



# PHS 6317 Nanoengineering of thin films

## *Course schedule – Winter 2024*

- 12 January Introduction – Scientific and technological challenges
- 19 Fabrication methods – Vacuum physics and vapor-phase techniques
- 26\* Fabrication methods – Plasma processes and process optimization
- 2 February Fabrication methods - Plasma-surface interactions and diagnostics
- 9\*\* Fabrication methods – Thermal/Plasma spray technologies
- 16\* Optics of thin films 1, optical characterization, *Miniquiz1 (5%)*
- 23\* Optics of thin films 2, design of optical filters
- 1\*\*\* March *Presentations – Emerging fabrication techniques (30%)*
- March 4-8 - Winter/Spring break***
- 15\*\* Tribo-mechanical properties of films and coatings
- 22\*\* Electrochemical properties – corrosion and tribo-corrosion(*filter-20%*)
- 5 April Functional films and coatings – Part 1, *Miniquiz 2 (5%)*
- 12 Functional films and coatings – Part 2
- 16 **Life cycle analysis and environmental impact, visits**
- 19\*\*\* *Presentations – Emerging applications of nanostructured films (40%)*

# Life cycle considerations

## Life cycle consideration – new challenges

- a) Background and polarized opinions
- b) The consumption of materials and waste
- c) Life cycle analysis and emerging industry standards
- d) Evolution in materials selection criteria

## Effects of our consumer lifestyles: a sobering thought

The world we live in is one of **gross consumption**. It is a force that drives us to new heights of material and energy use every year. This pushes where and how things are made to a global scale, since no one country alone has the resources to meet demand. From a humble hair clip, to massive sections of bridges, nearly everything we have goes on a long journey from the ground, to a finished object. Along the path of creation lie untold **stories of environmental destruction caused by the manufacture of our manmade universe of stuff.**

*Quote from <http://www.designlife-cycle.com>*

# Environmental impacts: Currently a high stakes and polarising topic

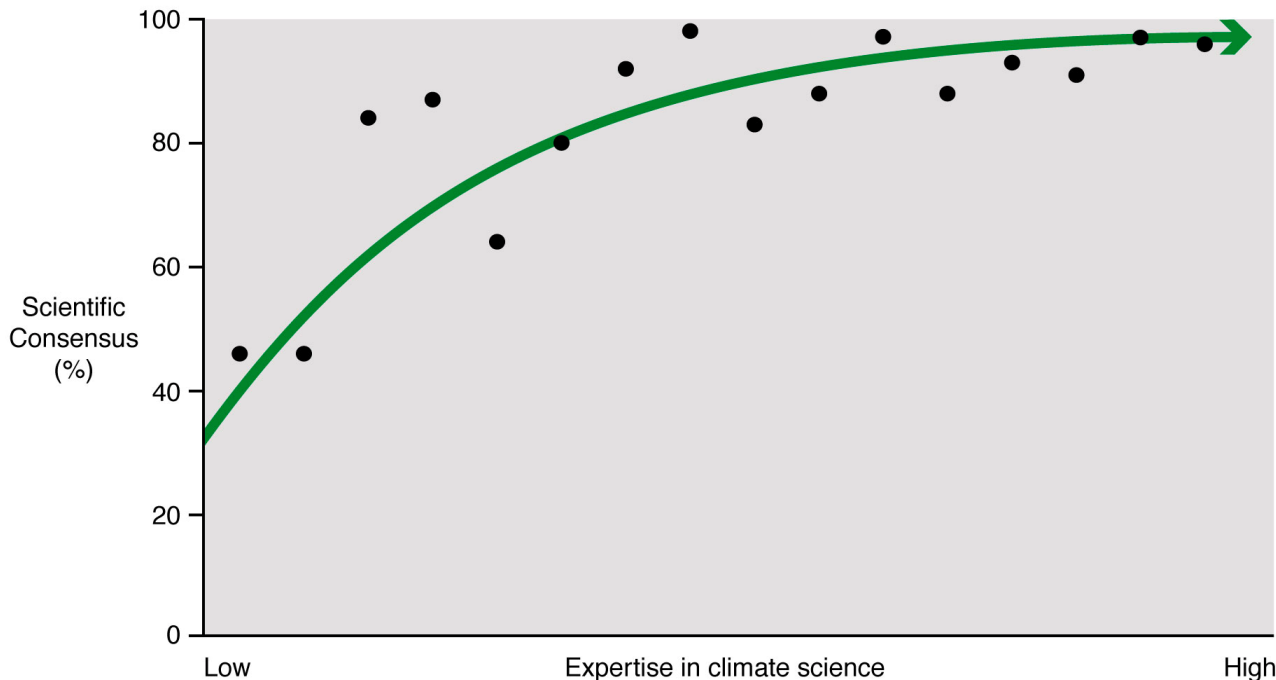


## *In politics*

- **2017 U.S. pulls out of Paris Climate Agreement and Trump drops climate change from list of national security threats**  
Trump expresses scepticism of a report, prepared with the input of 13 federal agencies and 300 scientists “One of the problems that a lot of people like myself — we have very high levels of intelligence, but we’re not necessarily such believers,” (interview with the Washington Post).
- Trump on Twitter: ***“The concept of global warming was created by and for the Chinese in order to make US manufacturing non-competitive.”*** and ***“It’s really cold outside, they are calling it a major freeze, weeks ahead of normal. Man, we could use a big fat dose of global warming!”***
- Tony Abbott, the prime minister who signed Australia up to the Paris agreement before losing the Liberal party leadership in 2015, now says Australia needs to pull out of the treaty to end “the emissions obsession that’s at the heart of our power crisis”. (the Guardian, Tue 3 Jul 2018)

# Environmental impacts: The science

- That humans are causing global warming is the position of the Academies of Science from 80 countries plus many scientific organizations that study climate science.
- Scientific consensus is extremely high at ~97% agreement that climate change is real and due to human activities. There is a strong correlation between the degree of consensus and the level of climate science expertise.
- Misinformation campaigns to deny the existence of the expert consensus have been successful, as the public badly underestimate the consensus of experts.



