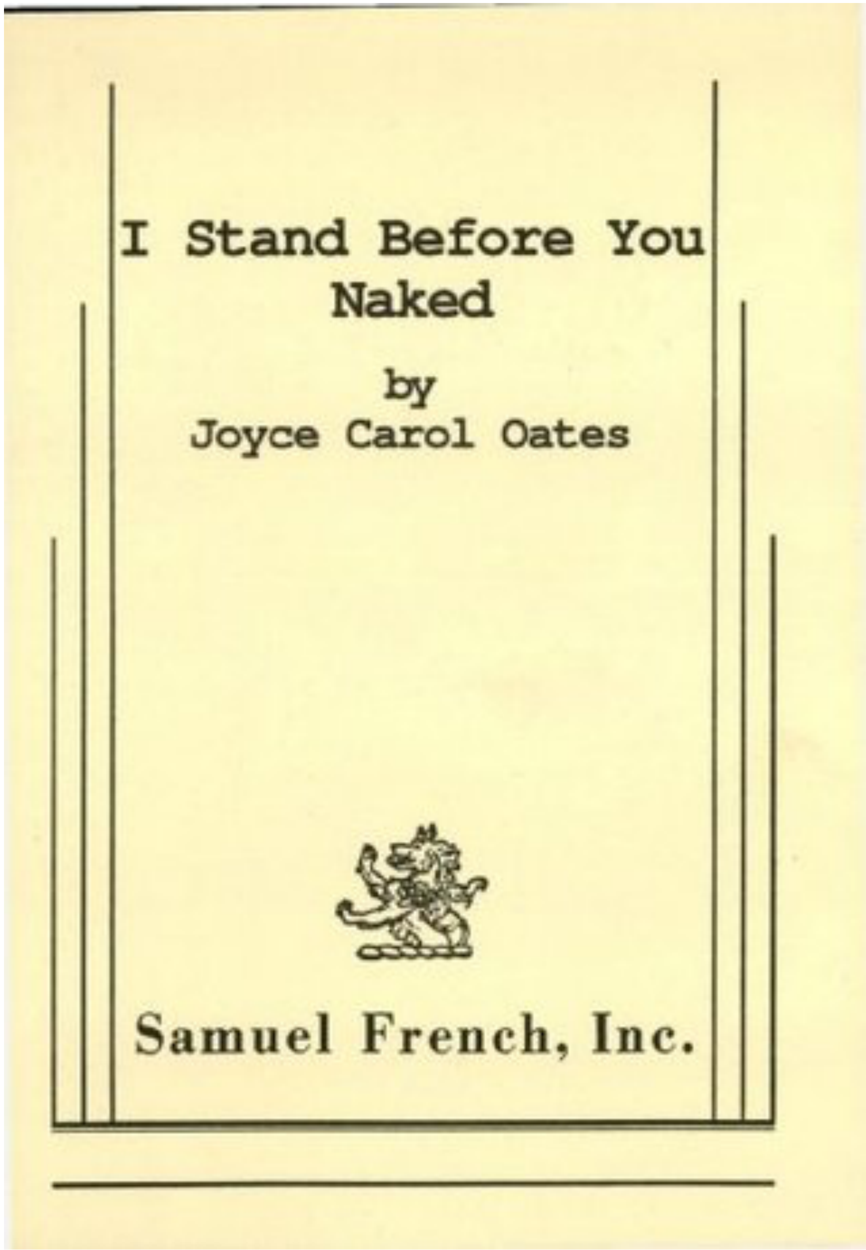
University of Basel

Conflicts Between Climate Change and Sustainability Goals from the Point of View of Materials Science

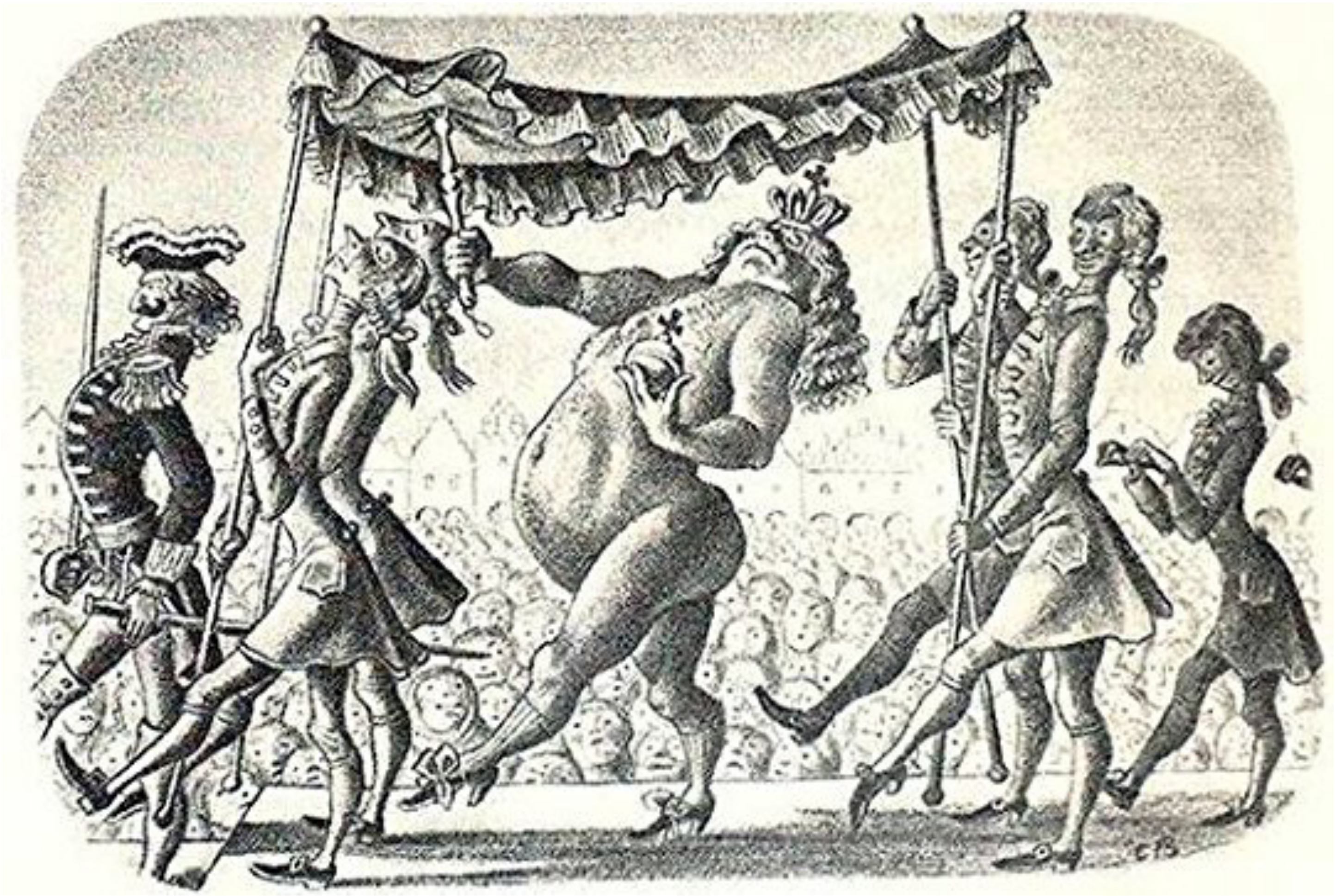
Ed Constable, Department of Chemistry, University of Basel
4th June 2018



”I stand before you naked.
You are strangers to me”

1	Rules of engagement
2	Welcome to the material world
3	Solar renewables …. The good, the bad and the ugly
4	Carbon trapping … burn, burn and recycle
5	Towards the brave new woreld

