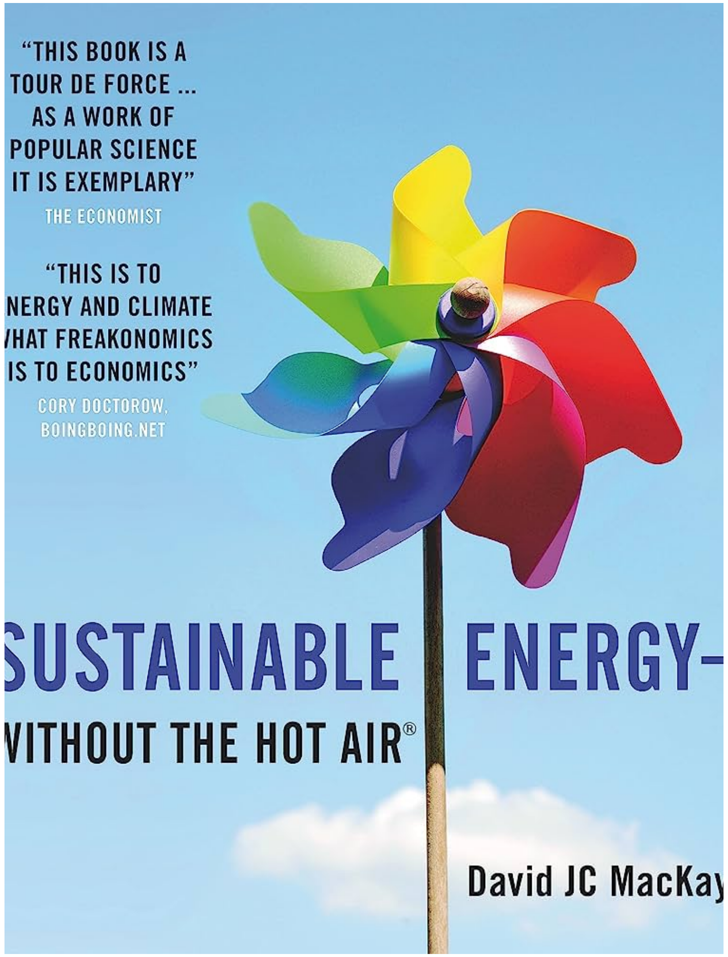
Concluding remarks

Francesco Romanelli

Joint EPS-SIF International School on Energy

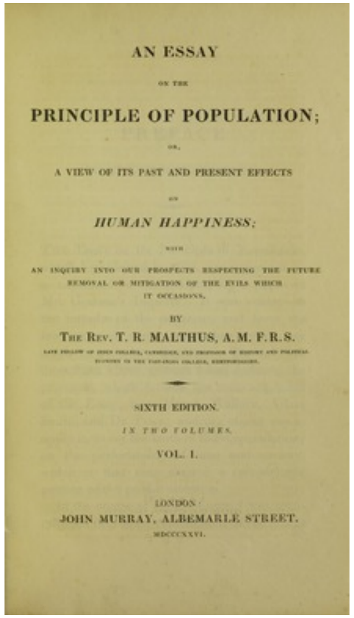
1st remark: Do not use ideology when discussing about energy

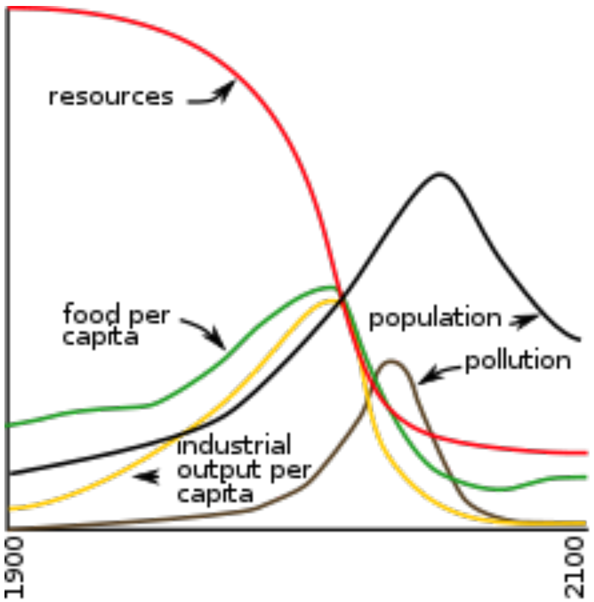
Whatever your motivation, the aim of this book is to help you figure out the numbers and do the arithmetic so that you can evaluate policies; and to lay a factual foundation so that you can see which proposals add up.
David McKay *Sustainable energy - without the hot air*



Energy mix is a political decision but must satisfy the needs of the society and not be driven by ideology

2nd remark: Predictions are often wrong





- *An essay of the principle of the population as it affects the future improvement of society* (Malthus, 1798)
- *The limits of growth* (MIT- Club of Rome 1972)

- …did not take into account technological improvements and the use of energy (1l diesel = 38MJ)

Feeding the world

	1950	**1919**
Population (millions)	**2500**	**7700**
With enough food	**890**	**7000**
Insufficient food	**65%**	**9%**

- 1kg bread -> 0.2l diesel
- 1kg meat -> 0.35l diesel
- 1kg tomato -> 0.15-0.5 diesel

Massive use of fertilizers (e.g. NH3)!

V. Smil *How the World really works* 2021

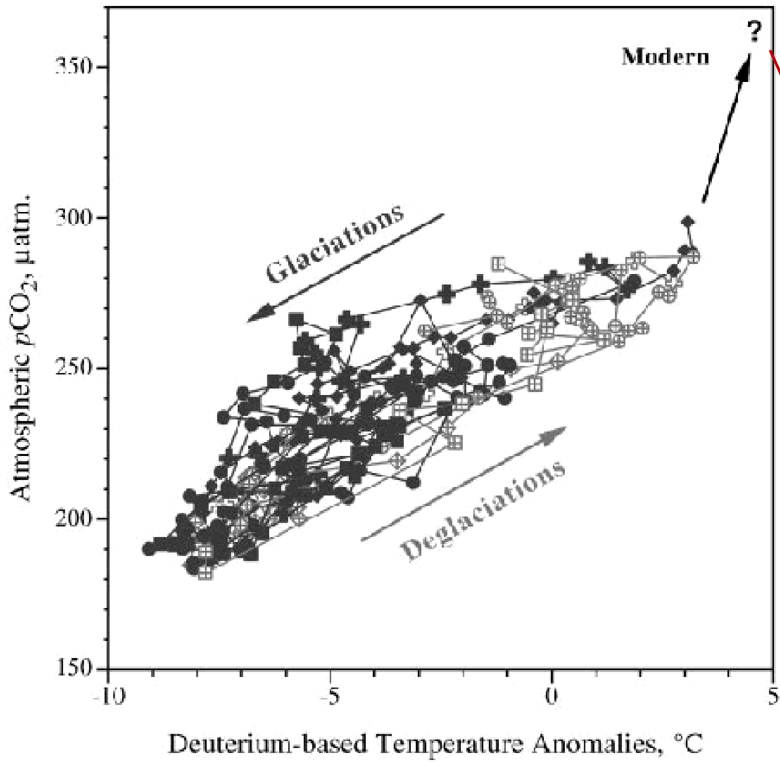
Topics covered in the school

- General
  - What is energy (S. Furfari)
  - Material availability (K. Tae-Yoon)
  - Human impact on atmosphere (M. Kanakidou)
  - Energy perspective (G. Graditi)
- Specific technologies
  - Fossil fuels (J. Craig)
  - Electrochemical conversion (V. Sofianos. M.A. Navarra)
  - Bioenergy (G. Mendez Sousa)
  - Smart cities, energy networks (C.A. Nucci, M. Cucuzzella)
  - Fission (S. Leray, R. De Salvo, M. Ripani, V Montoya, A. Mariani)
  - Fusion (A. Spagnuolo, D. Batani)
  - Solar (S. Guillerez, A. Bruno)
  - Wind (J. Peinke)

Why we discuss about energy?

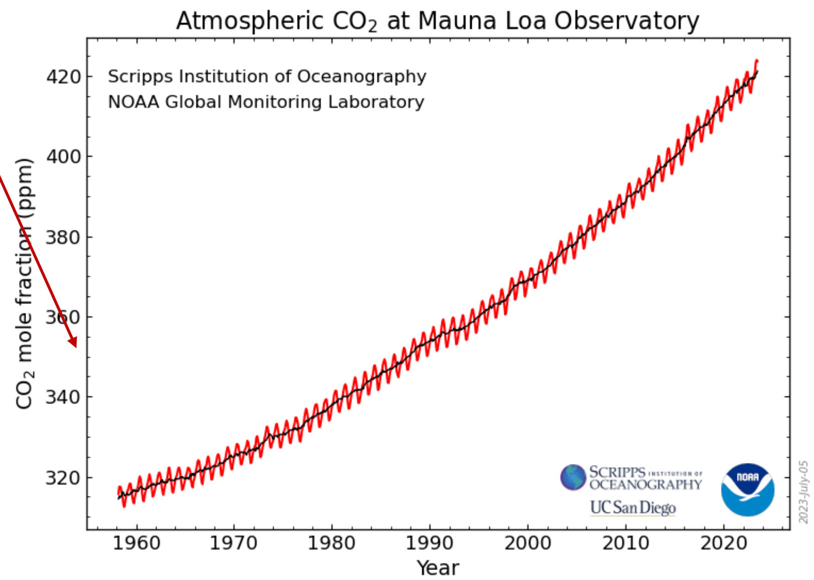
- Three challenges
  - Reduce CO_2 emission
  - Reduce energy poverty
  - Satisfy energy demand

Reduce CO_2 emissions



We are currently out of this 'safe' zone (CO_2, T) →.
CO_2 >100 ppm higher than max CO_2 the last 420 000 yrs.
Increasing rate of CO_2 10 - 100 times higher

13 OCTOBER 2000 VOL 290 SCIENCE www.science

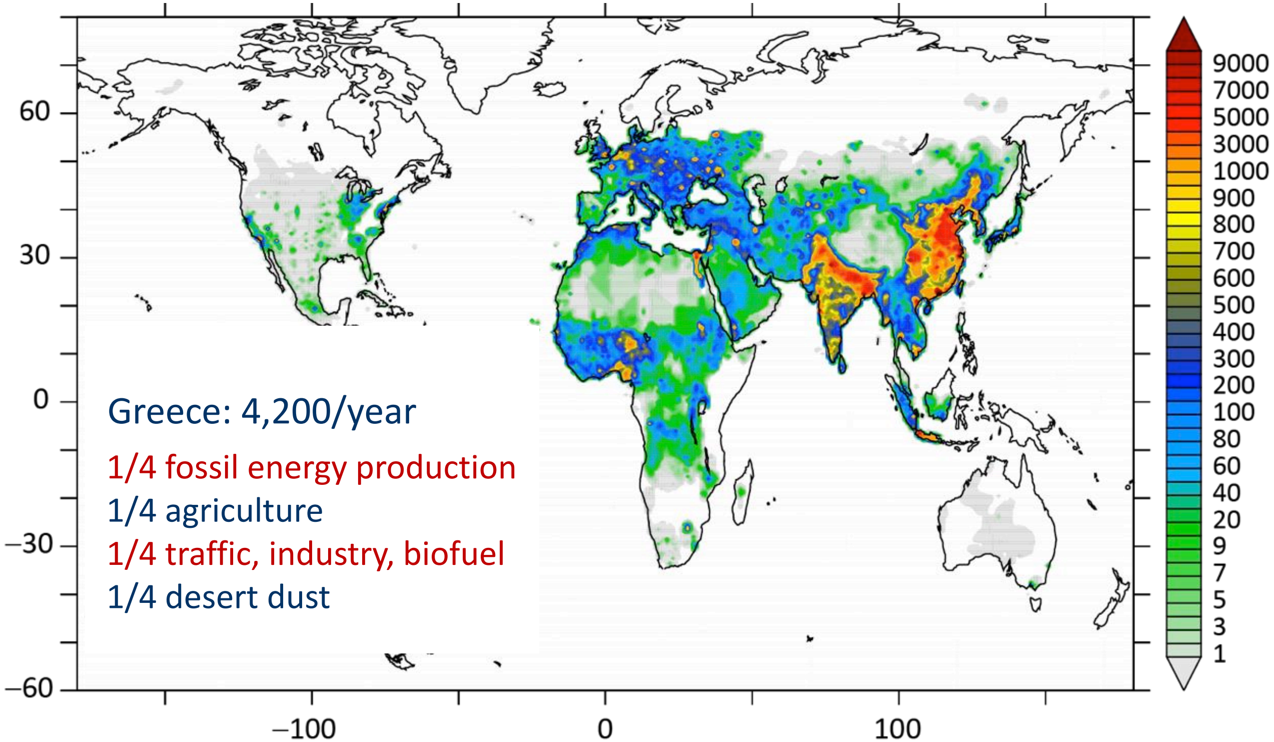


started by C. David Keeling of the Scripps Institution of Oceanography in March of 1958 at a facility of the National Oceanic and Atmospheric Administration *[Keeling, 1976]*

