THE ImpEE PROJECT

IMPROVING ENGINEERING EDUCATION

Recycling of Plastics

The Cambridge-MIT Institute

UNIVERSITY OF CAMBRIDGE

Notes

- This resource was developed by Dr. Sue Jackson and Dr. Tamás Bertényi, ImpEE Project, Department of Engineering, University of Cambridge.
- A portion was contributed by Prof. Mike Ashby of the Department of Engineering, University of Cambridge.
- version 3
- March 28th, 2006

Plastic waste in the UK

- 3 million tonnes of waste plastic are produced a year in the UK.
- 1 tonne = 20,000 plastic bottles
- 7% of this is recycled at present (2005)
- An estimated 9.2 billion plastic bottles are disposed of each year
- 200,000 tonnes of plastic rubbish is being sent 8,000 miles to China each year for recycling.

Notes

- Useful statistics on waste recycling , some of which are reproduced in this resource. Recoup
- An article on waste export to China at the Guardian

http://www.recoup.org: Useful statistics on waste recycling , some of which are reproduced here
http://www.guardian.co.uk/waste/story/0,12188,1308278,00.html: article on waste export to China

Things to think about...

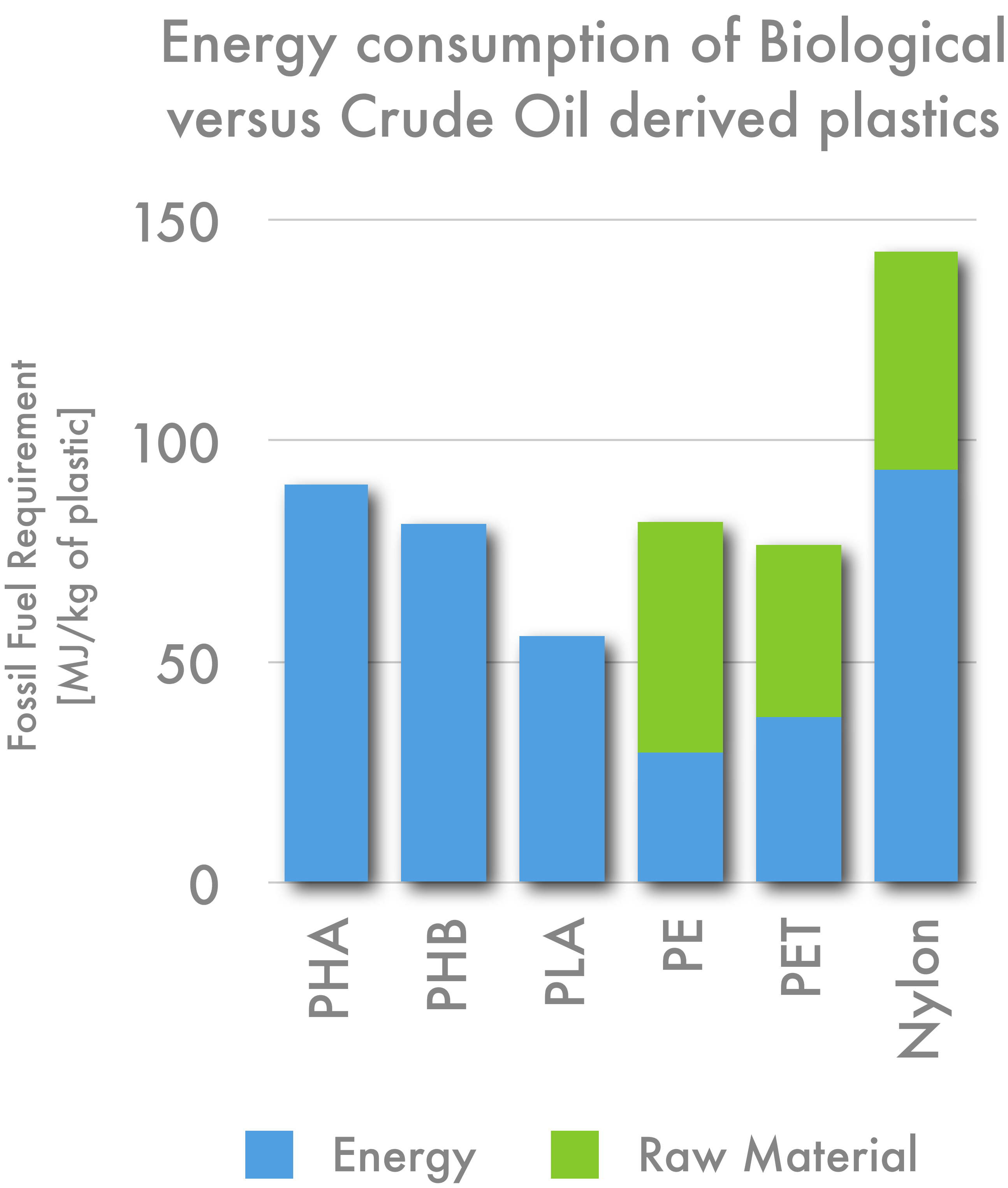
- The basic raw materials for plastic are petroleum and/or natural gas.
- Although plastics only consume around 4% of the world's oil, supplies are becoming depleted.
- Many plastic products are reaching the end of their lifecycle, forming non-biodegradable mountains of waste plastic.
- 11% of household waste is plastic, 40% of which is plastic bottles

Notes

- It is possible to produce polymers biologically from corn plant leaves, sugars and bacteria. However the energy costs for producing them are high. More details are available from DoITPoMS

http://www.doitpoms.ac.uk/tlplib/recycling-polymers/index.php

Biologically produced plastics



- PHA , PHB and PLA are biologically produced.
- Processing energy is relatively high.
- More fossil fuel energy is used in their production than for both Polyethylene and PET.
- So renewable plastics are not necessarily as environmentally friendly as they first appear.

