University of Amsterdam
Faculty of Science

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INDUSTRIAL HEAT+POWER 12,13,14 OKT. 2021 BRABANTHALLEN

Koolstof boven de grond als grondstof voor toekomstig plastic
Power to Chemicals

Gert-Jan Gruter, 14 oktober 2021

avantium

Catalysis

Foundational Technology and Expertise

Leading Systems and Services Provider for Catalyst R&D

Renewable Chemistries

Novel Chemical Technologies to Transform Renewable Carbon Into Chemical Building Blocks

DAWN® Technology: 2G glucose
RAY ® Technology: 1 step bio-MEG
VOLTA® Technology: e-chem

Renewable Polymers (formerly Synvina)

Polyesters

YXY® Technology: FDCA & PEF

Ticker: **AVTX**
Amsterdam & **Brussels**

HQ Amsterdam Science Park (VOLTA)
ChemiePark Delfzijl (DAWN and RAY)
Chemelot Geleen (YXY)

100+
patent families
Avantium, Furanix
Liquid Light

230

>75% scientists
20+ nationalities
30% female

University of Amsterdam

Avantium Corporate Technology
UvA - Industrial Sustainable Chemistry

Applied research with focus on sustainable polymers
With funding from EU, NWO, and Industry (e.g. Avantium, LEGO)

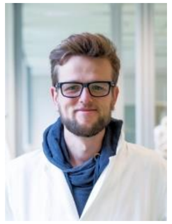
UNIVERSITY OF AMSTERDAM

IMPRESS NWO Funded by European Union avantium LEGO RESEARCH PRIORITY AREA SUSTAINABLE CHEMISTRY

Universiteit Leiden ELCOREL VU VRIJE UNIVERSITEIT AMSTERDAM ocean IBED Institute for Biodiversity and Ecosystem Dynamics

UvA Industrial Sustainable chemistry (ISC):

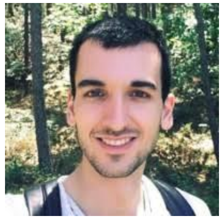
PhD students UvA:

Maria Murcia Valderrama

Eric Schuler

CO_2-based polymers & monomers



Jorge Bueno Moron
Lignocellulosic
Isosorbide monomer
Chemical recycling



Daniel Weinland

Bruno Bottega Pergher

Kevin van der Maas

Polymer Synthesis

Yue Wang
Biodegradation

Maria Zwicker
Social Psychology

PhD's with U Leiden:


Matt Philips

Davide Pavesi

Electrocatalytic CO_2 reduction

Post Docs:


Ewa Skoczynska

Lei Tian

Environmental plastics – PET fibers

Gert-Jan Gruter
Professor ISC

Daily supervision (Avantium Corp Tech):

Bing Wang
Polymers

Robert-Jan van Putten
Science Park

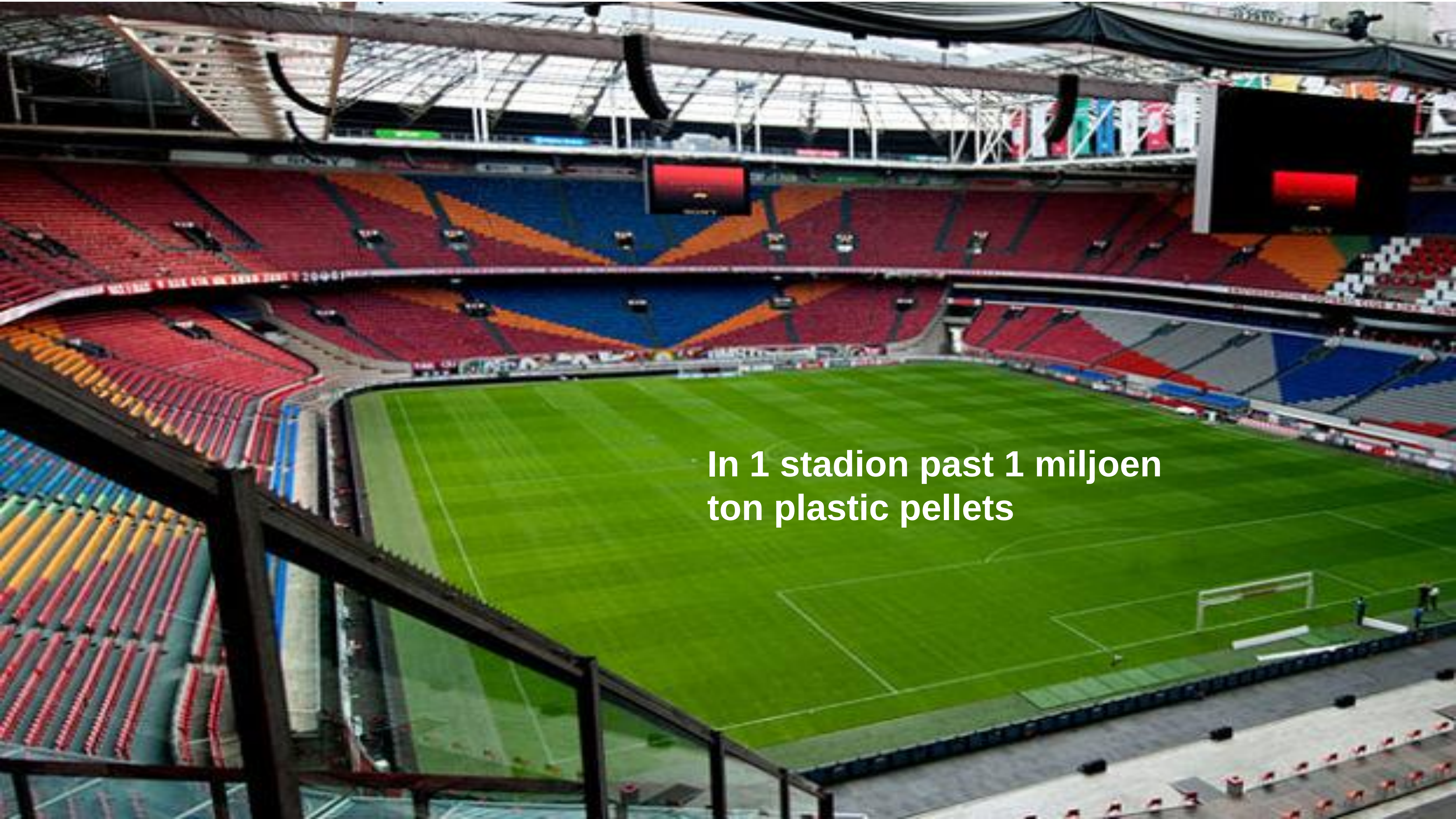
Gerard van Klink
Zekeringstraat

Plastics – waar staan we vandaag ?

Feiten over plastic*

- 2020 plastic productie: 400.000.000 ton (400 Mt) per jaar
- 5-6% van alle olie → plastics + 5% van de energie voor produktie
- Vandaag 2 Mt/ jaar bio-based (0.5% ☹)
- 9% van alle plastic ooit gemaakt werd gerecycled ☹
- 8 Mt/ jaar “lekt” in het milieu ☹
- > €1000 miljard geinvesteerd in fabrieken voor plastics
- 3-5% groei per jaar

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


In 1 stadion past 1 miljoen
ton plastic pellets

Plastics – waar staan we vandaag ?

