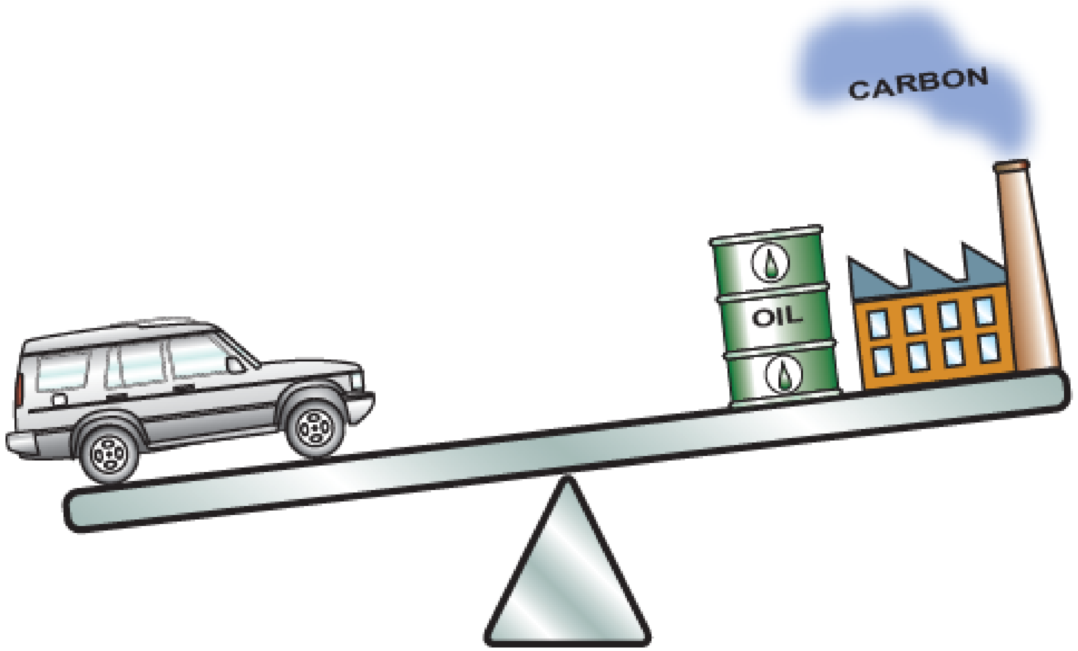
Eco Design and the Eco Audit Tool

introducing students to life-cycle thinking

Mike Ashby
Department of Engineering,
University of Cambridge



Learning objectives for this lecture unit

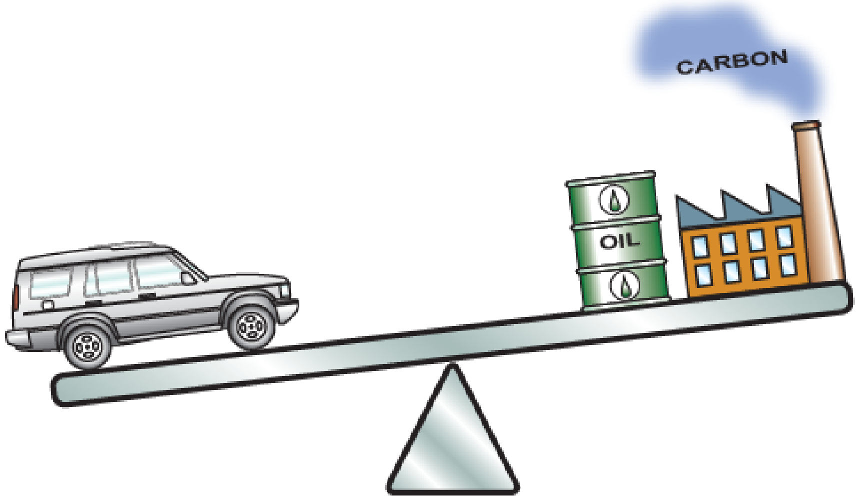
Ansys software mentioned	• Ansys Granta EduPack™, a teaching software for materials education

Intended Learning Outcomes	
Knowledge and Understanding	Knowledge and understanding of the material life-cycle
Skills and Abilities	Ability to use Eco Audits in the design process
Values and Attitudes	Awareness that environmental design objectives influence material selection

Resources

- Text: "**Materials and the Environment**", 3rd Edition by M.F. Ashby, Butterworth-Heinemann, Oxford 2021, UK. Chapters 1-10
- Text: "**Materials: engineering, science, processing and design**", 4th Edition by M.F. Ashby, H.R. Shercliff and D. Cebon, Butterworth Heinemann, Oxford 2019, Chapter 20
- Text: "**Materials Selection in Mechanical Design**", 5th Edition by M.F. Ashby, Butterworth Heinemann, Oxford, 2016. Chapter 14
- White Paper: Ansys Granta EduPack software Eco Audit Tool
- Poster: *Eco Design*

Agenda



- Eco data in the Ansys Granta EduPack software
- The product life-cycle
- Different strategies for eco-performance
- Performance index derivation: PET bottle
- Eco-selection with bubble charts
- LCA vs Eco Audit
- The Eco Audit tool
- Add your own data and records
- Comparisons of products over life-cycle
- The Advanced Eco Audit tool

Typical data records show eco-properties too

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, climate change and water

Climate change (CO2-eq) (virgin grade production)	* 3.51	3.87	kg/kg
Embodied energy (virgin grade production)	* 92.6	102	MJ/kg
Water usage	* 167	185	l/kg

Material processing: energy

Polymer extrusion, embodied energy	* 8.06	8.93	MJ/kg
Polymer molding (injection, blow), embodied energy	* 21	24.2	MJ/kg
Machining, coarse, embodied energy	* 16.8	21.3	MJ/kg
Machining, fine, embodied energy	* 21.3	31.8	MJ/kg
Machining, grinding, embodied energy	* 25.7	42.3	MJ/kg

Material processing: climate change

Polymer extrusion, climate change (CO2-eq)	* 0.53	0.589	kg/kg
Polymer molding (injection, blow), climate change (CO2-eq)	* 1.45	1.7	kg/kg
Machining, coarse, climate change (CO2-eq)	* 1.1	1.4	kg/kg
Machining, fine, climate change (CO2-eq)	* 1.39	2.08	kg/kg
Machining, grinding, climate change (CO2-eq)	* 1.68	2.77	kg/kg

Recycling and end of life

Recycle	✓		
Functional recycle	✗		
Climate change (CO2-eq), recycling	* 1.16	1.28	kg/kg
Embodied energy, recycling	* 17.6	19.4	MJ/kg
Recycle fraction in current supply	1		%
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?	✗		

Environmental notes

The acrylonitrile monomer is nasty stuff, almost as poisonous as cyanide. Once polymerized with styrene it becomes harmless. ABS is FDA compliant, can be recycled, and can be incinerated to recover the energy it contains.

Recycle mark

7 Other

Life-cycles and eco-informed design

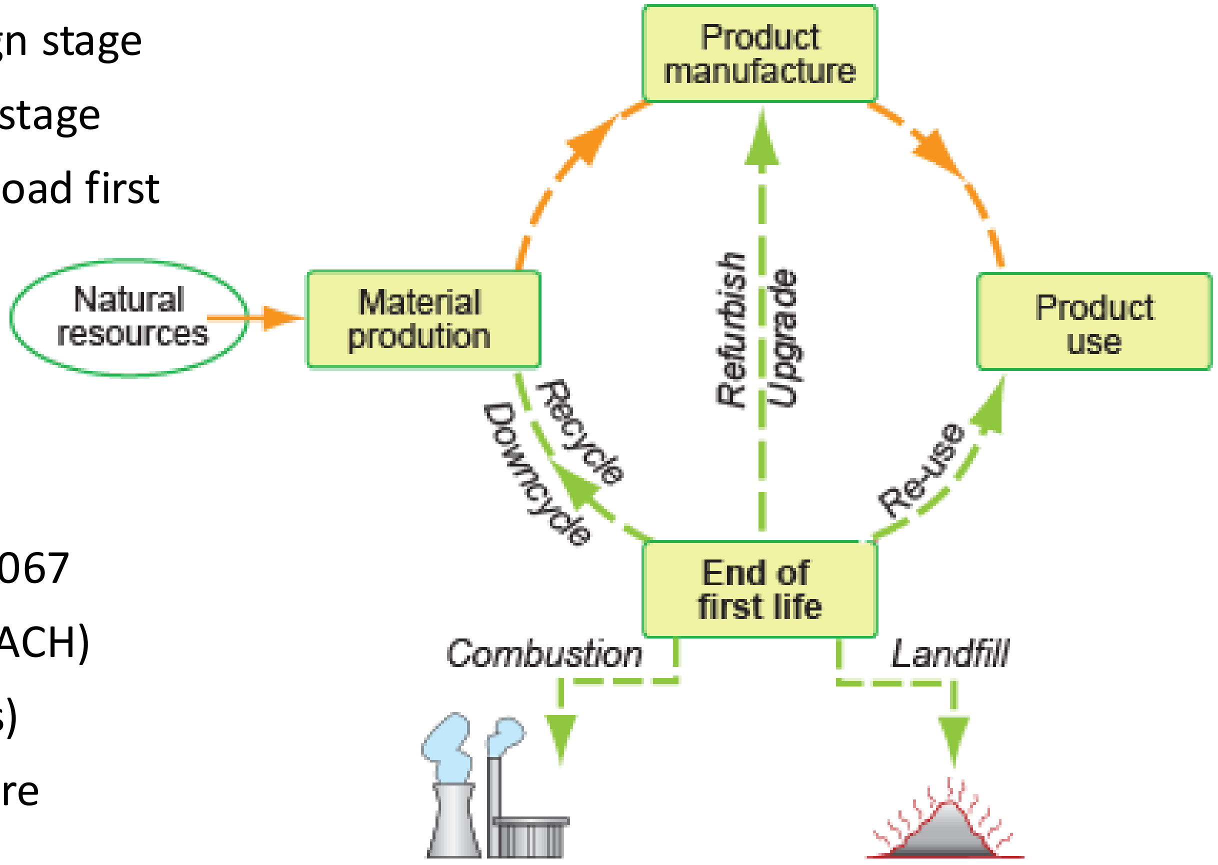
Eco-informed design

- 80% of eco-impact tied in at design stage
- Build-in eco criteria at the design stage
- Target the largest environmental load first

The drivers for eco-design

- Focus on carbon footprint, ISO 14067
- Legislation (Carbon taxes, EuP, REACH)
- Incentives (Subsidies, concessions)
- Urge for "responsible" manufacture
- Doing more with less = $$$

The product life-cycle



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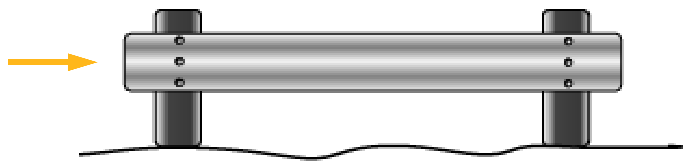
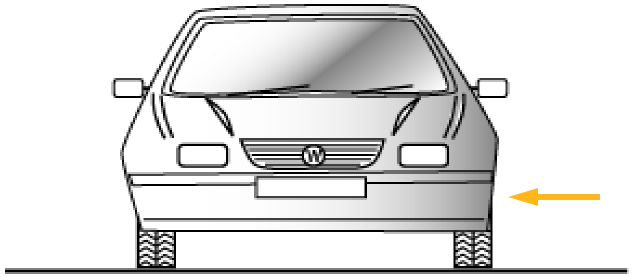
Materials for crash barriers – two important strategies

Static barrier

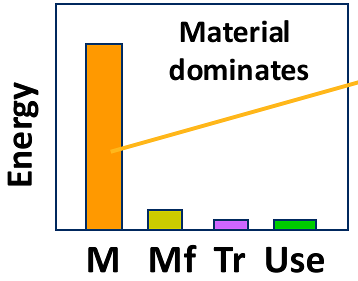


Mobile barrier

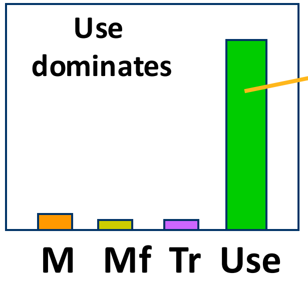


Function: *Absorb impact, transmit load to energy-absorbing units or supports*

Dominant phase of life:



Minimize embodied energy



Minimize mass

Criterion:

