Introdução à Eco-Seleção de Materiais

PMT 2200 - Escola Politécnica da USP

Baseada na metodologia do prof. Ashby, University of Cambridge, UK

Profs. Cesar Azevedo e Antonio Carlos Vieira Coelho –

Grande parte das transparências desta aula utilizaram recursos pedagógicos de autoria do Prof. M.F. Ashby

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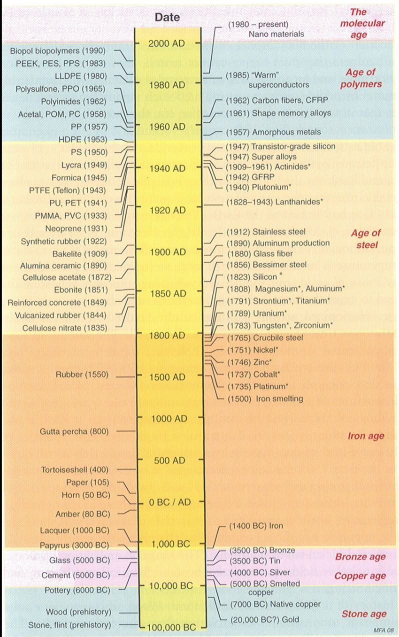


FIGURE 1.1 *The materials timeline. The scale is nonlinear, with big steps at the bottom, small ones at the top. A star (*) indicates the date at which an element was first identified. Unstarred labels give the date at which the material became of practical importance.*

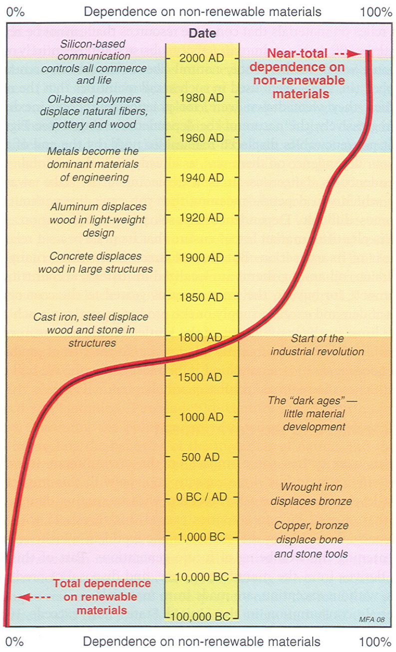
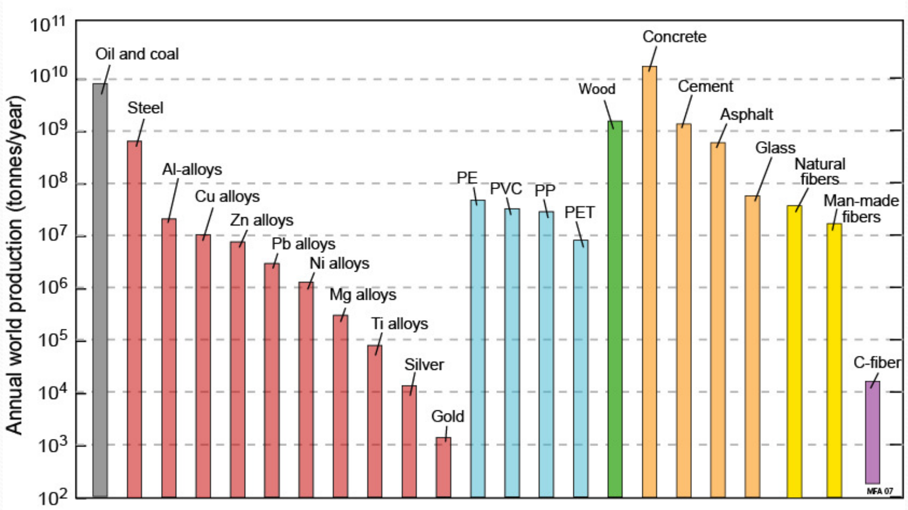


FIGURE 1.2 *The increasing dependence on nonrenewable materials over time, unimportant when they are plentiful but an emerging problem as they become scarce.*

Annual world materials consumption



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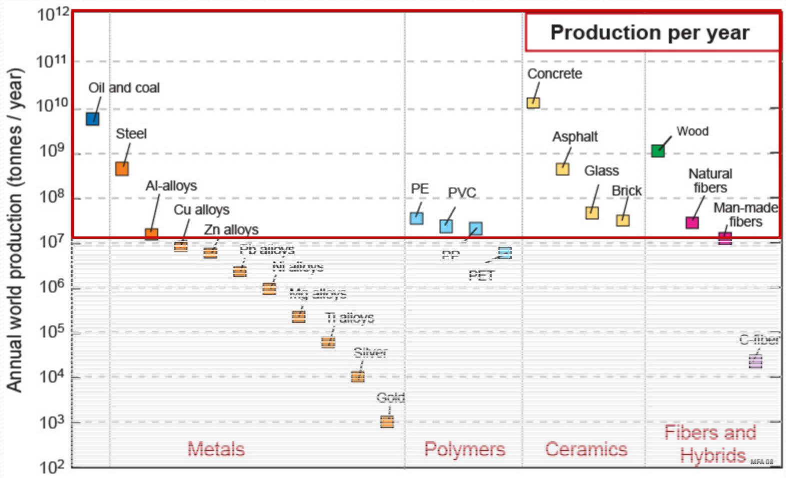
Material production

