Les matériaux composites, moteurs de la mobilité propre?

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swiss mobility days

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EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Motivation

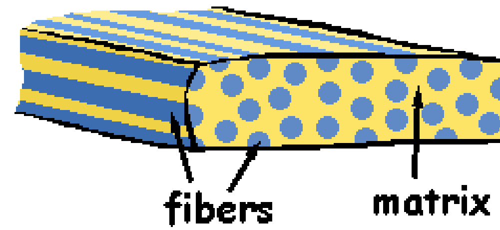
- Transport industry has been targeted for reduction of emissions by legislative authorities.

- Opportunities exist for emissions reductions through:
  - » *Increasing power train efficiency*
  - » *Alternative fuel approaches (fuel cell, hybrid etc)*
  - » *Lowering vehicle mass*

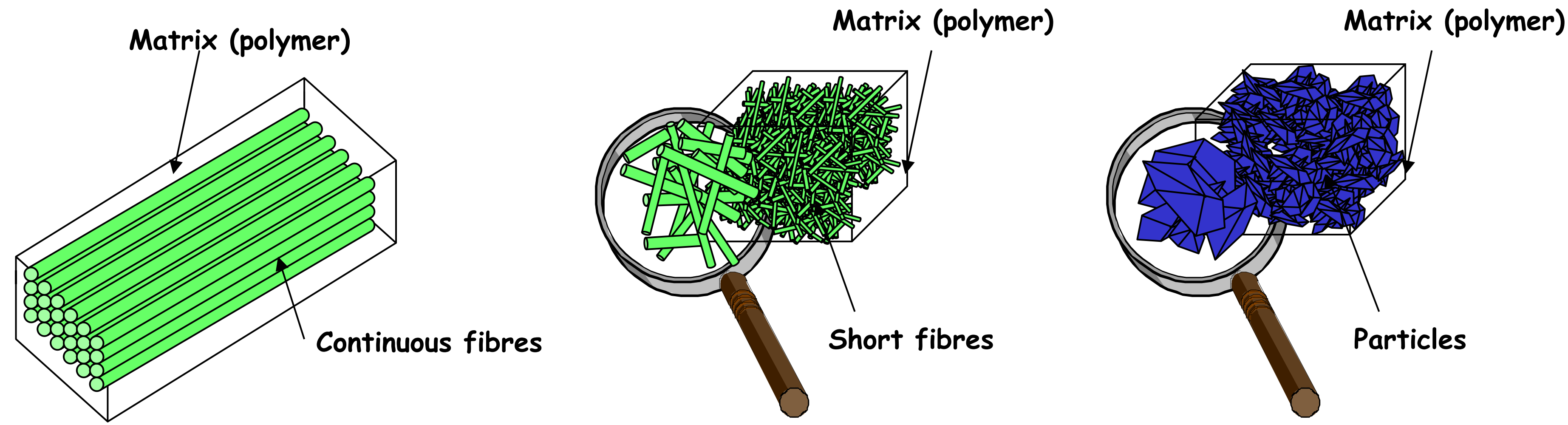
- Greatest opportunities lie within vehicle mass reduction
  - » *High strength steels*
  - » *Aluminium*
  - » *Magnesium*
  - » *Fiber reinforced polymer composites*

What are composite materials?

Composite materials are a synergistic combination of several distinct material phases, typically fiber reinforcement and a matrix



Various types of composites…



Carbon fiber reinforced plastics
Glass fiber reinforced plastics
Natural fiber composites: flax, hemp
Other long fibers: organic, basalt, ceramic…

Structural parts : BIW, roof, beams, axles, bulkhead

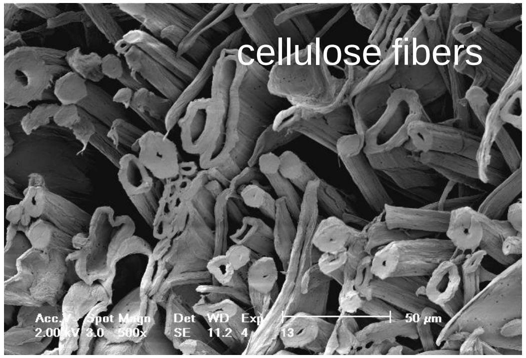
Sheet moulding Compound, Glass mat thermoplastics, injected glass reinforced Polyamide, etc…

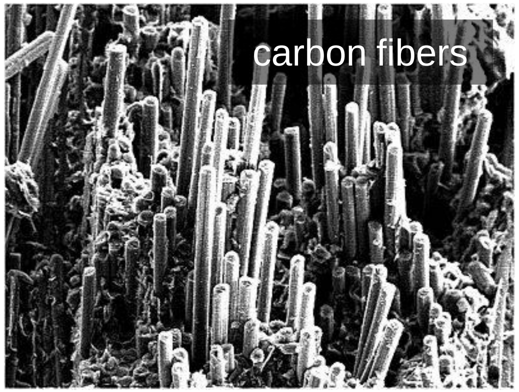
Semi-Structural parts : surface panels (hoods, hatch..), spare wheel well, …

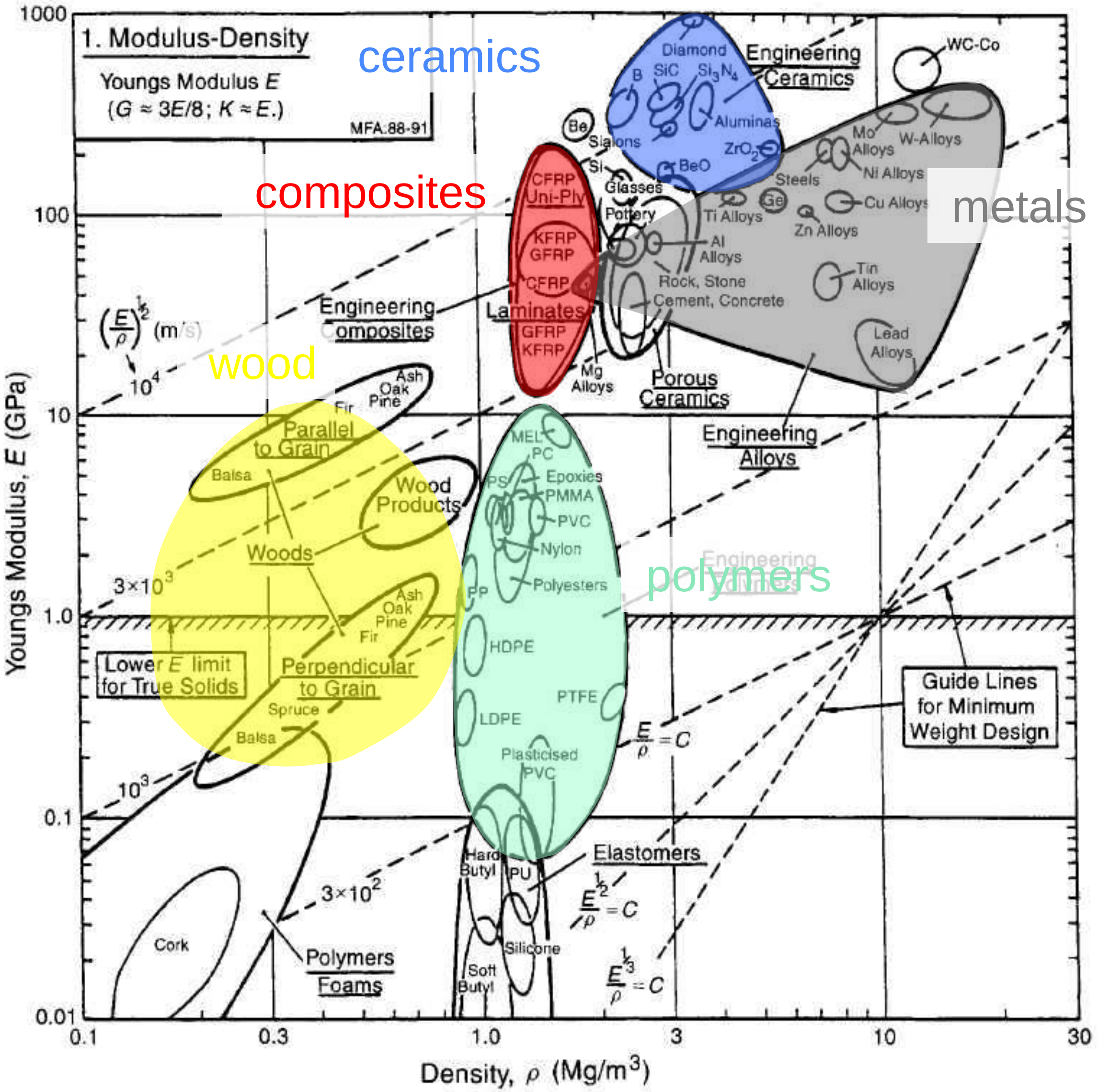
Glass or ceramic fillers for shrinkage reduction or wear resistance improvement

Non-Structural parts, or as filler with longer fibers

Stiffness/density compromise







LABORATOIRE DE TECHNOLOGIE DES COMPOSITES ET POLYMERES

Lightweighting potential - bending stiffness equivalence

Function — *Panel* with given width w and length L

Objective — *Minimise mass*, m, where

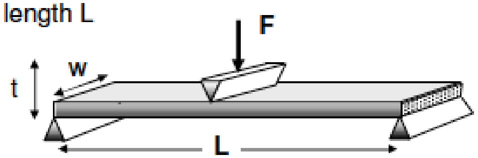
$$m = AL\rho = w\,t\,L\rho$$

Constraint — *Stiffness* of the panel S:

$$S = \frac{CEI}{L^3}$$

I is the second moment of area:

$$I = \frac{wt^3}{12}$$



- m = mass
- w = width
- L = length
- ρ = density
- t = thickness
- S = stiffness
- I = second moment of area
- E = Youngs Modulus

Free variables
- *Material choice.*
- *Panel thickness t.* Combining the equations gives:

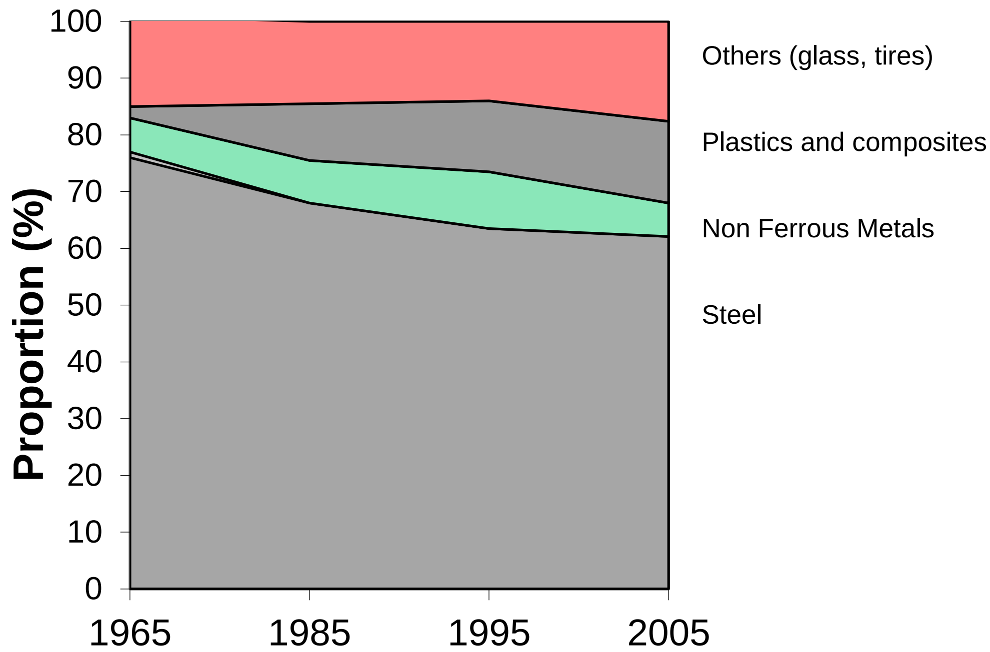
$$m = \left(\frac{12\,S\,w^2}{C}\right)^{1/3} L^2 \left(\frac{\rho}{E^{1/3}}\right)$$

