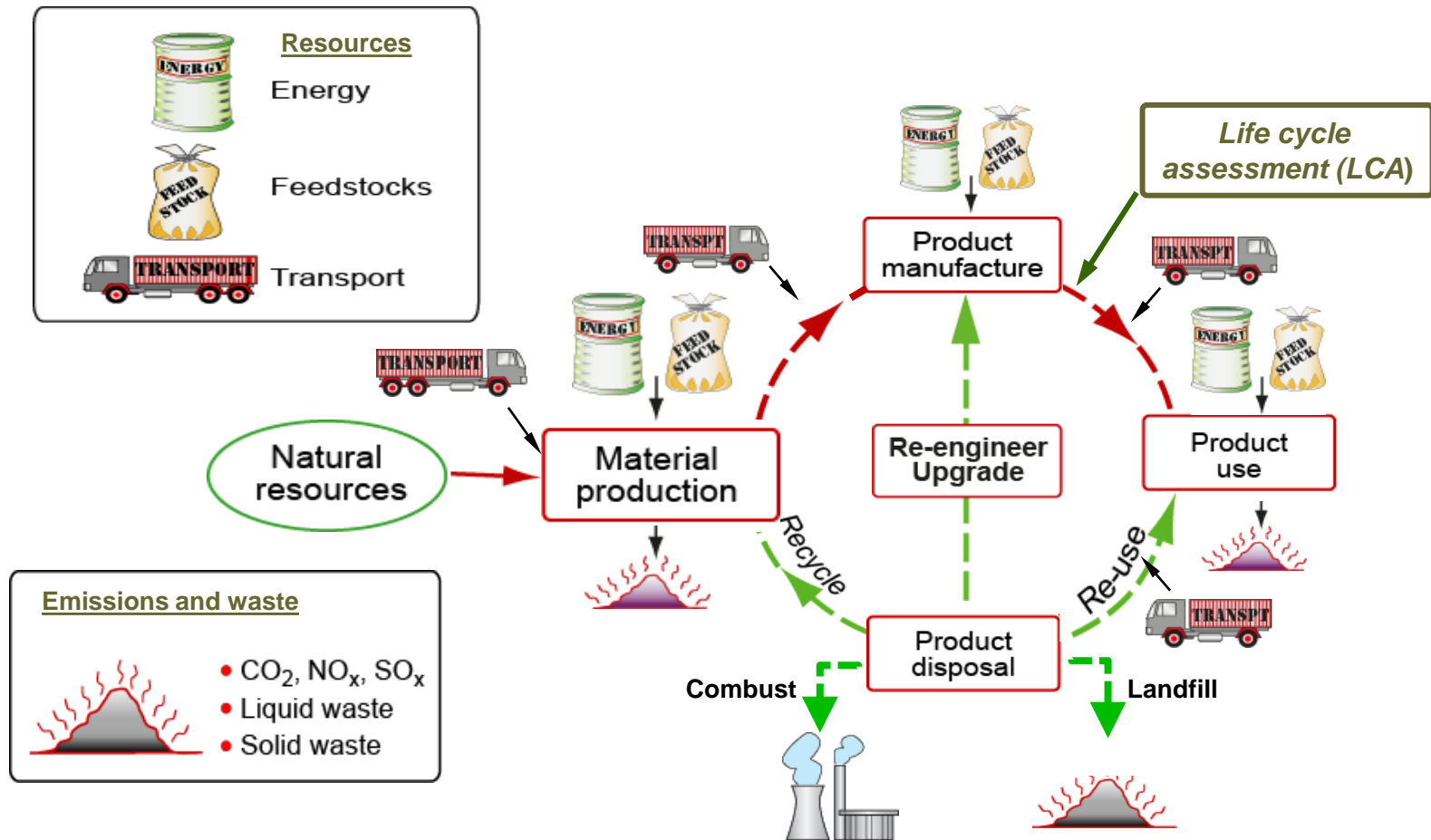




# Auditoria ecológica

# 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		
<i>Latas de alumínio, por 1000 units</i>		
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 <sub>2</sub>	211 kg
	• Emissions: CO	0.2 kg
	• Emissions: NO <sub>x</sub>	1.1 kg
	• Emissions: SO <sub>x</sub>	1.8 kg
	• Particulates	2.47 kg
Avaliação de impacto	• Ozone depletion potential	0.2 X 10 <sup>-9</sup>
	• Global warming potential	1.1 X 10 <sup>-9</sup>
	• Acidification potential	0.8 X 10 <sup>-9</sup>
	• Human toxicity potential	0.3 X 10 <sup>-9</sup>

Qual a situação de cada “eco-indicador” ?

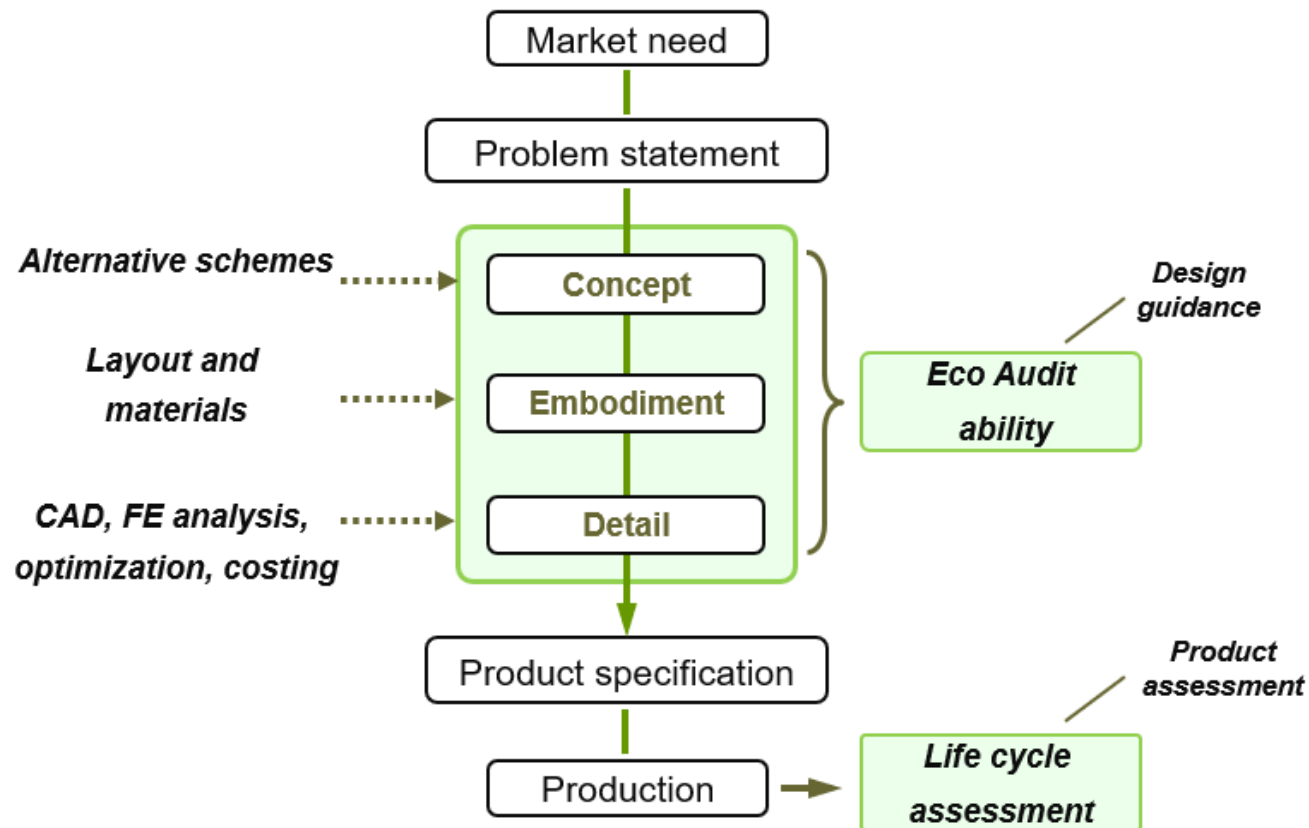
- Uma análise do LCA de um produto/material é um processo que requiere grande **detalhe** e **experiência**, sendo um **processo moroso** e como tal **caro**.

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

**Alternativa???**

# Auditoria ecológica

## Design vs análise do produto



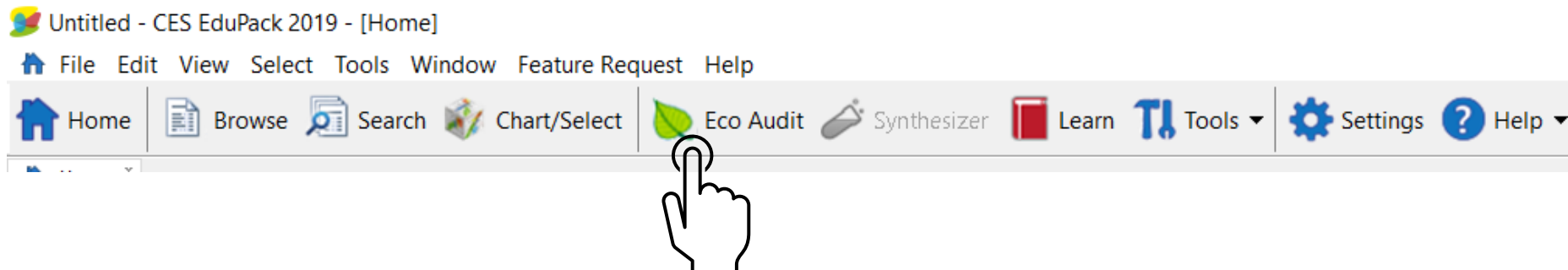
# Auditoria ecológica

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!**

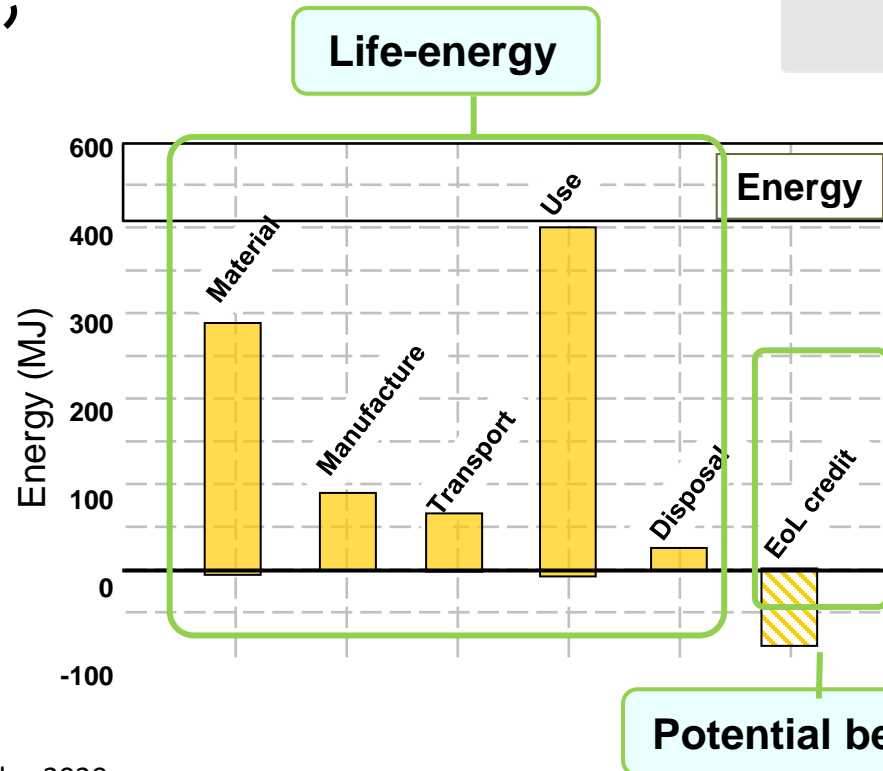
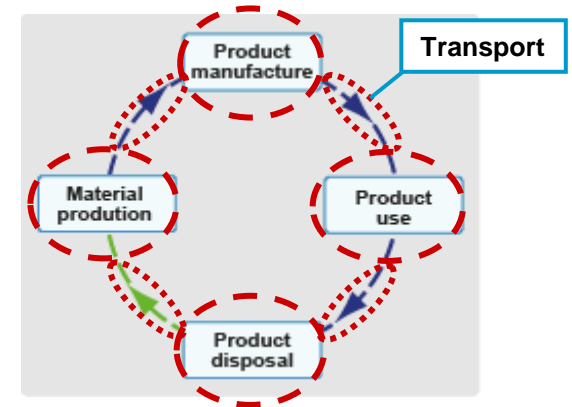
# Auditoria ecológica

