Progettazione di Materiali e Processi

Università degli Studi di Trieste
Facoltà di Ingegneria
Corso di Laurea in Ingegneria Chimica e dei Materiali
A.A. 2021-22

PRODUCT (MATERIALS) AND PROCESS DESIGN

Intro

- Design, Product, Process
- Product Design; Process Design; Product and Process Design
- Material, process, shape, properties, function

Design process

- Example
- Fundamentals
- Identification of needs (market; coevolution; true need)
- Types of design
- **Design tools**
  - **Databases**
  - **Analytical tools**
  - Simulation tools

- **Selection and design of materials and processes**
  - **Tools for optimal systematic selection**
  - Design of materials: case studies (nano, meso, microstructures; hybrid materials; composites)
- **Design and optimization of chemical processes**
- **Advanced tools and methods** (ad-hoc lectures and seminars: FEM, product/process economics, Life Cycle Assessment, …)
- **Special topic seminars** (Intellectual Property, product evaluation, materials in industrial design, theory of scenarios, rapid plant assessment, material selection in engines, design for recycle, refurbish, reuse)

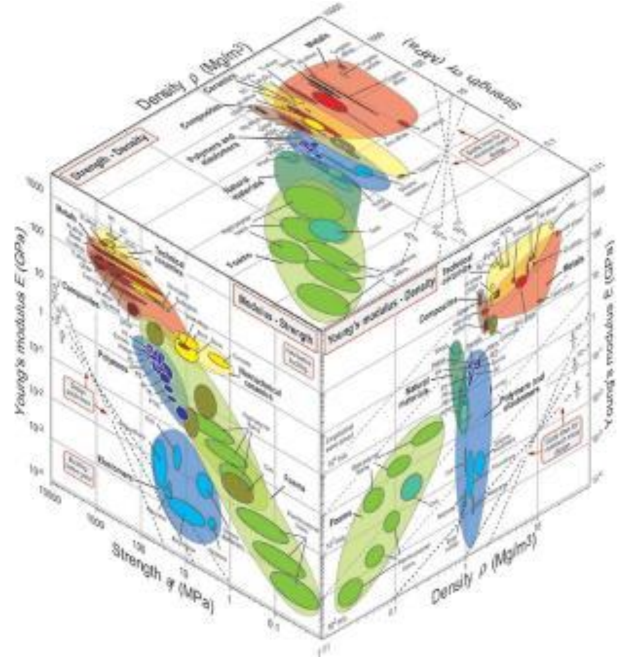
Progettazione di Materiali e Processi

Modulo 1
Selezione sistematica di materiali e processi

Lezione 1

- Strategia di selezione
- Database di materiali e processi

In this lecture…



- Selection strategy
- Review of important material properties
- Types of materials data
- Organizing a materials database
- Example of materials data table
- Representing materials properties (tables; 1D, 2D, 3D graphs)
- Selection tools:
    - Table comparison
    - Screening: 1D, 2D, multi-D (limit tool); simple property, multiproperity
    - Objective-driven: material index (examples)

The selection strategy

Selection (and design) of materials

Selection and Design of materials and processes:

- Dynamic
- An opportunity
- From euristic to systematic
- Interconnection with shape, function, properties

OUR GOAL: Design-led materials selection

The selection strategy: cars (function: ...?)

What do I want from a car?

Requirements
expressed as
Constraints *and*
Objectives

- Mid size family saloon
- 4 doors
- 200 + horse power
- *Least cost of ownership*

Data:
Performance
Economy
What car? rating

- Make and Model
- Dimensions
- Number of doors
- Power
- Fuel consumption
- CO2 rating ……

Comparison engine
- Screening
- Ranking
- Documentation

- Delivery time
- Service frequency
- Nearest dealer
- Warranty

The selection strategy: materials

Design requirements:
expressed as
Constraints *and*
Objectives

Data:
Material attributes
Process attributes
Documentation

- **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

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

Final selection

Translation

Translation: *"express design requirements as constraints and objectives"*

Design requirements

Constraints

What essential conditions must it meet ?

- ***Be strong enough***
- ***Conduct electricity***
- ***Tolerate 250 C***
- ***Be able to be cast***

Objectives

What measure of performance is to be maximized or minimized ?

- ***Mass***
- ***Volume***
- ***Eco-impact***
- ***Cost***

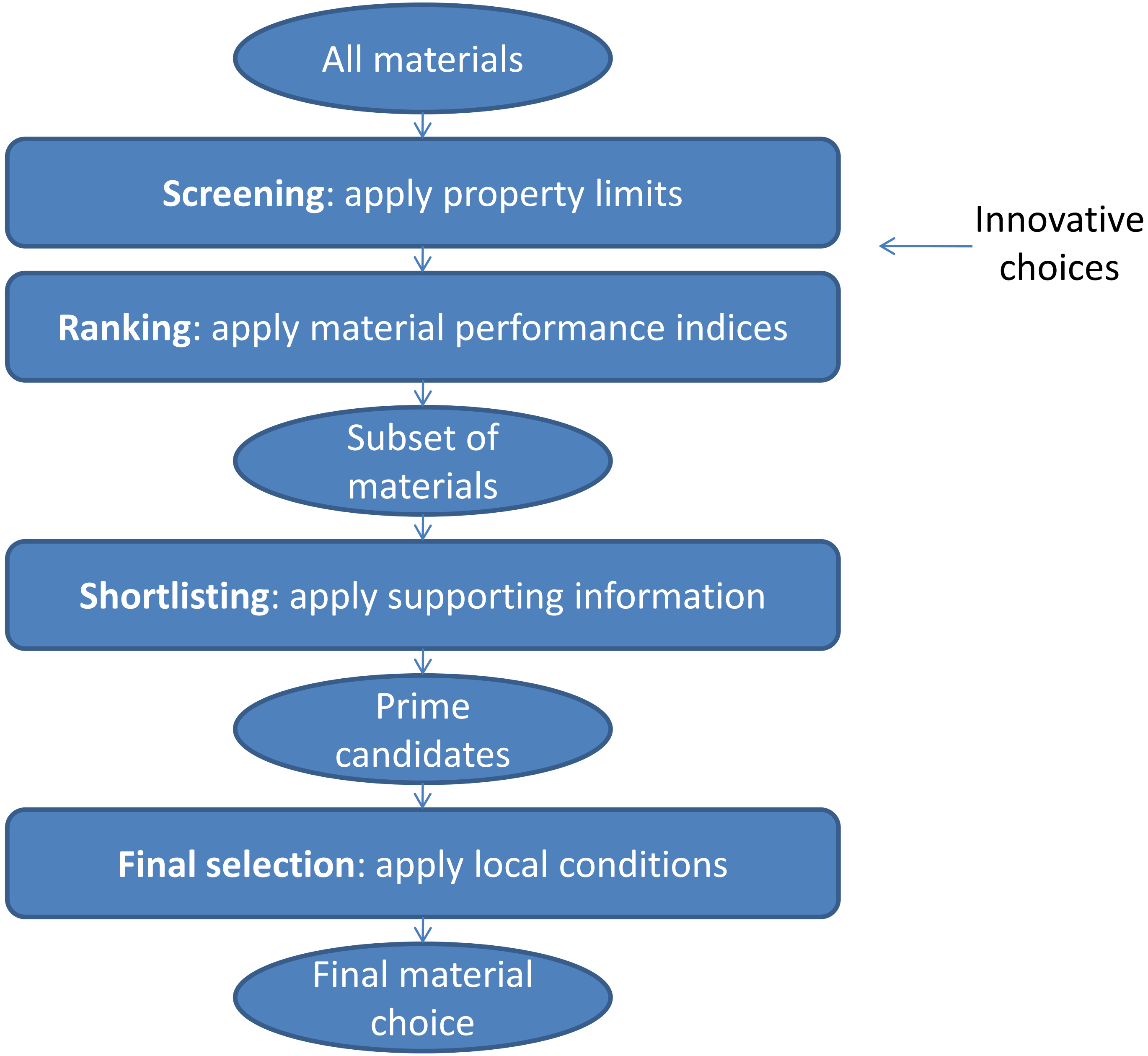
Screening: *"use constraints to eliminate materials that can't do the job"*

Function – Objectives - Constraints

Function	**What does the component do?** e.g.: support load, seal, transmit heat, bycicle fork, etc.
Objective	**What do we want to maximize (minimize)?** e.g.: minimize cost, maximize energy storage, minimize weight, etc.
Constraints	**What conditions must be met?** (non-negotiable or negotiable) e.g. geometry, resist a certain load, resist a certain environment, etc.

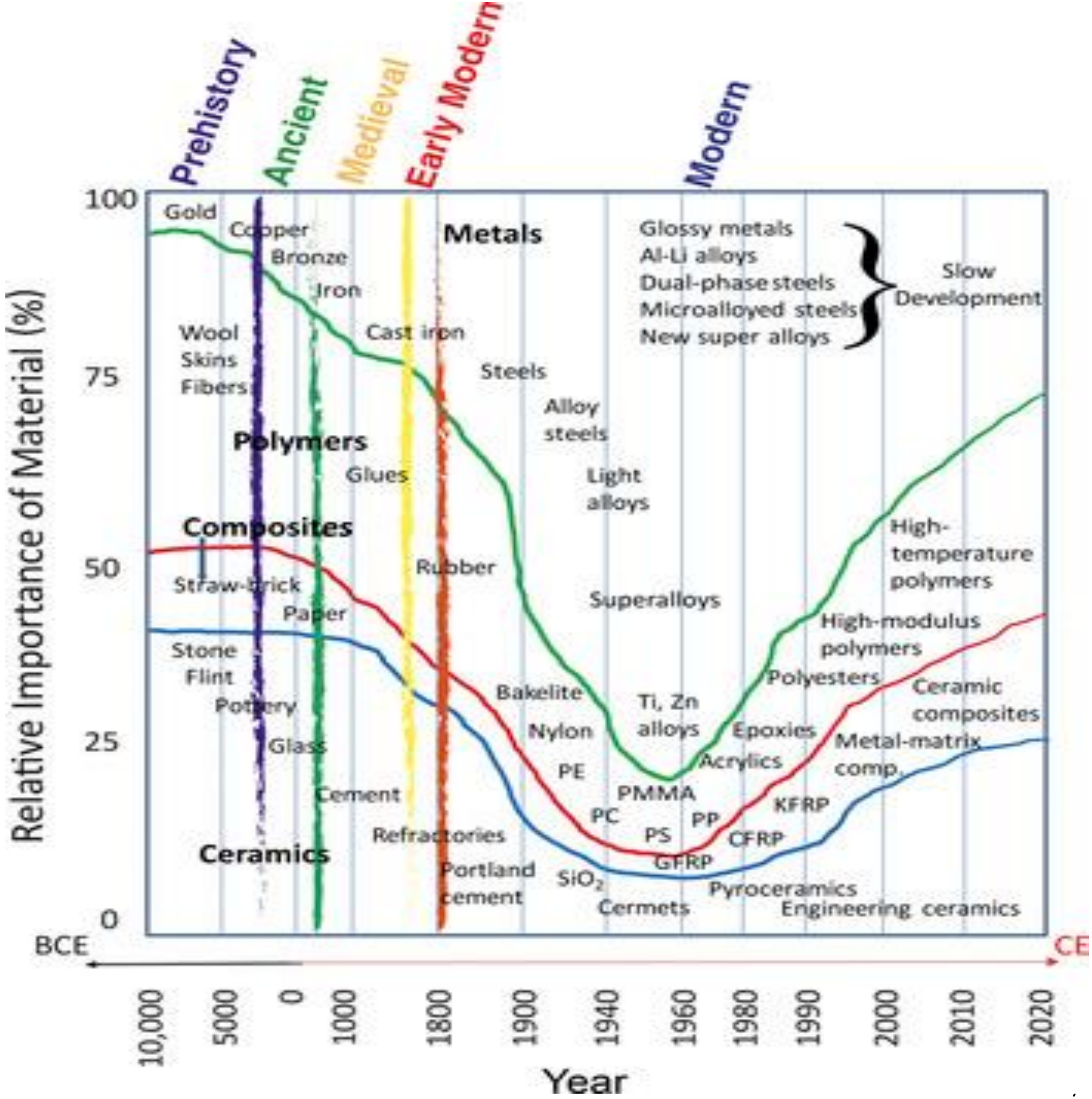
- Some functions are implicitly understood (e.g. tie, beam, shaft, column)
- Constraints often translate to property limits (temperature, conductivity, cost, …)
- Some constraints are more complex (e.g. stiffness, strength, etc.) as they are coupled with geometry -> need of a specific objective
- **Material indices** help unravel such complexity