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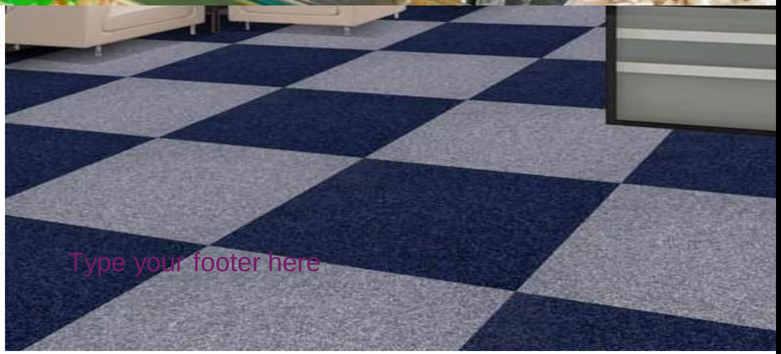
Mirrors
Hoods
Tailgates
Trunk Lids
Header &
Nose Panels
Tail
Lights
Radiator
Supports
Step
Bumpers
Grilles
A/C
Condensers
Bumpers
Headlights
Fenders
Radiators
Doors


NERES
7
HUNTELAAR
9
DE LIGT
4




© picture-alliance/Photoshot


NATIONAL GEOGRAPHIC
PLANET OR PLASTIC?
18 billion pounds of plastic ends up in the ocean each year.
And that's just the tip of the iceberg.


Volkskrant 4 January 2020

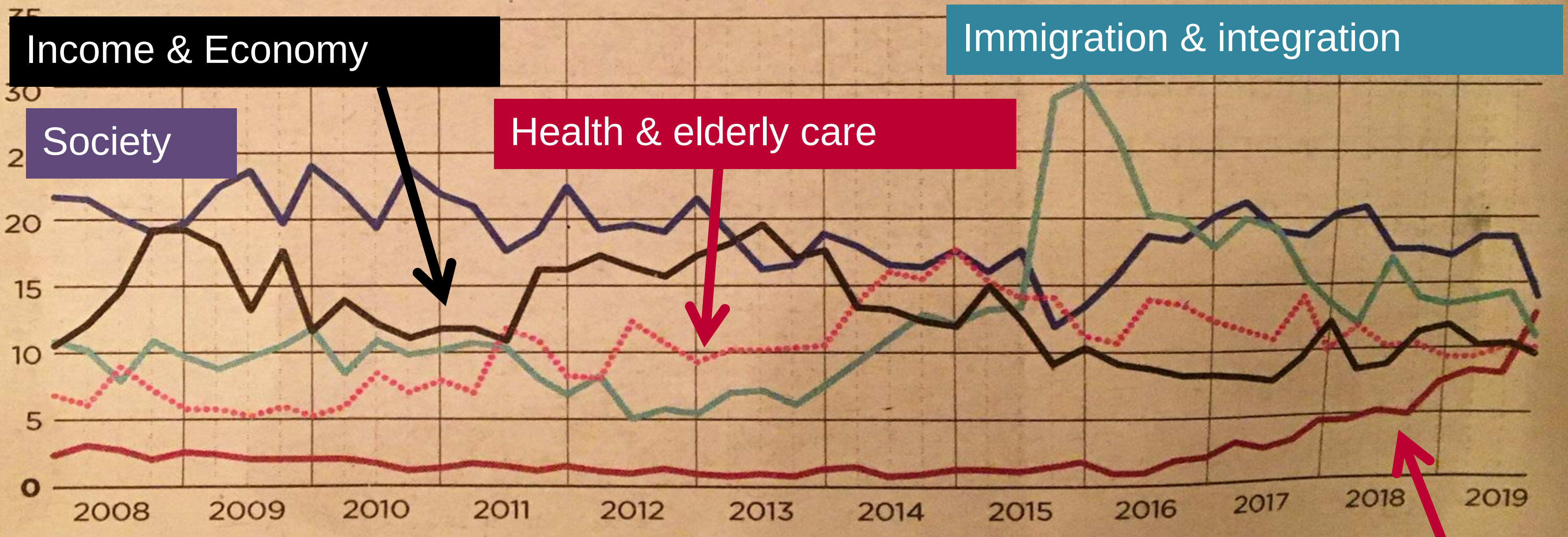
INFOGRAPHIC

De nieuwste cijfers

Hoe denken Nederlandse burgers over de staat van het land? Het SCP publiceerde daarover deze week de nieuwste cijfers. Wij vroegen ons af: waar maken Nederlanders zich druk om en waar moet de regering meer geld aan uitgeven?

WAAR MAKEN WE ONS HET MEEST DRUK OM?

Nationaal probleembesef: de vijf belangrijkste thema's waar Nederlanders (18+) zich druk over maken, in %



WAAR MOET MEER GELD NAARTOE?

Netto aandeel* van de Nederlandse bevolking (18+) dat meer uitgaven wil aan politiek doel (2019 - 4de kwartaal)

tegen is, in procentpu...

Graphic:

...estrijden van

De plastic transitie

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]

ALWAYS START WITH WHY

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%)

Source: @ CIEL


Emissions from the Plastic Lifecycle
Annual Emissions from the
Plastic Lifecycle
189
Coal
Plants
0.86
Gt CO_2e
295
Coal
Plants
1.34
Gt CO_2e
615
Coal
Plants
2.80
Gt CO_2e
Note: Compared to 500 megawatt coal-fired
power plants operating at full capacity.
2019
2030
2050


European Commission
CIRCULAR
PLASTICS
ALLIANCE

Plastics moeten “anders”

A Wealth of Carbon above the Ground

The three renewable carbon sources that enable a circular economy

Plant-based carbon	Air-based carbon	Man-made carbon
		

Electrochemical Reduction of CO_2
Electricity only cost

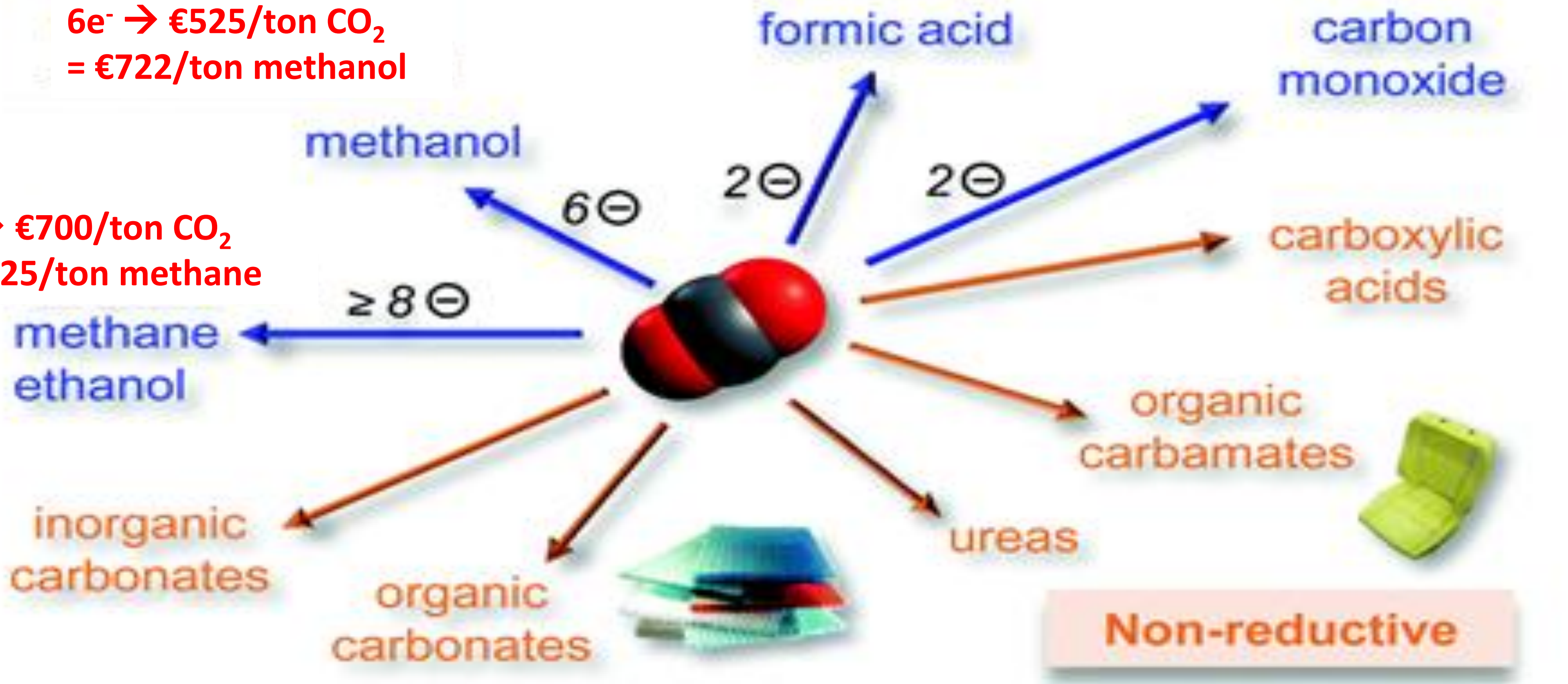
- Assume 2500 kWh electricity for 2 electron reduction of 1 ton CO_2
- Assume 0.05/kWh

