Tackling plastic waste in the framework of the New Circular Economy Action Plan

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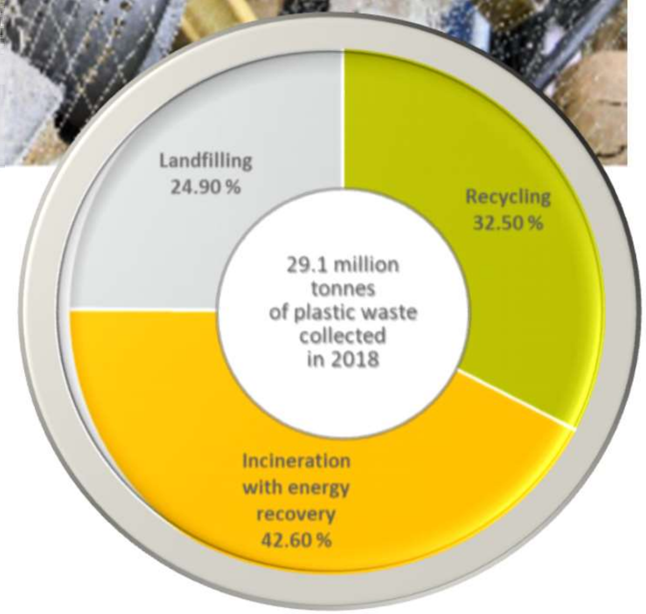
Why discuss plastics?

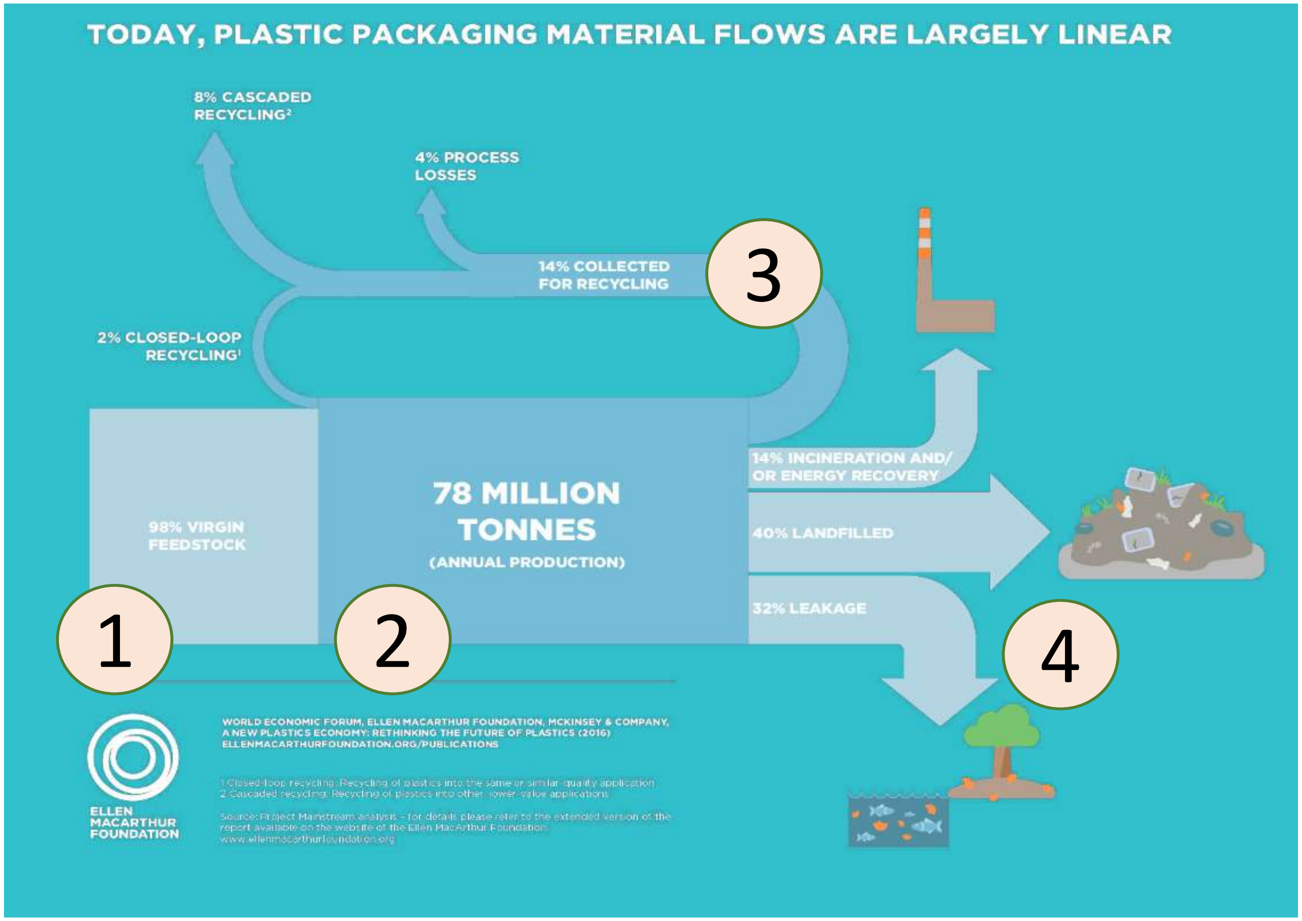
- Their use and production is now a threat to the planet
  - Exponential production increase: 1.5mt to 322mt; half since 2005; 98% is virgin feedstock
  - 20-fold increase in last 50 years; 20 times more in advanced economies
  - Every minute, one garbage truck of plastic enters the world's oceans
  - 8mt leaks to the oceans; in the oceans there would be more plastic than fish by 2050
- Our relationship with plastics builds on a wrong, linear, take-make-waste model that needs complete rethinking
  - 30% of packaging never to reuse; 14% is collected for recycling; 40% disposed of in landfill
  - In EU recycling is the lowest (40%) compared to metals (76%), paper (83%) and glass (73%)
  - Wasteful processes: 90% of cost in each water bottle depleting 7lt water and 120ml oil; It takes at least 450 years for a plastic bottle to degrade

