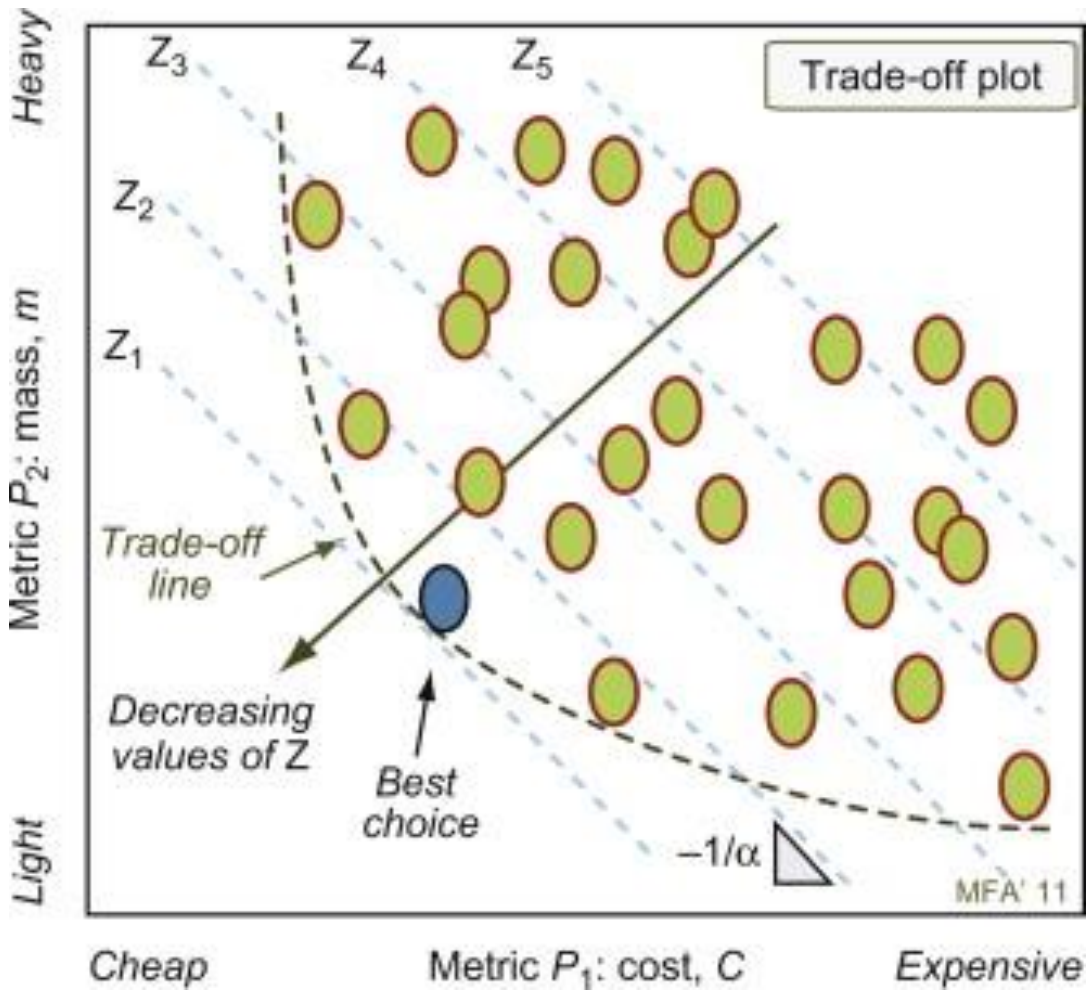
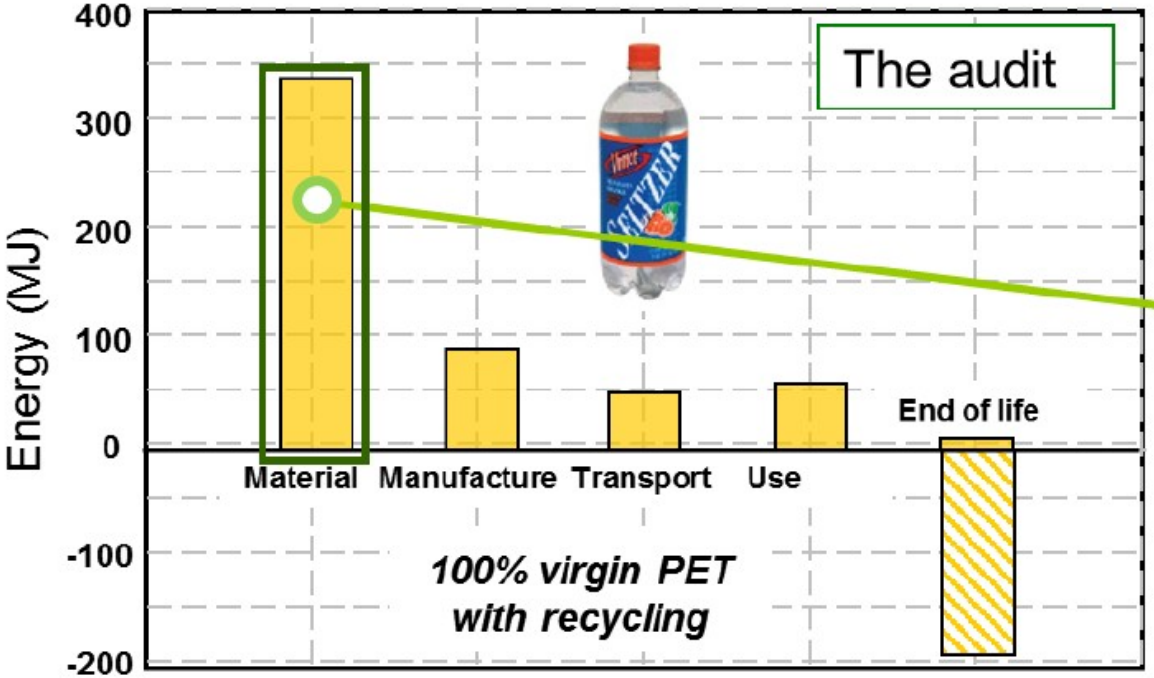


