Plastics in the Environment and the Circular Economy

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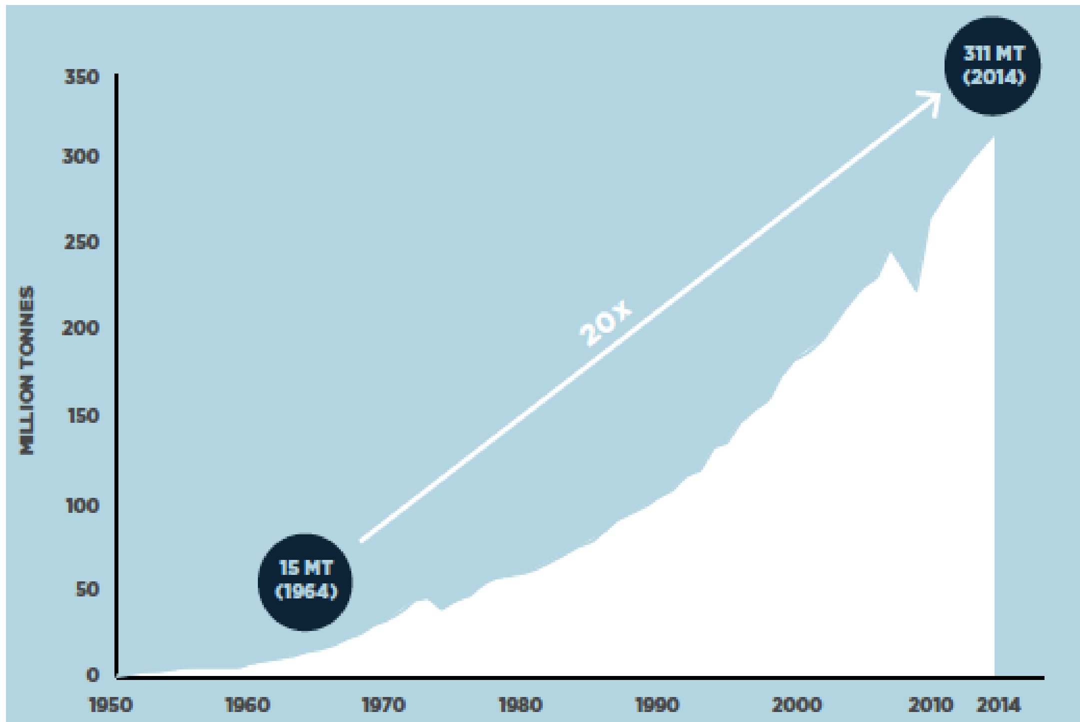
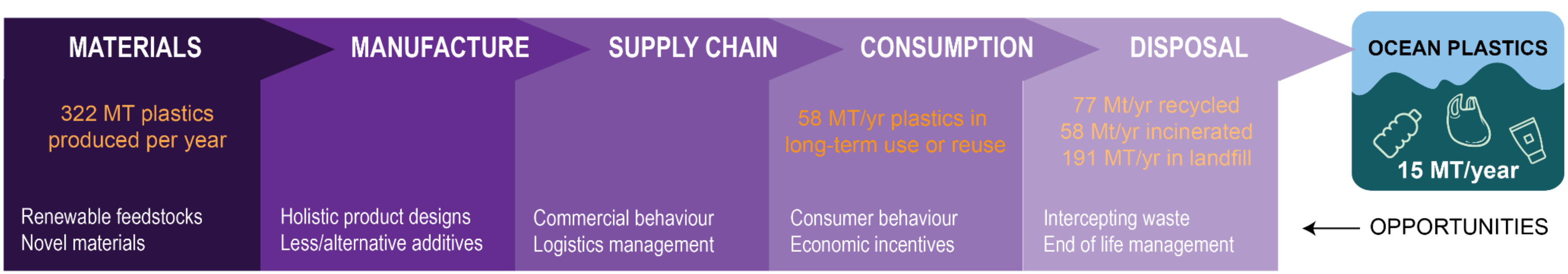
School of Chemical Engineering and the Dow Centre for Sustainable Engineering Innovation

U3A Tuesday 9th July 2019

The Background



But only 9% is recycled



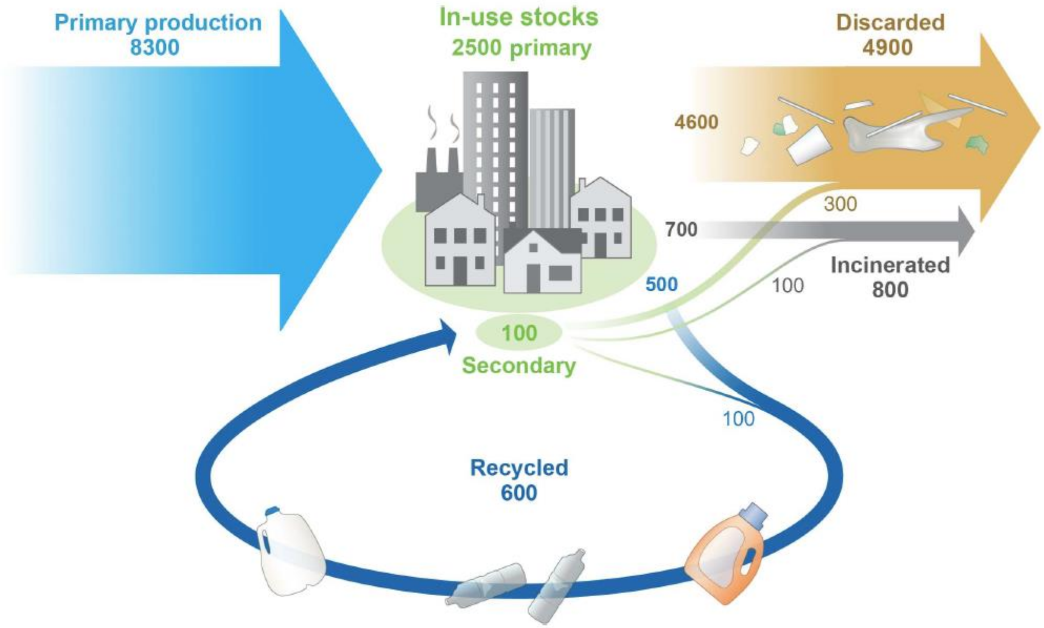
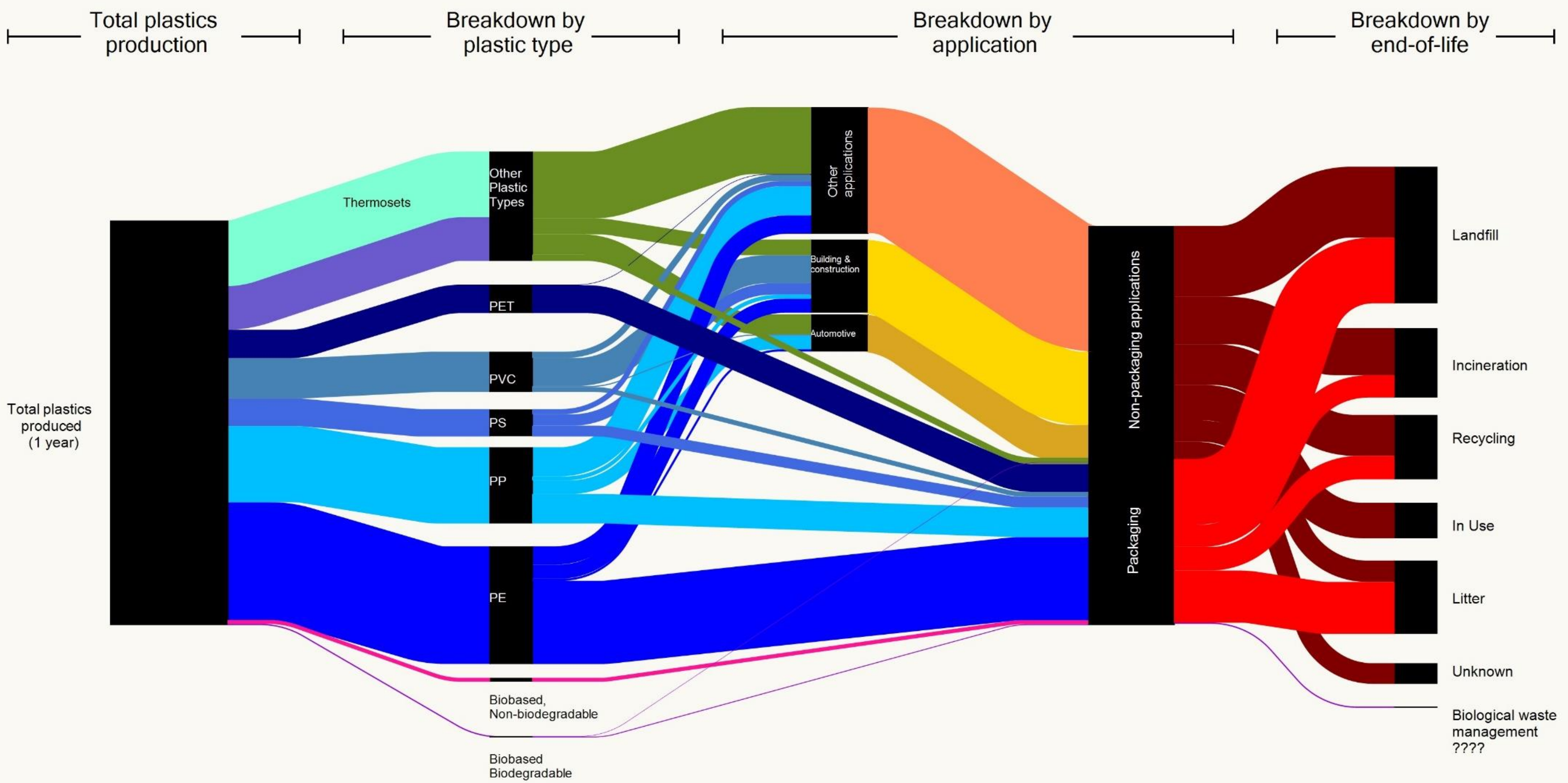


Fig. 2. Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons).

