

In most applications, a material is exploited as the *constituent* of a **component or device** (e.g. part of a car, tool). A component or a device has a specified **function** according to (more or less complex) mathematical equations.

As an example **Ohm's law**, for an electrical conductor (e.g. a cable), is ruled by:

$$\Delta V = R \cdot i$$

The **performance** of a conductor, e.g. the movement of electrical charges defining an electrical current of intensity i , is directly proportional to the electric potential difference, ΔV , by means of a property of the same component, known as electrical resistance R . The value of electrical resistance depends on both the adopted material and the geometrical feature. In fact, for a bar with a length l and a cross-sectional area A , R is expressed by:

$$R = \rho \cdot l / A = \rho \cdot FS$$

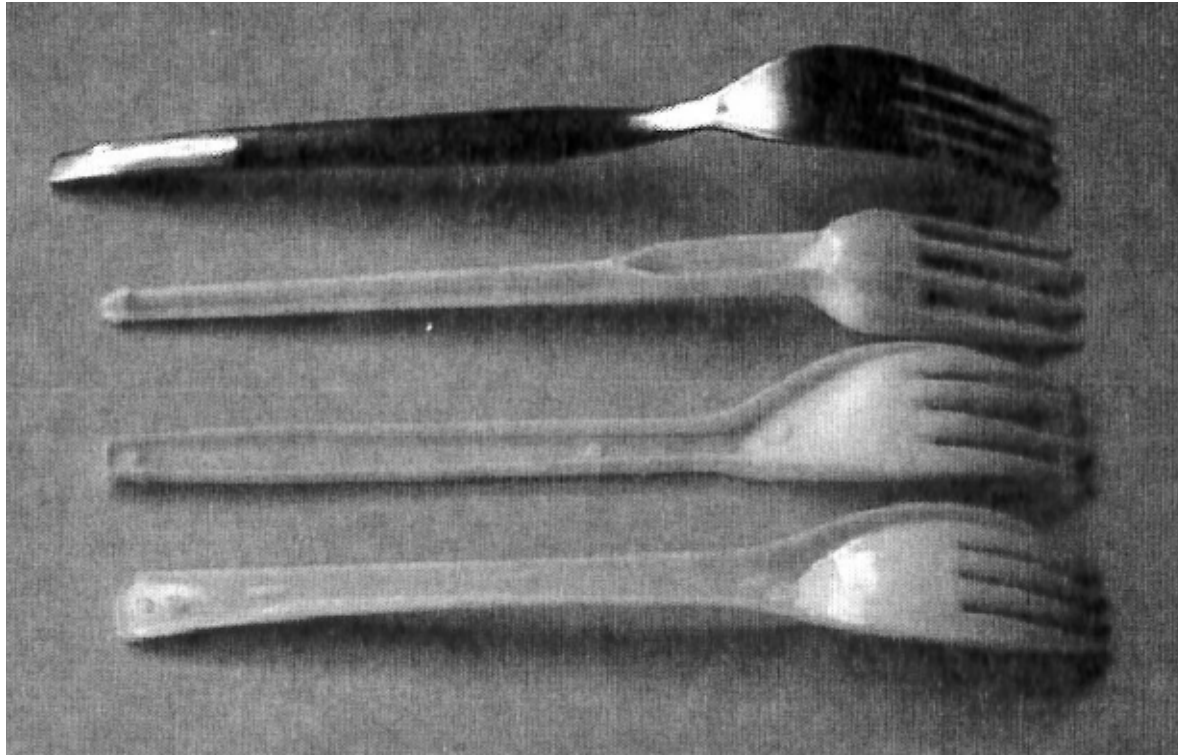
Where ρ is the electrical resistivity of the adopted material

FS = structural factor (factor of structure)

