University of BRISTOL

CADE20006: Structures and Materials

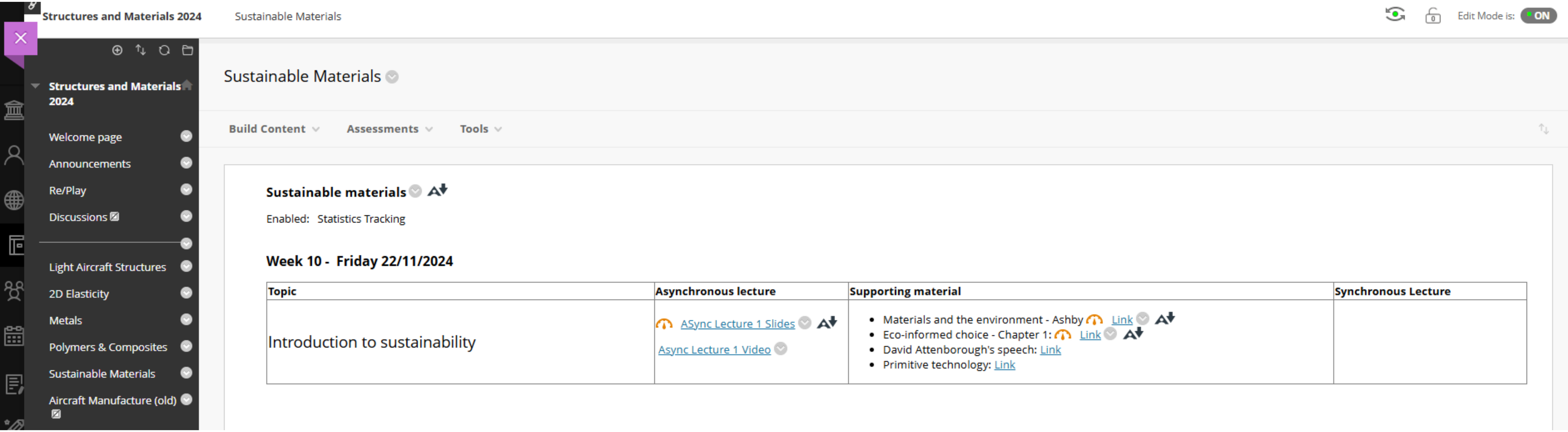
Theme:
Sustainable Materials and Manufacturing

Dr. Karthik Ram Ramakrishnan
Karthik.ramakrishnan@bristol.ac.uk
Room 0.56 Queen's Building

Overview

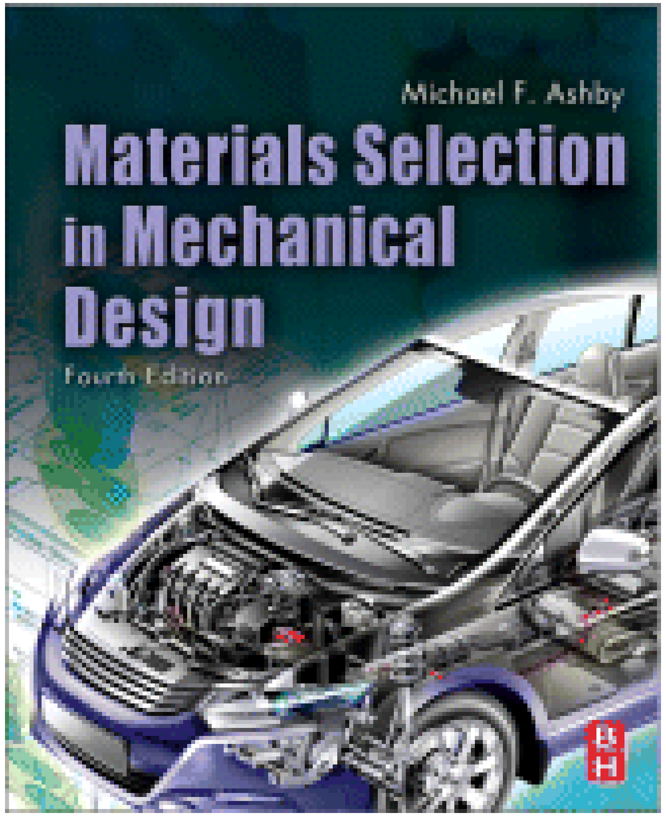
- Lecture 1: Introduction to sustainability, Factors affecting materials consumption, Strategic materials.
- Lecture 2: Material selection for Eco-design and case studies.
- Lecture 3: Embodied energy, LCA, Recycling and end of life options.
- Lecture 4: Composites for sustainability

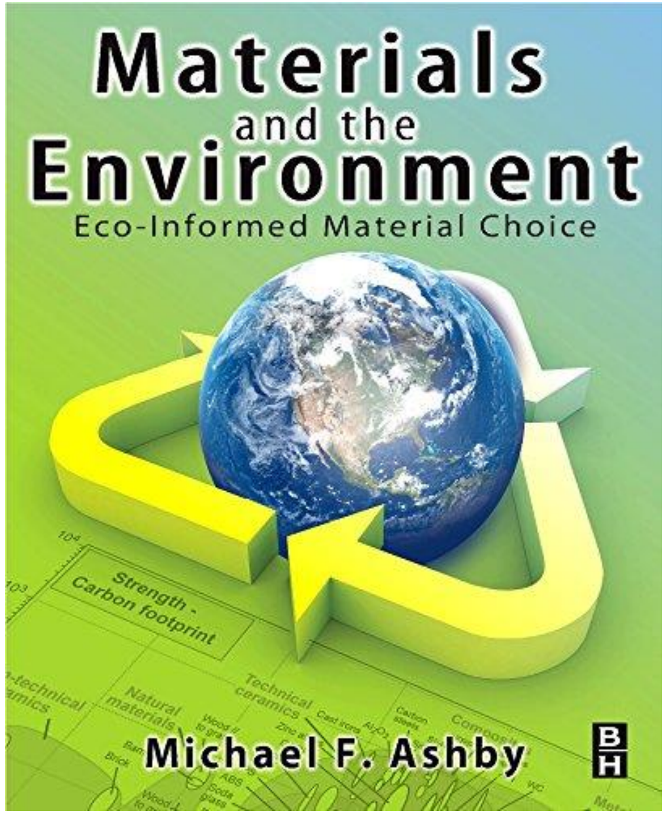
Blackboard



Structures and Materials 2024
Sustainable Materials
Edit Mode is: ON
Structures and Materials 2024
Welcome page
Announcements
Re/Play
Discussions
Light Aircraft Structures
2D Elasticity
Metals
Polymers & Composites
Sustainable Materials
Aircraft Manufacture (old)
Sustainable Materials
Build Content
Assessments
Tools
Sustainable materials
Enabled: Statistics Tracking
Week 10 - Friday 22/11/2024
Topic
Asynchronous lecture
Supporting material
Synchronous Lecture
Introduction to sustainability
ASync Lecture 1 Slides
Async Lecture 1 Video
Materials and the environment - Ashby Link
Eco-informed choice - Chapter 1: Link
David Attenborough's speech: Link
Primitive technology: Link

Resources


Michael F. Ashby
Materials Selection in Mechanical Design
Fourth Edition


Materials and the Environment
Eco-Informed Material Choice
Strength - Carbon footprint
Technical ceramics
Natural materials
Michael F. Ashby

Intended Learning Objectives

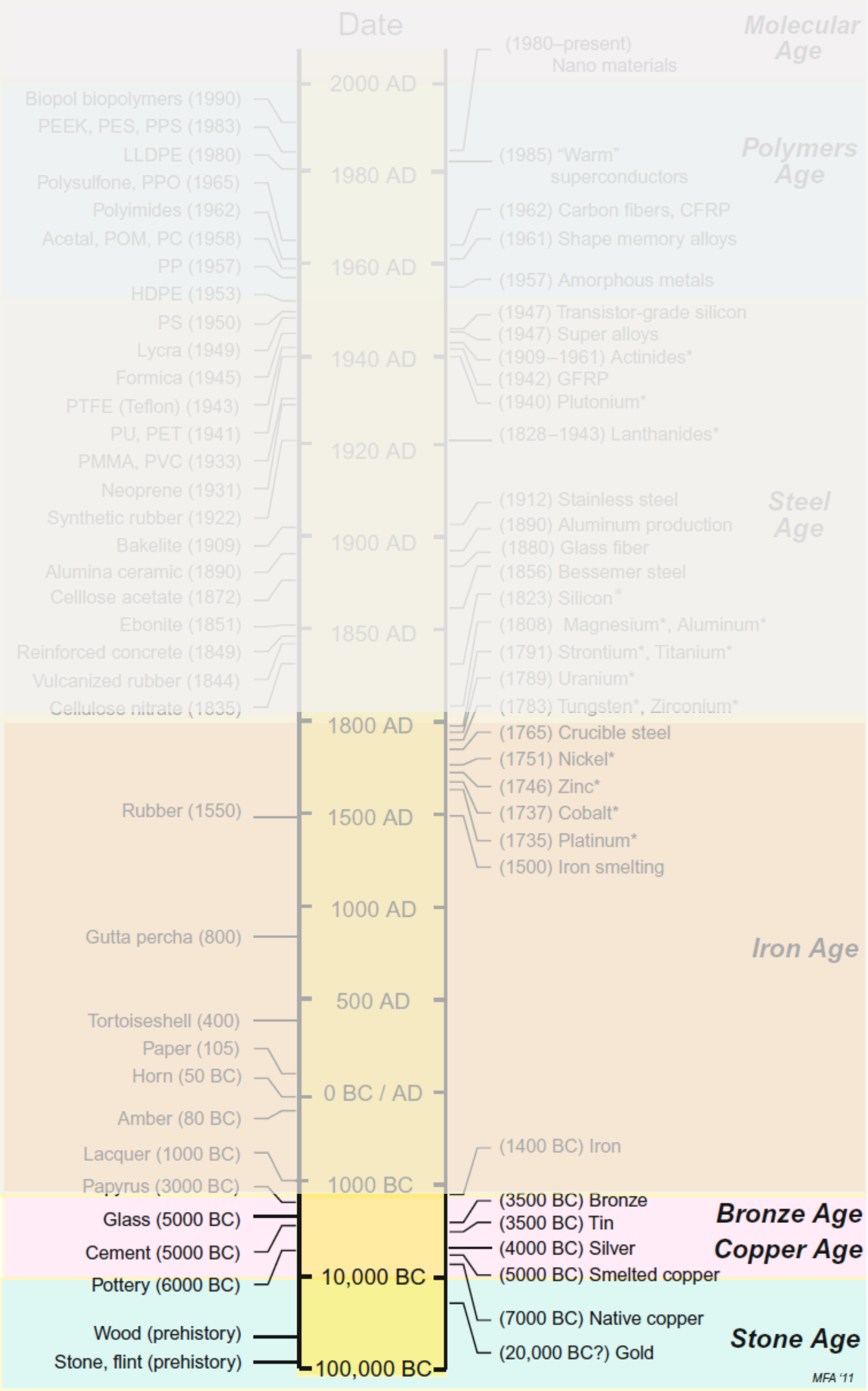
- Describe the main factors affecting materials consumption
- Demonstrate how to calculate rates of growth and consumption
- Identify strategic materials and their geographical sources
- Identify end of life options for materials and products
- Explain what is involved in undertaking an eco-audit
- Demonstrate that you understand how embodied energy can inform structural design
- Name the three capitals and their role in sustainable development
- Describe the process of assessing sustainable technology

Today’s Lecture Contents

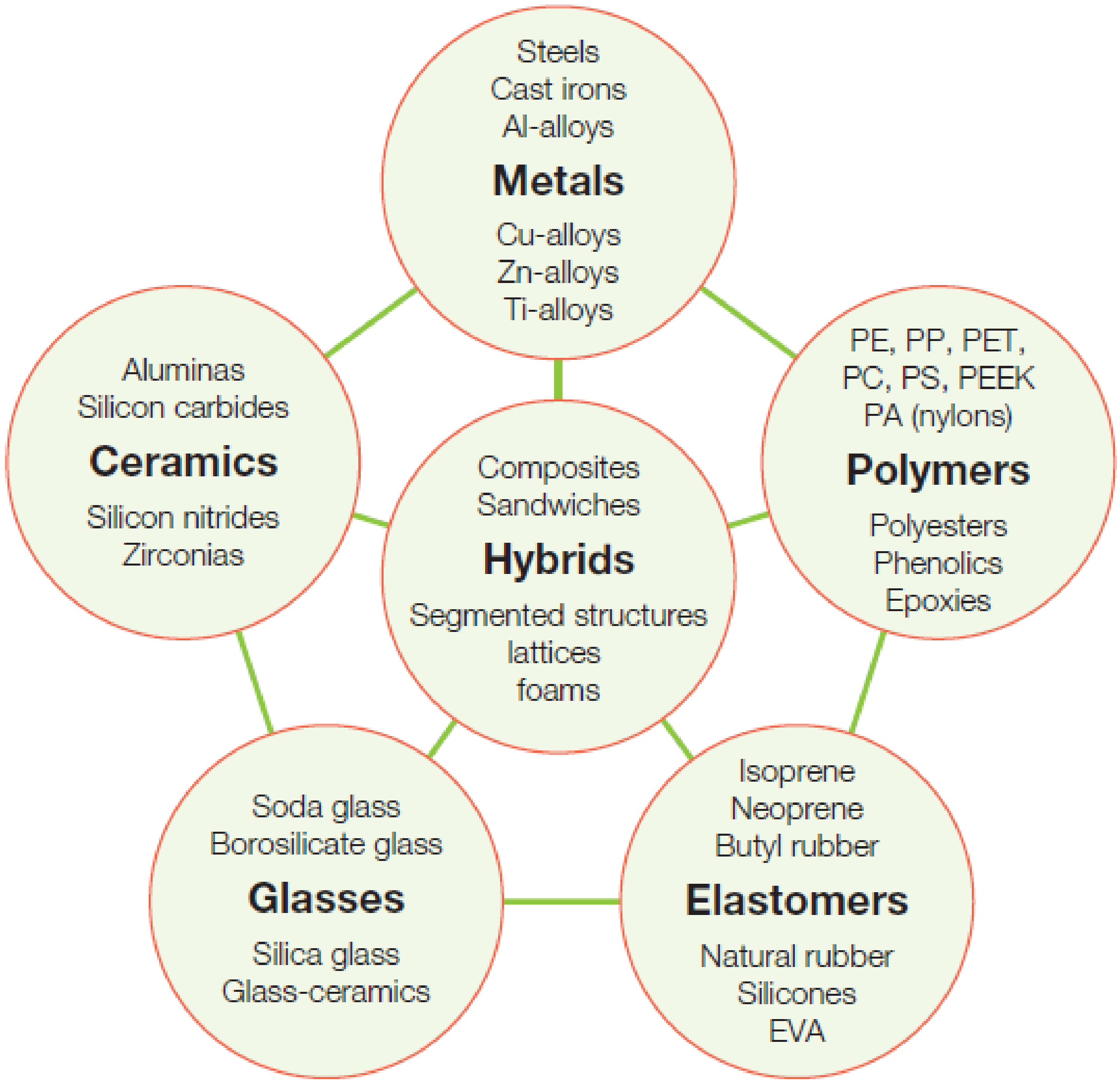
- History of materials
- Factors affecting materials consumption.
- Calculating growth rates.
- What are strategic (critical) materials?
- Introduction to sustainability
- Assessing sustainability

Source: Chapter 20, Leica Geosystems, Switzerland.