Notes

- It is possible to produce polymers biologically e.g.:
- **PHA (polyhydroxyalkanoate)** grown in genetically modified corn plant leaves.
- **PLA (polylactide)** produced by the fermentation of sugars extracted from plants.
- **PHA (polyhydroxyalkanoate)** produced by bacteria.
- However the energy costs for producing them are high. To degrade properly materials like PHB also need to be treated as compost rather than being dumped in landfills where there will not be suitable bacterial conditions to encourage rapid decay. There are worries that if PHB were to become more commonly used people would litter all the time, thinking that this was all right as the plastic would just degrade.[1]

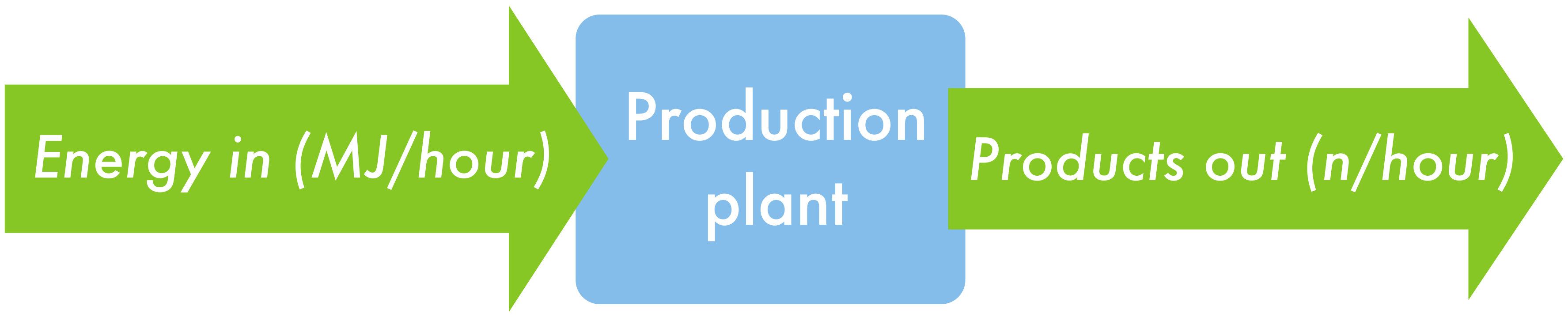
1. "TLP on Recycling Plastics", Produced by DoITPoMS. http://www.doitpoms.ac.uk/tlplib/recycling-polymers/index.php

Assessing embodied energy and CO_2 of plastics

The energy input during manufacturing is not calculated via thermodynamics because:

- Industrial processes have varying efficiencies ranging from a few % to about 50%
- The scrap-fraction ranges from a few % to 80% or more
- Some part of the energy to heat, light and maintain the plant must be included
- In any new enterprise there is an energy "mortgage" to be paid – the energy it cost to build the plant