Trade-off plot scanned by lines for decreasing values of penalty function

«Fully synthetic materials» vs bio-derived materials

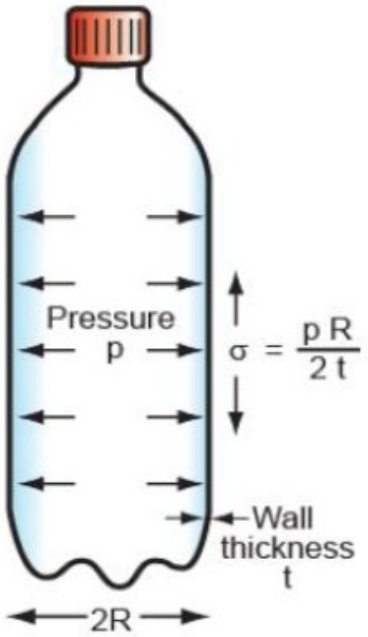
Containers for sparkling beverages



Material dominates

Minimize embodied energy

Problem: PET against PLA

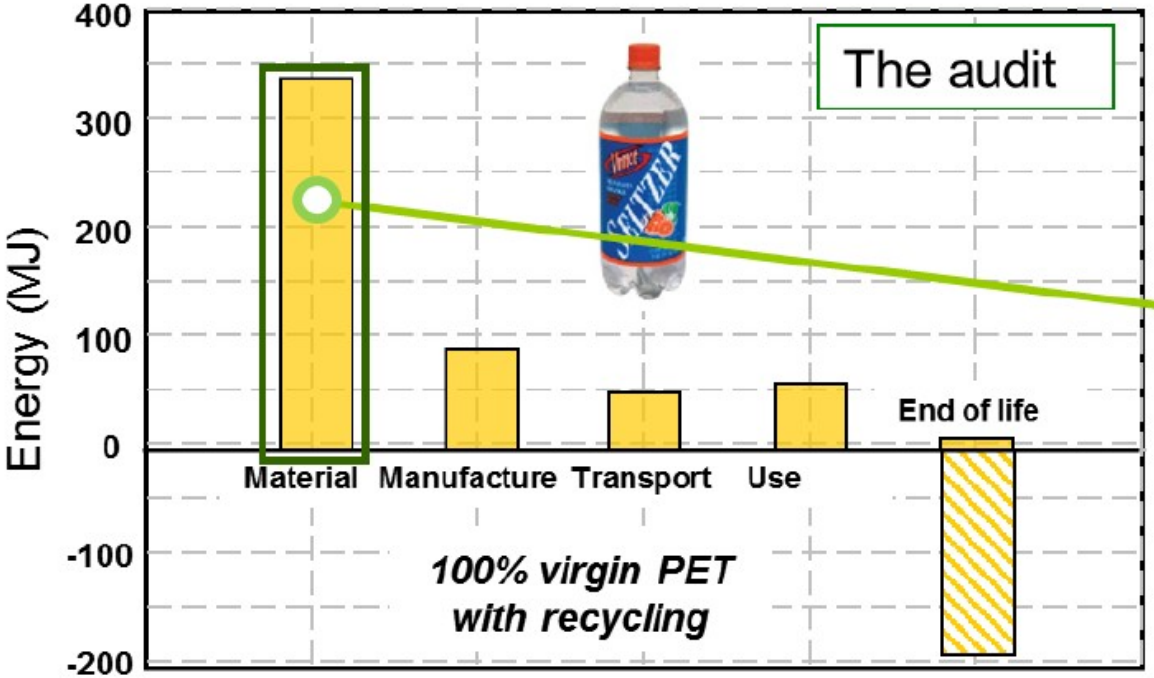


Graph: example of 'Eco-Audit' (to be explored later)

'Rough' definition of E-A: display of energy consumption distribution for a *product* in its 'life'

