Sustainable Polyesters to Replace High T_g CommodityPlastics

Robert-Jan van Putten

24 April 2025

Where are we today?

Some plastics facts & figures*

The bulk of this material costs <€2/kg

- 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% average demand growth per year

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

How much do we spend on plastics?

- World population ~8 billion
- Yearly consumption 50 kg per person (NL ~120 kg)
- ~€100 per person per year (NL ~€240)
- GDP per capita DK ≈ €60,000
- Sustainable alternatives are not affordable???

What premium are we talking about for Plantbottle PET ?

n PTA + n MEG → --$(OCH_2CH_2OCOC_6H_4CO)_n$-- + 2n H_2O
865kg + 323kg → 1000 kg + 188 kg

MEG is 27% of feedstock; bio-MEG is 100% more expensive → Plant bottle PET is 27% more expensive

Coca-Cola: 2 Mt/yr PET (@€1200/ton) = €2.4 Bn/yr → 27% premium is €650M/yr.
Consumer is blamed! (not willing to pay)

A problem for the consumer? 1L Coca-Cola PET bottle is 23.8 g (42 bottles/kg) → €0.0286/bottle.
27% premium bottle is **€0.0077 per bottle !**
365 1L bottles/year (8.3 kg) → €3,00 premium

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

ELSEVIER

UNIVERSITY OF AMSTERDAM

Maria Zwicker

Applying an attitude network approach to consumer behaviour towards plastic

Maria V. Zwicker[a,*], Hannah U. Nohlen[a], Jonas Dalege[a], Gert-Jan M. Gruter[b], Frenk van Harreveld[a,c]

sustainability

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]

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

ELSEVIER

75% of participants was prepared to pay €0.05 (or more) for 1L bottled water

Consumer attitudes and willingness to pay for novel bio-based products using hypothetical bottle choice

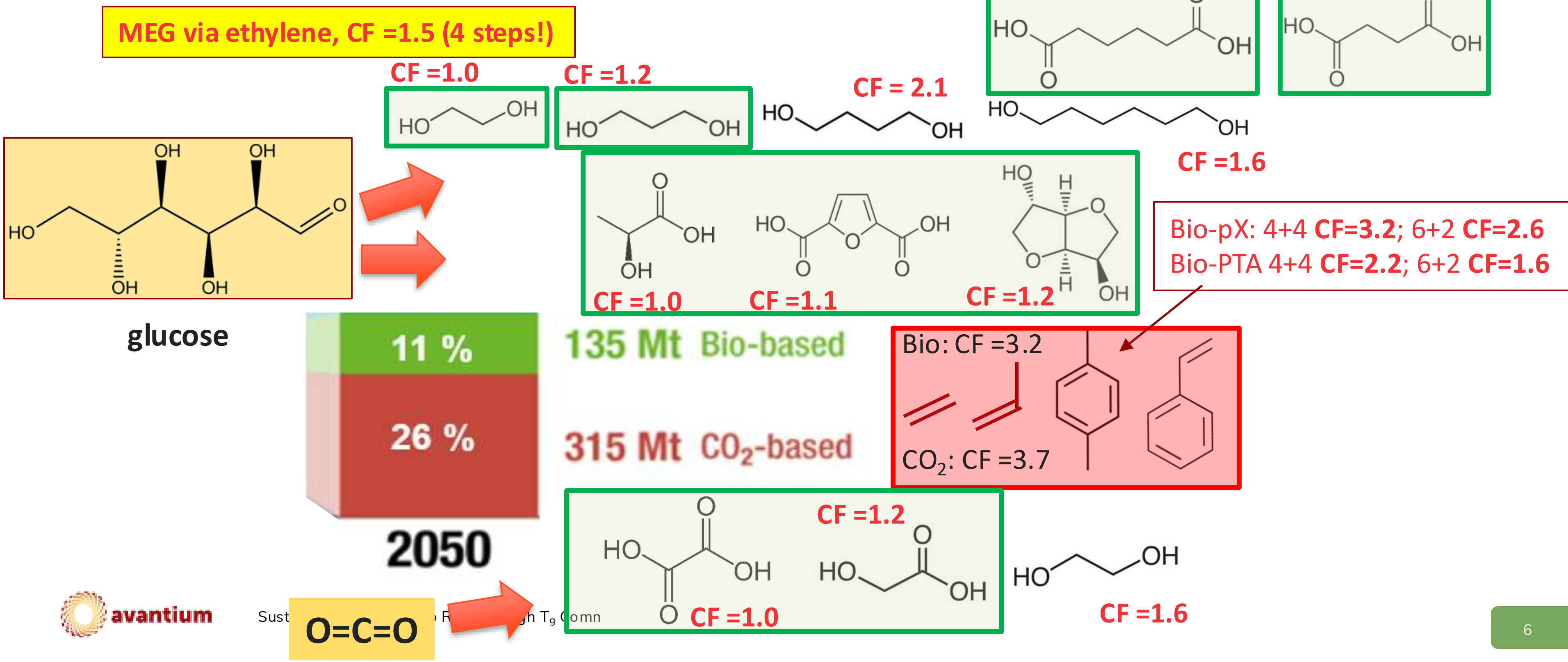
Maria V. Zwicker [a,*], Cameron Brick [a], Gert-Jan M. Gruter [b,c], Frenk van Harreveld [a,d]