Ferramenta Eco Audit (CES EduPack)

Opção para guiar um processo de decisão

- 1 resource – **energy** (*oil equivalent*)
- 1 emission – **CO<sub>2</sub>** *equivalent*
- Distinguish life-phases

■ **Audit: Energy**

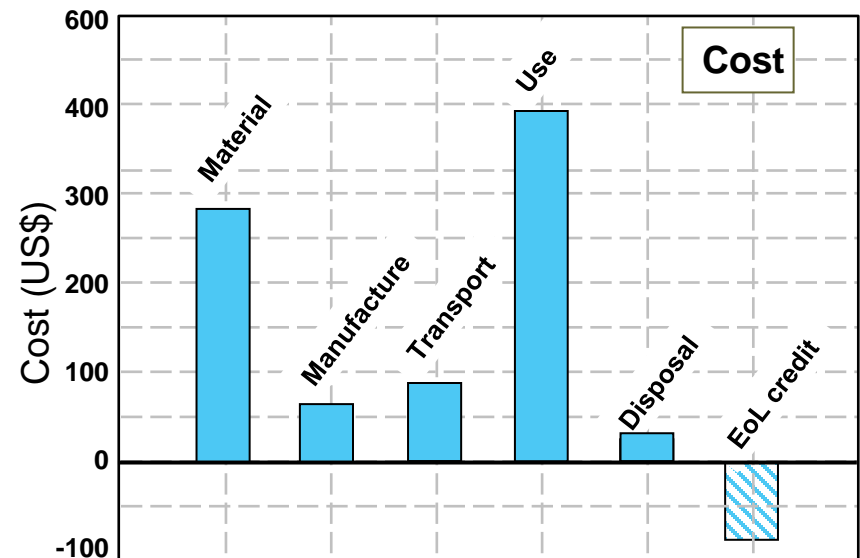
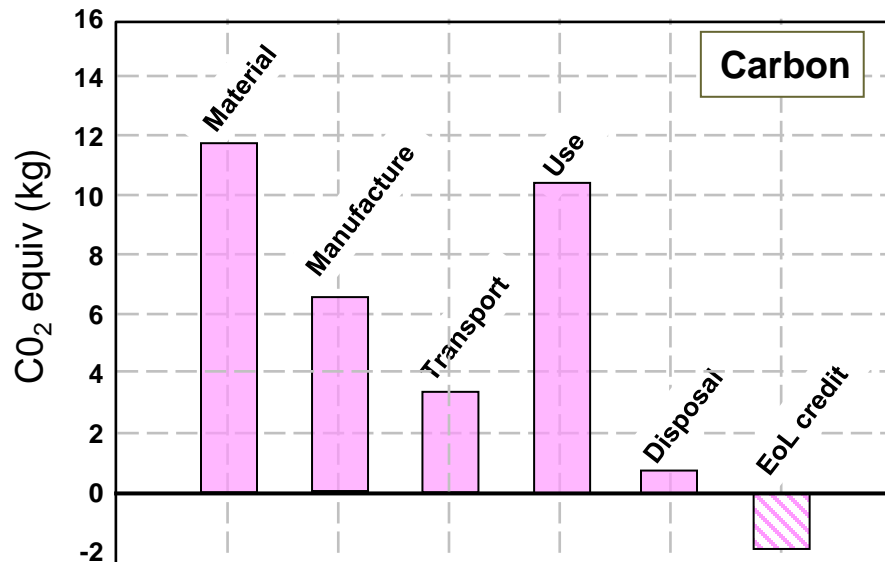


Distinguir as diferentes fases da vida de um produto

# Auditoria ecológica

## Ferramenta Eco Audit (CES EduPack)

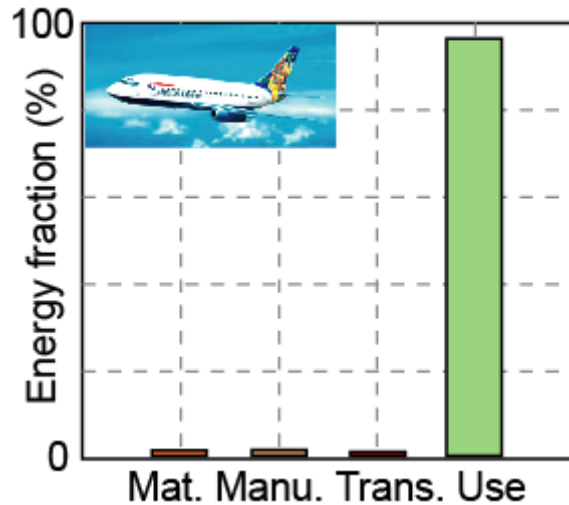
- 1 resource – **energy** (oil equivalent)
- 1 emission – **CO<sub>2</sub>** equivalent
- Distinguish life-phases
- Audit: Energy or Cost



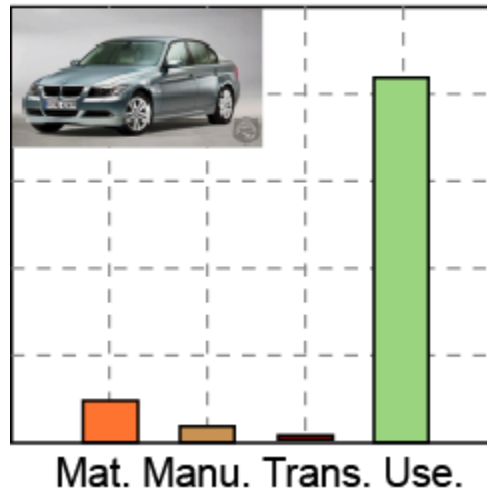
# Auditoria ecológica

## Grande panorama: consumo de energia dos produtos

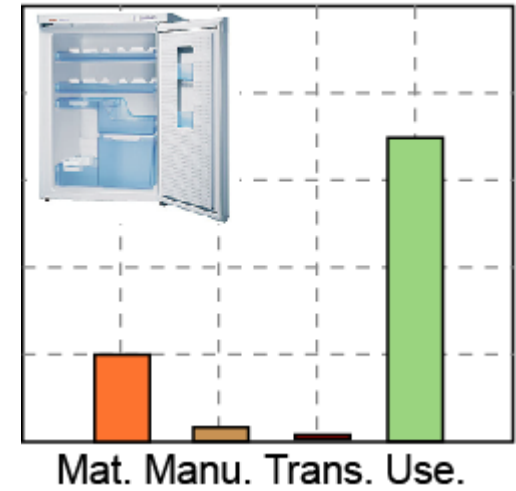
Civil aircraft



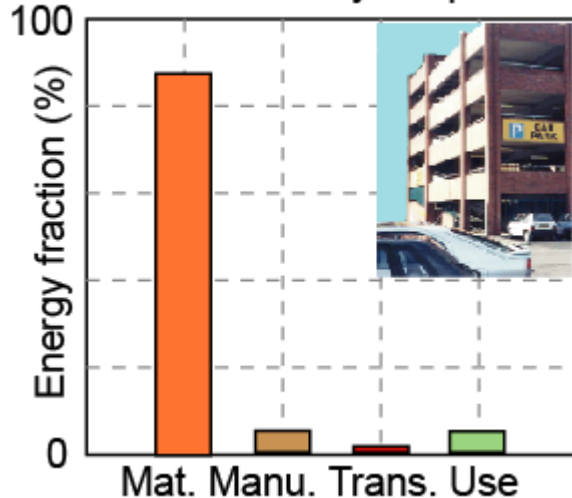
Family car



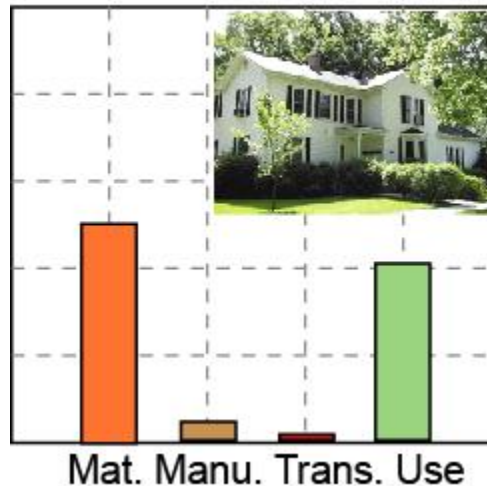
Appliance (refrigerator)



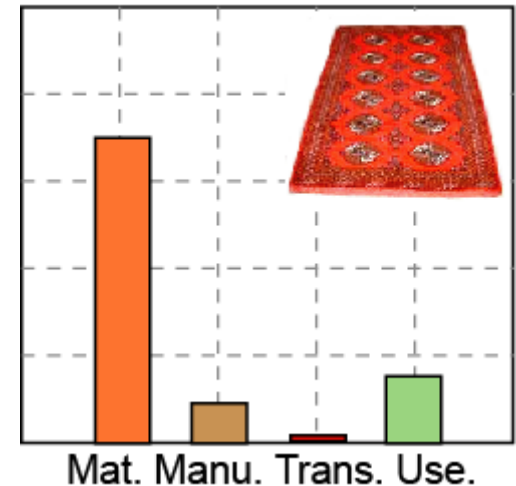
Multi-storey car park



Private house



Fibers (Carpet)