«Fully synthetic materials» vs bio-derived materials

Containers for sparkling beverages



Material dominates

Minimize embodied energy

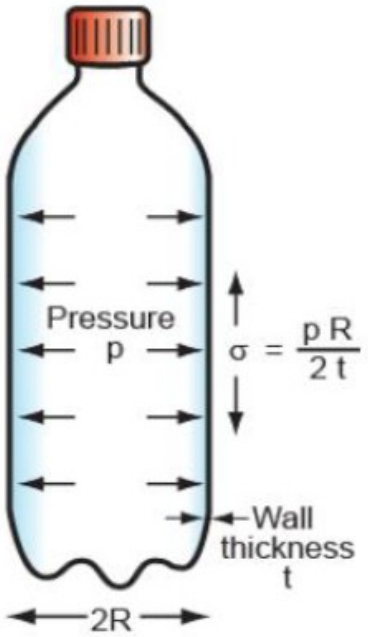
Focus on functionality

$$\sigma = \frac{p \cdot R}{t} \leq \sigma_f$$

Pressurized container:
to avoid failure

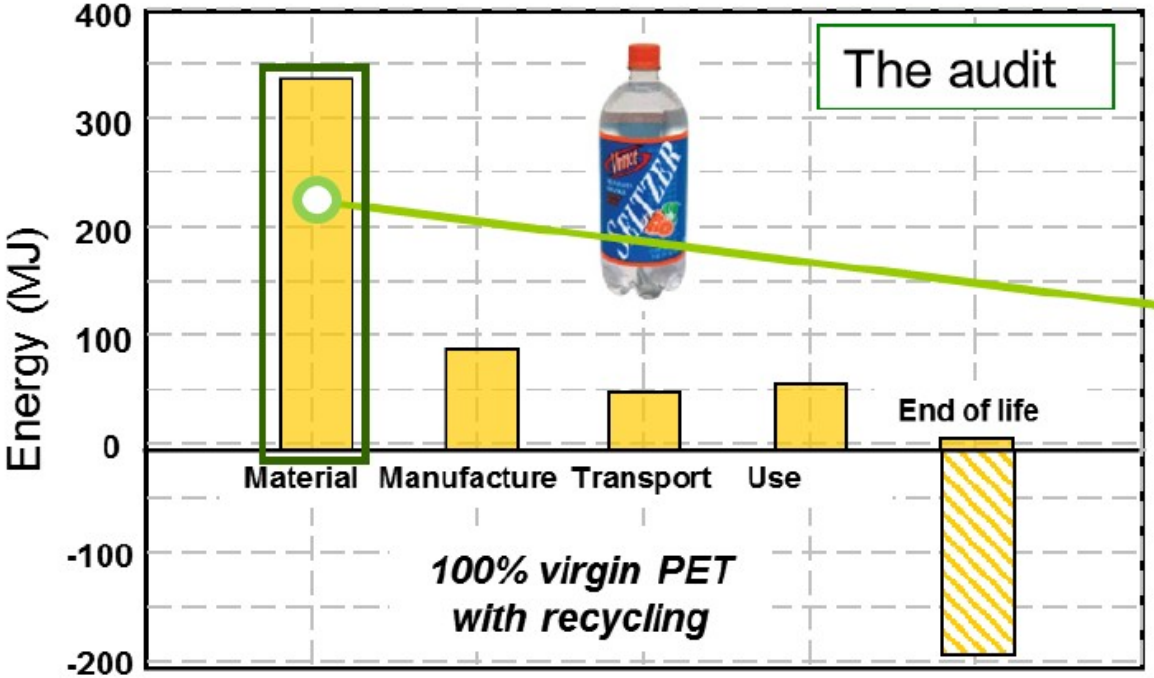
Strong materials enabling
thin containers

$$t \geq \frac{p \cdot R}{\sigma_f} = FS_t \cdot \frac{1}{\sigma_f}$$



«Fully synthetic materials» vs bio-derived materials

Containers for sparkling beverages: energy-cost trade-off



