Recycled PE in a circular economy

Chemical vision on mechanical recycling and ‘circular recycling’

Nov. 4th ‘21. Ulphard Thoden van Velzen, Marieke Brouwer, Ingeborg Smeding

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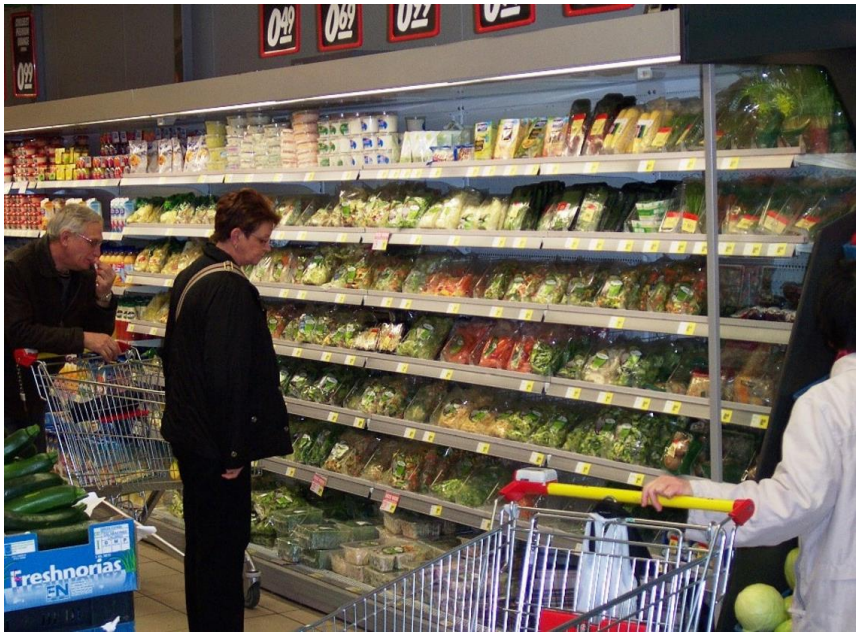
Content

- The flow of plastic packages through our society
- What recycled PE’s are composed of
    - Targeted polymers
    - Contaminants
- General reflection on how we can progress towards a circular economy for packaging plastics

Plastic packages

- Most protection
- Lightest weight
- Enables convenience products
- Transparency
- At limited cost...



But plastic (packages) have downsides

- Greenhouse gas emissions
- Littering and plastic soup

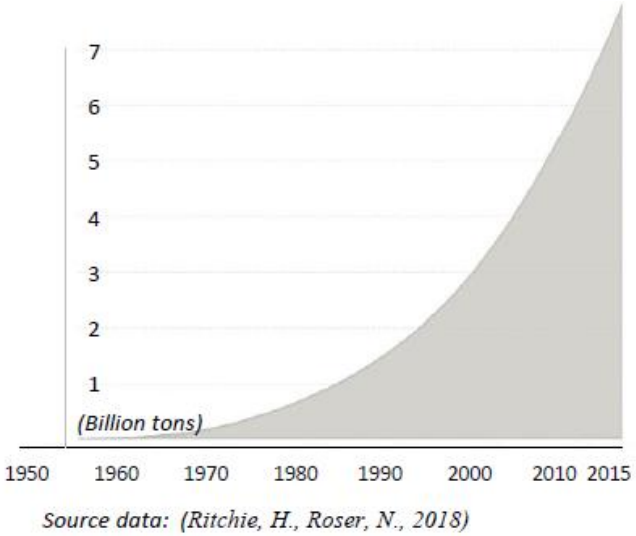
And the global use of plastics grows

Production in 2019:

Globally 368 Mton

EU+ 58 Mton, levelling off

Cumulative global plastic production

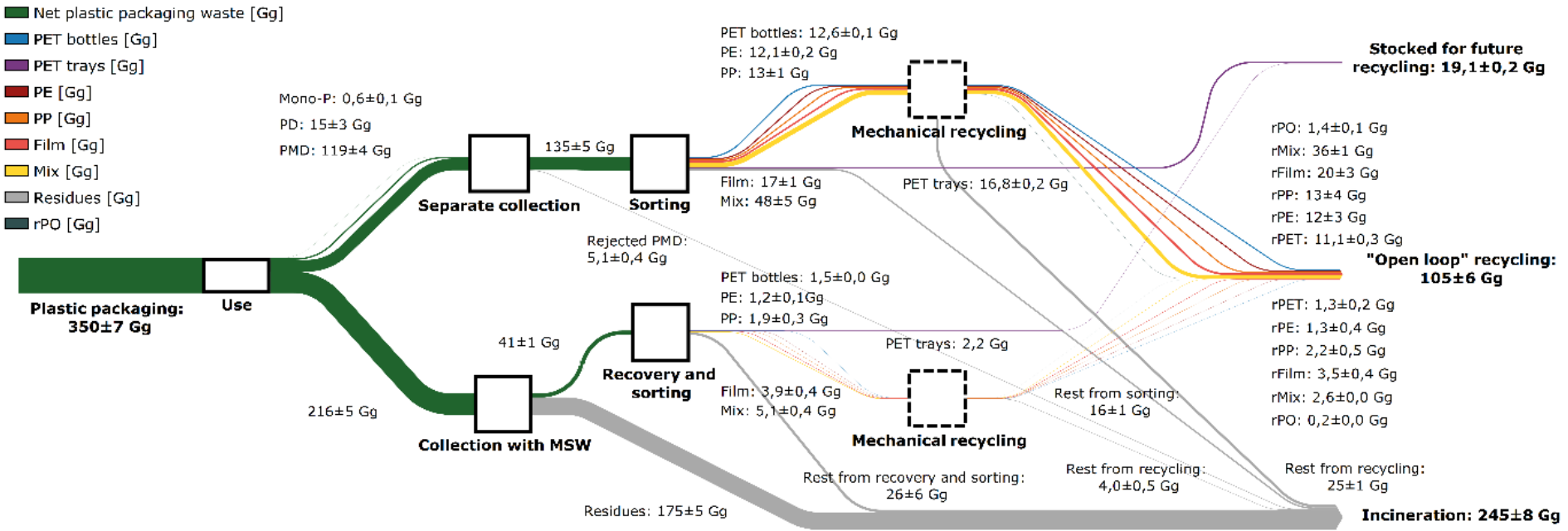


Our world in data

And so we got regulations... at least in the EU

- EU 1994/62 Packaging waste directive -> PPW RR 22.5%
- EU 2008/98 Waste framework directive
- EU 2008/282 Directive on FCM made from recycled plastics
- EU 2018 Plastic Strategy
- EU 2018/852 Revised packaging waste directive -> PPW RR 50%
- EU 2019/ SUP directive
- New revisions, taxes, bans, RC content obligations are expected

