Nuclear Energy

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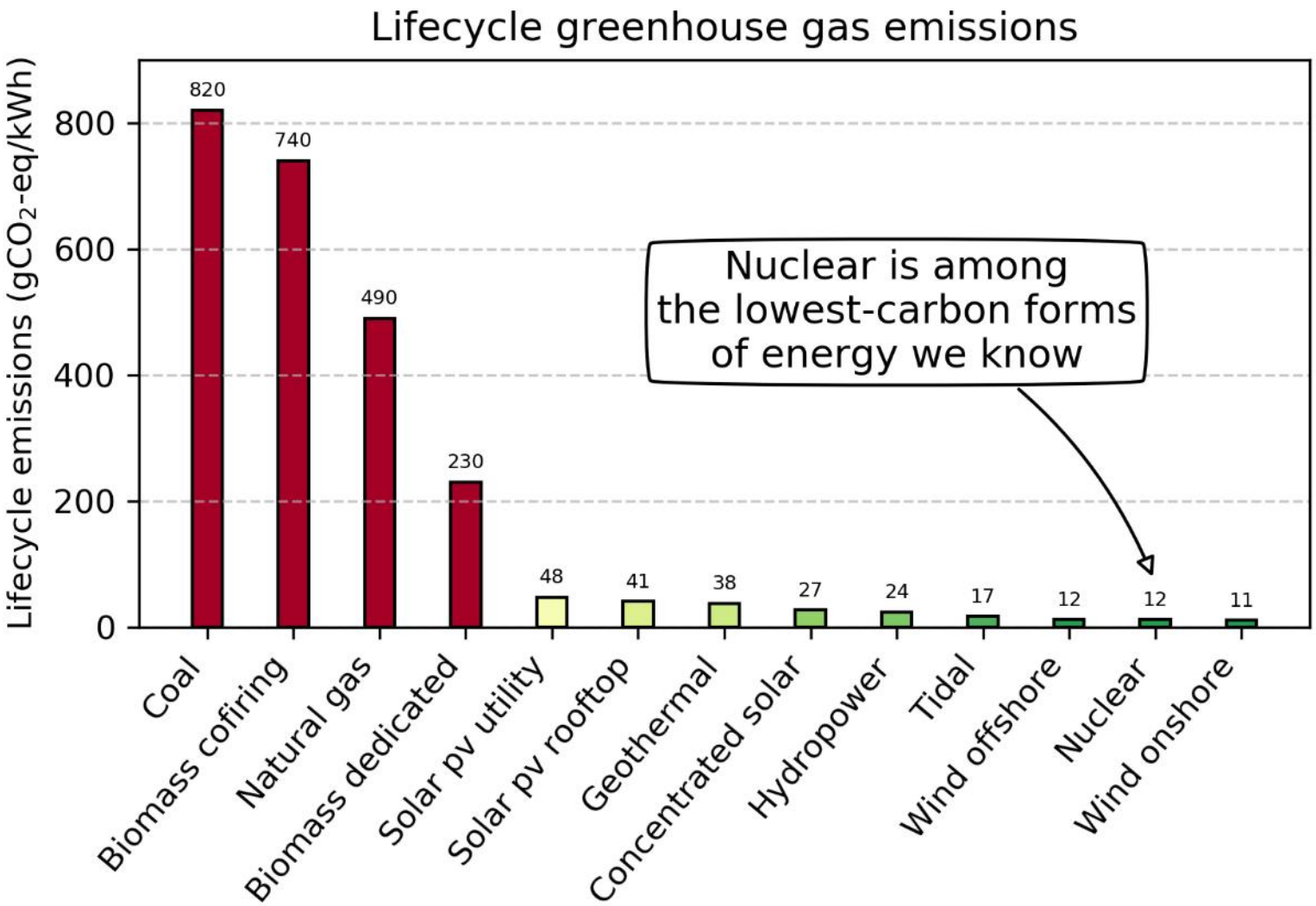
Nathan Read