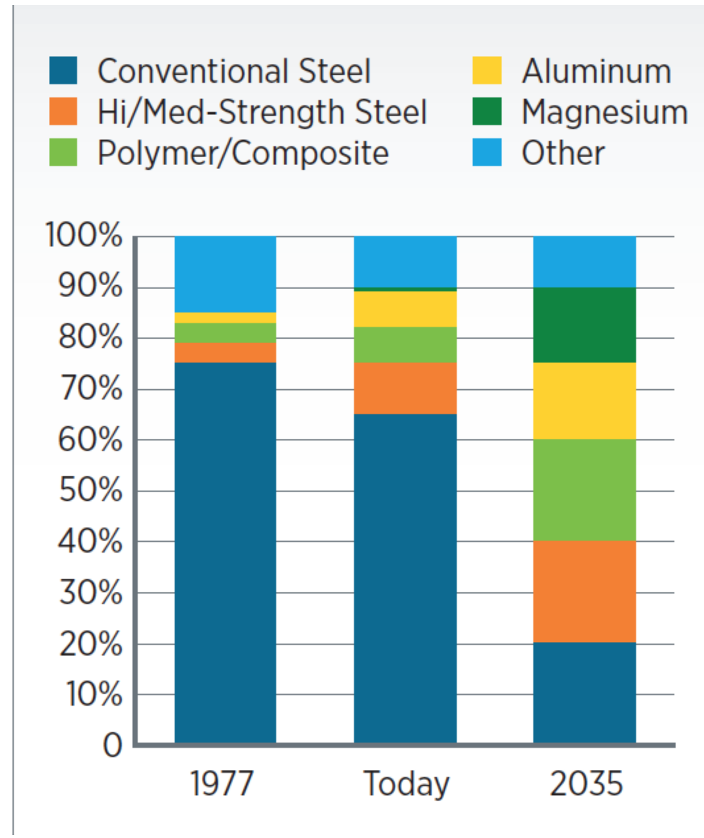
Chose materials with smallest $\left(\frac{\rho}{E^{1/3}}\right)$

$$m_i = m_b \cdot \frac{\rho_i \cdot E_b^{1/3}}{\rho_b \cdot E_i^{1/3}}$$

	Steel	Aluminium	Magnesium	Epoxy High T_g + CF	New material 1. PU (C) + CF	New material 2.a PP + 8%CF	New material 2.b PA + 12%CF
Density (g/m^3)	7,8	2,7	1,8	1,52	1,52	1,1	1,2
Young's Modulus (GPa)	200	70	50	50	50	7,5	10,1
Climate change (kg CO_2 eq / kg of material)	1,07	6,74	37,40	34,53	33,31	7,83	9,23
Weight equivalence (kg)	1,00	0,491	0,366	0,309	0,309	0,421	0,416
Potential weight reduction (%)	0	50,9	63,4	69,1	69,1	57,9	58,4
Density/$E^{1/3}$	1.35	0.66	0.5	0.42	0.42	0.56	0.55

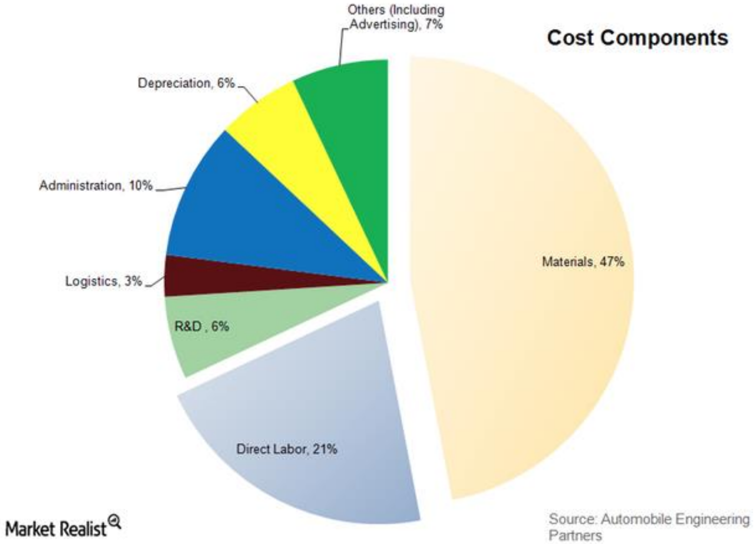
Proportion of materials in a car

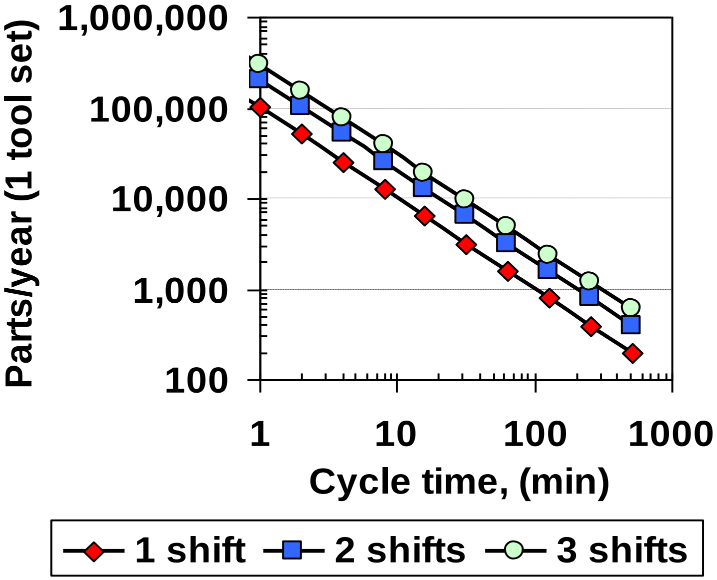




Sources : Smidt et Leithner, 1995 et Joint Research Center of the European Commission, 2008, US DOE, 2010

Les freins…



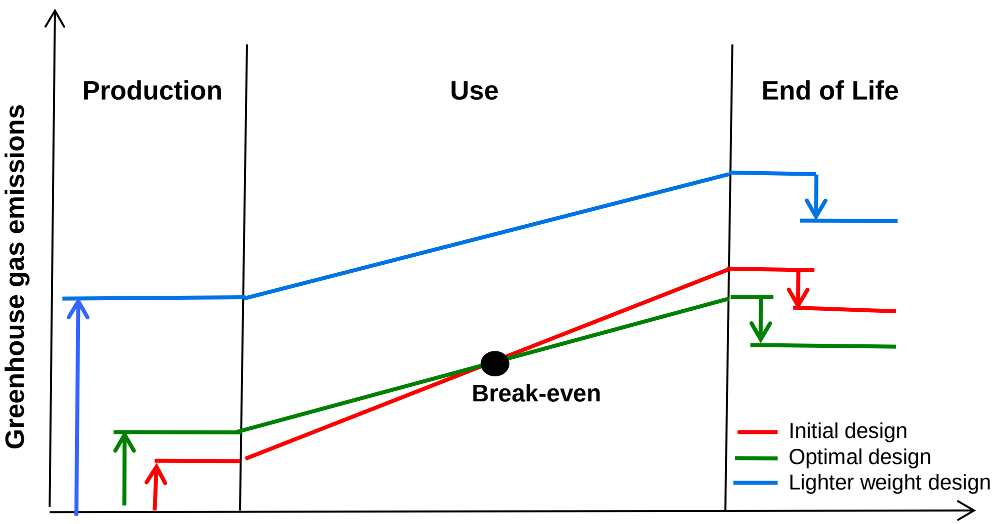


Coûts des matériaux

Temps de cycle

Materials comparison

	Carbon fibre	Glass fibre	Steel	Aluminium
Cost (€/kg)	10-30 (tow) 22 (NCF)	1.6 (tow) 3.2 (NCF)	0.6	2
CO_2(kg/kg)	22.4	2.5	1.7	12.6
Energy (MJ/kg)	286 (186-360)	45.6	26.4	160
E/ρ (GPa.cm^3/g)	130-250	31	25	25



- Great properties, but high cost and production impact!

- Risk of leading to higher environmental impact, despite a lower weight!

Approach

In parallel to the technical and scientific developments, use cost and life cycle analysis tools at an early stage of composite material and process design, to :

- help select materials and processes,
- pinpoint critical areas,
- defend your proposed solution, and
- orient further research and development

Strategy for full analysis

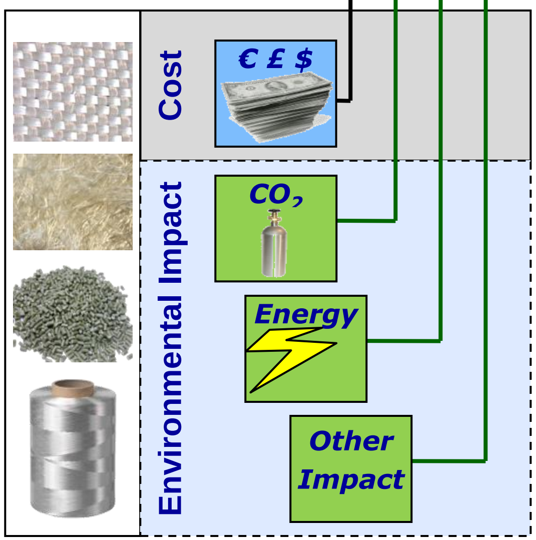
- **Technical, Financial & Environmental Cost Prediction**

Component

Input
Production Volume
Loading
Package
Environment

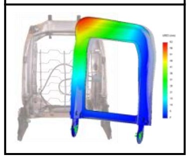
Materials

Input
Material costs
Performance
Environmental Burdens



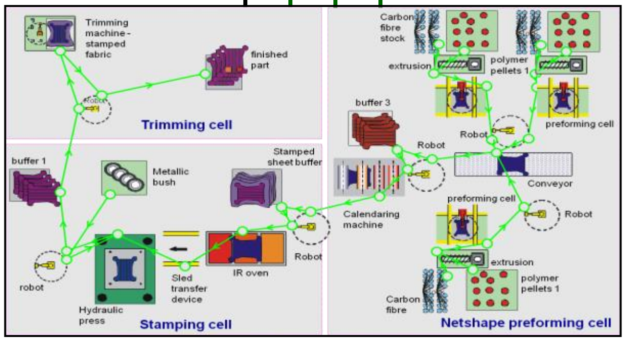
Design

Output
Geometry
Process flow
Equipment
Cycle time
Scrap
Tooling costs



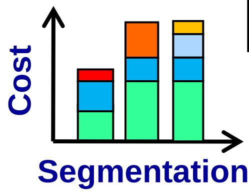
Process

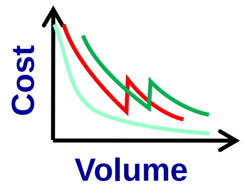
Input
Reject
Labour costs
Equipment costs
Tooling costs
Consumable costs
Overhead costs
Maintenance costs
Assembly costs
etc.



