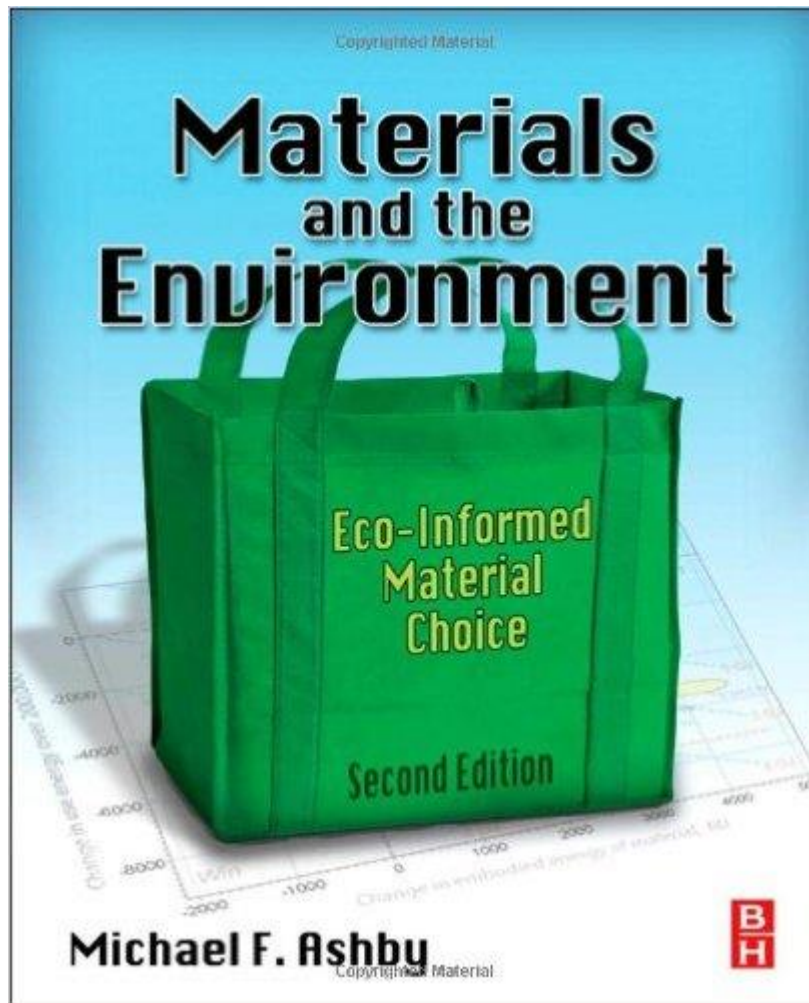




Materials Design and Selection for Circular Economy

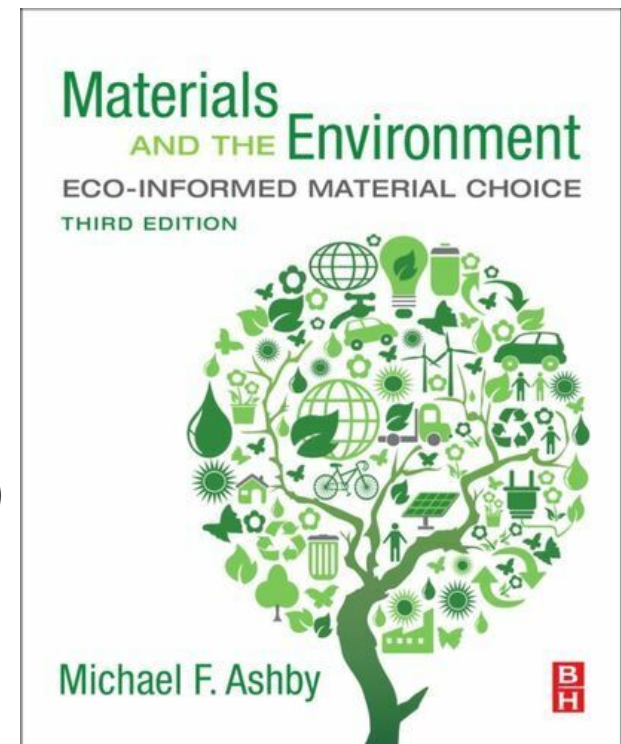
Eco-informed Materials Choice module

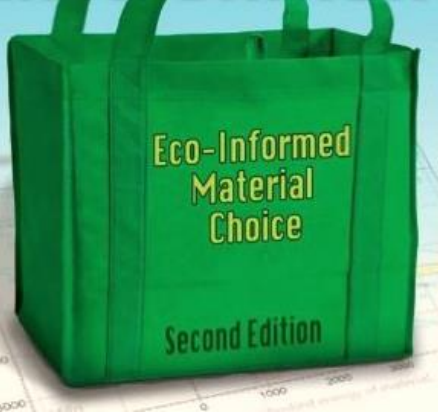
Prof. Enrico Bernardo

enrico.bernardo@unipd.it

Reference book, by Prof. Ashby (University of Cambridge, UK)
available @

<https://www.sciencedirect.com/book/9780128215210/materials-and-the-environment>





Introducing remarks



- **Availability of raw materials**
- **Key materials for industrialized society**
- **Availability of energy**
- **Energy-material correlations**

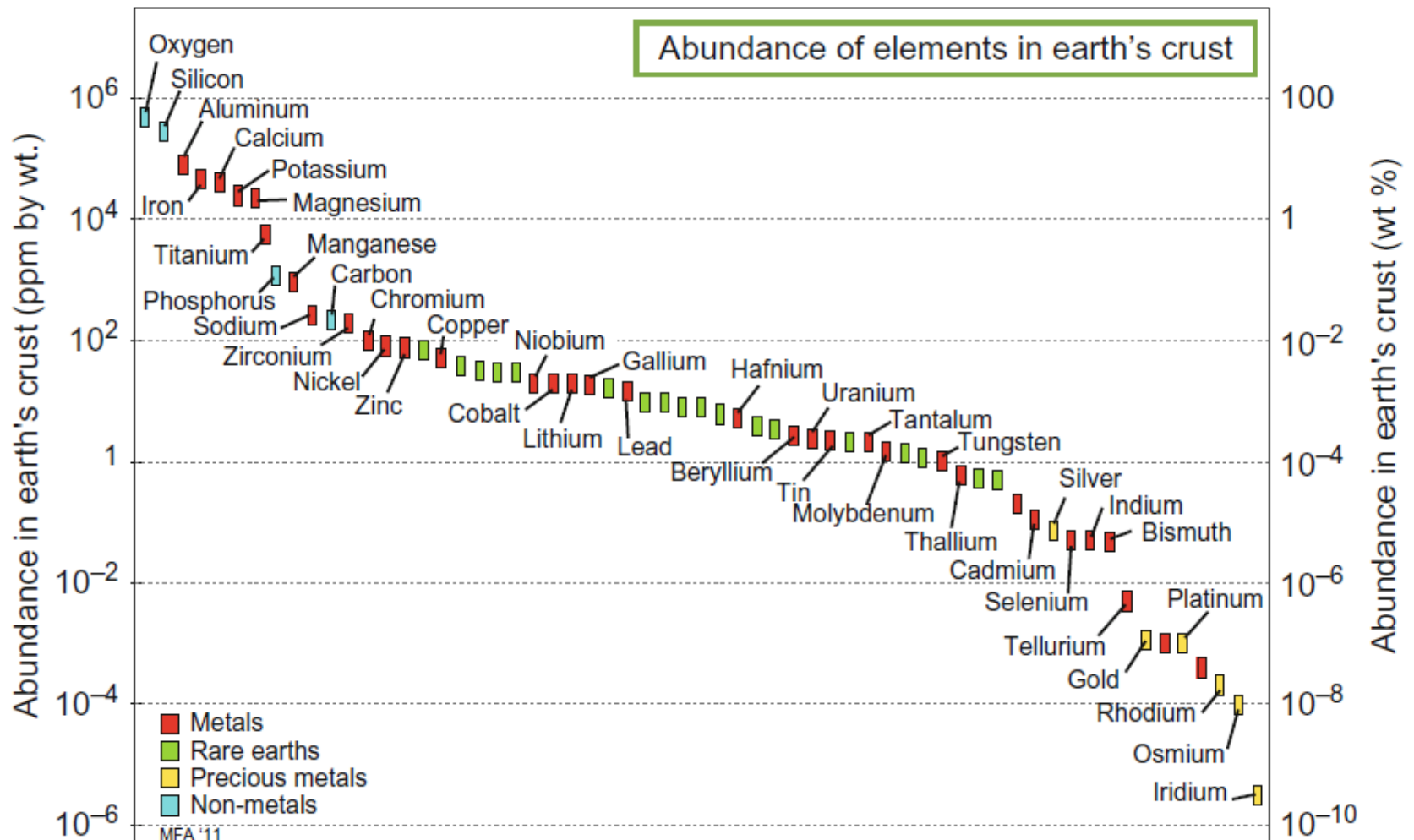


FIGURE 2.1 *The average concentration of the elements in the earth's crust, as parts-per-million (ppm) and as wt %. The top eight elements account for 98.5% of the total.*

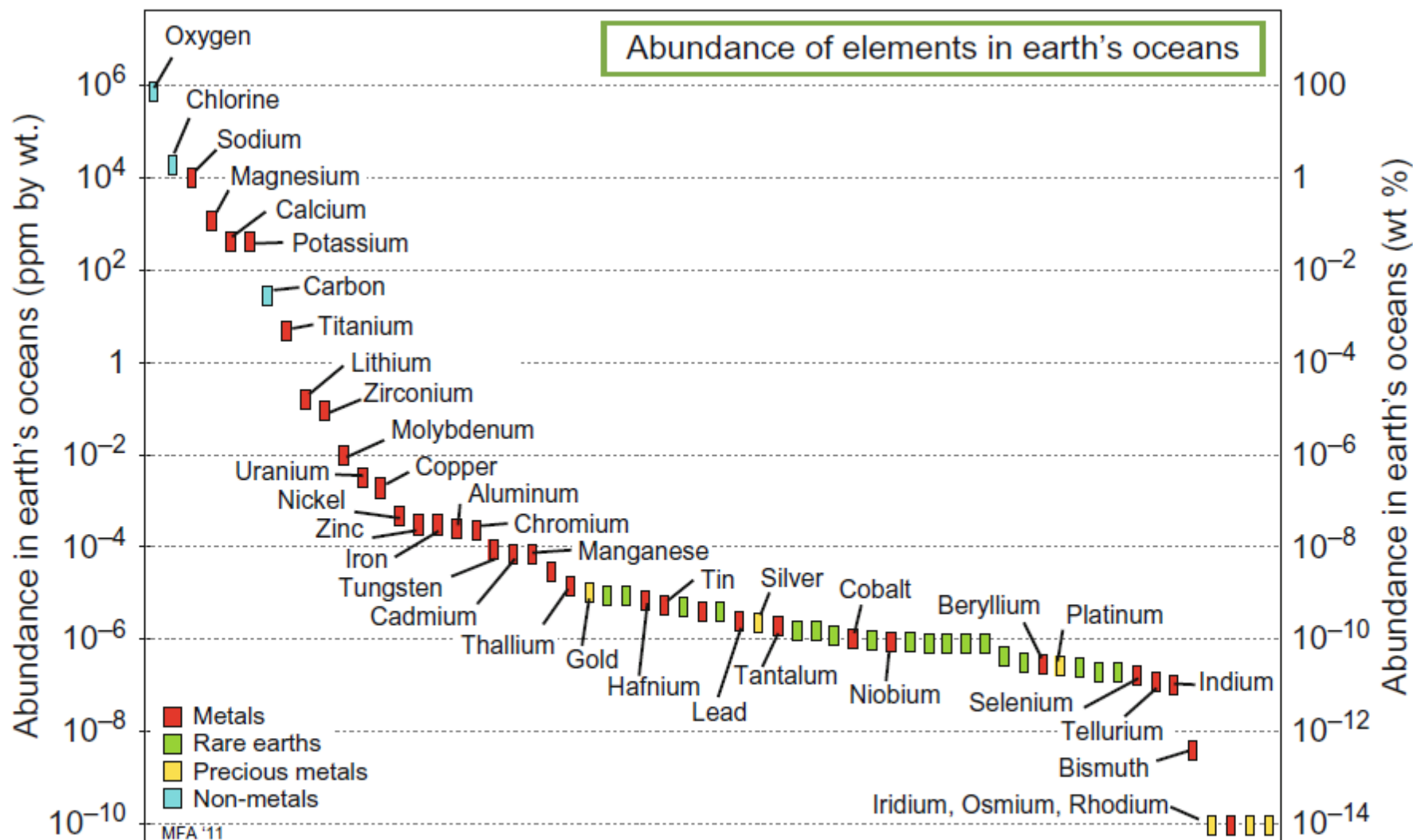


FIGURE 2.2 *The average concentration of the elements in the earth's oceans, as ppm and as %. Most are too dilute to allow for economical recovery.*