The Emperor's New Clothes - 1837



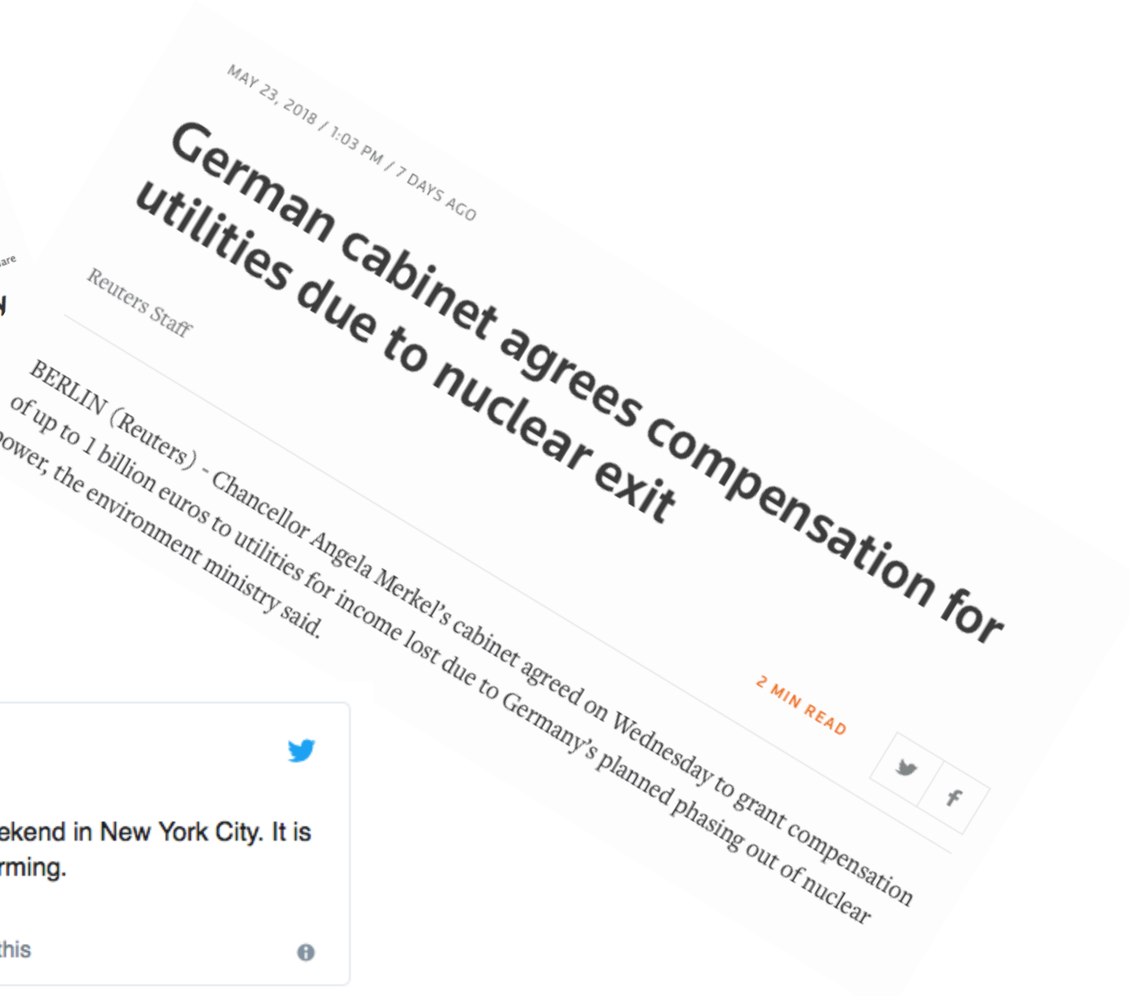
Fukushima 11 March 2011

The “disaster domino effect”

Phase-out plans in Europe

Country	Number of reactors	Phase-out	% of power
Austria	0	1978/1999	0
Belgium	7	2015 → 2025	?
Germany	17	2022	20
Italy	4	1990	0
Sweden	10	2010 → No phaseout	35-40
Switzerland	5	2034?	36.4
France	58	No phase out 50% by 2030-35	75%
Spain	7	No phase out	21%
United Kingdom	15	Ramp-up to 33%	25%

From euphoria to reality



Rules of engagement as a materials scientist

1. Politics and society can legislate to improve the human condition
2. Politics and society can debate the interpretation of scientific facts
3. Politics and society cannot change scientific facts
4. Politics and society cannot change fundamental scientific laws
5. Politics and society can enable mechanisms for innovative technology
   but cannot guarantee success of paradigm shift.

Climate change

Global and annual mean air temperature at the Earth's surface increased by roughly 0.8 °C since the 19th century. By 2100, the globe could warm by another 4 °C if emissions are not decisively reduced within the next decades

Climate Change 2013: The Physical Science Basis. Contri- bution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

Warming of this magnitude will have profound impacts both on the environment and on human societies

Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Climate change mitigation via a transformation to decarbonized economies and societies has to be achieved to prevent the worst of these impacts

Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

Desired technology

Reduce CO_2 emission

Transport

Renewables

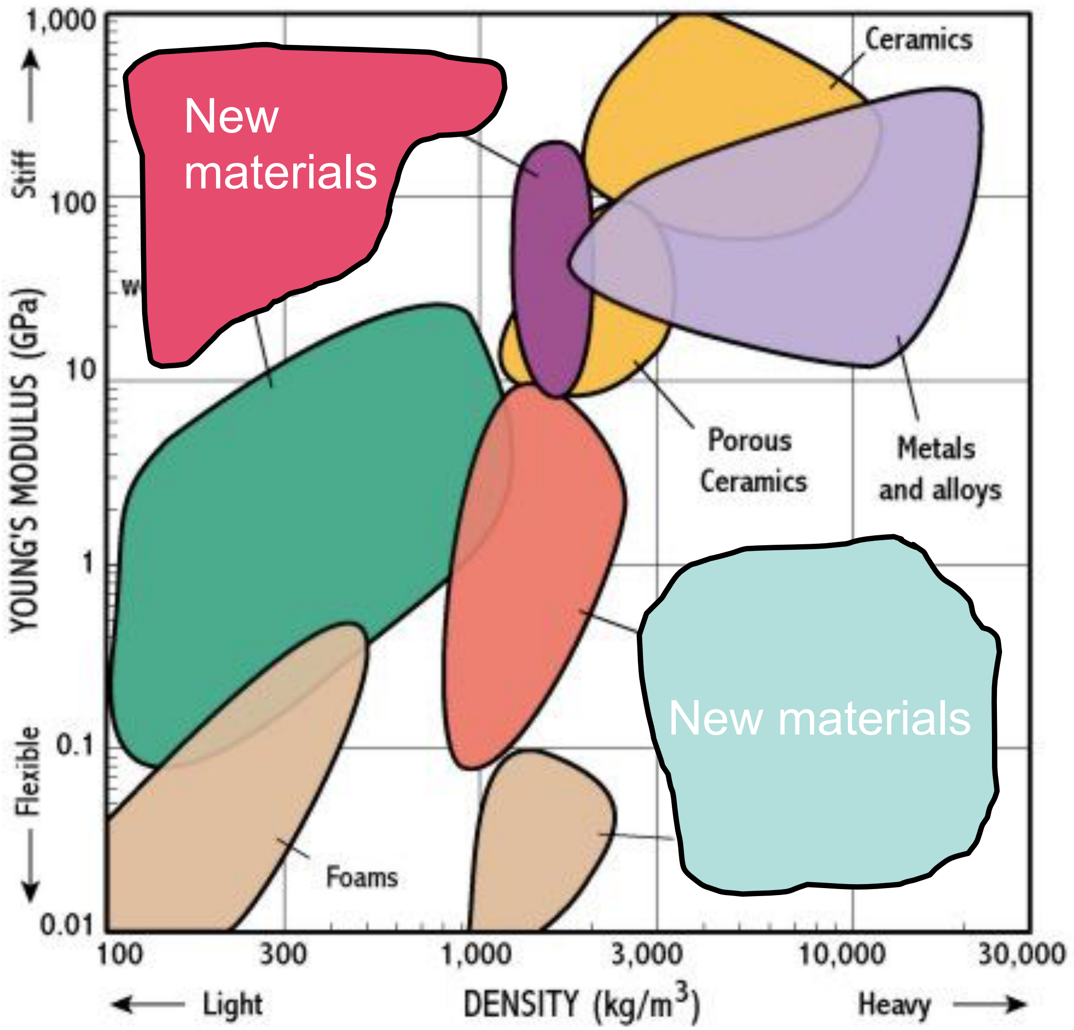
technology stagnating

Efficiency

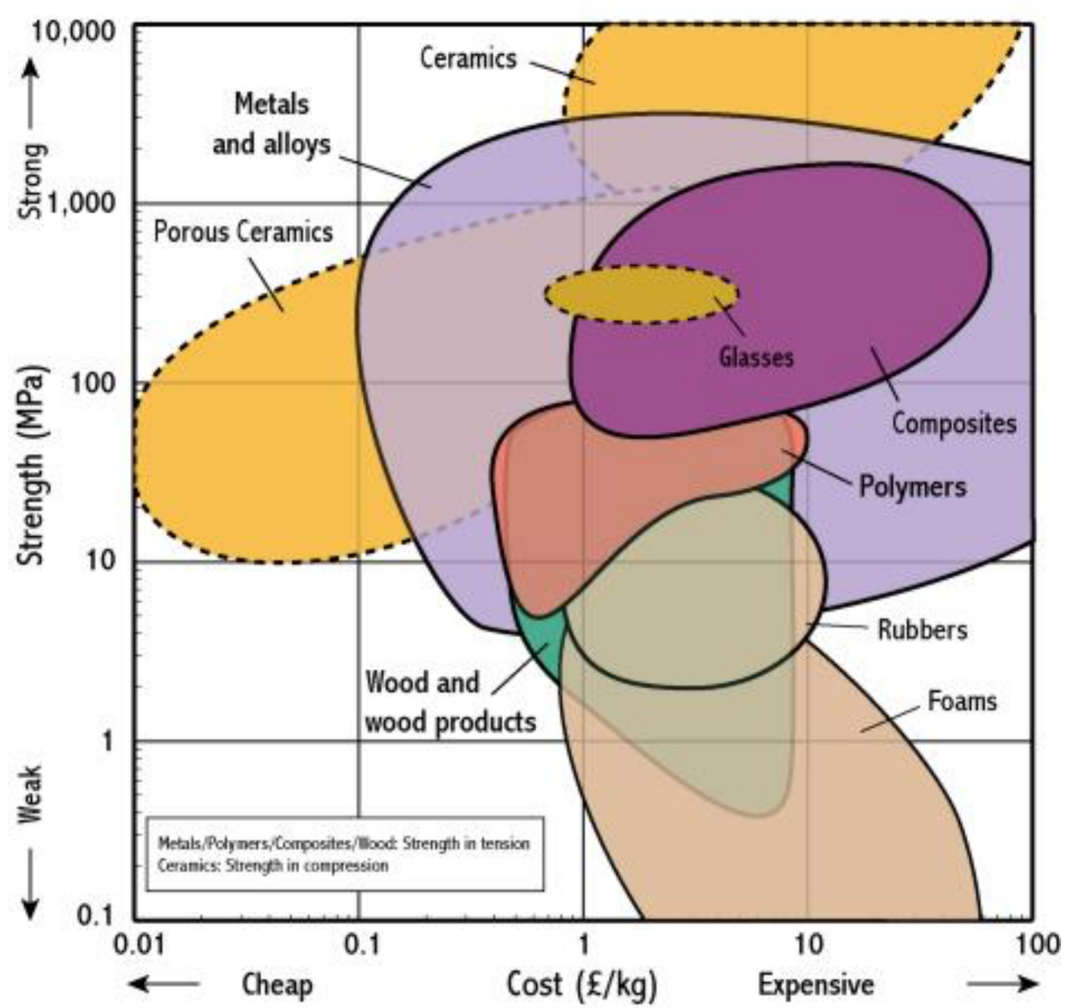
Carbon trapping

Paradigm shift needed

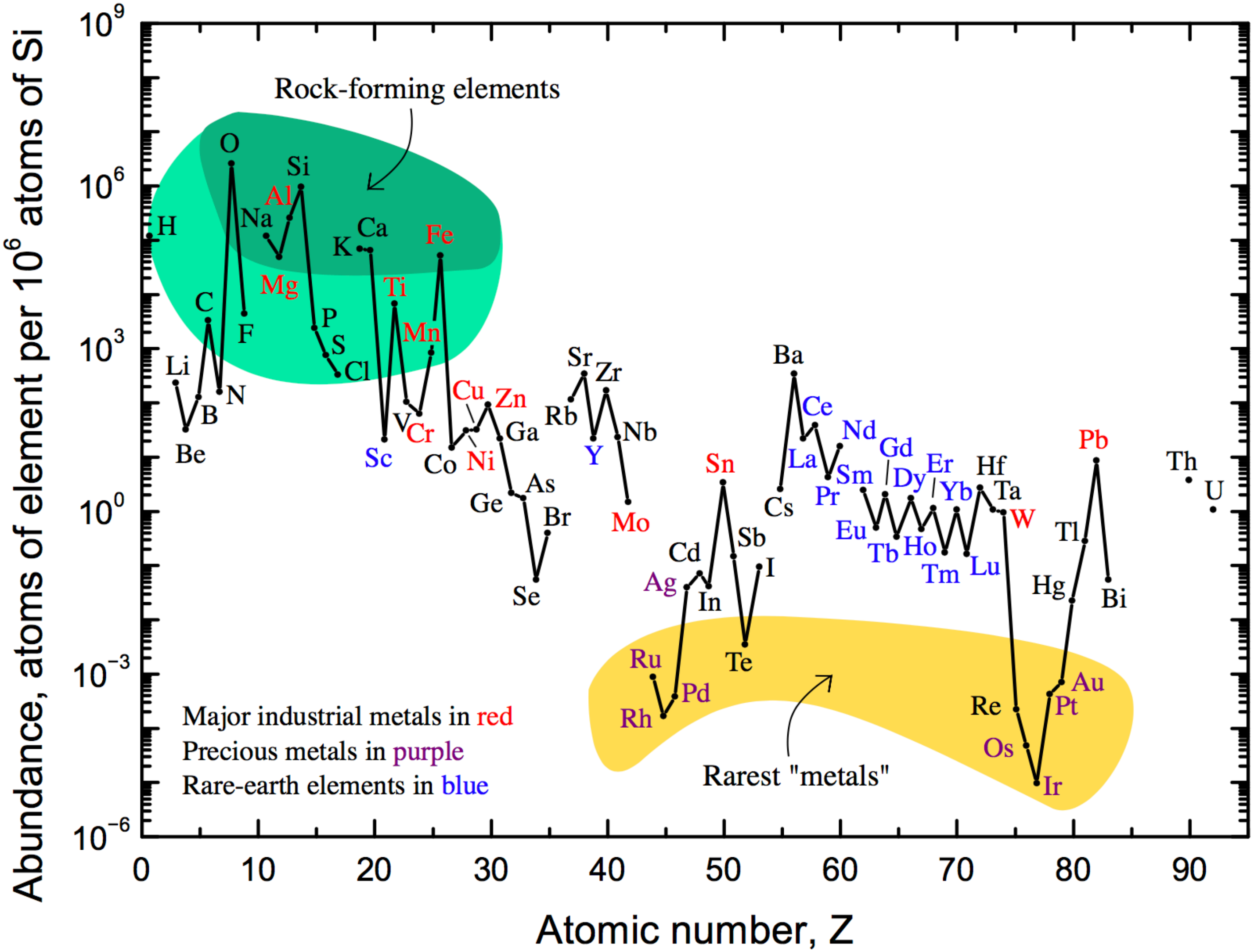
Examples of new needs – stiff and light or flexible and hard