World Plastic Flows



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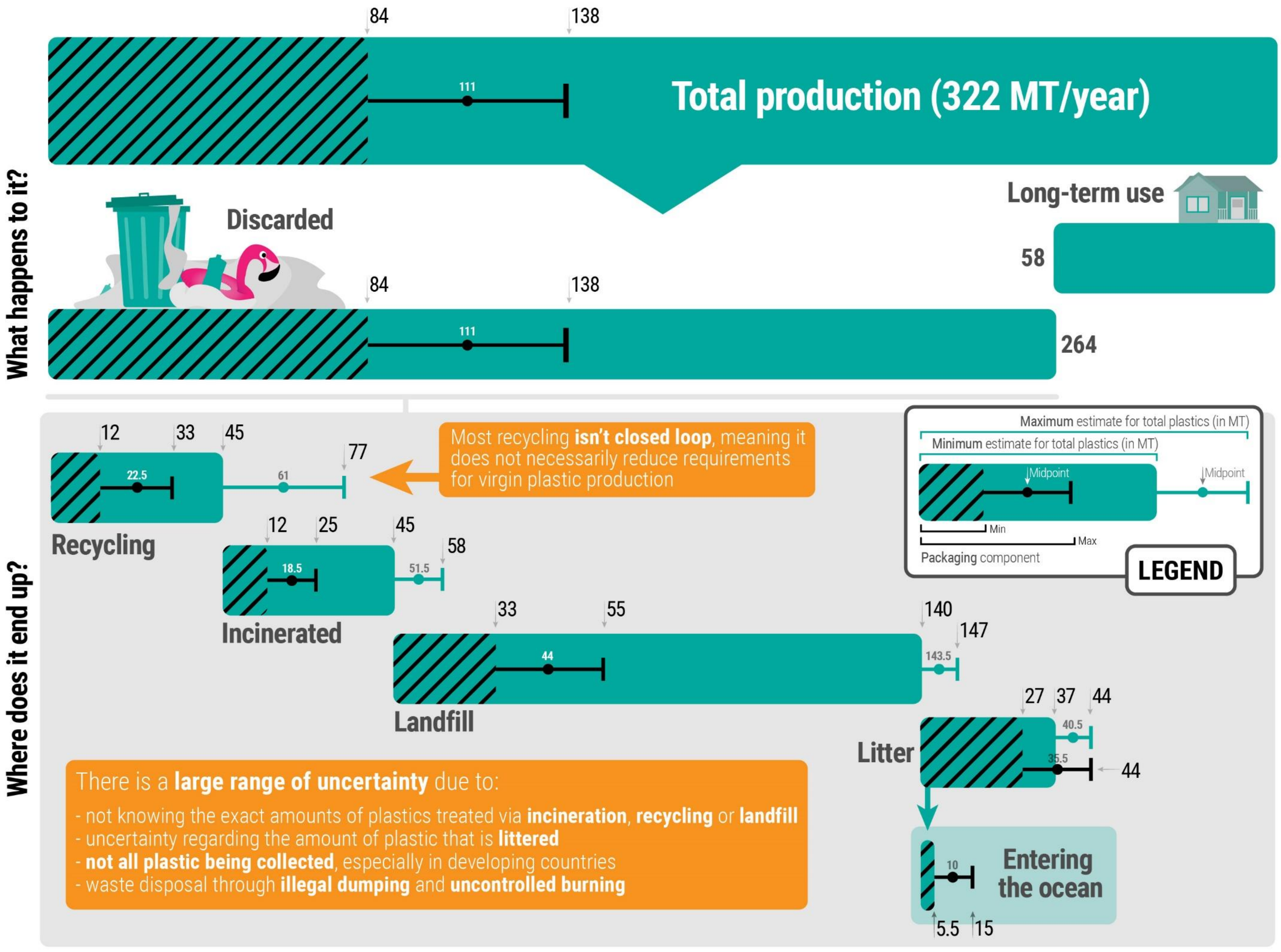
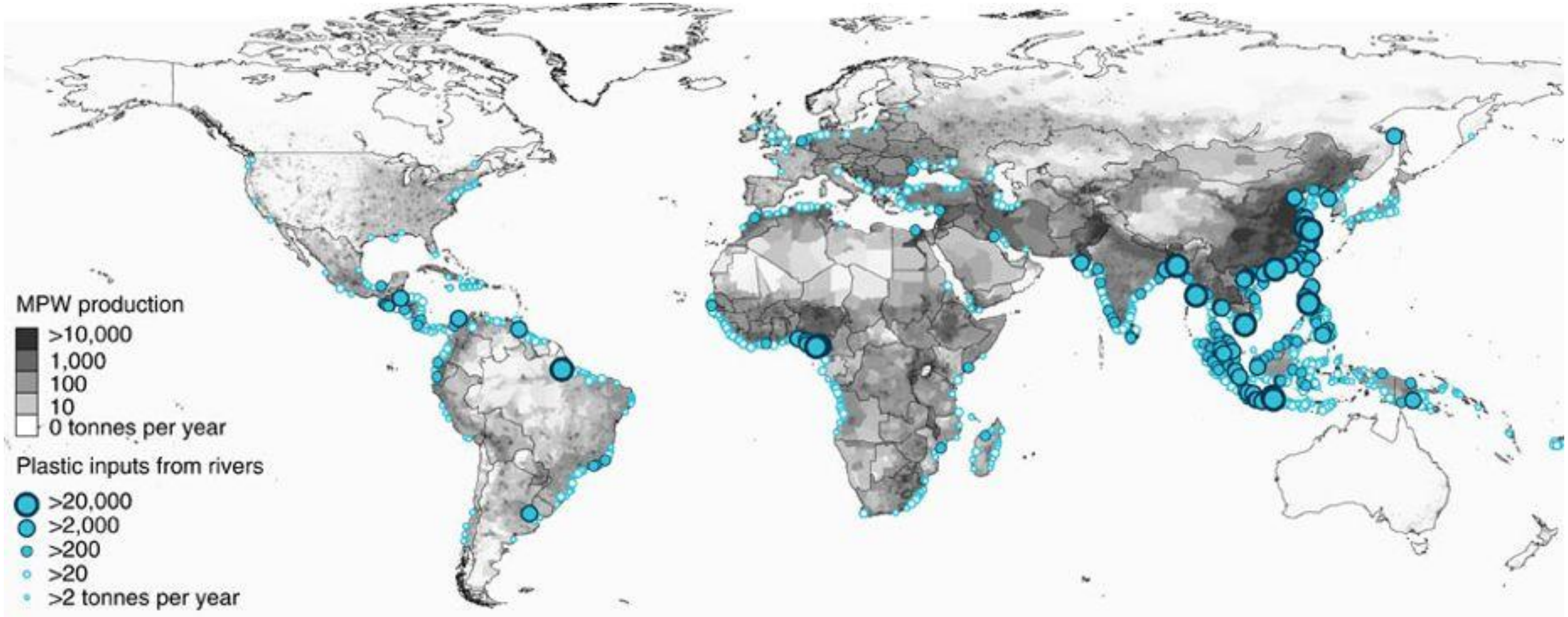
Create change

L. Dilkes-Hoffman, P. Ashworth, B. Laycock, S. Pratt, P. Lant, Public attitudes towards bioplastics – Knowledge, perception and end-of-life management, submitted to Resources, Conservation and Recycling, 28th June 2019



What happens to it?
84
138
111
Total production (322 MT/year)
Long-term use
58
Discarded
84
138
111
264
Where does it end up?
12
33
45
22.5
61
77
Recycling
Most recycling isn't closed loop, meaning it does not necessarily reduce requirements for virgin plastic production
12
25
45
18.5
51.5
58
Incinerated
33
55
44
140
147
143.5
Landfill
27
37
44
40.5
35.5
44
Litter
10
5.5
15
Entering the ocean
Maximum estimate for total plastics (in MT)
Minimum estimate for total plastics (in MT)
Midpoint
Midpoint
Min
Max
Packaging component
LEGEND
There is a large range of uncertainty due to:
- not knowing the exact amounts of plastics treated via incineration, recycling or landfill
- uncertainty regarding the amount of plastic that is littered
- not all plastic being collected, especially in developing countries
- waste disposal through illegal dumping and uncontrolled burning



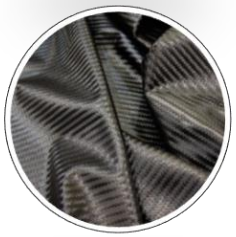
https://www.nature.com/articles/ncomms15611/figures/1

Bioplastics and Biocomposites Research at UQ

Translational Polymer Research Group • UQ Composites Group • Civil Composite Structures Group

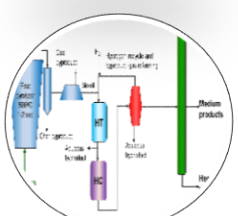
Examples of current projects

Biopolymers from waste and methane

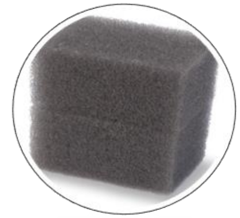


Carbon fibres from waste PE and bioderived sources

Wood biopolymer composites



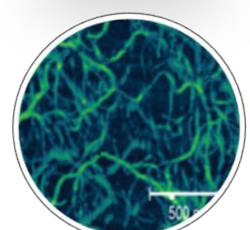
Low temperature catalytic depolymerisation



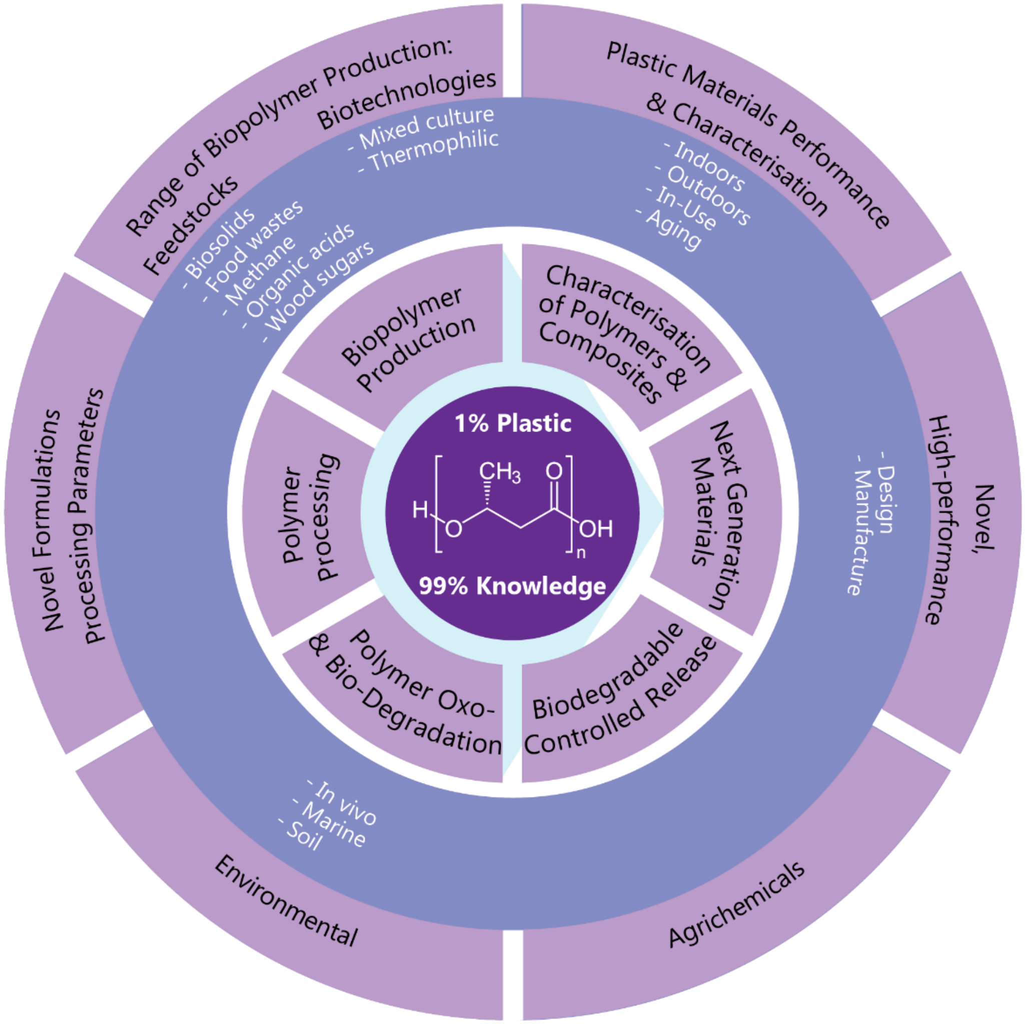
Lignin based polyurethane foams

Starch derived industrial products/nutrient recovery/films

Biobased controlled release products



Conducting self-assembled peptide nanowires


1% Plastic
CH_3
O
H
O
OH
n
99% Knowledge
Biopolymer Production
Characterisation of Polymers & Composites
Next Generation Materials
Biodegradable Controlled Release
Polymer Oxo- & Bio-Degradation
Polymer processing
Range of Biopolymer Production: Feedstocks
Biotechnologies
- Mixed culture
- Thermophilic
- Biosolids
- Food wastes
- Methane
- Organic acids
- Wood sugars
Plastic Materials Performance & Characterisation
- Indoors
- Outdoors
- In-Use
- Aging
Novel, High-performance
- Design
- Manufacture
Agrichemicals
Environmental
- In vivo
- Marine
- Soil
Novel Formulations Processing Parameters

