Role of structural materials in sustainable development

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What are structural materials?

- For the purpose of this discussion, a structural material is one which is used primarily because of its load carrying capacity.
- This covers a wide-ranging group of materials and applications.

How do structural materials fit within the clean energy challenge?

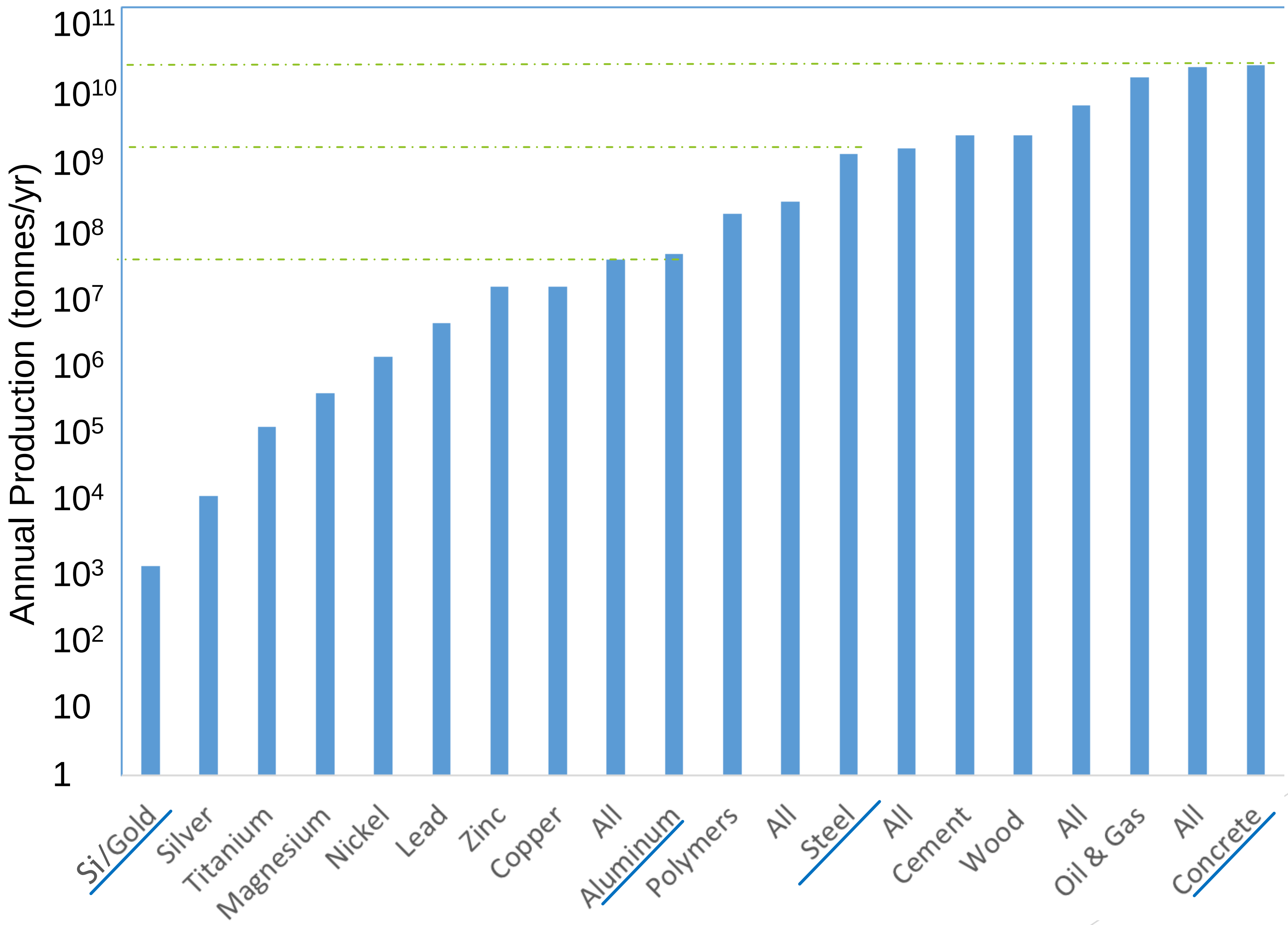
What are the similarities and differences between the challenges faced in functional and structural material development?

Can we proposed a visionary approach for the accelerated development of structural materials?

Addressing the question in an industrial context?

