Alternative carbon sources for plastics: Is circular bio-based plastic a solution?

Imperial Life Cycle Network Seminar
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πλαστικος

“Easy to process, shape and form”

- Moulded: Animal horns, ivory
- Direct use: natural resin for coating, wood, fibres

Industrial revolution in the 1800s: the rise of wood-based chemistry (modified cellulose)

- Celluloid obsoleted ivory in the 1870s
- Viscose invented in the 1890s as cotton and silk replacement

Irish horn spoon
Ca. 1650
National Museum of Ireland

https://www.jstor.org/stable/10.3318/priac.2018.118.05

In the first half of the 20th century…

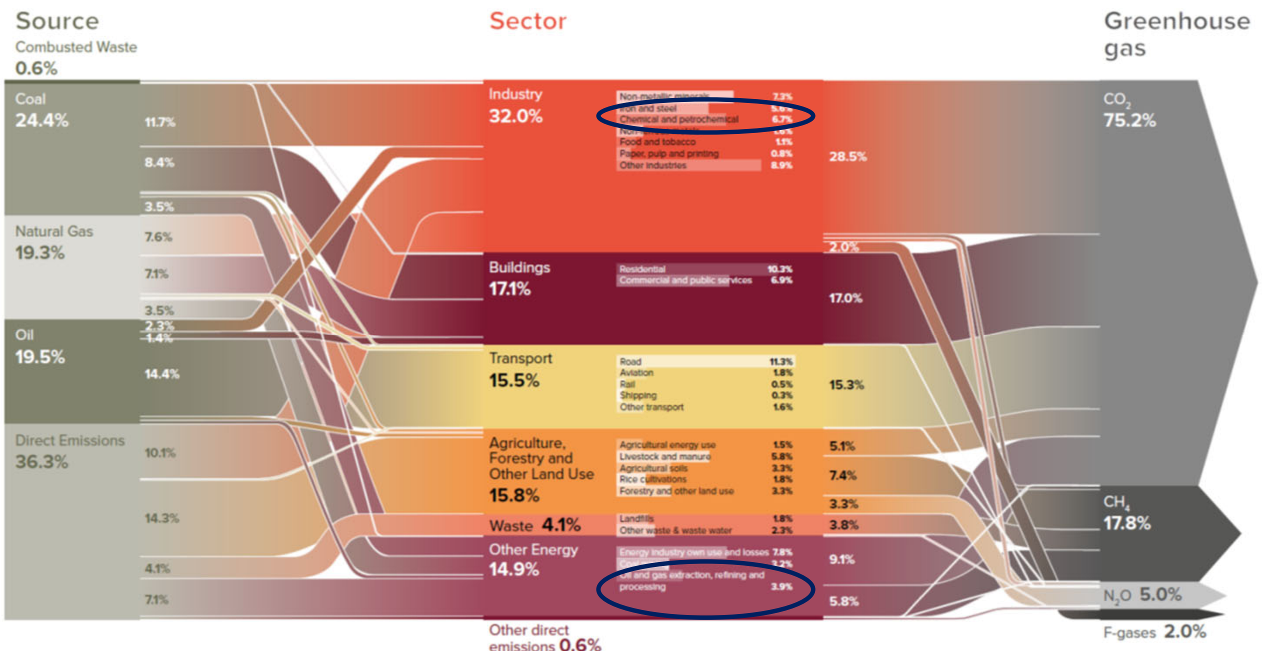
First plastics film: cellophane (1912)

Henry Ford's project of producing car parts out of soybeans (1920s-1940s)

Henry Ford (right) unveiling his handmade plastic automobile in Dearborn, Michigan, in August 1941. The body's plastic was made from soybean and fibers such as field straw, hemp, and flax. The car ran on gasoline and ethanol from corn. Source: Bloomberg https://www.bloomberg.com/news/features/2017-09-20/henry-ford-and-soy-set-up-antibiotic-resistance-deadly-superbugs

- Late 1930s: world-wide large scale oil extraction
- 1930-1950: invention and commercialisation of PVC, PS, PE, Nylons
- 1947: PET patented
- 1950s: commercialisation of PET, LLDPE, HIPS, PP, PUR and epoxy resin
- Global annual plastics production in 1950s: ca. 2 Mt

Every year, about 350-400 million metric tonnes of synthetic polymers are produced globally



Guidehouse, 2019

- Plastics are convenient.
- Plastics are problematic.
- **Can we live without plastic?**

Can we live without plastic? ......for a day?

The New York Times | https://www.nytimes.com/2023/01/11/style/plastic-free.html

Trying to Live a Day Without Plastic

It's all around us, despite its adverse effects on the planet. In a 24-hour experiment, one journalist tried to go plastic free.

By A. J. Jacobs

Jacobs is a journalist in New York who has written books on trying to live by the rules of the Bible and reading the Encyclopaedia Britannica from A to Z.

Jan. 11, 2023

“I had made 164 violations, by my count.”

https://www.nytimes.com/2023/01/11/style/plastic-free.html

If not, what now?

- Refuse, re-use: reduce demand, reduce waste
- **Make better plastics…..better?**

Part of the puzzle piece - alternative carbon sources:

1. Use biogenic carbon: “bio-based”: BIOSPRI
2. Recycle the biogenic carbon: “circular biobased”: biobased PEF vs PET

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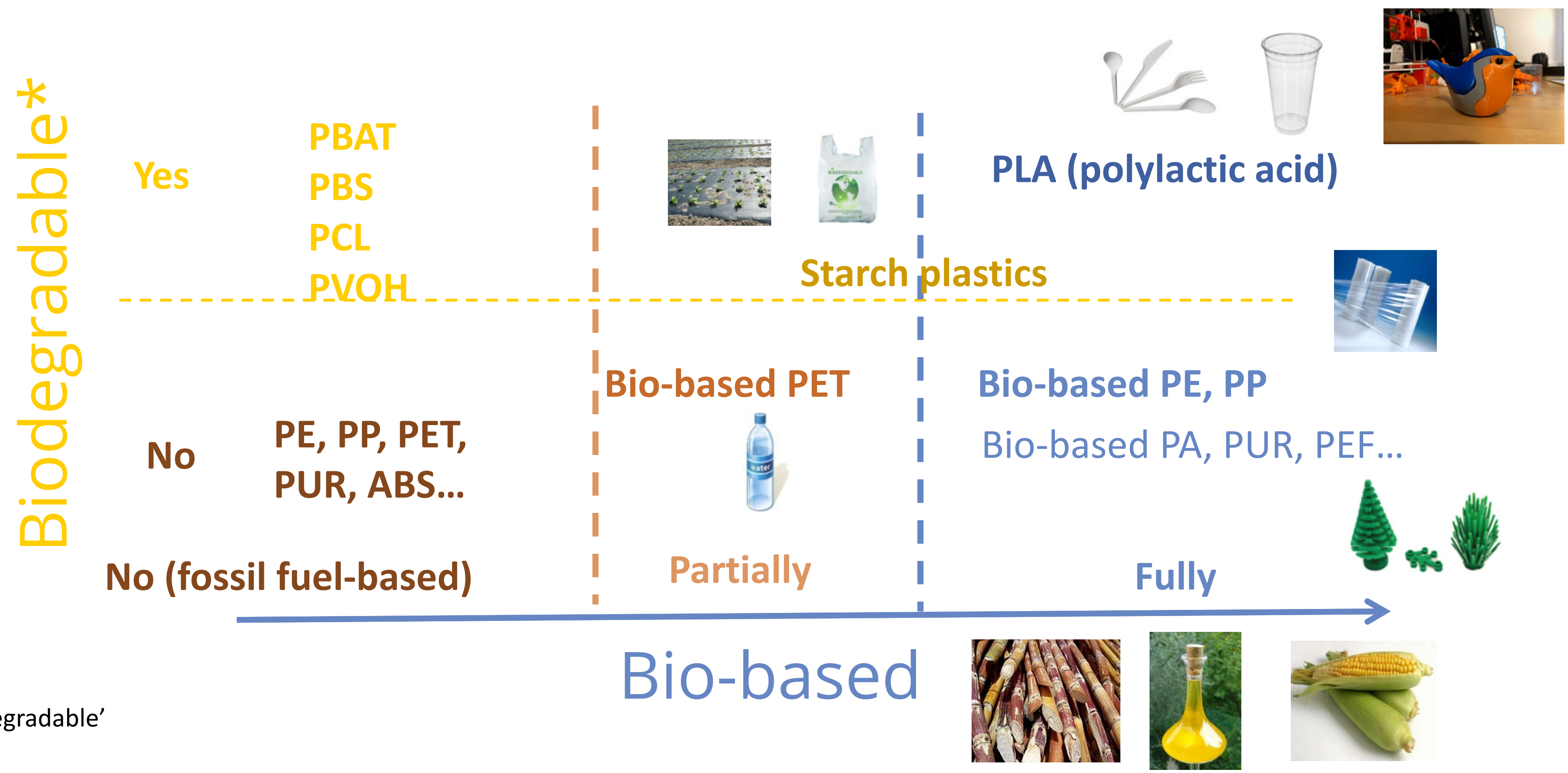
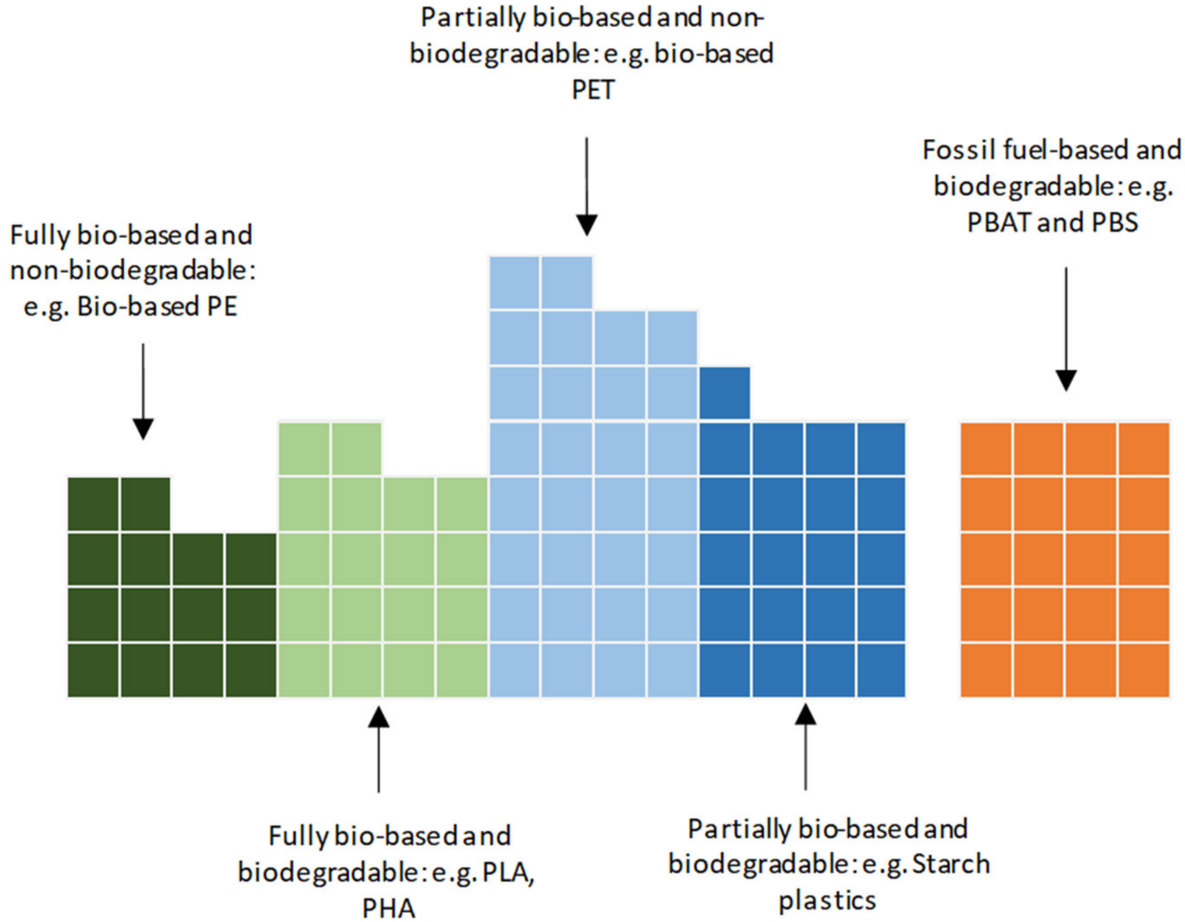
Are bio-based plastics a solution?

What is "bioplastic"?