History of materials - Timeline

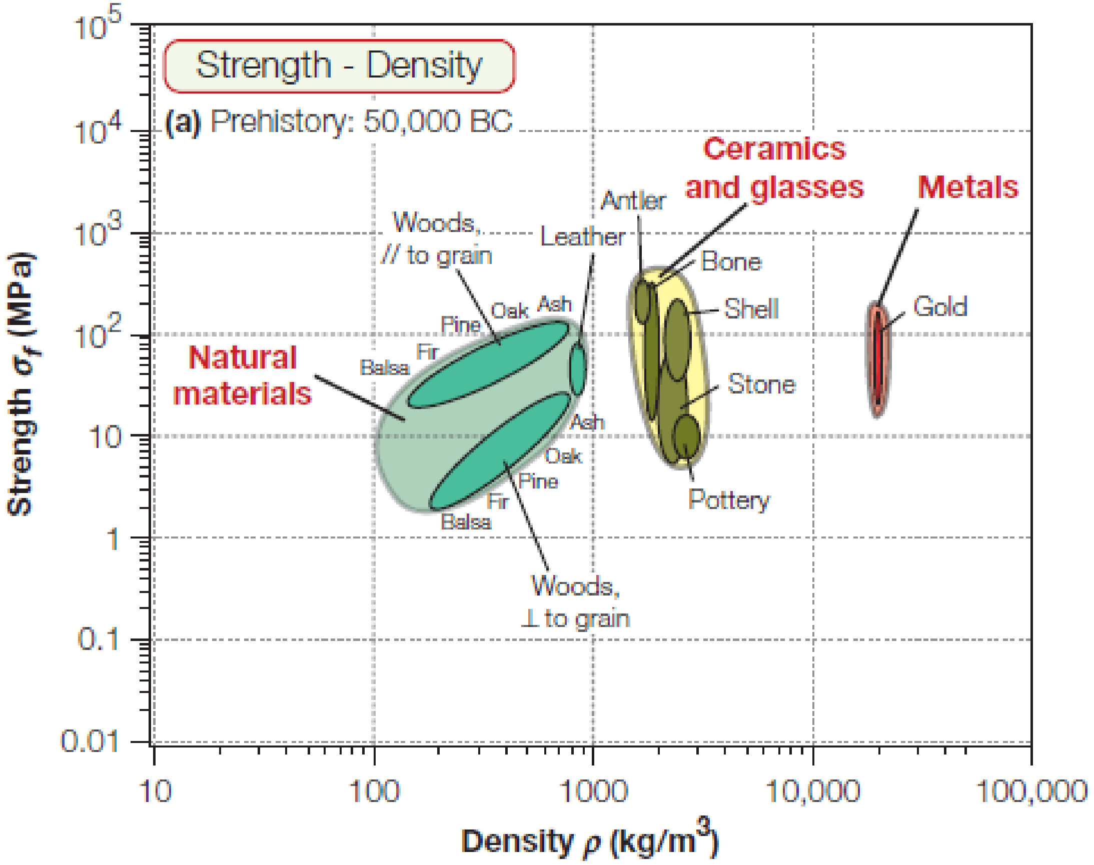


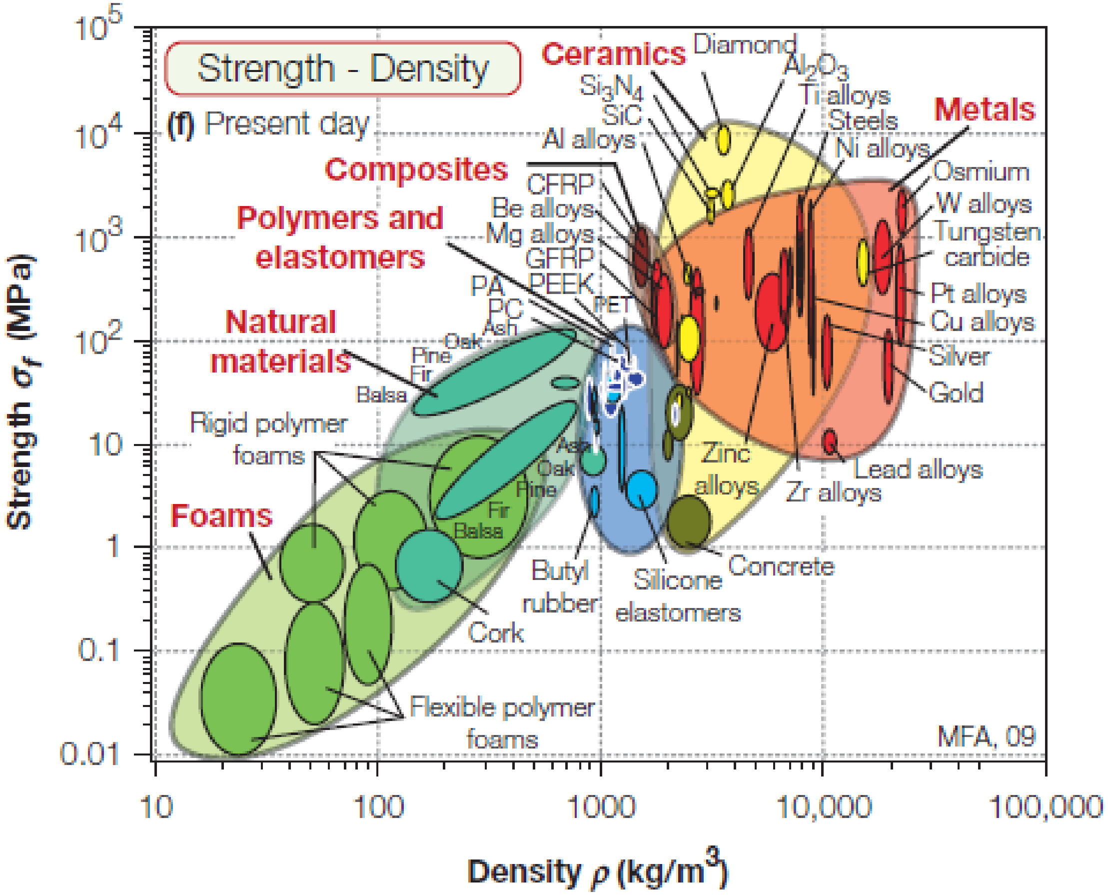
Material families



- **Metals:** Relatively high elastic moduli. Ductile, allowing them to be formed by deformation processes.
- **Ceramics:** Have high moduli, but unlike metal, brittle.
- **Glasses:** Noncrystalline("amorphous") solids. The most common are soda-lime and borosilicate glasses familiar as bottles and ovenware.
- **Polymers:** Moduli roughly 50 times lower than metals, but they can be strong. Polymers can be crystalline, amorphous, or a mix
- **Elastomers:** Long-chain polymers above their glass-transition temperature, Tg. unique properties: Young's moduli as low as 10^{-3} GPa and have enormous elastic extension.
- **Hybrids:** Combinations of two or more materials in a predetermined configuration and scale.

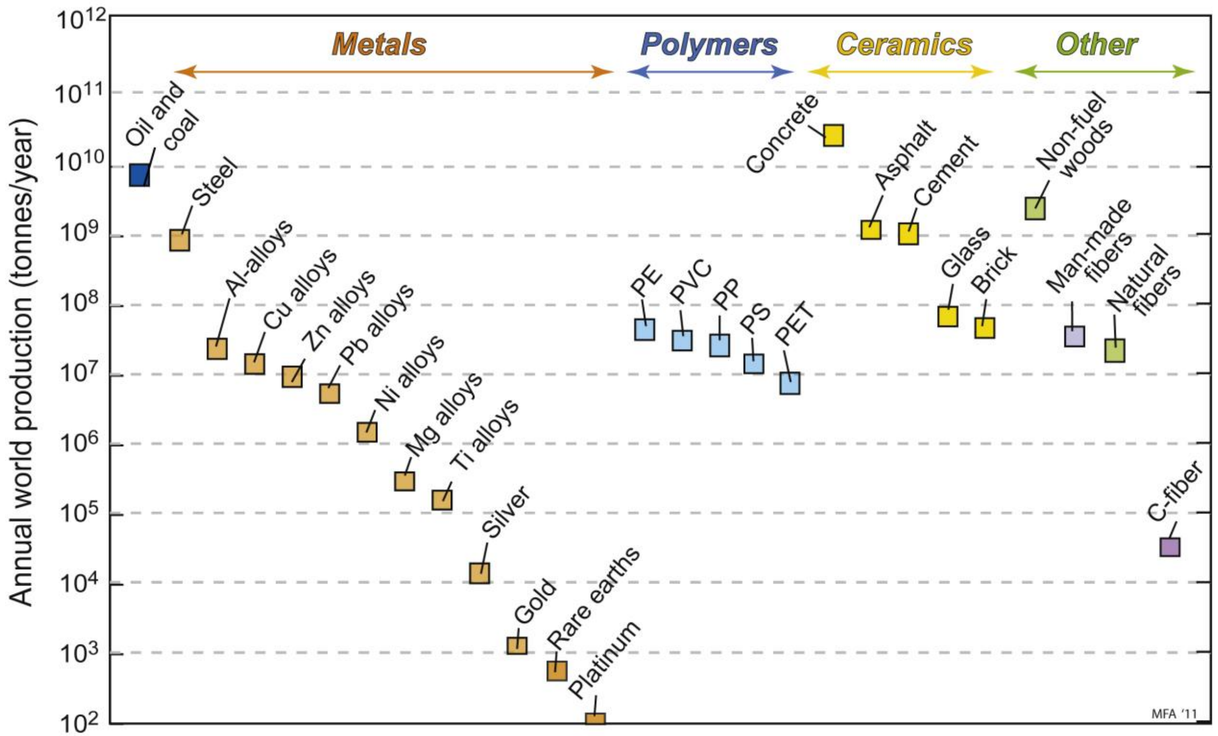
Evolution of materials





Evolution of materials

Materials Consumption



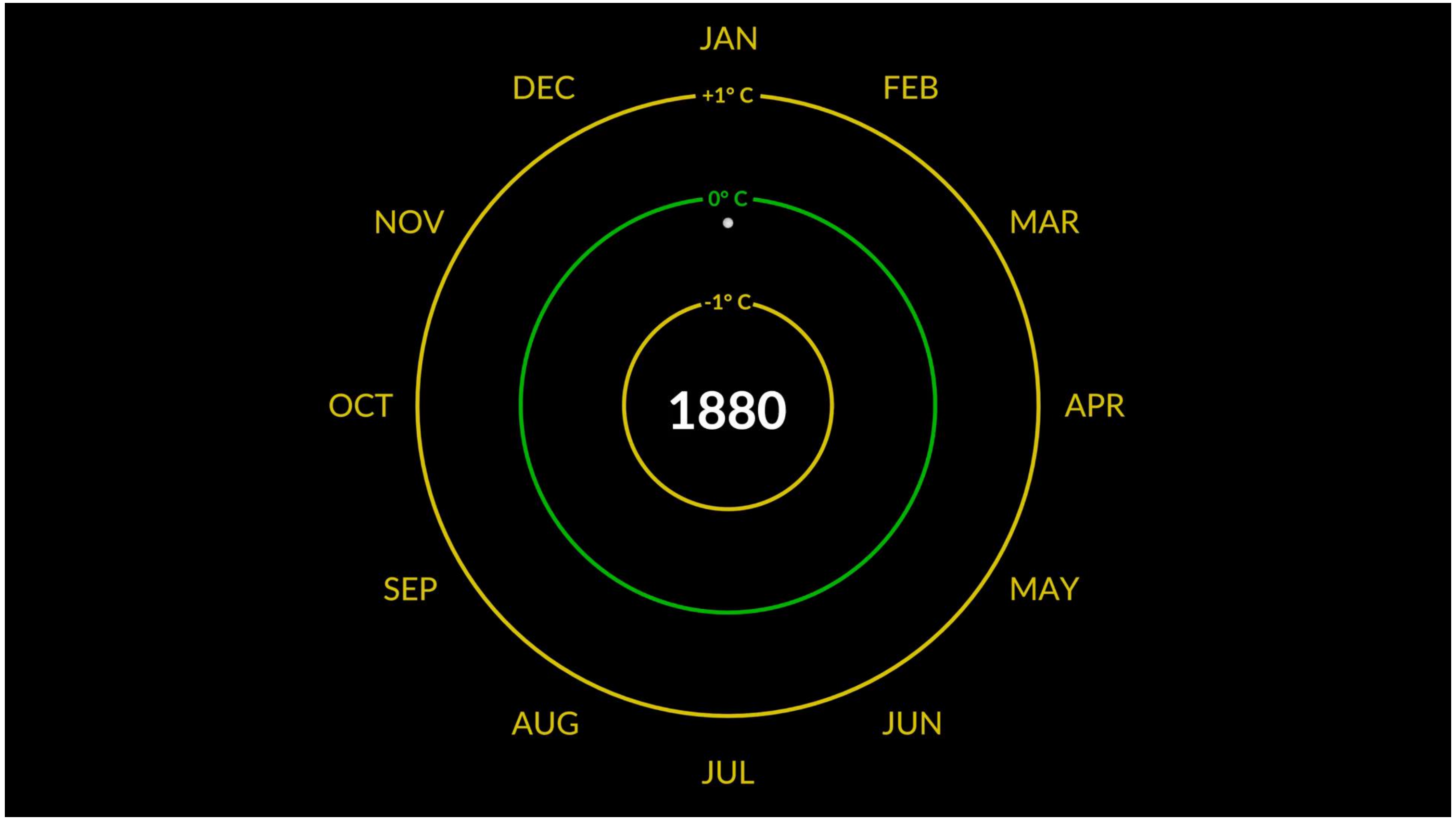
The consumption of hydrocarbons and engineering materials (see Fig. 20.1)