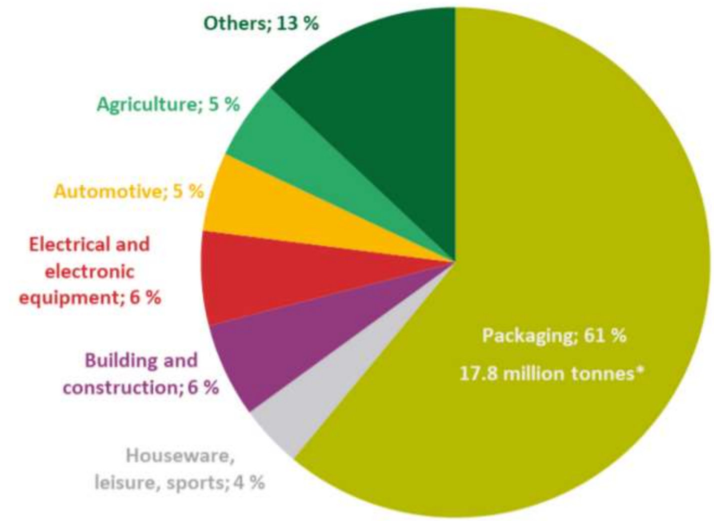


A real future for plastics?

- Plastics: mainstay or outcast?
  - — versatile materials with countless industrial and consumer applications
  - — cheap, versatile, lightweight, resistant
  - —banning plastics may occasionally be a solution, but substitution with another material (glass, paper, aluminium) may lead to negative, unintended consequences such as increased GHG, water use and food waste
- A circular economy is the single and only promise, but should
  - —build an economic system where materials used are not used up; plastics we use are reusable, recyclable or re-enter the economy, in closed cycles, as raw materials
  - —Prevent plastics ending up in the environment. Landfill, incineration or waste-to-energy are not long-term solutions
  - —Make governments set up collection infrastructures and regulatory and policy landscape; businesses responsible beyond the design and use of their products

The overall balance of plastics today





- Entire production depends on finite, virgin resources (1)
- Poor technology (2) and business models (3) for recycle and re-use
- Plastics discarded either as waste or in waste to energy projects (4)