***Concern 1*: Resource consumption, dependence**



96% of all material Usage

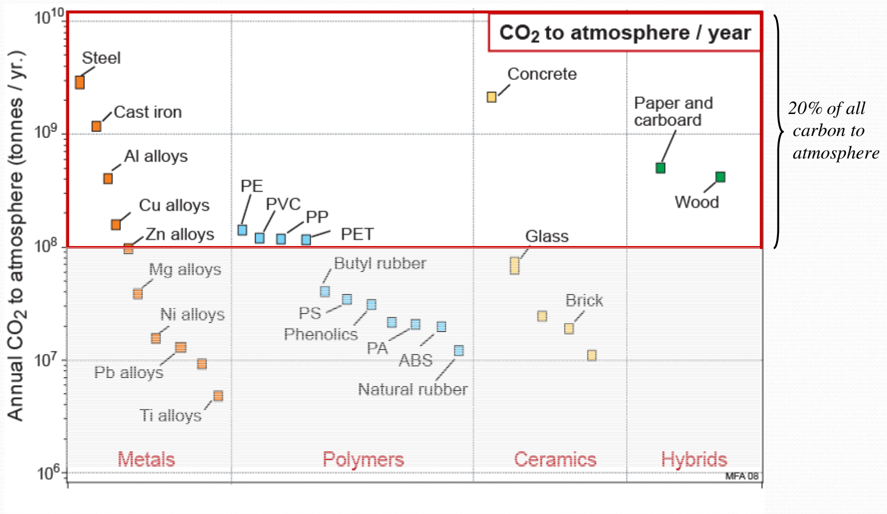
20% of Global energy

*OBS.: **Natural fibers**: cotton, silk, wool, jute*
***Man-made fibers**: polyester, nylon, acrylic, cellulosics*

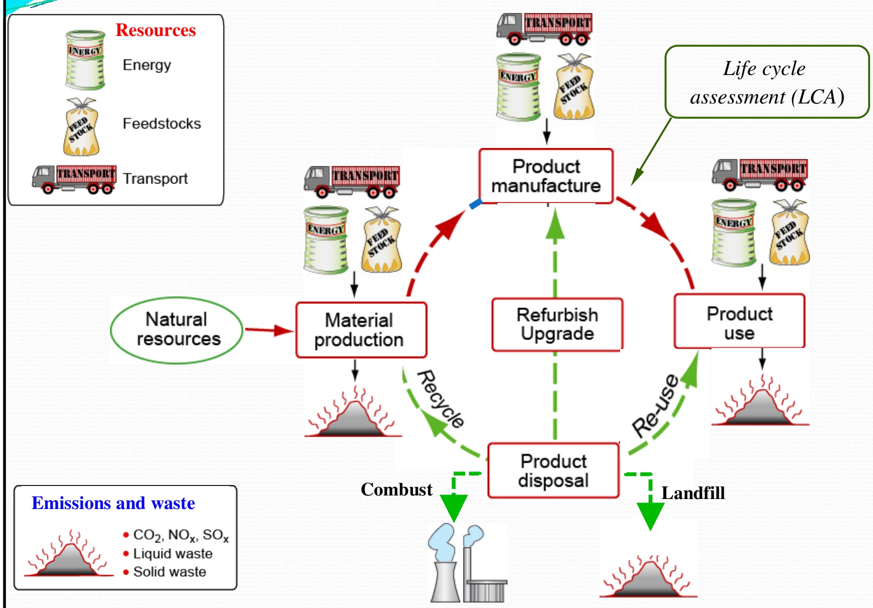
M.F.Ashby, 2011 - www.grantadesign.com/education/resources

Carbon to atmosphere

Concern 2**: Energy consumption, CO_2 emission**



Product life-cycle



Life-cycle assessment (LCA)

Typical LCA output:

- Resource consumption
- Energy consumption over life
- Water consumption
- Emission of CO_2, NO_x, SO_x etc
- Particulates
- Toxic residues
- Acidification..Ozone depletion..

Environmental "stressors"

Roll up into an *Eco-indicator* ?

- Full LCA *time consuming, expensive*, and requires great *detail* and even then is subject to uncertainty
- What is a designer supposed to do with these numbers?
- LCA is a *product assessment tool*, not a design tool

What is embodied energy of a material?

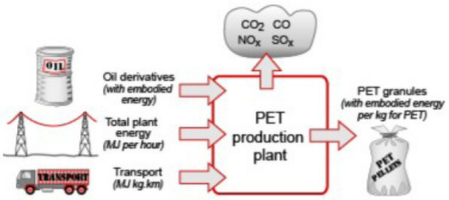
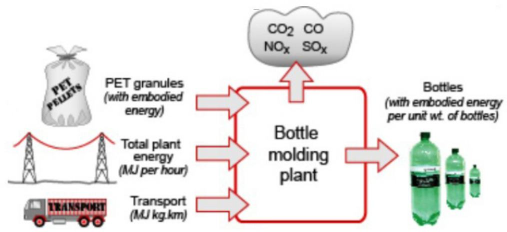


Figure 1. Input/output diagram for the production of PET granules.

definition and measurement. is the energy other than that from bio-fuels that is committed in making a unit weight of material from its ores and feedstock.
The *embodied energy* per unit weight (here, of the PET) is:

$$(H_e)_{PET} = \frac{\sum \text{Energy entering plant per year}}{\text{Mass of PET granules shipped per year}}$$

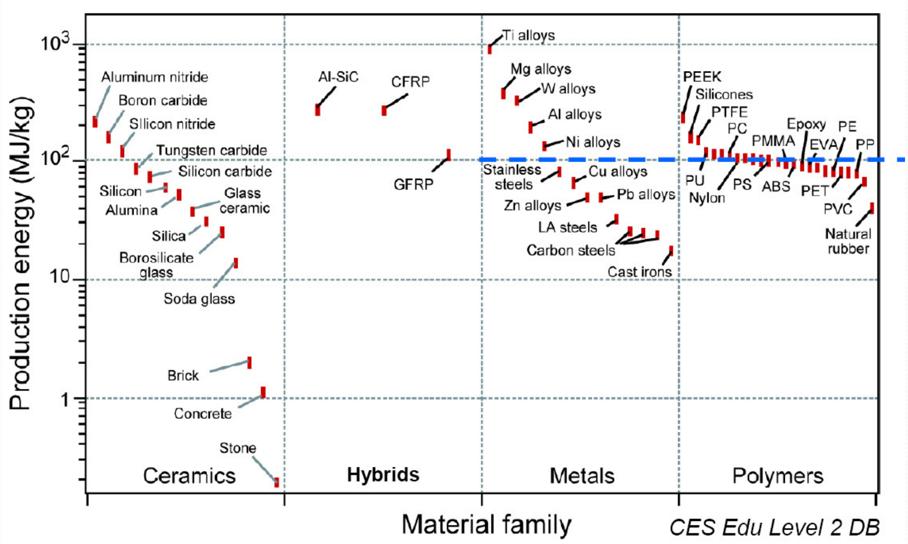
What is embodied energy of a product?