Globally, we consume 10^{10} tonnes of engineering 'stuff' *every year.*

- Hydrocarbon fuels (oil and coal) dominate - 9 x 10^{10} tonnes p.a.
- Construction industry consumes vast quantities of materials (wood, steel, concrete, asphalt (tarmac), glass).
- Big growth in carbon fibre (driven by expansion in aerospace)

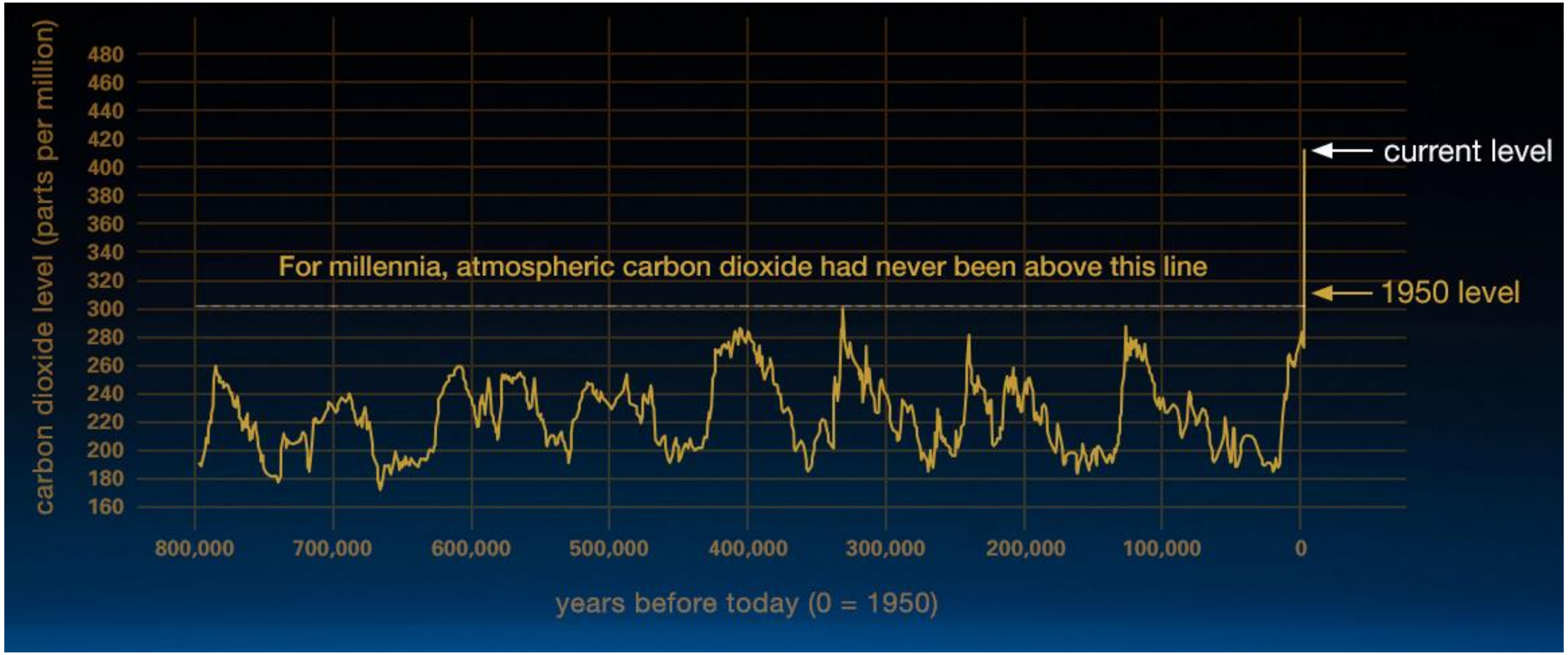
Climate Change

Climate change is real and the impacts are potentially devastating.

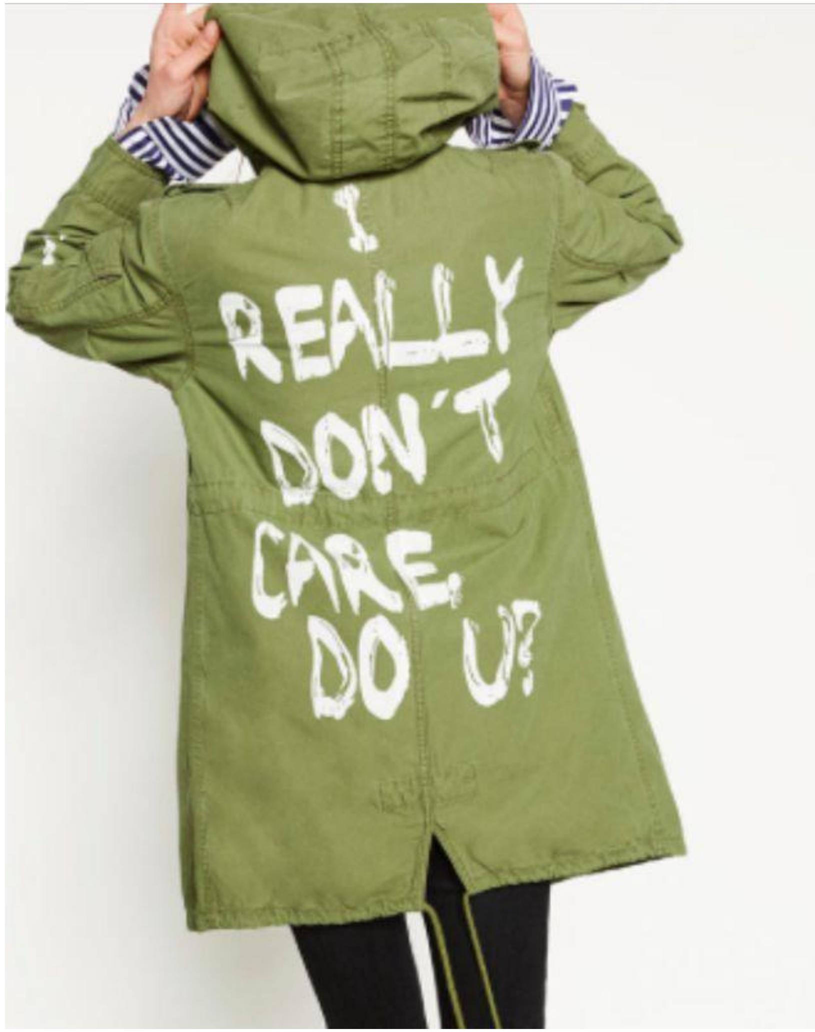


Source: https://climate.nasa.gov/climate_resources/300/video-climate-spiral/

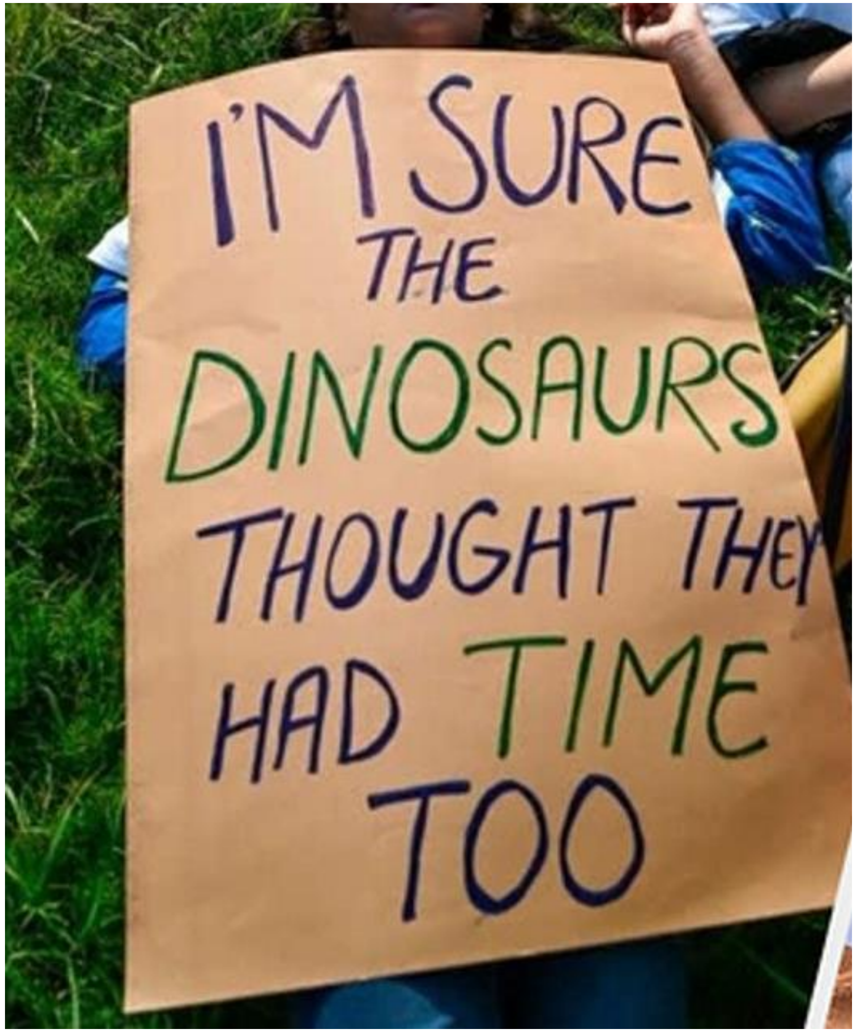
Smoking gun: carbon dioxide



Do I care?