Instead it is calculated by input-output analysis



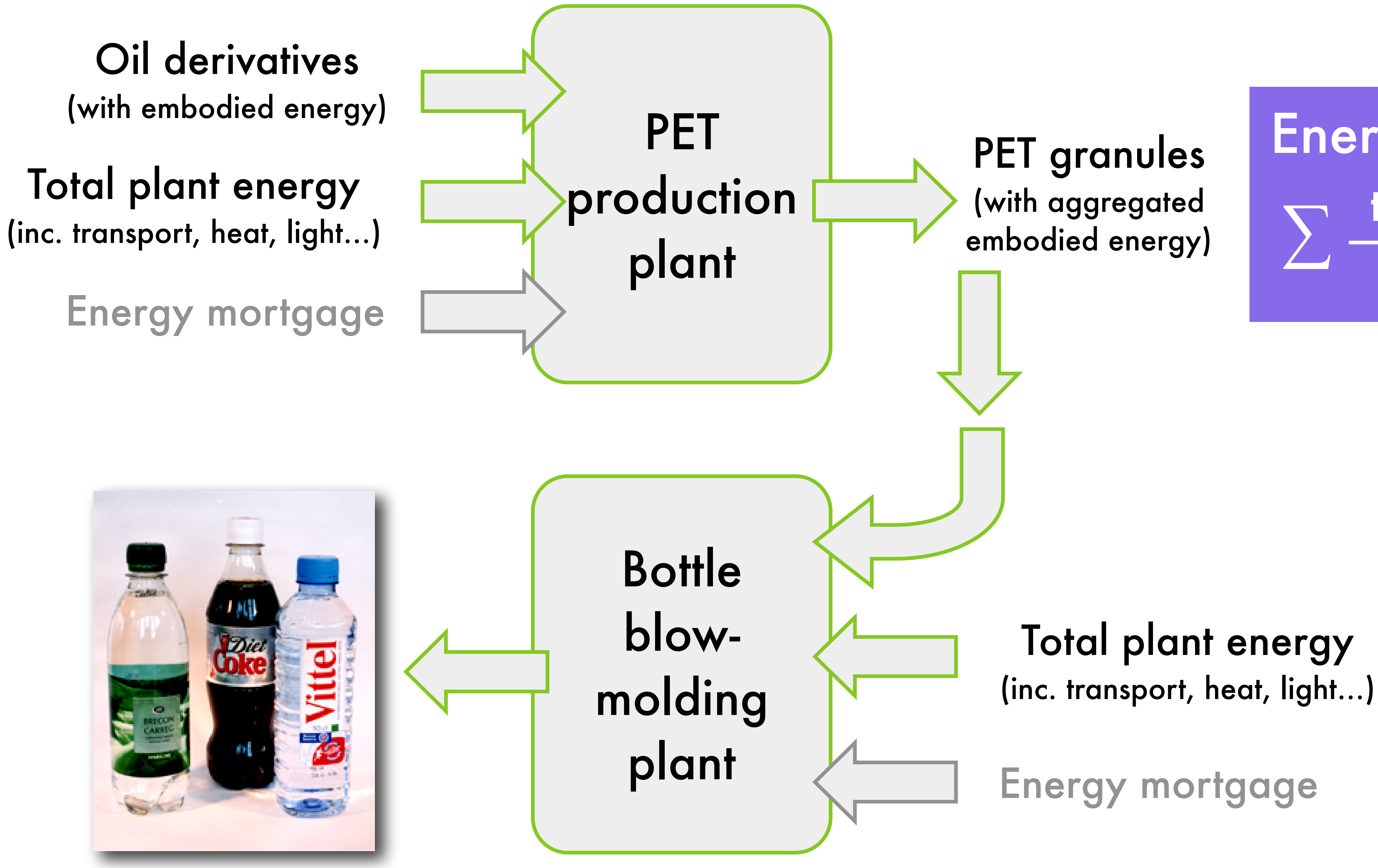
Energy/product = Energy in/Products out

Notes

- Calculating the embodied energy of a polymer based on its chemical and thermodynamic properties does not provide a realistic answer.
- Instead, the appropriate methodology is an input-output analysis.

Mike Ashby, Cambridge UK, 2006

EXAMPLE: primary production of PET bottles



Energy/kg PET =

$$\sum \frac{\text{total energy in}}{\text{kg of PET out}}$$

Energy/bottle =

$$\sum \frac{\text{total energy in}}{\text{number of bottles out}}$$

Notes

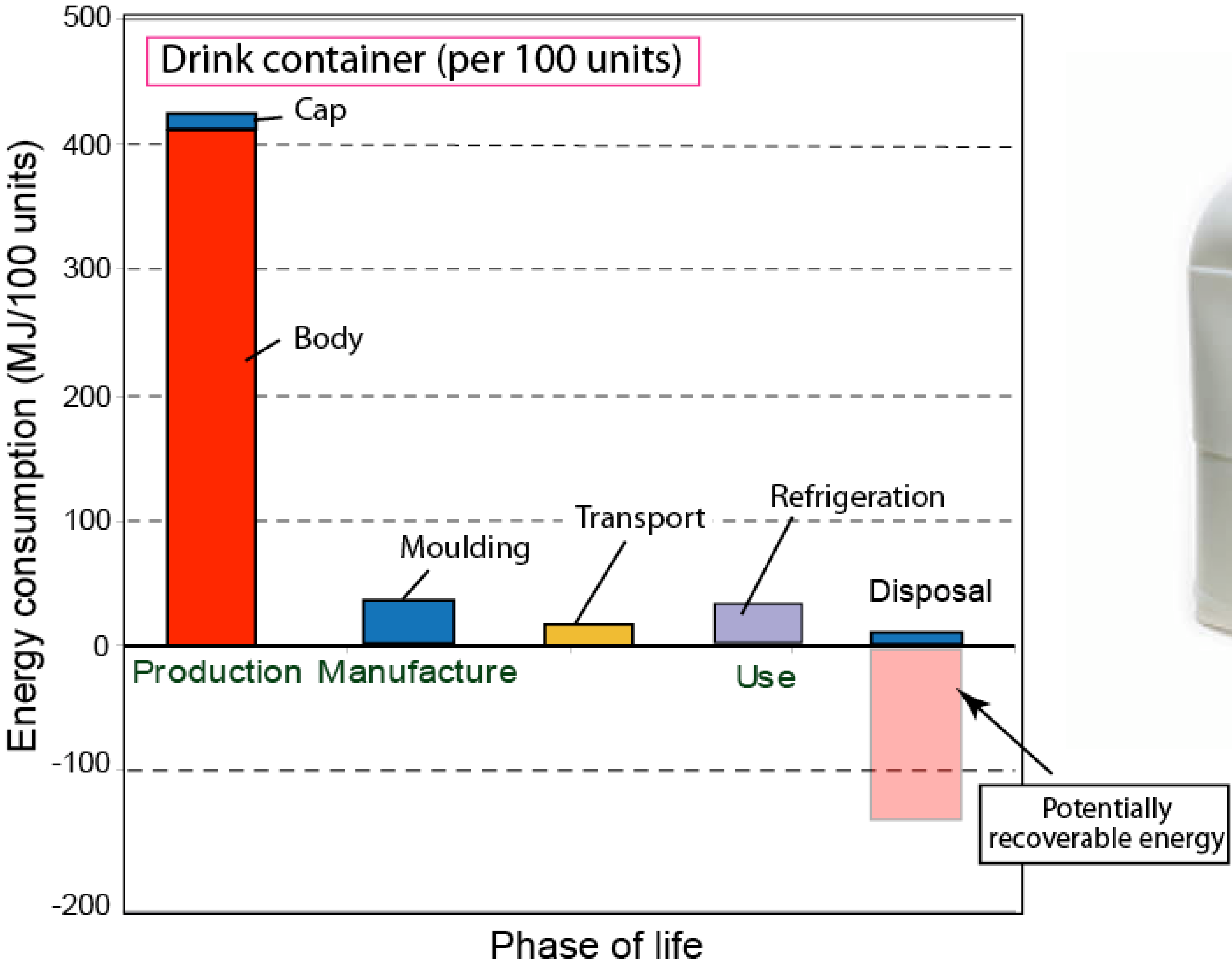
- This is an example of industrial Input-Output Analysis applied to the production of Polyethylene terepthalate (PET) bottles, including the production and manufacturing phase.

Mike Ashby, Cambridge UK, 2006

Life-Cycle Analysis

- In addition to the energy embodied in the plastic during production and manufacturing, products also require energy during use and disposal.
- An analysis that considers this whole process is referred to as life-cycle analysis.
- The next slide shows the results of such an analysis of a plastic drink container.