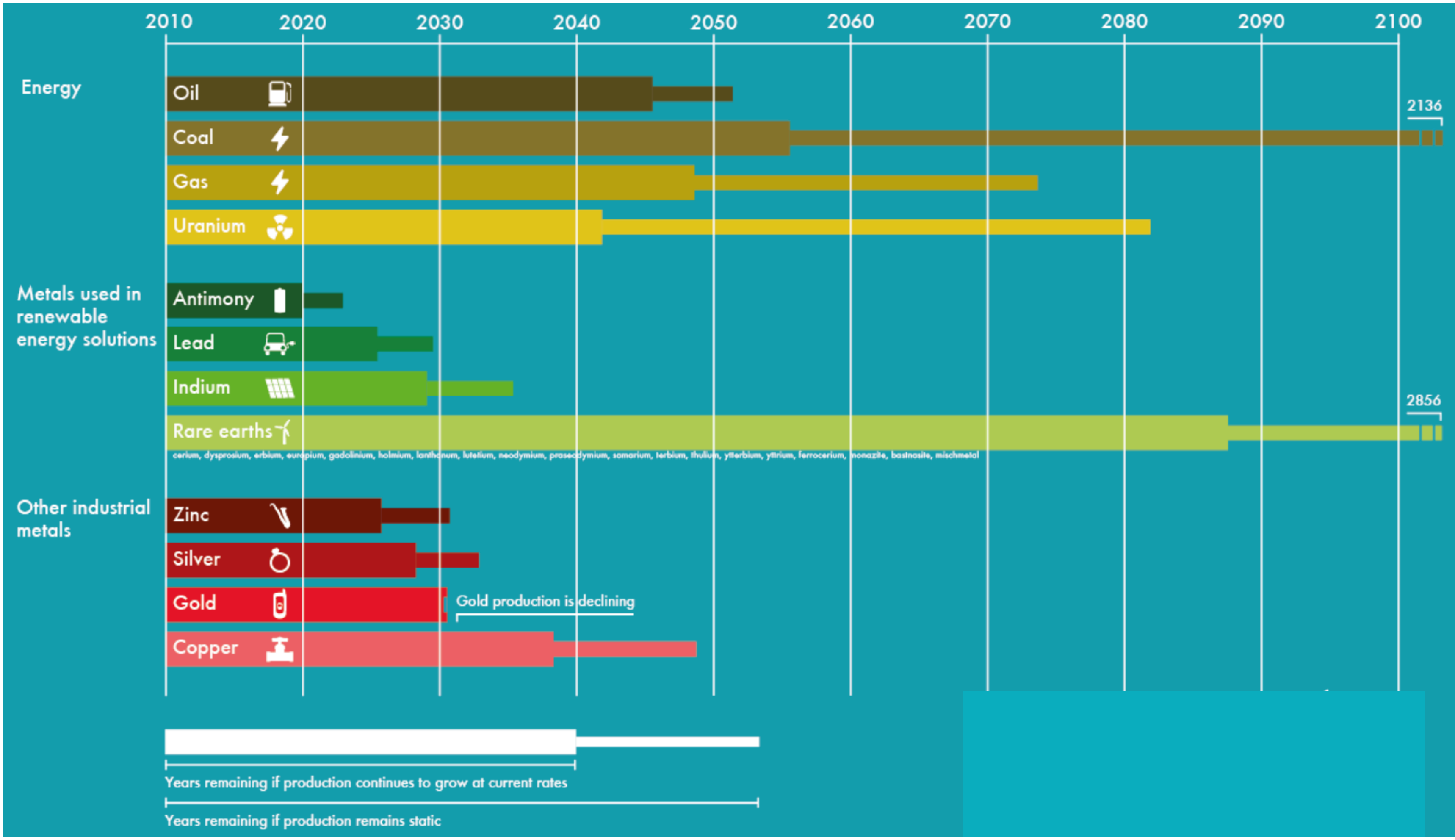
Reality check



Constraints on elements to be used in materials



Elements that should not be used in materials



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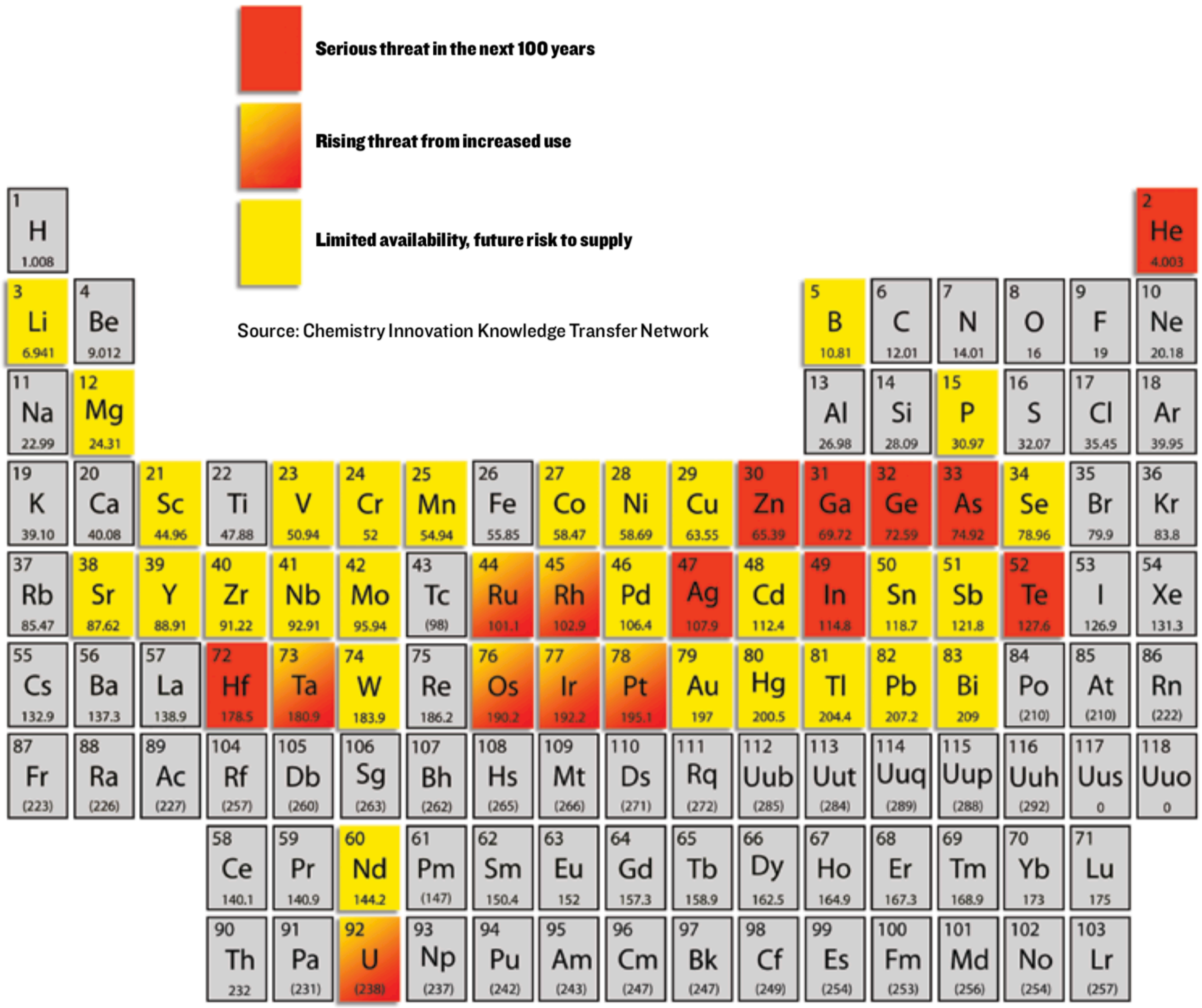

Materials science - Talking of many things

"The time has come," the Walrus said,
"To talk of many things:
Of shoes--and ships--and sealing-wax--
Of cabbages--and kings--
And why the sea is boiling hot--
And whether pigs have wings."

John Tenniel. Wood-engraving by the Dalziels

http://www.victorianweb.org/art/illustration/tenniel/lookingglass/4.2.html

The Walrus and The Carpenter
Lewis Carroll
Through the Looking-Glass and What Alice Found There
1872

Source: Uni Basel

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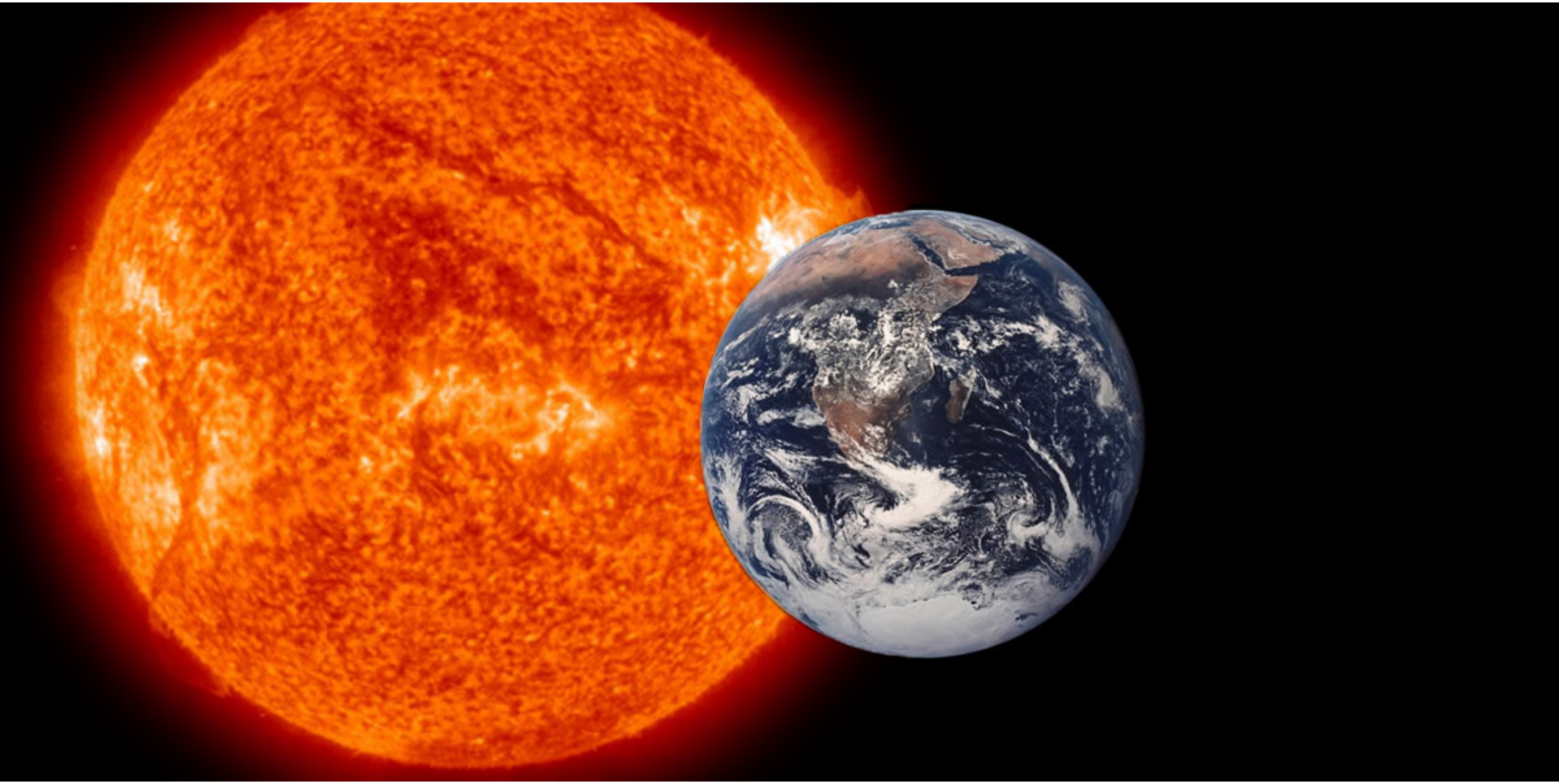
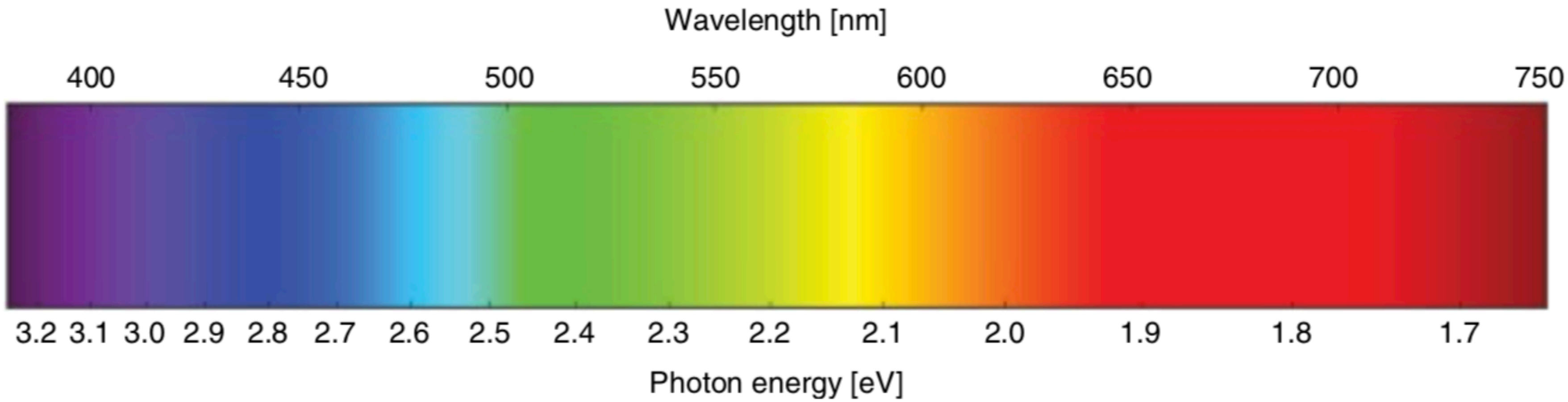
Case study 1 – solar energy photoconversion, from silicon to perovskites



