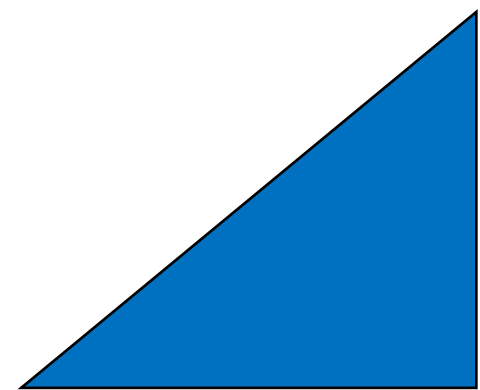




Materiais e Desenvolvimento Sustentável

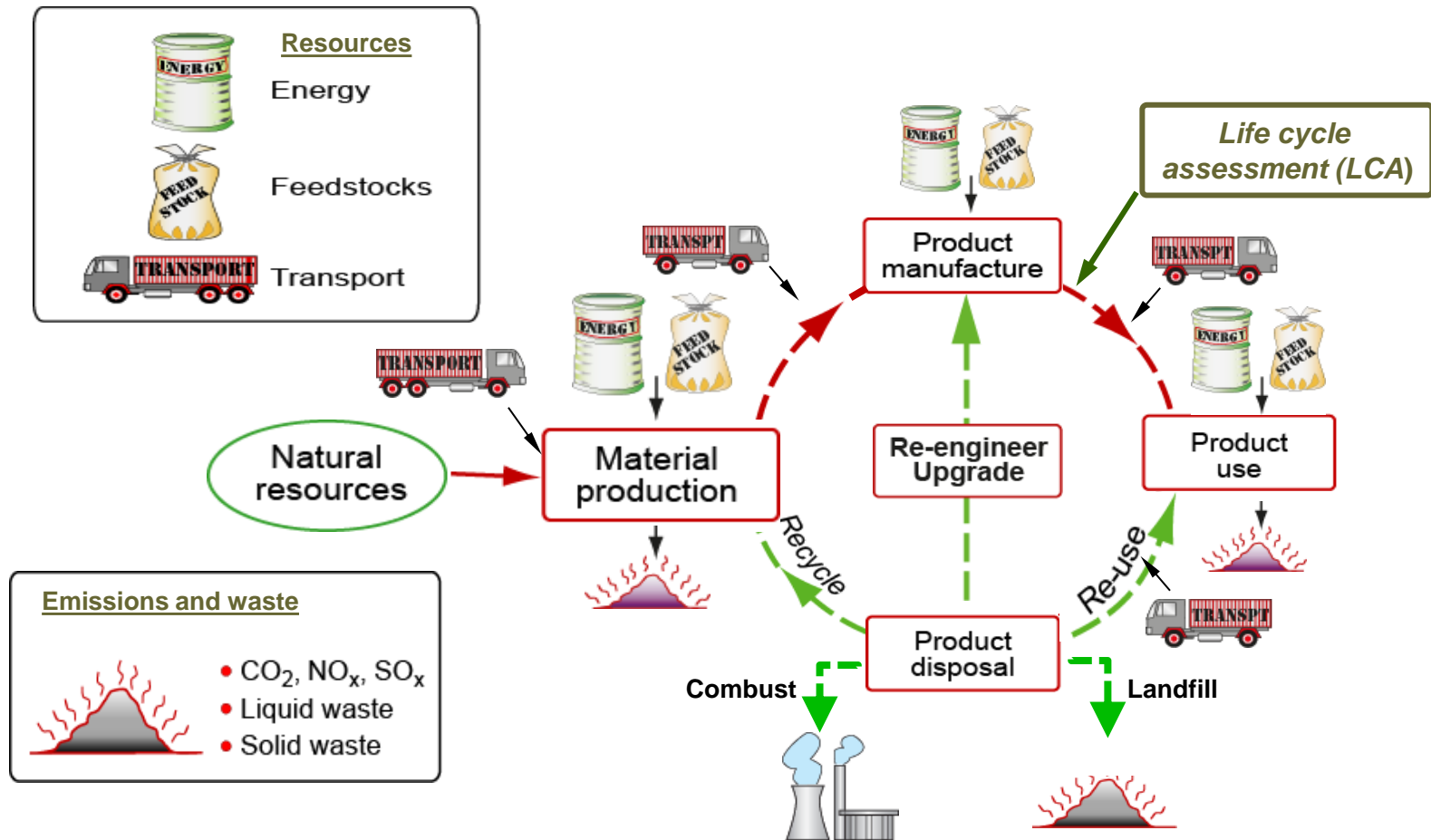
Auditoria ecológica

42295
2024/2025



Auditoria ecológica

Ciclo de vida do produto



Auditoria ecológica

Life cycle assessement (LCA)

ISO 14040 – Sistema de gestão ambiental

de gestão ambiental

Resultados típicos de um LCA		
Latas de alumínio, por 1000 units		
Consumo de recursos	• Bauxite	59 kg
	• Oil fuels	148 MJ
	• Electricity	1572 MJ
	• Energy in feedstock	512 MJ
	• Water use	1149 kg
Inventário das emissões	• 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
Avaliação de impacto	• Ozone depletion potential	0.2 X 10 ⁻⁹
	• Global warming potential	1.1 X 10 ⁻⁹
	• Acidification potential	0.8 X 10 ⁻⁹
	• Human toxicity potential	0.3 X 10 ⁻⁹

Qual a situação de cada “eco-indicador” ?

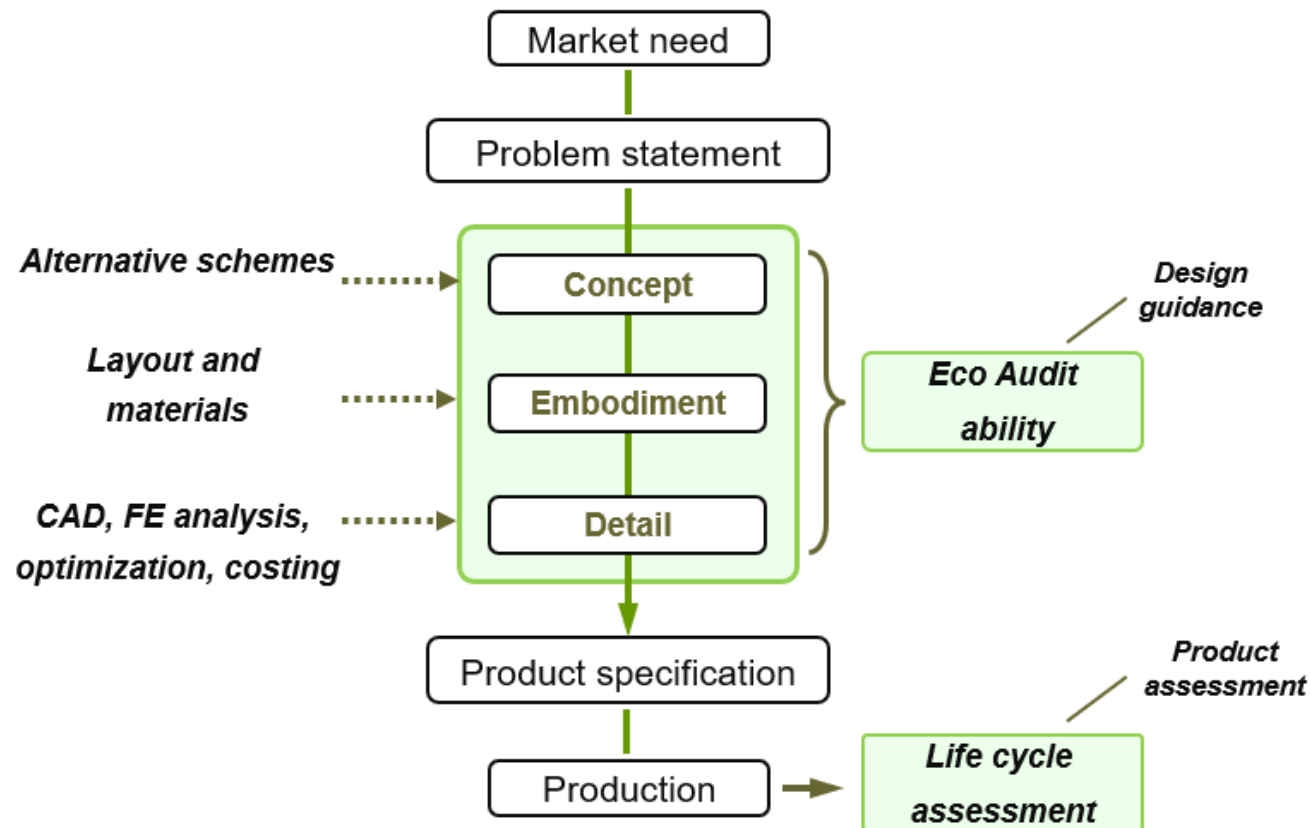
- Uma análise do LCA de um produto/material é um processo que requiere grande **detalhe** e **experiência**, sendo um **processo moroso** e como tal **caro**.

Consensual: o LCA é **inviável** como ferramenta de design de rotina.

Alternativa???

Auditoria ecológica

Design vs análise do produto



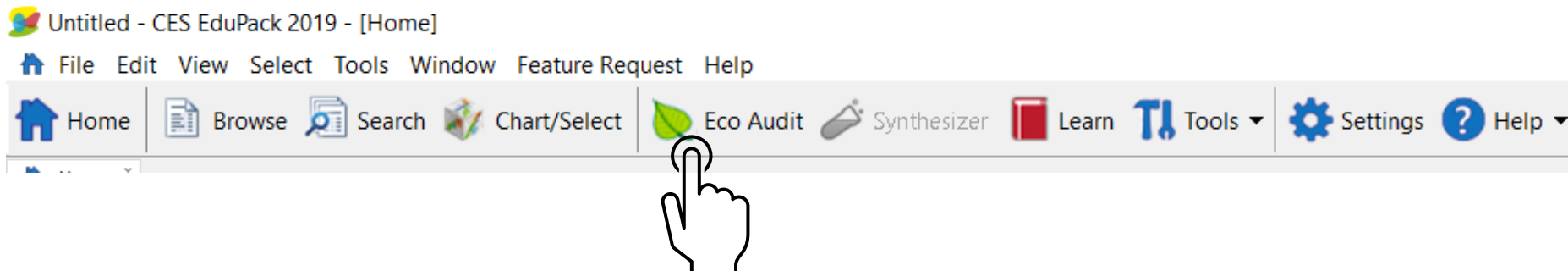
Auditoria ecológica

Desenvolvimento de estratégias para orientar a concepção

Necessidade:

Eco auditoria que combina o custo aceitável com precisão suficiente,
para ajudar na tomada de decisões

Ferramenta Eco Audit (CES EduPack)



Alternativa rápida, mas menos rigorosa do que um LCA!