Structural Materials and Clean Energy: 1) Quantity

- **Structural Materials are used in massive quantities.**



Annual Production (tonnes/yr)
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
Si/Gold
Silver
Titanium
Magnesium
Nickel
Lead
Zinc
Copper
All
Aluminum
Polymers
All
Steel
All
Cement
Wood
All
Oil & Gas
All
Concrete

Structural Materials and Clean Energy: 1) Quantity

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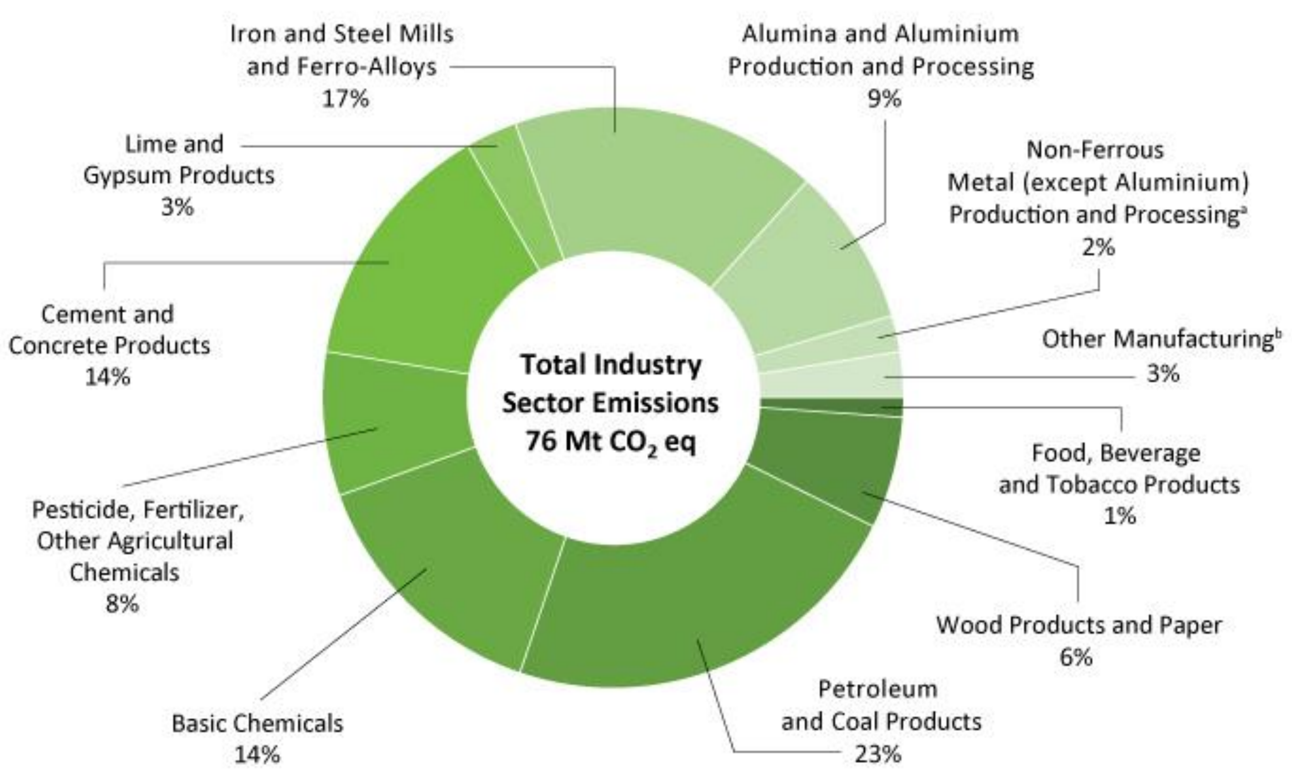
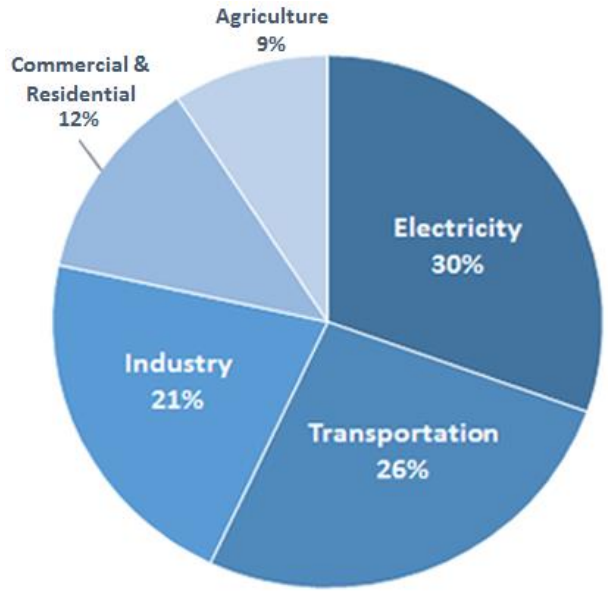
- **As a result, there is a strong environmental impact for producing these materials.**





