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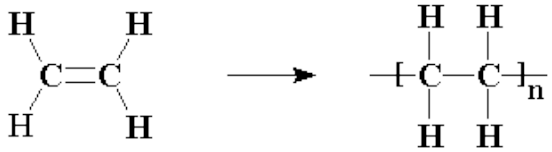
University of Leicester
Materials Centre

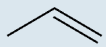
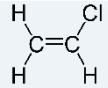
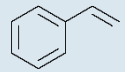
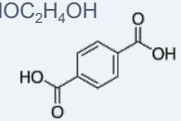
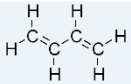
Plastics from potatoes and rubber from rice

Polymer vs Plastics

- Polymer is a macromolecules containing monomers
- Typical polymer chain is 0.2 to 2 μm in length
- Held together by knots which untangle as we heat them up
- A plastic is a material made from a polymer with a range of additives



Common polymers

Polymer	Monomer		Scale / 10^6 t p.a.
HDPE		Rigid plastics	80
LDPE		Flexible plastics e.g. bags	55
PP		Bottle tops	50
PVC		Window frames	18
PS		Rigid plastics	15
PET	HOC_2H_4OH 	Plastic bottles	28
Nylon	$HOOC(CH_2)_4COOH$ $H_2N(CH_2)_6NH_2$	Strong fibres, ropes	36
Polybutadiene		Rubber	17

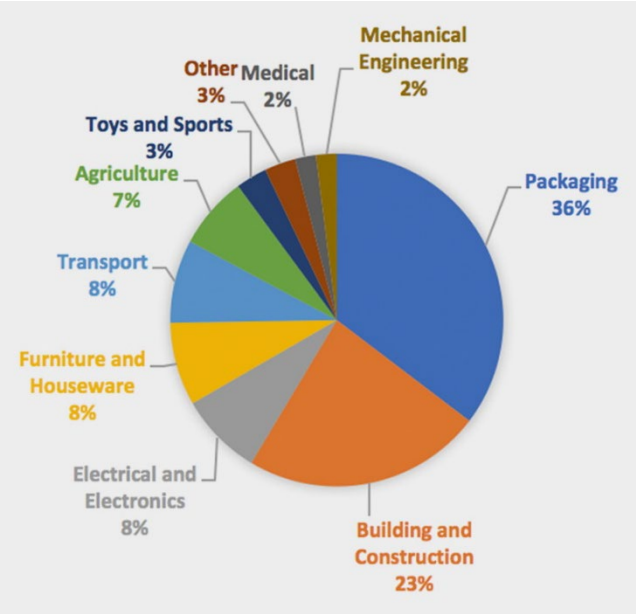
- Monomers need to be simple to make
- 7 of the world's top 20 chemicals are monomers

Plastics

- Annual requirements of thermoplastics has increased from around 5 million tonnes in the 1950s to nearly 335 million tonnes today
- That would cover Hyde Park to the height of the Shard!
- One tonne of plastics is equivalent to 20,000 two litre drinks bottles or 120,000 carrier bags.
- Plastics makes up around 7% of the average household dustbin
- About 7% of oil is used to make plastic

Plastic uses

- Packaging uses increasing



Media focus on plastic packaging

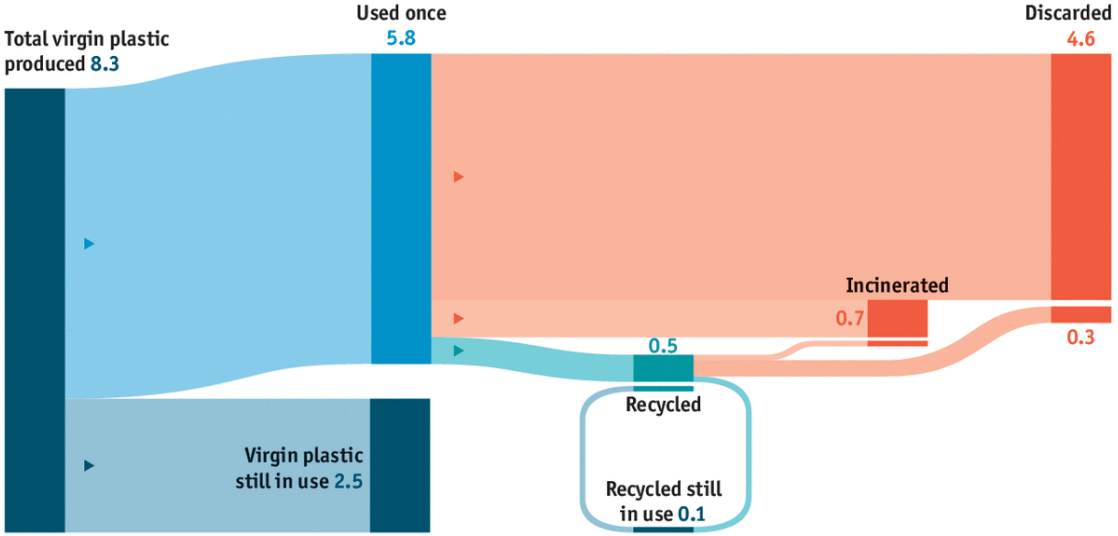
- Plastics are excellent for building and construction
- They are useful for food preservation
- They need to be disposed of properly