Bending strength per unit embodied energy

Bending strength per unit mass

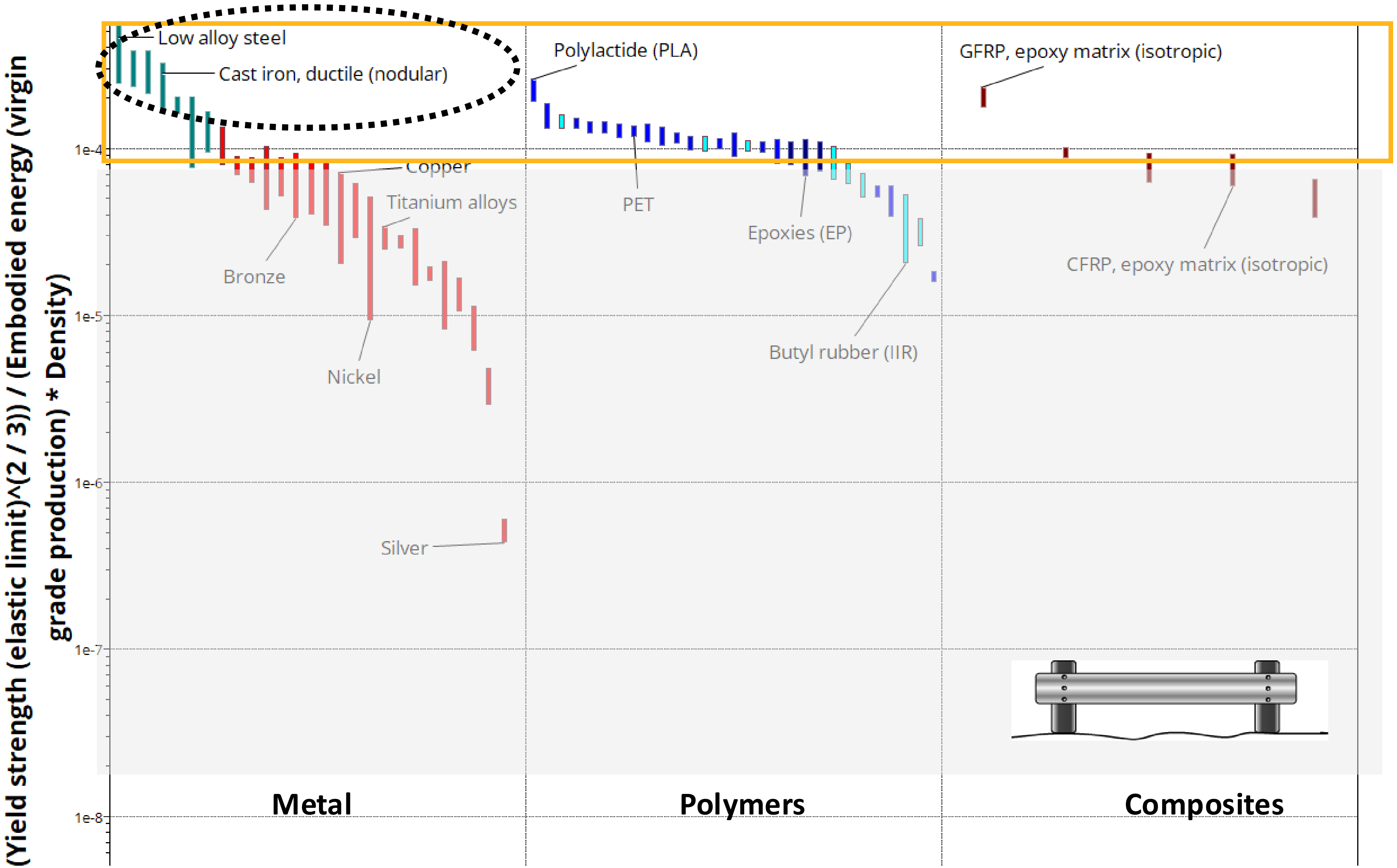
Performance Index:

$$\frac{\sigma_y^{2/3}}{H_m\,\rho}$$

$$\frac{\sigma_y^{2/3}}{\rho}$$

Static barrier: the Performance Index directly as bar chart

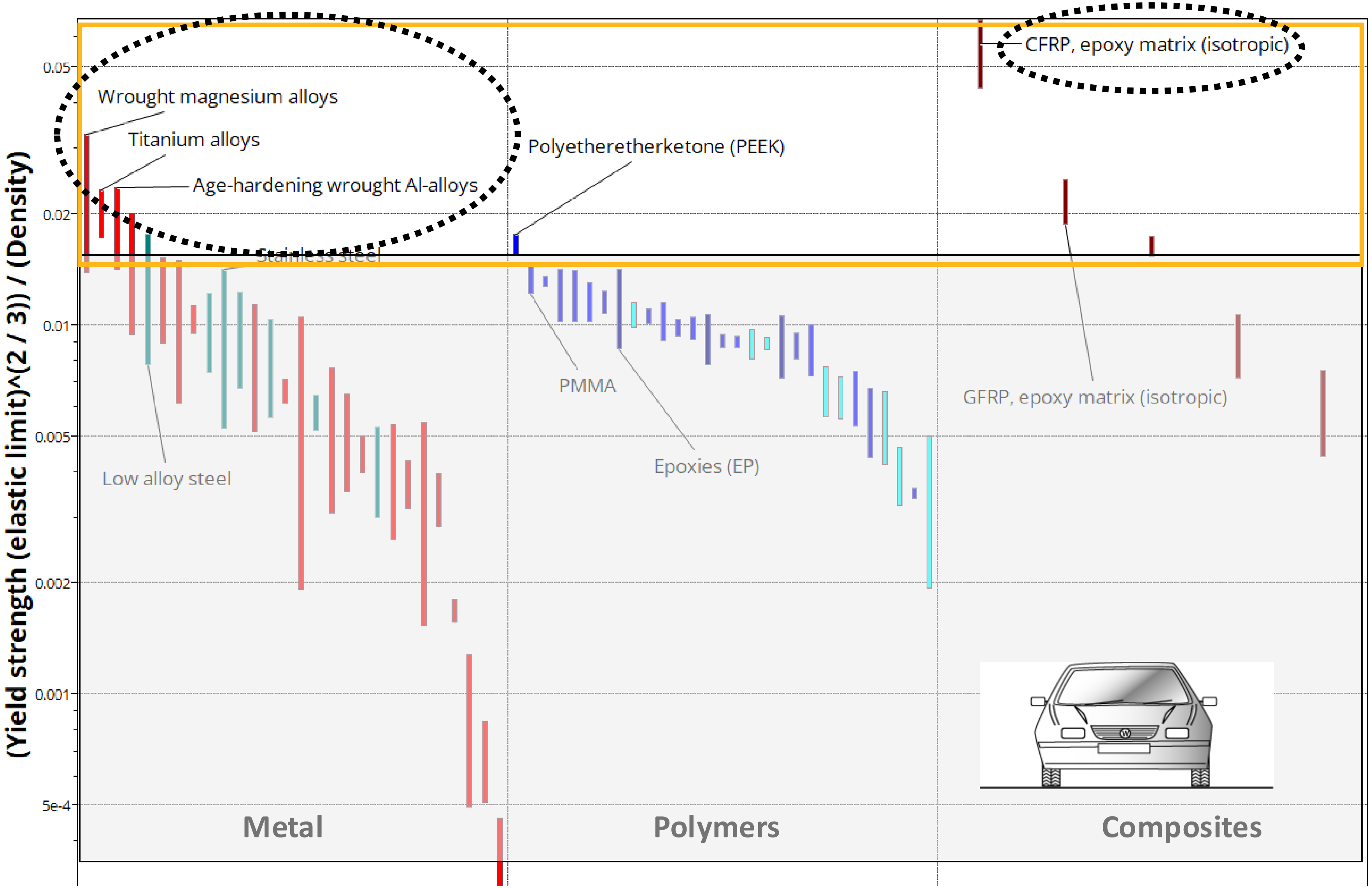
$$\frac{\sigma_y^{2/3}}{H_m \rho}$$



Selected materials: *Steels, Cast irons*

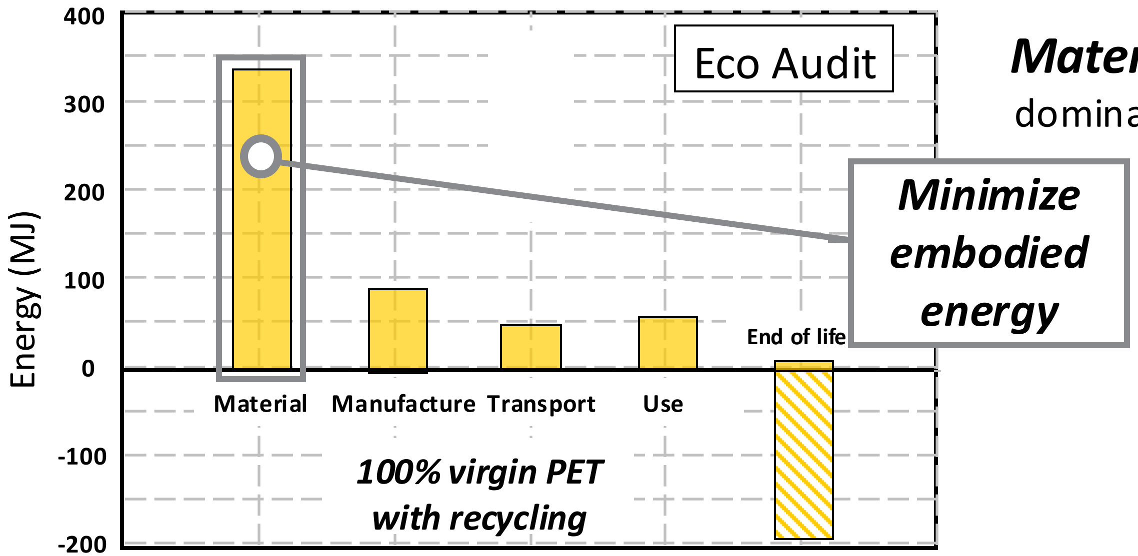
Mobile barrier: the Performance Index directly as bar chart

$$\frac{\sigma_y^{2/3}}{\rho}$$



Selected materials: *CFRP, Mg alloys, Ti alloys, Al alloys*

Eco-selection for a fizzy drink bottle



Material
dominates

Design brief

Improve green credentials of bottle

Translation

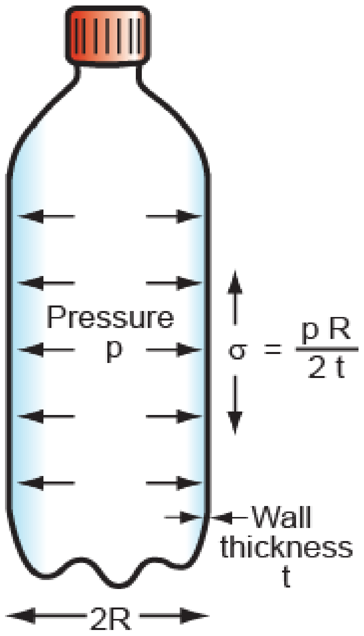
Constraints

- Able to be molded
- Transparent / translucent
- Able to contain pressure

Objectives

- Minimize embodied energy of bottle
- Minimize material cost of bottle

Modelling the bottle



R= Bottle radius
t = Thickness of bottle wall
p = Internal pressure
σ_y = Yield strength of material
ρ = Density of material
H_m = Embodied energy of material/kg
E = Embodied energy/m^2 of wall
C_m = Material cost per kg