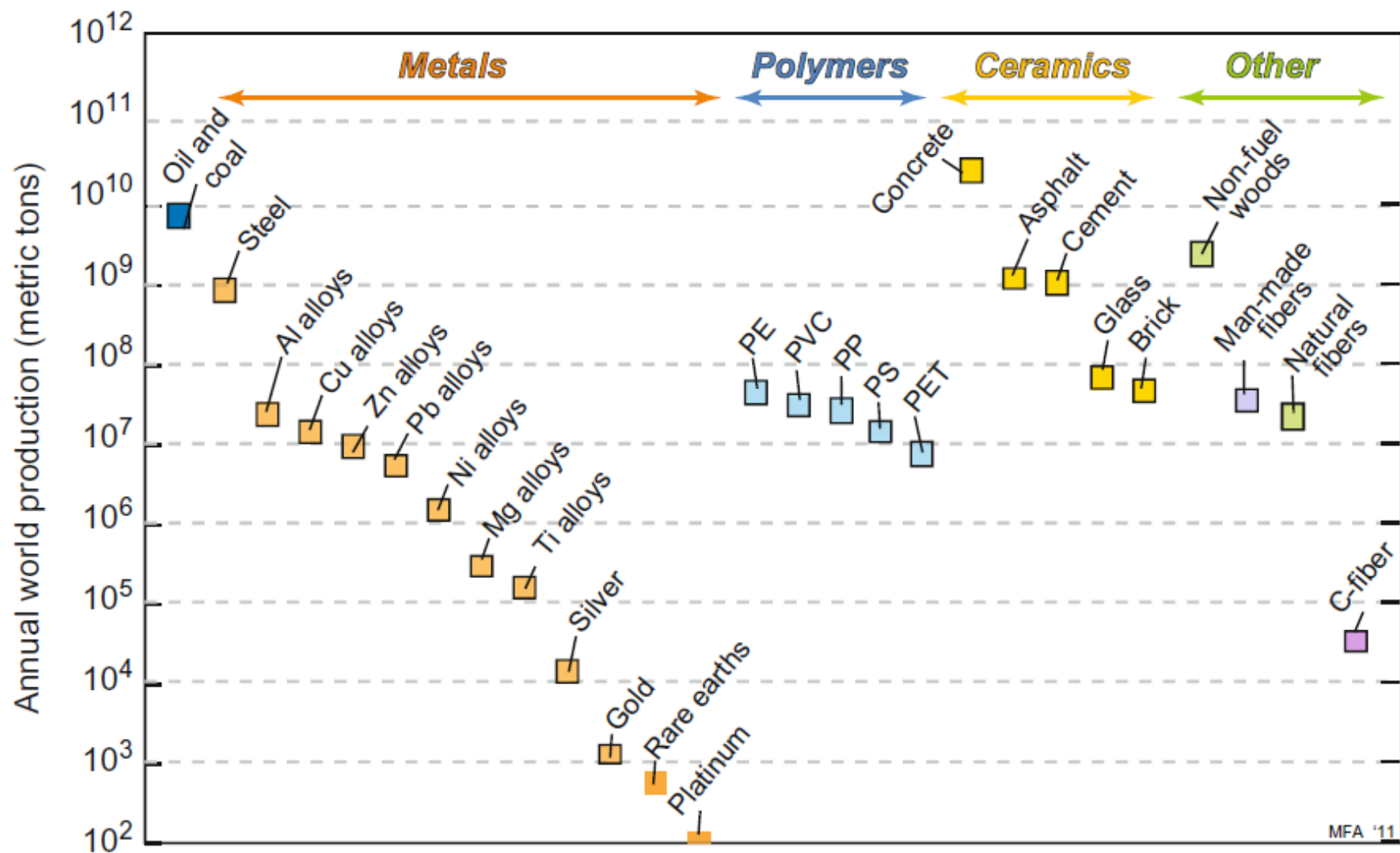


FIGURE 2.3 The annual world production of 27 materials on which industrialized society depends. The scale is logarithmic. The log scale conceals the great differences; the production of steel, for instance, is one billion (10^9) times larger than that of platinum.

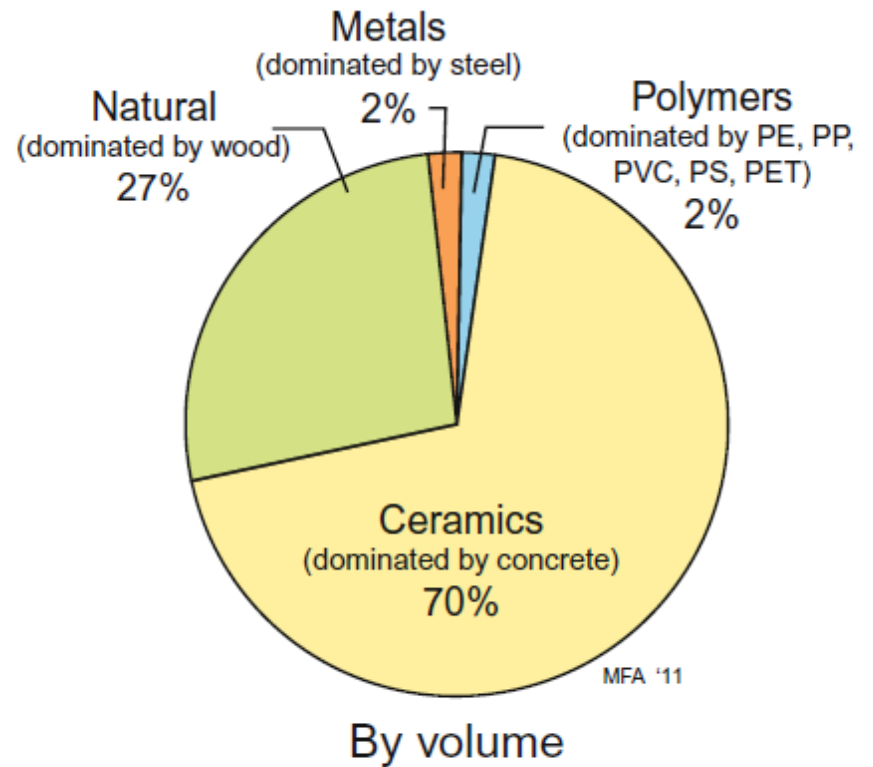
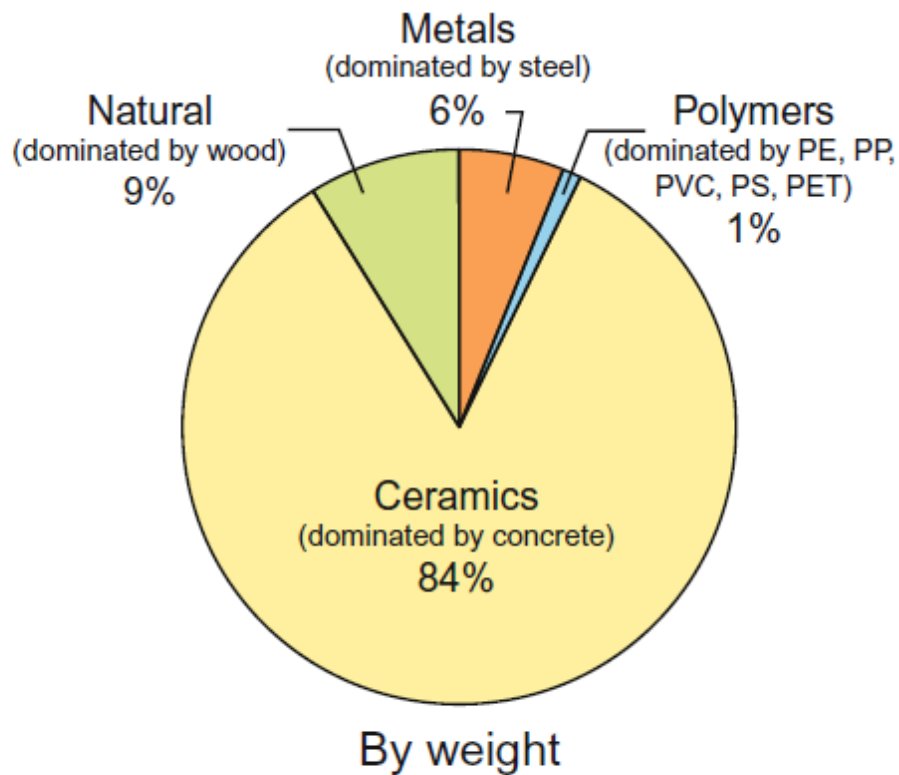


FIGURE 2.4 A pie chart of materials usage by family, by weight on the left, by volume on the right. Ceramics dominate because of the enormous annual consumption of concrete.

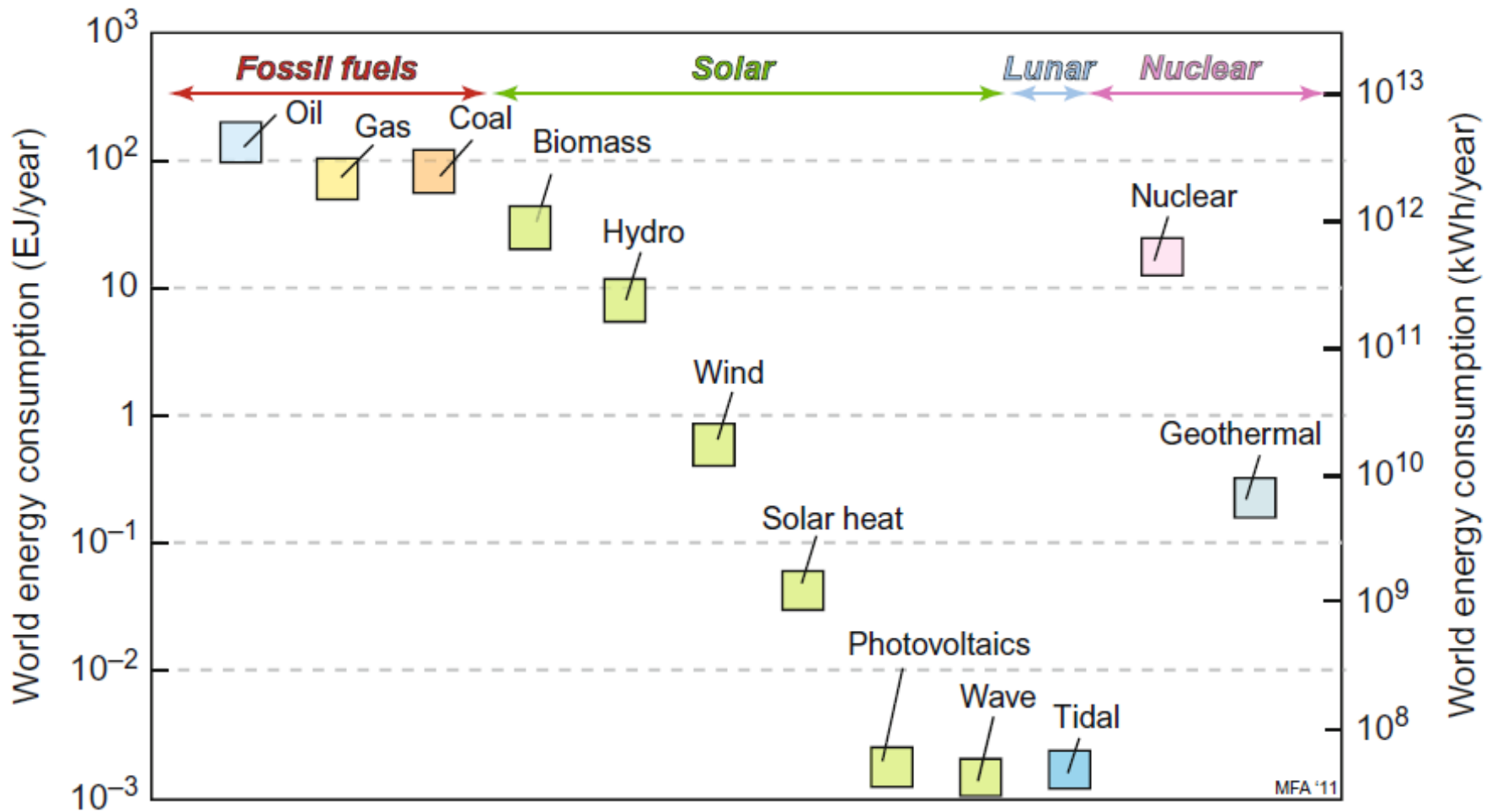


FIGURE 2.5 *The annual world consumption of energy by source. The units on the left are exajoules (10^{18} J); those on the right are the more familiar kWh. (Nielsen, 2005.)*

