Progettazione di Materiali e Processi

Modulo 1

Progettazione e selezione di materiali e processi

A.A. 2021-22

Vanni Lughi

vlughi@units.it

Outline

- Almost always 2 or more objectives – they conflict
- Trade-off methods
- Penalty functions and exchange constants
- *Demo*
- *Hands-on session with Exercises*

The selection strategy: materials

Design requirements:
expressed as
Constraints *and*
Objectives

- Able to be molded
- Water and UV resistant
- Stiff enough
- Strong enough
- *As cheap as possible*
- *As light as possible*

Comparison engine

- Screening
- Ranking
- Documentation

Final selection

Data:
Material attributes
Process attributes
Documentation

- Density
- Price
- Modulus
- Strength
- Durability
- Process compatibility
- More…….

Multiple constraints and objectives

Design requirements set **constraints** on material choice

objectives - criteria for optimising

Typical constraints

The material must be

- Electrically conducting
- Optically transparent.....

And meet target values of

- Stiffness
- Strength…..

And be able to be

- Die cast
- Welded .....

Dealing with multiple constraints is straightforward

Typical objectives

Minimize

- Mass **m** *(satellite components)*
- Volume *(mobile phones)*
- Energy consumption *(fridges)*
- Carbon footprint *(cars)*
- Embodied energy *(materials)*
- Cost **C** (*everything*)

Dealing with multiple objectives needs **trade-off methods**

Take, as example, simultaneously minimizing **mass m** and **cost C**

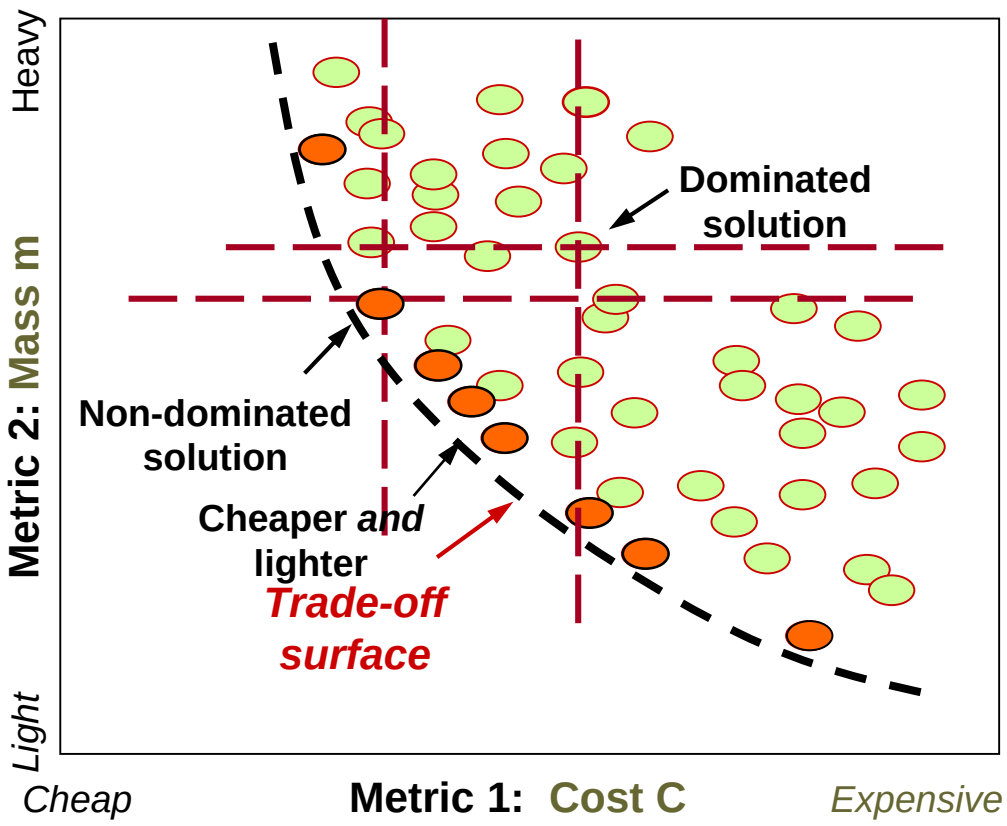
Multi-objective optimisation: *the words*

- ***"Solution":*** a viable choice, meeting constraints, but not necessarily optimum by either criterion.

- Plot solutions. (***Convention***: express objectives to be *minimized*)