Cylindrical pressure vessel

- Circumferential stress $\sigma = \frac{pR}{t} < \sigma_y$
- Embodied energy per unit area of wall

$$E = t H_m \rho = pR \frac{H_m \rho}{\sigma_y}$$

Embodied energy / kg of material

- Find material with lowest energy, seek largest

$$\frac{\sigma_y}{H_m \rho}$$

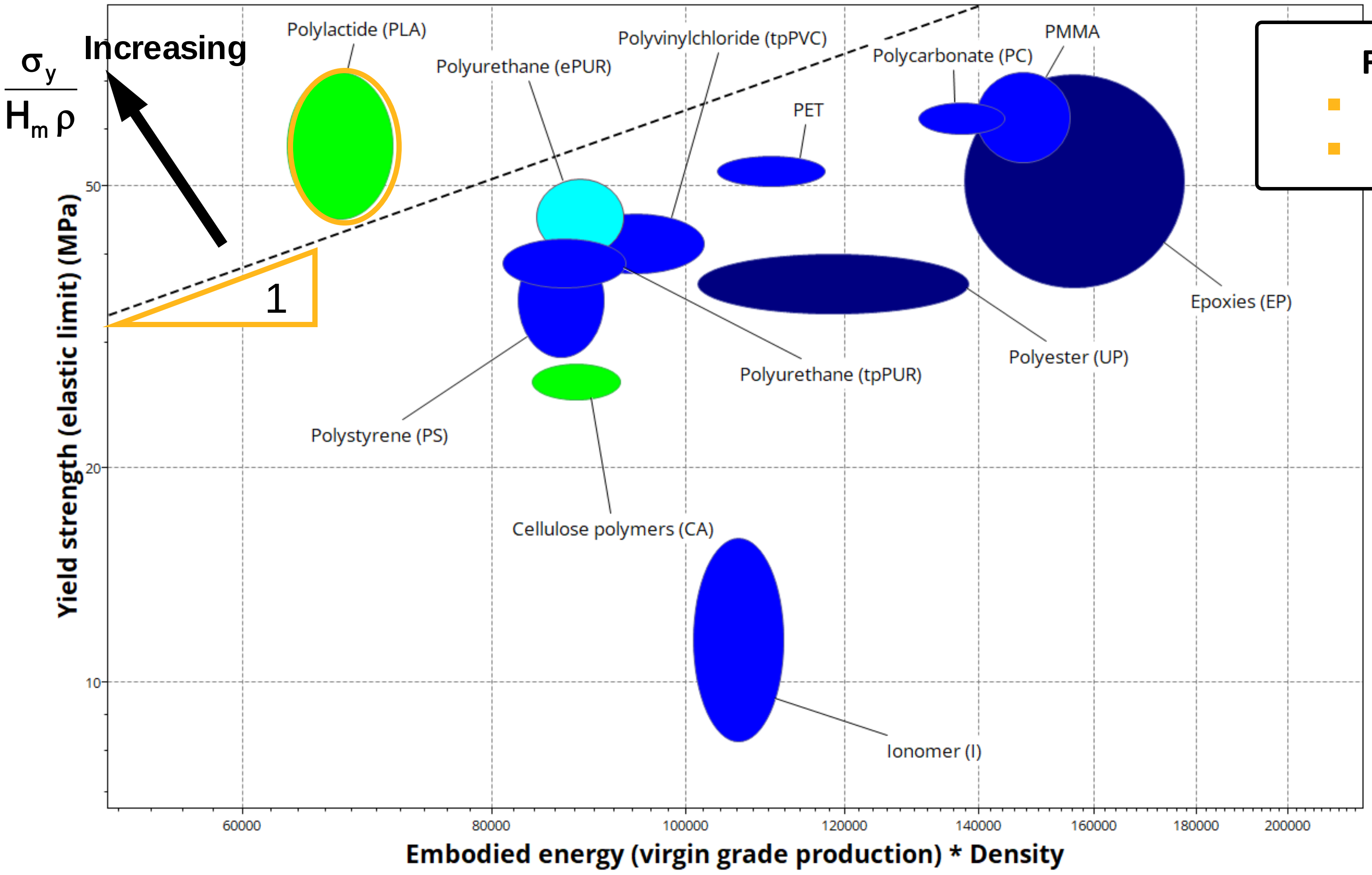
- Find material with lowest cost, seek largest

$$\frac{\sigma_y}{C_m \rho}$$

Price / kg of material

Selection to minimize embodied energy

First apply constraints, then use index to optimize choice



Further Constraints to Apply

- Able to be molded
- Transparent / optical quality

Bio-polymers are colored green

PLA meets the constraints at lowest embodied energy

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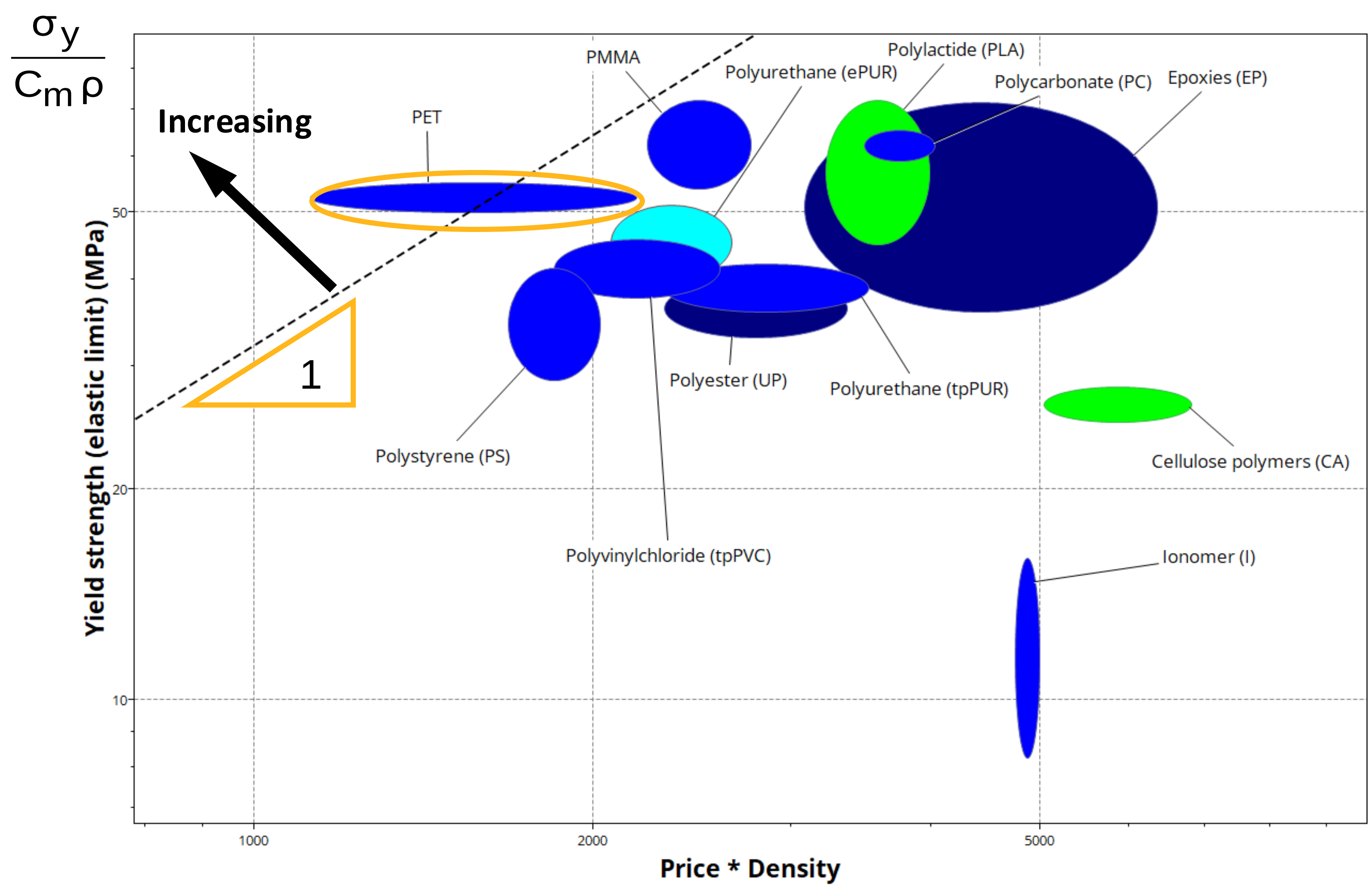
Selection to minimize cost

Can't ignore cost



Bio-polymers are colored green

PET meets the constraints at lowest cost

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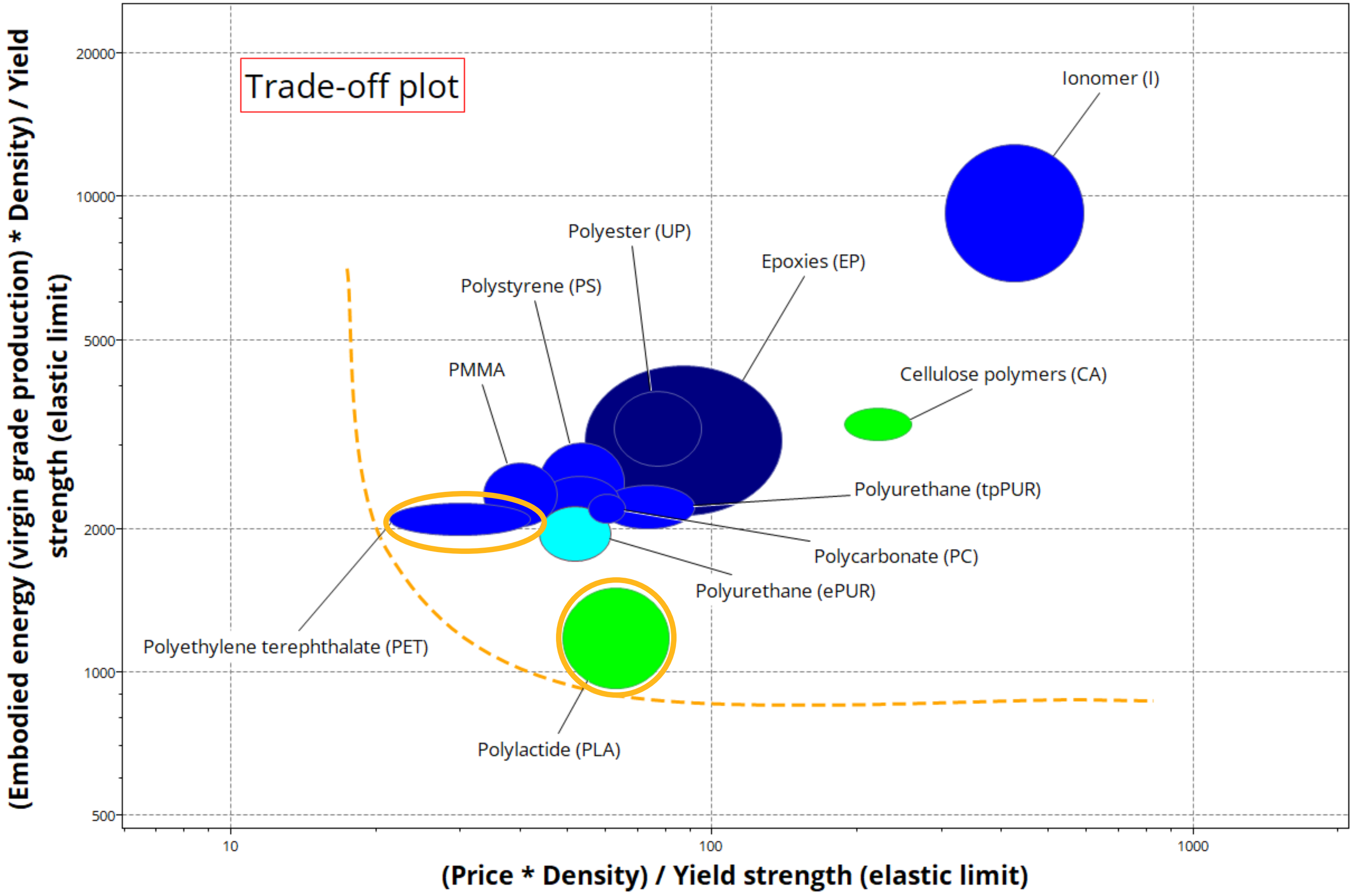
Trade-off plot