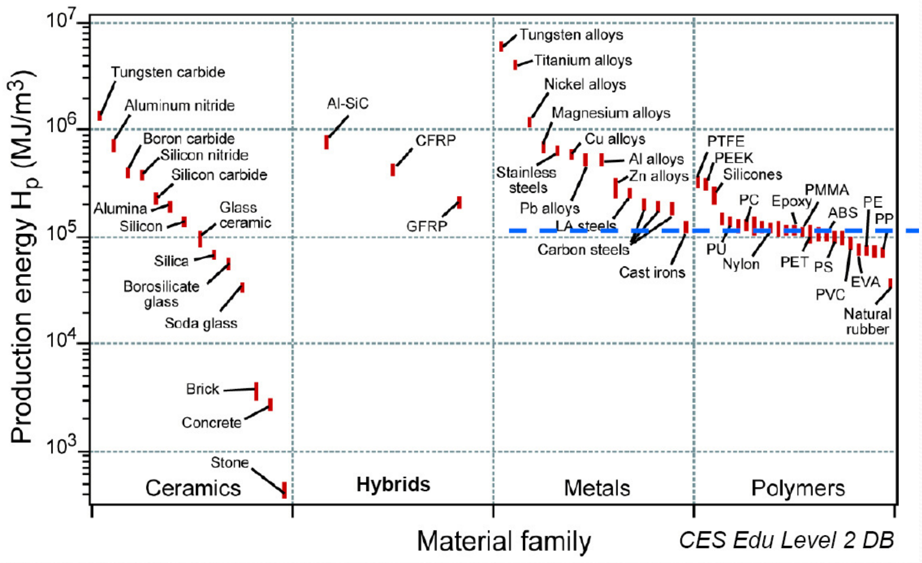
Materials are one input to a manufacturing plant. The energy and material flows are sketched as an input/output diagram in Figure 1.Granules and materials for finishing and packaging have an embodied energy. These are transported to the plant, consuming energy to do so, which in turn consumes energy to run and maintain the process equipment, provide heating, lighting, and other services. The total of these is the input energy to the plant. <u>This, divided by the weight of usable bottles shipped is the *embodied energy* of the product</u>:

$$\left(H_p\right)_{PET\,bottles} = \frac{\sum Energy\ entering\ plant\ per\ year}{Mass\ of\ PET\ bottles\ shipped\ per\ year}$$

Production energy of materials per kg



Production energy of materials per m^3



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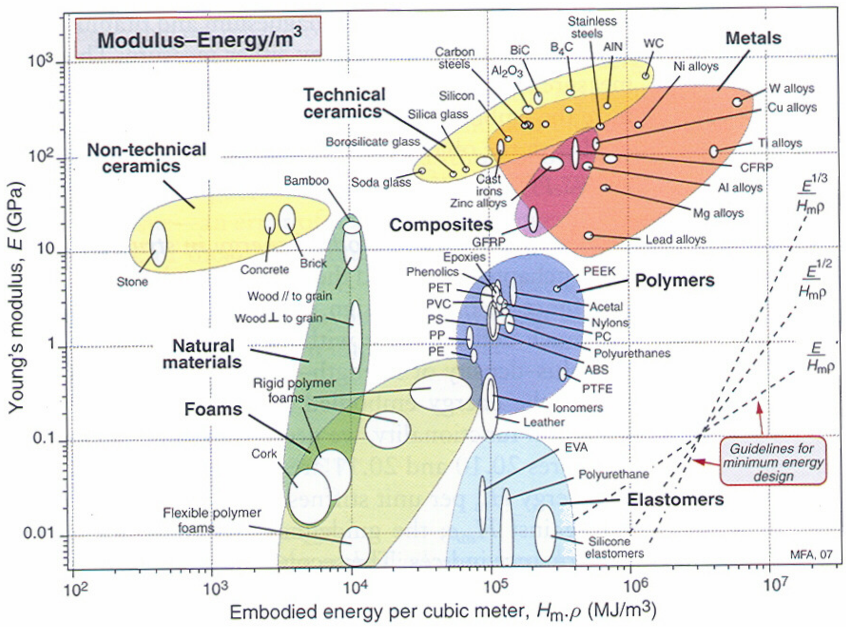
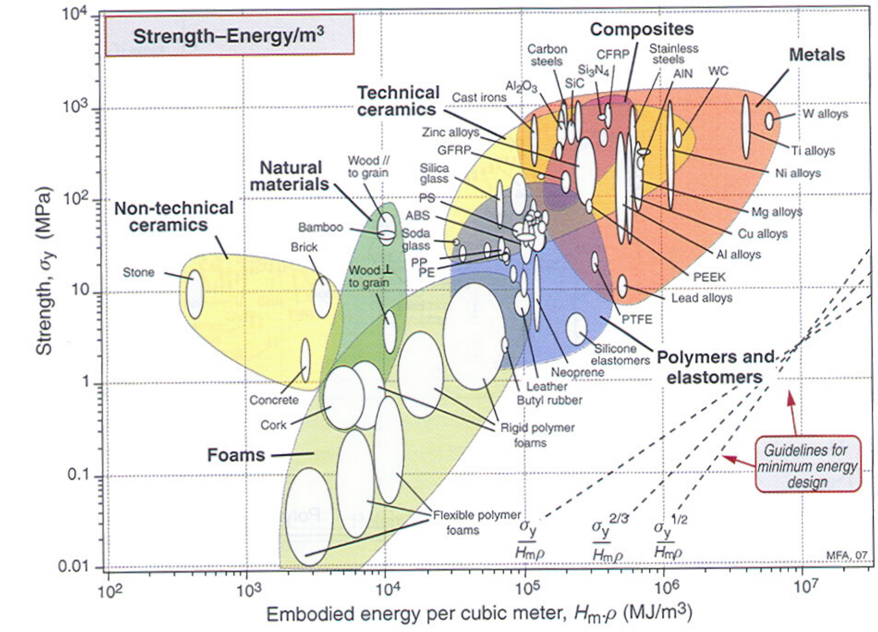


The modulus–embodied energy chart made with the CES software.