- ***"Dominated solution":*** one that is unambiguously non-optimal

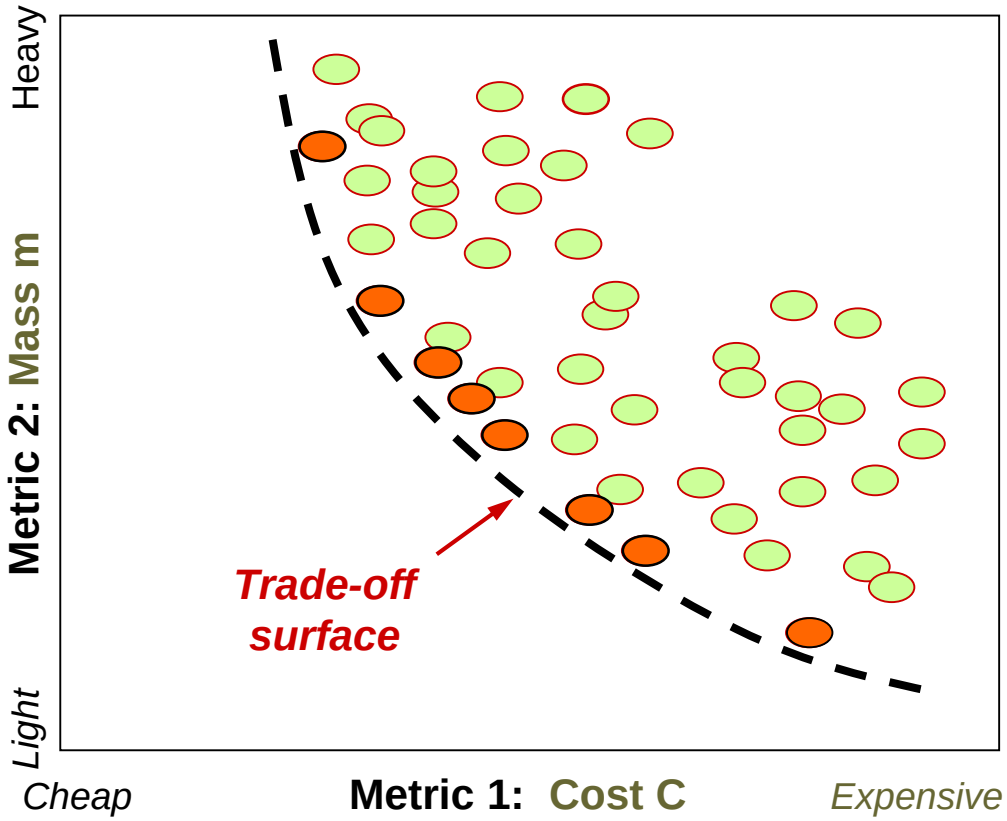
- ***"Non-dominated solution":*** one that cannot be improved by one metric without degrading the other ones



- ***"Trade-off surface":*** the surface on which the non-dominated solutions lie (Pareto Front)

Finding a compromise: strategy 1

- **Make trade-off plot**
- **Sketch trade-off surface**
- **Use intuition** to select a solution on the trade-off surface



- "Solutions" nearest the surface offer the best **compromise** between mass and cost
- 8 out of 50

- Choose from among these; the choice depends on how highly you value light weight, -- a question of ***relative values***

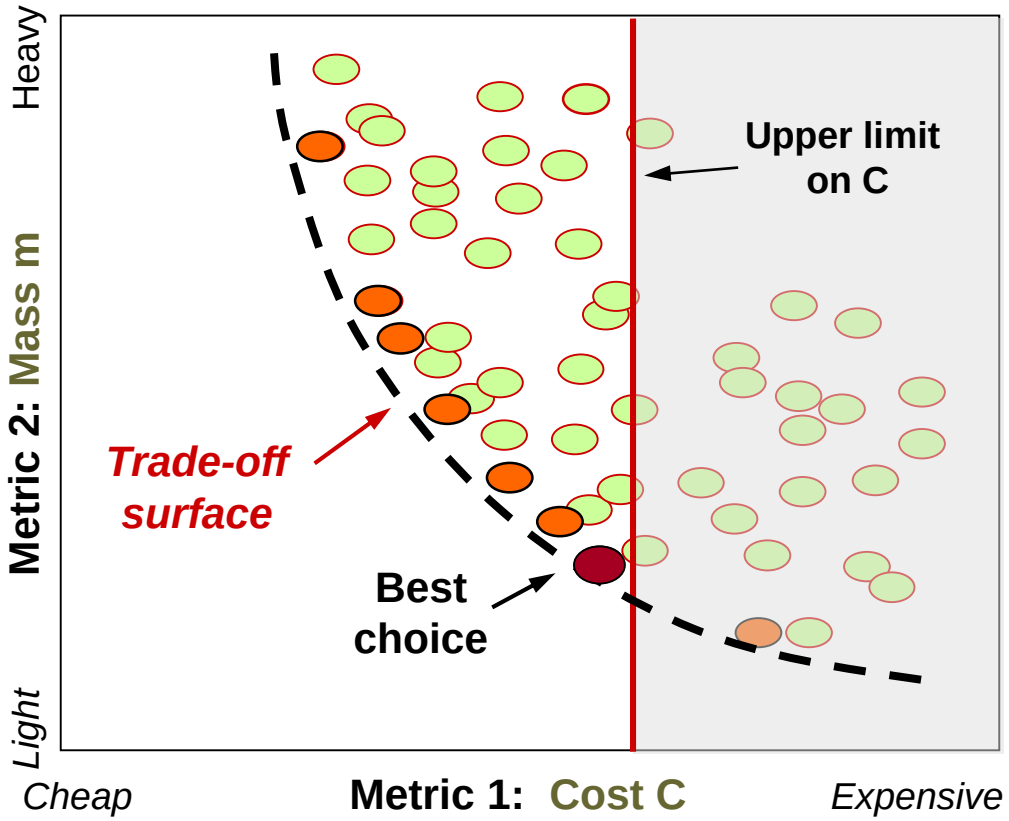
Finding a compromise: strategy 2

- ***Reformulate*** all but one of the objectives as constraints, setting an an upper limit for it

Good if budget limit

- **BUT….cheating**

Cost is treated as *constraint*, not *objective*.