Reduce CO_2 emissions

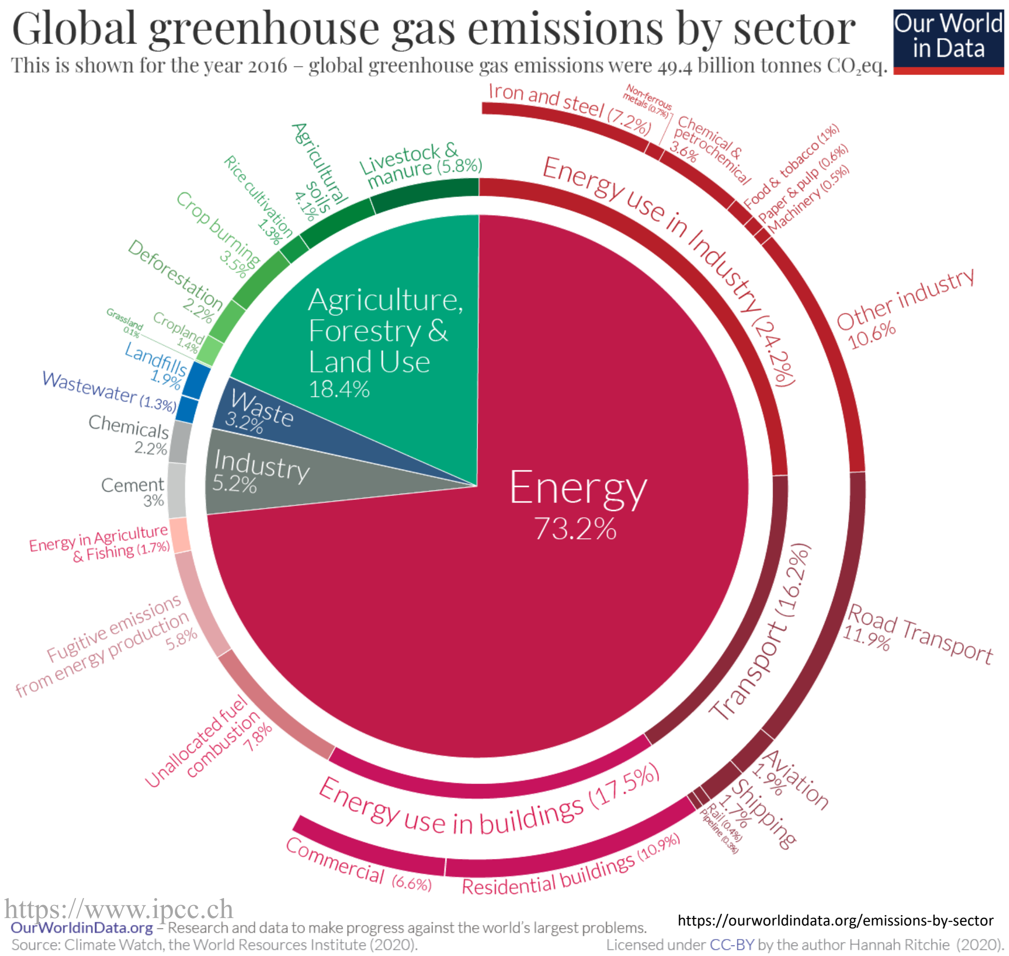
Annual premature mortality attributable to outdoor air pollution

Individuals per 100 × 100 km^2 – **Globally 3.3 million/year**



Lelieveld et al., 2015

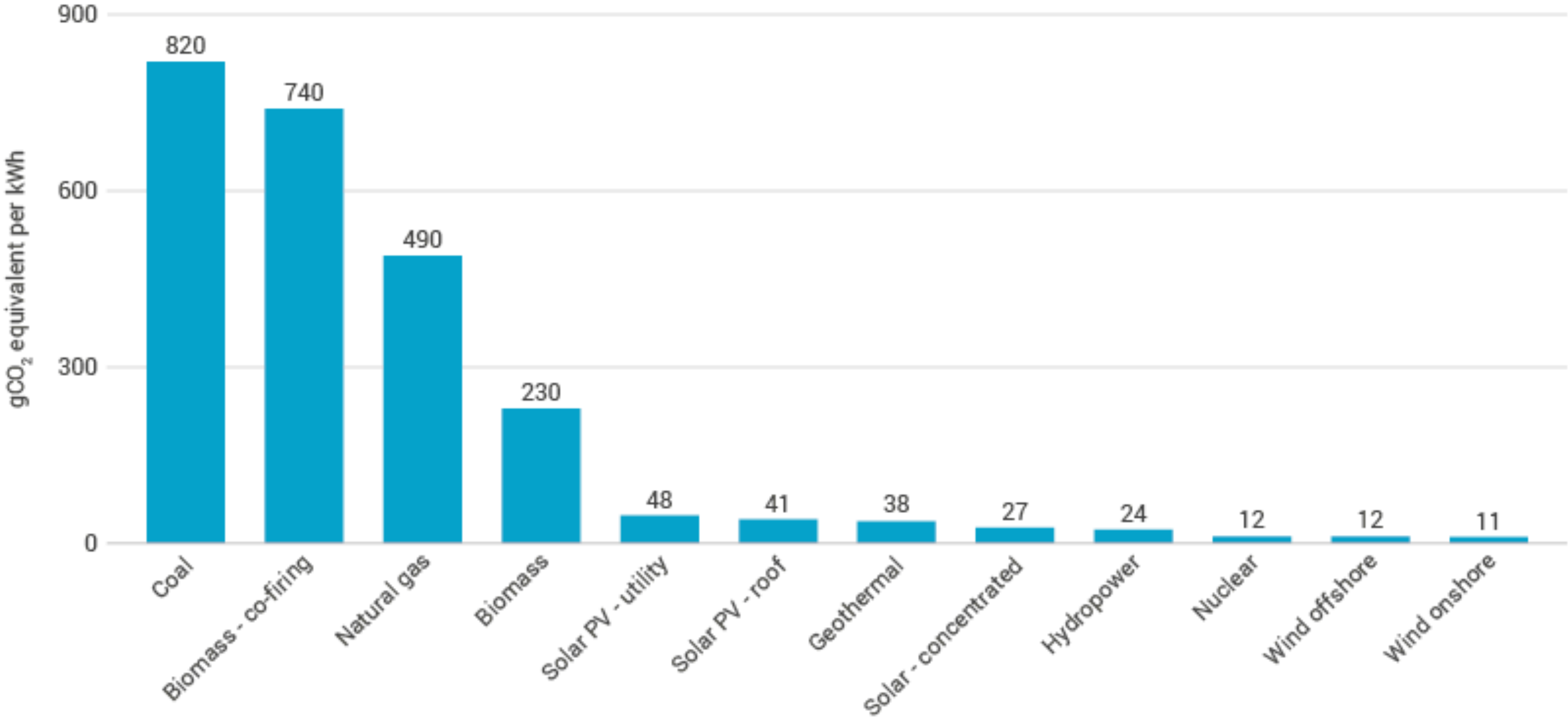
Reduce CO_2 emissions



https://www.ipcc.ch

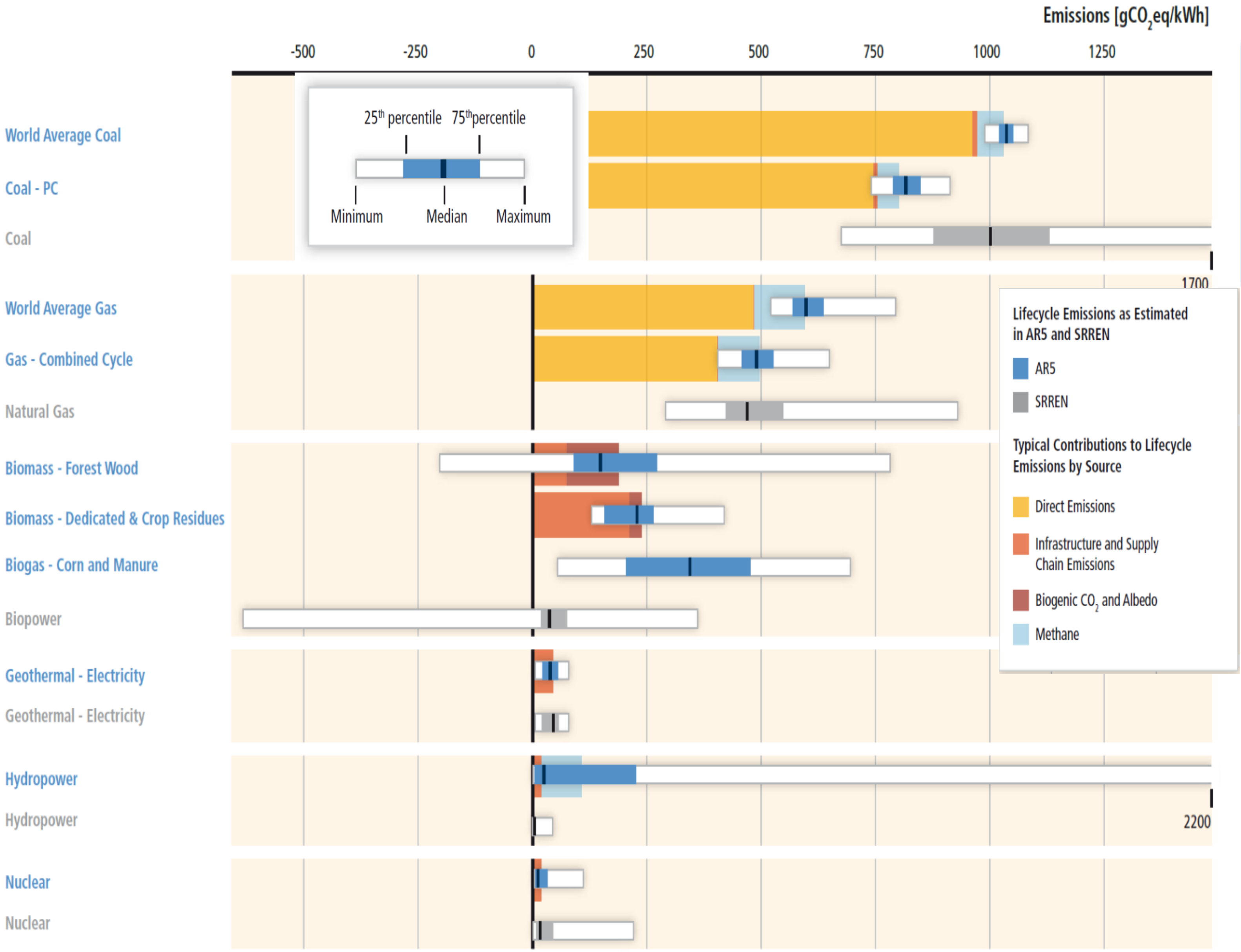
https://ourworldindata.org/emissions-by-sector