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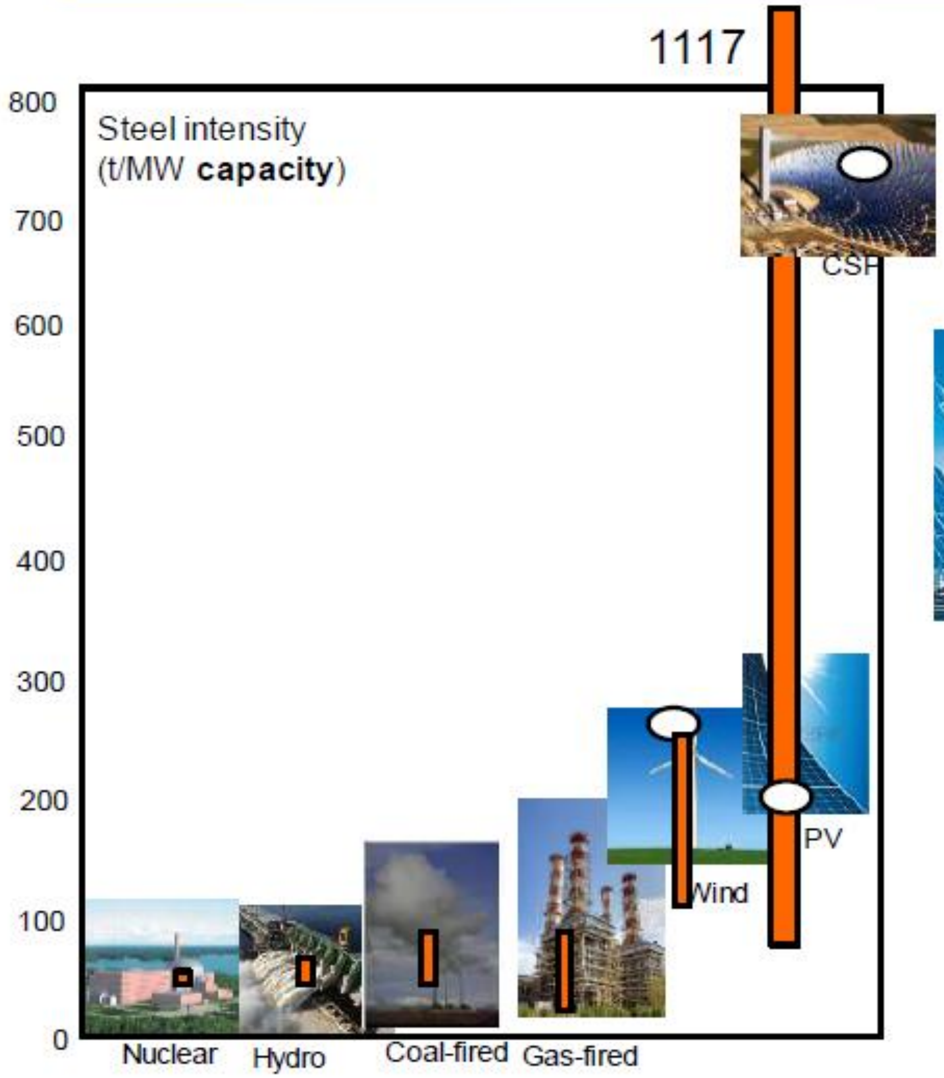
- **Clean energy production requires massive amounts of structural materials.**