Finding a compromise: strategy 3

Define locally-linear
Penalty function Z

$$Z = \alpha m + C$$

Seek solution with smallest Z

- Either **evaluate Z** for each solution, and choose materials with the lowest value

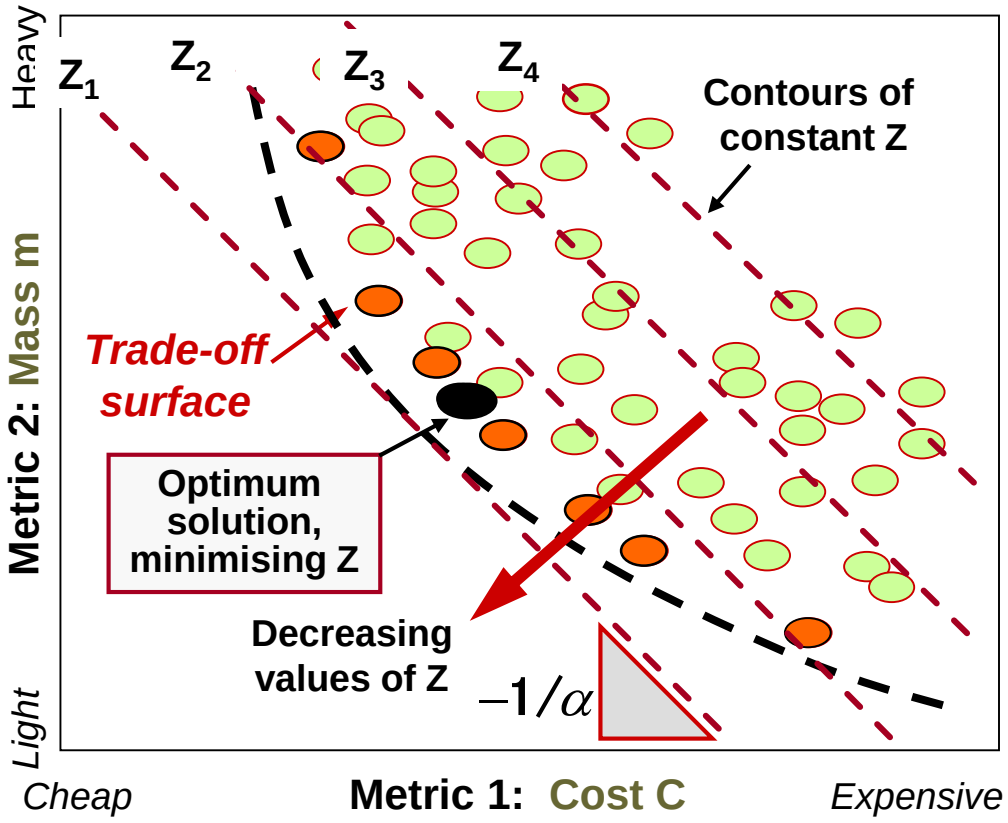
- Or make **trade-off plot**

Plot on it contours of Z

$$m = \boxed{-\frac{1}{\alpha}}C + \frac{1}{\alpha}Z$$

Lines of Z have slope -1/α
(needs linear scales)

- **Read off** solution with lowest Z



But what is the meaning of **α ?**

Materials for transport systems

Steel
Composites

Steel / Alu

Alu / (composite)

Alu / Ti / composites

Choice of material depends on system

- **Mass**, in transport systems, means **fuel**
- **Life cost** = Initial cost, **C** (\$) + Fuel cost over life, scaling with mass **m** (kg)
- **Penalty function** $Z = \mathbf{C} + \alpha m$ ($/kg)
- Must first establish **exchange constant,** α

The exchange constant α for transport

Exchange constants for transport systems

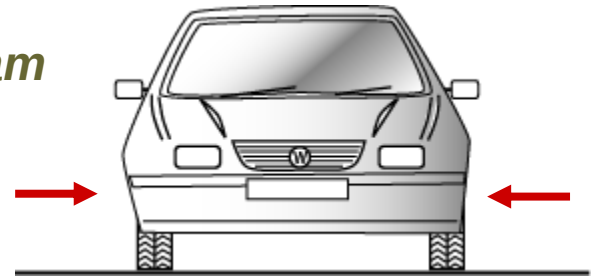
Transport system	α ($ per kg)
Family car	3 to 6
Truck	5 to 20
Civil aircraft	100 to 500
Military hardware	500 to 2000
Space vehicle	3000 to 10,000

How to get values of α?

- Full life costing: fuel saving, extra payload
- Analysis of historic data;
- Interviews, surveys

Materials for auto bumpers

Beam



Function	*Absorb impact, transmit load to energy-absorbing units or supports*
Objectives	*Minimize mass and material cost*
Criteria	***Cost C** per unit bending strength* ; ***Mass m** per unit bending strength*
Index: minimize	$C = \frac{C_m \rho}{\sigma_y^{2/3}}$; $m = \frac{\rho}{\sigma_y^{2/3}}$
Penalty function	$Z = C + \alpha m = \frac{\rho}{\sigma_y^{2/3}}\left(C_m + \alpha\right)$

C_m = Material cost / kg

ρ = Density, kg/m^3

σ_y = Yield strength, MPa

α = exchange constant , $/kg

Selection using the penalty function

$$Z = \frac{\rho}{\sigma_y^{2/3}}\left(C_m + \alpha\right)$$

*Use the "**Advanced**" facility to make the penalty function*

(Density / (Yield strength^0.66))