Minimizing both embodied energy and cost

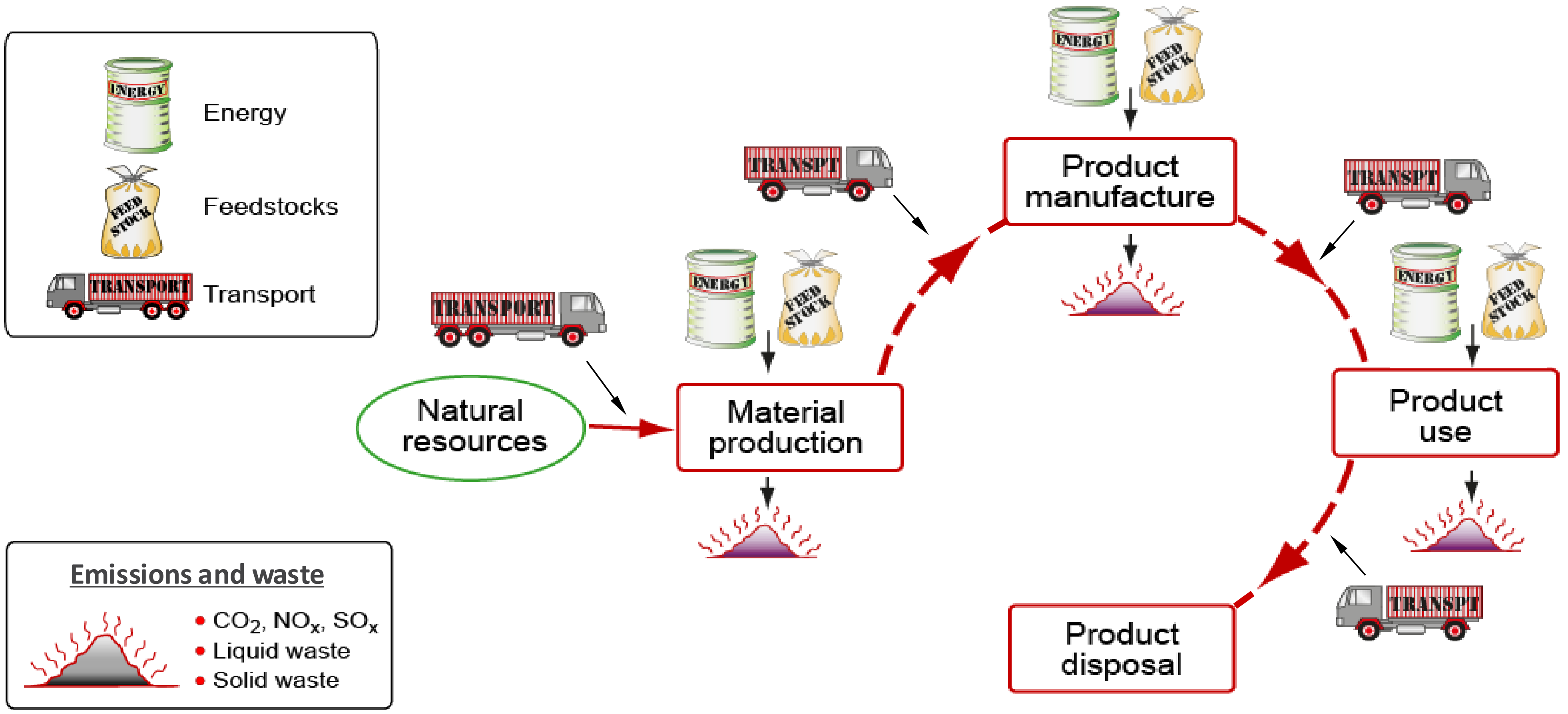


Bio-polymers are colored green

In a trade-off plot, the properties on the axes are to be minimized.

If cost/energy priority not established, both are good candidates

The product life-cycle in detail – 4 phases in first life (cradle-grave)



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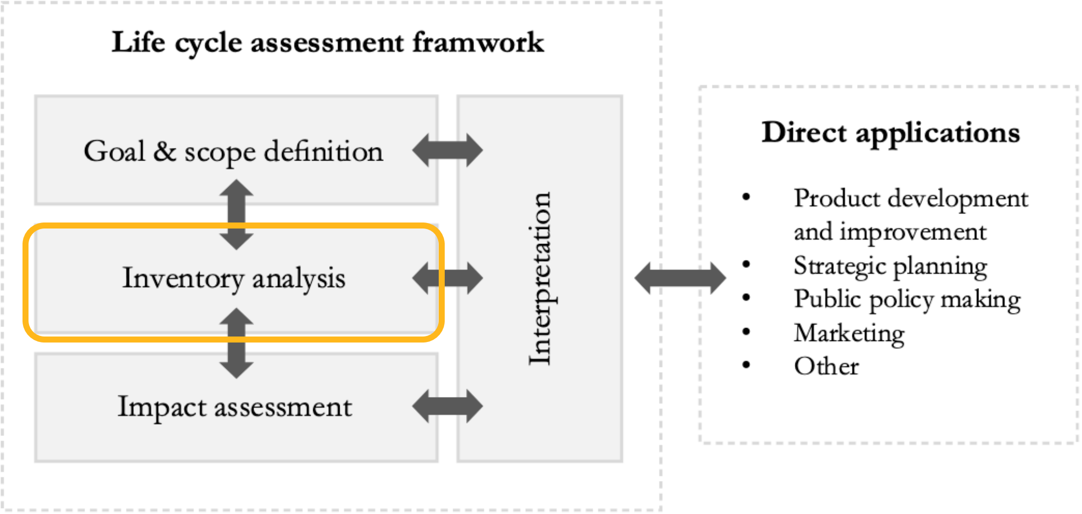
Life cycle assessment (LCA)

ISO 14040 series, International Standard



Simplified Life-Cycle Inventory (LCI) with Eco Audit

Typical LCA output

Aluminum cans, per 1000 units

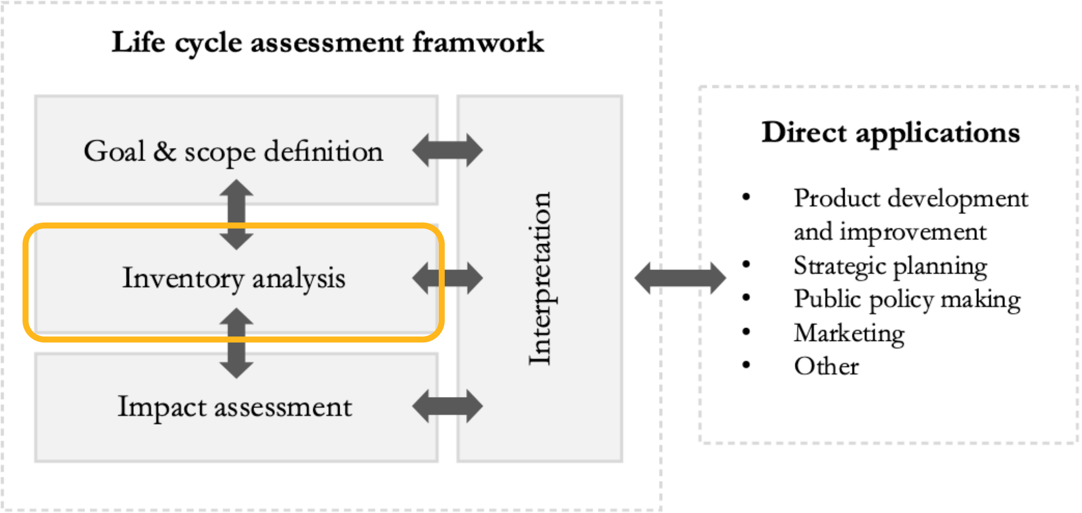
Resource consumption	*Bauxite*	*59*	*kg*
	Oil fuels	*148*	*MJ*
	Electricity	*1572*	*MJ*
	Energy in feedstock	*512*	*MJ*
	Water use	*1149*	*kg*
Emissions inventory	*Emissions: CO_2*	*211*	*kg*
	Emissions: CO	*0.2*	*kg*
	Emissions: NO_x	*1.1*	*kg*
	Emissions: SO_x	*1.8*	*kg*
	Particulates	*2.47*	*kg*
Impact 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}*	

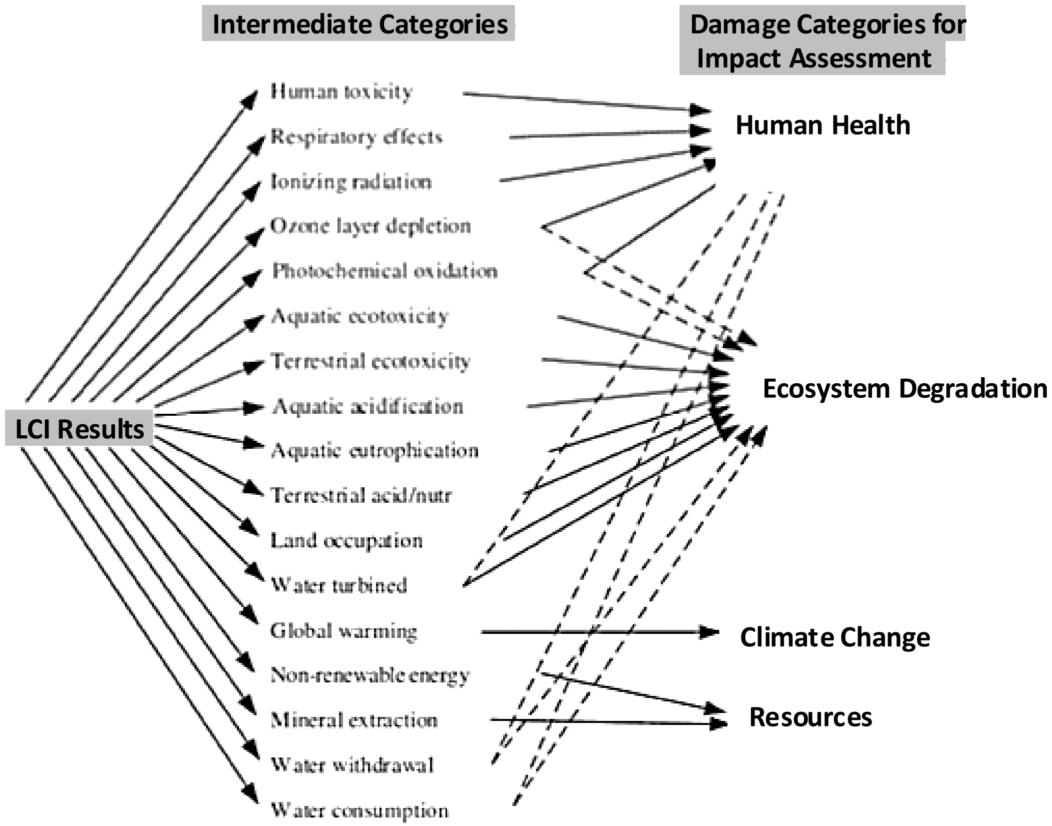
LCA Framework in ISO 14044:2006

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

Life cycle assessment (LCA) vs Life-cycle Inventory (LCI)

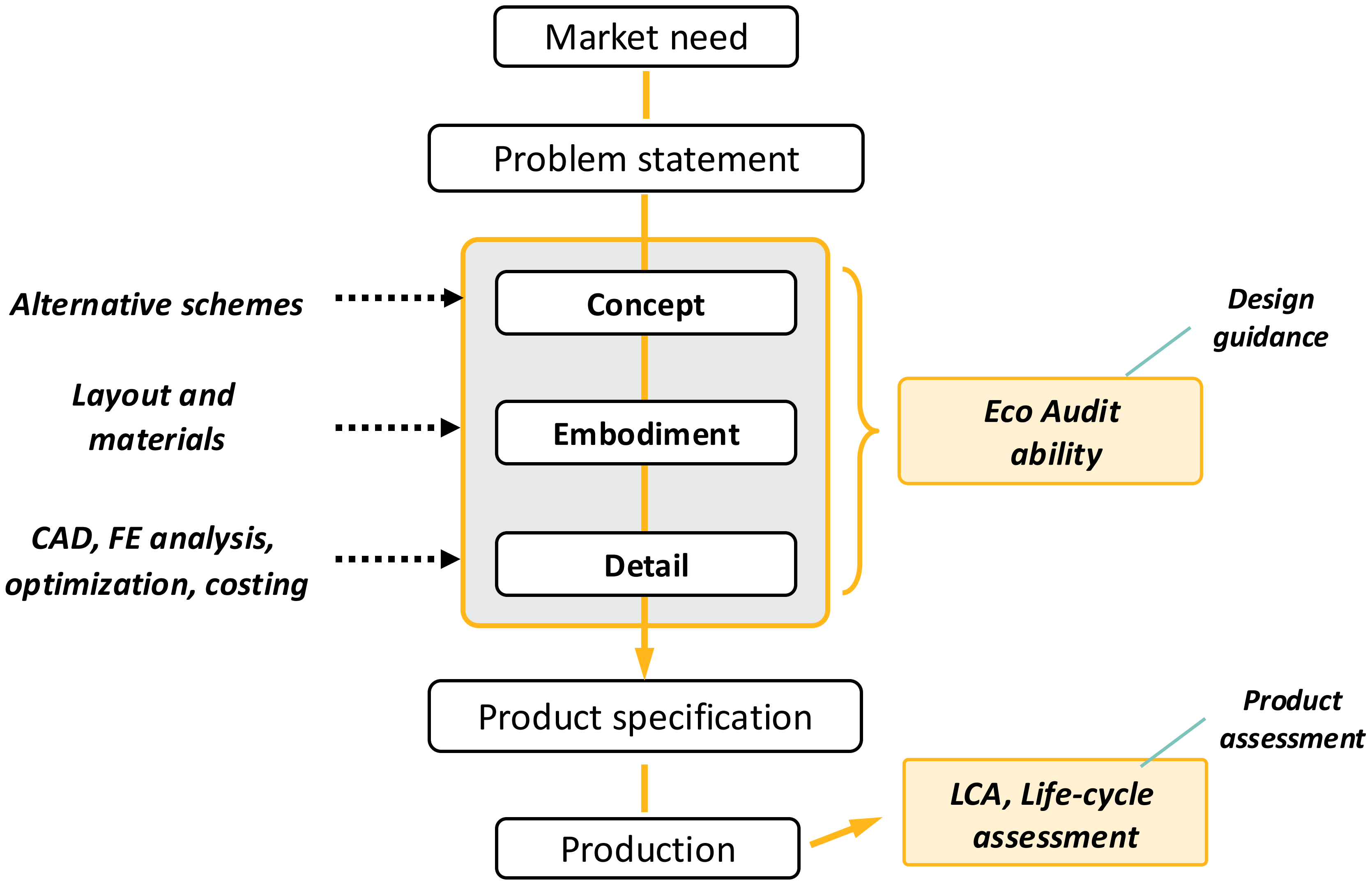
PAS 2050 by the British Standards Institute (BSI)
ISO 14040 series, International Standard