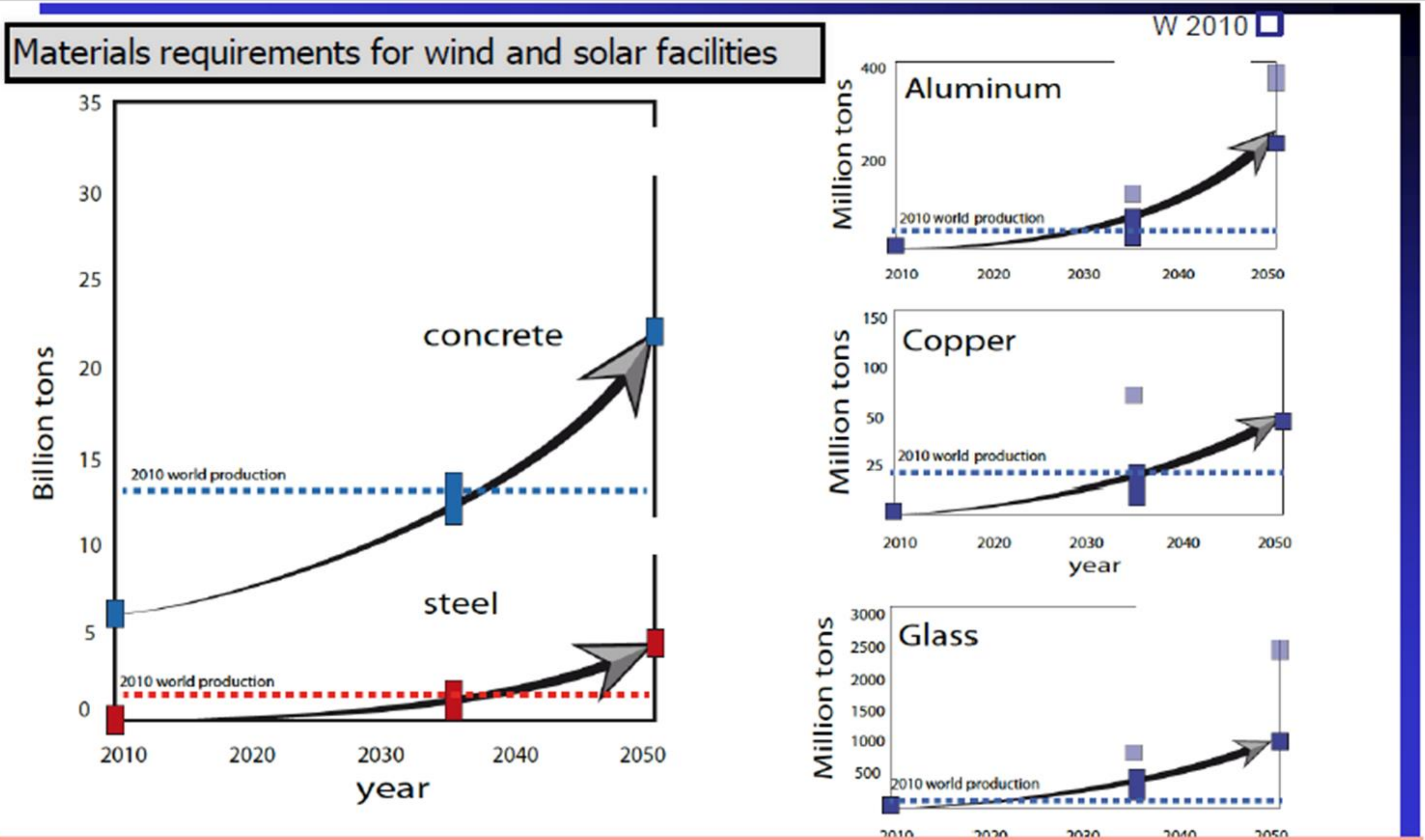


Vidal et al., 2013

PV: 8000m^2 for 1 MWe
25 kg steel/ m^2 => 200 t/MWe

CSP: 730 t/MW

Materials requirements for wind and solar facilities



In 2050, the cumulative amount of concrete, steel, Al, Cu and glass sequestered in wind and solar facilities will be 2 to 8 times the 2010 world production

Structural Materials and Clean Energy: 1) Quantity

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- As a result, there is a strong environmental impact for producing these materials.
- Clean energy production requires massive amounts of structural materials.
- **More efficient production of materials is an essential part of the energy challenge.**

Structural Materials and Clean Energy: 2) Life-time

- The operational life-time expectations of structural materials (i.e. the "need") is much longer than the actual life-time of the material.
- Think of all the infrastructure issues arising from this:
  - Replacing old water pipes.
  - Replacing bridges, reducing wear in road coatings.
  - Replacing the turbine blades in an engine.
  - Replacing gears on a wind-mill.
- It is essential to understand the degradation of materials over time and be able to predict their life-time.
- **Development of more durable materials is an essential part of the energy challenge.**

