Workshop: Lifecycle of Plastics

Product Development (with recycled plastics)

Prof. Kim Ragaert, Ghent University

08/09/2020, Network-Wide Training Event 1

C-PlaNeT
CIRCULAR PLASTICS NETWORK FOR TRAINING

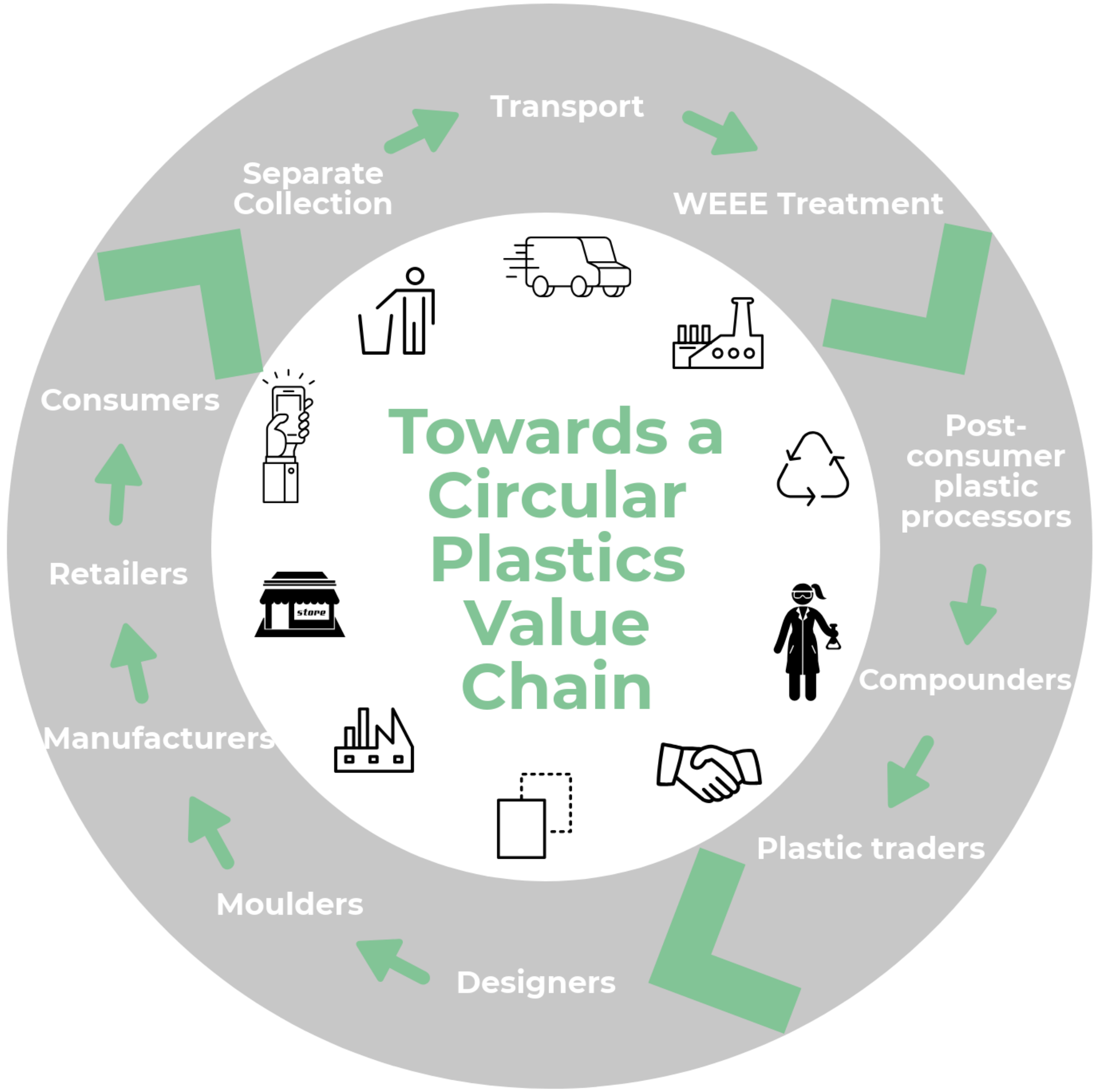
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 859885.

FRAMING THIS E-CLASS

- Assumed knowledge:
  - Basics of polymers, basics of polymer processing
- Target audience:
  - The C-PlaNeT ESRs = multidisciplinary audience (not necessarily engineers) at graduate level
  - Professionals not in product design, looking to get an introduction
- Goal of the class:
  - To give a basic insight into the art of designing products with (recycled) plastics
  - To make you realise it's all about applying common sense
- Focus:
  - Injection moulding products = 'consumer products'
  - (So not packaging)

CONNECTING H2020 PROJECTS

KNOWLEDGE TRANSFER FROM POLYCE



H2020 PolyCE: large-scale demontrator project for WEEE plastics to EEE products

PolyCE
POST-CONSUMER HIGH-TECH RECYCLED POLYMERS FOR A CIRCULAR ECONOMY

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730308

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CONTENT

- What is product development?
- Do’s and don’ts in plastic product design
- Designing with recycled plastics
- Legislative aspects
- Case studies

Every now and then , I will ask a question (purple box)
→ Answer via Chat function if you have an idea

Do you have questions youselves?
→ Type in the Chat and I will try to pick them up

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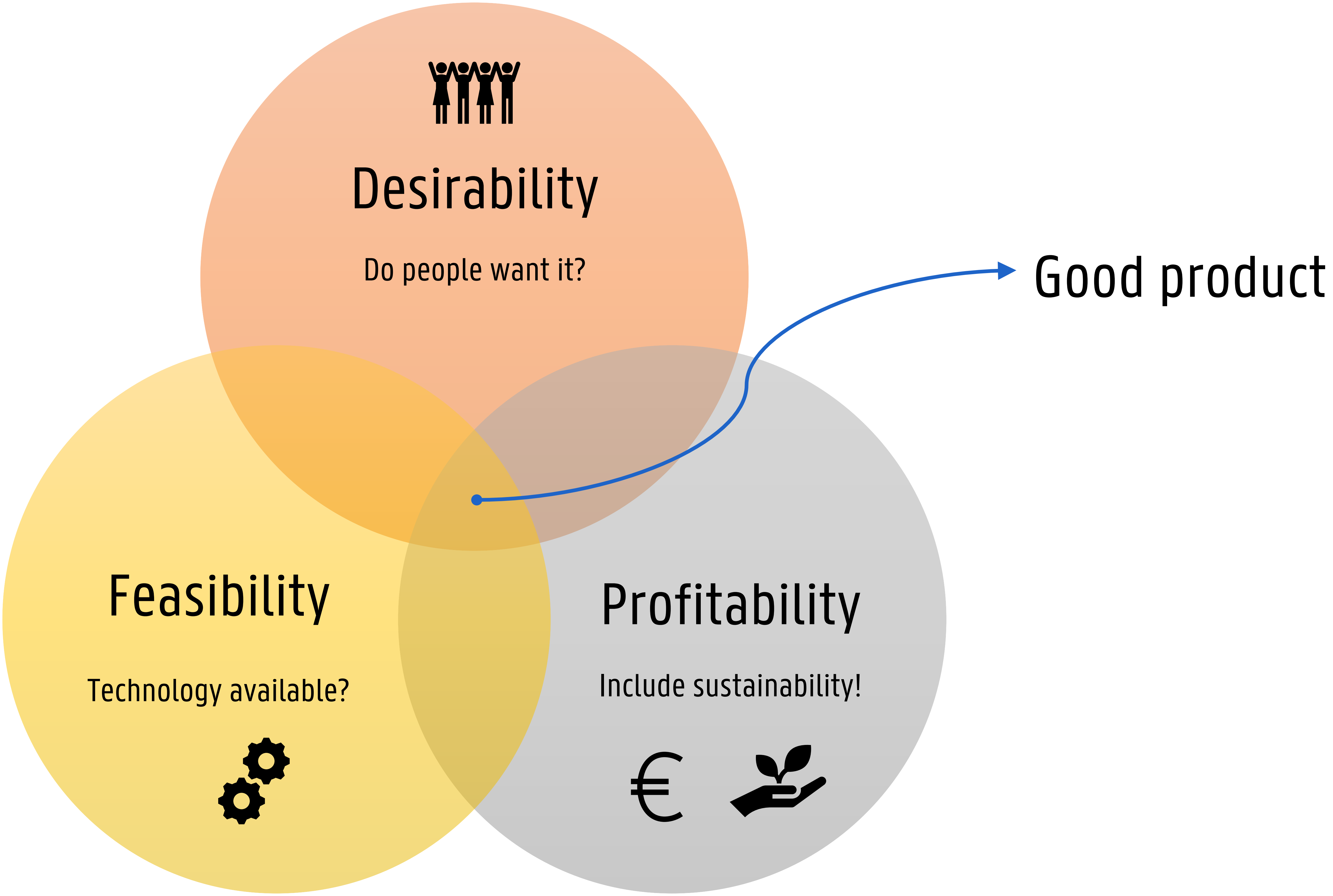
WHAT IS PRODUCT DEVELOPMENT?

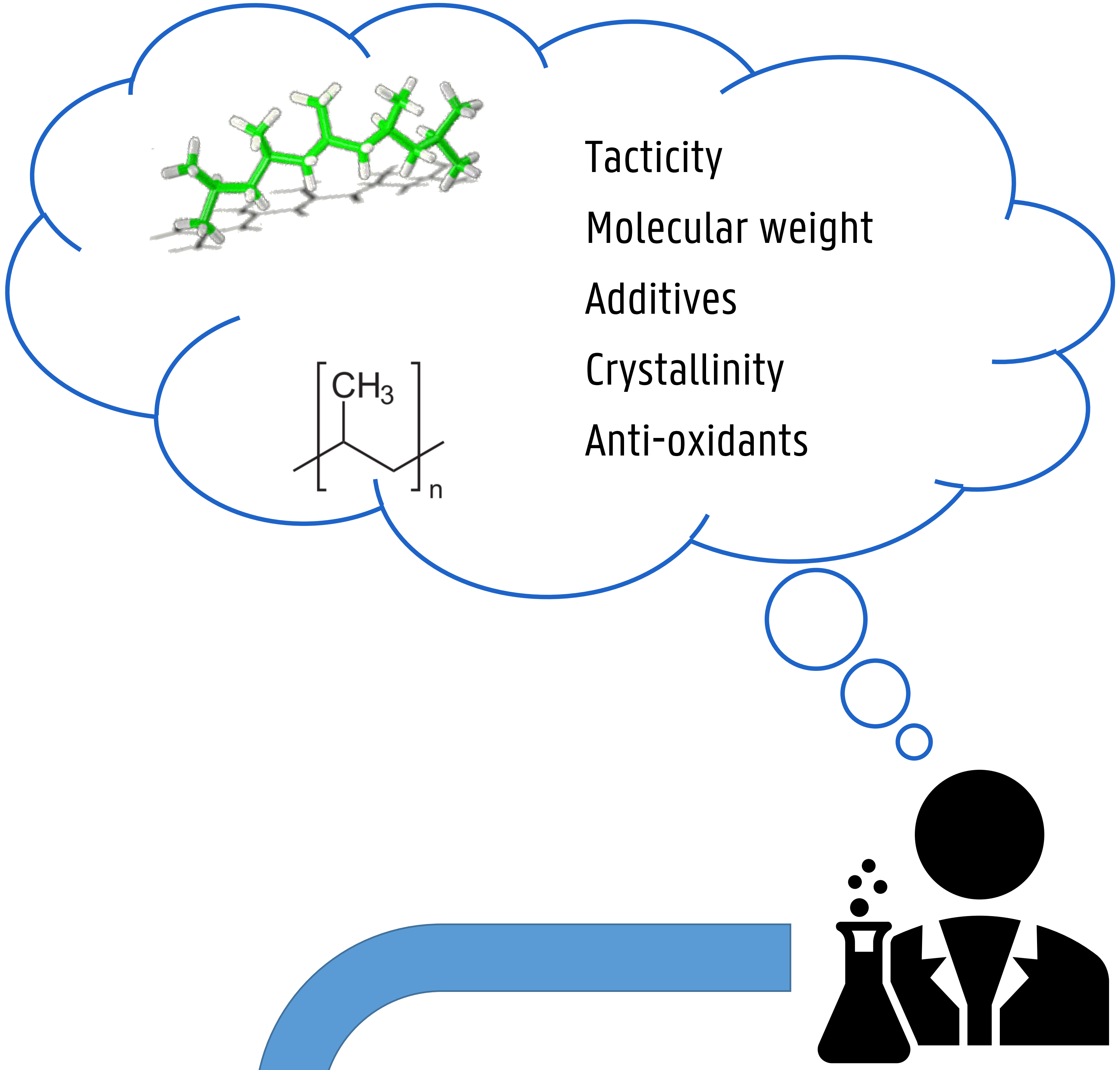
FOCUS: INJECTION MOULDING PRODUCTS = ‘CONSUMER PRODUCTS’

WHAT MAKES A GOOD CONSUMER PRODUCT



POLYMER SCIENCE

- Microstructure
- Morphology
- Rheology



The study of the material itself

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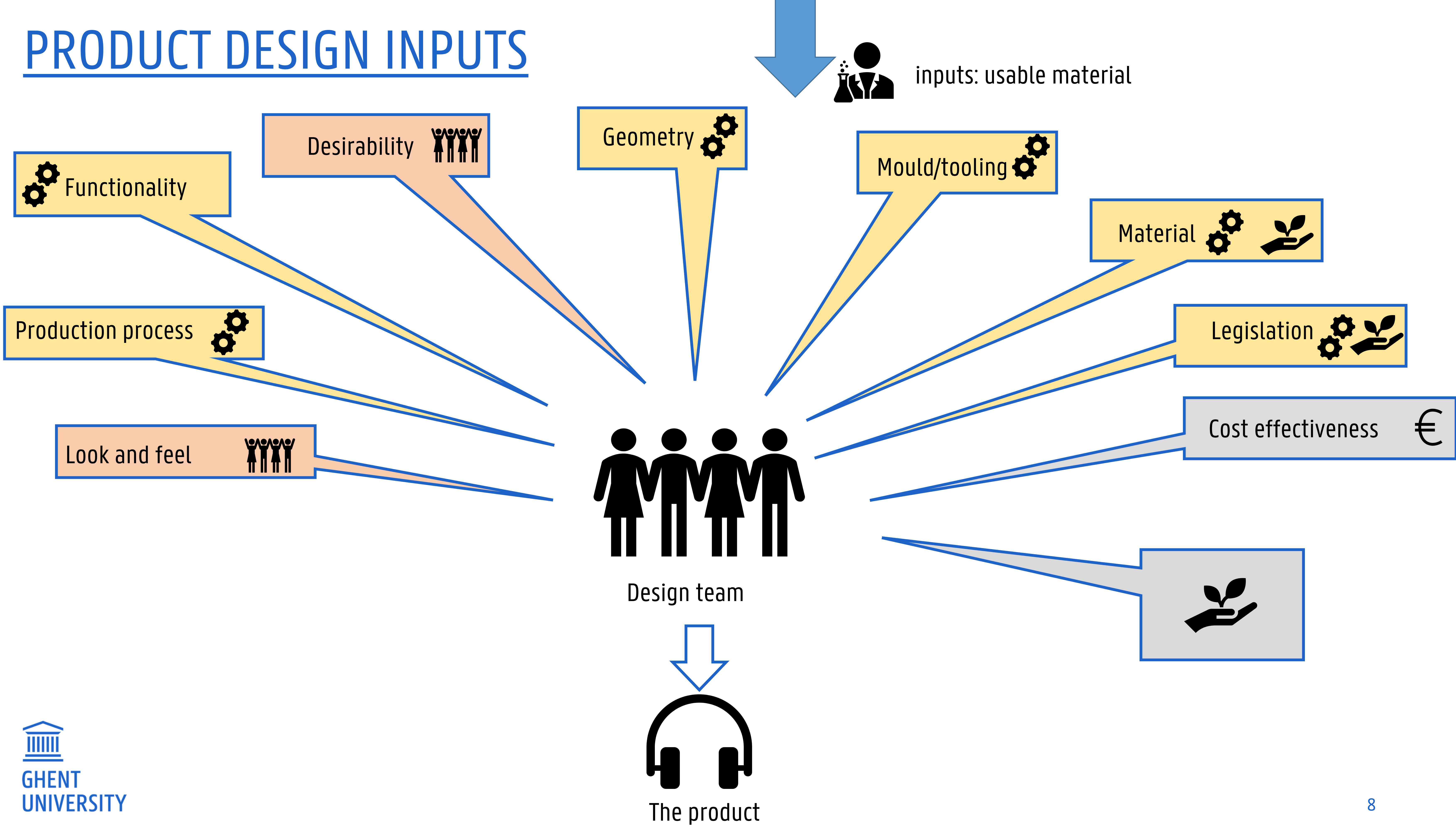
PRODUCT DESIGN INPUTS



MATERIAL SELECTION CRITERIA – FROM A TDS

Q: what does TDS stand for?