Reduce CO_2 emissions



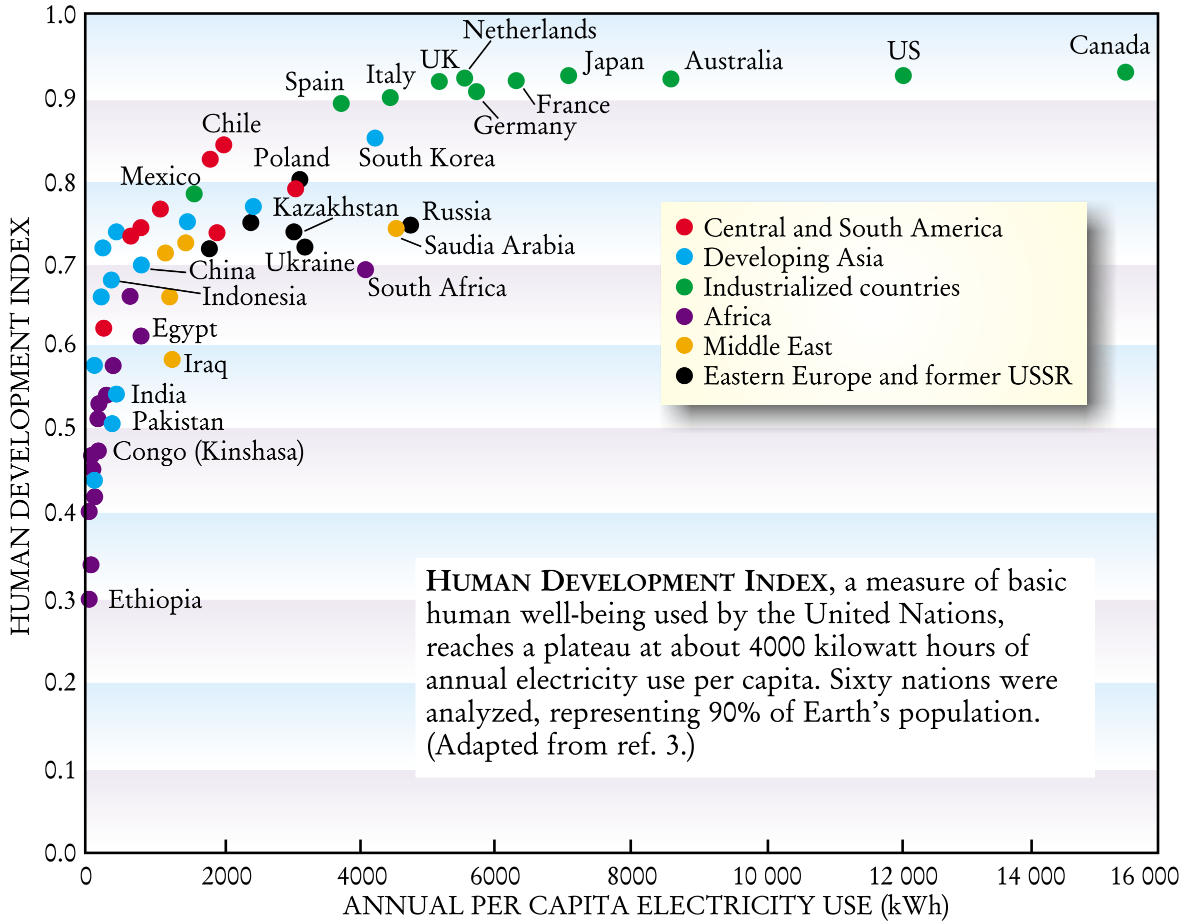
Source: IPCC 2014

Lifecycle emissions compared: IPCC



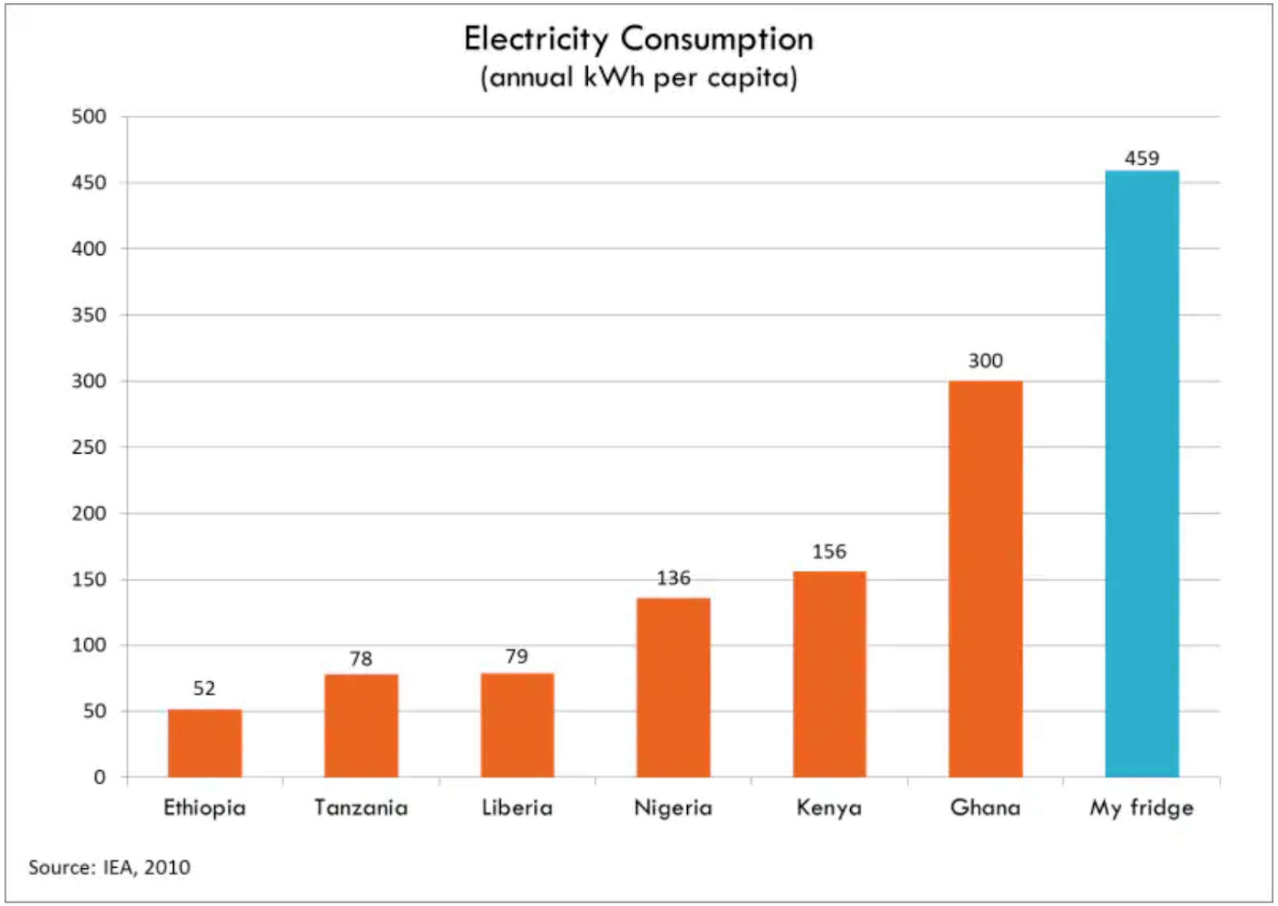
Source: [Climate Change 2014 Mitigation of Climate Change](), Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), p. 71 - Cambridge University Press -