Structural Materials and Clean Energy: 3) Complexity due to processing and length-scales

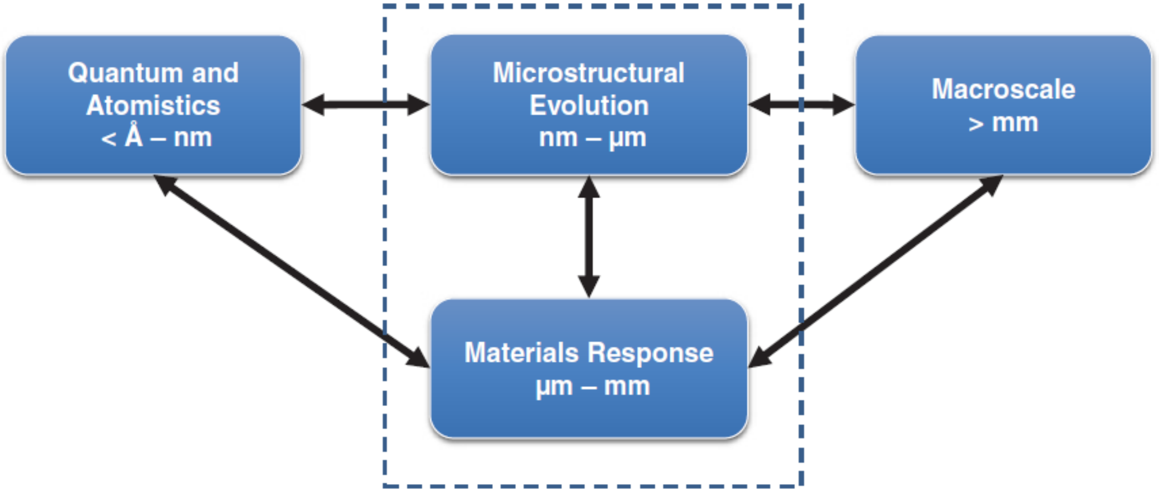
- **Production/Processing:**
  - **Net-shape and near-net-shape processing: Ex. Cast product, 3-D printed product.**
  - **More generally, plants produce semi-finished products that are shipped to other facilities for continued processing:**
    - Metal Production
    - Liquid metal processing
    - Casting
    - Reheating/homogenization
    - Hot-rolling (10 to 20 passes)
    - Coiling
    - Cold-rolling
    - Annealing/galvanizing
    - Welding
    - Forming
    - Painting

Place strong constraints on automation and high-throughput approaches due to very different infrastructure needed for different steps and long duration of some steps.