Expertise

Polymer Degradation

Oxo- and bio-degradables, accelerated aging, lifetime estimation, mechanistic studies

Polymer Characterisation

DSC, NMR, FTIR, TGA, rheology, etc

Polymer Chemistry

Compositional distribution, micro-scale architecture, thermal and mechanical properties, polymer synthesis and modification

Bulk Processing

Extrusion, injection moulding, solvent casting, blending

Modelling

Accelerated & environmental degradation, diffusion

Survey – attitudes to plastic

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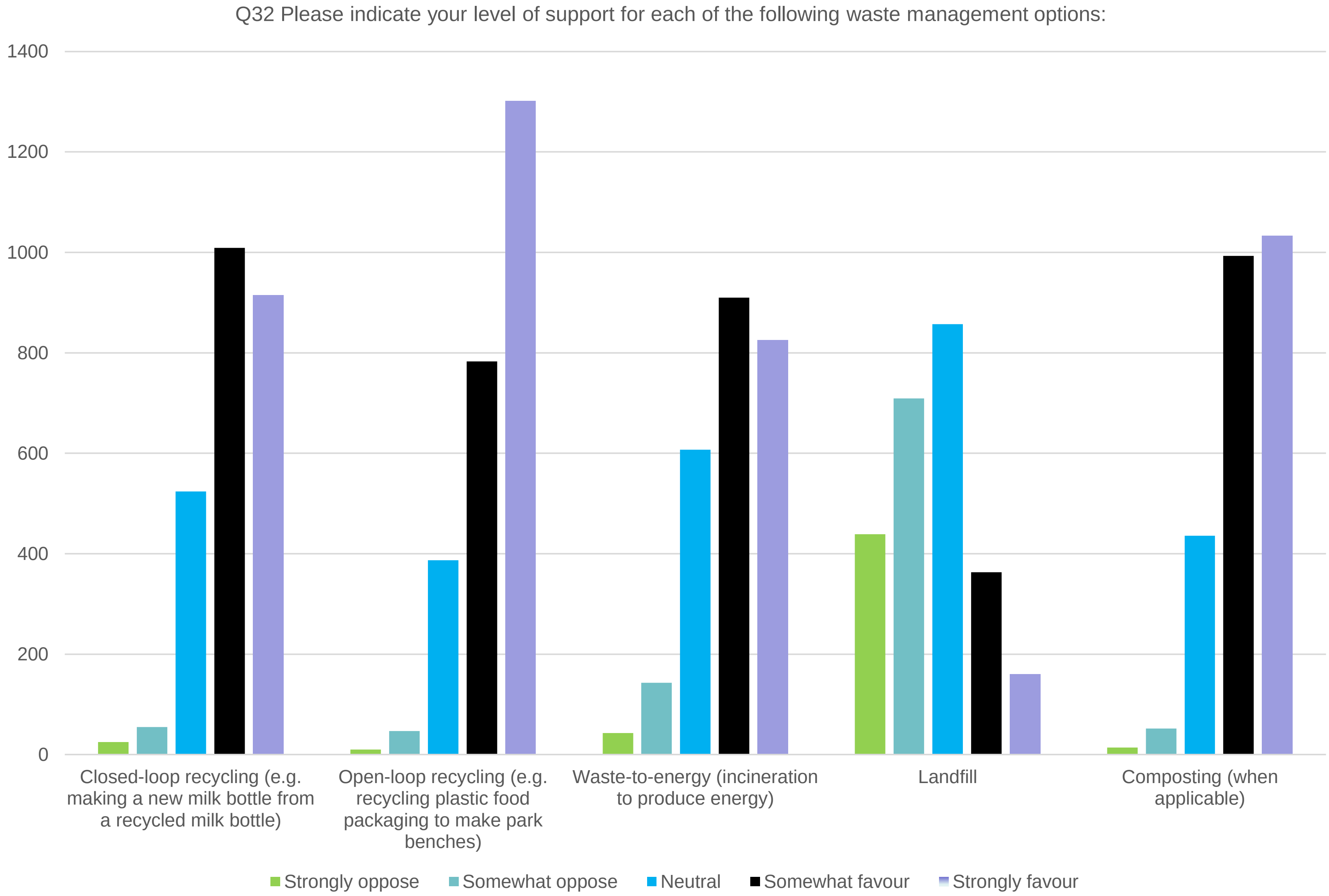
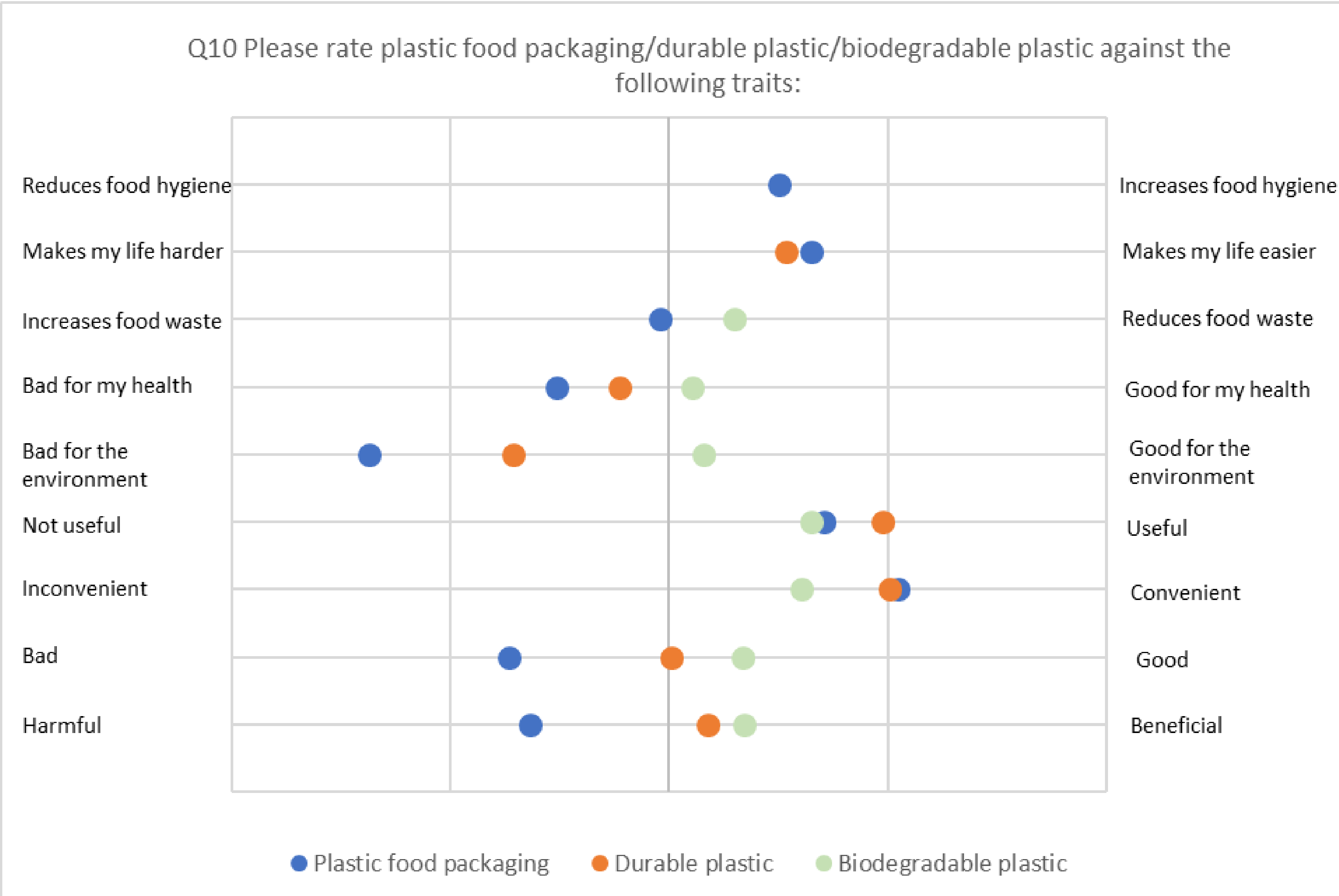
Responses to the question 'please indicate how serious you think each of the following environmental issues are (scale 1-10)'. **N = 2529**

End of life feedback





Q10 Please rate plastic food packaging/durable plastic/biodegradable plastic against the following traits:
Reduces food hygiene
Increases food hygiene
Makes my life harder
Makes my life easier
Increases food waste
Reduces food waste
Bad for my health
Good for my health
Bad for the environment
Good for the environment
Not useful
Useful
Inconvenient
Convenient
Bad
Good
Harmful
Beneficial
Plastic food packaging
Durable plastic
Biodegradable plastic

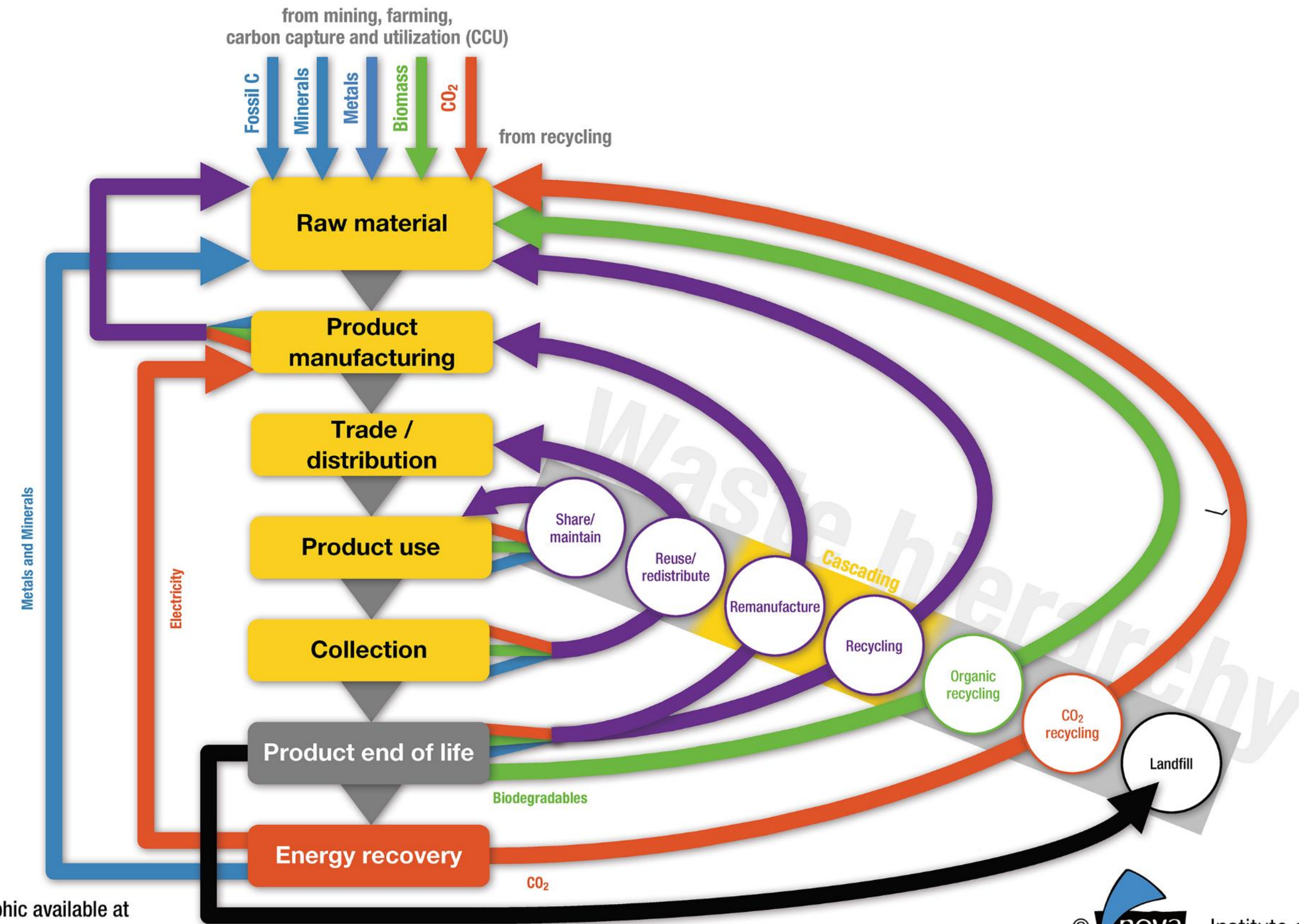
Confusion over bioplastics

Most Australians select ‘unsure’ when asked to respond to statements such as ‘all bioplastics are biodegradable’, ‘all plastics made from plants are biodegradable’, some bioplastics are indistinguishable from regular plastics’, ‘bioplastics can have negative environmental impacts’.

