University of Cambridge

# Eco-selection:

## environmentally informed material choice

*Mike Ashby, CUED, October 2005*

With acknowledgements (never enough) to

- *Ulrike Wegst*
- *Andrew Miller*
- *Fiona Rutter*
- *Hugh Shercliff*
- *Tracy Chen*
- *David Pearce*

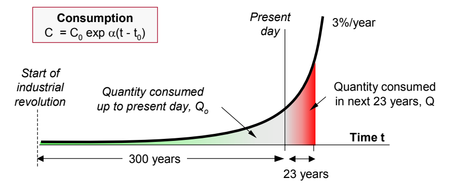
***Engineering Dept, Cambridge and***

***Granta Design, Cambridge***

## Materials and the environment

**Exponential growth and consequences**

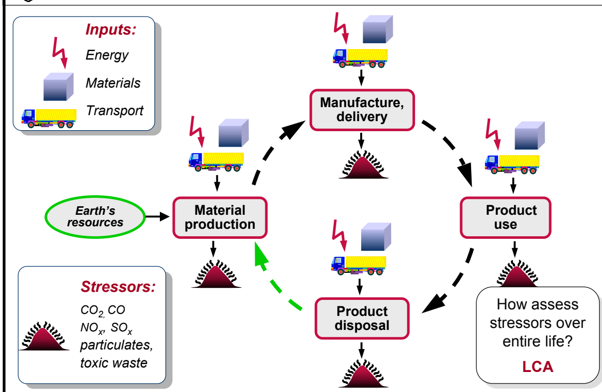
At a growth rate of **3% per year**, the quantity of a given resource we will consume in the next **23 years** is equal to the total consumed over all previous time




**Message:** *IF: Current material consumption exerts "stress" on the environment* — *THEN: Future growth depends on design that reduces stress/unit of production*



## The material life cycle






## Life cycle assessment

**Typical LCA output:**

- Energy consumption
- Water consumption
- Emission of $CO_2$, $NO_x$, $SO_x$ etc
- Particulates
- Toxic residues
- More …….

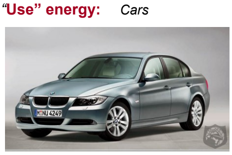
Roll up into "eco-indicator" ??

- What is a designer supposed to do with these figures?
- Full LCA very time consuming, expensive, requires great detail – and even then is subject to uncertainty
- 80% of environmental cost determined at design stage when many decisions still fluid



## Streamline LCA (1)

- **Step 1:** select single measure of stress
  - **Kyoto Protocol (1997):** international agreement to reduce greenhouse gasses
  - Practical solution: use **$CO_2$** or **Energy**
  - **"Use" energy:** *Cars* — *Some appliances*



**Official fuel economy figures:**
**Combined: 6 – 11 litre / 100km**
**$CO_2$ emissions: 158 – 276 g / km**

**Energy efficiency: A**
**Volume 0.3 m$^3$:**
**330 kWhr / year**



## Eco-materials audit of products

- A draft EU directive 2003/0172 (COD):
  "On establishing a framework for the setting of Eco-design requirements for Energy-Using Products (EuPs)"
  is currently before the European Parliament.
- Manufactures of EuPs must demonstrate that they have considered the use of materials and energy of their products raw material selection and use for:
  - Materials
  - Manufacture
  - Packaging, transport and distribution
  - Use
  - End of life
- For each phase, the consumption of materials and energy shall be assessed. Steps to minimise these shall be identified and the cost implications explored.