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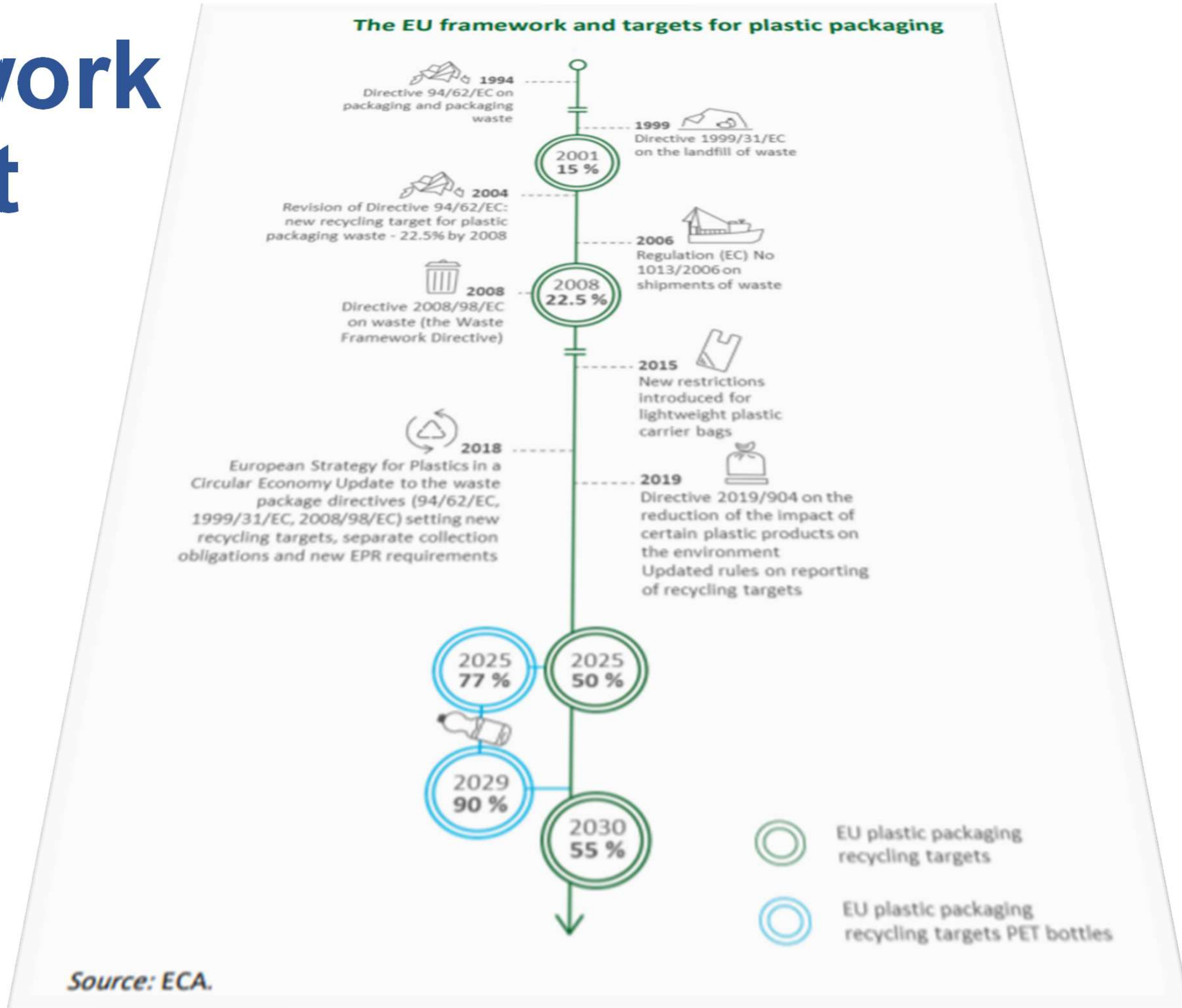
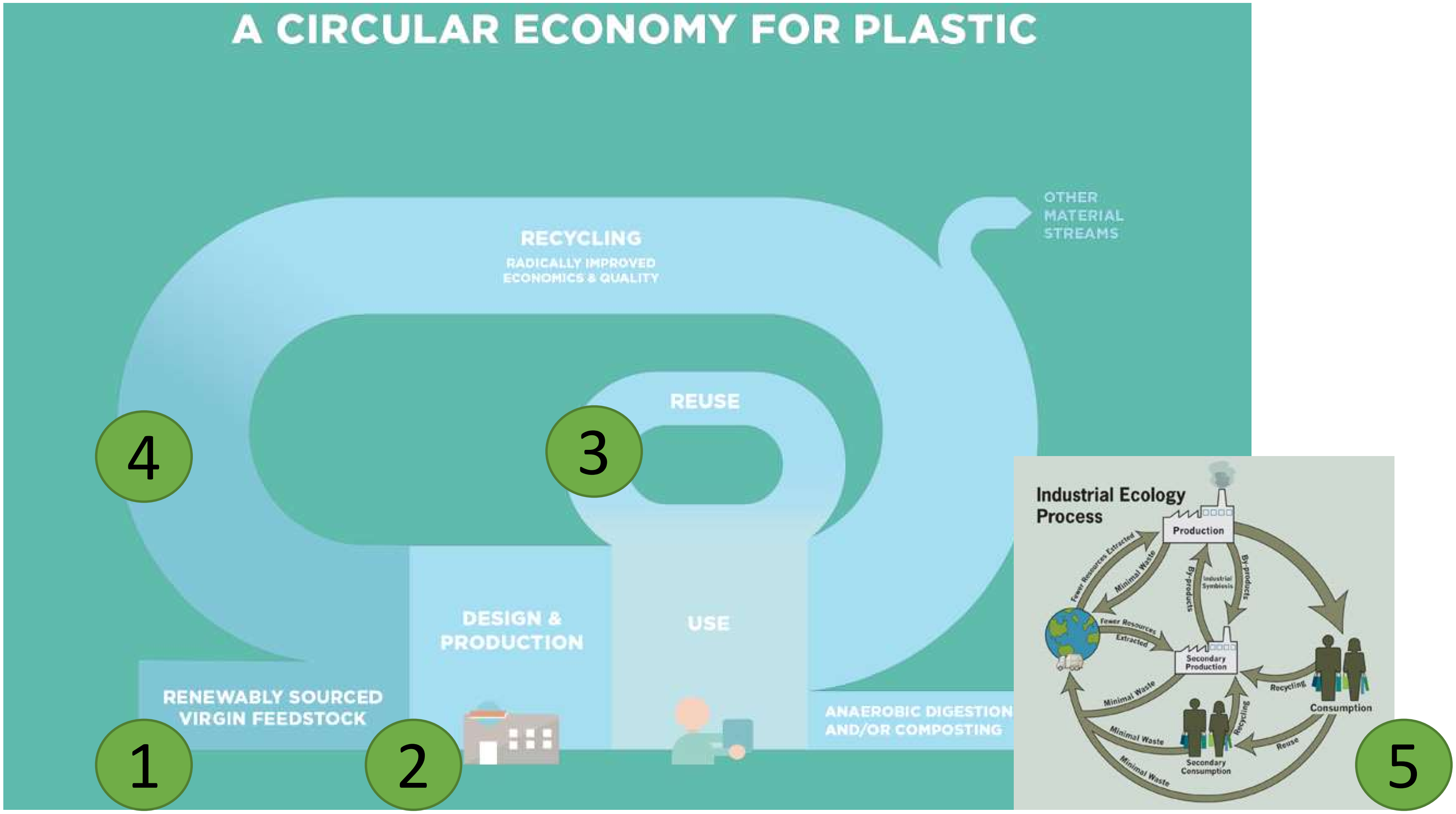
EU framework to meet targets