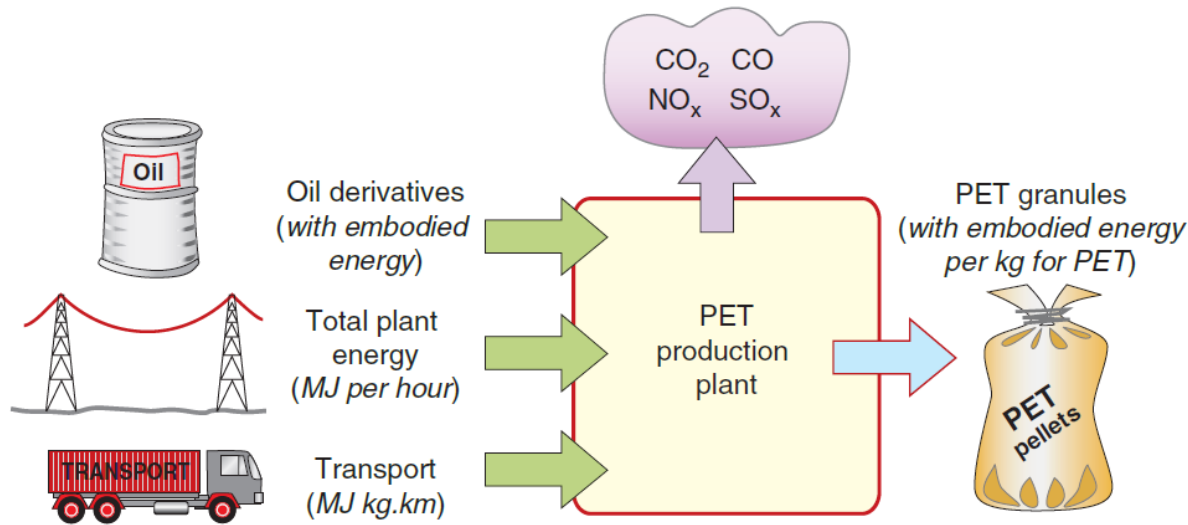




# Auditoria ecológica

## 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.

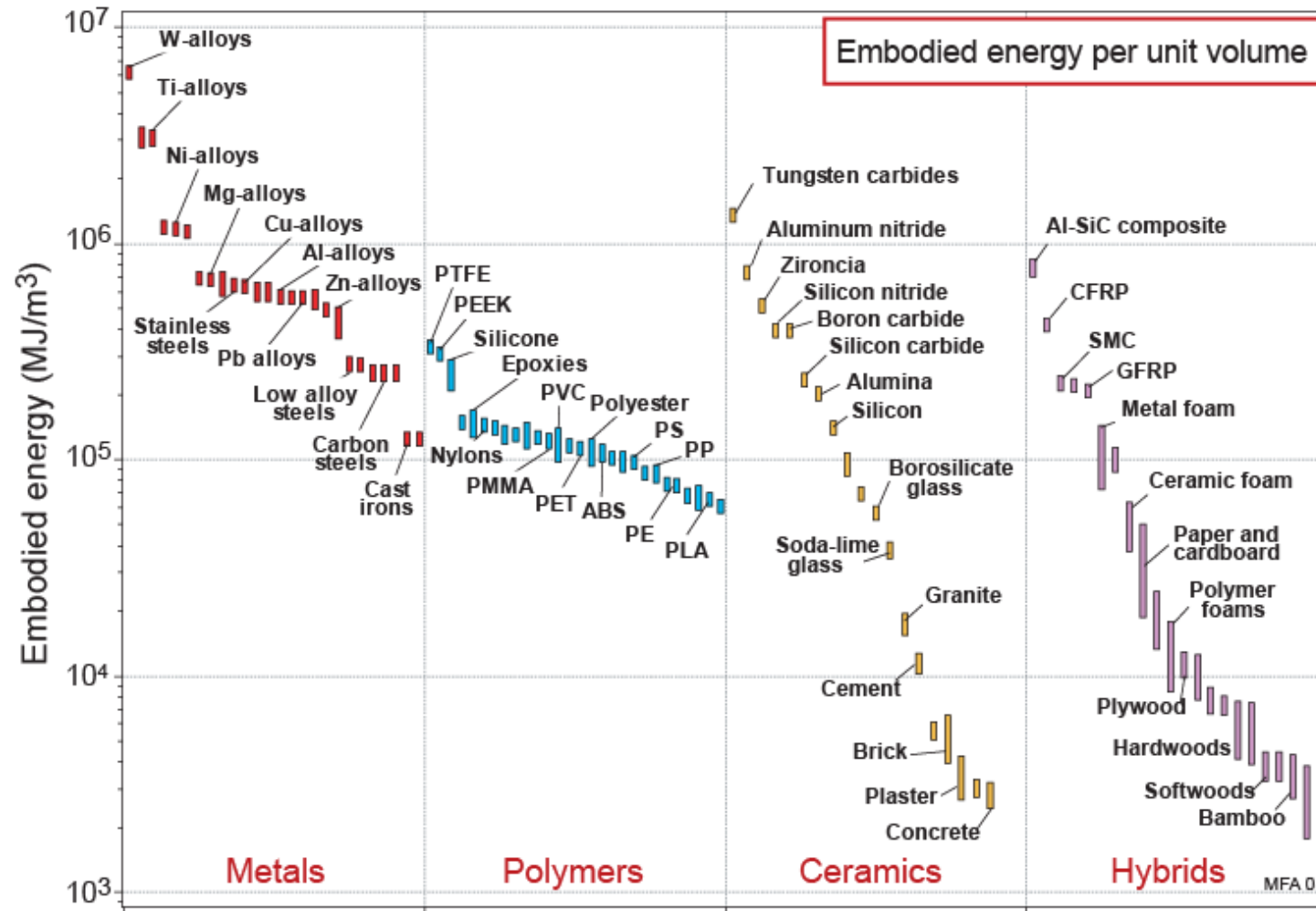
$$\text{Energia incorporada} = \frac{\sum \text{energias que entram na fábrica por hora}}{\text{massa grânulos de PET produzidos por hora}}$$