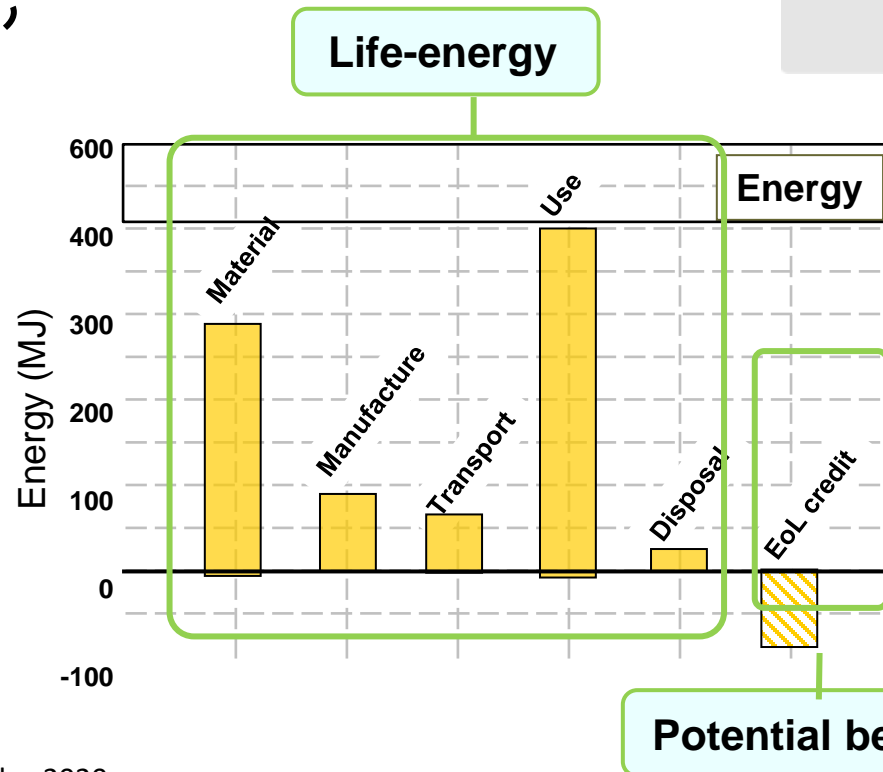
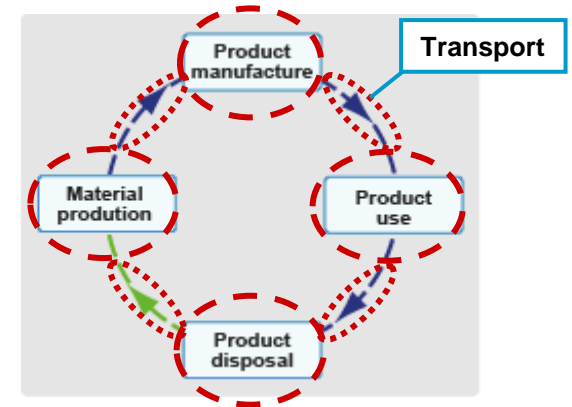
Auditoria ecológica

Ferramenta Eco Audit (CES EduPack)

Opção para guiar um processo de decisão

- 1 resource – **energy** (*oil equivalent*)
- 1 emission – **CO₂** *equivalent*
- Distinguish life-phases

Audit: Energy

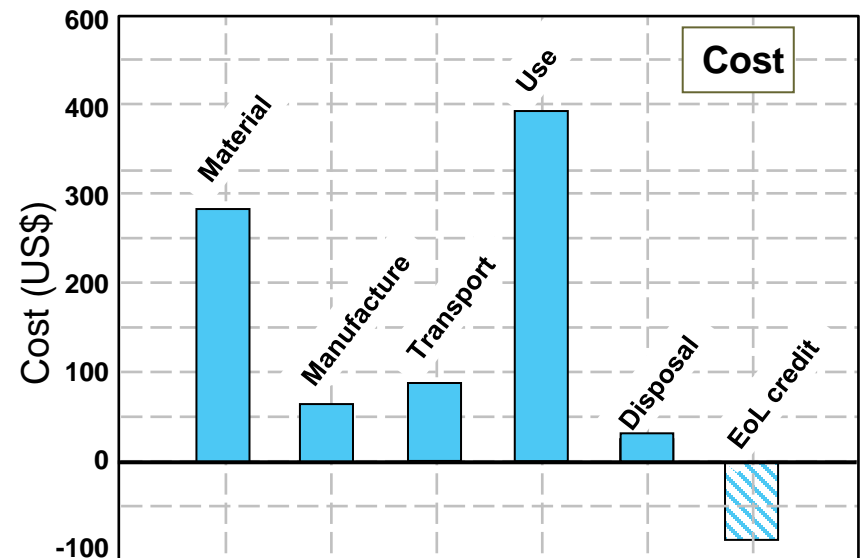
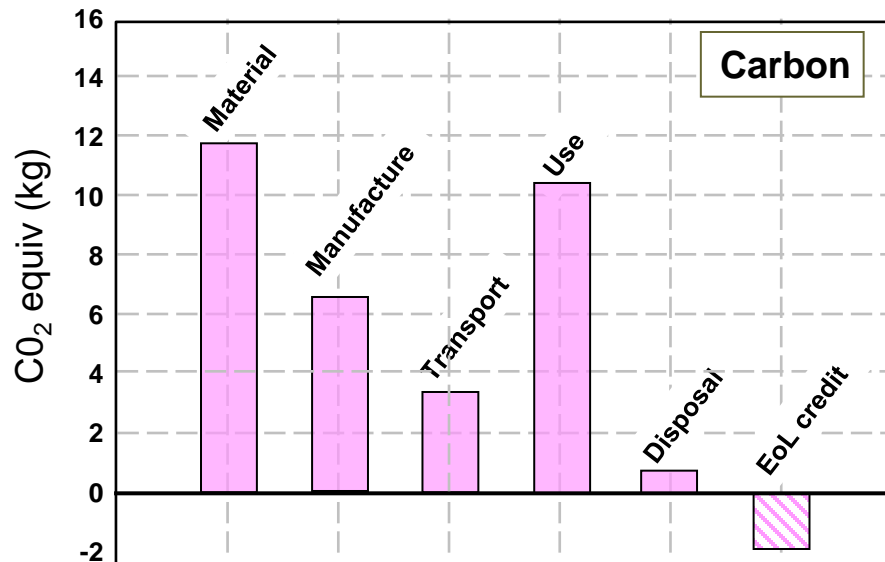


Distinguir as diferentes fases da vida de um produto

Auditoria ecológica

Ferramenta Eco Audit (CES EduPack)

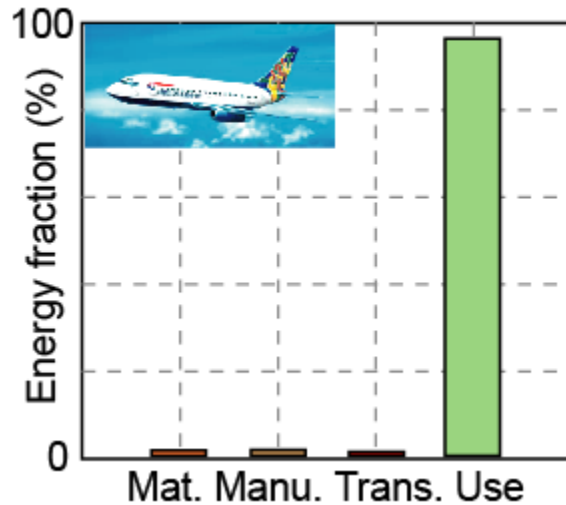
- 1 resource – **energy** (oil equivalent)
- 1 emission – **CO₂** equivalent
- Distinguish life-phases
- Audit: Energy or Cost



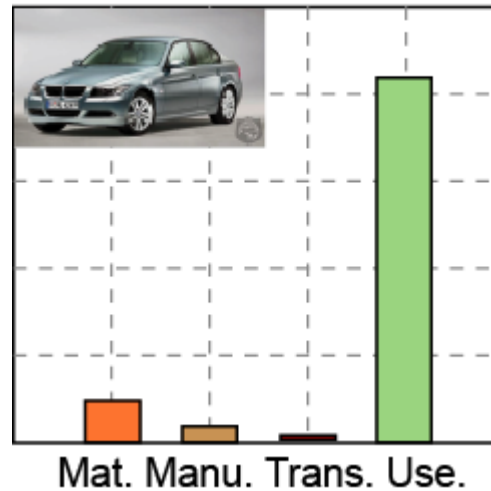
Auditoria ecológica

Grande panorama: consumo de energia dos produtos

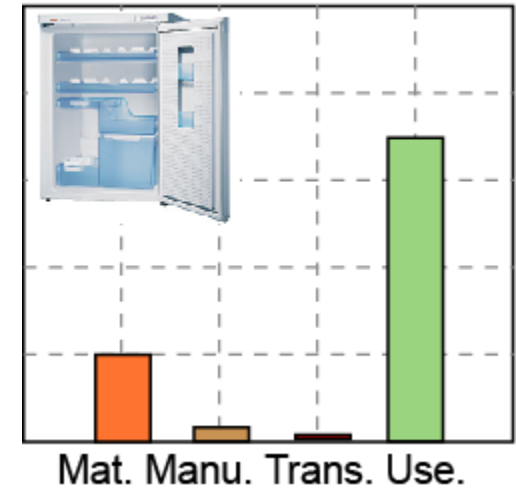
Civil aircraft



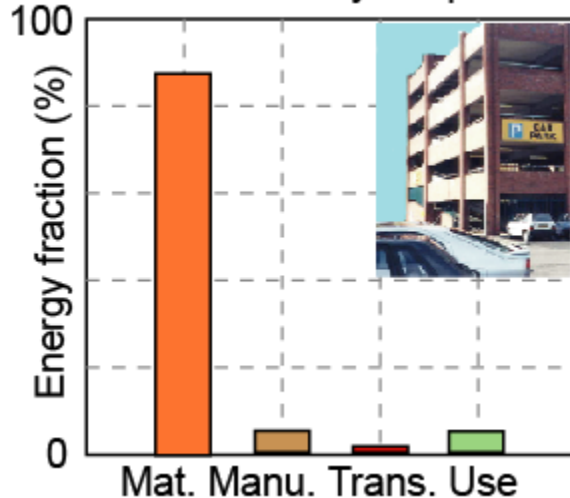
Family car



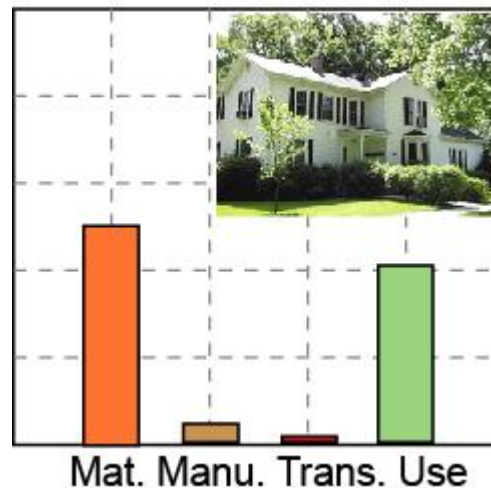
Appliance (refrigerator)



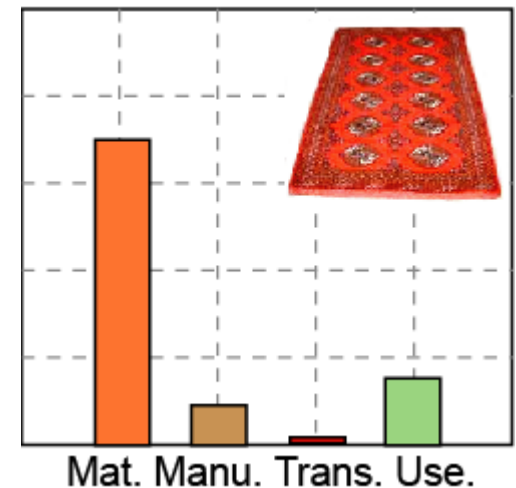
Multi-storey car park



Private house



Fibers (Carpet)