November 2022

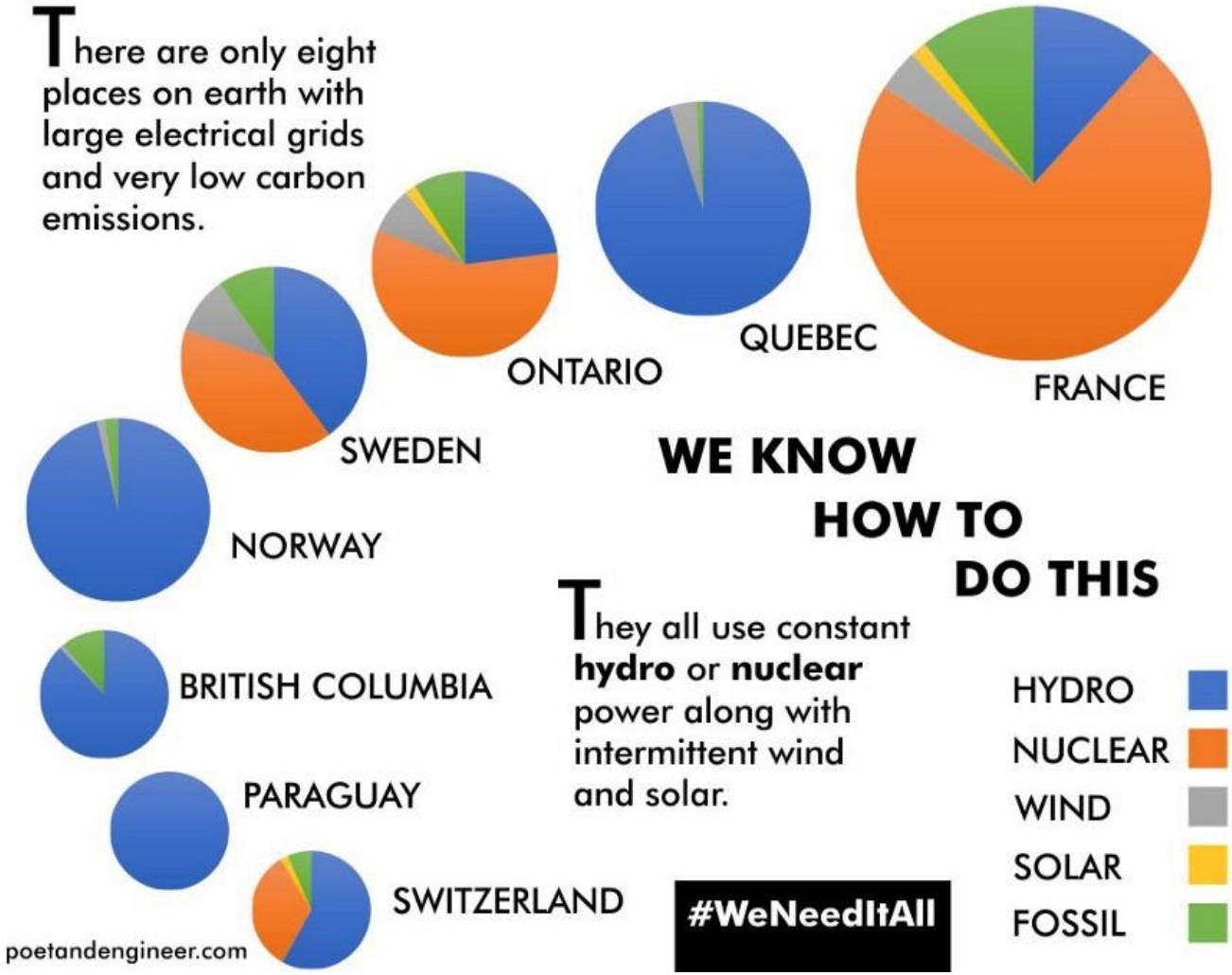
Agenda

- Is nuclear in or out of the net-zero game?
  - Carbon emissions
  - Costs
  - Sustainability
  - Safety
  - Waste
- How can I help?
  - Nuclear industry career: is it for me?
  - Nuclear Energy MPhil course

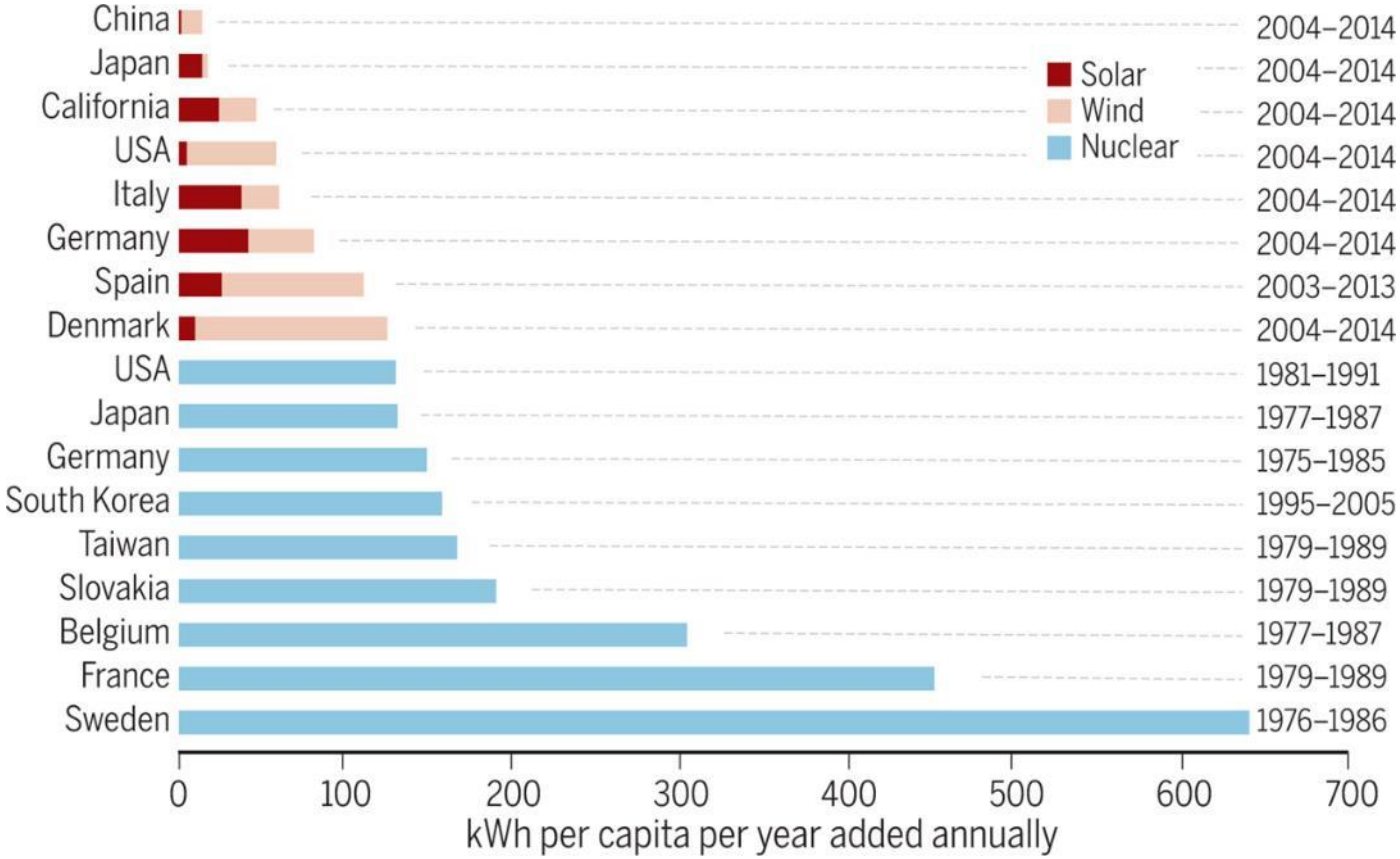
Carbon emissions



Schlömer S., et.al., 2014: Annex III: Technology-specific cost and performance parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the IPCC (Table A.III.2, pg 1335). Plot by whatisnuclear.com.