Energy breakdown for PE bottle



Notes

- This graph shows that for a Polyethylene (PE) bottle of this type, the bulk of the energy usage is in the production of the raw material. Thus recycling is an important way of reducing the energy of production (and hence associated CO_2 emissions). (Note that the cap is made of a different polymer).
- Transport does not have a great impact on the energy life cycle of this product.
- Use phase includes such energy requirement as – in this case – refrigeration.
- This method of analysing the energy consumption of a product shows the dominant energy-consuming phase of its life, the one to concentrate on in order to make the most effective difference.

Eco-impact per unit of function

Function: *contain 1 litre of fluid*

	Glass	PE	PET	Alu	Steel
Container Type					
Mass [g]	325	38	25	**20**	45
Mass/volume [g/litre]	433	38	62	**45**	102
Energy/Mass [MJ/kg]	**14**	80	84	200	23
Energy/Volume [MJ/litre]	8.2	3.2	5.4	9.0	**2.4**

The winner is steel.
The losers are glass and aluminium.

Recycling changes the picture a little – but not simple

Notes

- To deal with environmental impact at the production phase properly we must seek to minimize the energy, the CO_2 burden or some other *eco-indicator value* per unit of function.
- The masses of five competing container–types, the material of which they are made, and the specific energy content of each are listed in this frame Their production involves moulding or deformation; approximate energies for each are listed. All five of the materials can be recycled.
- The bottom row gives the result, calculated from the data in the rows above. The steel can is the most energy–efficient, followed by polyethylene. Glass, although it has the lowest energy per kg of material, has a much higher energy per unit of function (almost as high as aluminum) because glass bottles are so heavy.
- For full details of this methodology, see the accompanying resource on product design.

Things to think about

- Plastics are not necessarily the waste and energy culprits that some people think they are. Plastics can be very energy efficient.
- It takes less energy to manufacture a plastic ketchup bottle than a glass ketchup bottle. And since plastics are lightweight, it takes less energy to transport a truckload of plastic ketchup bottles than a truckload of glass ketchup bottles.
- Up to 40% less fuel is used to transport drinks in plastic bottles compared to glass bottles

Why Recycle?

- In landfill, both synthetic and naturally occurring polymers don’t get the necessary exposure to UV and microbes to degrade.
- Here they are taking up space and none of the energy put into making them is being reclaimed.

Photo of tip.

Notes

- Some environmentalists consider that the fact that plastics do not degrade in landfill is good, as this means there is no toxic spread of materials. [Mindfully.org](http://www.mindfully.org/Plastic/Incineration-For-Energy.htm)

http://www.mindfully.org/Plastic/Incineration-For-Energy.htm

Why Recycle?

- Reclaiming the energy stored in the polymers can be done through incineration, but this can cause environmental damage by release of toxic gases into the atmosphere.
- Recycling is a viable alternative in getting back some of this energy in the case of some polymers.
- As petroleum prices increase it is becoming more financially viable to recycle polymers rather than produce them from raw materials.

Notes

- This is a contentious issue as many environmentalists claim that incineration releases carcinogens into the atmosphere.
- Some data on relative energy recoverable through incineration is given by The Society of the Plastics Industry .

http://www.plasticsindustry.org/outreach/environment/2110.htm

Recycling of polymers: the reality

In-house scrap (generated at the source of production) is near-100% recycled already.

Recycling of used plastics (here PET bottles): few plastic recycling plants make a profit. Many have closed.

Why, if recycling is energy-efficient? And is it?

- Collection is time-intensive, so expensive
- Sorting of mixed plastic waste is difficult – contamination is inevitable.
- Removing labels, print, all but impossible at 100% success rate
- Contamination of any sort compromises re-use in "hi-tech" applications (a carbonated water bottle is a pressure vessel – a failure is unacceptable to the supermarkets that sell them)

The consequence: most plastic (apart from in-house) is reused in lower-grade applications

- PET: cheap carpets, fleeces
- PE and PP: block board, park benches

Notes

- The products of plastic recycling include building materials for outdoor furniture and clothing like fleeces.
- PET is also spun into fibres to make filling for pillows and quilts. It takes 35 two-litre PET bottles to make enough fibrefill for a sleeping bag.