Simplified Life-Cycle Inventory (LCI) with Eco Audit

Design guidance *vs* product assessment



Life-cycle overview – Example: Jug Kettle

Design

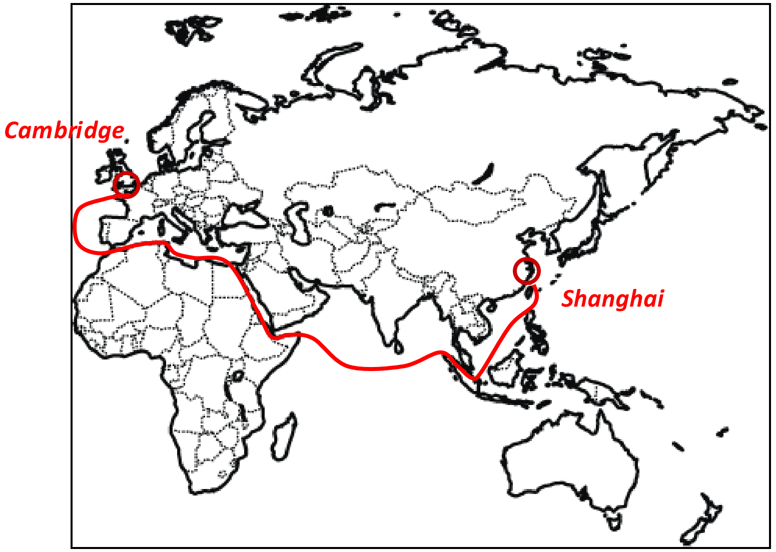
China

Materials kg

- PP 0.4
- Stainless 0.25
- Nichrome 0.05
- Copper 0.1

Product

Transport

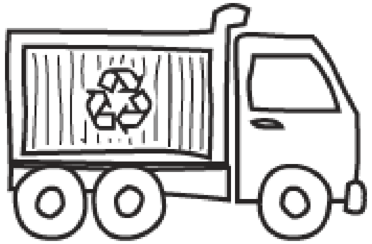


11, 866 miles – 21,950 km sea
192 km by road

Use

2 kW, 2 minutes,
Three times a day 3 years

End of life



Recycle

Ansys Granta EduPack software Eco Audit Tool

User inputs

User interface

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

2 kW electric kettle

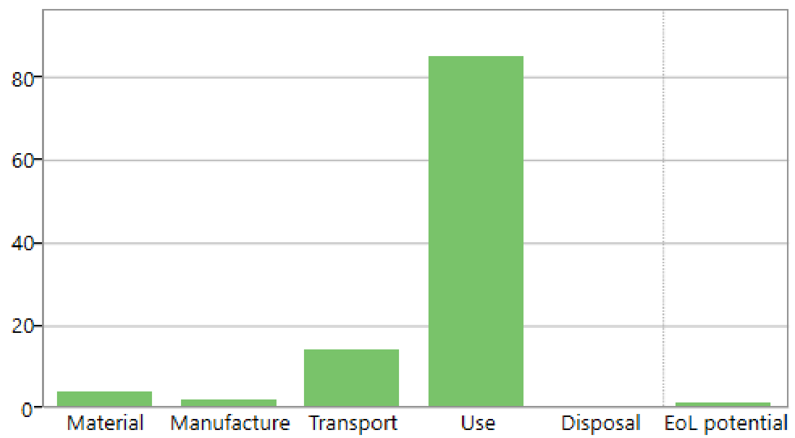
Eco Audit model

Database

Eco data

- ***Embodied energies***
- ***Process energies***
- ***Climate change (CO_2-eq)***
- ***Unit transport energies***
- ***Recycling / combustion***

Outputs:



Use is 88% of life-energy

Full report

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

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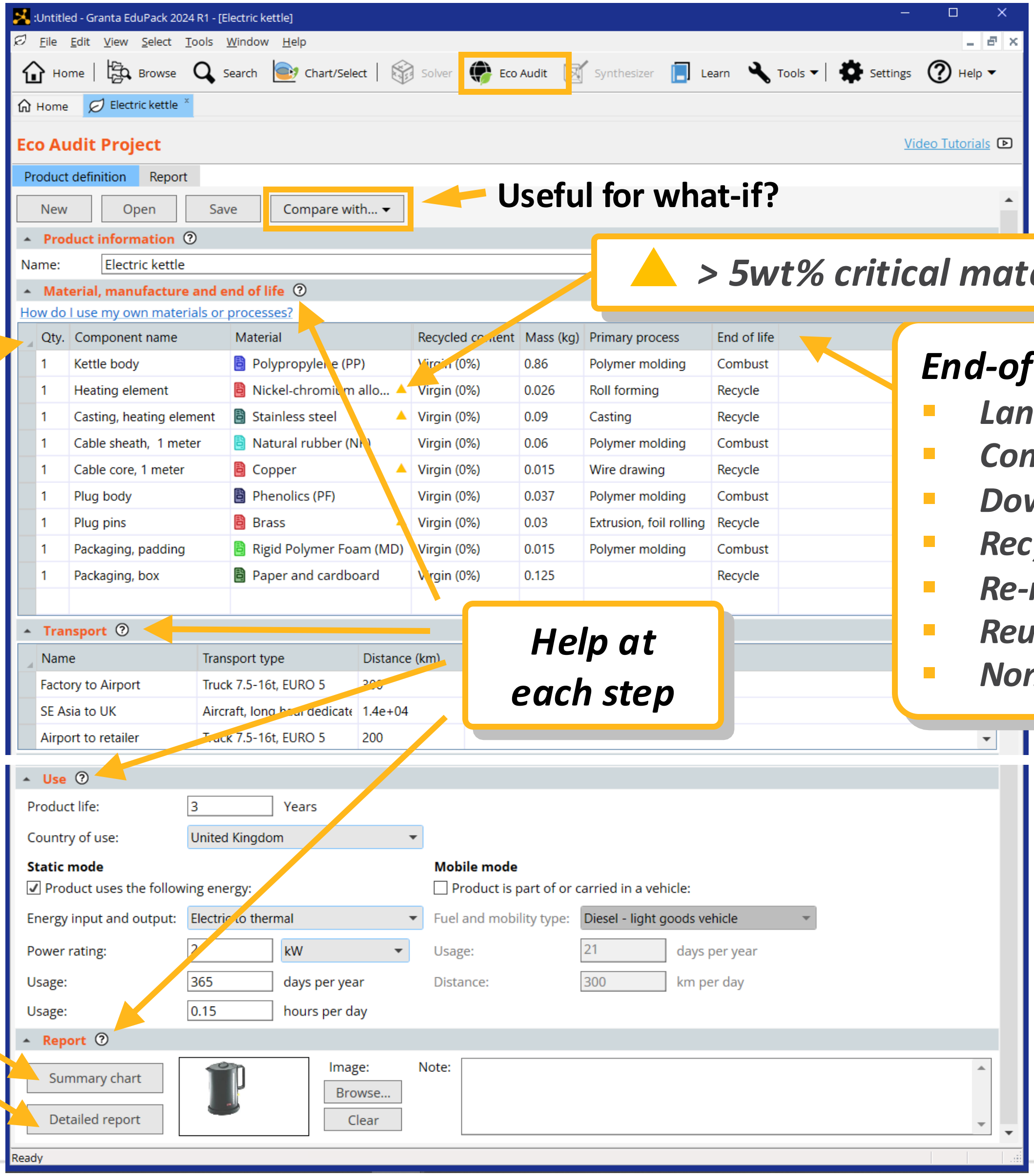
The Eco Audit input interface at Level 2



Useful for what-if?

> 5wt% critical material

Bill of Materials (Input or file)

End-of-Life

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

Help at each step

Output data (Detailed info)

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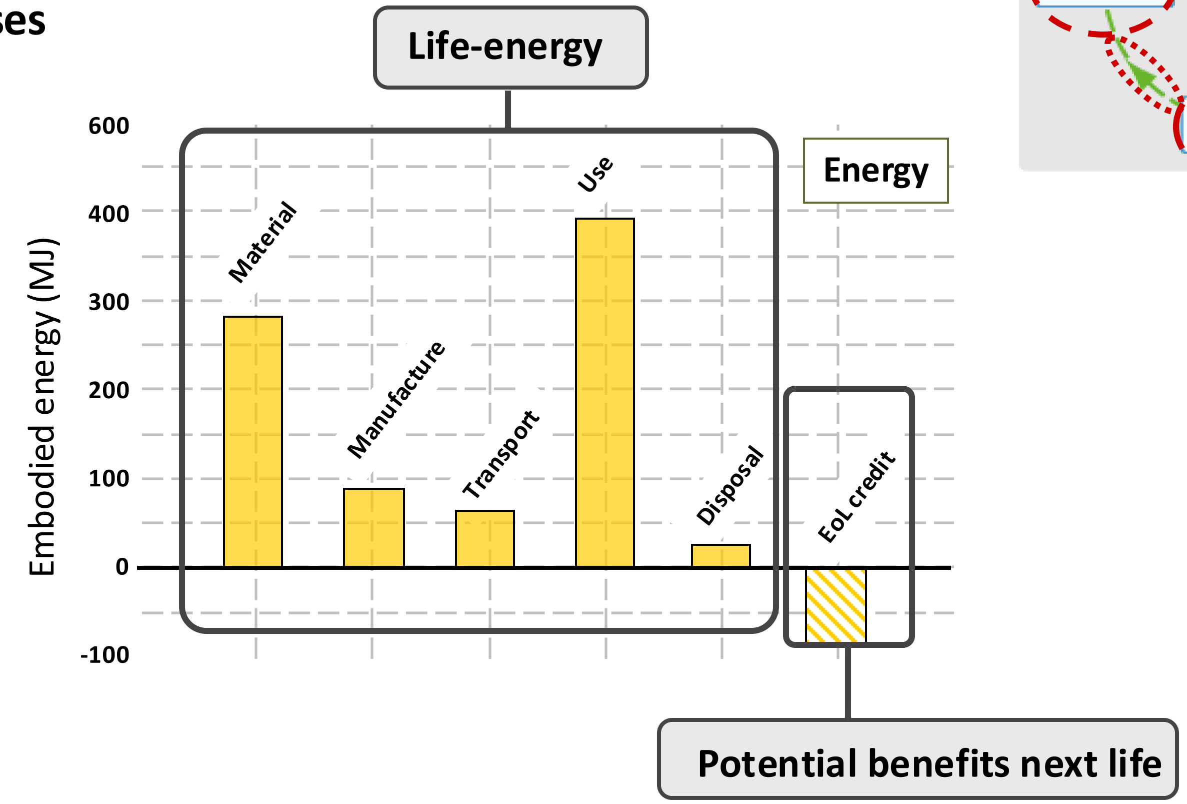
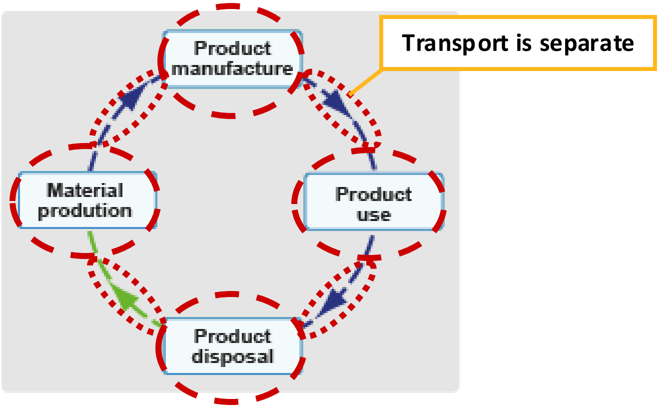
Eco Audit output for design