Plastic Disposal

Since 1950s 8.3 bn tonnes of plastic have been produced
Only 7% of plastic has ever been recycled

The end of all things

Global plastic production and use, 1950-2015, tonnes, bn



Source: "Production, use, and fate of all plastics ever made" by R. Geyer et al., *Science Advances*

Economist.com

Plastic in the Environment

Waste Management

- Estimated that 20 countries are responsible for 83% of the plastic in the world's oceans.
- Of 275 million metric tons of plastic waste each year 4.8–12.7 million of mismanaged plastic waste end up in the oceans (2-5%)
- Most important aspect of plastic is **waste management**

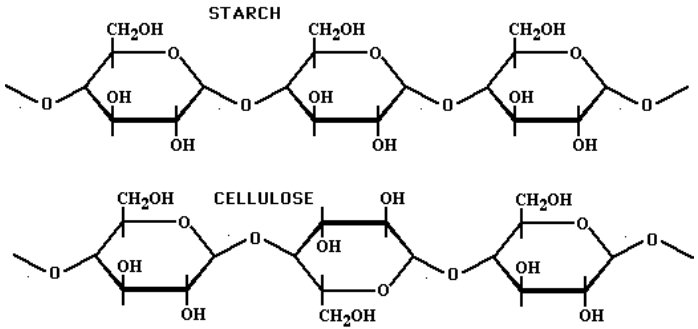
Jambeck et al., Science 2015, 347, 768-771

Important message

- The types of plastics we use will not change in a big way in the next century
- They are relatively Green in terms of the energy and material that goes into their production
- The way we treat them after use is poor – many materials are poorly designed

Carbohydrates

- 85% of organic carbon is in the form of carbohydrates
- Starch alone cannot form films with satisfactory mechanical properties
- Hygroscopic nature of starch dictates this material is unsuitable for high-moisture and liquid food products.
- Most biomaterials now produced are composites of starch and biopolymers.



Biodegradable Plastics

- Range of materials with different green credentials

Cellulose based film

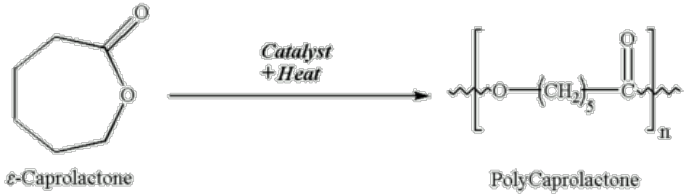
Polyethylene – starch composites

PLA- starch composites

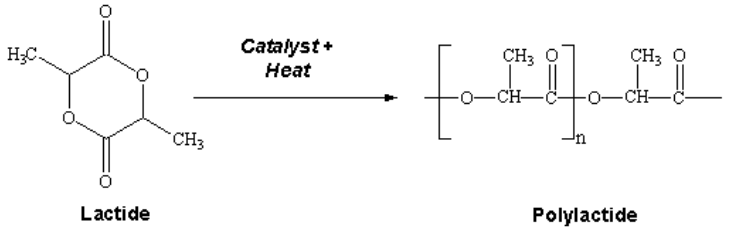
PLA degrades in 100 days in industrial composter

Biodegradable Polymers

- PCL – polycaprolactone
  - Not-renewable (crude oil)



- PLA – polylactic acid
  - Biodegradable

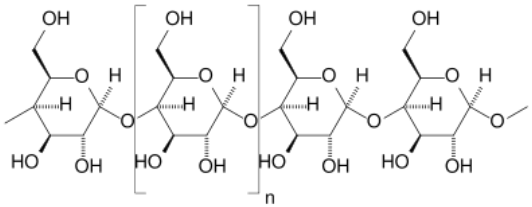


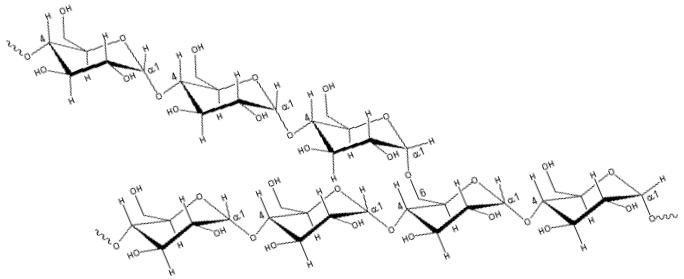
Renewable (Lactic acid formed by fermentation of corn starch)