Cost

Output
Investment
Production cost



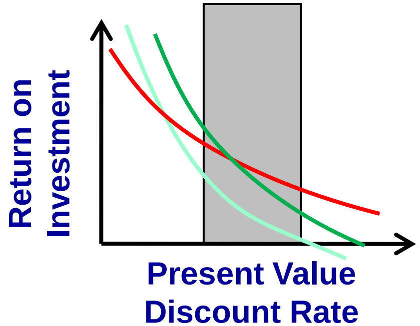


Supplier

Input
Tax costs
Discount rate
Price / profit

Bus. Case

Output
Return on investment
Pay back time
Lifetime environmental impact
etc.



Assessment of the Business Case & Environmental Impacts related to technology

Case studies

- **Rear bulkhead: Choice of material and process route, effects of material substitution on life cycle costs/ environmental burdens,**
- **B-Pillar: Effect of part design optimisation and areas of improvement,**
- **Recycling or incineration, for reuse in transport applications?**

Case study on automotive application

Materials

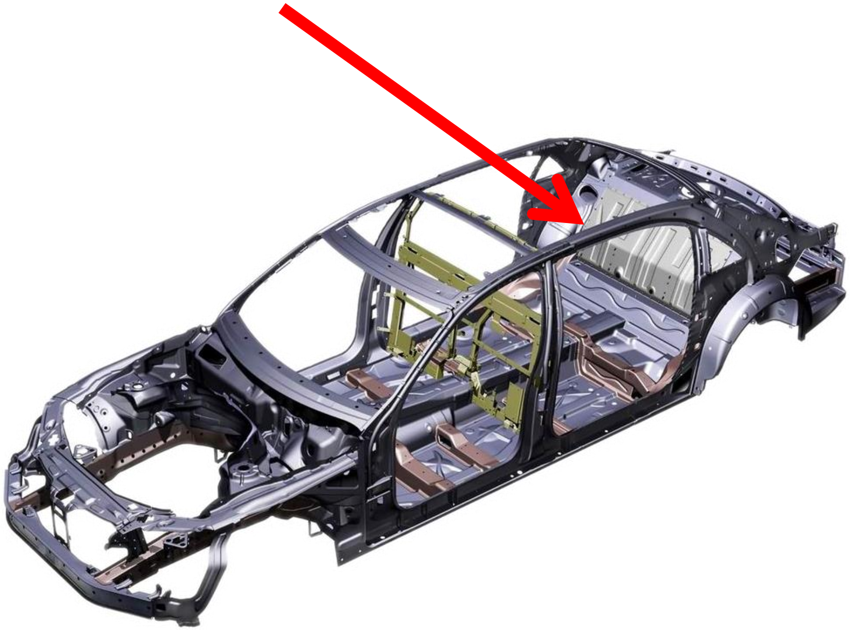
Bulk head panel

- **Effects of material substitution on life cycle costs/ environmental burdens, burden transfers**
- **6 Materials: Steel, Magnesium, GMT, SMC, SRIM (carbon / glass fibre)**

How do we do this?

A simplified first example:

- Steel reference
- Magnesium
- Carbon composite
- Glass composite



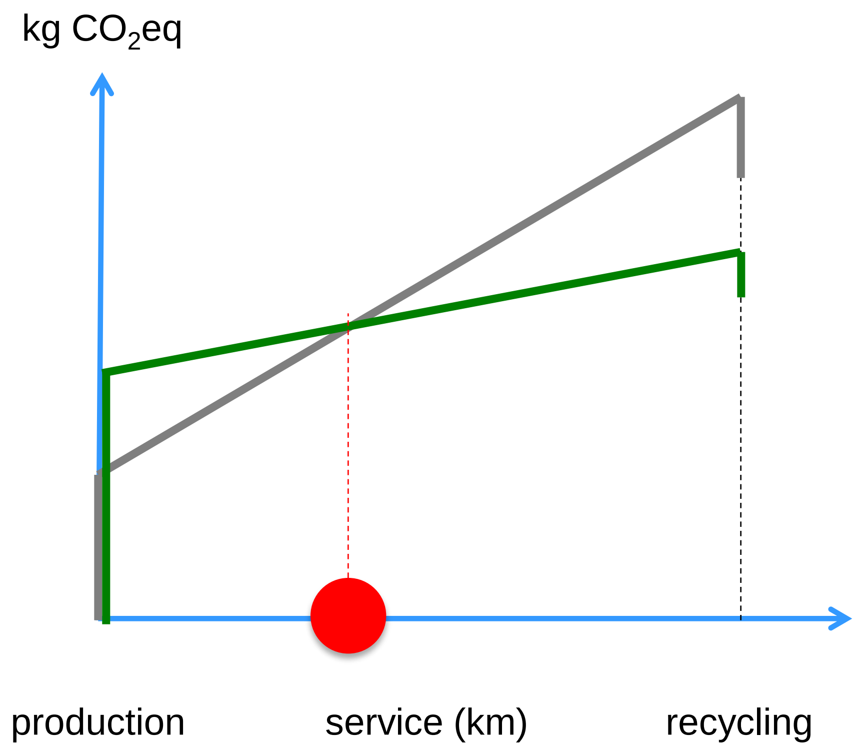
- Question : After how many km run by the vehicle do we pass the break-even point?

Material	Part weight (kg)	Fabrication	kg CO_2 emitted to produce 1 kg of material	Recycle after use?	kg CO2 avoided by end of life treatment
Steel	5.8	stamping	1.75	95% recycled	1.5
Magnesium	2.2	casting	45.8	May be recycled	?
Composite Glass-PA GMT	2.4	Hot pressing	8.8	incinerat ed	0.65
Composite carbon-époxy	1.8	Resin transfer moulding	48.1	incinerat ed	0.82