The public is also unsure whether they have used a bioplastic before.

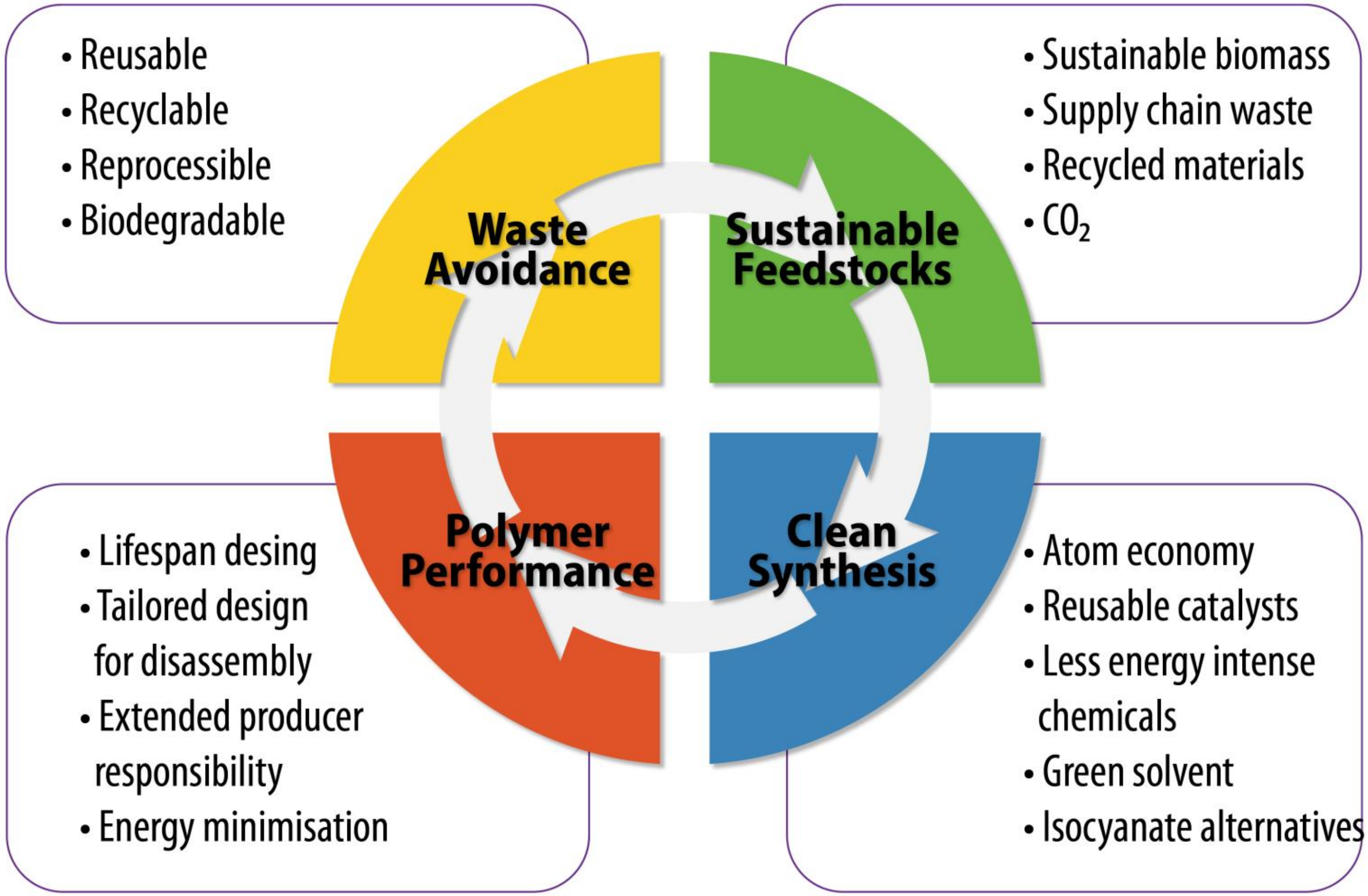
When asked about bioplastics in open-ended word association questions, the most common response is ‘don’t know’.