Two key equations and a picture!

$$E = \frac{hc}{\lambda}$$

$$E = h \cdot \nu$$



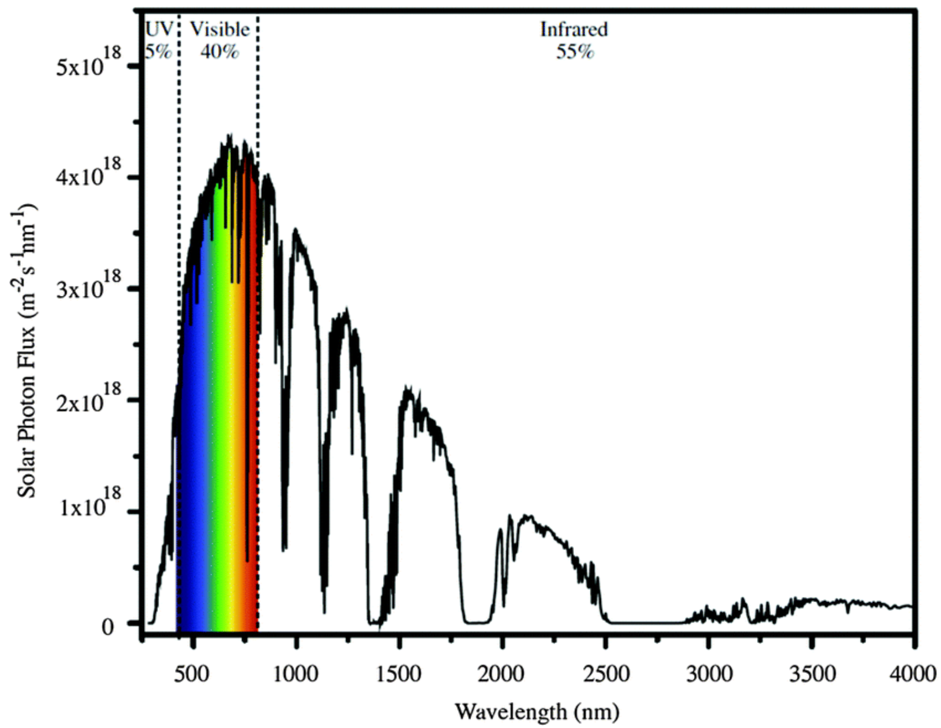
A more meaningful representation

Spectral irradiance is irradiance of a surface per unit wavelength.

This is a measure of the energy associated with solar radiation at a given wavelength.

About 1.08 x 10^{14} kW reaches the surface of the earth.

The typical maximum normal irradiance is approximately 1000 J s^{-1} m^{-2} at sea level on a clear day.



Most absorptions due to H_2O
O_2 760 nm, CO_2 at 2000 and 2006 nm

How much do we need?

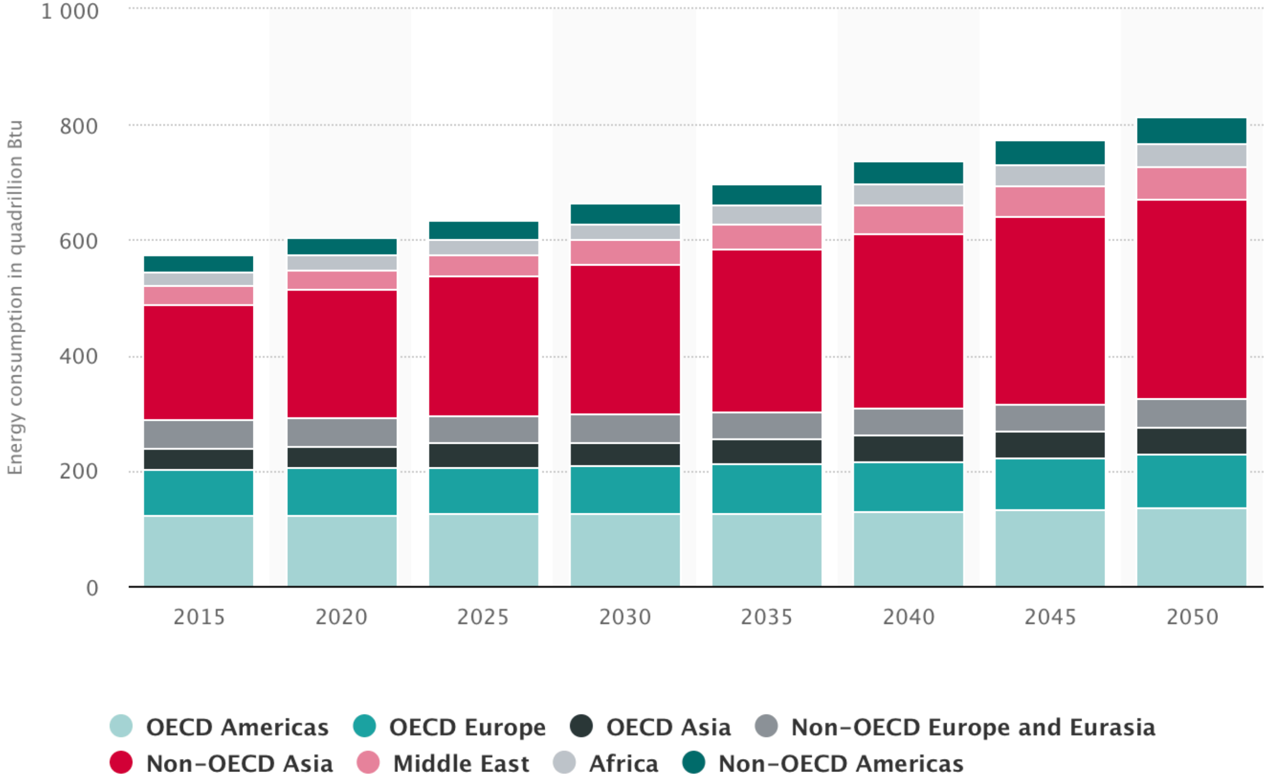
The total world energy consumption in 2012 was 559.8 EJ

(http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf)

1 exajoule = 10^{18} joules

The WEC estimates that consumption will increase globally to 696 - 879 EJ in 2050.

BTU ≅ 1kJ



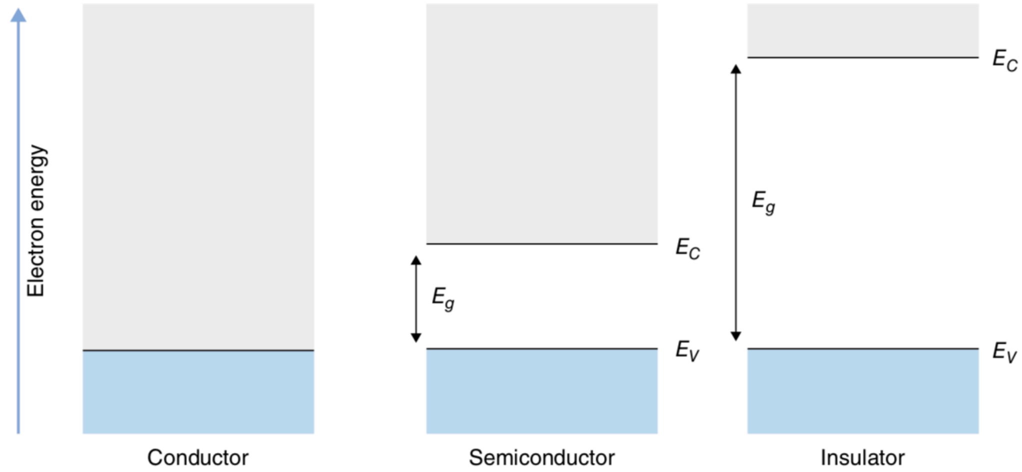
A future?

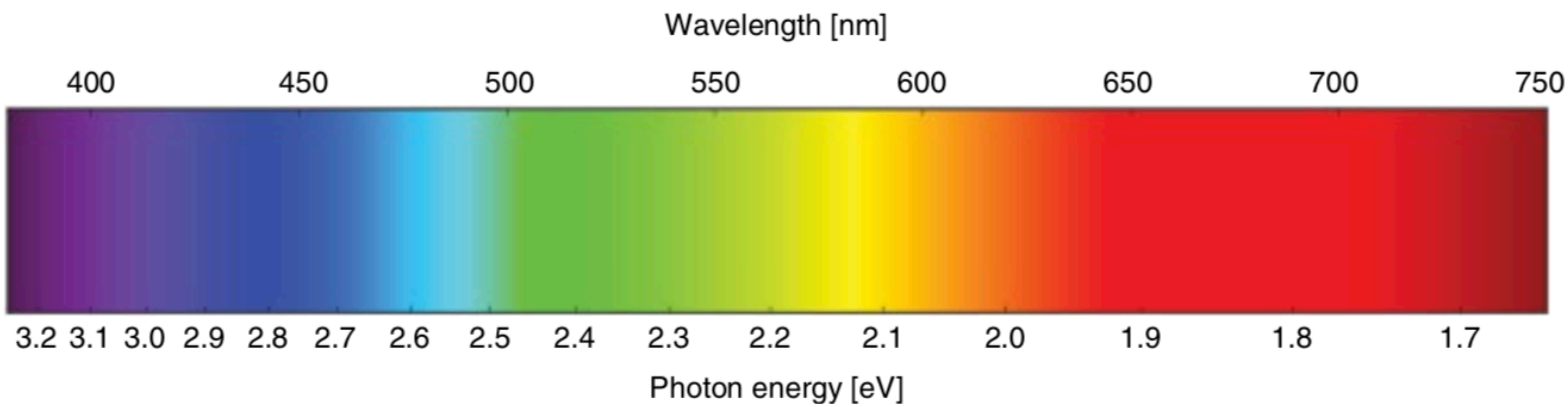
The solar radiation reaching the earth's surface in just one year is approximately 3 400 000 EJ

This is an order of magnitude greater than all estimated non-renewable energy resources

The total annual solar radiation falling on the earth is more than 7 500 times the world's total annual primary energy consumption of circa 500 EJ.