Reduce energy poverty



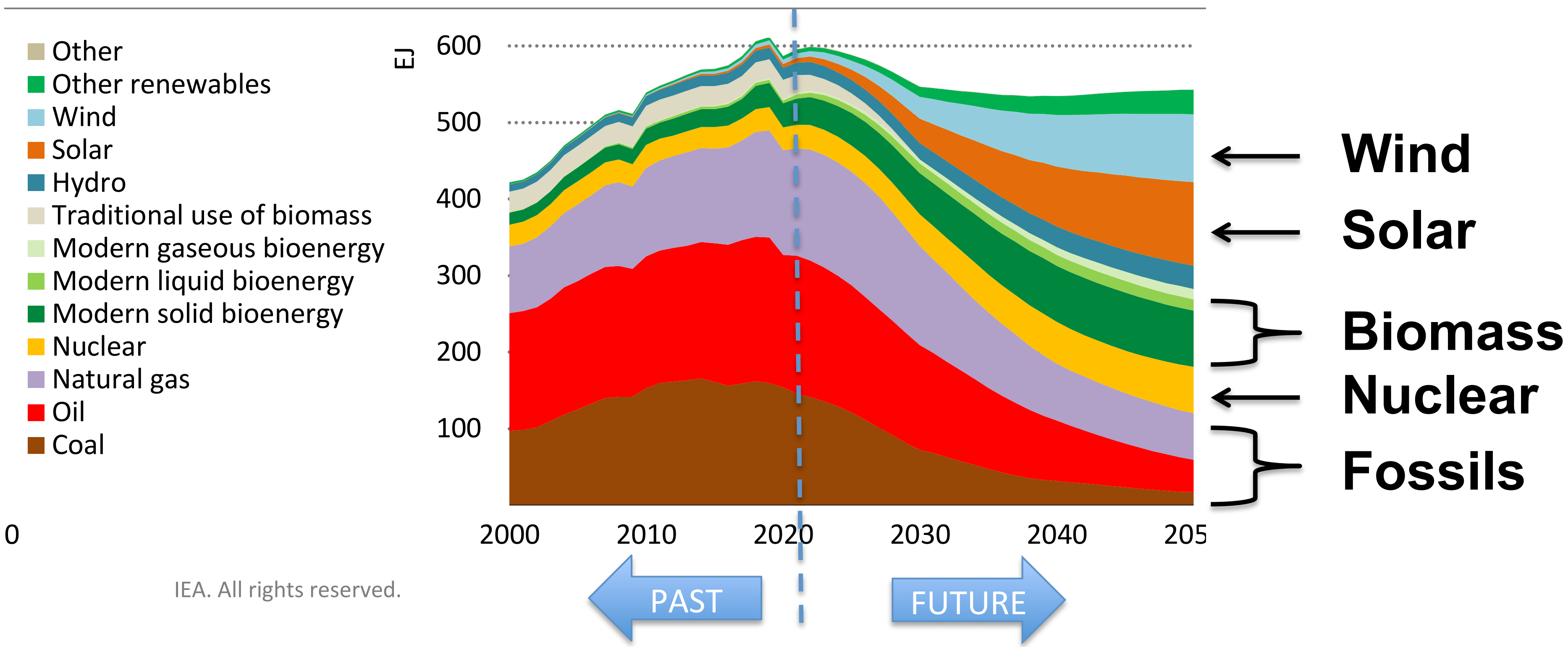
Source: Phys. Today 2002

Reduce energy poverty



Satisfy energy demand

Figure 2.5 ▹ Total energy supply in the NZE

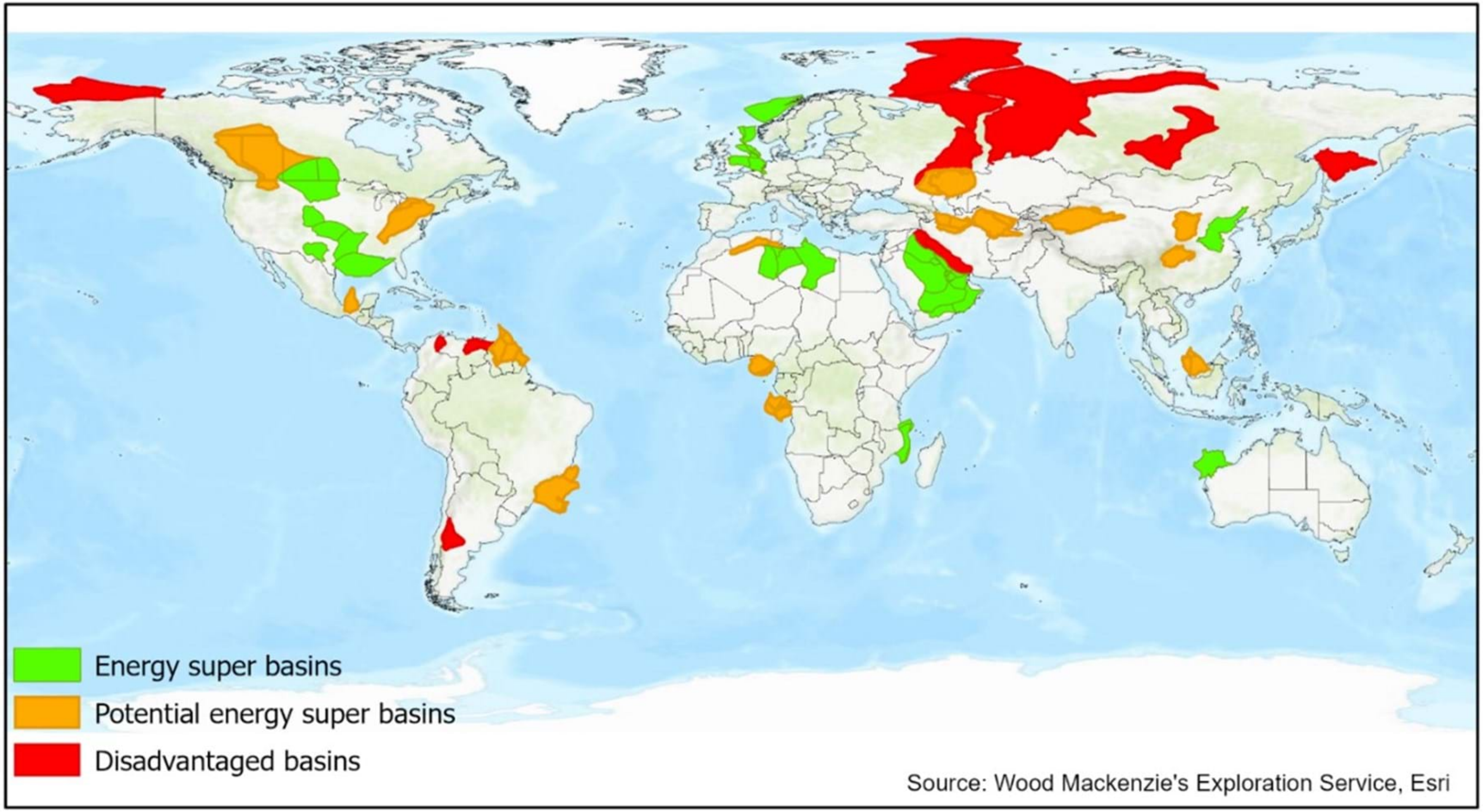


…**but the data of the last two years confirm the trend of the past!**

Fossil fuels

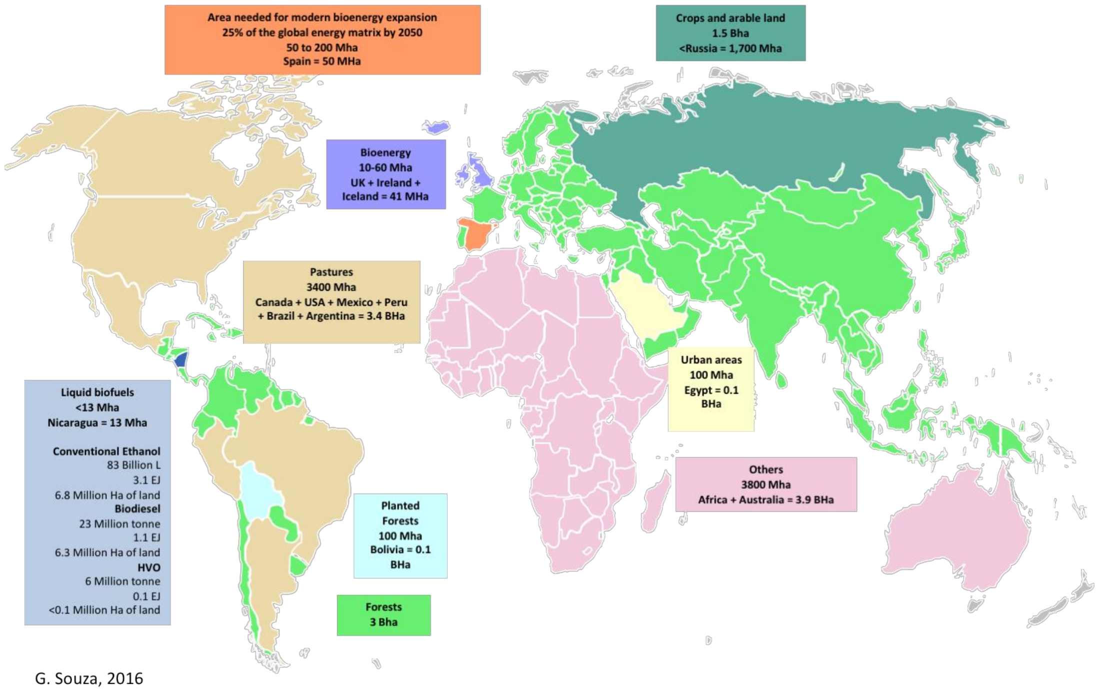
- Fossil fuels are going to remain around for long time.
- Reduction in fossil fuels extraction may have short term impact on availability of other materials
  - 80% of sulphur is a waste product from oil&gas production
- Carbon Capture Use and Storage will be necessary to cope with CO_2 emissions
- Energy superbasins
  - Abundant oil and gas resources
  - Plentiful clean energy
  - Hub scale CUS

Fossil fuels



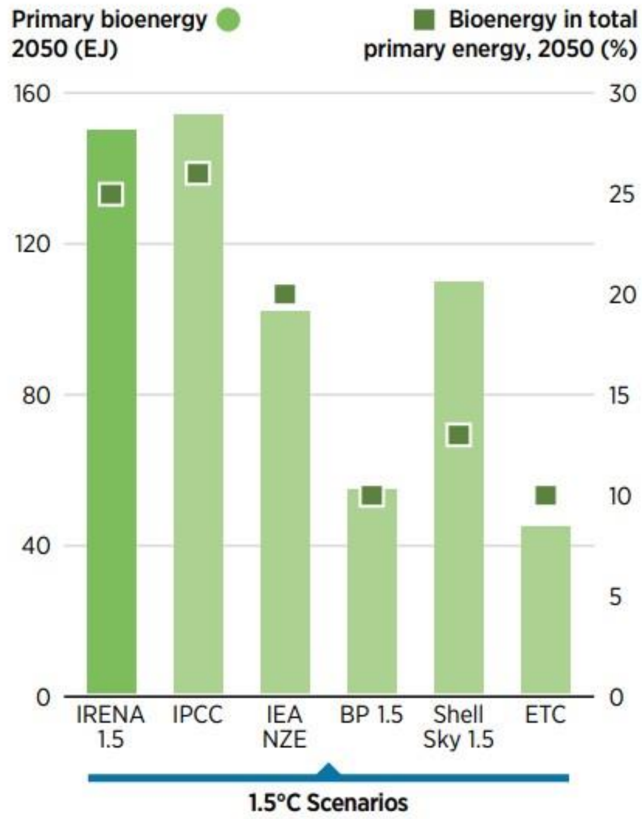
Bioenergy

Total global land is 13 Billion Hectares



G. Souza, 2016

Based on Woods, J. *et al.* (2015). Land and Bioenergy. Em: Souza, G. M., Victoria, R., Joly, C., & Verdade, L. (Eds.). (2015). *Bioenergy & Sustainability: Bridging the gaps* (Vol. 72, p. 258-300). Paris: SCOPE. ISBN 978-2-9545557-0-6.

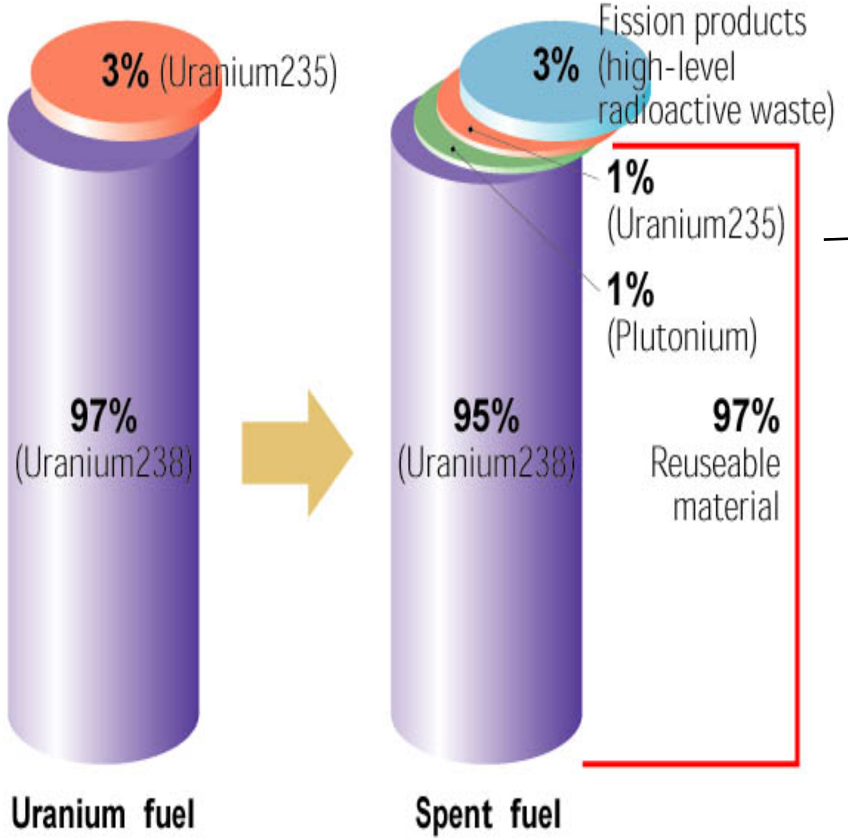


Fission

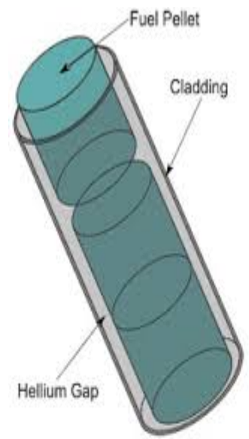
- Energy efficient
  - 1g $^{235}U = 8.2 \times 10^7$ kJ
  - 1g D-T=3.4×10^8 kJ
- Uranium resources
  - One through cycle waste a lot of fuel
  - Need advanced technologies
  - Thorium?
- Waste
  - Minimize waste via Pu and actinides separation