Mechanical properties

Stiffness

Creep

Fatigue

Impact

Thermal/safety properties

HDT/Vicat

RTI

Flammability

Processability

MFI

Shrinkage

Warpage

Dimensional stability

Environmental

Chemical resistance

Environmental stress cracking

UV resistance

Weathering

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MATERIAL SELECTION CRITERIA – NOT ON STANDARD TDS

Legal requirements

IEC, UL, ISO norms

Rohs, Reach, POP's legislation

Nonnegotiable!

Sustainability

Production footprint

Recycled or not?

End-of-life fate

Functional requirements

Visual requirements: high gloss, soft touch, texturing

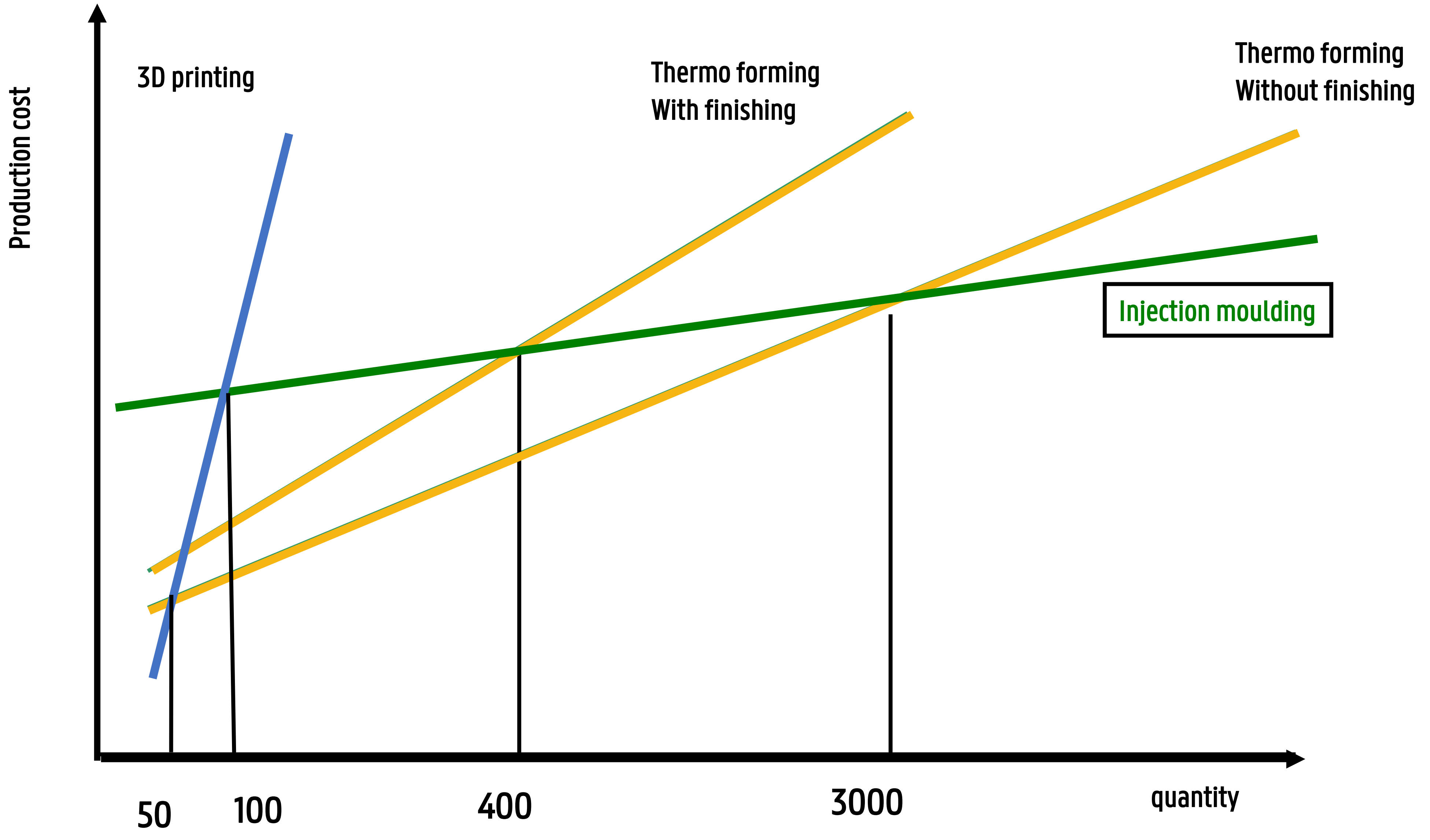
Optical requirements: transparent, translucent, diffusion

Printability

Weldability

PRODUCTION PROCESS – THE INFLUENCE OF PRODUCTION SIZE

- Driving factors in selection
  - Availability of equipment
  - Quantity
  - Quality
  - Costs



Disclaimer: concept numbers (dependent on size and complexity)

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GEOMETRY ⇔ MOULD/TOOLING

- Can you make it?
  - Production process: part **and** mould
  - Post processing?
  - Assembly: screw, glue, snaps, tape, weld, ...
  - Features: undercuts, holes, bosses, ...

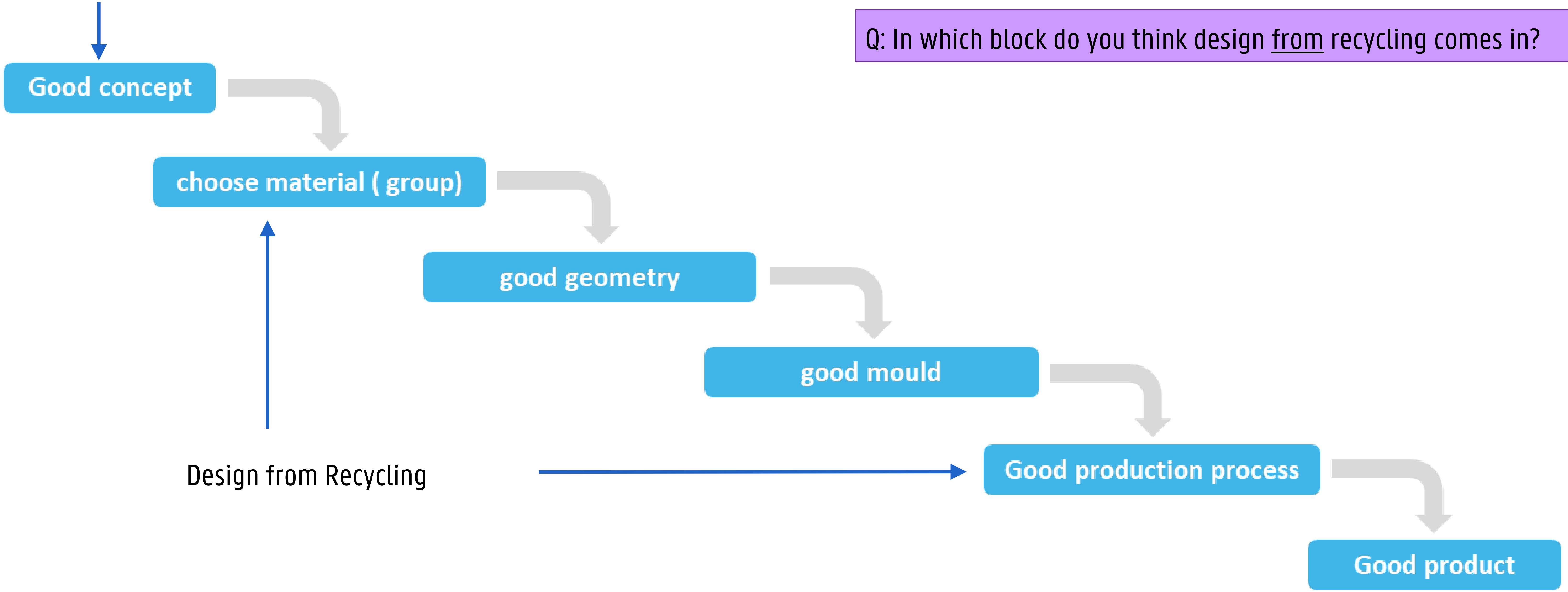
More complexity → €€€

DESIGN WATERFALL (BY PEZY GROUP innovation accelerators)

Q: In which block do you think design for recycling comes in?

Q: In which block do you think design from recycling comes in?

Design for Recycling



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SUSTAINABILITY - DESIGN FOR RECYCLING

CIRCULAR ECONOMY
Closing the loop
AN AMBITIOUS EU CIRCULAR ECONOMY PACKAGE

*'As a first step, and under the framework of the Ecodesign directive, the Commission has developed and will propose shortly to Member **States mandatory product design** and marking requirements to make it **easier and safer to dismantle, reuse and recycle** electronic displays'*

*'The Commission is also proposing to **encourage better product design** by differentiating the financial contribution paid by producers under **extended producer responsibility** schemes **on the basis of the end-of-life costs** of their products. This should create a **direct economic incentive to design products that can be more easily recycled or reused**.'*

'The designed-for-recycling method incorporates recycling and recyclability criteria into the design phase of products, with the aim of obtaining recycled and/or recyclable products.'

Julio Rodrigo and Francesc Castells, Rovira i Virgili University

Design for Recycling relates to:

- design for disassembly
- eco-design (*EU Ecodesign directive*)

  = designing a product to make it easier to recycle into the individual composing **materials** at its **end-of life**

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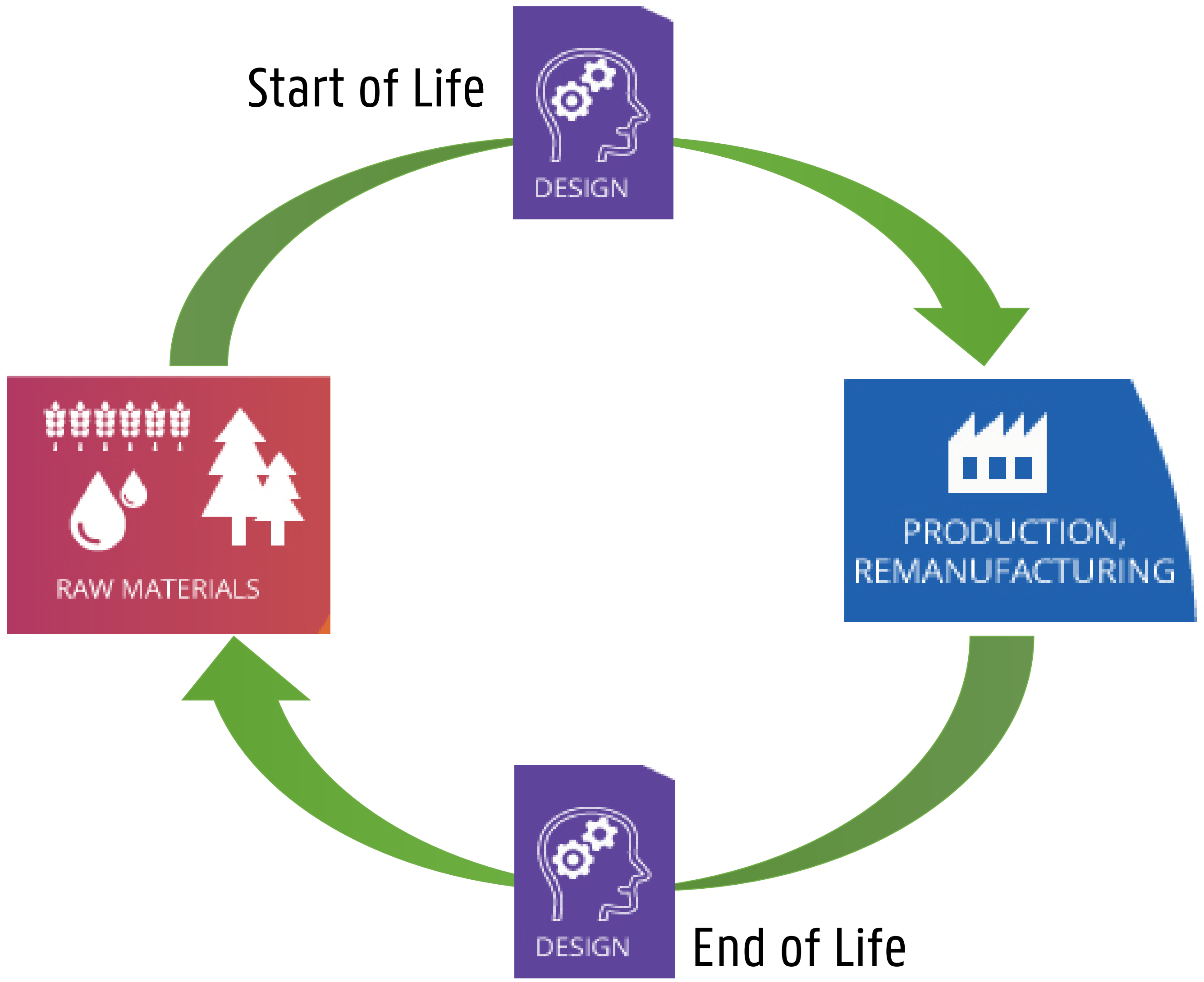
SUSTAINABILITY - DESIGN FOR RECYCLING

Q: Does design for recycling facilitate the 'start of life' or the 'end of life' ?

making it easier to recycle the individual **materials** making up the product at its **end-of life**



DESIGN FOR RECYCLING

Source: EU Parliament, 2015, Circular economy: the importance of re-using products and materials

DESIGN FOR SUSTAINABILITY GUIDELINES

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INCREASE LIFETIME

REDUCE THE AMOUNT OF MATERIAL USED WITHOUT LOOSING FUNCTIONALITY

AIMING AT USING FEWER DIFFERENT MATERIALS

AVOID PERMANENT CONNECTIONS

- GLUES
- 2K MOULDING

USE LOW IMPACT MATERIALS WHERE POSSIBLE

EASY TO RECYCLE CONSTRUCTION

AVOID DARK COLOURS

AVOID HARD TO RECYCLE ADDITIVES/POLYMERS

-HAZARDOUS ADDITIVES

-MULTILAYERS

use easy to separate or compatible materials

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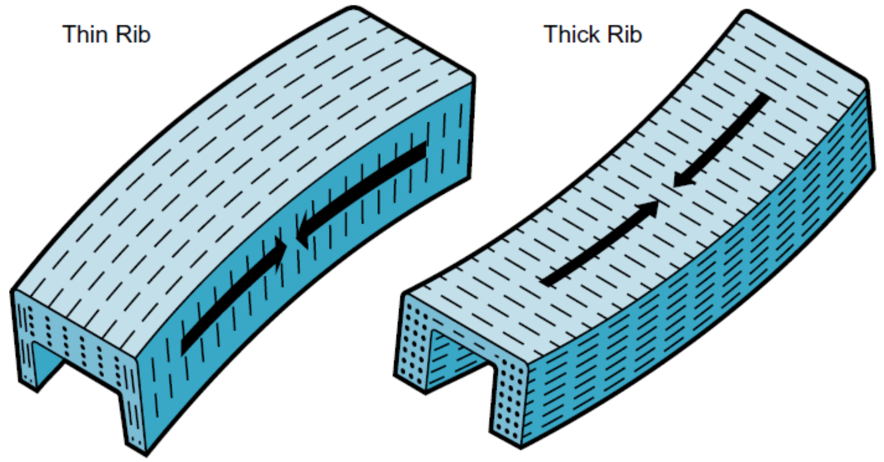
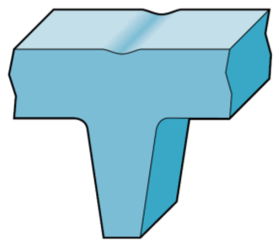
DO'S AND DON'TS

OF DESIGNING WITH PLASTICS

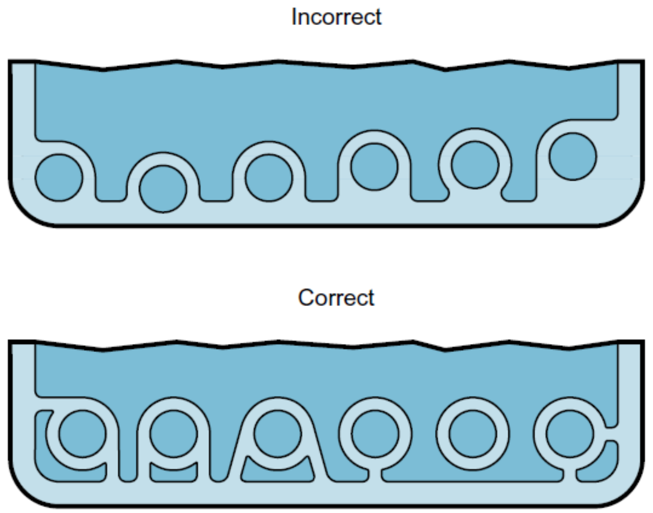
APPLYING COMMON SENSE TO SOME TYPICAL PLASTICS 'THINGIES'