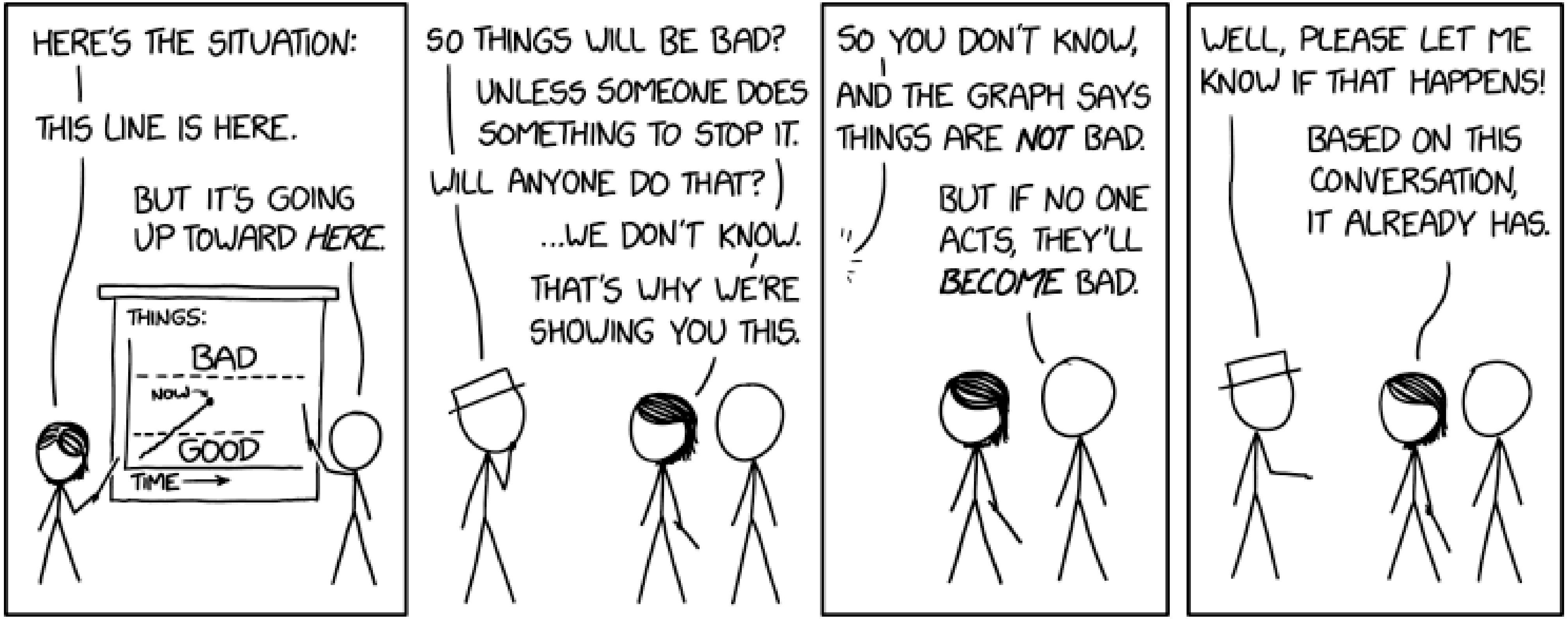


Zara, AP/Andrew Harnik



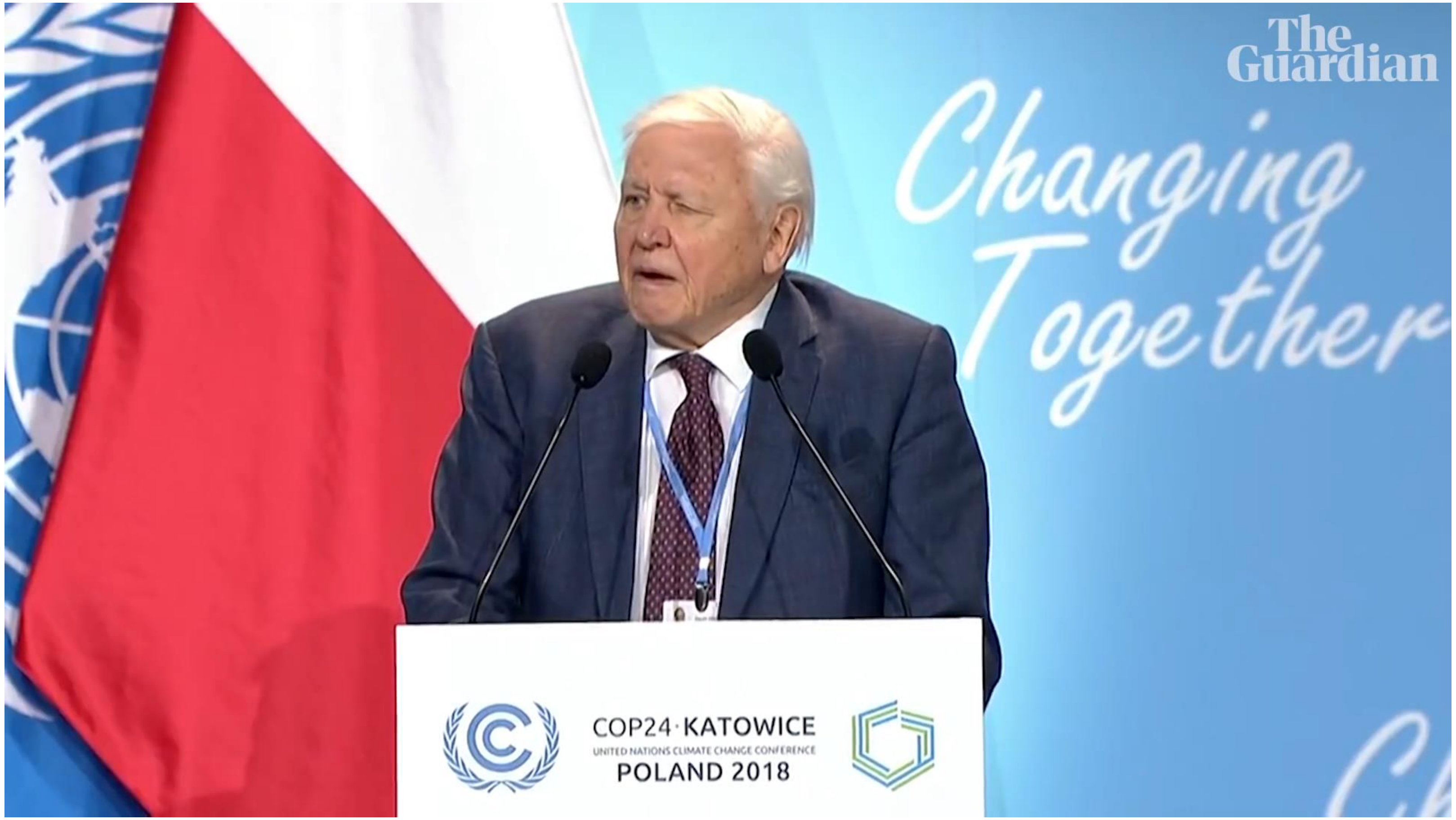
Aamir Qureshi / AFP / Getty Images

And so…



https://www.explainxkcd.com/wiki/index.php/2278:_Scientific_Briefing

Why Study Sustainable Development?



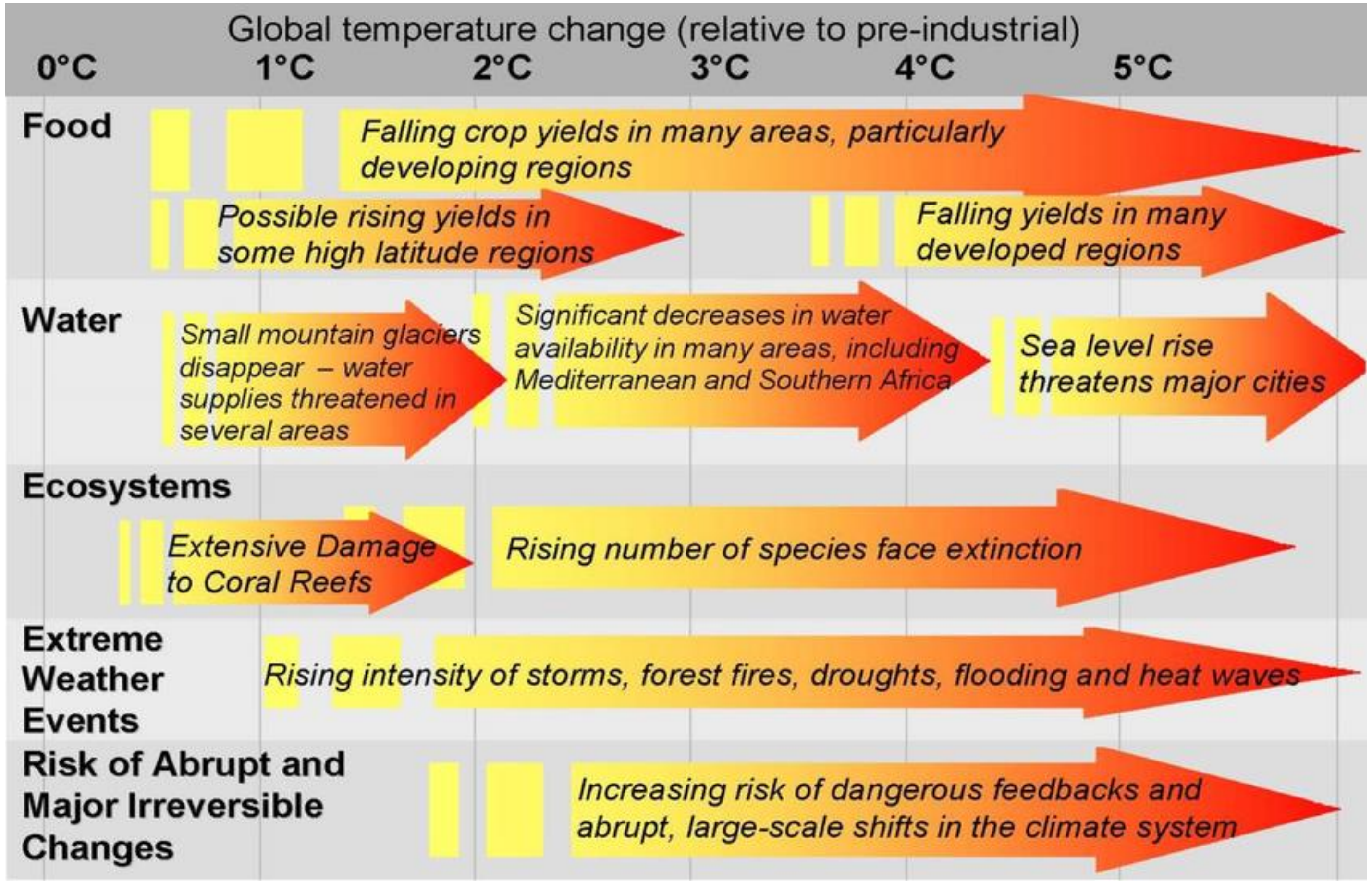
‘Continuation of civilisation is in your hands’

Keynote Address: Sir David Attenborough

https://youtu.be/b6Vh-g0oZ9w

UN Climate Conference, Katowice, Poland, 03 Dec- 14 Dec 2018

Projected impacts of climate change

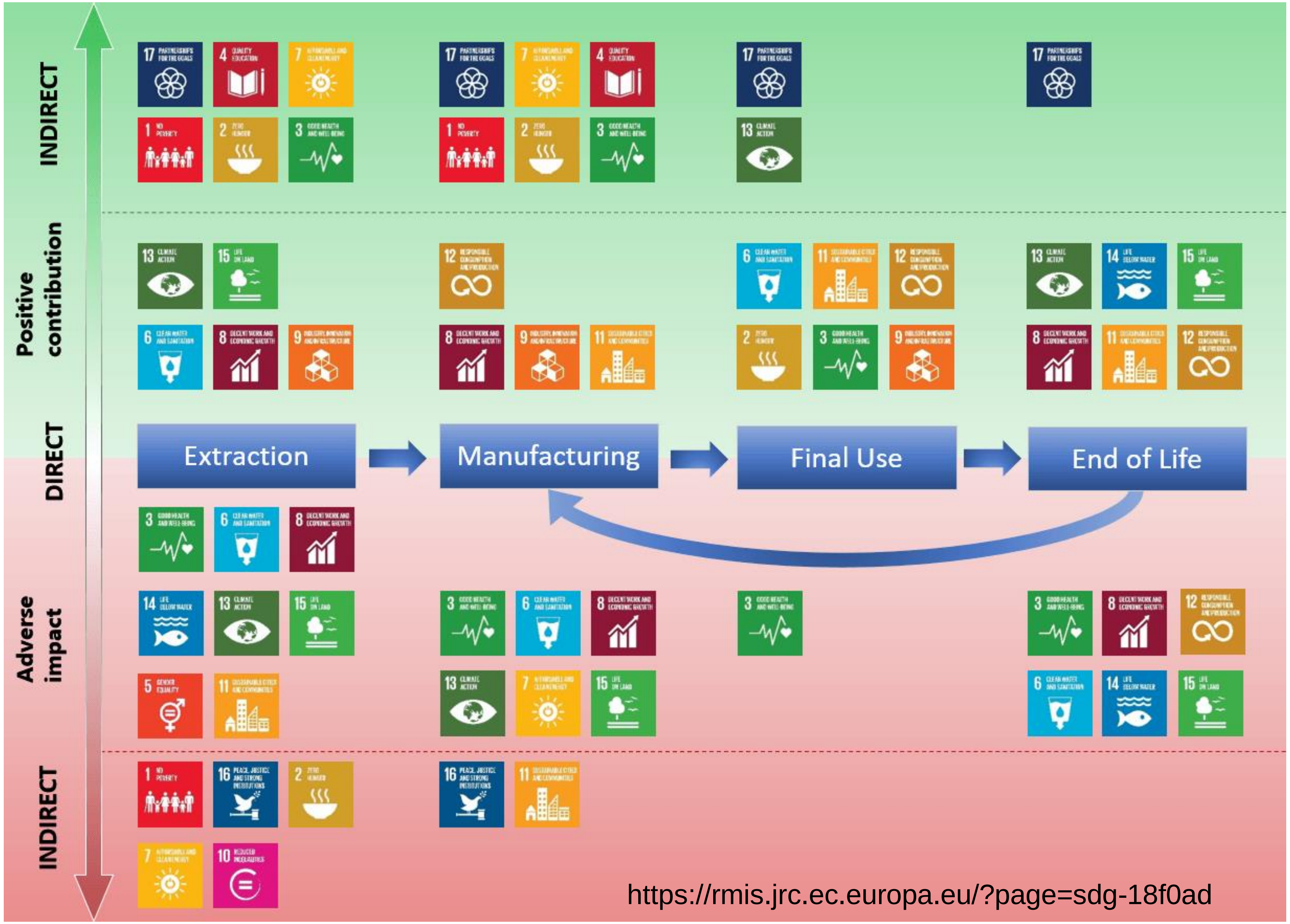


Sustainable development

"Meeting the needs of the present without compromising the ability of future generations to meet their own needs."