$2e^-$ → €175/ton CO_2
= €175/ton formate

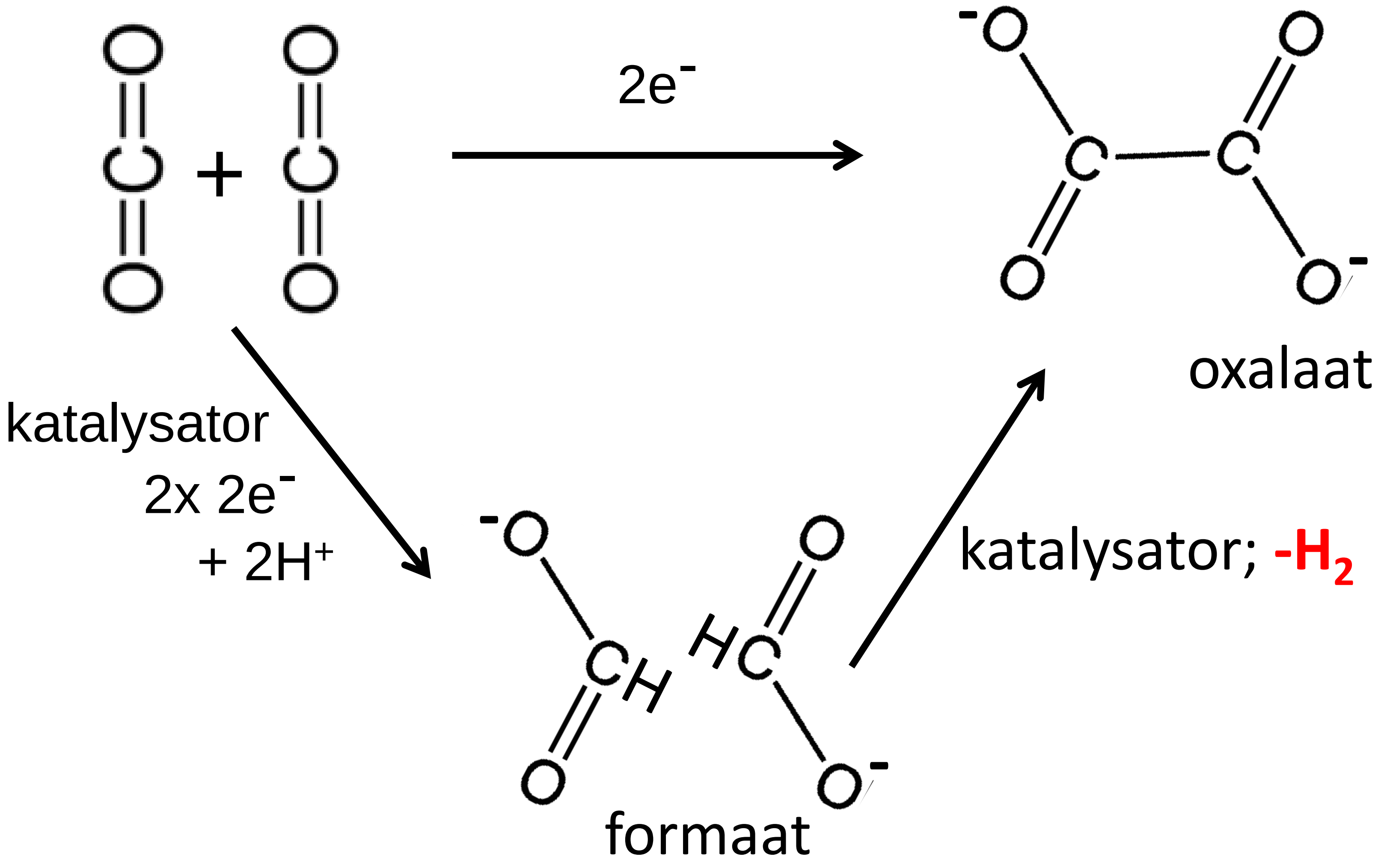
$2e^-$ → €175/ton CO_2
= €286/ton CO

$6e^-$ → €525/ton CO_2
= €722/ton methanol

$8e^-$ → €700/ton CO_2
= €1925/ton methane



CO_2 als grondstof



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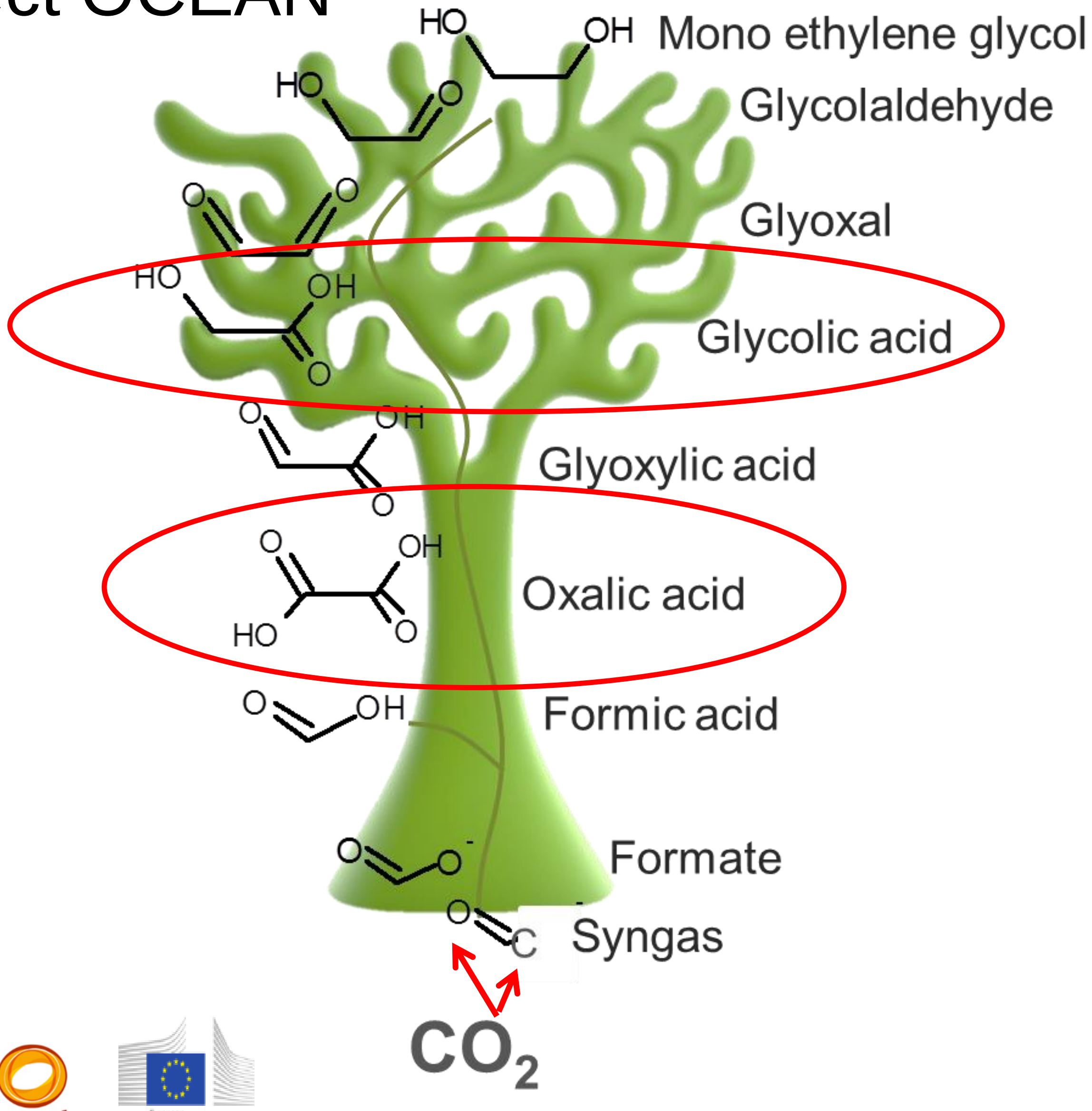
EU Project OCEAN