Post-consumer plastic waste recycling NL 2017



Gg= gigagram or kilotonne

https://doi.org/10.1016/j.wasman.2019.09.012

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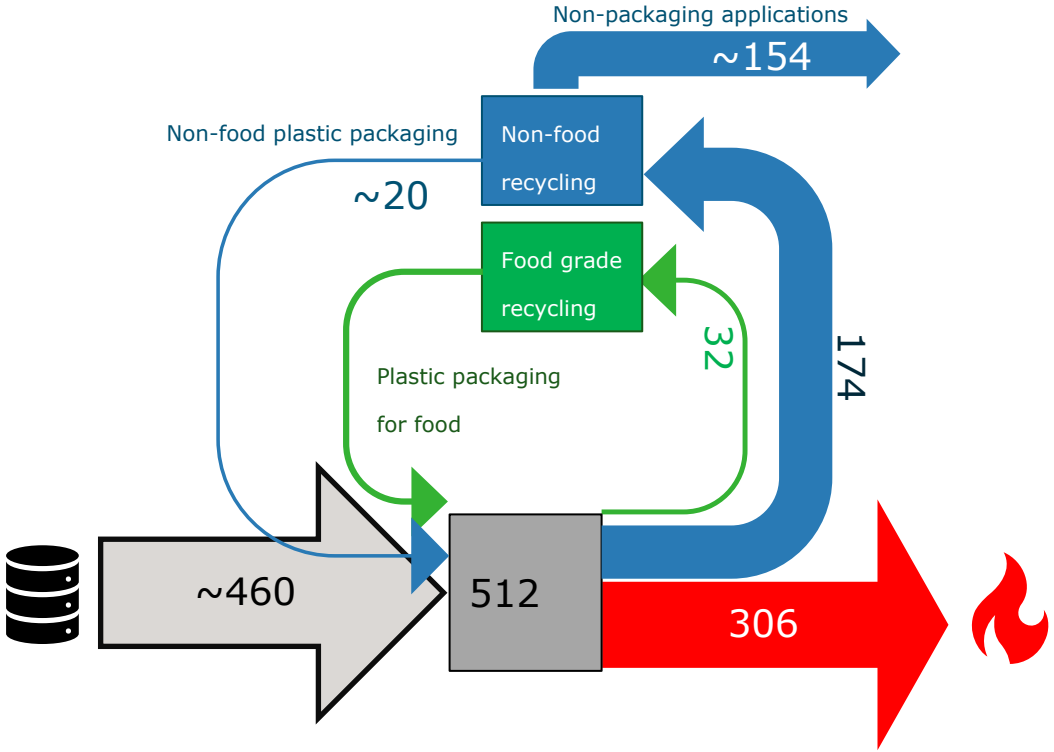
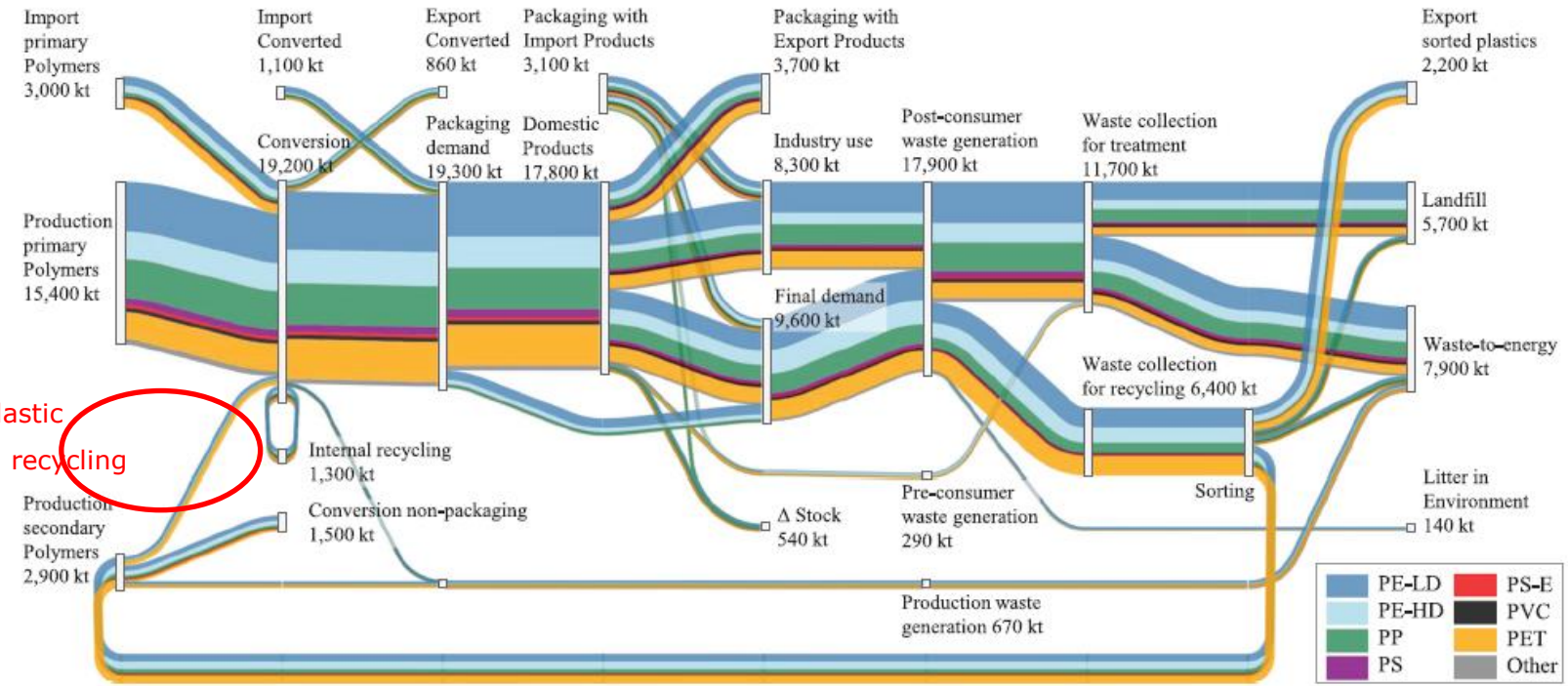
Recycling of plastic packages in NL, 2017

kiloton



Doi:10.3390/su122310021

Plastic packaging flows in EU-28 for 2014



Circular plastic packaging recycling

Cimpan. C.. et al. (2021). Plastic packaging flows in Europe: A hybrid input-output approach. *J Ind Ecol*. 1–16. https://doi.org/10.1111/jiec.13175

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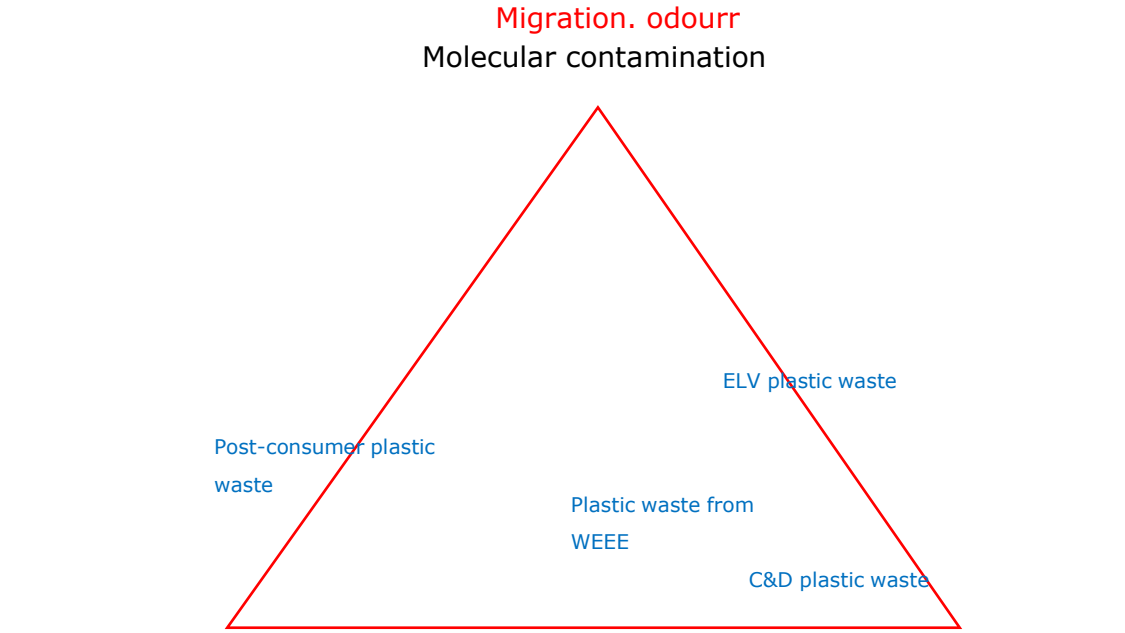
What do scientists understand of recycled PE?

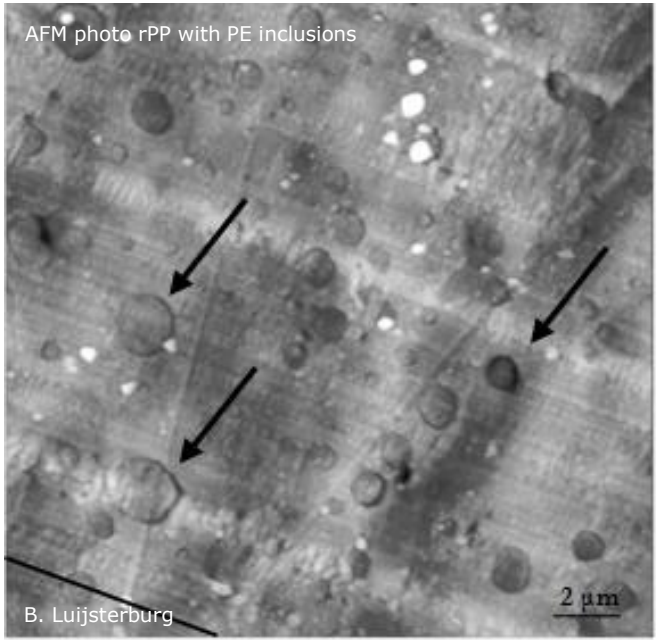
2008: 3 main quality decay mechanisms



DOI: 10.1002/mame.200700393

Recycled post consumer plastic packages

- Almost all are blends !
- Most common particles are other polymers
- But also inorganic particles are found