- *For constant geometrical features*, the performance may change by selecting a material according to its electrical **resistivity: ρ** as **performance index [material property index]**
- We cannot exclude **equivalent solutions**, when structural factors and material property indices compensate for each other differences:

$$R = \rho_A \cdot FS_A = \rho_B \cdot FS_B$$

- **Selection cannot be separated from design (= geometrical definition)**



Example of material substitution (polypropylene or polystyrene in place of stainless steel) by means of a ***material-shape compensation***: a flexural stiffness above a minimum threshold (for the specific use) is obtained by using a material with **poorer fundamental properties (elastic modulus), compensated by a high structural factor** [from M.M. Farag, *Materials and Process Selection for Engineering Design*, CRC Press, Boca Raton 2008]

- Equivalent solutions are the basis for the replacement of materials, or the adoption of a new material, instead of the one previously used, by definition of new shapes
- In many cases, **different solutions are equivalent for a certain performance**, but have a **different characterization in terms of other factors, objective** (secondary functionality, cost, compatibility with a production process, availability of raw materials, recyclability, etc.) **or subjective** (e.g. customers' impressions).
- Example: racing bicycles, *extremely light* and with frames of *adequate stiffness for professional use*, can be produced with different materials: the adoption of a solution in place of the other depends on the simultaneous assessment of several parameters; the main functionality has a *determining* but *not exclusive* impact.



Aluminum alloy
(forks: CFRP)