**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

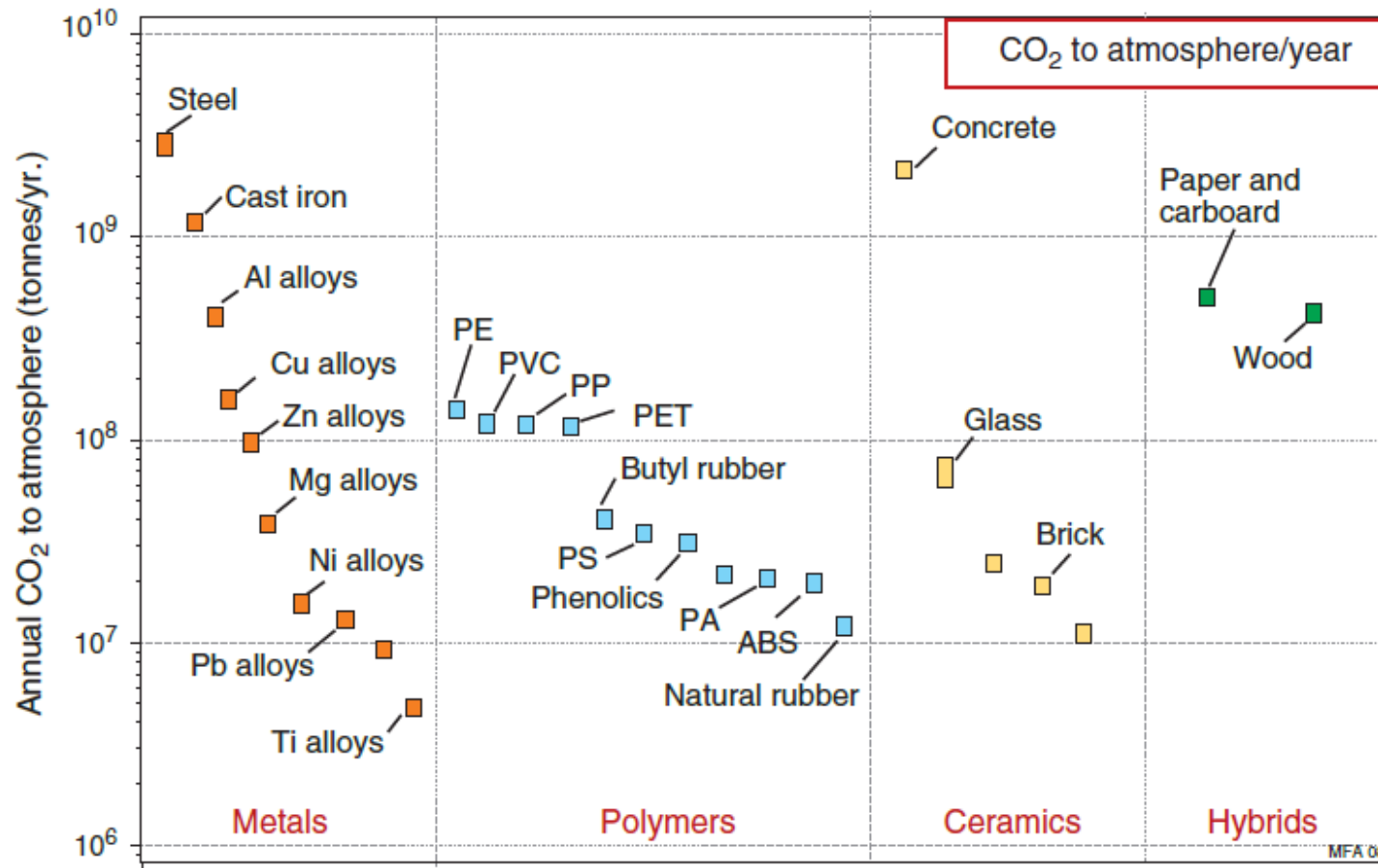
## Extração do material



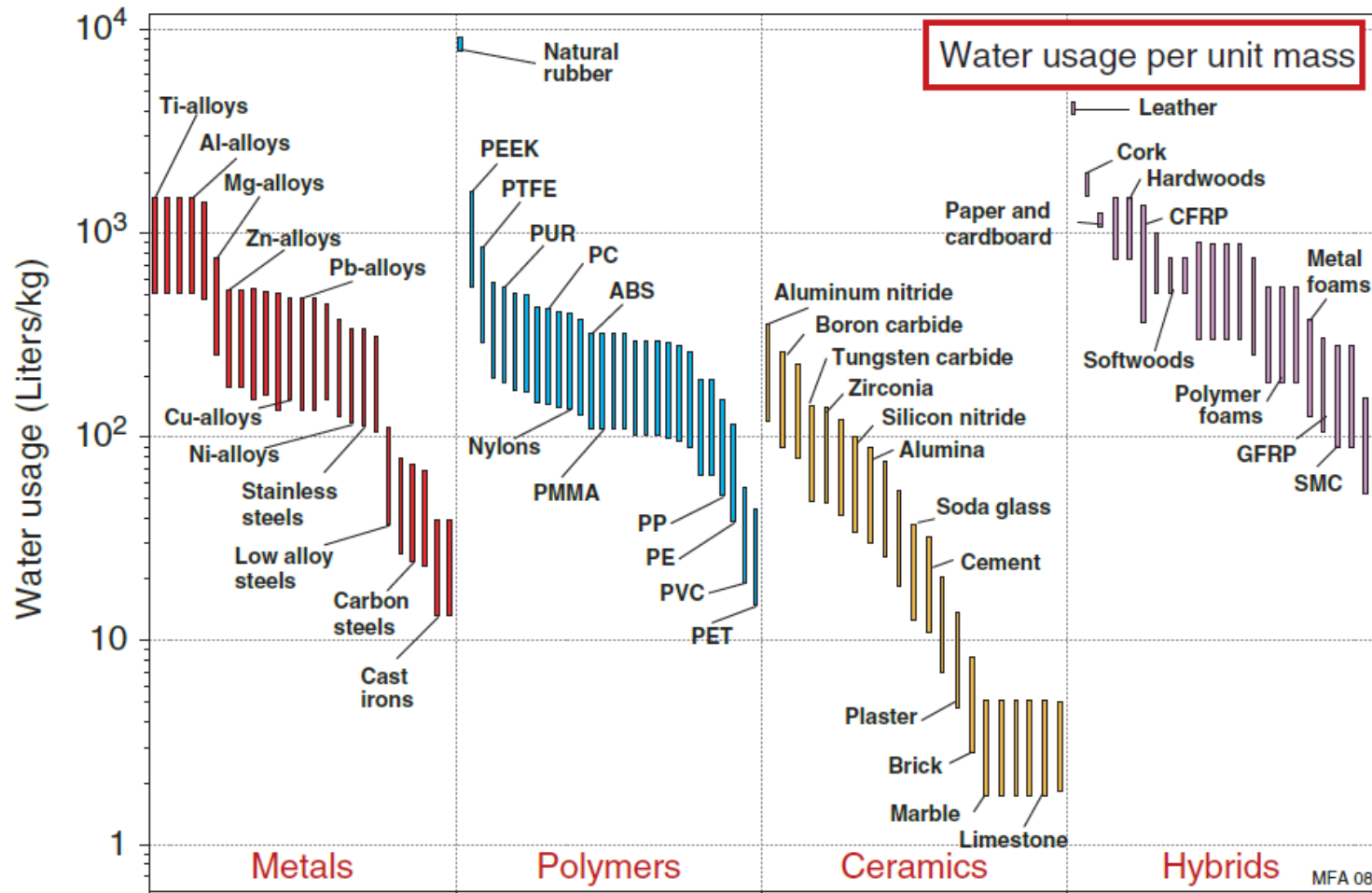
# Eco informação no CES EduPack

## Extração do material

**Representação dos eco dados:** Libertação de CO<sub>2</sub> para a atmosfera por ano



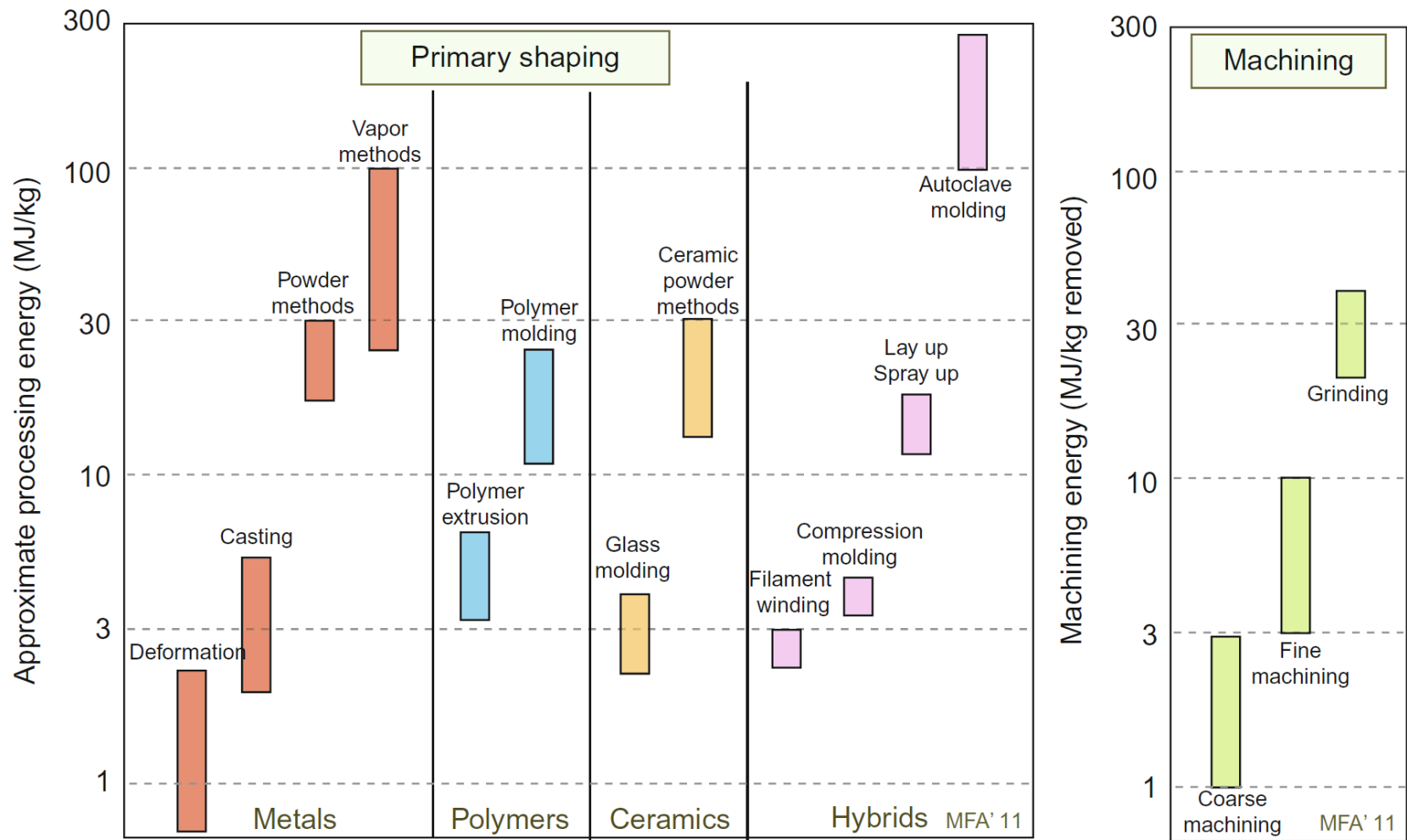
**Representação dos eco dados:** quantidade de água utilizada por unidade de massa



# Eco informação no CES EduPack

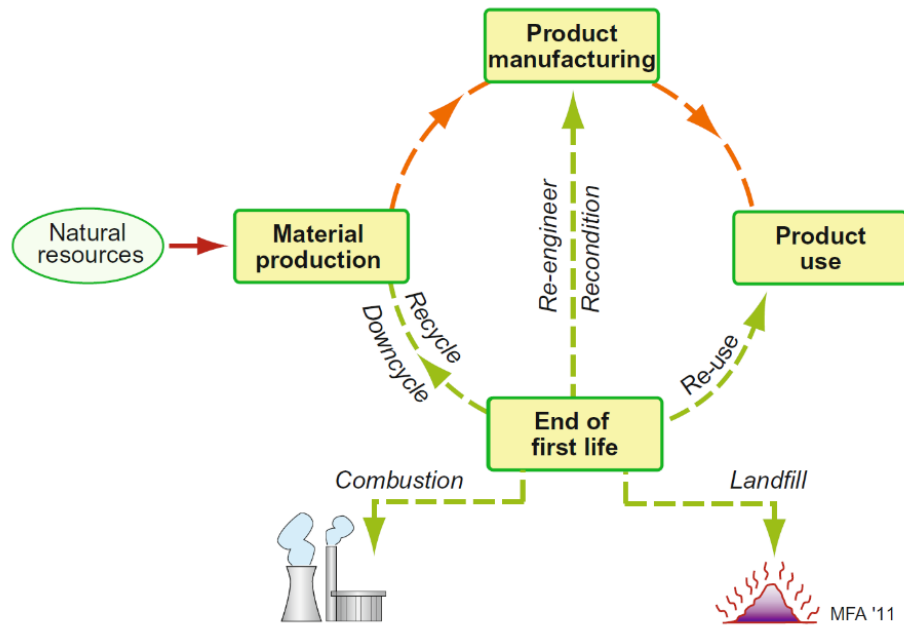
## Fabrico do produto

### Energia associada ao processamento do produto



# Eco informação no CES EduPack

destino no final do ciclo de vida útil

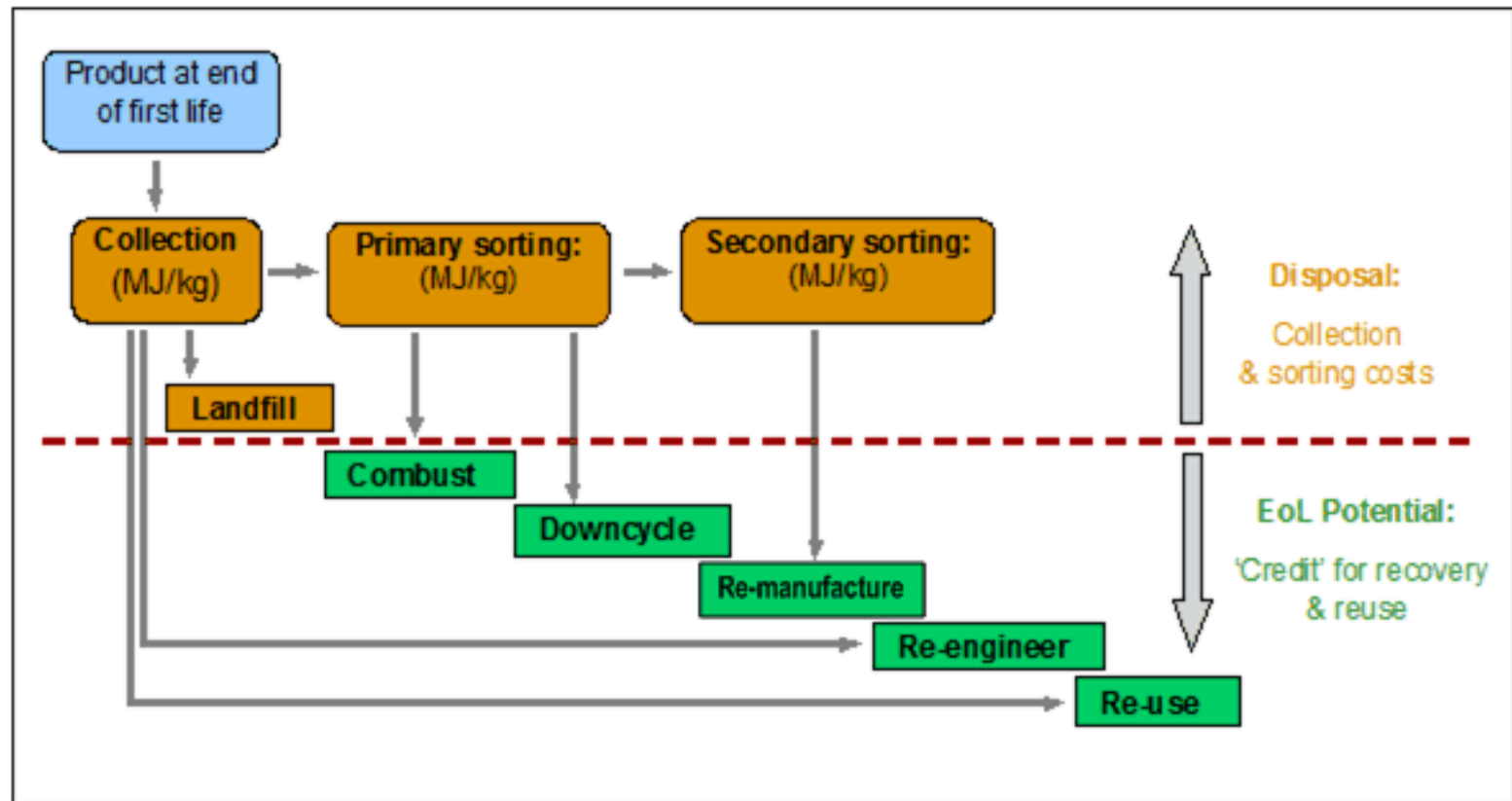


Opção de fim de vida	Descrição	Impacto ambiental
Re-use	Prolongamento da vida do produto por reutilização	Menor
Re-engineer	Utilização do material num novo produto	
Recycle	Reprocessamento do material e sua reutilização na cadeia de produção	
Downcycle	Reprocessamento com perda de qualidade do material 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

