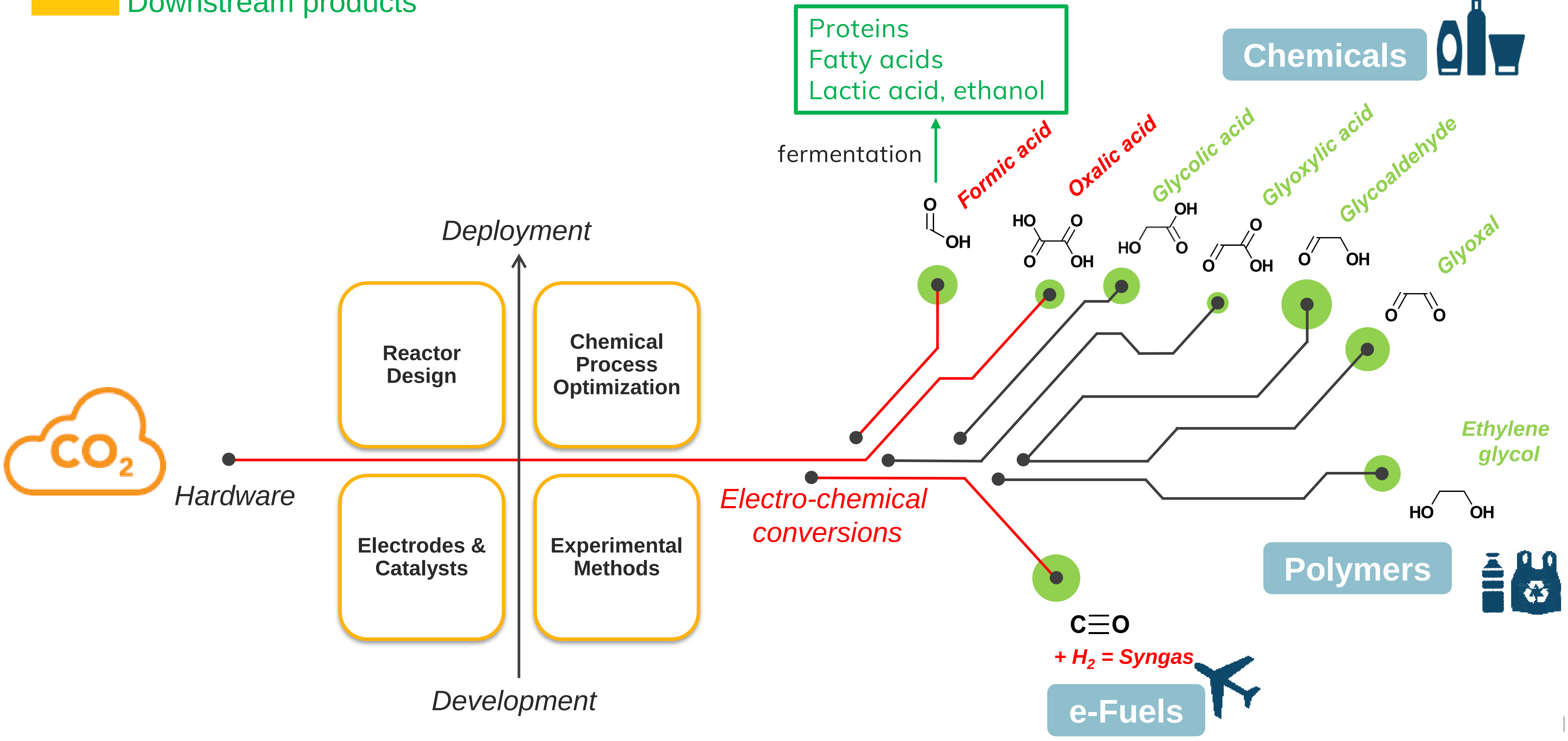
Feedstock – CO_2

Avantium Volta Technology

Combining cutting-edge technology with versatility

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

Downstream products

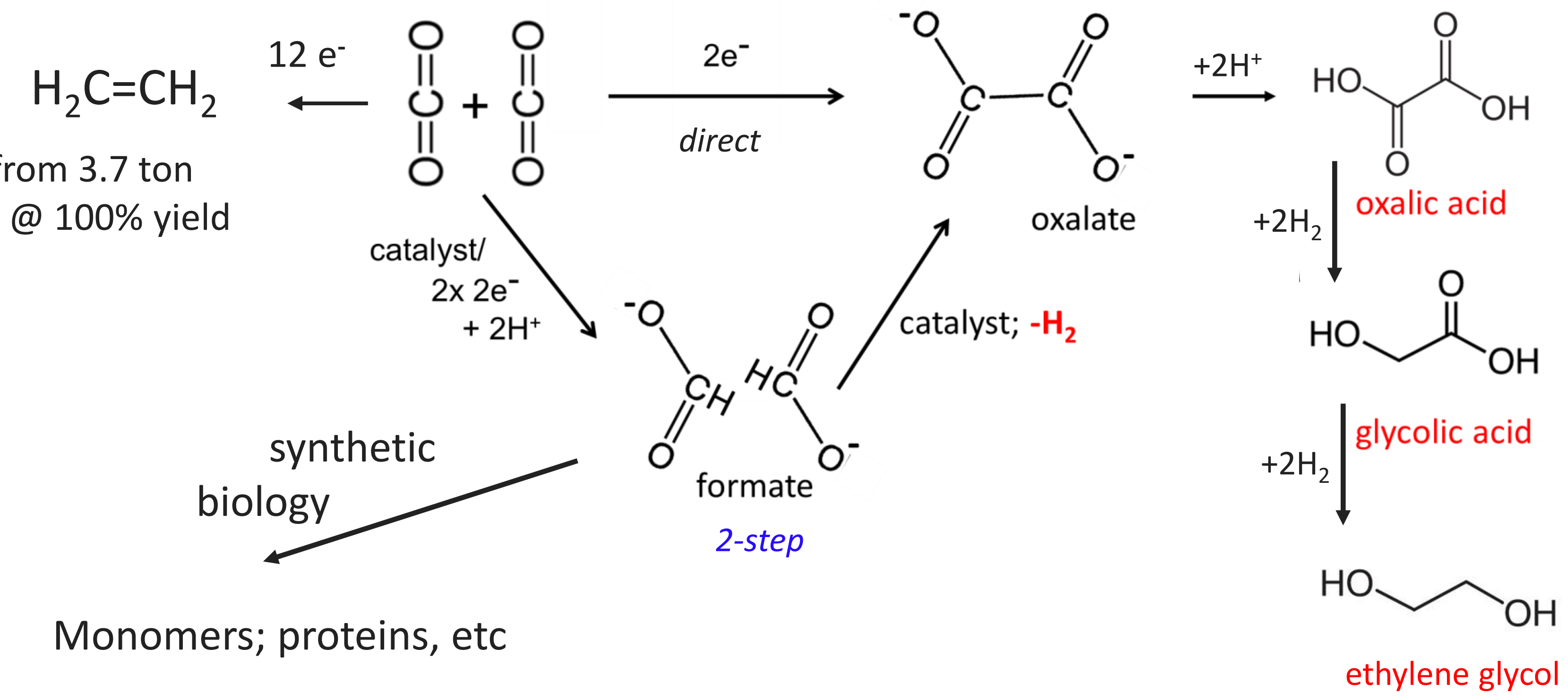


Benefits of CO_2 Reduction

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)