The selection process

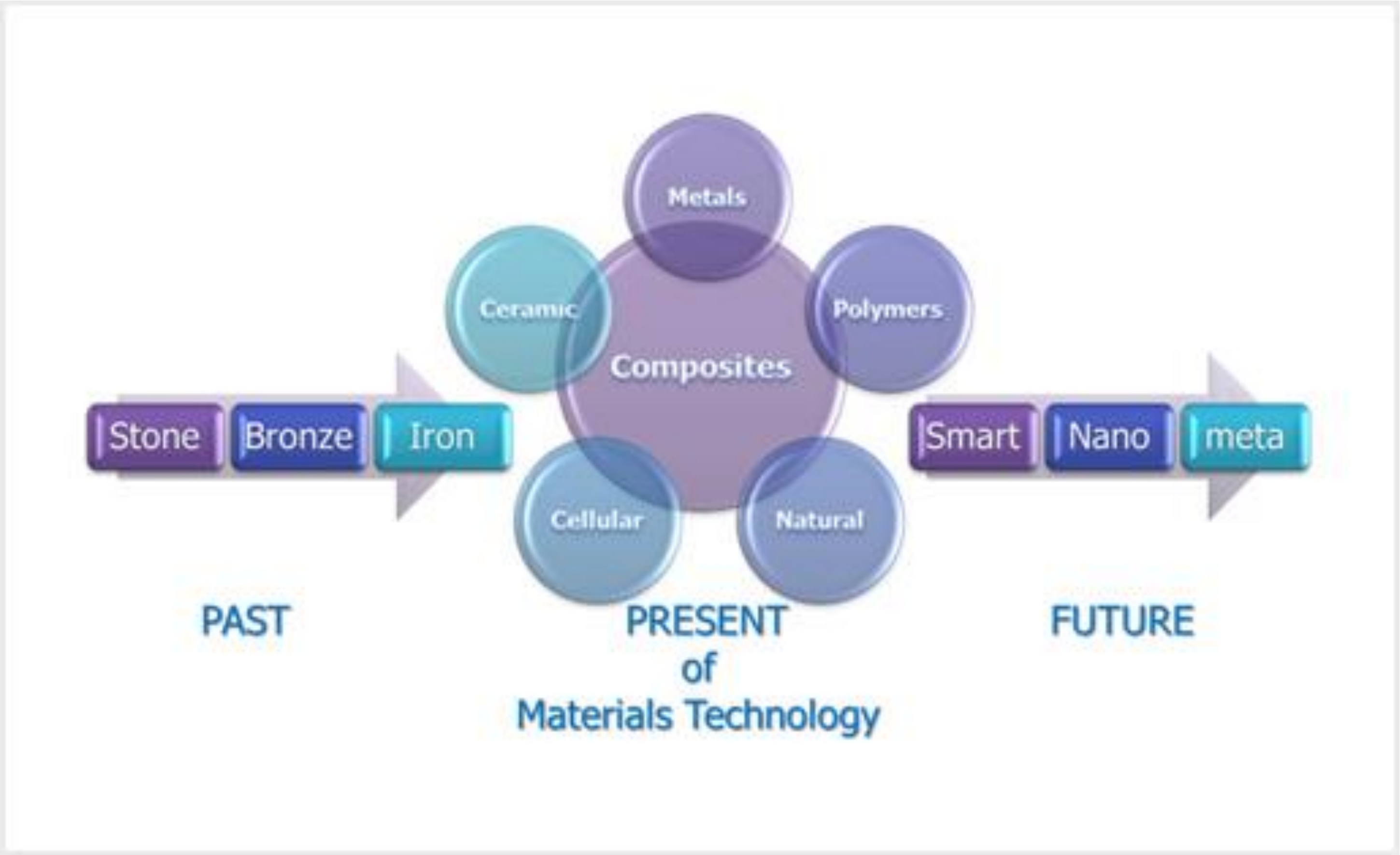


Databases for materials and processes

Evolution of Materials



Evolution of Materials

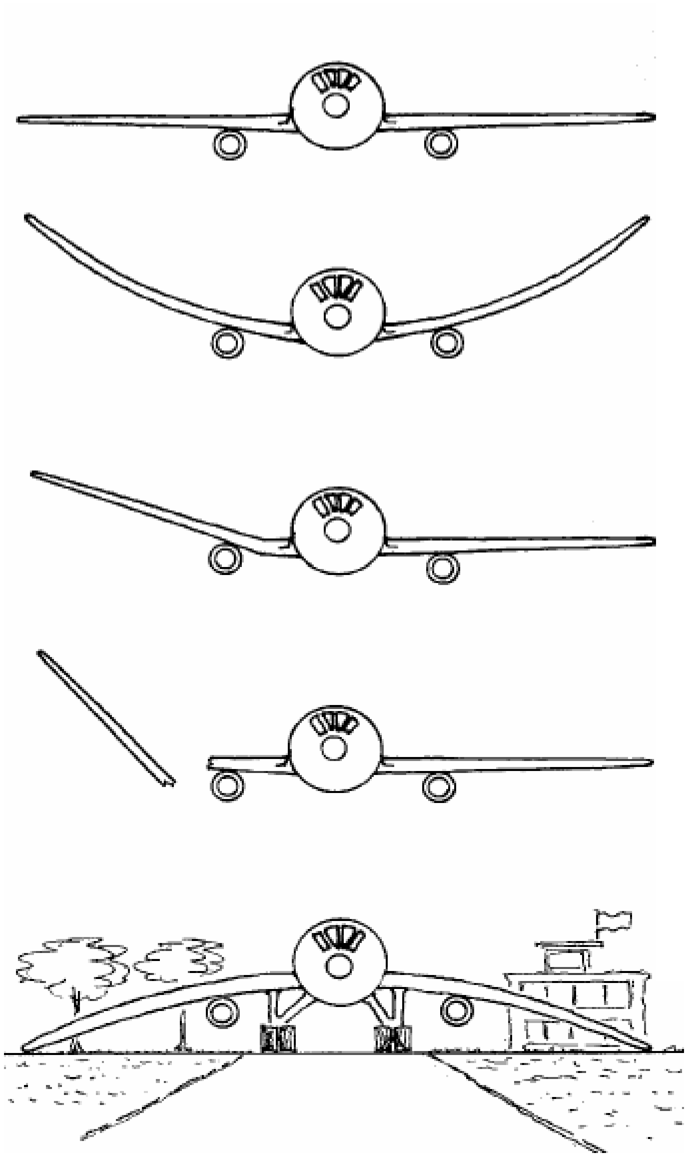


www.atoastech.com/materials_technology.htm Sept 2011

Material properties

Class	Property	Order of magnitude
General	Cost	€/kg, €/m^3
	Density	
Mechanical	Elastic moduli (Young, Shear, Bulk)	
	Strenght (yield, ultimate, fracture, MOR)	
	Resilience	
	Hardness	
	Fracture Toughness	
	Damping (Loss coefficient)	
	Fatigue limit	
Thermal	Thermal conductivity	
	Thermal diffusivity	
	Specific heat	
	Melting point	
	Glass temperature	
	Thermal expansion coefficient	
	Creep resistance	
Wear	Wear constant	
Corrosion	Corrosion rate	
Oxidation	Parabolic rate constant	