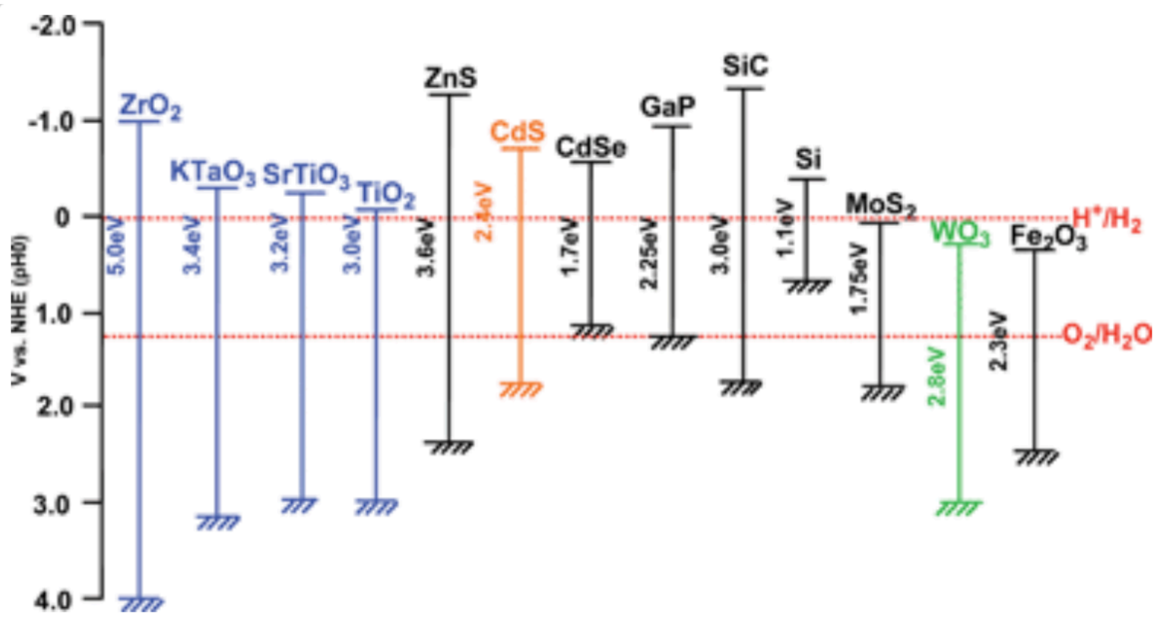
Enter the semiconductor!

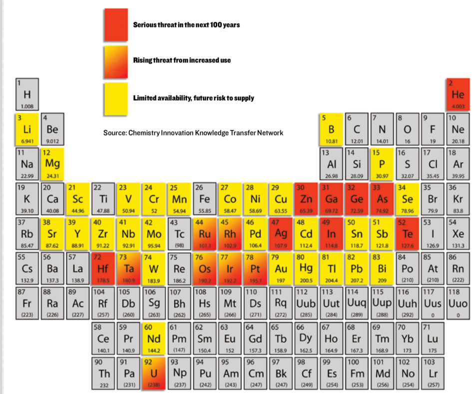


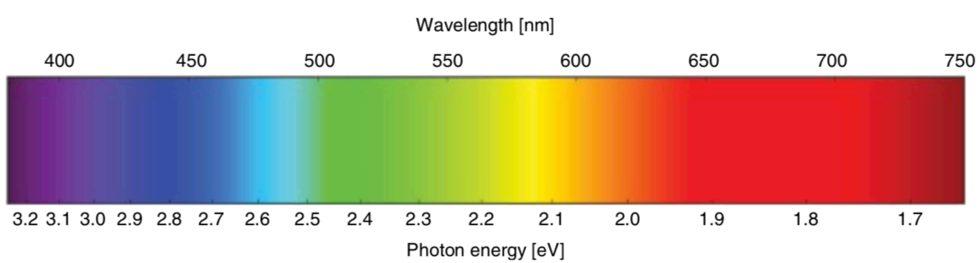


Photovoltaic Solar Energy: From Fundamentals to Applications Editor(s): Angèle Reinders, Pierre Verlinden, Wilfried Sark, Alexandre Freundlich, Wiley 2017

Enter the semiconductor!

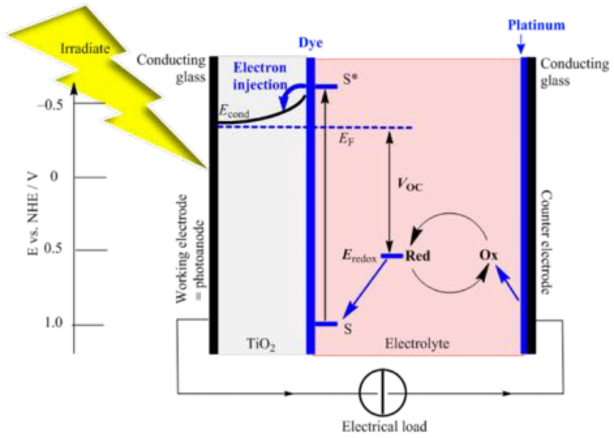


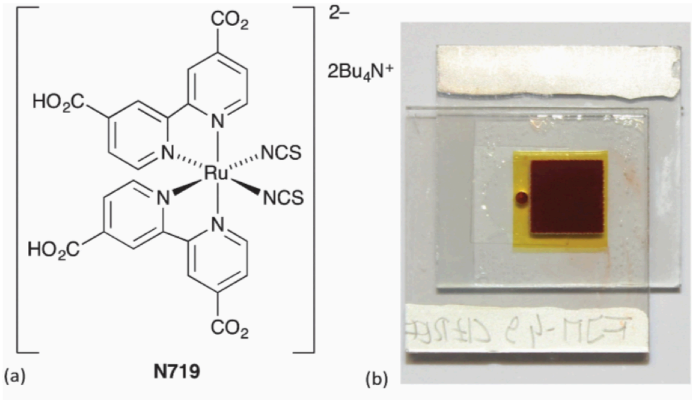


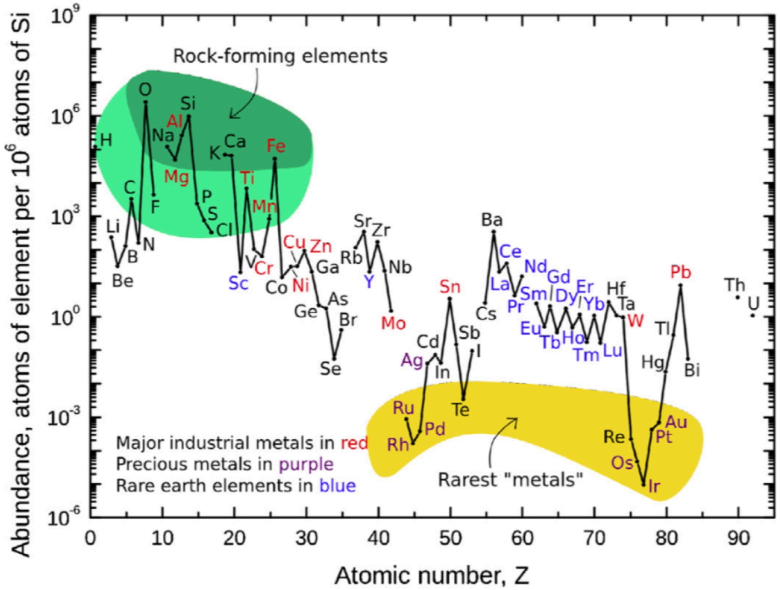


Chemistry » "Advanced Catalytic Materials - Photocatalysis and Other Current Trends", book edited by Luis Enrique Norena and Jin-An Wang, ISBN 978-953-51-2244-9, Published: February 3, 2016 under CC BY 3.0 license.

