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Plastics: Use, re-use, benefits and harm

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Outline

- What are plastics?
- What do we use them for?
- Plastic waste: the problem
- Balanced responses: lifecycle analysis
- What happens to plastics at end-of-life?
  - Recycling?
- What should we do about plastic packaging?

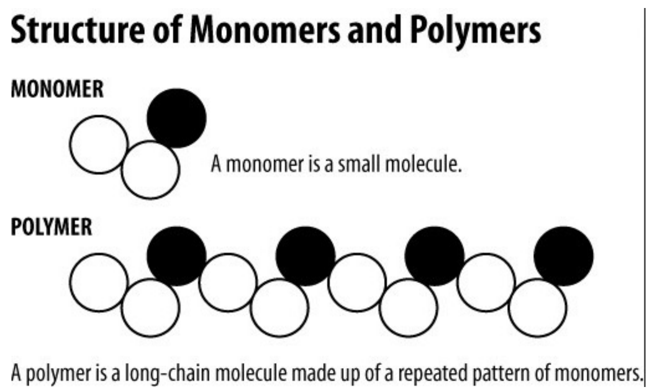
What is plastic?

Any of a group of synthetic or natural organic materials that may be shaped when soft and then hardened, including many types of resins, polymers, cellulose derivatives, casein materials, and proteins *Dictionary.com*

A synthetic material made from a wide range of organic polymers such as polyethylene, PVC, nylon, etc., that can be moulded into shape while soft, and then set into a rigid or slightly elastic form. *Oxforddictionaries.com*

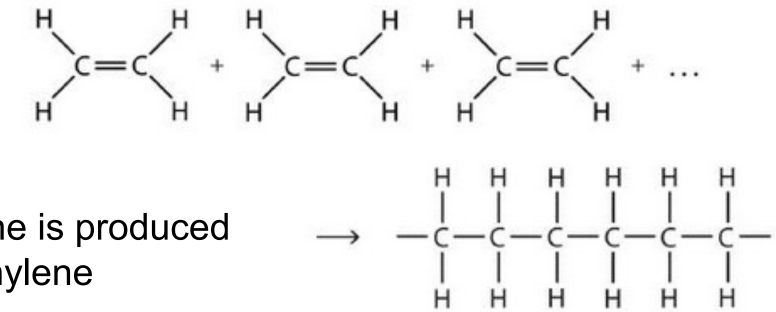
Polymer?

a compound of high molecular weight derived either by the addition of many smaller molecules, as polyethylene, or by the condensation of many smaller molecules with the elimination of water, alcohol, or the like, as nylon. Dictionary.com



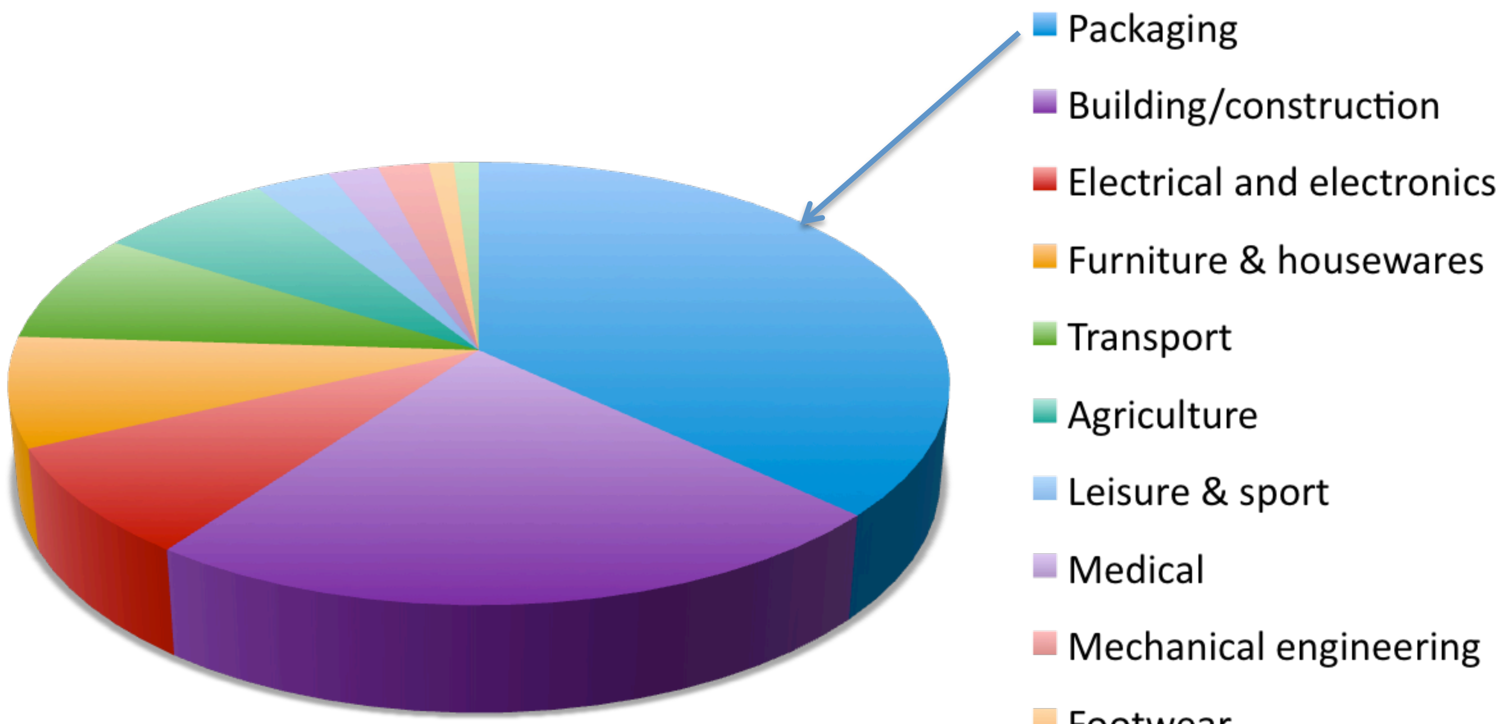
Socratic.org

Example: polythene is produced from monomer ethylene molecules



Chemistry libretexts

UK plastics consumption by market sector



38%: Packaging
22%: Building
6%: Electrical
7%: Transport
7%: Furniture/homeware
2%: Medical
18%: Other

Plastics applications

Construction e.g. Pipes, cladding, window frames, insulation, door and window seals

Electronics and electrical e.g. domestic appliances, wiring, small electronic devices

Transport e.g. small boats, fibreglass cars, aircraft interiors

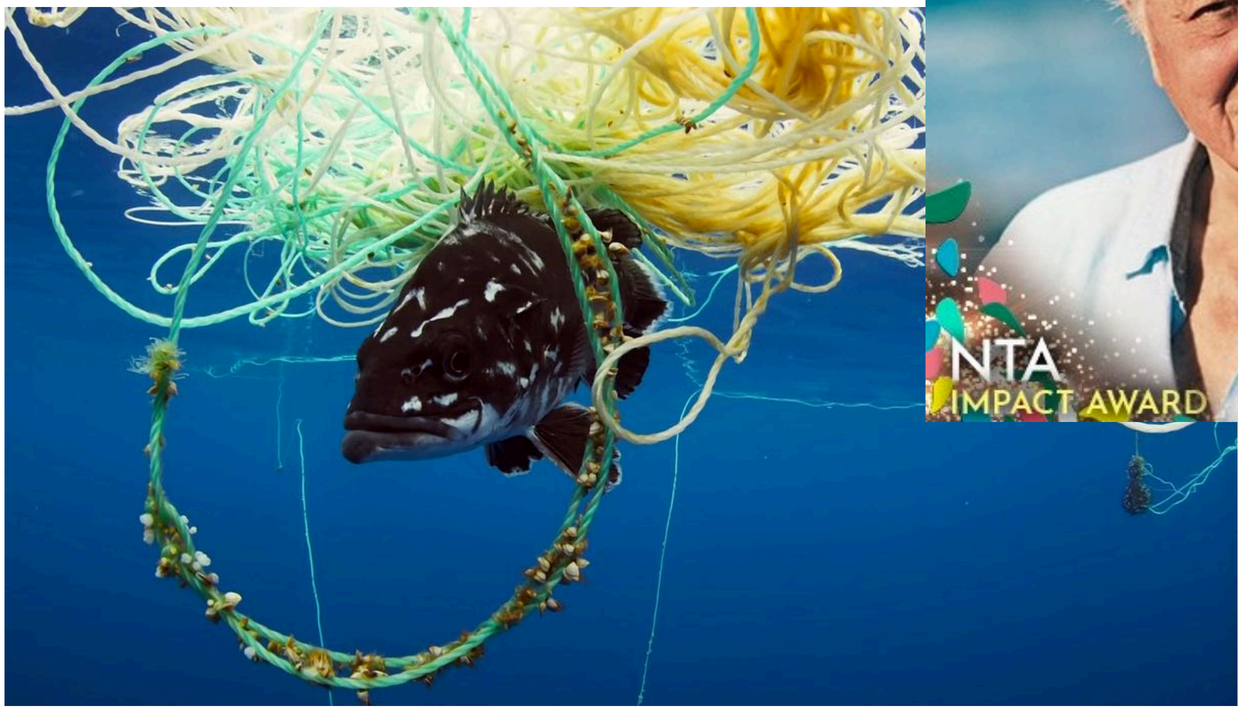
Medical e.g. bearing surfaces for artificial hips and knees, artificial heart, contact lenses

So what’s gone wrong with our perception of plastic?