***(Price + 10)**

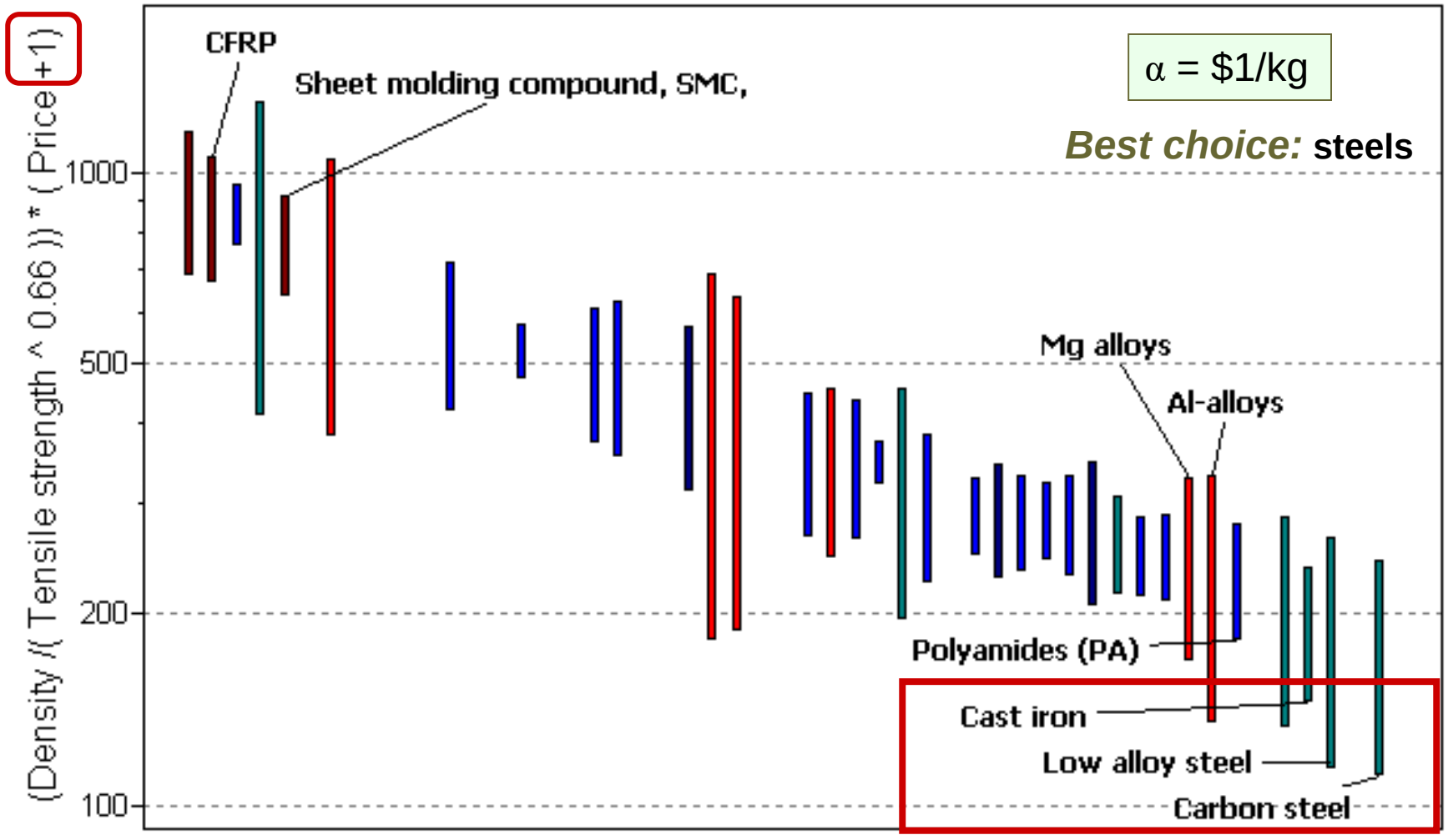
The value of the exchange constant

+ **-** **/** ***** **^** **(** **)**

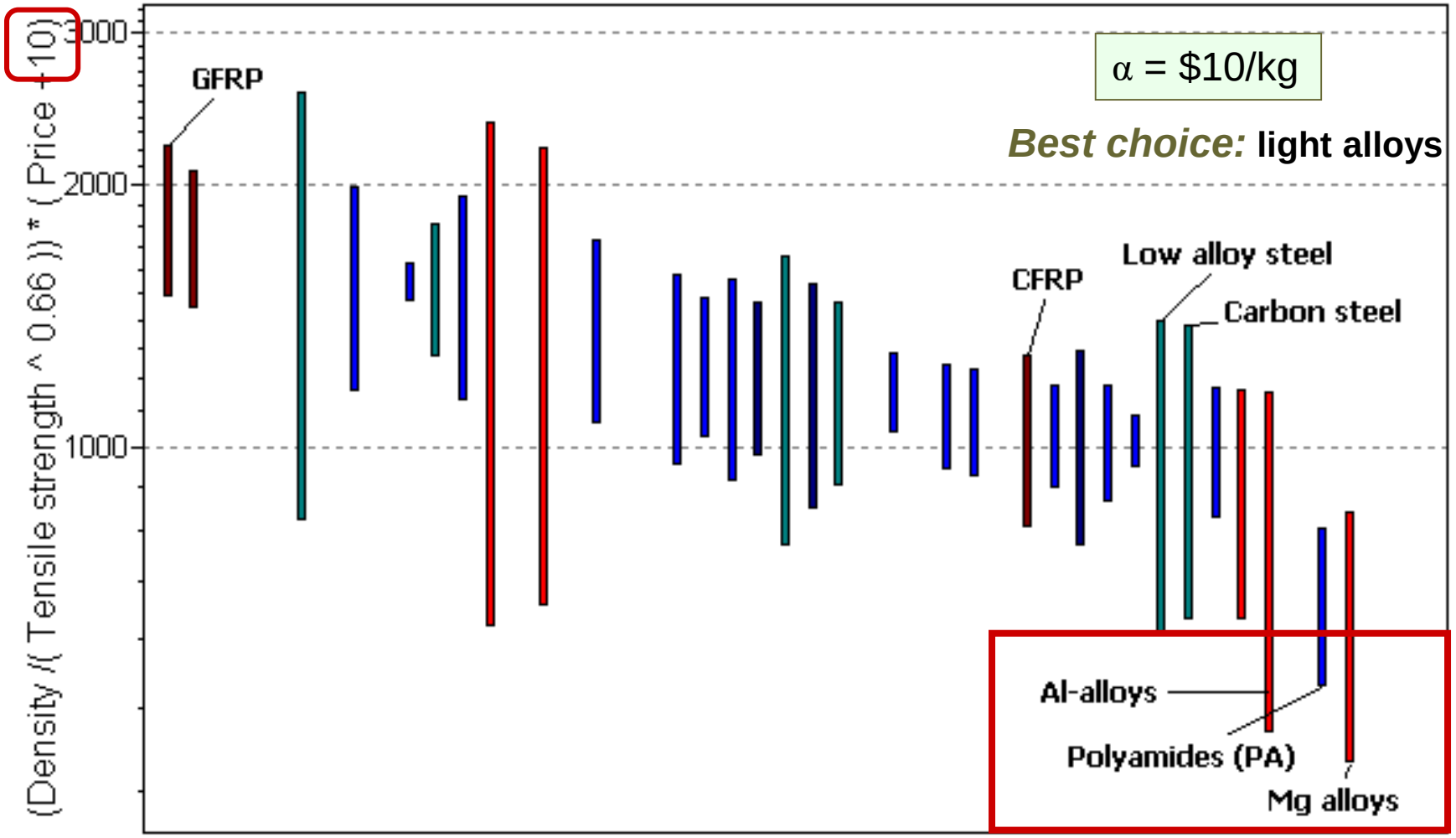
List of properties

- **Density**
- **Price**
- **Tensile strength**
- **etc**