Carbon footprint of energy

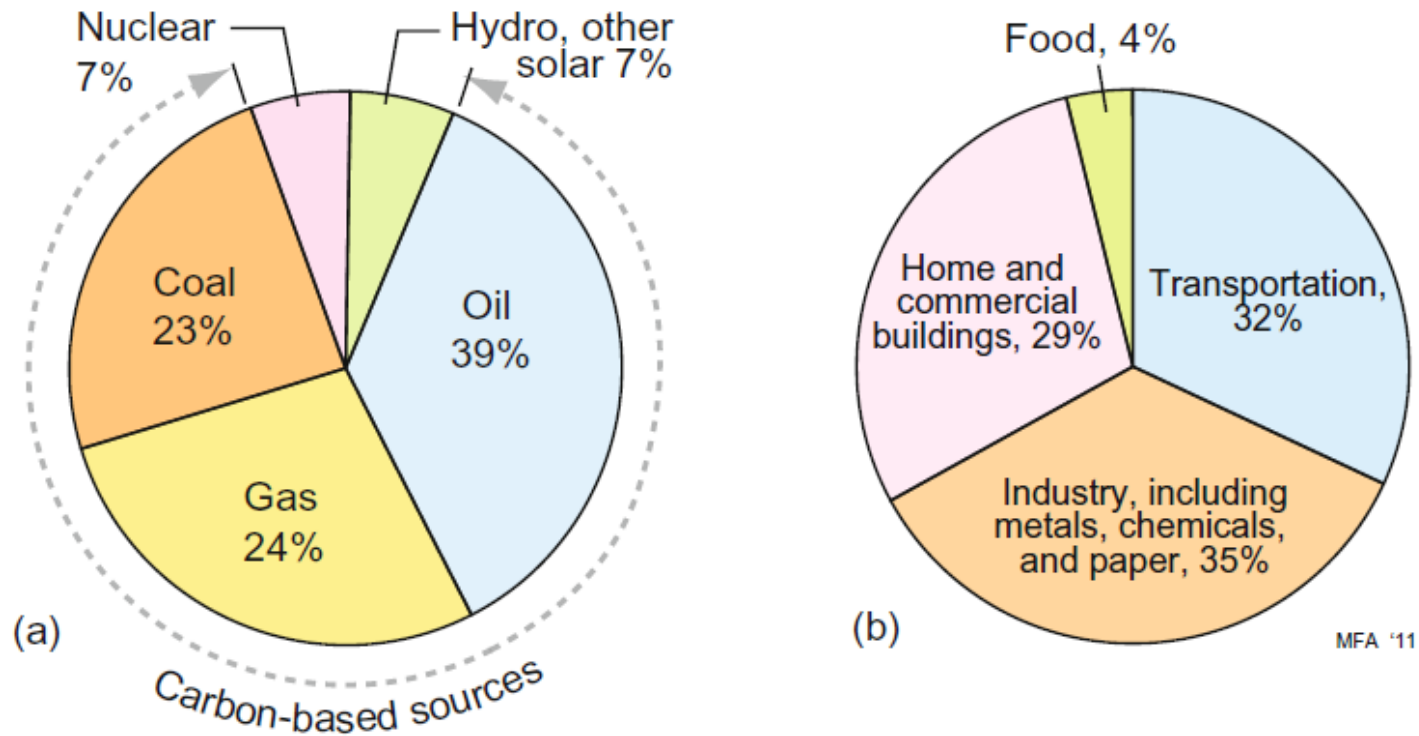


FIGURE 2.6 World energy consumption (a) by source and (b) by use. The nonrenewable carbon-based fuels, oil, gas, and coal, account for 86% of the total.

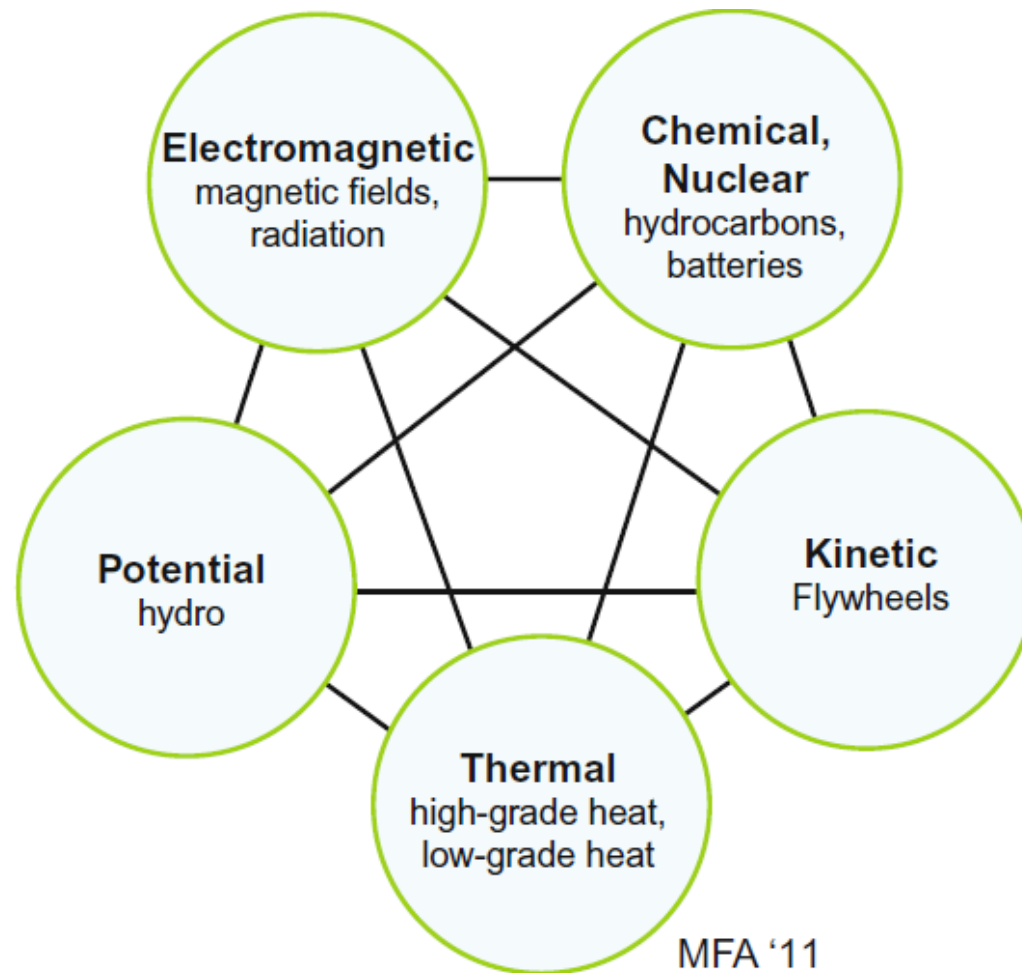


FIGURE 2.7 *Five types of energy. Each can be transformed into the others, as indicated by the linking lines, but at conversion efficiencies that differ greatly.*

Table 2.1 Some approximate efficiency factors for energy conversion

Energy conversion path	Efficiency, direct conversion (%)	Efficiency relative to oil equivalence (%)	Associated carbon (kg CO ₂ per useful MJ)
Gas to electric	37–40	37–40	0.18
Oil to electric	36–38	36–38	0.2
Coal to electric	33–35	33–35	0.22
Biomass to electric	23–26	23–26	0
Hydro to electric	75–85	75–85	0
Nuclear to electric	32–34	32–34	0
Fossil fuel to heat, enclosed system	100	100	0.07
Fossil fuel to heat, vented system	65–75	65–75	0.10
Biomass to heat, vented system	33–35	33–35	0
Oil to mechanical, diesel engine	20–22	19–21	0.17
Oil to mechanical, gasoline engine	13–15	12–14	0.15
Oil to mechanical, kerosene gas turbine	27–29	25–27	0.15
Electric to thermal	100	37–40	0.20
Electric to mechanical (electric motors)	80–93	30–32	0.23
Electric to chemical (lead-acid battery)	80–85	29–32	0.24
Electric to chemical (advanced battery)	85–90	31–33	0.23
Electric to em radiation (incandescent lamp)	12–15	4–6	1.17
Electric to em radiation (LED)	80–85	29–32	0.23
Light to electric (solar cell)	10–22	–	0

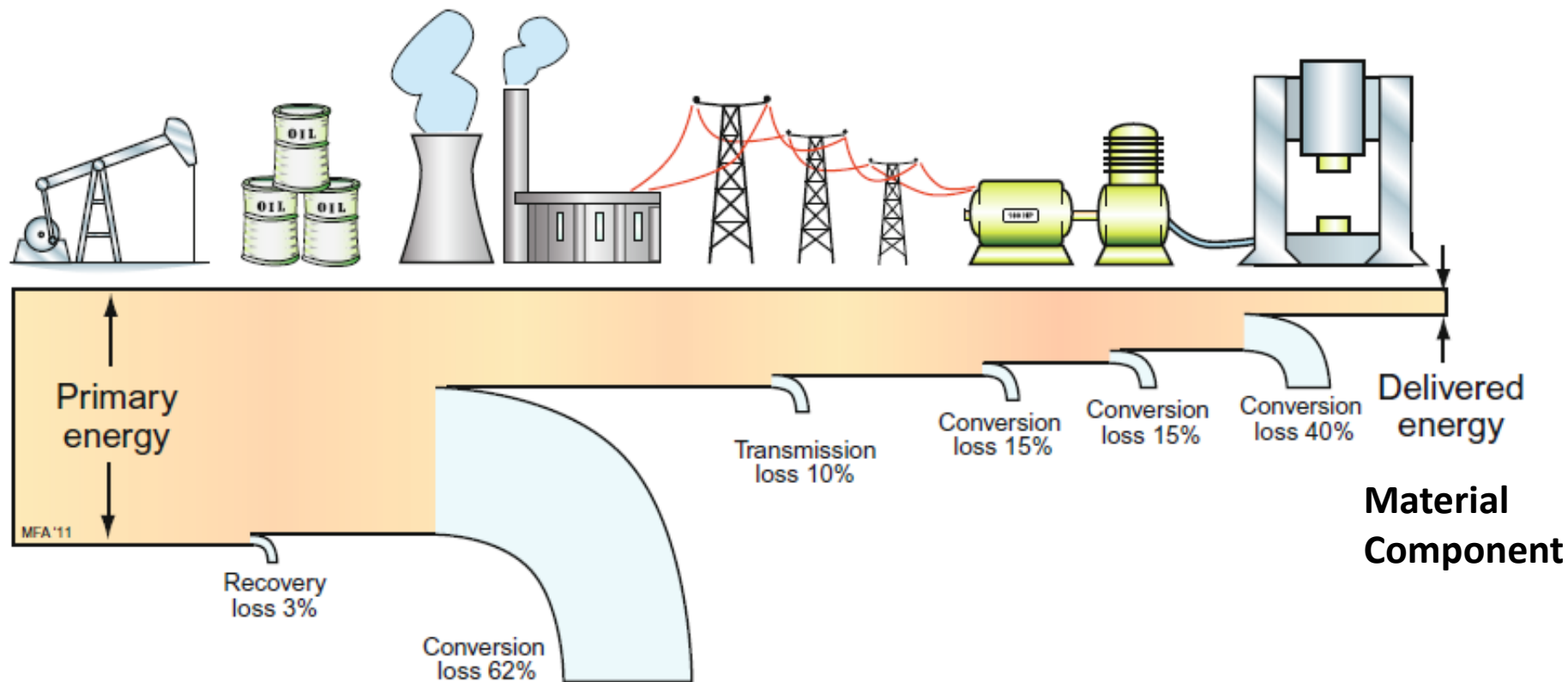


FIGURE 2.9 *A chain of energy-conversion and transmission steps, each with a "loss" of energy as low-grade heat*