4e- (direct)
1 ton from 1 ton of CO_2 @ 100% yield

8e- (direct)
1 ton from 1.2 ton of CO_2 @ 100% yield

1 ton from 3.7 ton of CO_2 @ 100% yield

Monomers; proteins, etc

Demonstration at TRL5/6

CO_2 → Formate

Oxalic acid → Glyoxylic acid

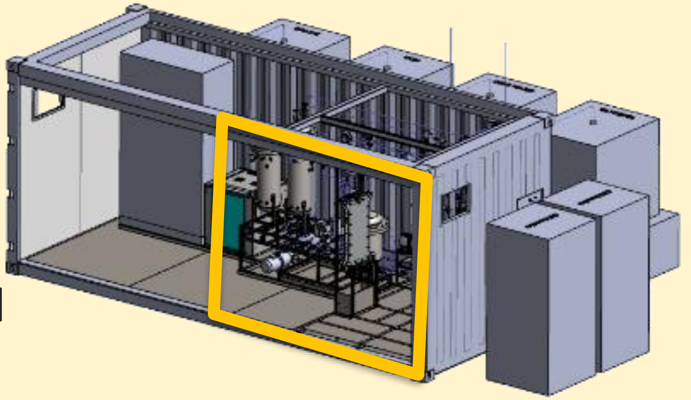
- 20 ft containers
- 0.25 – 0.5 kg/h
- Cell size 0.2 m^2