OCEAN (UvA) Scope:

- Electrochemical reduction of CO_2 to formate
- Chemical conversion of formate to oxalate
- Chemical conversion of oxalic acid to glycolic acid.
- Polymerization of GA

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 767798

Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

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ANALYSIS

National Renewable Energy Laboratory, Golden, CO, USA.
E-mail: Joshua.schaidle@nrel.gov, Ling.tao@nrel.gov

† A complementary website including interactive visualizations of the cost data presented in this article can be found at: https://www.nrel.gov/bioenergy/co2-utilization-economics/.

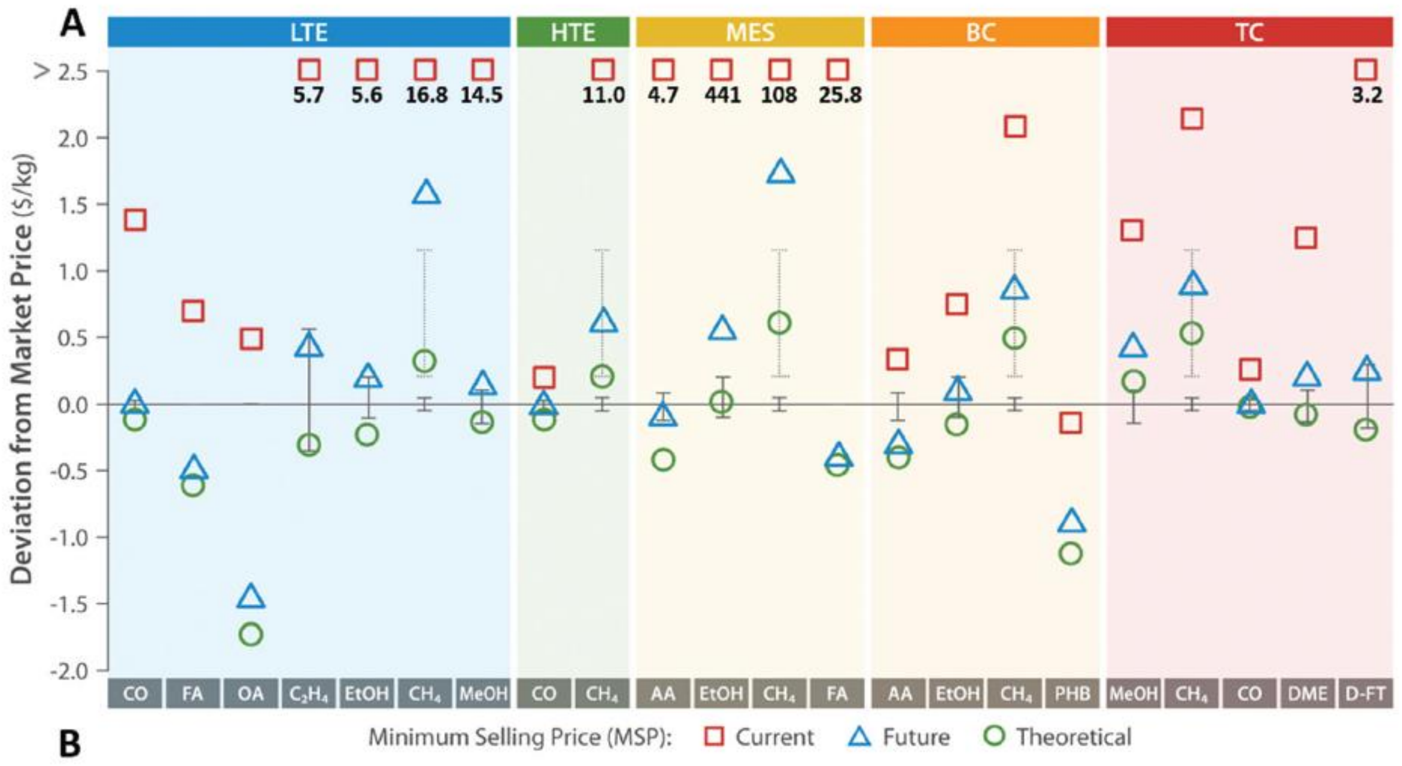
View Article Online
View Journal | View Issue

Check for updates

Cite this: *Energy Environ. Sci.*, 2021, **14**, 3664

The economic outlook for converting CO_2 and electrons to molecules†‡

Zhe Huang, § R. Gary Grim, § Joshua A. Schaidle * and Ling Tao *



LTE = low T electrolysis,
HTE = high T electrolysis,
MES = microbial electrosynthesis,
BC = biological conversion,
TC = thermochemical conversion