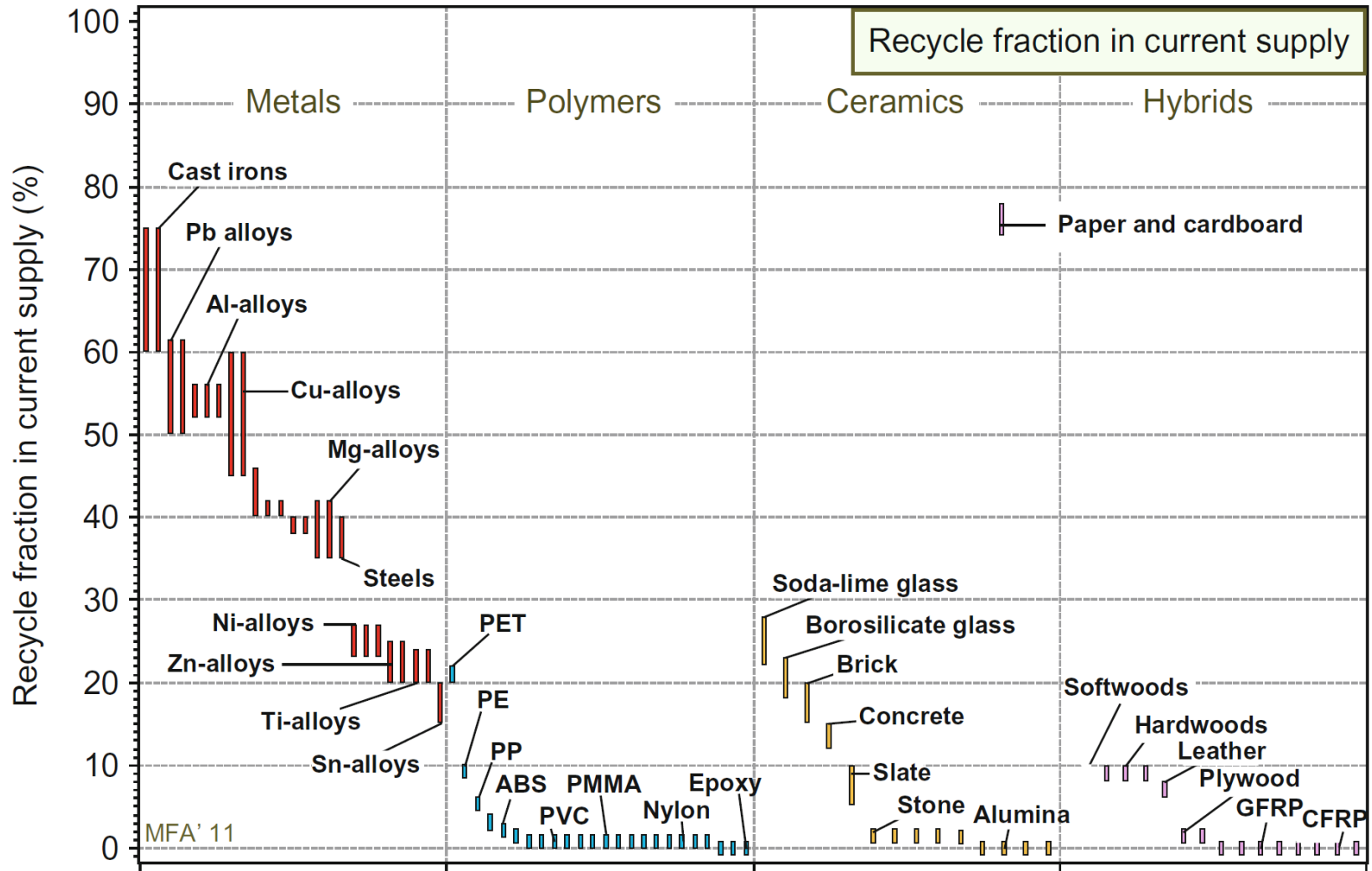
Potencial de fim de vida (*end of life (EoL) potential*) – crédito por reciclar ou reutilizar o material



# 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

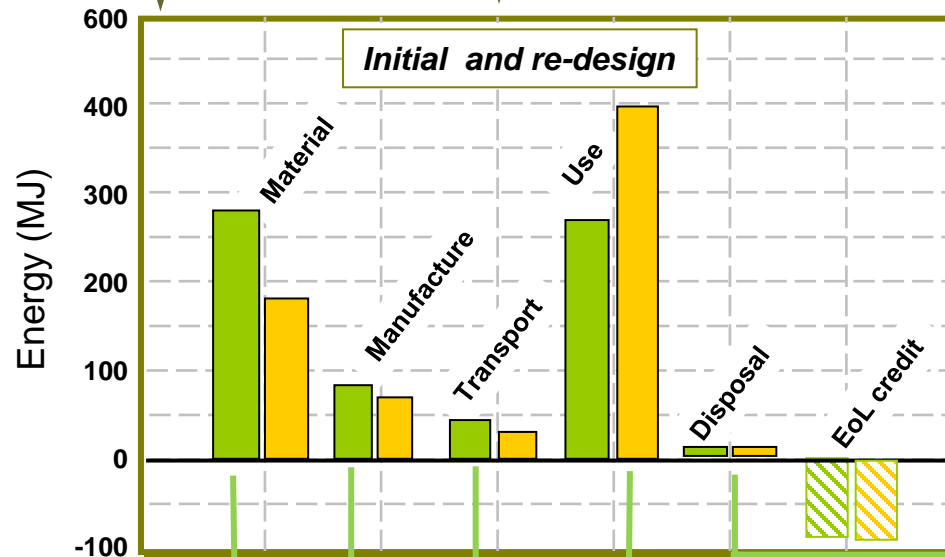
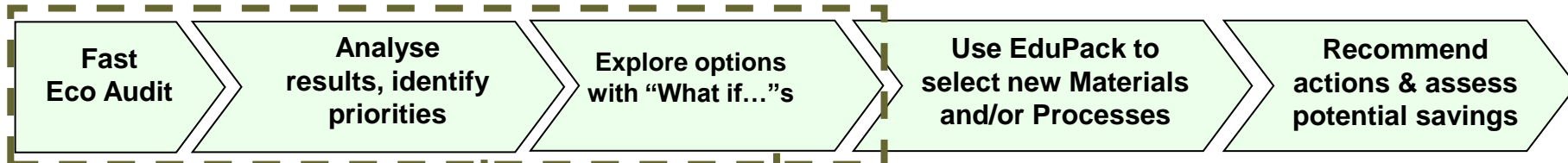
ProcessUniverse

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
- CO<sub>2</sub>/ kg

### Manufacture

Minimize:

- process energy
- CO<sub>2</sub>/kg

### Transport

Minimize:

- mass
- distance
- transport type

### Use

Minimize:

- mass
- thermal loss
- electrical loss

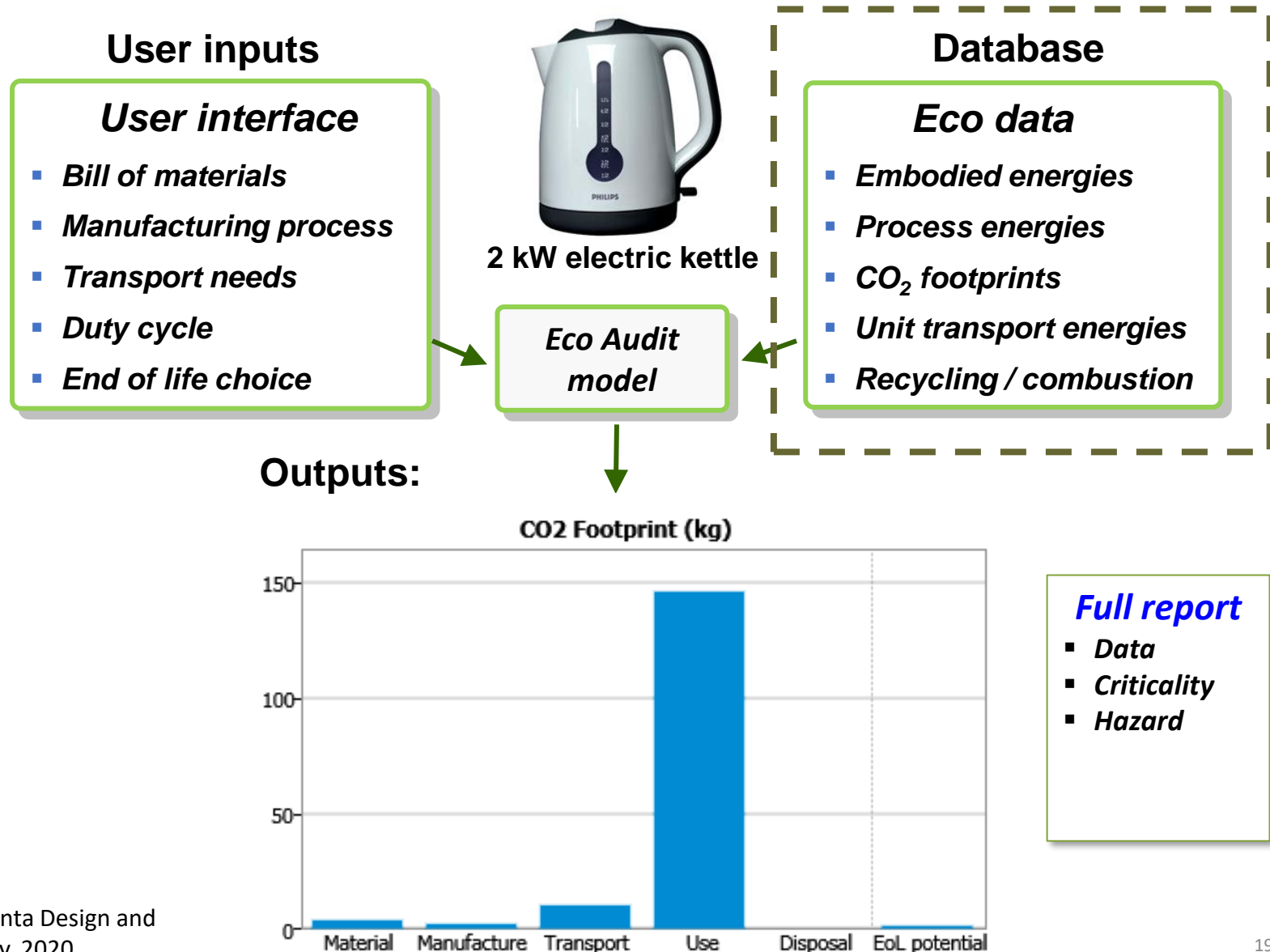
### End of Life

Select:

- recyclable materials
- non-toxic materials

# Auditoria ecológica

## Ferramenta Eco Audit (CES EduPack)



# 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

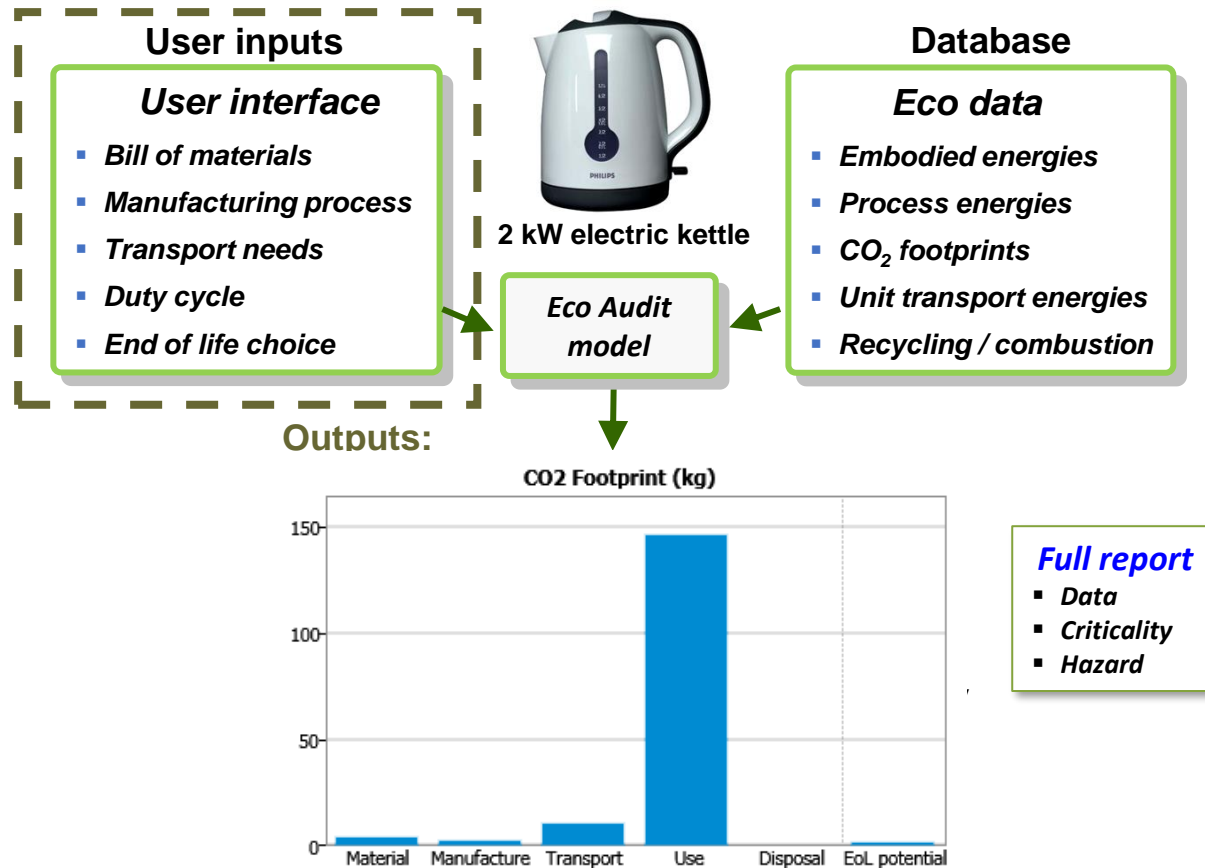
**Material recycling: energy, CO2 and recycle fraction**

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 information", "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. Annotations include:

- Bill of Materials (Input or file)**: Points to the "Material, manufacture and end of life" table.
- Help at each step**: Points to the "Product information", "Material, manufacture and end of life", "Transport", and "Use" sections.
- Useful for what-if?**: Points to the "Compare with..." button.
- > 5wt% critical material**: Points to the "Recycled content" column in the material table.
- End-of-Life**: Points to the "End of life" column in the material table, which lists options: Landfill, Combust, Downcycle, Recycle, Re-manufacture, Reuse, and None.
- Output data (Detailed info)**: Points to the "Summary chart" and "Detailed report" buttons.

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	Injection molding	Combust
1	Plug pins	Brass	Virgin (0%)	0.01	Cast	Combust
1	Packaging, padding	Rigid Polymer Foam	Virgin (0%)	0.01	Extrusion	Combust
1	Packaging, box	Paper and cardboard	Virgin (0%)	0.01	Printing	Recycle

# Auditoria ecológica

## 1º passo: materiais e energia do processo/ CO<sub>2</sub>

Component name

*Component 1*

Material

*Aluminum alloys*

Process

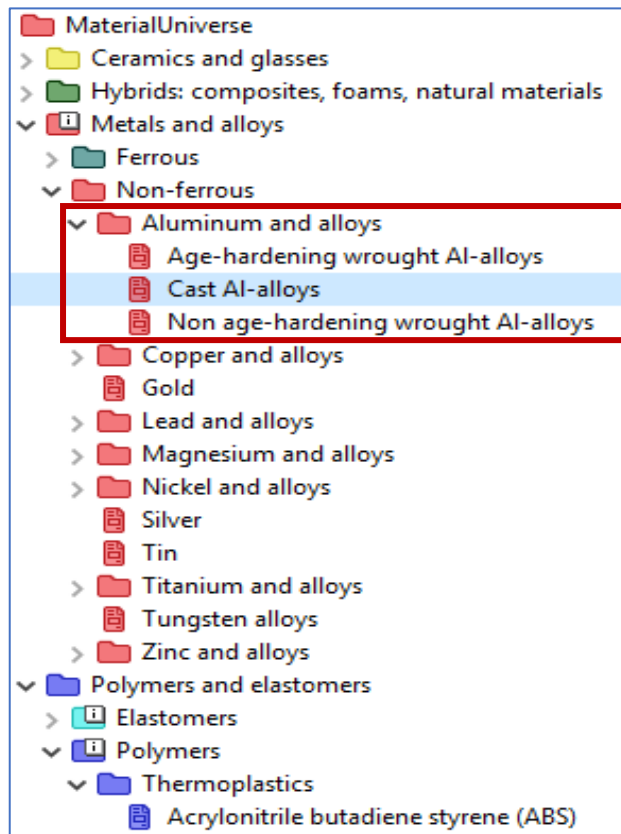
*Casting*

Mass (kg)

*2.3*

End of life

*Recycle*



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

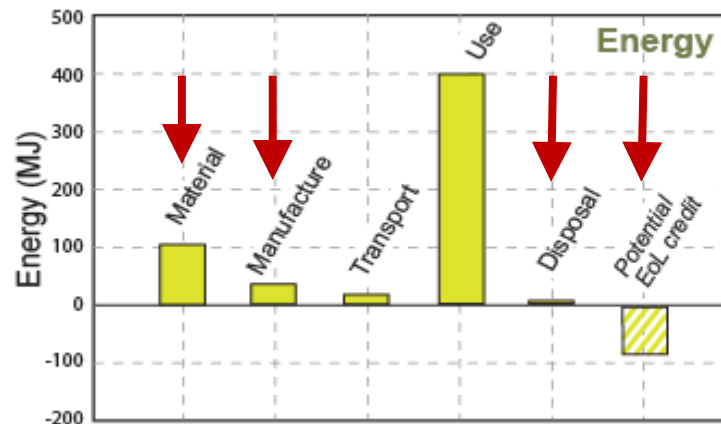
- Landfill
- Downcycle
- Recycle
- Re-manufacture
- Reuse
- None

*End of life options*

# Auditoria ecológica

## 1º passo: materiais e energia do processo/ CO<sub>2</sub>

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 ▼
<div> <div>Total embodied energy</div> <div>Total process energy</div> <div>Total mass</div> <div>Total end of life energy</div> </div>				





# Auditoria ecológica

## 2º passo: transporte

Transport stage	Transport type	Distance (km)
Stage 1	32 tonne truck	350
Stage 2	Coastal freight	12 000
	<div> Coastal freight  River/canal freight  Rail freight  55 tonne (8 axle) truck  40 tonne (6 axle) truck  <b>32 tonne (4 axle) truck</b>  26 tonne (3 axle) truck  14 tonne (2 axle) truck  Light goods vehicle  Air freight - long haul  Air freight - short haul  Helicopter </div>	Transport energy Transport CO <sub>2</sub>

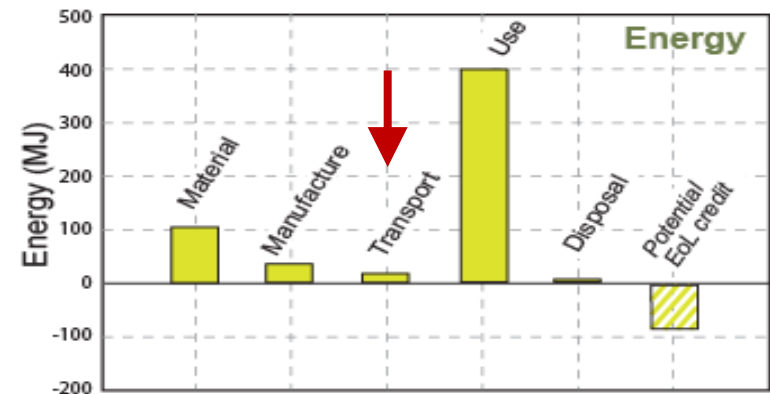


Table of transport types:  
MJ / tonne.km  
CO<sub>2</sub> / tonne.km

# Auditoria ecológica

## 3º passo: fase de utilização – Modo estático

Energy input and output

*Electric to mechanical*

Power rating

1.2

kW

Usage

365

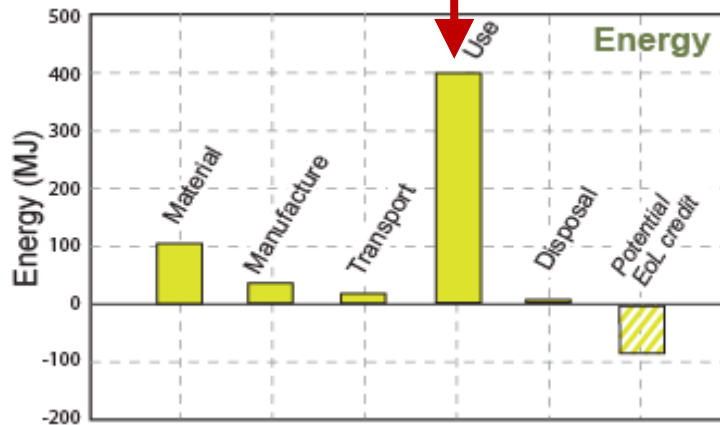
days per year

Usage

0.5

hours per day

Total energy or  
CO<sub>2</sub> 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

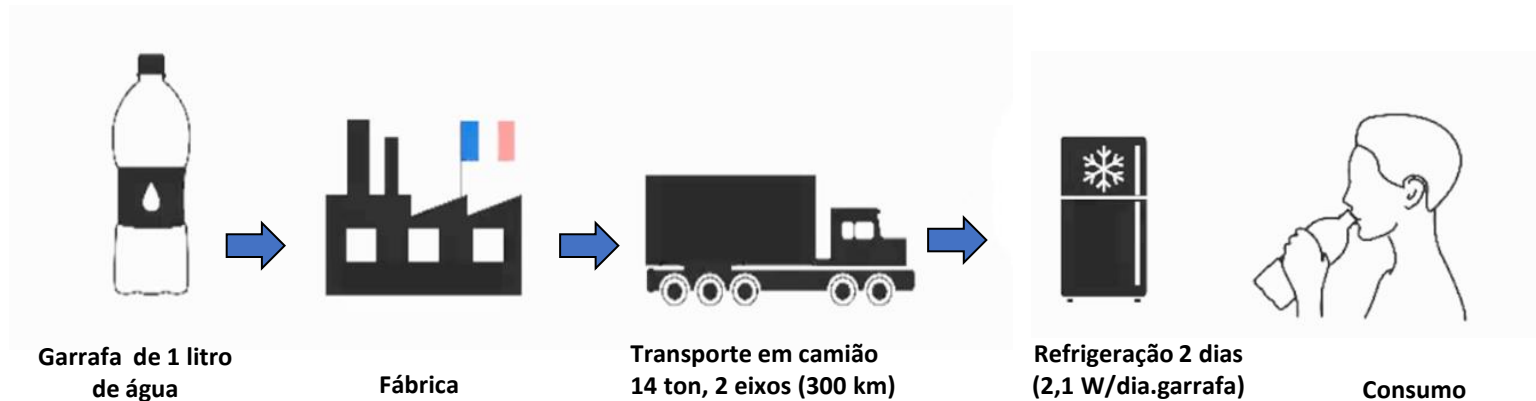
Fossil fuel to mechanical, steam turbine