Material dominates

Minimize embodied energy

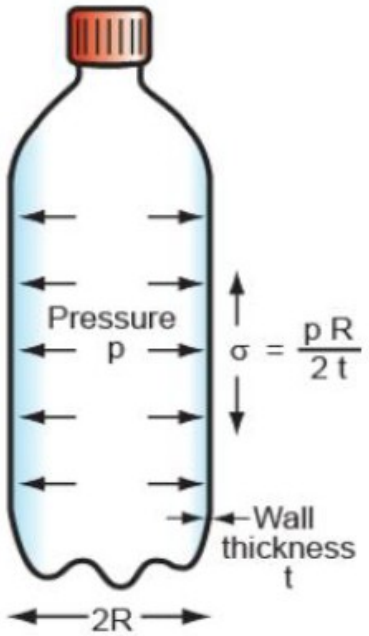
$$t \geq \frac{p \cdot R}{\sigma_f} = FS_t \cdot \frac{1}{\sigma_f}$$

Mind: Hp may be updated with recycling (not considered now)

$$\boldsymbol{E_{prod}} = H_P \cdot \rho \cdot t = FS_E \cdot \frac{\boldsymbol{H_P \cdot \rho}}{\boldsymbol{\sigma_f}}$$

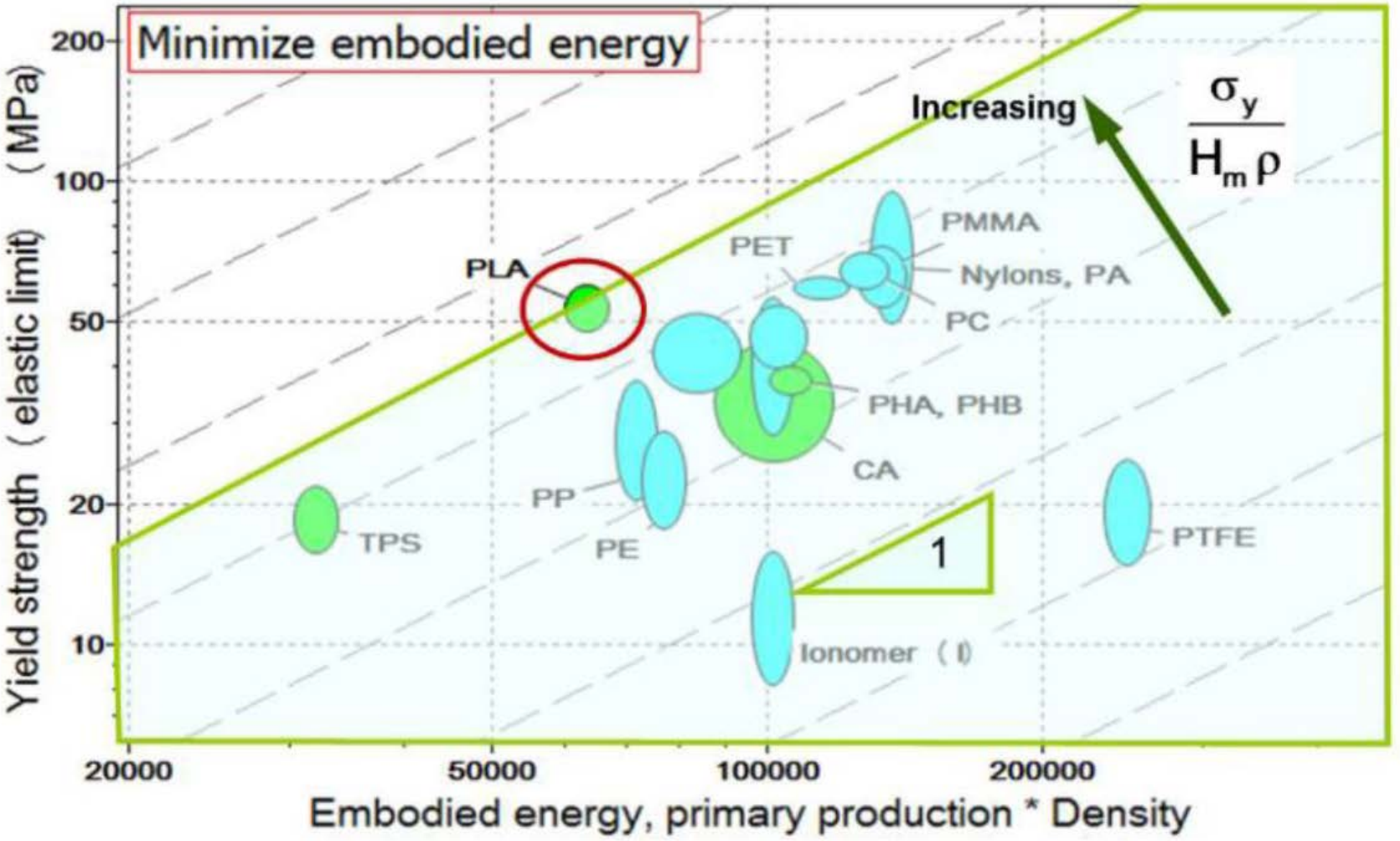
$$\boldsymbol{C} = C_m \cdot \rho \cdot t = FS_{\mathbf{C}} \cdot \frac{\boldsymbol{C_m \cdot \rho}}{\boldsymbol{\sigma_f}}$$