Which molecules make (most) sense from Glucose and CO_2

(technologically and economically)

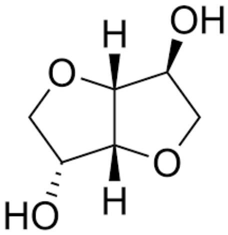
CF = ton glucose or CO_2 per ton product @ 100% yield

*in some cases 2O from O_2 is incorporated

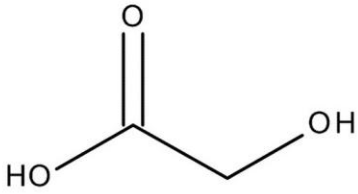


Promising and available monomers

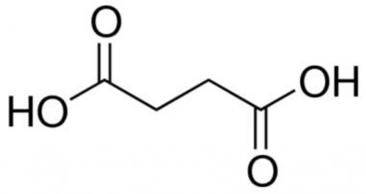
From (potentially) sustainable sources



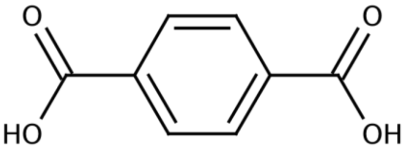
Isosorbide



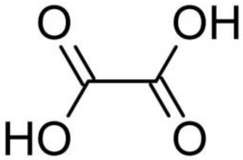
Glycolic acid



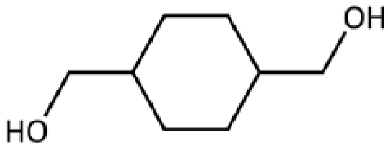
Succinic acid



Terephthalic acid



Oxalic acid



1,4-cyclohexanedimethanol
(CHDM)