<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



University of Amsterdam
Faculty of Science

Bio-based polyesters

PLGA with high GA

avantium

Maria A. Murcia Valderrama

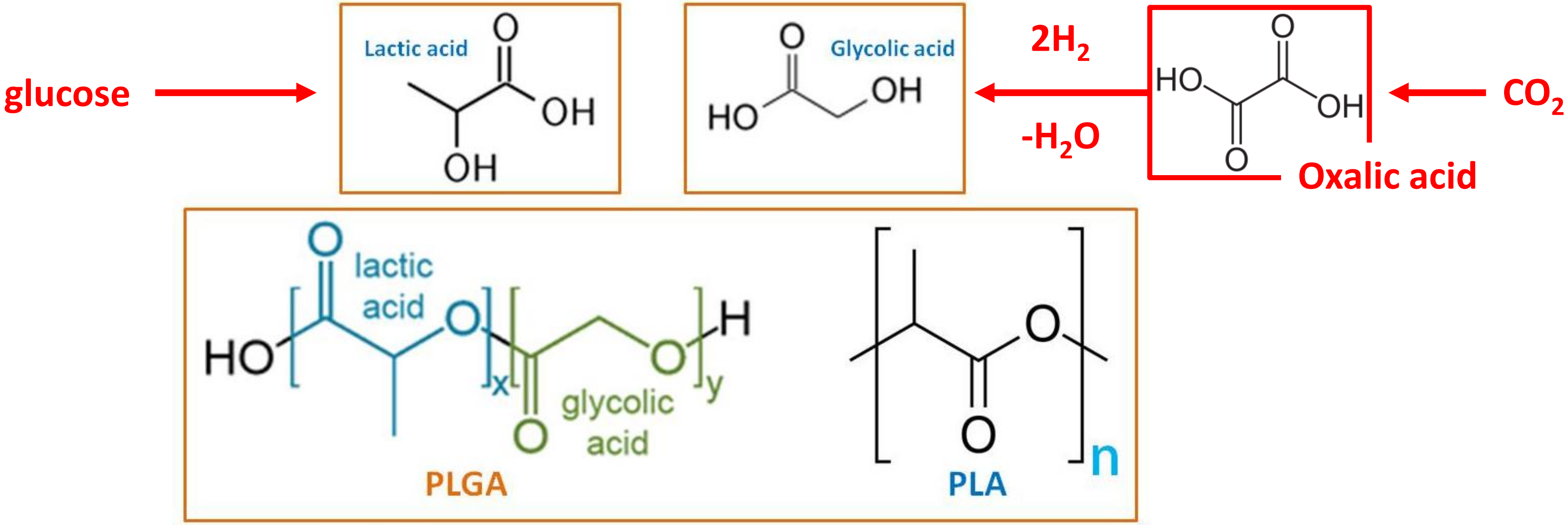
ACS APPLIED POLYMER MATERIALS