Mike Ashby, Cambridge UK, 2006

Problems with recycling plastics

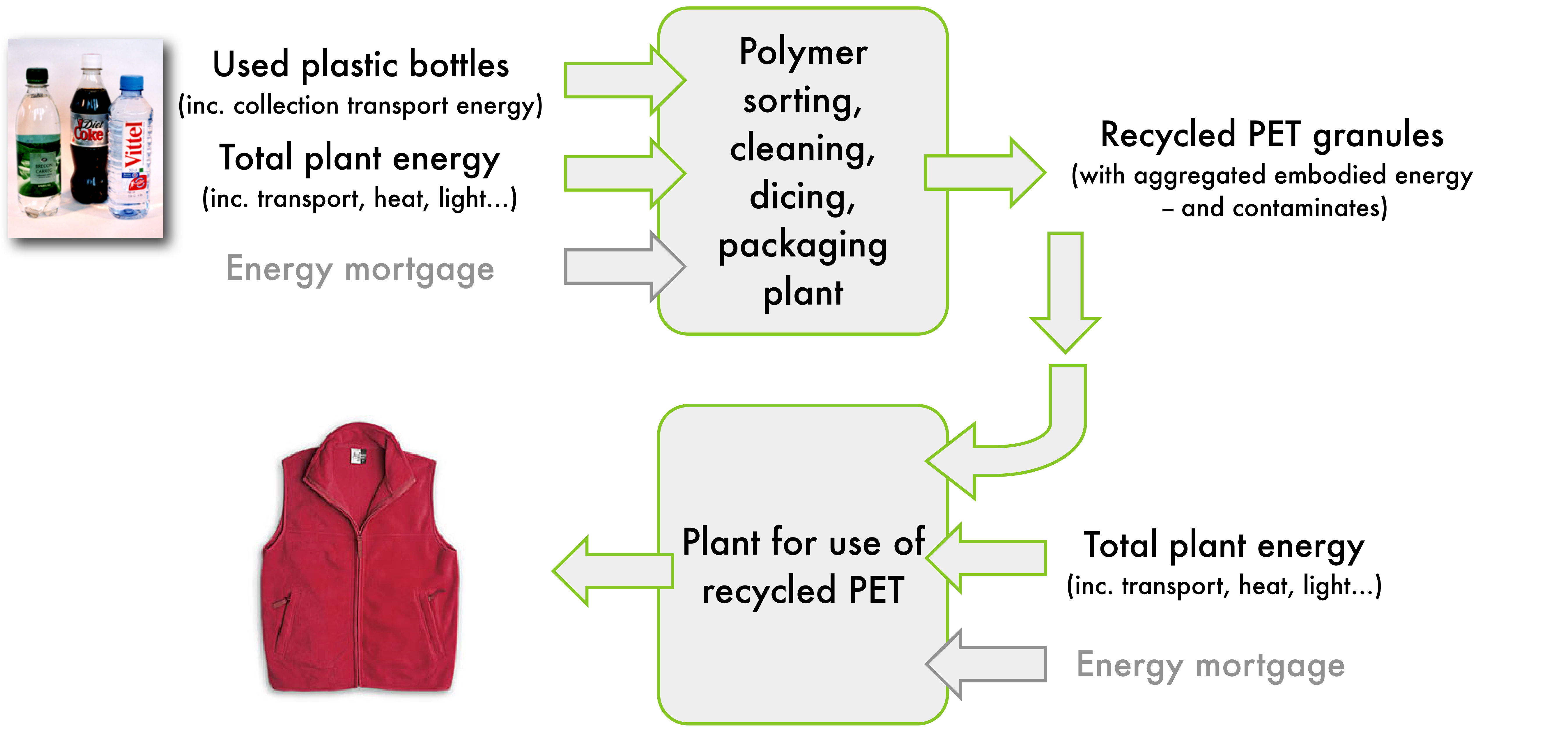
- PET and PVC have many problems with cross contamination as the two polymers appear very similar to the naked eye and share the same specific gravity so cannot be separated by conventional float-sink techniques used in the plastic recycling industry.
- The correct separation of plastics is extremely important. Just one PVC bottle in a batch of 10,000 PET bottles can ruin the entire melt!

Notes

- PET (Polyethylene terephthalate ($CO(C_6H_4)COOCH_2CH_2)_n$) is one of the most commonly recycled plastics. It is used for applications such as fizzy drinks bottles because it has sufficient CO_2 storage capabilites (it is sufficiently ordered to produce a degree of crystallinity which makes it strong but not brittle), is compatible with the storage material (fizzy drink), is cheap, has high strength and is sufficiently transparent.
- PVC is an example of a polymer that is difficult to recycle.
- PVC is a heat sensitive material that degrades by dehydrochlorination – that is, by releasing hydrochloric acid. To combat this, heat stabilizers are added so that the compound can be formed into a product before it degrades.
- Additive such as calcium-zinc heat stabilizers are used in applications such as blow moulded PVC for food contact, pipes for drinking water, packaging film and PVC sheets. They can provide high clarity and low odour properties. However, the stabilization power of calcium-zinc in PVC is relatively weak and therefore the mechanical recycling (i.e. by melting down) capability is poor.
- There are also problems with cross contamination between flexible and rigid types of PVC. If plasticised PVC is added to rigid PVC then rigidity is lost and if too much rigid PVC is added to plasticised PVC embrittlement can occur. PVC products may be clear plastic, but more often than not they are filled, coloured or textile-reinforced which leads to problems of separation when recycling.
- The maximum PVC contamination allowed for recycling of PET bottles is in the range of 10PPM.
- An interesting account of the PET bottles recycling story can be found at GM Engineering.

http://www.ledarecycling.it/docs/PET_bottles_recycling_system.html gives an interesting account of the PET bottles recycling story.

Energy (and use) audit of recycling of PET



Energy per kg of fleece =

$$\sum \frac{\text{total energy in}}{\text{kg of fleece out}}$$

Notes

- In order to assess the energy recovered during the recycling process, one must also account for the energy lost during the process. A method similar to the input-output analysis described in Slide 6, to evaluate embodied production and manufacturing energy can be used.
- Note that the analysis must also reflect the fact that the quality of the recycled material does not match the virgin material.

Mike Ashby, Cambridge UK, 2006

Energies and prices of virgin and recycled plastics

Commodity plastics	Embodied energy, virgin material (MJ/kg)	Price*, virgin material ($/kg)	Embodied energy, recycled material (MJ/kg)	Price*, recycled material ($/kg)
HDPE	77 - 85	1.9 – 2.0	≈ 35 - 45	0.84 – 0.97
PP	75 - 83	1.8 – 1.85	≈ 35 - 45	0.99 – 1.1
PET	79 - 88	2.0 – 2.1	≈ 60 - 64	1.1 – 1.2
PS	96 - 105	1.5 – 1.6	≈ 40 - 50	0.75 – 0.86
PVC	63 - 70	1.4 – 1.5	≈ 35 - 40	0.77 – 0.99