More expensive than petroleum based polymers

Starch

- Starches from a number of different sources
- Made up of amylose (linear) and amylopectin (branched)





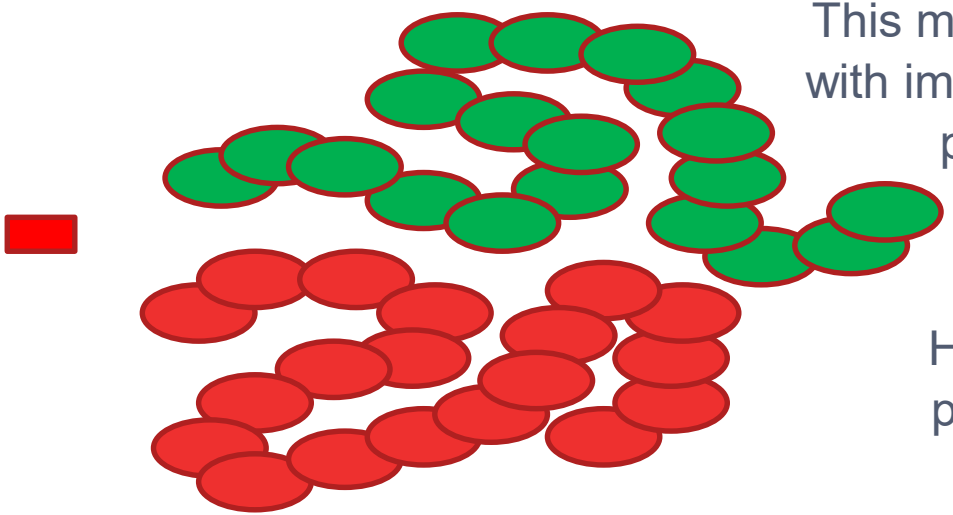
- Ratios and molecular weight of respective components changes with starch type
  - Typically 10-20% amylose and 80-90% amylopectin
  - Different flour gives different bread!

Starch-based materials

Pumpernickel Recipe	Brioche Recipe
1 cup water 0.25 cup molasses 2 tablespoons vegetable oil 0.5 cup whole wheat 0.5 cup rye flour 0.25 cup cornmeal 2.25 cups bread flour 1.5 teaspoon salt 2 teaspoons active dry yeast 1 tsp caraway seed (optional)	2 tsp dried yeast 3 tbsp milk, hand-hot 200 g strong white flour large pinch of salt 1 tbsp caster sugar 50 g butter 2 eggs, beaten

Is starch packaging viable?

- It takes 8 tonnes of potatoes to produce 1 tonne of starch which can make approx 43,500 trays.
- The typical 20% UK potato crop wastage, **1.2 million tonnes**, is equivalent to **6.5 billion trays.**
- One of the major supermarket chains uses **2.5 billion trays p.a.**
- It would require **1.5 to 2 million tonnes of potatoes** to replace all EPS and PVC food packaging in GB with potato starch based products.



This makes a material with improved physical properties

Heating in the presence of a modifier

Two starch molecules

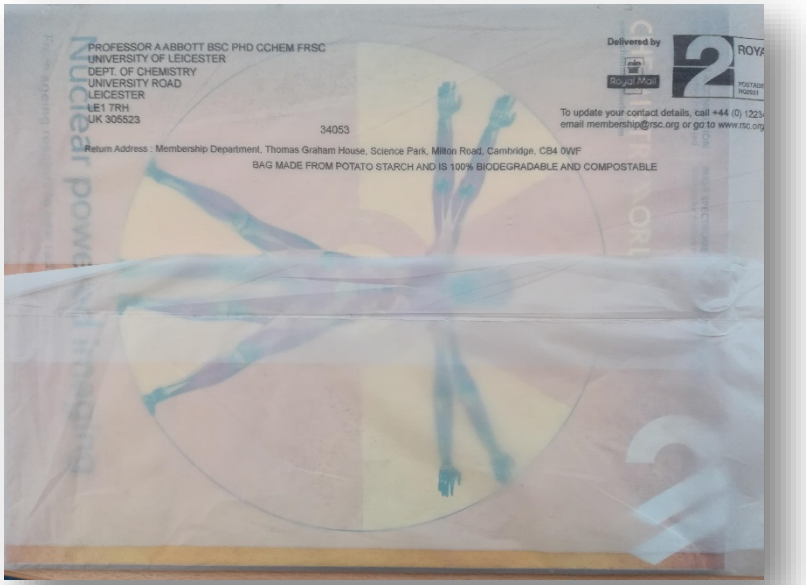
Limited interaction occurs between each of the molecules