Comprehensive Concept of Circular Economy

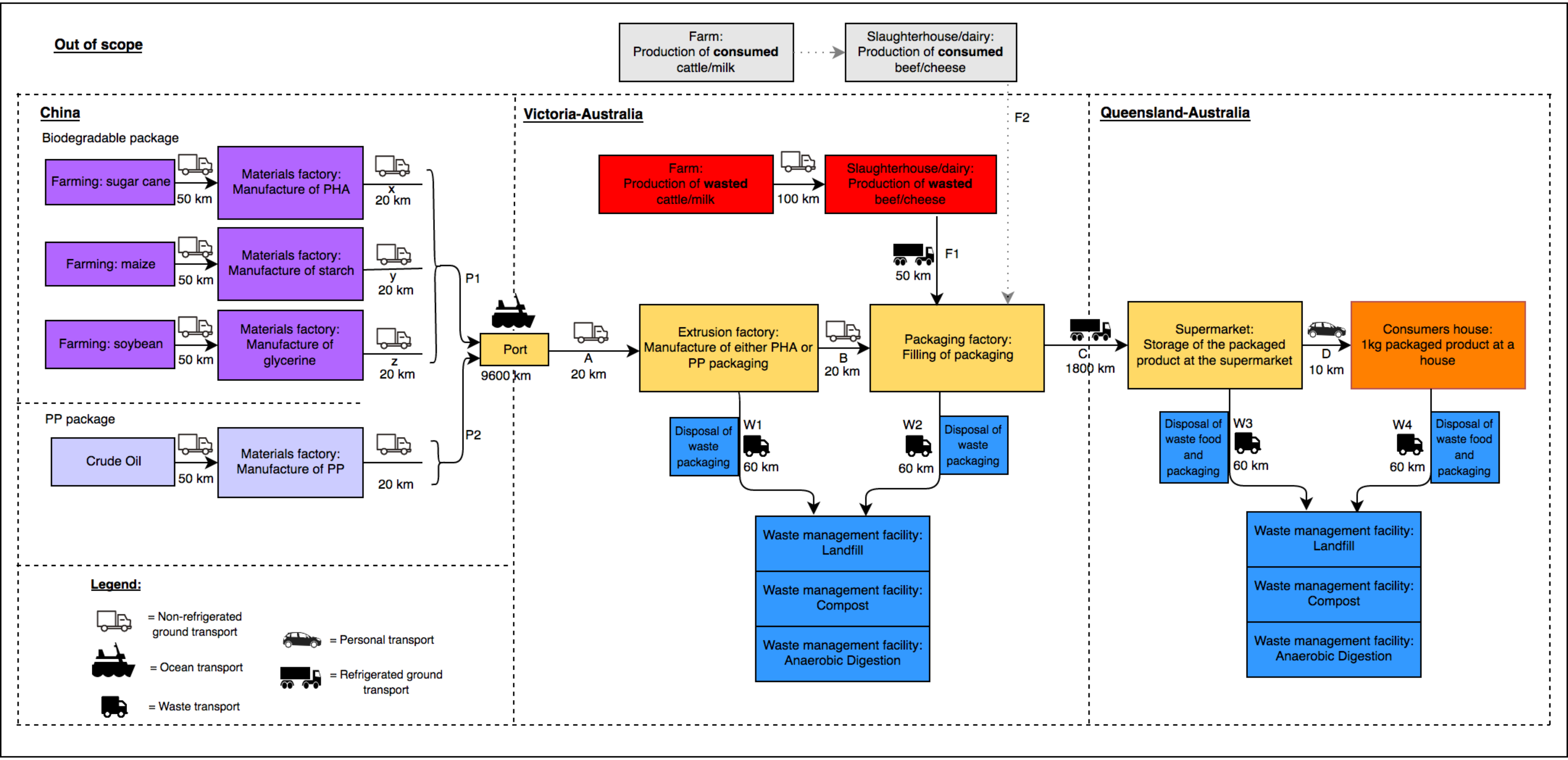


Graphic available at
bio-based.eu/graphics

Circular Economy Design Considerations

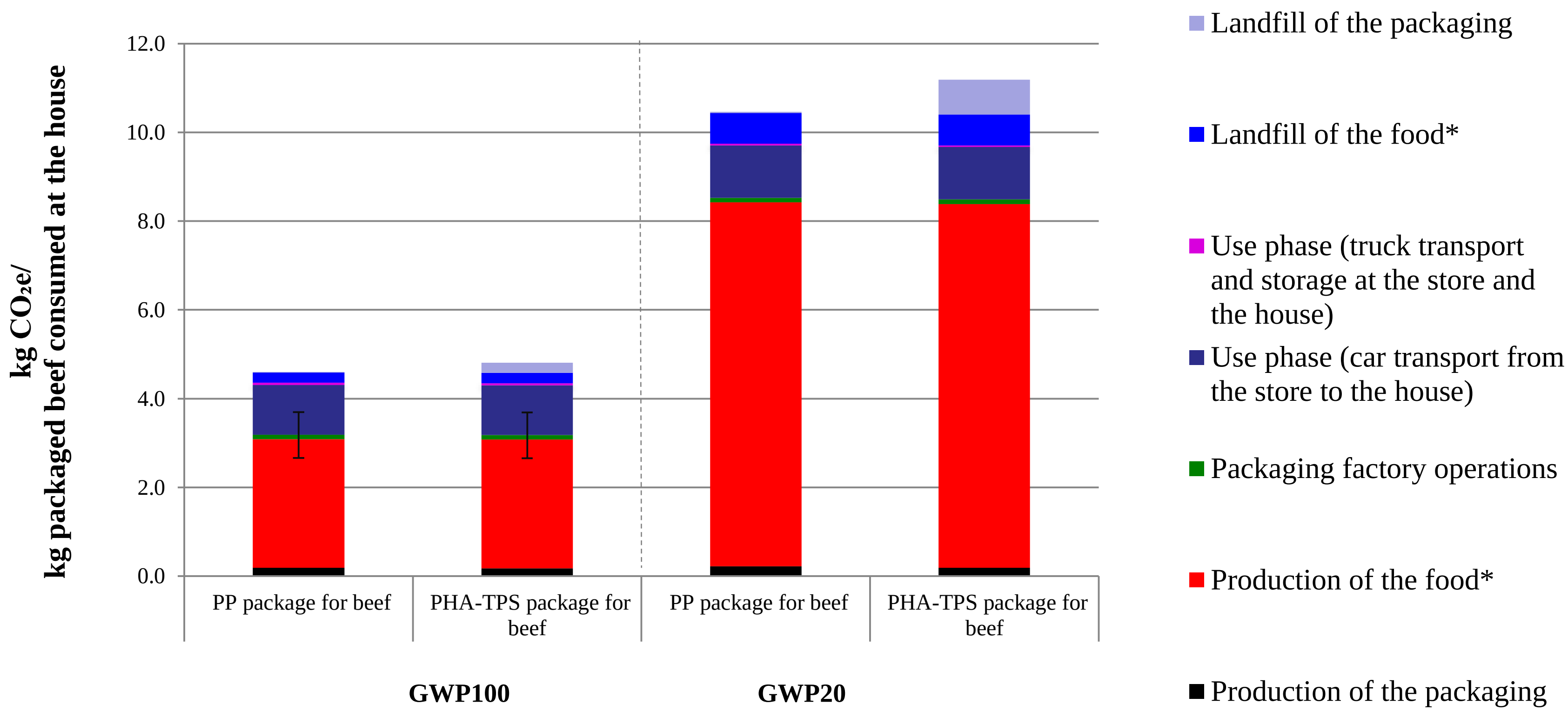


LCA – PHA/starch packaging versus PE



Journal of Cleaner Production Volume 180, 10 April 2018, Pages 325-334

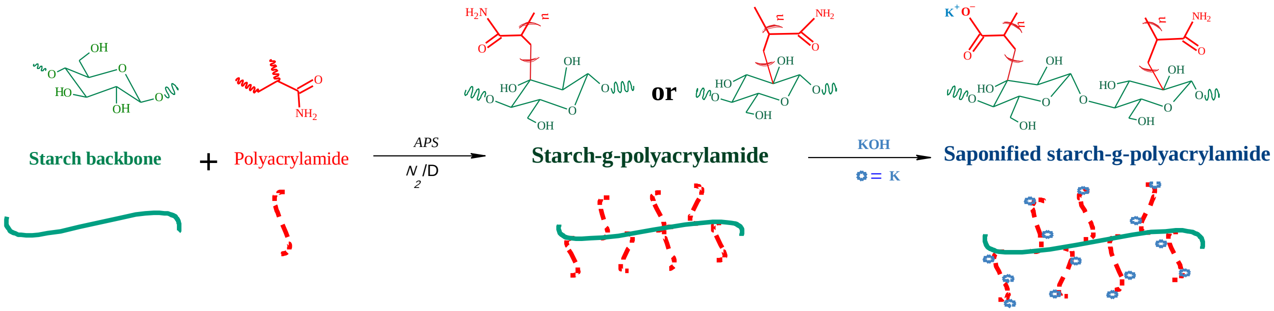
One result: The full system boundary

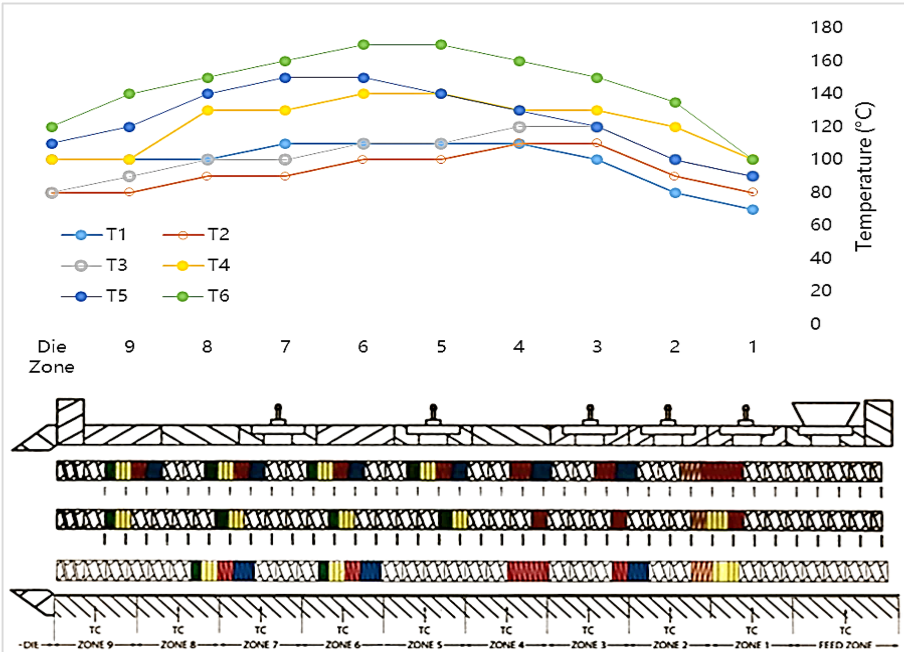


kg CO_2e emissions for the full system boundary for 1kg of packaged beef consumed at the house.