The strength–embodied energy chart made with the CES software.

Life-cycle assessment (LCA)

ISO 14040 series

Typical LCA output

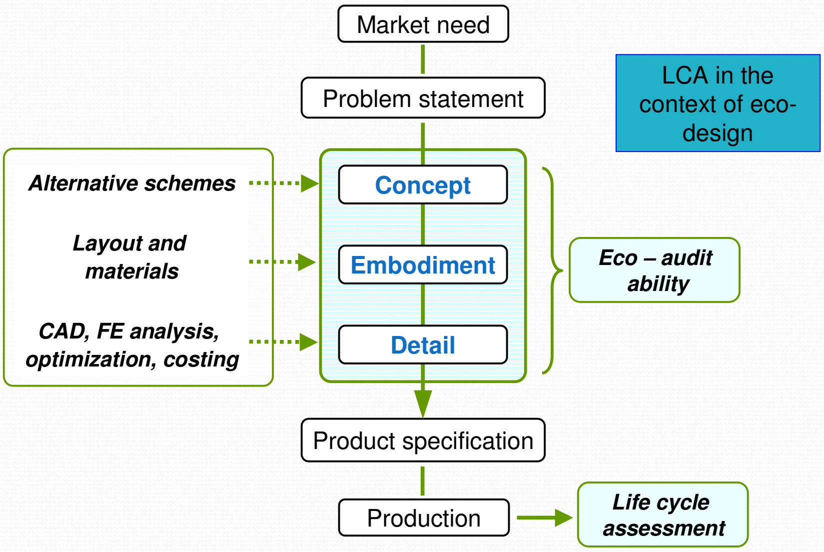
Aluminum cans, per 1000 units

Resource consumption	Bauxite	59	kg
	Oil fuels	148	MJ
	Electricity	1572	MJ
	Energy in feedstock	512	MJ
	Water use	1149	kg
Emissions inventory	Emissions: CO_2	211	kg
	Emissions: CO	0.2	kg
	Emissions: NO_x	1.1	kg
	Emissions: SO_x	1.8	kg
	Particulates	2.47	kg
Impact assessment	Ozone depletion potential	0.2×10^{-9}	
	Global warming potential	1.1×10^{-9}	
	Acidification potential	0.8×10^{-9}	
	Human toxicity potential	0.3×10^{-9}	

Roll up into an *"eco-indicator"* ?

- Full LCA *expensive*, and requires great *detail and skill* – and even then is subject to uncertainty
- How can a designer used these data?

Design guidance vs. Product assessment



Strategies for guiding eco-design

- **Step 1:** Seek method that combines acceptable cost burden with adequate accuracy to guide decision making – a *design tool*

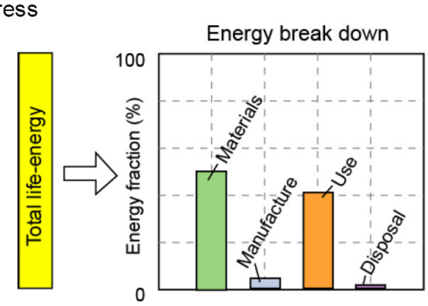
Increasing detail, cost and time

Eco-screening →	*Scoping LCA* →	*Streamline LCA* →	***Complete LCA***
Minutes	*Hours*	*Days*	*Months*

- **Step 2:** Seek single measure of stress – energy or CO_2

(ou consumo de água = “pegada hídrica”)

- **Step 3:** Separate life-phases



- Why energy or CO_2?
  - **Kyoto Protocol (1997): international agreement to reduce greenhouse gasses**
  - **EU directives such as the EuP directive (2006)**
  - **Practicality:** CO_2 and Energy are related and understood by the public

- ***Cars: use-energy and CO_2 cited***

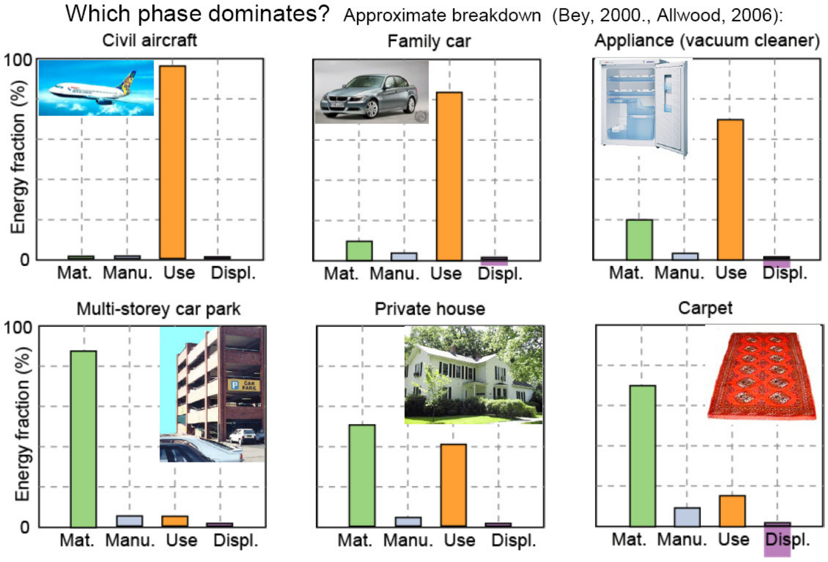
Appliances: use-energy cited

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

Efficiency rating: A
Volume 0.3 m³
330 kWhr / year

Energy consumption of products

Which phase dominates? Approximate breakdown (Bey, 2000., Allwood, 2006):

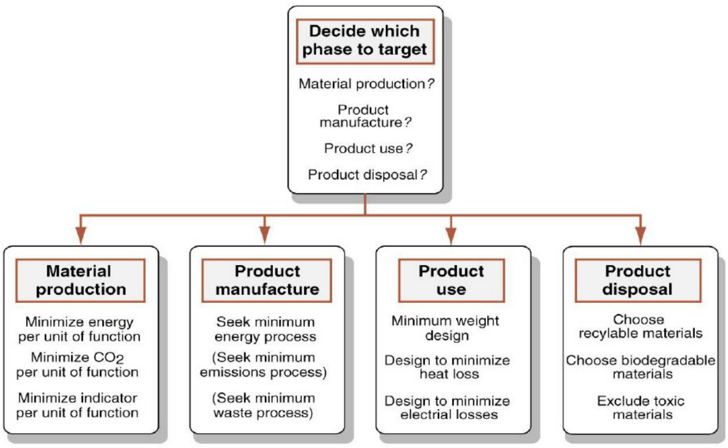


Strategies

- What should strategic tools do?
- Example: drink containers

- Aims:
  - to assess energy or CO_2 burden quickly and cheaply
  - to explore alternatives

Strategies



Rational design for the environment starts with an analysis of the phase of life to be targeted. This decision then guides the method of selection to minimize the impact of the phase on the environment.