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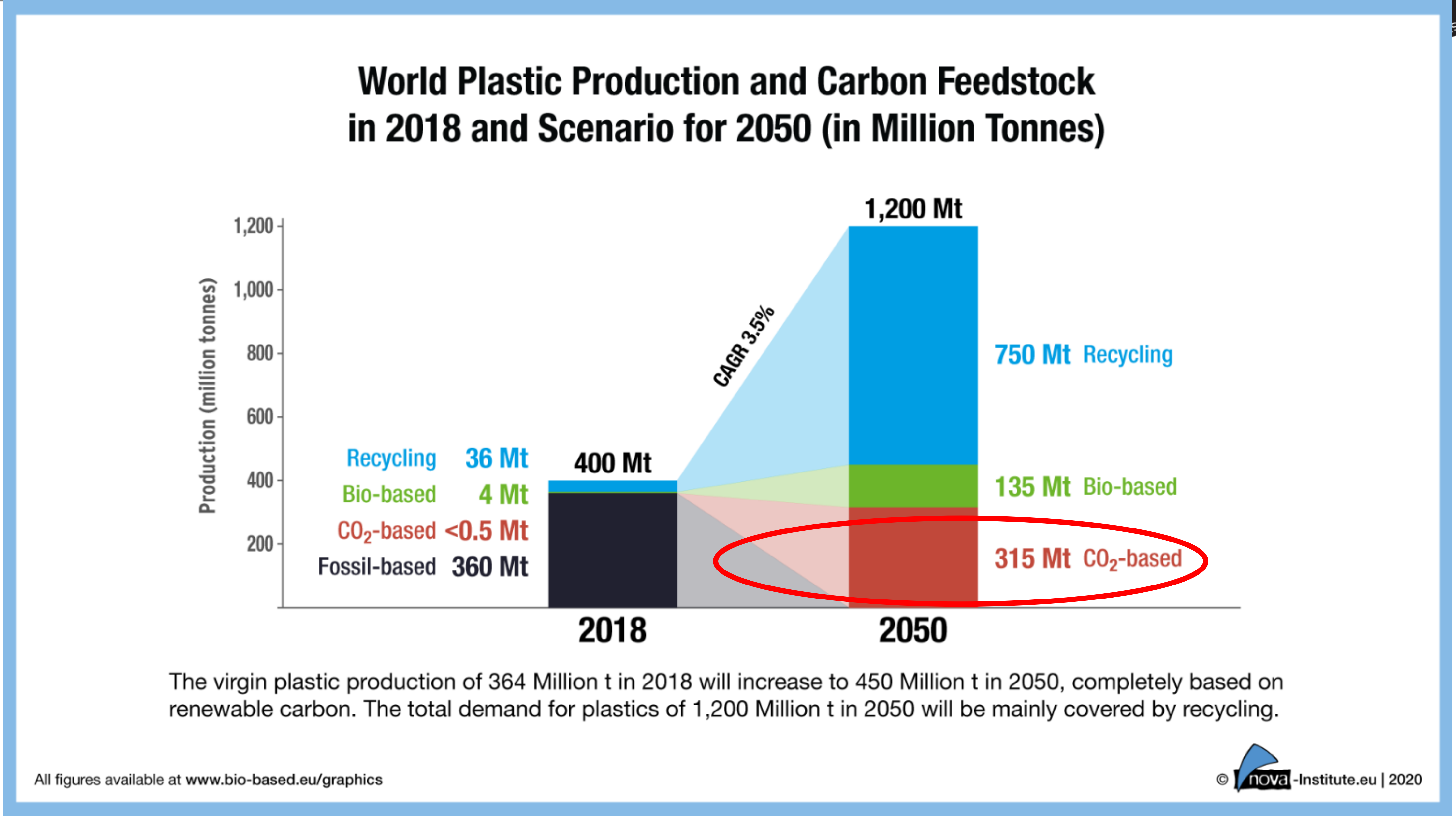
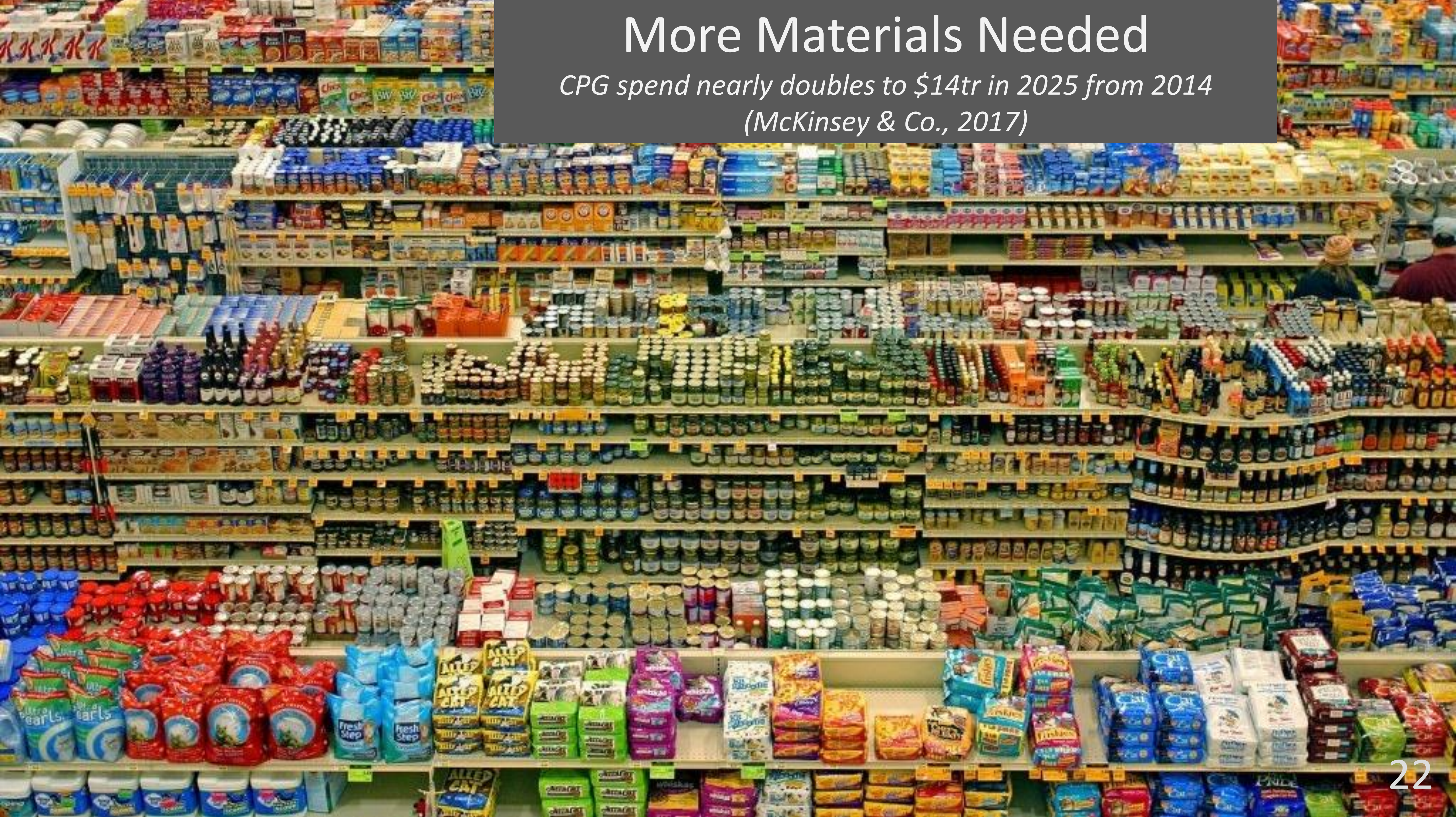
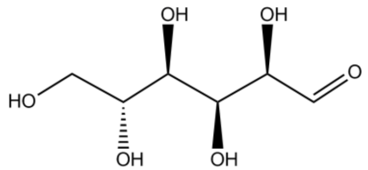
Research Priority Area Sustainable Chemistry



More Materials Needed

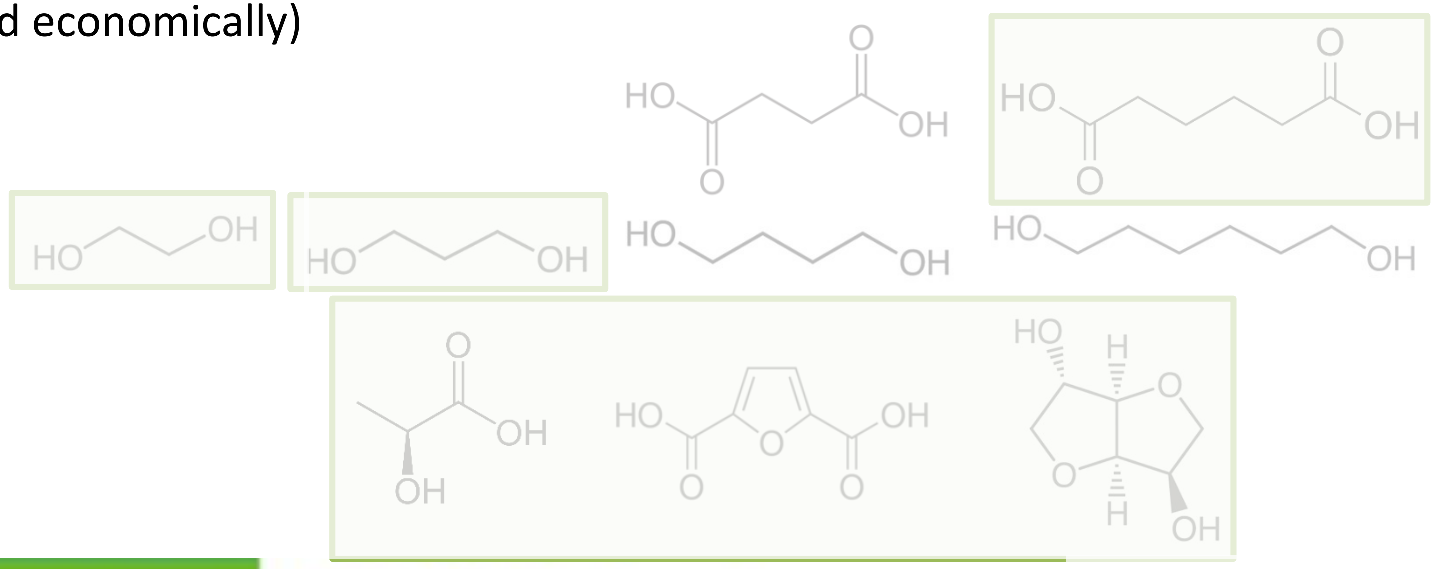
CPG spend nearly doubles to $14tr in 2025 from 2014
(McKinsey & Co., 2017)