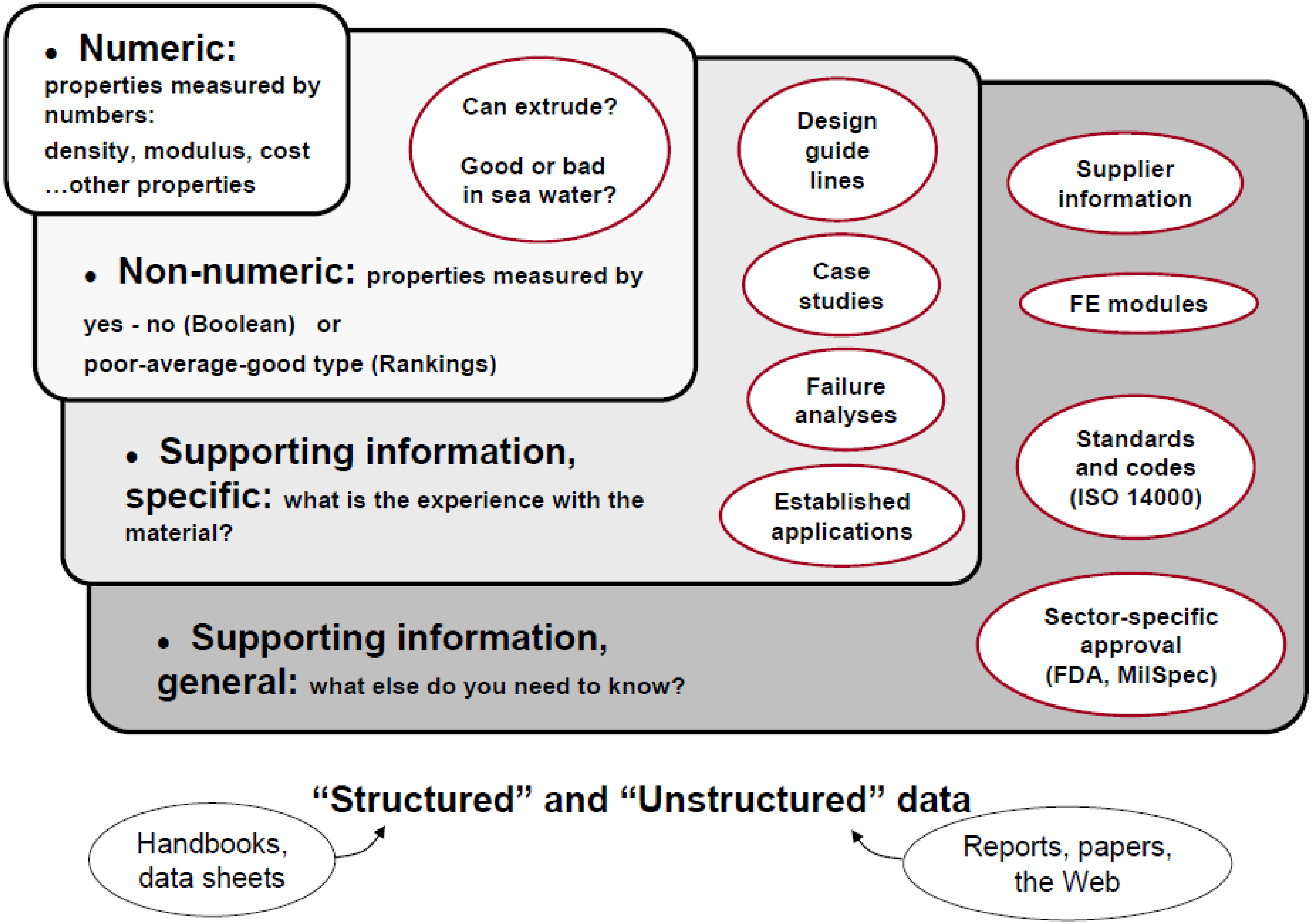
Mechanical Properties



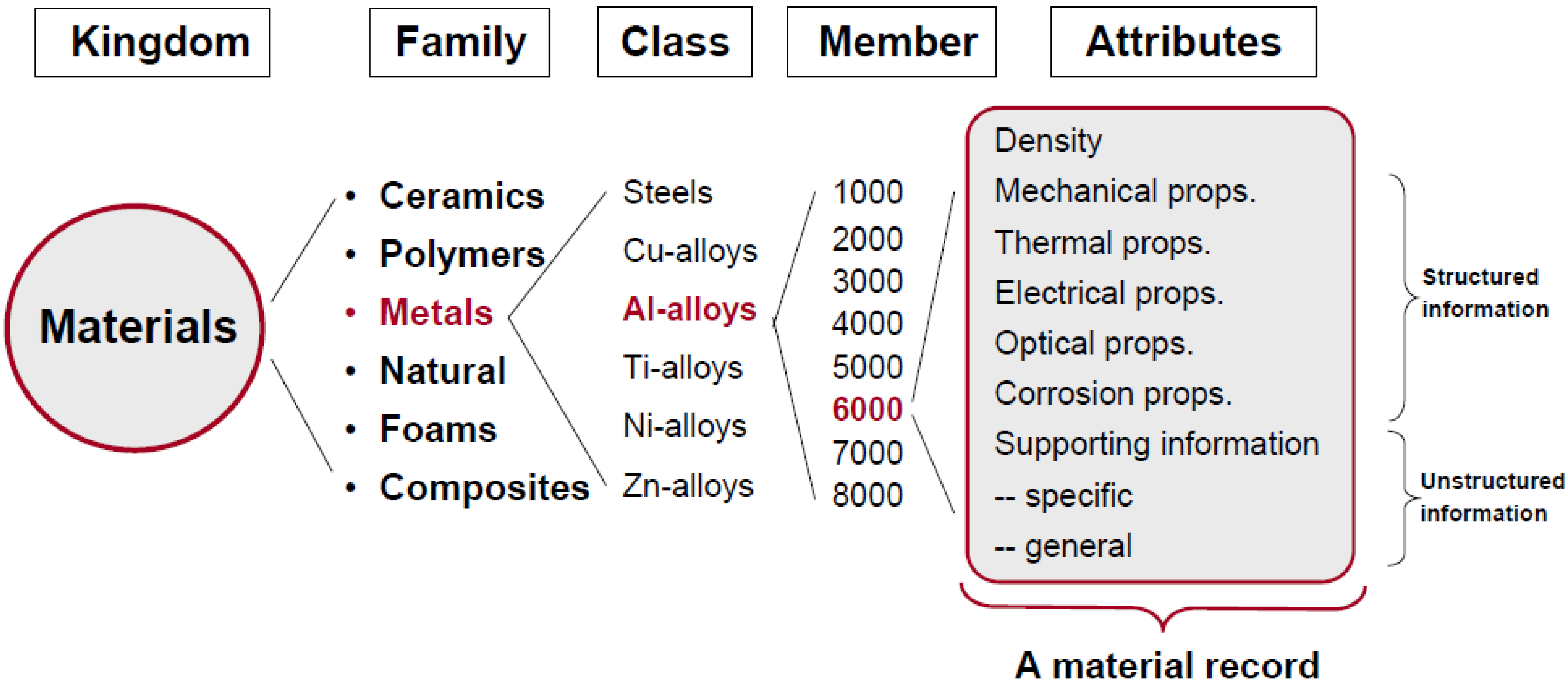
Material Properties

Class	Property	Order of magnitude
General	Cost	€/kg, €/m^3
	Density	0.1 – 20 10^3 kg/m^3
Mechanical	Elastic moduli (Young, Shear, Bulk)	0.01 – 1000 GPa
	Strenght (yield, ultimate, fracture, MOR)	up to 2000 MPa
	Resilience	up to MPa
	Hardness	H (MPa) ~ $3\sigma_f$ Hv (kg mm^{-2}) = H/10
	Fracture Toughness	0.1 – 300 MPa m$^{0.5}$
	Damping (Loss coefficient)	10^{-6} - 10
	Fatigue limit	up to 600 MPa
Thermal	Thermal conductivity	0.02 – 1000 W/m K
	Thermal diffusivity	5 10^{-8} – 5 10^{-3} m^2/s
	Specific heat	10^3 J/kg K
	Melting point	20 – 4300 °C
	Glass temperature	-70 – 220 °C (polymers); 150 – 1200 °C (glasses)
	Thermal expansion coefficient	1 - 500 μm/m K
	Creep resistance	
Wear	Wear constant	
Corrosion	Corrosion rate	
Oxidation	Parabolic rate constant	

Materials Data



Materials Data



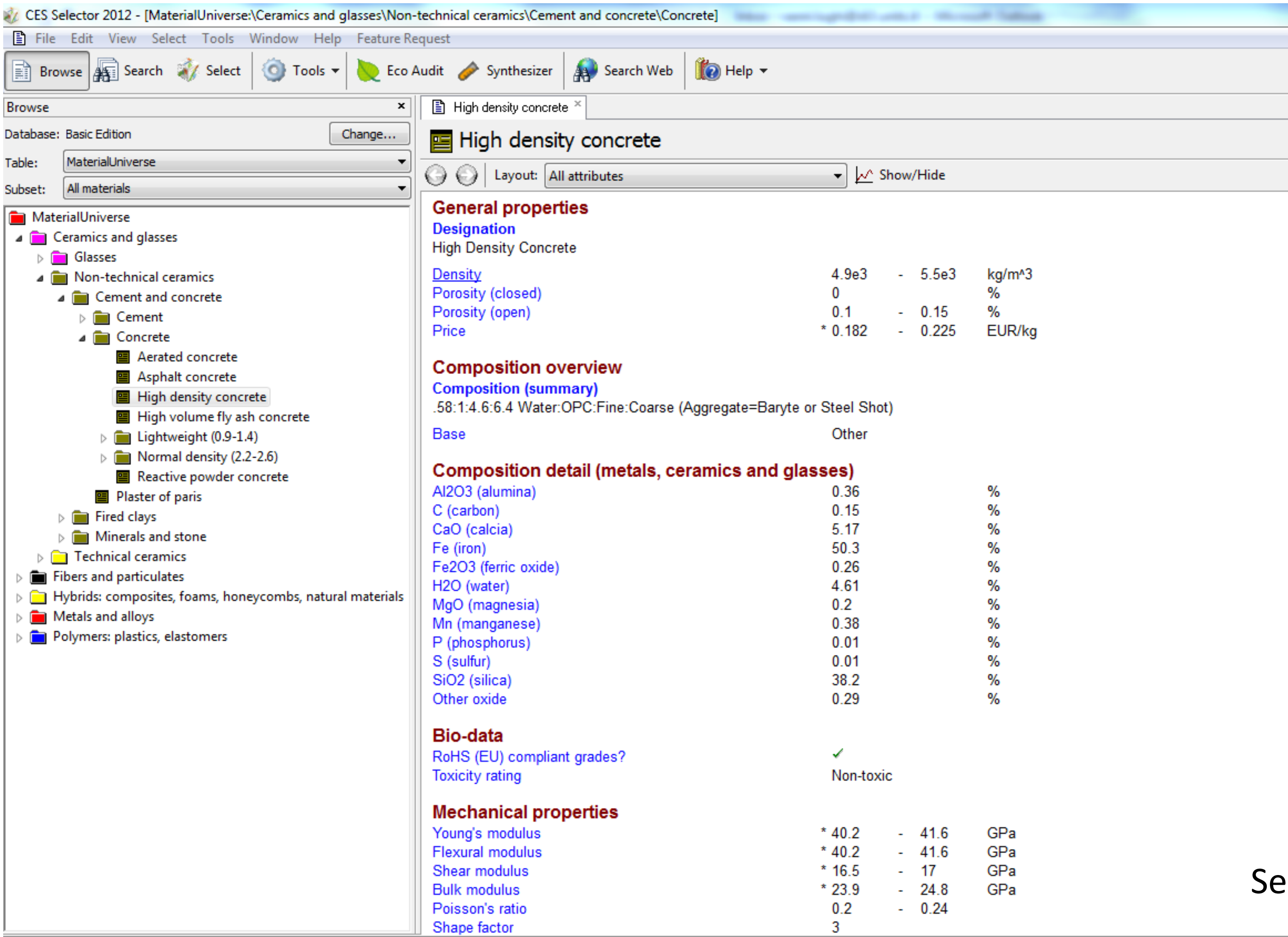
Some Material Databases

- Maptis
- **NIST**
- **CES**
- Matweb
- **Matbase**
- Matnavi (NIMS)
- Some more, application specific