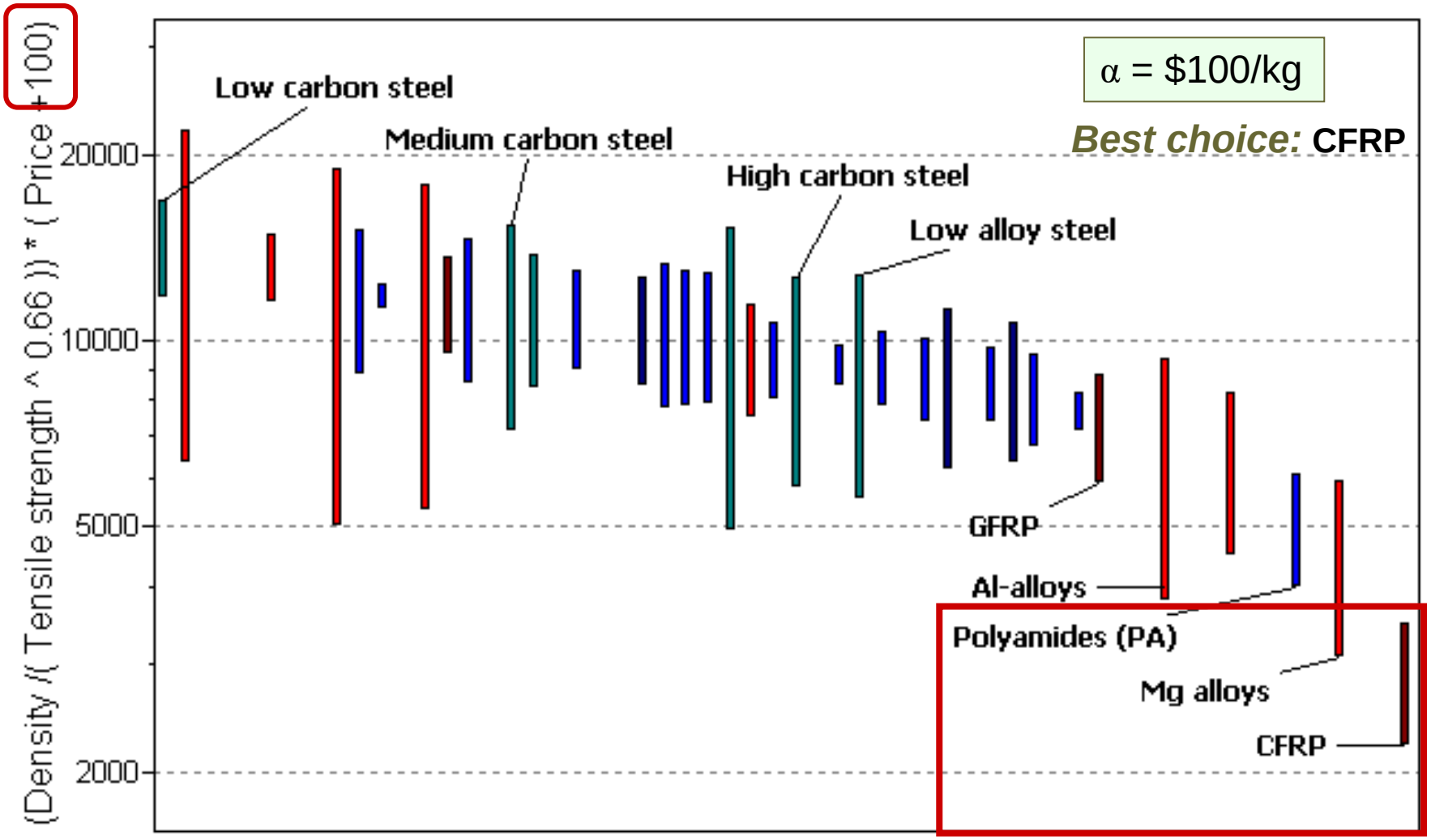
Selection using the penalty function



Selection using the penalty function

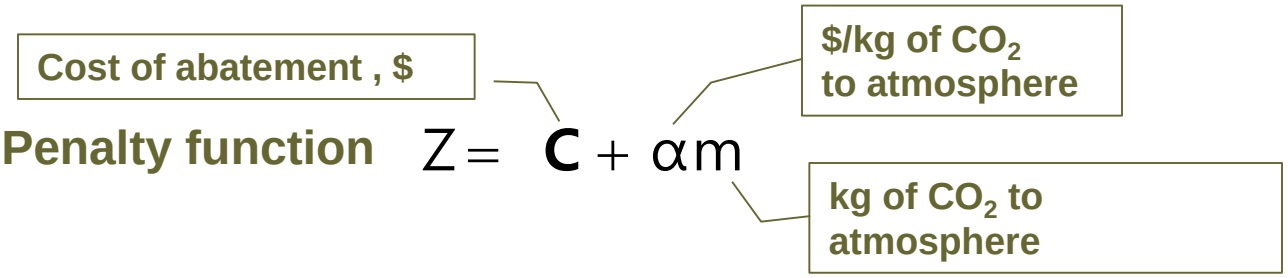


Selection using the penalty function



Other exchange constants

Carbon tax is an exchange constant