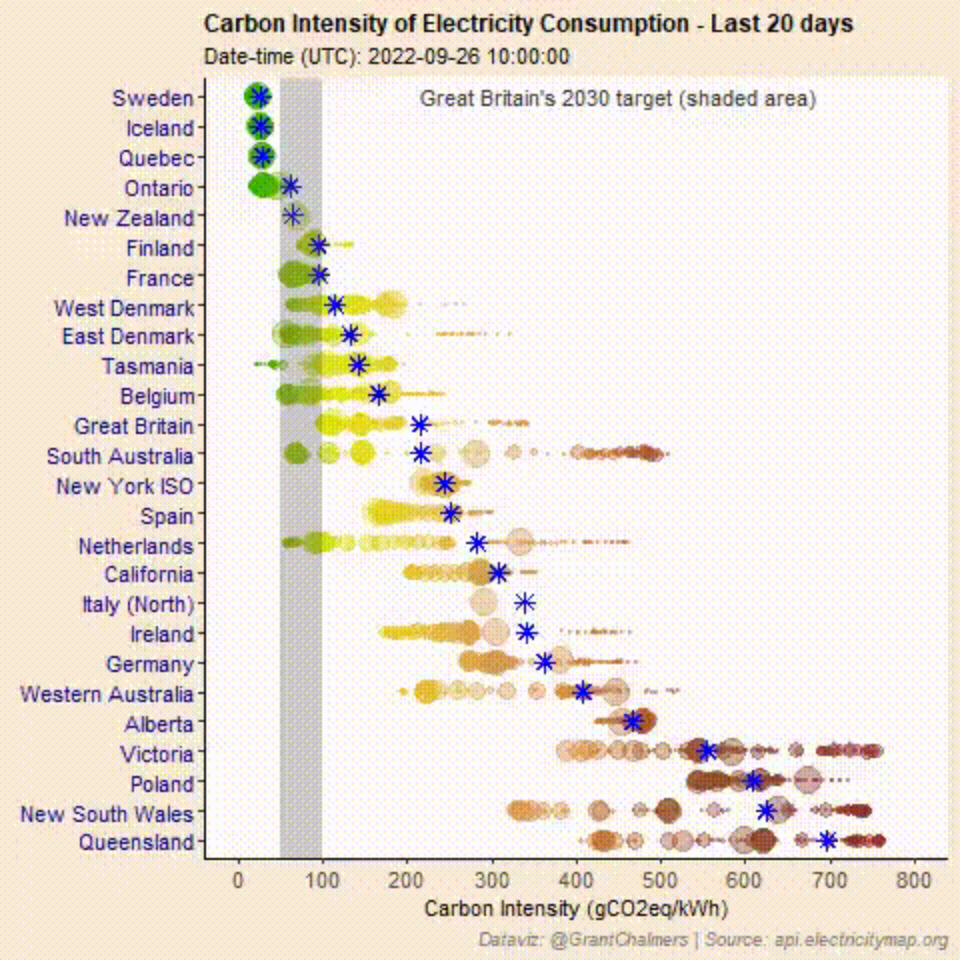

There are only eight places on earth with large electrical grids and very low carbon emissions.
QUEBEC
FRANCE
ONTARIO
SWEDEN
NORWAY
BRITISH COLUMBIA
PARAGUAY
SWITZERLAND
WE KNOW HOW TO DO THIS
They all use constant hydro or nuclear power along with intermittent wind and solar.
HYDRO
NUCLEAR
WIND
SOLAR
FOSSIL
#WeNeedItAll
poetandengineer.com

Average annual increase of carbon-free electricity per capita during decade of peak scale-up



Cao, J., Cohen, A., Hansen, J., Lester, R., Peterson, P., & Xu, H. (2016).
China-US cooperation to advance nuclear power. *Science*, *353*(6299), 547-548.