Definition of *Embodied Energy*

Element	Free energy of formation		Embodied energy MJ/kg	Apparent efficiency %
	kJ/mol	MJ/kg		
Al	796	30	203	15
Cu	134	2.1	68	3
Fe	374	6.7	29	23
Mg	626	26	360	7
Ni	233	4.0	127	3
Pb	233	1.1	53	2
Sn	552	4.7	40	12
Ti	907	19	600	3
Zn	339	5.2	65	8

Free energy = truly embodied energy (energy for reduction of metal oxide into metal)

Total embodied energy = Free energy + energy lost in primary processes

Some examples

Al₂O₃ conversion into Al is quite difficult = high energy of formation (the highest!) + energy for electrolysis (low efficiency process)

Fe₂O₃ conversion into Fe feasible from reaction with C: a lot of energy is lost in form of hot gases escaping from blast furnaces

Summary of (Industrial) Eco-engineering

Optimization of
materials-energy,
materials-carbon,
carbon-energy
correlations

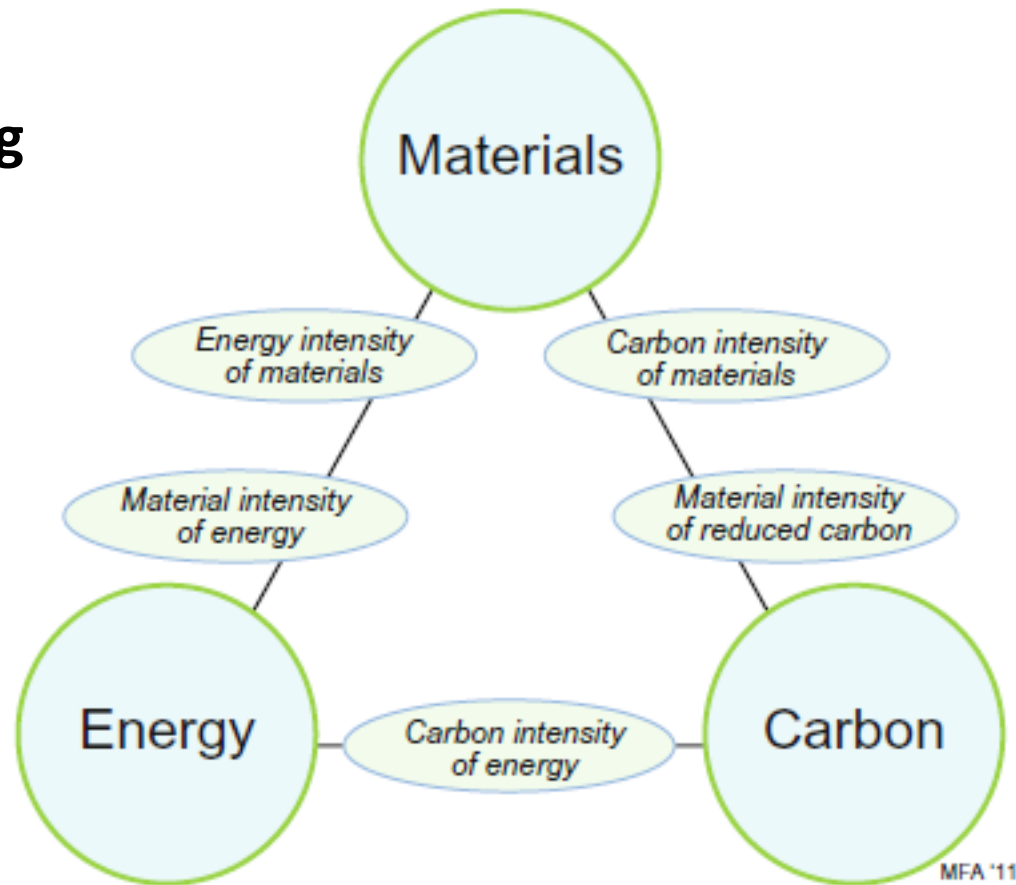
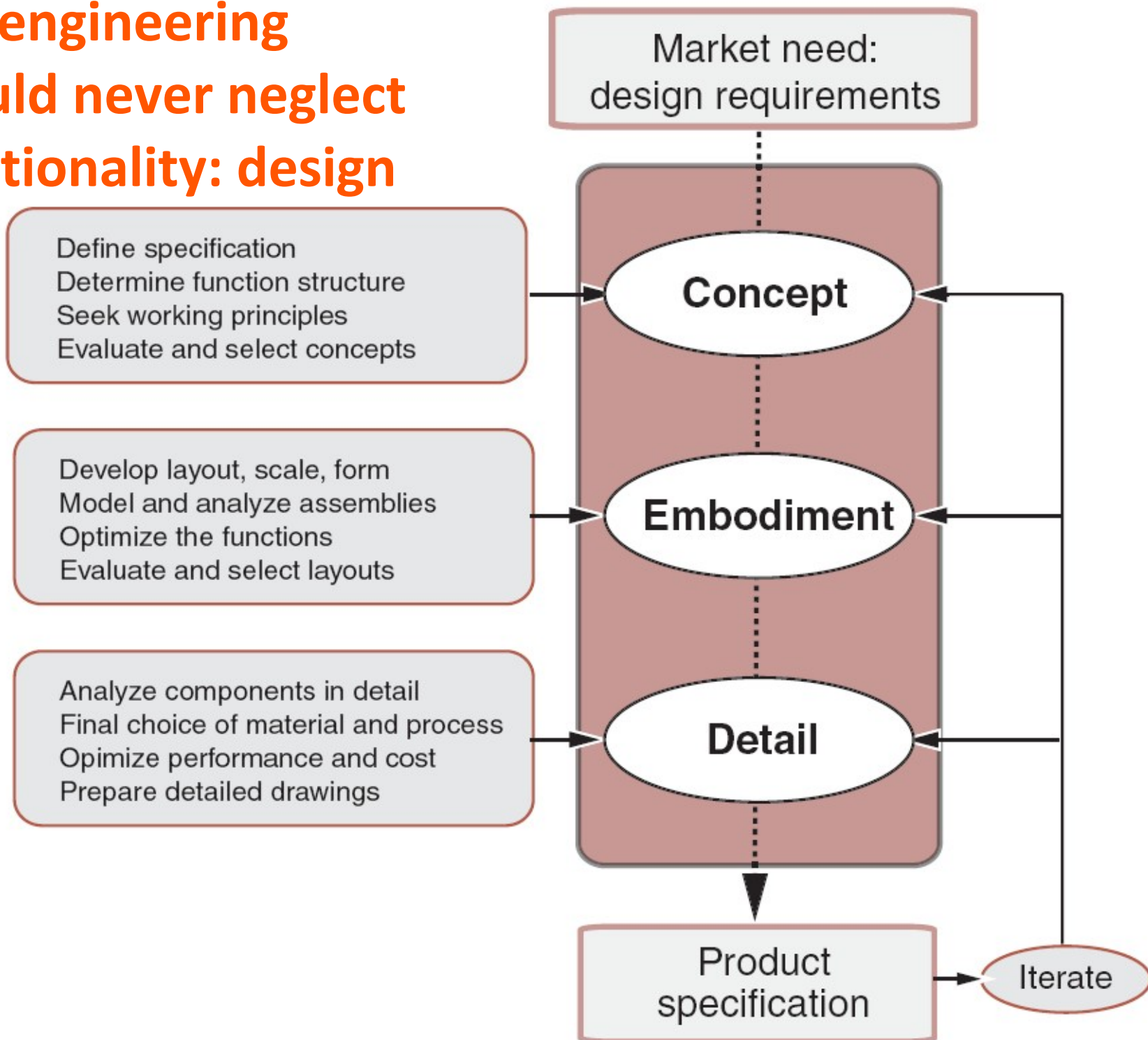


FIGURE 2.19 *The materials-energy-carbon triangle. Each depends on the other two such that reducing the drain on one often increases the drain on another. Using resources efficiently requires a balance between the three.*

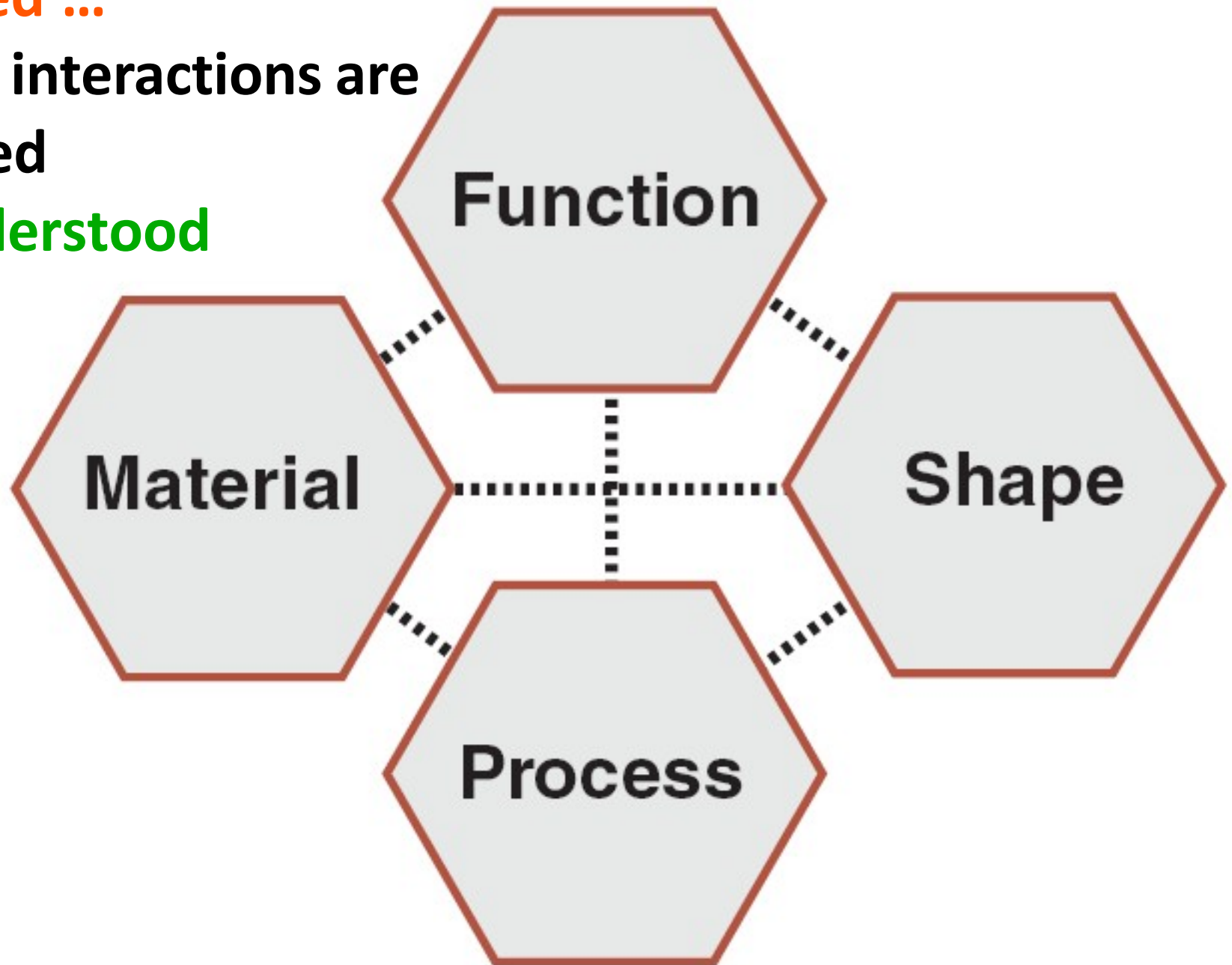
Eco-engineering should never neglect functionality: design