*certified as 'biodegradable'

Global production capacity 2019: 2.11 million metric tonnes



Compiled based on European Bioplastics (2021)

LCA bio-based plastics (1/2)
What we learned from the "classical LCAs" for innovative biobased plastics:

Compared to their petrochemical counterparts *:

- The established biobased systems often have lower cradle-to-gate GHG emissions:
  - If biogenic carbon removals are accounted as a direct credit (e.g. as defined in PAS 2050).
  - (bio)chemical conversion processes can be carbon-intensive.
  - Sensitive to the choice of allocation/multifunctionalities

- Biobased systems often lead to a higher impact on land and water – the tradeoffs are not always fully understood

* See Broeren et al (2017) DOI: 10.1002/bbb

LCA bio-based plastics (2/2)
What we did not learn from the "classical LCAs":

What are the environmental impacts of innovative biobased systems, if

- the impacts of indirect land use changes are accounted for?
- the end-of-life impacts are included in the scope?

BIO-SPRI (2017-2019)

“Support to Research and Innovation Policy for Bio-based Products”

Goal of the LCA: “Provide science-based evidence to support policy decisions”

- Identify the key environmental hotspots of innovative bio-based plastics
- Compare the environmental impacts with the fossil fuel-based counterparts

Selection of the case studies

5 Criteria, 16 sub-criteria

- Market potential
- Promise for deployment
- Available LCA data
- Innovation
- Potential sustainability benefits

Seven case studies :

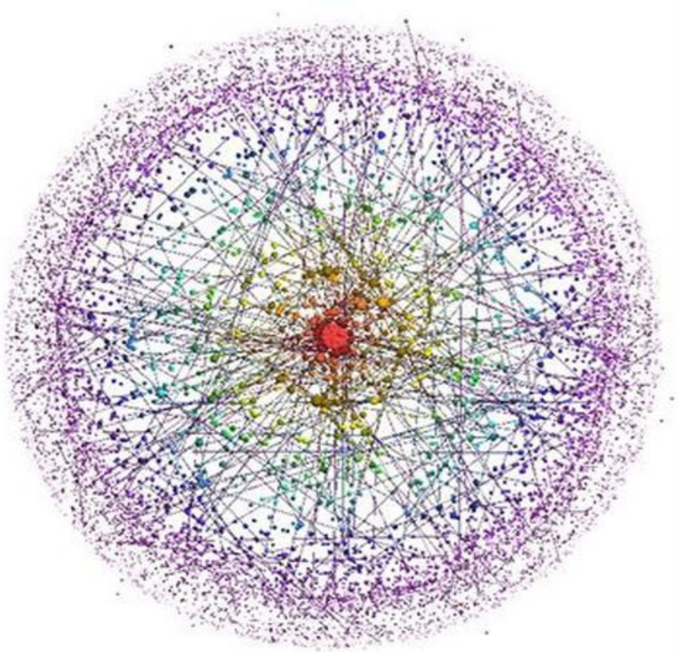
- Beverage bottles
- Horticultural clips
- Single-use drinking cups
- Single-use carrier bags
- Food packaging films
- Single-use cutlery
- Agricultural mulch films





Life Cycle Assessment

"Best framework for assessing the potential environmental impacts of products" (COM (2003)302)



Picture courtesy to Dr. Blanca Corona Bellostas

Take PEFCR as the guidance (v.6.3, 2018)

Cradle to grave
Geographical: products sold, consumed and disposed of in Europe
Technological: established technologies
Temporal: Status-quo (2018), very near future
16 Impact assessment categories
Normalisation: EU 27 NF for 2010 (ILCD)
Weighting: JRC-EF (2018)

Beyond:

- **Effects of land use changes**

Overview of the case studies in BIO-SPRI

Case studies	Bio-based baseline	Bio-based alternatives	Reference system(s)
Beverage bottles	30% bio-based PET	30% PET from EU ethanol (fictional)	PChemPET
Single-use drinking cups	PLA	PLA from EU maize (fictional) Bio-based PP from UCO	PET PP
Single-use cutlery	PLA	n/a	PS
Food p	PLA	PLA from EU maize (fictional) Bio-based PP from UCO	PP
Hor	Starch plastics	Starch sourced from potato waste	PP
Agricult	Starch plastics	n/a	LDPE
Single-use carrier bags	Starch plastics	Bio-based LDPE	LDPE

Status-quo average technology mix; primary data from industry.

PET=polyethylene terephthalate; PLA=Polylactic acid, UCO=Used cooking oil, PP=polypropylene, PS=polystyrene, LDPE=low-density polyethylene
PChem=petrochemical

End-of-life challenges

Case studies (baseline vs. ref.)	(Est.) *Current* EOL for the bio-based (av. EU mix)	Intended EOL	Current EOL PChem reference (av. EU mix)
Beverage bottles (bio-based vs. Pchem. PET)	Recycling, MSWI and landfilling	Recycling	Recycling, MSWI and landfilling *
Single-use drinking cups (PLA vs. PET, PP)	Recycling, Composting MSWI, landfilling	Recycling and composting	
Single-use cutlery (PLA vs. PS)			
Food packaging films (PLA vs. PP)			
Horticultural clips (Starch plastics vs. PP)	In-situ soil biodegradation	In-situ soil biodegradation	
Agricultural mulch films (Starch plastics vs. LDPE)			
Single-use carrier bags (Starch plastics vs. LDPE)	Composting, MSWI and landfilling	Composting	

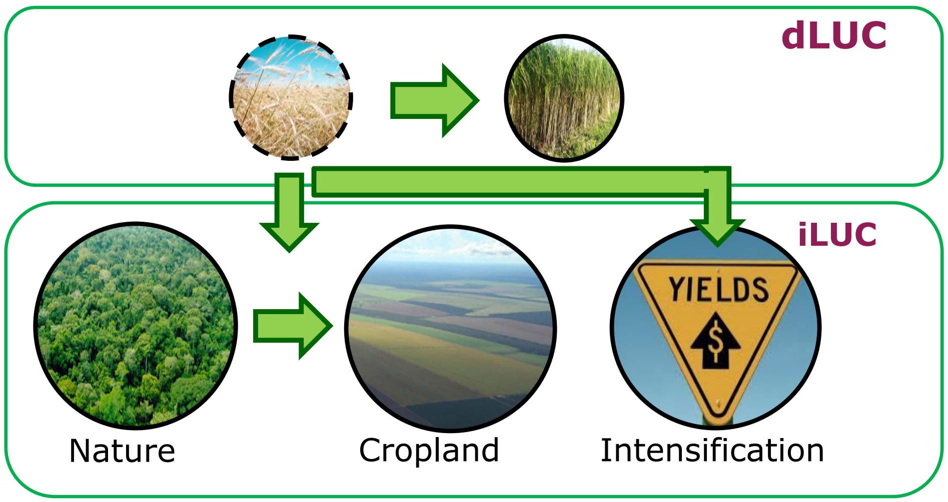
*Ratios are different based on different applications