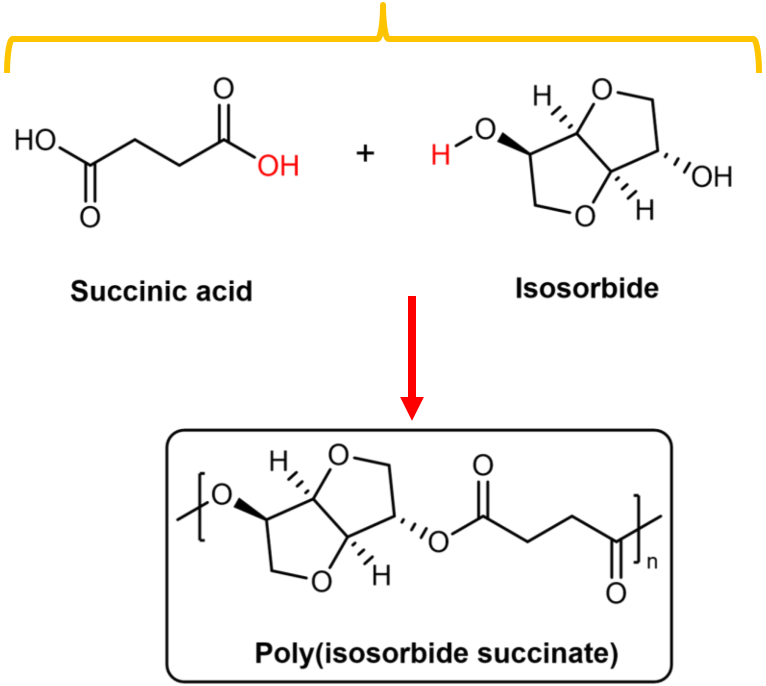
Our target: isosorbide

- (Co)polyesters with isosorbide + renewable diacids
- Example: Poly(isosorbide succinate)

Diacid/diester	M_n [kg/mol]	PDI	T_g [°C]	Ref.
Succinic acid	3.1 [a]	1.6	68	9
Succinic acid	2.9	1.3	73	30
Succinic acid	1.2 [a]	2.5	59	31
Succinic acid	7.3 [b]	1.7	65	12
Dimethyl succinate	13.4 [a]	1.6	56	11
Succinic anhydride	2.9 [a]	1.7	74	32
Succinyl chloride	8.6 [a]	1.9	78	33
Succinyl chloride	7.7 [a]	1.8	36	29
Succinyl chloride	10.8 [b]	2.1	56	34
Succinyl chloride	7.5 [a]	1.4	65	35

Molecular weights were determined by SEC. [a] Polystyrene was used as a SEC calibration standard. [b] Poly(methyl methacrylate) was used as a SEC calibration standard.