J. Cook, et al, *Environmental Research Letters* Vol. 11, 2016 [DOI:10.1088/1748-9326/11/4/048002](https://doi.org/10.1088/1748-9326/11/4/048002)

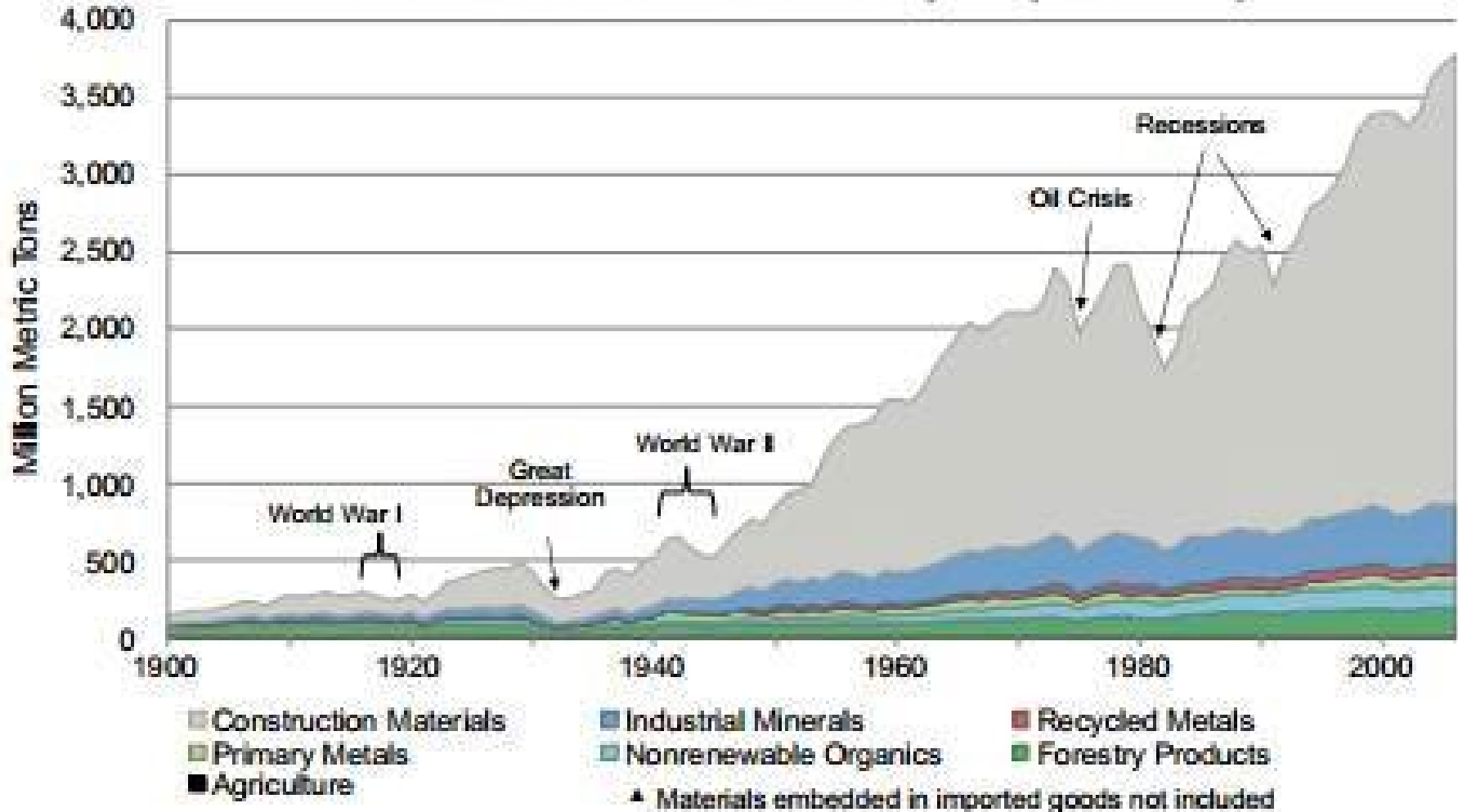
# Increasingly serious problems

- Limited resources – materials scarcity
- Pollution of the planet through waste disposal practices
- Greenhouse gas emissions induced climate change / global warming