- Datasheet

Materials Data

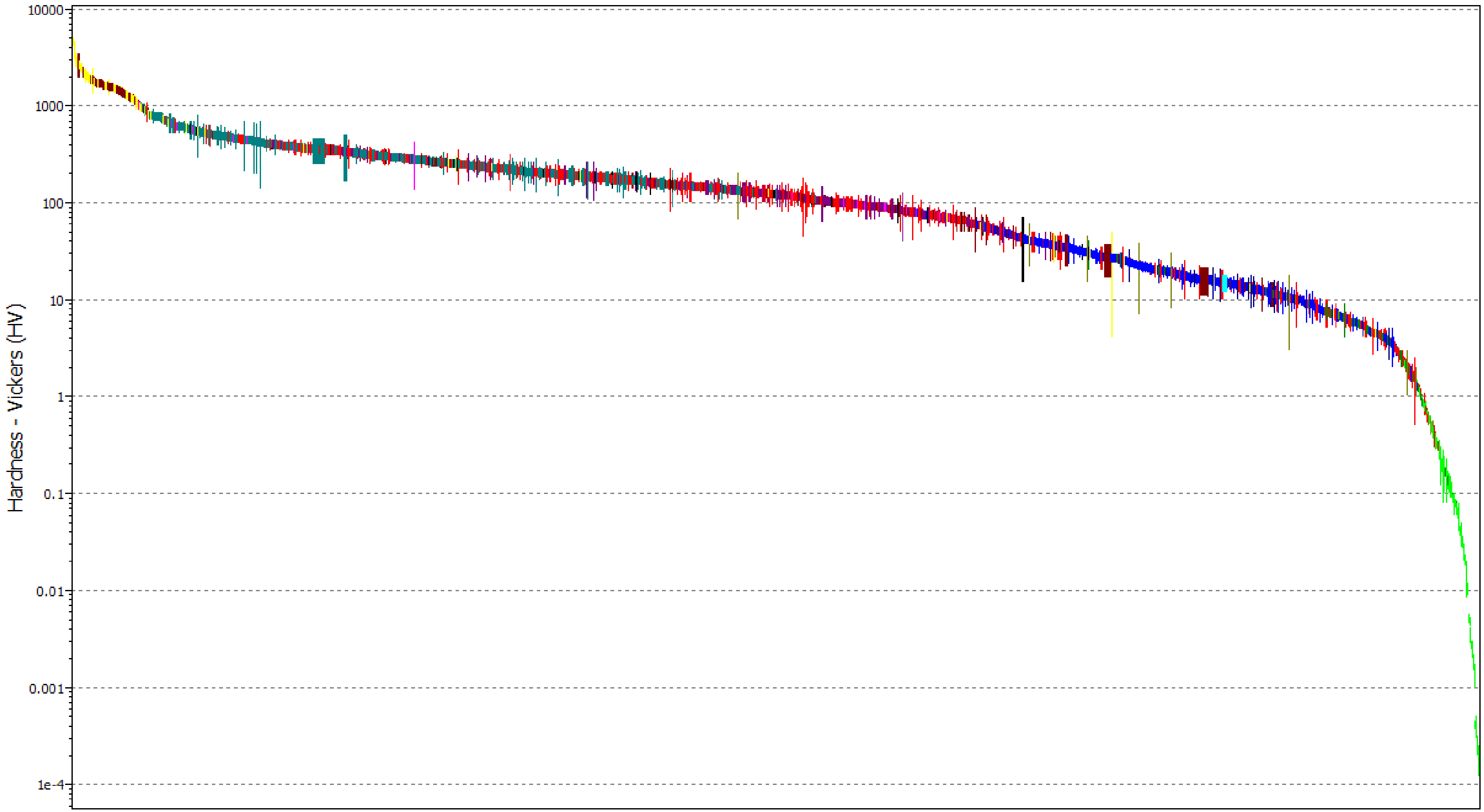
Example of material property table



See CES

Materials Data

Example of single property graph



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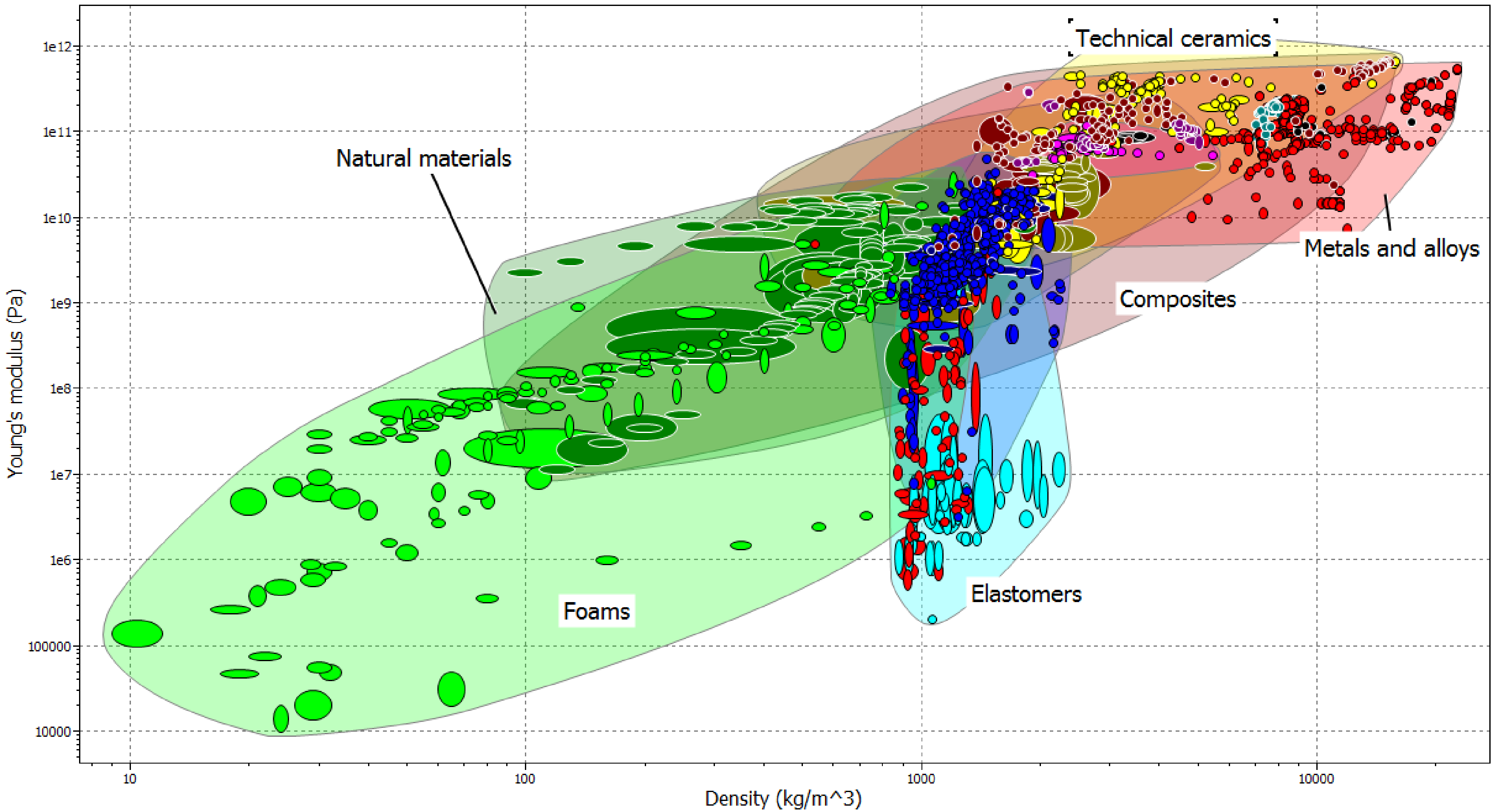
Materials Data