Modifier enables stronger interactions between molecules

Modifier

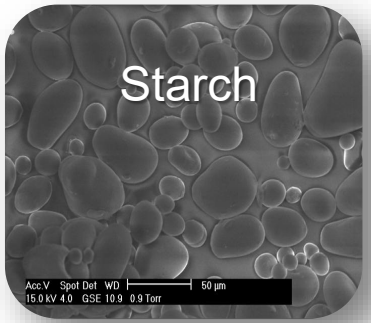
Starch + Glycerol

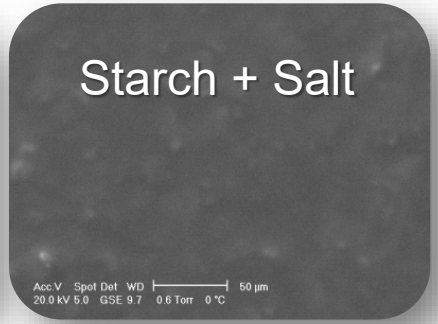
- Glycerol is a waste material from the soap and biodiesel industry and can be used to plasticise starch.
- Not very strong



Starch and Salts

- We use salts to open up the starch structure
- Above approx. 70 °C solution starts to gel
  - Starch granules burst and start gelation
  - Forms strongly interacting macromolecular structure
  - 1:1 ratio of starch: modifier is baked and forms a solid cheese





Similar to salt dough 2 parts flour, 1 part water and 1 part salt

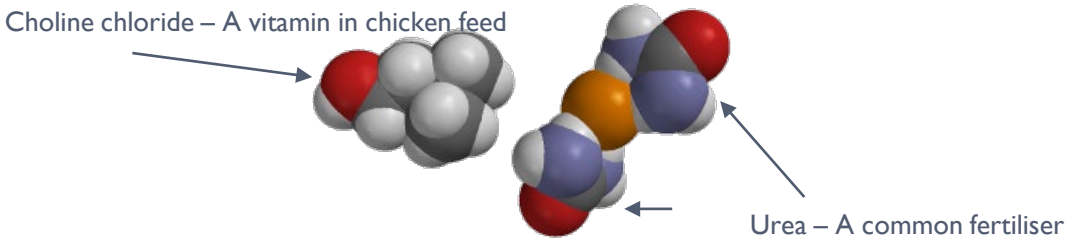
Slime

- Starch interacts with salts

Keeping the salt liquid

Mix a simple salt with a complexing agent

Biodegradable salt and complexing agent



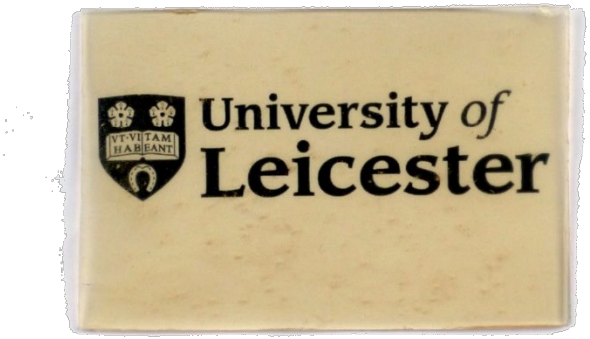
- e.g. urea, acetamide or glycerol

Keeping the salt liquid

- Mix two solids to make a liquid

Transparent starch-based plastics

- Compression moulding starch with salts leads to clear sheet
- Rapid setting time (<5 min for 1 mm thick sheet)
- Strength comparable to HDPE



Corn starch 1 kbar 160°C 1 min

Thermoplastic wood

- MDF uses urea - formaldehyde and phenol formaldehyde resins
- Formaldehyde is a carcinogen and means that the boards cannot easily biodegrade

Salt modified starch can also be used as a binder

Thermoplastic wood

- Starch board mixes wood fibre with salt and starch
- Easier to process than MDF

			
a) sawn, routed, screwed and drilled	*b) glued and laminated*	*c) lacquered*	*d) Vacuum formed*