Redesigning the take-make-waste model

- Alternative, renewable feedstocks including CO2
  - —Secure quality, build efficiencies; support innovations
- Sustainable by design – new materials and production technology
  - —Material design: Extend lifetime; material usage vs performance; increase recyclability and biodegrability; micro/nano-plastics
  - —Article design: design for dismantling; decrease material usage; monolayer pouches; refillable and recyclable PETs
- Sustainable recycling – recycling technology and business models
  - —Plastics preparation and sorting; chemical and mechanical recycling
  - —Innovations in re-use and business models
  - —Explore digitalization technology
- Circular Plastics Alliance (CPA) established in Dec 2018
  - —Voluntary pledges by industry; more than 200 signatories
  - —Build value chains from 10 mt recycled plastics by 2025 under Strategy for Plastics in circular economy

Towards a sustainable circular model



- New feedstocks: renewables and re-used plastics
- Production to enhance re-use and lifetime in internal cycles
- Sustainable recycling in the context of circular economy and industrial symbiosis

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Can we really meet and cope with these challenges?

1 Biobased, renewable feedstocks

Polymer types		Value chains
Fossil-based	**Bio-based**	
PU/PUR	PLA	Packaging
PS, PS-E, PS-EI	Starch-based	Building & Construction
PE, PE-LD, PE-LLD, PE-HD, PE-MD	PHA/PHB	Automotive
ABS-SAN	TPS	Electrical & Electronics
ABS-HIPS	PEF	Household, Leisure & Sports
PET	PBS/PBSA	Agriculture
PP	PT	Medical
PA	Bio-PET	Healthcare
PVC	Bio-PE	Textile