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*

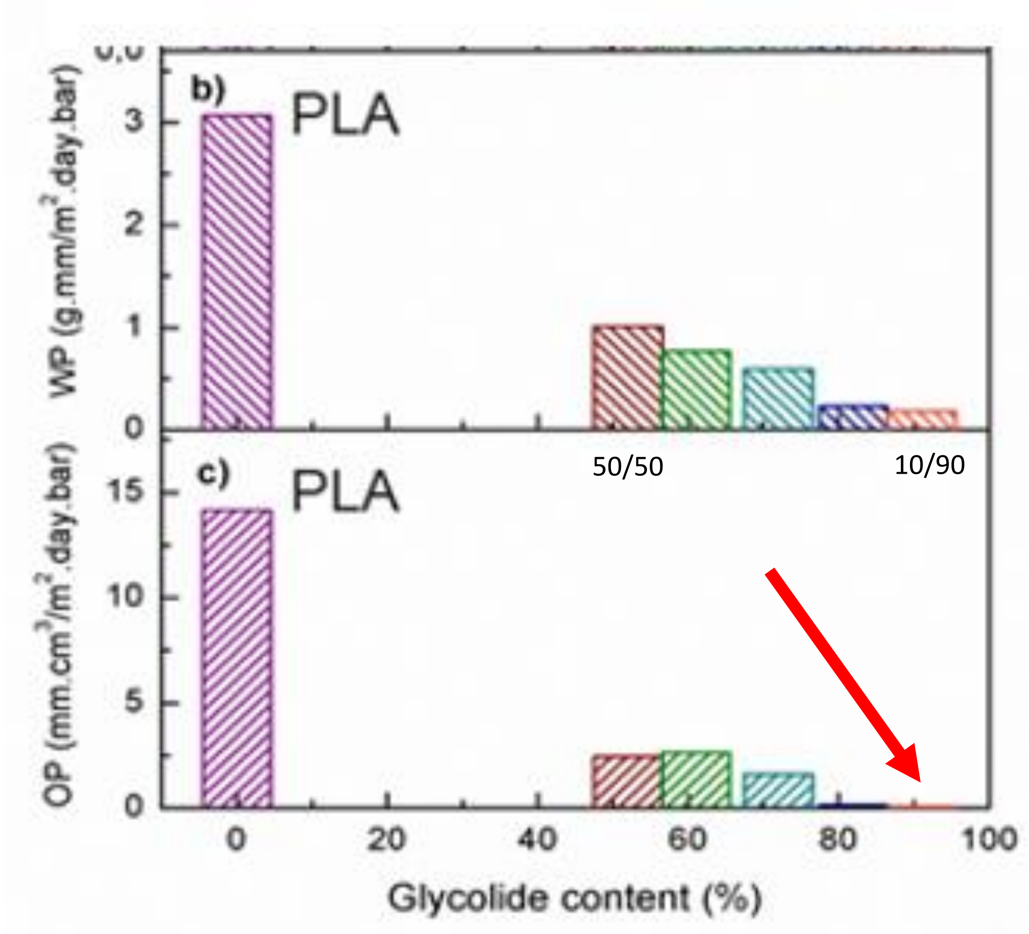


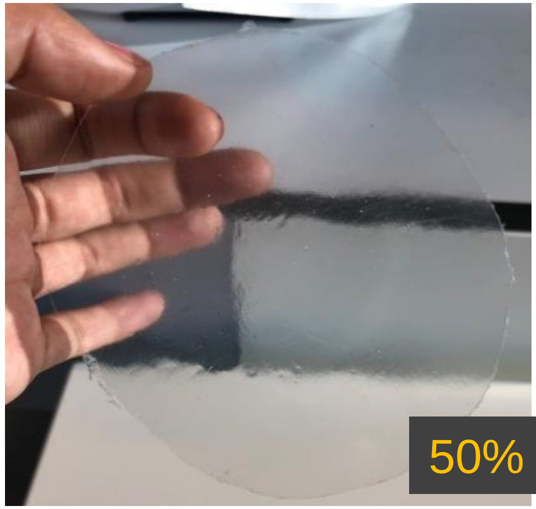
Oxygen permeability (OP) and Water permeability (WP) for PLGA copolymers at 70% RH and 30 °C

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%)