Journal of Cleaner Production Volume 180, 10 April 2018, Pages 325-334

Rapid processing – reactive extrusion



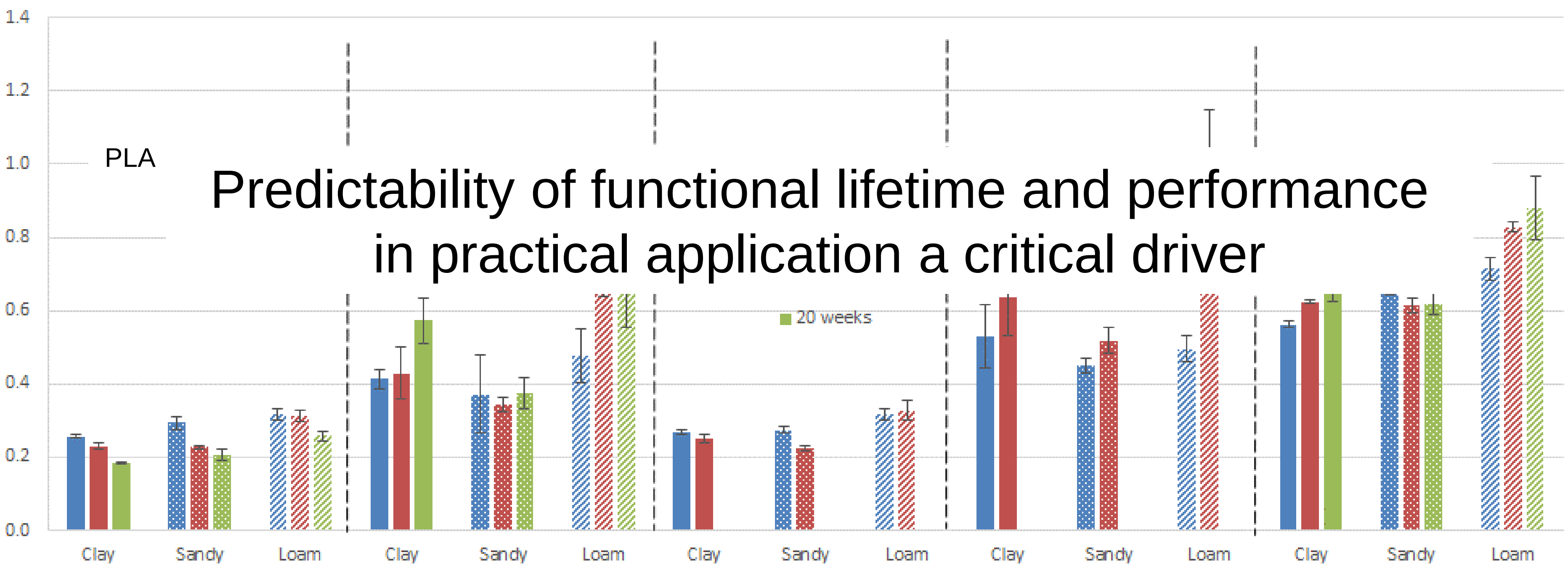


Example of approach to repurposing of polymer waste

Rapid, industrially relevant, chemically efficient, solvent free

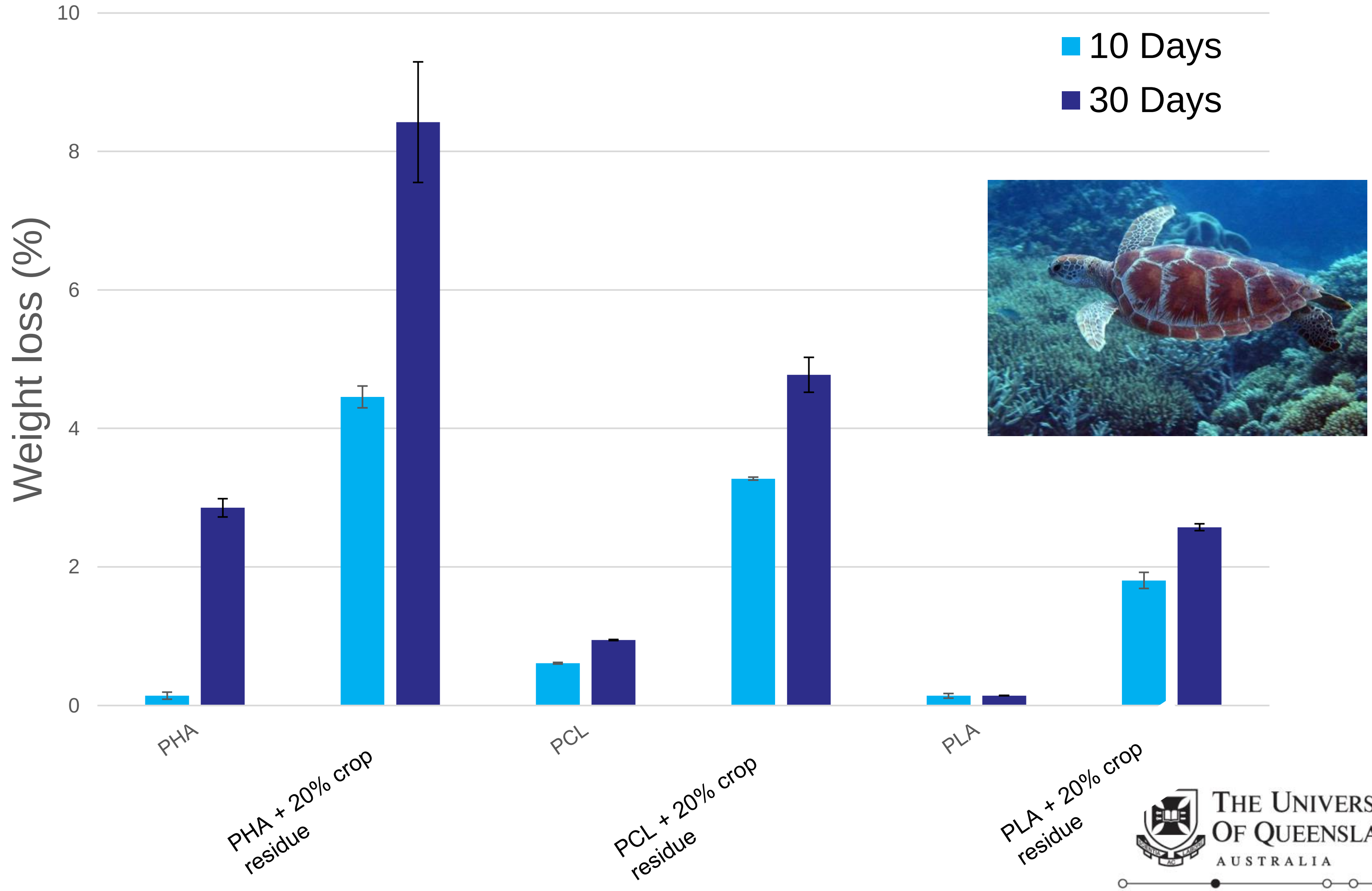
Controlled release of agrichemical

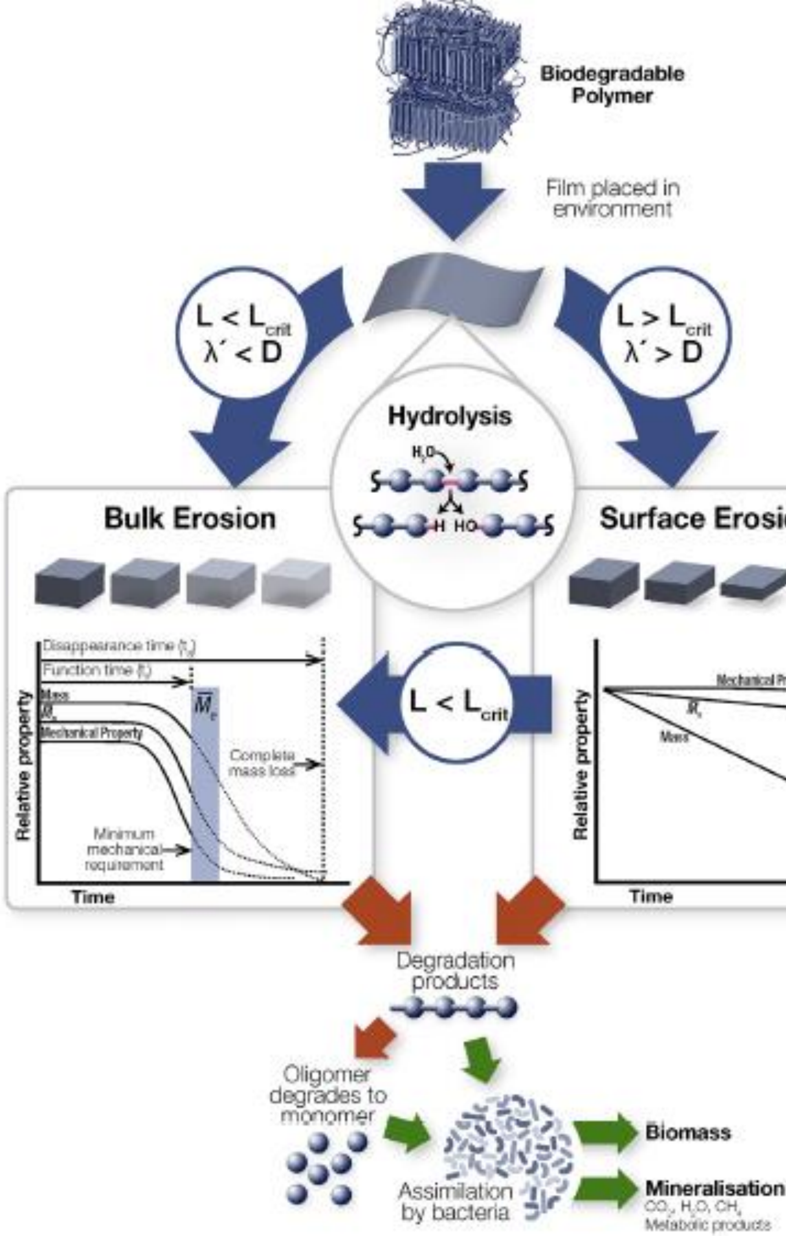
PLA, PHA and commercial product blends @ 3, 9, 20 weeks in 3 different soils



Predictability of functional lifetime and performance in practical application a critical driver

Rumen fermentation trial: slow release of toxin





Laycock B, et al. Lifetime prediction of biodegradable polymers. Prog Polym Sci (2017), http://dx.doi.org/10.1016/j.progpolymsci.2017.02.004

Complexity of environmental biodegradation

Polymer characteristics

Diffusivity, morphology, crystallinity, density, voids, surface properties (chemistry, charge, hydrophobicity), micro- and macro-phase separation

Environmental factors

Temperature, pH, oxygen, rainfall, pressure, metals present, nutrients, UV exposure (less important)

Material bulk characteristics

Particle size, shape, pore size, distribution, geometry, localised stress, mechanicals, hetero- vs. homogeneity, surface properties (roughness)

Biological environment

Microbial community (density, enzymes available), fungi, roots, hyphae, macrofauna

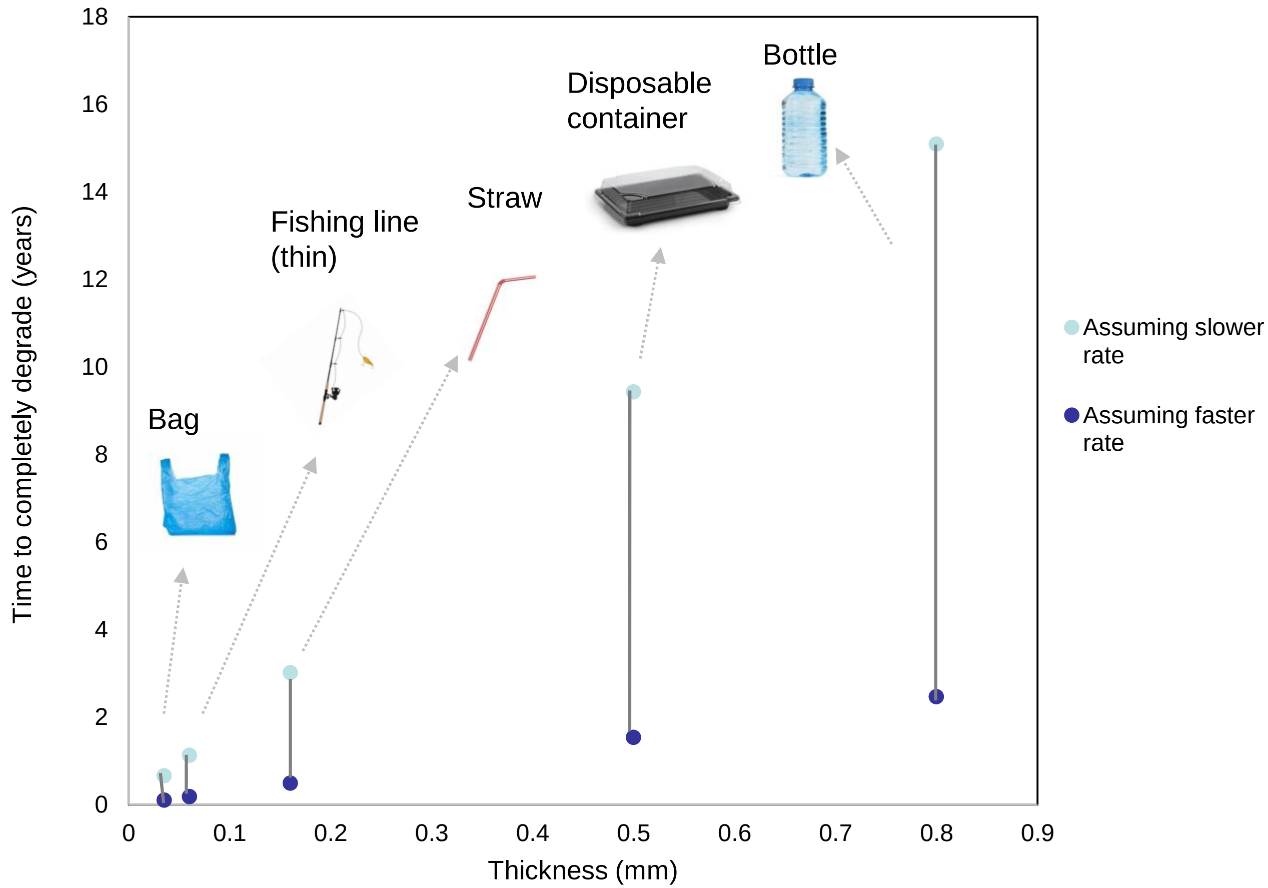
Degradation environment

Aerobic vs. anaerobic, soil (type, WHC etc.), air, fresh water (sediment, mid column, surface), marine (sediment, mid column, surface), anaerobic digestion, in vivo, stomach (ingestion)

Processing

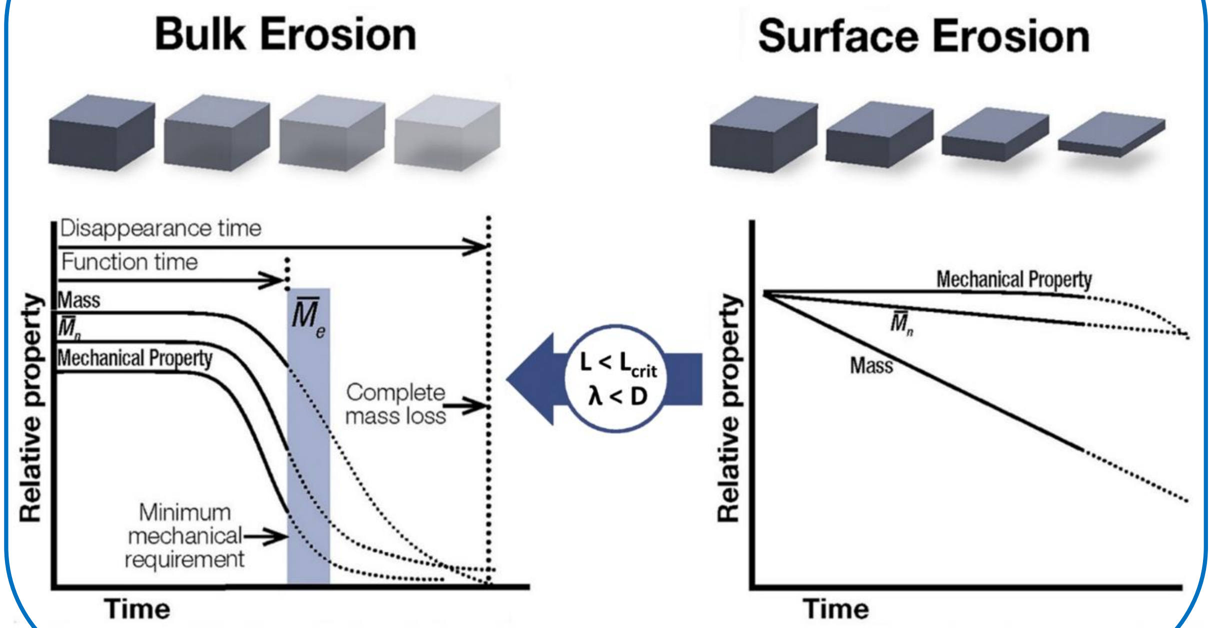
Solvent cast, melt pressed, extruded, pressure formed, orientated vs. non-orientated, post processing (annealing)

BUT….Marine biodegradation - literature

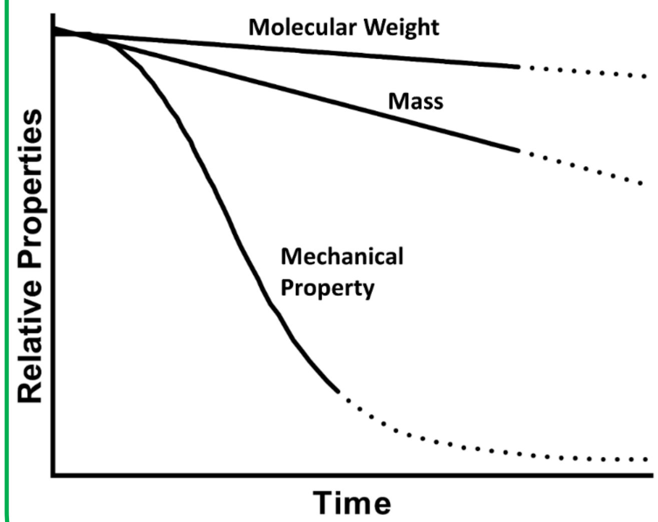


AND……heterogeneity effects

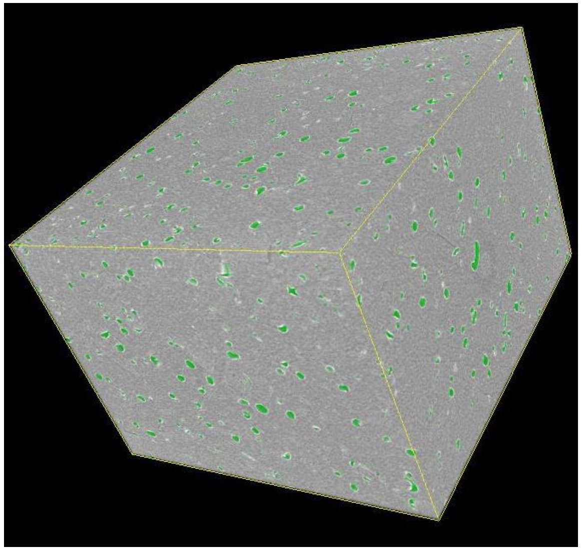
For PHA in literature (also observed in this work):