Can both be made from glucose



NOT possible to make sufficient mol. weight

nature communications

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

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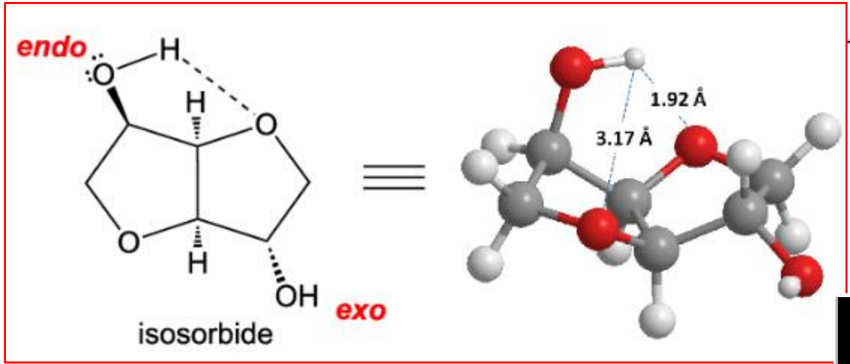
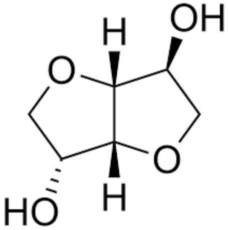
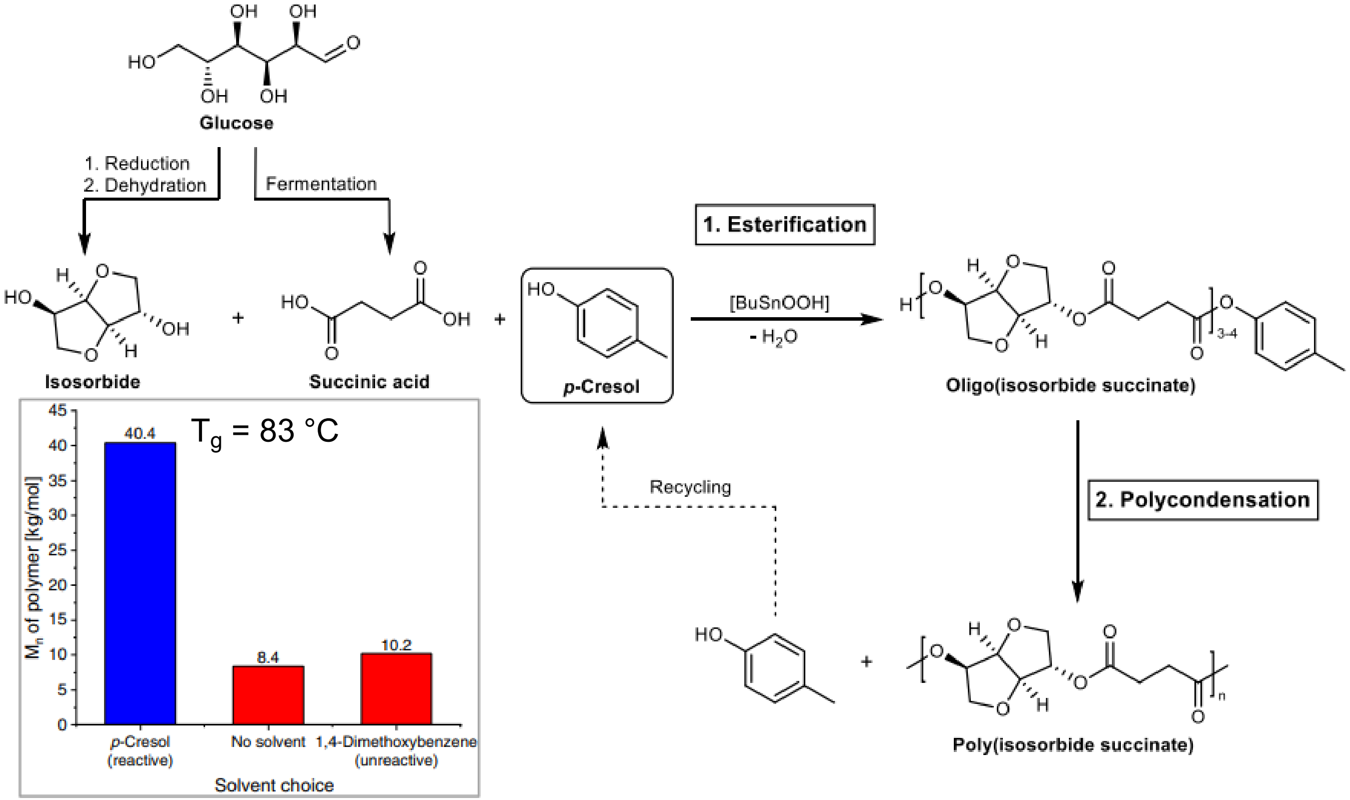


Daniel Weinland



How did we overcome this?



Polymer Chemistry

ROYAL SOCIETY OF CHEMISTRY

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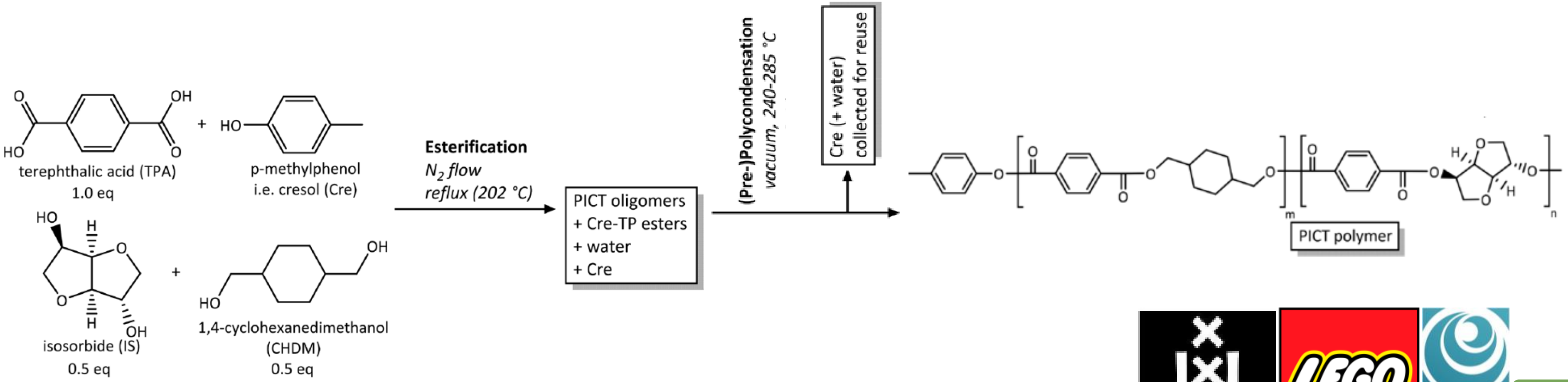
Bruno Bottega Pergher