**A component is 'materials
engineered'...**

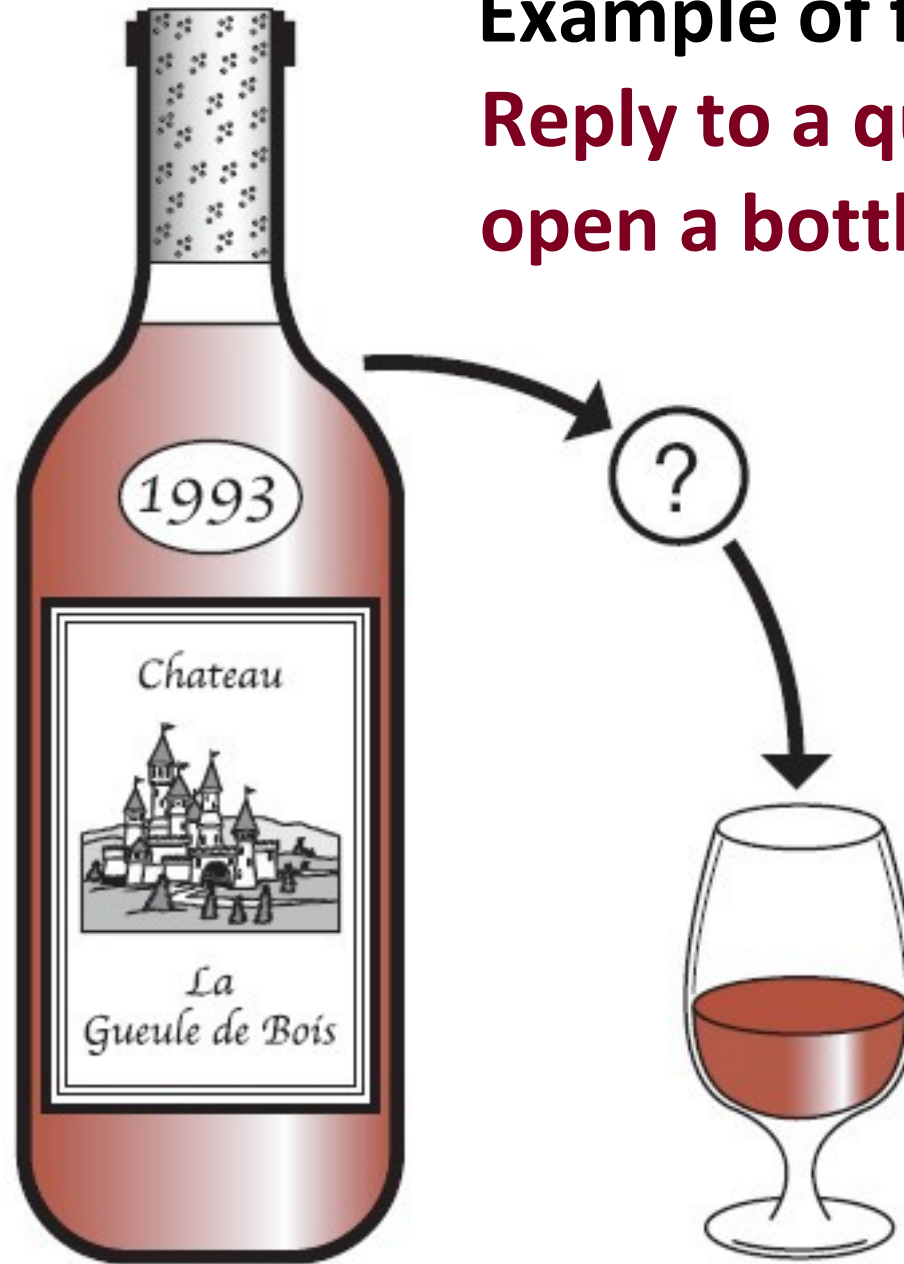
**when key interactions are
established**

...and understood

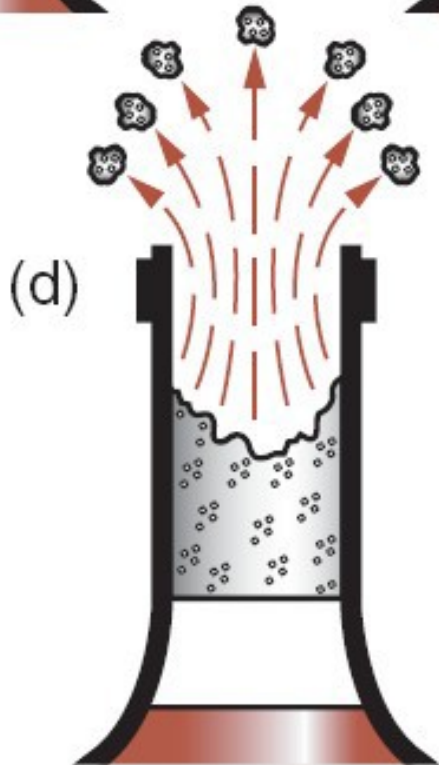
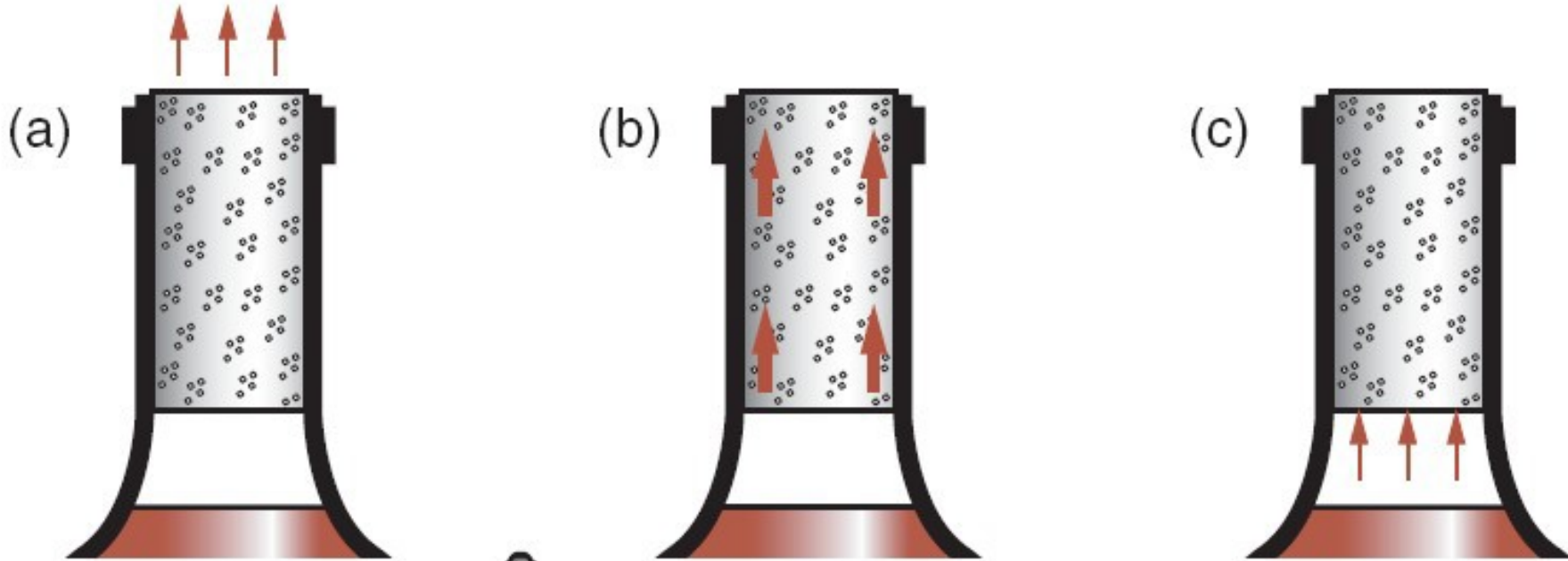


Example of function

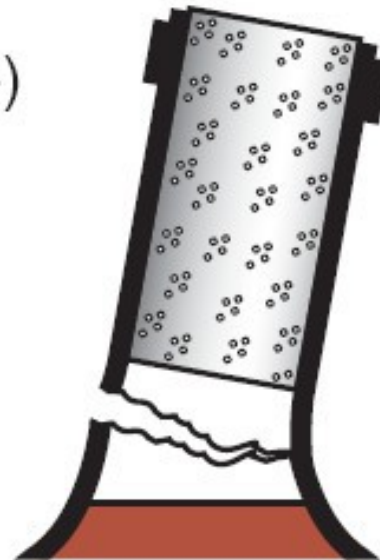
**Reply to a question: how to
open a bottle of wine?**



Example First concept: the cork is removed if...



(e)

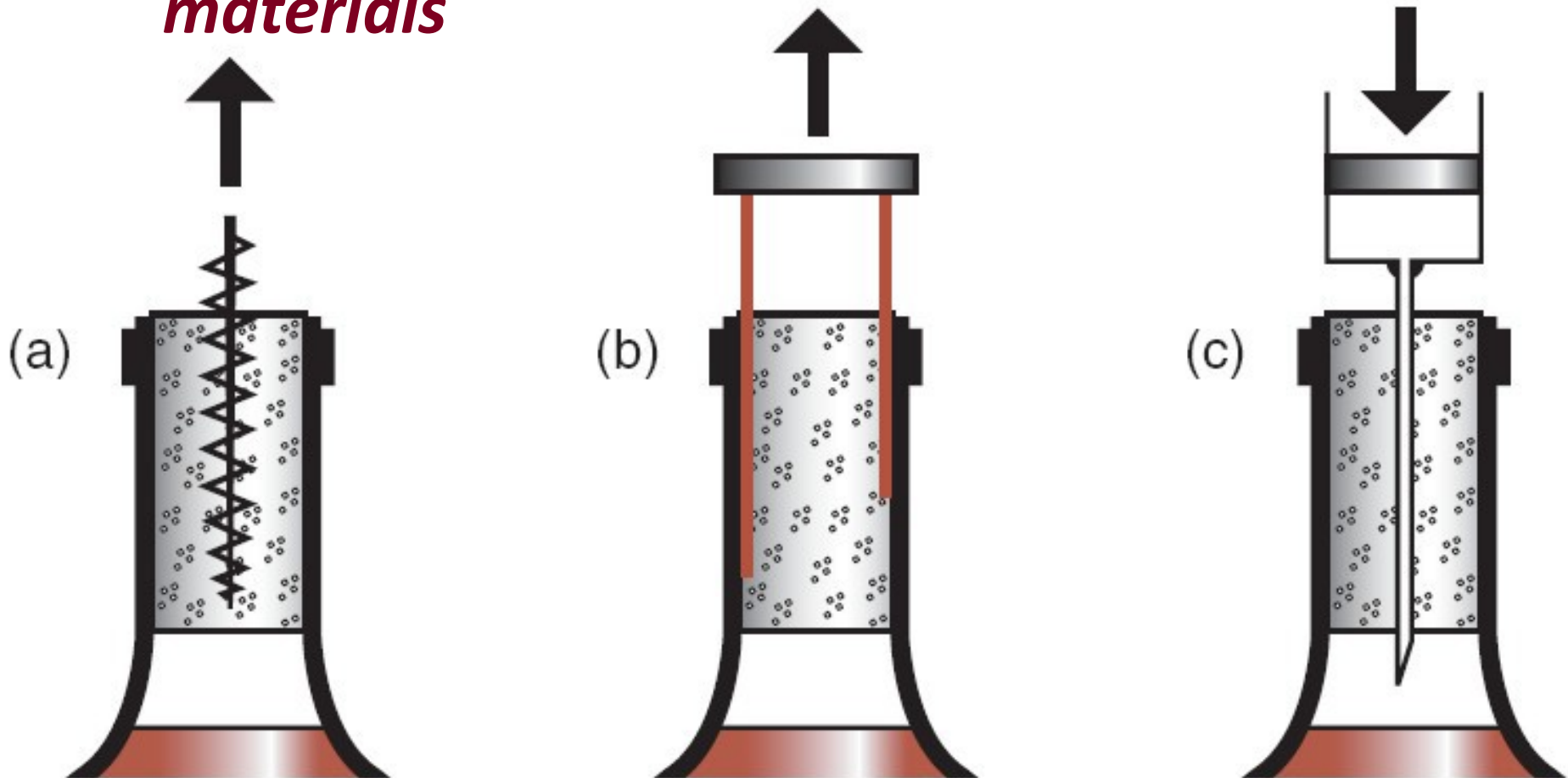


Different solutions...
at least
some of them
imply
materials
selection

Example 2nd phase “Embodiement”