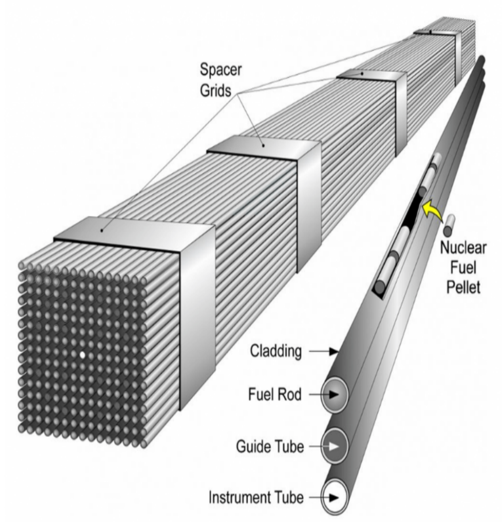
Radioactive waste – Spent fuel

Composition of spent nuclear fuel – HLW

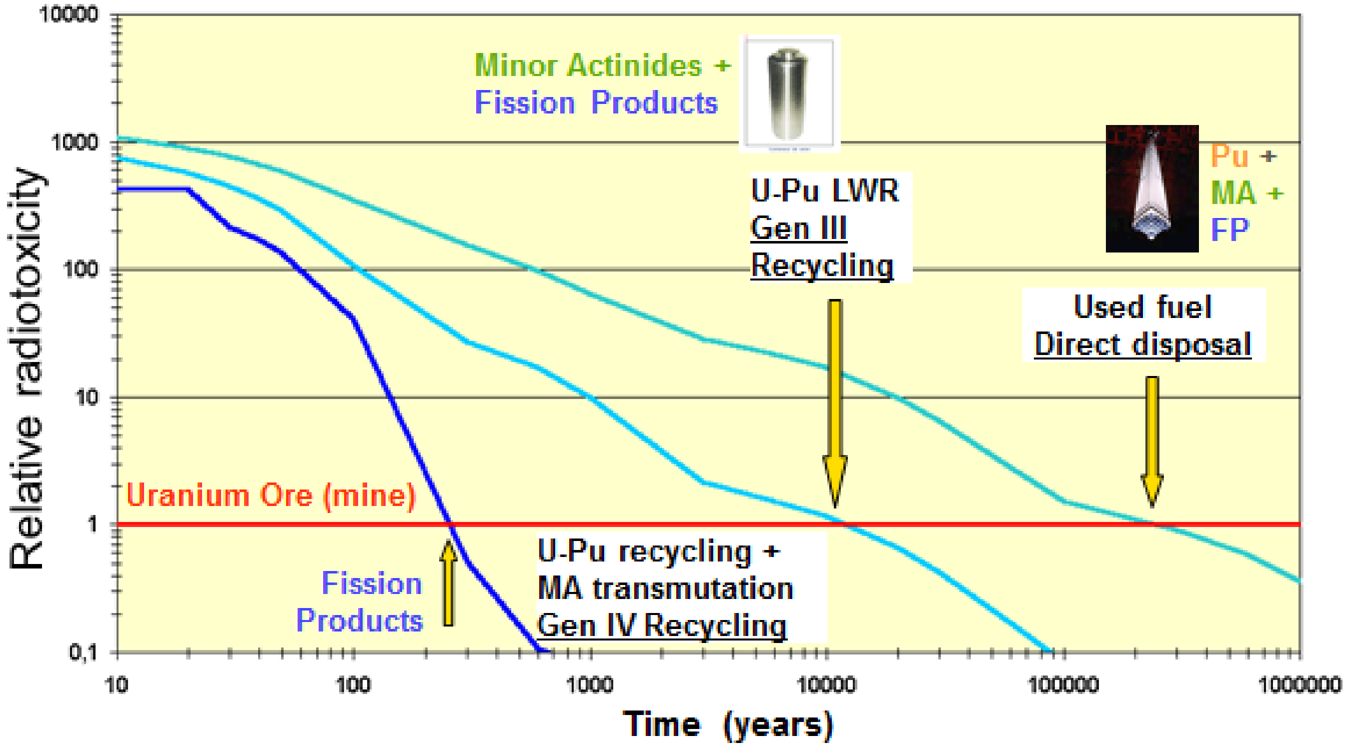


UO_x pellets





Radiotoxicity of UOX spent fuel relative to uranium ore, versus time (years)

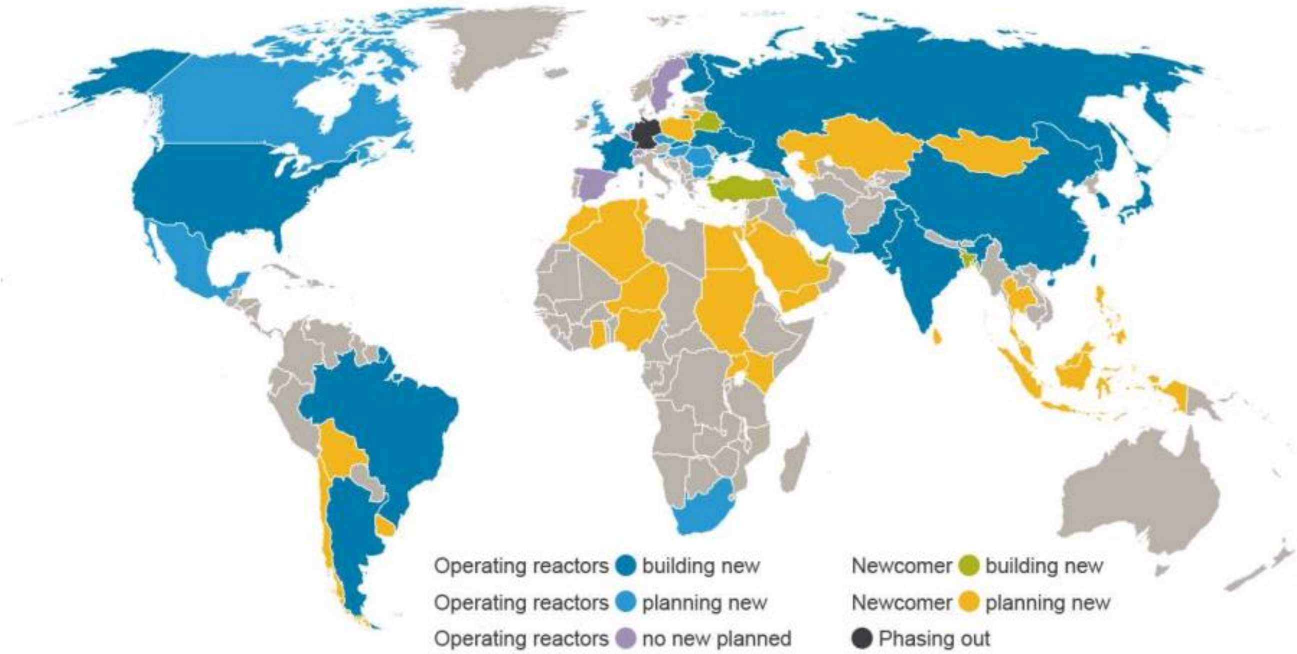


Abderrahim et al. (2015)

WORLD NUCLEAR ASSOCIATION

New build and new countries

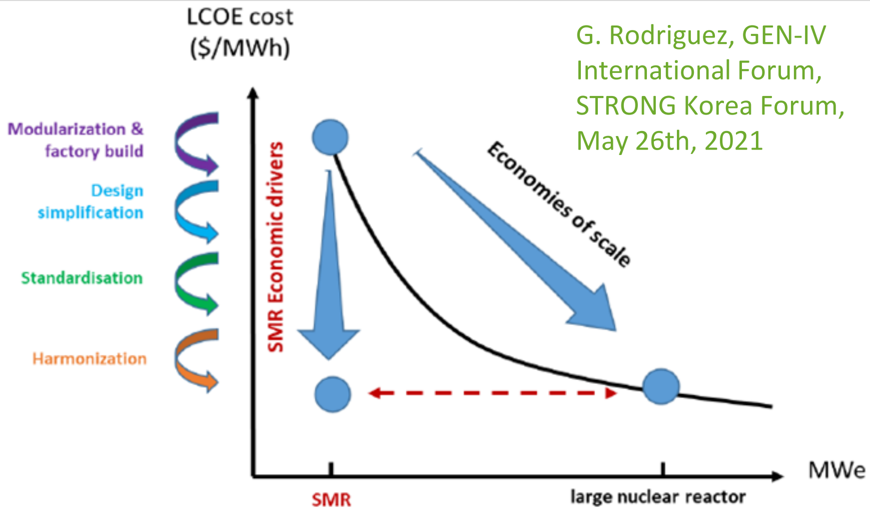
Agneta Rising, World Nuclear Association, March 2018



- **56 reactors under construction, of which 16 in China, 6 in Russia, 7 in India**
- **152 reactors planned, of which 43 in China, 25 in Russia, 14 in India**

The emergence of small / micro modular reactors

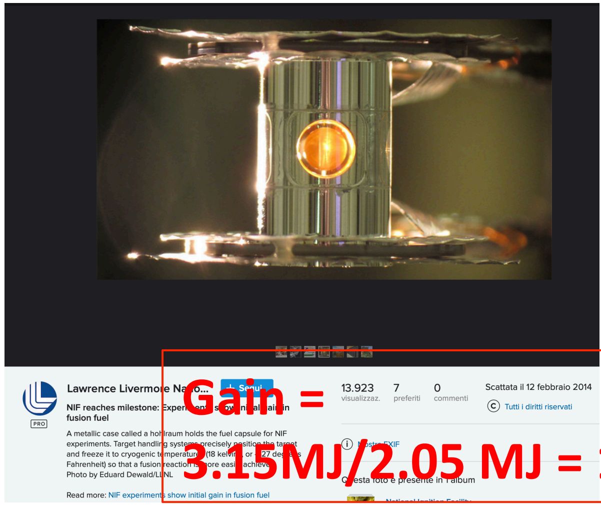
- **Definitions: SMR / AMR / MMR**
  - **Small Modular Reactor (SMR):** <500 MWe max, usually between 50 and 200 MWe, generally based on GEN-III technology (PWR, BWR, sometimes HTR)
  - **Advanced Modular Reactor (AMR):** SMR type but of GEN-IV type system (Molten salt, Na, Pb, Gas, SuperCritical Water)
  - **Micro Modular Reactor (MMR) or Very Small Modular Reactor (vSMR) :** Electro- and/or calogen nuclear reactor of a range power from 1 to 20 MWe



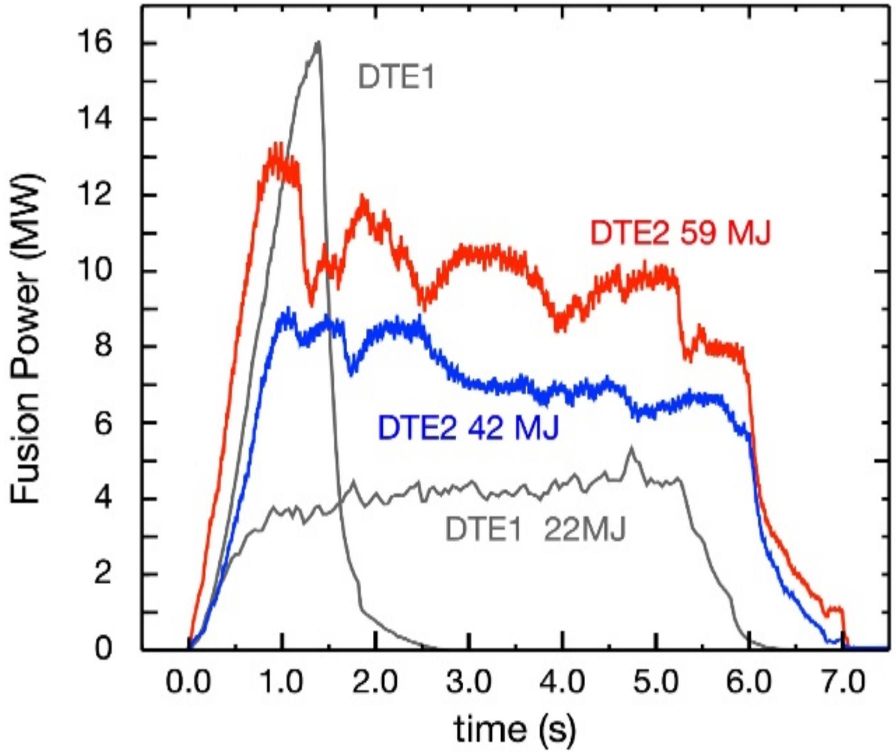
G. Rodriguez, GEN-IV International Forum, STRONG Korea Forum, May 26th, 2021