Per unit wall surface



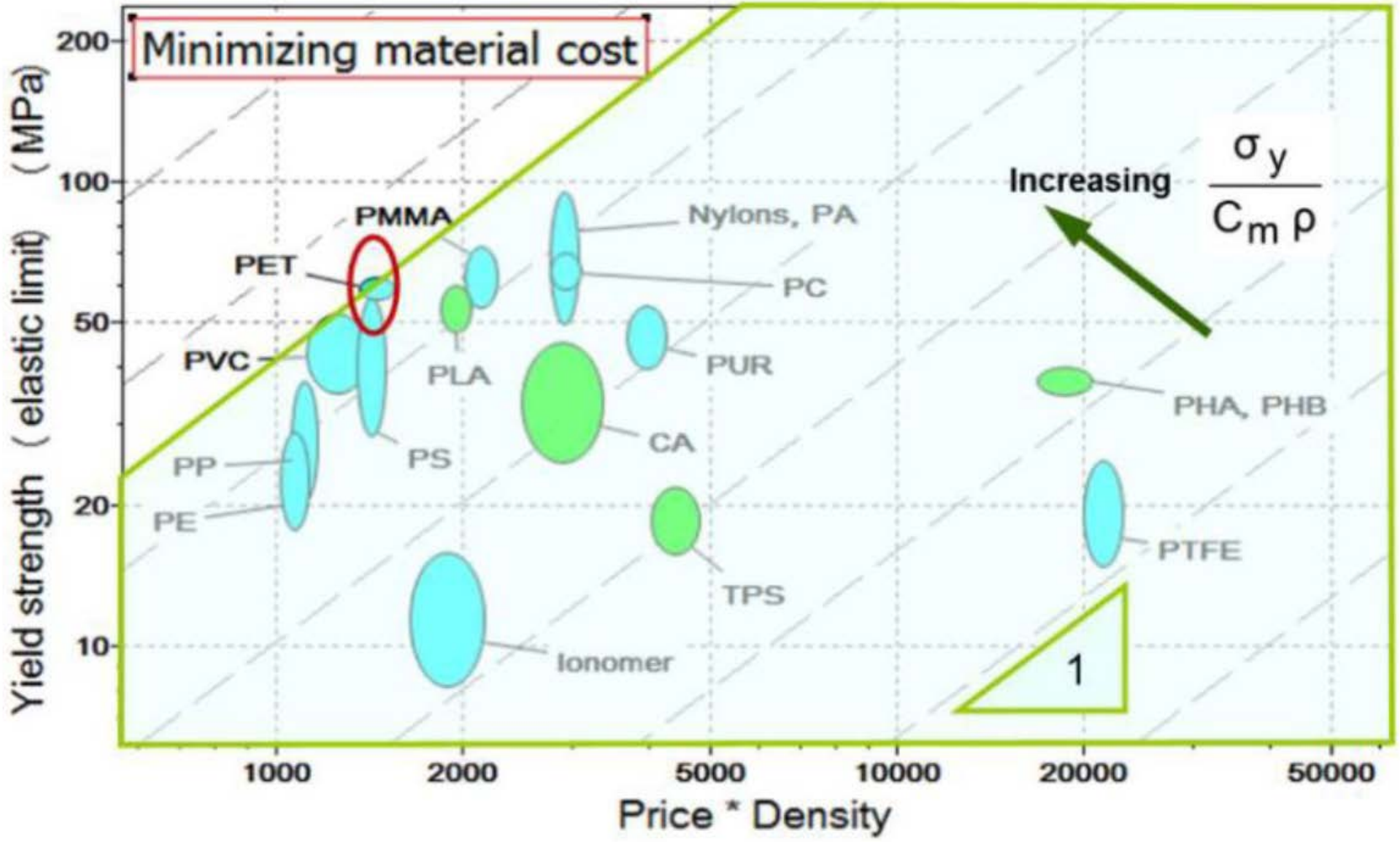
«Fully synthetic materials» vs bio-derived materials
Analysis of primary production energy: PLA is attractive

$$I_1 = \frac{\sigma_f}{H_P \cdot \rho} \quad \rightarrow \quad Log\ \sigma_f = Log\ (H_P \cdot \rho) + Log I_1$$



«Fully synthetic materials» vs bio-derived materials
Analysis of cost: PLA is far less attractive

$$I_2 = \frac{\sigma_f}{C_m \cdot \rho} \quad \rightarrow \quad Log\ \sigma_f = Log\ (C_m \cdot \rho) + Log I_2$$