- Promising leads: FDCA to furanoates (PEF) to replace PET; muconic acid in PA
- C6/C5 sugars – several options; lignin to aromatics; challenge to cope with their complex matrix; improve process and energy efficiencies
- Integrating Cascading Catalytic Pyrolysis: building blocks for ABS, PS, PET, PO
- Further scope: develop additives; use of synthetic biology. **TRL – wide range from 5 to 9**

1 Alternative feedstocks including CO2 & CO

Polymer types	
Fossil-based	**Bio-based**
PMMA	Bio-PP
PBT	Bio-PA
POM	Bio-PUR
PTFE	
DCPD	**CO_2/CO-based**
PC	PPC
	PU
Fibre Reinforced Polymer (FRP) matrices	PC
Epoxy	PEC
PU	PE

- CO2 as feedstock: still uneconomic; needs technology demonstration and industrial scale-up
- Natural fibers combined with biobased thermoplastic matrix (Sulapac)
- High costs in CO2 capture. Critical technologies: membranes, catalysis, sorbents (e.g. solvent free process or porous optimization)

- Promising leads: direction production of polycarbonate alcohols (etherols), poly(propylene) carbonates, and polyesters
- PO, PS, PMMA can be derived from different routes; non-olefinic intermediates (e.g. PTHF or PU) can be developed without isocyanate.
- **TRL – from 5 to 7**

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Examples of market and business innovations

- **Ooho**: Dutch company (Just Eat food delivery platform)
- Produces alginate sachets to contain sauce and water replacing single-use plastic

- **Apeel**: plant-derived coating to slow down water loss and oxidation
- Replace shrink wrap with favoriable LCA performance
- ASDA and Kroger retailers

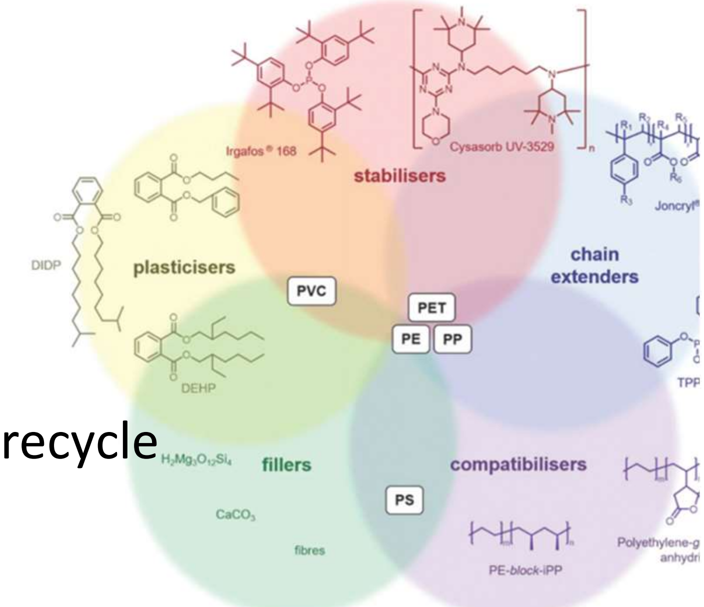
- **Lush** – UK founded with 850 stores
- E-model eliminates packaging selling solid health products sold naked at stores

2

Sustainable plastics by design – life-time, performance, material use

- Embrace safe-by-design concepts, circular and resource efficient materials (durable, recyclable, easy to dismantle)
- Adequate performance and functionalities (weight, strength, etc.).
- Material design:
  - —repair and preserve polymer properties: withstand extreme conditions; fails in delamination and matrix cracking lead to 20-30% scrap rates;
  - —self-healing polymers reactions (Diels-Alder; disulphide thiol exchange reactions; UV, T, pH etc.). **TRL from 3 to 5**
  - —Improve ageing: withstand extreme conditions; support matrix structure; especially on bio-based (PLA, PHA). **TRL from 4/5 to 7**
- Material usage vs performance
  - —Use of composites require less material for similar strength sometimes better than metals; new precursors. **TRL from 5 to 8**