Plastic waste is the major culprit!

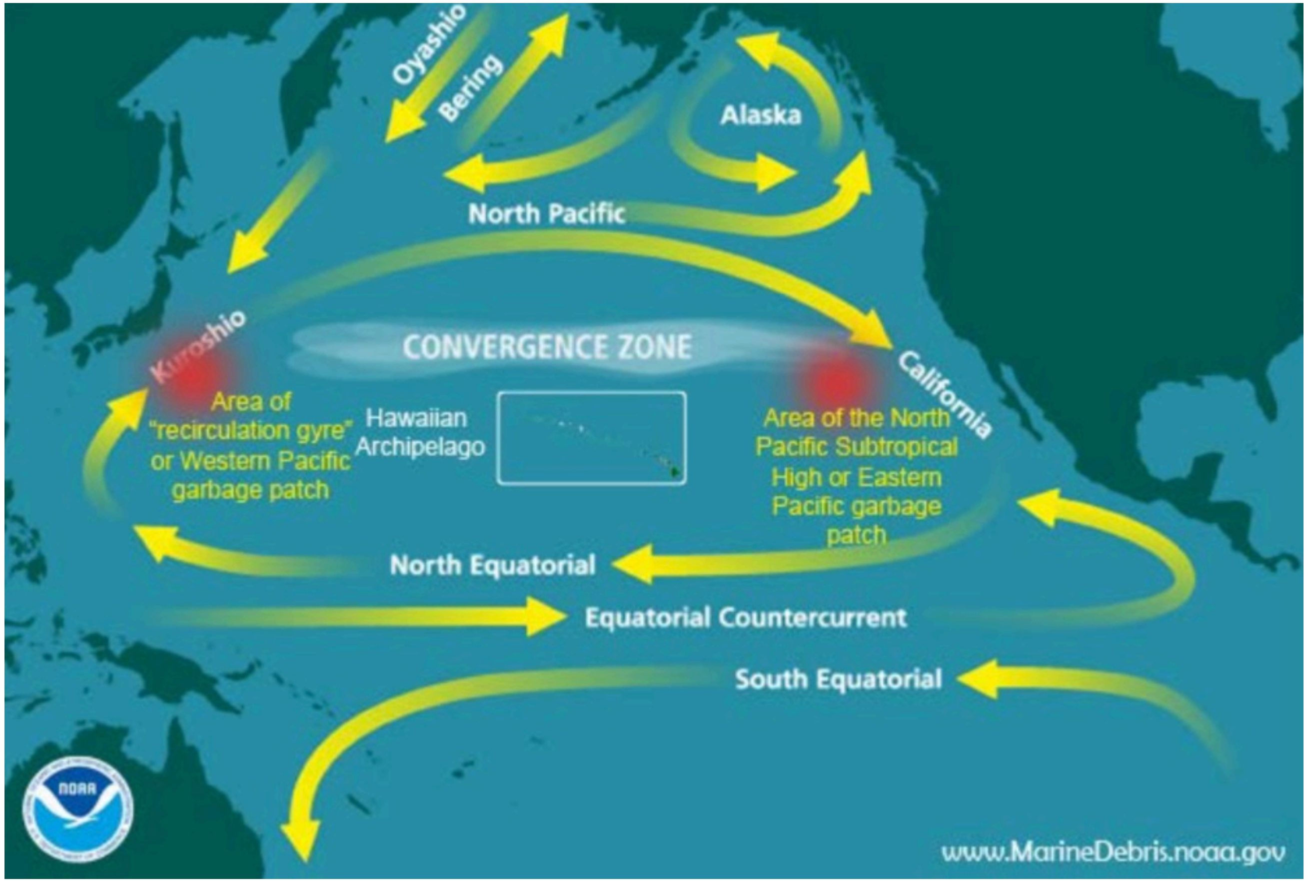
The Blue Planet Effect

Global impact of David Attenborough's BBC TV series broadcast in autumn 2017



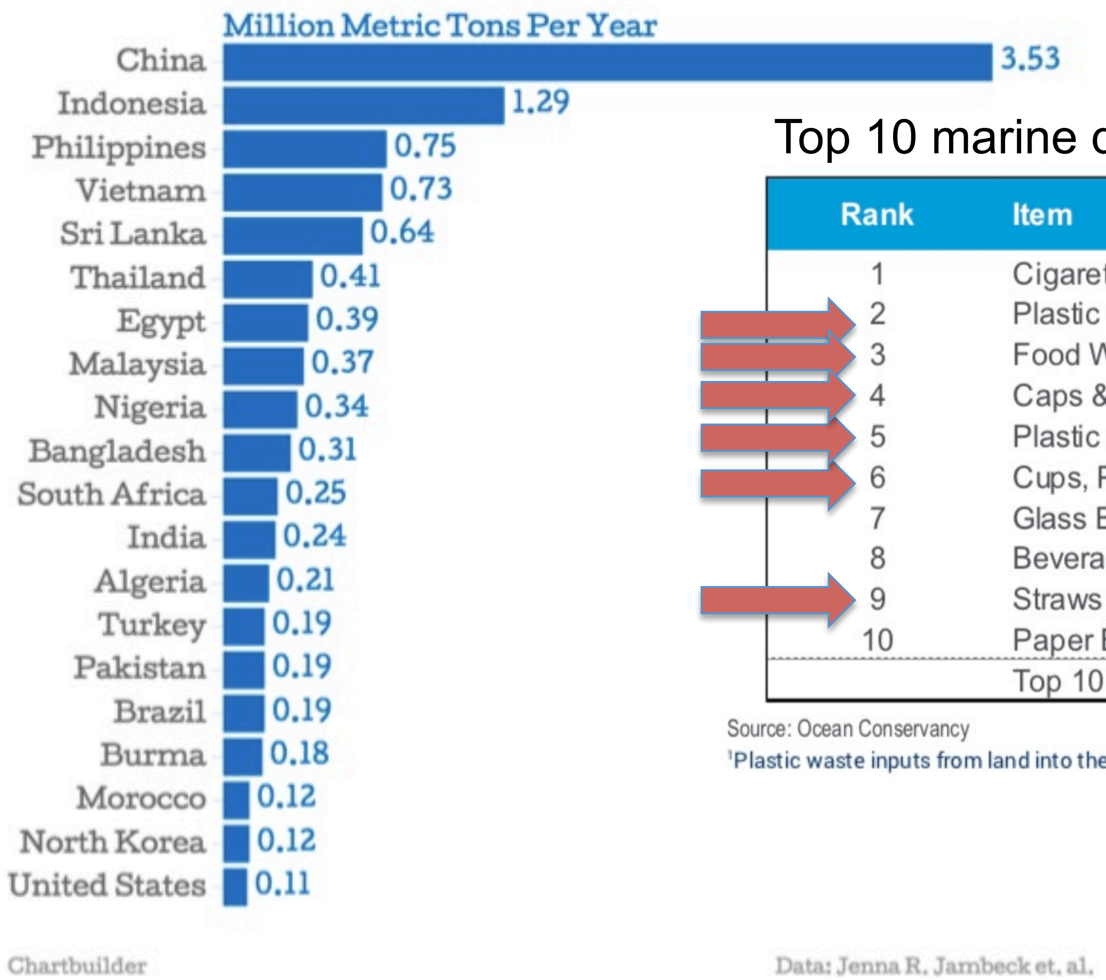
Marine plastic waste

in ‘The great Pacific Garbage Patch’



Plastic waste pervades the whole world: it’s found even in remote locations that were previously thought to be ‘pristine’

Marine plastic waste



Top 10 marine debris items

Rank	Item	% of Total Debris
1	Cigarettes	21%
2	Plastic Bags	11%
3	Food Wrappers/Containers	9%
4	Caps & Lids	9%
5	Plastic Beverage Bottles	9%
6	Cups, Plates & Utensils	5%
7	Glass Beverage Bottles	4%
8	Beverage Cans	4%
9	Straws & Stirrers	4%
10	Paper Bags	3%
	Top 10	79%

Source: Ocean Conservancy

[1]Plastic waste inputs from land into the ocean, Science, 13 Feb 2015: Vol. 347, Issue 6223, pp. 768-771

How does it get into the oceans?