*Spot prices, November 2005

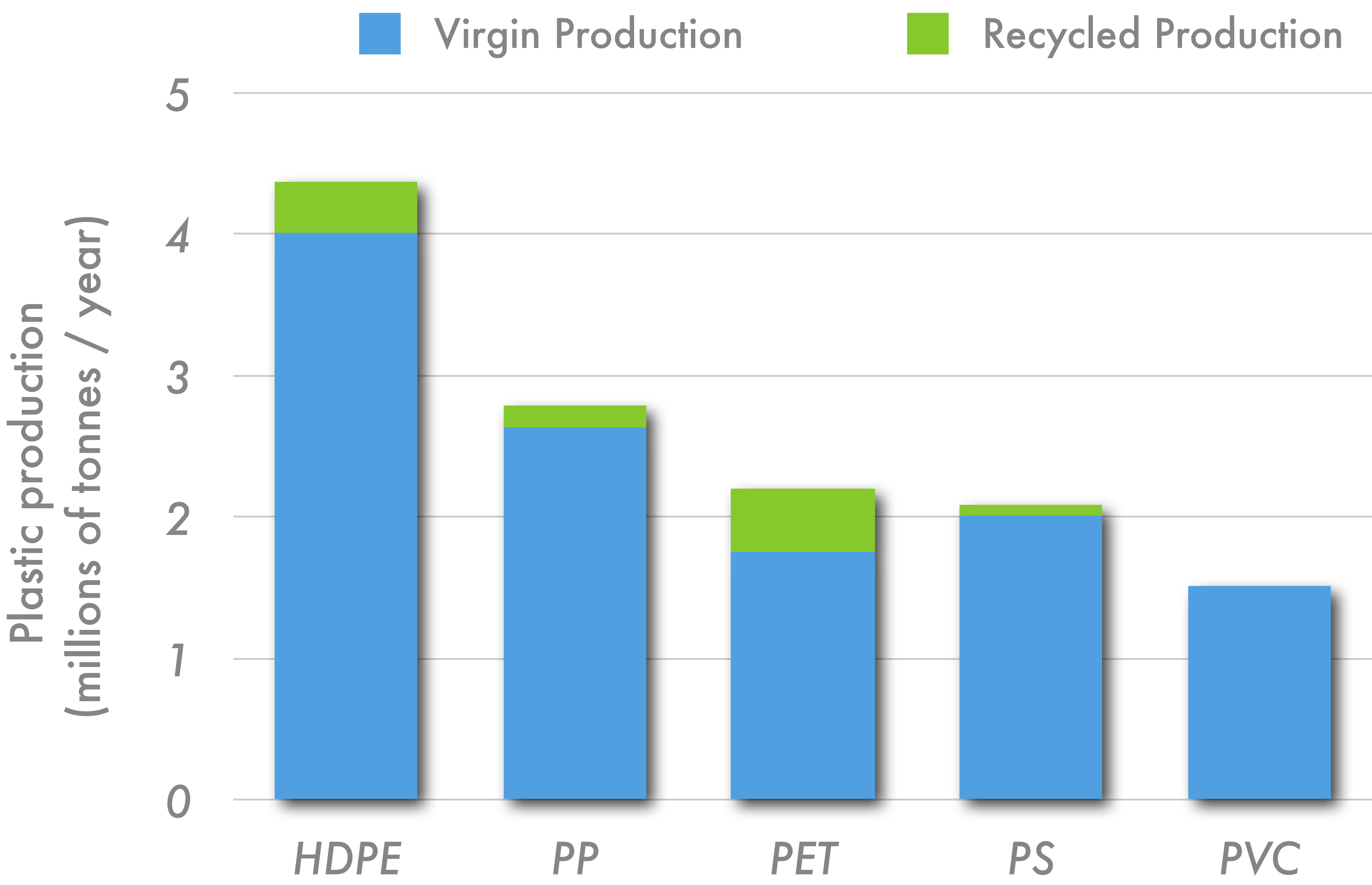
The messages:

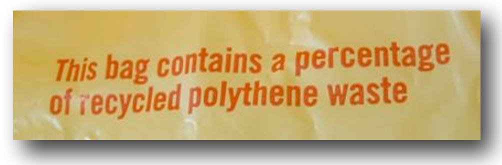
- Both the embodied energy and price of recycled plastics are about half that of virgin material
- The lower price reflects the lower quality of the recycled material, limiting its use
- Because of this the contribution of recycling to current plastic consumption is small

Notes

Recycling of polymers: the reality

Because of the problems outlined on the previous slides, the contribution of recycling to current plastic consumption is small.





Notes

Mike Ashby, Cambridge UK, 2006

Things to think about?

- Since most oil is extracted to be burned directly as fuel, is it so wrong to turn it into plastic first, and then burn it to recover the energy?

Things to think about

- China drives the global waste trade, importing more than 3 million tonnes of waste plastic a year.
- Western plastic companies are setting up in China, but some of the poorest people are employed to sort and recycle the plastic.
- Is it better to send rubbish to China to be recycled than to put it in landfill in Britain?

Notes

- This is one of the societal issues that engineers should be encouraged to think about.
- The economics of transportation and labour costs are one thing:the ethics are another,and provide a good topic for debate.

How plastics are sorted

Symbol	Acronym	Full name and uses
1	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
2	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
3	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
4	LDPE	Low density polyethylene - Carrier bags and bin liners.
5	PP	Polypropylene - Margarine tubs, microwave-able meal trays.
6	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
7	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