2 Sustainability by design: recyclability

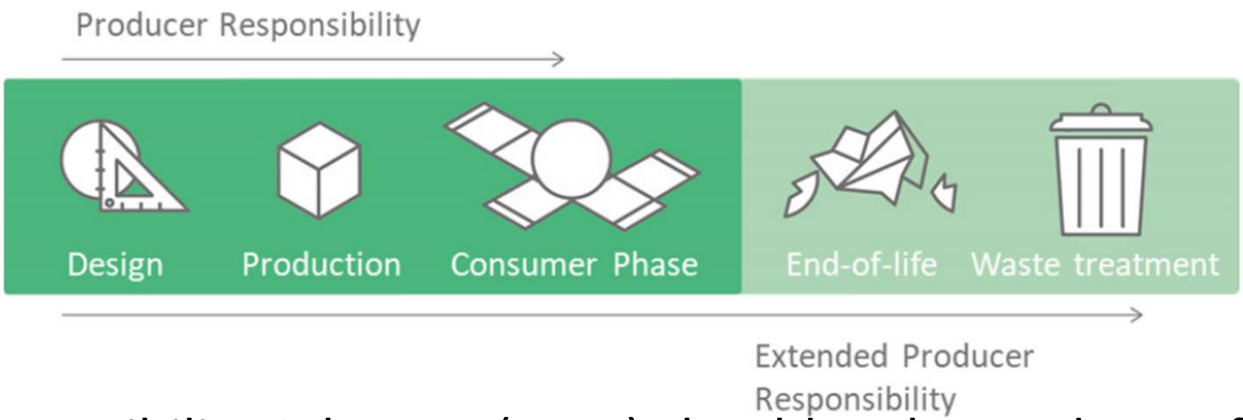


- Increase inherent recyclability:
  - ‘Degrade on demand’ into recyclable building blocks
  - Multi-layer and electrical/electronic waste difficult to recycle
  - durability vs degradability
  - common plastics (PE, PP) have no ‘break points’;
  - Compatibilizers: convert multi-component/multi-layer compositions to multi-phase mixtures; homoplastic composites: multiple functions across the chain. **TRL from 3-5 to 6-8**
  - Thermosets based on chemically modified polymers (e.g., PS) can facilitate thermal degradation not affecting their properties. **TRL from 5 to 8**
- Biodegradation
  - Interplay between properties and environment (ISO 18606/EN 13432); important when difficult to collect (mulch films); not necessarily circular. **TRL from 4 to 7**
  - Build material adapted to bacteria. PP, PE, PS: break to shorter hydrocarbons; industrial biotechnology (IBISBA research infrastructure). **TRL from 3 to 5**
- Micro and nano-plastics
  - Technologies need to analyze and quantify microplastics in the environment. Plastics generated on-land but pollution ends up in the marine.

Circular re-use business models and digitalization

- Different B2C and B2B re-use models differing in packaging ‘ownership’. ICT is major and promising technology driver.
- Possible to explore apply immediately
- Refill users retain ownership
  - Refill at home: users refill reusable container at home (e.g., refills delivered through a subscription service)
  - Refill on the go: users refill reusable containers away from home (e.g., at in-store dispensing systems)
- Return users share ownership with business or ownership stays with business
  - Formerly considered burdensome and a thing of the past;
  - May deliver superior user experience, customize products to individual needs, gather user insights, build brand loyalty, optimize operations, save costs

3 EPR schemes and incentivization



- Producer Responsibility Schemes (EPRs) should make producers financially and organizationally responsible
- Connect reuse models with economic incentives and reciprocating gains; duplicate benefits through collaborative schemes with end-users and customers:
  - — Agrofood (catering, distributors, food chains by reducing processing costs, storage, and waste): support refill and delivery services
  - — Tourism, recreation (holiday resorts, hotels): promote quality standards ('green' stars in handling plastics)

- Challenge: significant lack of data and methodological difficulties in distinguishing impacts
  - — Produce reliable figures and monitor volumes of recycled products:
  - — Set up and operate 'reuse observatories'; digitization can be of great assistance

3 Challenges and economics of circularity

- Fee typically reflects cost of processing waste, not connected to re-use or recycle.
  - No credit to circularity and sustainable practices
- Cost charged by weight. A 500ml PET accordingly decreased from 24g in 1990 to 9.5 gr in 2013.
  - Less material may translate into weaker bottles, less lifetime and loss of recyclability
- Eco-modulation of fees to promote recycling; transfer credits from waste-to-energy installations to re-use and recycle promoters
- Examples of national modulation schemes
  - Dutch Packaging Waste Fund: reward use of rigid plastics using KIDV checks; use of bonus over bonus-malus to incentivize
  - Deposit-return-schemes (DRS) reached PET collection by 80%; DRS cost 800€M/yr to run in Germany
- Integrated data platforms could reduce costs but also enable the application of innovative reciprocating models that we have not seen yet