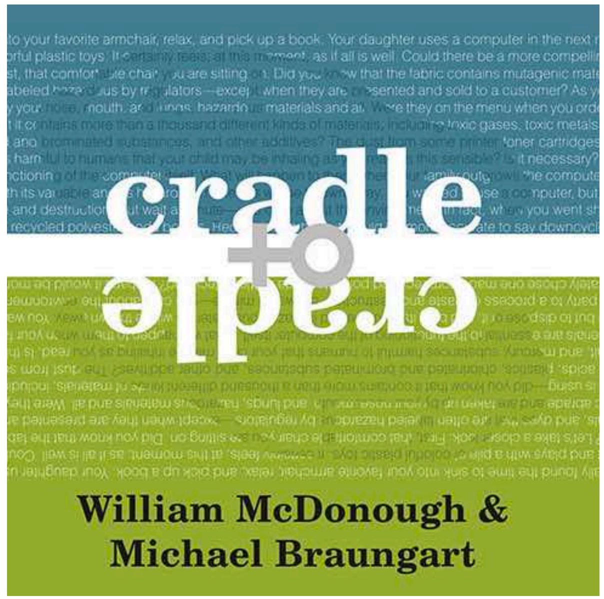
Main sources are

Uncontrolled landfill sites

Uncontrolled waste disposal

William McDonough

We used to be able to throw things away. Remember that? Things went “away.” Where is “away” now? “Away” is here. “Away” is someone’s backyard. We now see that we inhabit a smaller and smaller planet. “Away” has become very close indeed.



Focus on plastic packaging
Functions of primary packaging?

Function	**Achieved by**	**Example**
Product handling	Containers for loose goods and liquids; clustering of small items.	Bottle, box, bag (liquids, powders) Tray, bag (meat, cheese, loose foods and other products)
Barrier; hygiene	Prevents contact between atmosphere/environment and product; selective passage of gases; protect from light; prevent odours escaping.	Plastic bag for foods Multi-layer packaging for cheese
Protection	Fragile items: impact-resistant packaging; surface damage for other items	Egg box; blister pack
Increased product life	Barrier function; inert atmosphere; reduce handling	Foods in protective atmosphere or in vacuo
Tamper-evidence	Sealed container	Tamper-evident tabs; removable metal can lids
Information; advertising	Writing and pictures on packaging	Labels stuck on; printing directly on to packaging

Functions of primary packaging

	Original packaging	New packaging	Result
Bananas	Sold loose	Perforated polyethylene bags	Lasted 15 days unpackaged versus 36 days in bags
Beef	Polystyrene foam tray with cling wrap	Vacuum packing in oxygen barrier film	Shelf life extended from four days to up to 30 days
Bell peppers	Sold loose	Modified atmosphere packaging with perforated polypropylene film	Lasted four days sold loose versus 20 days in packaging
Bread	Paper bag	Biaxially oriented polypropylene film	Food waste reduced from 11.0% to 0.8%
Cheese	Sliced at counter and wrapped in paper	Polyester tray with a polyethylene and polyester lid	Food waste reduced from 5.00% to 0.14%
Cucumbers	Sold loose	Polyethylene shrink wrap	Shelf life extended from three days to 14 days
Grapes	Sold loose	Perforated bags	Bagging leads to a 20% reduction in in-store waste

American Chemical Society

Quantitative data: Packaging reduces food waste as a result of its mechanical protection and barrier function

Case study: product and lifecycle analysis

Cheese packaging: *not just a plastic bag*

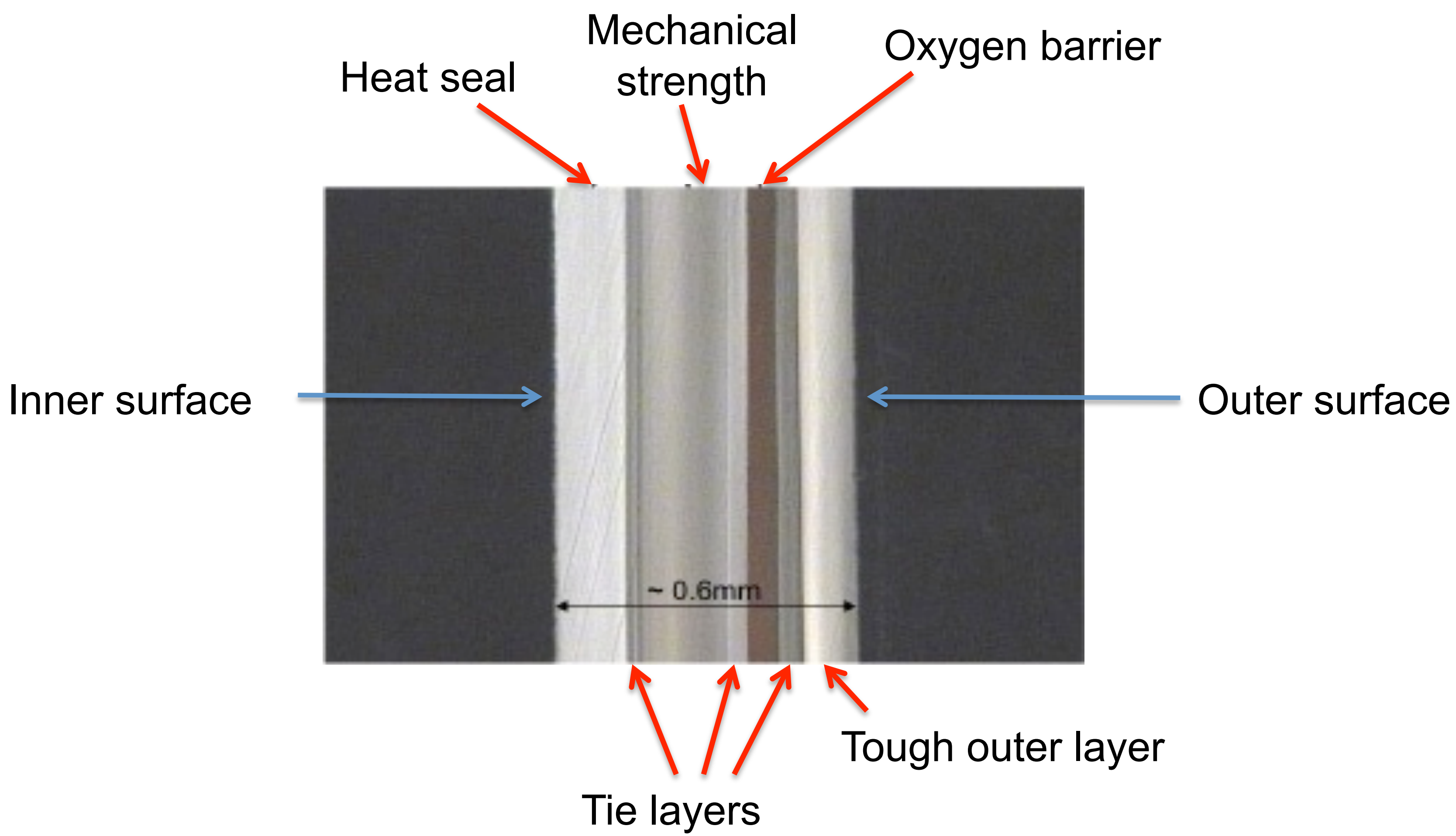
Selective barrier for molecules
Cheese matures in the package: releases CO_2

Packaging has to
- let CO_2 get out
- stop water from getting out
- stop oxygen from getting in
- keep smells in

Without packaging, cheese loses 10% of its weight in 3 days from water evaporation.
Changes to colour and texture make the cheese unsaleable

Packaging can increase shelf life to weeks or months

Cheese packaging: film structure



7 layers; 5 different polymers. "Impossible to recycle":
Incompatible polymers, and oxygen barrier degrades on heating (EVOH, releases HCl)
Ideal challenge for a PhD project! Recycled material successfully made, but no market

Cheese packaging: could we use a single polymer?