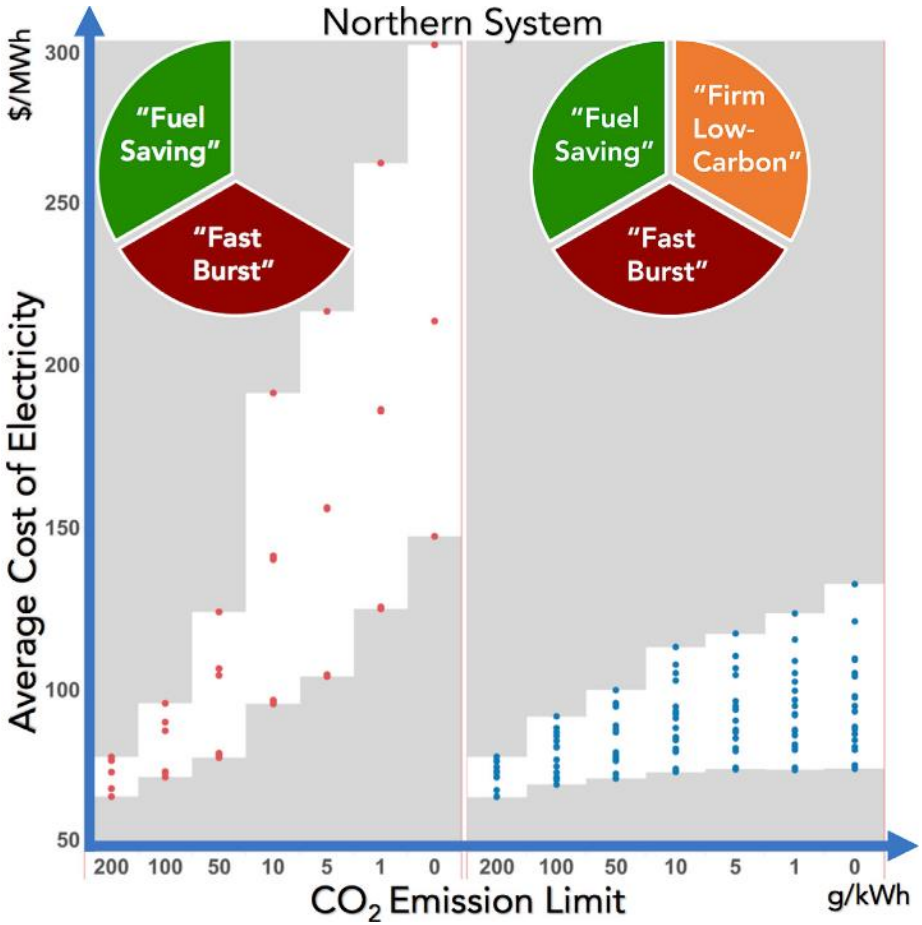
Comparing energy choices



Data from api.electricitymap.org
Visualisation by Grant Chalmers

Value of firm power

- Consistently lowers electricity costs across all studies
- Per-unit-energy cost (LCOE) comparisons are highly misleading in system design
- Major effect at near-zero emissions
- Batteries and demand flexibility do not substitute for firm low-carbon power



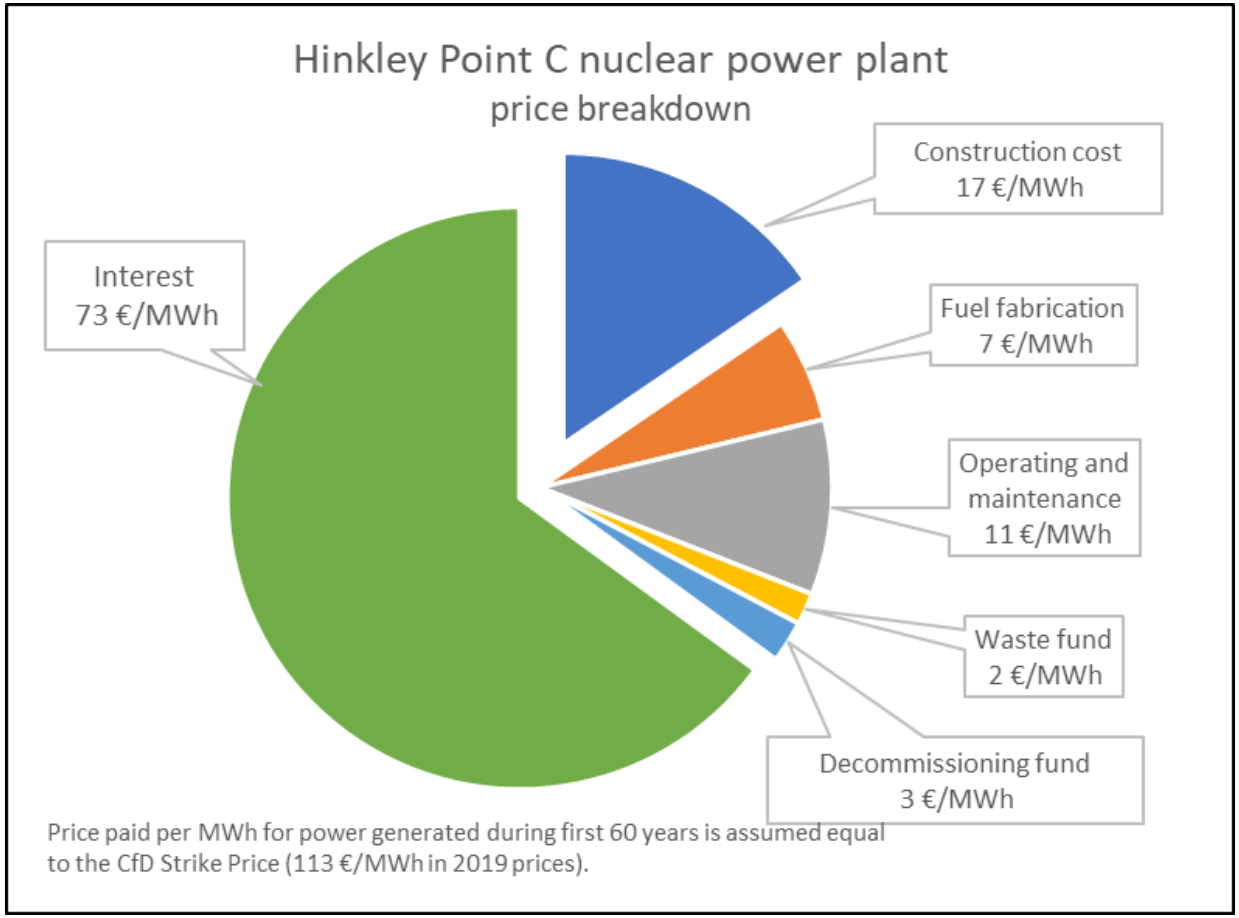
Sepulveda et al., Joule 2, 2403–2420
November 21, 2018

The cheapest or quickest way to add one megawatt of low-carbon power to the grid might not be the optimal next step on the **path to deep decarbonisation**