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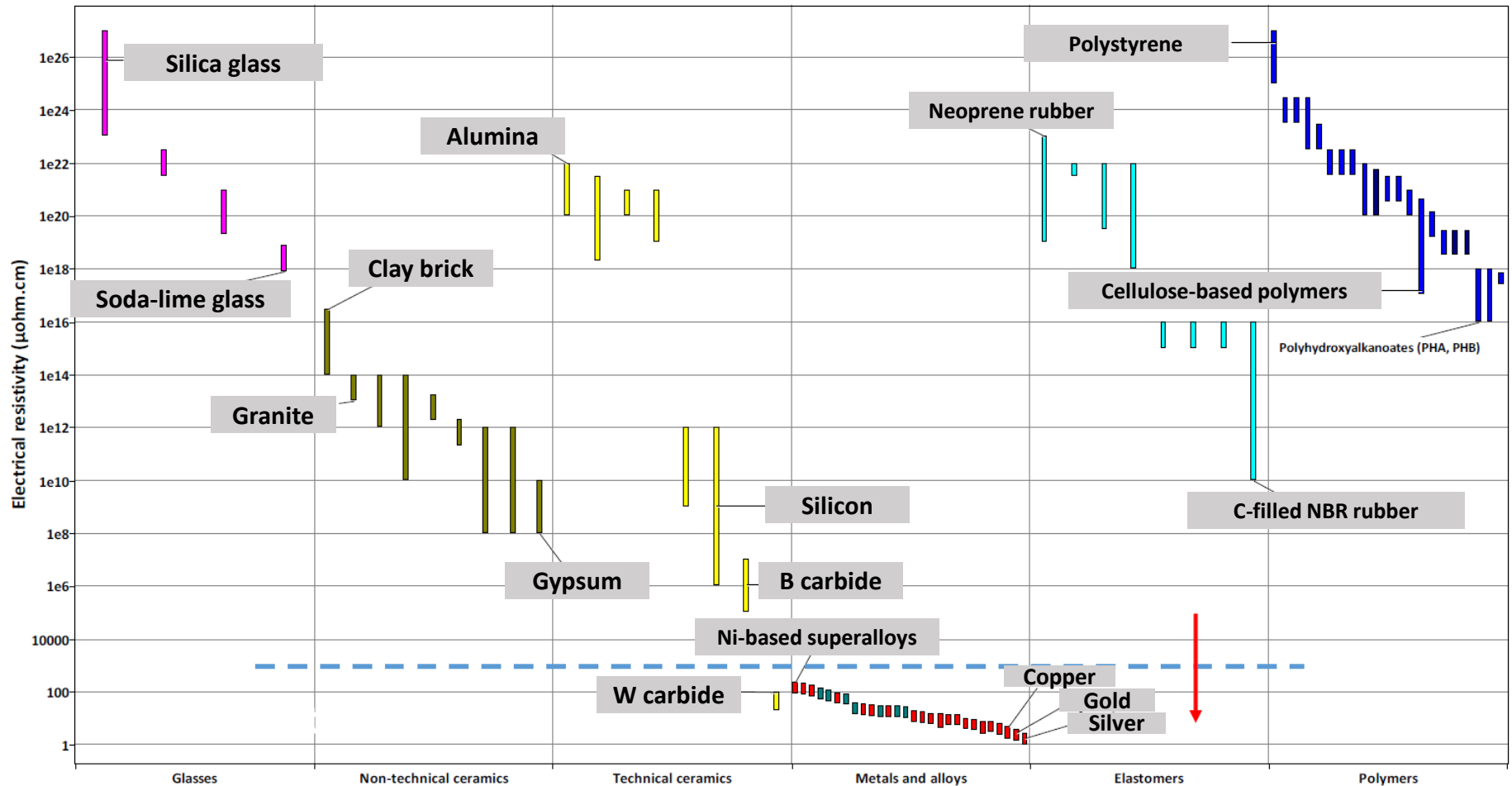
Titanium alloy