A concept of cork removal is transferred to a tool design

Different concept, different design, different stress distributions...perhaps different materials



Usual stuff



*Strange but
real*



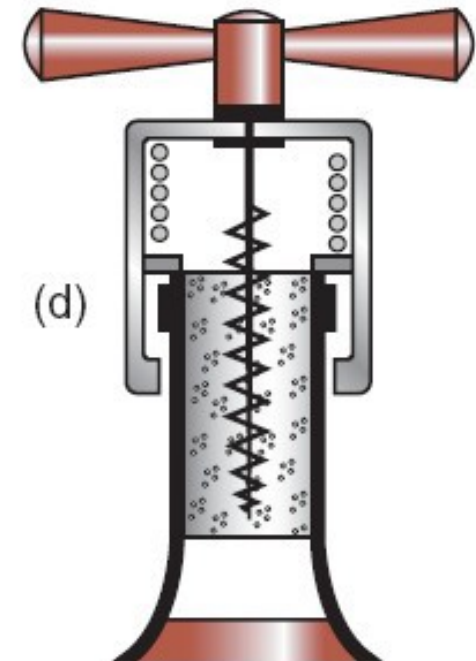
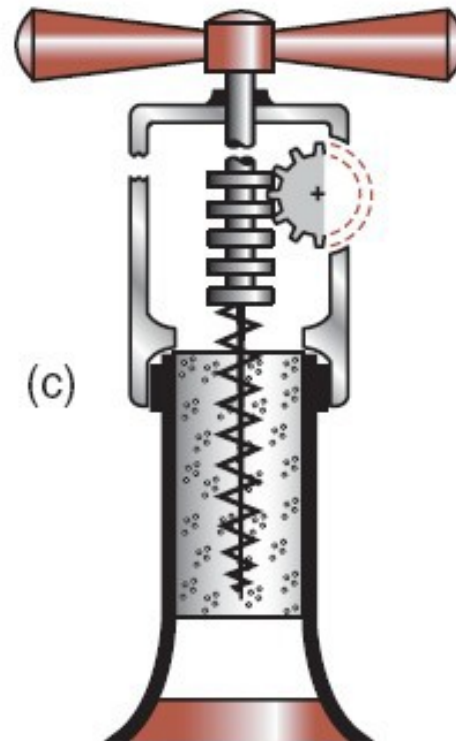
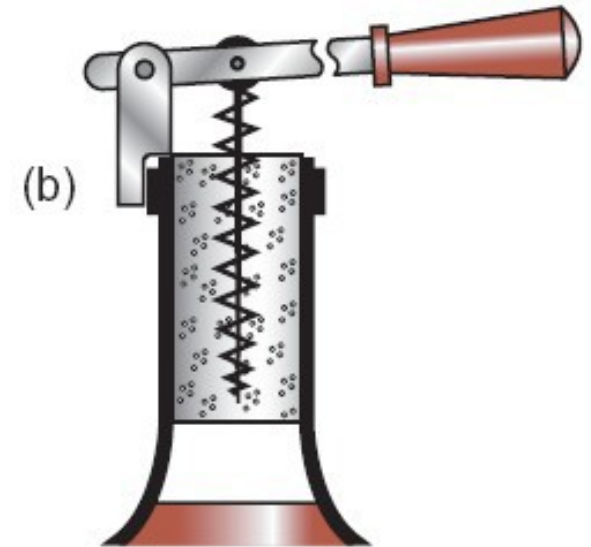
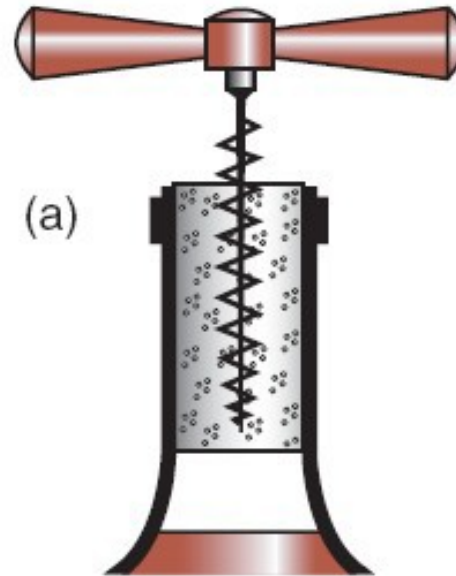
Usual stuff



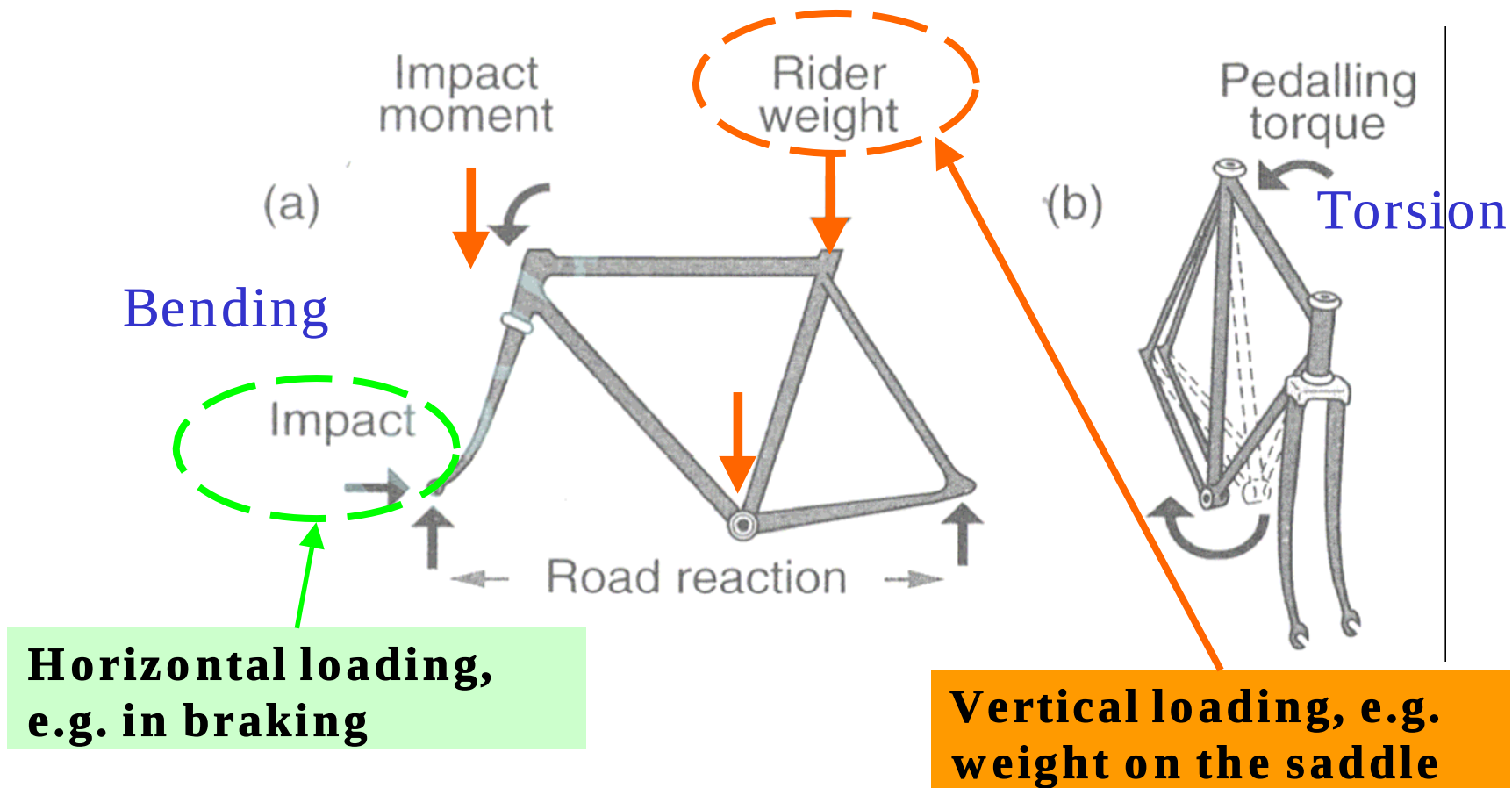
*Strange but
real*



Example
3rd phase=design
Different
materials
depending on the
loading condition
(e.g. “buckling”)
Materials to be
evaluated with
SHAPES
Equivalent solutions
are feasible

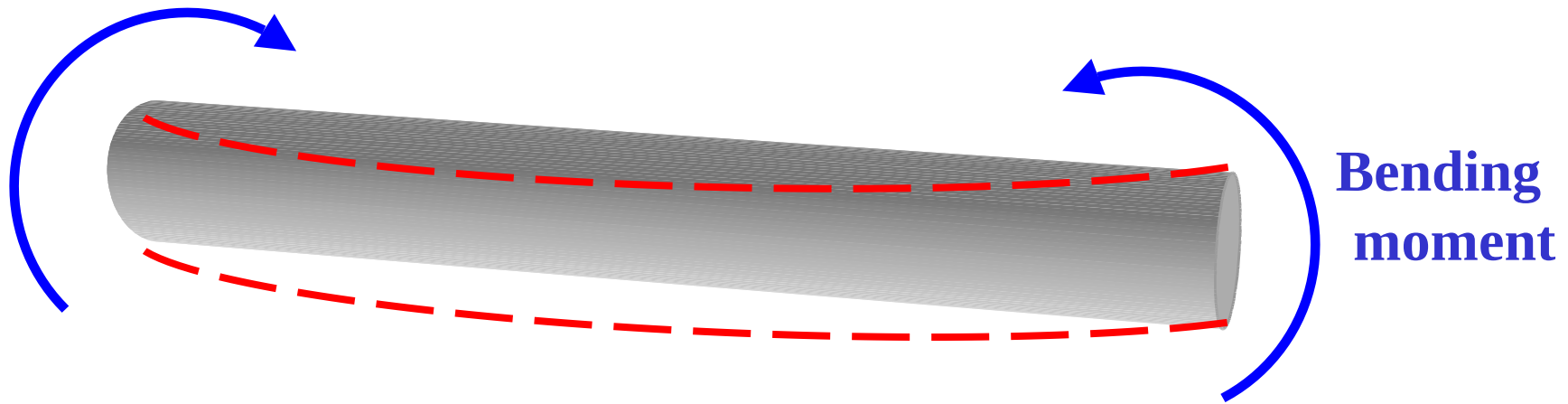


Bike frames and forks



Dynamic conditions, not static

Further examples...