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

- **1 resource** – ***Embodied energy [MJ/kg]***
- **1 emission** – ***Climate change (CO_2-eq) [kg/kg]***
- **Distinguish life-phases**
- **Audit: Energy**





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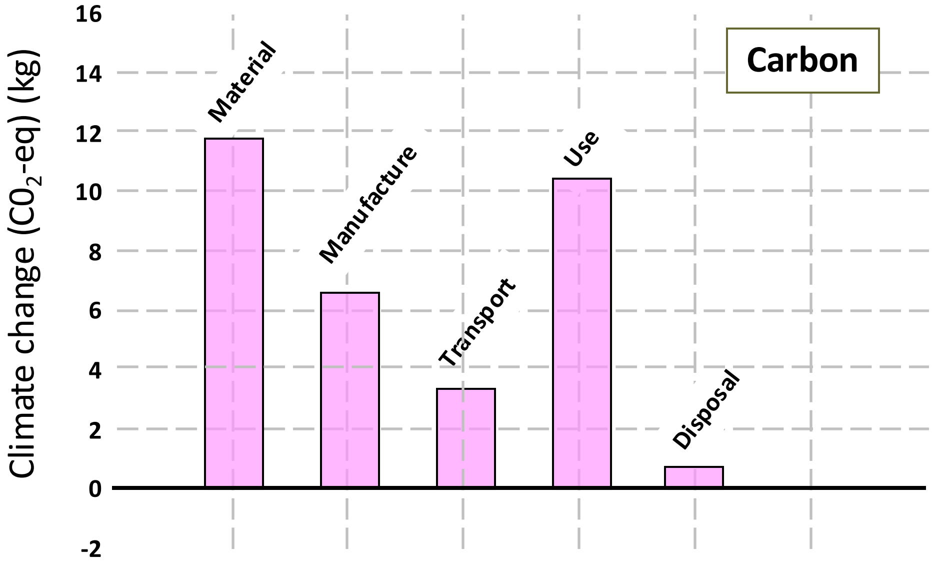
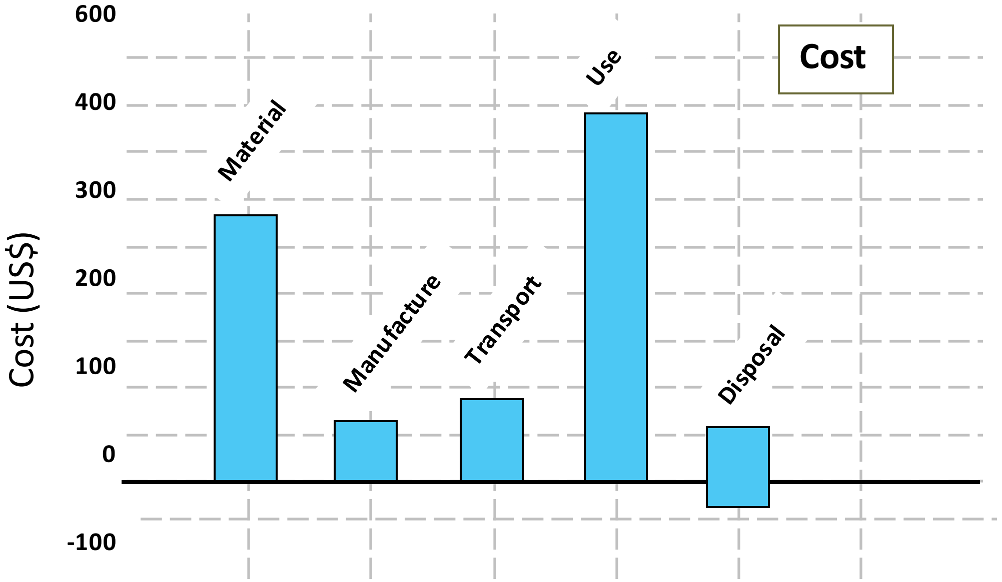
Eco Audit output for design

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

- **1 resource** – ***Embodied energy [MJ/kg]***
- **1 emission** – ***Climate change*** *(****CO_2-eq****)* ***[kg/kg]***
- **Distinguish life-phases**
- **Audit: Energy, CO_2 or Cost**





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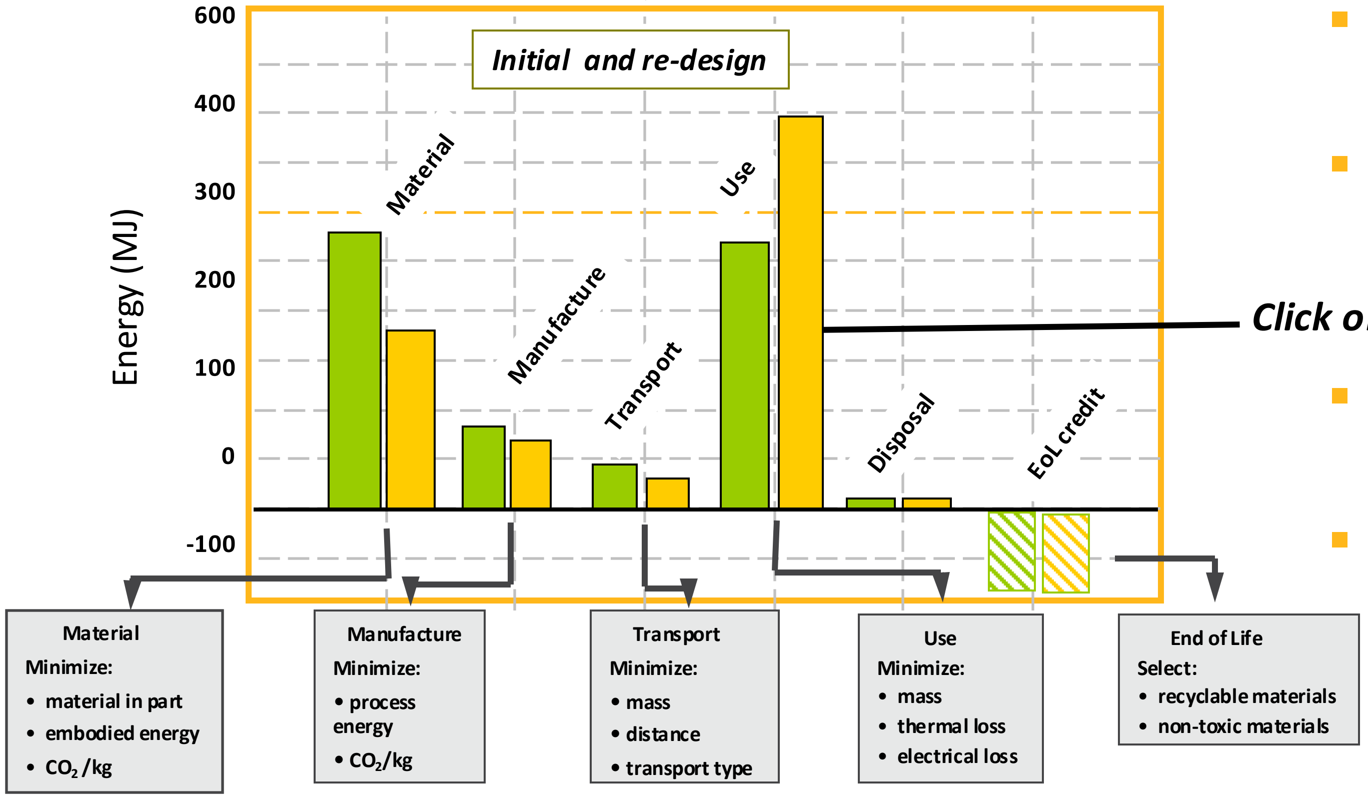
Eco-informed selection: the strategy

The steps

Fast Eco Audit → **Analyse results, Identify priorities** → **Explore options with “What if...”s** → **Use software to select new Materials and/or Processes** → **Recommend actions & assess potential savings**

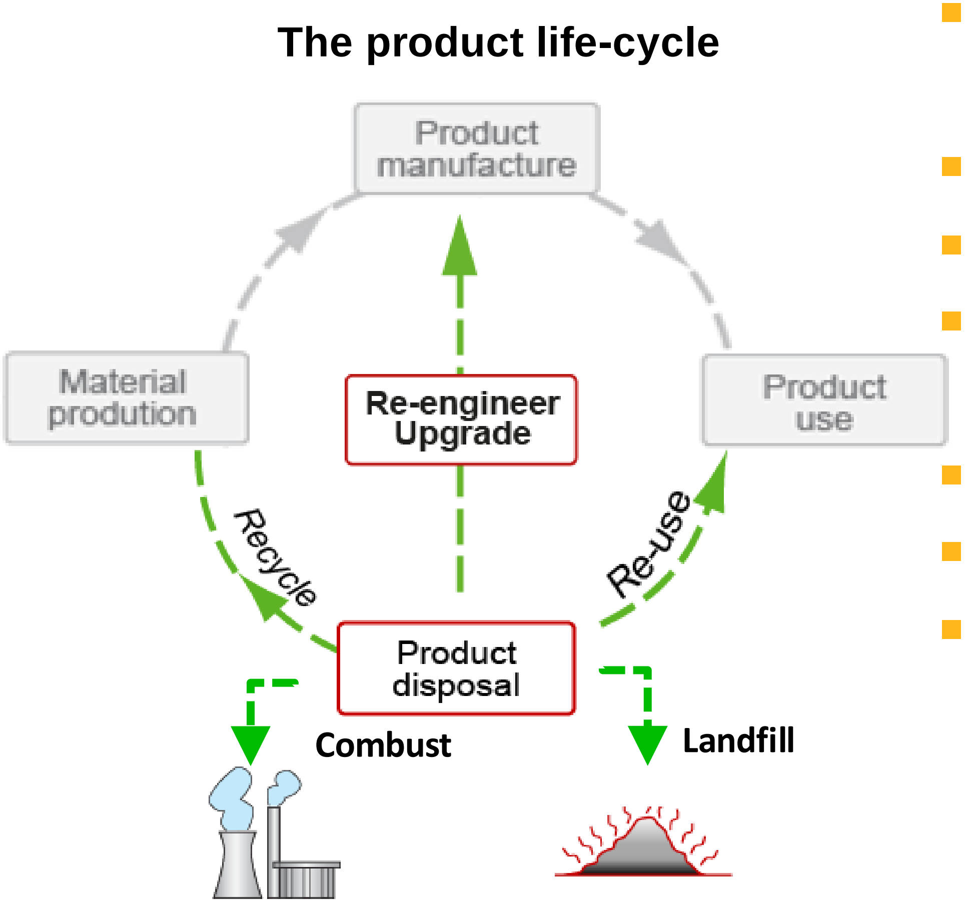


- When we did “what if’s” we were guessing
- Can we do better? Be systematic?

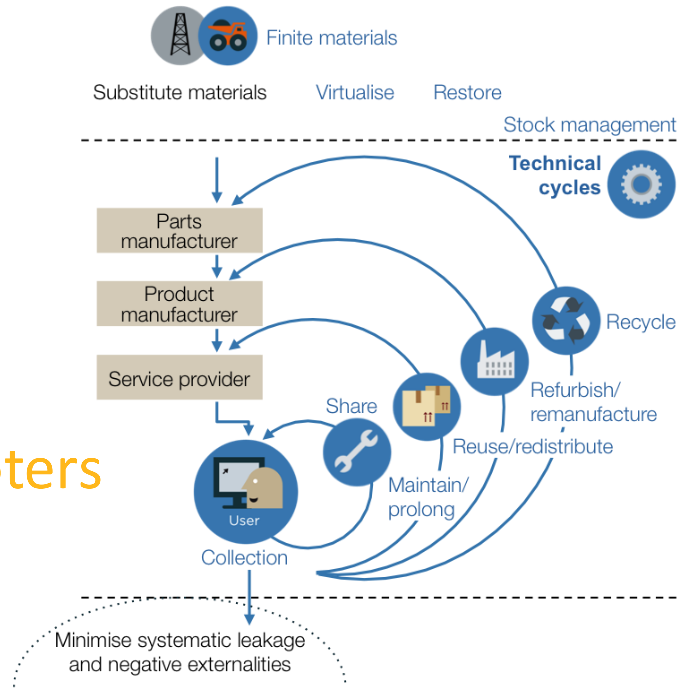
Click on bar for advice

- Use Eco Audit or other tools to explore design improvements
- Apply the selection methodology