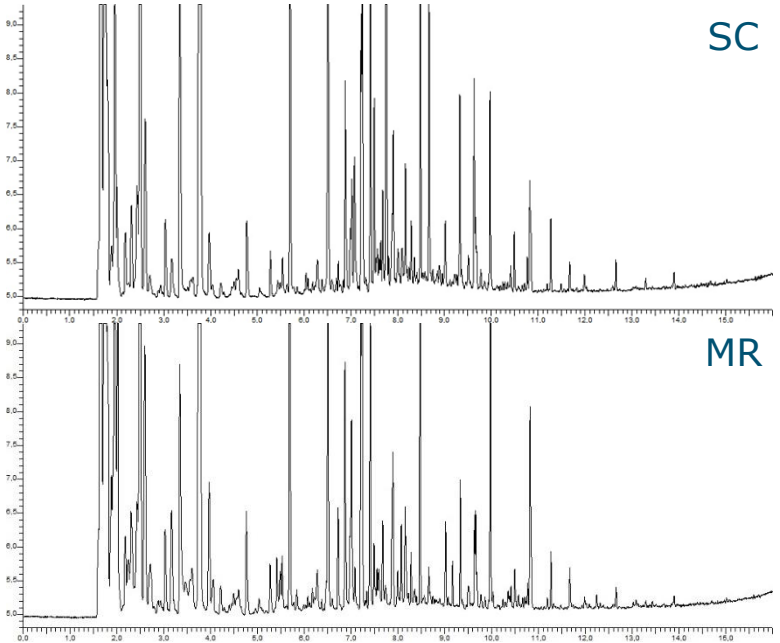
Particle & polymer contamination

- Inorganic inclusions -> SEM EDX (Al, Si, K, Ca...)
- Black spots -> SEM EDX / Micro-IR -> C (burnt paper?)
- PET -> partisol
    - Virgin ~ 10 million particles/gram
    - Recycled > 100 million particles/gram

- Results in Haze, holes, reduced impact strength, etc.

Molecular contamination

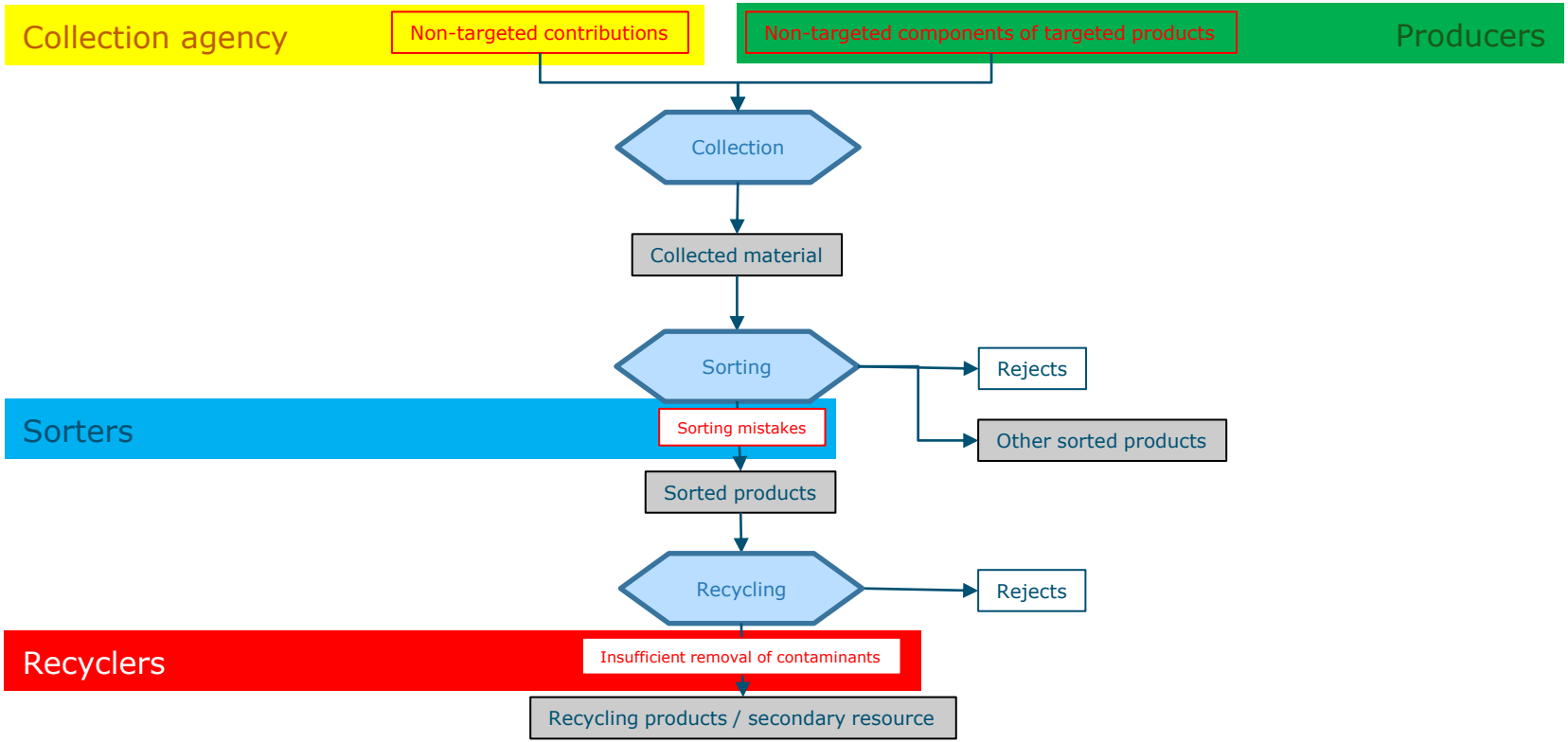
- Headspace GC of volatile compounds from recycled film made from separately collected (SC) plastic packaging waste and mechanically recovered (MR) plastic waste.



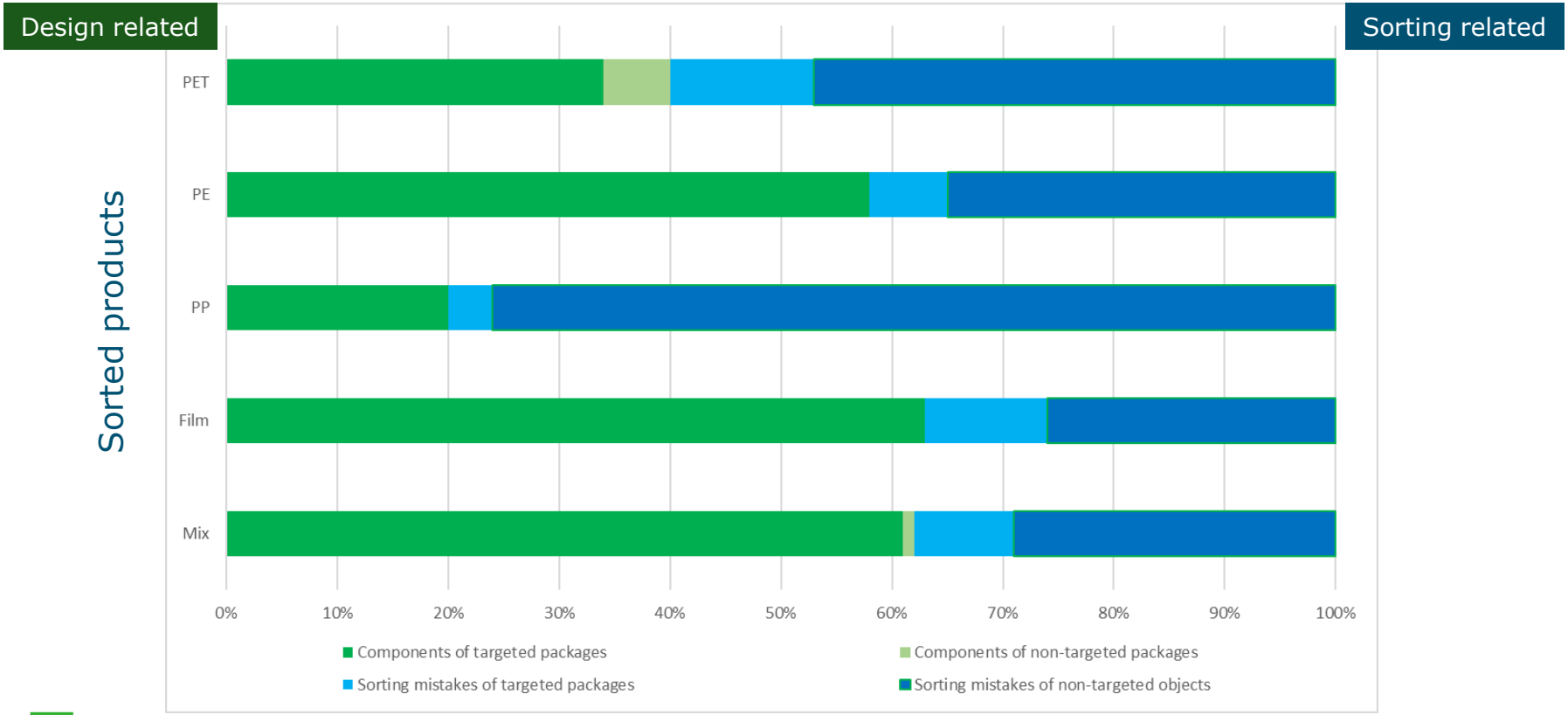
What type of molecules are present?