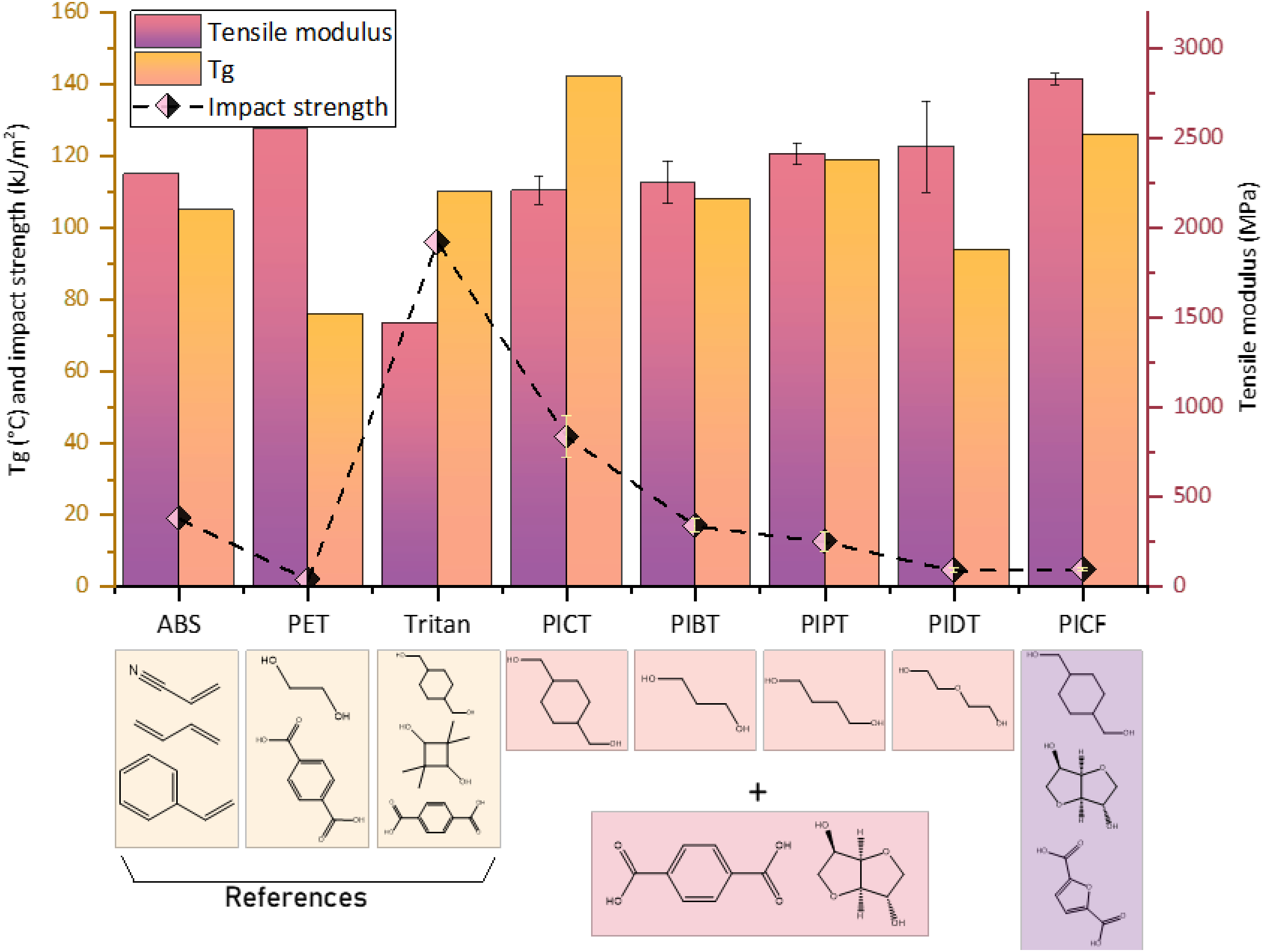
Reactive phenolic solvents applied to the synthesis of renewable aromatic polyesters with high isosorbide content†