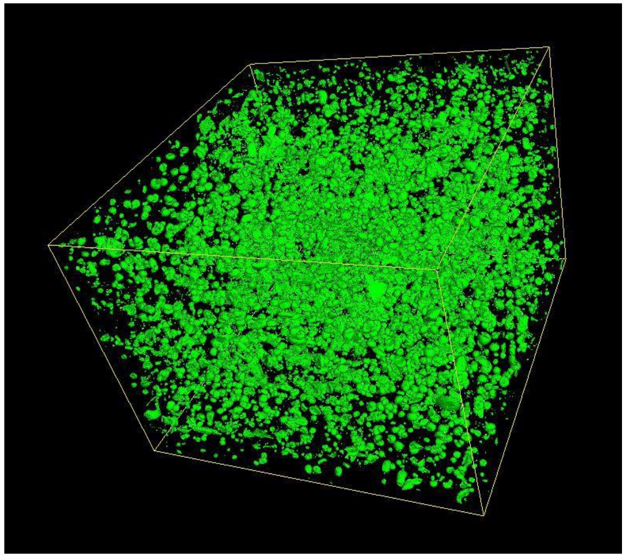


Observed from wood-PHA composites:

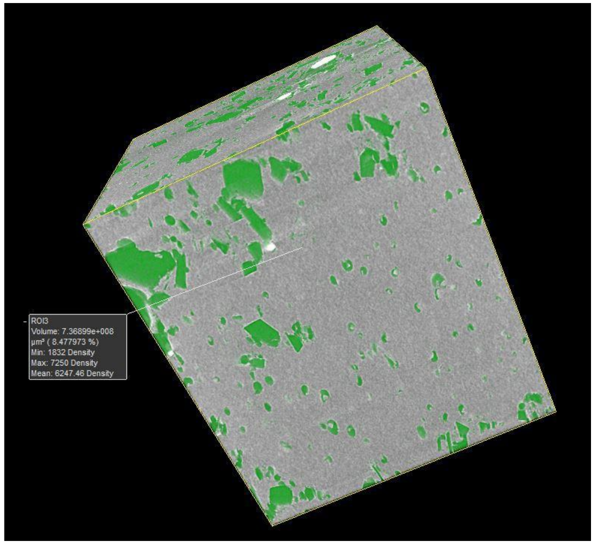


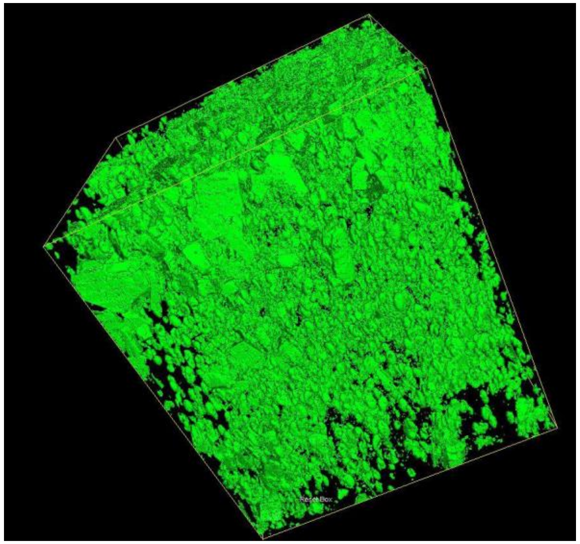
Non-Arrhenius behaviour - Localised stress leading to crazing/stress cracking/crack propagation and pathways for permeation





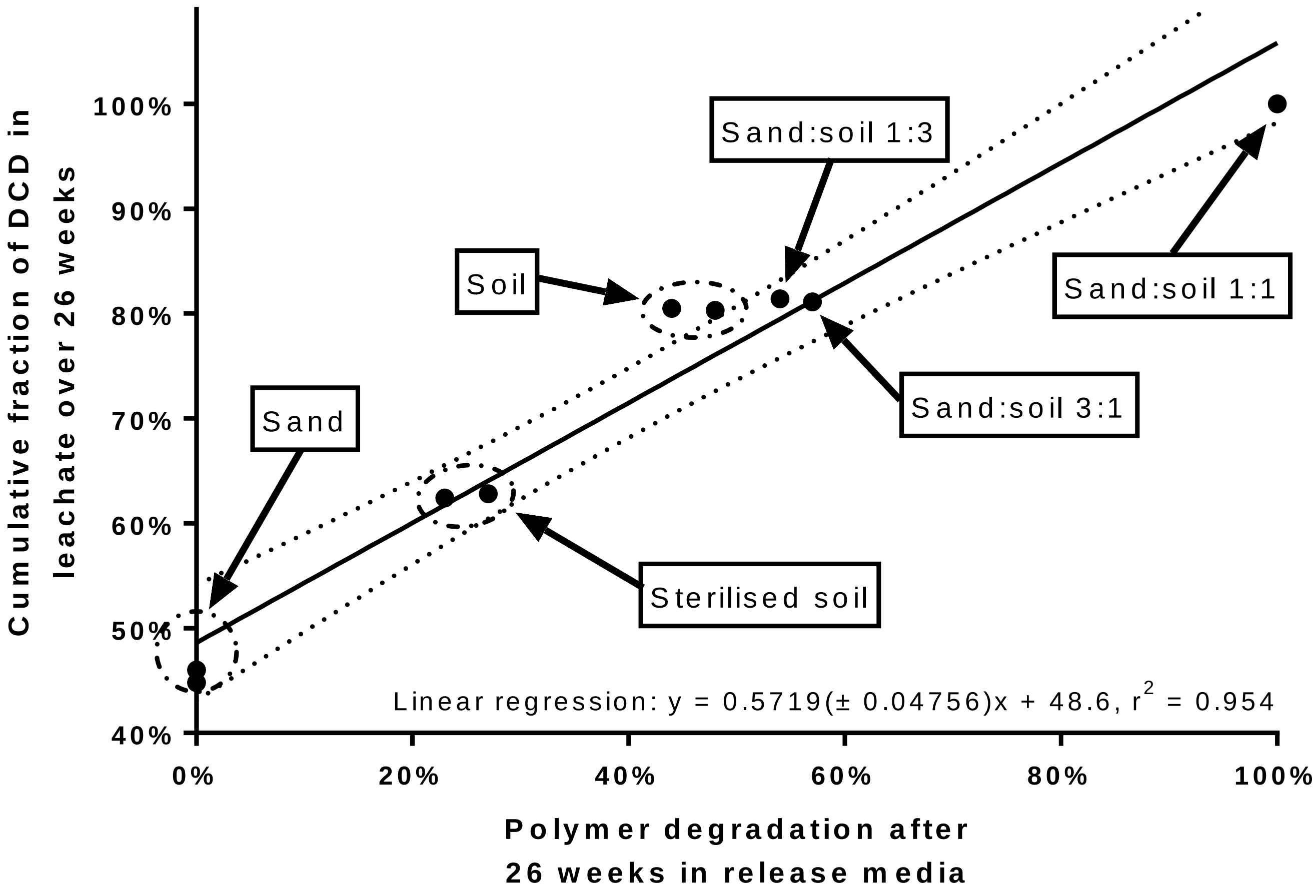
Before elution/ degradation – 2.3% voids





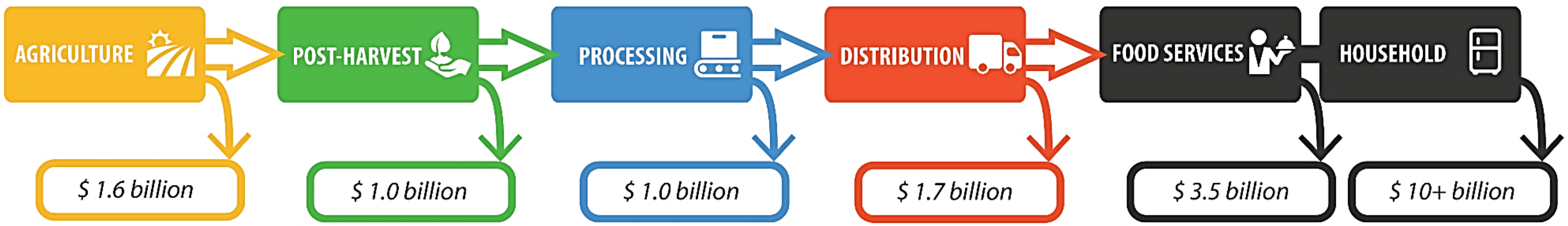
After elution/ degradation – 8.5% voids

Release profile



ANOTHER OPPORTUNITY

Value-chain Food Waste losses: $19 billion p.a.



CRC Programs

REDUCE
food waste throughout the supply chain

TRANSFORM
unavoidable waste into valuable co-product

ENGAGE
with industry and consumers to deliver change

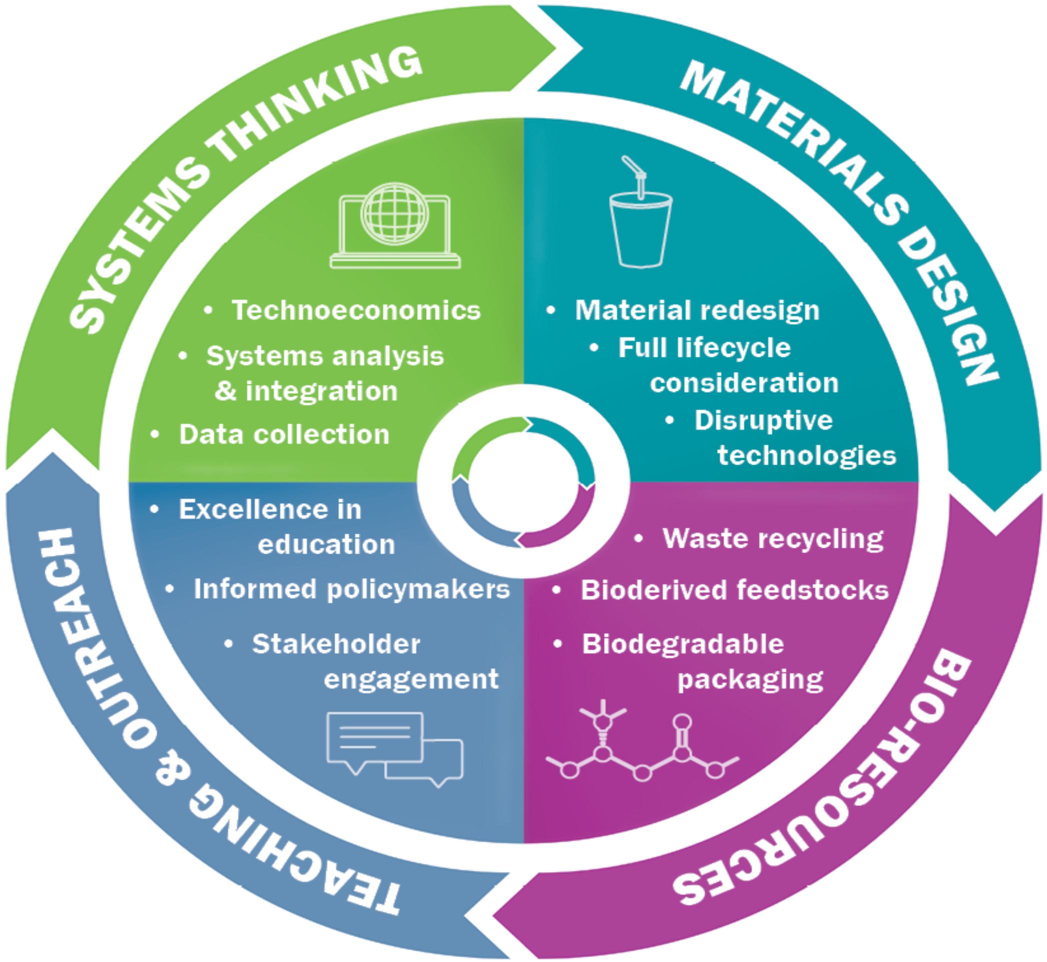
$131 million research program over 10 years – integrates packaging with waste transformation