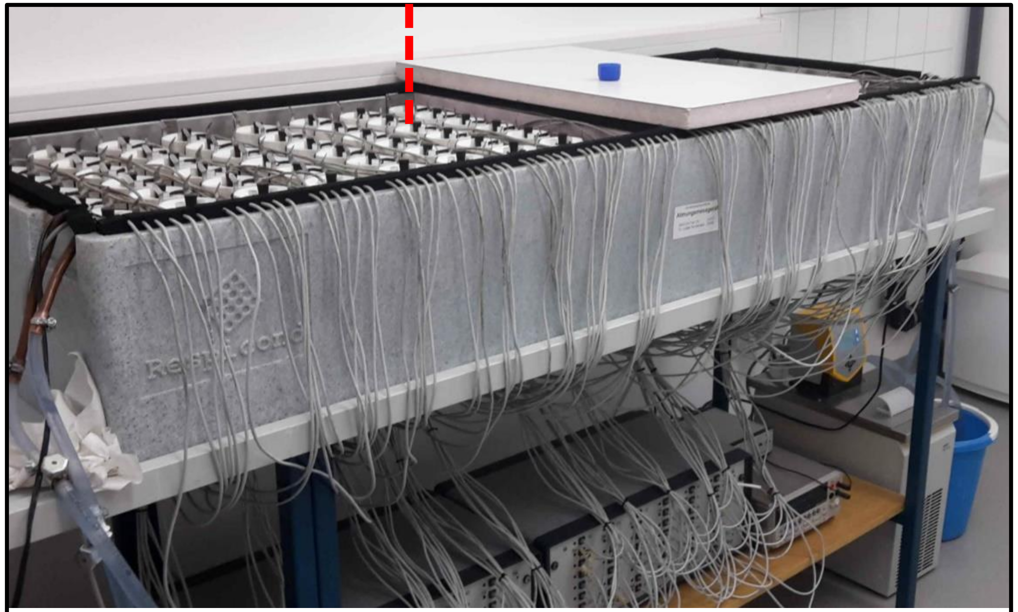
50% GA + 50% LA

90% GA potentially
90% CO_2-based

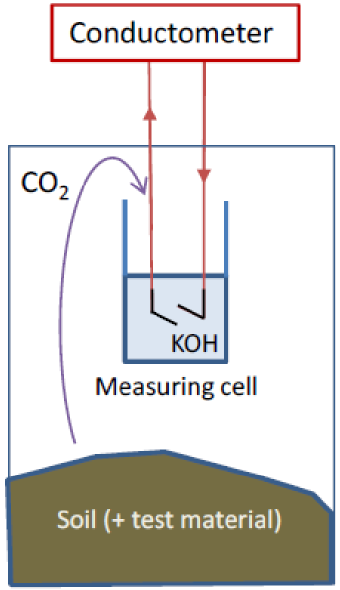
Yue Wang

Biodegradability of PLGA

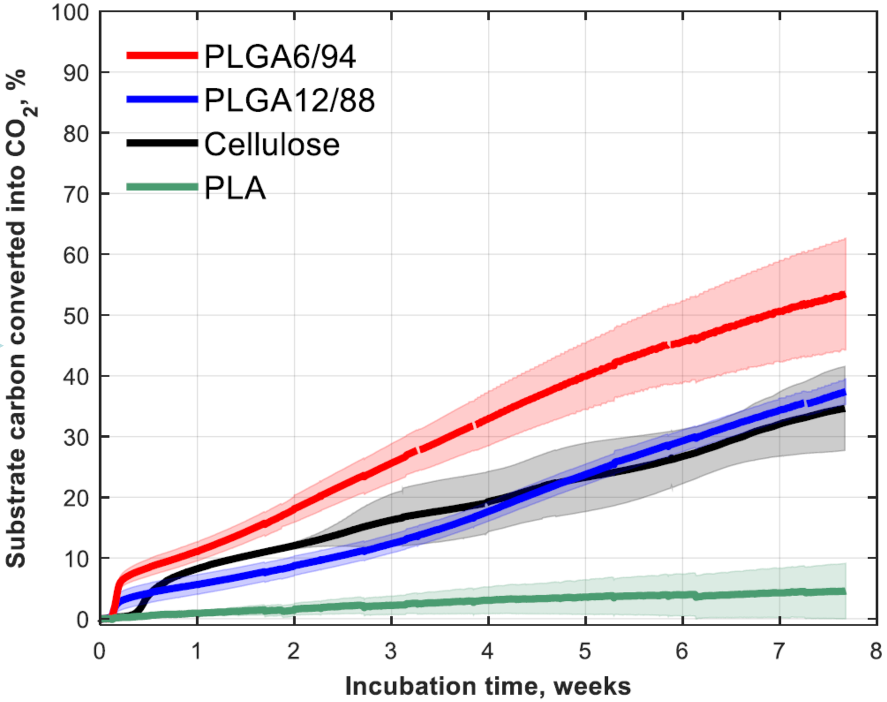
PLGA biodegradability in soil was determined under ambient conditions (25 °C)