In each of these tables, polymers are normalized against the ‘best’ material

		PVDC	EVOH	HDPE	LDPE	PET
Oxygen barrier function only	Relative thickness	1.4	1	607	1786	20
	Relative CO_2 footprint	2.5	1	350	571	22
	Relative cost	2.5	1	4.5	13	0.2

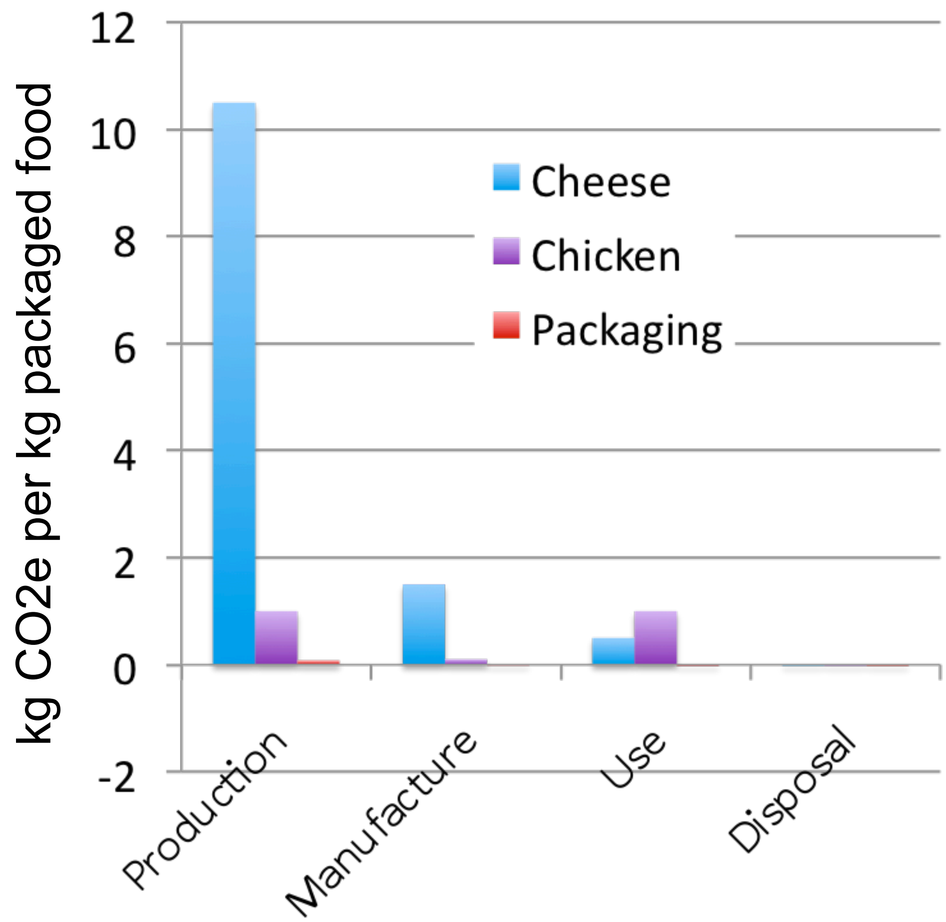
Oxygen barrier: EVOH is best, PVDC is a close second best.

		PVDC	EVOH	HDPE	LDPE	PET
Moisture barrier function only	Relative thickness	3.3	26	1	10	18
	Relative CO_2 footprint	10	48	1	9	32
	Relative cost	1000	45000	1	12	27

Moisture barrier: HDPE is best, PVDC and LDPE next best (PVDC is expensive)

Conclusion: Carbon footprint is minimised by using multi-layer film
Best single polymer is PVDC – but it’s difficult to recycle and expensive
Best easily recyclable polymer is PET

Food packaging in context: lifecycle carbon footprint? Eco-indicator analysis

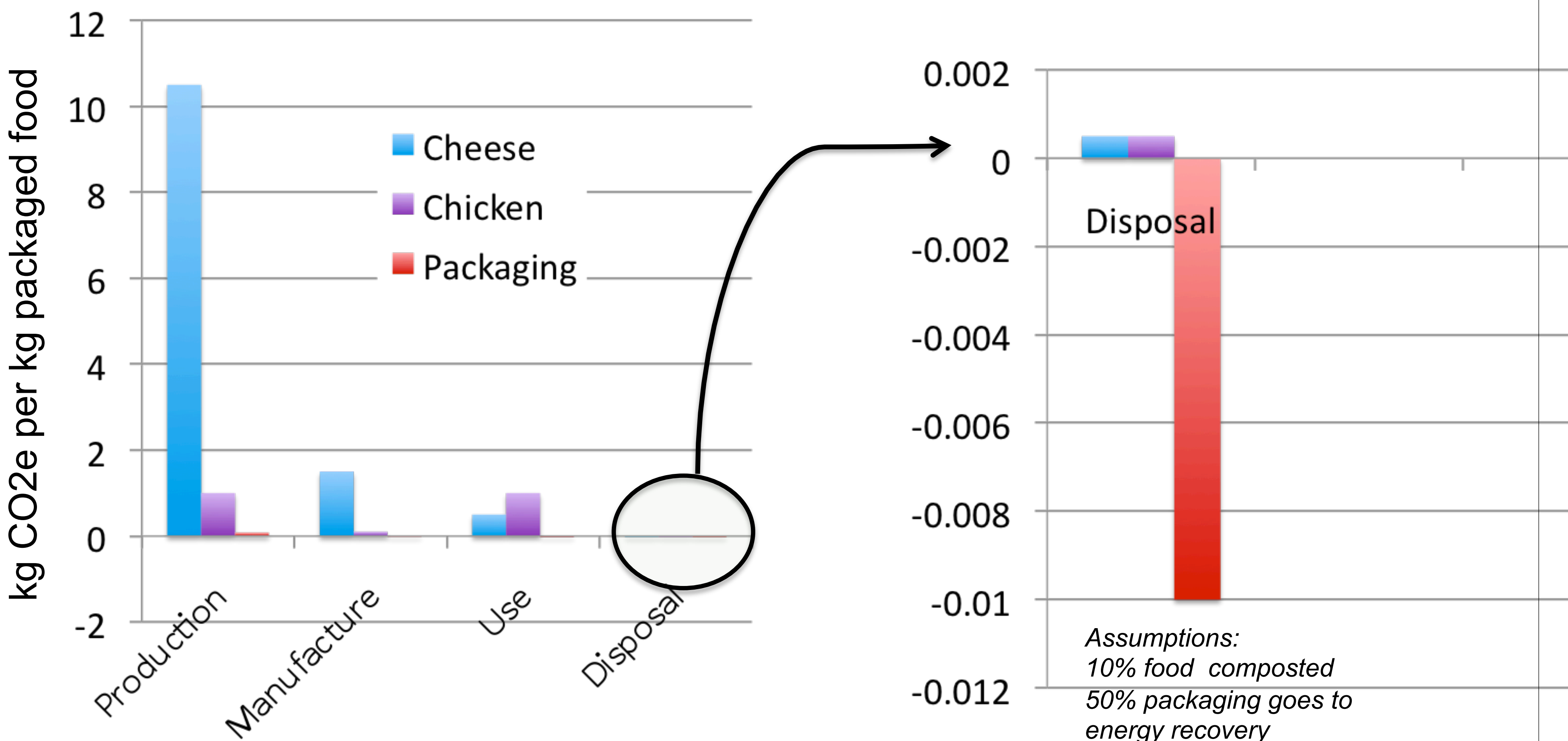


Most of the carbon footprint comes from production of food. Packaging adds a tiny amount to the carbon footprint.

Carbon footprint for 1kg packaged cheese and chicken

Barlow, C. Y., & Morgan, D. C. (2013). Polymer film packaging for food: An environmental assessment. *Resources, Conservation and Recycling*, *78*, 74-80.

Packaging in context: is it worth recycling?



Carbon footprint for 1kg packaged cheese and chicken

Assumptions:
10% food composted
50% packaging goes to energy recovery
If packaging to landfill, impact is +0.0001

Conclusion: Packaging footprint tiny compared with food production footprint. Recycling saves a little energy, but there are other reasons for recycling

IfM

UNIVERSITY OF CAMBRIDGE

UK plastics waste arisings

2014 data (most recent comprehensive report)

UK plastics waste 3.7 million tonnes, of which packaging was 2.2 million tonnes (59%)

Packaging waste origins:

1.5 million tonnes from consumer sector (e.g. households);

0.7 million tonnes from industry, construction and demolition and agriculture.