Category	Type of molecules (MC)	Relative concen-tration	Odour activity
Oligomers & degradation products	Homologous series of alkanes and alkenes	High	Hardly
Additives	Anti-oxidants (Irgafos), anti-slip agents (calcium stearate)	Limited	Non to hardly
Additives from prints and labels	Plasticiser (DEHP, etc.), BPA, MOSH solvents	Moderate	Non to hardly
Incidental contamination with product residues	Strongly varying, for example: + paint residues (pinenes) + food (oleic acid) + pain relief lotion (menthyl salicylate) + odorants (limonene) + phenolic compounds from printing ink	High	Varying between hardly and high
Microbiological metabolites and degradation products	Strongly varying: + Geosmine, 2-methyl-isoborneol, 2,4,6-trichloro-anisole. etc. + Short chain fatty acids, butyric acid + methyl sulfides and amines	Very low	Very high

Quality: Source of (polymeric) contaminants



Source of polymeric contaminants



Composition of washed milled goods

Feedstock/ Sorted product	Main polymer	Polymeric Contamination	Residual waste
PET Deposit	99.3%	0.6%	0.1%
PET SC	97.2%	2.8%	0.0%
PET MR	99.4%	0.2%	0.4%
PE SC	90.6%	9.3%	0.1%
PE MR	94.0%	3.0%	3.0%
PP SC	90.6%	9.2%	0.2%
PP MR	95.0%	4.2%	0.8%
Film SC	76.4%	22.7%	0.9%
Film MR	96.8%	2.8%	0.4%
Mix SC	63.5%	30.2%	6.3%
Mix MR	72.6%	25.6%	1.8%

Main milled goods obtained with a standard mechanical recycling process

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Quality matters

Sorted product	Recycling process	Molecular contamination	Polymeric contamination
PET bottles	Standard	Low after SSP	~0.1 – 1.0%
	Advanced	Low after SSP	<0.1%
PE DKR 329	Standard	Very high	5-10%
	Advanced	Very high	1-3%
PP	Standard	High	5-10%
	Advanced	High	1-3%
Film	Standard	Very high	8-15%
	Advanced	Very high	1-3%

Not suitable for food applications

Not suitable for packaging

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Systematic analysis recycled PE

Code	
1	Only transparent PE milk bottle bodies
2	PE bottle bodies (all colors)
3	Only complete PE bottles and PE flasks including packaging components made from non-PE polymers such as labels. caps and closures
4	Only complete PE packages. hence including PE films
5	PE packages including faulty sorted objects from predominantly PP and PET
6 warm	SC DKR 329. sorted PE including faulty sorted objects and attached residual waste. washed with 50°C 0.01 M NaOH solution
6 cold	SC DKR 329. sorted PE including faulty sorted objects and attached residual waste. washed with cold 0.01 M NaOH solution

Test set-up

1. Determine the object-wise composition of PE DKR 329
2. Mechanically recycle the 6 samples
3. Determine the milled goods composition with NIR
4. Extrude (50 µm melt-filter) the rPE
5. Injection mould test-specimen
6. Test the specimen with Impact. Tensile strength. IR. DSC. Colour

Results Manual NIR assisted Flake sorting

	PE	PP	PS	PVC	PET	Black	Paper	Textile	Rest
1	100%								
2	100%								
3	97.16%	2.26%	0.06%	0.02%	0.22%	0.18%	-	-	0.1%
4	95.85%	3.87%	-	-	0.02%	0.14%	0.02%	-	0.1%
5	89.66%	8.27%	0.03%	0.1%	0.05%	0.61%	-	-	1.06%
6	90.03%	8.15%	0.2%	0.25%	0.17%	0.44%	0.08%	0.02%	0.66%

Uncertainty increases for the smaller contaminants

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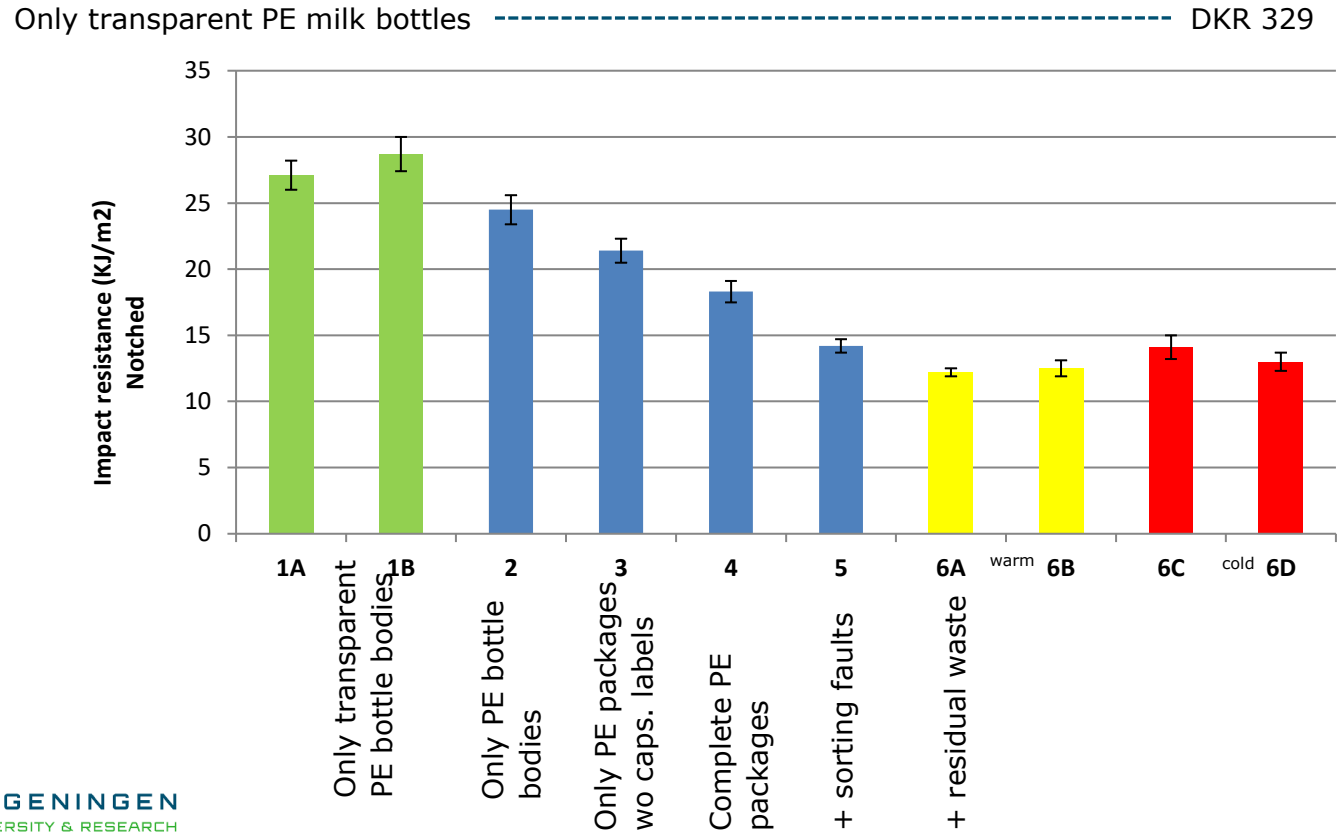
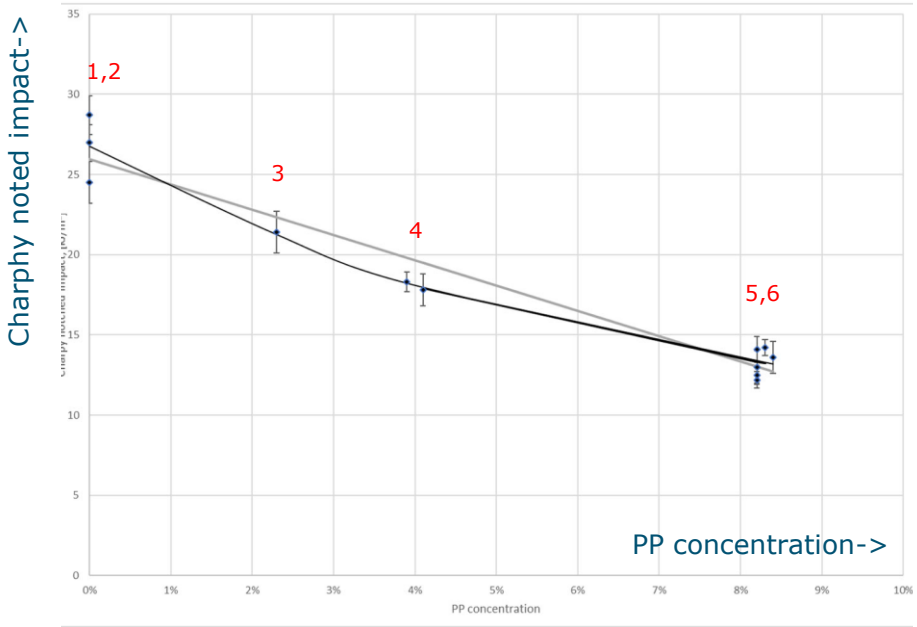
Results mechanical properties