«Fully synthetic materials» vs bio-derived materials
Containers for sparkling beverages: energy-cost trade-off
Definition of a penalty function

$$Z = \alpha_E \cdot \frac{1}{I_1} + \alpha_C \cdot \frac{1}{I_2} = \alpha_E \cdot \frac{H_P \cdot \rho}{\sigma_f} + \alpha_C \cdot \frac{C_m \cdot \rho}{\sigma_f}$$

$$\frac{H_P \cdot \rho}{\sigma_f} = -\frac{\alpha_C}{\alpha_E} \cdot \frac{C_m \cdot \rho}{\sigma_f} + \frac{Z}{\alpha_E}$$

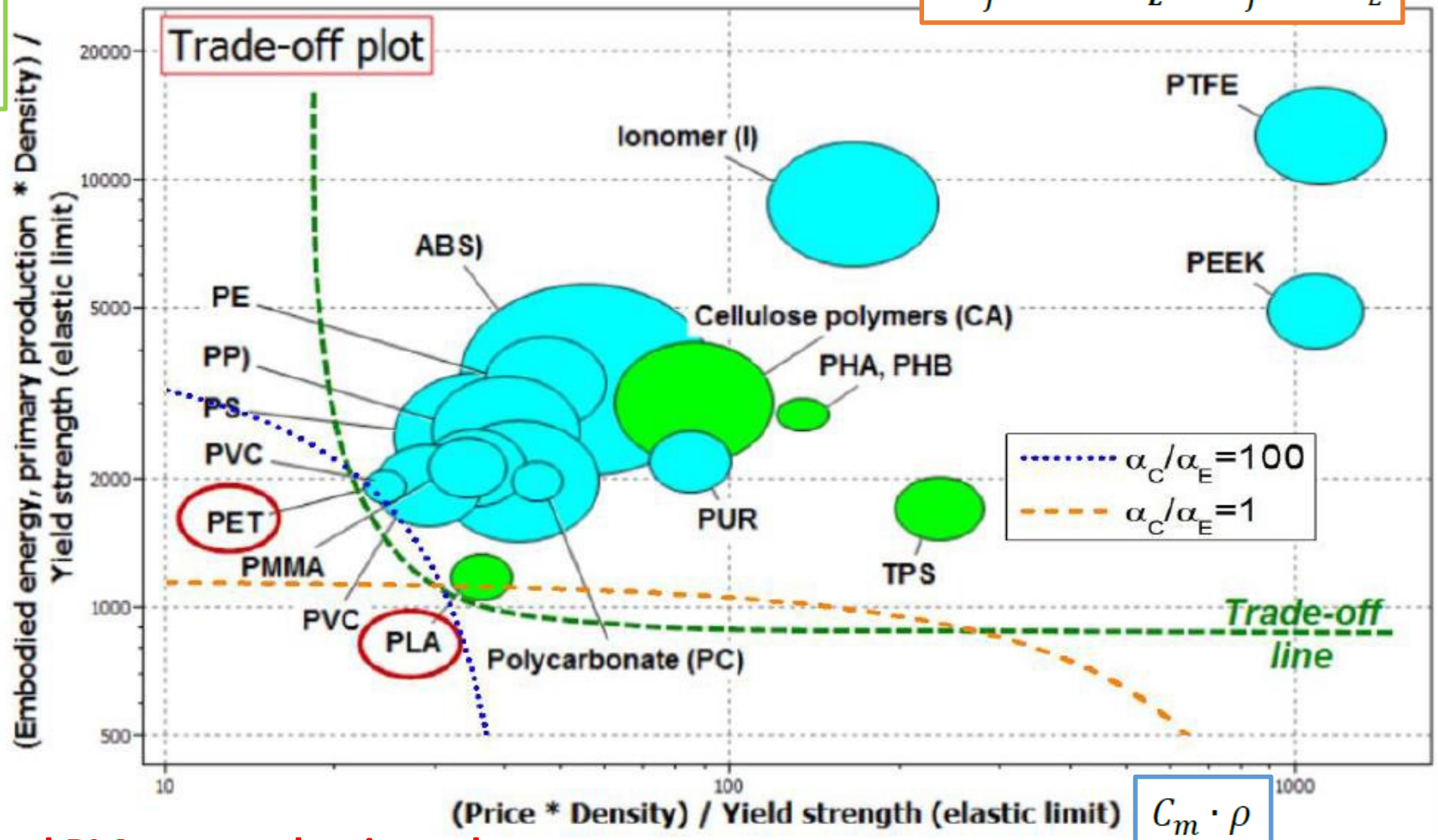
Overall sustainability provided by penalty value

Attention to the directions….both indices should be minimized

Overall sustainability provided by penalty value

Attention to the directions….both indices should be minimized

$$\frac{H_P \cdot \rho}{\sigma_f} = -\frac{\alpha_C}{\alpha_E} \cdot \frac{C_m \cdot \rho}{\sigma_f} + \frac{Z}{\alpha_E}$$



PET and PLA as non-dominated solutions

Overall sustainability provided by penalty value

Attention to the directions….both indices should be minimized

$$Z = \alpha_E \cdot \frac{1}{I_1} + \alpha_C \cdot \frac{1}{I_2} = \alpha_E \cdot \frac{H_P \cdot \rho}{\sigma_f} + \alpha_C \cdot \frac{C_m \cdot \rho}{\sigma_f}$$

$$\frac{H_P \cdot \rho}{\sigma_f} = -\frac{\alpha_C}{\alpha_E} \cdot \frac{C_m \cdot \rho}{\sigma_f} + \frac{Z}{\alpha_E}$$

PET convenient for HIGH $\frac{\alpha_C}{\alpha_E}$ [current condition]

PLA convenient for LOW $\frac{\alpha_C}{\alpha_E}$

NB The excessive gas permeability of PLA was not considered [permeability could be studied as constriaint or as a further property in an overall penalty function]; synthetic polymers are favoured

ANY WEAKNESS?