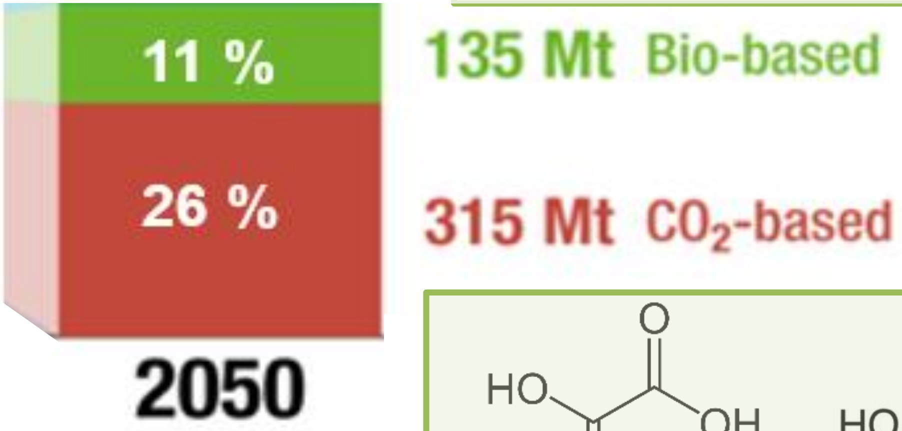


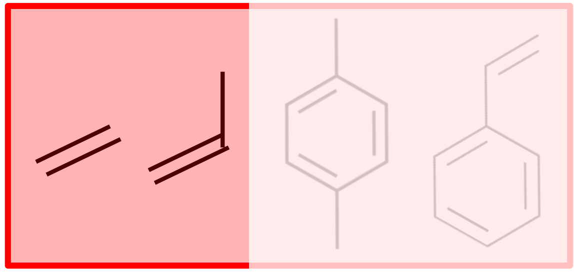


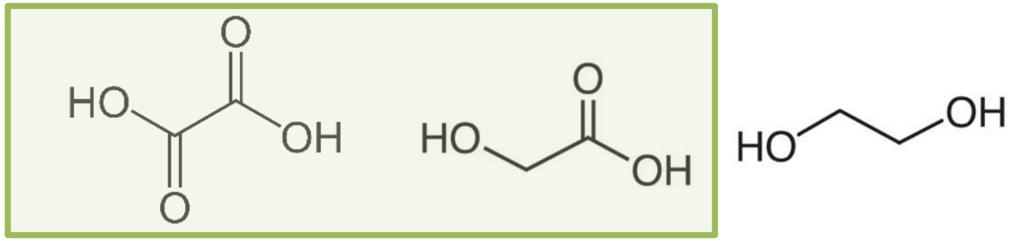
Which molecules make (most) sense from Glucose and CO_2

(technologically and economically)









Gluc: C_6O_6
SA: C_4O_4
AdA: C_6O_4
MEG: 3x C_2O_2
PDO: 2x C_3O_2
BDO: C_4O_2
HDO: C_6O2
LA: 2 x C_3O_3
FDCA: C_6O_5
IS: C_6O_4

← **No oxygen**

CO_2
OA: C_2O_4
GA: C_2O_3
MEG: C_2O_2

PE uit CO_2-gebaseerde etheen is niet competitief

- CO_2 to ethylene requires 6 electron reduction per carbon or ~10.5 MWh electricity per ton CO_2 or **33 MWh per ton ethylene**.
- CO_2 to oxalate requires 1e reduction per carbon or ~1.75 MWh electricity per ton CO_2 **AND** **1.75 MWh per ton oxalate** (!!)
- For making 315 Mt CO_2-based ethylene, we need 10400 TWh electricity (42% of current global electricity consumption).
- For making 315 Mt of CO_2-based oxalic acid we need 550 TWh electricity (2% of current global electricity consumption).

CO_2 to formate (HCOOM) - **TRL 6** @ RWE Germany

Avantium EC Cell coupled to CO_2 emission stream from energy plant

Goal: High Current density > 2kA/m2 + high Faraday efficiency (>90%) + catalyst stability

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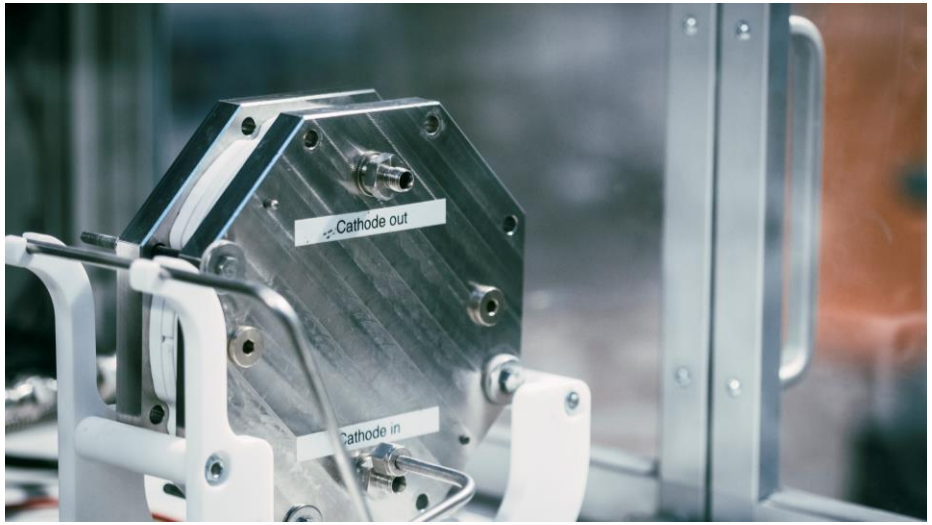