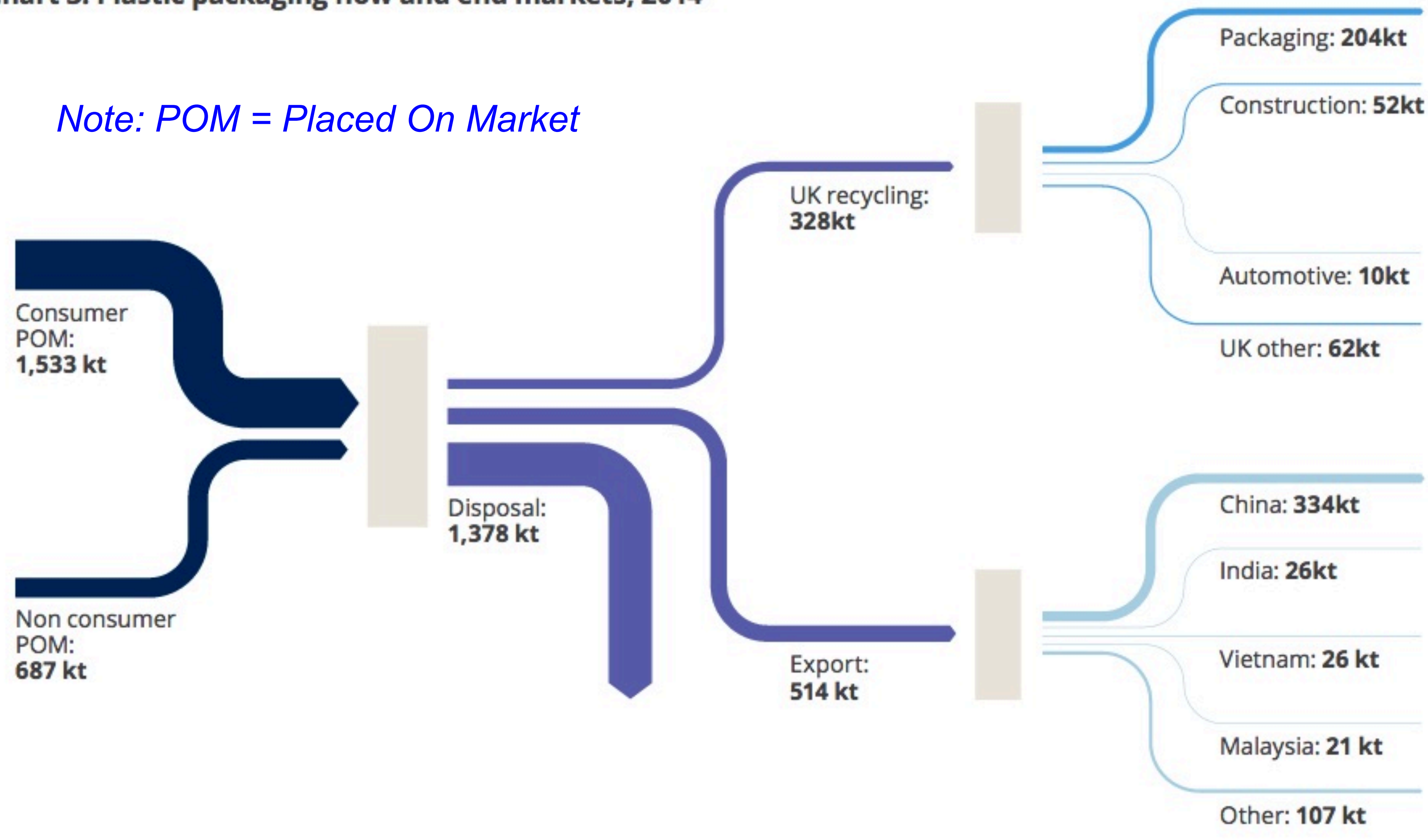
Com

	Polythene LDPE, LLDPE	Polythene HDPE	PET	Polypropylene PP	Other
Bottles	0	390	420	10	10
Other rigid	10	40	300	160	130
Film	410	110	50	100	100

What happens to UK polymers at end-of-life?