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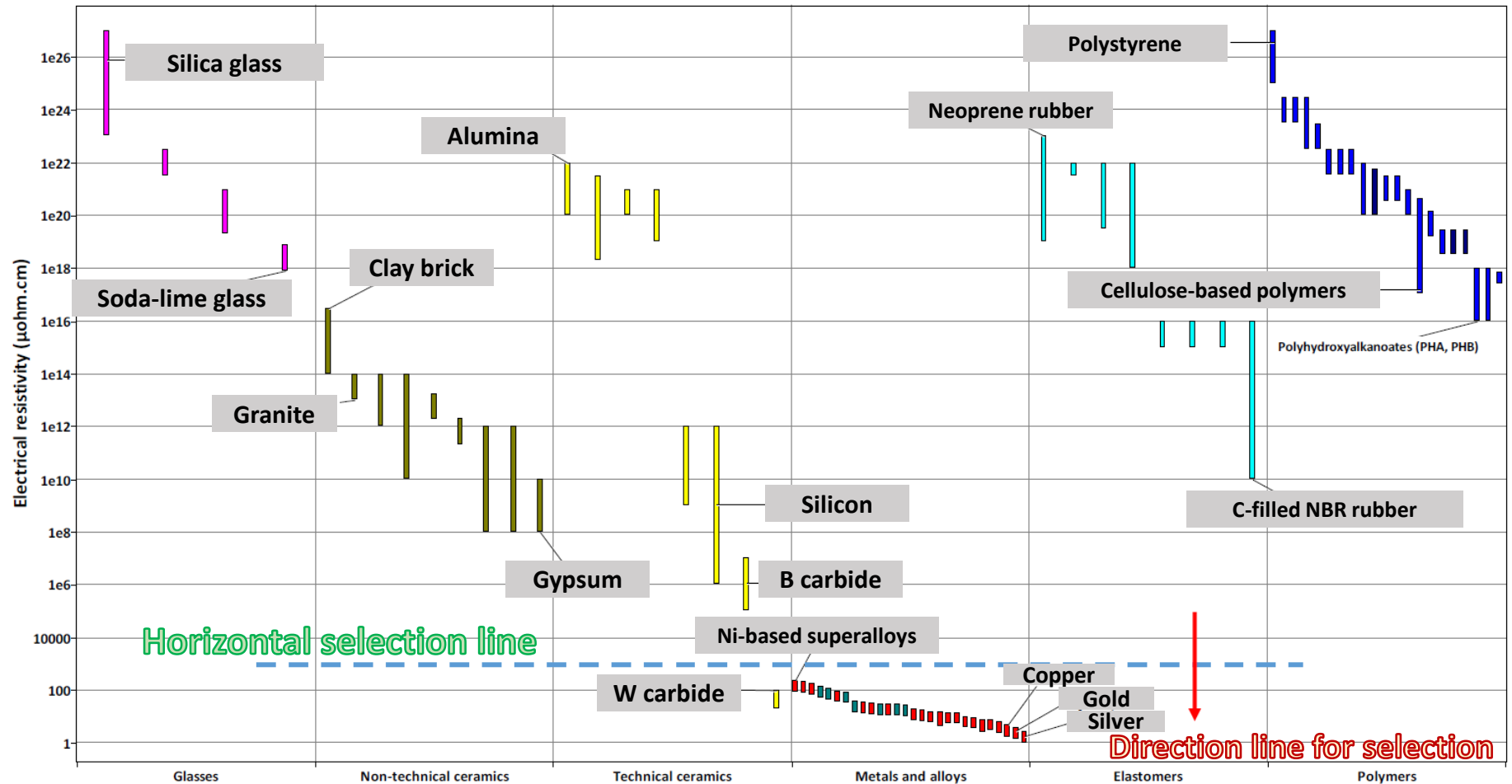