Cost

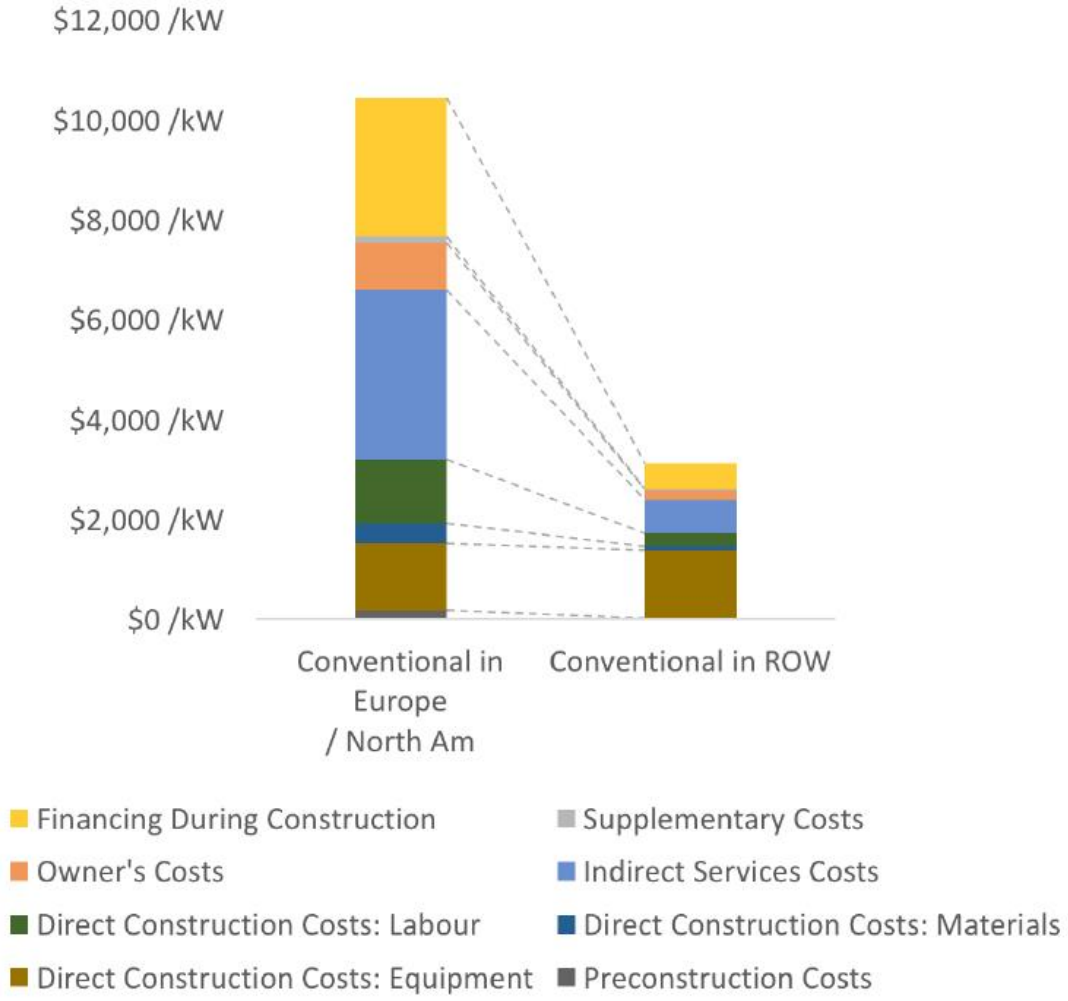
Why is nuclear expensive? (per-energy cost)

- Most of the cost of a nuclear power plant project is in financing



Why is nuclear expensive? (per-power cost)

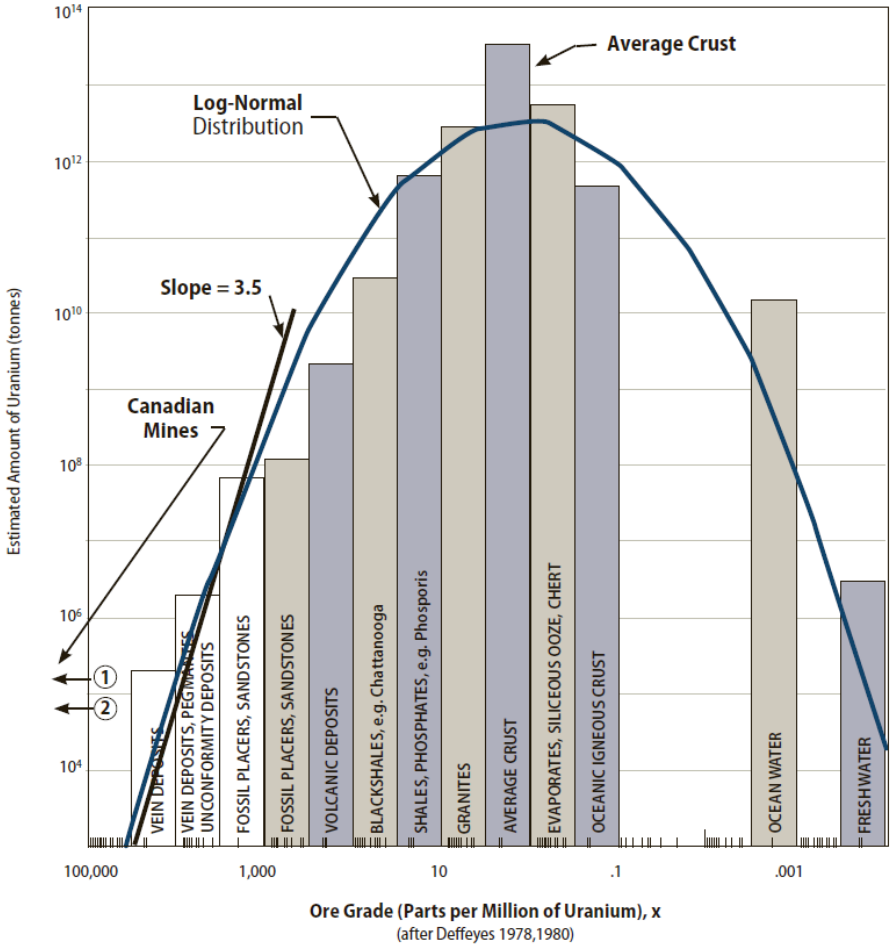
- First-of-a-kind projects in the West versus focused programmes