**Tubes mainly
subjected to bending**

2 objectives

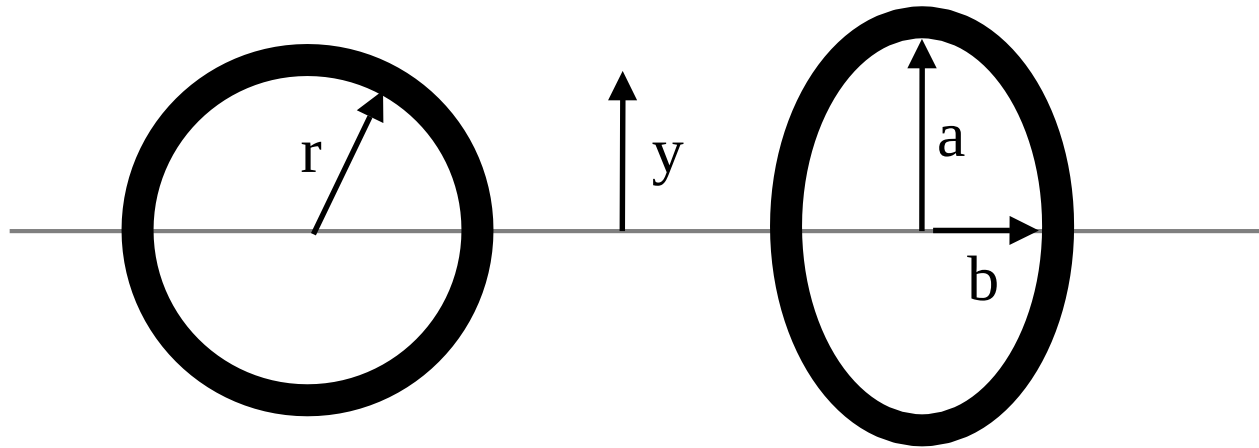
1. **Strength** (the structure should not fail during operation)
2. **Stiffness** (the structure should not dissipate energy in deformation; energy transformed into speed...)

Stiffness is often dominant...

Stiffness of structures does NOT depend only on materials

Attention to the distribution of solid

Fundamental quantity = **Moment of inertia (J)**

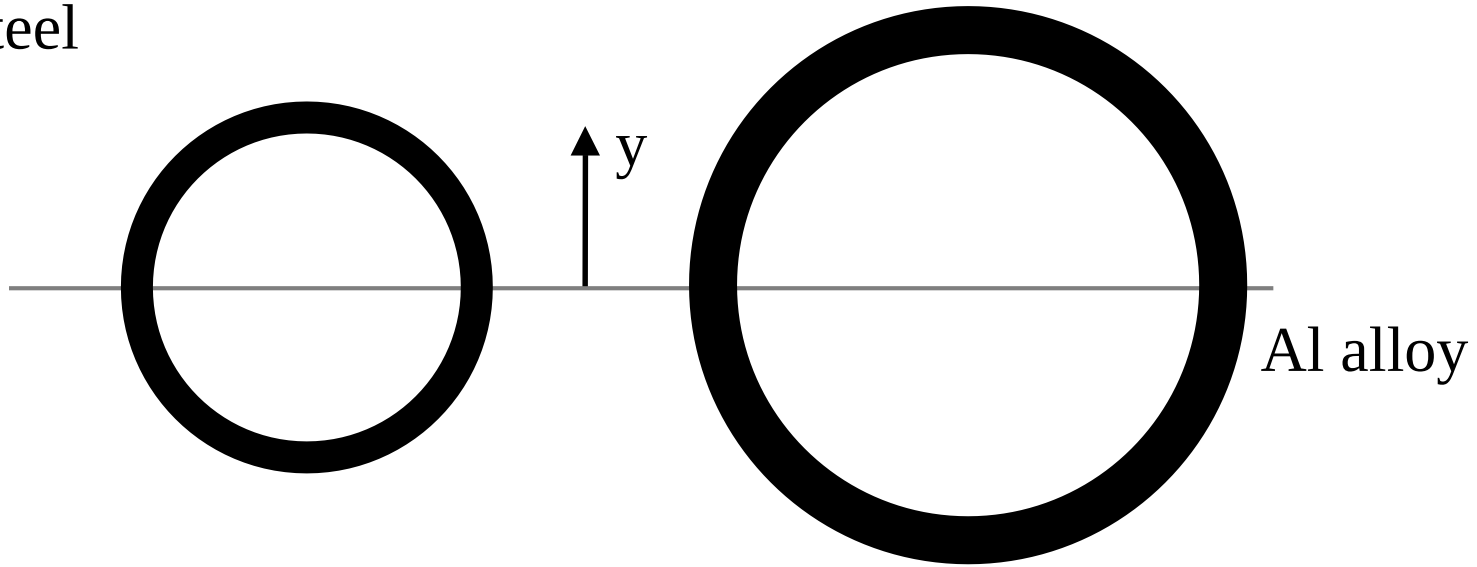


Circular tube
J depends on r^4

Elliptical tube
Anisotropy of J
 $J_a \gg J_b$
Same quantity of solid, J
maximized in a plane

Different materials, different radius, so different J

Steel



*Aluminum-based structures may be bigger in term of VOLUME
Given the low density (density of Al = 1/3 of the density of steel)
Al-based structure remain lighter (lower MASS) than those of
steel*

Examples of embodiment Materials + Shape: racing bikes



www.guidorubino.com

www.scapin.com

steel frames

**Quite thin tubes (limited diameter
and limited wall thickness)**

Al alloy

Tubes are evidently larger in cross-section



www.derosanews.com

Mind the forks:
CFRP offer distinctive advantages
(vibration damping)

Magnesium alloy



www.pinarello.com

Mind the forks:
CFRP offer distinctive advantages
(vibration damping)

Titanium alloy



www.guidorubino.com

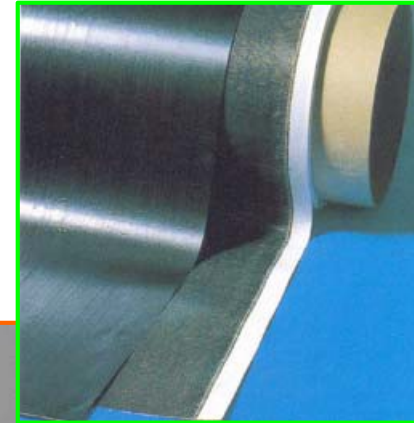
www.passoni.com

www.litespeed.com

Quite difficult handling: well known difficulties in welding

Mind the forks:
CFRP offer distinctive advantages
(vibration damping)

CFRP Monocoque



www.derosanews.com
www.c4carbon.com



Bamboo bike

www.calfeedesign.com

www.likecool.com

jschumacher.typepad.com/..
[./bicycle-museum-.html](http://jschumacher.typepad.com/..)