CFRP
(forks: CFRP)

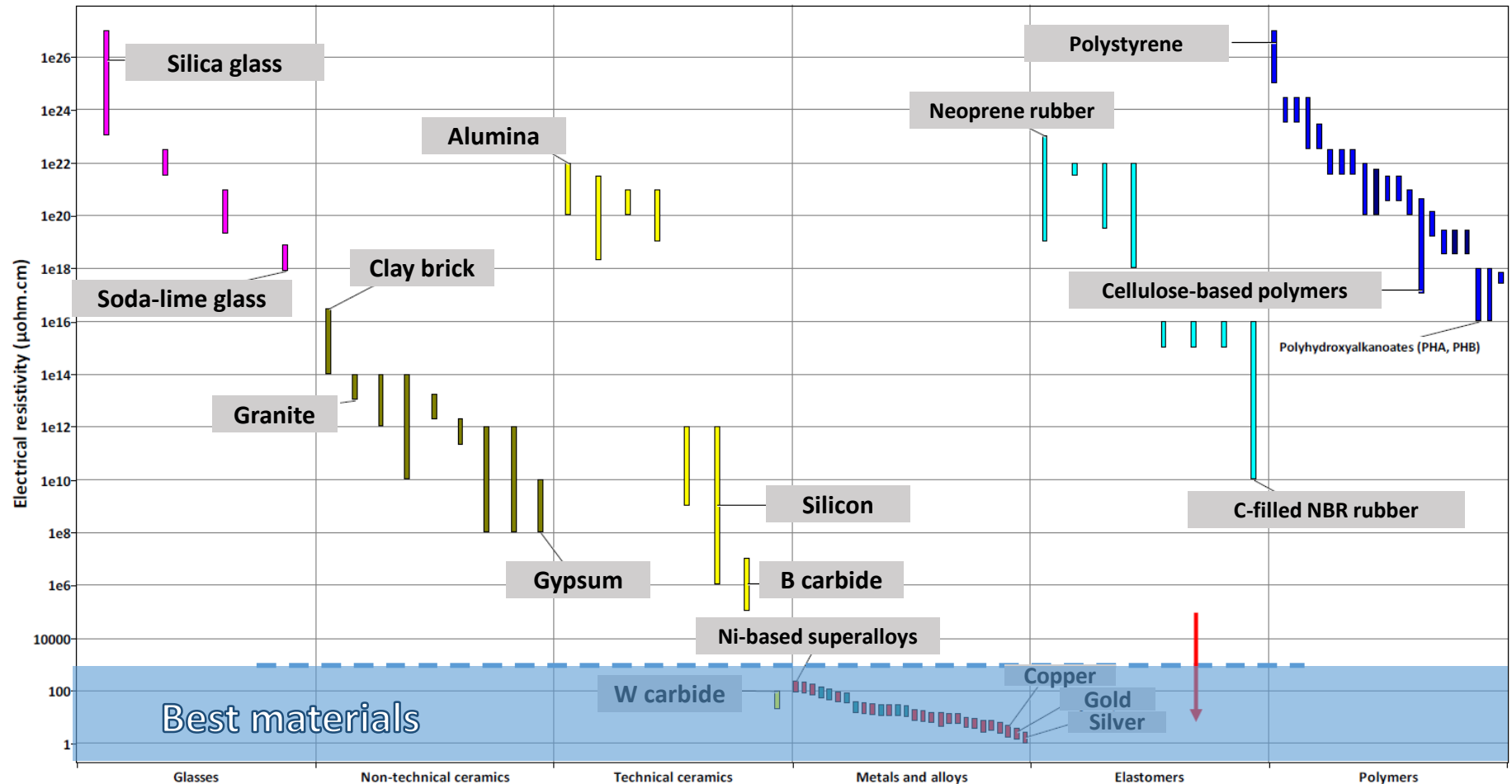
Graphical selection by means of **Cambridge Engineering Selector** [CES] (monoproperty graph): **materials for electrical conductors**