IF $Z = \alpha_E \cdot \frac{H_p \cdot \rho}{\sigma_f} + \alpha_c \frac{C_m \cdot \rho}{\sigma_f}$

α_E AND α_c DO NOT FEATURE THE SAME UNIT

$$\left[\frac{H_p \cdot \rho}{\sigma_f}\right] = \frac{J/kg \cdot \frac{kg}{m^3}}{MPa}$$

$$\left[\frac{C_m \cdot \rho}{\sigma_f}\right] = \frac{\$/kg \cdot kg/m^3}{MPa}$$

$\frac{\alpha_c}{\alpha_E}$ SHOULD HAVE A SPECIFIC UNIT

MEANING?

SOLUTION α_E AND α_c AS 'WEIGHTS'
= PURE NUMBERS

SYNTAX $Z = \alpha_E \frac{I_{10}}{I_1} + \alpha_c \frac{I_{20}}{I_2}$

I_{10}, I_{20} = INDICES FOR A STANDARD MATERIAL

FOR BOTTLES I_{1PET}, I_{2PET}

PET = TRADITIONAL (CONVENTIONAL)
POLYMER MATERIAL FOR CONTAINERS

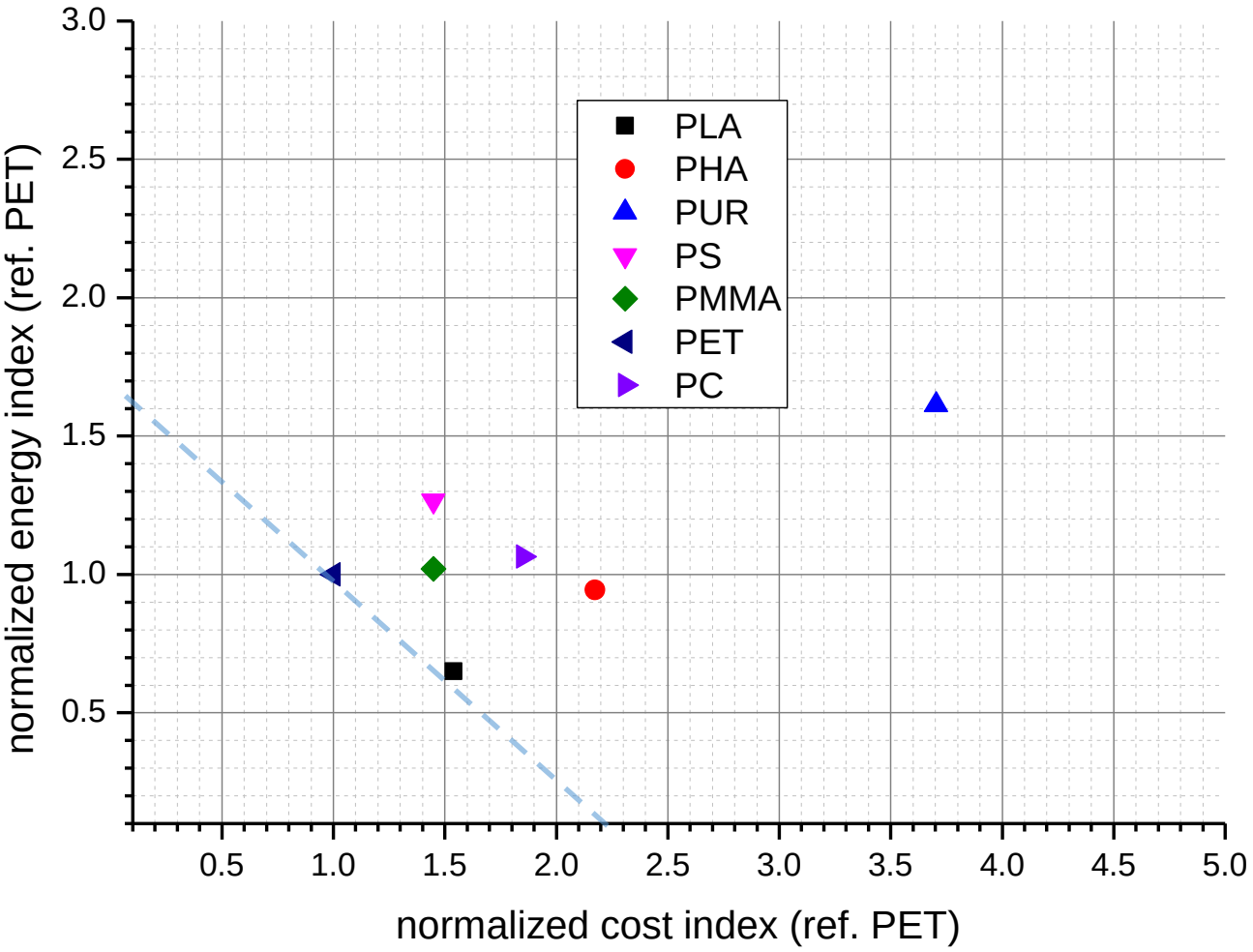
$Z_{PET} = \alpha_E + \alpha_c$

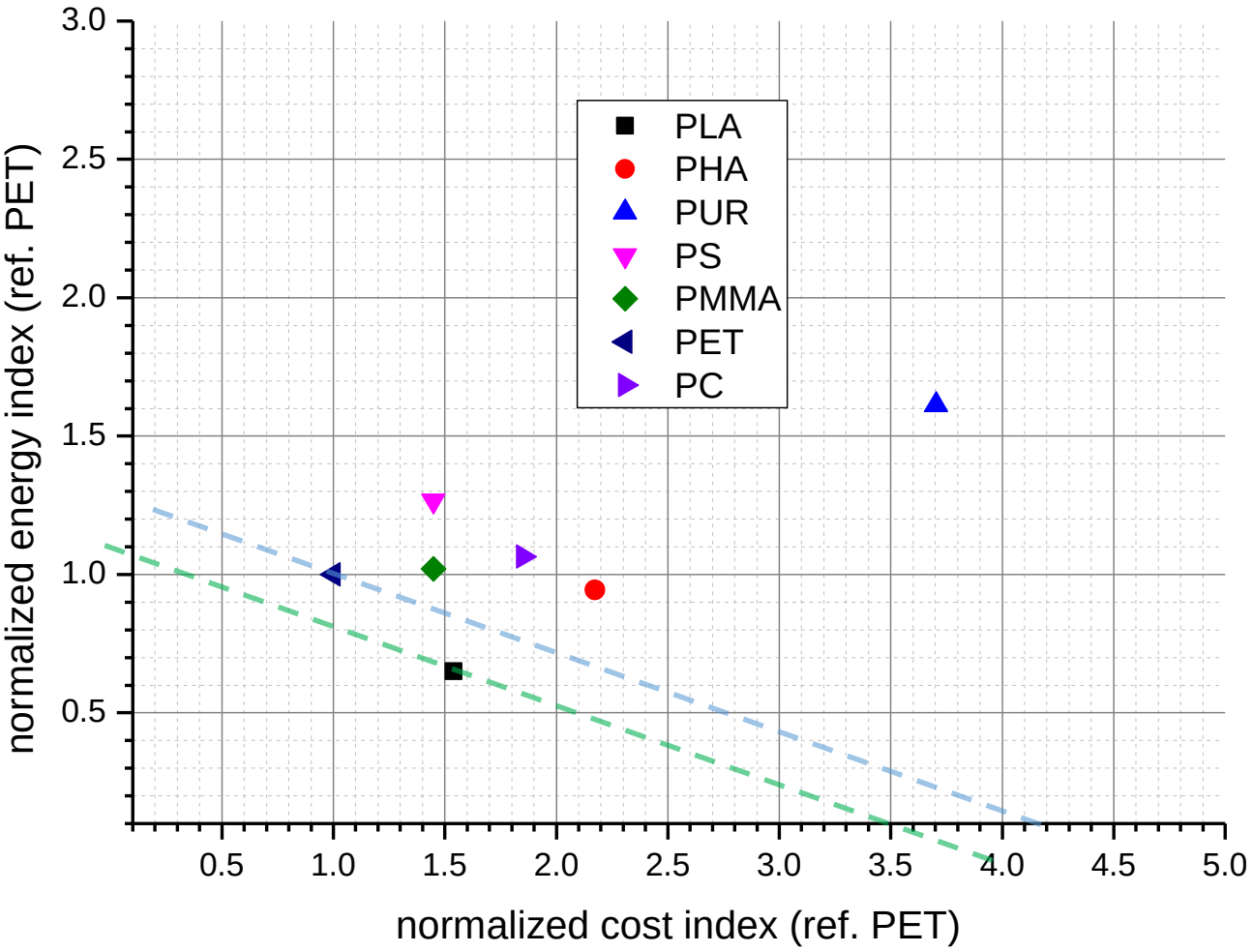
$Z = Y \cdot \alpha_E + X \cdot \alpha_c$