Auditoria ecológica

Representação dos eco dados: energia incorporada

Extração do material

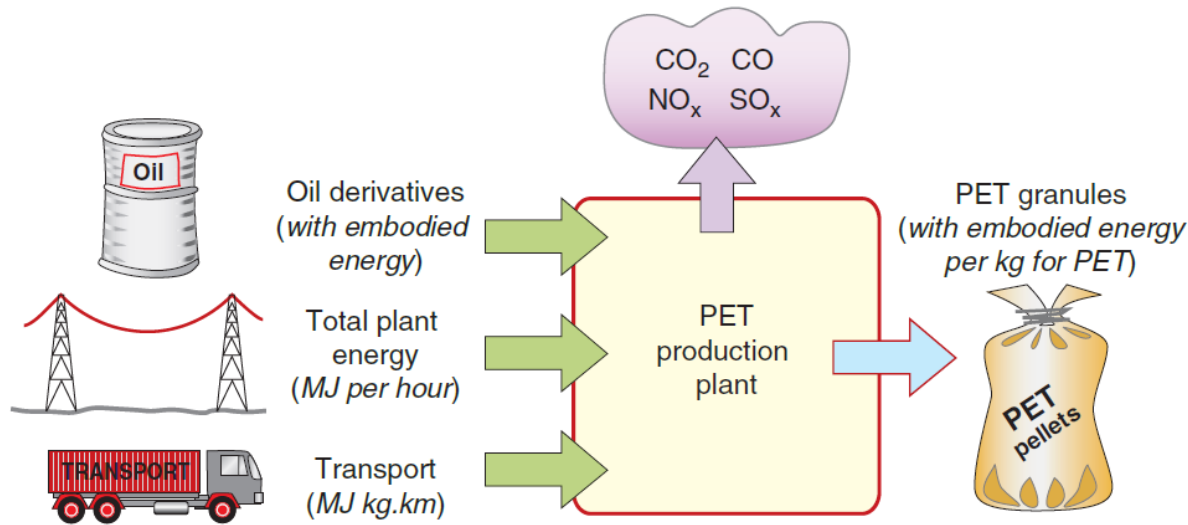


FIGURE 6.1 The idea of embodied energy. Energy, in various forms, enters or is required by the plant. Its output is a material. The energy per kg of usable material is the embodied energy of the material.

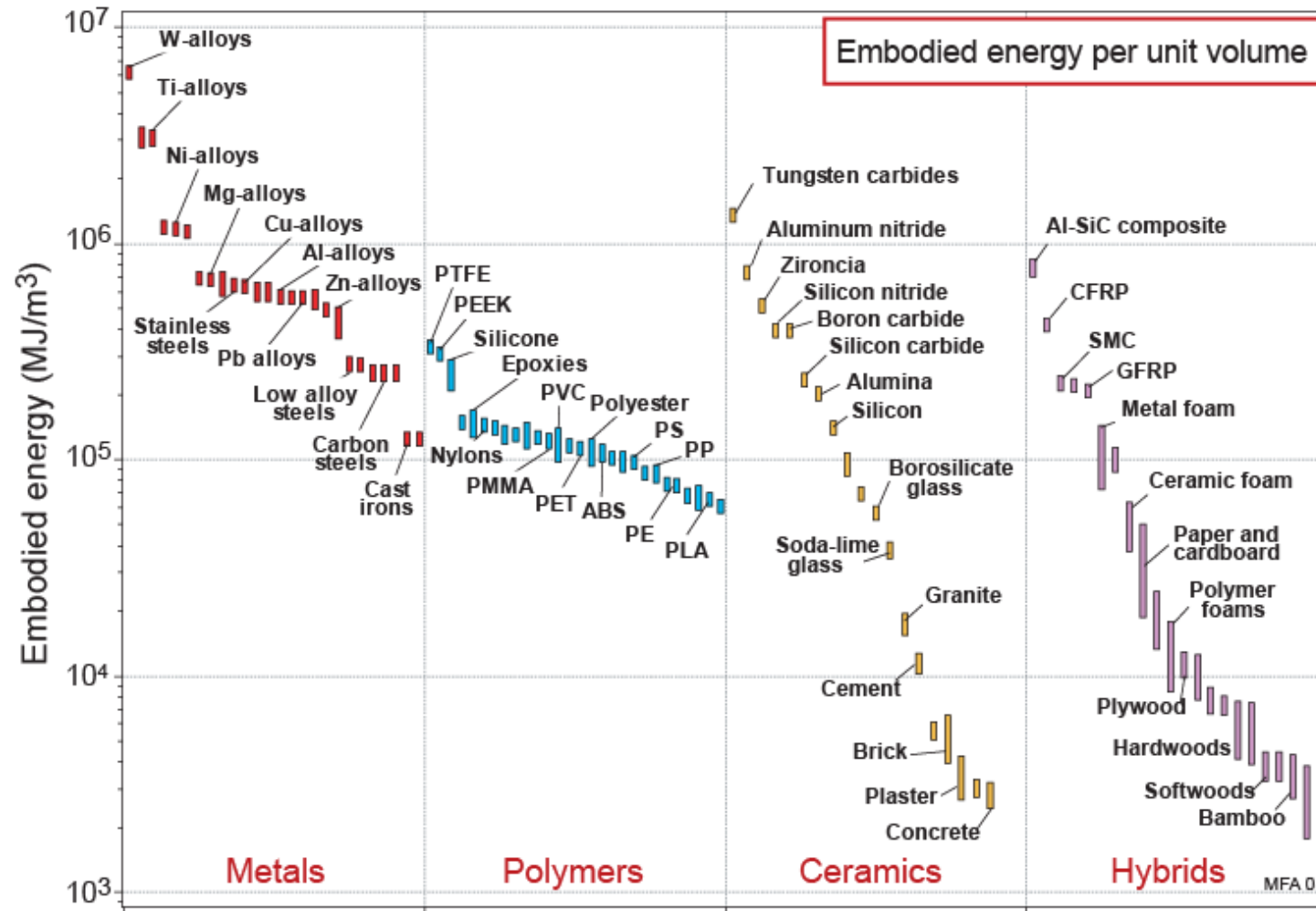
$$\text{Energia incorporada} = \frac{\sum \text{energias que entram na fábrica por hora}}{\text{massa grânulos de PET produzidos por hora}}$$

Energia incorporada primária (primary embodied energy) – soma das energias necessárias para produzir um bem ou serviço (expressa em MJ/kg)