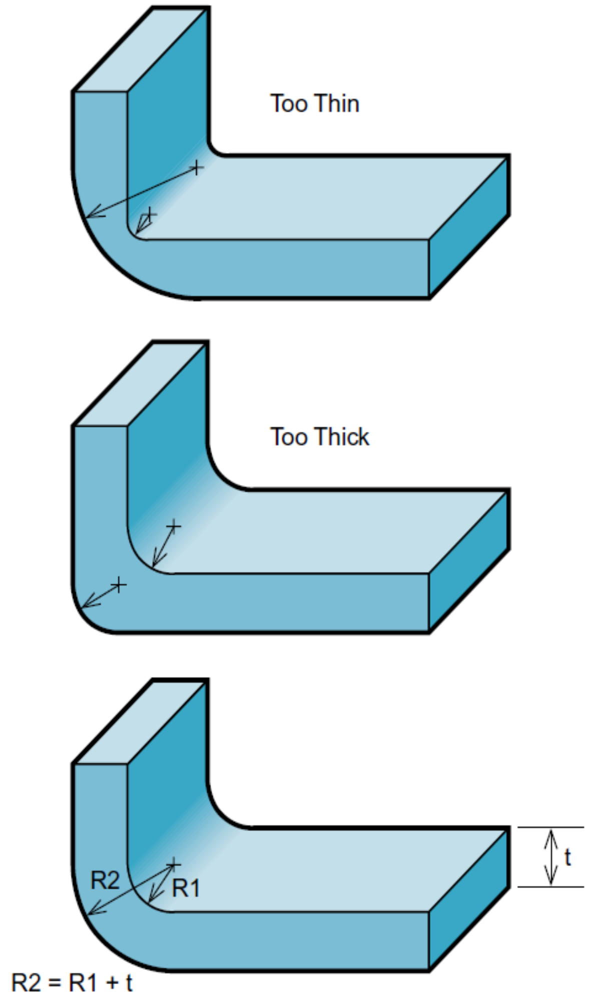


- Semi-crystalline polymers will shrink when solidifying
  - Spots of material concentration will shrink more
    - Sink marks



    - Products with different wall thicknesses will shrink unevenly
      - Uneven shrink = warpage
- So…
  - Prevent mass imbalance
    - Use even wall thickness
    - Apply coring





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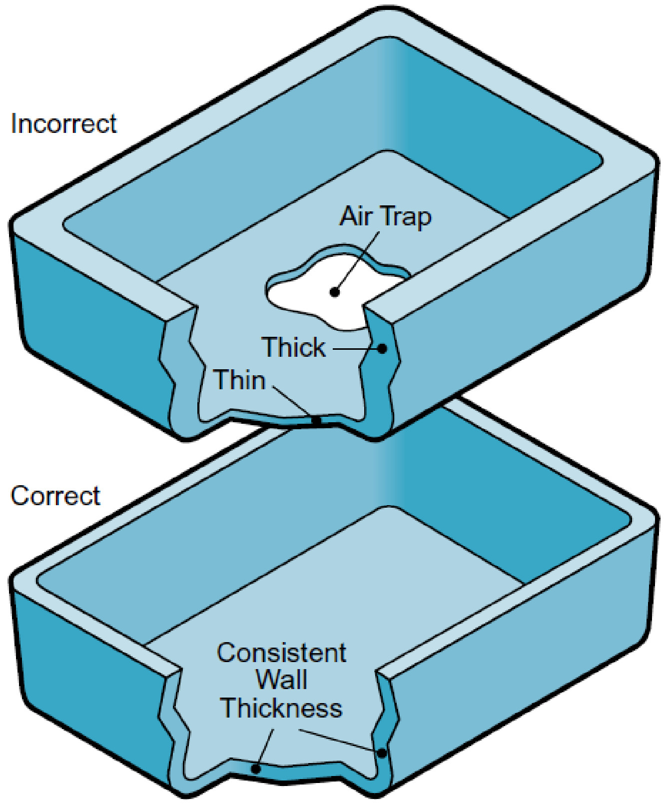
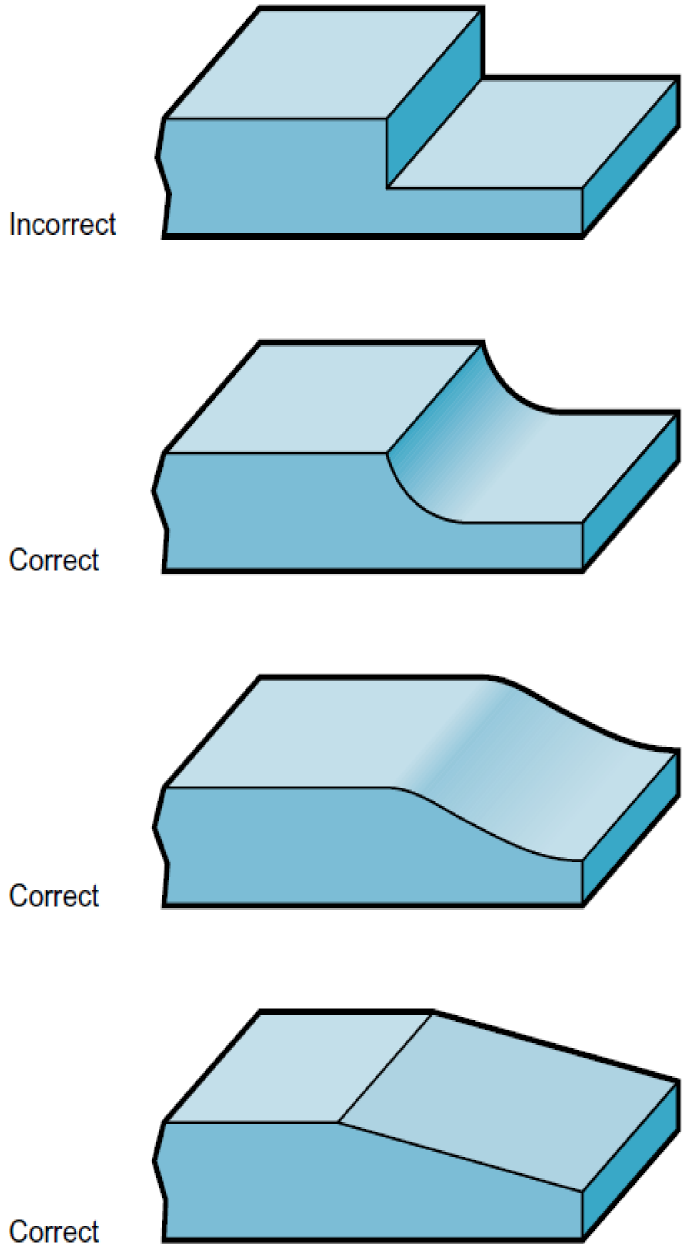
Q: why do semi-crystalline plastics shrink when solidifying?

APPLYING COMMON SENSE TO SOME TYPICAL PLASTICS 'THINGIES'

- Polymers (in processing) flow as a viscous mass
- Once the polymer solidifies (sufficiently), the flow stops
- In thin sections, cooling rate is higher
  - We may not completely fill our product
- So...
  - Prevent overly high shear rate
  - Observe "freeze" rate
  - Use gradual flow direction changes
  - Flow length: gate to last filled area





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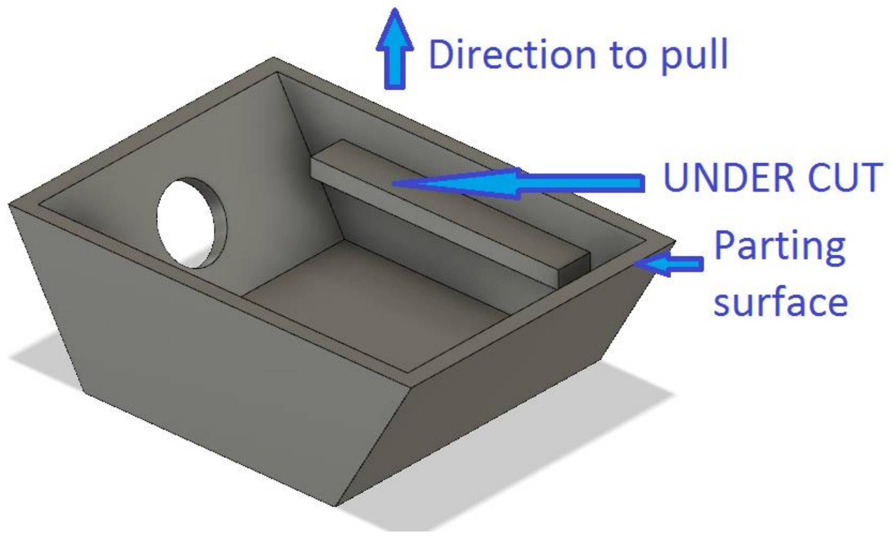
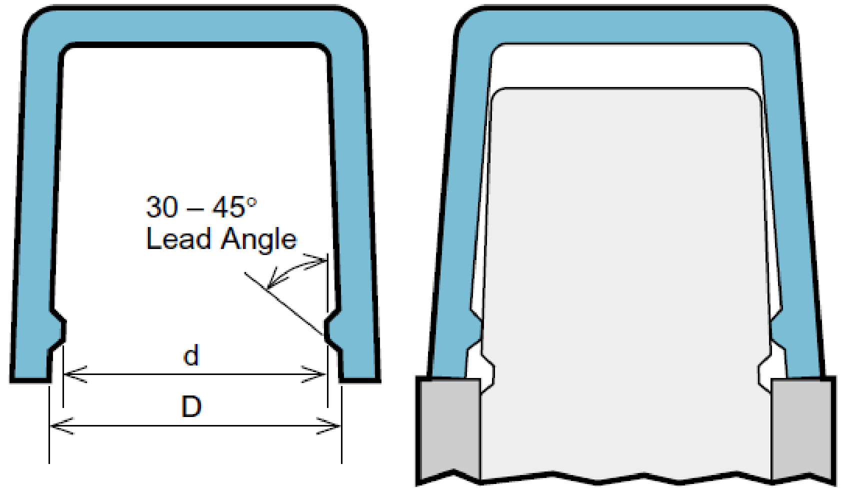
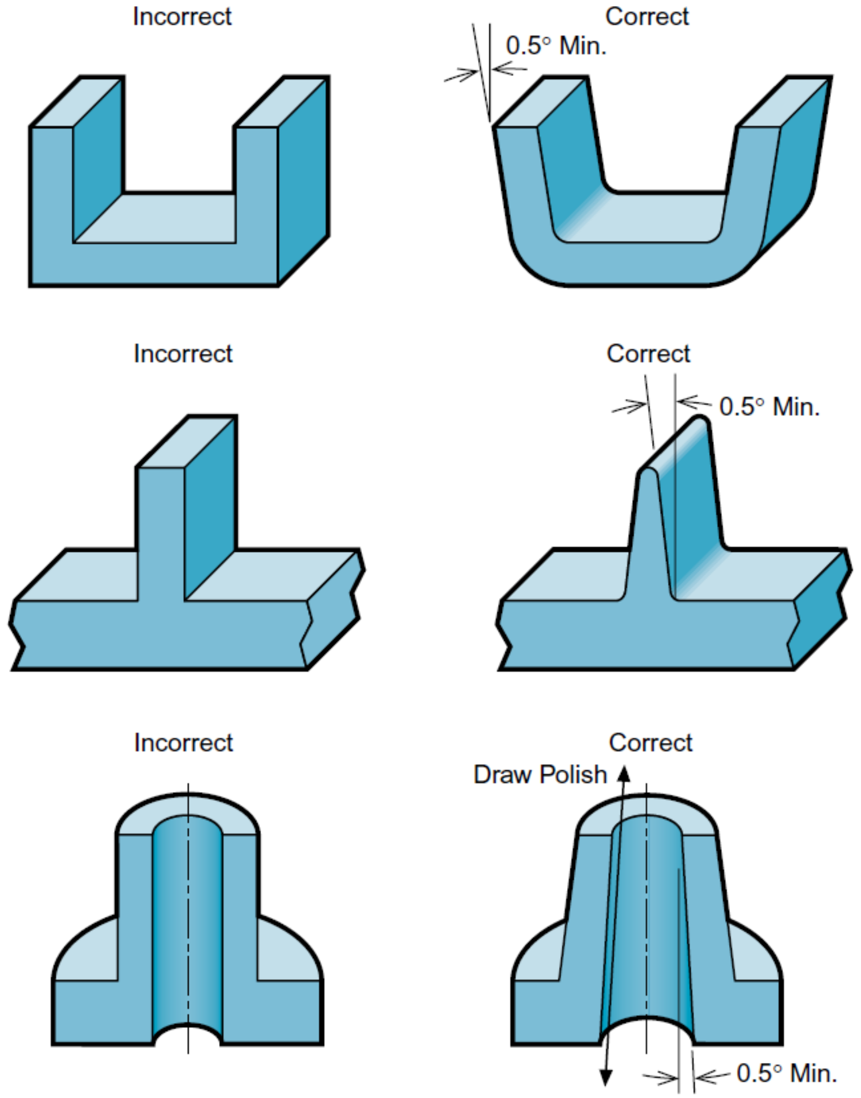
APPLYING COMMON SENSE TO SOME TYPICAL PLASTICS 'THINGIES'

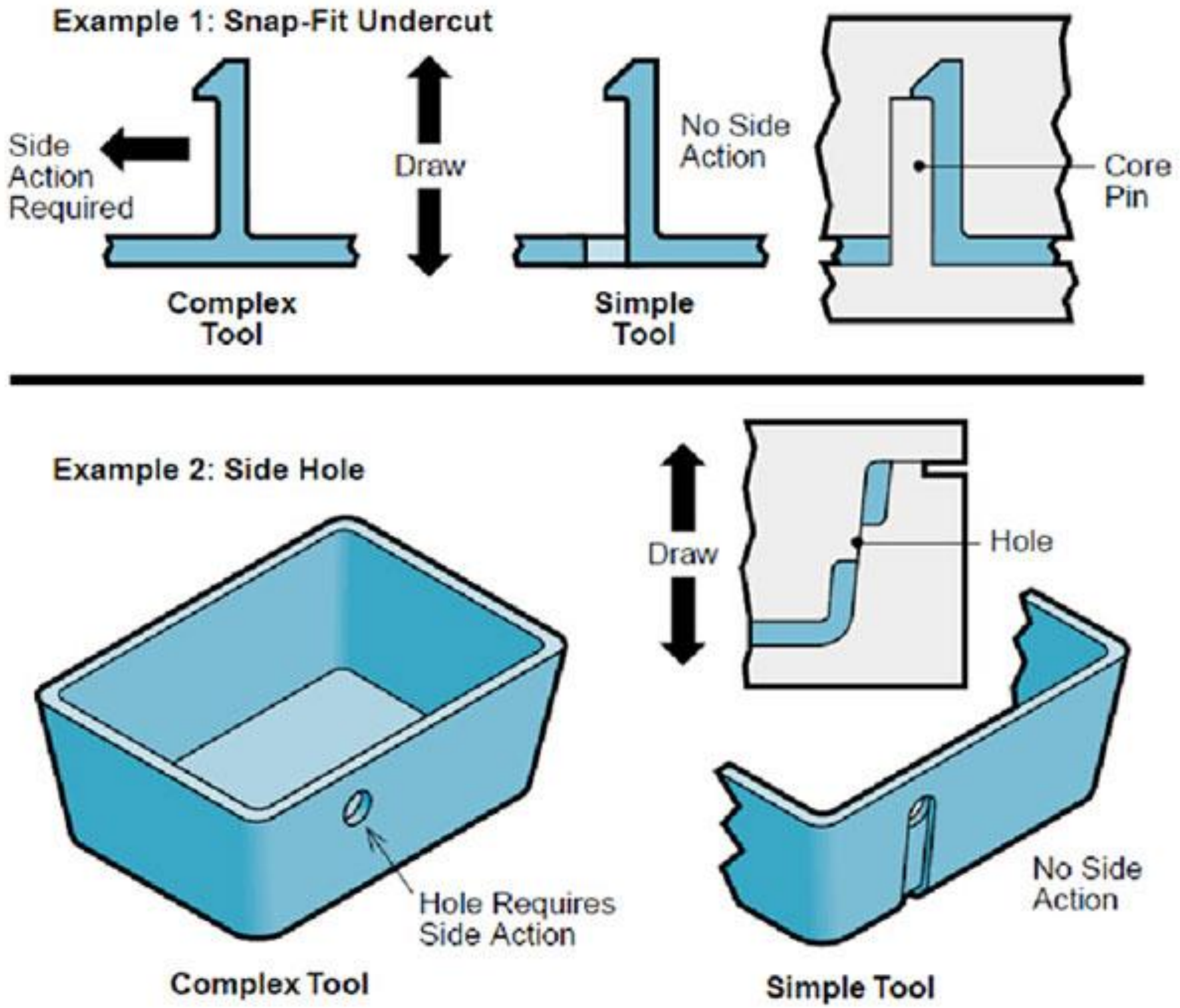
- In injection moulding, we need to 'demould' the product by use of ejector pins
- (think back to previous: many plastics shrink when cooling)
  - A plastic product will shrink itself onto the core, thus gripping itself stuck
    - We will not be able to eject the product, or break the ejectors
- So…
  - Avoid undercuts (small undercuts allowed in flexible plastics)
  - Include draft angles







DEALING WITH UNDERCUTS



Q: which is the cheaper solution?