## Streamline LCA (2)

■ **Step 2:** Seek method that combines acceptable cost burden with adequate accuracy to guide decision making

*Increasing detail, cost and time* →

| ***Eco-screening*** | ***Streamline LCA*** | ***(Complete LCA)*** |
|---|---|---|

- **Assess** contributions of each phase of life
- **Distinguish** sub-systems (components)
- **Focus** on main components; **ignore** small contributions

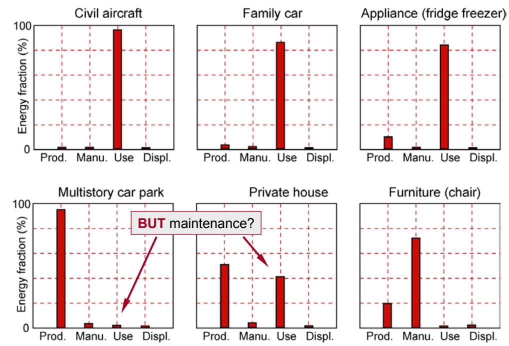
} Interested in *relative magnitudes*

- Precise conclusions can be drawn from imprecise data



## Big pircture: energy consumption of products

Which phase dominates? Approximate breakdown (Bey, 2000):






## Drink container

**Materials**
- PE body 38 g
- PP cap 5 g

**Manufacture**
- PE body moulded 38 g
- PP cap moulded 5 g

**Use**
- Refrigeration 5 days
- Transport 200 km

**Disposal**
- Transport 100 km
- Recycling ? Yes

**Transport, MJ / tonne.km**
- Sea freight 0.11
- Barge (river) 0.83
- Rail freight 0.86
- Truck 0.9 – 1.5
- Air freight 8.3 – 15

**Refrigeration, MJ / m$^3$.day**
- Refrigeration (4ºC) 10.5
- Freezing (-5ºC) 13.0



## CES Edu record for PE

**Polyethylene (PE) - $(CH_2\text{-}CH_2\text{-})_n$**

**General Properties**

| | | | | |
|---|---|---|---|---|
| Density | 939 | - | 960 | kg/m$^3$ |
| Price | 1.3 | - | 1.45 | US $/kg |

**Mechanical Properties**

| | | | | |
|---|---|---|---|---|
| Young's Modulus | 0.6 | - | 0.9 | GPa |
| Elastic Limit | 17.9 | - | 29 | MPa |
| Tensile Strength | 20 | - | 45 | MPa |
| Elongation | 200 | - | 800 | % |
| Hardness - Vickers | 5.4 | - | 8.7 | HV |
| Fracture Toughness | 1.4 | - | 1.7 | MPa.m$^{1/2}$ |

**Thermal Properties**

| | | | | |
|---|---|---|---|---|
| Max Service Temp | 100 | - | 120 | C |
| Thermal Expansion | 126 | - | 198 | $10^{-6}$/K |
| Specific Heat | 1810 | - | 1880 | J/kg.K |
| Thermal Conductivity | 0.4 | - | 0.44 | W/m.K |

**Electrical Properties**

| | | | | |
|---|---|---|---|---|
| Resistivity | 3 x $10^{22}$ | - | 3 x $10^{24}$ | $\mu\Omega$.cm |
| Dielectric constant | 2.2 | - | 2.4 | |

**Eco-properties: production**

| | | | | |
|---|---|---|---|---|
| Production energy | 77 | - | 85 | MJ/kg |
| Carbon dioxide | 1.9 | - | 2.2 | kg/kg |
| Recycle ? | ✓ | | | |

**Eco-properties: manufacture**

| | | | | |
|---|---|---|---|---|
| Injection / blow moulding | 12 | - | 15 | MJ/kg |
| Polymer extrusion | 3 | - | 5 | MJ/kg |

**Environmental notes.** PE is FDA compliant - indeed it is so non-toxic that it can be embedded in the human body (heart valves, hip-joint cups, artificial artery).



## Eco DB: eco-data for PE

**Material: Medium density PE** (branched homopolymer)

**Production energy and emissions**

| | | | | |
|---|---|---|---|---|
| Production Energy | 84 | - | 93 | MJ/kg |
| Carbon Dioxide | 2.2 | - | 2.4 | kg/kg |
| Nitrogen Oxides | 11.4 | - | 12.6 | g/kg |
| Sulphur Oxides | 8.6 | - | 9.5 | g/kg |

**Eco-Indicators**

| | | | | |
|---|---|---|---|---|
| Eco Indicator | 340 | - | 380 | millipoints / kg |
| EPS value | 722 | - | 798 | |