Unit for high throughput biodegradability studies



Working principle



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

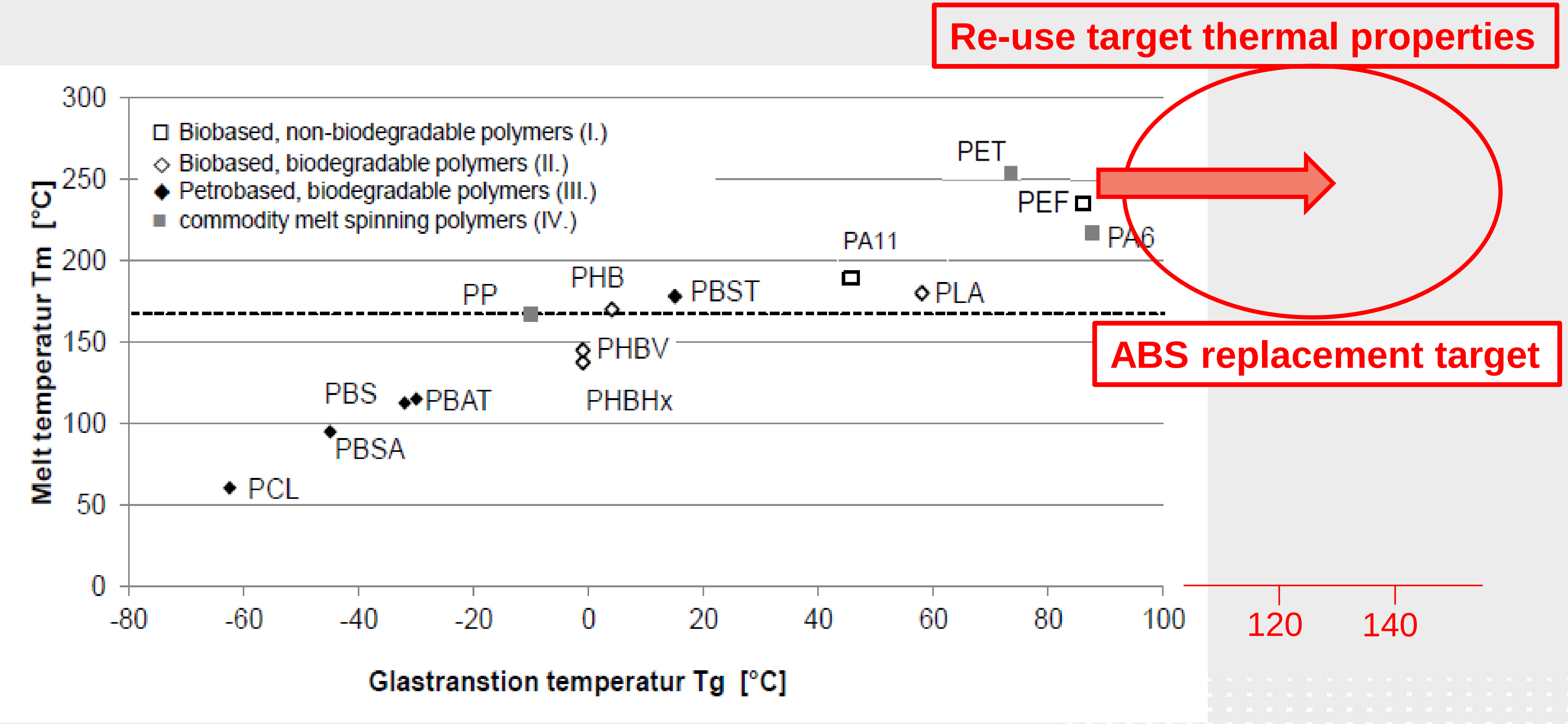
PLGA Market Potential

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)
- ....

Avantium | Parana

NWO TA project with LEGO and Avantium – Rigid copolyesters for high performance applications (5 PhD's)



Thesis Dolmans ITA, RWTH 2013

nature communications

Article https://doi.org/10.1038/s41467-022-34840-2

Overcoming the low reactivity of biobased, secondary diols in polyester synthesis

Received: 26 April 2022

Accepted: 7 November 2022

Published online: 30 November 2022

Daniel H. Weinland[1], Kevin van der Maas[1], Yue Wang[1], Bruno Bottega Pergher[1], Robert-Jan van Putten[1,2], Bing Wang[2] & Gert-Jan M. Gruter[1,2]