Chart 3: Plastic packaging flow and end markets, 2014

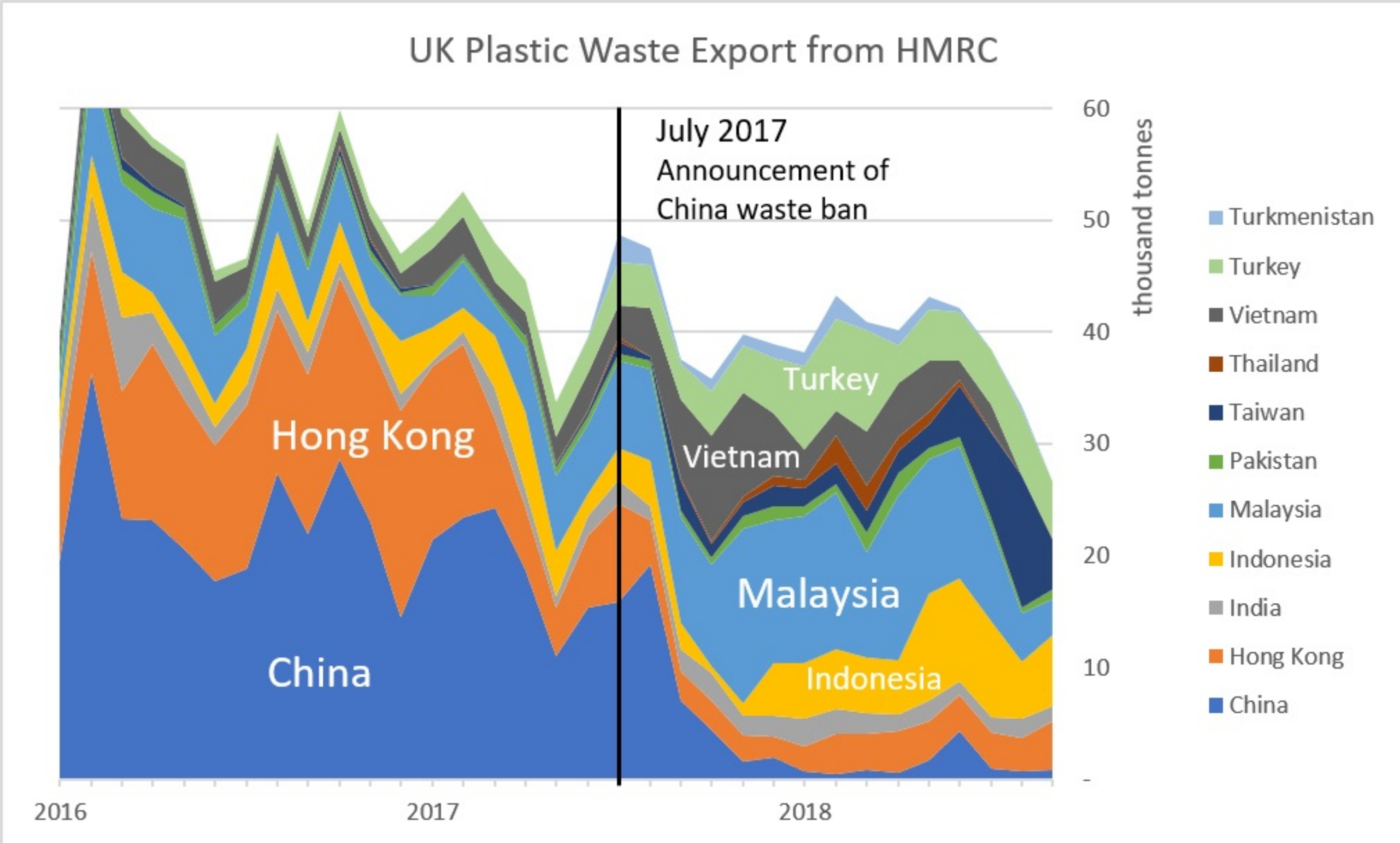
Note: POM = Placed On Market



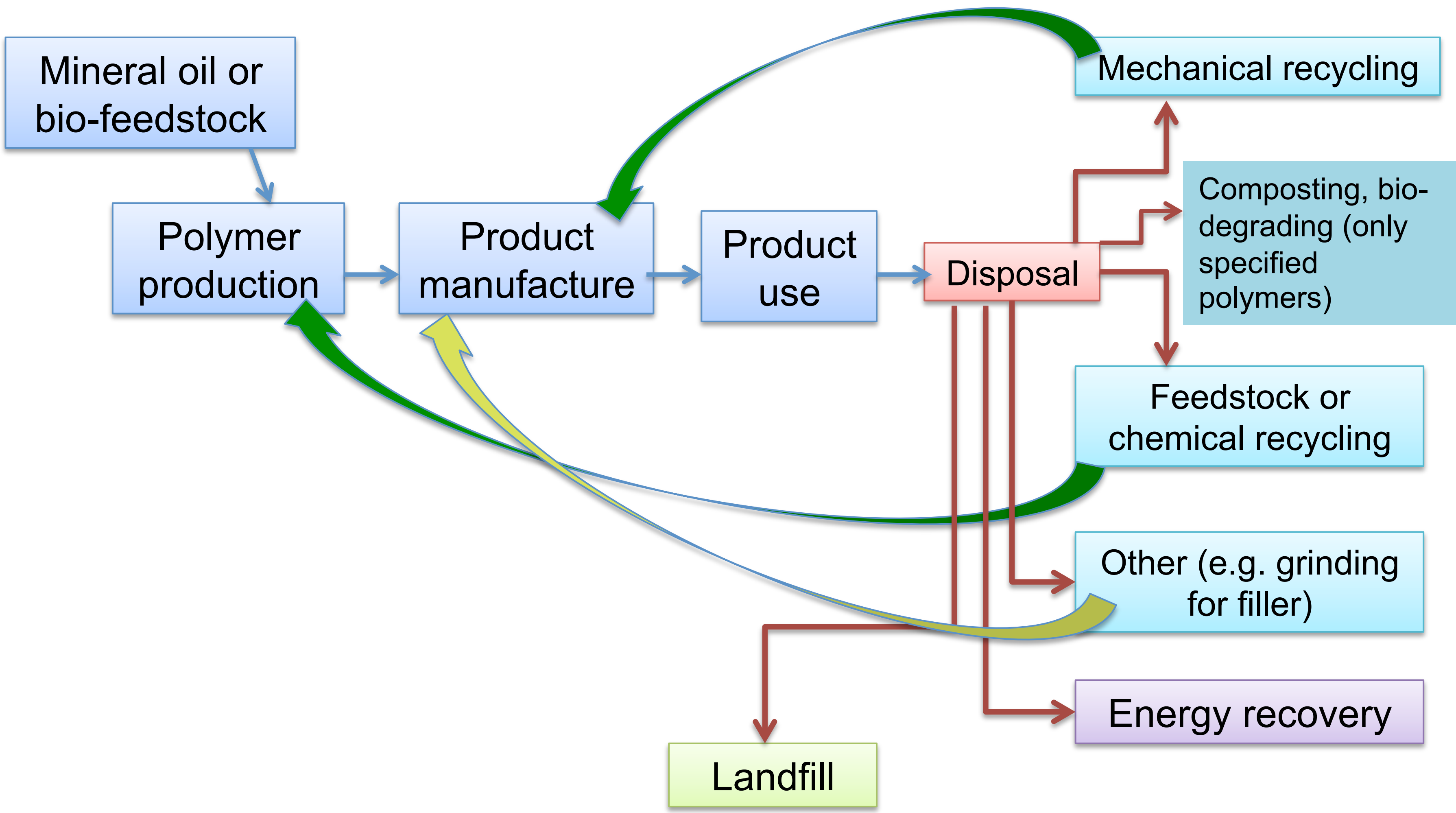
Source: WRAP estimates

China stopped importing waste plastic in 2017

What happened to UK waste?



What happens to polymers at end-of-life?



Why recycle polymers?

Ideal scenario: End-of-life polymers are used for the same application again
Closed-loop recycling

Reduces the amount of polymer that needs to be manufactured

There are very few examples of 100% closed-loop recycling

Mostly less than 30% recycled content in bottles (HDPE for milk, PET for water and soft drinks)

But it can be done (involves higher costs, changes in design) 100% recycled material *rPET* has been used by Ribena since 2007 and is currently being trialed by Highland Spring

Most recycling involves ***downcycling***: use of polymer for lower-grade application, so doesn't save resources in the same way

- e.g. Patagonia fleeces from PET bottles
- Water butts from polythene bottles
- Polymer waste mixed with wood to make e.g. outdoor furniture, decking

Material (mechanical) recycling of polymers

Post-consumer waste (domestic or commercial)

- Sort
- Clean
- Shred
- Melt in screw extruder
- Cut into pellets

Pellets (mixed with virgin polymer) used for making more product

Sorting?

Plastics must be sorted, shredded, cleaned and reprocessed

Sorting is critical

Waste dumped onto a conveyer belt at a MRF (Materials Recycling Facility)

Automated identification: air jets to sort into bins

Some sorting by *shape* (bottles, film, 'other rigid plastic' trays, tubs)

Then sort by ***polymer type***

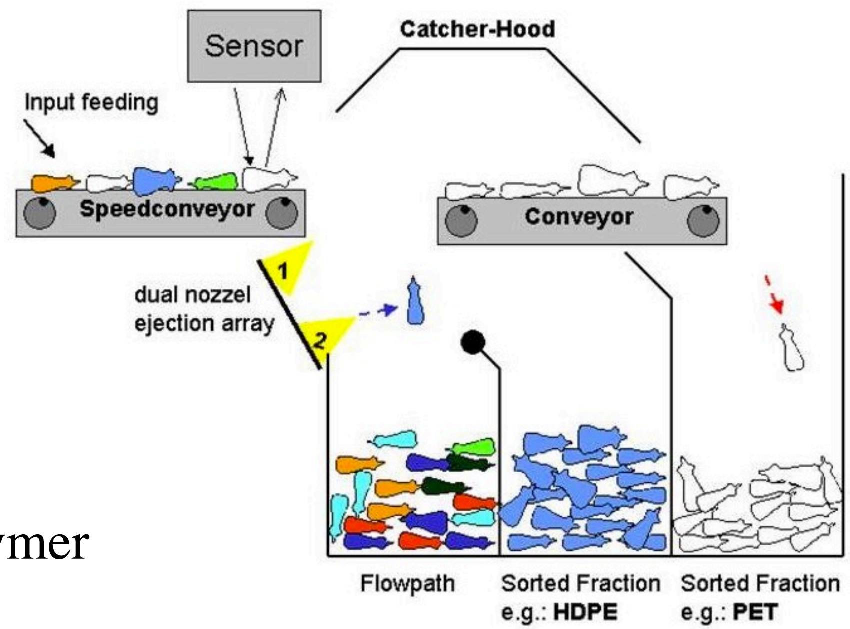
Commonly used high-speed automated methods:

- near-infra-red spectroscopy (NIR)
- optical recognition, including colour

Other methods include

- electrostatics
- X-ray fluorescence
- density methods including flotation
- melting point

Increasingly done on *flakes* of shredded polymer



Automated Sorting of Plastics Waste

Why are polymers so difficult to recycle?

Quality of input material is critically important to value of output:

•Polymers cannot be refined or purified: everything that goes into the mechanical recycling process is incorporated into the output recycled material

•Difficult to analyse polymers to know exactly what is in them

Ideal input: single polymer, clean, uncoloured

Single polymer?

Many polymers are used in combination (e.g food film packaging) and cannot easily be separated

Clean?

Obvious problems:

Not mixed with other materials (e.g. metal, paper).

Not contaminated by food, or by anything else (e.g. bottle used for bleach)

Less obvious problems:

Polymers contain small amounts of many different additives, e.g.

to improve processing

to stabilise against environment in service: includes UV, fire resistance

Consequence: Applications of recycled polymer are controlled

What are the real barriers to polymer recycling?

Oil prices are low
Virgin polymer costs are low
Recycled polymers aren't much cheaper than virgin polymers because:

* It's difficult to guarantee the quality, because
  Sorting must be close to 100% confidence level to enable high-quality polymer

Polymer prices are critically dependent on quality: you pay for what you get. Unless the quality of the recycled polymer matches that of virgin polymer, people don't want it.