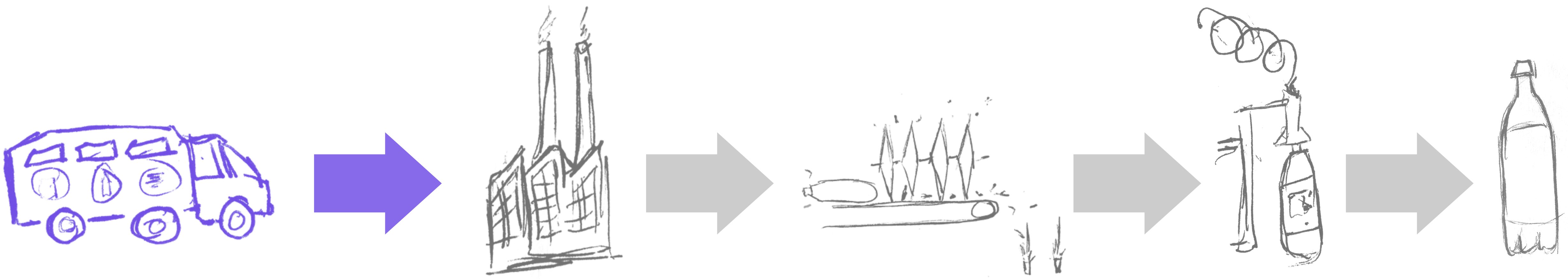
Notes

- The DoITPoMS web site gives a simple test method for polymer identification

http://www.doitpoms.ac.uk/tlplib/recycling-polymers/sorting.php

How the recycling occurs

1. The recyclables can be collected from individual homes or from collection points such as tips, schools and supermarkets. After transport to the recycling plant, plastics are hand sorted according to their recycling code. Some materials recovery facilities can mechanically sort different plastic codes. Each plastic type is processed separately.



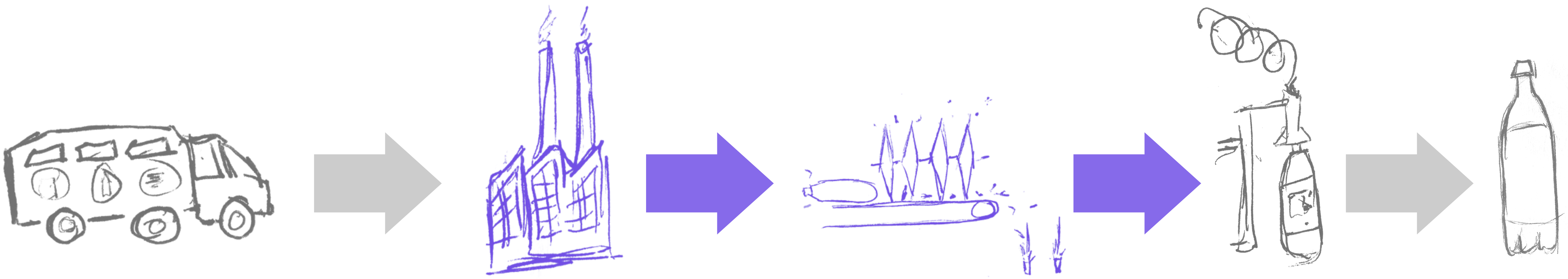
Notes

- Sink-float tanks are the most common and easy way to separate plastics by density. Normally plain water is used to separate olefins from other thermoplastics and sometimes water is added with salts to make it heavier than one, and make to float some polymers while the rest sinks etc.
- There seem to be a number of methods of sorting polymers: use of UV light, electrostatic separation, differences in melting points and froth flotation.

How the recycling occurs

2. The plastic is sliced into flakes and the flakes go through a washing process.

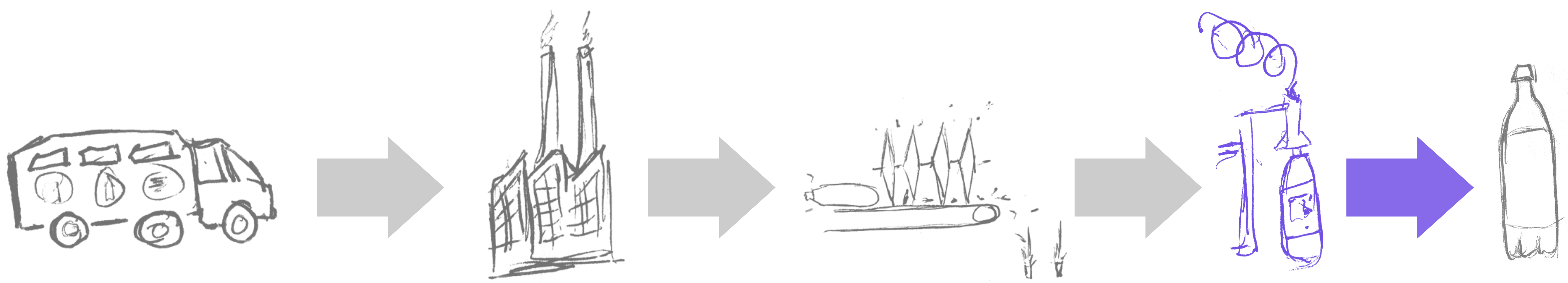
3. The clean plastic flakes are melted together, extruded through small holes, and chopped into pellets.



How the recycling occurs

4. The bags of recycled plastic pellets are taken to factories where they are melted and made into new products.

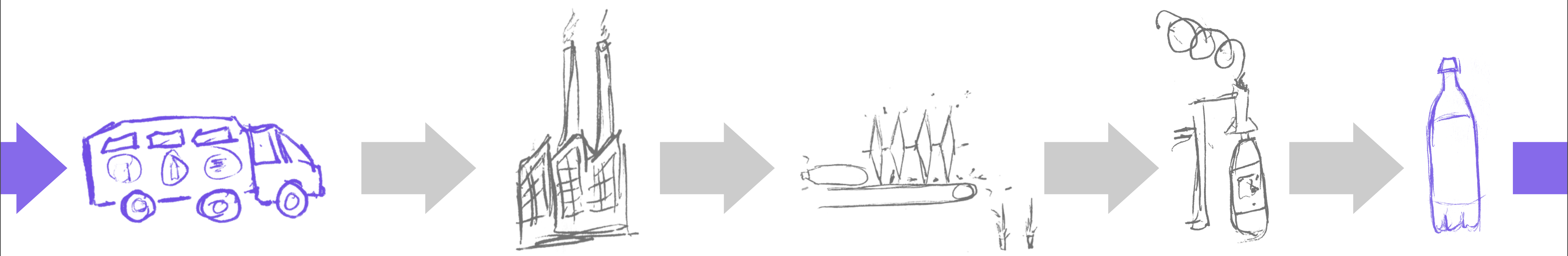
5. In the case of soft drink bottles the recycled pellets are combined with virgin material fresh from petroleum. These are then melted and moulded into preforms.