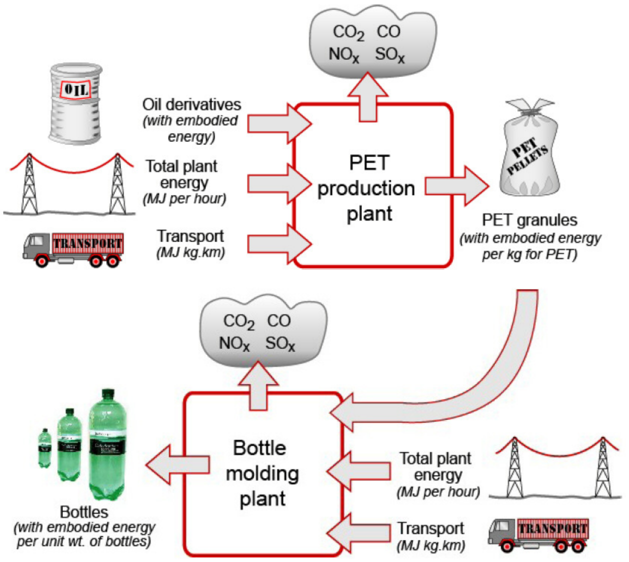
Eco-evaluation

PET bottle

- Separate the phases of life
  1. Material production: the embodied energy
  2. Bottle manufacture: the processing energy
  3. Delivery and use: transport and refrigeration
  4. Disposal: collection, recycling, energy recovery
- To assess, need both *local and generic data.*

From: Ashby, M.F.; Shercliff, H.; Cebon, D. – Materials, engineering, science, processing and design

Embodied energy



Generic data

Material energy MJ / kg
- Database of embodied energies for materials

Process energy MJ / kg
- Database of processing energies for materials

Transport, MJ / tonne.km

Sea freight	0.11 – 0.15
Barge (river)	0.75 – 0.85
Rail freight	0.80 – 0.9
Truck	0.9 – 1.5
Air freight	8.3 – 15

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Use energy and disposal

1. Material production: the **embodied energy**

2. Bottle manufacture: the **processing energy**

3. Delivery and use: **transport and refrigeration**

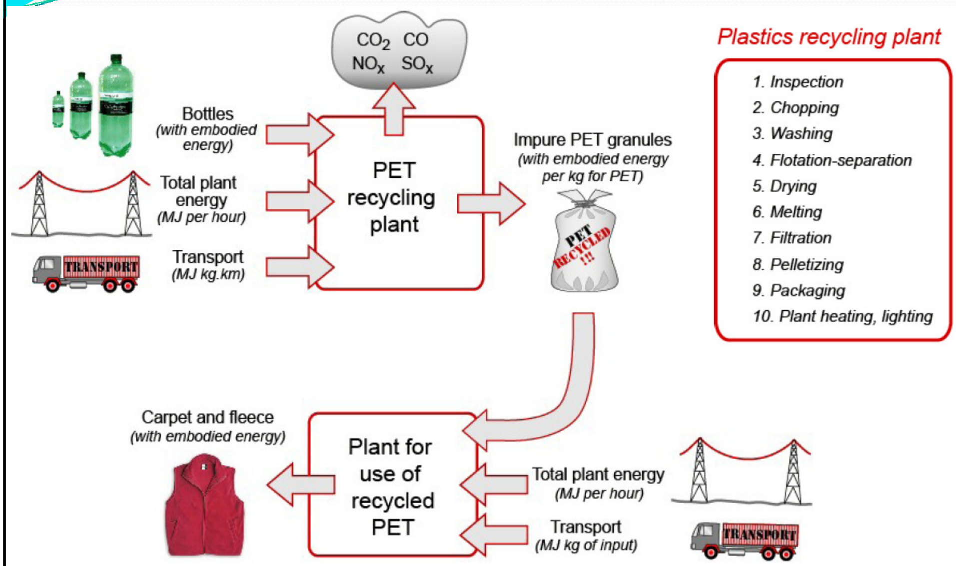
4. Disposal: **collection, recycling, energy recovery**