Examples of two-property graph



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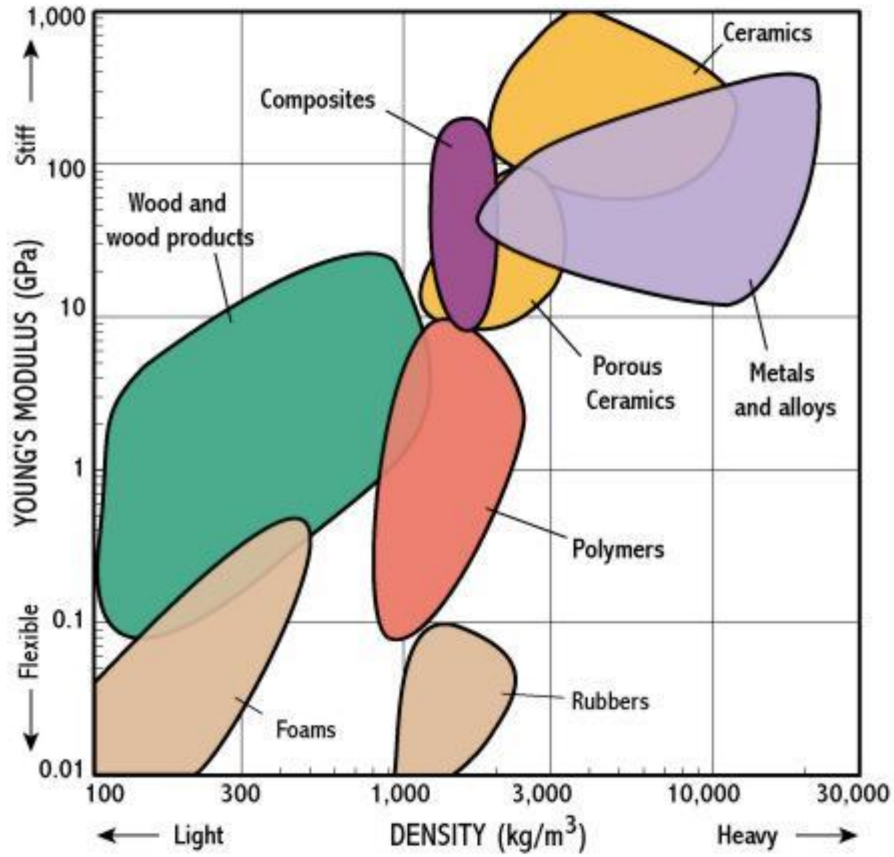
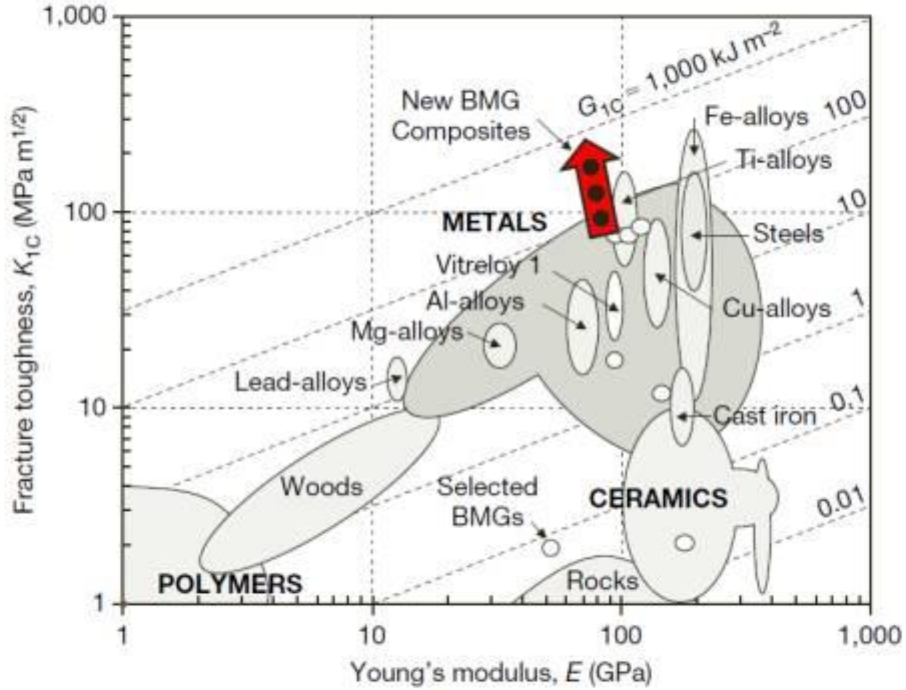
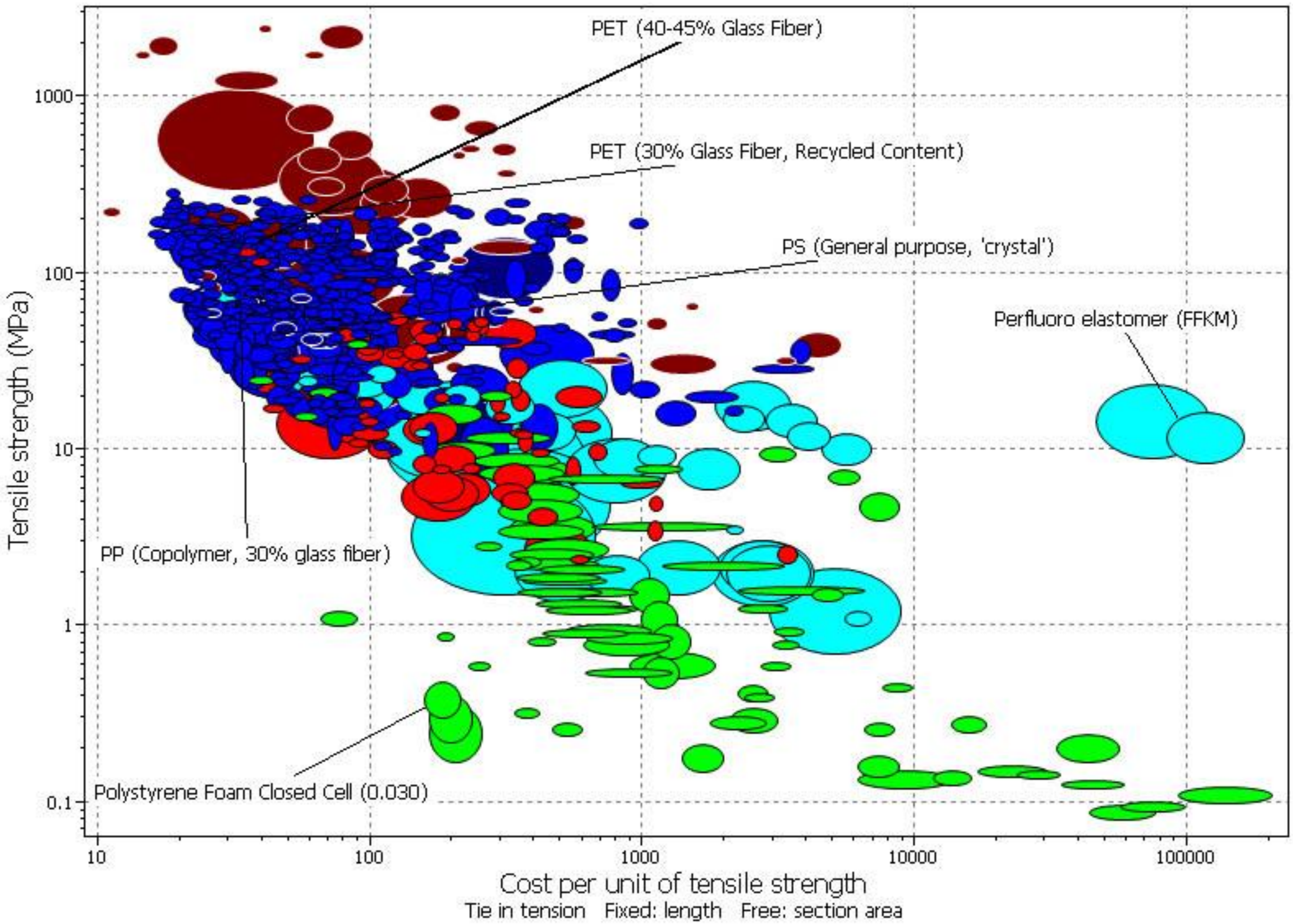
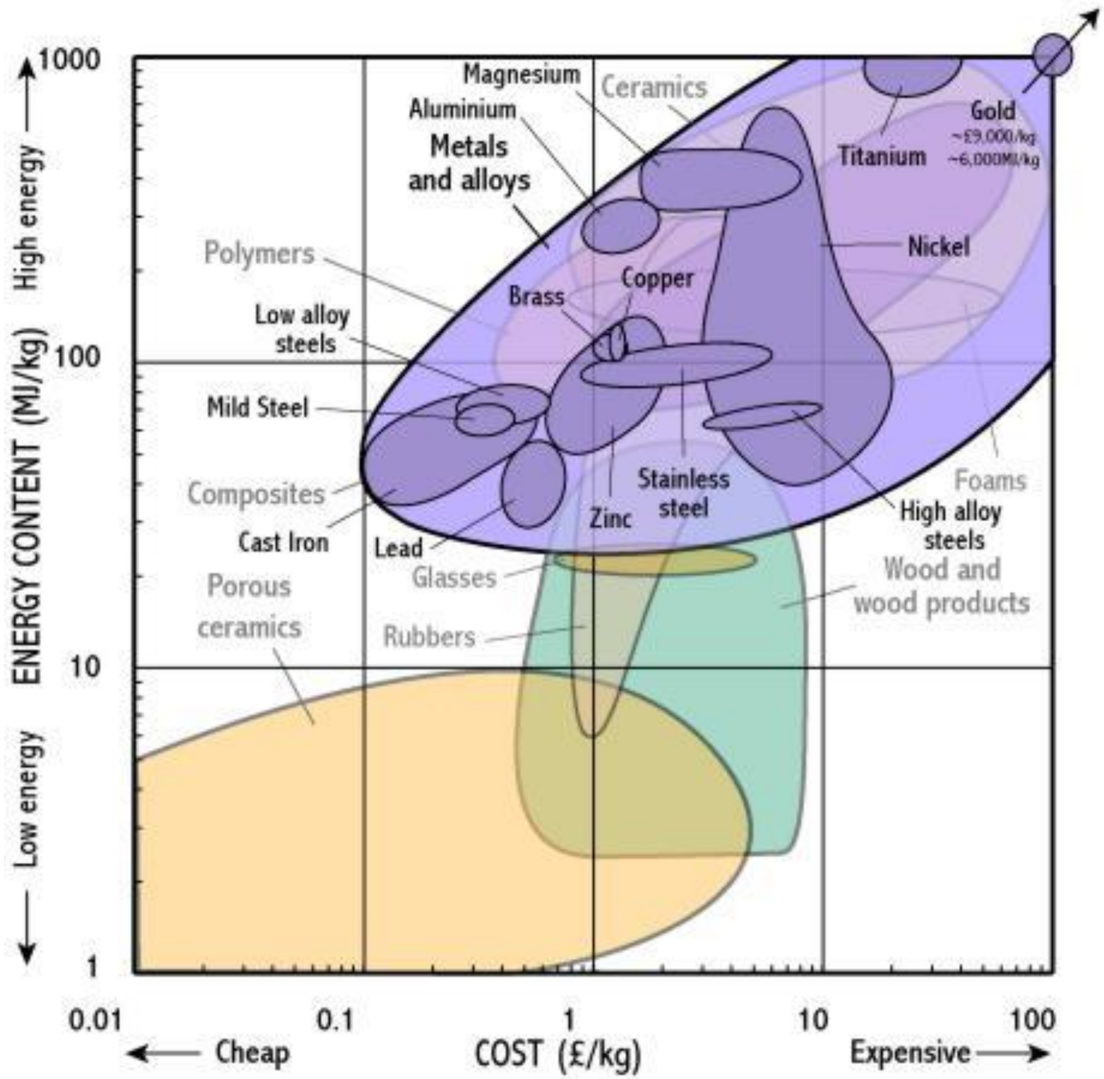


1,000
100
10
1
0.1
0.01
Stiff
Flexible
YOUNG'S MODULUS (GPa)
Ceramics
Composites
Wood and
wood products
Porous
Ceramics
Metals
and alloys
Polymers
Rubbers
Foams
100
300
1,000
3,000
10,000
30,000
Light
DENSITY (kg/m3)
Heavy