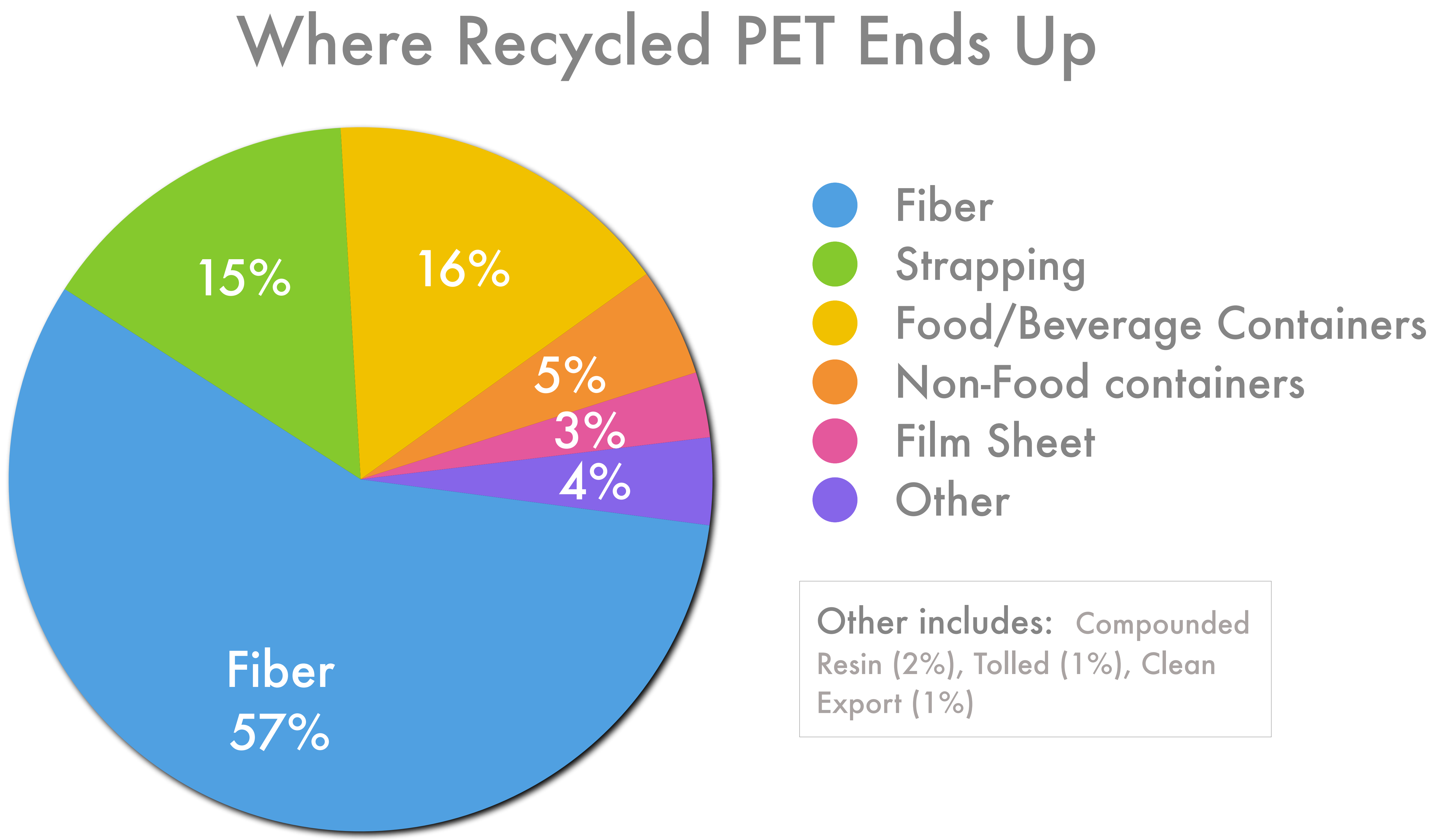
How the recycling occurs

6. The bottles are blown into another mould to form the full size bottle this is often done at the bottling plant where they are filled and sealed.

7. Once consumed they are delivered back to the recycling plant after household recycling.



Recycling Statistics



Notes

- Source:DoITPoMS

Source:http://www.doitpoms.ac.uk/tlplib/recycling-polymers/index.php

A different viewpoint...

- It takes one day to collect a kilo of thin plastic bags from a tip by hand
- For one kilo, the rag picker typically earns R1.5 in India
- Some cities in India are banning the use of thin plastic bags

Notes

- The issues of recycling plastics in the UK do not reflect a world view. We might think that thin plastic bags are better than thick ones, but other nations have a different perspective:
- Rag pickers in India trawl the streets and rubbish dumps looking for recyclable material as a way of earning money. Thin plastic bags which might seem desirable from a environmental viewpoint are not worth the harvesting time. They therefore get left in the streets and clog up sewers causing flooding and consequent disease.
- ecologycenter.org http://www.ecologycenter.org/iptf/
- mindfully.org http://www.mindfully.org/Plastic/Ragpickers-Hate-Plastic.htm
- The issue of thin versus thick plastic bags is also an issue in South Africa: bbc.co.uk http://news.bbc.co.uk/1/hi/world/africa/3013419.stm

THE ImpEE PROJECT

The Cambridge-MIT Institute

UNIVERSITY OF CAMBRIDGE

The Cambridge-MIT Institute

ImpEE is based at the Department of Engineering at the University of Cambridge and is funded by the CMI Institute.