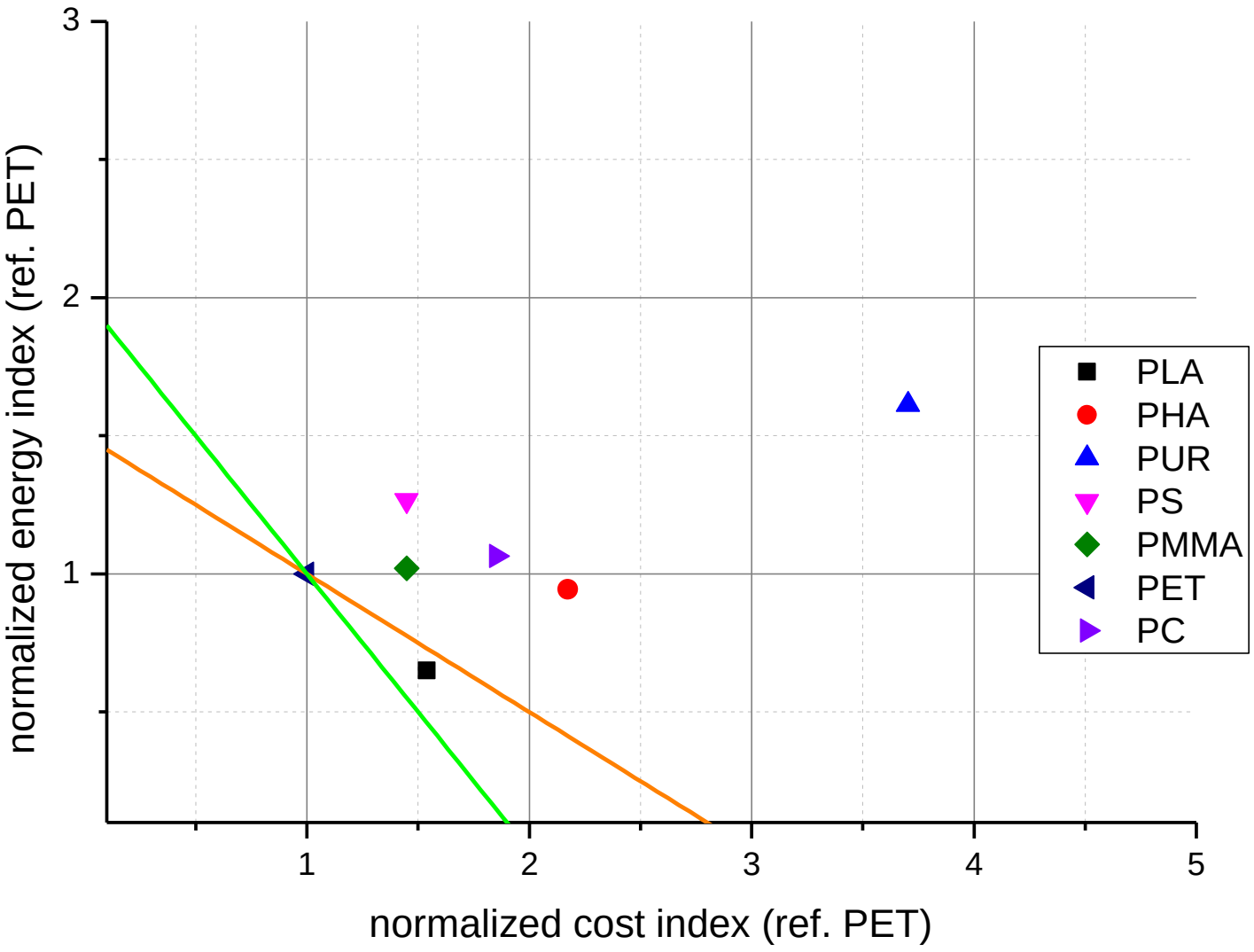
Y ↑ NORMALIZED ENERGY INDEX

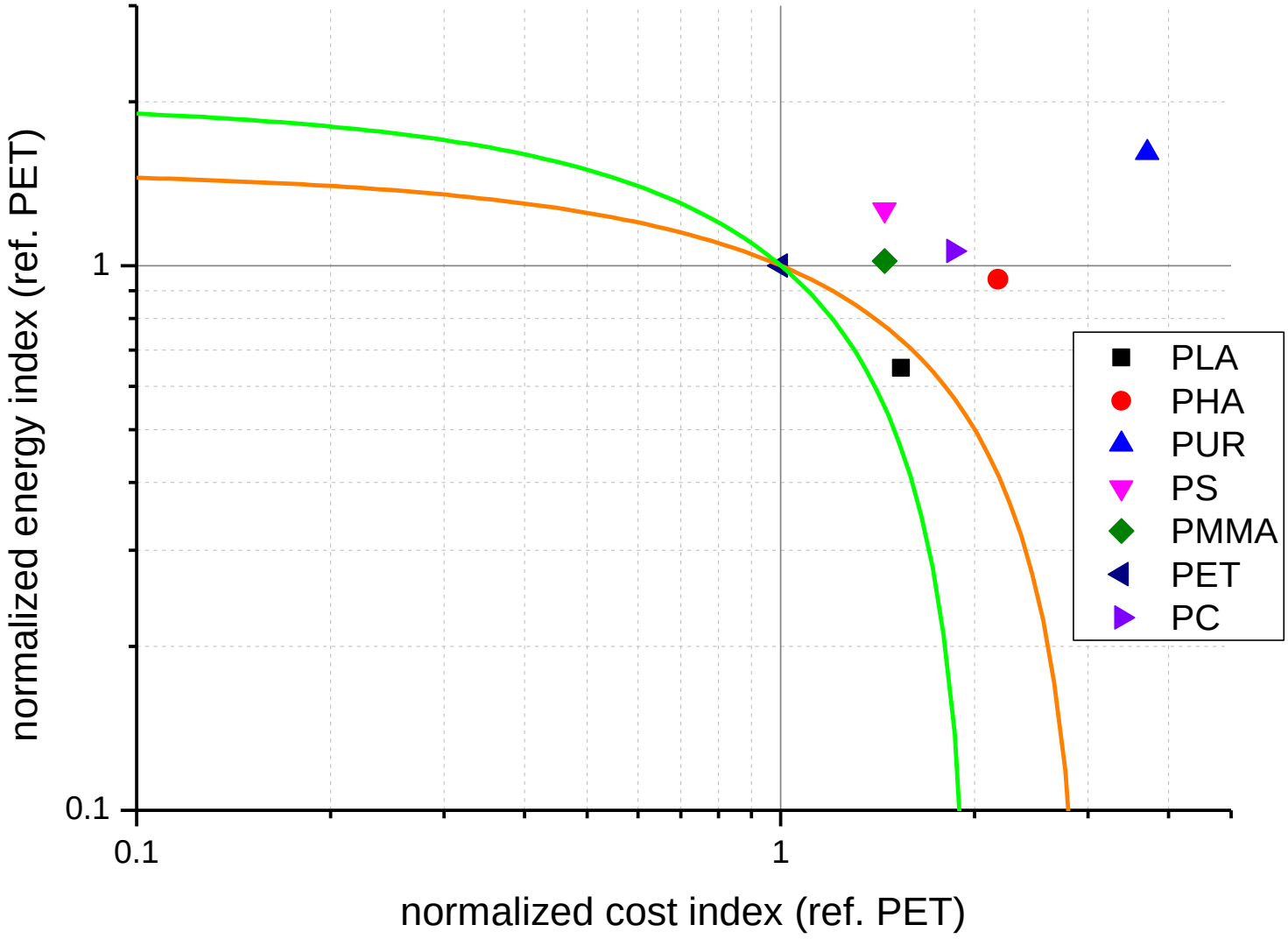
X ↑ NORMALIZED COST INDEX

$Y = -\frac{\alpha_c}{\alpha_E} \cdot X + \frac{Z}{\alpha_E}$


normalized energy index (ref. PET)
normalized cost index (ref. PET)
3.0
2.5
2.0
1.5
1.0
0.5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
PLA
PHA
PUR
PS
PMMA
PET
PC


normalized energy index (ref. PET)
normalized cost index (ref. PET)
PLA
PHA
PUR
PS
PMMA
PET
PC
3.0
2.5
2.0
1.5
1.0
0.5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


normalized energy index (ref. PET)
normalized cost index (ref. PET)
1
2
3
4
5
PLA
PHA
PUR
PS
PMMA
PET
PC


normalized energy index (ref. PET)
1
0.1
0.1
1
normalized cost index (ref. PET)
PLA
PHA
PUR
PS
PMMA
PET
PC

Stage 1: (53 / 111220) * Embodied energy, primary production (virgin grade) * Density / Yield strength (elastic limit) vs. (53 / 1072) * Price * Density / Yield strength (elastic limit)