Thermoplastic wood

- Process has been scaled up
  - 1 x 1 x 0.017 m starch boards have been made

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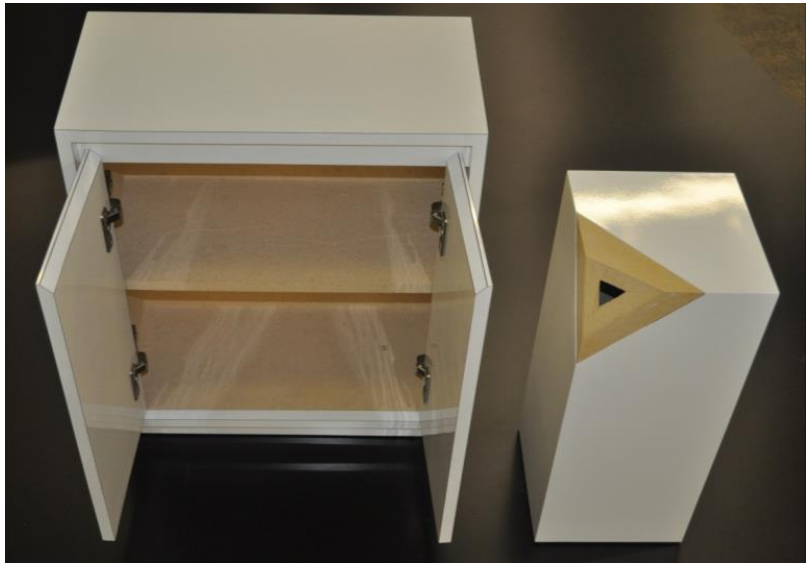
Thermoplastic wood

- 20 boards were made and demonstration cabinets were produced



Thermoplastic wood

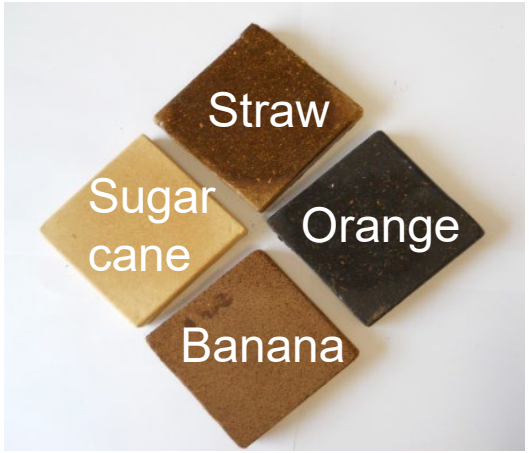
- Because it is a thermoplastic it can be recycled
- The product is called *Starboard*

Starch-based thermoplastic wood after forming (left), after grinding (centre) and then after reforming (right). This shows that it can be effectively recycled.

Food vs. Plastic

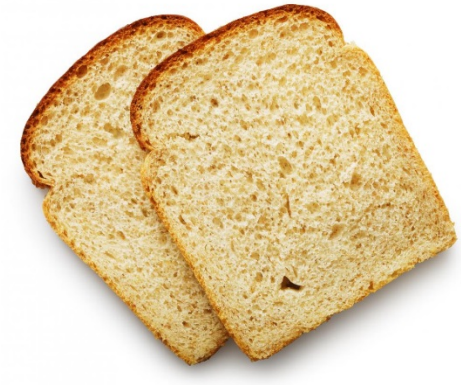
- Lots of controversy when crops are used for applications other than food.
- A lot of material is waste in food production.

L to r: banana peel, potato, orange peel and corn starch



The ultimate waste

- These boards are made from the ultimate waste
- 680,000 tonnes of this waste is thrown away each year in the UK at a cost of £1.1bn.



Eggshell plastic

- Approached by a company that produces boiled egg
- Waste is c.a. 1 tonne per day

Eggshell plastic

- Eggshell is just calcium carbonate (chalk) which can be cleaned, ground and used as a filler in plastic
- Can be used up to 40 wt % as a filler
- Gives plastics a hard wearing surface
- Process plant opened in 2015.

Conclusions

- Plastics must not be thought of as disposable
- More materials must be designed for recycling
- Better education required on the properties of materials
- Biomaterials are part, but not all, of the answer
- Smarter packaging needs to be developed

Acknowledgements

- Tariq Abolibda
- Omaymah Alaysuy

Dr William Wise

Dr Andrew Ballantyne

Dr Stefan Davis

THE ROYAL SOCIETY

EPSRC

Justegg
Chilled foods Ltd

Food and Drink iNet
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