An enduring, balanced approach to economic activity, environmental responsibility and social progress

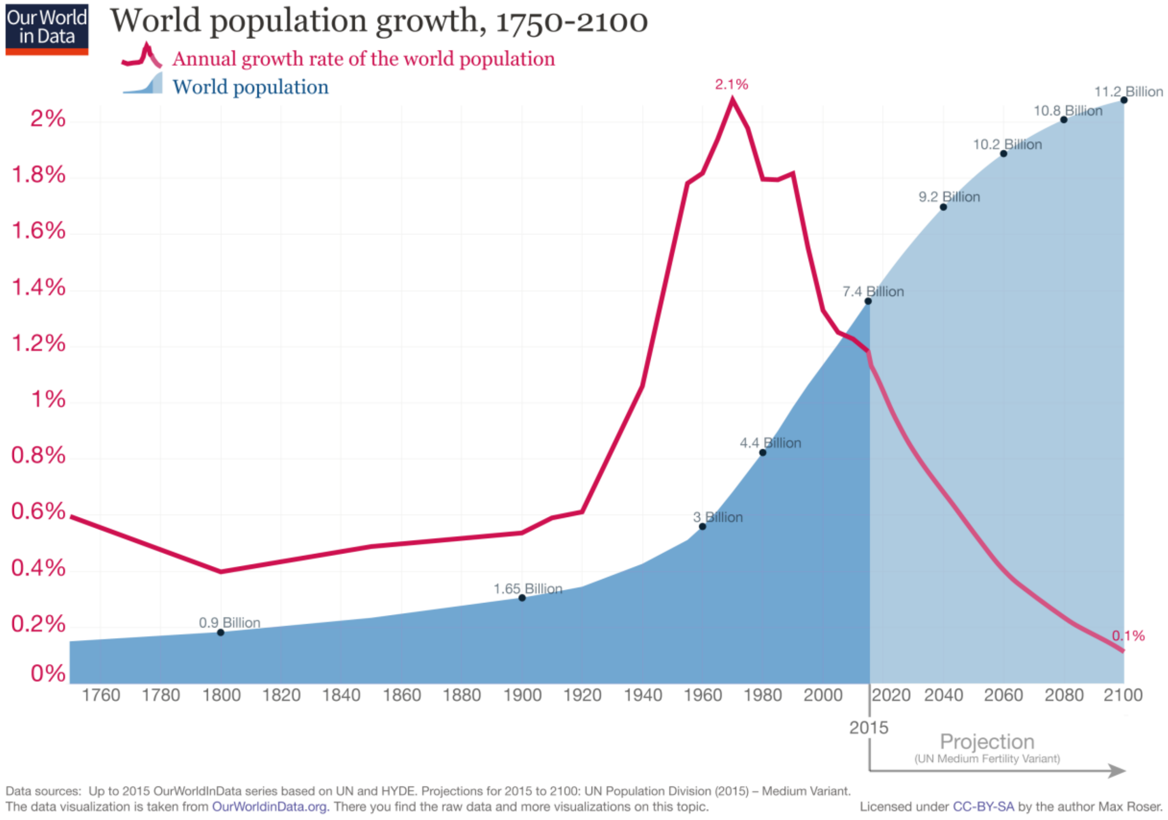
SDGs and materials

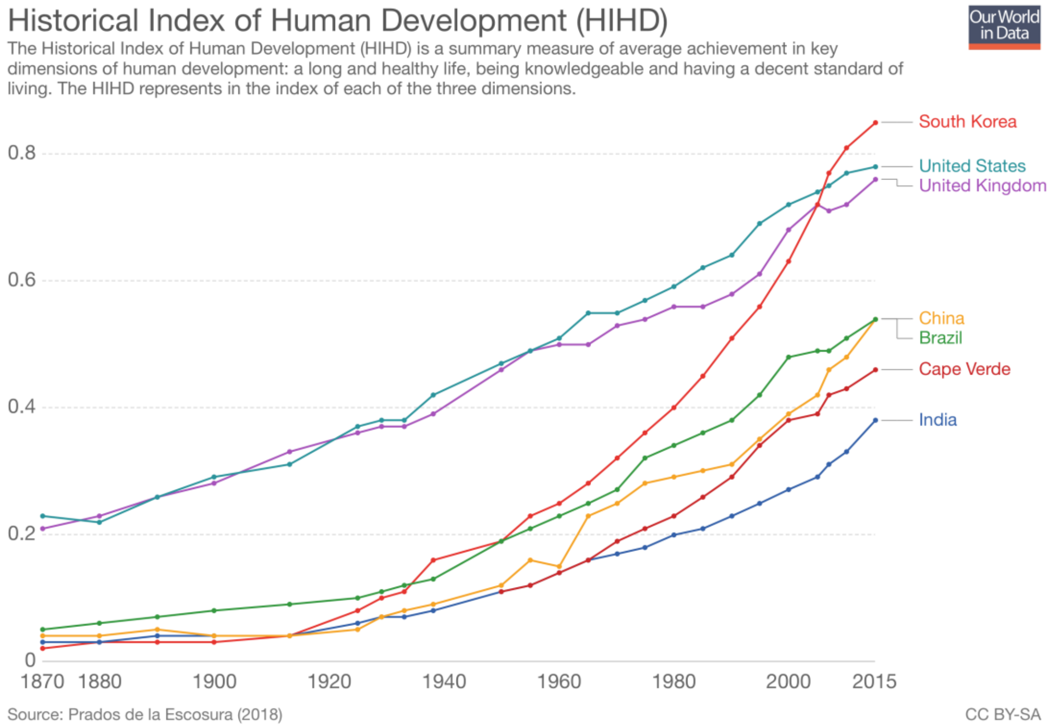


https://rmis.jrc.ec.europa.eu/?page=sdg-18f0ad

Population and Living Standards

- A growing population for the foreseeable future.
- Increasing human longevity, wealth, health, living standards.



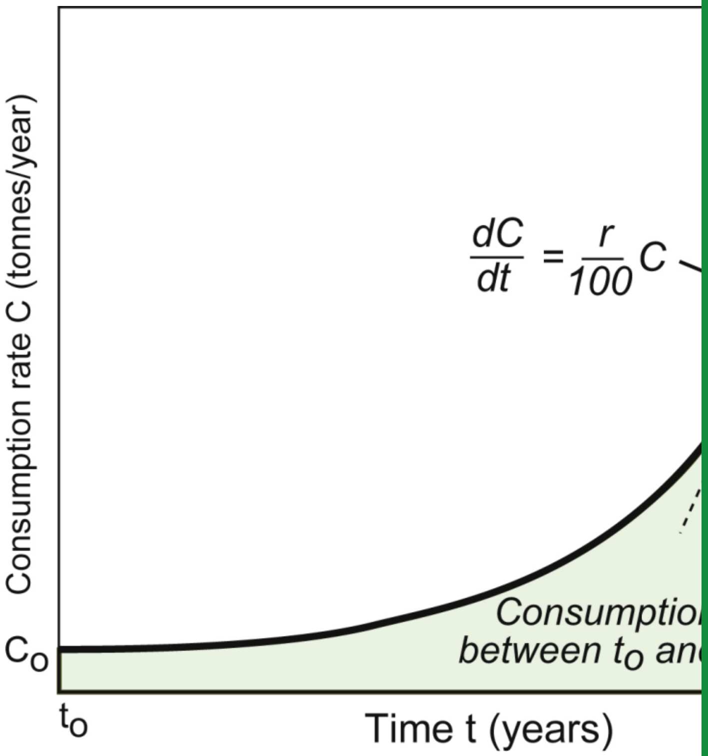


Source: Our World in Data
https://ourworldindata.org

The Growth of Materials Consumption

Most materials consump … e.

- Both population and livin …



$$\frac{dC}{dt} = \frac{r}{100} C$$

urrent rate of
umption in tonnes/year.

Exponential growth (see Fig. 20.2)

Rates of Materials Consumption

Small growth rates (1-5% per year), consider *r* as percentage fractional rate of growth per year.

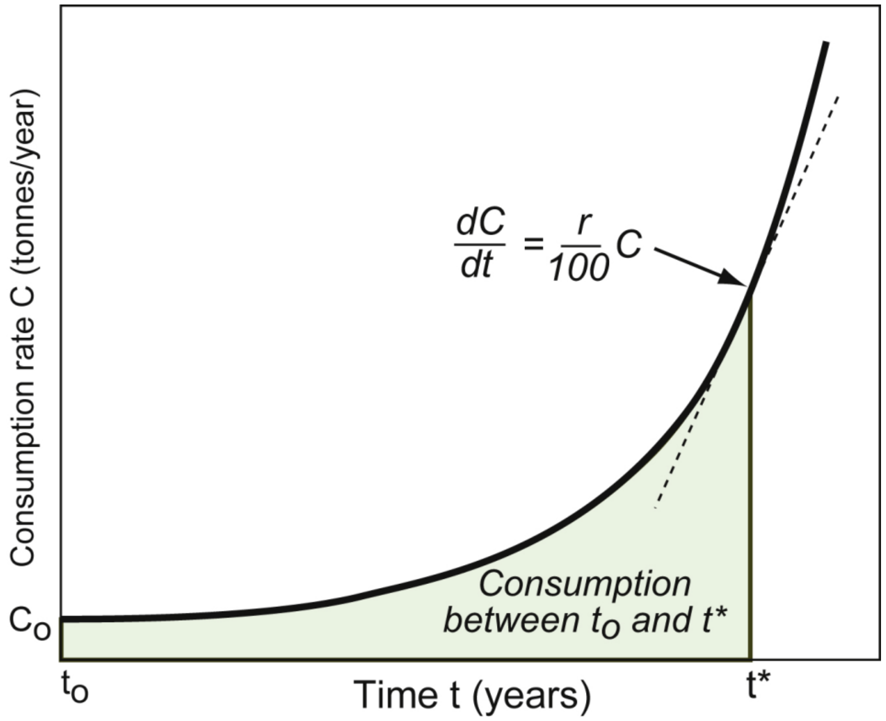
Integrating over time:

$$C = C_0 exp\left\{\frac{r(t - t_0)}{100}\right\}$$

where C_0 is consumption rate at $t = t_0$,

The doubling-time t_D of consumption rate obtained by setting C/C_0 to give

$$t_D = \frac{100}{r} log_e(2) \approx \frac{70}{r}$$



At a global growth rate of just 3% per year we will mine, process, and dispose of more 'stuff' in the next 25 years than in the entire history of human engineering.

Calculating Growth Rates

Example 1: Annual growth rate.

World production of silver in 1950 was 4000 tonnes/year. By 2010 it had grown to 21,000 tonnes/year. Assuming exponential growth, what is the annual growth rate of silver production?

Answer:

$$P = P_0 exp\left\{\frac{r(t - t_0)}{100}\right\}$$

where P_0 is production rate at $t = t_0$. Setting P = 21,000 tonnes/year, (P_0 = 4000 tonnes/year) and ($t - t_0$) = 60 years, then solving for growth rate, r:

$$r = \frac{100}{(t - t_0)} \ln\left(\frac{P}{P_0}\right) = 2.8\% \text{ per year}$$

Calculating Cumulative Growth

Example 2: Cumulative growth.

A total of 5 million cars were sold in China in 2007; in 2008 the sales totalled 6.6 million. What is the annual growth rate of car sales, expressed as %/year?

Answer:

$$C = C_0 exp\left\{\frac{r(t - t_0)}{100}\right\}$$

where C = 6.6 x 10^6, C_0 = 5 x 10^6, $(t - t_0)$ = 1 year, then solve for r: 27.8%/year.

Calculating Cumulative Growth

Example 2: Cumulative growth (continued).

If there were 5 million cars already on Chinese roads, by the end of 2007 and this growth rates continues, how many cars will there be in 2020, assuming that the number that are removed from the roads in this time interval can be neglected?

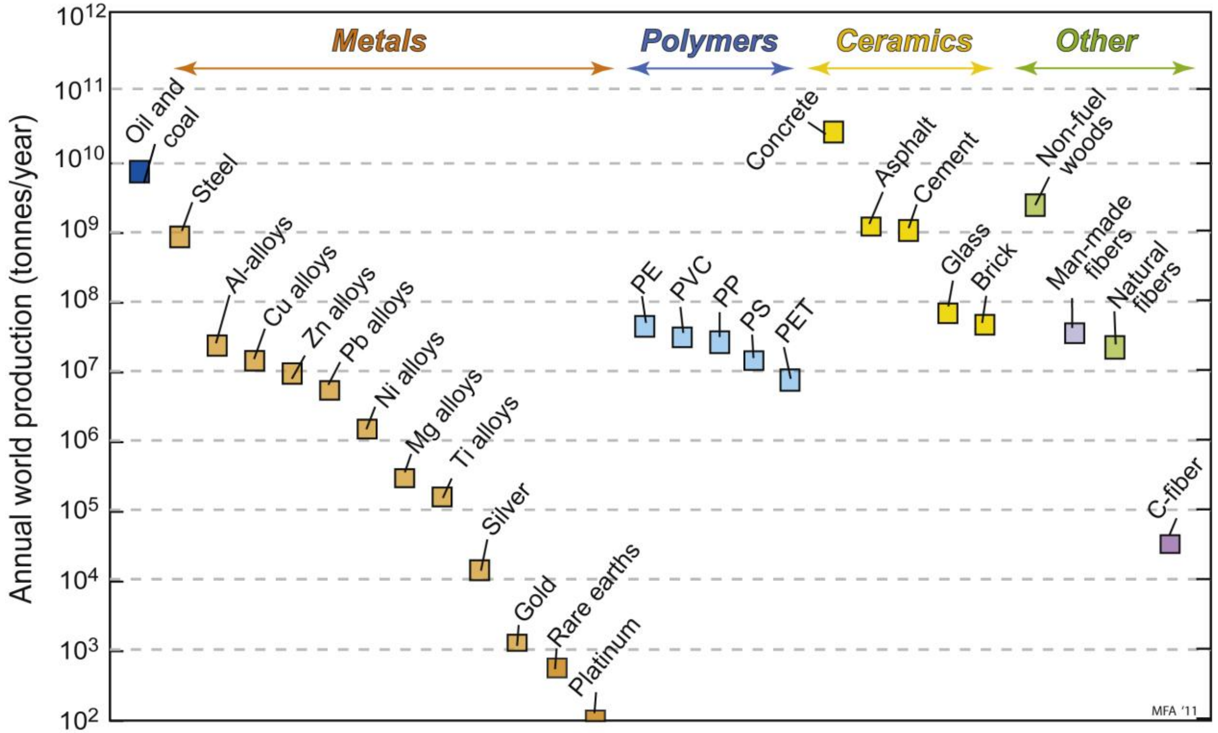
Answer:

$$Q_{t*} = \int_{t_0}^{t^*} C\,dt = \frac{100C_0}{r}\left(exp\left\{\frac{r(t^* - t_0)}{100}\right\} - 1\right)$$

C_0 = 5 x 10^6 (number in 2007), r = 27.8%/year, time interval (t^*-t_0) = 13 years (to 2020)
Additional number of cars by 2020 Q_{t*} = 650 x 10^6.

Total number of cars on Chinese roads in 2007 = 5 x 10^6 + 650 x 10^6 = 655 x 10^6.