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DESIGN FROM RECYCLING

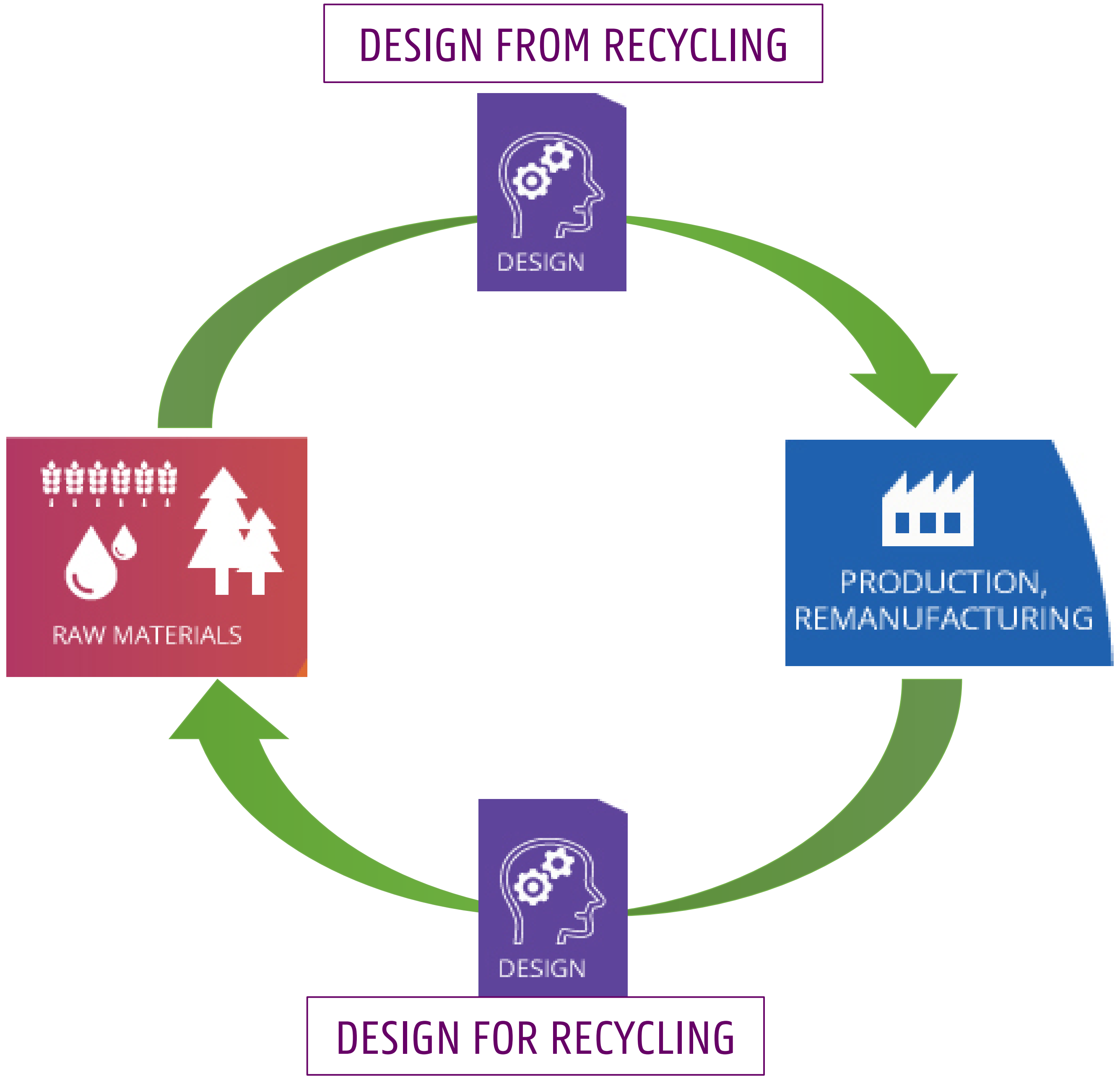
= DESIGNING WITH RECYCLED PLASTICS

DESIGN FROM RECYCLING

FROM = Developing new **products**, based on available recycled materials, at **start-of life**.

Material-driven design approach

1. Knowing the possibilities and properties of the available recycled polymers
2. Matchmaking between products and available r-polymers
3. 'tweaking' r-polymers if you have to (remain cost-effective)
4. Adapted product design for r-polymers
   - *This includes mould design*



FOR = Making it easier to recycle the individual **materials** making up the product at its **end-of life**.

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DESIGN FROM RECYCLING

Developing new **products**, based on available recycled materials, at **start-of life**.

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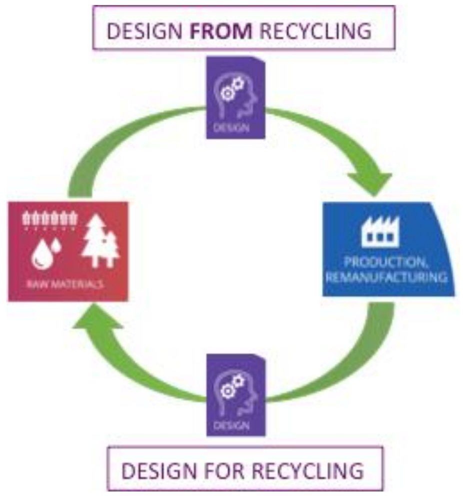
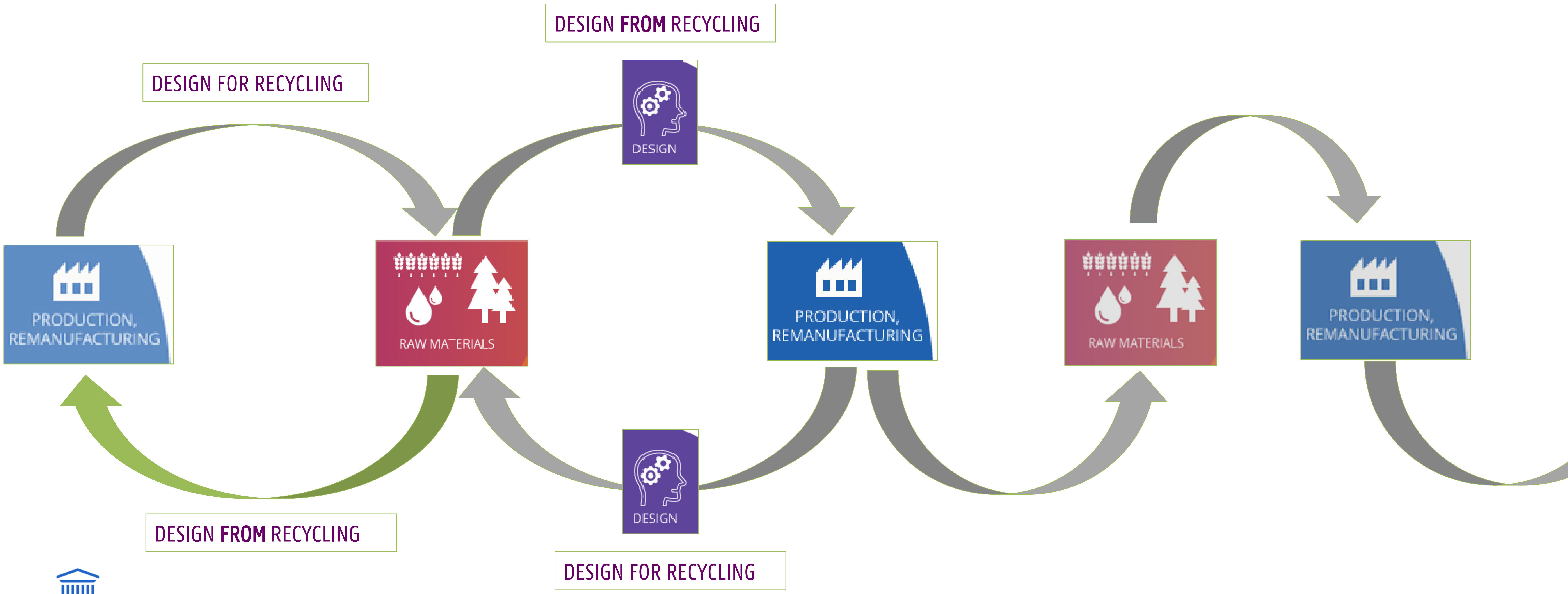
challenges

- Engineer-speak vs designer-speak
- Recycling the recycled
  - *Retained functionality of additives*
- Industrial inertia
  - *Prices of virgin feedstock*



DESIGN FOR + FROM RECYCLING



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DESIGN FROM RECYCLING

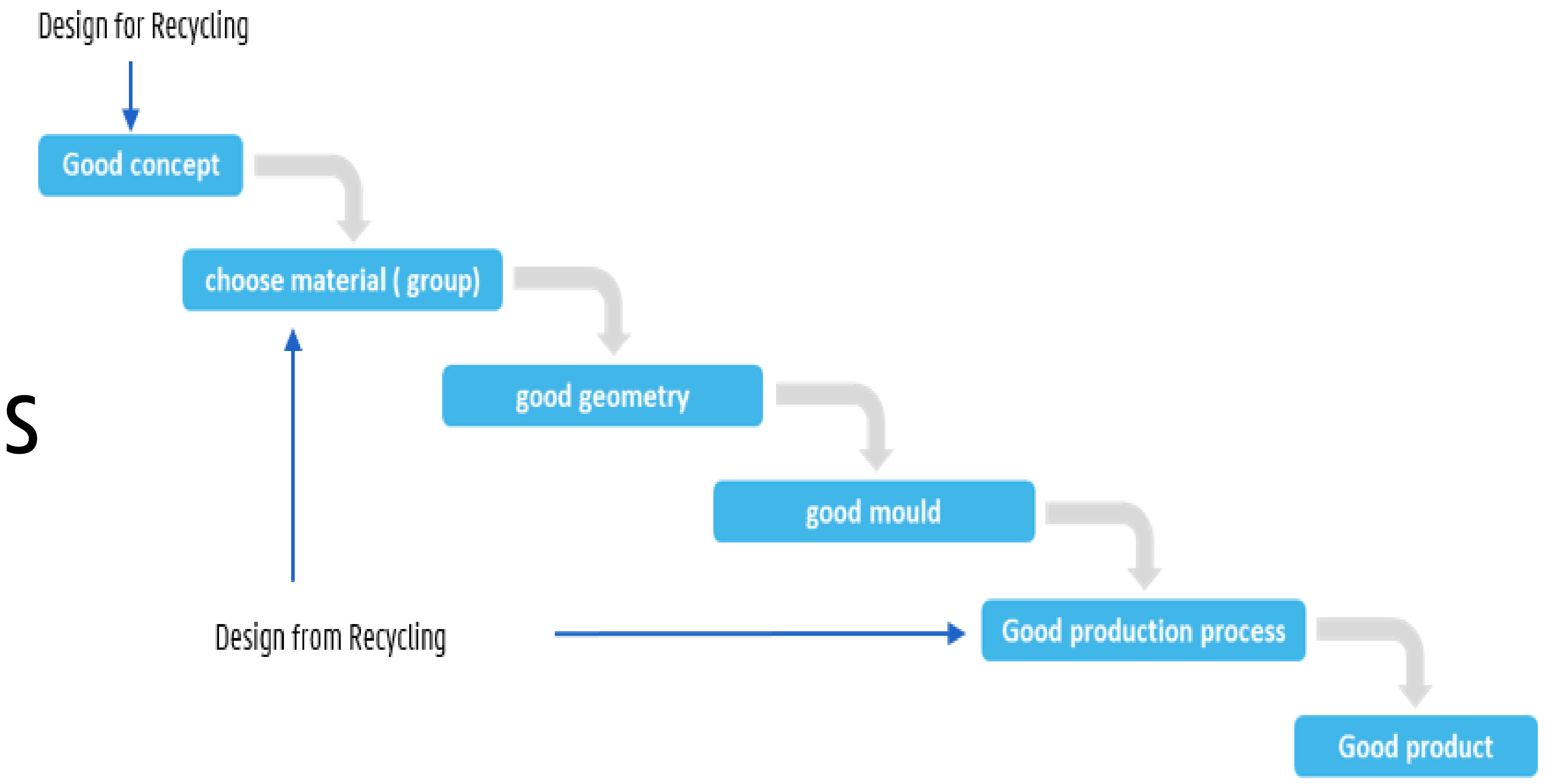
MATERIAL CENTERED DESIGN

ANALYSE AVAILABLE MATERIAL

BRAINSTORM AROUND PROPERTIES

DESIGN PRODUCT WITH MATERIAL IN MIND

DESIGN FROM RECYCLING STRATEGIES



Strategy A: Design as usual

– No difference to usual design process

Strategy B: Drop-in

– Matching properties

Start with easy parts to build up experience

WHY TDS IS NOT THE HOLY GRAIL

Q: why not? What info is it missing?

It does not give us:

- Non-initial mechanical parameters
- General look and feel
- Potential for texturing or high gloss
- Mouldability parameters like formation of weld lines, filling of/around square section, living hinges,...
- Response to snapping, threading...

Material properties ≠ product properties

TYPICAL PROPERTY VALUES

Revision 20181012

PROPERTIES	TYPICAL VALUES	UNITS	TEST METHODS
POLYMER PROPERTIES			
Melt Flow Rate			
at 230 °C and 2.16 kg	40	dg/min	ISO 1133
Density	905	kg/m³	ASTM D1505
FORMULATION			
Antistatic agent	☑	-	-
Clarified	☑	-	-
MECHANICAL PROPERTIES			
Tensile test			
stress at yield [1]	27	MPa	ISO 527-2 1A
strain at yield	13	%	ISO 527-2 1A
tensile modulus [2]	1000	MPa	ISO 527-2 1A
Izod impact notched			
at 23 °C	4.0	kJ/m²	ISO 180/1A
at 0 °C	2.0	kJ/m²	ISO 180/1A
Charpy Impact Strength Notched			
at 0 °C	2.0	kJ/m²	ISO 179/1eA
at 23 °C	5.5	kJ/m²	ISO 179/1eA
Hardness Shore D	62	-	ISO 868
THERMAL PROPERTIES			
Heat deflection temperature [3]			
at 1.80 MPa (HDT (A))	50	°C	ISO 75
at 0.45 MPa (HDT(B))	75	°C	ISO 75
Vicat Softening Temperature [4]			
at 50 N (VST (B))	68	°C	ISO 306
at 10 N (VST (A))	126	°C	ISO 306