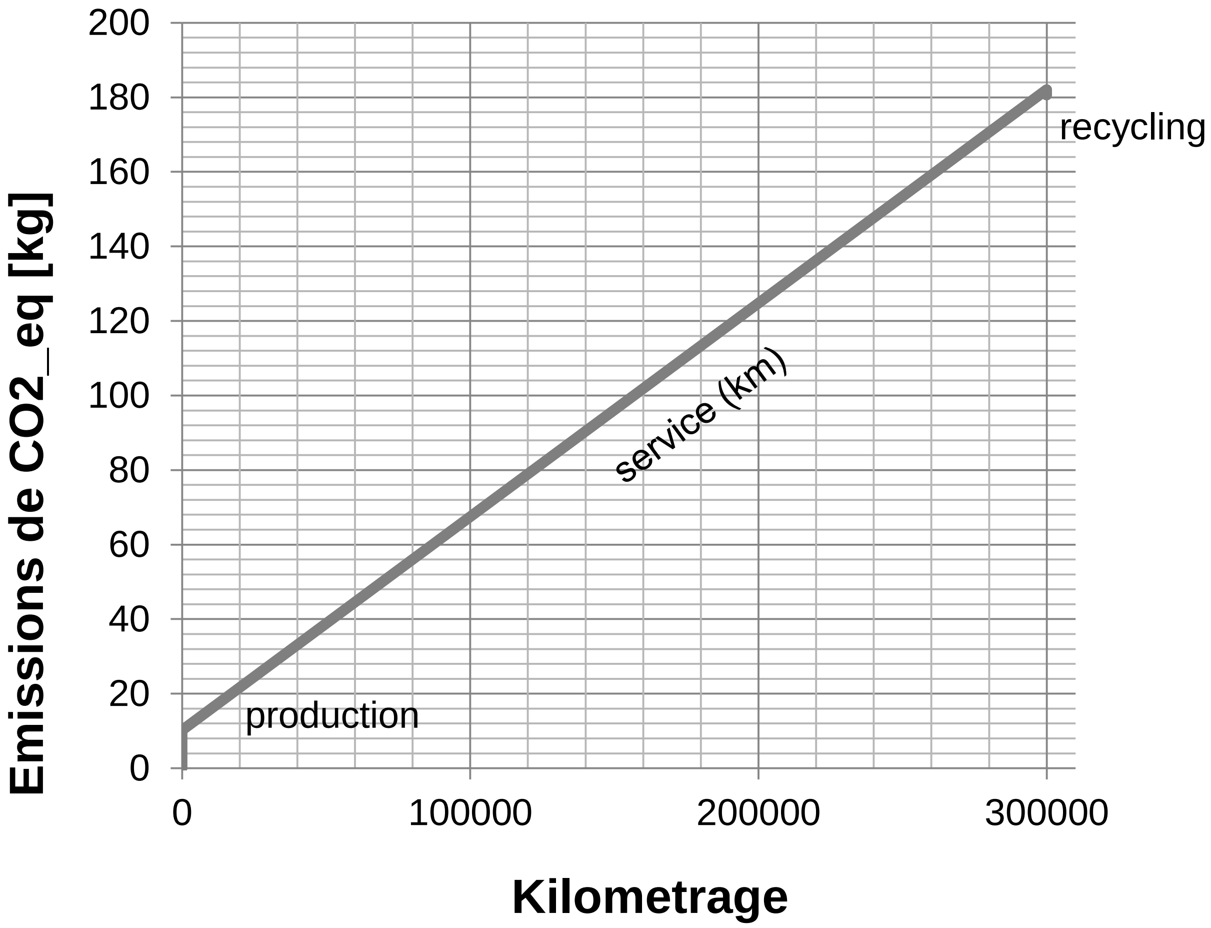
Fuel consumption: 0.4 l/100 km/100 kg

CO_2 emission : 2.47 kg CO_2 / liter

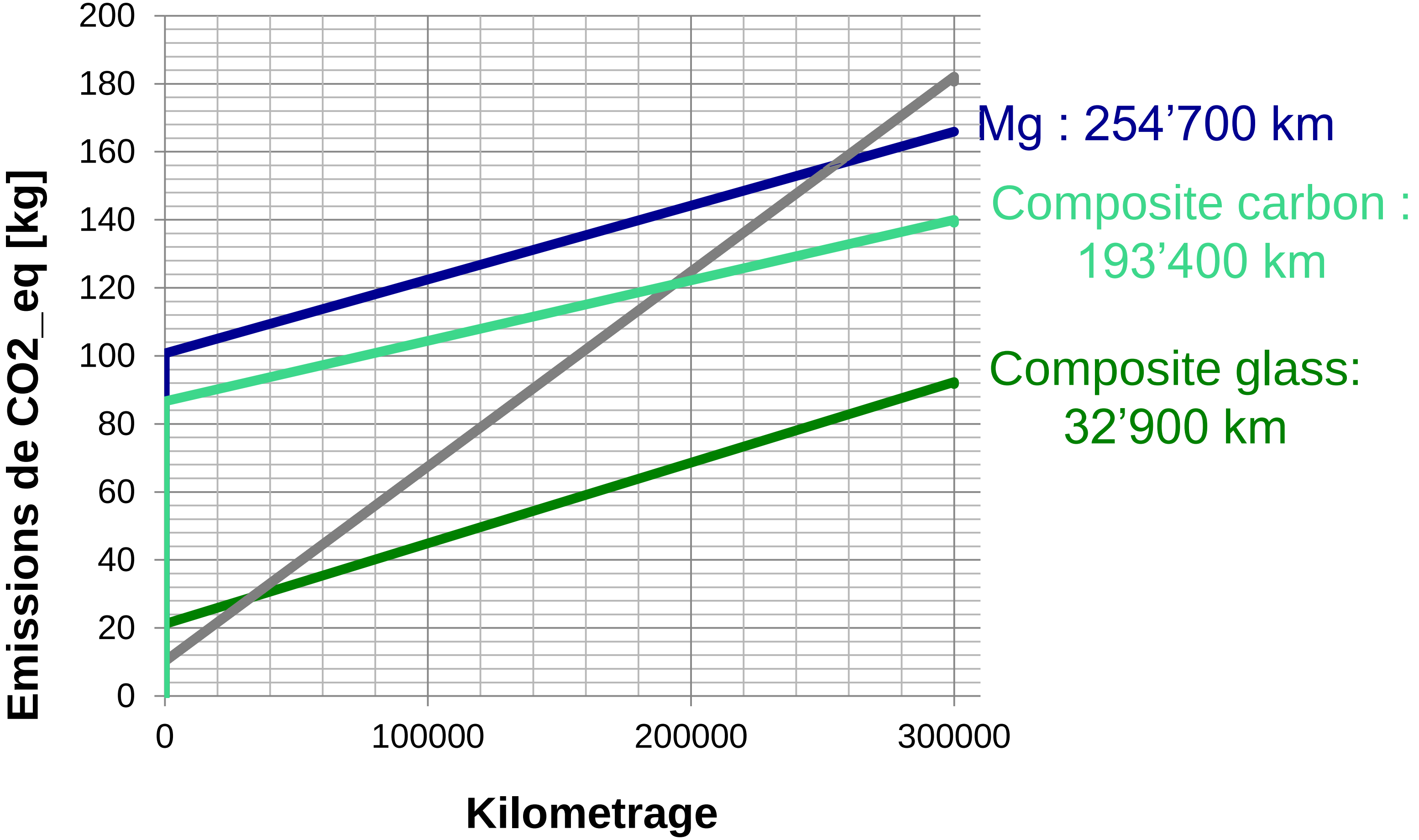
Question



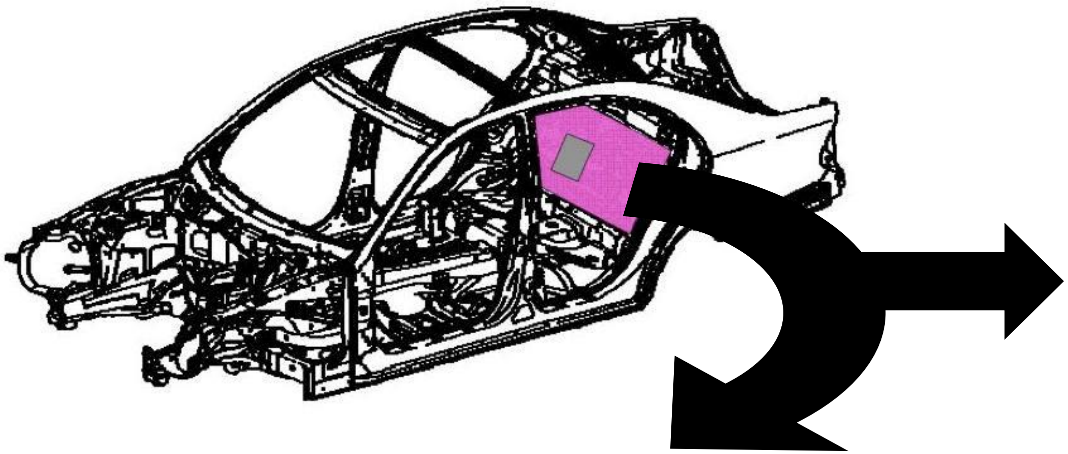
Results for steel



Overall results



Full study

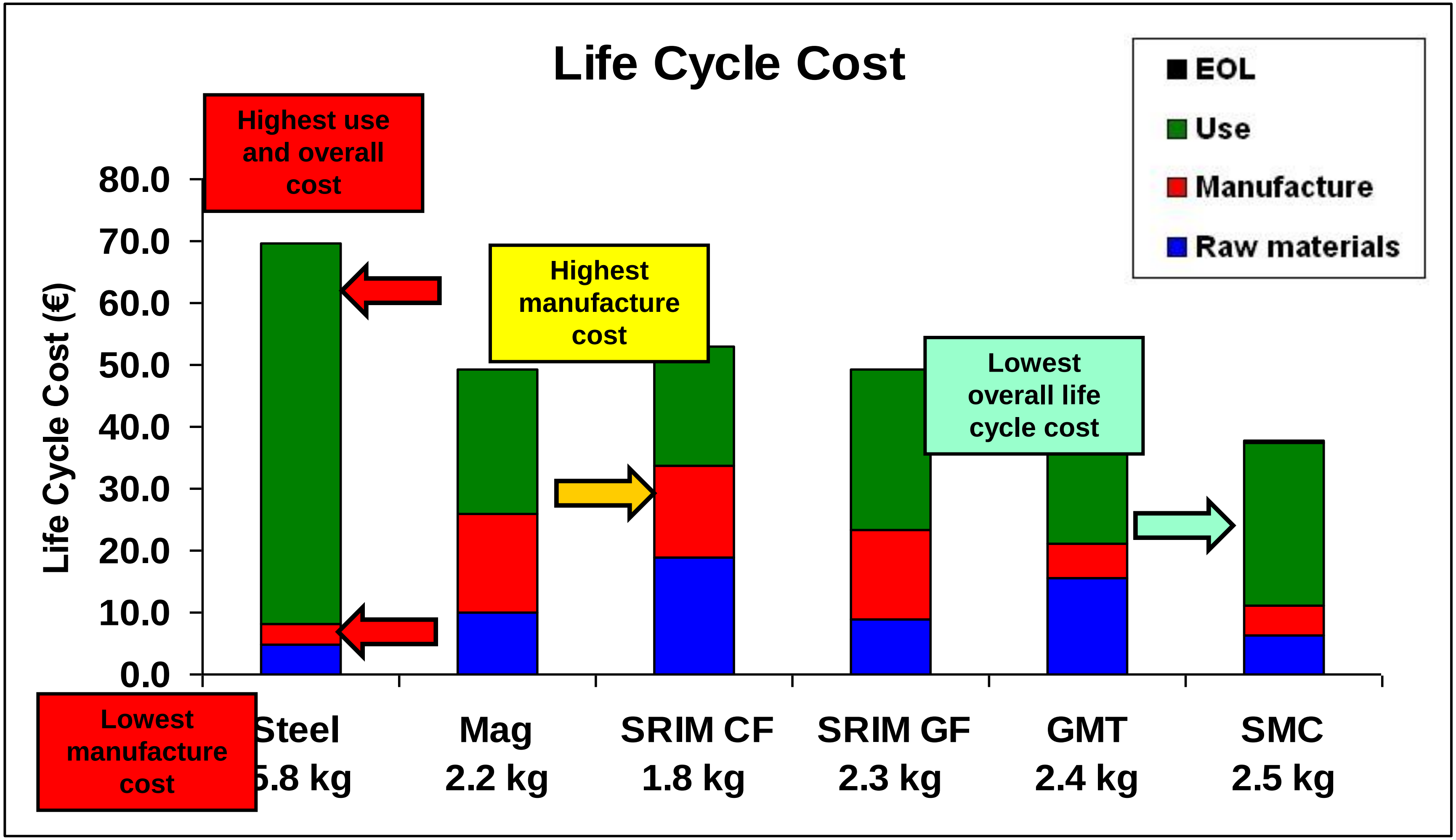


Material	Processing	Component Weight (kg)	Weight Reduction
Steel	Stamping	5.8	Baseline
Magnesium (AZ91)	Die-Casting	2.2	62%
SMC	Press molding	2.5	57%
GMT	Press molding	2.4	59%
Glass fibers	Reactive injection molding	2.3	60%
Carbon fibers	Reactive injection molding	1.8	69%

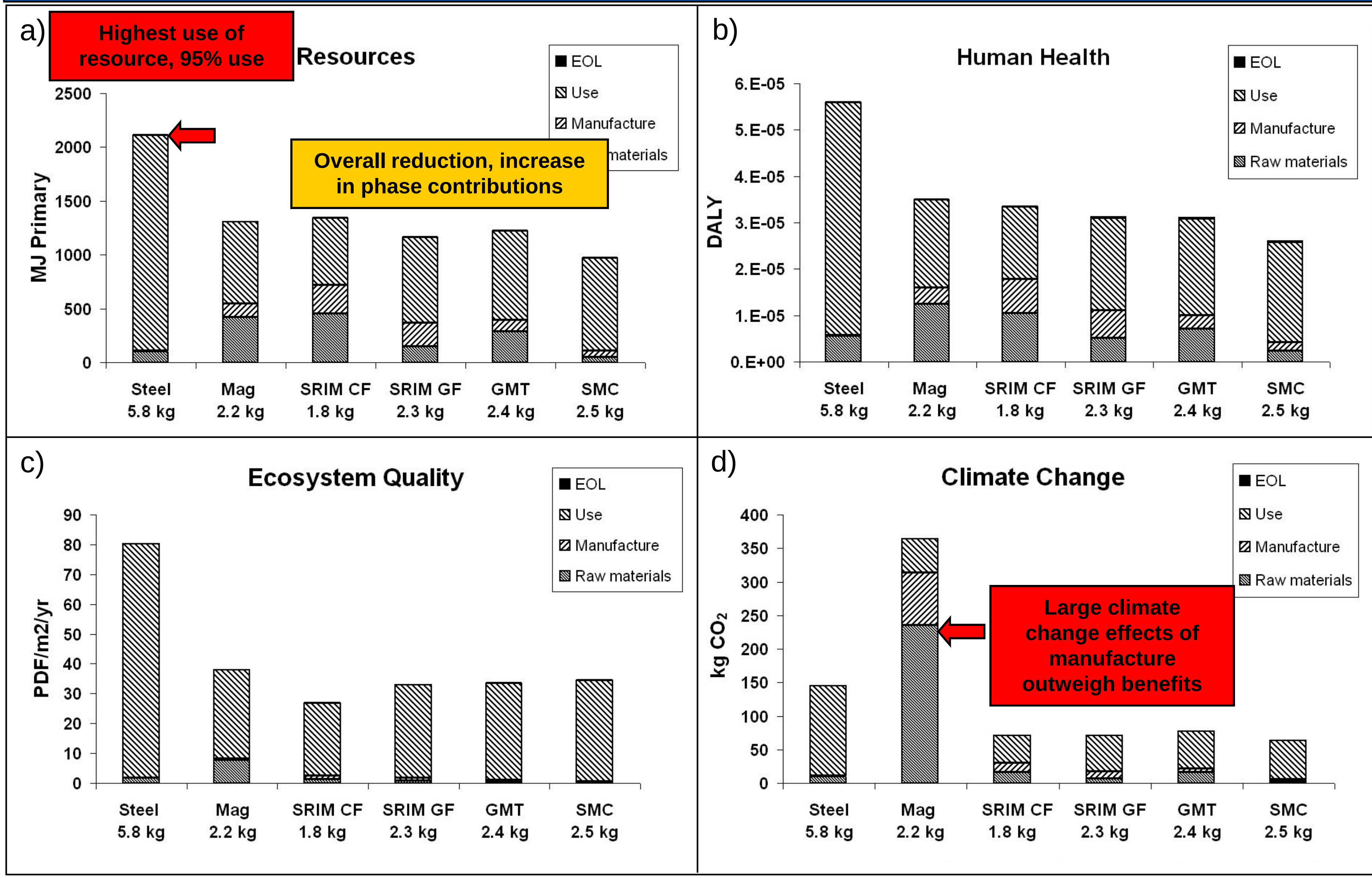
Curved Structural Panel

- » ***typical of BIW***
- » ***e.g. rear bulkhead***
- » ***temperature capability if needed***
- » ***primary material focus = CF/epoxy***
- » ***benchmark = magnesium***