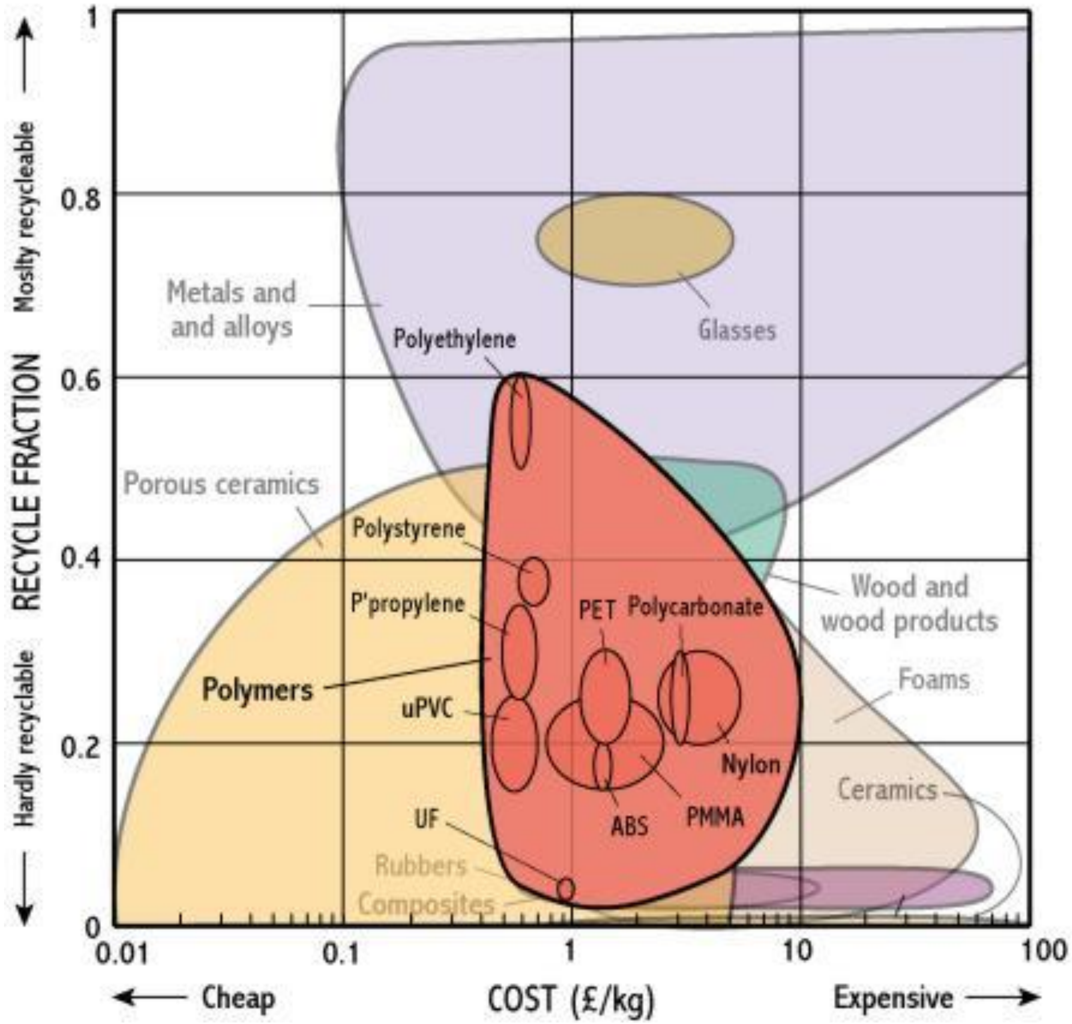


New BMG Composites
G_{1C} = 1,000 kJ m^{-2}
100
10
1
0.1
0.01
Fe-alloys
Ti-alloys
Steels
Cu-alloys
Cast iron
METALS
Vitreloy 1
Al-alloys
Mg-alloys
Lead-alloys
Woods
Selected BMGs
CERAMICS
Rocks
POLYMERS
Fracture toughness, K_{1C} (MPa m$^{1/2}$)
Young's modulus, E (GPa)
1
10
100
1,000


PET (40-45% Glass Fiber)
PET (30% Glass Fiber, Recycled Content)
PS (General purpose, 'crystal')
Perfluoro elastomer (FFKM)
PP (Copolymer, 30% glass fiber)
Polystyrene Foam Closed Cell (0.030)
Tensile strength (MPa)
1000
100
10
1
0.1
10
100
1000
10000
100000
Cost per unit of tensile strength
Tie in tension Fixed: length Free: section area



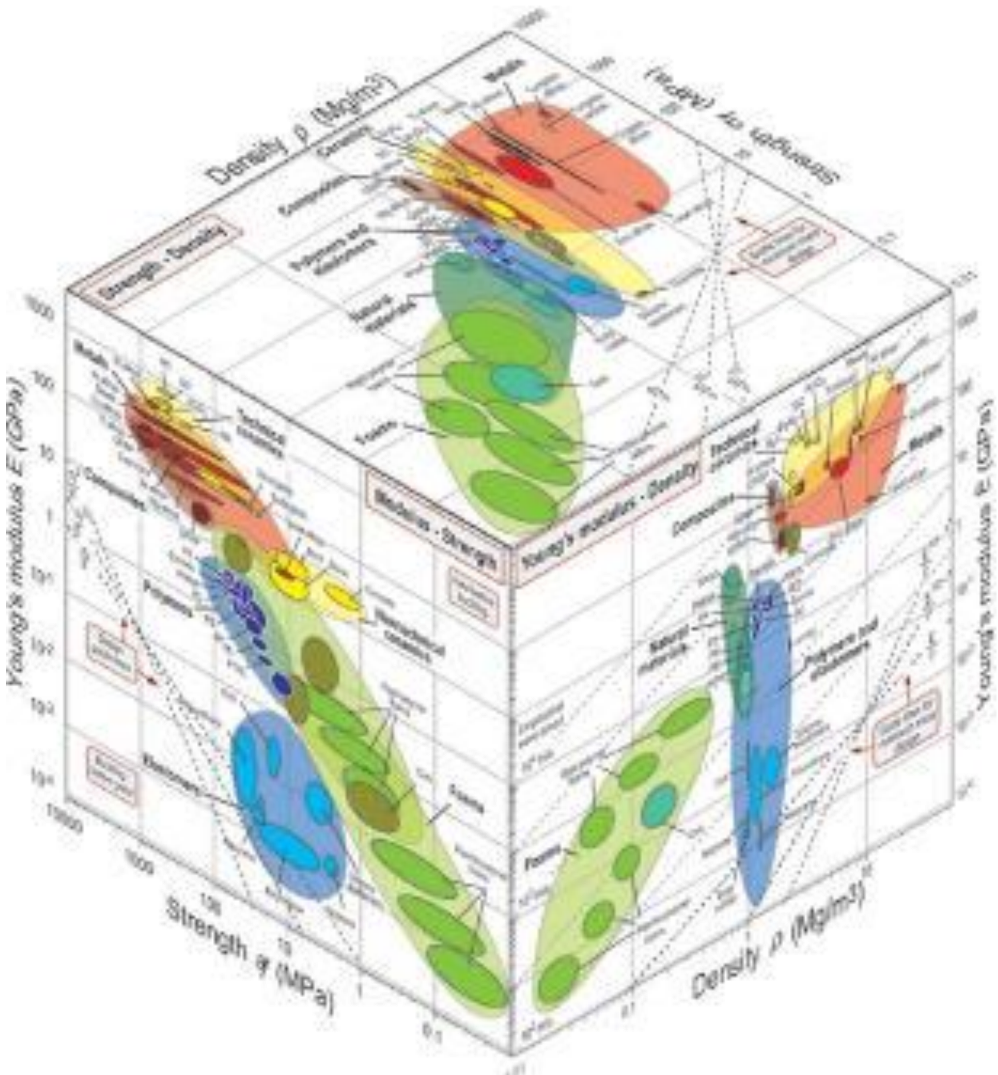
1000
100
10
1
0.01
0.1
1
10
100
High energy
Low energy
ENERGY CONTENT (MJ/kg)
Cheap
COST (£/kg)
Expensive
Magnesium
Ceramics
Aluminium
Metals
and alloys
Gold
~£9,000/kg
~6,000MJ/kg
Titanium
Polymers
Nickel
Brass
Copper
Low alloy
steels
Mild Steel
Composites
Cast Iron
Lead
Zinc
Stainless
steel
Foams
High alloy
steels
Glasses
Wood and
wood products
Porous
ceramics
Rubbers



Mosity recycleable
RECYCLE FRACTION
Hardly recyclable
1
0.8
0.6
0.4
0.2
0
0.01
0.1
1
10
100
Cheap
COST (£/kg)
Expensive
Metals and
and alloys
Polyethylene
Glasses
Porous ceramics
Polystyrene
P'propylene
Polymers
uPVC
UF
Rubbers
Composites
PET
Polycarbonate
Wood and
wood products
Foams
Nylon
Ceramics
ABS
PMMA

Materials Data

Example of three-property graph



Selection tools

Example of comparison table

Comparison - MaterialUniverse

All Data | Project Data | Ranges | Averages | #. Values | % Change | Highlight % Change > 10 | Apply

	Concrete (normal (Portland cement))	High density concrete	Aerated concrete	Concrete (high performance)
General properties				
Density (kg/m^3)	2200 - 2600	4900 - 5500 ↑	400 - 900 ↓	2200 - 2600
Porosity (closed) (%)	0	0	0	0
Porosity (open) (%)	0,1 - 0,15	0,1 - 0,15	0,53 - 0,85 ↑	0 - 0,03 ↓
Price (EUR/kg)	0,0291 - 0,0436	0,182 - 0,225 ↑	0,0436 - 0,0582	0,0582 - 0,124 ↑
Composition overview				
Base	Other	Other	Other	Other
Composition detail (metals, ceramics and glasses)				
Al2O3 (alumina) (%)	0,59	0,36 ↓	0,81 ↑	0,94 ↑
C (carbon) (%)	0	0,15 ↑	0	0
CaO (calcia) (%)	8,55	5,17 ↓	11,6 ↑	13,6 ↑
Fe (iron) (%)	0	50,3 ↑	0	0
Fe2O3 (ferric oxide) (%)	0,43	0,26 ↓	0,58 ↑	0,68 ↑
H2O (water) (%)	7,9	4,61 ↓	10,7 ↑	5,65 ↓
MgO (magnesia) (%)	0,33	0,2 ↓	0,44 ↑	0,52 ↑
Mn (manganese) (%)	0	0,38 ↑	0	0
P (phosphorus) (%)	0	0,01 ↑	0	0
S (sulfur) (%)	0	0,01 ↑	0	0
SiO2 (silica) (%)	81,7	38,2 ↓	75,2 ↓	77,9 ↓
Other oxide (%)	0,49	0,29 ↓	0,67 ↑	0,78 ↑
Bio-data				
RoHS (EU) compliant grades?	✓	✓	✓	✓
Toxicity rating	Non-toxic	Non-toxic	Non-toxic	Non-toxic
Mechanical properties				
Young's modulus (GPa)	15 - 25	40,2 - 41,6 ↑	12 - 18	32 - 43 ↑
Flexural modulus (GPa)	15 - 25	40,2 - 41,6 ↑	12 - 18	32 - 43 ↑
Shear modulus (GPa)	6,5 - 10,9	16,5 - 17 ↑	5,1 - 7,6	13,9 - 18,7 ↑
Bulk modulus (GPa)	7,1 - 11,9	23,9 - 24,8 ↑	6,3 - 9,5	15,2 - 20,5 ↑
Poisson's ratio	0,1 - 0,2	0,2 - 0,24	0,17 - 0,2	0,1 - 0,2
Shape factor	3	3	3	3
Yield strength (elastic limit) (MPa)	1 - 1,2	3,1 - 3,7 ↑	0,6 - 1,1	5,3 - 9,3 ↑
Tensile strength (MPa)	1,1 - 1,3	3,1 - 3,7 ↑	0,6 - 1,1	5,3 - 9,3 ↑
Compressive strength (MPa)	13,3 - 30	30,6 - 36,6 ↑	1,2 - 1,87 ↓	53,3 - 93,3 ↑
Flexural strength (modulus of rupture) (MPa)	1,7 - 2,4	3,7 - 4,4 ↑	0,7 - 1,3 ↓	6,4 - 11,2 ↑