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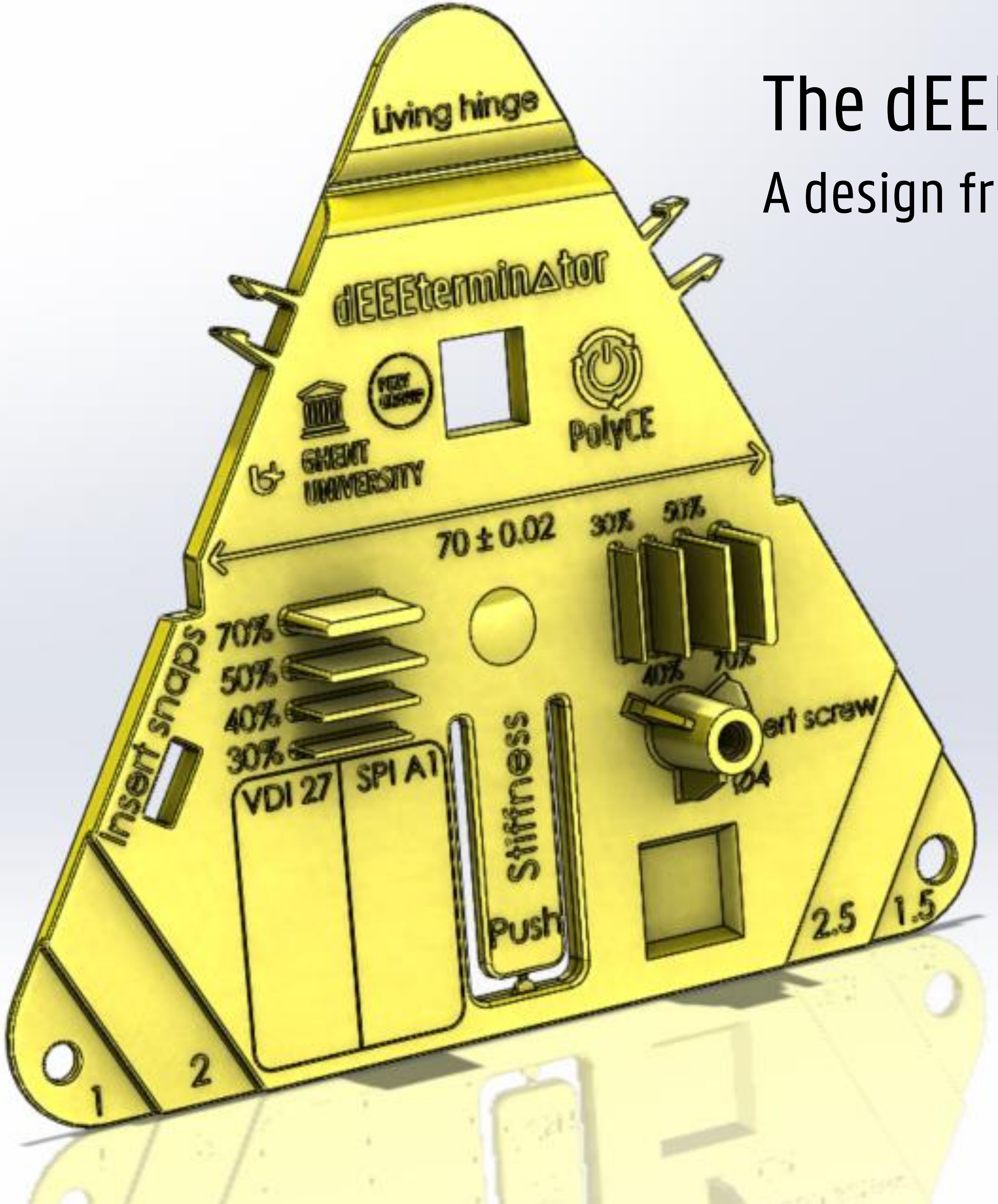

The dEEEterminΔtor

A design from recycling complimentary tool

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DESIGN FROM RECYCLING TOOLS

dEEEterminator

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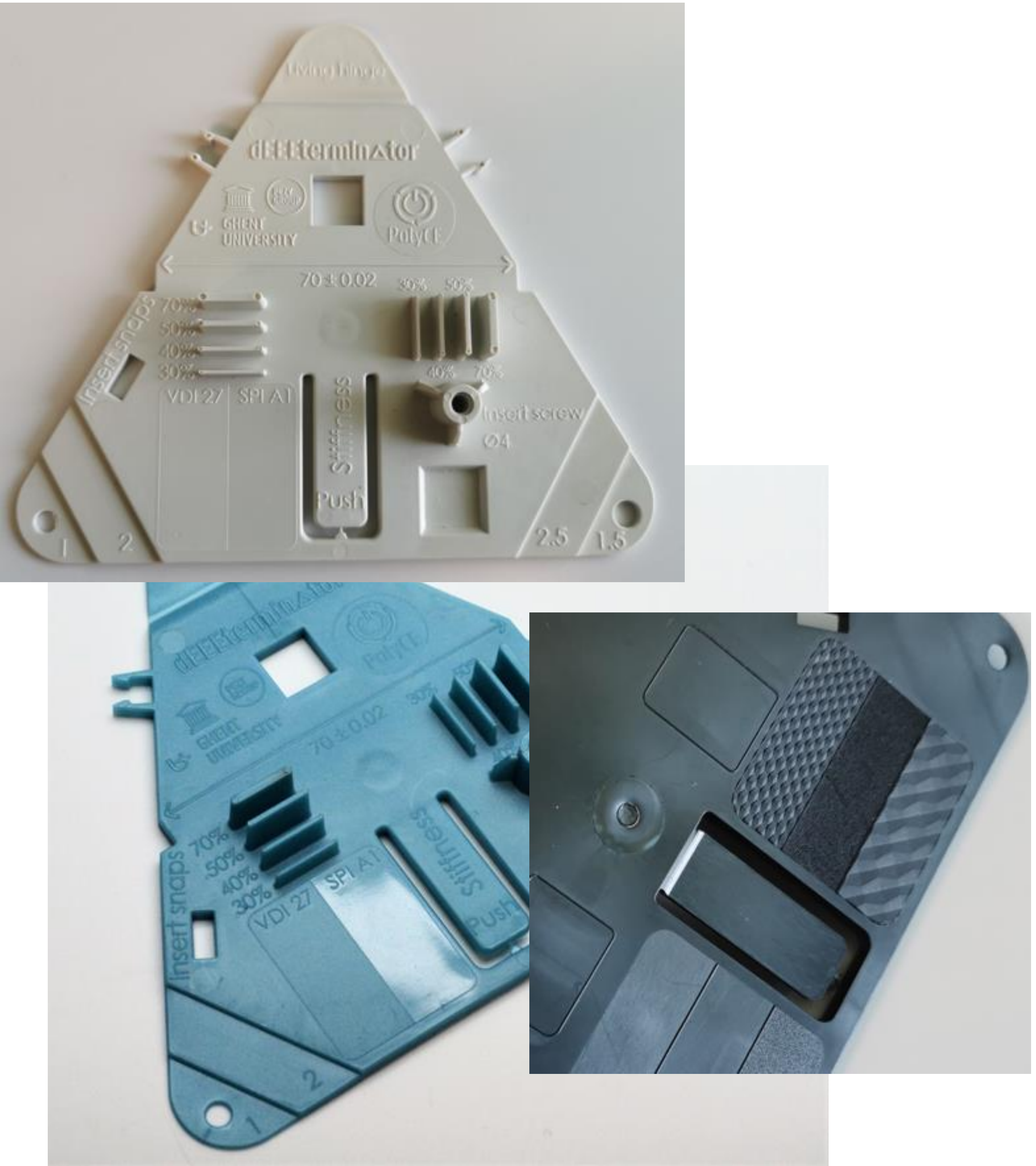
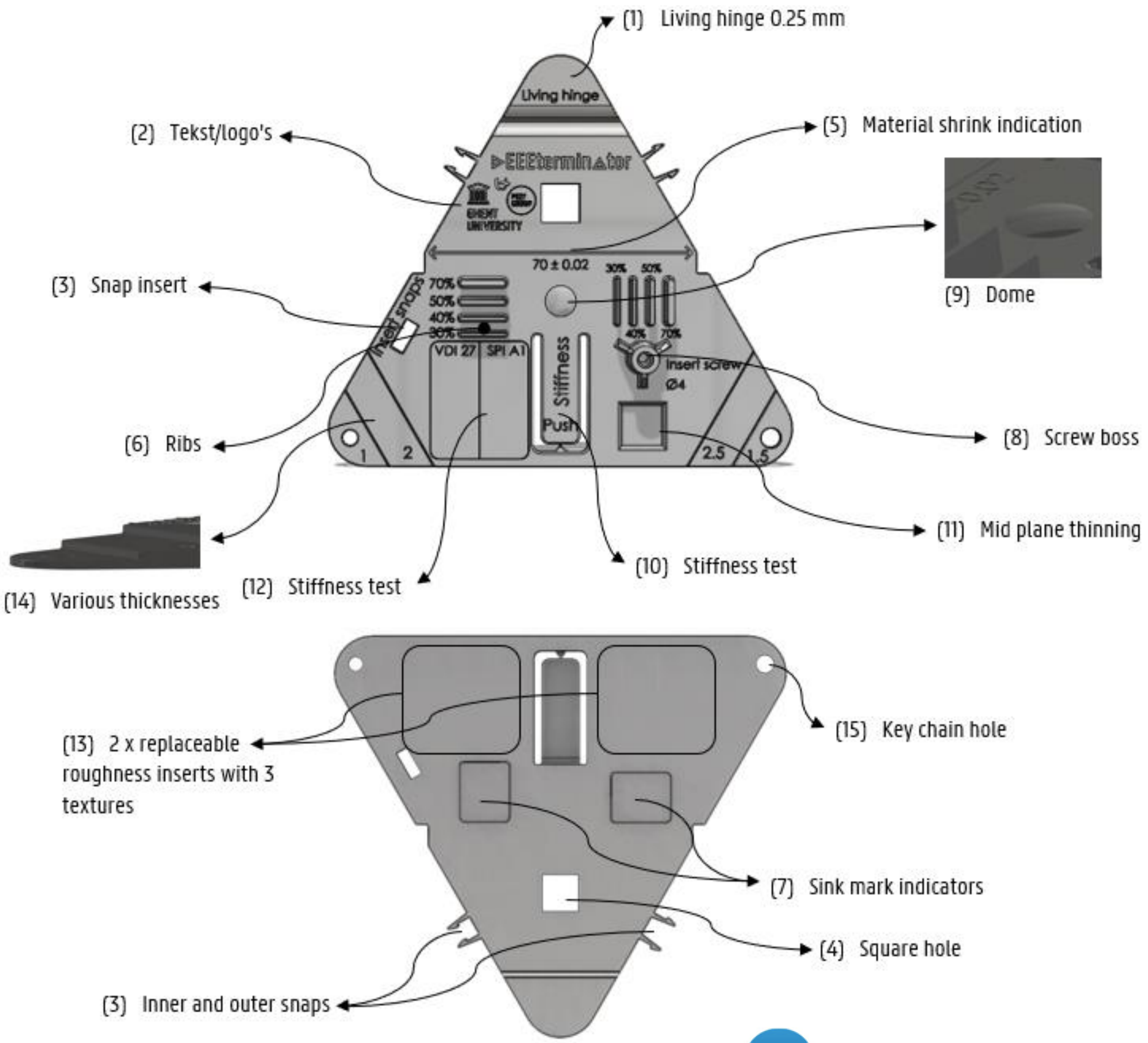
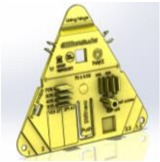




PEZY GROUP innovation accelerators

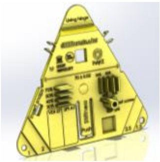
Productontwikkeling Universiteit Antwerpen

TYPICAL ATTENTION POINTS FOR RECYCLED PLASTICS



Smell
- “recycling” smell?

Colour
- Dark
- White
- Grey tints



Quantity
- Limited

Material type
- Only most common types are recycled PE,PP, PET, …

Price
- Stable
- usually lower

Usage
- Food application limited

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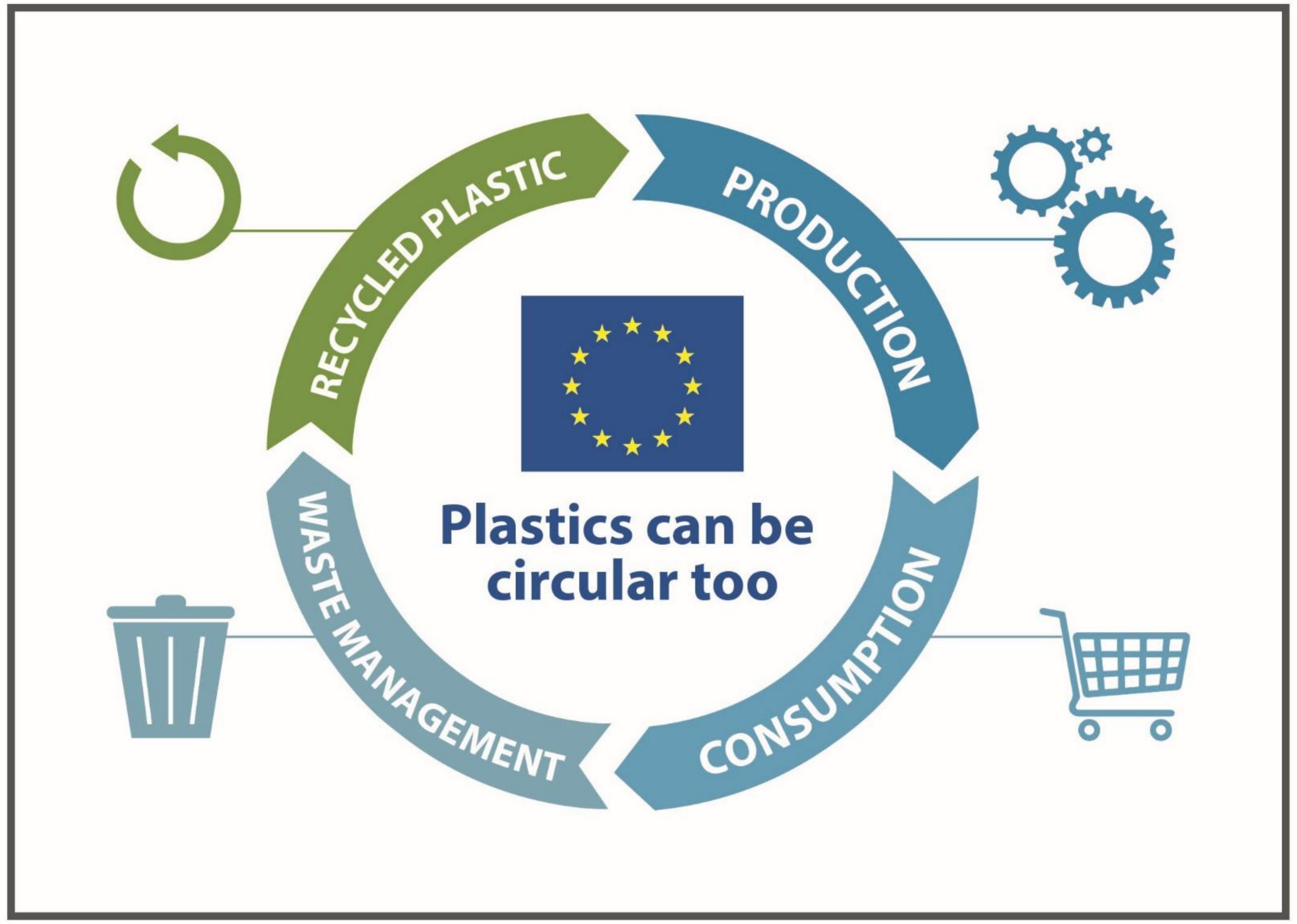
LEGISLATIVE ASPECTS

PLASTICS IN A CIRCULAR ECONOMY – EU FRAMEWORK

- Life cycle thinking
- EU goals:
  - All plastic packaging reusable or recyclable by 2030
  - 55% of all plastic packaging recycled by 2025
- Recent approval of tax on non-recycled plastic waste (effective 2021)



➔ Increase uptake rates?

➔ Food contact applications

LEGISLATION FOR PLASTICS (RECYCLING)

Why?

- Protect human health, environment and free market

How?

- Set requirement to producers/recyclers

Applicable legislation?