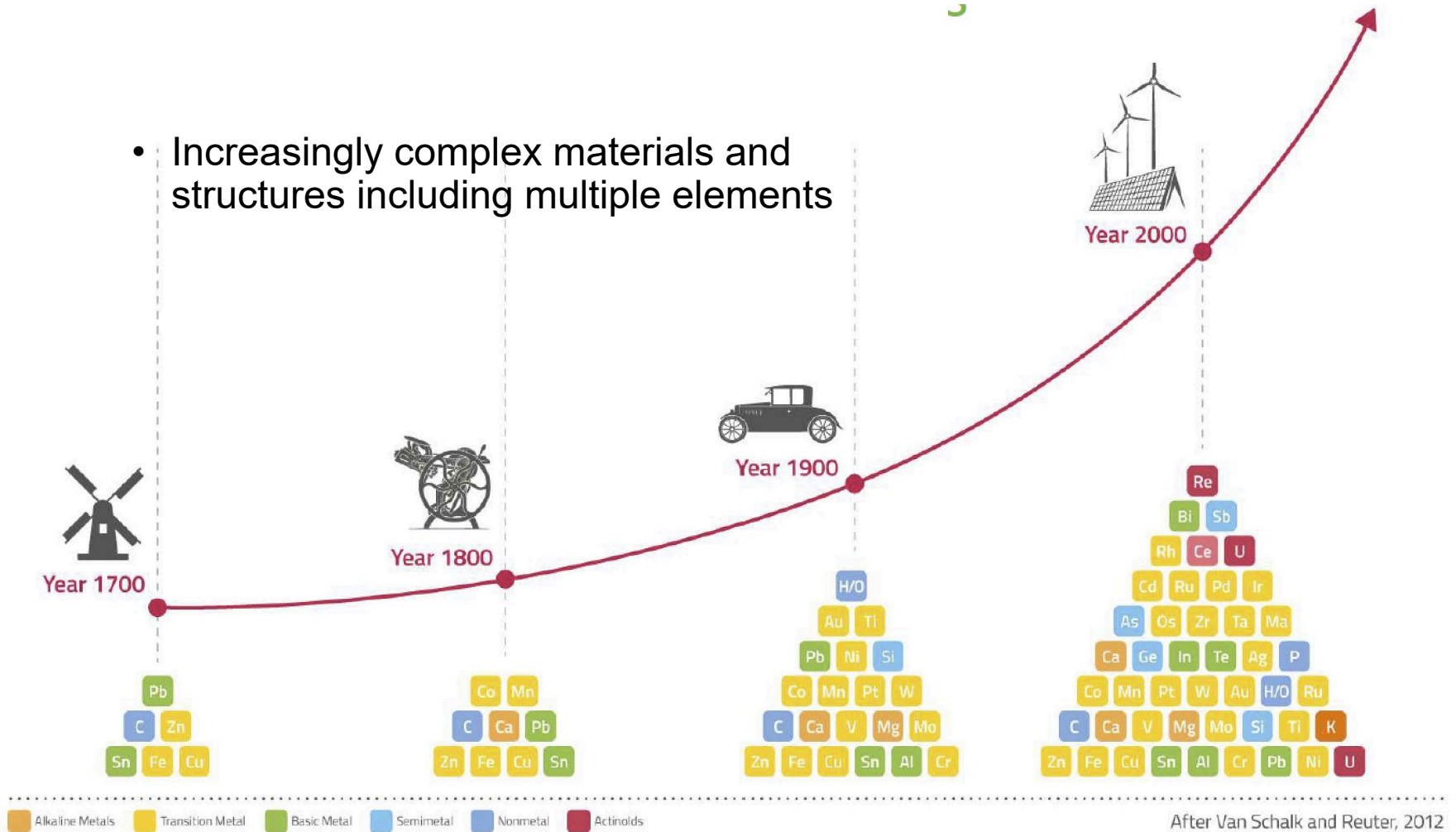
# Increasing amount of raw materials

U.S. Nonfuel Materials Consumption (1900-2006)<sup>2</sup>



# Dramatic expansion of variety of materials used

- Increasingly complex materials and structures including multiple elements

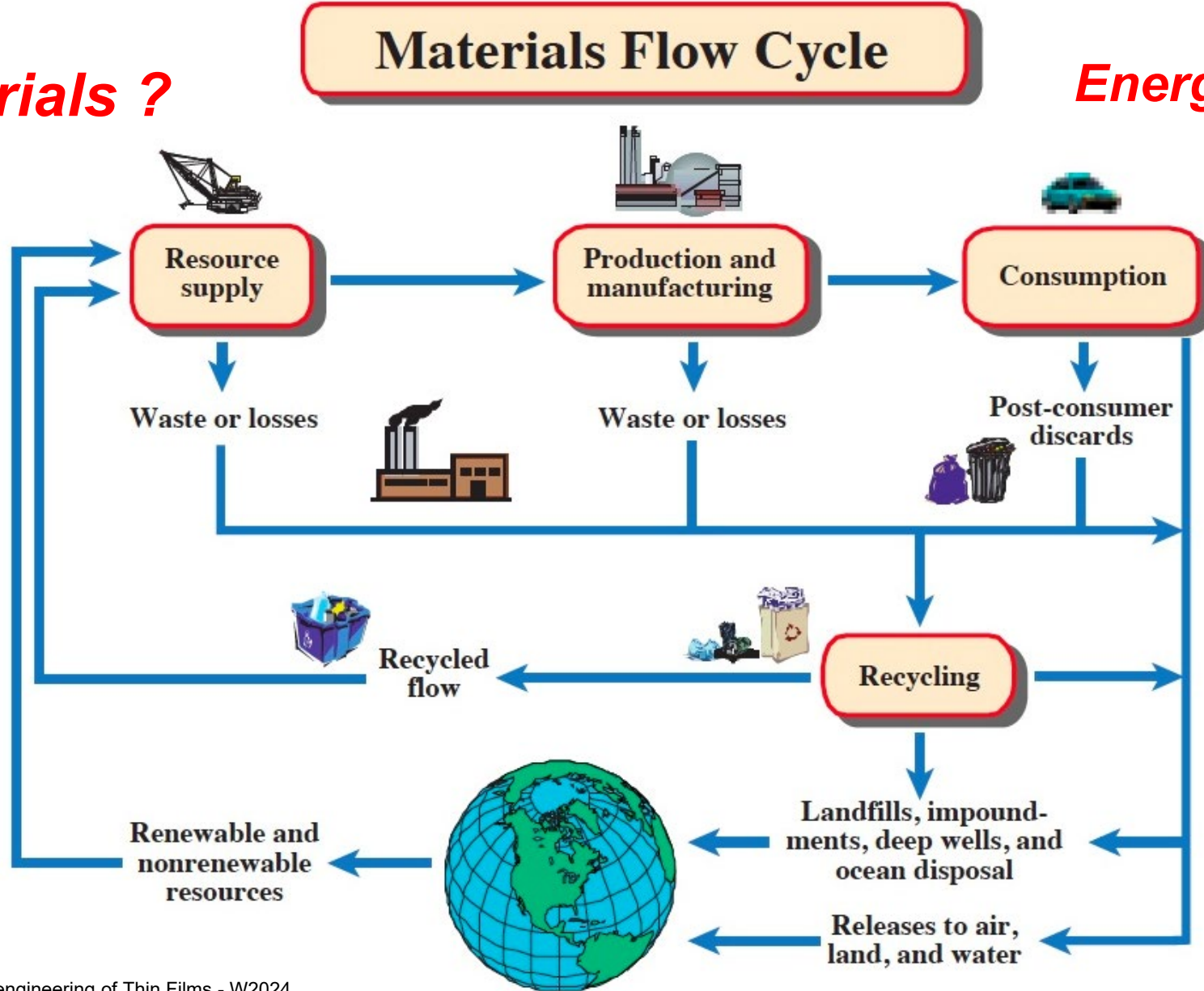




# Multiple Considerations

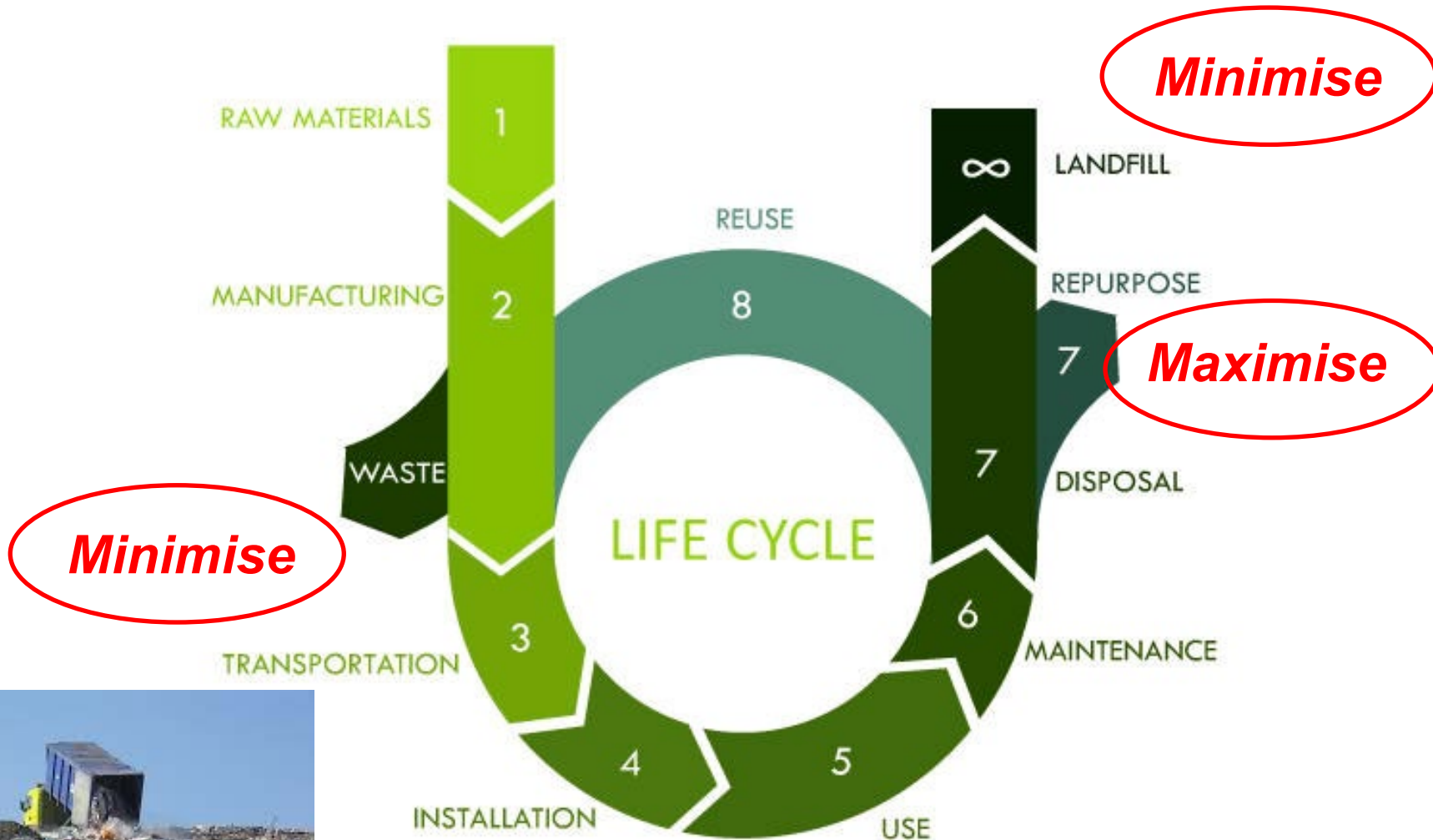
*Materials ?*

*Energy ?*



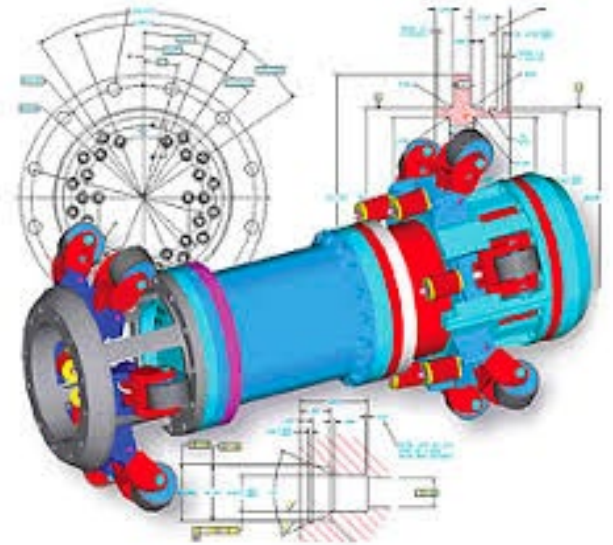


# The product life-cycle: a materials perspective



# Engineering design phase considerations

- reduce the amount of raw materials
- reduce the number of components
- reduce the products energy requirements
- increase the useful life cycle
- maximize the use of renewable and recyclable materials
- assess and minimize the environmental impact over the entire life cycle of the product



**Renewable Materials:** materials that do not use up non-renewable resources and can be produced in high enough volume to be economically useful, e.g. Bamboo, cork, polylactic acid (PLA - a biopolymer derived from corn), recycled glass.