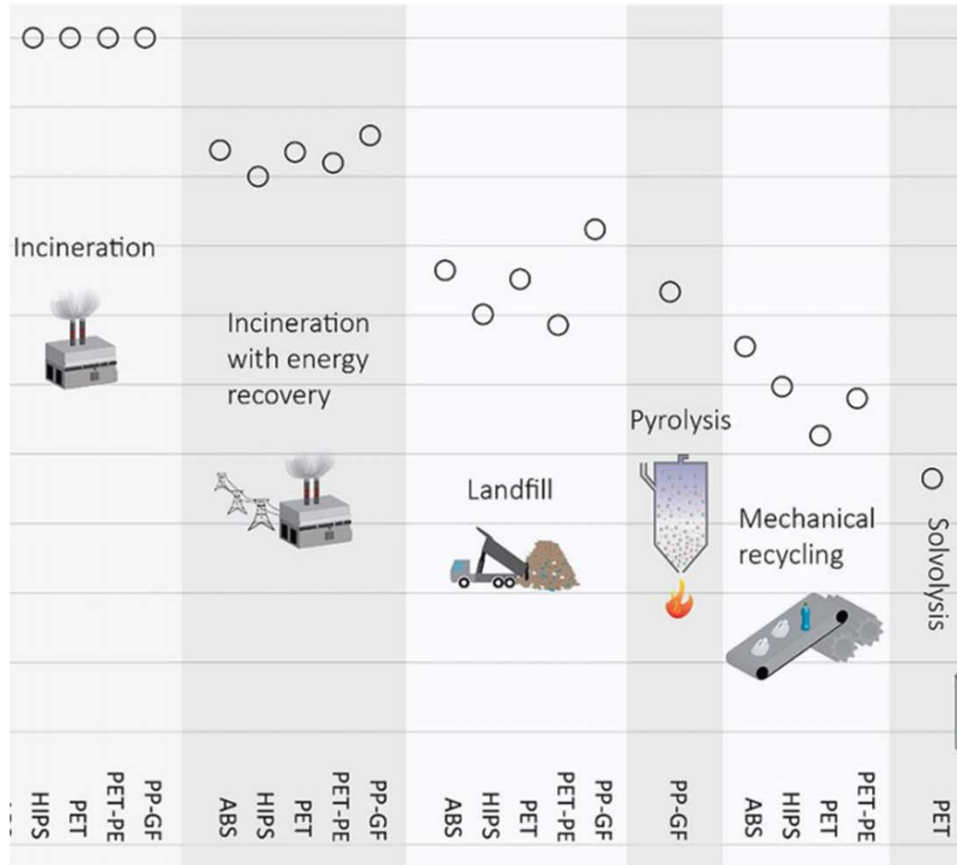
4

Sustainable recycling – sorting and separation

- Sorting of constituent materials is critically important. Challenges: solid and liquid contaminants; odors in farm films (70% of mulching packaging); inks and imprints.
- Sorting technologies:
  - Wet and dry sorting (solvation, flotation, etc.) require enhancements. Several optical methods (UV, NMR, LIBS, NIR, MIR-T, TBS) should improve traceability.
  - Some mature technologies (e.g., NIR for GPPS/HIPS). Scope for novel tracers.
- Build inherent separation capabilities.
  - Reuse of multi-layer polymers and composites are not separable. Dynamical chemical crosslinks (nucleation with low crosslinking) on CL thermosets and FRP can return building blocks; reversible production paths for adhesives
  - Reuse PE: 50% of plastics consumption. Decontamination is energy intensive. Maceration can expand the space in PE-matrix to wash out contaminants.
- Significant scope for process optimization, customization and AI.
- **Wide range of TRL from 3 to 8**

4 Sustainable mechanical and chemical recycling

- Mixes of grades. Depolymerize to building blocks and produce clean and refined material
  - —Pyrolysis/gasification: conventional, plasma, microwave assisted: various TRL; bio-technological processes: low TRL more options
  - —For low Tc: PS, PMMA, PET (<400°C). High yields and efficiencies on PS (Agilyx process); PET, PS, PA (solvolysis); PE and PP produce added-value products
- Smart mechanical recycling:
  - —Intelligent monitoring. ABS & PS recycling **close to TRL 9**; PE promise on presorting & devolatilization of melt (EREMA degassing)
  - —FRP much less developed; use of repair agents at high temperature in twin-screw extruders; additives in functionalization & reactive compatibilization