* Logistics of gathering end-of-life polymers is expensive
* Washing, processing, sorting are expensive

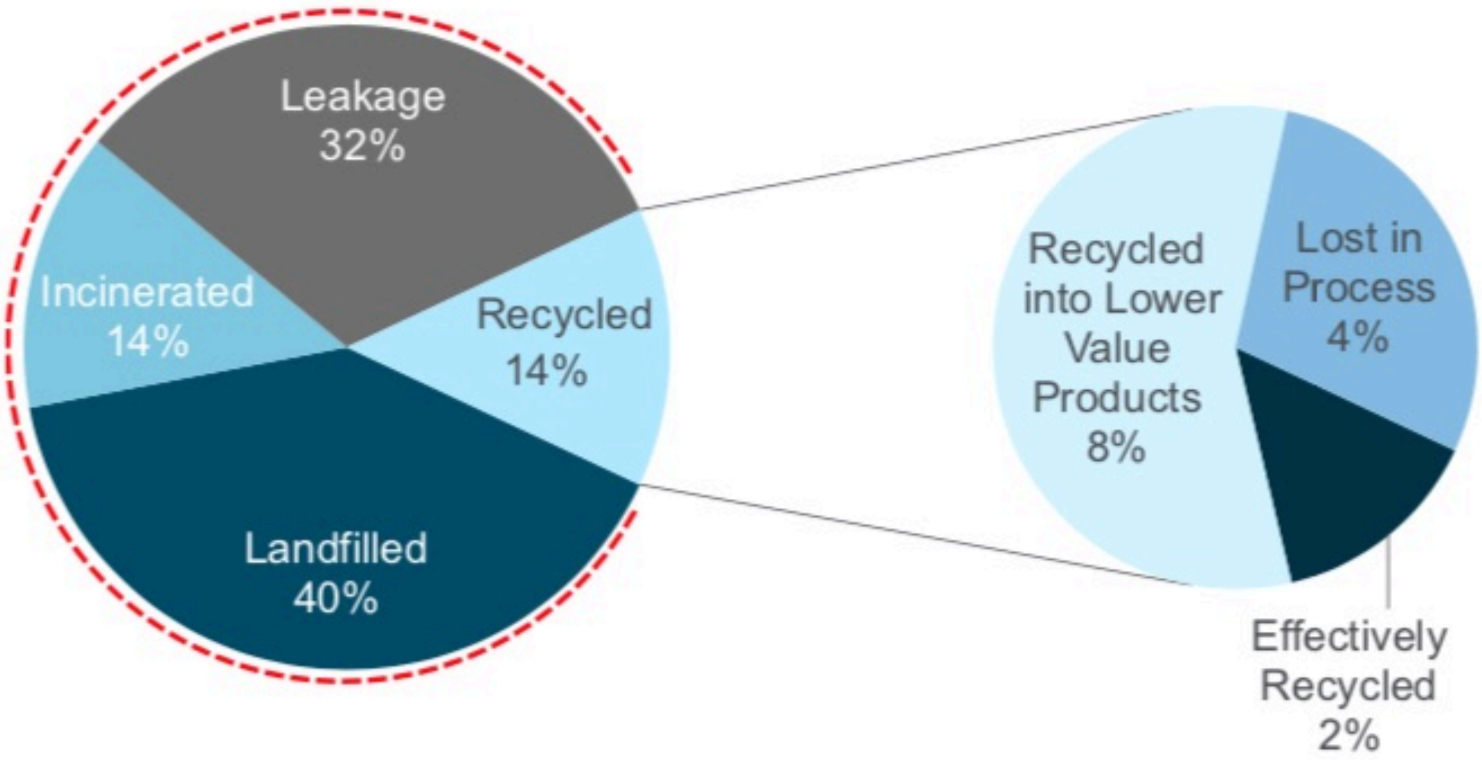
Processors must be able to sell the recycled polymer for a good price to cover their costs

Real barrier:

Economics

So how much polymer is really recycled?

86% of Packaging waste is disposed or littered



Source: Citi Research, UNEP

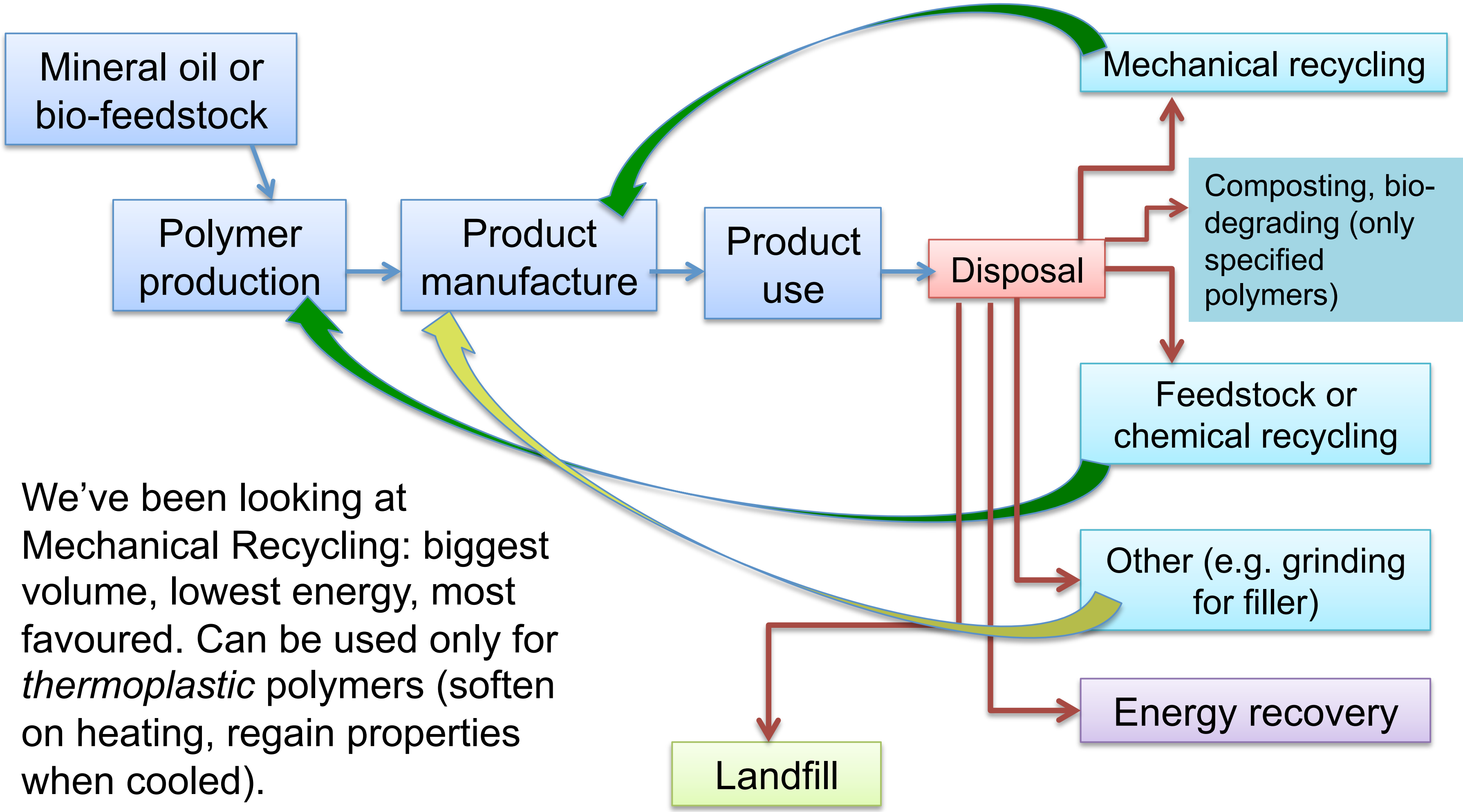
Aside:
Is the situation different for metals recycling?

- Metals have always been recycled: the material from tools and ornaments from the bronze age or iron age was too valuable to discard
- Infrastructure is quite well-established (collection, transport, sorting)
- Recycling processes closely related to traditional manufacturing processes (typically melting and chemical treatment to remove impurities)
- Analysis and purification of metals is relatively easy
- Recycled metals can be as high quality as virgin material
- Metals have relatively high value

BUT

- Collection, transport, sorting all cost money
- Although less resource-intensive than primary manufacture, there are significant environmental impacts of recycling processing (energy, pollution)
- A surprisingly high proportion of metal goes to China for recycling…

What happens to polymers at end-of-life?



We've been looking at Mechanical Recycling: biggest volume, lowest energy, most favoured. Can be used only for *thermoplastic* polymers (soften on heating, regain properties when cooled).

What happens to polymers at end-of-life?

Feedstock or Chemical recycling can be used for more polymers, but is energy-intensive. Small volumes currently; expected to increase.

Energy recovery (energy from waste)
Polymers are energy-dense oil
Reclaiming this energy to make electricity (typically) saves fuel
e.g. Cory: Energy from waste, London
Waste from London is transported by river to the Riverside facility at Belvedere
High-efficiency clean combustion used to create super-heated steam
This drives a turbine that powers the electricity generator
Generates 525,000 MWh, enough power for 160,000 households

Landfill: put in a hole in the ground.
Has been cheap and easy; relatively low environmental impact

Incineration: Energy from waste

Incineration with energy recovery (electricity, sometimes heat as well)

Plastics are high-energy fuel. 10% of EU municipal waste would provide 5% of EU energy needs, saving 14 million tonnes of oil per year

Is it safe?