# ISO 14001 Standard



- Issued by the International Organization for Standardization (ISO) and formally adopted in 1996.
- “sister” standard to ISO 9001 the quality control standard.
- **The purpose of ISO 14001 is the creation of an environmental management system (EMS) to systematically support improved environmental performance.**
- An EMS is defined by ISO as: "part of the overall management system, that includes organizational structure, planning activities, responsibilities, practices, procedures, processes, and resources for developing, implementing, achieving, and maintaining the environmental policy.
- Adoption of the standard is voluntary
- It is based on the Plan-Do-Check-Act (PDCA) cycle aiming at continual improvement in each cycle. Establish objectives and processes required for improving environmental outcomes with identified measurables; Implement the processes; Measure and monitor the processes and report results; Take action to improve performance of EMS based on results.



Performance,  
Credibility,  
Transparency

# Eco-Management and Audit Scheme (EMAS)

- Established in 1993 by European Commission
- Currently, more than 4,600 organisations and more than 7,900 sites are EMAS registered
- The EMAS Regulation includes the environmental management system requirements of the international standard for environmental management, ISO 14001, and additional requirements for EMAS registered organisations such as employee engagement, ensuring legal compliance or the publication of an environmental statement. Because of its additional requirements, EMAS is known as the premium instrument for environmental management.
- Voluntary adoption as for ISO 14001

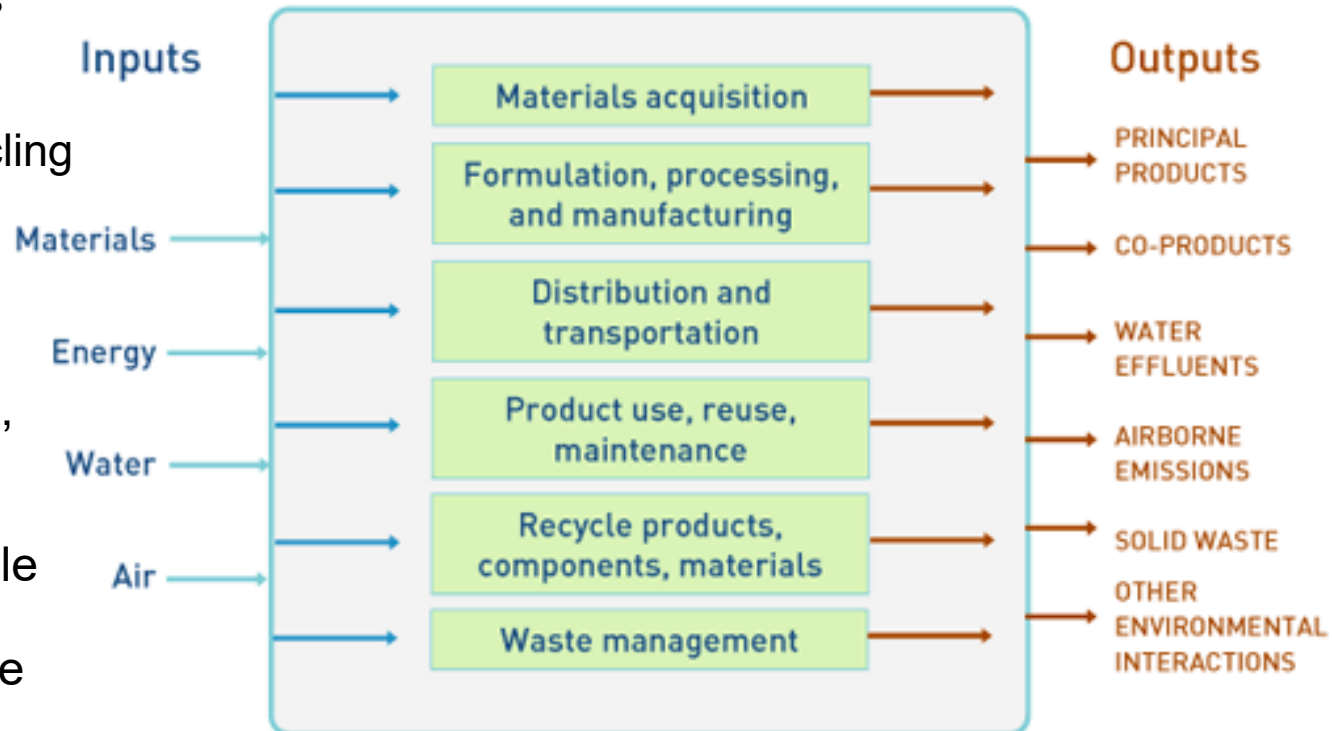
## Product decisions : e.g. Aluminum cans vs glass bottles ?



- Packaging footprint: An aluminium can has a smaller carbon footprint than the glass bottle. Also, the bottle has a paper label on it, and paper has a lot of water content in it. Part of the reason the carbon footprint for an aluminium can is lower is that the aluminium can has more recycled content than any other beverage container. It's approximately 68% and if you make a can out of recycled content, it requires 95% less energy.
- LCA footprint: Between the mine and the brewery's loading dock, at least, glass bottles are the clear winner. Aluminium is made from bauxite, which requires substantial, land-scarring effort to extract from the Earth. Glass, by contrast, is made from the more easily accessible silica. As a result of bauxite mining's environmental toll, manufacturing a 12-ounce aluminium can is twice as energy-intensive as making a similarly sized glass bottle: 2.07 kilowatt hours of electricity for the can vs. 1.09 kilowatt hours for the bottle.
- Recycling footprint: Recycling 100 beer bottles requires more energy than recycling 100 aluminium cans, but making the aluminium cans requires a lot more energy. The environmental impact is dominated by what it takes to make it in the first place. When you recycle the aluminium you significantly reduce the impact of making it.
- In **1969**, Coca Cola commissioned the first study to examine the whole environmental impact of a package, laying the framework for the **life cycle assessment (LCA)**. ISO standardisation occurred in the 1990s