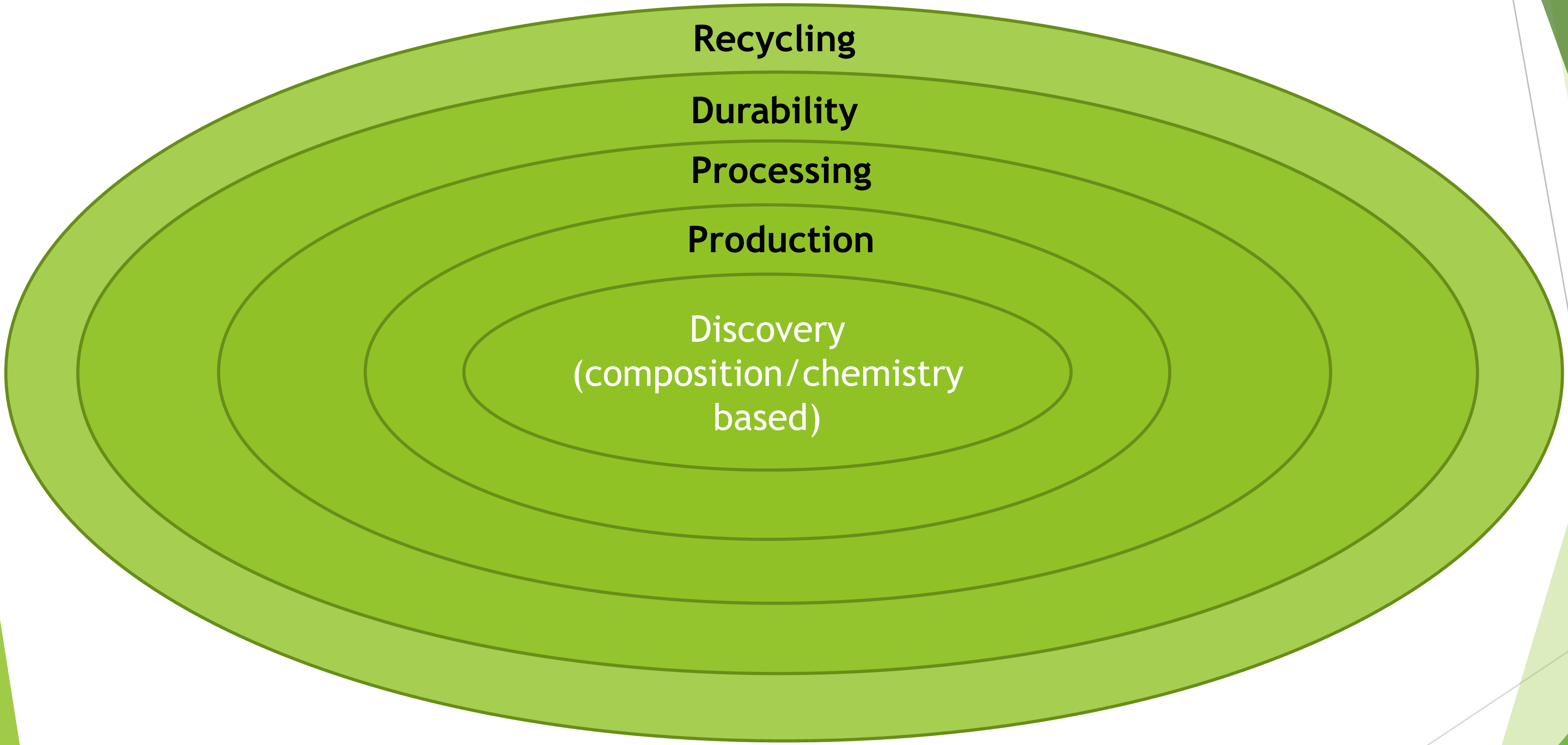
In addition, the material needs to meet multiple design constraints (strength, formability, weldability, corrosion resistance, wear resistance… etc.)

Structural Materials and Clean Energy: 3) Complexity due to processing and length-scales

- **Length-scales:**
  - Different length scales control different material properties.
    - Some properties could be measured at the micron-scale (strength)
    - Some require samples of several mm’s (ductility, fracture)
    - Other could only be assessed on samples that are several mm to cm range (hole expansion, welding).



Development of advanced multi-scale models is a key part of the clean energy challenge