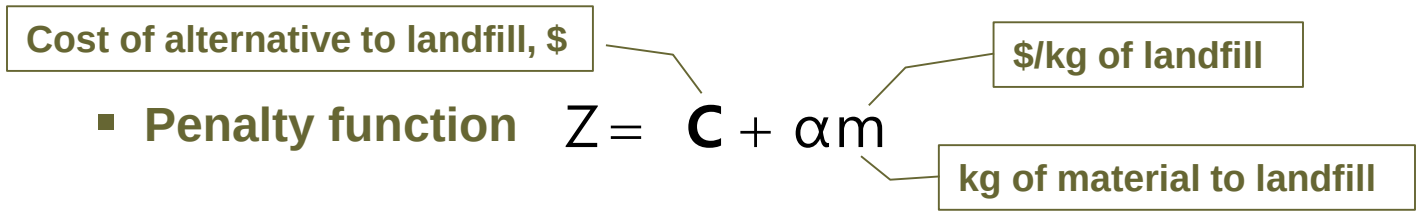


Set $\alpha = 0$ Result: no abatement. Cost of CO_2 is "externalised"

$\alpha = \infty$ Result: total ban on CO_2 release

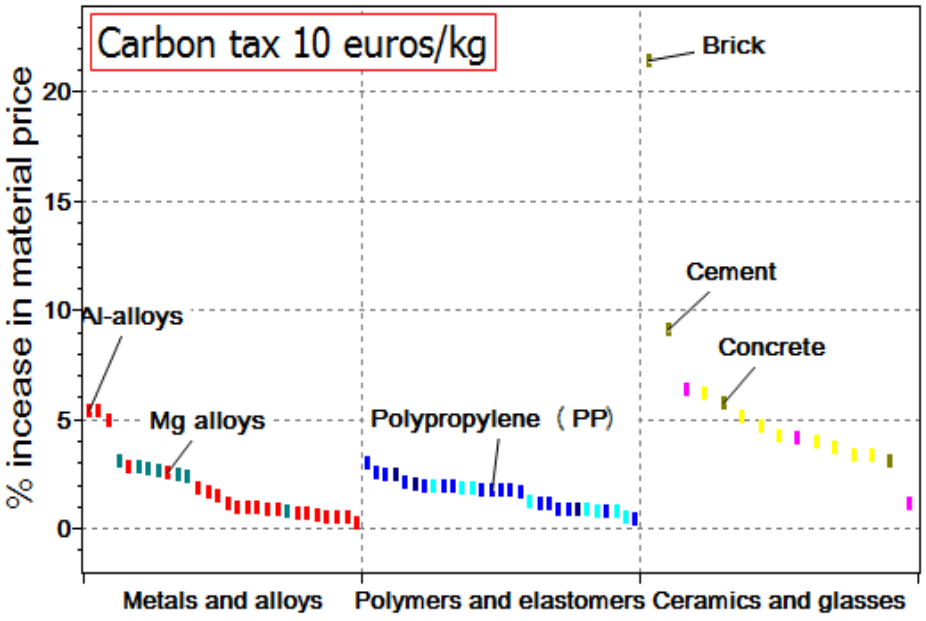
Currently $\alpha = €\ 0.02/kg$ Is it enough?