Bruno Bottega Pergher,[a] Narcisa Girigan,[a] Sietse Vlasblom,[a] Daniel H. Weinland,[a] Bing Wang,[b] Robert-Jan van Putten[a,b] and Gert-Jan M. Gruter *[a,b]



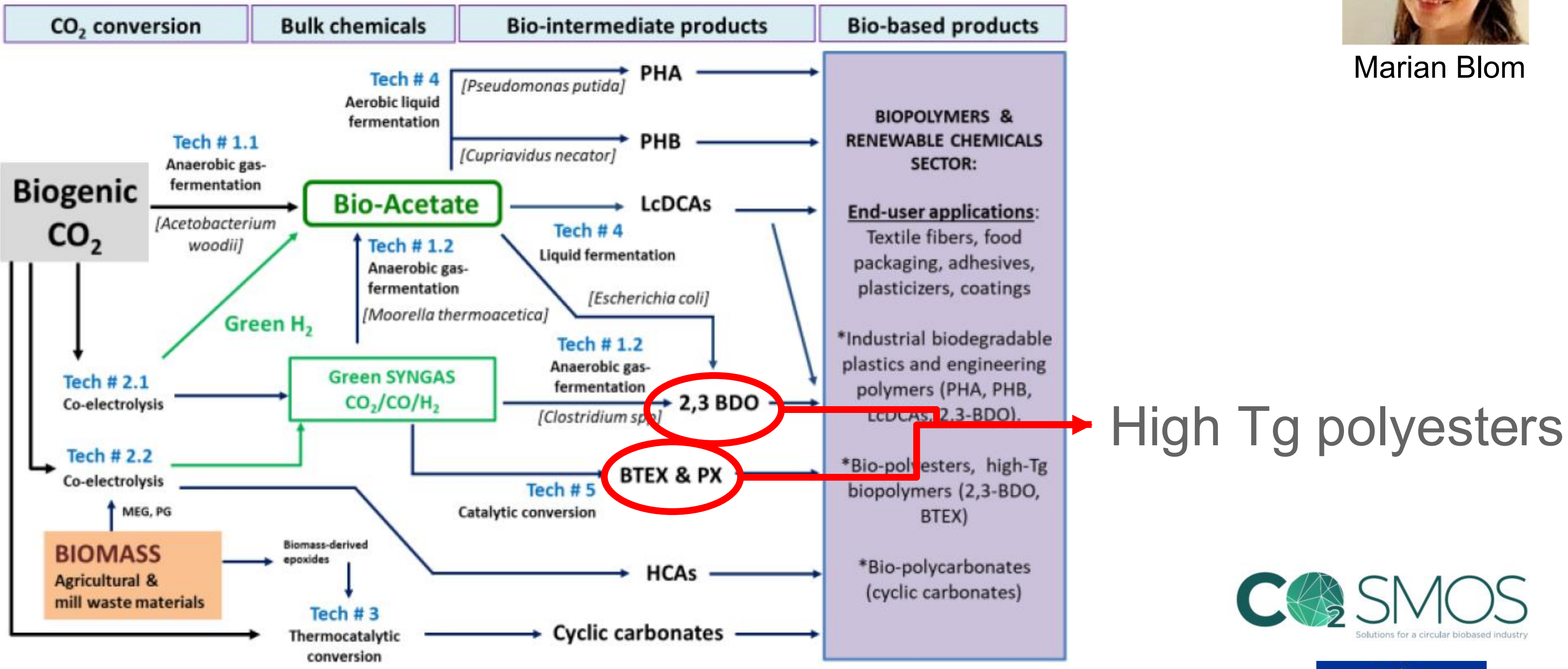
ABS

- Acrylonitrile, butadiene, styrene
- Essentially non-recyclable
- Market ~15 Mt/yr @ ~€2.10 per kg
- Consumer electronics, toys, car parts, etc.
- Cost of application dwarfs cost of material



The CO2SMOS project (15 partners)

Marian Blom



CO2SMOS
Solutions for a circular biobased industry

The CO2SMOS project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101000790.