Land Use Changes

- DLUC Modelled in accordance with the PEFCR Guidance (v.6.3); consistent with PAS2050 requirements.
- ILUC modelled separately based on a *deterministic method* adapted for this study

Picture courtesy to Dr. Lorie Hamelin

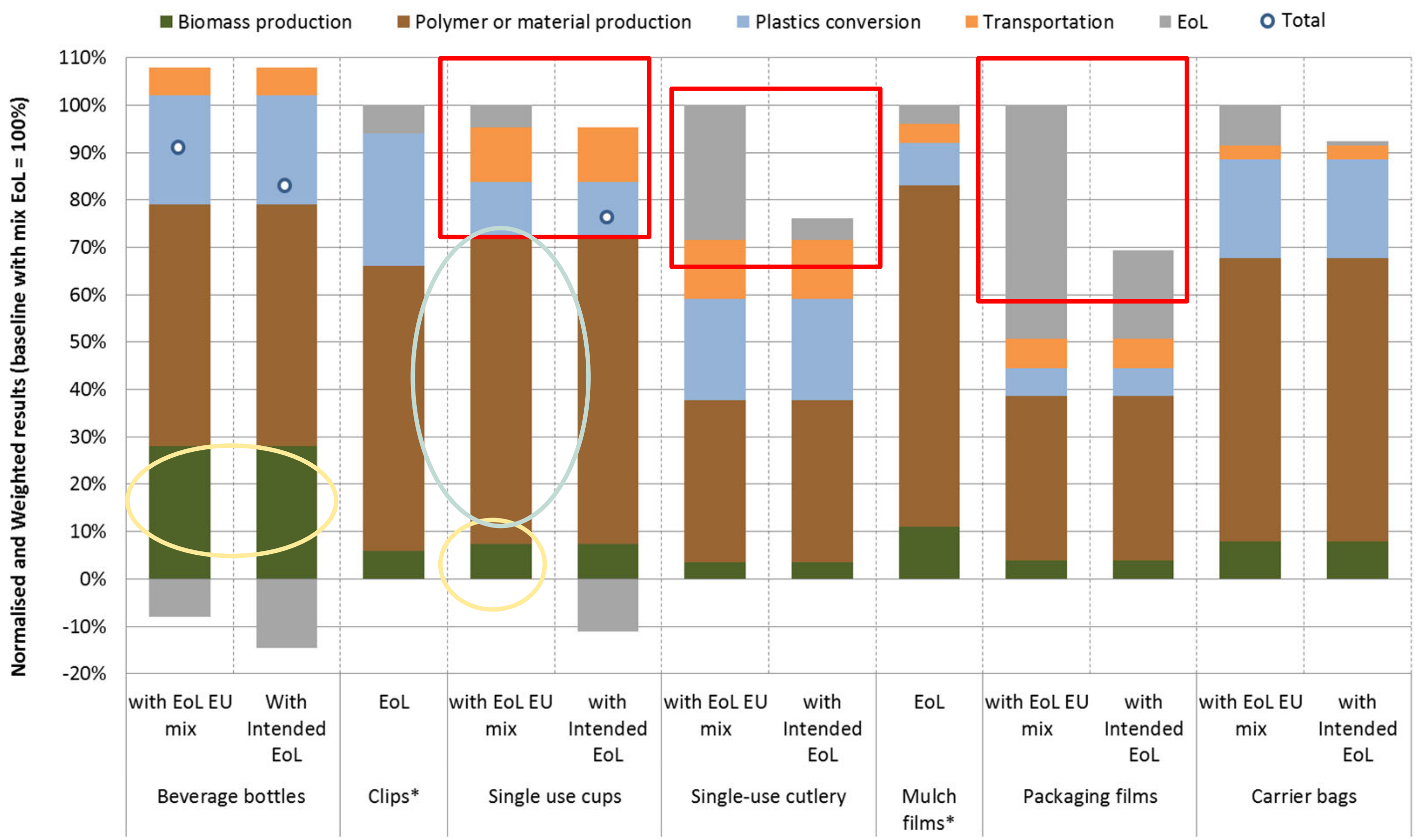
Indirect land use changes: a deterministic model*



1. Establish plausible cause-effect chain events, understanding of service displaced and reacting supply.
2. Determine expansion/intensification based on *past* time-series data (e.g. FAO).
3. Calculate impacts resulted from expansion
4. Calculate impacts resulted from intensification

** GCB Bioenergy 8, 690–706. (2016); Slide credit Dr. Lorie Hamelin*

Cradle-to-grave impacts of seven bio-based products, normalised and weighted results without LUC effects, comparing EoL EU mix with intended EoL



*** For case studies Clips and Mulch films, the EoL mix is assumed the same as the intended EoL, which is in-situ soil biodegradation.**

Comparing with the petrochemicals…

Out of 16 PEFCR impact categories, only ***five*** are recommended to be used for comparison

Cradle to grave baseline results excluding LUC effects, environmental impact reduction on median values (with ranges)

Climate Change (GWP 100a)

Abiotic depletion (fossil fuels)

Particulate matter

Photochemical ozone formation

Terrestrial eutrophication

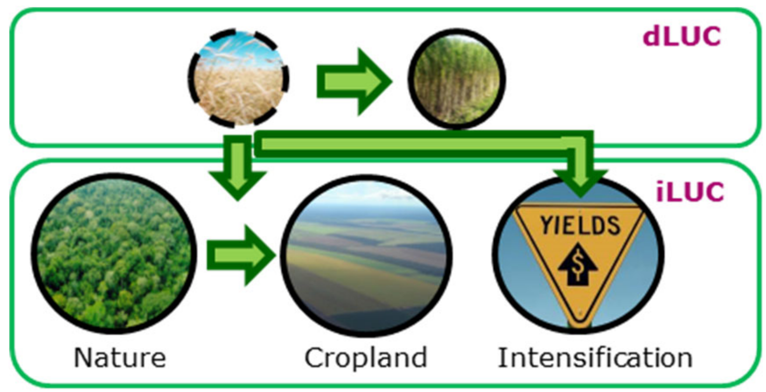
*Median savings based on the eight comparisons of the seven case studies (two comparisons were made for single-use cups).