# LCA definition

- Life cycle analysis is the process of performing an environmental evaluation of a product's development during each stage of its useful life:
- Extraction of the raw materials
- Refining of raw materials
- Manufacture and packaging
- Transport at all stages
- Use over its life
- Disposal, reuse, recycling



Product take back—is a highly contentious issue, it is the idea that the company that produces the product is responsible for its disposition at the end of its useful life cycle



# Need to understand all impacts to make sound decisions

- Indirect impacts can easily be missed but they can be major when taken together
- Reduce, reuse, recycle, recover, redesign & remanufacture is usually a good idea but impacts of the recycling/recovery and remanufacturing processes need to be considered
- Triple bottom line – Economy, environment and society is required to look at impacts to all stakeholders
- Clearly an incredibly complex process is required to capture everything accurately



# Life cycle inventory

- inventory of flows from and to nature for a product system that include inputs of water, energy, and raw materials, and releases to air, land, and water. The input and output data needed for the construction of the model are collected for



all activities within the system boundary, including from the supply chain.

- **Data from supply chains not usually**

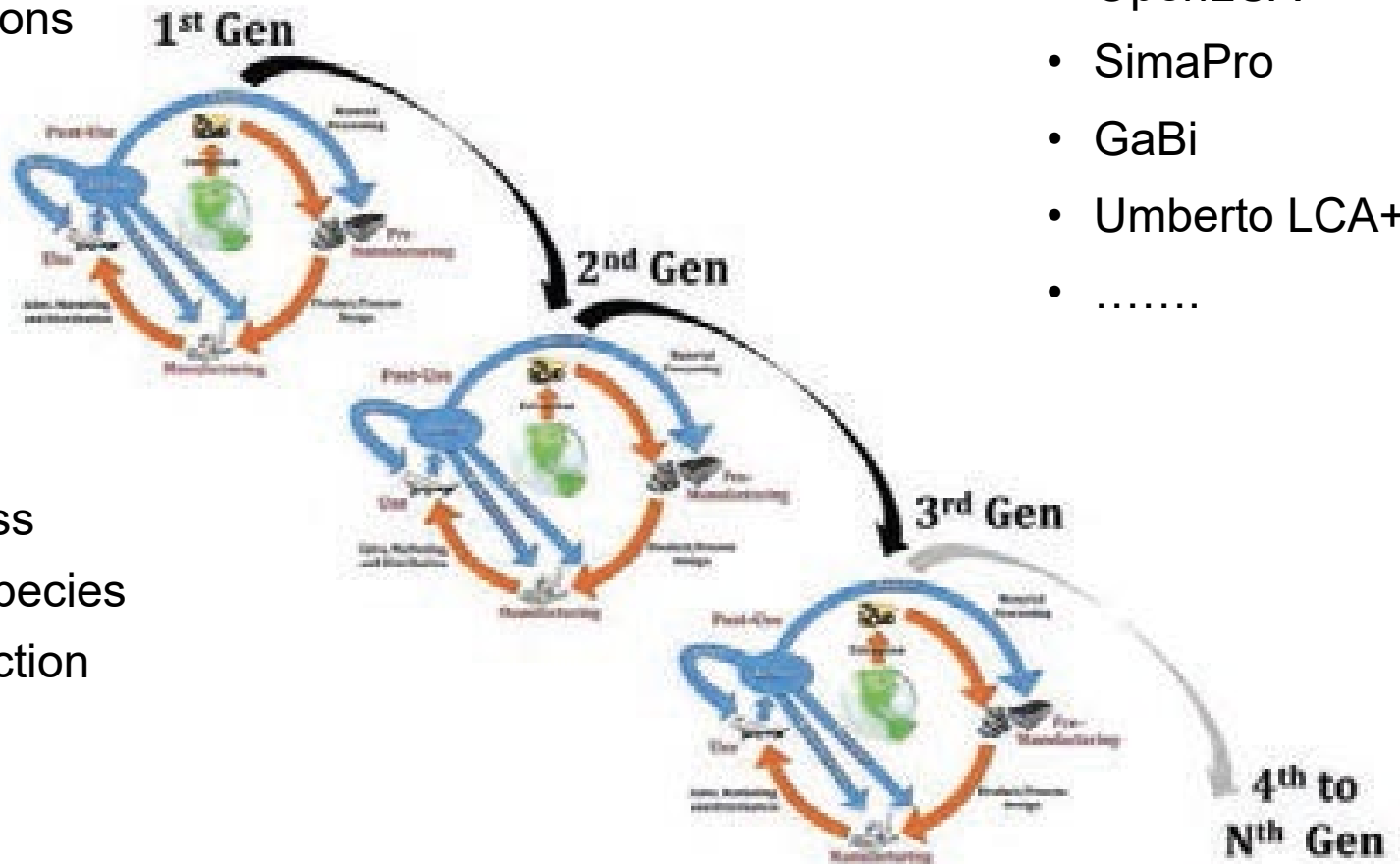
**available** (need to make assumptions, use third party database and justify how it applies).

# Impact categories

- Land use
- Carbon emissions
- Water use
- Toxicity
- Smog
- Carcinogens
- Air pollution
- Eutrophication
- Biodiversity loss
- Extinction of species
- Habitat destruction
- .....

Software tools for LCA:

- OpenLCA
- SimaPro
- GaBi
- Umberto LCA+
- .....