Polyesters synthesized P23BET (a PETG)

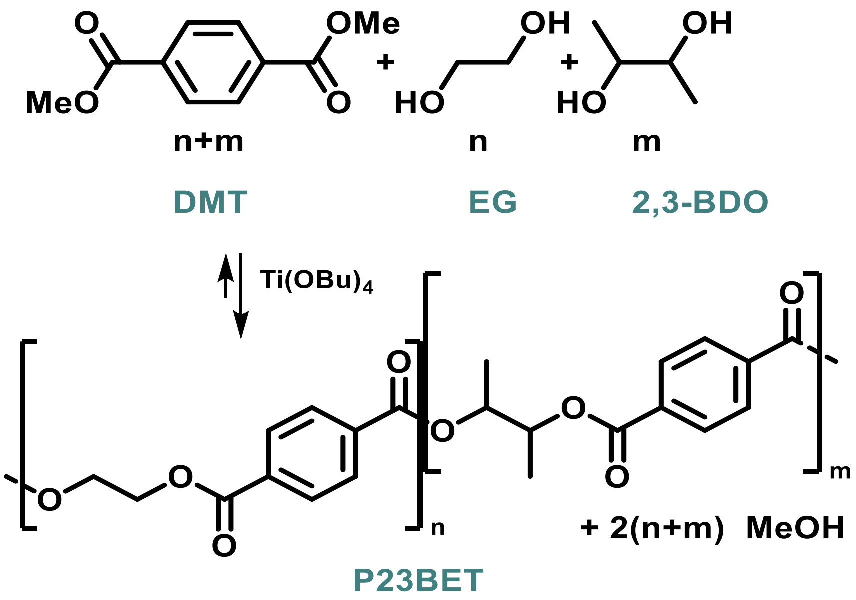
TE step
- Excess diol
- Overnight
- T_{oil} 210 °C

PC
- Reduced pressure (remove excess)
- T_{oil} 210 → 250 °C

High % 2,3-BDO:
x Reaction time ↑
x Molecular weight ↓

Polymers[1]

2,3-BDO %	Mn (kDa)	T_g (°C)
28 %	31.5	88
43 %	24.1	92
46 %	26.6	94
58 %	24.6	99
78 %	18.1	104
100 %	9.8	104

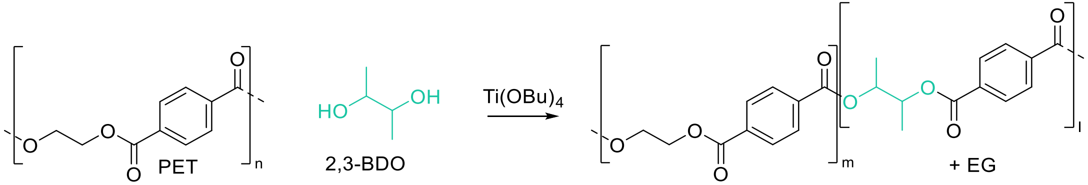


1. Blom, M.; Van Putten, R.-J.; Van Der Maas, K.; Wang, B.; Klink, G. P. M. V.; Gruter, G.-J. M.. *Polymers* **2024**, *16* (15), 2177. https://doi.org/10.3390/polym16152177.