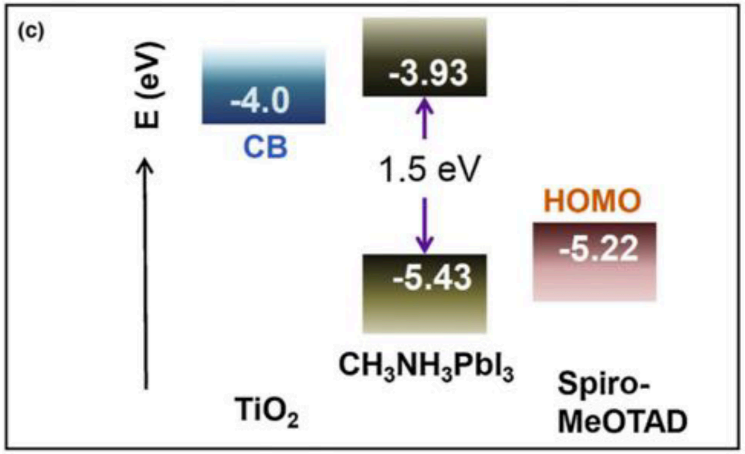
Dye sensitized solar cell

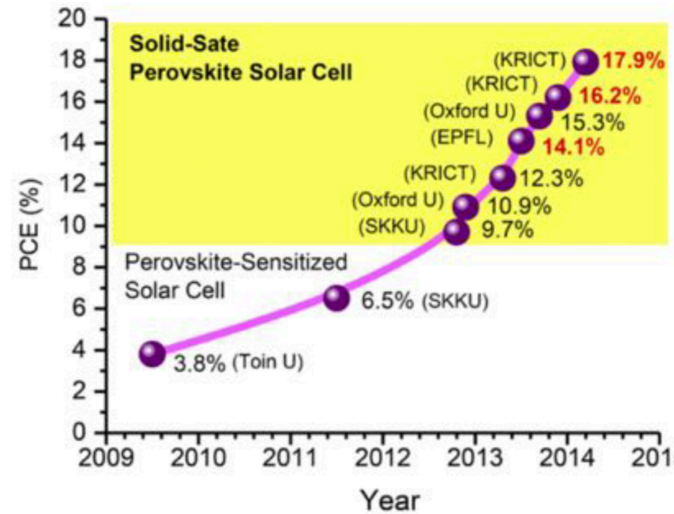


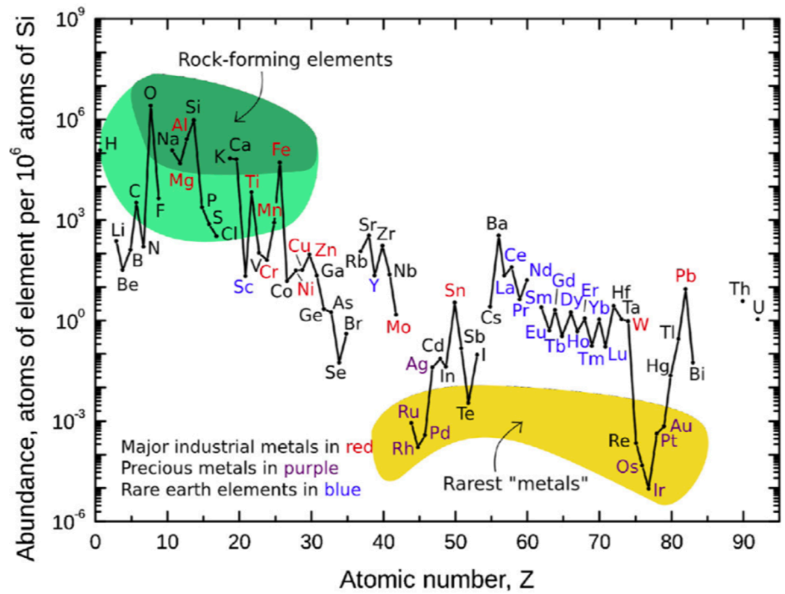




New wonder materials - perovskites







Complying with Lead Laws and Regulations

Compliance and enforcement laws and regulations are the tools that EPA uses to ensure that governments, businesses and industry understand and follow our nation's environmental laws and regulations. Compliance helps organizations or individuals meet their obligations under environmental laws and regulations. Read about lead enforcement.

EPA uses various methods to achieve compliance:

- **Compliance assistance** provides resources and training and tools to help businesses, federal facilities, local governments and tribes meet their environmental requirements.
- **Compliance incentives and auditing** encourages the regulated community to assess its regulatory obligations and self-disclose non-compliance. Voluntary self-disclosure and prompt correction of environmental violations can reduce or eliminate certain penalties.
- **Compliance monitoring** ensures that the regulated community follows environmental laws and regulations through on-site visits by qualified inspectors and by reviewing the information EPA or a state/tribe requires to be submitted.

Doing the energy balance on conventional solar cells

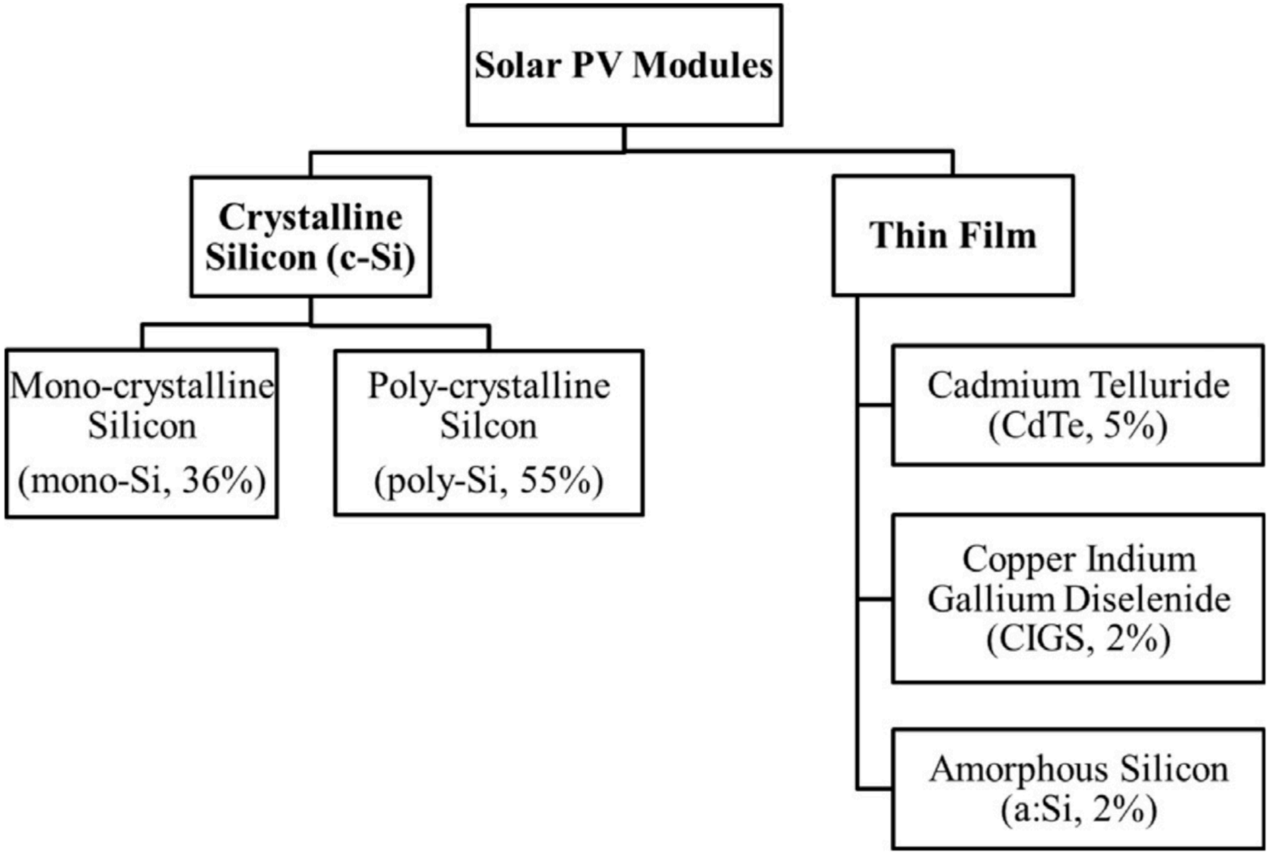


Fig. 1. Technologies included in this study and their estimated percentage of market share. These market share percentages were calculated in 2013 [19].

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Energy payback time and energy returned on energy invested

$$\text{EPBT (year)} = \frac{\text{Embedded (primary) energy (MJ m}^{-2})}{\text{Annual (primary) energy generated by the system (MJ m}^{-2}\text{ yr}^{-1})} = \frac{W_1(\text{MJ m}^{-2})}{W_2(\text{MJ m}^{-2}\text{ yr}^{-1})} = \frac{W_1}{(I \times \eta \times \text{PR}/\varepsilon)} \quad (1)$$

$$\text{EROI} = \text{lifetime energy output/Embedded energy} = \frac{W_3\ (\text{MJ m}^{-2})}{W_1\ (\text{MJ m}^{-2})} = \frac{W_2\ (\text{MJ m}^{-2}) \times \text{LT (year)}}{W_2\ (\text{MJ m}^{-2}\text{ yr}^{-1}) \times \text{EPBT (year)}} = \frac{\text{LT (year)}}{\text{EPBT (year)}} \quad (2)$$