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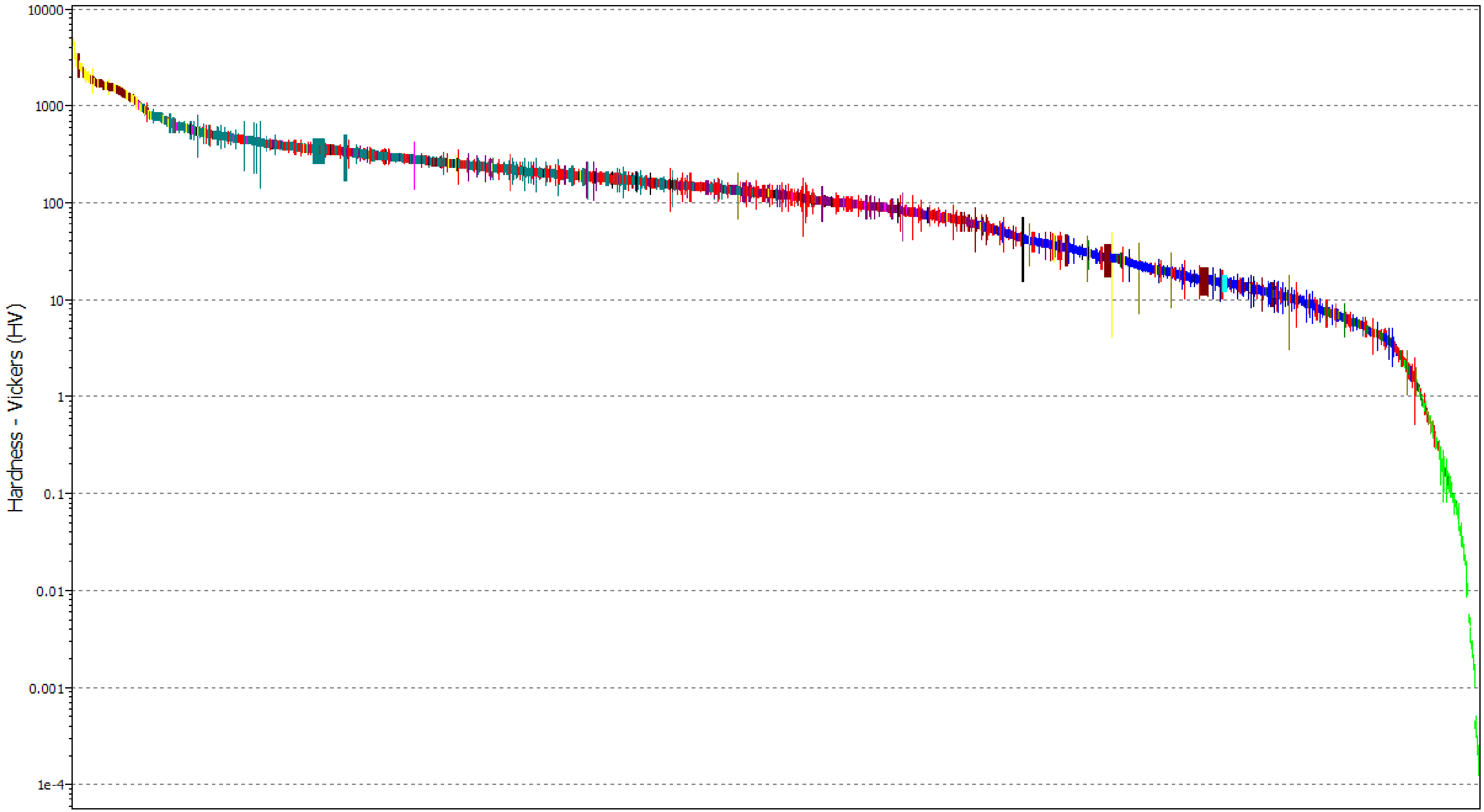
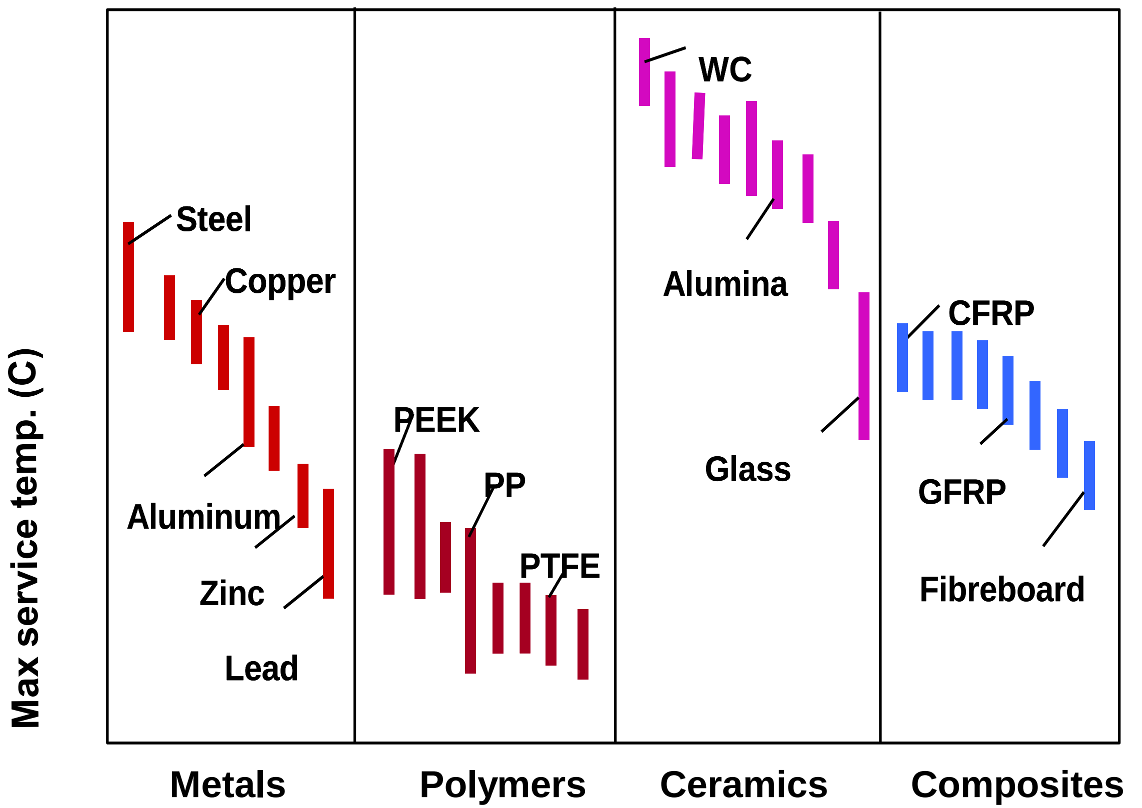
Selection tools

Using 1D graphs – 1 constraint



Selection tools

Using 1D graphs – 1 constraint



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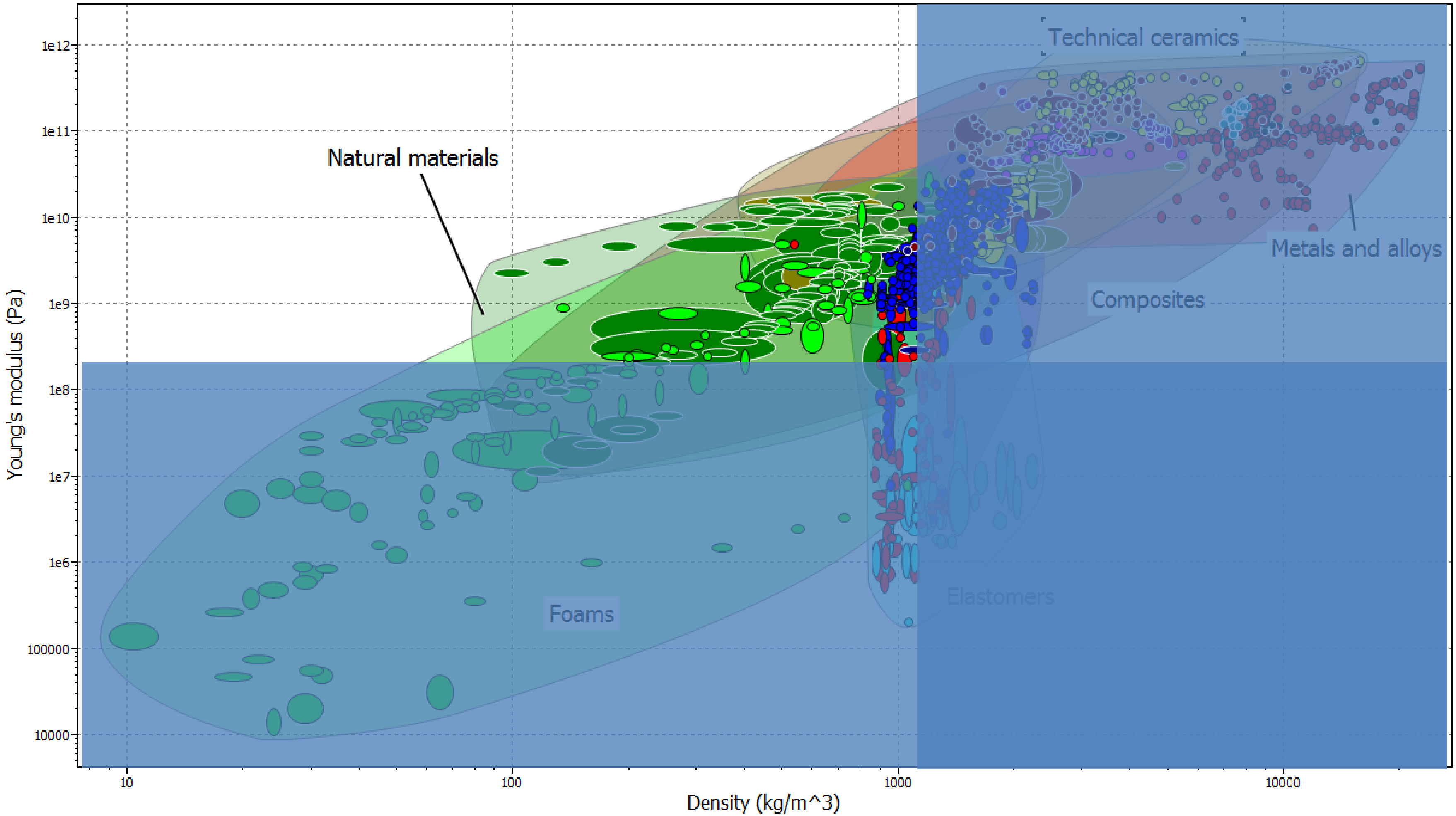
Selection tools