- Scale effect => modularization plus off-site fabrication
- Design simplifications allowed by a reduced power => limitation of the Emergency Planning Zones
- Series effect => Reduction of construction time & costs
- Opening towards new specific markets => remote areas, non-electrical applications, electricity/heat cogeneration …

Fusion

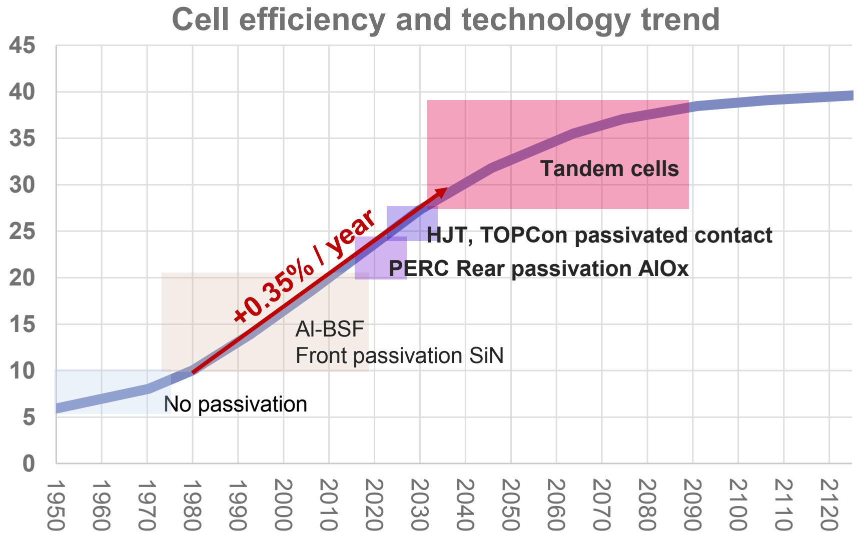


Gain = 3.15MJ/2.05 MJ = 1.54



- Even more energy efficient
- Virtually unlimited fuel
- Intrinsic safety
- Limited waste
- Not yet mature for commercial use but receiving attention of private investors
- Recent results have achieved breakeven and consolidate the basis for experiments demonstrating substantial fusion gain

Solar

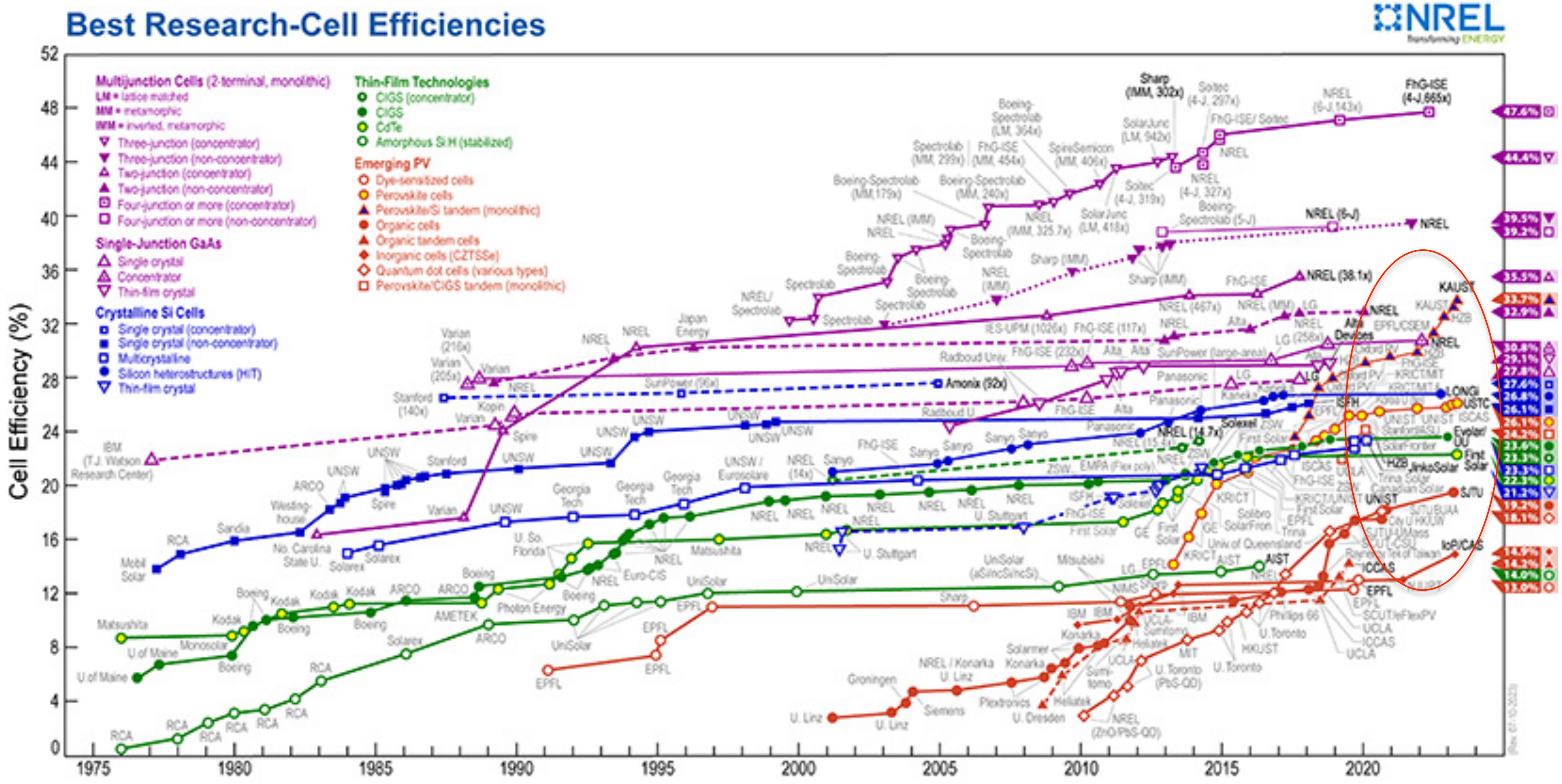


Adapted from W. Hoffmann et al; Proc. 36th EUPVSEC (2019)

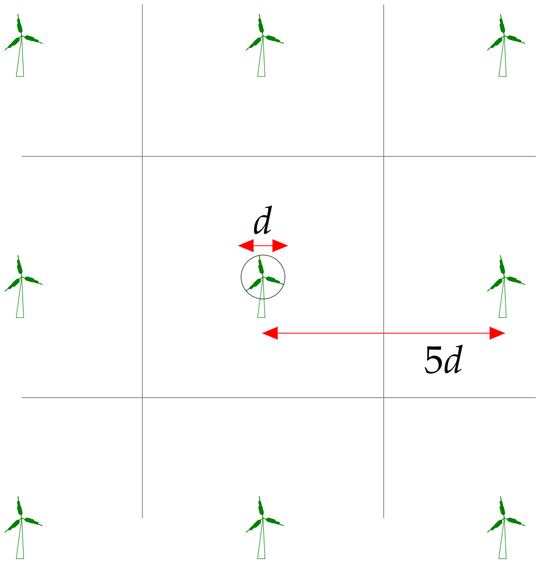
- Mature technology
- Rapidly developing – PV cell efficiency increasing at 0.35%/y rate
- Consolidated c-Si technology (Si extraction and purification main source of C emission 30-40gCO_2/kWe).
- Average Sun power at Rome 200W/m^2
  - 40W/m^2 with 20% efficiency
  - 80W/m^2 with 40% efficiency

Solar

- New materials (perovskite) under rapid development

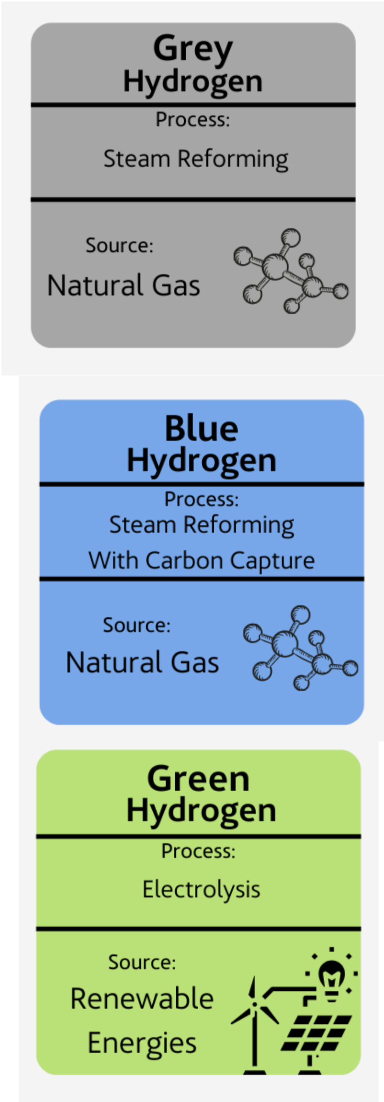


Wind



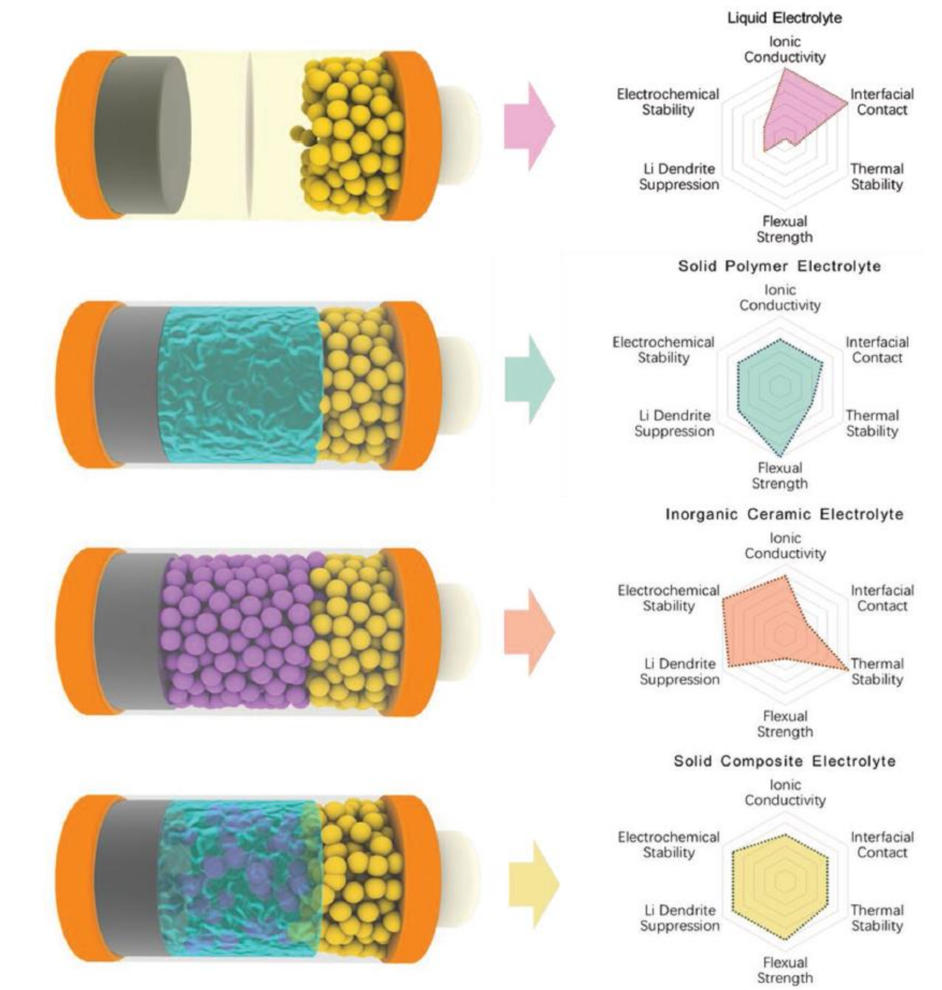
- Wind is a cheap source, a well established technology and a topic for fundamental turbulence studies.
- Wind velocity fluctuations can produce substantial damage and must be properly taken into account in the design.
- Low power density per unit of occupied area
  - $P_{ave}(W/m^2) = 500 \times \pi\ (d/2)^2\ /(5d)^2$ 20% = $3W/m^2$