Land use change in BIOSPRI project

Land use change will lead to marginal increases in impacts:

- 14% for climate change
- 10% for photochemical ozone formation
- 0.01-2.4% for all other impact categories

Simplified: the shorter the production chain, the stronger effect observed from LUC



Land use impacts are more complex than the current LCIA models can offer: impact of "carbon removals"

For perennial crops and woody biomass, land use and land use changes disturb:

- Carbon balances
  - Direct carbon balance change: biomass growth
  - Indirect carbon balance change: soil organic carbon content
- Nitrogen balances
- Available fresh water
- Biodiversity

Spatial and temporal explicit models are urgently needed for LCA

If not, what now?

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- **Make better plastics.....better?**

Part of the puzzle piece - alternative carbon sources:

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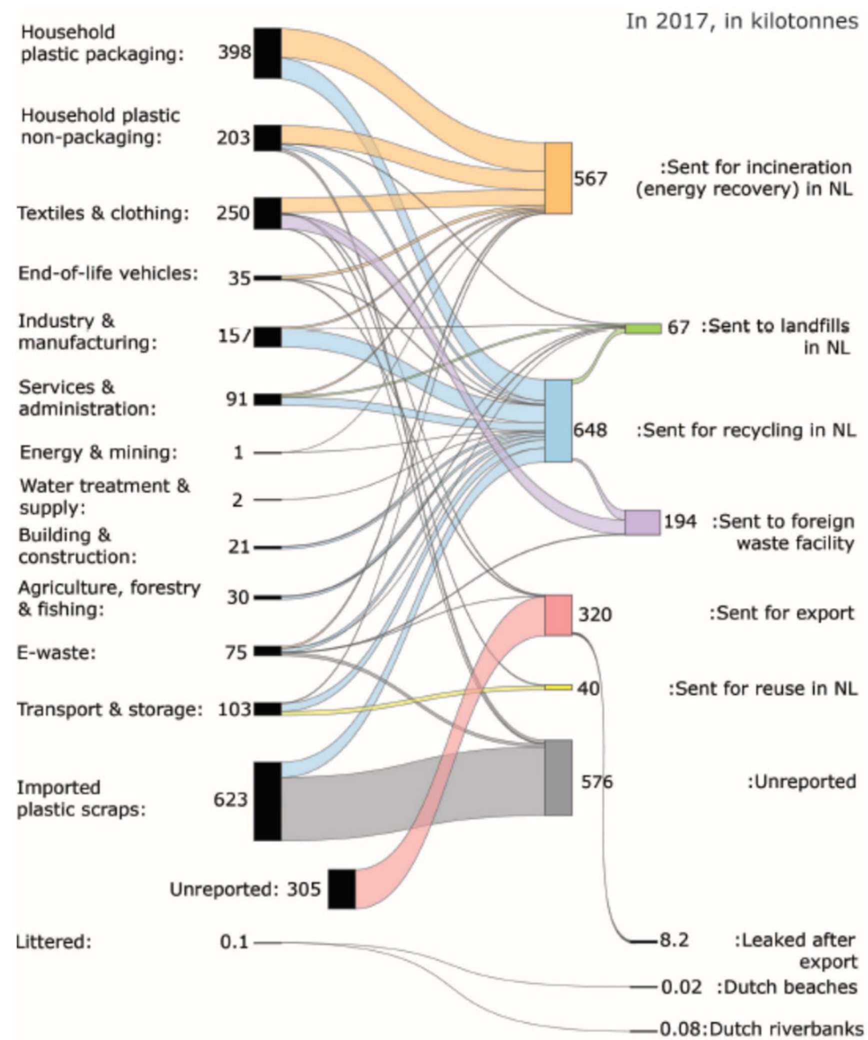
In the NL, about 2 Mt of plastic waste was reported in 2017 (including import)

Domestic generated (70%) and Imported (30%)

Over 40% (ca. 842 kt) was sent for recycling, of which
- 648 kt was sent for recycling in the NL, and
- 194 kt sent to recycling outside of NL

About 30% (ca. 570 kt) was incinerated with energy recovery
- Excluding imported RDF

Leaked into the environment:
- 0.02-0.07 kt on the NL beaches and river banks
- 4-13 kt leaked foreign environment



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Lobelle et al. Knowns and unknowns of plastic waste flows in the Netherlands (forthcoming)

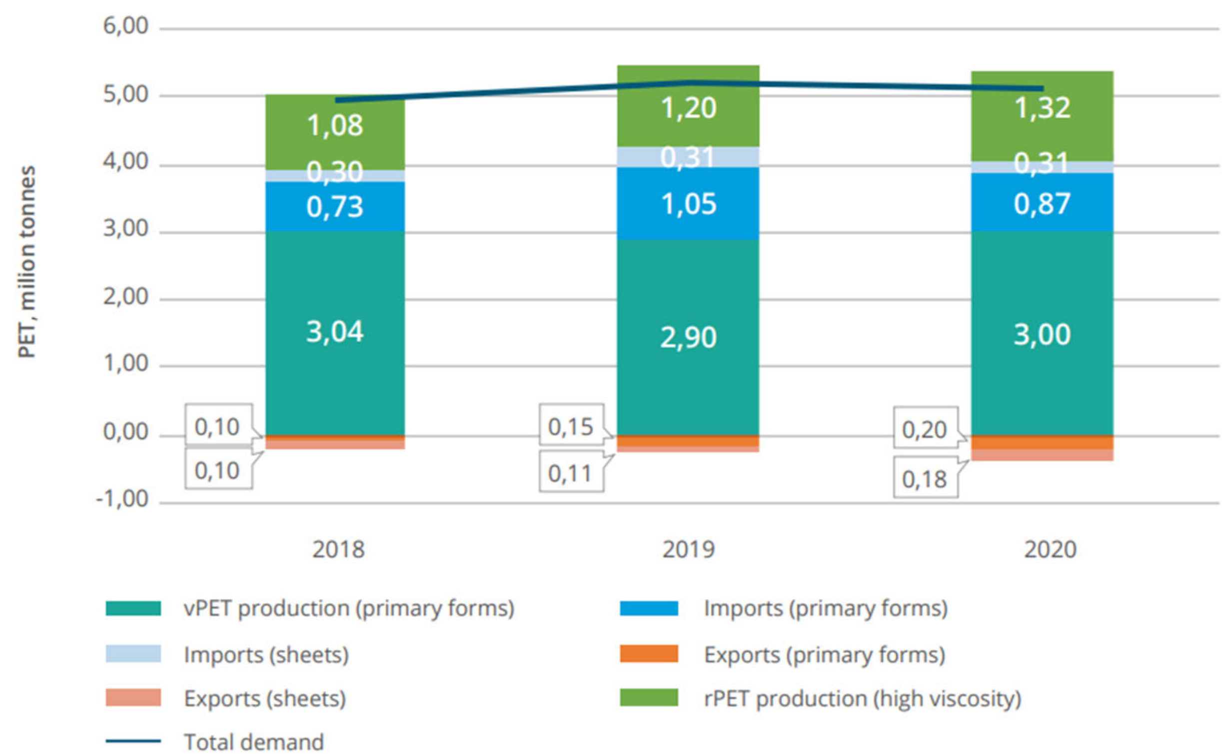
In Europe, PET is the most recycled polymer