Materials Consumption



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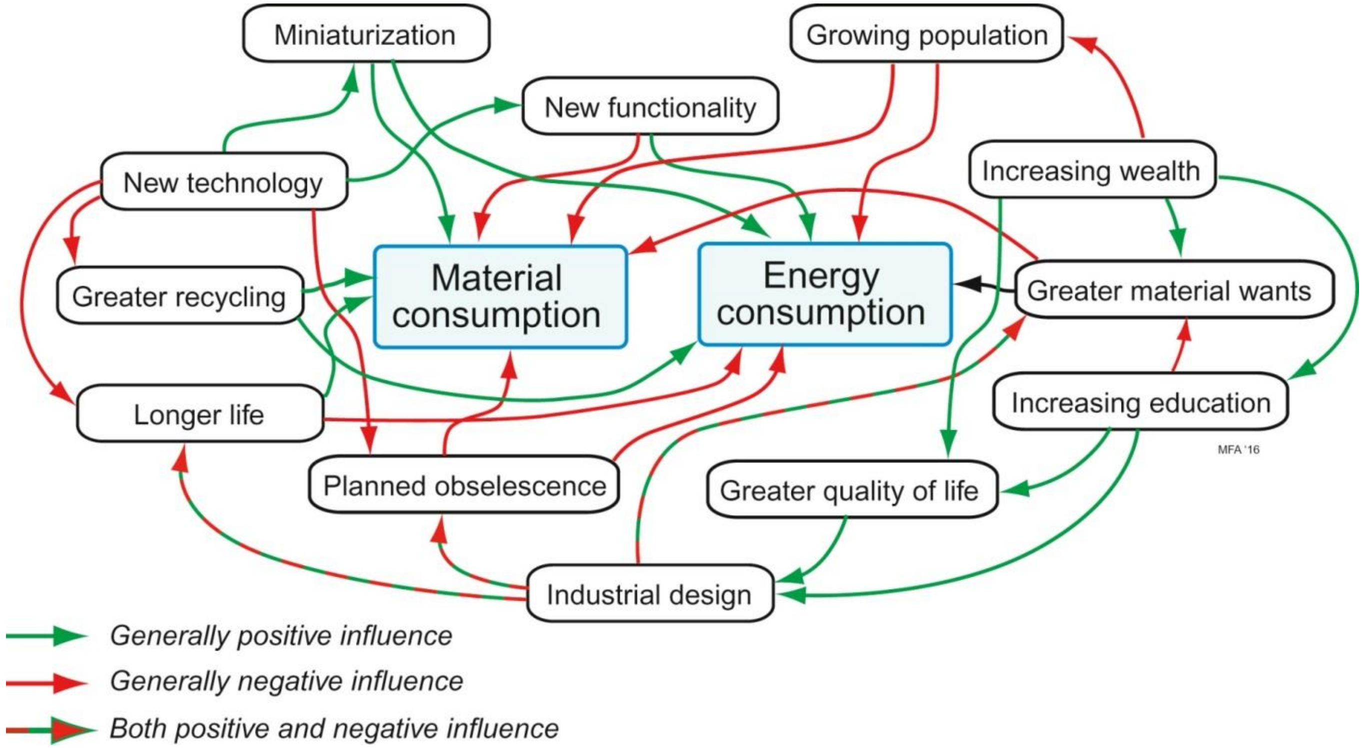
What Drives Consumption?

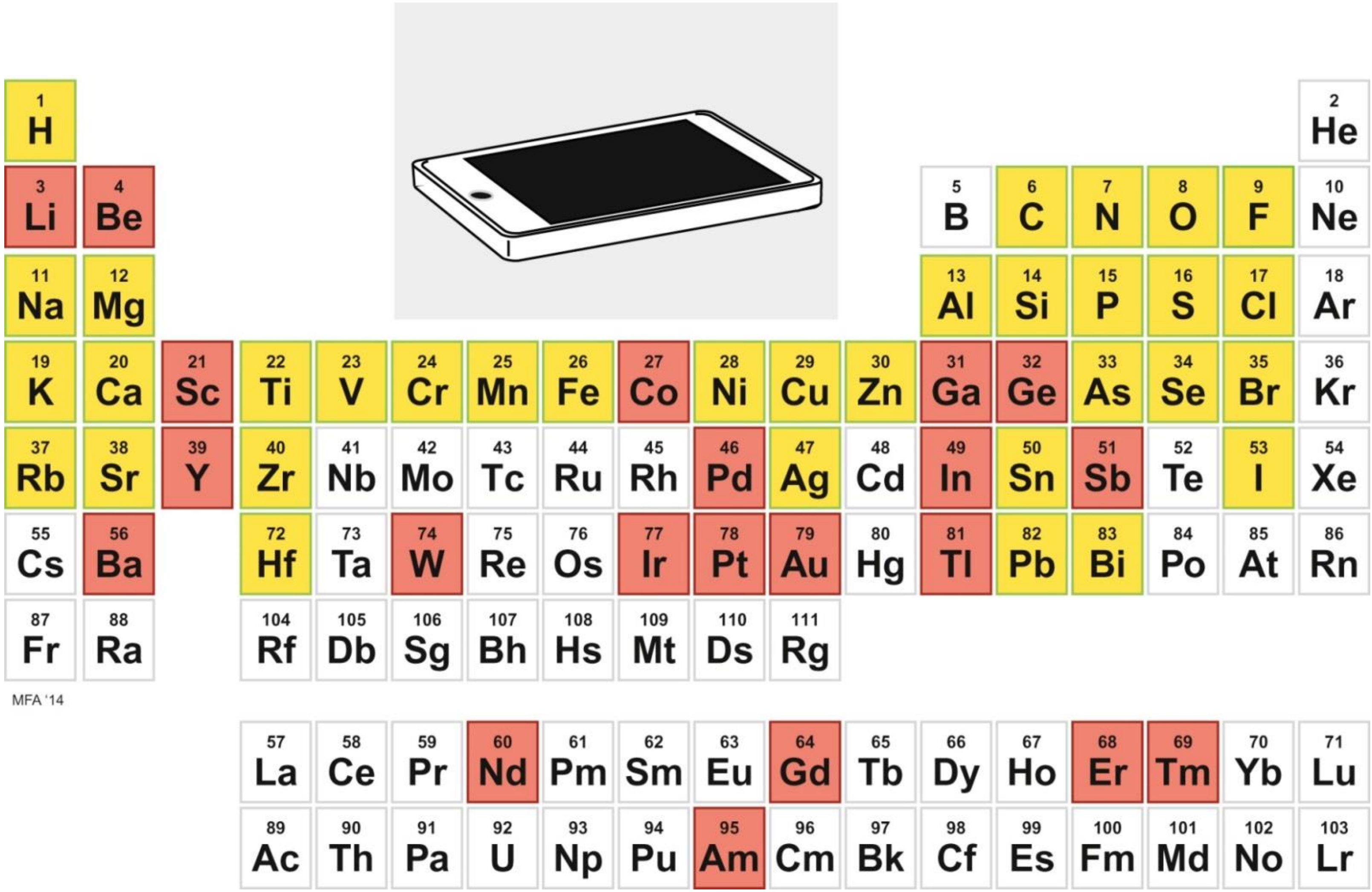
Eco-systems are complex (materials and energy interconnected).

- Primary catalysts of consumption: increasing wealth, population growth, new technology, planned obsolescence.



The influences on consumption of materials and energy (Materials Selection in Mechanical Design, Fig. 16.4)

‘The Periodic Table of Smart Phones’



Smart phones are dependent on many elements.

Materials Selection in Mechanical Design (see Fig. 16.4)

Strategic (Critical) Materials

Mineral resource bases – generally large and widely distributed.

- *e.g.* resource bases supplying steel and aluminium chain
- Vital to economy, but energy resource more likely to limit production

Why are materials ‘strategic’?

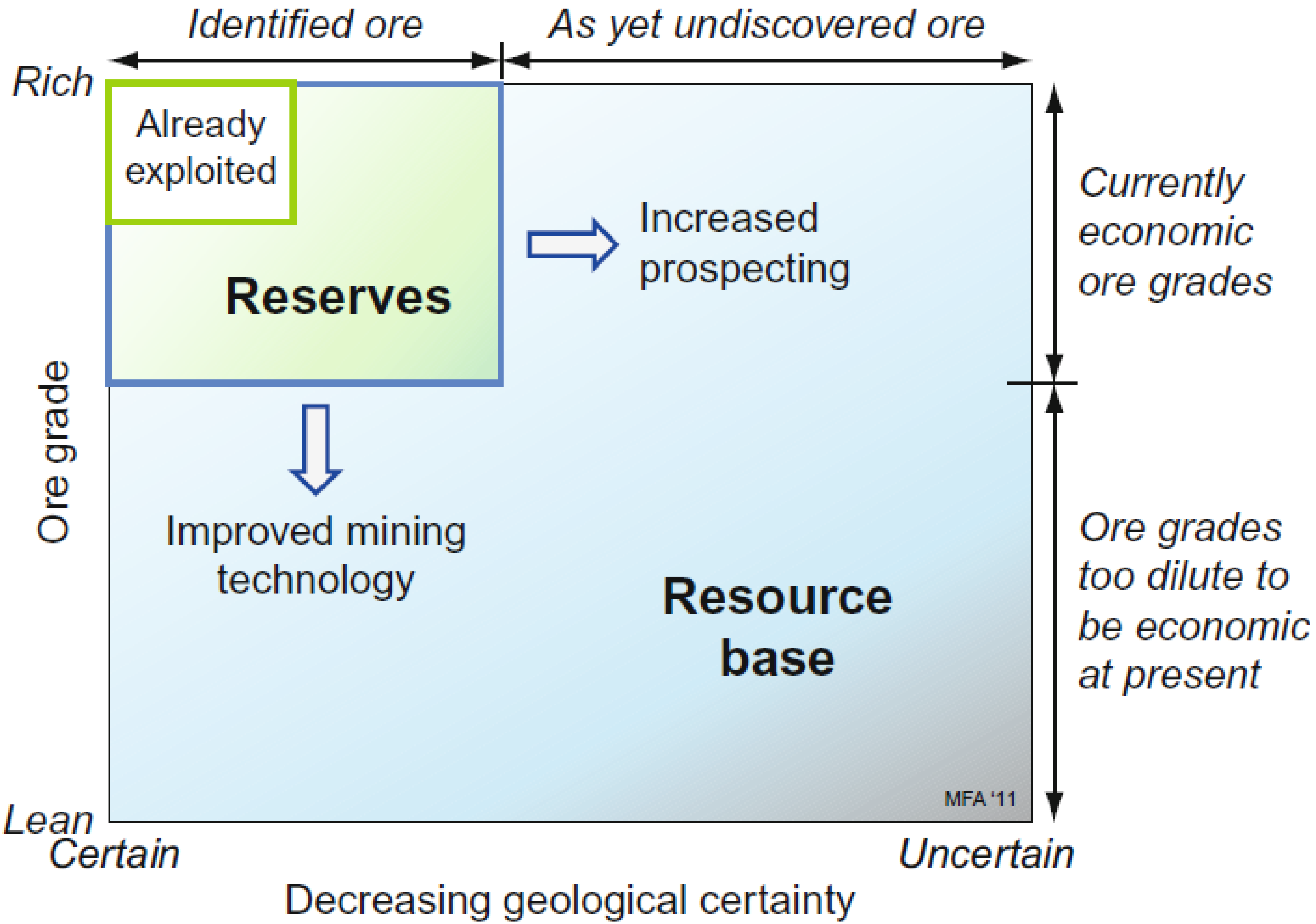
	Element	Critical applications	Principal global sources
General Engineering	Copper	Electrical conduction (wiring) in all electro-mechanical items	Canada, Chile, Mexico
	Manganese	Essential alloying element in steels	South Africa, Russia, Australia
	Niobium	Micro-alloyed steels, superalloys, superconductors	Brazil, Canada, Russia
	Tantalum	Ultra-compact capacitors (smart phones), alloying in steels	Australia, China, Thailand
	Vanadium	High speed tool steels, micro-alloyed steels	South Africa, China
	Titanium	Light, high strength, corrosion-resistant alloys	China, Russia, Japan
Electronics	Lithium	Lithium ion batteries, Al-Li alloys for aircraft	Russia, Kazakhstan, Canada
	Gallium	Gallium-arsenide Photo-Voltaic devices, semi-conductors	Canada, Russia, China
	Indium	Transparent conductors, InSb semi-conductors, LEDs	Canada, Russia, China
	Germanium	Solar Cells	China
Catalysts	Platinum	Catalyst in chemical engineering and engine exhausts	South Africa, Russia
	Palladium	Catalyst in chemical engineering and engine exhausts	South Africa, Russia
	Rhodium	Catalyst in chemical engineering and engine exhausts	South Africa

Strategic (Critical) Materials (continued)