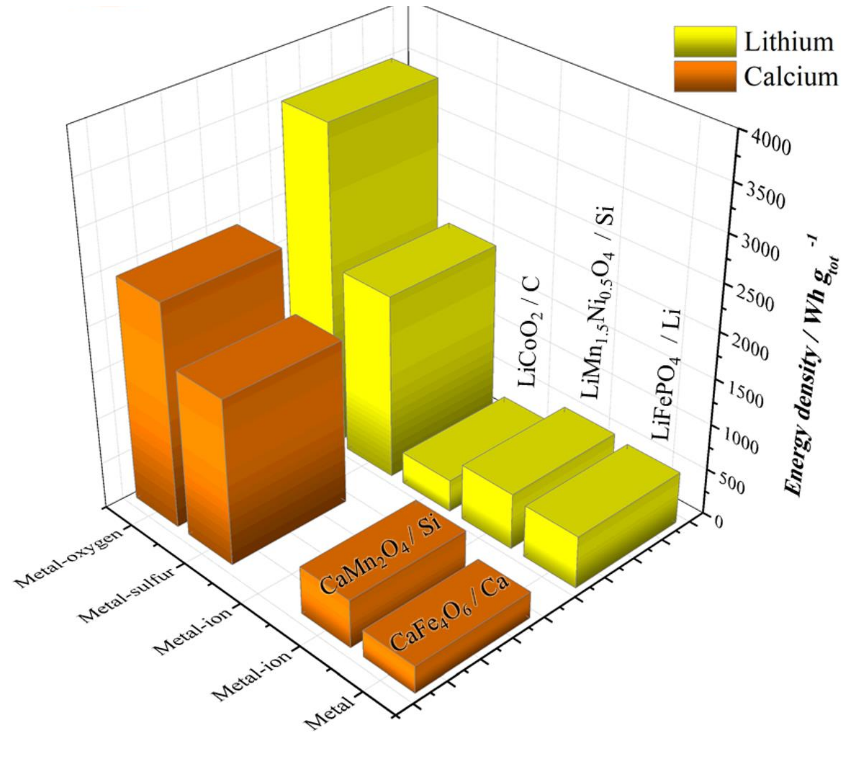
Electrochemical conversion 1/2



- Hydrogen as energy vector in a decarbonized economy.
- Mostly obtained by steam methane reforming: energetically favorable with respect to electrolysis but producing CO_2.
- Cost of green H_2 50% large than grey H_2. Requires a further improvement of electrolyzer efficiency.
- Fuel cells produce electricity from H2 and are classified according to their operating temperature. Efficiency presently <70%.
- High cost of electrocatalyst and H_2 production main obstacles to FC diffusion.

Electrochemical conversion 2/2

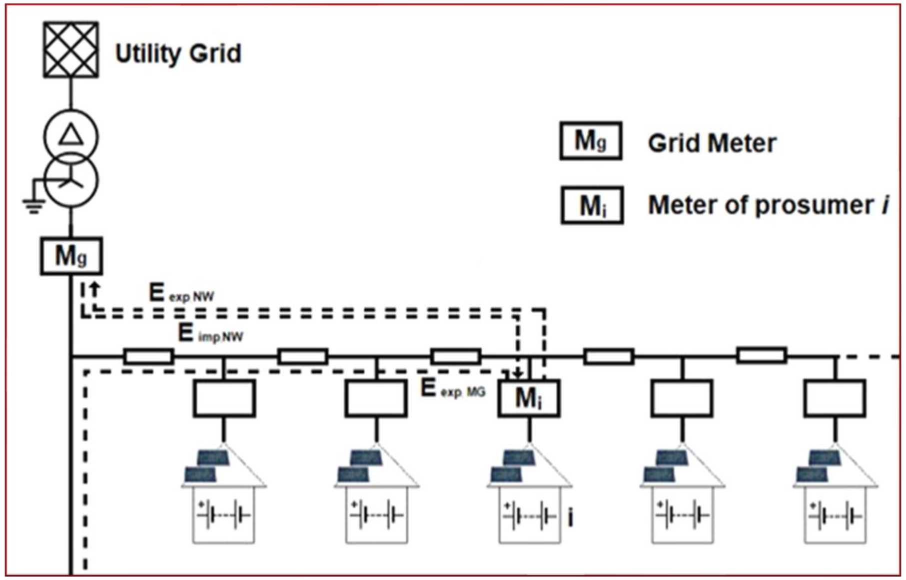




Ca based batteries a better alternative to Li based batteries?

Smart cities/Energy networks

EU and Renewable Energy Communities



Renewable Energy Community

DIRECTIVES

RED 2

DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 11 December 2018

on the promotion of the use of energy from renewable sources

(recast)

(Text with EEA relevance)

DIRECTIVES

IEMD

DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 5 June 2019

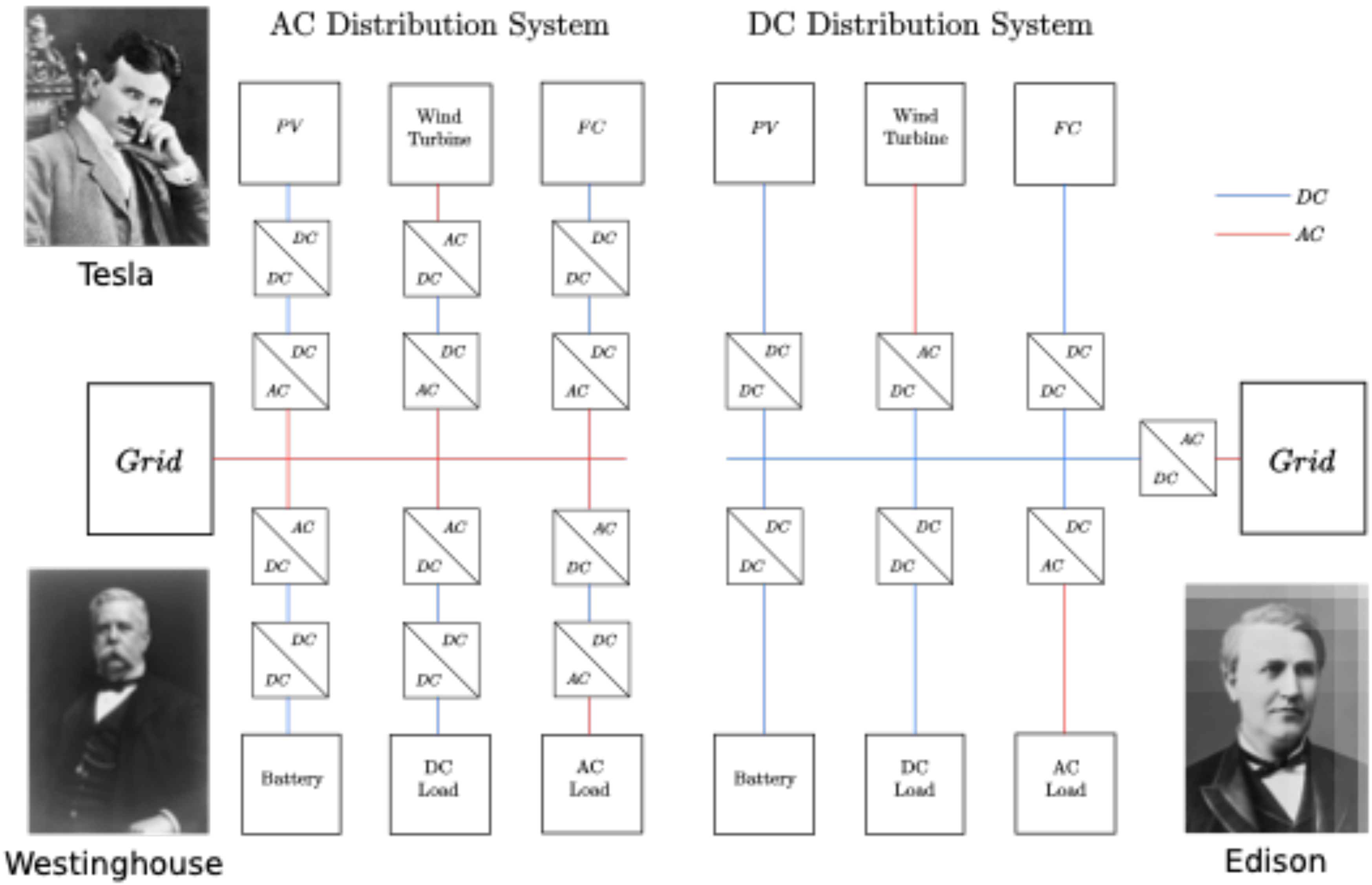
on common rules for the internal market for electricity and amending Directive 2012/27/EU

(recast)