About 25% of the PET market demand is met by rPET in EU27+UK

- Established deposit return systems in many European countries: high collection rate (65-96%)
- Heavier than water
- Improved packaging design
- Polyester

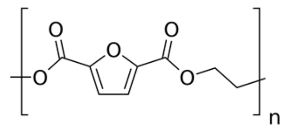
Figure 2: Total Demand for PET (Primary Forms and Sheet), 2018-2020 (EU27+UK)

Source: CPME, Eurostat, Annual PET Recyclers Survey (PRE)



Eunomia, "PET Market in Europe" 2022

One of the bio-based alternative of PET is PEF, polyethylene furanoate



Sugar-based.

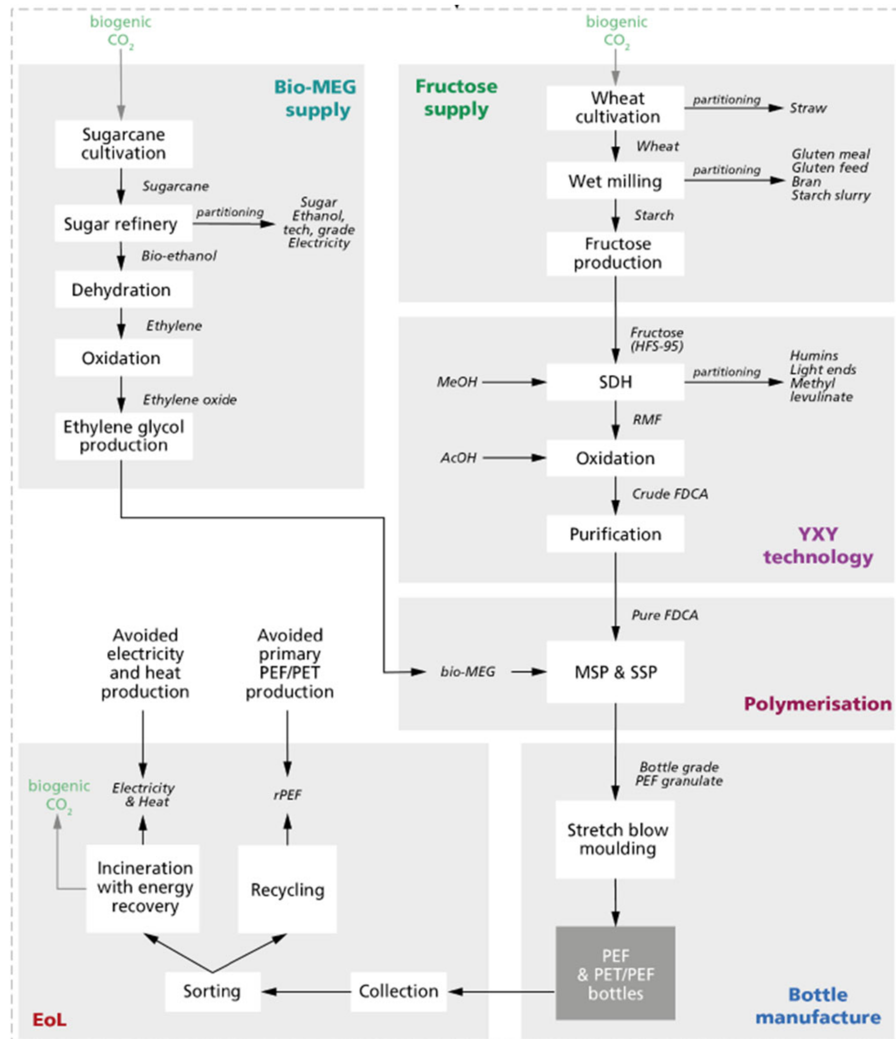
First commercial production in 2024.

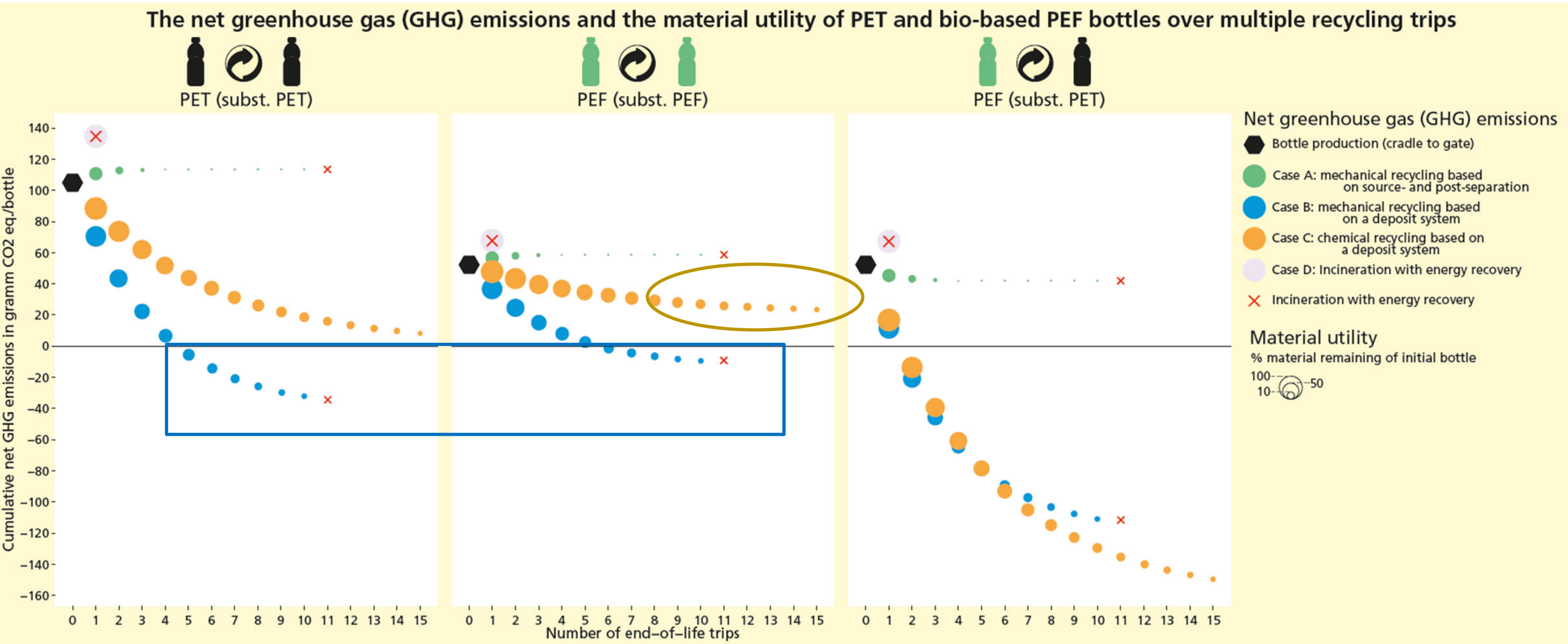
Compared to PET:

- Good gas barrier (esp. O2 and CO2)
- Can be recycled similarly to PET
- Published LCA shows potential GHG reduction compared to PET (33-55% reduction depending on the scope)

But:

- Little known about the differences between MR and CR.
- Does recycling of PEF offers environmental benefits?
- How circularity is assessed and can it be reflected by LCA for bio-based plastics with multiple recycling trips?

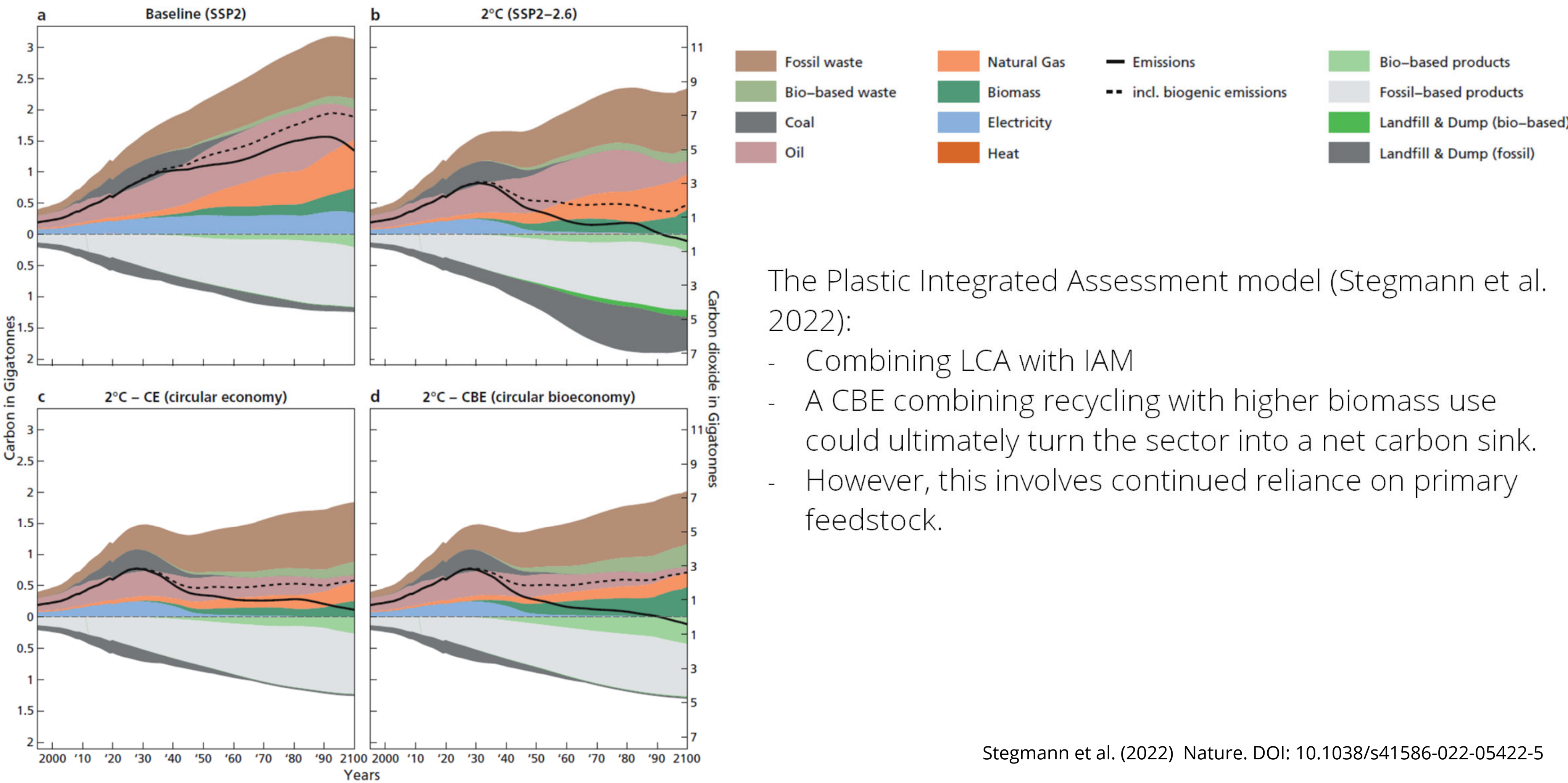




Circularity does not always lead to Sustainability.

Stegmann et al. Forthcoming

Carbon balance of the plastic sector over the entire life cycle: the PLAIA model



The Plastic Integrated Assessment model (Stegmann et al. 2022):

- Combining LCA with IAM
- A CBE combining recycling with higher biomass use could ultimately turn the sector into a net carbon sink.
- However, this involves continued reliance on primary feedstock.