Auditoria ecológica

Representação dos eco dados: energia incorporada

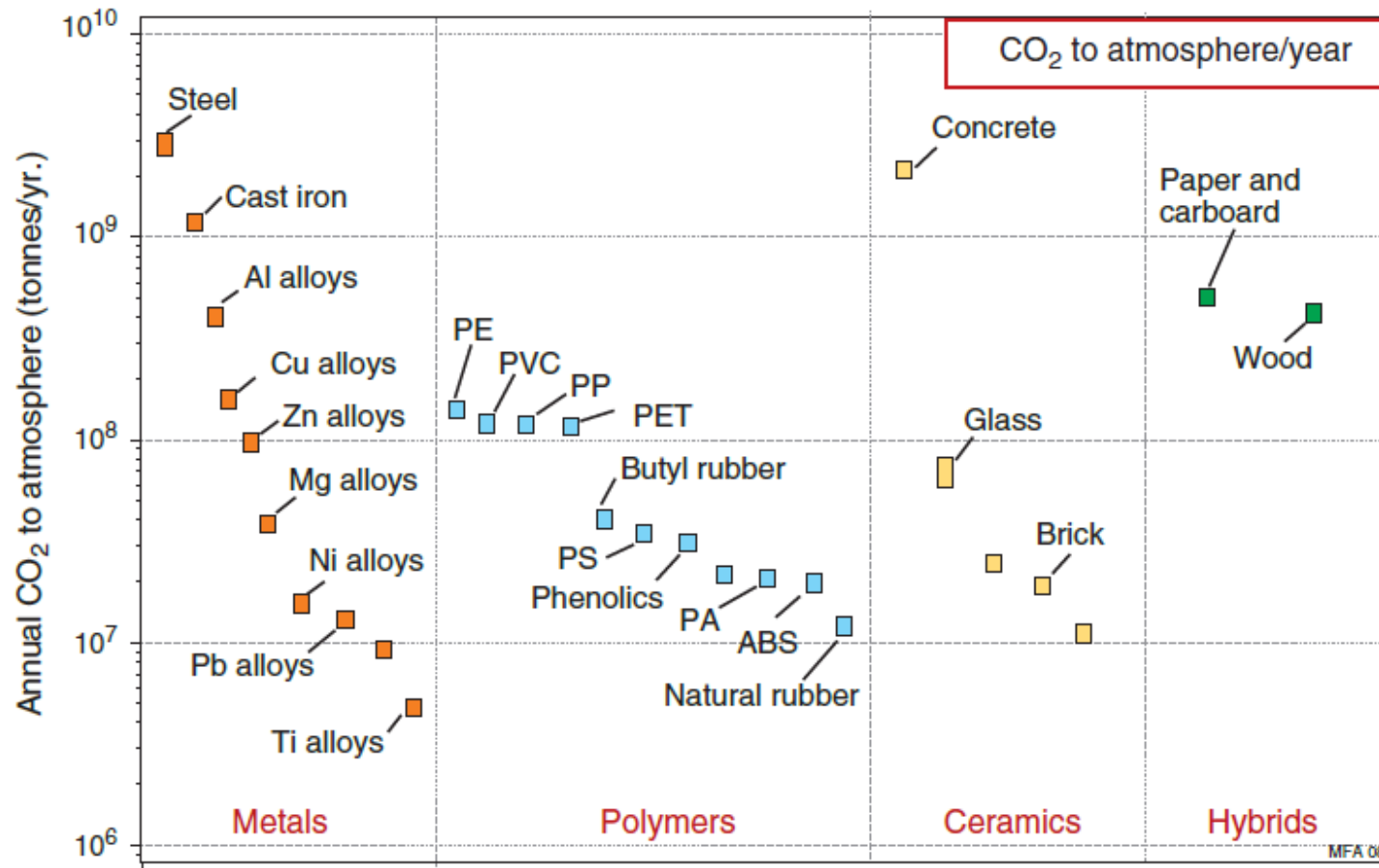
Extração do material



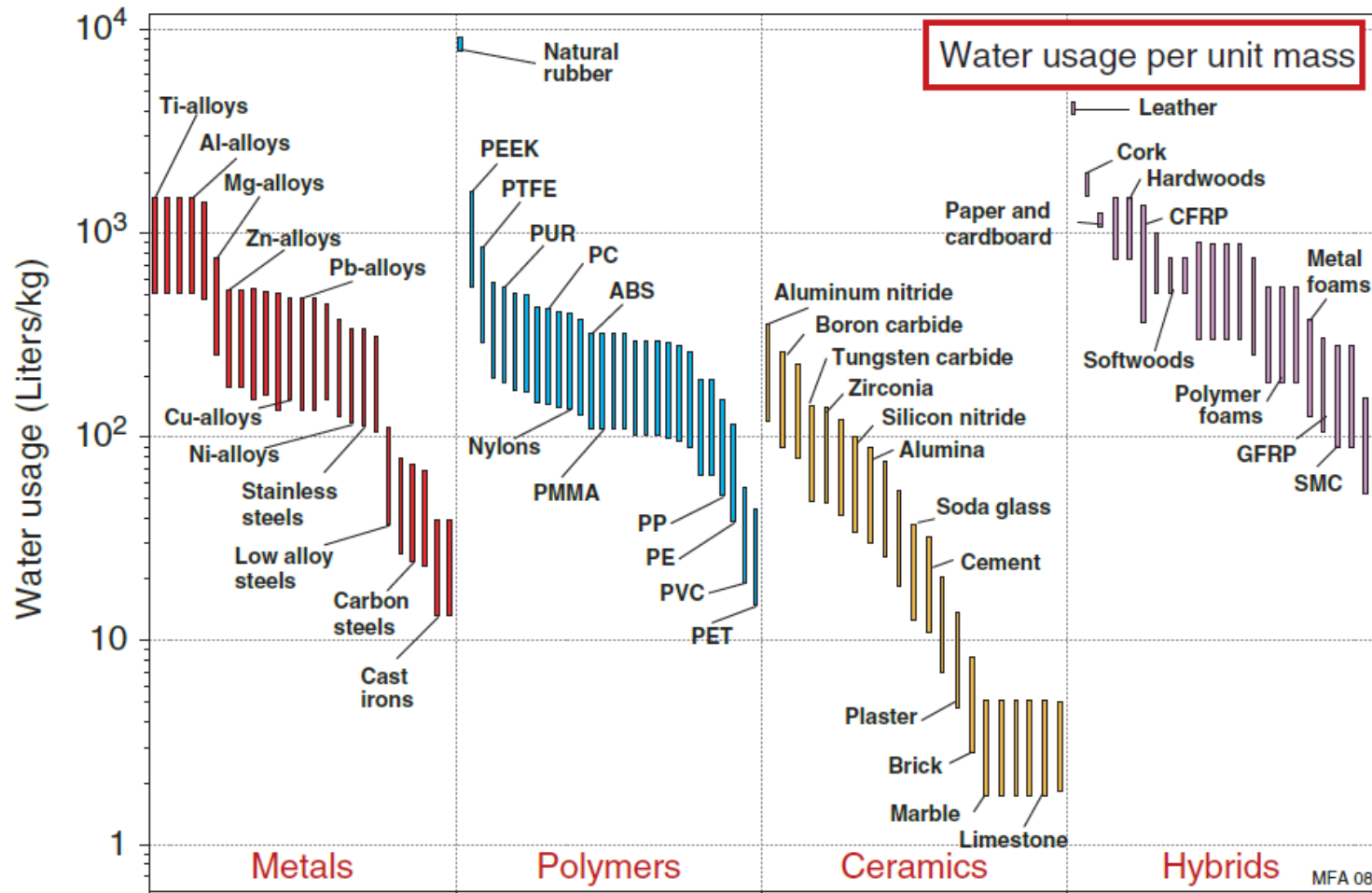
Eco informação no CES EduPack

Extração do material

Representação dos eco dados: Libertação de CO₂ para a atmosfera por ano



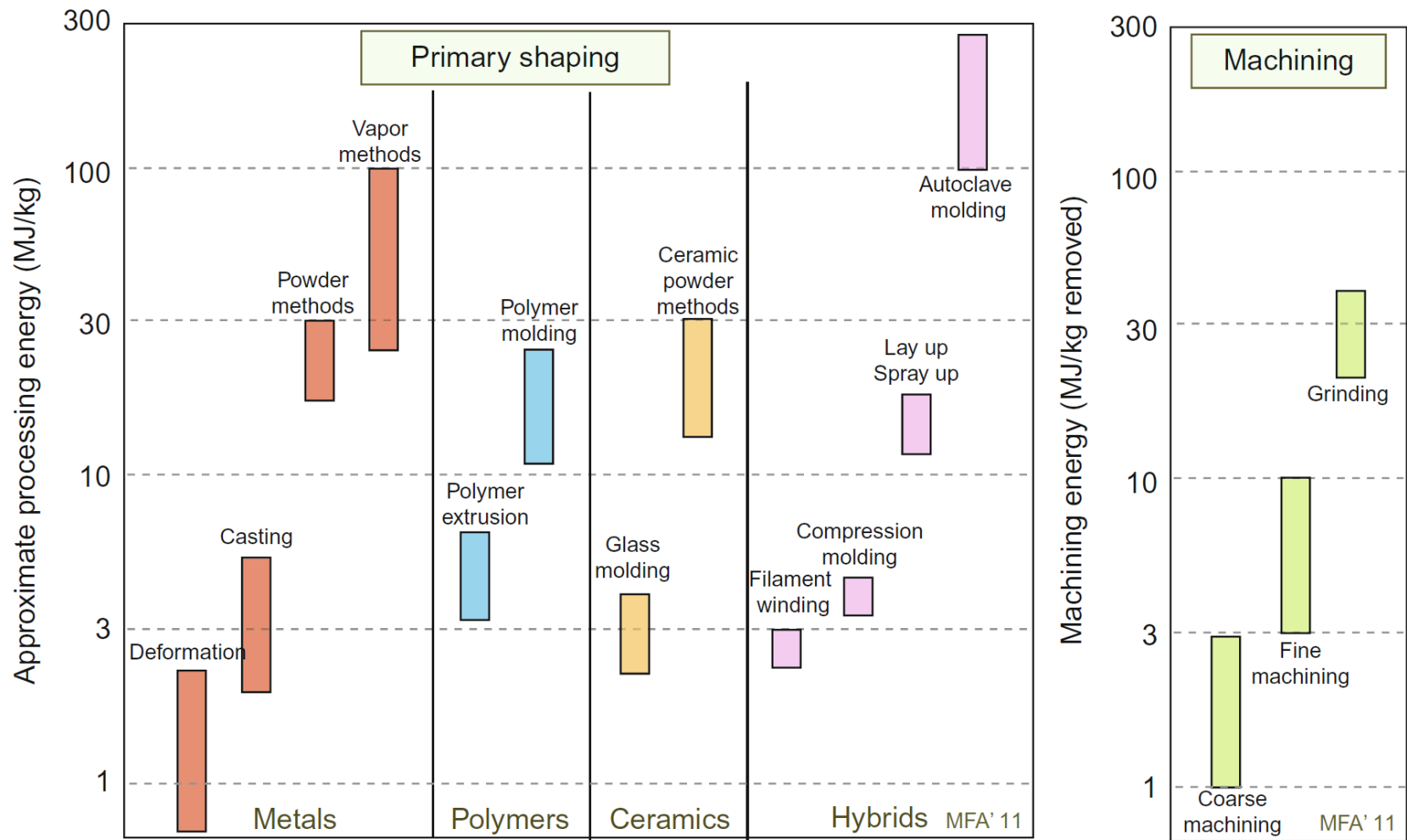
Representação dos eco dados: quantidade de água utilizada por unidade de massa



Eco informação no CES EduPack

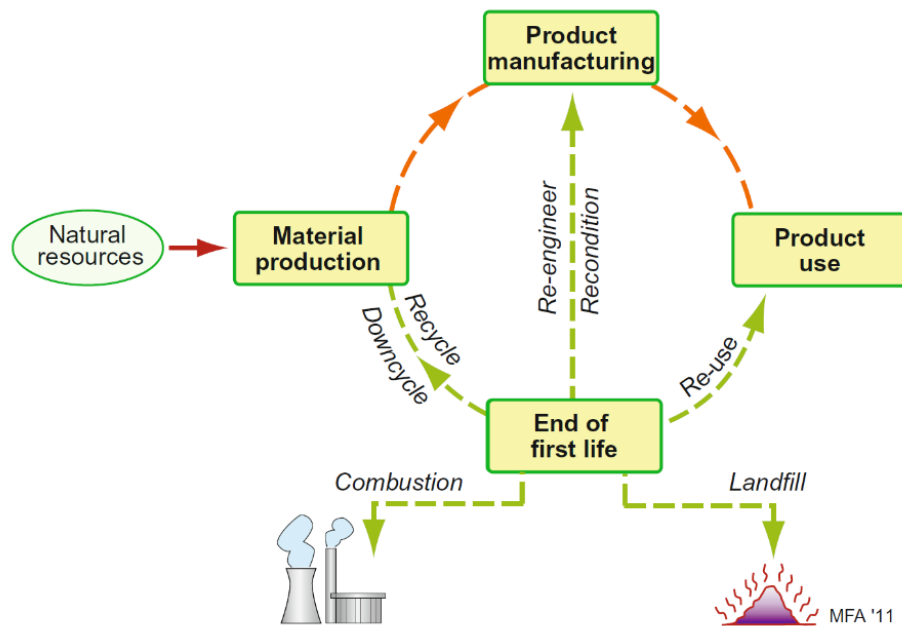
Fabrico do produto

Energia associada ao processamento do produto



Eco informação no CES EduPack

destino no final do ciclo de vida útil

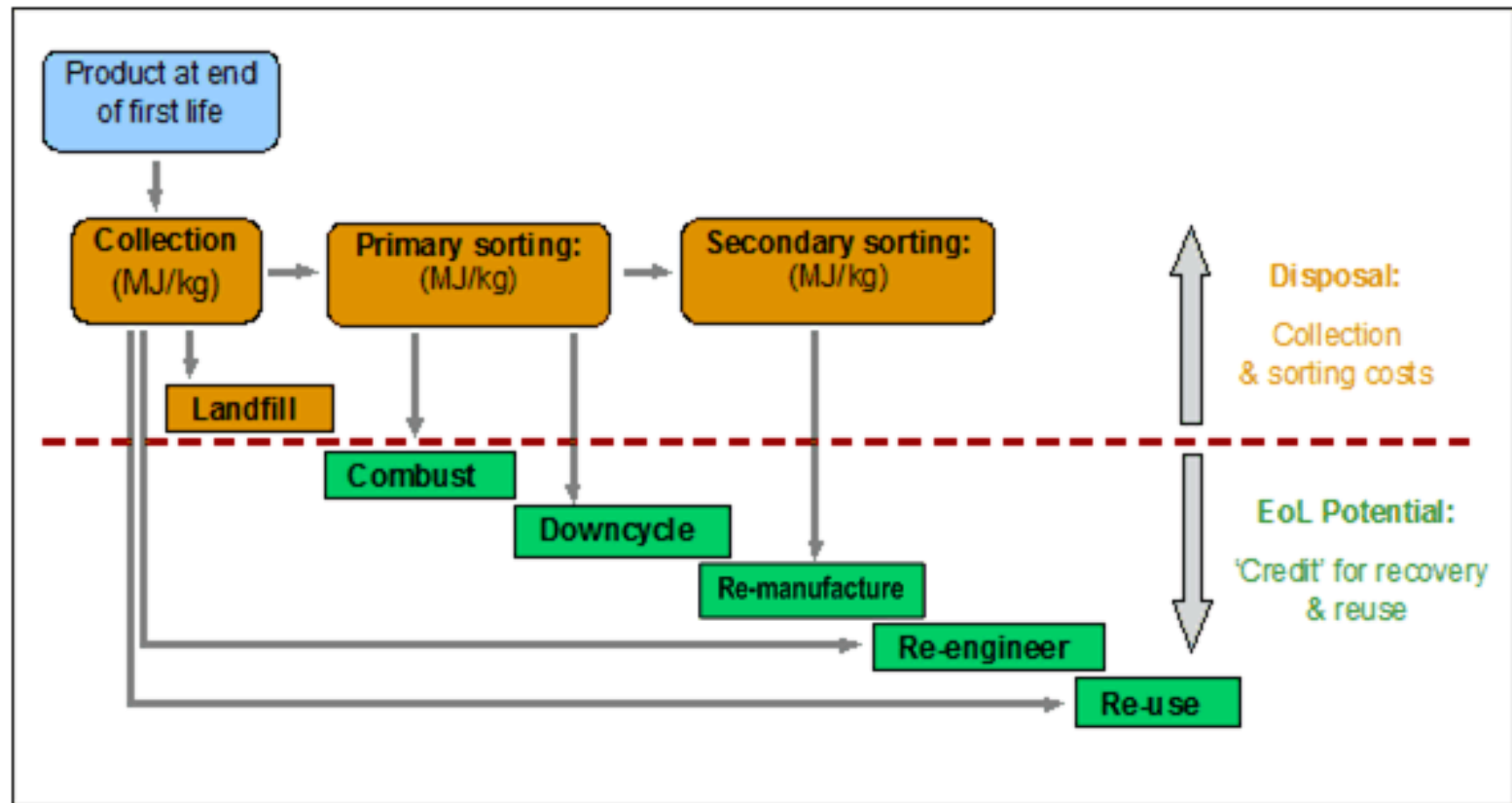


Opção de fim de vida	Descrição	Impacto ambiental
Re-use	Prolongamento da vida do produto por reutilização	Menor
Re-engineer	Utilização do material num novo produto	
Recycle	Reprocessamento do material e sua reutilização na cadeia de produção	
Downcycle	Reprocessamento com perda de qualidade do material e sua reutilização na cadeia de produção	
Combustion	Recuperação do conteúdo calorífico do material	
Landfill	Eliminação do material em aterro	Maior