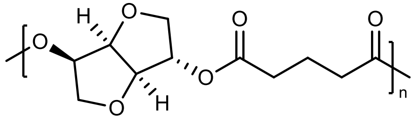
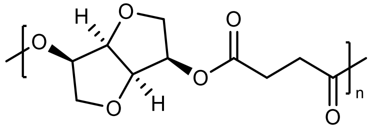
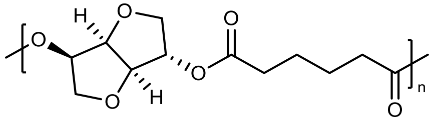
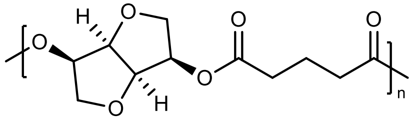
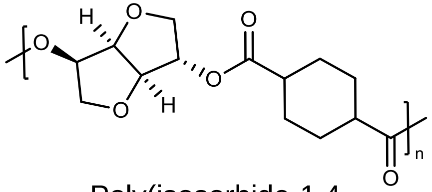
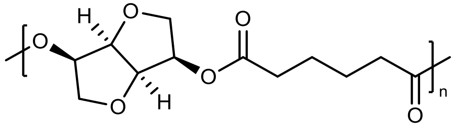
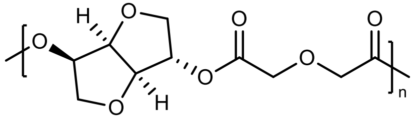
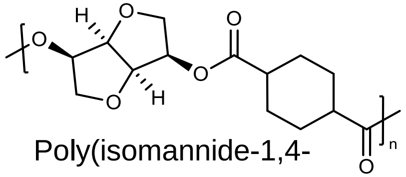
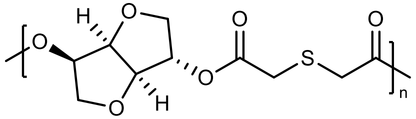
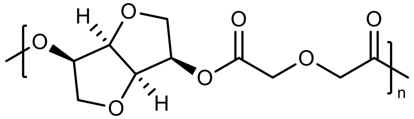
Daniel Weinland

Easy one pot synthesis

avantium

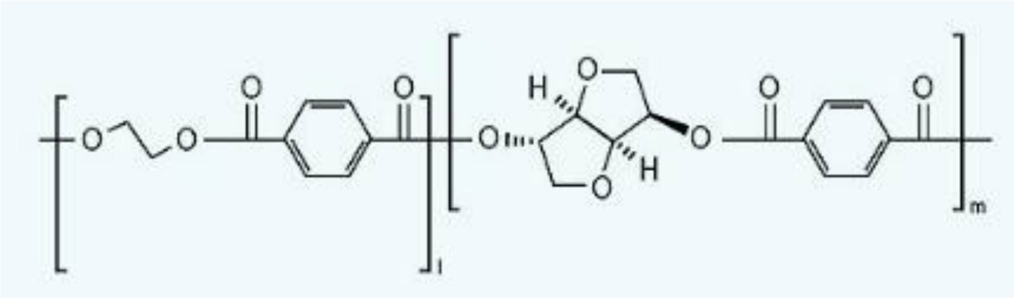
Scope

Higher molecular weights than previous works (indicated in (brackets))

Polymer	M_n [kg/mol]	T_g [°C]	Polymer	M_n [kg/mol]	T_g [°C]
 Poly(isosorbide glutarate)	41.0 (16.0)	52.4 (28)	 Poly(isomannide succinate)	28.3 (29.0)	82.3 (82)
 Poly(isosorbide adipate)	29.4 (10.1)	34.6 (20)	 Poly(isomannide glutarate)	40.1 (11.0)	50.9 (37)
 Poly(isosorbide-1,4-cyclohexanedicarboxylate)	40.1 (18.3)	133.4(128)	 Poly(isomannide adipate)	30.2 (20.0)	35.3 (28)
 Poly(isosorbide diglycolate)	22.3 (/)	83.0	 Poly(isomannide-1,4-cyclohexanedicarboxylate)	32.6 (/)	133.5
 Poly(isosorbide thiodiglycolate)	16.9 (/)	57.0	 Poly(isomannide diglycolate)	20.4 (/)	79.8

PET upcycling to PEIT:

Targeting Tg > 100 °C



The materials transition is a great chance to enhance and re-design our plastic portfolio

- Polyesters are the logical choice for:
  - Winning techno-economics from carbohydrates (sugars) and CO_2 (atom efficiency),
  - Product performance and fit in the industry value chain (compete on performance, on top of cost)
  - Circularity and fit in the installed base of mechanical recycling (close the loop)
- The number of sustainable polyester materials that we can produce from CO_2 and biomass is endless!

University of Amsterdam
Van 't Hoff Institute for Molecular Sciences

Acknowledgements

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IMPRESS
NWO
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VU Vrije Universiteit Amsterdam
ocean
IBED Institute for Biodiversity and Ecosystem Dynamics