Stegmann et al. (2022) Nature. DOI: 10.1038/s41586-022-05422-5

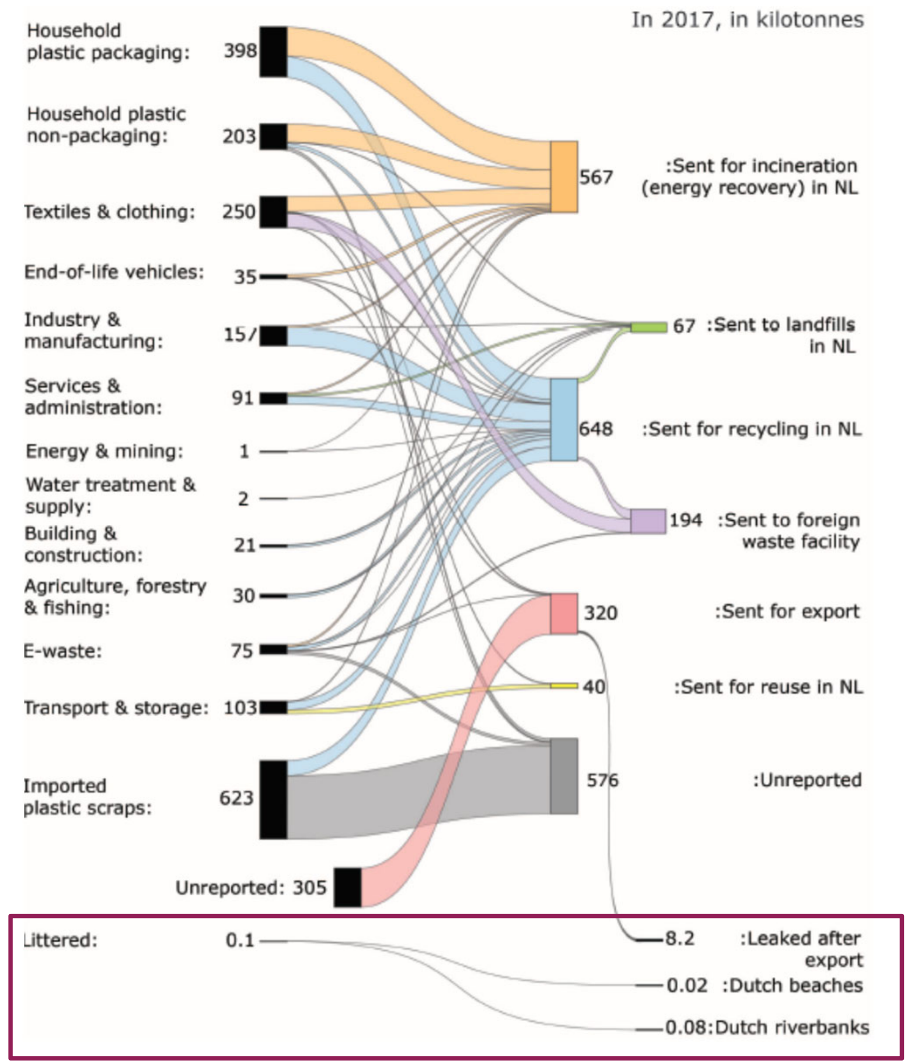
Circular biobased plastics - Some reflections from LCA practitioner's view (1/2)

- Align *both* circularity performance and environmental sustainability*
- Blurred system boundaries: using waste as input
- Consequential LCA needed to understand the full implications of biobased circular economy:
  - System expansion/enlargement in combination with high-resolution MFA: for both the challenges in land use/changes and recycling
  - Spatial and temporal explicit assessment for land use impacts
  - Do not limit to GHG emissions, focus on the environmental trade-offs

Corona et al, RCR 151 (2019)

Circular biobased plastics: Some reflections from LCA practitioner's view (2/2)

- Small quantity compared to the total produced, but the impact can be substantial
- Cause-effect models not yet established
- Lacking fundamental understanding:
  - The effects on ecosystem and human health.
  - Their fates in air, soil, water and in the ocean, e.g. microplastics and nanoplastics – and what can they carry?
  - In the ocean: climate change will in return affect how plastics will travel .
  - Impacts of plastic additives are worrying.



Are we too technocentric?

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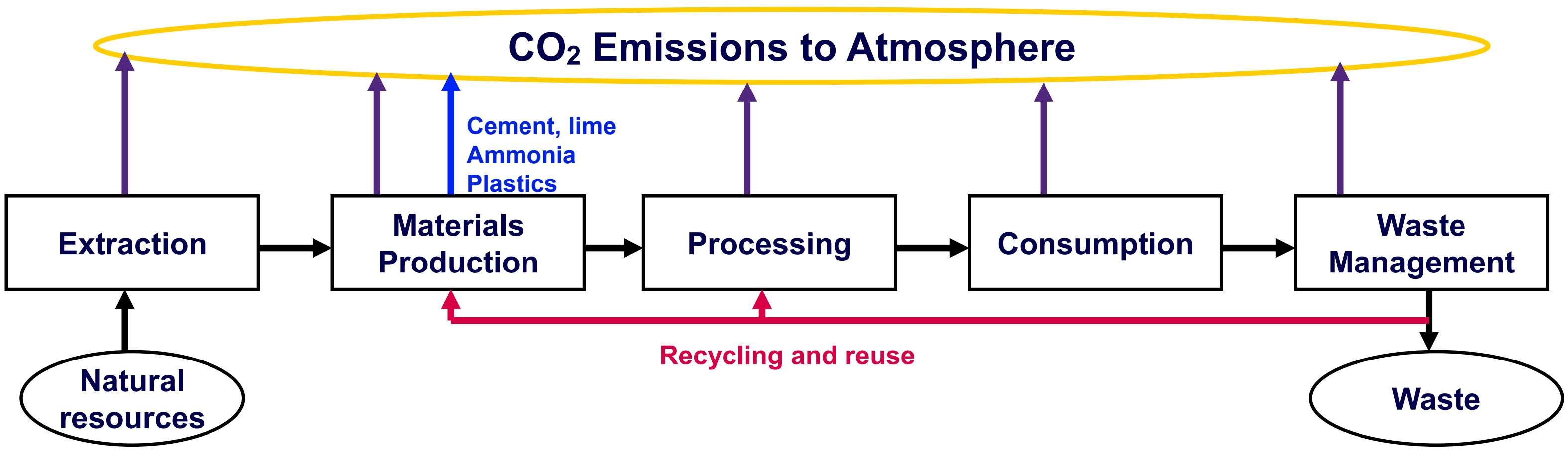
https://www.nytimes.com/2023/01/11/style/plastic-free.html

Do we fully understand circular bio-based systems?



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