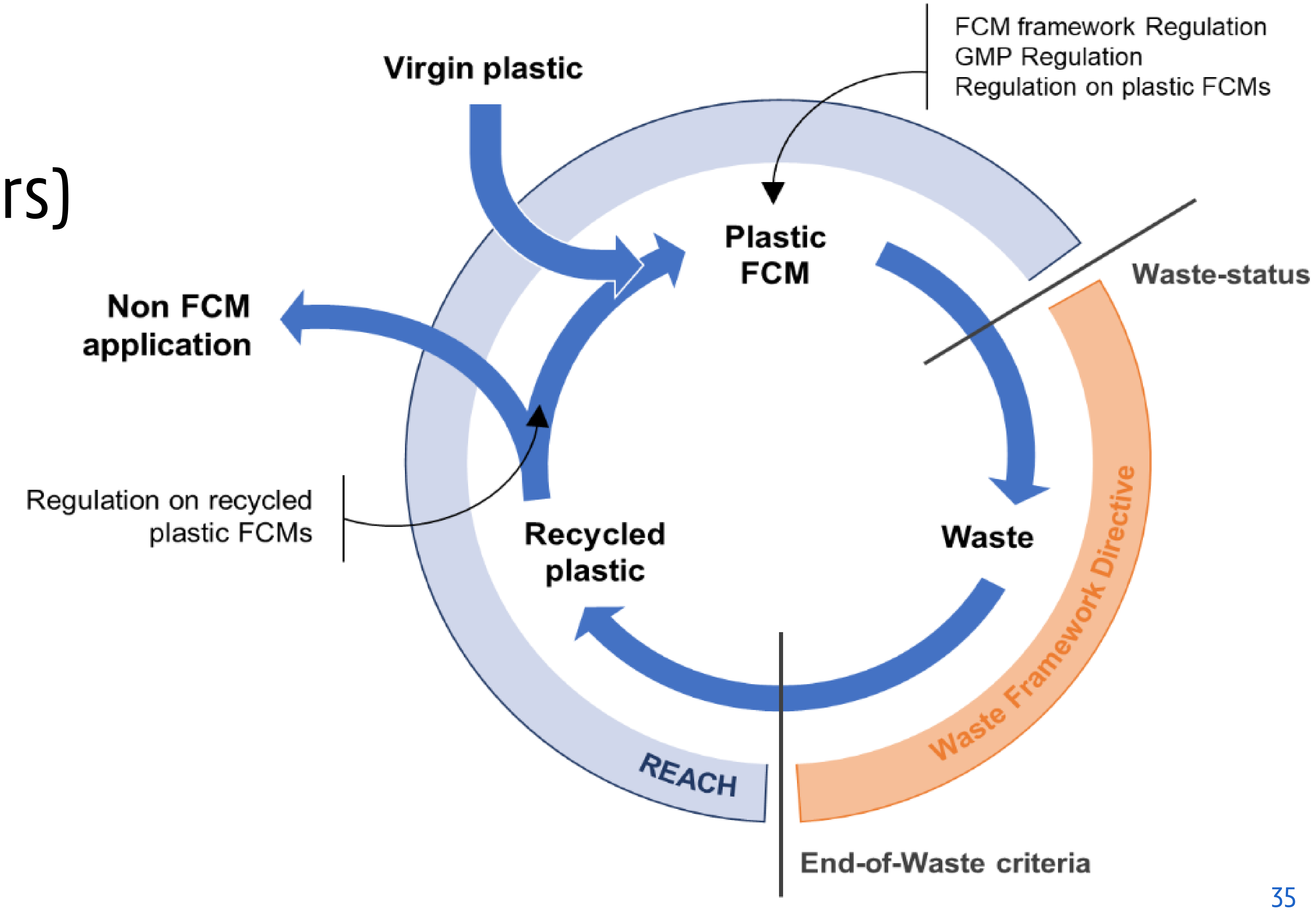
- Reach, FCM framework, GMP, Plastic FCM, recycled plastic FCM, ...

REACH

Overarching regulation

- Trade of chemical substances
- Registration of substance
  - Basis for (e)SDS
  - On substance level (monomers)
- SVHC
  - Additional measures

Q: what are all these abbreviations?
eSDS, SVHC, FCM,...



Applicability ends at waste stage

- Waste Framework Directive

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FOOD SAFETY LEGISLATION

Declaration of Compliance
- Compliance with applicable regulations
- Along the supply chain (except retail)

Good manufacturing practice (GMP)
- Documented quality assurance
- Quality control
- Documentation of manufacturing stages

Plastics specific
- Positive/union list
- Migration limits
- NIAS

Even more of these abbreviations?

What is a NIAS?

Who is EFSA?

Recycled Plastics specific
- Authorised recycling process
- Case-by-case (EFSA)

Exclusions
- Depolymerized plastics
- Unused offcuts
- Functional barriers

Challenges
- Full traceability
- Potential misuse
- FCM vs. Non-FCM

BRIEFLY CONCLUDING ON LEGISLATION FOR RECYCLED FCM PLASTICS

Complex interplay

Lack of transparency in supply chain

Better-safe-than-sorry mentality

Recycled FCM non-existent other than PET

Regulatory grey-zones

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CASE STUDIES

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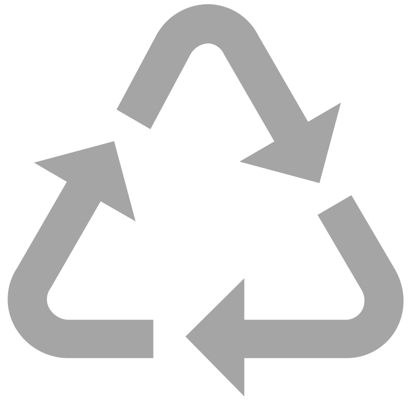
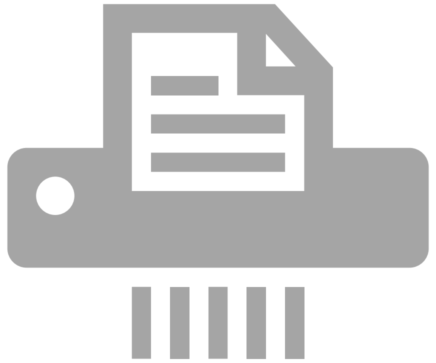
STRATEGY A (DESIGN AS USUAL) : WIRELESS VALUE



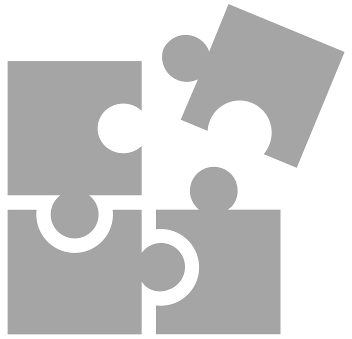
Design for/from recycling

- One material type
- In-mould textured logo



Designed for shredding

- No glue or tape
- Battery easily removable



Modular

- Colour indication

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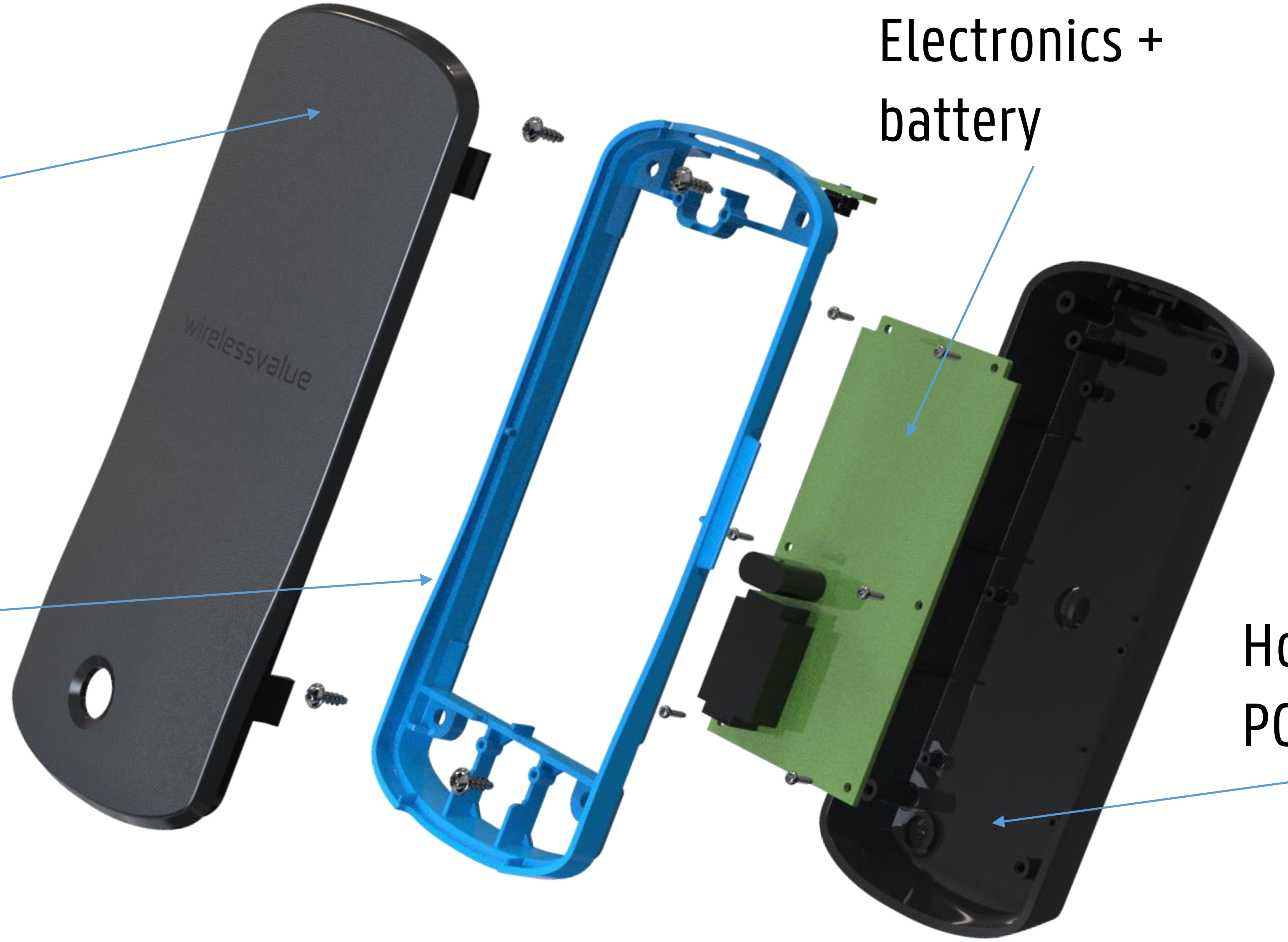
STRATEGY A (DESIGN AS USUAL) : WIRELESS VALUE

Top housing -
PCR ABS

Coloured ring
- PIR ABS €€€
- Virgin + MB €



Electronics +
battery

Housing -
PCR ABS

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PEZY GROUP innovation accelerators

STRATEGY B (DROP-IN): PHILIPS FROM STANDARD TO HIGH END

- No compromises
- Using 100% PCR ABS
- 70% recycled content

STRATEGY B (DROP-IN): PHILIPS FROM STANDARD TO HIGH END

Standard version

-unlacquered high-gloss ABS

High-end version

-Lacquered ABS

In the final stages for product release

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PHILIPS

STRATEGY B (DROP-IN): PHILIPS SHAVER

Inner frame of Philips shavers

- PCR PC/ABS
- UL listing approved
- Fit for application

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PHILIPS

DETAILED CASE STUDY (DROP-IN):

PET-PP BLENDS -INDUSTRIAL

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Samsonite

CASE SETUP

Samsonite

- Post-industrial waste Samsonite:
  - PP, contaminated with low % PET
  - Intended for internal re-use
  - Typical for samsonite products: high impact required

- ‘as is’ characterization:

property	units	Mean ± stdev
MFI (250°C – 2,16kg)	g/10 min	4,73 ± 0,23
E_f	MPa	1414 ± 117
$\sigma_{max,f}$	MPa	40,4 ± 1,4
$\sigma_{y,f}$	MPa	18,3 ± 0,2
Impact strength (Charpy notched)	kJ/m^2	3,56 ± 0,35
E_t	MPa	1225 ± 84

Q1: what does the MFI value tell us?

Q2: can you scale the modulus (E) value
→ to what polymer does it compare?

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CASE SETUP

Samsonite

vs. required properties for new product

property	units	Mean ± stdev
MFI (250°C – 2,16kg)	g/10 min	4,73 ± 0,23
E_f	MPa	1414 ± 117
$\sigma_{max,f}$	MPa	40,4 ± 1,4
$\sigma_{y,f}$	MPa	18,3 ± 0,2
Impact strength	kJ/m^2	3,56 ± 0,35
E_t	MPa	1225 ± 84

property	requirement
MFI	sheet extrusion
E_f	>900 MPa
$\sigma_{max,f}$	> 25 MPa
Impact strength	> 8 kJ/m^2

Q: what is/are the property(ies) we need to focus on for improvement?

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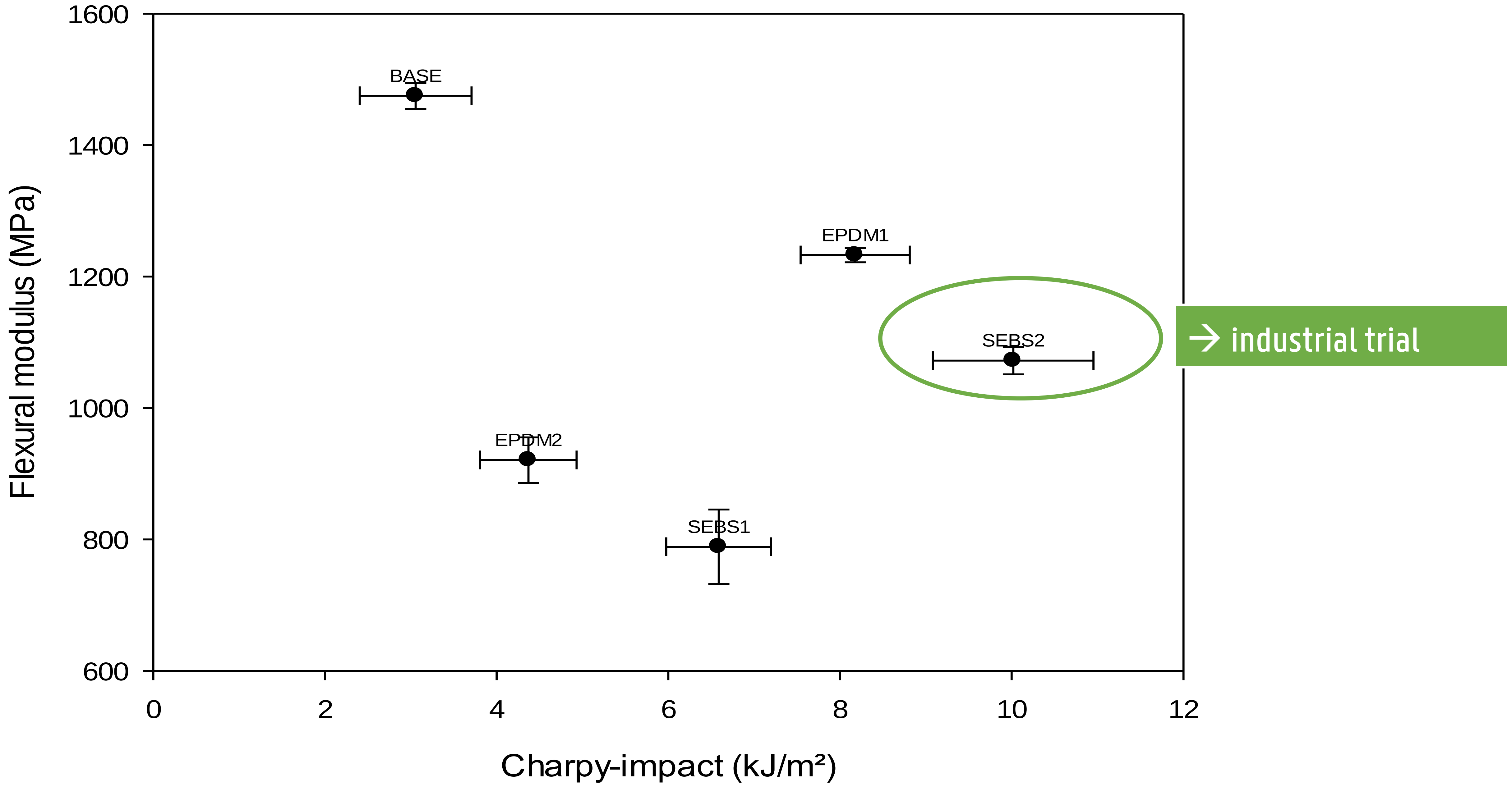
PHASE 1: IMPACT MODIFICATION

- Choice to add only impact modifier, based on:
  - low %PET (2-4 wt%)
  - Influence of PET on mixture appears negligible
  - Previous results from other research group show limited gain from use of SEBS-g-MA
  - cost
- Phase 1: choice of impact modifier
  - Selection of impact modifiers, based on supplier guidelines
  - EPDM and SEBS
  - 10 wt%

PHASE 1: IMPACT MODIFICATION



EPDM1: Nordel IP 3722P (DOW) – EPDM 70% ethylene content
EPDM2: Novalene 7300P (Novapolymer) – EPDM:HDPE (60:40)
SEBS1: G1645M (Kraton): PS content 13% (enhanced rubber segment)
SEBS2: G1657 (Kraton): PS content 13%