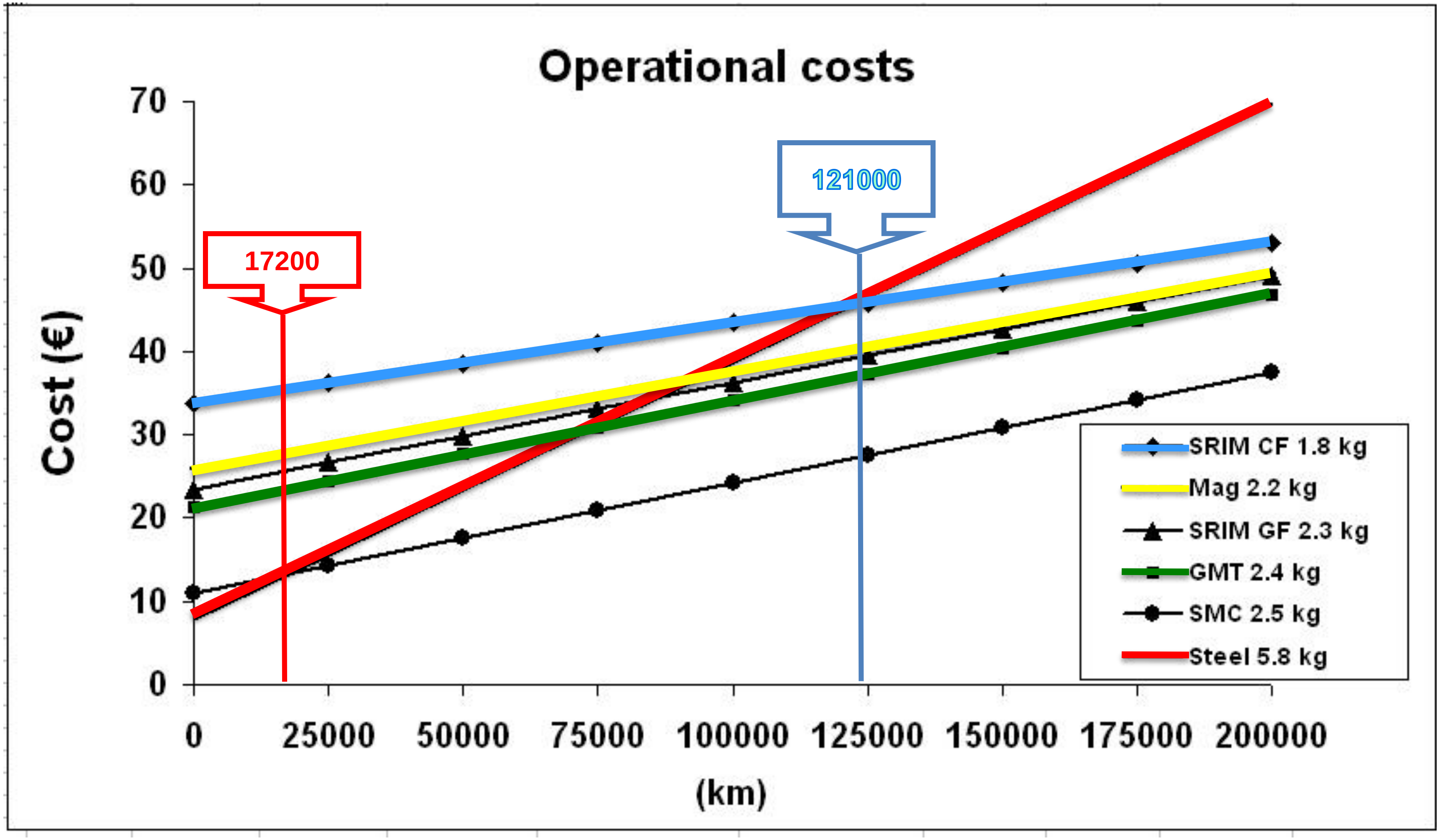
Life cycle costs



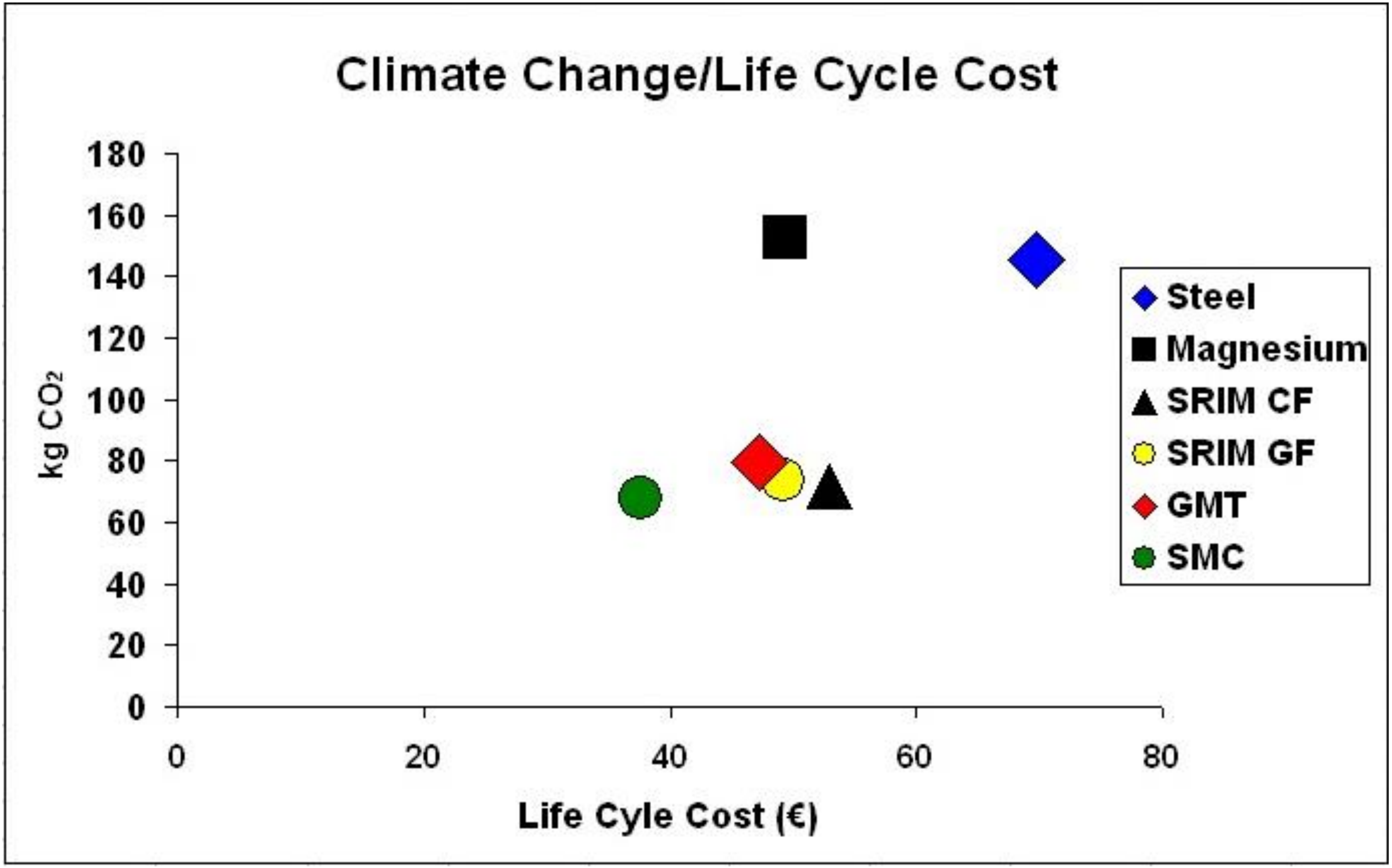
Life cycle assessment results



Break even analysis (€)