**Manufacture at 30% efficiency**

| | | | | |
|---|---|---|---|---|
| Min. Energy to Melt | 2.8 | - | 3.1 | MJ/kg |

**End of life**

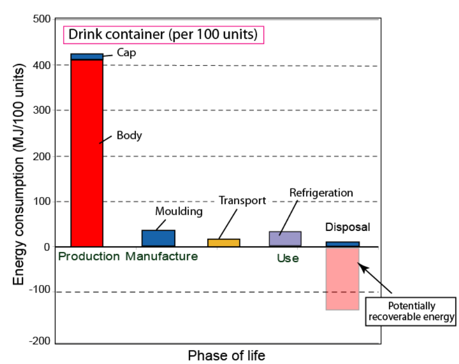
| | | | | |
|---|---|---|---|---|
| Recycle | ✓ | | | |
| Downcycle | ✓ | | | |
| Biodegrade | ✖ | | | |
| Incinerate | ✓ | | | |
| Landfill | ✓ | | | |
| Recycling Energy | 35 | - | 40 | MJ/kg |
| Recycle fraction of current supply | 3 | - | 4 | % |

**Bio-data**

| | |
|---|---|
| Toxicity rating | Non-toxic |
| FDA approved (skin & food contact) | ✓ |
| WEEE prohibited material | ✖ |



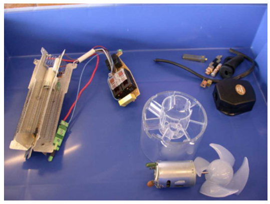
## Energy breakdown for PE bottle



## Typical small energy-using product (EuP)

**The hairdryer**

**The sub-systems**



**Materials and manufacture**

| | | |
|---|---|---|
| ABS | Injection moulded | 180 g |
| Nylon | Injection moulded | 80 g |
| Copper | Drawn | 20 g |
| Iron | Rolled | 40 g |
| Nichrome | Drawn | 7 g |
| Alnico | PM methods | 22 g |
| PVC | Moulded | 13 g |
| Muscovite | Pressed | 18 g |

**Transport**
10,000 km, sea or air

**Power**
Heater 1.7 kW
Fan 0.15 kW

**Duty cycle**
5 mins per day, 300 days/year, 3 years

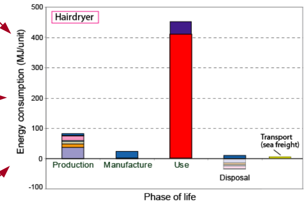


## Fast assessment: spread sheet

**Enter:**
- Materials and approximate quantities
- Power and duty cycle
- Transport distance and mode

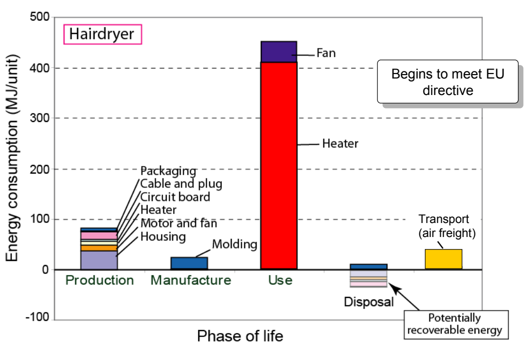
**Retrieve from database:**
- Energy for material production / kg
- Energy for manufacture / kg

**Transport energy**
- Sea freight 0.1 MJ / tonne.km
- Air freight 9 MJ / tonne.km






## Energy breakdown for hairdryer



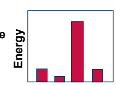



## Strategy for material selection

*Spreadsheet*

**Assess energy use over life**

Production
Manufacture
Use
Disposal




*Then consider:*

**Production**
Minimize:
- energy/kg or
- CO2/kg

times mass of components

**Manufacture**
Minimize:
- process energy/kg
- CO2/kg

times mass of components

**Use**
Minimize:
- weight
- heat loss
- electrical loss

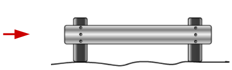
and thus (energy consumption)