A closer look at Product disposal and End-of-life – phase 4

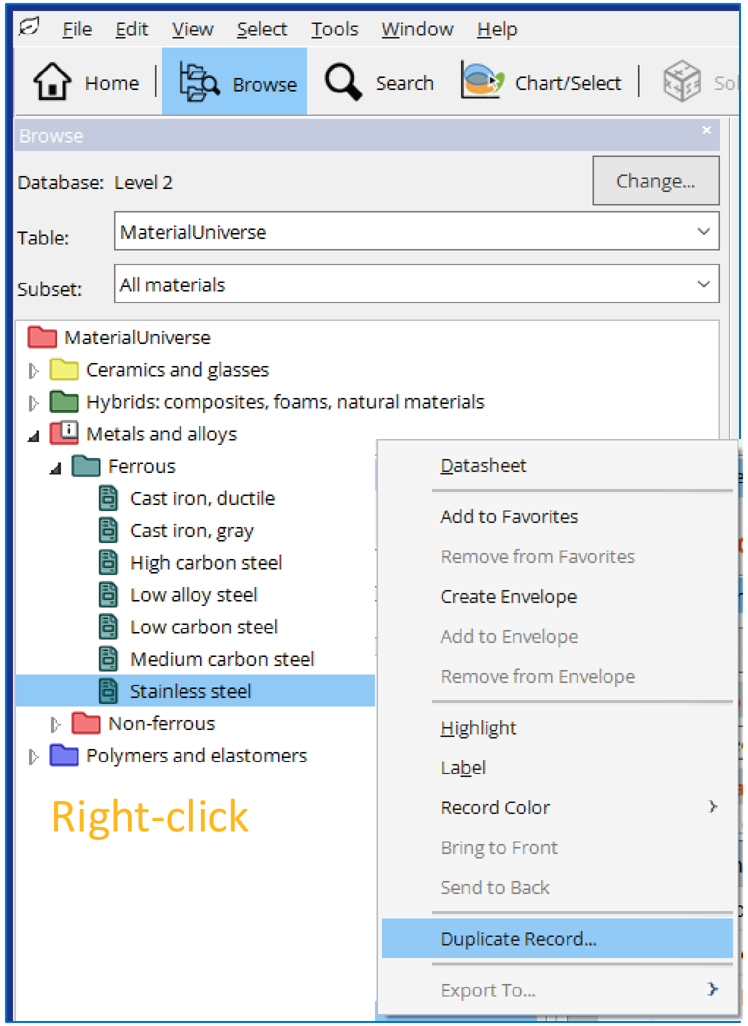


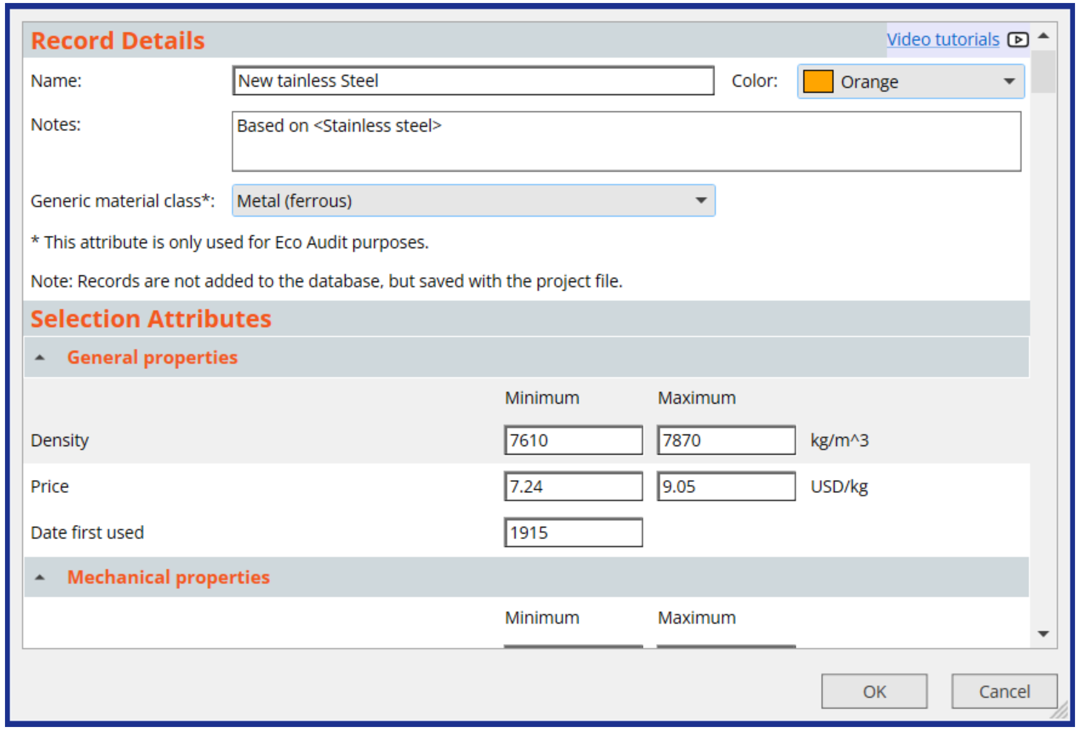
- Landfill (not good – to avoid)
- Combust (energy recovered but material lost)
- Downcycle (non-functional)
- Recycle (functional recycling)
- Re-engineer/Upgrade (repair, modernize)
- Re-use (second hand, inherit)
- Sharing (carpool, electric scooters
- Circularity – `next life:



SOURCE: Adopted from original by the Ellen MacArthur Foundation

Add your own records, based on existing ones, to Eco Audit





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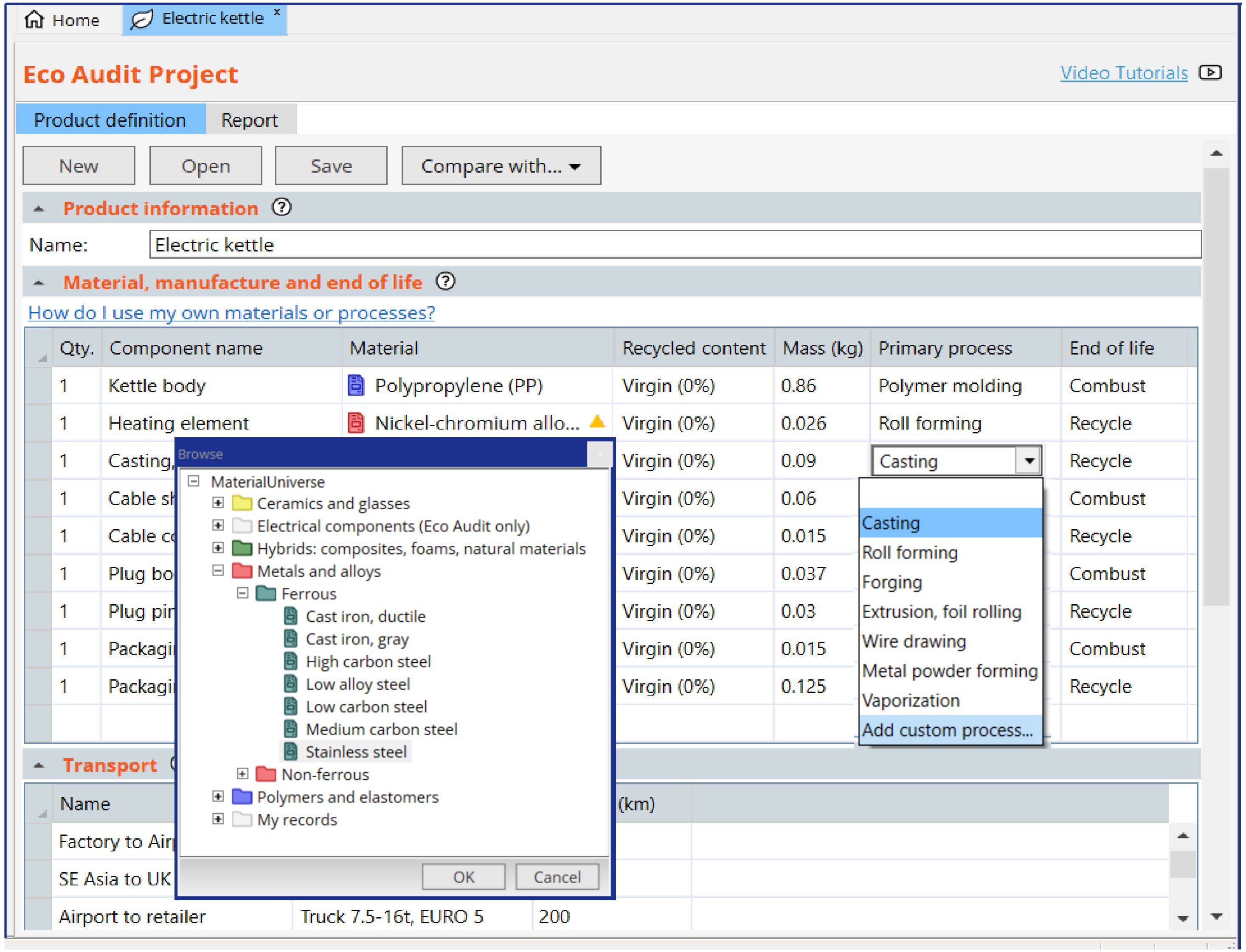
Both custom Materials and Processes can be included in Eco Audit



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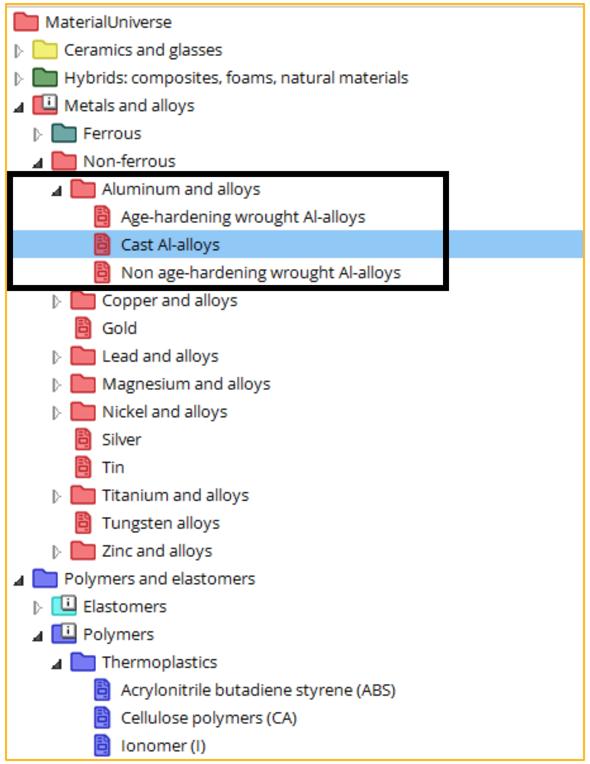
Glass bottle with cap: Step 1. Material and process energy / CO_2

Component name	Material	Process	Mass (kg)	End of life
Component 1	*Aluminum alloys*	*Forging/Rolling*	*0.002*	*Recycle*

Granta EduPack materials tree



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

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

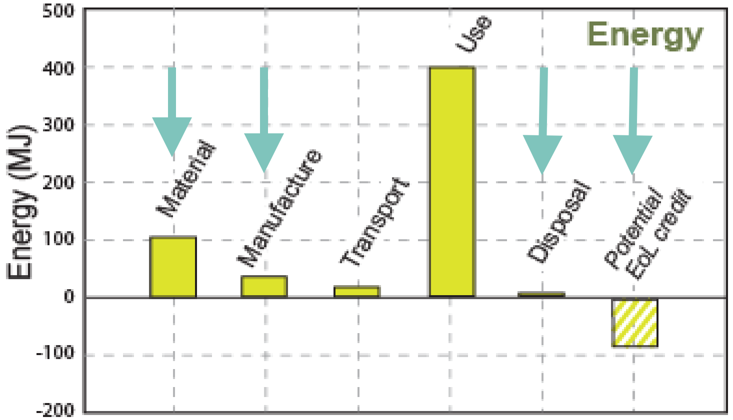
End of life options

Glass bottle with cap: Step 2. Material and process energy / CO_2

Component name	Material	Process	Mass (kg)	End of life
Component 1	*Aluminum alloys*	*Rolling*	*0.002*	*Recycle*
Component 2	*Glass*	*Glass molding*	*0.45*	*Reuse*