Using 2D graphs – 2 constraints



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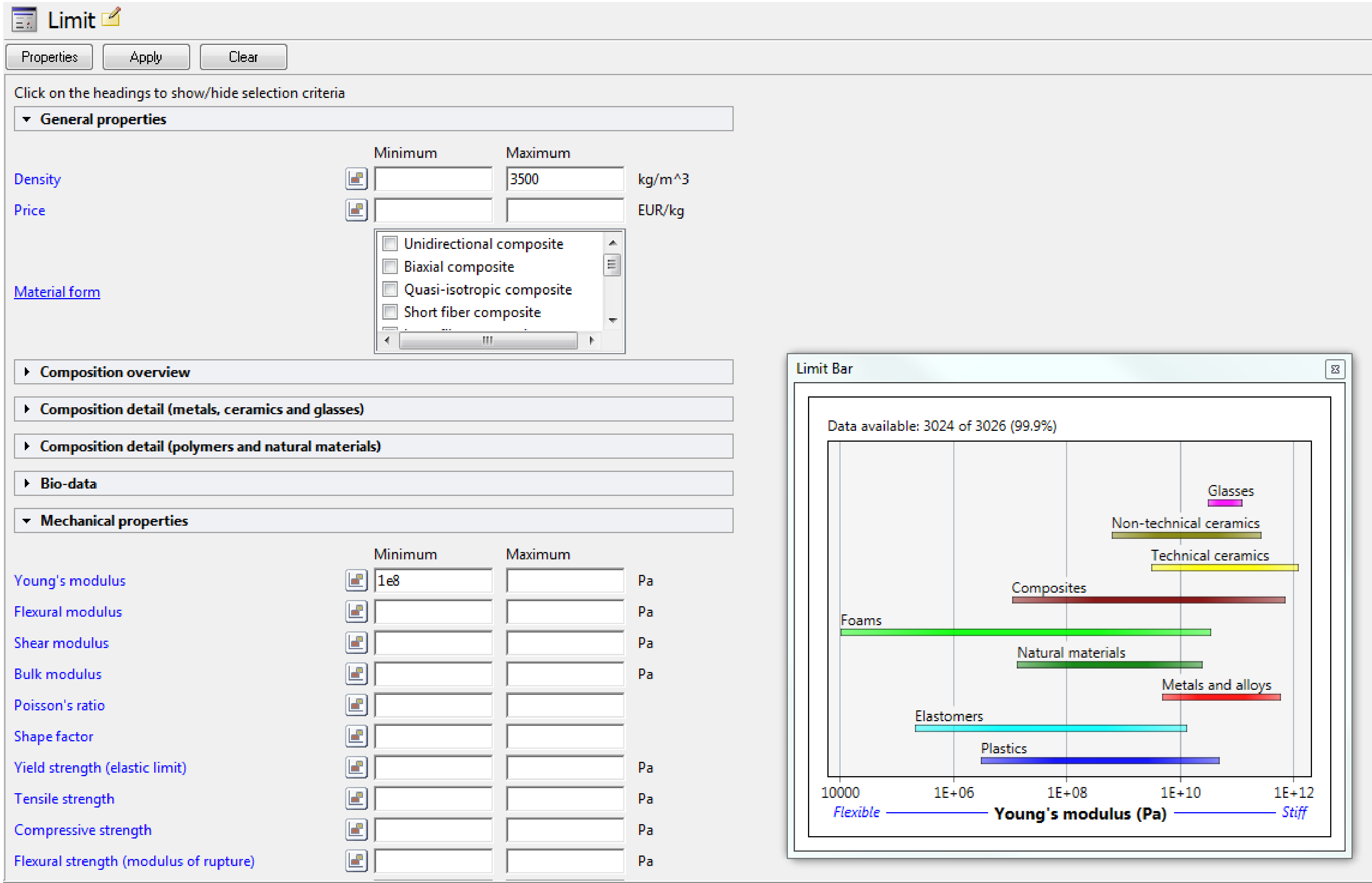
Selection tools

Using software – multiple constraints



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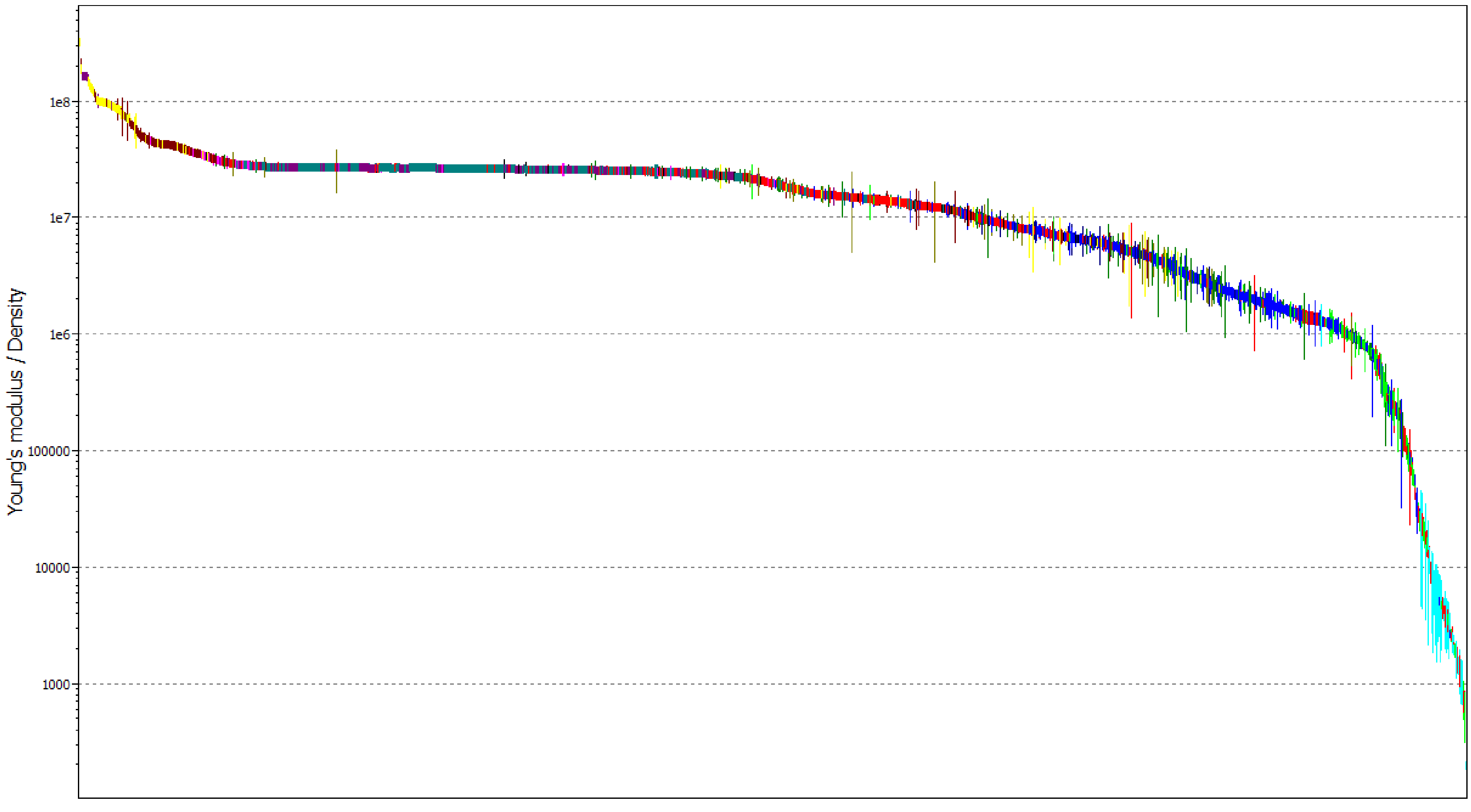
Selection tools

Using 1D graphs - multiproperty



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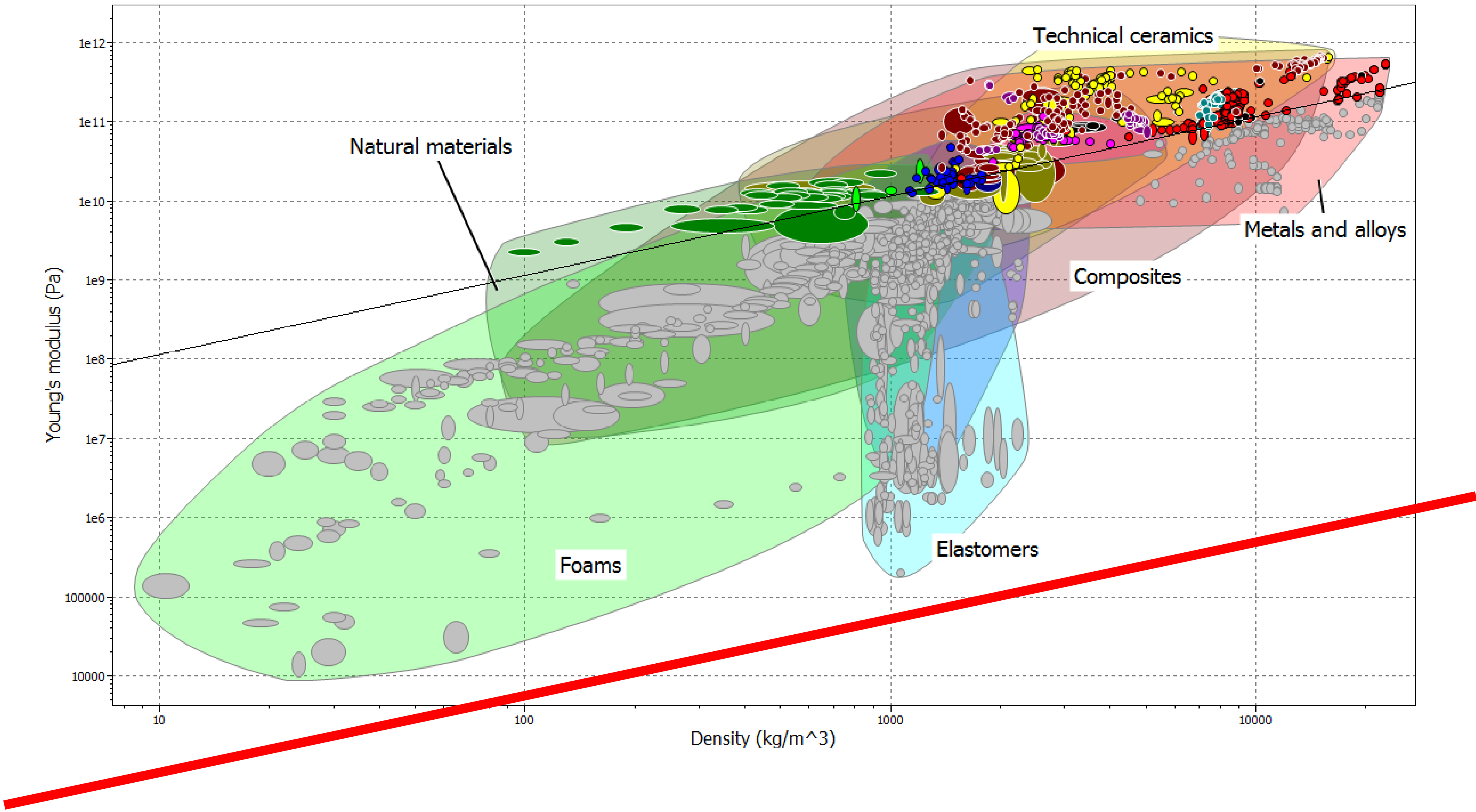
Selection tools

Using 2D graphs - multiproperty



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