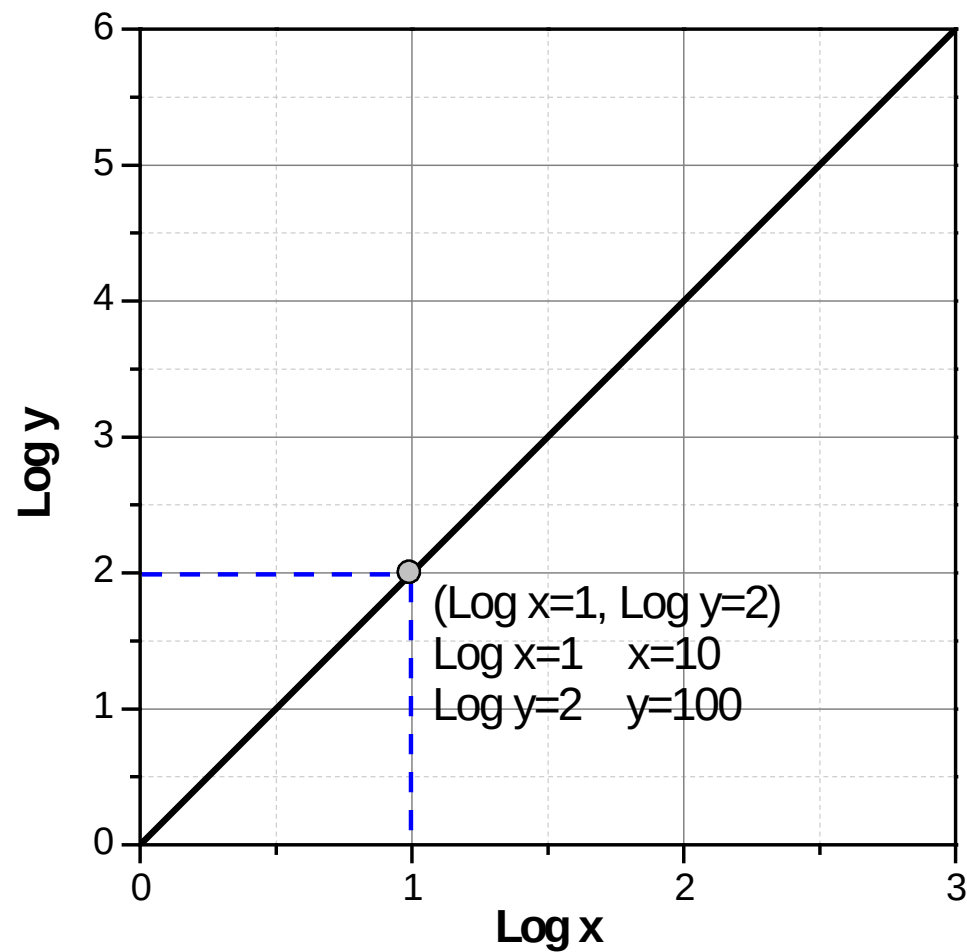
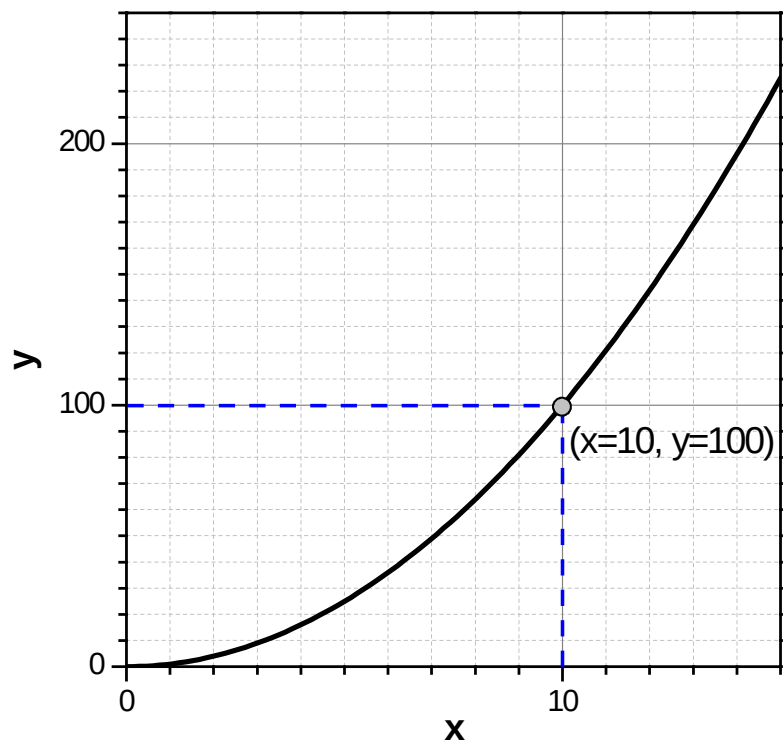
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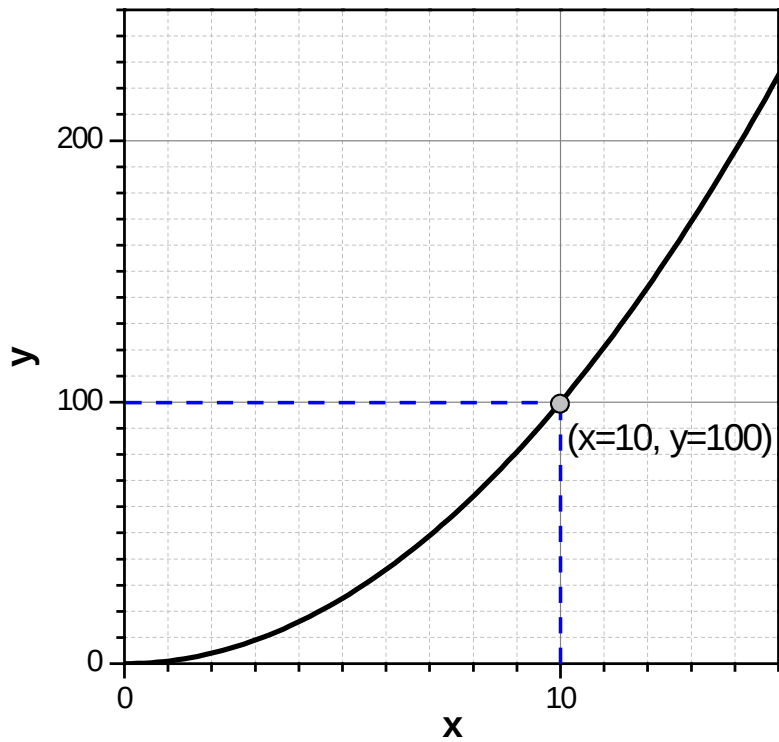