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INDUSTRIAL TRIAL 1

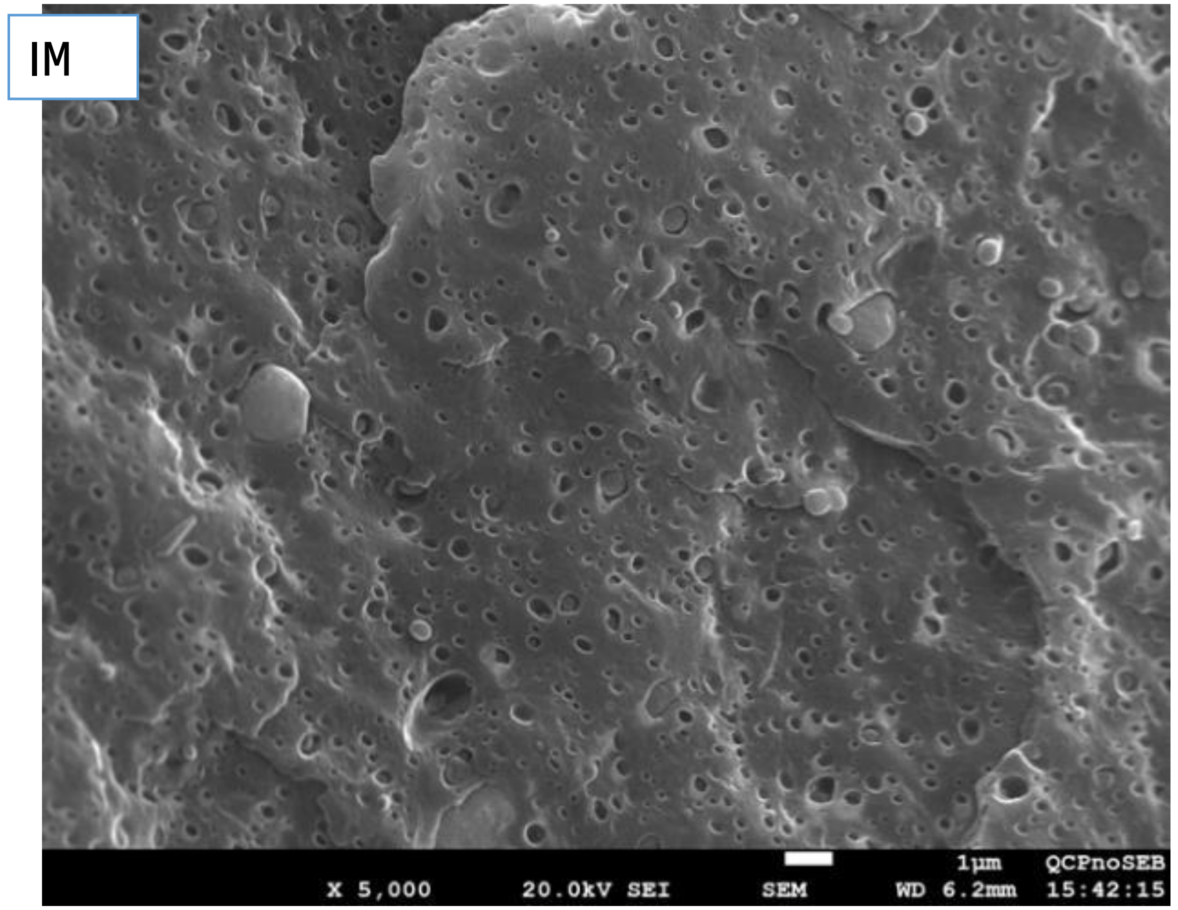
QUALITY CIRCULAR POLYMERS

- External compounding (QCP) of 800 kg with 10wt% SEBS2 (Kraton G1657)
- Samsonite: sheet extrusion → thermoforming case
- Unexpected FAIL in drop test

→ Failure analysis: why is impact property lower in thermoformed case than predicted in research lab?

FAILURE ANALYSIS (SEM, SEBS ETCHED OUT)

IM



All products made from QCP compound

IM = injection moulded (UGent)

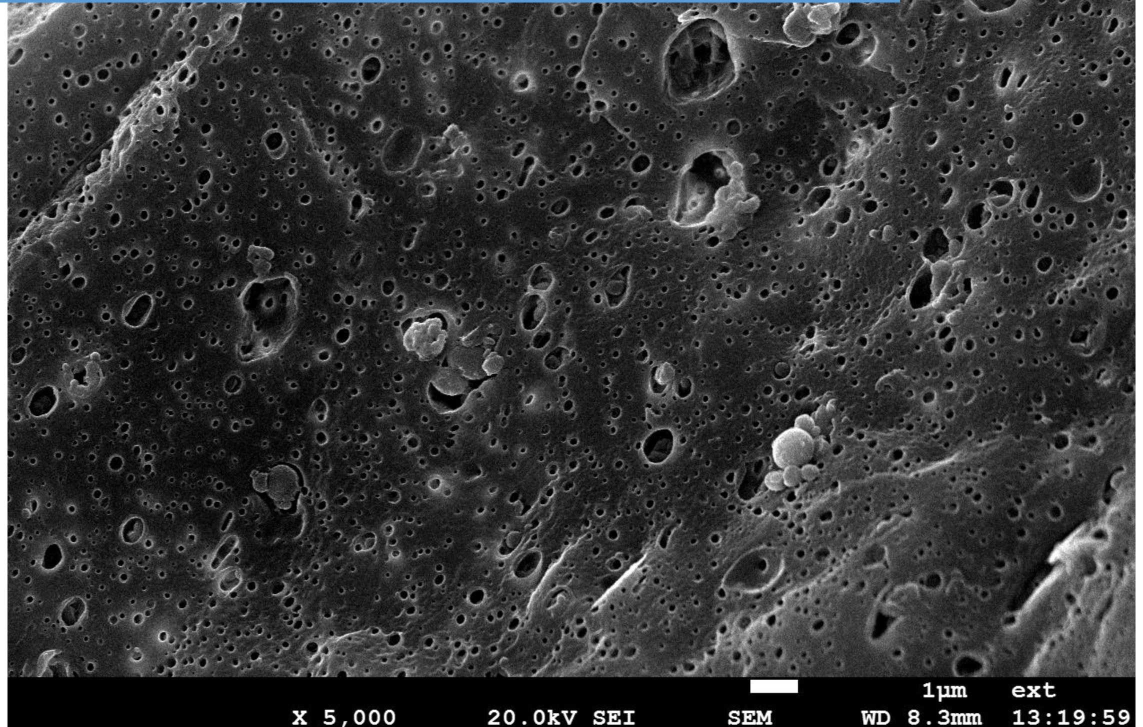
EXT = extruded sheet (Samsonite)

TF = thermoformed case(Samsonite)

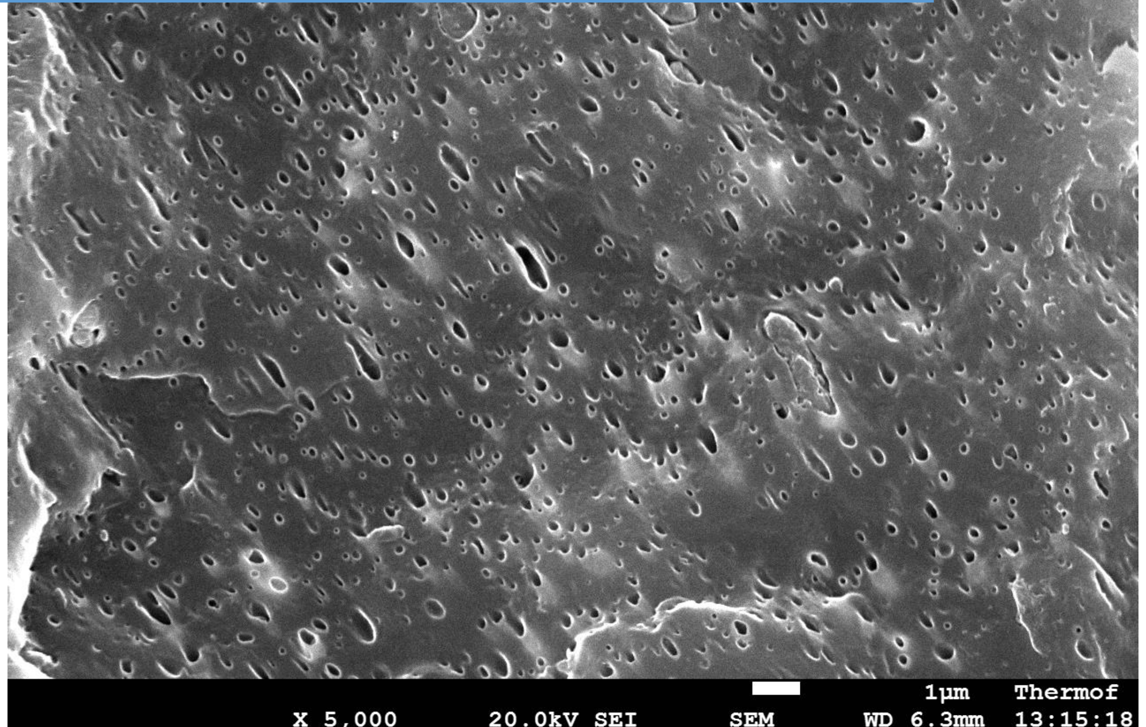
All white scale bars 1 mm (magn x 5000)

Impact decreased by processing effects

EXT
→Coalescence of SEBS into large spheres
→ Impact reduction



EXT+ TF
→Elongation of SEBS spheres to ellipsoids = stress concentrators
→Further impact reduction



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PHASE 2: NEW FORMULATION

Rubber phase to 15 wt% in 2 combinations

(reduction of ligand thickness, ‘buffer’ for property reduction)

- 12,5 wt% SEBS2 + 2,5 wt% SEBS-g-MA (Kraton FG 1901):
  - compatibilization of PET (and SEBS)
  - Prevent coalescence of SEBS

- 15 wt% ethylene octene copolymer (Engage XLT8677- DOW)
  - cost reduction option

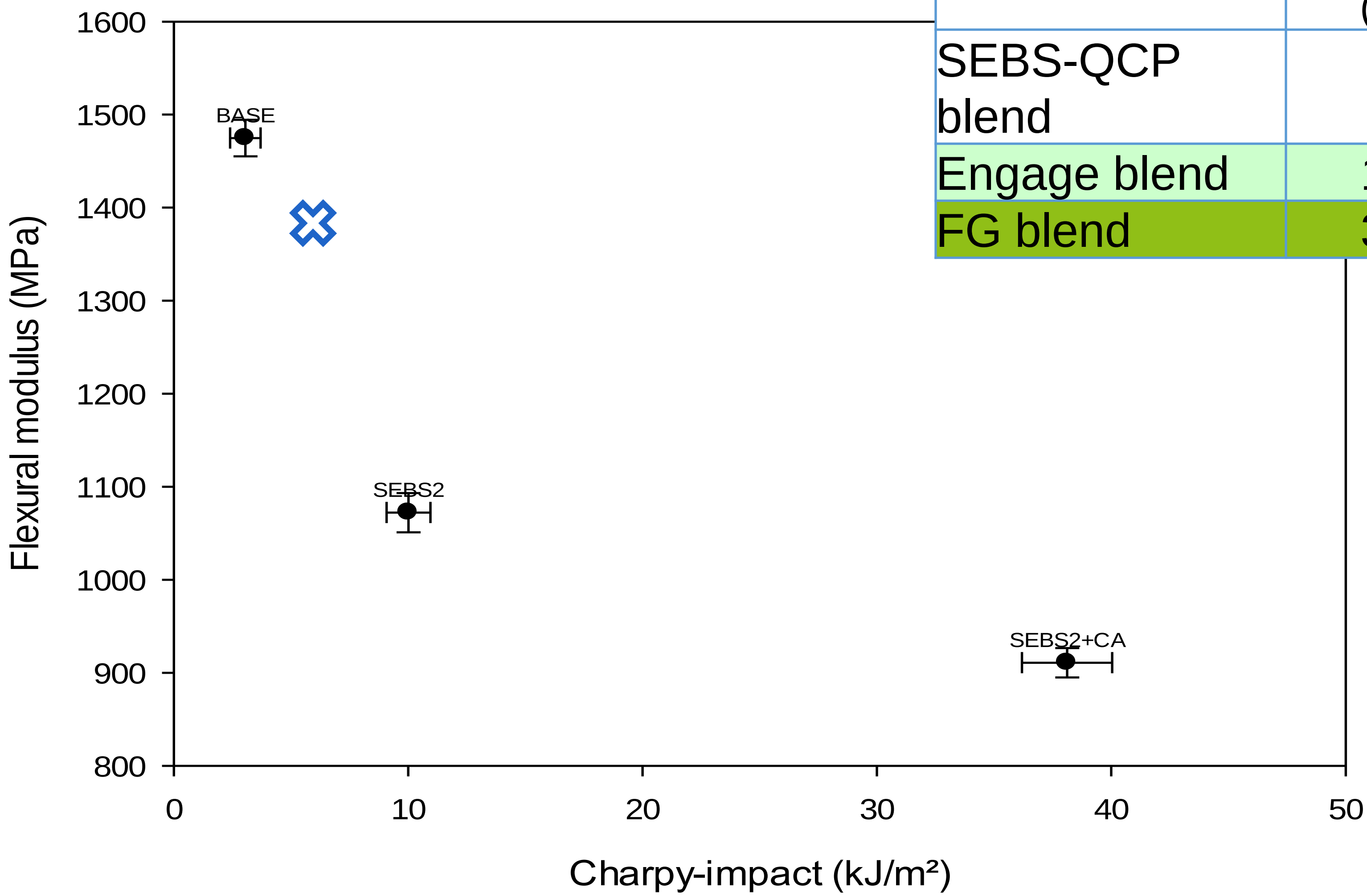
PHASE 2: NEW FORMULATION

Rubber phase to 15% in 2 combinations

- 15 wt% Engage
- 12,5 wt% SEBS2 + 2,5 wt% SEBS-g-MA

→ huge gain in impact

	Impact (J/m²)	stdev (J/m²)	E flex (MPa)	stdev (MPa)
SEBS-QCP blend	7,1	0,7	1069	29
Engage blend	15,0	1,1	934	20
FG blend	38,1	1,9	911	16