Sustainability

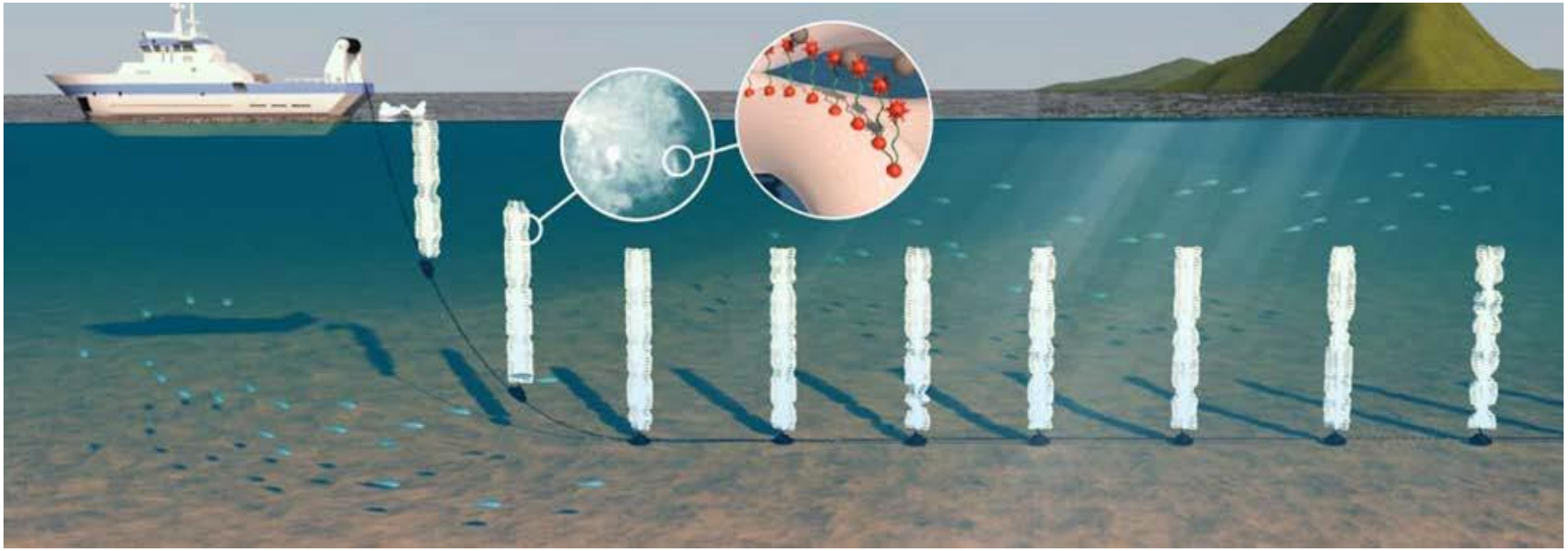
Sustainability

- Raw fuel materials are minor part of nuclear energy cost
- Stable price of U (and most other minerals) for the past 100y
- Even the most ambitious expansions can be sustained