Clear relationships between [PP] and Impact

- The more polymeric contaminants, the more blend ‘particles’ in the morphology and the worse the impact strength

- The antagonistic mixing behaviour



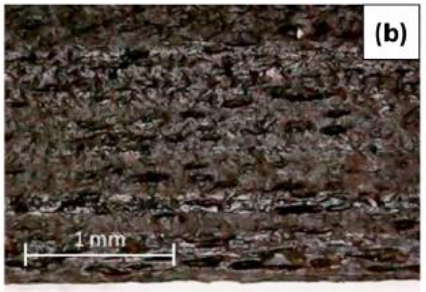
DOI: 10.1002/pts.2551

But... It is not just about polymeric purity

Code	Composition	Charpy notched impact [kJ.m^{-2}]	MFI g/10 min. @ 240°C and 2.16 kg
1A	Milk container bodies	27.0 ± 1.1	0.84 ± 0.01
1B	Milk container bodies	28.7 ± 1.2	0.84 ± 0.01
2	PE bottle bodies	24.5 ± 1.3	1.11 ± 0.02
3	Complete PE bottles flasks	21.4 ± 1.3	0.69 ± 0.01

Also the grade purity becomes important when progressing towards higher qualities

New revelations, 1



- Garofalo and colleagues revealed that:
  - Recycled polyolefins are hygroscopic!
  - During thermal processing steam cavities can be formed in the recycled plastic, reducing the properties.
  - Pre-drying helps to mitigate these issues.
  - Polar contaminants (ink residues, pigments, glues?) are to blame

https://doi.org/10.1016/j.jclepro.2021.126379

New revelations, 2

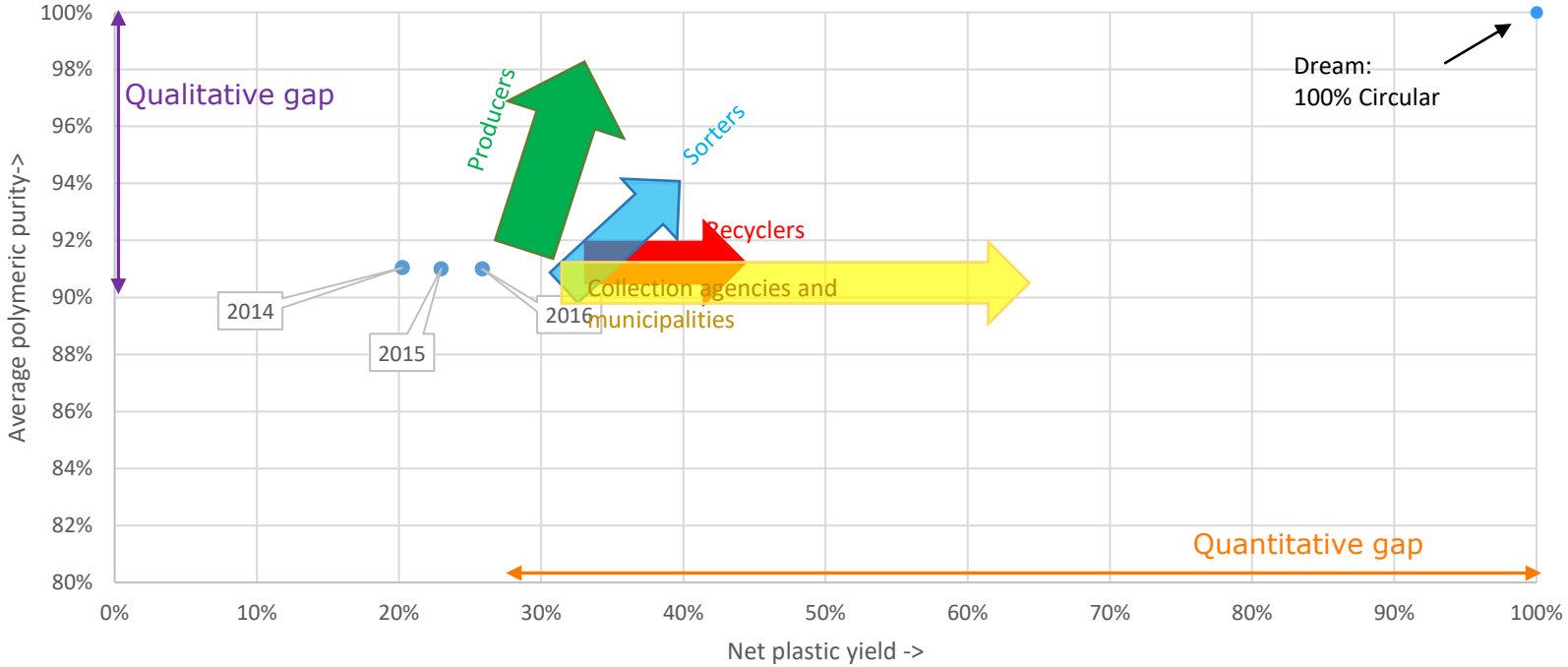
- UV-cured inks that are commonly used on plastic packages and labels produce an avalanche of NIAS molecules, of which the are several of potential concern.

- PI + Polymer + UV -> hundreds of NIAS

doi:10.3390/molecules24193592

So, how could we progress towards a CE?

Future outlook for the Netherlands



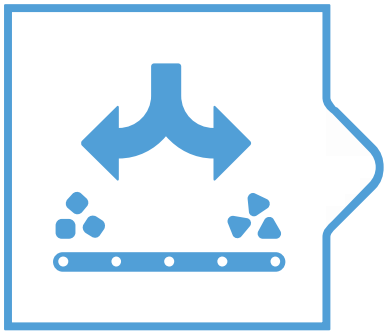
How to approach the circularity potential?

Prerequisites for an ideal circular PPW chain

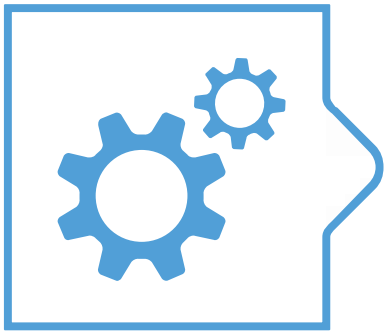
"All stakeholders are completely committed to the performance of this overall system."

Packaging designs
fit the recycling scheme

Collection system
retrieves all the targeted packaging objects and a minimum of non-targeted materials



Sorting process
maximises the production of mono-material sorted products and minimise mixed plastics sorted products



Recycling technology
for all packaging materials

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Circularity potential - modelling

Modelling the 'best practice' of all stakeholders

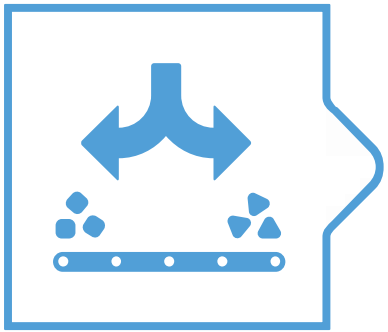
(on the basis of the model for 2017):