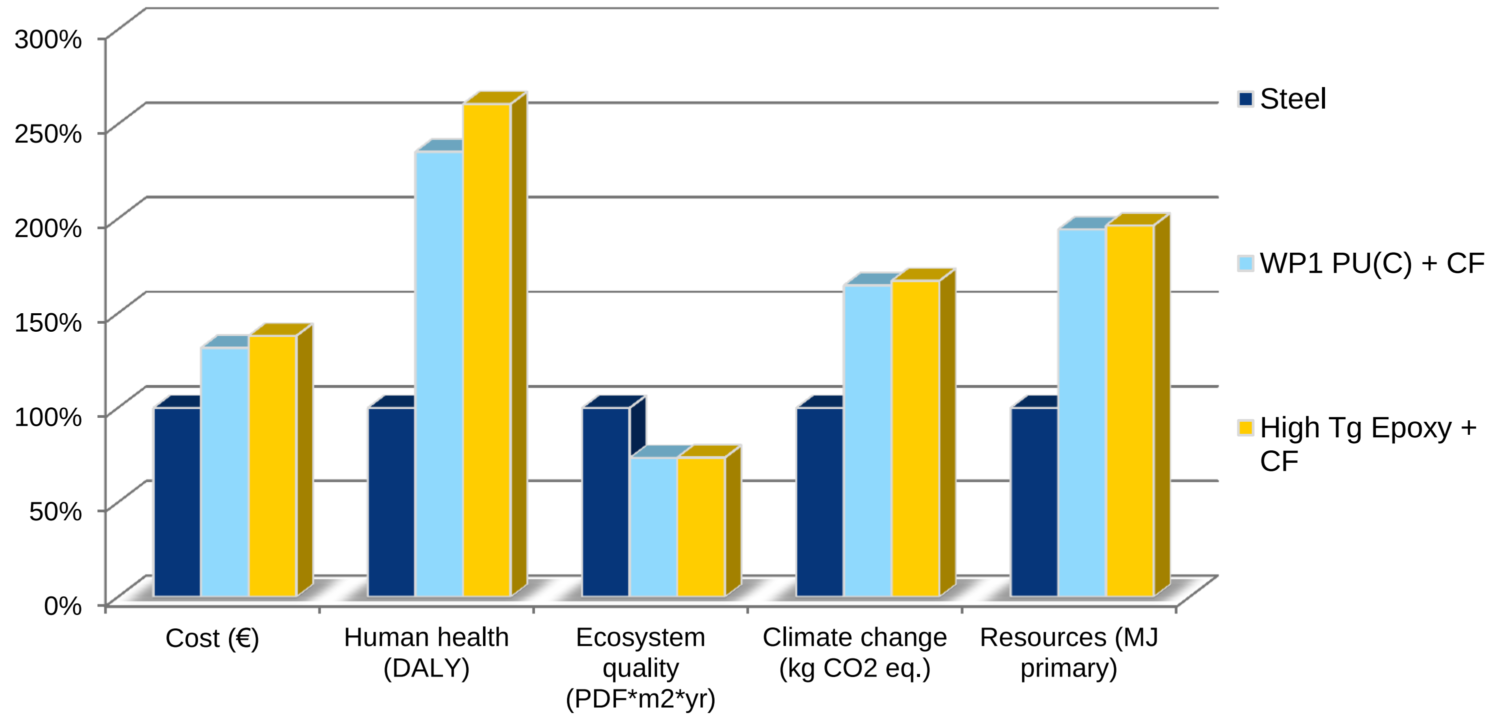
Material ranking



R. Witik, J. Payet, V. Michaud, C. Ludwig and J.-A. E. Månson, Life Cycle Cost and Life Cycle Assessment of Lightweight Materials in Automobiles, *Composites Part A* vol.42, issue 11, pp.1694-1709, 2011

LCA/LCC ANALYSIS OF DEMONSTRATOR: *VW B-PILLAR*

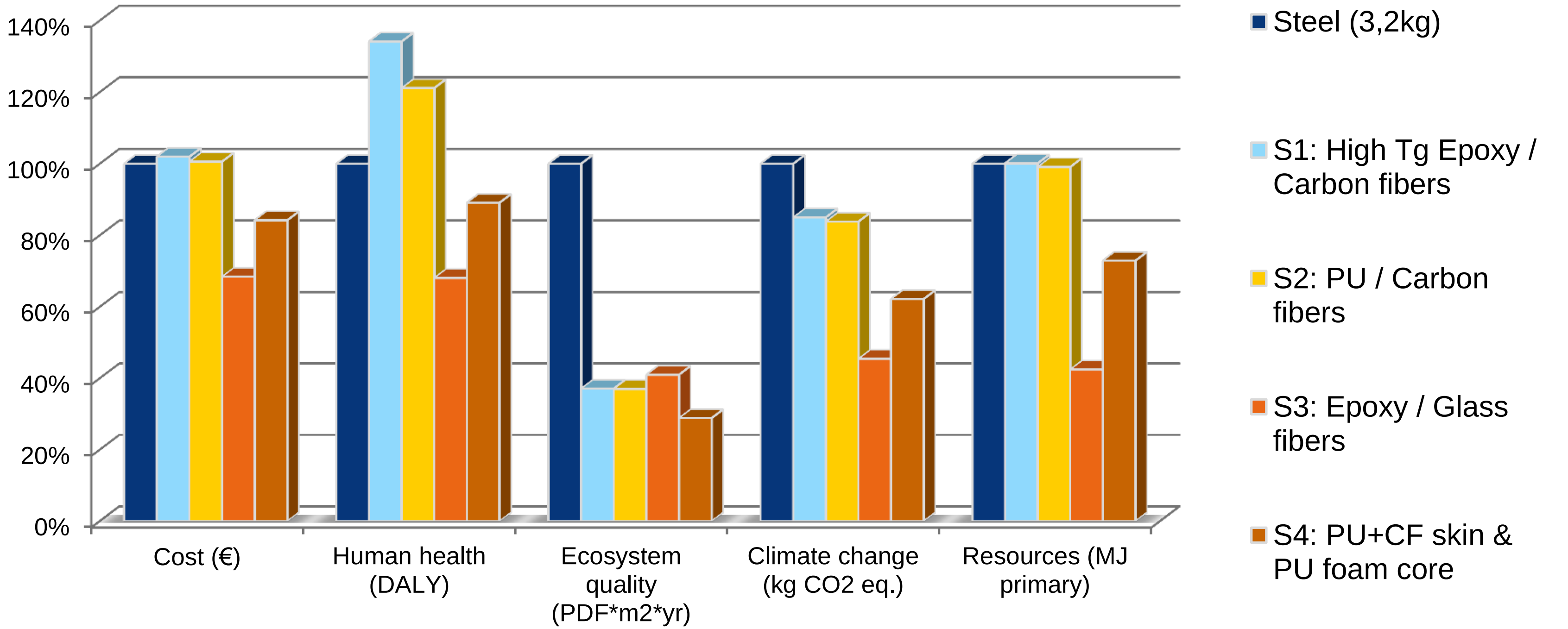
- Case study: VW B-Pillar – 200 000km
  - Steel, weight=3.2 kg
  - **Preliminary** Demonstrator
    - Part thickness dictated by mold designed for GF, weight=2kg
    - PU (C) / Carbon fibers compared to Epoxy High Tg / Carbon fibers



LCA/LCC FOR OPTIMIZED PARTS OR SCENARIOS: *VW B-PILLAR*

- Case study: VW B-Pillar, 200 000km
  - Reference Scenario: Steel, 3.2kg
  - Scenarios:

1. High Tg Epoxy Benchmark / CF, weight=1kg
2. PU (C) / CF, weight=1kg
3. Epoxy / GF, weight=1.27kg
4. **Sandwich, Skin: PU/CF, Core: PU foam, weight=0.792kg**

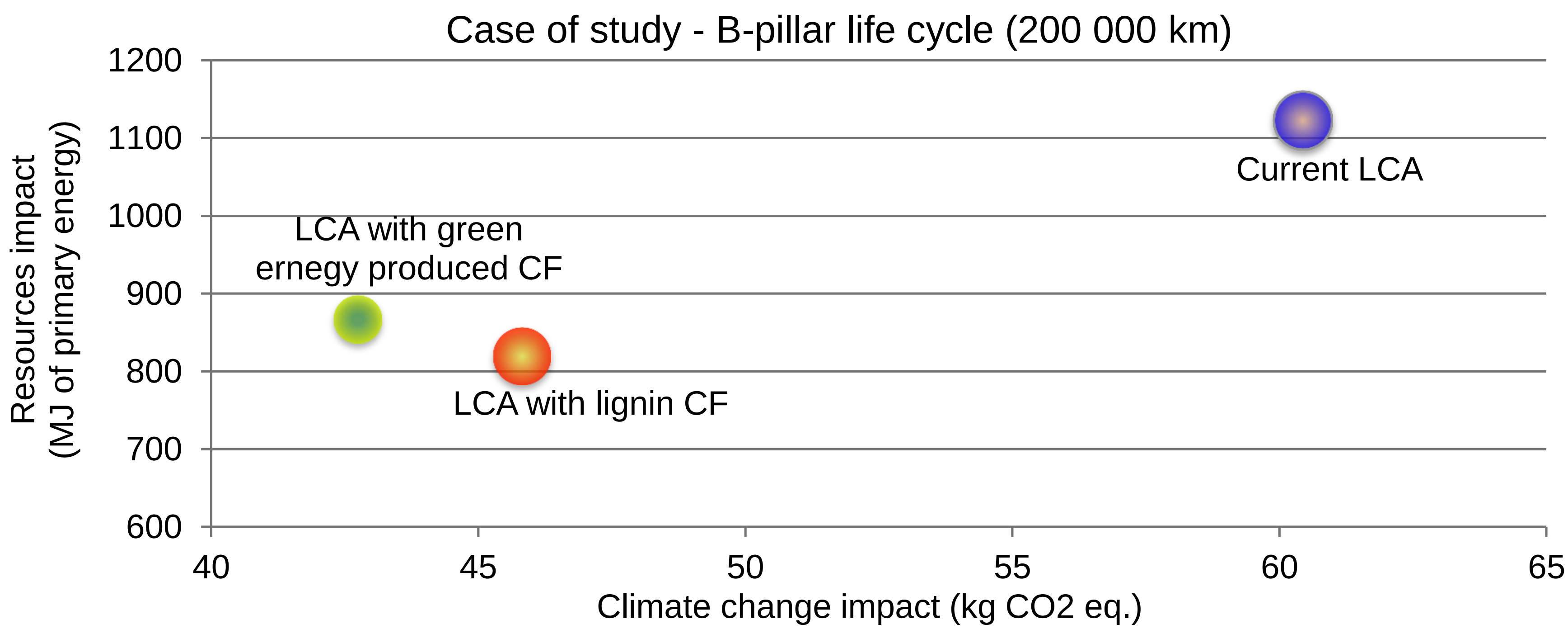


LCA/LCC FOR OPTIMIZED CARBON FIBRE PRECURSOR : *VW B-PILLAR*

- Case study: VW B-Pillar, 200 000km
  - Sensitivity analysis: Carbon fibers impact, Data:

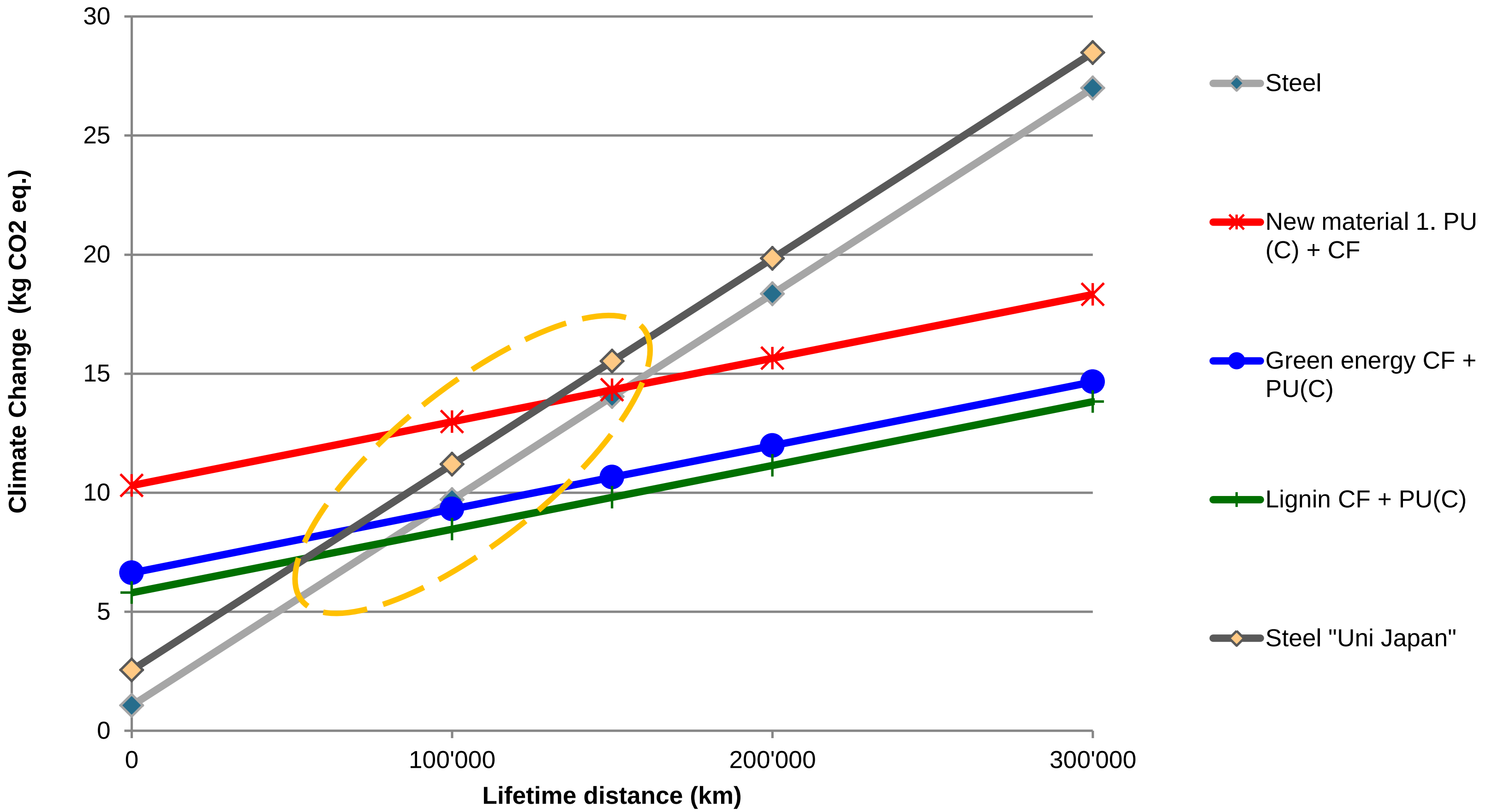
	Climate change (kg CO2 eq)	Resources (MJ primary)
Carbon Fibres - standard production	53	1122
Carbon Fibres - green energy	31	704
Carbon Fibre - lignin precursor	24	670

  - Results with reference Scenario: PU (C) / CF, weight=1kg



LCA/LCC FOR OPTIMIZED CARBON FIBRE PRECURSOR

- New PU + different carbon fibers for a part equivalent to 1kg steel part



- The ‘**cross-over point**” between steel and CFRP strongly depends on the **precursor** and **energy source** used for making the carbon fibres.

Issues about recycling

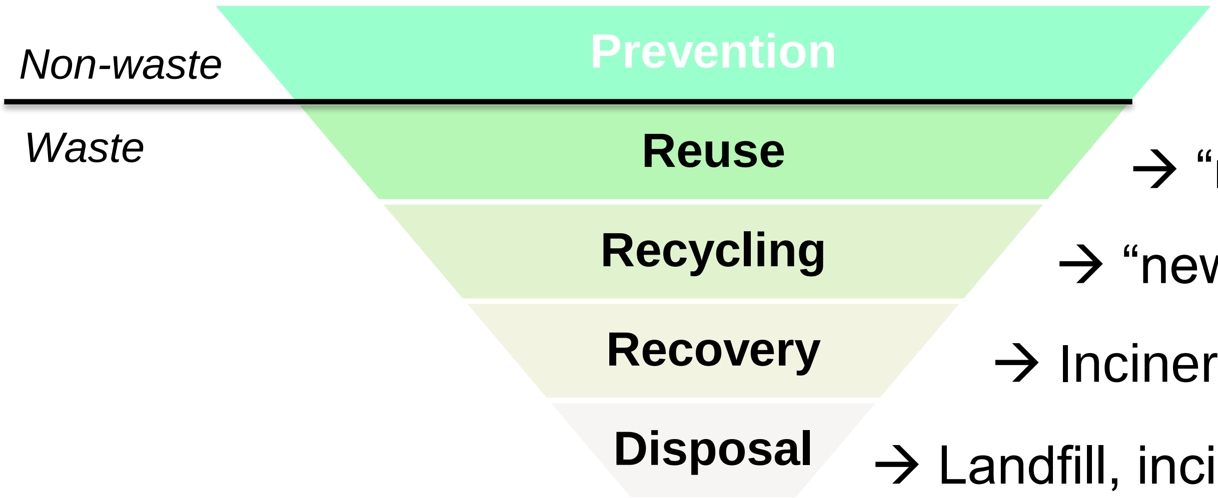
- Recycling is now compulsory to meet European requirements for automotive industry.
- Does it make sense from an economic and environmental global perspective for composite materials?

R. A. Witik, R. Teuscher, V. Michaud, C. Ludwig, J-A. E. Månson, Carbon Fibre Reinforced Composites Waste : an Environmental Assessment of Recycling, Recovery and Landfilling, *Composites: Part A* 49 (2013) 89–99

Waste treatments leads to various outcomes

European waste hierarchy:

Most favourable option



→ “new” *product*

→ “new” *raw material*

→ Incineration with *energy* recovery

→ Landfill, incineration without recovery,…

Least favourable option

Current status for carbon fibre composites:

- Landfilling and some incineration

Focus of research today:

- Recycling of carbon fibers: development of process, characterisation, manufacture…
- Commercial plants already existing

Directive 2008/98/EC – Waste Framework directive

Is recycling environmentally beneficial?

Recycling in politics and industry:

- European Union favours recycling against incineration
- Typical suggestions of the industry:

“carbon fiber can be recycled […] using less than 5 percent of the electricity required [for virgin carbon fiber production]”

Simplified criteria:

Environmental Impact		Environmental Impact
Incineration of waste with energy recovery + Production of virgin materials	? >	Recycling of waste

New products made of recycled materials substitute the production of virgin materials

Wood K. Carbon fiber reclamation: Going commercial. *High-Performance Composites*, March, (2010).

Short fibre composites

- EoL Waste is generally reduced in size
- We are looking to substitute existing products made of short fibres

Structural/semi-structural composites made of short fibres:

Virgin continuous Carbon Fibers (**CF**)

Or

Glass fibers (**GF**)

→

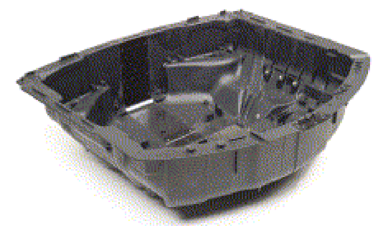
Sheet Molding Compound production (SMC): fibre chopping and resin lamination

→

SMC Compression molding

→

Part made of **Carbon Fibre** Sheet Molding Compound (**CF SMC**)



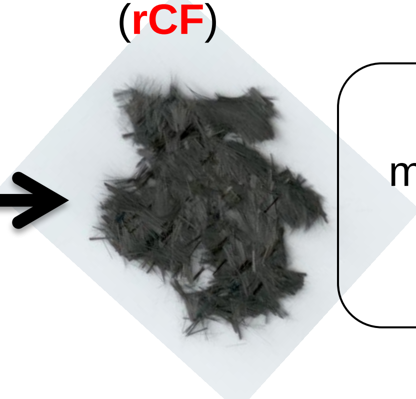
Part made of **Glass Fibre** Sheet Molding Compound (**GF SMC**)

A potential application for recycled fibres

Short fibres in SMCs could be replaced by recycled fibres:

Recycling EoL CFRP

Recycled Carbon Fibre (**rCF**)



Material manufacturing and processing

CASE 1

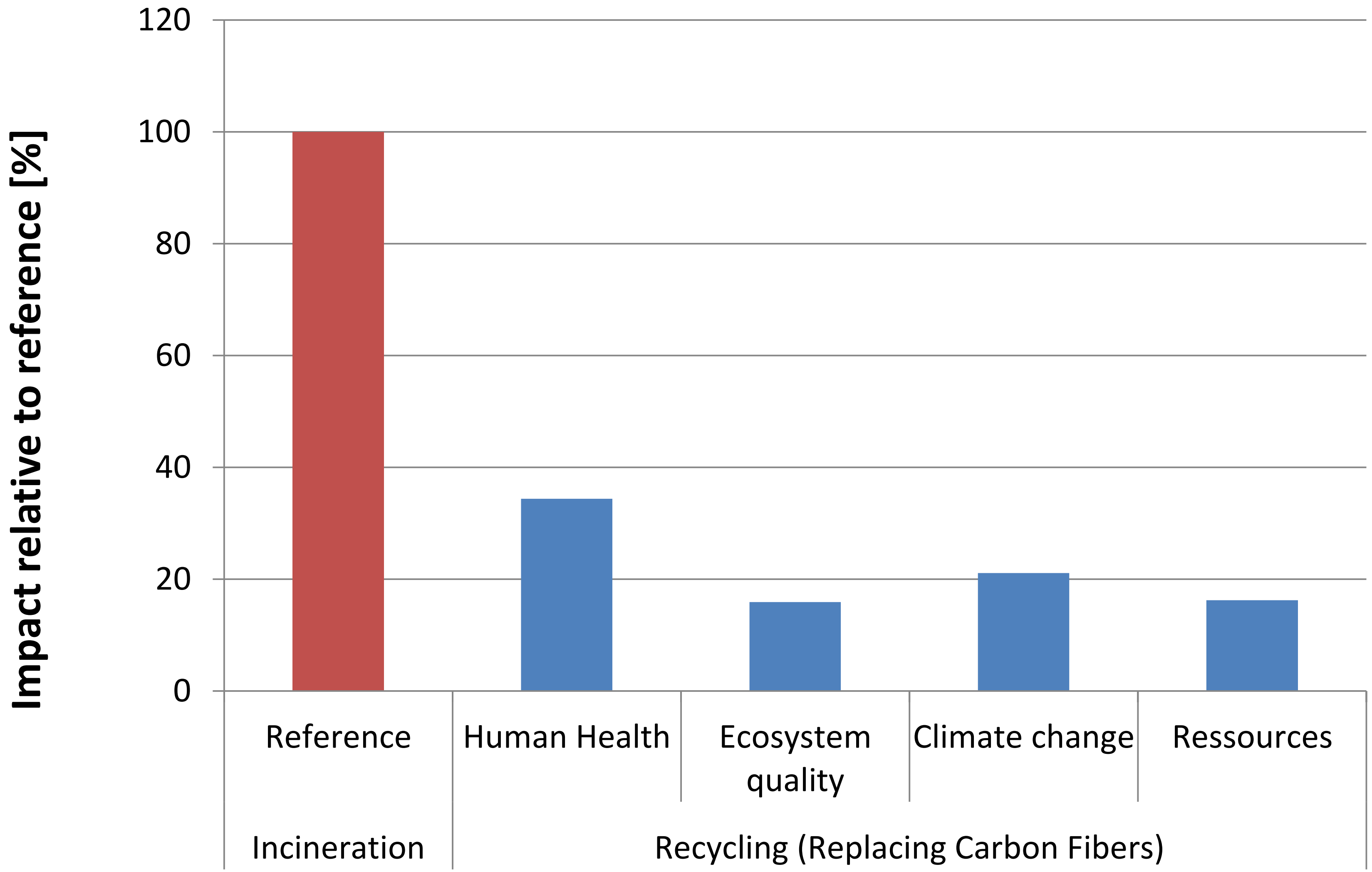
Original part made of **Carbon Fibre** Sheet Molding Compound (**CF SMC**) substituted by a recycled carbon fibre composite (**rCF composite**)