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	<i>Bottles</i>	<i>PET</i> ▼	<i>Molding</i> ▼	<i>0.04</i>	<i>Recycle</i> ▼
100	<i>Caps</i>	<i>Polyprop</i> ▼	<i>Molding</i> ▼	<i>0.001</i>	<i>Landfill</i> ▼
100	<i>Water</i>	▼	▼	<i>1.0</i>	▼

## Transport

*Stage 1*

*14 tonne truck* ▼

*550 km*

*Survey charts*

*Full report*

## Use - refrigeration

*Electric to mechanical*

*0.12 kW* ▼

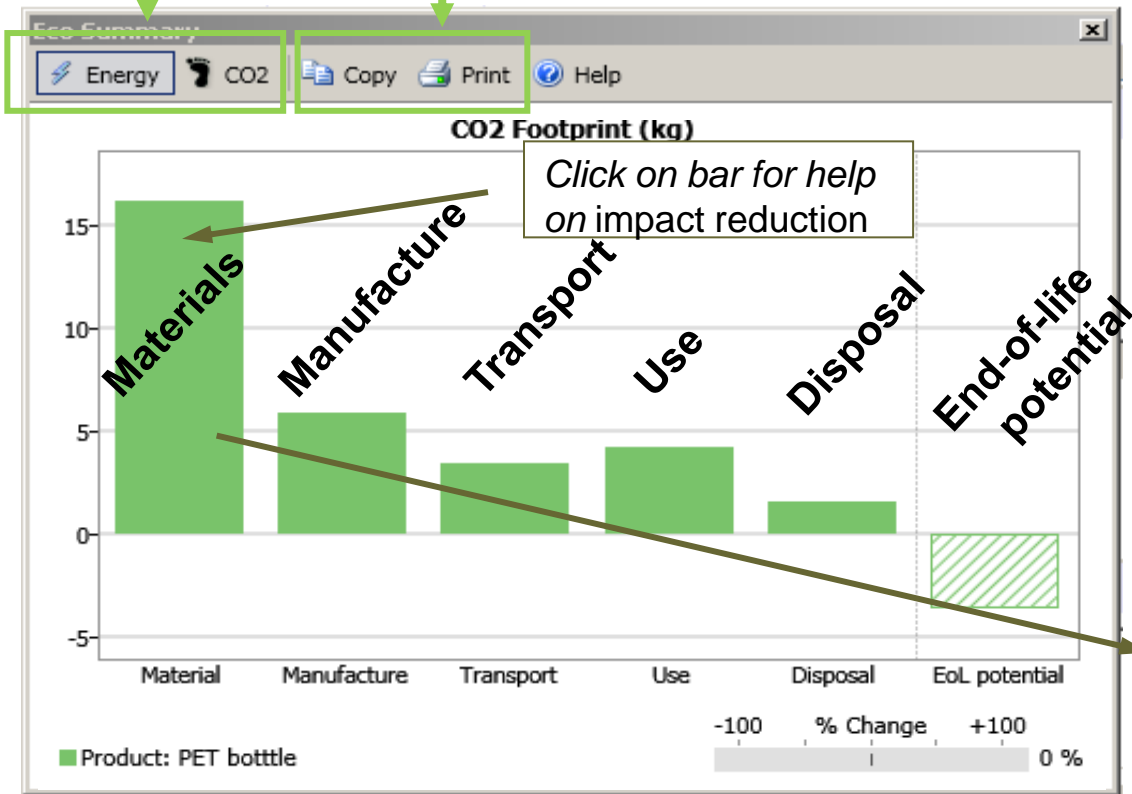
*2 days*

*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 CO<sub>2</sub> footprint / unit of function.

### Actions

Select material with lowest embodied energy and CO<sub>2</sub> footprint per unit of function.

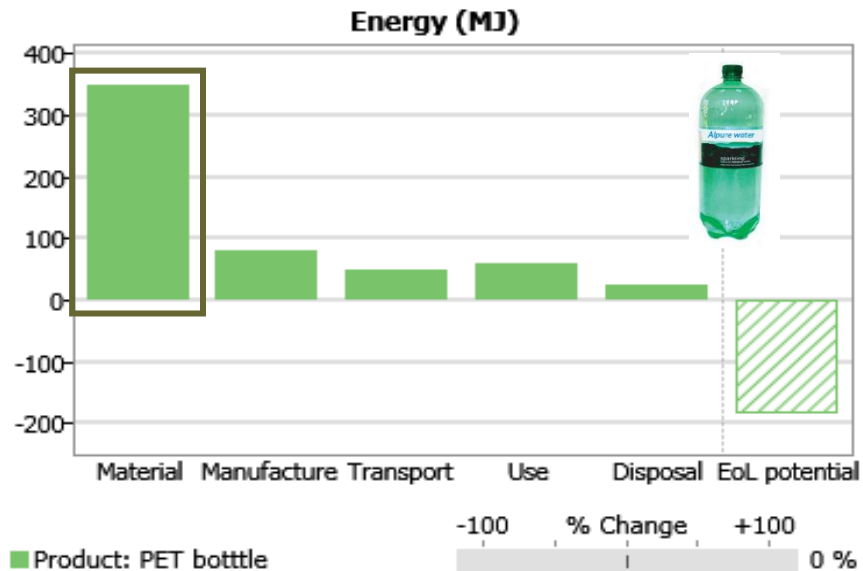
Use as large a 'recycled content' in the material as possible.

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.

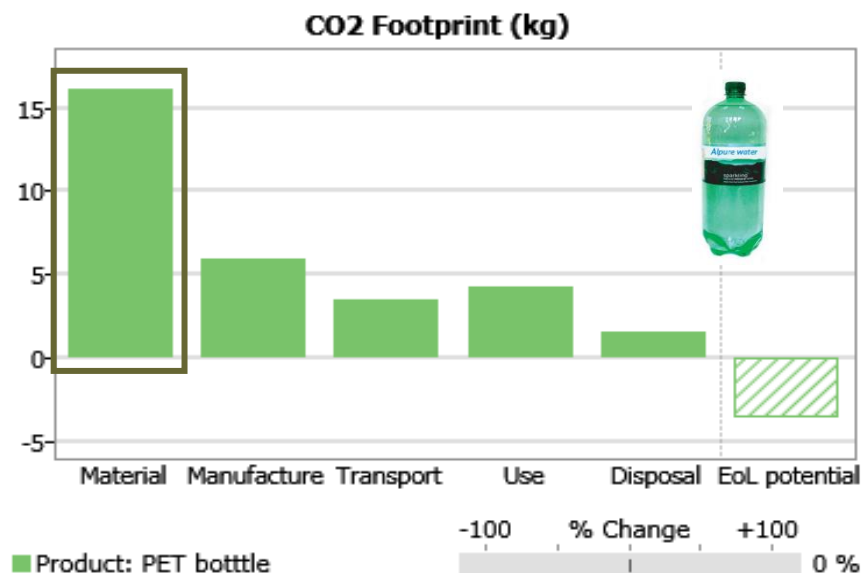
# Exemplo de uma Auditoria ecológica



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



**PET**

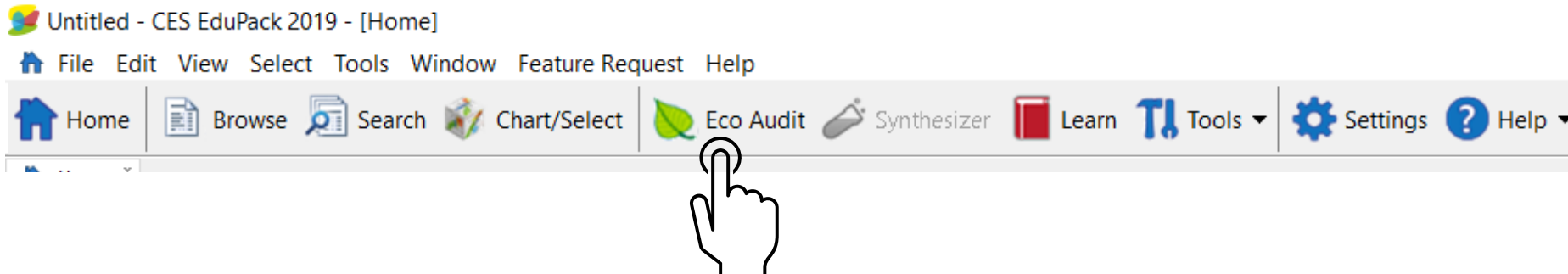


Fonte: Granta Design and Mike Ashby, 2020.

# Exemplo de uma Auditoria ecológica

## Detalhes...

**1º passo:** seleccionar o nível 1 e a opção “Eco Audit”



**2º passo:**

preencher os campos “product information” e “material, manufacture and end of life”

Product information ?

Name:

Material, manufacture and end of life ?

Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	End of life
100	garrafa	Polyethylene terephthala...	Virgin (0%)	0.04	Polymer molding	Recycle
100	tampa	Polypropylene (PP)	Virgin (0%)	0.001	Polymer molding	Landfill
100	água			1		None

# Exemplo de uma Auditoria ecológica

## Detalhes...

3º passo: preencher os campos **transporte** e **uso**

Transport ?			
Name	Transport type	Distance (km)	
Da fábrica até à loja	14 tonne (2 axle) truck	550	

Use ?			
Product life:	1	Years	
Country of use:	United Kingdom ▼		
<b>Static mode</b>		<b>Mobile mode</b>	
<input checked="" type="checkbox"/> Product uses the following energy:		<input type="checkbox"/> Product is part of or carried in a vehicle:	
Energy input and output:	Electric to mechanical (electric moto ▼)		Fuel and mobility type: Diesel - ocean shipping ▼
Power rating:	0.12	kW ▼	Usage: 0 days per year
Usage:	2	days per year	Distance: 0 km per day
Usage:	24	hours per day	