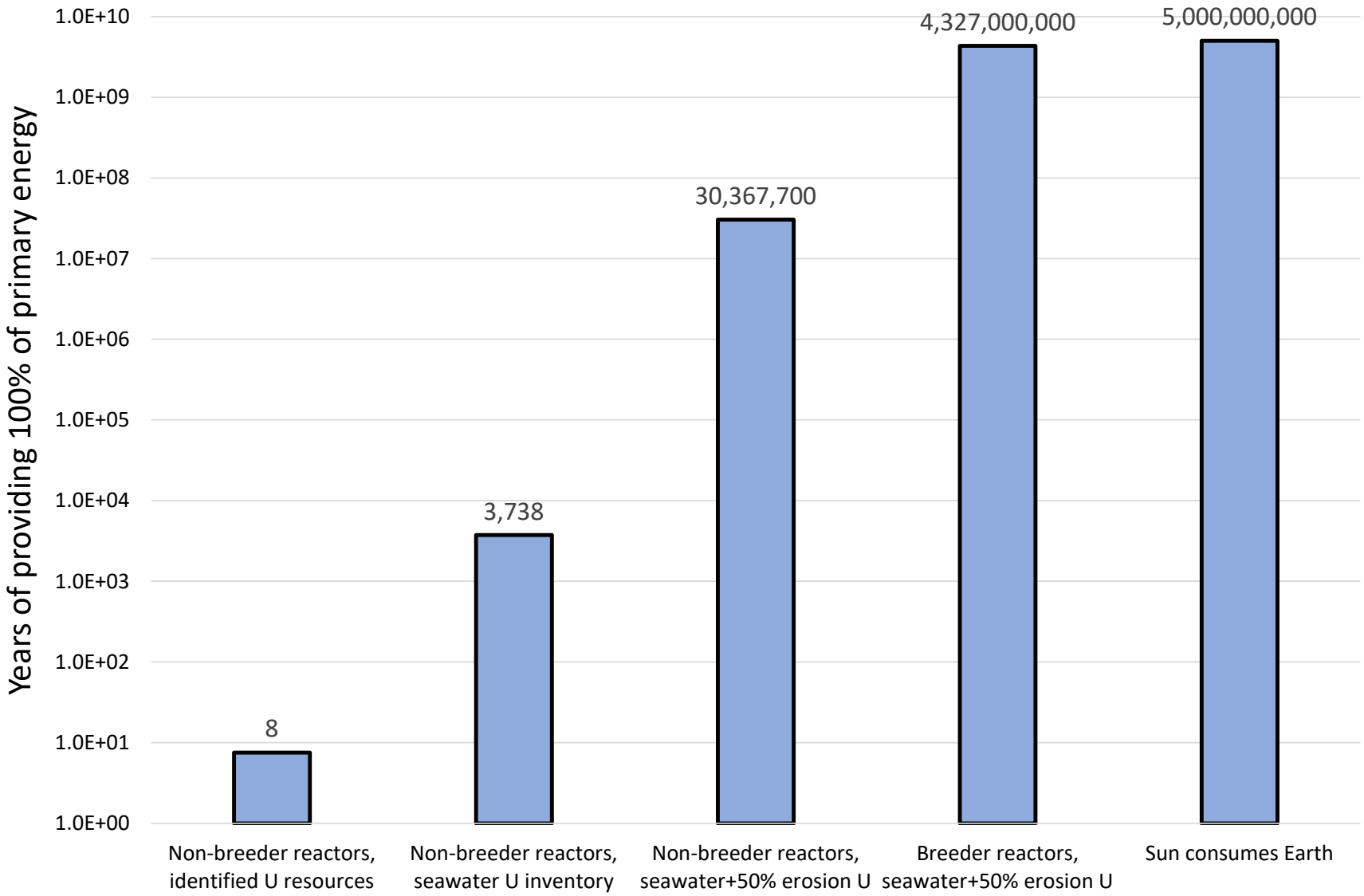


Sustainability

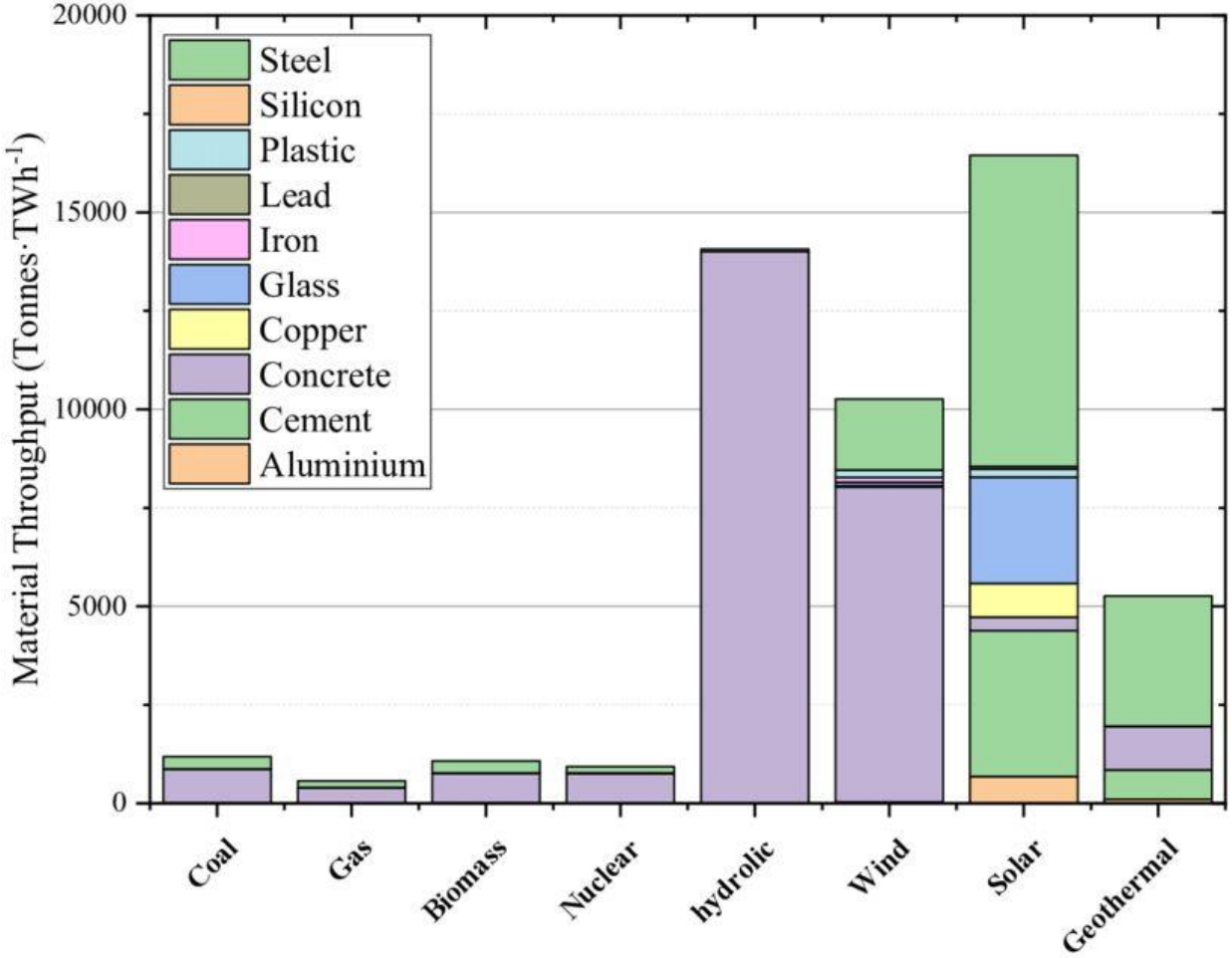
- 4.5 billion tons of U in oceans
- 100 trillion tons of U in Earth crust
- U is in chemical equilibrium with seabed
- Always ~3ppb of U in sea water