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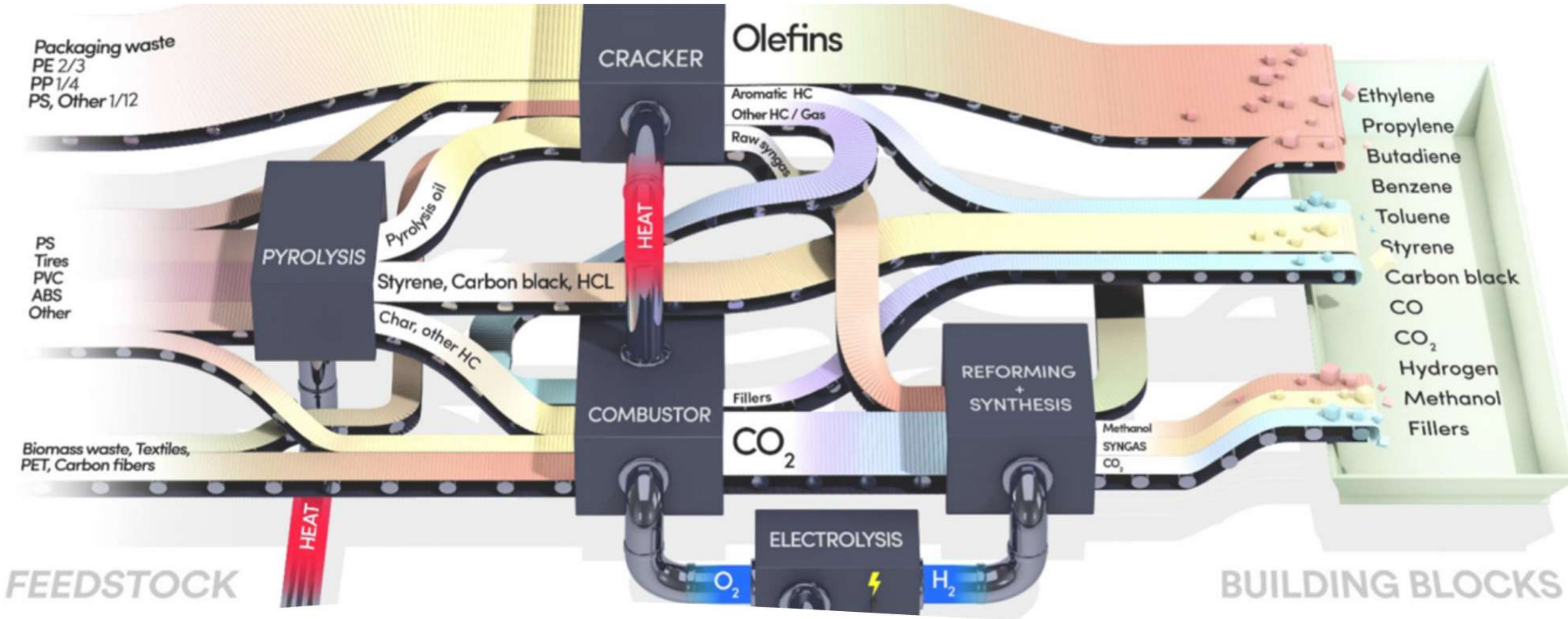

Sustainable and circular building blocks

- Mature technologies such Energy demanding pyrolysis (moderate temperatures), ICCP through BTX, and gasification through CO/H2 Scope for better catalysts. TRL from 6-7 to 9
- Several converging technologies such as Solvolysis (water, alcohol, glycols): Relatively high yields, low T; good choice for PU, PET, polyesters. TRL from 4-5 to 7
- Less developed technologies for the dissolution of multi-polymer systems: Lack of compatibility in building blocks; types of contaminants. TRL from 3 to 6.

Concluding remarks

- There is encouraging scope to develop and strengthen circularity at all levels (renewable feedstocks, sustainable production and recycle, re-use models, links with other industrial sectors)
- Technology readiness ranges from 3 to 9 much depending on the technology and the plastic type
- Eco-modulation of fees to promote circularity not waste management
- Circular business models can be put in place immediately and be particularly assisted by ICT and digital technologies
- Benefits are much higher for sites (and countries) less developed in handling plastics as substitution savings in GHG can be 3-4 times higher
- Demonstration are invariably required for validation; EPR should be directed to these efforts, rather than waste management

Resources and references

SUSCHEM
European Technology Platform for Sustainable Chemistry

CP4

EUPC

cefic

PlasticsEurope
Association of Plastics Manufacturers

ELLEN MACARTHUR FOUNDATION

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Thank you!

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