Chemical upcycling

From PET synthesis:

R-PET from supermarket
tomato & grapes packaging



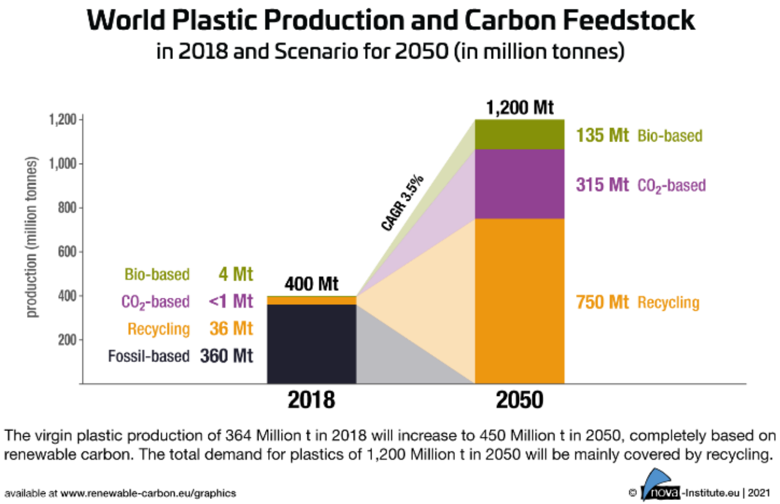
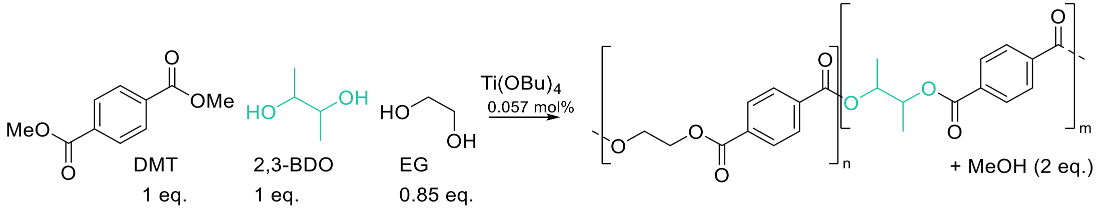
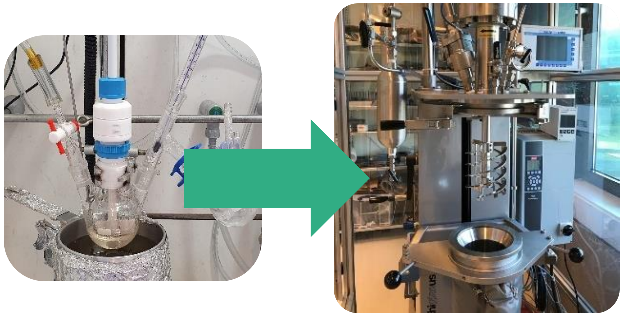


Figure World Plastic Production and Carbon Feedstock. Nova insttute: https://renewable-carbon.eu/publications/product/world-plastic-production-and-carbon-feedstock-in-2018-and-scenario-for-2050-graphic/

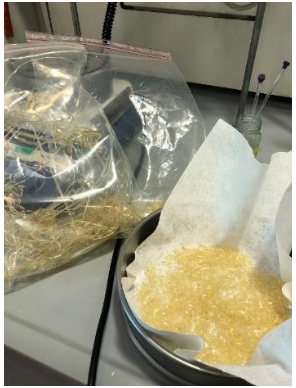
Polyester at larger scale





final polyester			
2,3-BDO %	Mn (Kda)	Mw (Kda)	Tg (°C)
34	15.5	36	82

Long reaction time overnight
Degradation → sample Mn 20



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Questions?