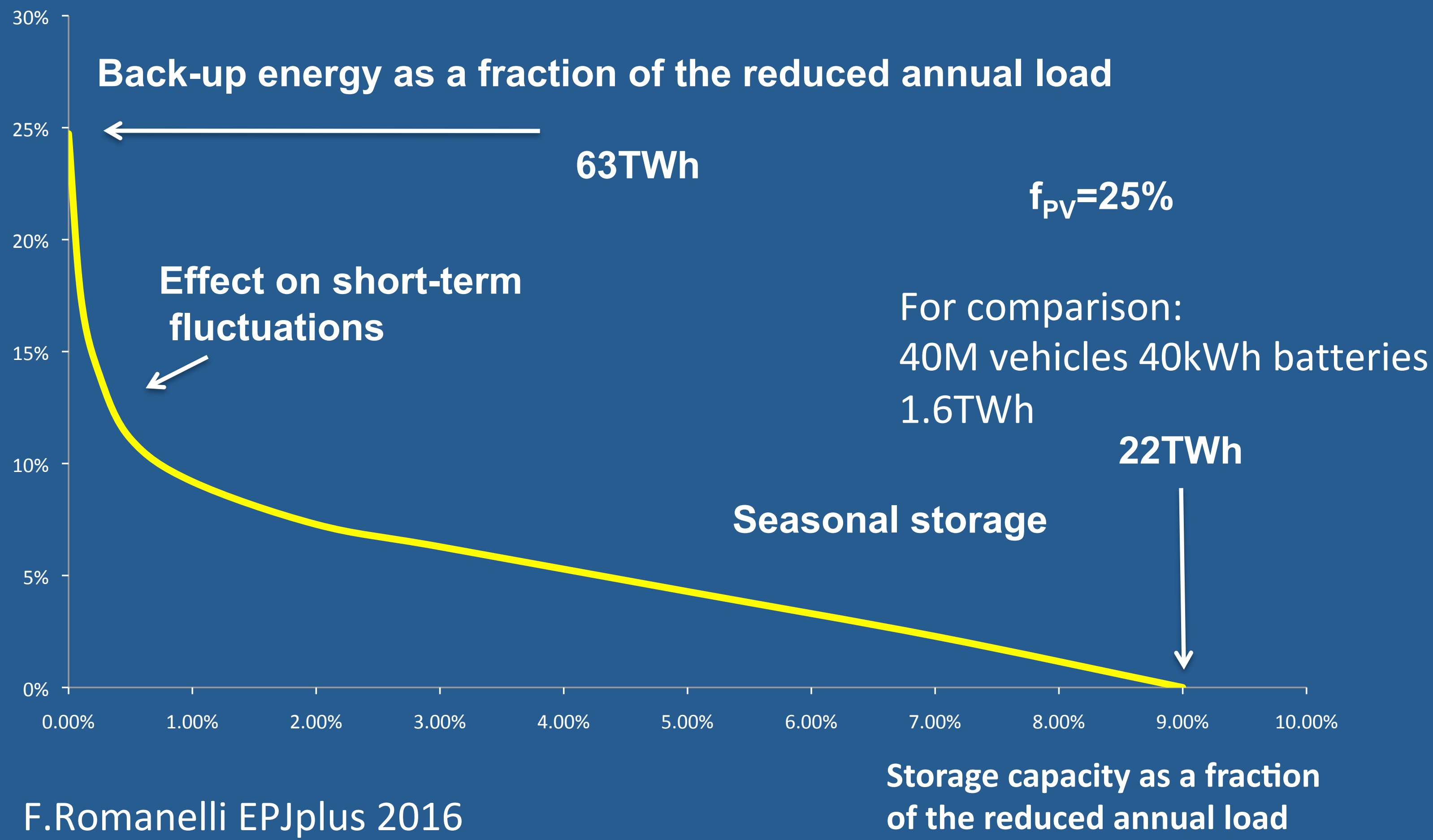
(Text with EEA relevance)

Energy communities may allow a better management of the distributed production (consumer -> prosumer). Experience still preliminary.

The war of the currents

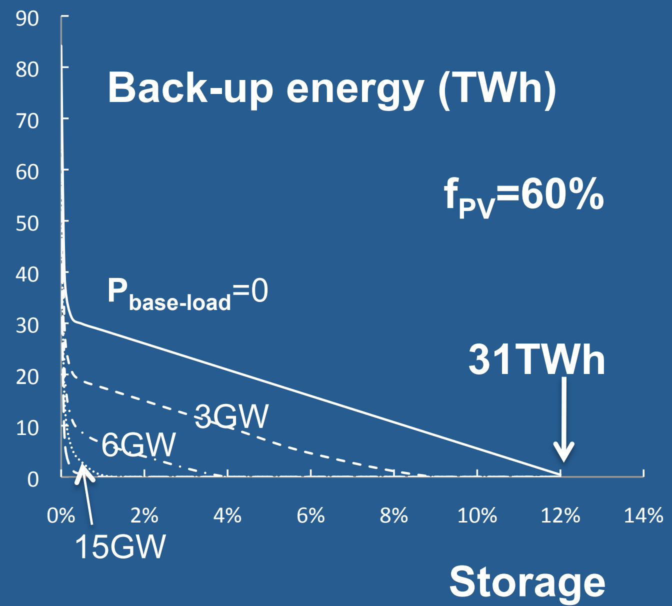


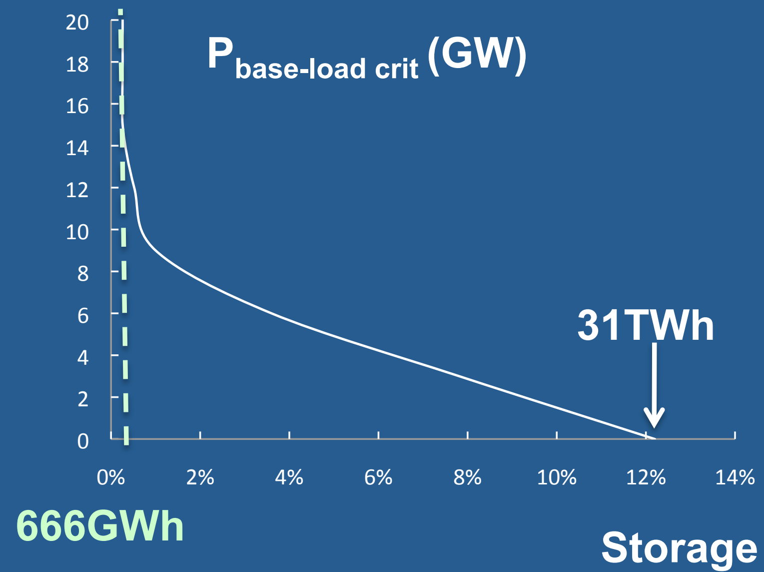
Storage is effective in reducing back-up energy



F.Romanelli EPJplus 2016

Use of base-load + storage

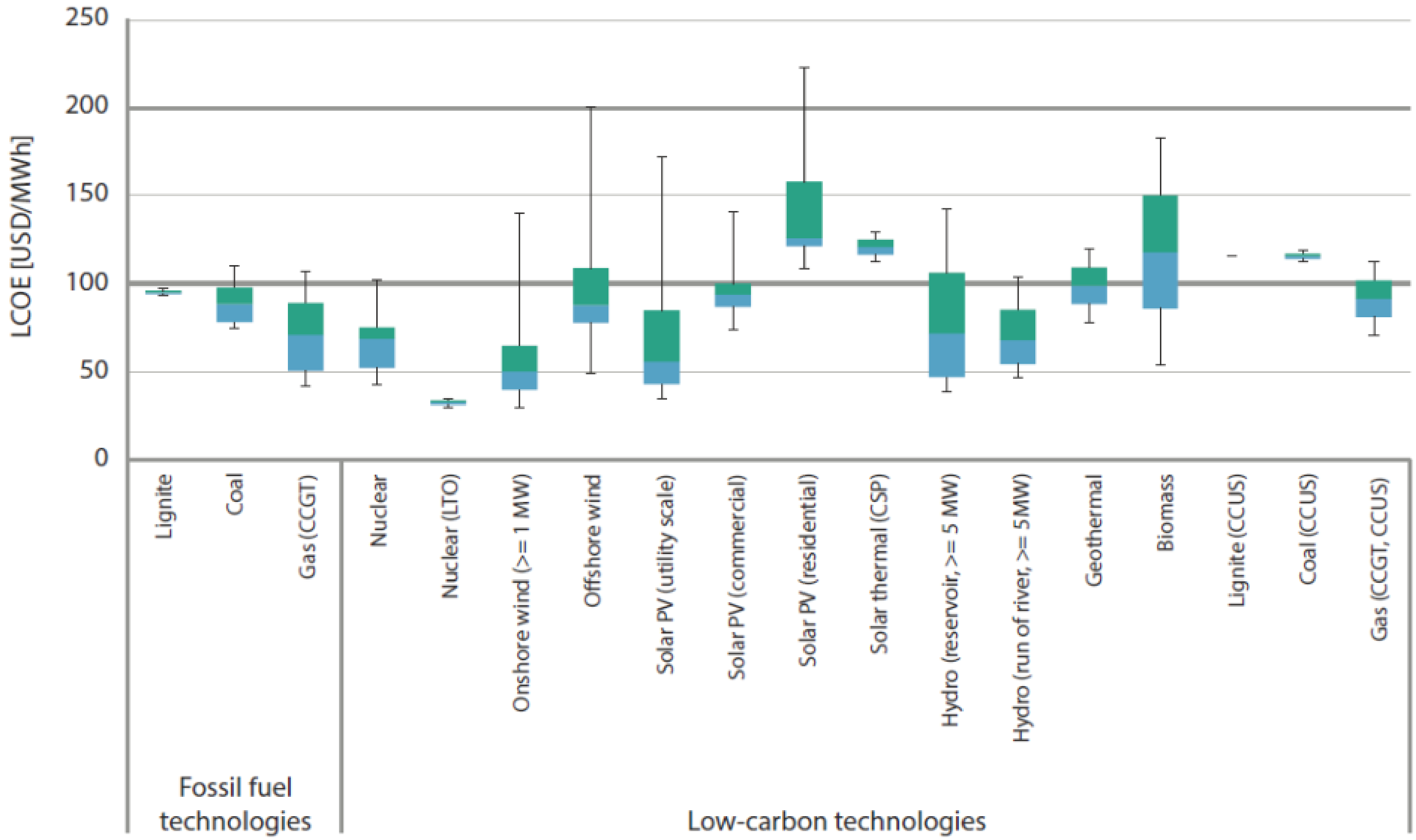




F.Romanelli EPJplus 2016

Cost of generating electricity

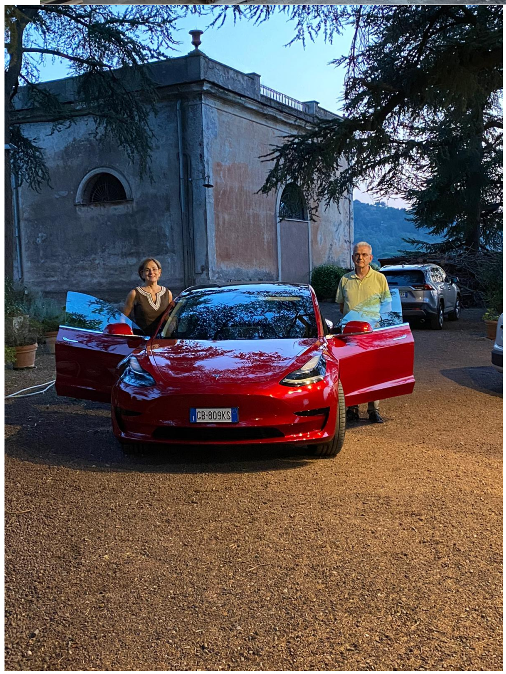
Figure ES1: LCOE by technology

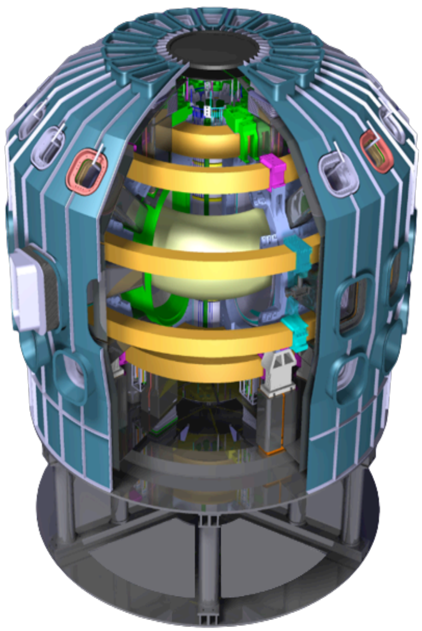


Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

Source:
[IEA/NEA, Projected Costs of Generating Electricity, 2020]

The energy solutions will come from a mix of different technologies






1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
THE GLOBAL GOALS
For Sustainable Development
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE AND JUSTICE STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

Have a safe trip back home!