Generic data

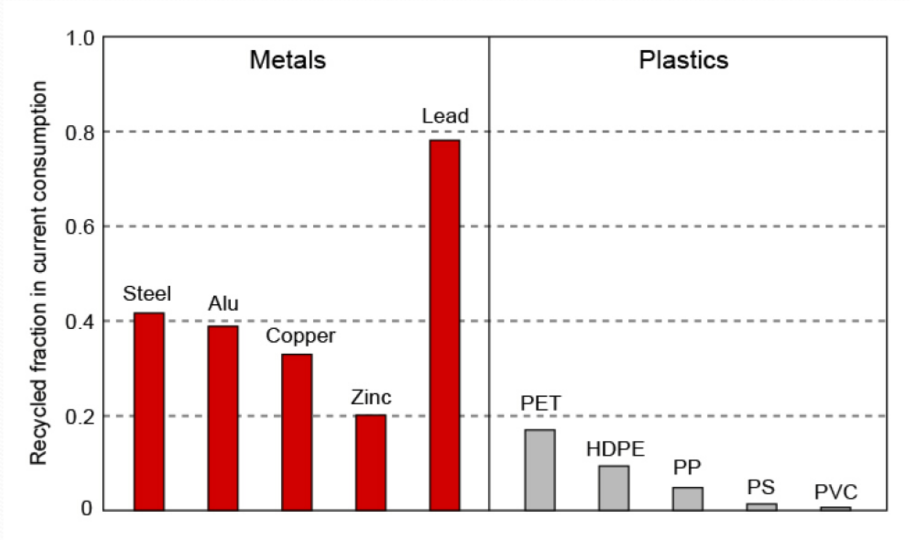
Transport, MJ / tonne.km
- As before

Refrigeration, MJ/m³.day
- Refrigeration (4°C) 10.5
- Freezing (-5°C) 13.0

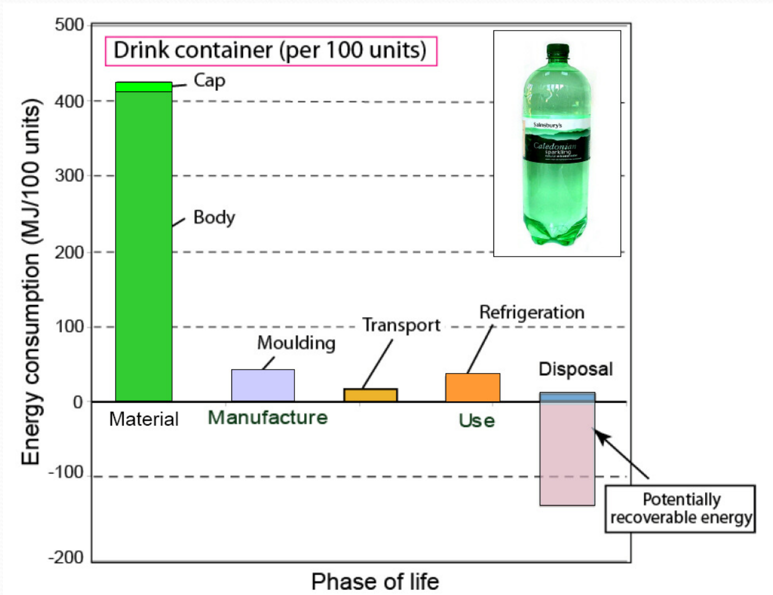
Disposal / Recycling – the problems



Disposal / Recycling



Energy breakdown for PET bottle



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Embodied energy for unity of function

Function: ***contain 1 litre of fluid***

	Glass	PE	PET	Aluminum	Steel	
Mass	325	38	25	**20**	45	**g**
Mass/litre	433	38	62	45	102	**g/litre**
Emb. energy	**14**	80	84	200	23	**MJ/kg**
Energy/litre	8.2	3.2	5.4	9.0	**2.4**	**MJ/litre**

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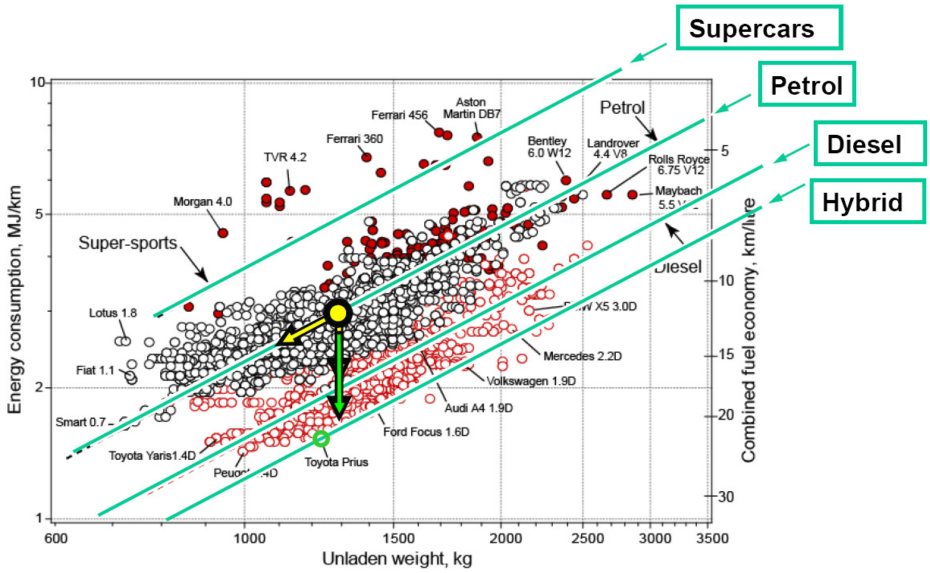
Cars



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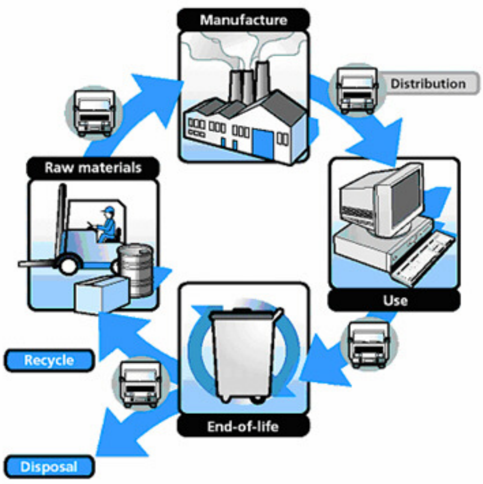
What is eco-design?

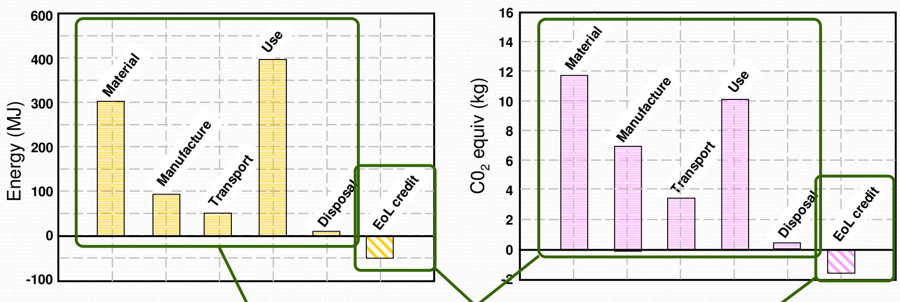
- Costs and impacts across the life cycle
- Resource productivity
  - Get more out with fewer inputs and less waste
- Less hazardous materials/wastes
- Marketing benefits