Total embodied energy	Total process energy	Total mass	Total end of life energy

- Don't forget to put the number of each component



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Step 3. Transport

- Eco Audit assumes optimal (fully) loaded transports

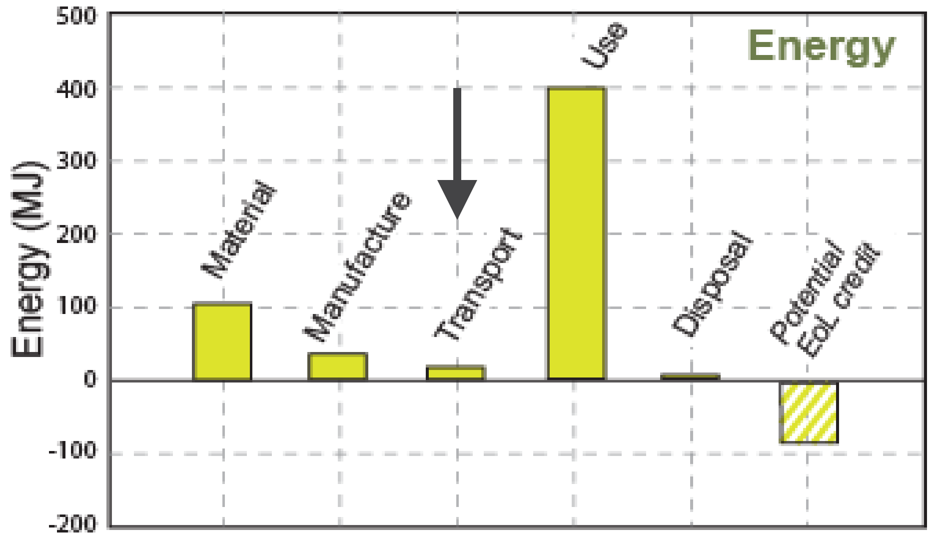
Transport stage	**Transport type**	**Distance (km)**
Stage 1	***Truck 3.5-7.5t, EURO 5***	***350***
Stage 2	***Sea, bulk carrier***	***12 000***

Light commercial vehicle
Truck 3.5-7.5t, EURO 3
Truck 3.5-7.5t, EURO 4
Truck 3.5-7.5t, EURO 5
Truck 3.5-7.5t, EURO 6
Truck 7.5-16t, EURO 3
Truck 7.5-16t, EURO 4
Truck 7.5-16t, EURO 5
Truck 7.5-16t, EURO 6
Truck 16-32t, EURO 3
Truck 16-32t, EURO 4
Truck 16-32t, EURO 5
Truck 16-32t, EURO 6
Truck >32t, EURO 3

Table of transport types:
MJ / tonne.km
CO_2 / tonne.km

Transport energy

Transport $CO_{2\ Eq}$



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Step 4. Use phase – static mode

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-eq for use

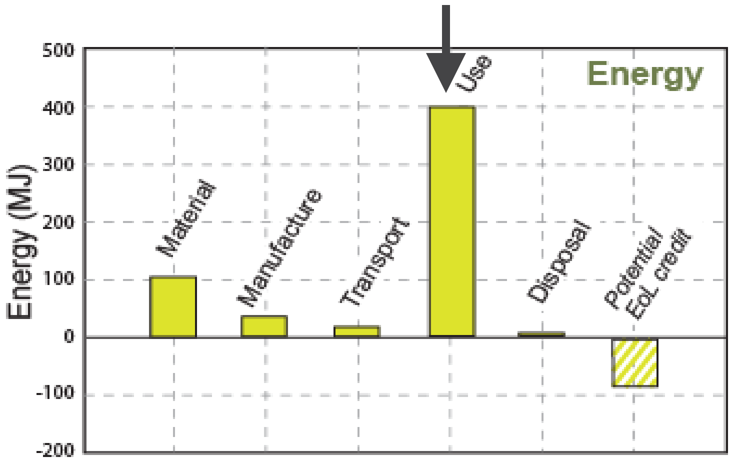
Energy input and output

- 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)

W
kW
MW
hp
ft.lb/sec
kCal/yr
BTU/yr



- A fridge has electric to mechanical energy losses, due to the compressor

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New example. Bottled water in PET (100 units)

- 1 litre PET bottle with PP cap
- Blow molded
- Filled in France, transported 550 km to UK
- Refrigerated for 2 days, then drunk

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*	*Polypropylene*	*Molding*	*0.001*	*Landfill*
100	*Water*		*1.0*		

Transport

Stage 1 | *Truck 7.5-16t, EURO 5* | *550 km*

Use - refrigeration

Electric to mechanical | *0.12 kW* | *2 days* | *24 hrs/day*

Survey charts

Full report

Change the materials

- 1 litre **glass bottle** with **aluminum cap**
- **Glass molded**
- Filled in France, transported 550 km to UK
- Refrigerated for 2 days, then drunk

Copy of current project
New project
Saved project

Product name: *Glass bottle*

New | Open | Save | Compare with...

Number	Name	Material	Process	Mass (kg)	End of life
100	*Bottles*	*Soda glass*	*Glass molding*	*0.45*	*Recycle*
100	*Caps*	*Aluminum*	*Forging/Rolling*	*0.002*	*Landfill*
100	*Water*		*1.0*		

Transport

Stage 1	*Truck 7.5-16t, EURO 5*	*550 km*

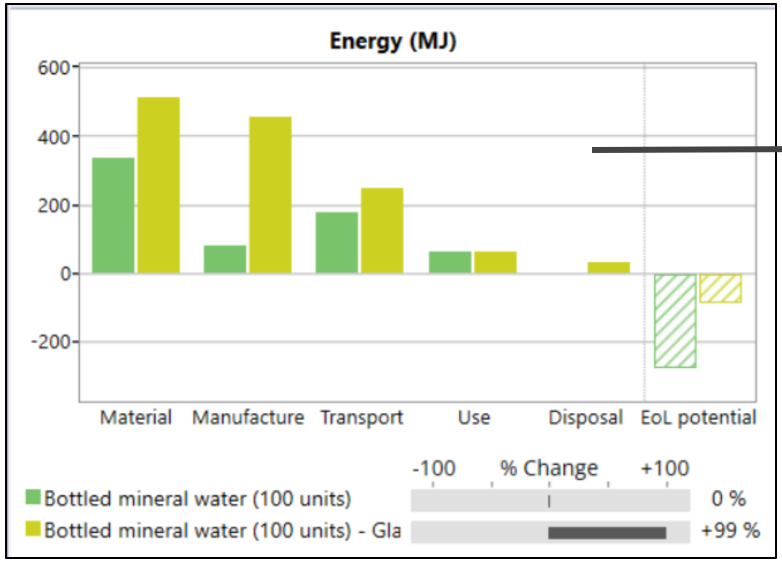
Use - refrigeration

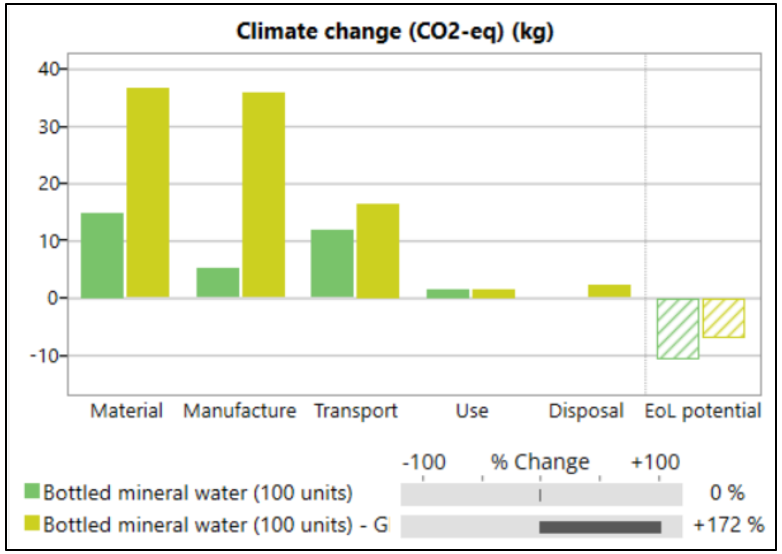
Electric to mechanical	*0.12 kW*	*2 days*	*24 hrs/day*

Actions and comparisons

Virgin PET

Glass





The fast comparison allows design decisions on-the-fly

Reducing impact

Actions

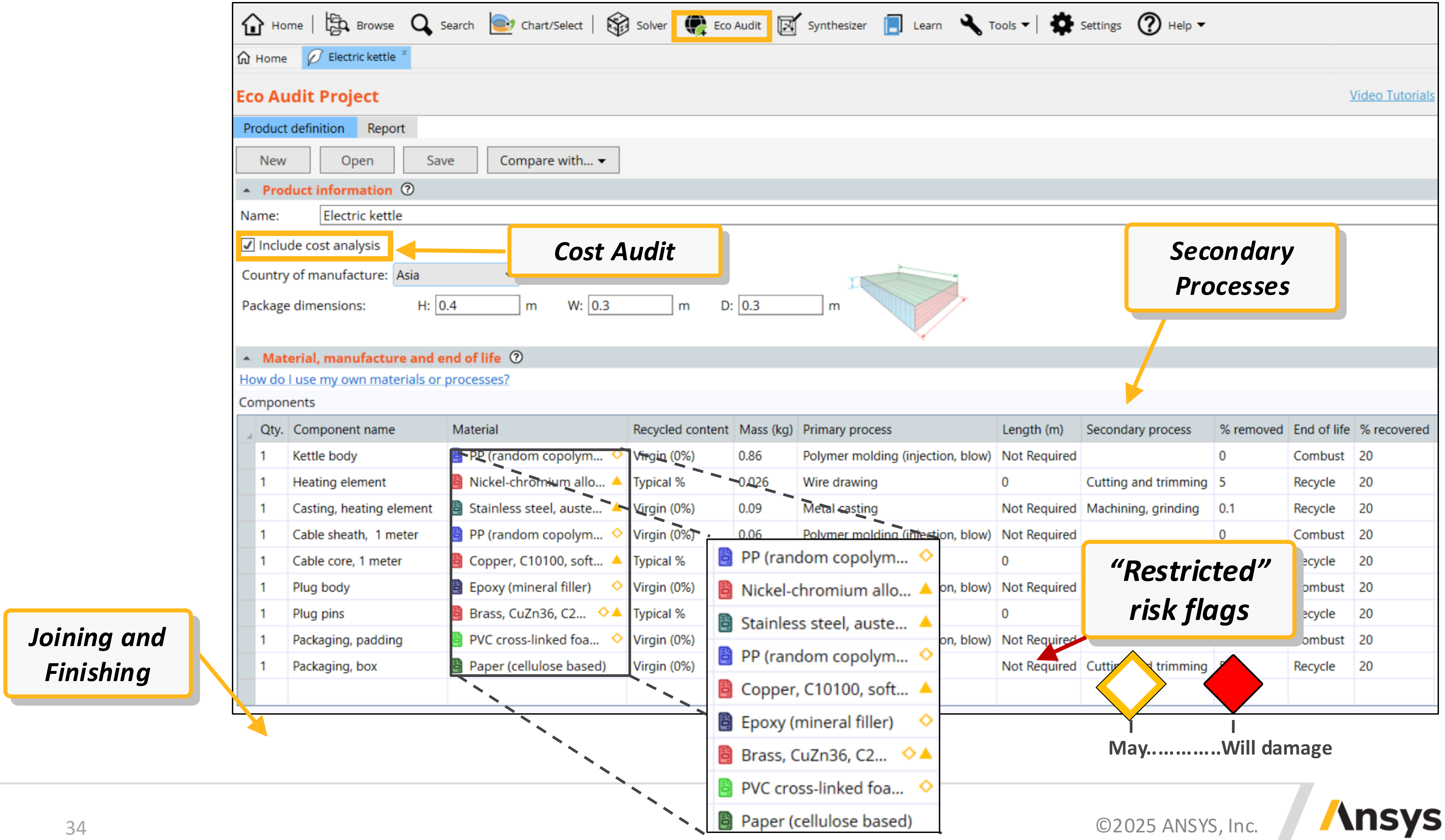
- Use as large a 'recycled content' in the material as possible.

Can explore:

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

Many projects are available as project files.

The Enhanced Eco Audit tool



Ansys / GRANTA EDUPACK

Summary

The Ansys Granta EduPack software has **two resources** to help explore the materials dimension of environmental design

1. **Selection strategies** allows selection to re-design products using eco-properties and employ systematic methods.

2. **The Eco Audit tool** allows students to implement quick, approximate “portraits” of energy / $CO_{2\ Eq.}$ character of products.

Eco Audits reveal the eco-fingerprint of products and suggest approaches to making them less environmentally damaging. The Enhanced Eco Audit gives Cost information and flags restricted or critical materials risk

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Document Information

This lecture unit is part of a set of teaching resources to help introduce students to materials, processes and rational selections.

Ansys Education Resources

To access more undergraduate education resources, including lecture presentations with notes, exercises with worked solutions, microprojects, real life examples and more, visit www.ansys.com/education-resources.