- There are stringent safety and planning requirements

Local opposition in UK: nobody wants to live nearby

- Rubbish transported over large distances
- High volumes of traffic around incinerator plants
- Anxiety over gaseous emissions, toxic chemicals in residues

However, in mainland Europe energy from waste is common and doesn’t cause public opposition

UK capacity has quadrupled in last 5 years

For contaminated plastics, it’s the favoured solution for now

How can polymer recycling be increased?

How could the financial equations be altered?

Government subsidies

Legislation forcing increased recycling – e.g. required minimum recycled content in products

Oil prices rise, so re-processed polymer becomes more valuable

Design for recyclability:

- Narrower range of polymers
- Think about joining methods
- Use sub-optimised material (but increases weight of article, uses more material)
- No coloured plastics

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Advances in recycling technology to produce higher-grade higher-value material

- Improved sorting
- Better tolerance of impurities in mechanically recycled plastics
  - *e.g. Using calcium carbonate to react with chlorine from PVC*
  - Processing of mixed plastics
  - *e.g. Research into 'compatibilising' mixed polymers, including using shear processes to break chains, generating new block co-polymers*
- More chemical recycling

Alternative packaging scenarios

Food packaging is heavily contaminated with food, so difficult to recycle economically

Why not use packaging that will decompose in the same way as food?

'Biodegradable packaging'

Decomposes to biomass in contact with air (composting)

Cardboard, paper

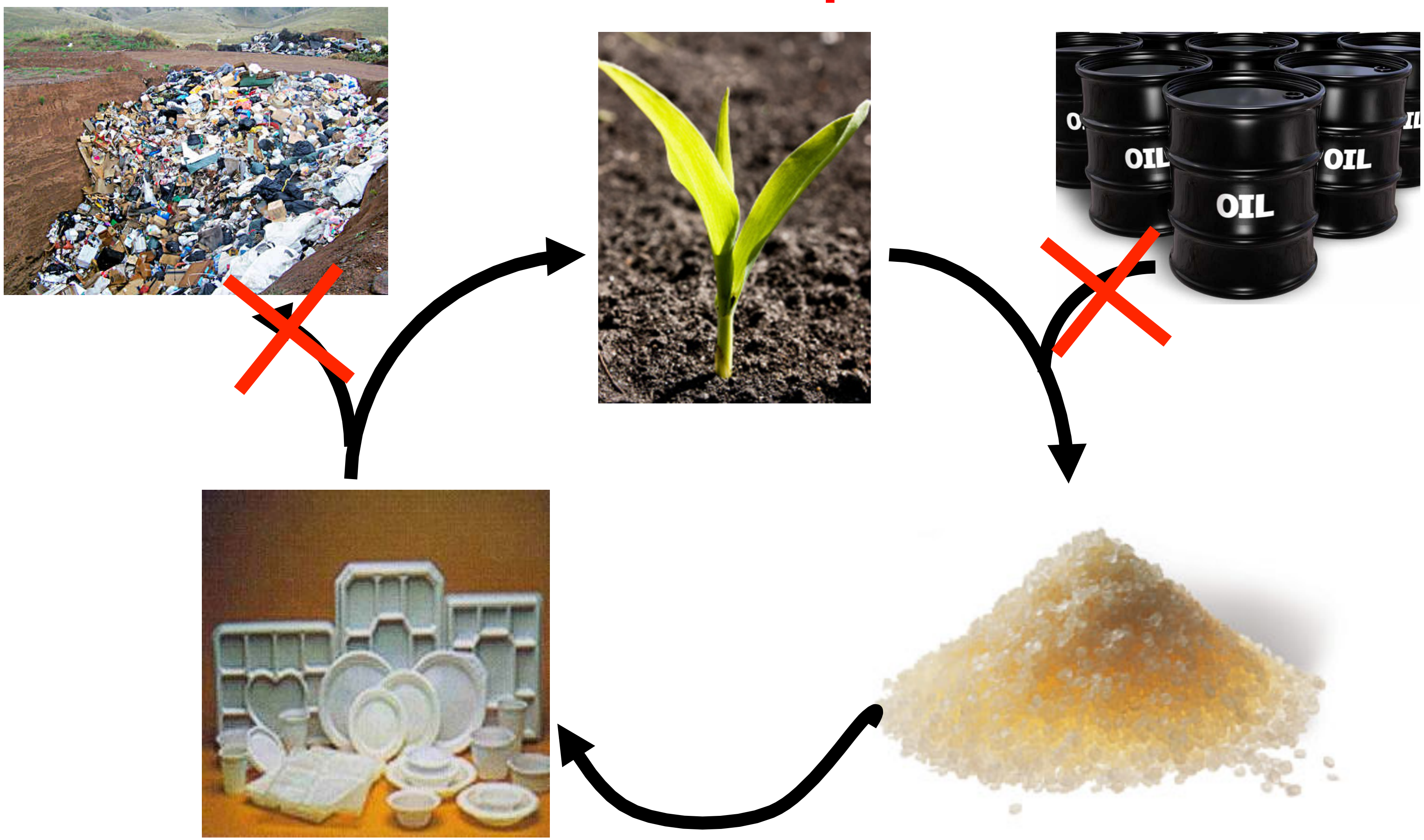
- Naturally permeable to gases and moisture
- Barrier properties require coating or impregnating
- *e.g. Greaseproof paper: high-density refined paper impregnated with starches or alginates*

Carbon footprint of cardboard? May be higher for cardboard than for polymers (energy-intensive production; decomposes to methane)

How about biopolymers?

Why Biopolymers?

The sales pitch:



Issues associated with biopolymers

- Intensive agriculture (monoculture)
- Capacity (less than 1% of total polymer production)
- Competition with food production
- Energy requirements (fuel, fertiliser, pesticides)
- Water requirements
- Cost
- Disposal?

Packaging to be thrown away with food. What happens to *food* in disposal environments?

- Home and industrial composting
  - Degraded by aerobic micro-organisms into carbon dioxide and water
  - Timescale: days to weeks

- Anaerobic digestion
  - Degrade in the absence of oxygen through a series of processes ultimately resulting in carbon dioxide and methane, e.g. sewage treatment
  - Timescale: days to a few weeks

- Landfill
  - Either zero or anaerobic degradation
  - Timescale: weeks to years, or longer

Issues with Biopolymer Disposal

Mostly not suitable for home composting (temperatures not high enough)

May not degrade sufficiently fast in industrial composters

Anaerobic digestion becoming more popular: biopolymers mostly don't degrade

May not degrade in natural environment

Can contaminate conventional polymer recycling streams

And another thing: 'Biodegradability'?

Polymers that degrade in the environment

Includes *Oxo-degradable* plastics

- Polythene or other polymer plus heavy metal additive
- Breaks down into fragments over typically 12-24 months

Degraded product: polymer fragments, contaminated with toxic heavy metal

Now banned in some EU countries

Responses: what should we do about plastics?

Knee-jerk reactions:

Get rid of all plastics

Ban all single-use plastic

Global initiatives

2002: Plastic bag ban, Bangladesh. Introduced following devastating floods in 1988 which were exacerbated by plastics blocking drainage systems.

(This has been followed by bans in other countries globally; UK introduced charge for plastic bags in 2015 which reduced plastic bag usage by 83%)

India will introduce ban on single-use plastics in 2020, but several cities have already initiated bans, e.g. Mumbai:

Plastic bags, cups, bottles banned, with fines of $70 for first-time offences and up to $350 and three months jail for repeat offenders

Global initiatives

Source: Citi Research, Maharashtra Pollution Control Board

Conclusions: what should we do about plastic packaging?

Knee-jerk reactions:

Get rid of plastic packaging
Ban all single-use plastic

Superficially plausible but problematic:

Use bio-based, biodegradable polymers

Food packaging: use alternative materials that don’t look like plastic and will degrade in the same way as food

Lots of interest in using waste natural products e.g. from mushroom growing, sugar-cane waste, maize (corn) waste, wood products

Conclusions: what should we do about plastics?

Plastics are versatile and have made huge positive contributions

Be careful about knee-jerk reactions

Ask questions about bio-based, biodegradable polymers: they aren’t all good

Alternative materials: Lots going on

Reduce: Stop using un-necessary plastics

More re-use?

More recycling: Increase UK capacity, stop uncontrolled exports

More energy from waste, but only as a medium-term