# Exemplo de uma Auditoria ecológica

## Detalhes...

**4º passo:** gerar o relatório (resumo e em detalhe)

 **Report** 

Summary chart

Detailed report

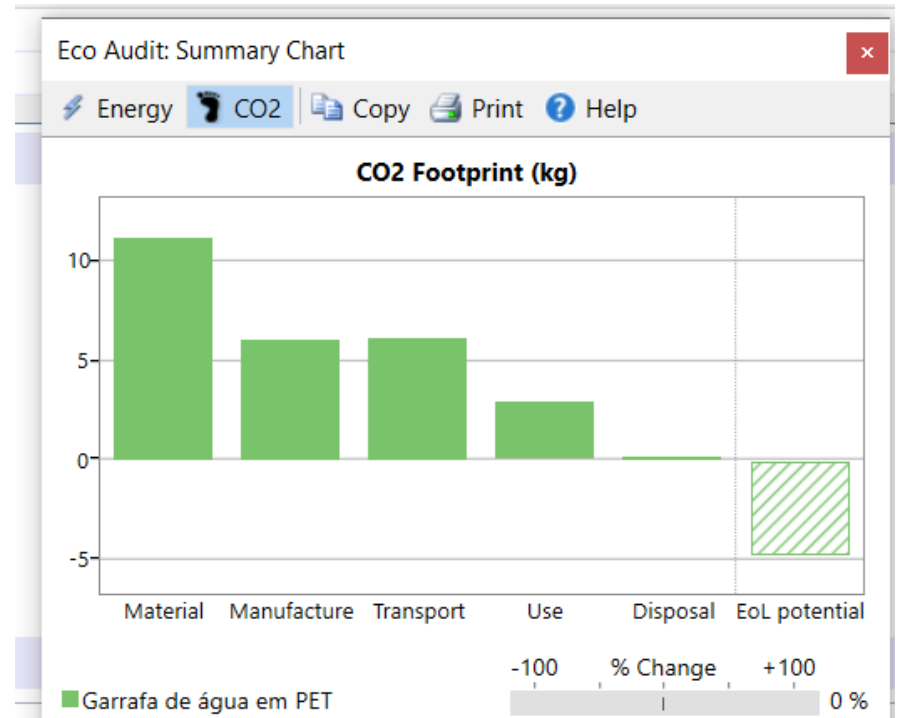
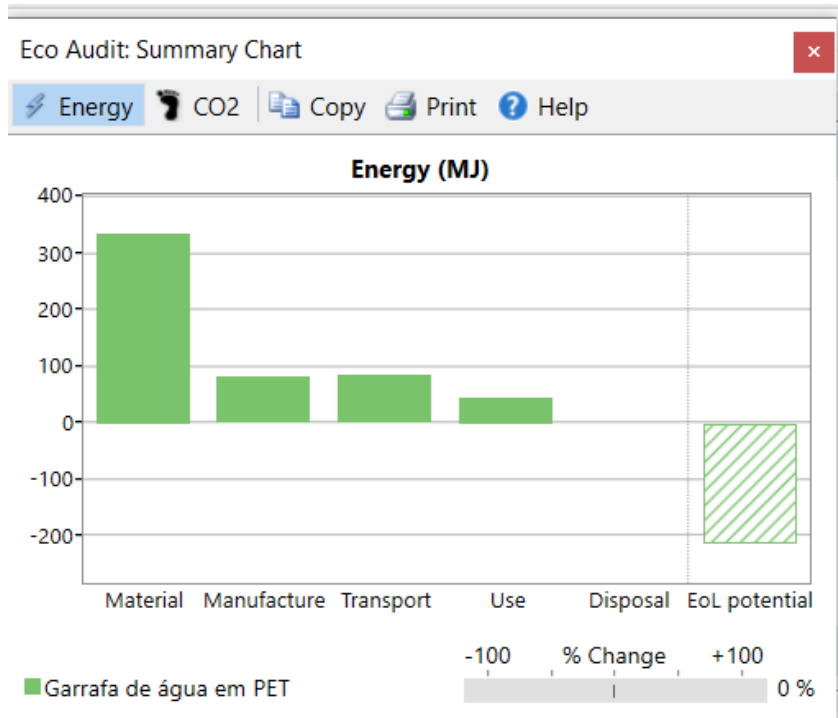


Image:

Browse...

Clear

Note:



# Exemplo de uma Auditoria ecológica

## Detalhes...

**4º passo:** gerar o relatório (resumo e em detalhe)

 **Report** 

Summary chart

Detailed report

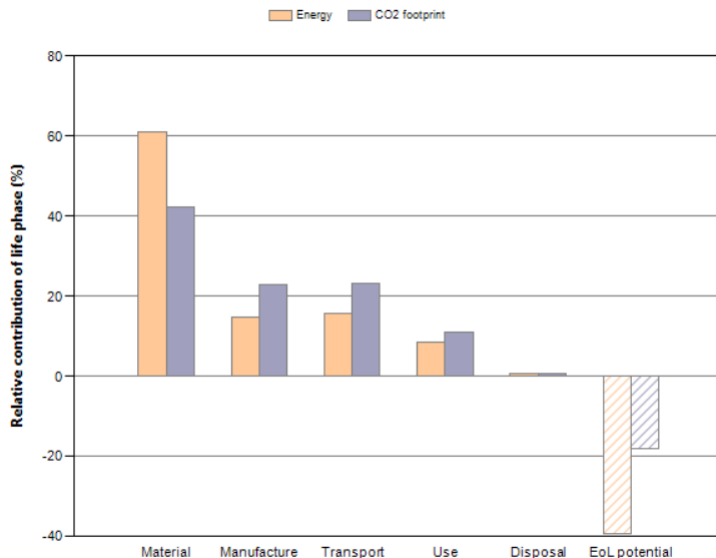


Image:

Browse...

Clear

Note:



Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	336	60.9	11.2	42.2
Manufacture	80.6	14.6	6.05	22.8
Transport	85.9	15.6	6.18	23.3
Use	46.4	8.4	2.89	10.9
Disposal	2.82	0.5	0.197	0.7
Total (for first life)	552	100	26.5	100
End of life potential	-217		-4.79	

Garrafa de água PET2.prd

NOTE: Differences of less than 20% are not usually significant.

[See notes on precision and data sources.](#)

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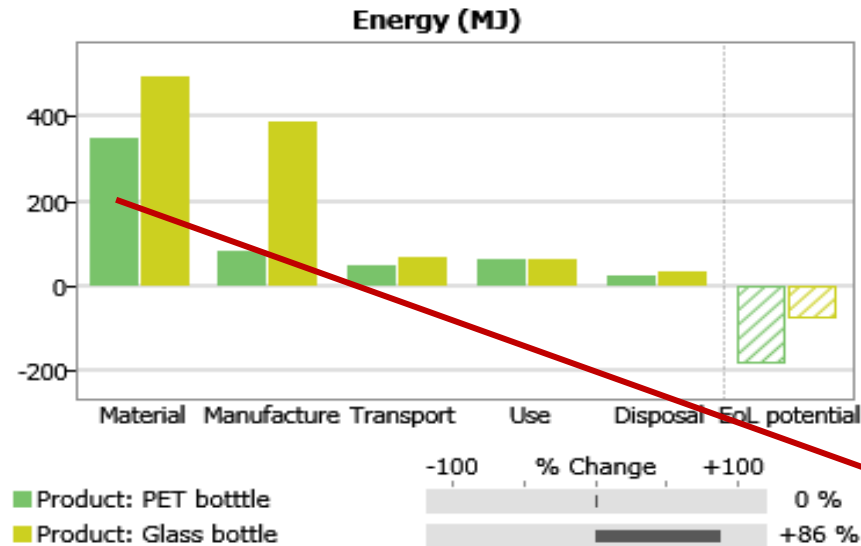
# Exemplo de uma Auditoria ecológica

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



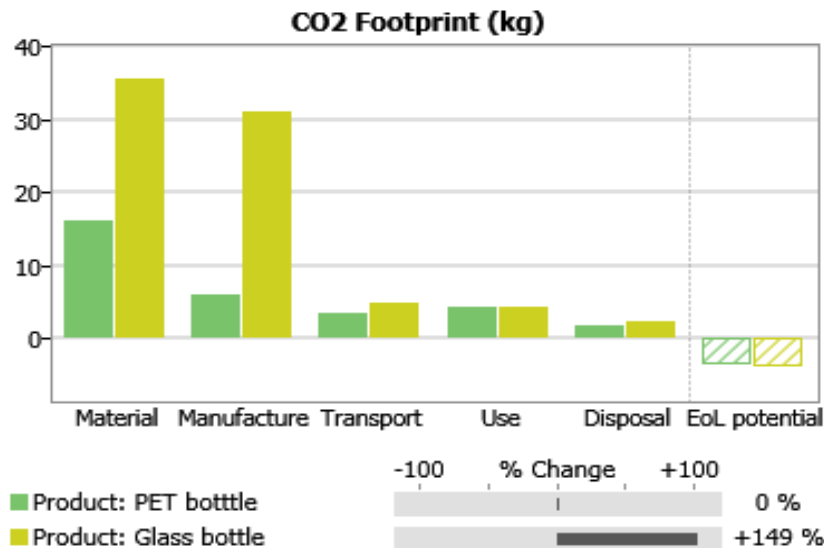
The fast comparison allows design decisions on-the-fly

Reducing impact

## Actions

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

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



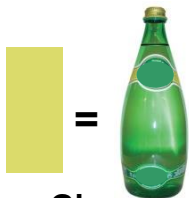
# Exemplo de uma Auditoria ecológica

**Click**  
Compare with....  
Copy of current  
content

**Set Recycle content**  
**to 100%**



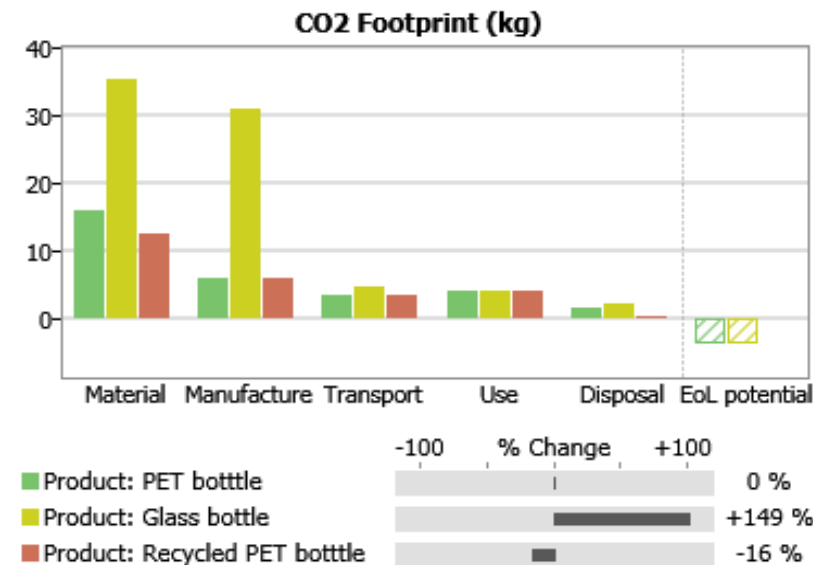
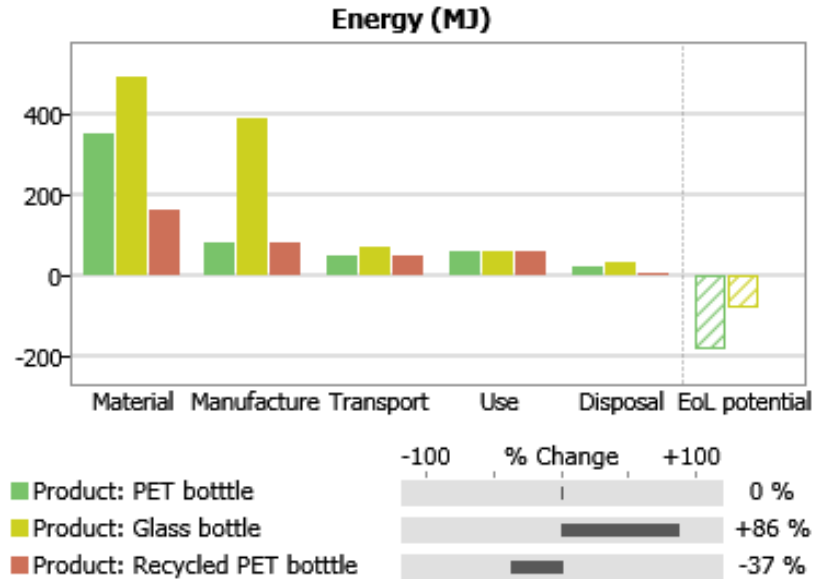
**Virgin PET**



**Glass**



**Recycled PET**



**Can explore:**

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