Bamboo

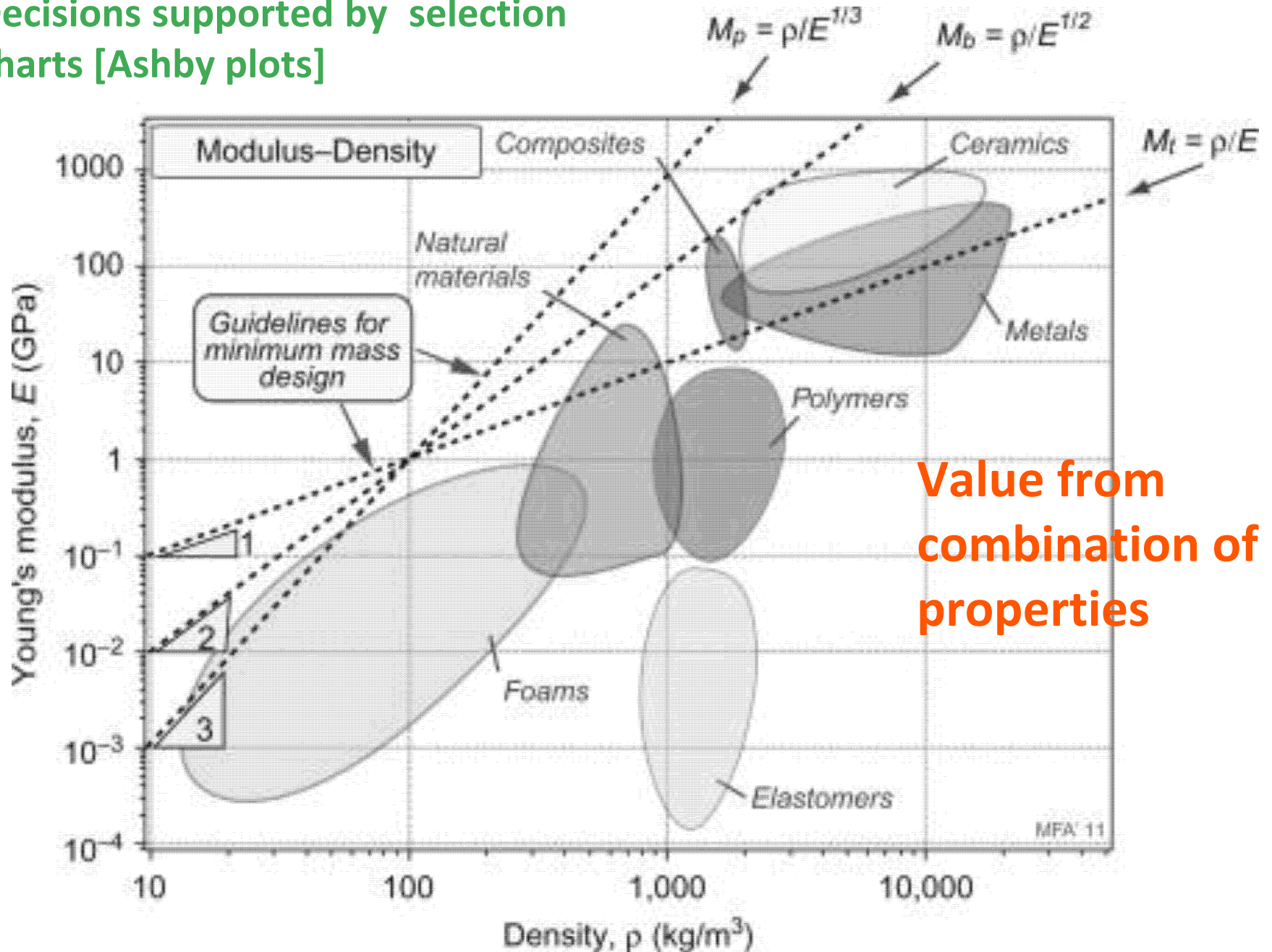


Other wood

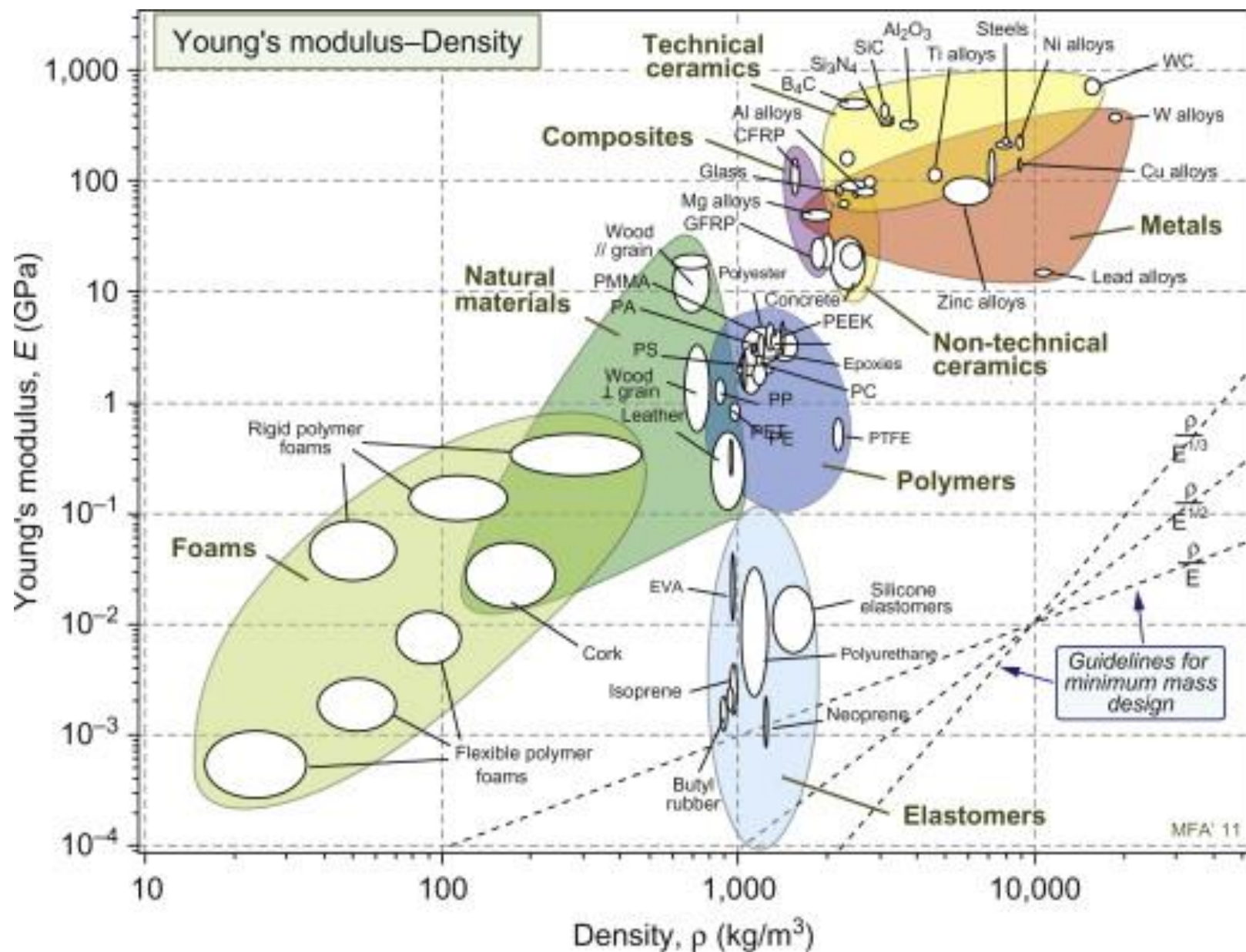


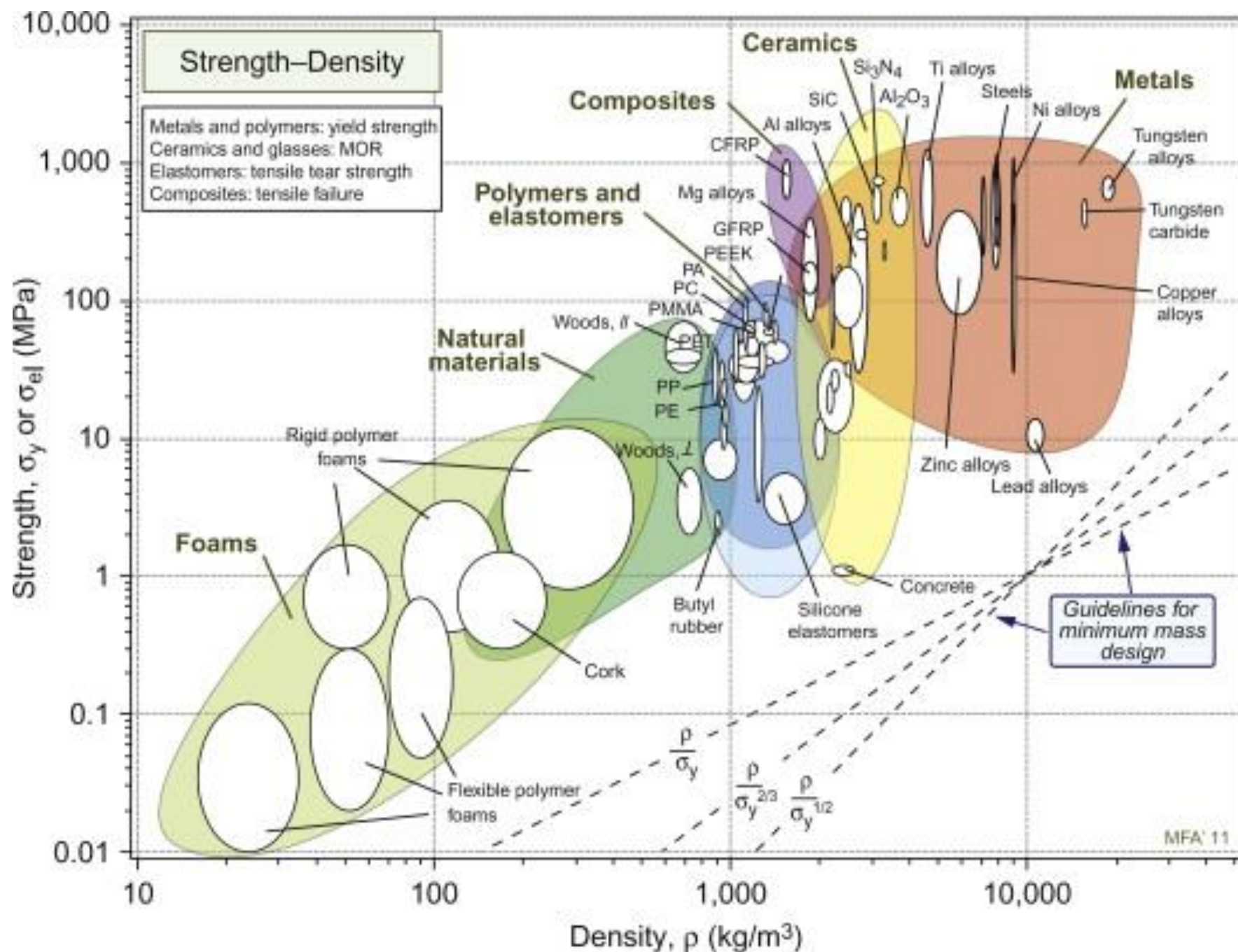
Thermoplastic polymer

Decisions supported by selection charts [Ashby plots]



Value from
combination of
properties







USING MORE SUSTAINABLE MATERIALS

New challenges

Using more sustainable materials is a major long term goal for us as a responsible business.

The planet's resources are dwindling. Choosing and using materials responsibly will not only benefit our environment, it will also help us tackle future price fluctuations as demand for these precious resources increases.

Recycled Aluminium

The amount of recycled aluminium we use in our vehicles continues to rise. We work in partnership with the REAL CAR initiative who develop ways to employ recycled aluminium in our products.

Together we have identified a method of re-melting scrap aluminium generated in our own presses with those of our principle suppliers into a high-grade sheet metal alloy. Both the latest **Jaguar XJ** and the **All New Range Rover** feature recycled aluminium sheets.

We also now have a closed loop waste recovery and recycling system at our Castle Bromwich Jaguar production centre, as well as a trial process at Solihull, where Land Rover's new all-aluminium models (The Range Rover and Range Rover Sport) are manufactured.

Switching to Organic Materials

Beyond the main car body, there are even wider opportunities to make responsible choices. We are reducing our use of synthetics and plastics by looking at more organic materials such as leather and natural rubber. (A key feature of the new Range Rover – whose leather interiors were sourced from Bridge of Weir in Scotland). Wood too, can be sourced responsibly from a sustainably managed forest to make stylish, premium interiors for our vehicles.

MULTIMEDIA



Using More Sustainable Materials in the All New Range Rover

READ MORE



JAGUAR: THE STORY OF ALUMINIUM



THE ALL NEW RANGE ROVER

DESIGNING FOR FUEL EFFICIENCY

Typically, over 70% of a vehicle's lifetime carbon footprint will come from the fuel it uses, when driven. Designing fuel efficient vehicles is therefore key to reducing our impact on the environment, as well as delivering cost savings for customers.

We are aiming to reduce our fleet tailpipe emissions by 25% by 2015. This calls for fresh thinking at the product design stage. Analysing engine performance, aerodynamics and more to inspire new ways to drive down emissions.

Our approach focuses on four key areas:

1. Lightweight Body Structures

Jaguar pioneered the use of **lightweight, aluminium body structures**. More lightweight and malleable materials not only offer improved aerodynamics, they also reduce the size of the engines required to deliver power.

2. Hybrid & Electric Solutions

We have a team of 260 engineers exploring how internal combustion engines can work with electric motors as well as ways in which vehicles can recover the energy they lose in braking and driving. This work has led to the **launch of our Range Rover Sport Hybrid** - the world's first hybrid luxury SUV. With CO₂ emissions as low as 169g/km and 44 miles per gallon, emissions from the Range Rover Sport Hybrid are 26% lower than the standard diesel model.

3. Stop/Start Technology

This kind of **intelligent technology** offers significant fuel saving opportunities. In the All New Range Rover, the system shuts down the engine in just 300 milliseconds when the vehicle comes to rest, then restarts as the driver's foot leaves the brake pedal - reducing fuel consumption and CO₂ by between 5% to 7%.

4. Powertrain Efficiency

Advances in powertrain efficiency are helping us create engines that deliver high performance with fewer emissions.

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Efficient Technologies

READ MORE



JAGUAR ANNOUNCES ALL-NEW TECHNICALLY ADVANCED ALUMINIUM ARCHITECTURE AND REVEALS C-X17 SPORTS CROSSOVER CONCEPT



LAND ROVER LAUNCHES ITS FIRST HYBRID RANGE ROVER MODELS



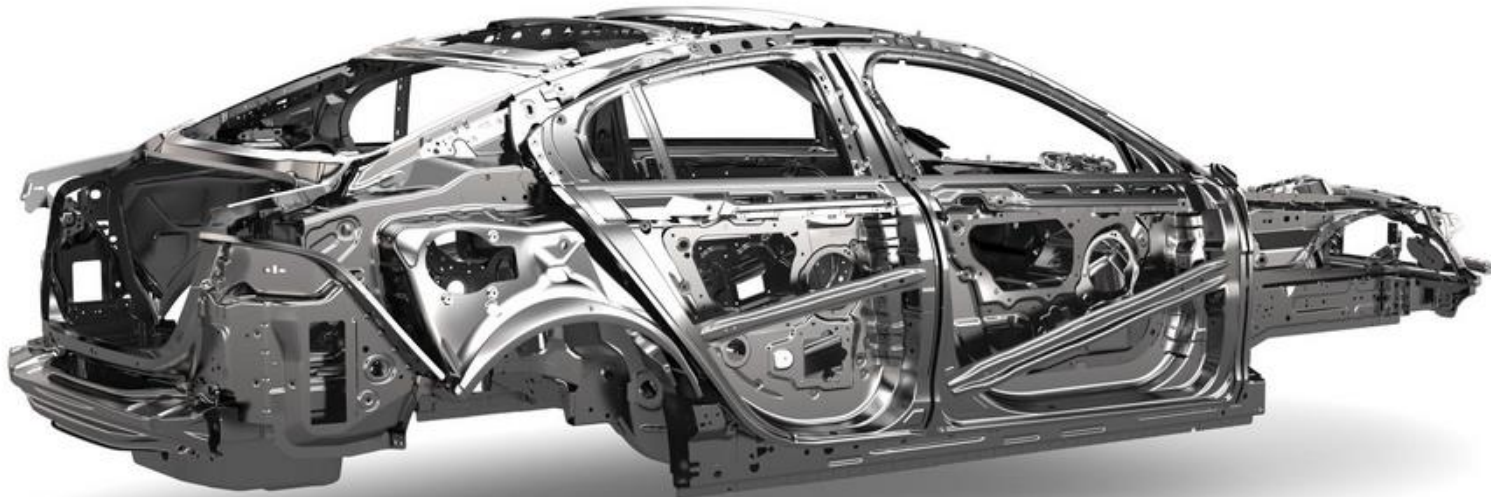
ALL-NEW RANGE ROVER OFFERS INCREASED POWERTRAIN CHOICE WITH ADVANCED SUPERCHARGED V6 PETROL ENGINE



JAGUAR EXPANDS POWERTRAIN CHOICE



JAGUAR LAND ROVER ANNOUNCES ADVANCED POWERTRAIN RESEARCH PROJECT TO PUSH BOUNDARIES OF HYBRID AND BATTERY-ELECTRIC VEHICLE TECHNOLOGY



<http://blogs.youwheel.com/2015/02/10/short-analysis-jaguars-advantages/>

(Above: Jaguar XE's aluminum body-in-white)

1. Aluminum car body structure across the full product line. Almost all Jaguar models are using full aluminum unibody construction (*aluminum monocoque*). Starting from 2003, the XJ has been full aluminum for two generations (X350, X358, X351); The latest XK and F-Type are also full aluminum. The cheapest XE also has a car body composed of 75% aluminum. The only exception is the XF, which was designed back in the days when Ford still owned Jaguar, which is based on the Ford DEW platform. But the redesigned XF is coming out very soon.