# Material Selection Criteria: Traditional Considerations

Market and end-user demands drive:

- Design
- Product Function
- Structural Requirements
- Thermal Requirements
- Environmental Durability Requirement
- Aesthetics
- Individual Component Cost
- Production Method
- Cycle Time
- Final Product Cost

# Material Selection Criteria: Sustainability Considerations

- Useful lifetime
- Overall Energy footprint
- Module Design
- Design for Reusability
- Design for Disassembly
- Separation Techniques
- Ease of reuse and or recycling at the component or sub-assembly level

## **Trend in surface engineering:**

**Simplicity of composition vs. complexity of micro/nanostructure**

# Example: Low-E architectural glass and glazing



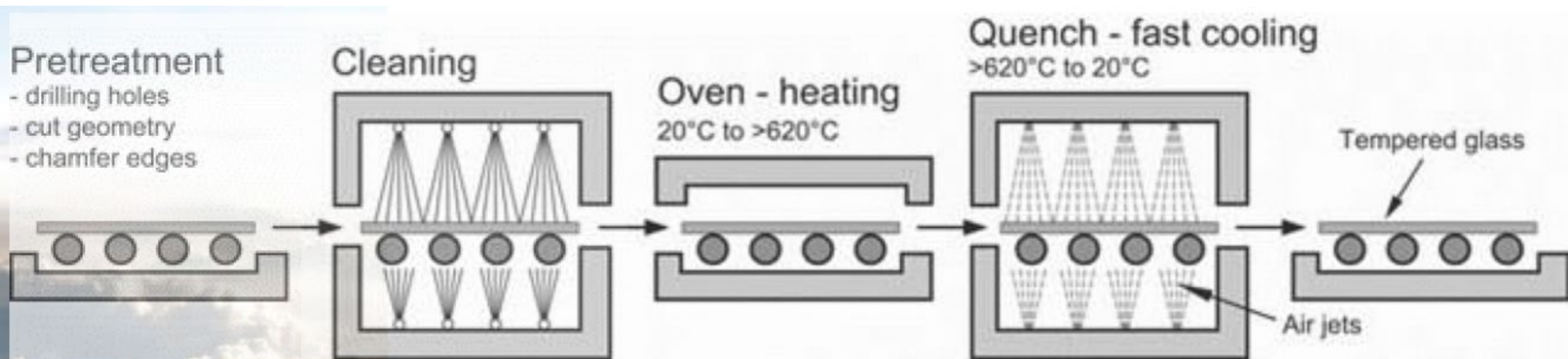
## **Total world annual production:**

About 500,000,000 m<sup>2</sup> of coated glass  
typically 10 to 20 layers, 5-20 nm thick; glass 6 m x 3.2 m.

*Courtesy of Guardian Industries*



# Production of float glass and of glazing



# Implementation of architectural glass in the buildings

But do we know, how does the choice of design affect the embodied carbon, all else being equal?