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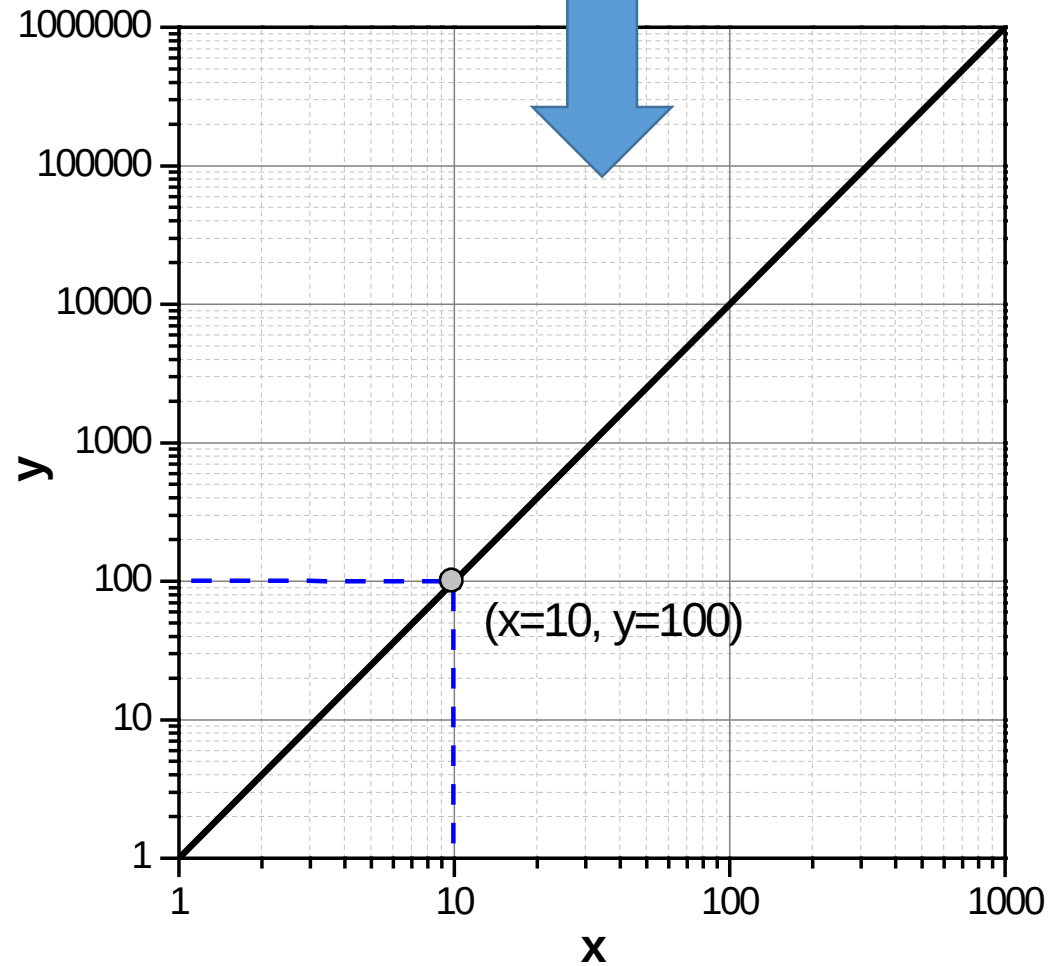
‘Dual-property’ graphs: **mind the scales!**