Packaging design

- PET. PE and PP
- Black → colour
- Performance parameters

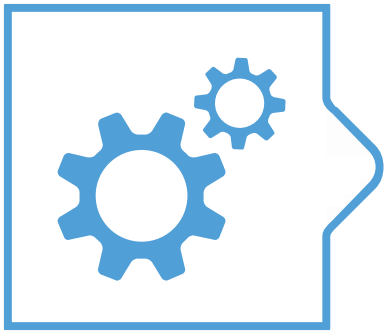
Collection system

- Collection rate = 70%
- Less non-targeted contributions



Sorting process

- Maximal technical feasible sorting fates
- Additional sorting of PE flexibles



Recycling technology

- Additional recycling of PET trays

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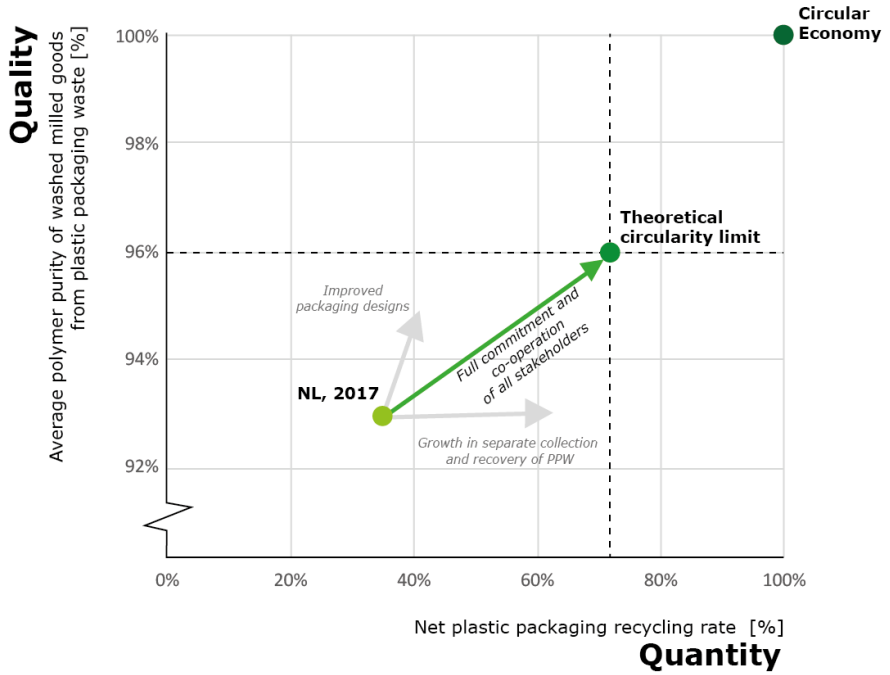
Circularity potential

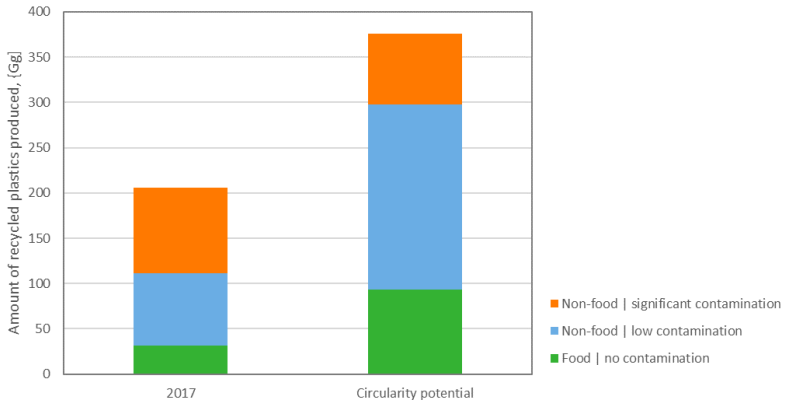
Circularity potential:

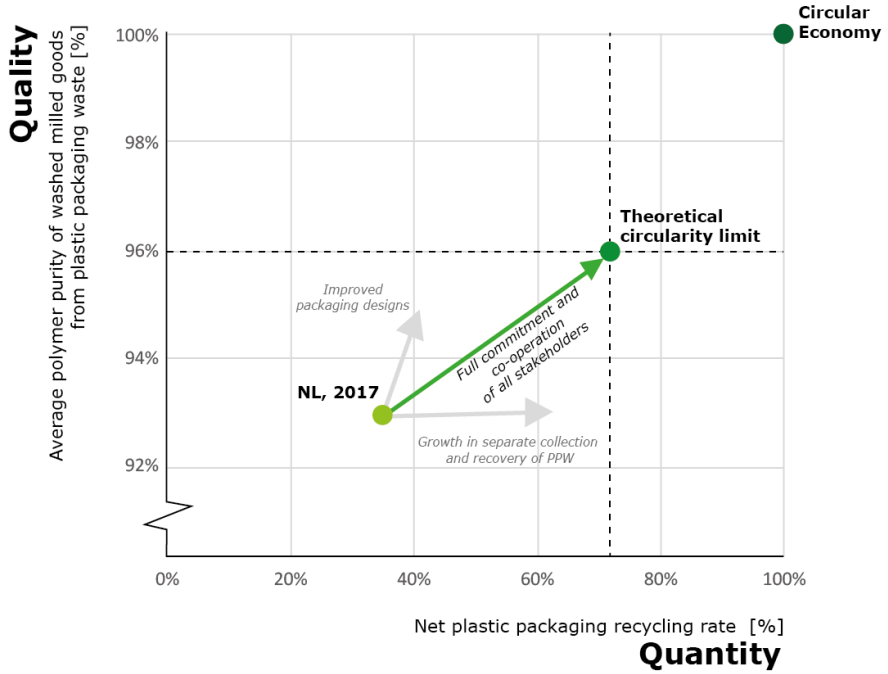
- Recycling rate: 72%
- Polymer purity: 96%



Circularity potential

- More recycled plastic for food application
- More recycled plastic for new packages/consumer products
- Less recycled plastics for bulky applications





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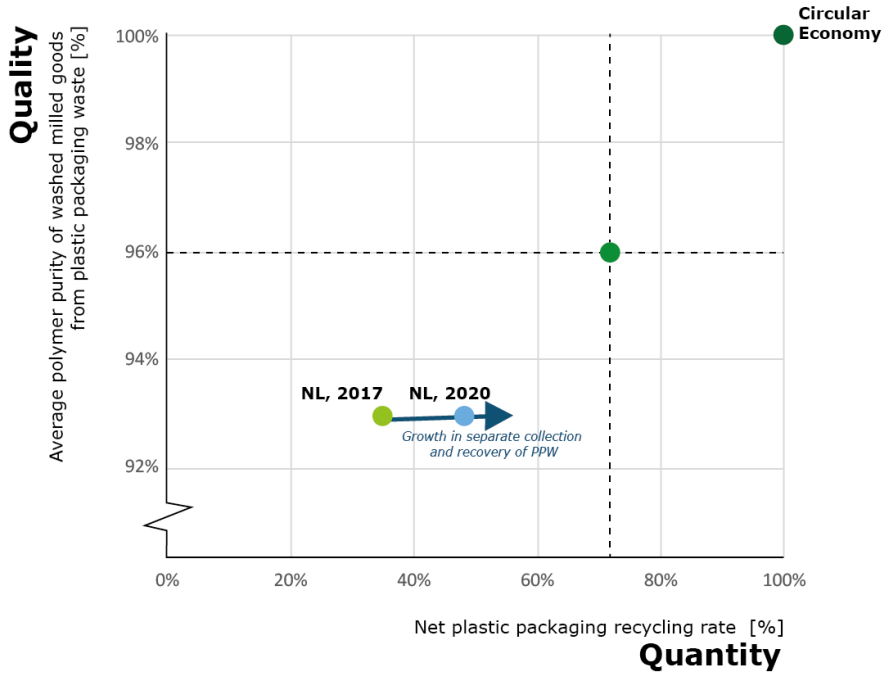
Recycling of PPW. progress in NL 2017-2020

Status 2020*:

- Recycling rate: ~48%
- Average polymer purity: ~93%

Higher separate collection rates and additional recovery of PPW resulted in a higher recycling rate.