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Bio-based polyesters

PLGA with high GA

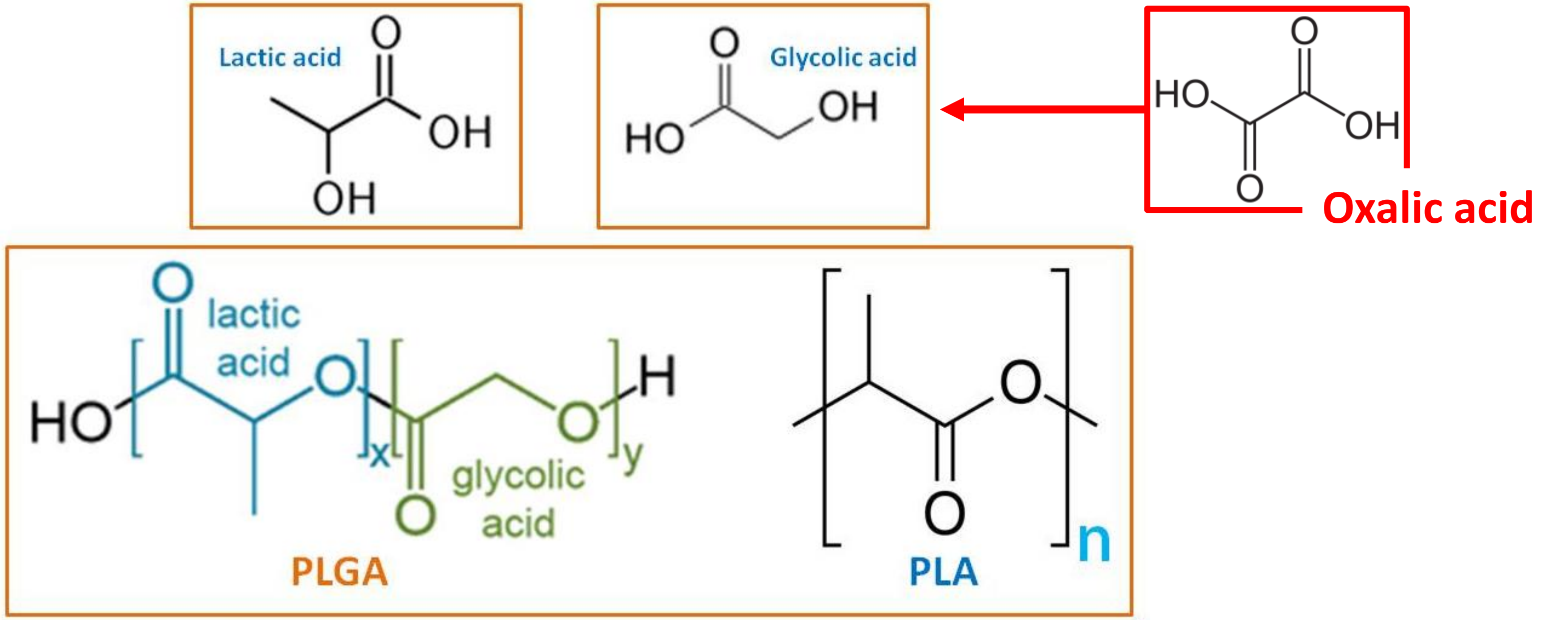
ACS APPLIED POLYMER MATERIALS

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*

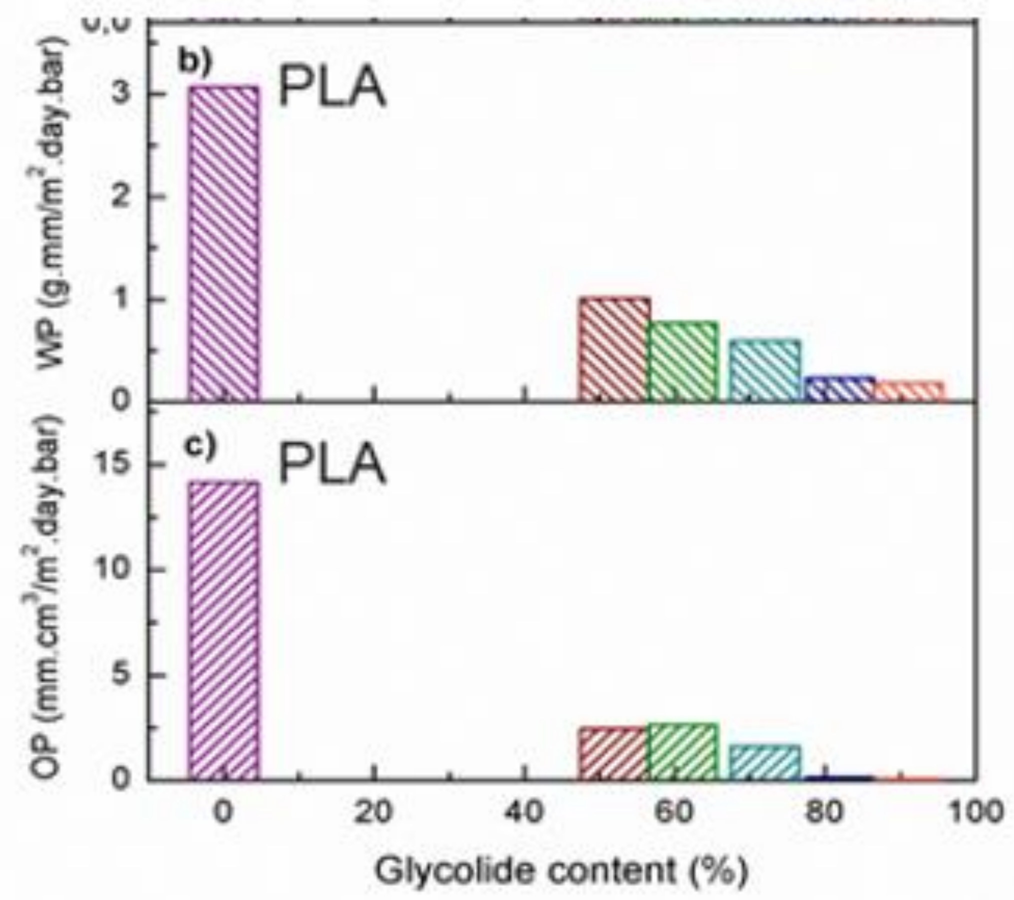


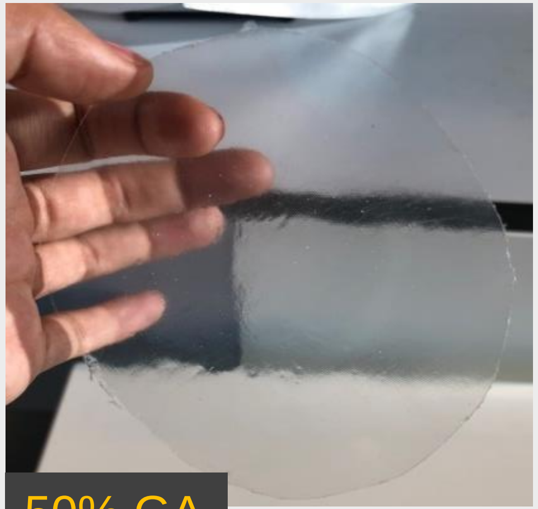
In the diagram, x and y in PLGA and n in PLA indicate the number of times each units repeats.

Oxygen permeability and Water permeability for PLGA copolymers at 70% RH and 30 °C

Film thickness = 0.17 mm;
Increased barrier to O_2 and water vapor with increasing GA content (50, 60, 70, 80, 90%)