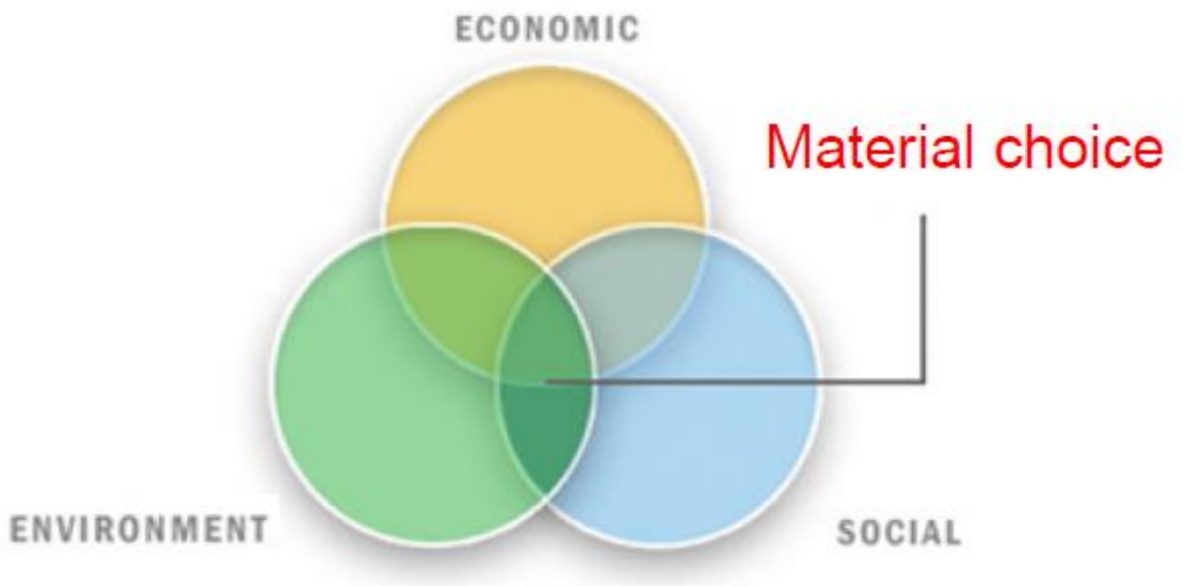
Rare Earth Elements

Element	Critical applications	Principal global sources
Lanthanum	High RI glass, H storage, battery electrodes (hybrid cars), camera lenses	China, Japan, France
Cerium	Catalysis, alloying element in aluminium alloys	China, Japan, France
Praesodymium	Rare earth magnets, materials for lasers	China, Japan, France
Neodymium	**Rare earth permanent magnets, materials for lasers**	**China, Japan, France**
Promethium	Nuclear batteries (beta-emissions to electric power)	China, Japan, France
Samarium	Rare earth magnets, lasers, neutron capture	China, Japan, France
Europium	Red and blue phosphors, lasers, mercury-vapour lamps	China, Japan, France
Gadolinium	Rare-earth magnets, high RI glass, garnets, lasers, X-ray tubes, computer memory	China, Japan, France
Terbium	Green phosphors, lasers, fluorescent lamps	China, Japan, France
Dysprosium	Rare earth magnets, materials for lasers	China, Japan, France
Holmium	Materials for lasers	China, Japan, France
Erbium	Materials for lasers, vanadium steel	China, Japan, France
Ytterbium	Infrared lasers, high temperature superconductors	China, Japan, France
Lutetium	Catalyst in petroleum industry	China, Japan, France

Material extraction



Three pillar thinking



- Along with economic considerations, the social and environmental performance of a material is crucial for making sustainable decisions.
- Traditional view: environmentalists vs. business
- Radically redesign our industrial systems to create more value with fewer resources

New design paradigm

Design for *Environment*.

- Generally interpreted as effort to adjust present product design efforts to correct known, measurable environmental degradation
- Timescale around 10 years (average product’s life).

https://www.weforum.org/agenda/2017/06/when-willwe-see-the-airplane-equivalent-of-a-tesla-the-2017-sae-roadmap-to-more-electric-flight/-

Design for *Sustainability.*

- Longer term view, much greater intervention
- Adaptation to lifestyle to meet present needs of future generations
- Timescale measured in decades or centuries

http://theprereq.com/new_sustainability-building-design/incredible_sustainability-building-design-singapore-energy-efficient-green-heart

Design for Environment

Materials down-selection

- Avoid use of hazardous or toxic materials
- Avoid use of materials known to have a high energy content
- Design in a way which minimises materials use and waste
- Minimise the number of different types of materials you use
- Design with natural materials or recycled materials

Production

- Avoid using hazardous or toxic consumables or other materials required during manufacture
- Avoid energy intensive processes or multiple process steps which require energy input
- Optimise use of heat exchangers/other ways to utilise waste heat
- Minimise manufacturing waste
- Minimise energy use from production facility through efficient use of temperature controls/lighting/material storage etc.

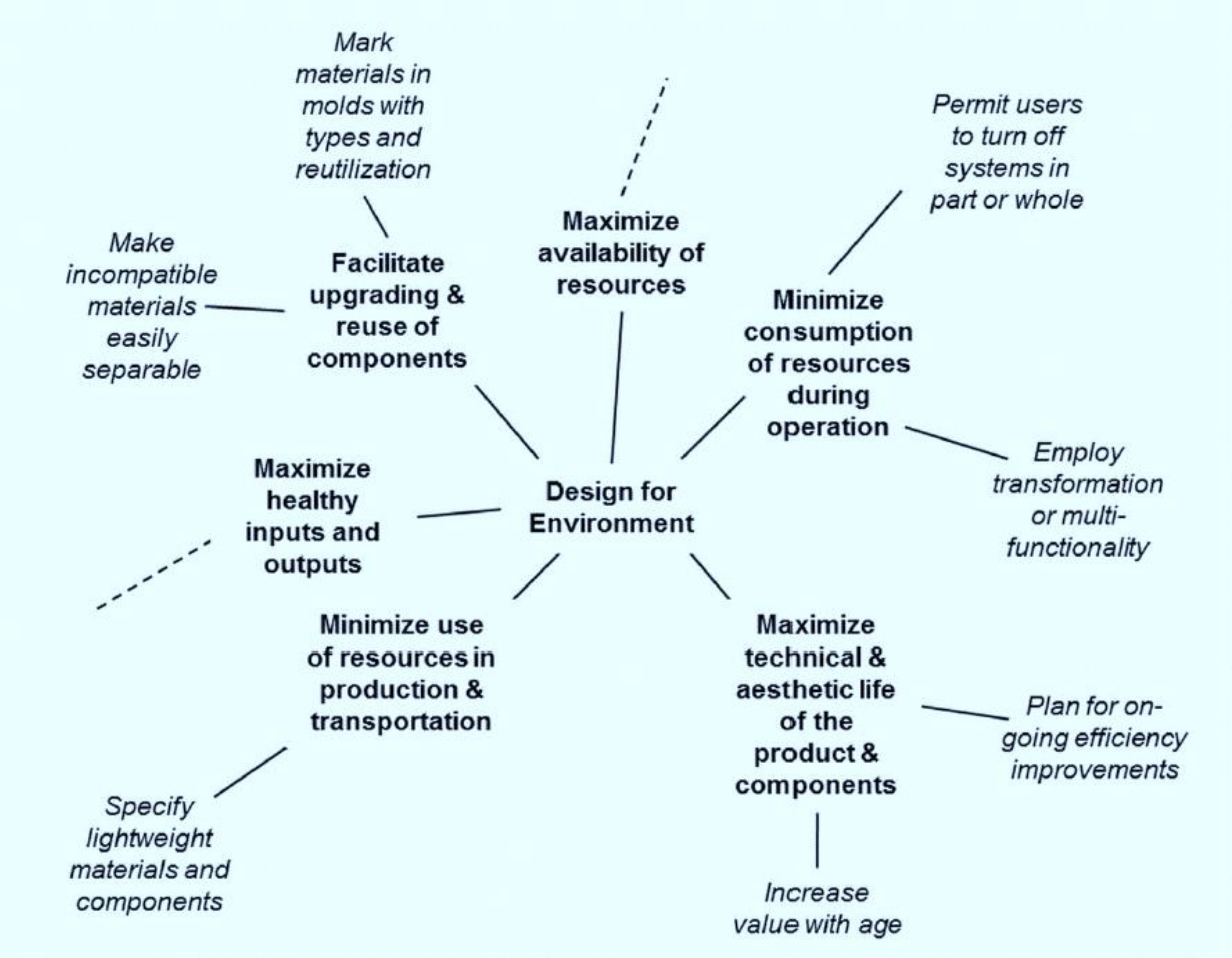
Sustainable material selection

- Sustainable material selection involves choosing materials that have a minimal impact on the environment throughout their lifecycle, from extraction or production to disposal or recycling.
- This approach aims to reduce environmental degradation, conserve resources, and minimize pollution.

Strategies

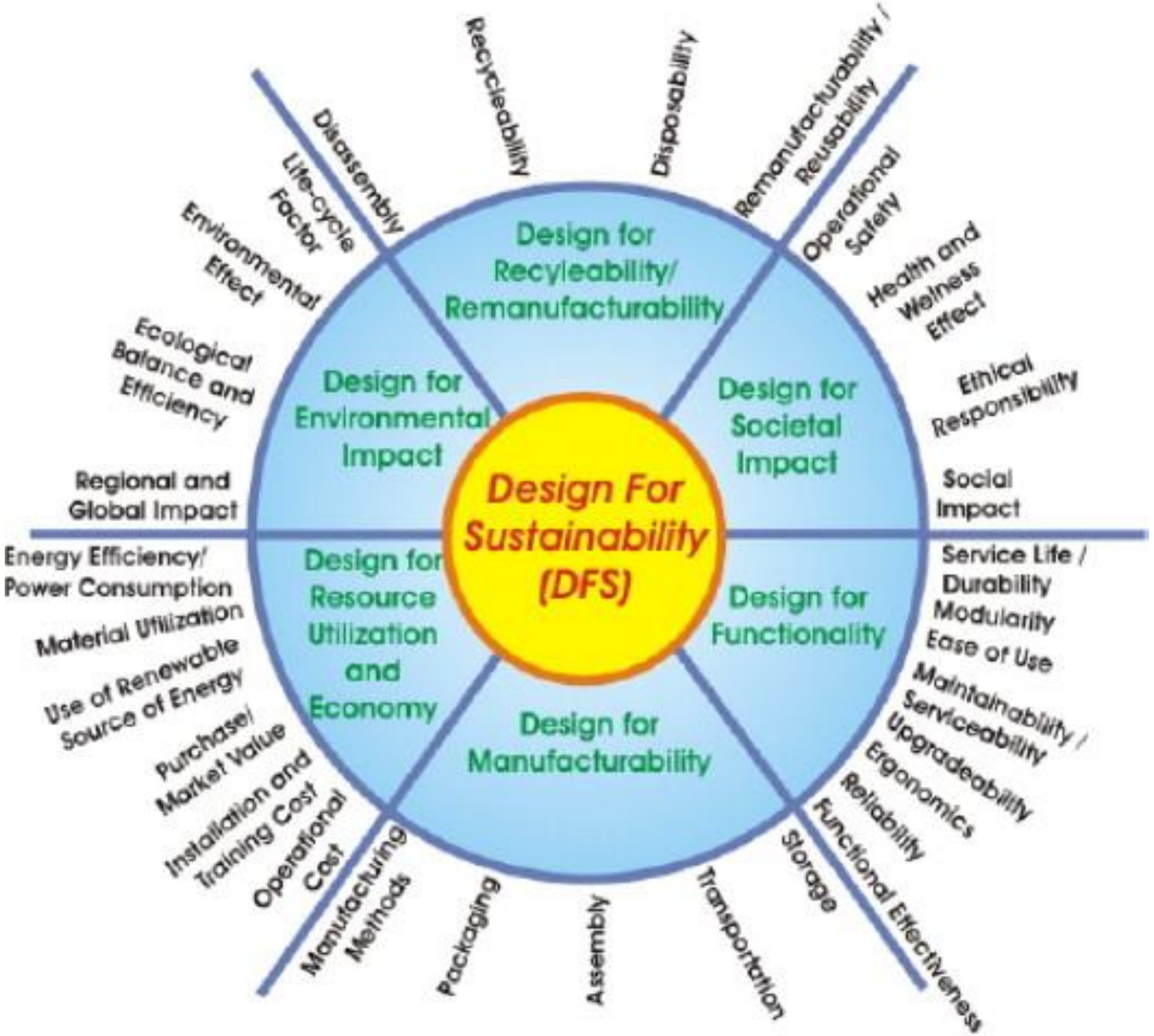
- **Renewable Resources**
- **Recyclability and Reusability**
- **Durability and Longevity**
- **Energy and Resource Efficiency**
- **Life Cycle Analysis (LCA)**

Design for environment



Telenko C, O'Rourke JM, Conner Seepersad C, Webber ME. A compilation of design for environment guidelines. Journal of Mechanical Design. 2016 Mar 1;138(3):031102.

Design for sustainability

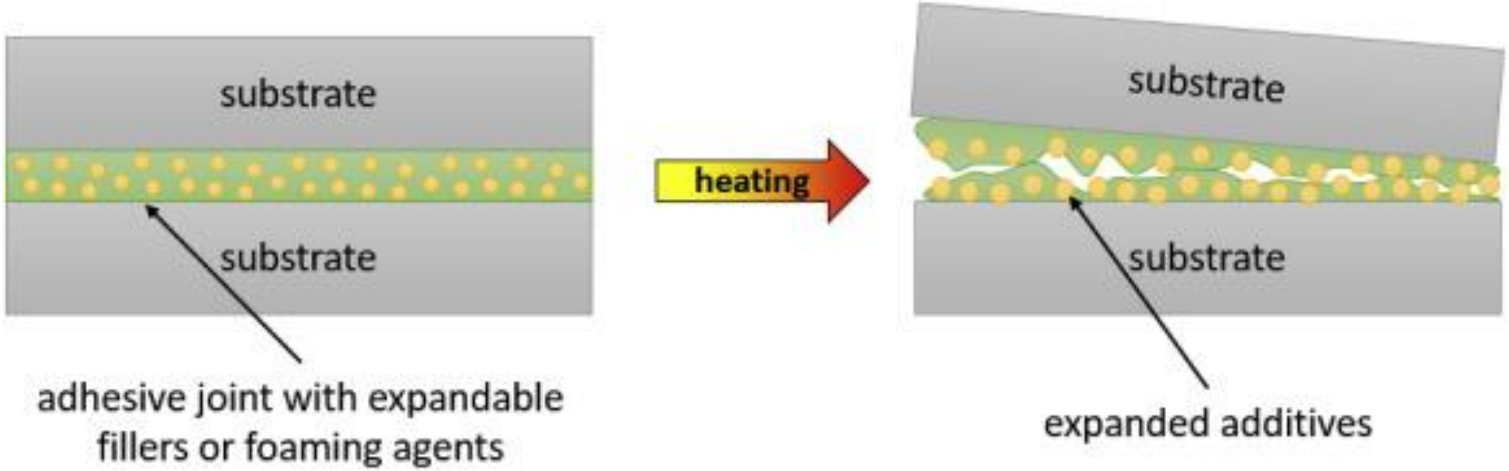


DfS is an approach to product design focused on minimizing environmental impact and enhancing resource efficiency throughout the product lifecycle.
Goal: Reduce negative environmental impacts while maximizing social and economic benefits.