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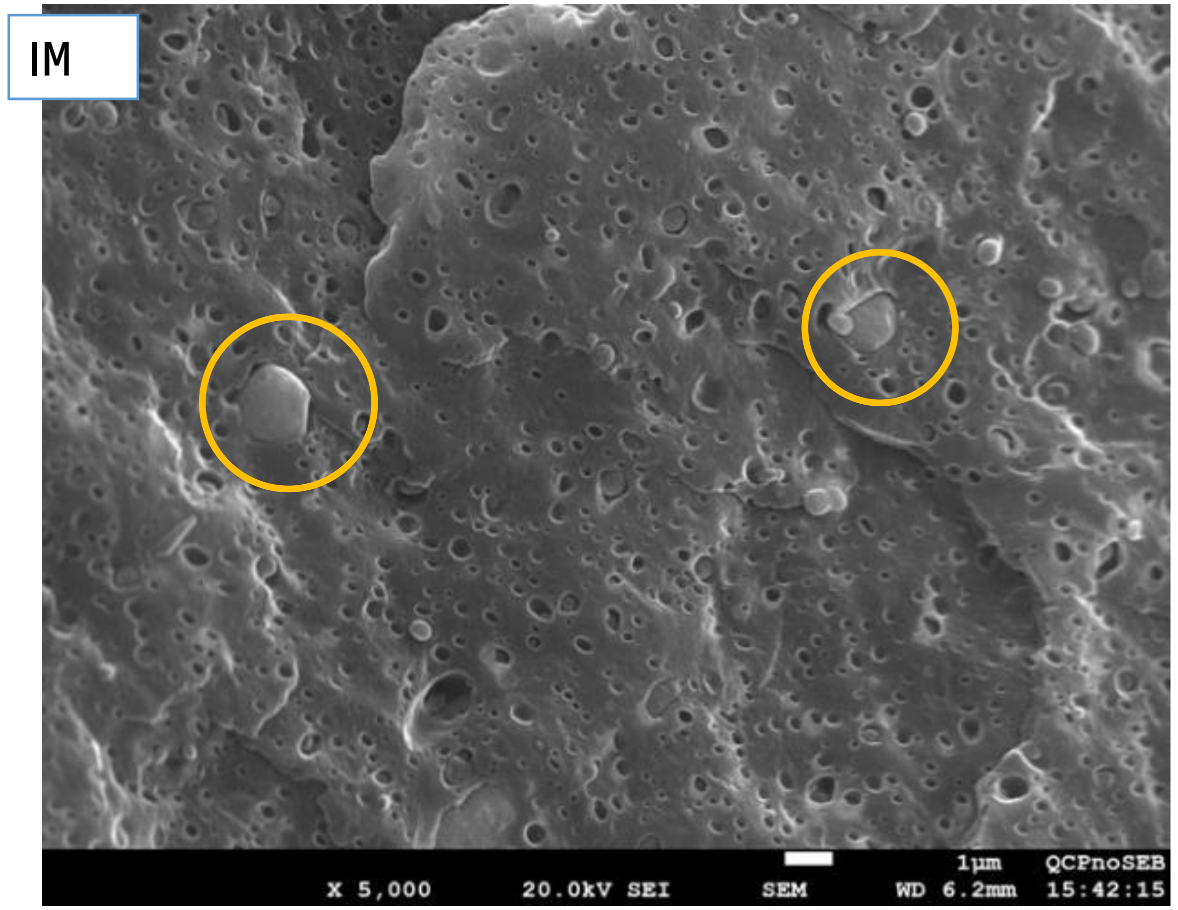
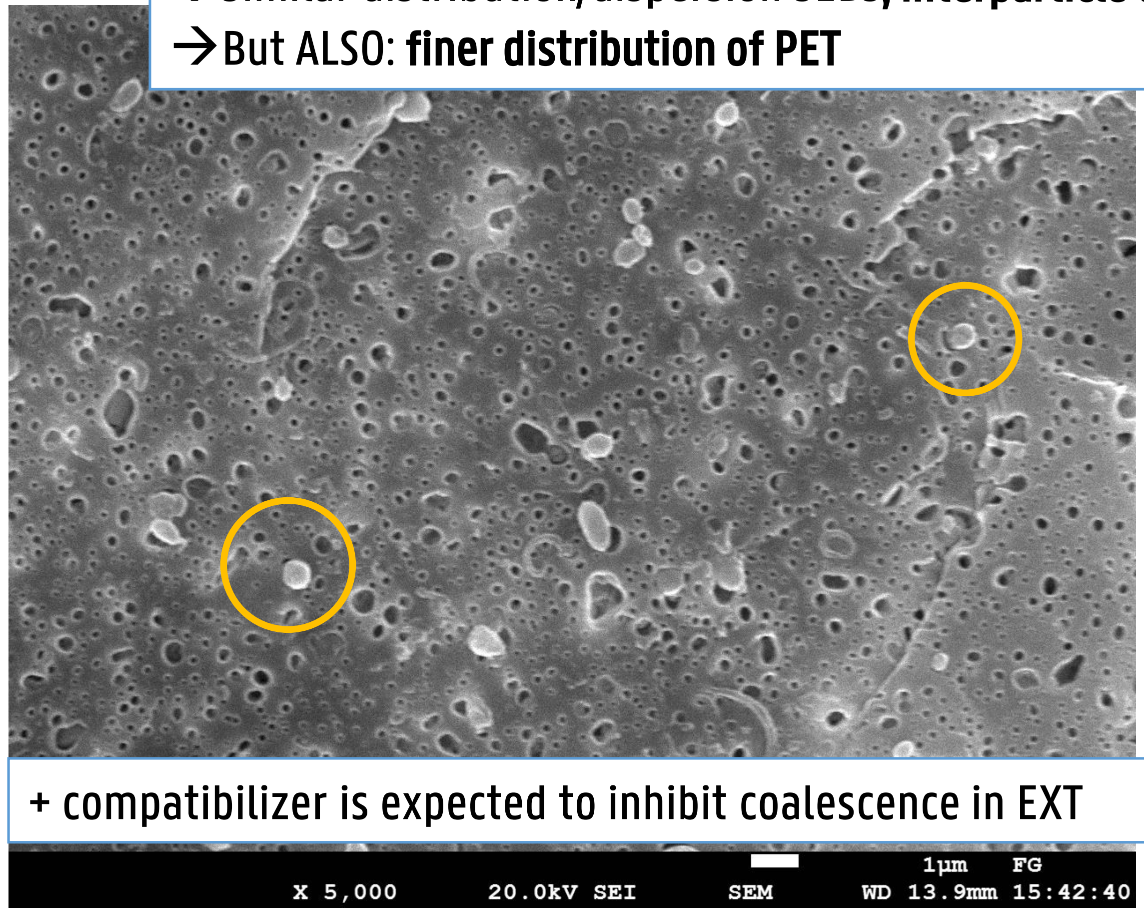
PHASE 2: + SEBS-G-MA (SEM, SEBS ETCHED OUT)

IM

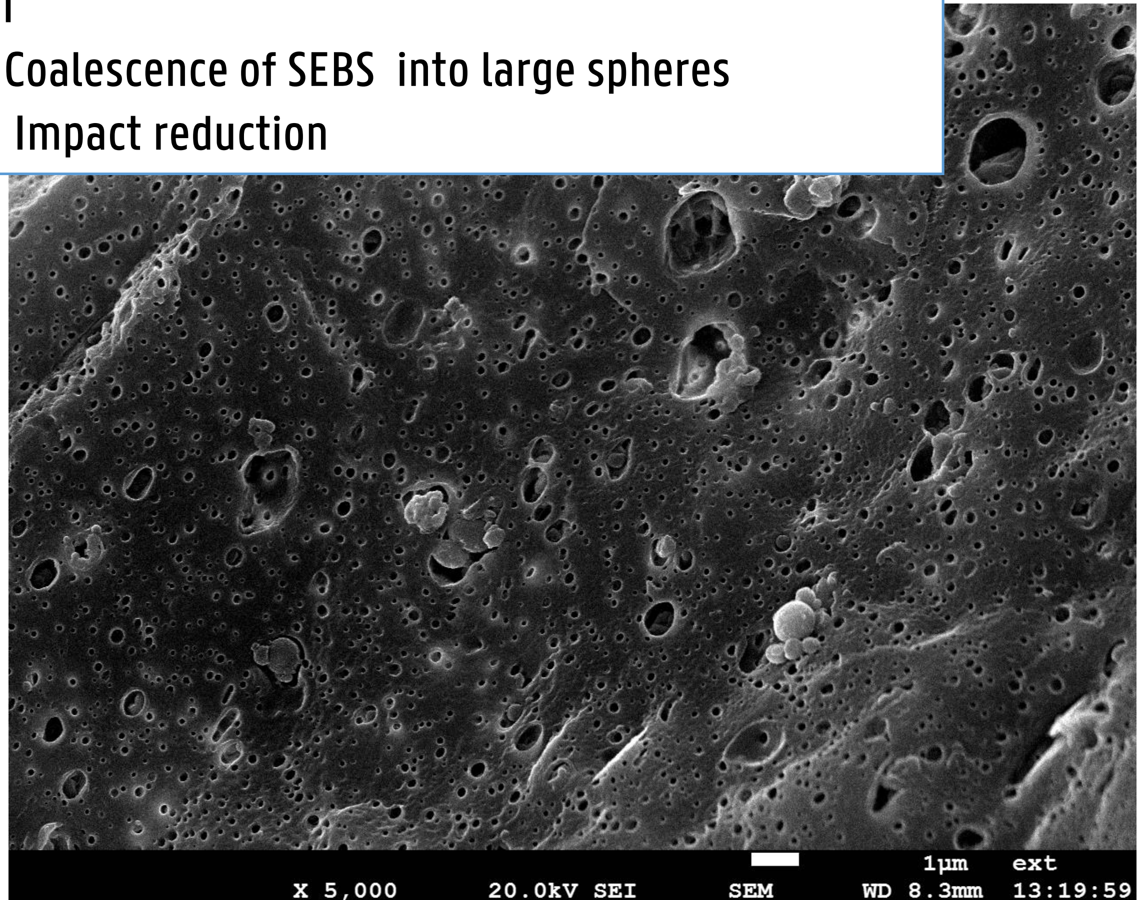


IM 12,5% SEBS + 2,5% SEBs-g-MA
→Similar distribution/dispersion SEBS, **interparticle distance** ↓ (higher wt%)
→But ALSO: **finer distribution of PET**

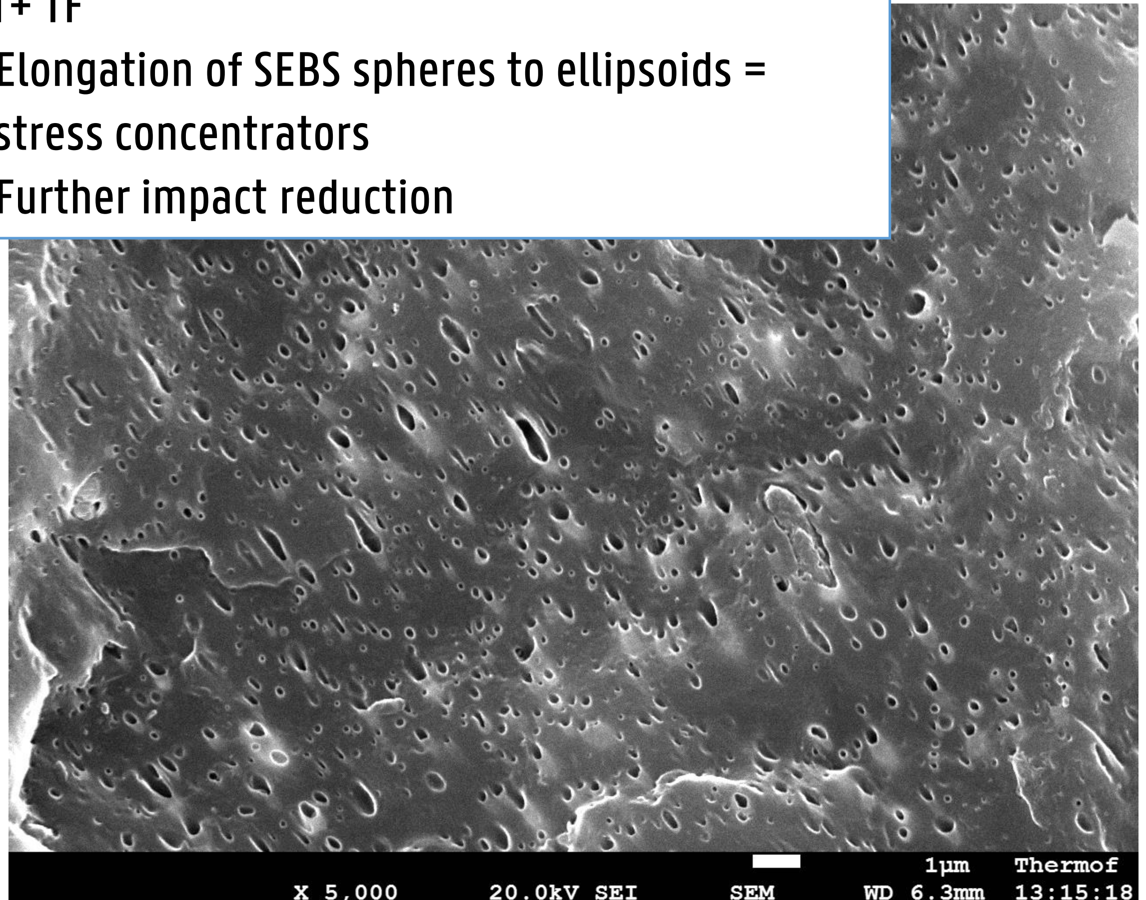


+ compatibilizer is expected to inhibit coalescence in EXT

EXT
→Coalescence of SEBS into large spheres
→ Impact reduction



EXT+ TF
→Elongation of SEBS spheres to ellipsoids = stress concentrators
→Further impact reduction



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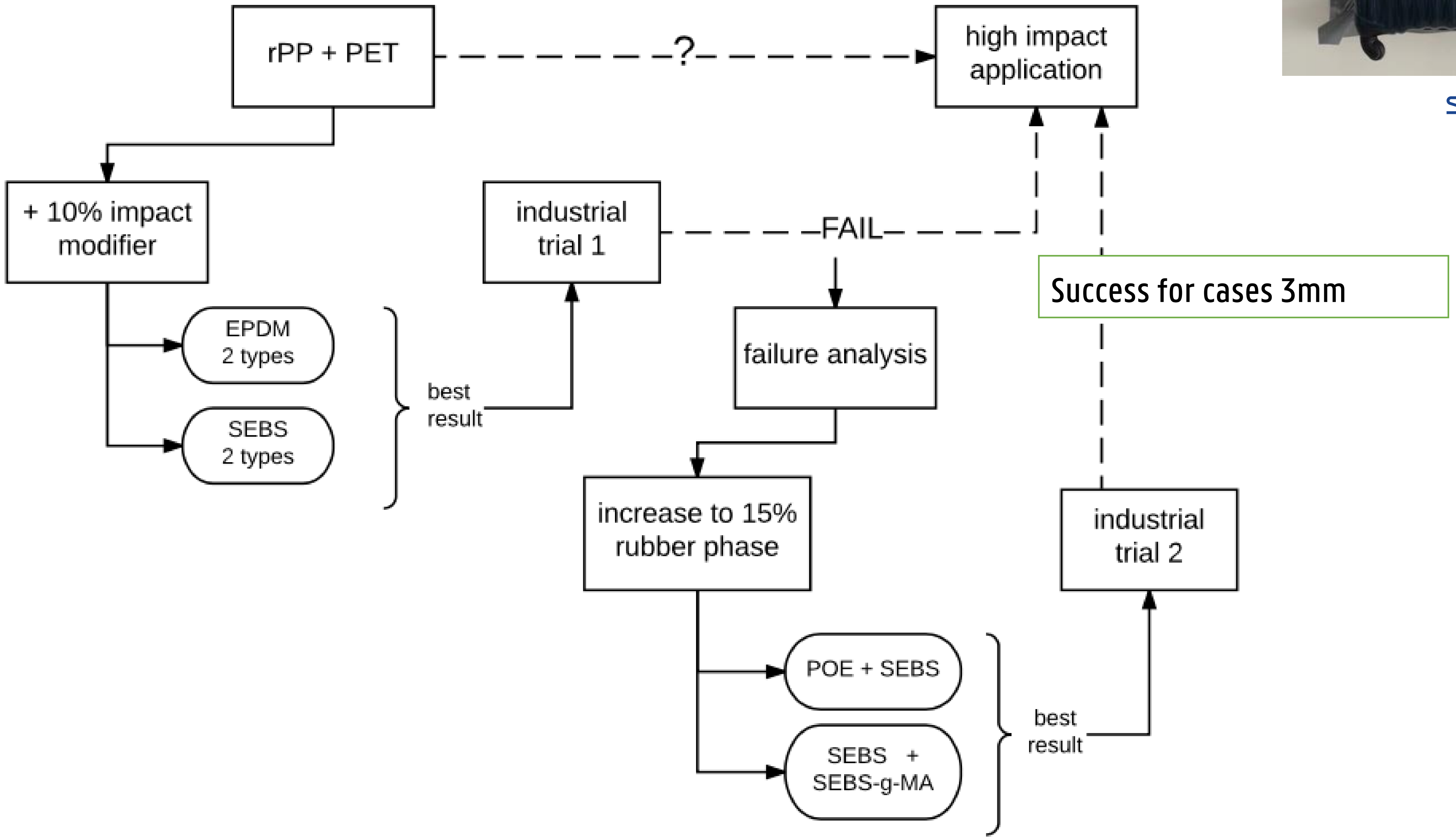
CASE OVERVIEW



Samsonite

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TAKE-AWAY MESSAGES

- Technically, designing with recycled plastics is basically the same as with virgin plastics, it's just the 'starting material properties' that are different
- Legally, it may be a different story, especially for FCM
- Establish your boundary conditions and then apply common sense

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Prof. Dr. Kim Ragaert

Circular Plastics

Chair of CAPTURE-Plastics to Resource

capture-resources.be

kim.ragaert@ugent.be

+32 9 331 03 91

Ghent University

Faculty of Engineering and Architecture

MATCH – CPMT (cpmt.ugent.be)

Tech Lane Ghent Science Park – campus A

Key publications:

- Astrid Van Belle , …, and Kim Ragaert. Microstructural contributions of different polyolefins to the deformation mechanisms of their binary blends. (2020) Polymers.
- Kim Ragaert, Sophie Huysveld, Gianni Vyncke, Sara Hubo, Lore Veelaert, Jo Dewulf and Els Du Bois. Design from recycling: A complex mixed plastic waste case study. (2019) Resources, Conservation and Recycling. 155.
- Sophie Huysveld,Sara Hubo; Kim Ragaert; Jo Dewulf. Advancing circular economy benefit indicators and application on open-loop recycling of mixed and contaminated plastic waste fractions, Journal of Cleaner Production 211 (2019) .
- Thoden van Velzen U., Brouwer M., Augustinus A., Soethoudt I., De Meester S. and Ragaert K. Predictive model for the Dutch post-consumer plastic packaging recycling system. Waste Management 71 (2018), 62–854.
- Ragaert K.,Delva L. And Van Geem K. (2017). Mechanical and Chemical Recycling of Solid Plastic Waste. Waste Management 69 (2017) 24–58.
- Sofie Huysman, Jonas De Schaepmeester, Kim Ragaert, Jo Dewulf and Steven De Meester. Performance indicators for a circular economy: A case study on post-industrial plastic waste. Resources, Conservation and Recycling 120 (2017)

- Kim Ragaert. Plastics Rehab. TEDx Vlerick, Ghent, April 2019.