Eco informação no CES EduPack

destino no final do ciclo de vida útil

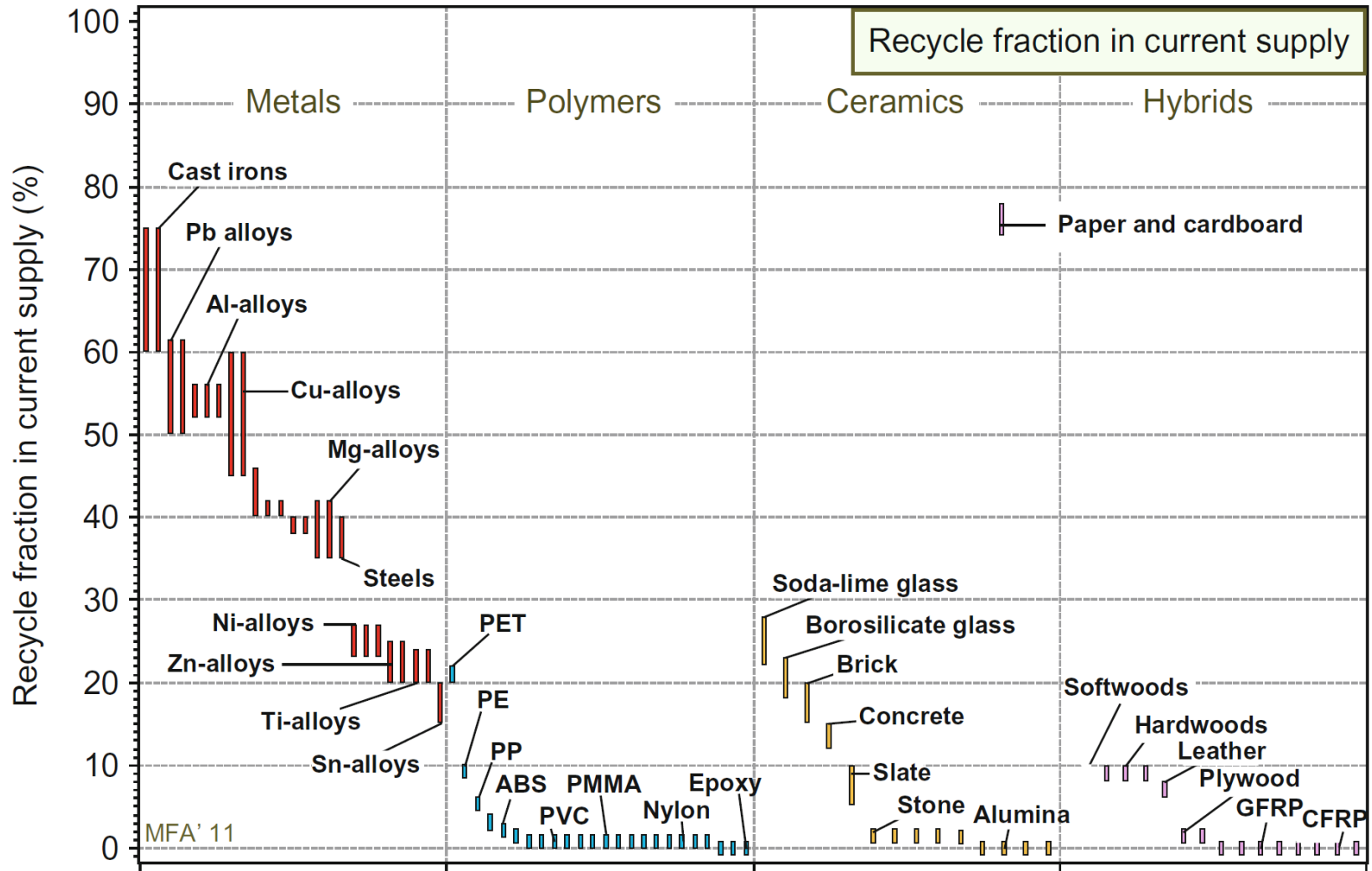
Potencial de fim de vida (*end of life (EoL) potential*) – crédito por reciclar ou reutilizar o material



Eco informação no CES EduPack

destino no final do ciclo de vida útil

Fração reciclada por material



Eco informação no CES EduPack

Science note

Back Forward Copy Print

Eco properties: recycling and disposal

[End of life options.](#)
[Recycling and downcycling.](#)
[Further reading.](#)

End of life options. Materials have a life-cycle. They are extracted and refined, manufactured into products, used, and at end of first life, rejected as “waste”. But what is waste to some markets is a resource to others, creating a number of alternative channels down which the materials continue to flow. Figure 1 introduces the options: commit to landfill, combust for heat recovery, recycle (or downcycle), re-engineer (refurbish or recondition) and reuse. They are not easy to quantify – the last two (re-engineer, re-use) in particular, depend on the nature of the relative cost of goods and labor and on standard of living. One – recycling – can be analyzed, at least approximately. The database contains data for the energy and carbon footprint of recycling and for the fraction of recycled material entering current supply.

Figure 1. The material life-cycle with, superimposed, the end-of-life options.

[Top](#)

Recycling and downcycling. There are two sorts of *scrap*, by which we mean “material with recycle-potential”. *In-house scrap* is the off-cuts, bits and ends left in a material

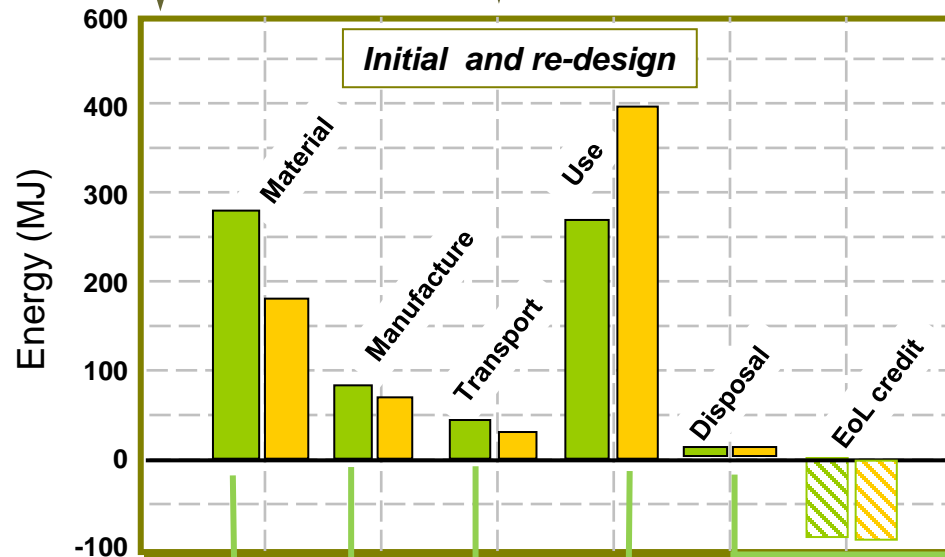
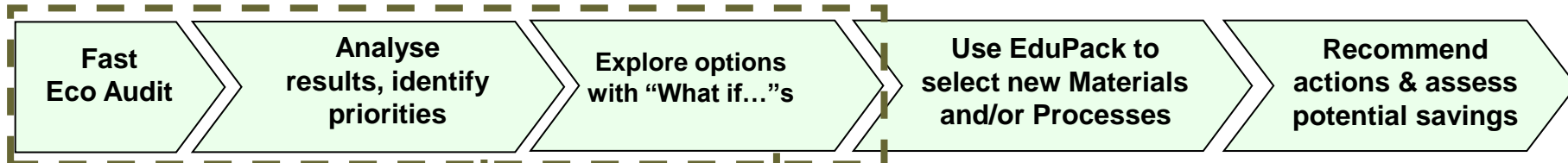
ProcessUniverse

NUM

Auditoria ecológica

Estratégia para a seleção dos materiais

The steps



Duas ferramentas:

- 1) Eco Auditoria***
- 2) Design***

Material

Minimize:

- material in part
- embodied energy
- CO₂/ kg

Manufacture

Minimize:

- process energy
- CO₂/kg

Transport

Minimize:

- mass
- distance
- transport type

Use

Minimize:

- mass
- thermal loss
- electrical loss

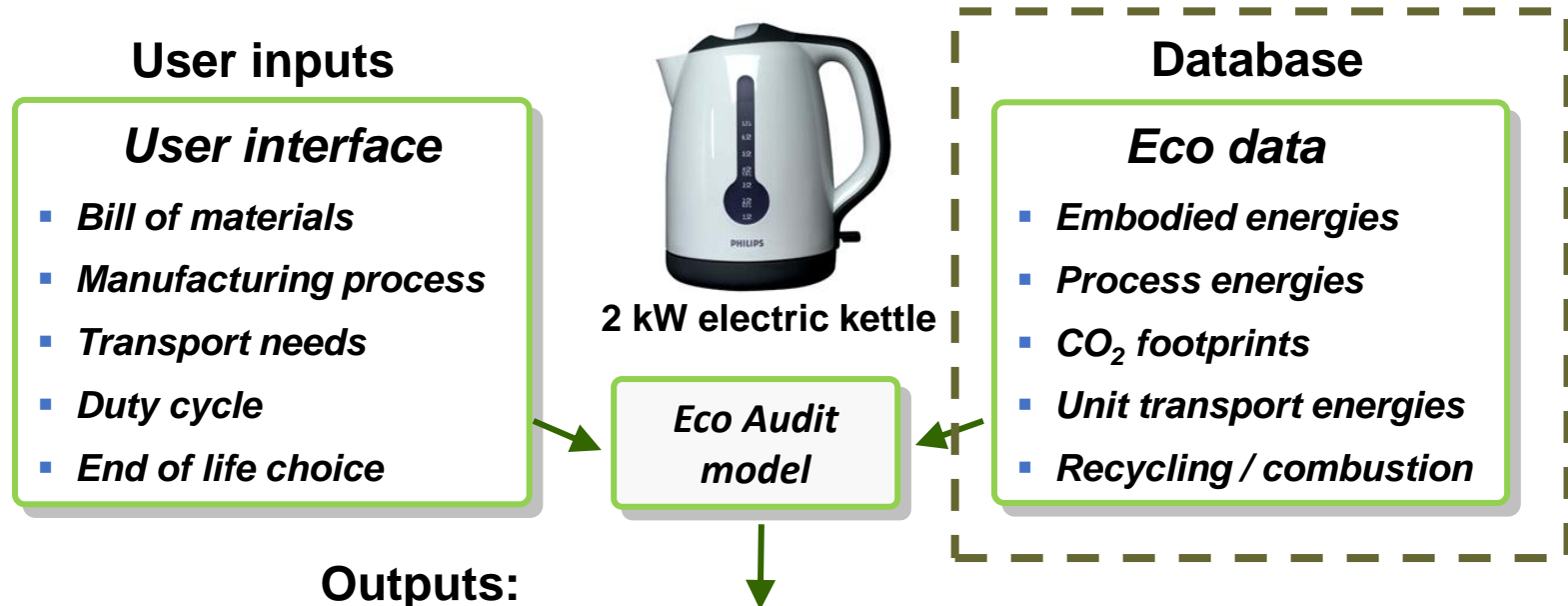
End of Life

Select:

- recyclable materials
- non-toxic materials

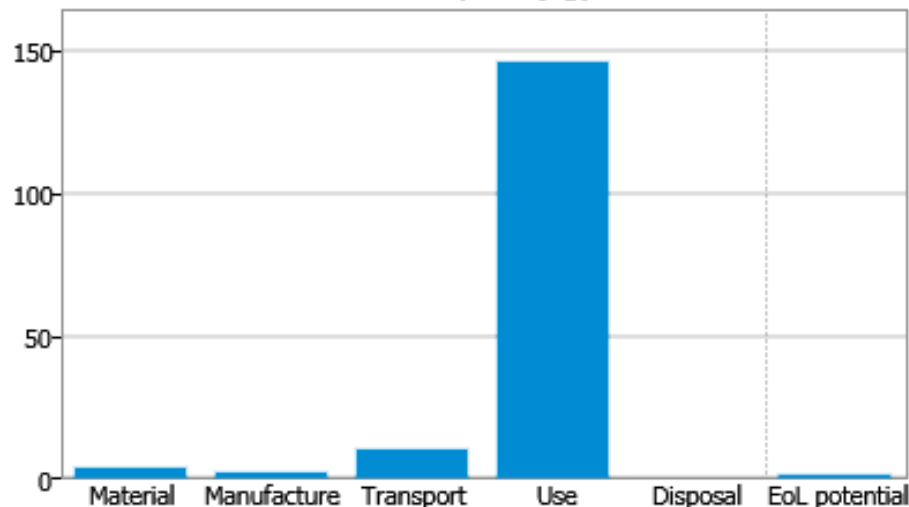
Auditoria ecológica

Ferramenta Eco Audit (CES EduPack)



Outputs:

CO2 Footprint (kg)



Full report

- *Data*
- *Criticality*
- *Hazard*

Auditoria ecológica

Eco dados no CES EduPack

GE :Untitled - GRANTA EduPack 2020 - [MaterialUniverse:\Polymers and elastomers\Polymers\Thermoplastics]

File Edit View Select Tools Window Feature Request Help

Home Browse Search Chart/Select Solver Eco Audit Synthesizer Learn Tools Settings Help

Browse

Database: Level 2 Change...

Table: MaterialUniverse

Subset: All materials

MaterialUniverse

- Ceramics and glasses
- Hybrids: composites, foams, natural materials
- Metals and alloys
- Polymers and elastomers
 - Elastomers
 - Polymers
 - Thermoplastics
 - Acrylonitrile butadiene styrene (ABS)
 - Cellulose polymers (CA)
 - Ionomer (I)
 - Polyamides (Nylons, PA)
 - Polycarbonate (PC)
 - Polyetheretherketone (PEEK)
 - Polyethylene (PE)
 - Polyethylene terephthalate (PET)
 - Polyhydroxyalkanoates (PHA, PHB)
 - Poly lactide (PLA)
 - Polymethyl methacrylate (Acrylic, PMMA)
 - Polyoxymethylene (Acetal, POM)
 - Polypropylene (PP)
 - Polystyrene (PS)
 - Polytetrafluoroethylene (Teflon, PTFE)
 - Polyurethane (tpPUR)
 - Polyvinylchloride (tpPVC)
 - Starch-based thermoplastics (TPS)
- Thermosets

Acrylonitrile butadiene styrene (ABS)

Datasheet view: All properties Show/Hide Find Similar

Geo-economic data for principal component

Annual world production, principal component	8.07e6	tonne/yr
Reserves, principal component	7.13e7 - 7.88e7	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	87.7 - 96.7	MJ/kg
CO2 footprint, primary production	3.27 - 3.61	kg/kg
Water usage	* 167 - 185	l/kg

Material processing: energy

Polymer extrusion energy	* 5.86 - 6.47	MJ/kg
Polymer molding energy	* 19.7 - 21.7	MJ/kg
Coarse machining energy (per unit wt removed)	* 1 - 1.11	MJ/kg
Fine machining energy (per unit wt removed)	* 5.76 - 6.37	MJ/kg
Grinding energy (per unit wt removed)	* 11 - 12.2	MJ/kg

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.439 - 0.485	kg/kg
Polymer molding CO2	* 1.47 - 1.63	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0.0753 - 0.0832	kg/kg
Fine machining CO2 (per unit wt removed)	* 0.432 - 0.477	kg/kg
Grinding CO2 (per unit wt removed)	* 0.828 - 0.916	kg/kg

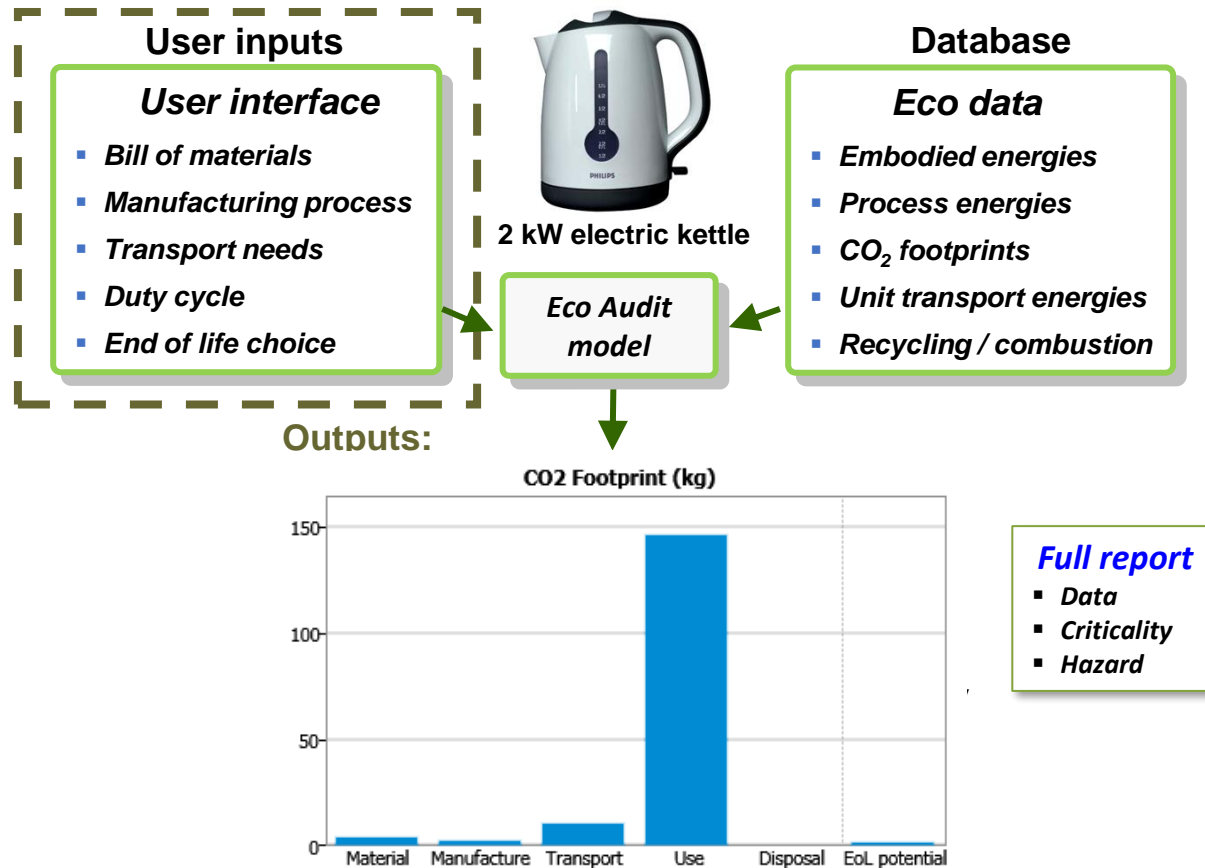
Material recycling: energy, CO2 and recycle fraction

Recycle	✓	
Embodied energy, recycling	* 30.7 - 34	MJ/kg
CO2 footprint, recycling	* 1.17 - 1.29	kg/kg
Recycle fraction in current supply	3.8 - 4.2	%
Downcycle	✓	
Combust for energy recovery	✓	
Heat of combustion (net)	* 37.6 - 39.5	MJ/kg
Combustion CO2	* 3.06 - 3.22	kg/kg
Landfill	✓	
Biodegrade	✗	
Toxicity rating	Non-toxic	
A renewable resource?	✗	

Ready

Auditoria ecológica

Ferramenta Eco Audit (CES EduPack)



Auditoria ecológica

Ferramenta Eco Audit (CES EduPack)

The screenshot shows the GRANTA EduPack 2020 Eco Audit interface. The main window is titled "Eco Audit Project" and contains several sections: "Product definition", "Material, manufacture and end of life", "Transport", and "Use". The "Material, manufacture and end of life" section displays a table of materials and their properties. The "Transport" section shows a table of transport data. The "Use" section contains input fields for product life, country of use, static mode, and mobile mode. The "Report" section at the bottom has buttons for "Summary chart" and "Detailed report".

Annotations:

- Bill of Materials (Input or file):** Points to the "Material, manufacture and end of life" table.
- Help at each step:** Points to the "Eco Audit" button in the top menu bar, the "Compare with..." button, and the "Report" section.
- Useful for what-if?:** Points to the "Compare with..." button.
- > 5wt% critical material:** Points to the "Recycled content" column in the "Material, manufacture and end of life" table.
- End-of-Life:** Points to the "End of life" column in the "Material, manufacture and end of life" table.
- Output data (Detailed info):** Points to the "Detailed report" button.

Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	End of life
1	Kettle body	Polypropylene (PP)	Virgin (0%)	0.86	Polymer molding	Combust
1	Heating element	Nickel-chromium alloys	Virgin (0%)	0.026	Roll forming	Combust
1	Casting, heating element	Stainless steel	Virgin (0%)	0.09	Cast	Combust
1	Cable sheath, 1 meter	Natural rubber (R)	Virgin (0%)	0.06	Polymer molding	Combust
1	Cable core, 1 meter	Copper	Virgin (0%)	0.015	Wire drawing	Recycle
1	Plug body	Phenolics (PH)	Virgin (0%)	0.037	Polymer molding	Combust
1	Plug pins	Brass	Virgin (0%)	0.01	Cast	Recycle
1	Packaging, padding	Rigid Polymer Foam	Virgin (0%)	0.01	Polymer molding	Combust
1	Packaging, box	Paper and cardboard	Virgin (0%)	0.01	Printed	Recycle

- End-of-Life**
 - Landfill
 - Combust
 - Downcycle
 - Recycle
 - Re-manufacture
 - Reuse
 - None

Auditoria ecológica

1º passo: materiais e energia do processo/ CO₂

Component name

Component 1

Material

Aluminum alloys

Process

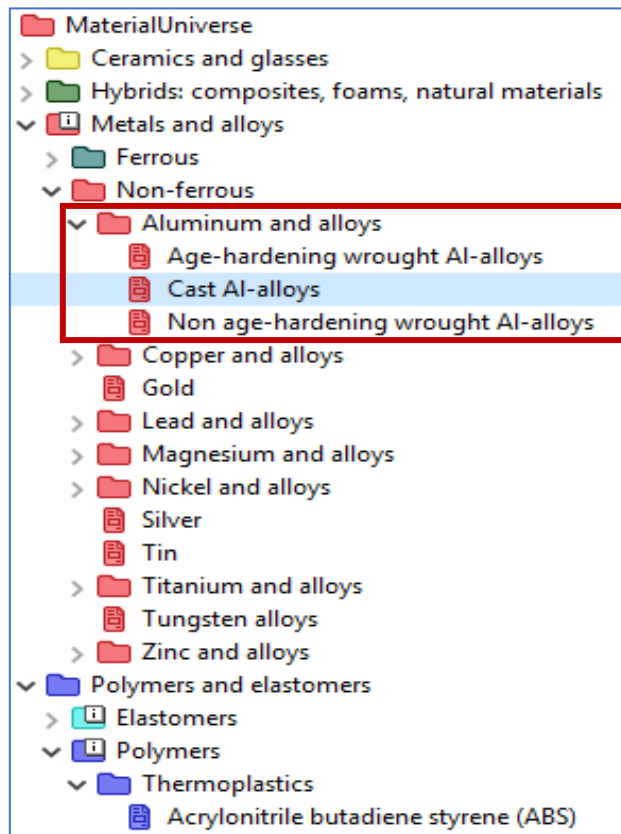
Casting

Mass (kg)

2.3

End of life

Recycle



- Casting
- Forging / rolling
- Extrusion
- Wire drawing
- Powder forming
- Vapor methods

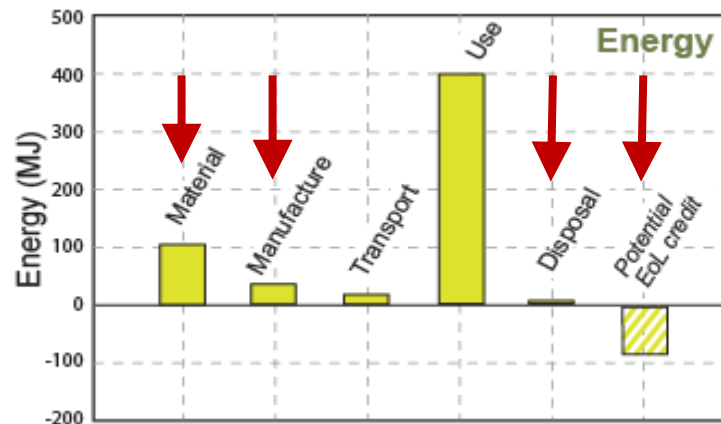
- Landfill
- Downcycle
- Recycle
- Re-manufacture
- Reuse
- None

End of life options

Auditoria ecológica

1º passo: materiais e energia do processo/ CO₂

Component name	Material	Process	Mass (kg)	End of life
Component 1	Aluminum alloys	Casting	2.3	Recycle
Component 2	Polypropylene	Polymer molding	1.85	Landfill
Component 3	Glass	Glass molding	3.7	Reuse
Total embodied energy	Total process energy	Total mass	Total end of life energy	



Auditoria ecológica

2º passo: transporte

Transport stage	Transport type	Distance (km)
Stage 1	32 tonne truck	350
Stage 2	Coastal freight	12 000

Transport energy

Transport CO₂

Coastal freight

River/canal freight

Rail freight

55 tonne (8 axle) truck

40 tonne (6 axle) truck

32 tonne (4 axle) truck

26 tonne (3 axle) truck

14 tonne (2 axle) truck

Light goods vehicle

Air freight - long haul

Air freight - short haul

Helicopter

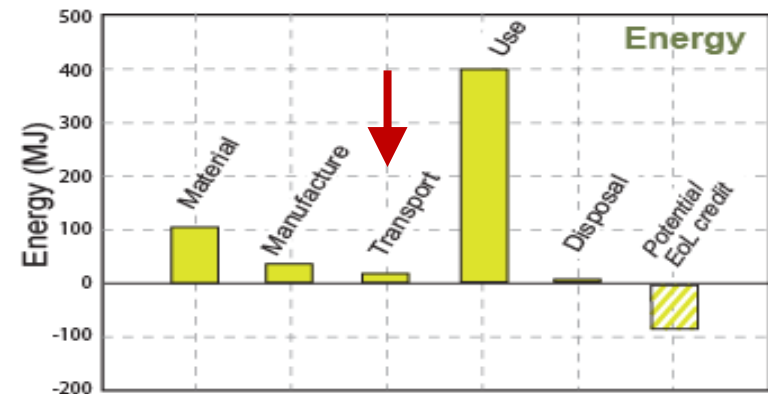


Table of transport types:
MJ / tonne.km
CO₂ / tonne.km

Auditoria ecológica

3º passo: fase de utilização – Modo estático

Energy input and output

Electric to mechanical

Power rating

1.2

kW

Usage

365

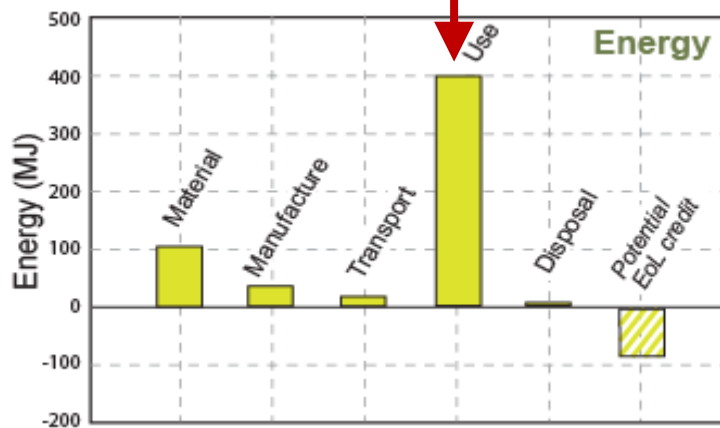
days per year

Usage

0.5

hours per day

Total energy or
CO₂ for use



Energy input and output

Electric to thermal

Electric to mechanical (electric motors)

Electric to chemical (lead acid battery)

Electric to chemical (advanced battery)

Electric to em radiation (incandescent lamp)

Electric to em radiation (LED)

Fossil fuel to thermal, enclosed system

Fossil fuel to thermal, vented system

Fossil fuel to electric

Fossil fuel to mechanical, internal combustion

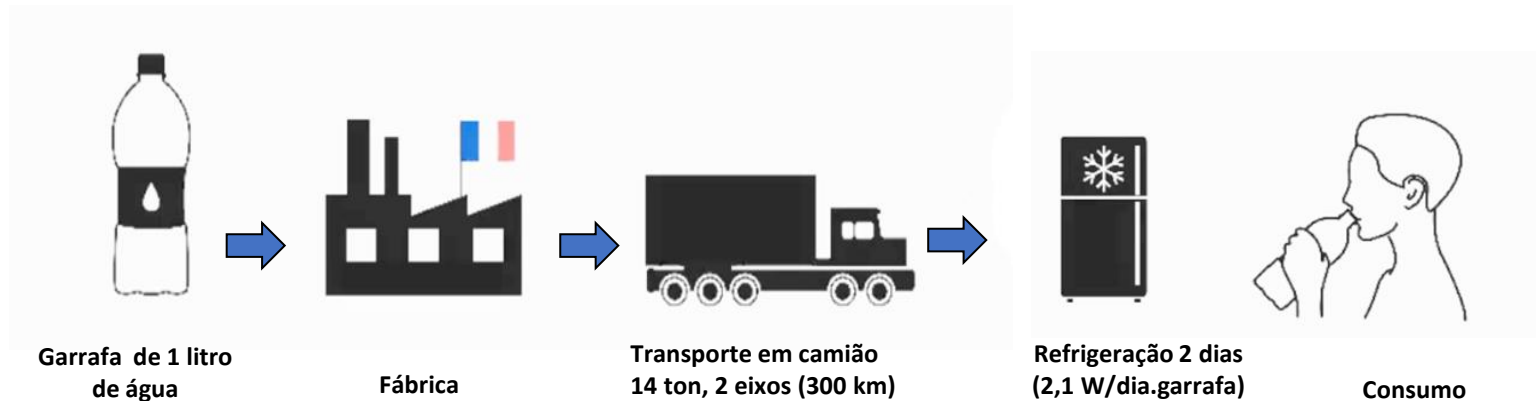
Fossil fuel to mechanical, steam turbine

Fossil fuel to mechanical, gas turbine

Light to electric (solar cell)

Exemplo de uma Auditoria ecológica

100 unidades de água engarrafada



- Garrafa em PET de 1 litro, com tampa de PP
- Moldadas por sopro
- Fabricada em França, transportados 550 km para o Reino Unido
- Refrigerada durante dois dias, depois bebida

Exemplo de uma Auditoria ecológica

100 unidades de água engarrafada

Product name: **PET bottle**

New

Open

Save

Compare with... ▼

Number	Name	Material	Process	Mass (kg)	End of life
100	Bottles	PET ▼	Molding ▼	0.04	Recycle ▼
100	Caps	Polyprop ▼	Molding ▼	0.001	Landfill ▼
100	Water	▼	▼	1.0	▼