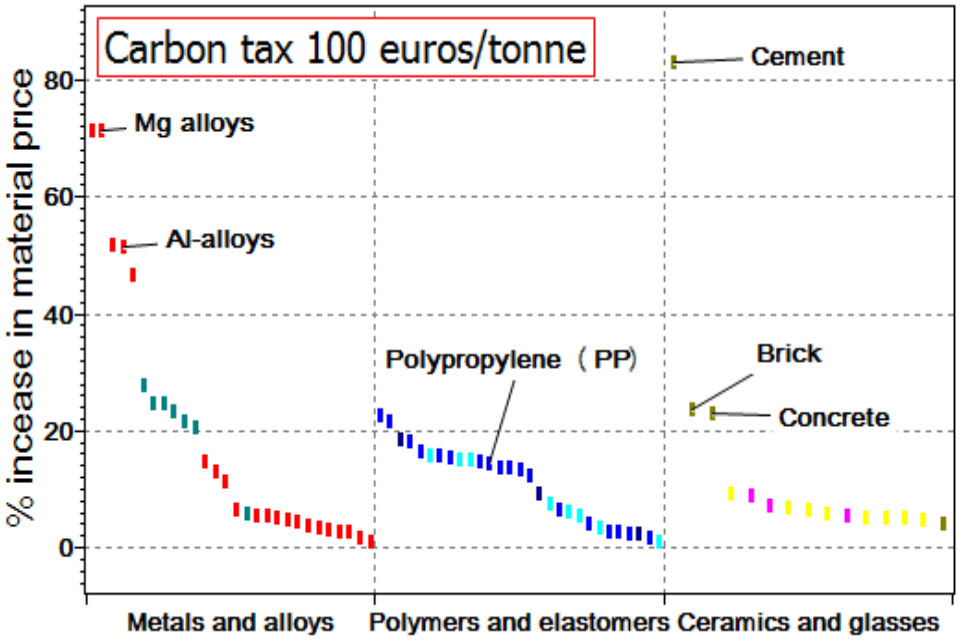
Landfill tax is an exchange constant

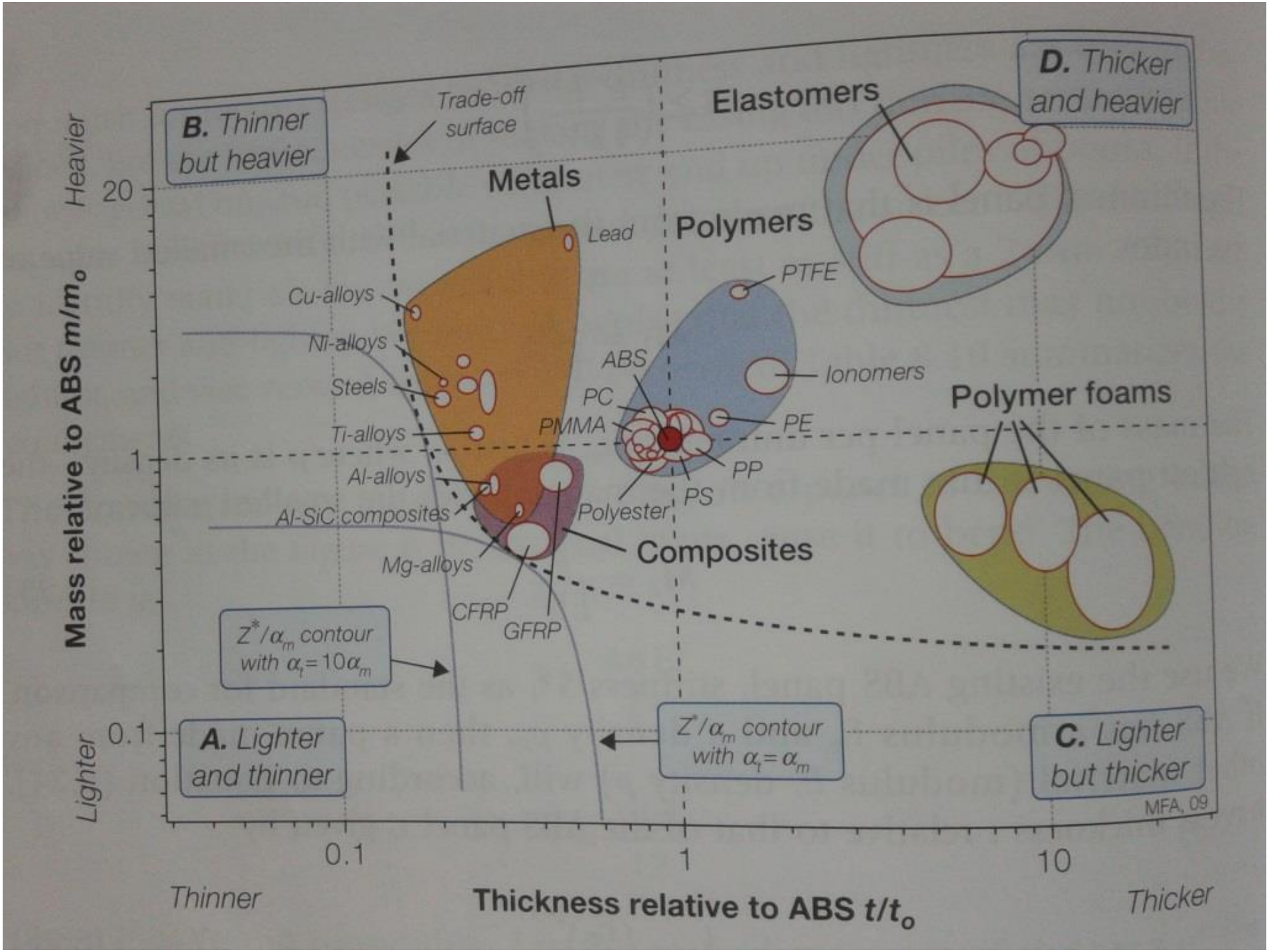


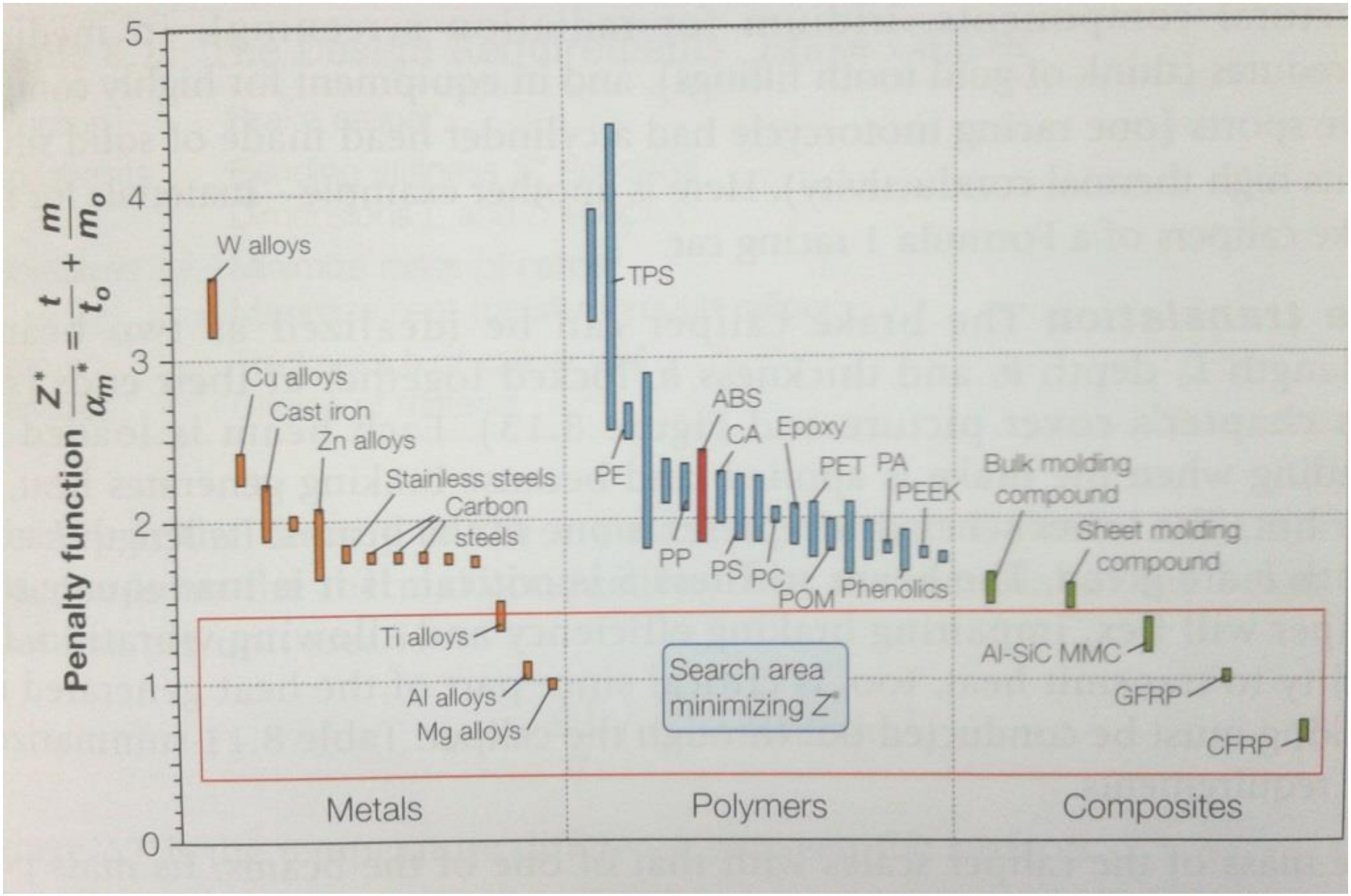
Currently $\alpha = €\ 0.08/kg$ Is it enough?

Demo


Carbon tax 10 euros/kg
% incease in material price
20
15
10
5
0
Al-alloys
Mg alloys
Polypropylene （PP)
Brick
Cement
Concrete
Metals and alloys
Polymers and elastomers
Ceramics and glasses


Carbon tax 100 euros/tonne
% incease in material price
80
60
40
20
0
Mg alloys
Al-alloys
Polypropylene （PP)
Cement
Brick
Concrete
Metals and alloys
Polymers and elastomers
Ceramics and glasses


B. Thinner but heavier
Trade-off surface
Metals
Lead
Cu-alloys
Ni-alloys
Steels
Ti-alloys
Al-alloys
Al-SiC composites
Mg-alloys
CFRP
GFRP
Polymers
PTFE
ABS
PC
PMMA
PE
PP
PS
Polyester
Ionomers
Elastomers
D. Thicker and heavier
Polymer foams
Composites
Z^*/α_m contour with $\alpha_f = 10\alpha_m$
Z^*/α_m contour with $\alpha_f = \alpha_m$
A. Lighter and thinner
C. Lighter but thicker
MFA, 09
Heavier
Lighter
Mass relative to ABS m/m_o
20
1
0.1
0.1
1
10
Thinner
Thickness relative to ABS t/t_o
Thicker


Penalty function $\frac{Z^*}{\alpha_m^*} = \frac{t}{t_o} + \frac{m}{m_o}$
5
4
3
2
1
0
W alloys
Cu alloys
Cast iron
Zn alloys
Stainless steels
Carbon steels
Ti alloys
Al alloys
Mg alloys
TPS
PE
PP
ABS
CA
PS
PC
Epoxy
PET
POM
PA
PEEK
Phenolics
Bulk molding compound
Sheet molding compound
Al-SiC MMC
GFRP
CFRP
Search area minimizing Z^*
Metals
Polymers
Composites