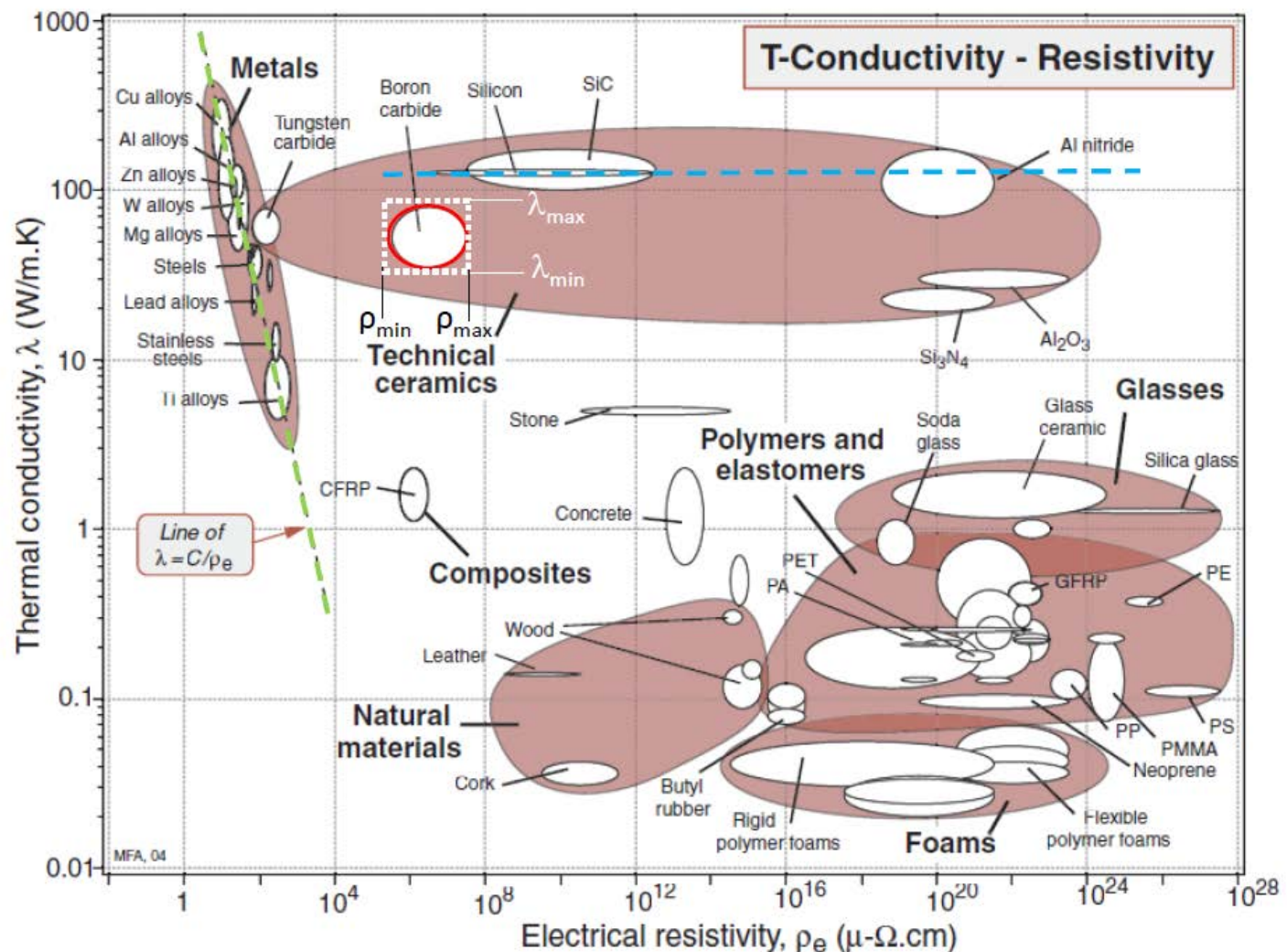


'Dual-property' graphs: mind the scales!



Optimized representation





Metals: direct proportionality between thermal and electrical conductivity:

$$\lambda = C \cdot \sigma_e \quad [C=\text{constant}]$$

The equation can be rewritten introducing electrical resistivity:

$$\lambda = C / \rho_e$$

Again, by applying logarithms:

$$\text{Log } \lambda = \text{Log } C - \text{Log } \rho_e$$