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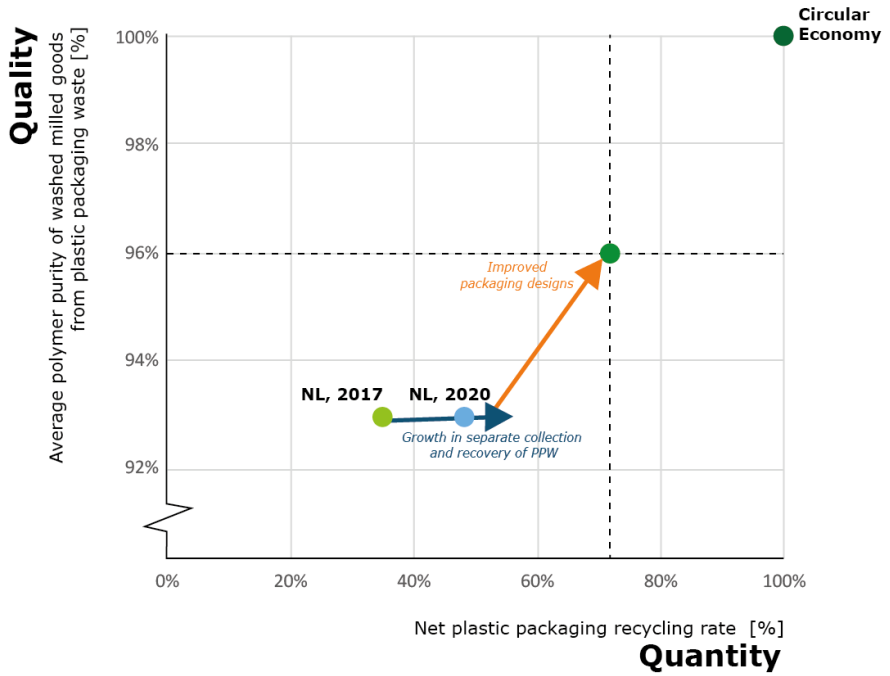
*calculated estimate

More circular recycling

- The recycled plastics resulting from this system are of **insufficient quality** for the application packages and consumer product

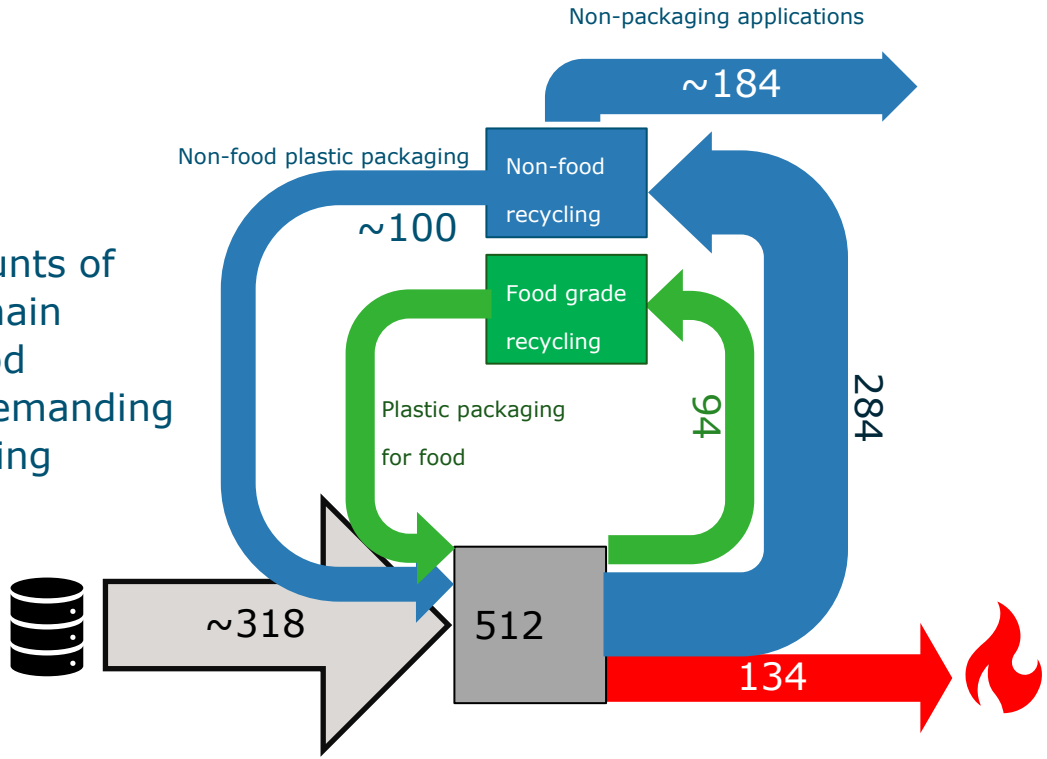
Design for recycling:

- improves the quality of the recycled plastics
- improves the chain efficiency



Circularity potential with current technologies

Substantial amounts of virgin plastic remain necessary for food packaging and demanding non-food packaging



kiloton

Recycle guides

- There are many different recycle guides ..
- ... and they are not always consistent

ready to recycle
circpack®

RecyClass™
Design Matters!

cyclos-HTP
Institut für Recyclingfähigkeit und Produktverantwortung

	YES	CONDITIONAL	NO
	Full compatibility – materials that passed the testing protocols with no negative impact	Limited compatibility – materials that passed the testing protocols if certain conditions are met	Low compatibility – materials that failed the testing protocols OR
Container			
Size			
Colours			
Barrier			
Additives			

EPBP

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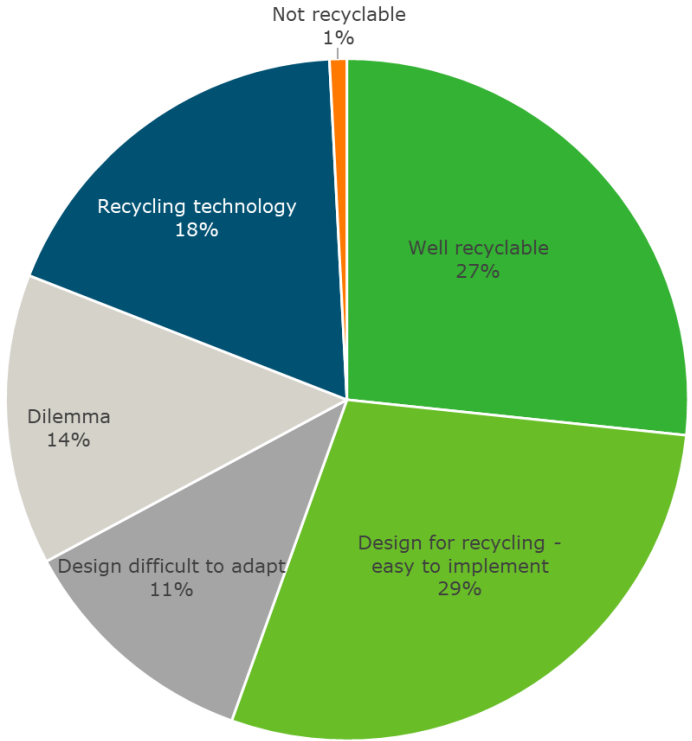
Design for recycling opportunities

- 29% easy to implement
- 11% difficult to adapt
- 14% dilemma’s (e.g. food waste)
- 18% recycling technology



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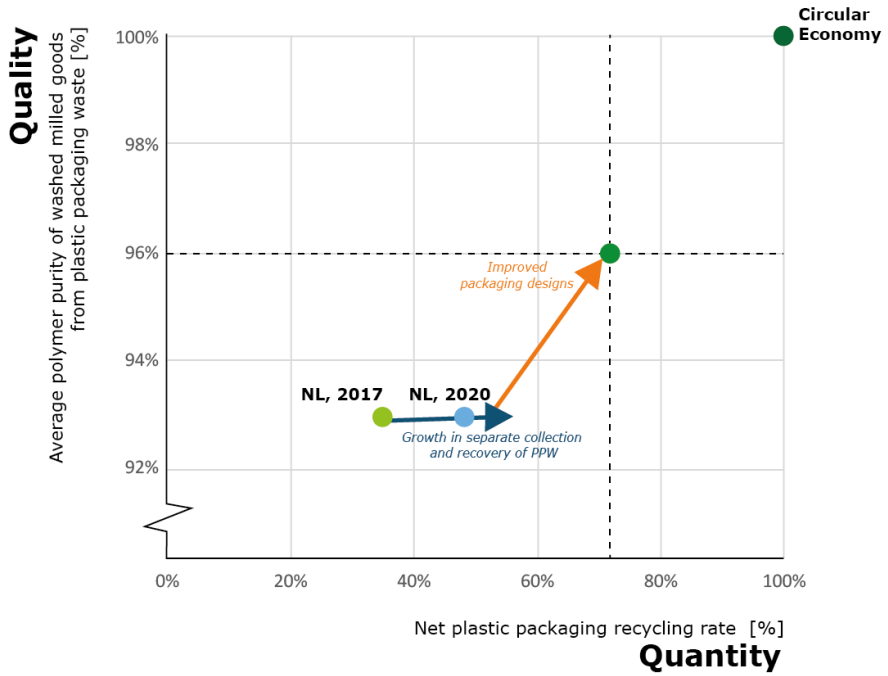
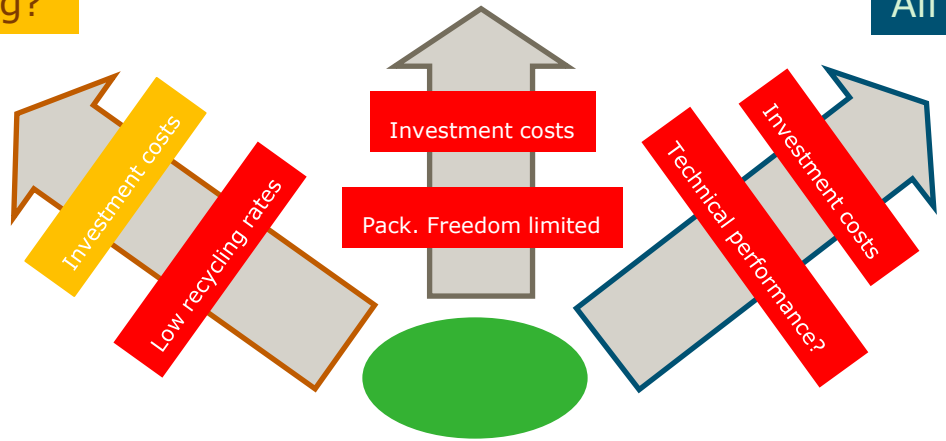


How to progress beyond the limit?