CURTAINWALL



RIBBON

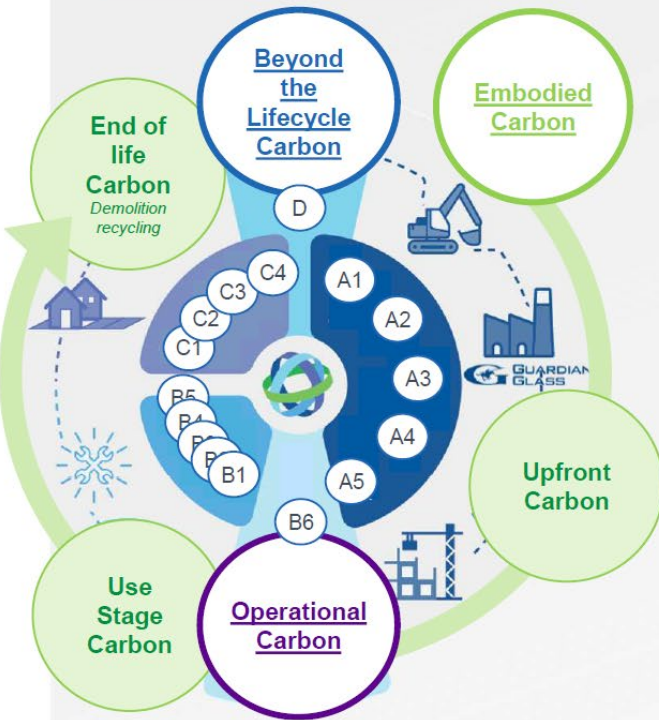


PUNCHED

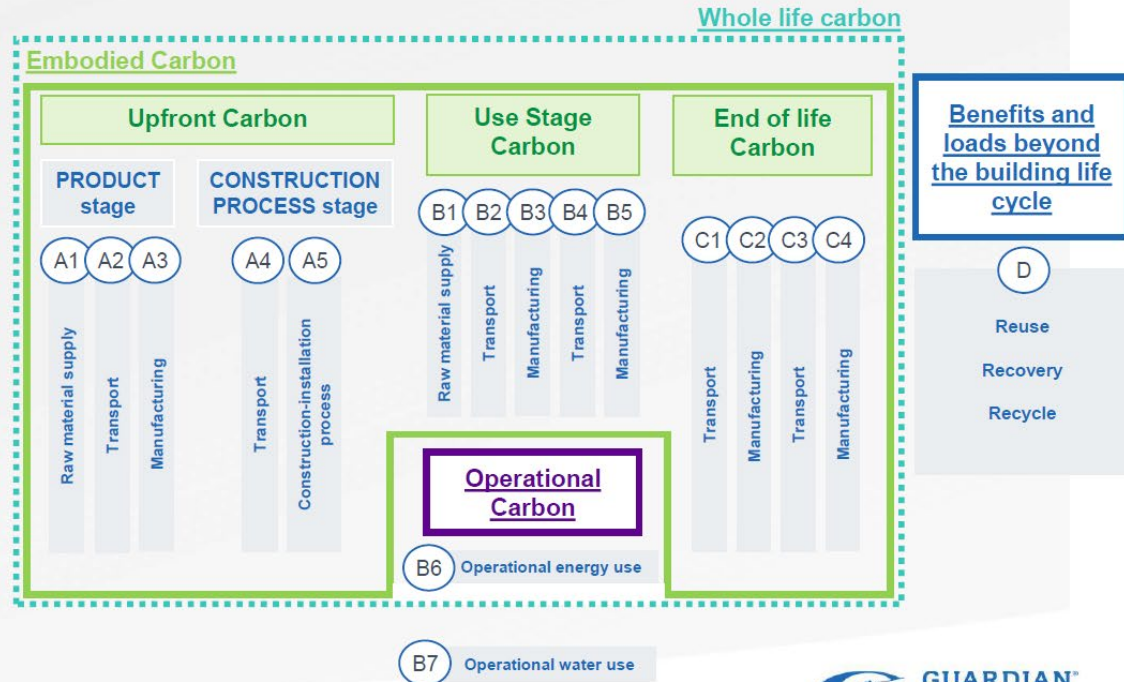
# LCA of architectural glass

Whole Life Carbon = Operational + Embodied

## Carbon in a Product Lifecycle



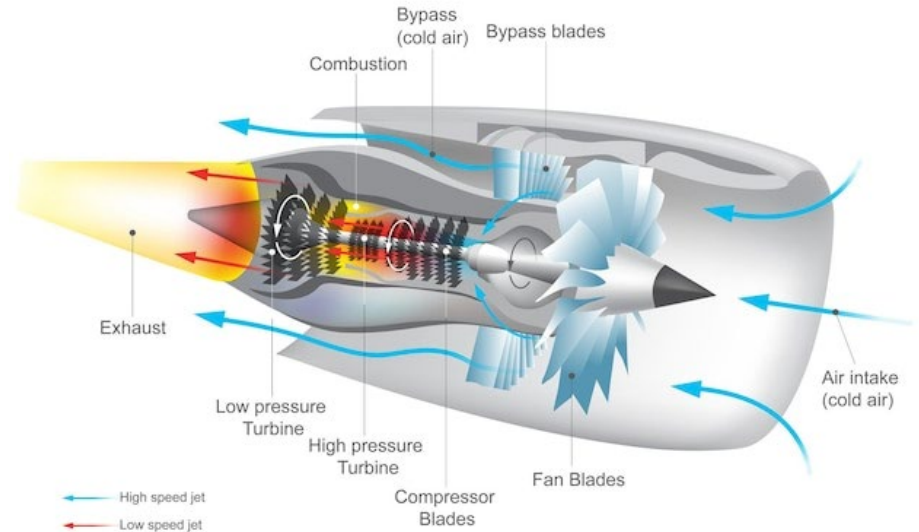
## Life Cycle Assessment: LCA



Source: 'Bringing embodied carbon upfront', World Green Building Council, September 2019, www.worldgbc.org



# Aerospace applications



## Added complexity

Effect of the increased operation temperature on other materials, droplet formation, ...

Effect of alternative fuels ...



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## Visit of the FCSEL/LaRFIS

Functional coating and surface engineering laboratory

Laboratoire des revêtements fonctionnels et  
d'ingénierie des surfaces

### Visit 1 (5<sup>th</sup> floor, Aleksandra, Marie-Andrée, Ludvik):

Multitarget sputtering system – plasma, Surface characterization –  
XPS, TOF-SIMS, Tribology lab

### Visit 2 (5<sup>th</sup> floor, Bill):

Multitarget sputtering system with diagnostics, ALD, optical  
characterization tools

### Visit 3 (2<sup>nd</sup> floor, Jolanta Sapieha, Oleg):

Mechanical testing tools, optical profilometry, pilot deposition  
systems: DIBS, e-beam evaporation, PECVD

**3 groups:** Alexandre L., Mathieu, Veronika,



## Project #3: Applications of nanostructured films and coatings Friday, April 19, B-530.2

8:30 Thomas Sicotte and Alexandre Gamache - Cellules photovoltaïques à pérovskite

8:48 Alexandre Carrière et Youssef Ben Mami - Électrodes transparentes pour cellules solaires

9:06 Veronika Cervenkova - Solar-thermal energy conversion - Transition metal nitrides

9:19 Alexandre Lussier - Fenêtres intelligentes thermochromiques

9:32 Alexandre Fall - Carbon nanotubes for sodium-ion batteries

### **9:45 Break**

10:00 Luc Montpetit - Passivation of CdZnTe for x-ray detectors

10:13 Émilien Martel - Electrochromic, photochromic and gasochromic coatings-consumer optics

10:26 Étienne Tremblay et Nathan Sasseville - Couches minces pour l'él. organique – OLEDs

10:44 Christelle Abou Zeidan – Carbon nanotubes for flexible electronics

10:57 Thomas Lapointe - Photodétecteurs et leur conception/optimisation

### **11:10 Break**

11:25 Alexandre Pinel - Couches minces d'hydroxyapatites pour les implants en biomedical

11:38 Bastien Izacard – Atomic oxygen barrier coatings for satellites

11:51 Arghavan Yazdanpanah Ardakani - Hydrophobic coatings for aircraft surfaces

12:04 Mathieu Bruzzese – Oxidation-resistance barrier coatings for aerospace applications

12:17 Mohamed Ammari - Thermal barrier coatings for aerospace gas turbine engine

**12:30 End and course evaluation**

## Deadlines:

### Project #1 – Fabrication technique:

Choice of the subject: **26 January**

Abstract and references: **9 February**

Report and presentation: **1<sup>st</sup> March**

### Projet #2 – Design of an optical filter:

Choice of the subject: **23 February**

Report: **22 March**

### Projet #3 – Application of nanostructured thin films:

Choice of the subject: **16 February**

Abstract and references: **15 March**

Presentation: **19 April p.m.**

Report: **22 April at 23:59**