Eco-audit design

Need: Fast **Eco-audit** with sufficient precision to guide decision-making

- **1 resource** – ***energy*** ***(oil equivalent)*** **1 emission** – ***CO_2 equivalent***
- **Distinguish life-phases**

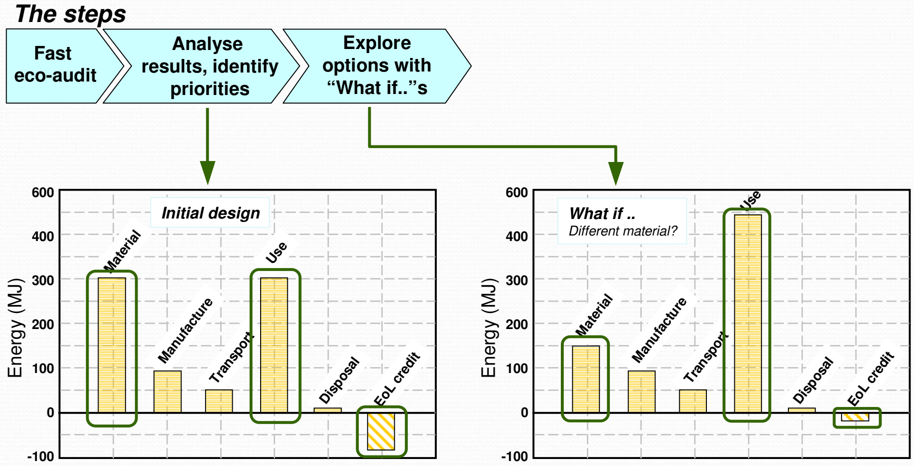


This is the life-energy and life-CO_2
(as prescribed in ISO 14040 and PAS 2050)

These are potential benefits
(could be recovered at end of life)

Eco-aware design: the strategy (1)

The steps

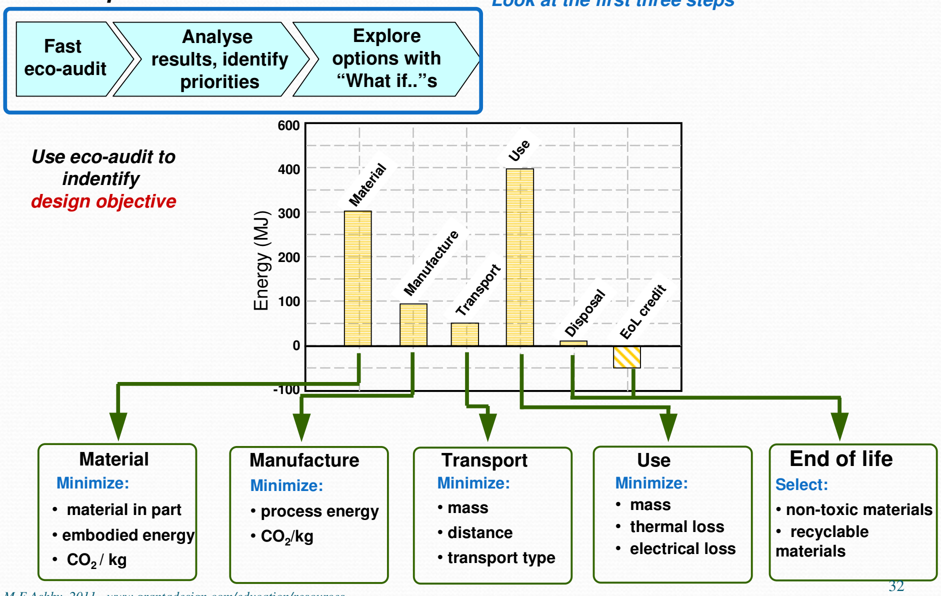


Eco-aware design: the strategy (2)

The steps

Look at the first three steps

Use eco-audit to indentify design objective



The main points

Scoping LCA gives quick, approximate "portrait" of energy / CO_2 burden of products. A practical tool for assessing eco-burden and guiding (re)-design.

Separate the life-phases

- Material
- Manufacture
- Use
- Disposal

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

Consider system dependence

- Optimise within one concept
- Explore alternative concepts

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The CES Eco-audit tool

User inputs

User interface

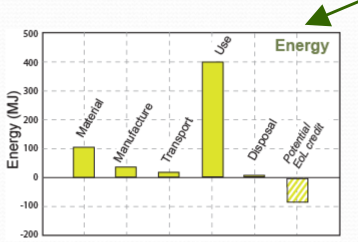
- ***Bill of materials***
- ***Manufacturing process***
- ***Transport needs***
- ***Duty cycle***
- ***End of life choice***

Data from CES

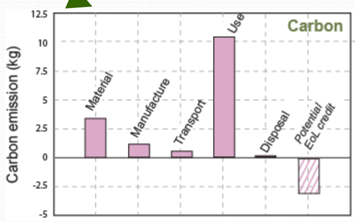
Eco database

- ***Embodied energies***
- ***Process energies***
- ***CO_2 footprints***
- ***Unit transport energies***
- ***Recycling / combustion***

Eco audit model



Outputs
(including tabular data)



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Jug kettle

2 kW jug kettle

- Made SE Asia
- Air freight to UK
- Life: 3 years

Bill of materials and processes

Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	End of life
1	Kettle body	Polypropylene (PP)	Virgin (0%)	0.86	Polymer molding	Recycle
1	Heating element	Nickel-chromium alloys	Virgin (0%)	0.026	Wire drawing	Recycle
1	Casing, heating element	Stainless steel	Virgin (0%)	0.09	Rough rolling, forging	Recycle
1	Internal insulation	Alumina	Virgin (0%)	0.03	Incl. in material value	Landfill
1	Thermostat	Copper alloys	Virgin (0%)	0.02	Rough rolling, forging	Recycle
1	Plug body	Phenolics	Virgin (0%)	0.037	Polymer molding	Landfill
1	Plug pins	Brass	Virgin (0%)	0.03	Extrusion, foil rolling	Recycle
1	Cable sheath, 1 meter	Natural rubber (NR)	Virgin (0%)	0.06	Polymer molding	Landfill
1	Cable core, 1 meter	Copper	Virgin (0%)	0.015	Wire drawing	Recycle
1	Packaging, foam	Rigid Polymer Foam (MD)	Virgin (0%)	0.015	Polymer molding	Landfill
1	Packaging, cardboard	Paper and cardboard	Virgin (0%)	0.125	Incl. in material value	Recycle
1	Residual components	Polycarbonate (PC)	Virgin (0%)	0.04	Polymer molding	Downcycle