Unlocking the Potential

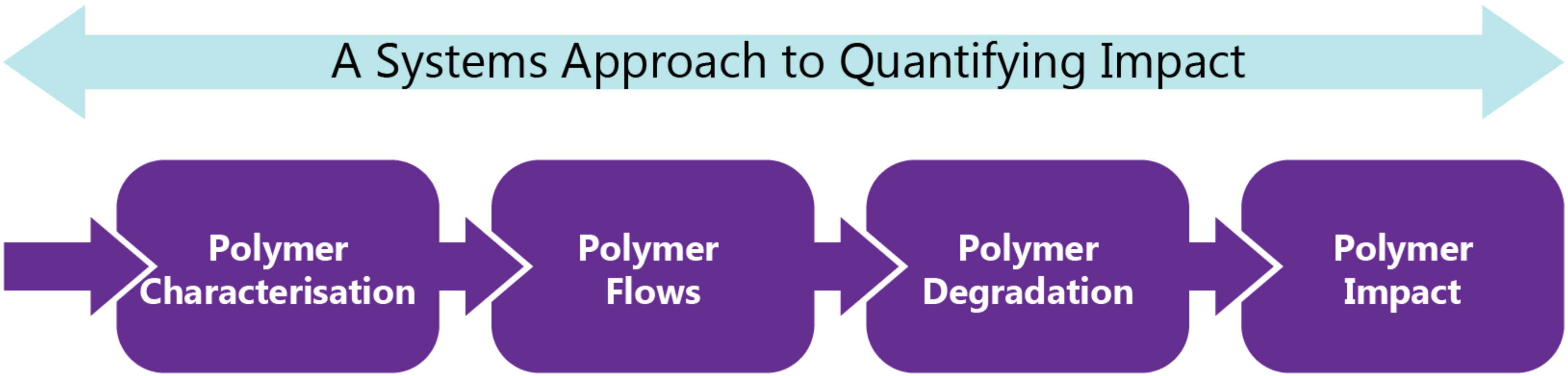
Partnerships to better understand and model:

- Polymer flows/pathways – from manufacture to end of life
    - Types, morphologies, applications, particle sizes, design and tailoring, repurposing
- Degradation product analysis
    - Mechanisms of breakdown, toxicity assessment, physical impacts
- Degradation modelling and lifetime estimations
- Systems framework for understanding the impact of polymers in the environment and integration of biopolymers into a sustainable circular economy

Concept for plastics innovation for the new economy



Polymers in the Environment



Polymer Characterisation

- Type
- Morphology
- Material characteristics

Polymer Flows

- Mapping strategies
- Model studies

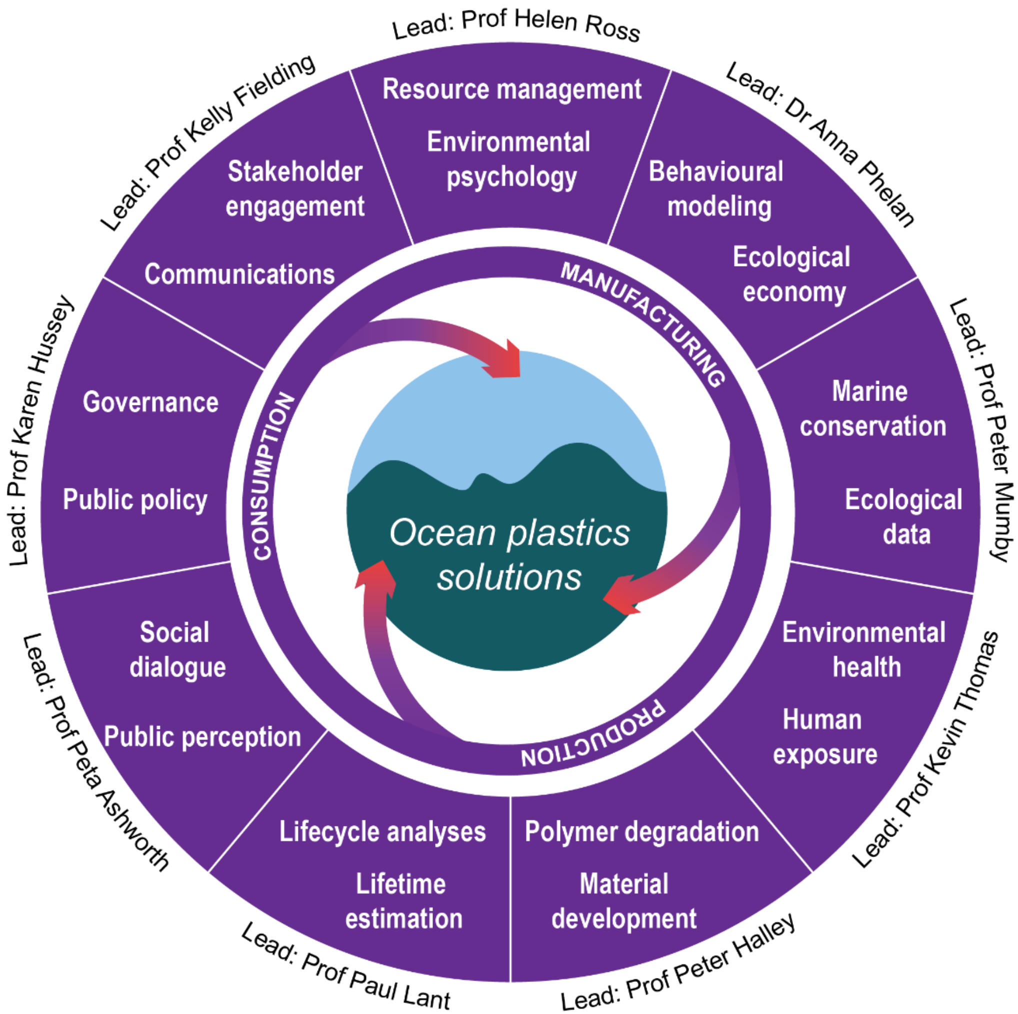
Polymer Degradation

- Mechanisms
- Lifetime estimation
- Structure-property relationships

Polymer Impact

- Toxicity
- By-products
- Toxin concentration potential
- Physical impacts

UQ capabilities more broadly



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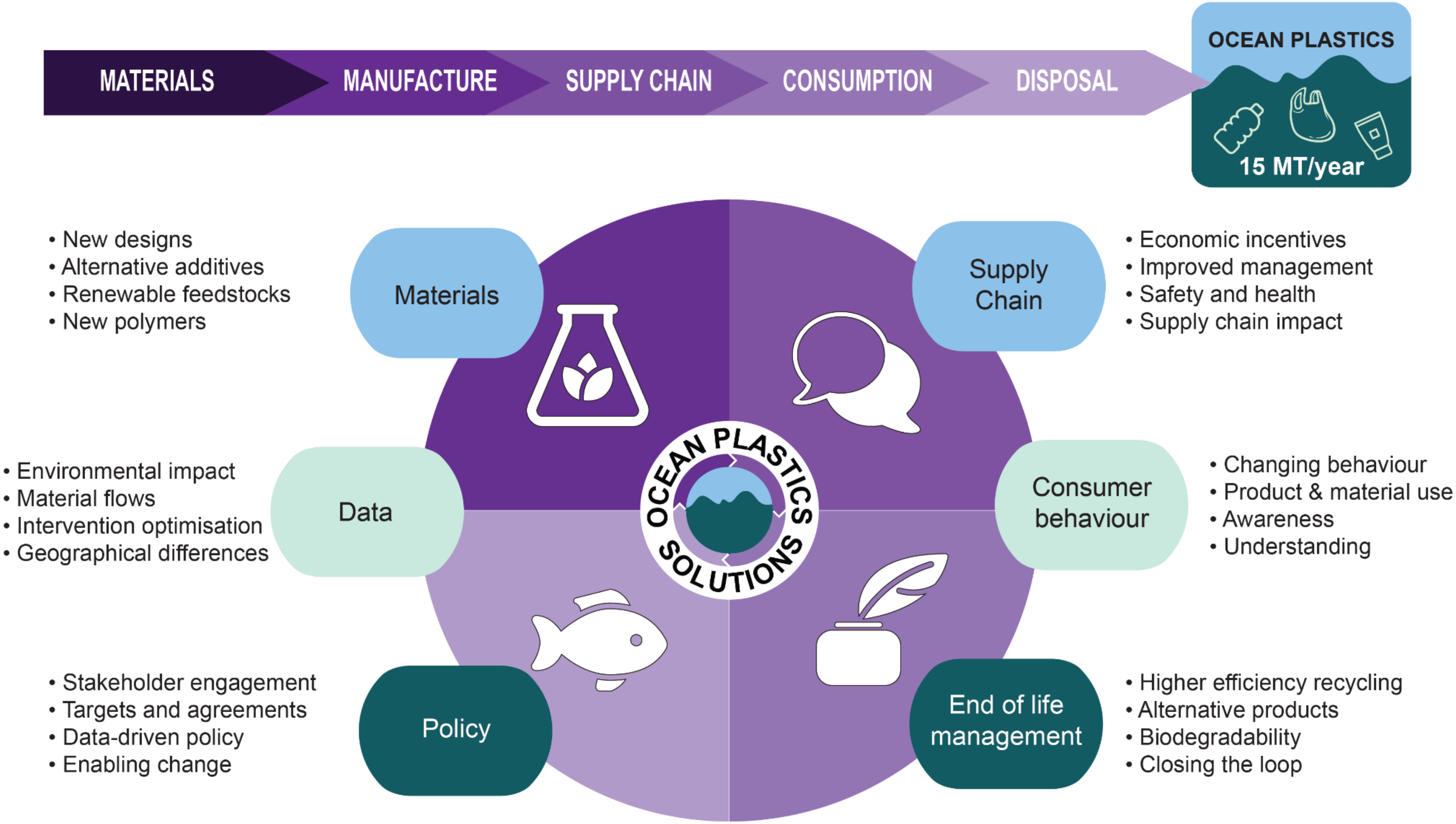
Create change



MATERIALS
MANUFACTURE
SUPPLY CHAIN
CONSUMPTION
DISPOSAL
OCEAN PLASTICS
15 MT/year
OCEAN PLASTICS SOLUTIONS
Materials
• New designs
• Alternative additives
• Renewable feedstocks
• New polymers
Supply Chain
• Economic incentives
• Improved management
• Safety and health
• Supply chain impact
Data
• Environmental impact
• Material flows
• Intervention optimisation
• Geographical differences
Consumer behaviour
• Changing behaviour
• Product & material use
• Awareness
• Understanding
Policy
• Stakeholder engagement
• Targets and agreements
• Data-driven policy
• Enabling change
End of life management
• Higher efficiency recycling
• Alternative products
• Biodegradability
• Closing the loop

Acknowledgements

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Clement Chan

Samira Siyamak

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36