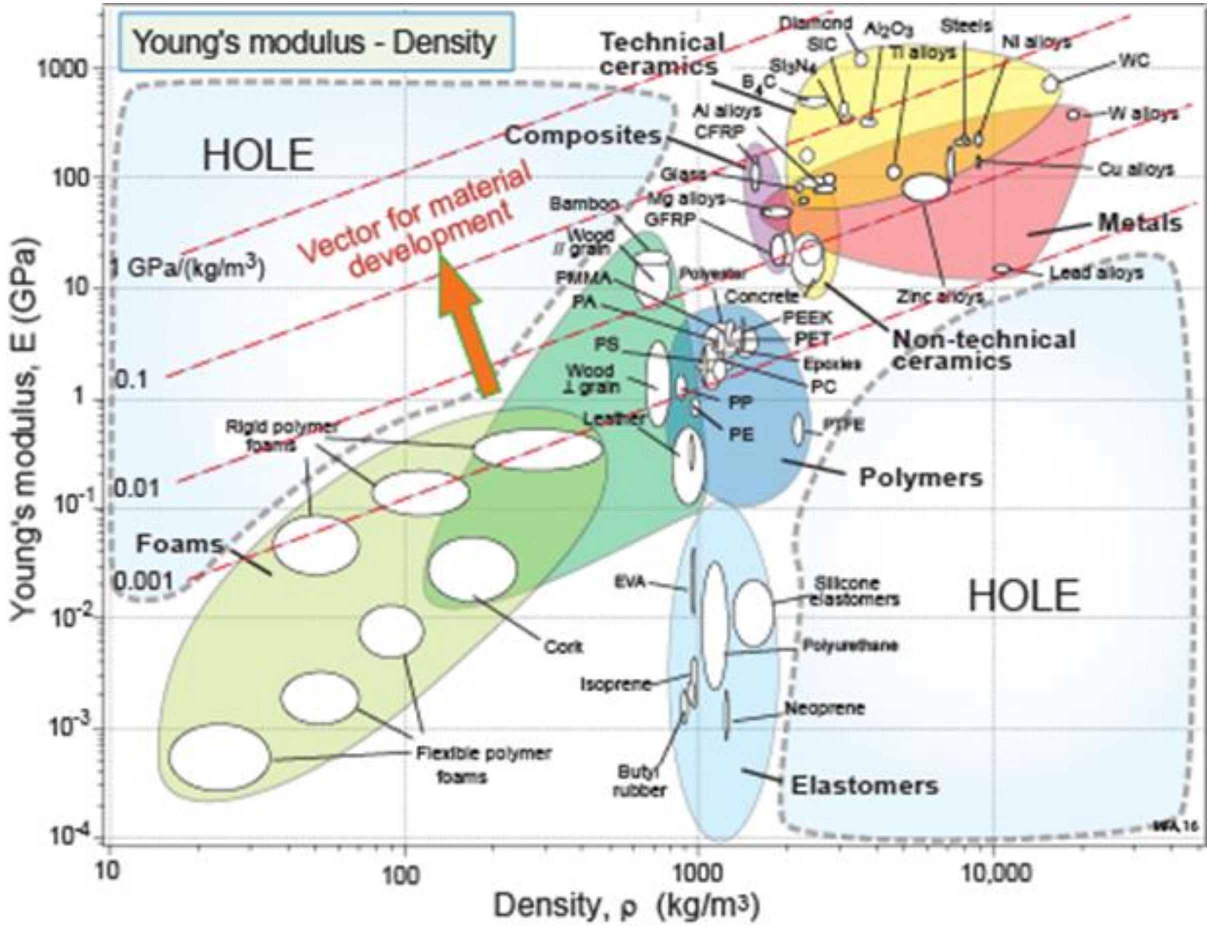

Recycling
Durability
Processing
Production
Discovery (composition/chemistry based)

Accelerated Development of Structural Materials for Clean Energy

- **Discovery (going beyond Chemistry).**
- **Processing (Smart Processes that lower emissions associated with making structures and components)**
- **Durability (Smart components that provide feedback).**

Discovery

Opportunities beyond chemistry. Innovative solutions based on architecture, hybrid materials, composites.