**Disposal**
Select:
- recyclable
- non- toxic materials

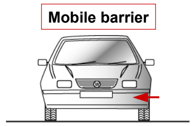


## Material choice depends on function and system

**Static barrier**

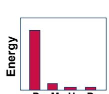


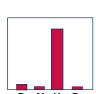
**Mobile barrier**



**Function** *Absorb impact, transmit load to energy-absorbing units or supports*

**Dominant phase of life**

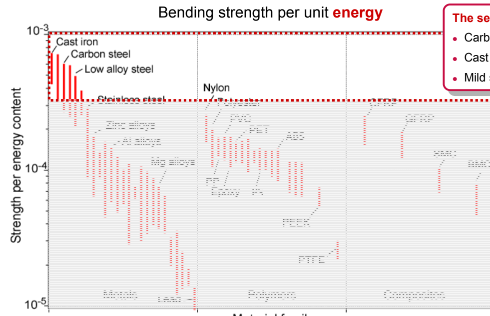



| | Static barrier | Mobile barrier |
|---|---|---|
| **Criterion** | *Bending strength per unit material energy* | *Bending strength per unit mass* |
| **Selected materials** | *Cast iron, steel* | *CFRP, Ti-alloy, Al-alloy* |

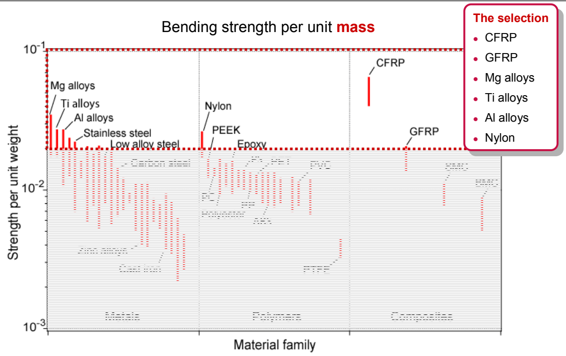


## Selection for the static barrier using CES



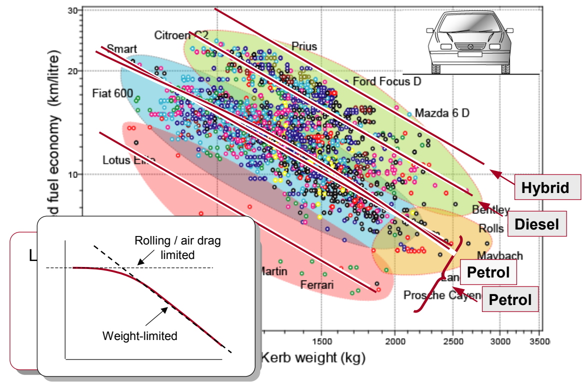

**The selection**
- Carbon steel
- Cast iron
- Mild steel

## Selection for the mobile barrier using CES





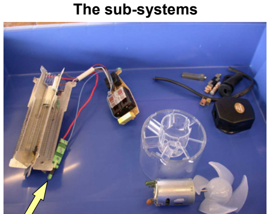

## System dependence: auto power train






## System change

The sub-systems



**The ioniser**

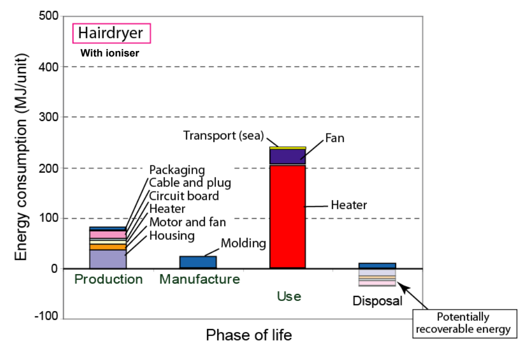
**Power**
**Gas discharge** **> 0.01 kW**

**The claim:**

**"Reduces drying time by half"**



## Energy breakdown for hairdryer






## The main points

**Streamline LCA** gives quick portrait of energy / $CO_2$ burden of products

**Separate the life-phases**
- Material
- Manufacture
- Use
- Disposal

**Base material choice on relative contributions to stress**

**Consider system dependence**
- Refine within one concept
- Explore alternative concepts



## End of Unit 6