CASE 2

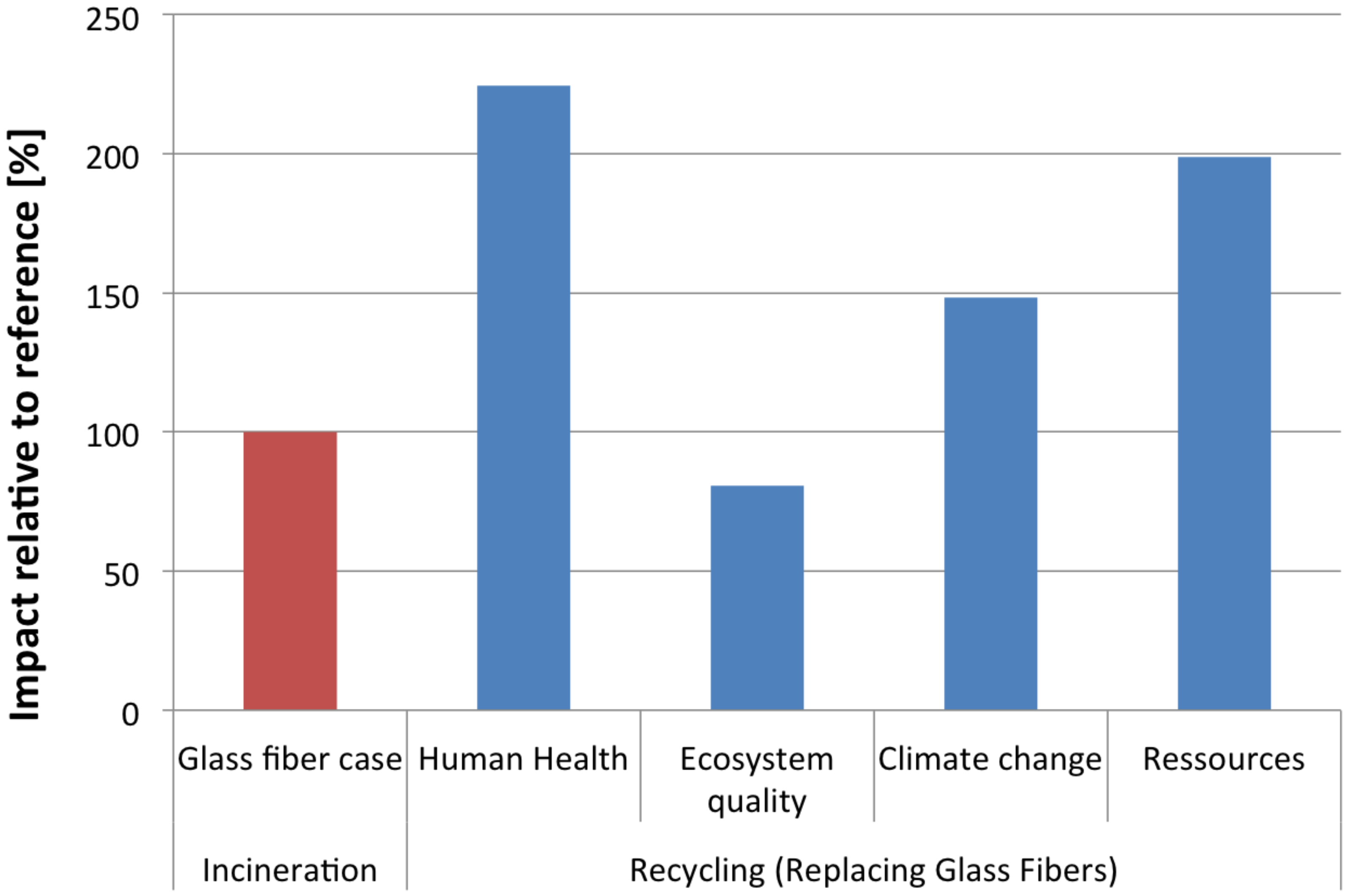
Original part made of **Glass Fibre** Sheet Molding Compound (**GF SMC**) substituted by a recycled carbon fibre composite (**rCF composite**)

Pimenta S., Pinho S. Recycling carbon fibre reinforced polymers for structural applications: Technology review and market outlook. *Waste Management*, 31, pp. 378-392 (2011).

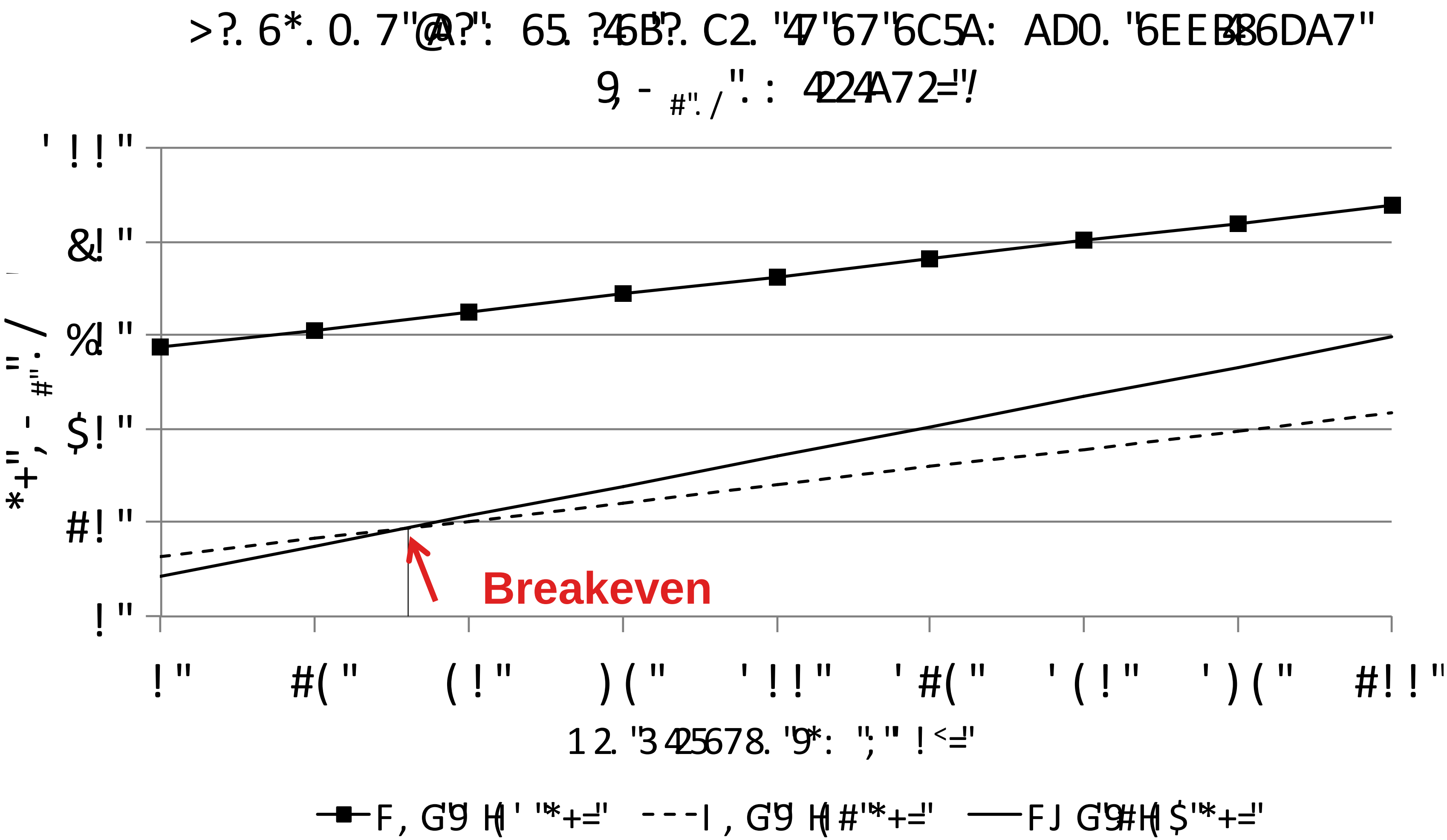
rCF composite substitutes carbon fibre SMC



rCF composites substitutes glass fibre SMCs



How does the application change the benefit?



Conclusions

- Are composite materials sustainable for transport applications? In principle, yes, through light-weighting, but we could make these even better, and guide technical development with associated cost and LCA.

- Composites are not one material type but thousands, which may lead to a paralysing choice matrix…: reinforcement nature and architecture, matrix, process route, cycle time reduction…

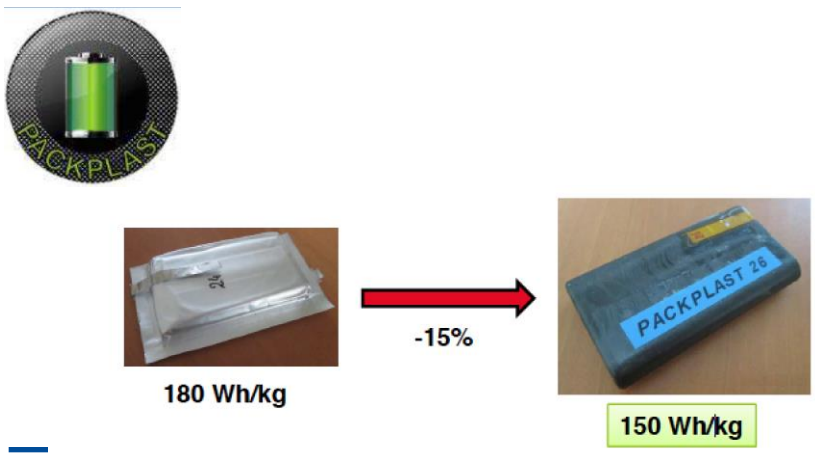
- The analysis provides ideas for further material or process development (low energy cure, alternative fibers, geographic effects, influence of recycling ...).

- Inventory data for composite materials and processes lack or are sometimes misleading, collaboration is needed between LCA and cost analysts, materials producers and process engineers to improve the databases.

- Recycling is not always the best in terms of environmental impact for composites, this needs to be carefully analysed for each case.

Outlook

- Integration of functions: composite structures, that also incorporate functional aspects: transmission of information, power generation and storage (batteries, energy harvesting…), heat management, etc.
- Development of reinforcement materials that are specifically for automotive applications, eg new carbon fibers, lower modulus but less energy intensive.
- Hybrid materials and processes may be the key to best compromises…



Questions?

- Support by FP6 Marie Curie Momentum project, FP7 Hivocomp, FP7 Clean sky, Interreg Packplast, SCCER

- Thanks Dr S. Jespersen , Dr R. Witik, P. Jaquet, M.Benavente, R. Teuscher, D. Vionnet