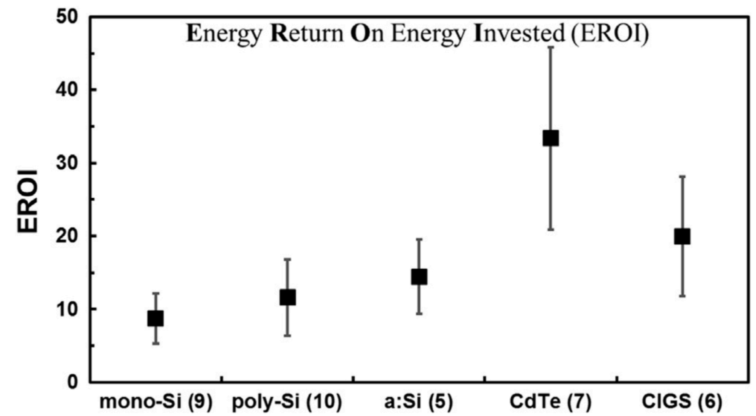
where

W_1 = embedded (primary) energy (MJ m^{-2});
W_2 = annual energy generated by the system expressed as primary energy (MJ m^{-2} yr^{-1});
W_3 = total energy generated by the system over its lifetime expressed as primary energy (MJ m^{-2});

ε = electrical to primary energy conversion factor;
I = total solar insolation incident on the unit-surface, per year (MJ m^{-2} yr^{-1});
η = average module efficiency (%);
PR = system performance ratio (%);
LT = lifetime of the system (year)

Across all technologies, the mean harmonized EPBT ranged from 1.0 to 4.1 years in the following order: CdTe < CIGS < a:Si < poly-Si <mono-Si

Perovskites claimed to be two months



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The dream

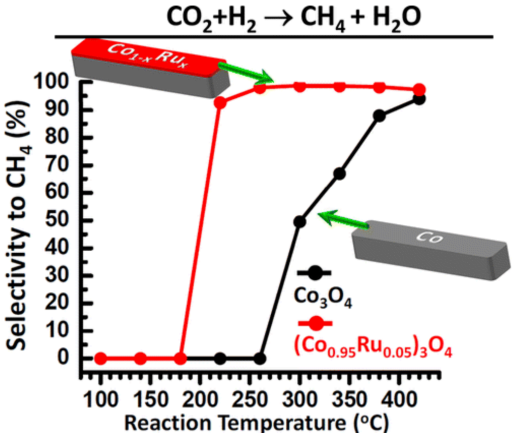
A closed carbon cycle

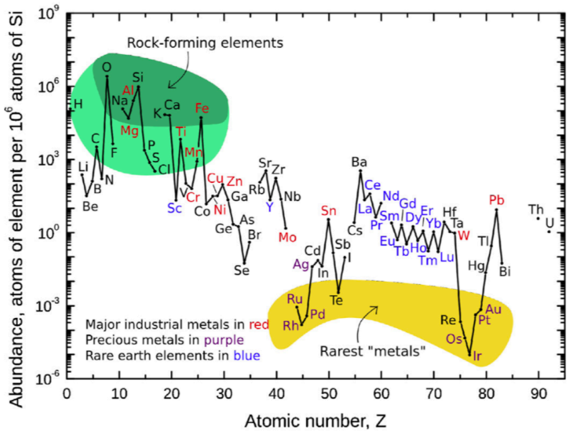
$CH_4 \rightarrow CO_2$ Combustion

$CO_2 \rightarrow CH_4$ Catalysis

Catalytic Conversion of Carbon Dioxide to Methane on Ruthenium–Cobalt Bimetallic Nanocatalysts and Correlation between Surface Chemistry of Catalysts under Reaction Conditions and Catalytic Performances

ACS Catal. 2, 11, 2403-2408



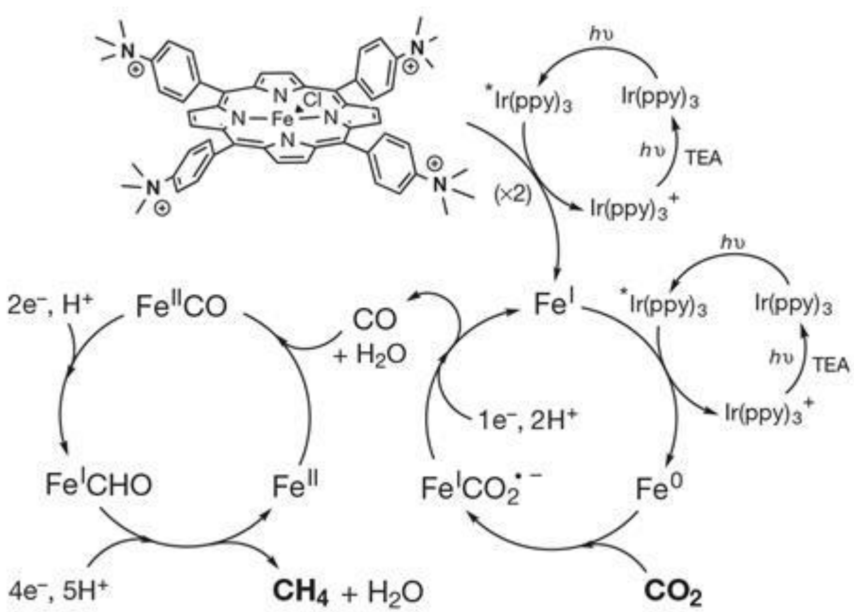


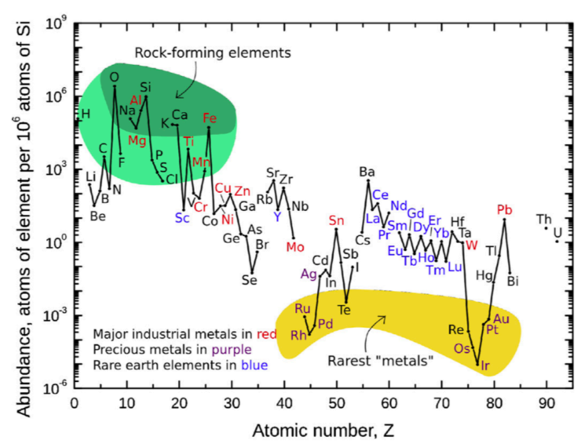
The dream and a hint of success

Nature, 2017, DOI: 10.1038/nature23016

$CH_4 \rightarrow CO_2$ Combustion

$CO_2 \rightarrow CH_4$ Catalysis





CO_2 reduction strategies

Summary of CO_2 reduction strategies.

Strategy	Application area/sector	Advantages	Limitations
Enhance energy efficiency and energy conservation	Applied mainly in commercial and industrial buildings.	Energy saving from 10% to 20% easily achievable.	May involve extensive capital investment for installation of energy saving device.
Increase usage of clean fuels	Substitution of coal by natural gas for power generation.	Natural gas emits 40–50% less CO_2 than coal due to its lower carbon content and higher combustion efficiency; cleaner exhaust gas (lower particulates and sulfur dioxide emissions).	Higher fuel cost for conventional natural gas. Comparable cost for shale gas.
Adopt clean coal technologies	Integrated gasification combined cycle (IGCC), pressurized fluidized bed combustor (PFBC) etc. to replace conventional combustion.	Allow the use of coal with lower emissions of air pollutants.	Significant investment needed to roll out technologies widely.
Use of renewable energy	Hydro, solar (thermal), wind power, and biofuels highly developed.	Use of local natural resources; no or low greenhouse and toxic gas emissions.	Applicability may depend on local resources availability and cost. Power from solar, wind, marine etc. are intermittent and associated technologies are not mature; most current renewable energies are more costly than conventional energy.
Development of nuclear power	Nuclear fission adopted mainly in US, France, Japan, Russia and China. Nuclear fusion still in research and development phase.	No air pollutant and greenhouse gas emissions.	Usage is controversial; development of world's nuclear power is hindered due to the Fukushima Nuclear Accident in 2011, e.g. Germany will phase out all its nuclear power by 2022.
Afforestation and reforestation	Applicable to all countries.	Simple approach to create natural and sustainable CO_2 sinks.	Restricts/prevents land use for other applications.
Carbon capture and storage	Applicable to large CO_2 point emission sources.	It can reduce vast amount of CO_2 with capture efficiency $> 80\%$.	CCS full chain technologies not proven at full commercial scale.

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CO_2 reduction strategies

Comparison of different separation technologies.

Technology	Advantage	Disadvantage	Reference
Absorption	– High absorption efficiency (> 90%). – Sorbents can be regenerated by heating and/or depressurization. – Most mature process for CO_2 separation.	– Absorption efficiency depends on CO_2 concentration. – Significant amounts of heat for absorbent regeneration are required. – Environmental impacts related to sorbent degradation have to be understood.	[30,33,35]
Adsorption	– Process is reversible and the absorbent can be recycled. – High adsorption efficiency achievable (> 85%).	– Require high temperature adsorbent. – High energy required for CO_2 desorption.	[43–45,212]
Chemical looping combustion	– CO_2 is the main combustion product, which remains unmixed with N_2, thus avoiding energy intensive air separation.	– Process is still under development and there is no large scale operation experience.	[58–60]
Membrane separation	– Process has been adopted for separation of other gases. – High separation efficiency achievable (> 80%).	– Operational problems include low fluxes and fouling.	[35,61,63,213]
Hydrate-based separation	– Small energy penalty.	– New technology and more research and development is required.	[13,19,67,68]
Cryogenic distillation	– Mature technology. – Adopted for many years in industry for CO_2 recovery.	– Only viable for very high CO_2 concentration > 90% v/v. – Should be conducted at very low temperature. – Process is very energy intensive.	[72,74]

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The Emperor's New Clothes - 2018

"The Emperor shivered, for he suspected they were right. But he thought, 'This procession has got to go on.' So he walked more proudly than ever, as his noblemen held high the train that wasn't there at all."

University of Basel

Thank you
for your attention.

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