Transport

Stage 1

14 tonne truck ▼

550 km

Survey charts

Full report

Use - refrigeration

Electric to mechanical

0.12 kW ▼

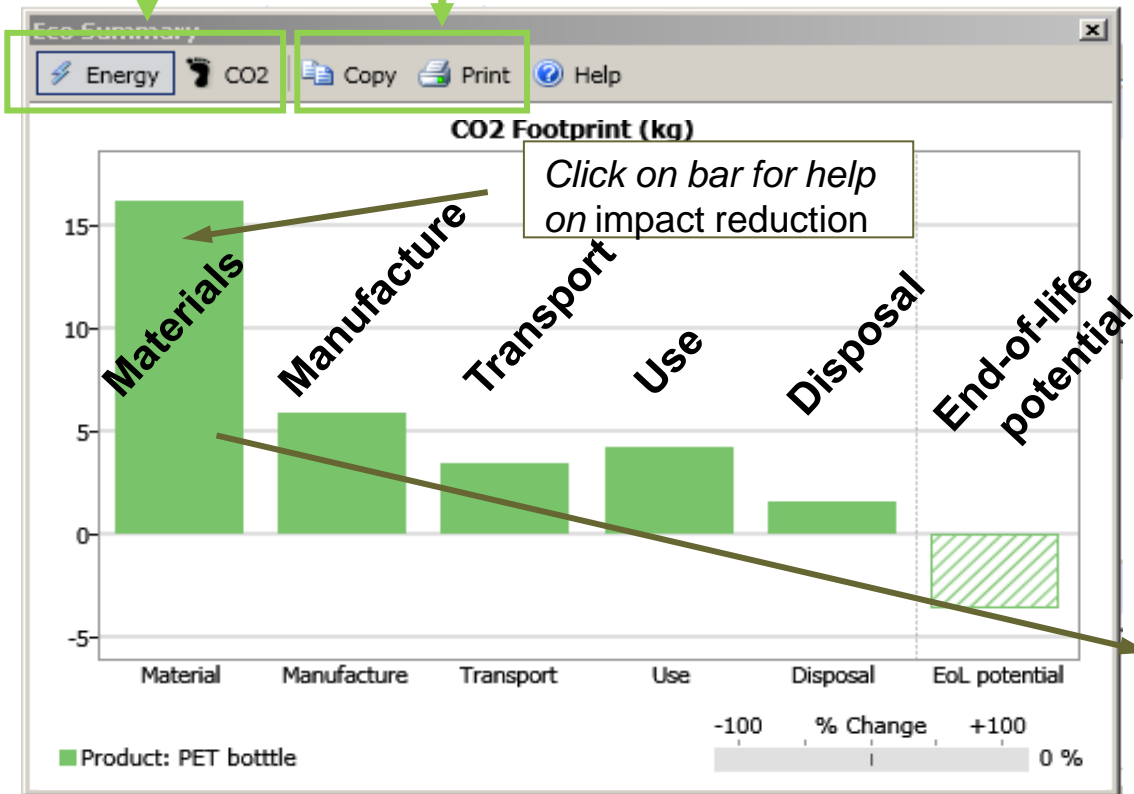
2 days

24 hrs/day

Exemplo de uma Auditoria ecológica

Toggle between energy and carbon footprint

Copy or print the chart



Which phase has the largest impact?

Materials!

Reducing Material-phase impact

Aim

Minimize embodied energy or CO₂ footprint / unit of function.

Actions

Select material with lowest embodied energy and CO₂ footprint per unit of function.

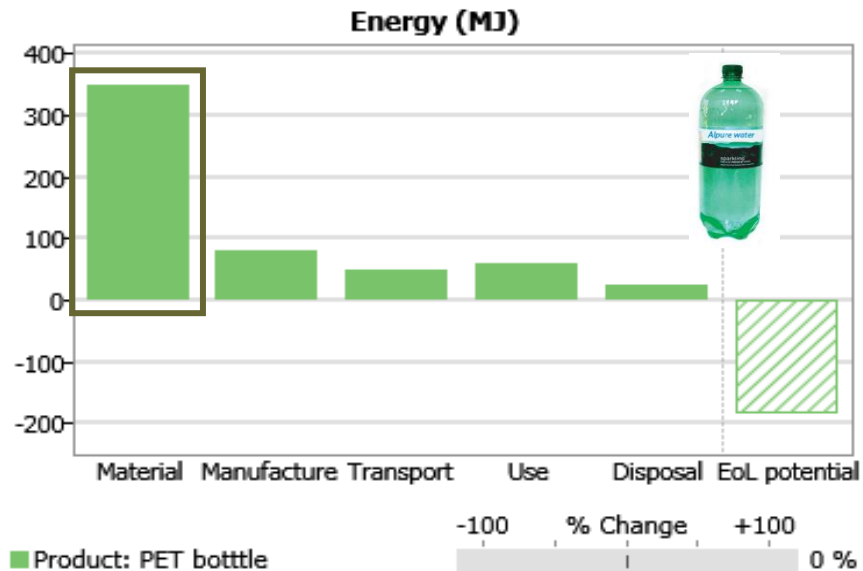
Use as large a 'recycled content' in the material as possible.

Use as little material as possible while retaining enough redundancy for safety.

Conflicts

Watch out for conflict with the Use phase. The material with the lowest direct eco-impact may not be the lightest or the cheapest. Use trade-off methods to resolve the conflict.

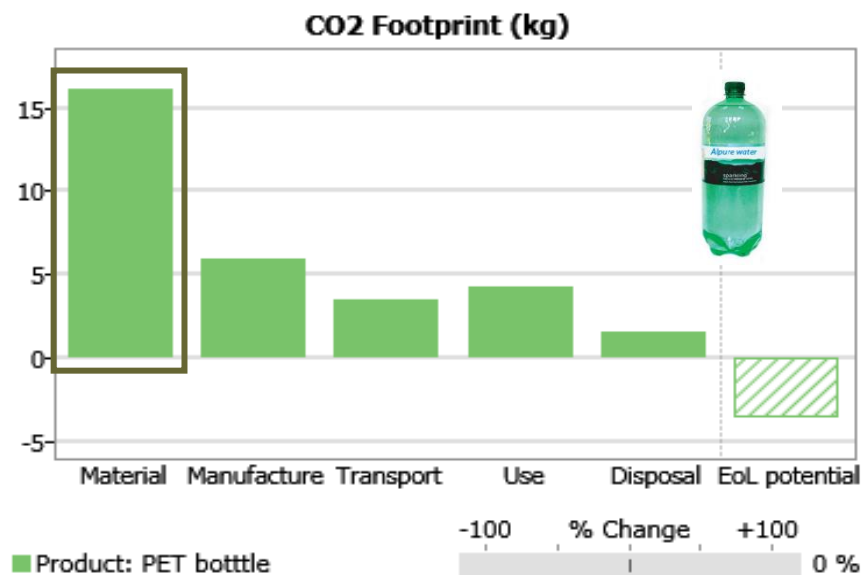
Exemplo de uma Auditoria ecológica



The audit reveals the most energy and carbon intensive steps...



PET



Fonte: Granta Design and Mike Ashby, 2020.

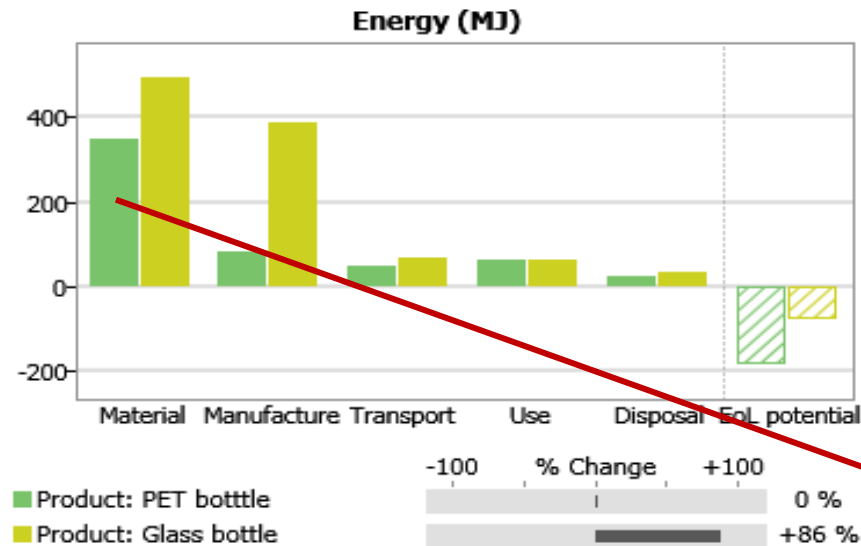
Exemplo de uma Auditoria ecológica

Esta ferramenta permite também **testar alternativas/hipóteses**, tais como a utilização de outros materiais, estratégias de fim de ciclo de vida diferentes, etc.

Será que as garrafas de vidro seriam uma melhor alternativa à utilização de garrafas à base de PET?



Exemplo de uma Auditoria ecológica



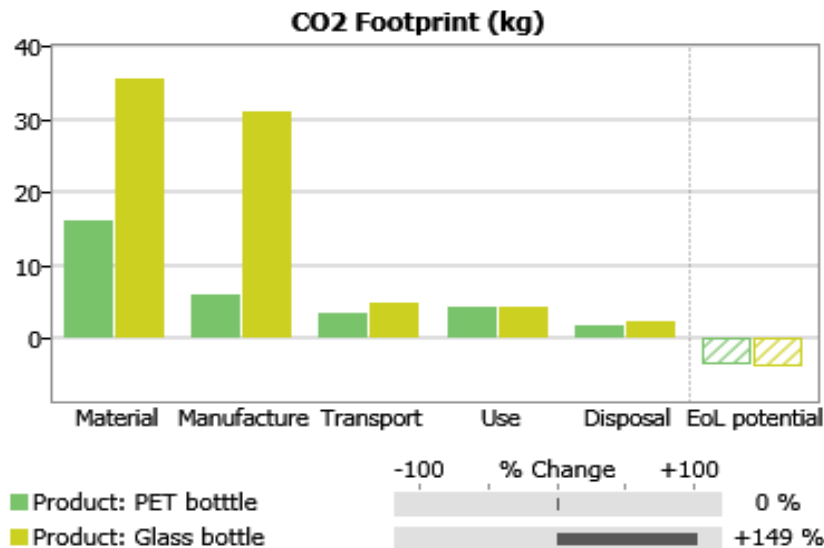
The fast comparison allows design decisions on-the-fly

Reducing impact

Actions

- Use as large a 'recycled content' in the material as possible.

What if.....
100% recycled PET?



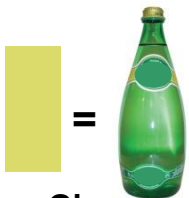
Exemplo de uma Auditoria ecológica

Click
Compare with....
Copy of current
content

**Set Recycle content
to 100%**



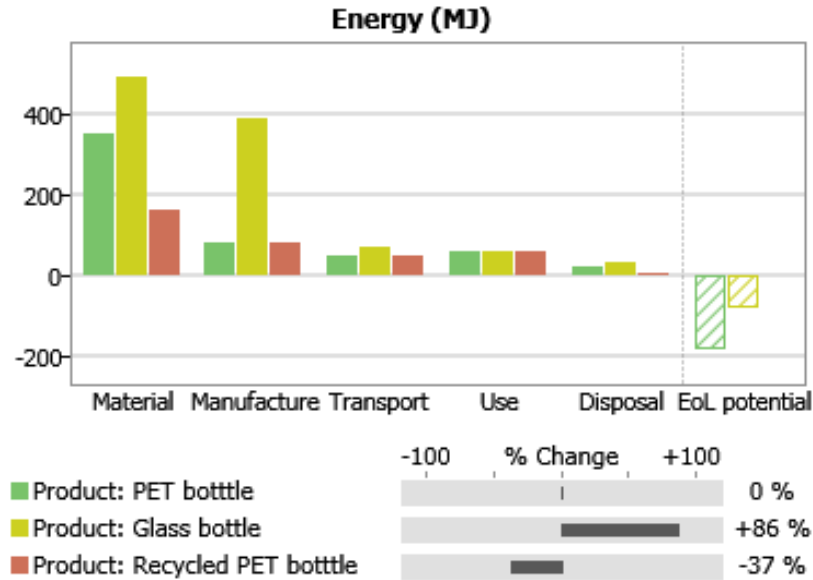
Virgin PET



Glass



Recycled PET



Can explore:

- Material choice
- Recycle content
- Transport mode
- Transport distance
- Use pattern
- Electric energy mix
- End of life choice