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





50% GA

90% GA potentially
90% CO_2-based

98 parallel vessel automated soil & (sea)water respirometer

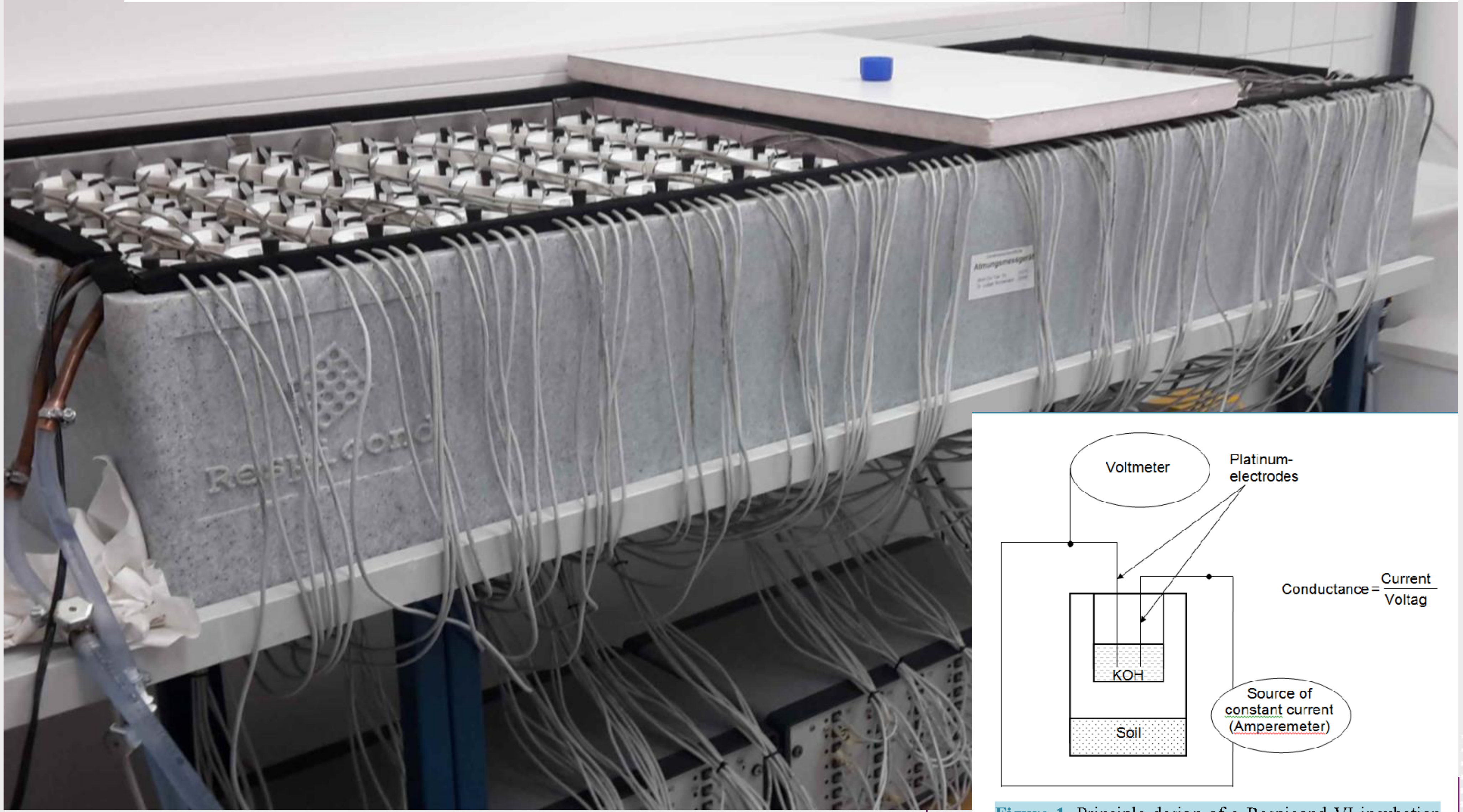
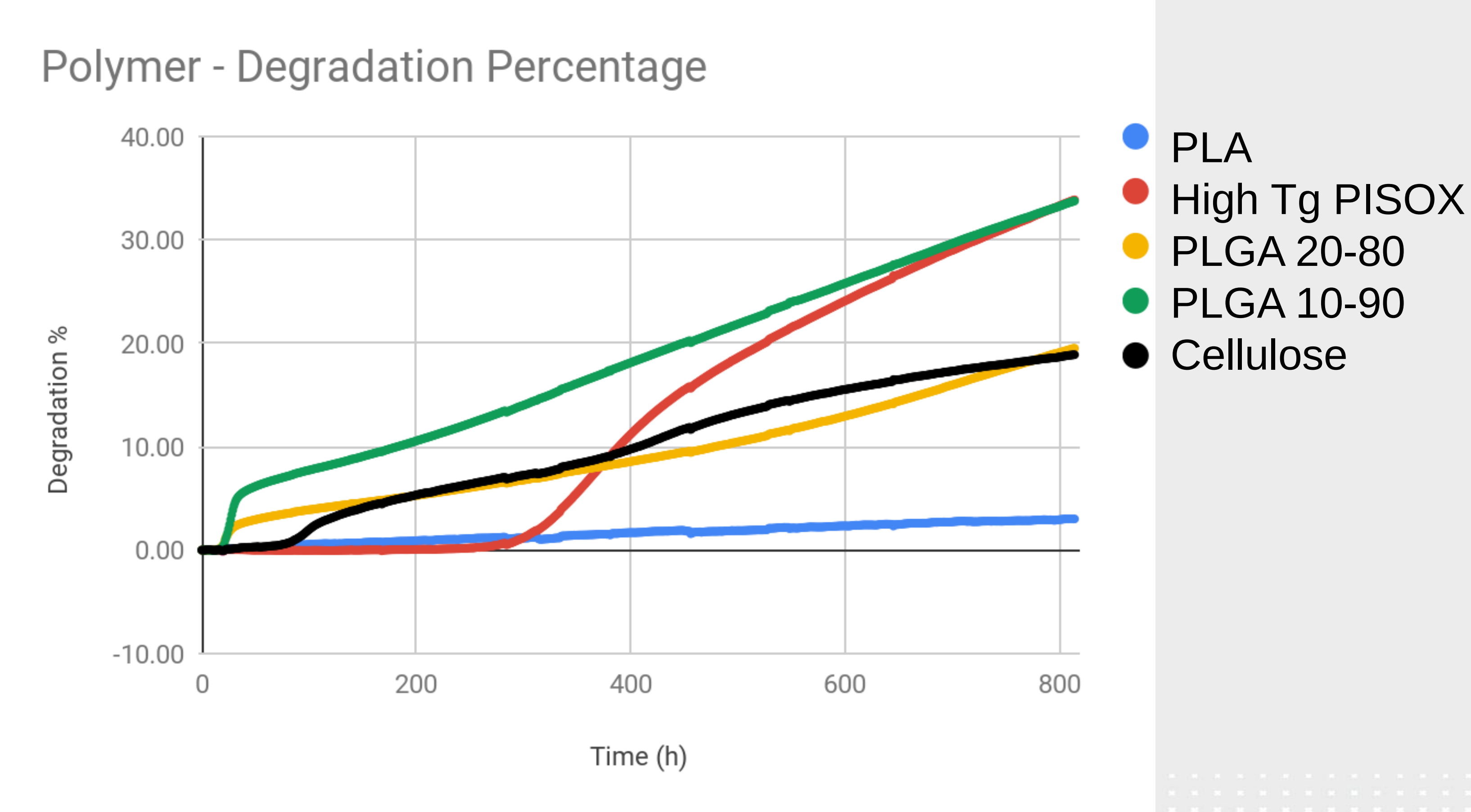


Figure 1. Principle design of a Respicond VI incubation vessel and the measuring unit.

Ambient temperature soil (bio)degradation)



CCU processes - considerations

- Electrocatalytic conversion requires energy input. The amount depends very much on target product.
- Fossil based grid mix might even increase CO_2 emissions (in that case CO_2-neutrality can then only be achieved by combination with CCS)
- CCU from fossil CO_2 can contribute to early climate goals as long as there is fossil based industry – but it should not contribute to maintain it. Fossil CO_2 should be avoided or compensated by CCS towards 2050.
- LCA and TEA* required: environment & economy

Life Cycle Analysis & Techno Economic Analysis

Conclusions

- De materialen transitie is een geweldige KANS om onze plastics te re-designen !
- Condensatie polymeren zijn heel logisch vanuit koolhydraten (suikers) en CO_2, met name polyesters (atom efficiency = winning economics).
- Polyesters (in tegenstelling tot polyolefinen) KUNNEN closed-loop gerecycled worden.
- Veel polyesters zijn biodegradeerbaar (omstandigheden ? Tijdschaal ?)
- Het aantal duurzame polyester materialen die we uit hydroxy-zuren (melkzuur, glycol zuur, etc), diolen en di-zuren kunnen maken is eindeloos.
- Grootste horde: korte termijn (kleine schaal) zijn nieuwe materialen altijd duurder
- Betere eigenschappen leiden tot concurrentie op performance terwijl drop-in kan alleen concurreren op prijs !