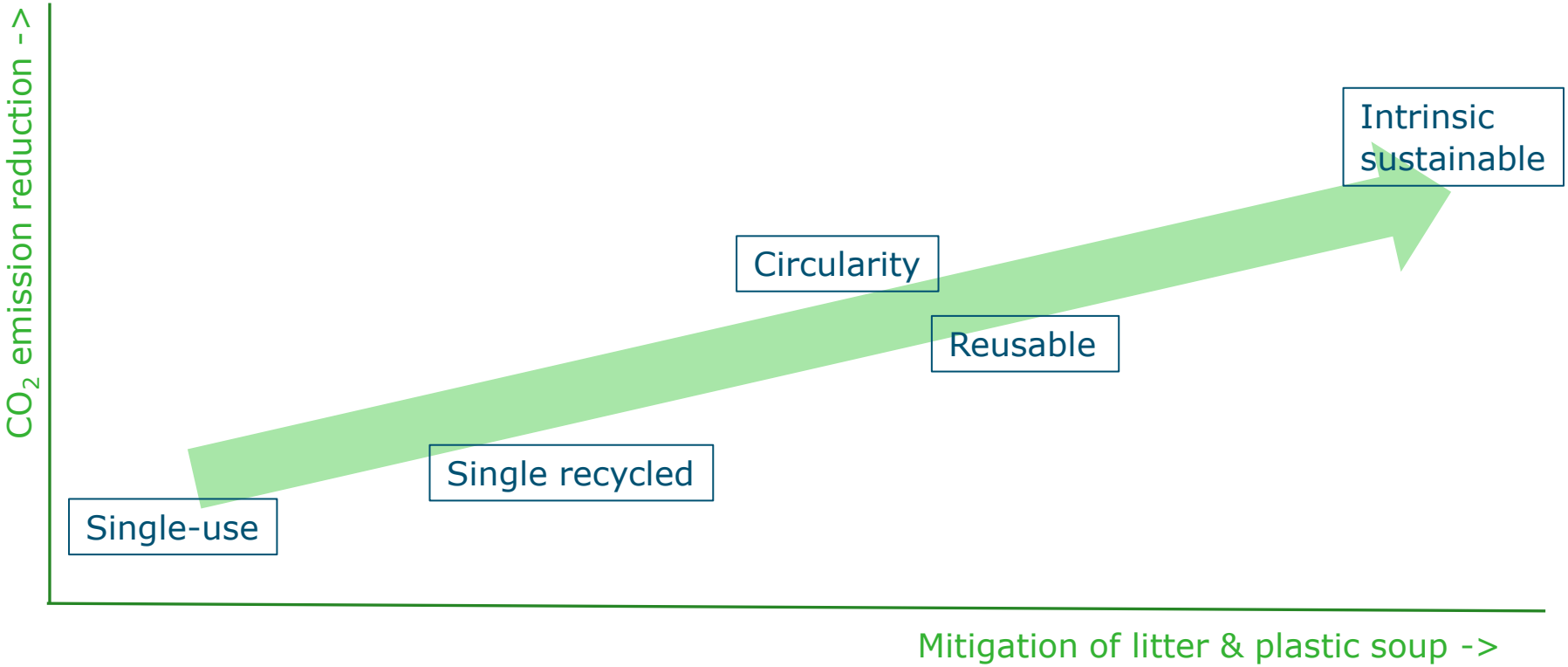
Standardisation. grade selective sorting?

Chemical recycling?

All polyester system?

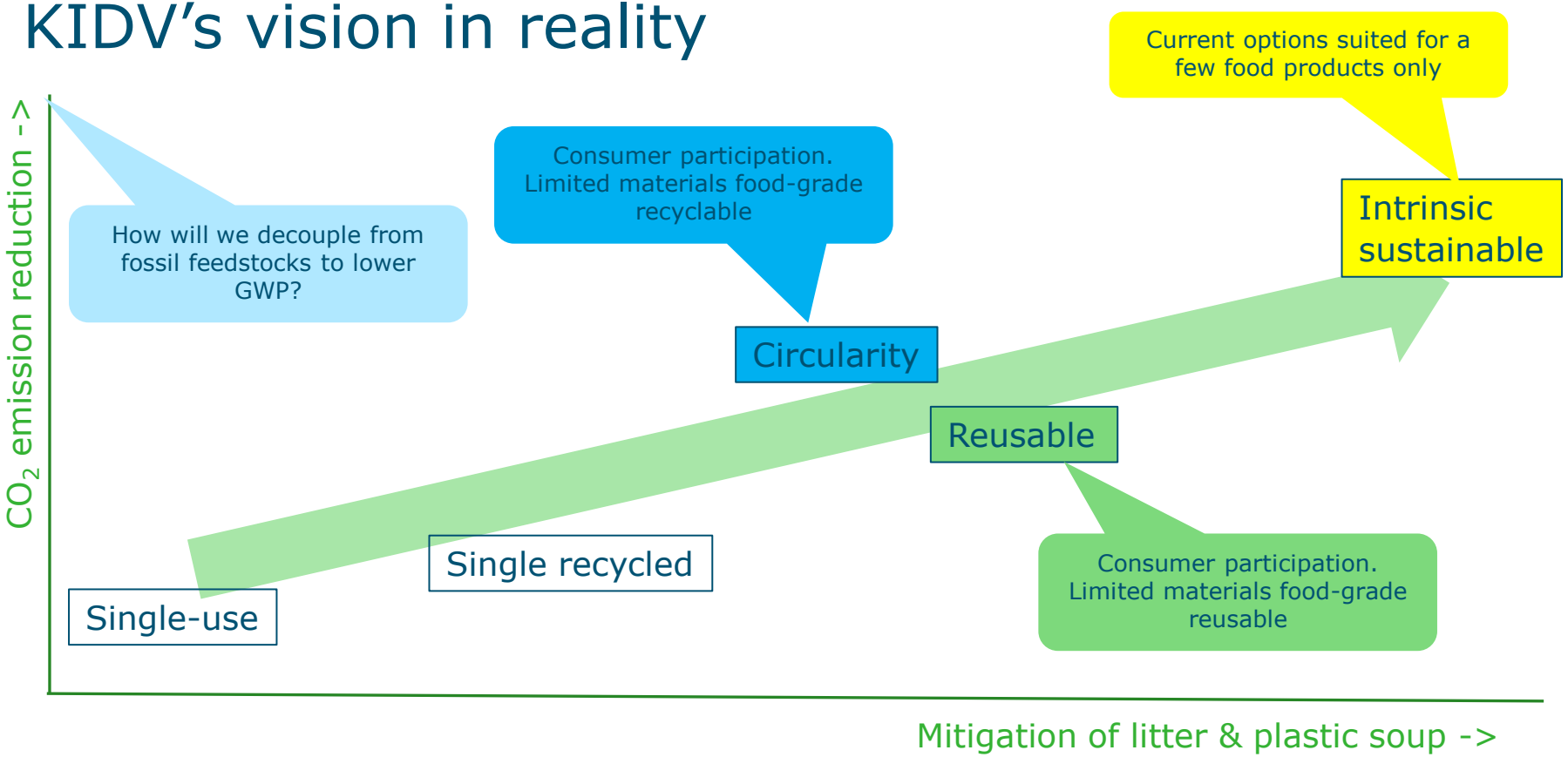


KIDV's vision



KIDV. State of Sustainable Packaging. 2020

KIDV's vision in reality



KIDV. State of Sustainable Packaging. 2020

We need a concerted action of all stakeholders

- But... most stakeholders:
  - Do not feel the urgency to act, have other priorities
  - Believe in different solutions
  - Do not understand the complexity

Thank you for your interest

Plastic packaging waste can be recycled and is one of the easier types of plastic waste to recycle. The challenges are even higher for less wealthy countries and other types of plastic waste

Plastic waste deserves serious attention

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