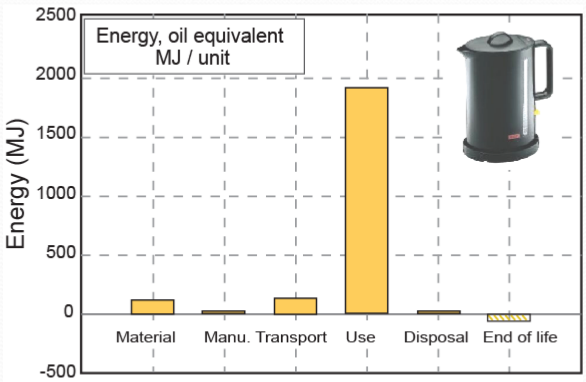
Transport

- 12,000 km, air freight
- 250 km 14 tonne truck

Use

- 6 minutes per day
- 300 days per year
- 3 years

Eco-audit: jug kettle



What do we learn?

- **Little gained by change of material for its own sake**
- **Much gained by insulation – double wall with foam or vacuum**
- **Or make hot water on the fly – only as much as needed**

Susteinability

ENVIRONMENTAL CARE
(**P**LANET)

+

ECONOMIC VIABILITY
(**P**ROFIT)

+

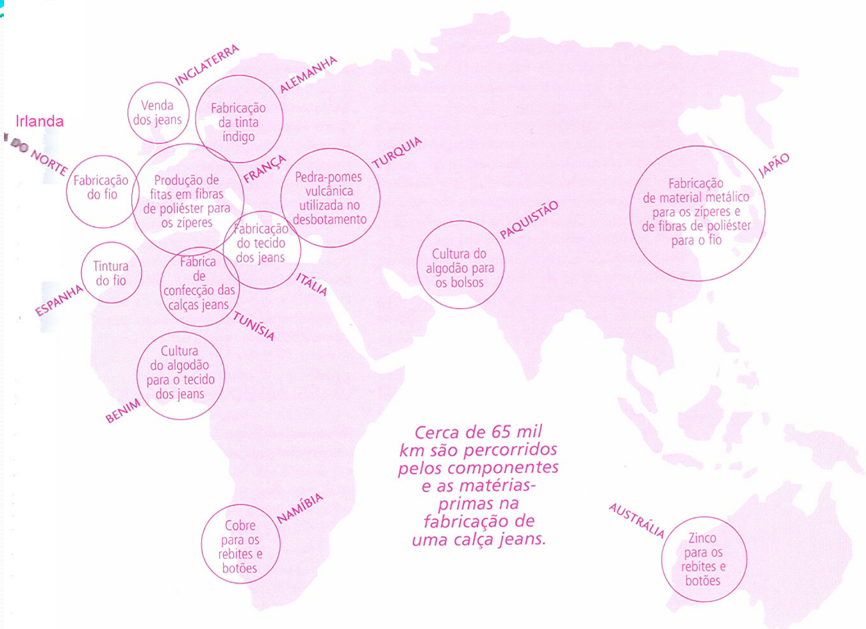
SOCIAL RESPONSIBILITY
(**P**EOPLE)

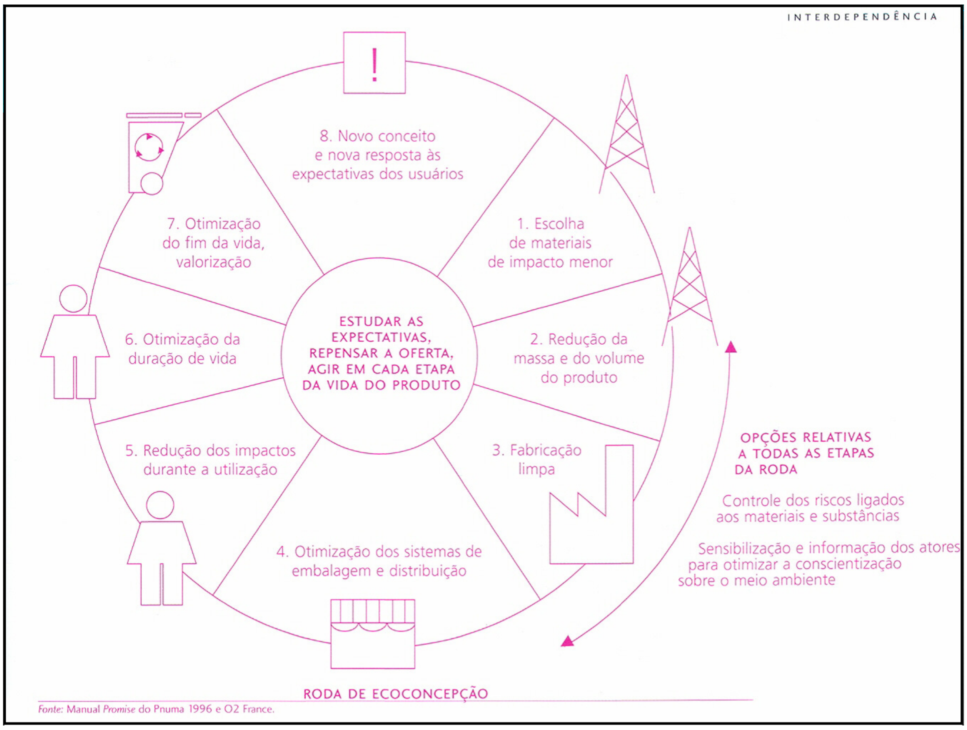
Em português: desenvolvimento sustentável
Em francês: développement durable

A VOLTA AO MUNDO NA FABRICAÇÃO DE UMA CALÇA JEANS

Fonte: Fran Abrams & James Asill, "Le tour du monde d'un jeans", em *Courrier International*, 2-22 de agosto de 2001.

(...Lee, vendido no UK...)





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