Design for disassembly

- A sustainable design approach focused on creating products that can be easily disassembled at the end of their life.
- Facilitates recycling, repair, and reuse to support a circular economy and minimize waste.

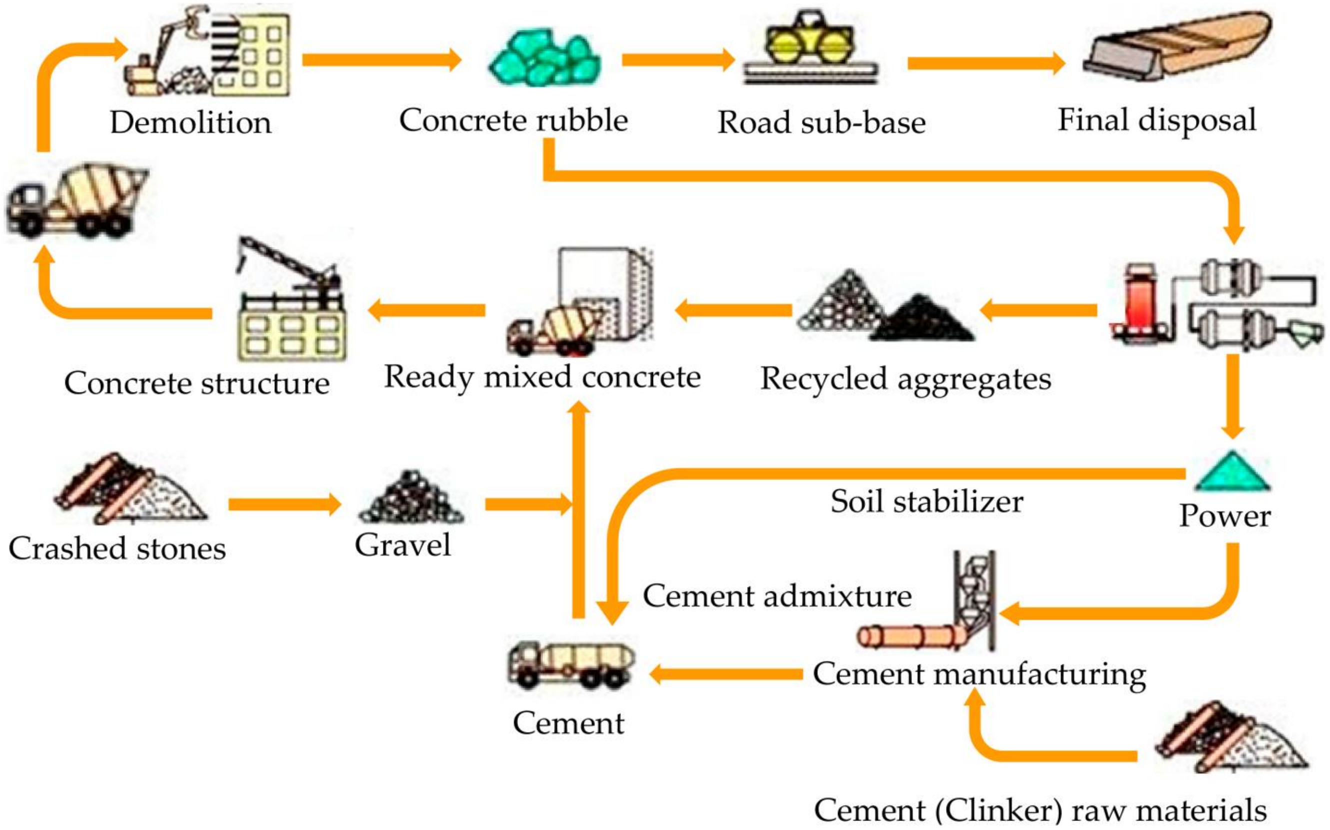
- Modular Design
- Material Compatibility
- Standardized Connections
- Minimize Components



https://doi.org/10.1016/j.ijadhadh.2020.102585

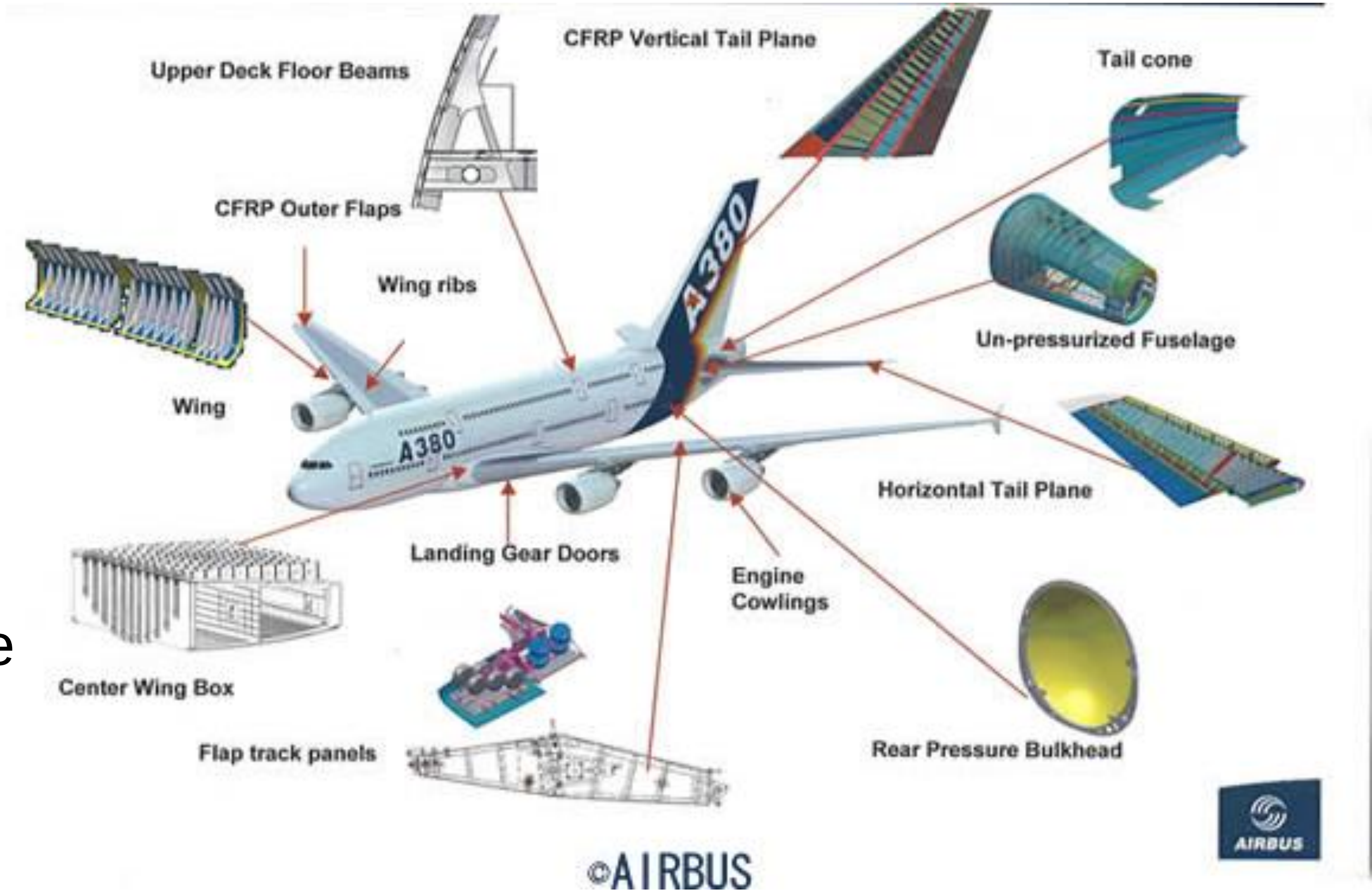
Example – Construction industry

- Recycled Steel
- FSC-Certified Wood
- Reclaimed wood
- Bamboo Flooring
- Recycled Concrete
- Insulation from Recycled Materials



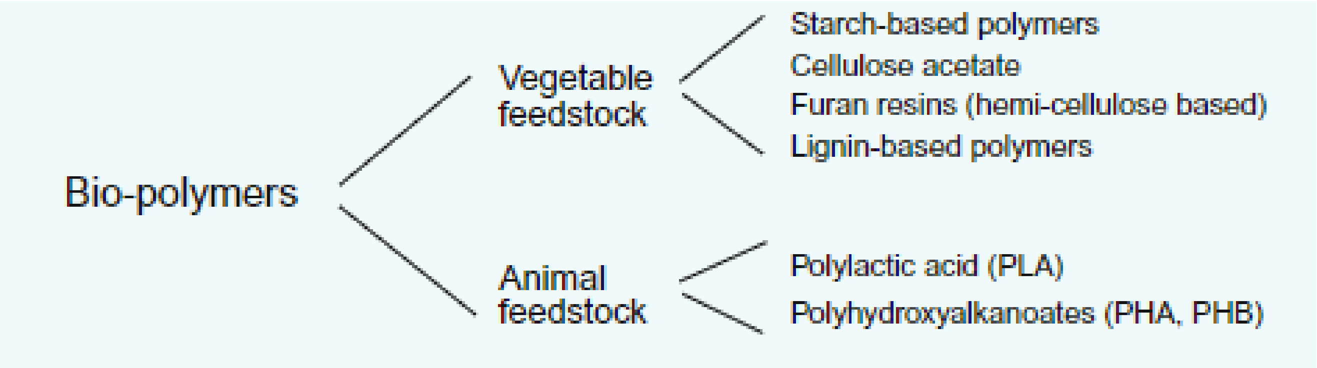
Example – Aerospace/Automotive

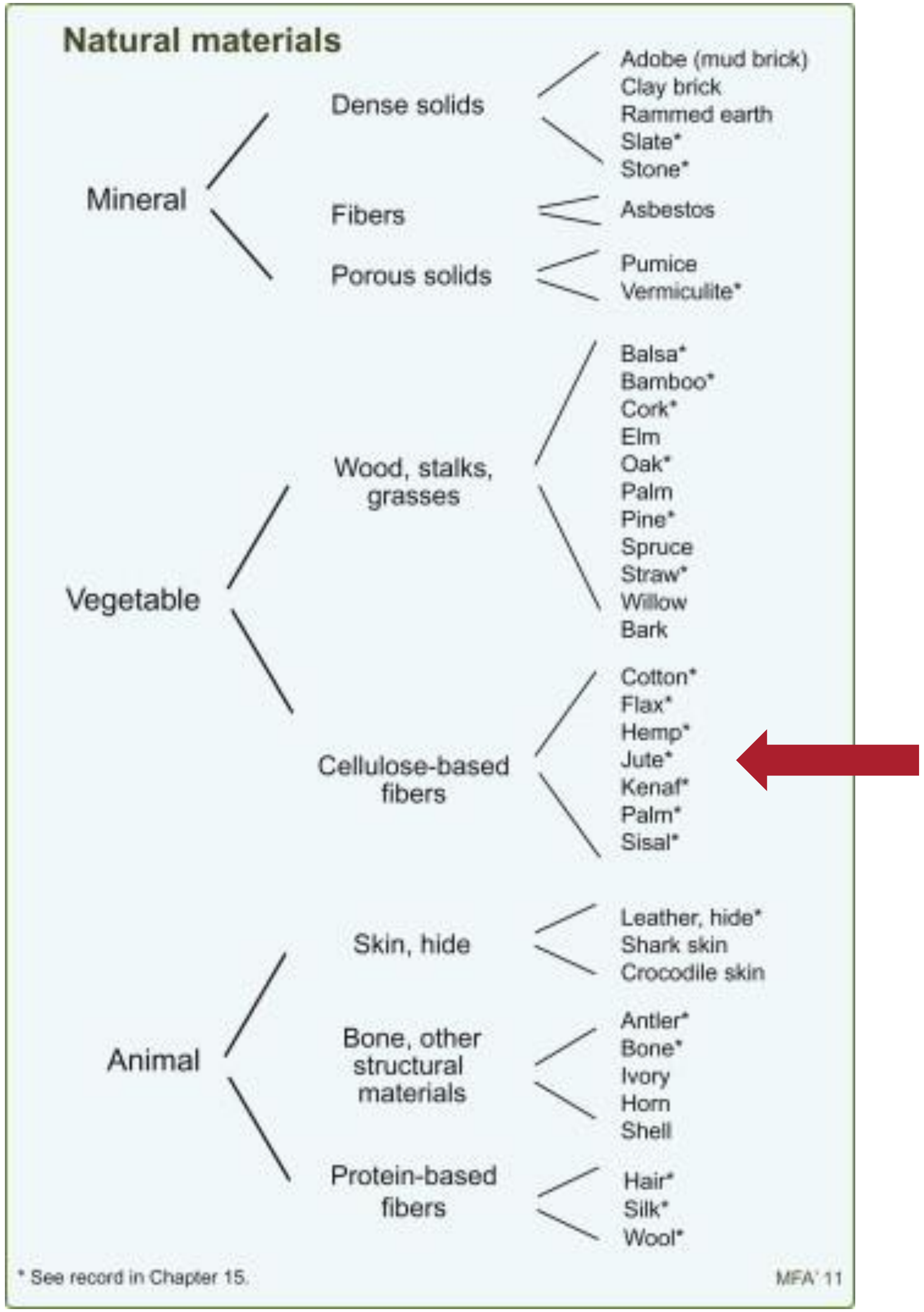
- Material selection – CFRP
  - Replace aluminium/steel
- Weight savings
  - Fuel emissions
- Durability
- Advanced manufacturing
  - Automated tape laying/ fibre placement



Renewable materials

- Research driven discovery of biobased and other renewable materials
- Vegetable materials: Wood, plant based fibres
- Flax and hemp fibres





Summary

- Need for sustainable materials
- Design for environment/ Design for sustainability
- Triple Bottom line
- Sustainable business practice requires three balance columns show positive balances
- 3 capitals: Natural, Manufactured and Human
- Assessing sustainability
- Renewable materials research