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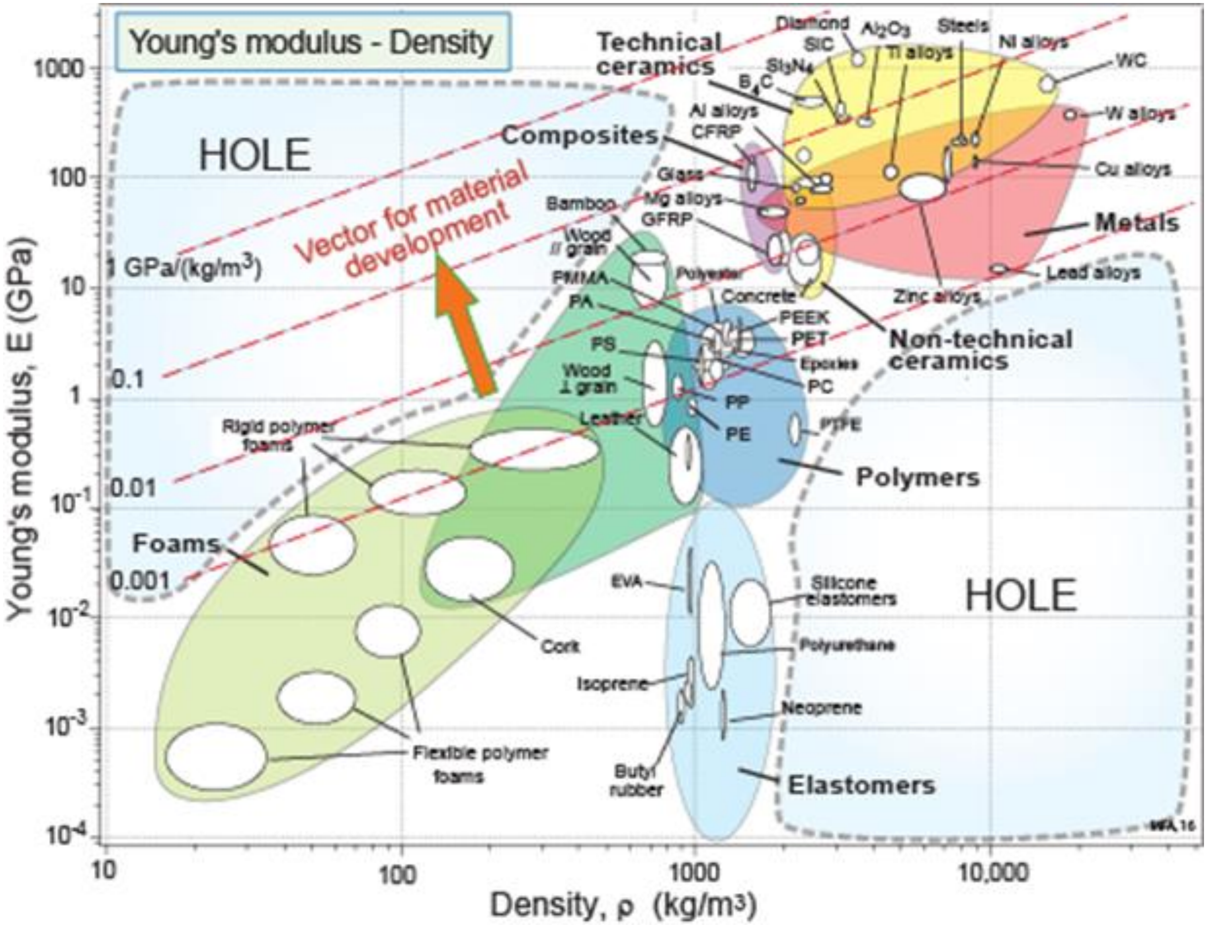

Tool Kit
Inverse Design *AI for Materials*
Applications
Ideally suited for 3-D printed architectured materials. Could imagine integrating *modular material robotics* and trying to ultimately build an *autonomous discovery platform*.

Processing:

- The opportunities lie in Process optimization with the goal of reducing emissions. This can be done at an unprecedented level:
  - Opportunities for inserting sensors and collecting big data
  - Opportunities for optimization using AI.
  - Opportunities for process automation and “closing the loop for process optimization”
  - Discovery/Development of new processes.

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Tool Kit
Inverse Design *AI for Materials* *Data Infrastructure & Exchange*
Applications
Ideally suited for a wide range of industrial processes. We can think of built-in sensors that can lead to a wealth of data. Could ultimately lead to "virtual" *autonomous discovery platforms* that identify new processing routes.

Durability:

- Extending the life-time can have enormous benefit for reducing emissions.
- The opportunities lie in predicting and extending durability:
  - Reduced development and testing times through modelling and accelerated testing.
  - Instrumentation and sensors for monitoring the component during service.
  - Optimization of operating conditions.
  - Self-healing materials.
  - Recycling.

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Tool Kit
Bridging length and time scales *AI for Materials* *Data Infrastructure & Exchange*
Applications
New paradigm in which the component provides continuous feedback to the operator with the possibility of modifying operating conditions to enhance performance. A tool could notify the operator when it is time for replacement or modify machine speed to extend tool-life.

Addressing decarbonation in an industrial context of a materials producer

A variety of strategies

- **The "Product performance"** (i.e. their ability to reduce, for the user, the CO_2 footprint)
- **The "Product footprint",**
  - the footprint related to matter,

  (using less carbonated , or less constraints raw materials, or lower quantities)

  - the footprint related to processes

  (using less carbonated energy, or less energy)

- **The "New products"** which may emerge form a general trend to a decarbonated economy.

Examples

Improving the existing products and processes

- *Improving thermal insultation glazings*
- *finding more efficient building insulation*
- *Decreasing CO2 emission in processes such as glass making and gypsum calcination*
- *CO2 capture and mineralisation*

New products for a decarb economy

- *for heating networks the competence in insulating materials is essential,*
- *for battery production, the processability of ceramics is a major asset,*
- *for hydrogen economy, the key issues are transportation and storage: both for composite reservoirs (gaz under pressure) and for liquid gaz transportation (cryogenic insulations) …*