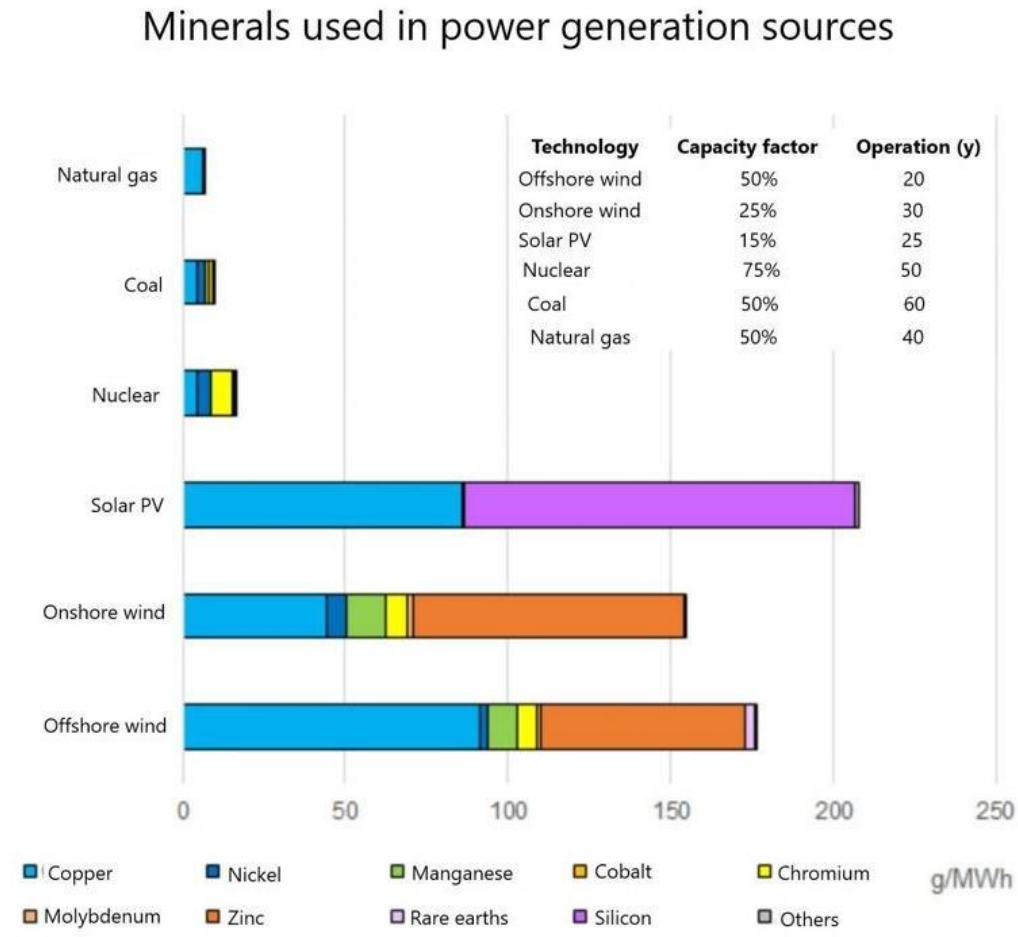
Sustainability



Raw materials requirements



Raw materials requirements



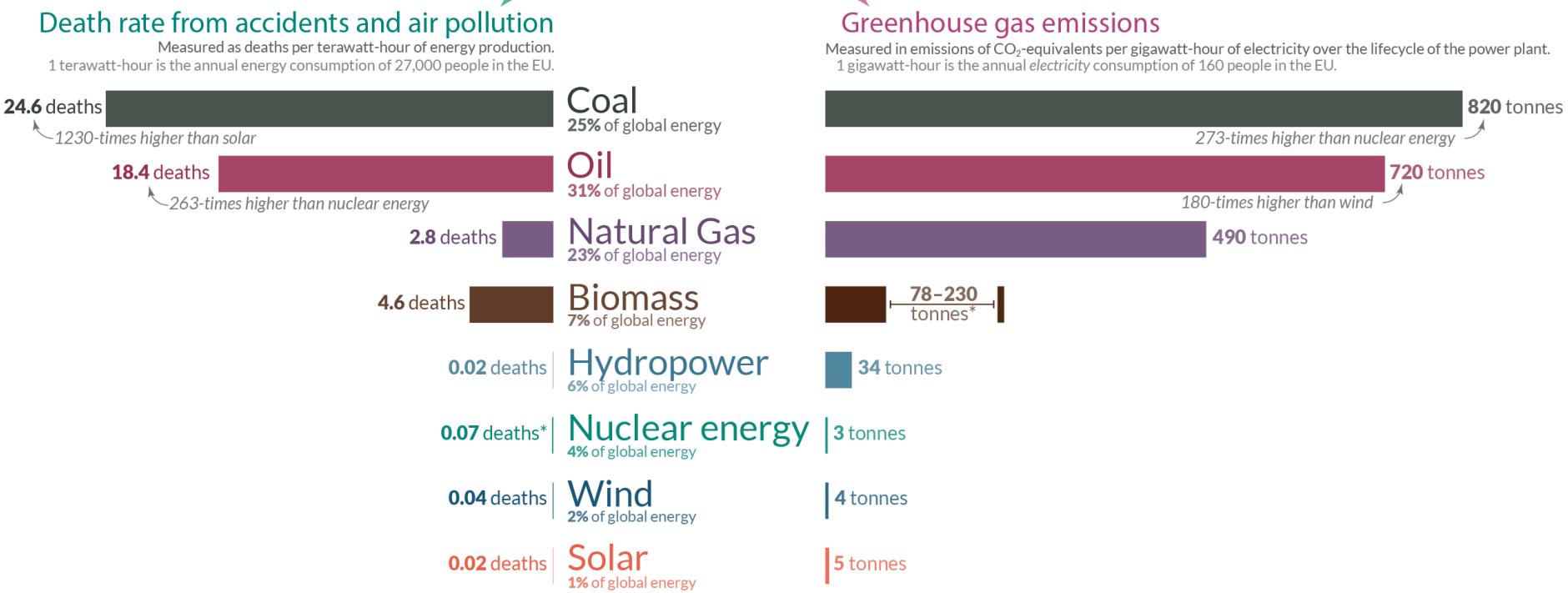
Technology	Capacity factor	Operation (y)
Offshore wind	50%	20
Onshore wind	25%	30
Solar PV	15%	25
Nuclear	75%	50
Coal	50%	60
Natural gas	50%	40

https://www.iea.org/data-and-statistics/charts/minerals-used-in-clean-energy-technologies-compared-to-other-power-generation-sources

Safety

Our World in Data

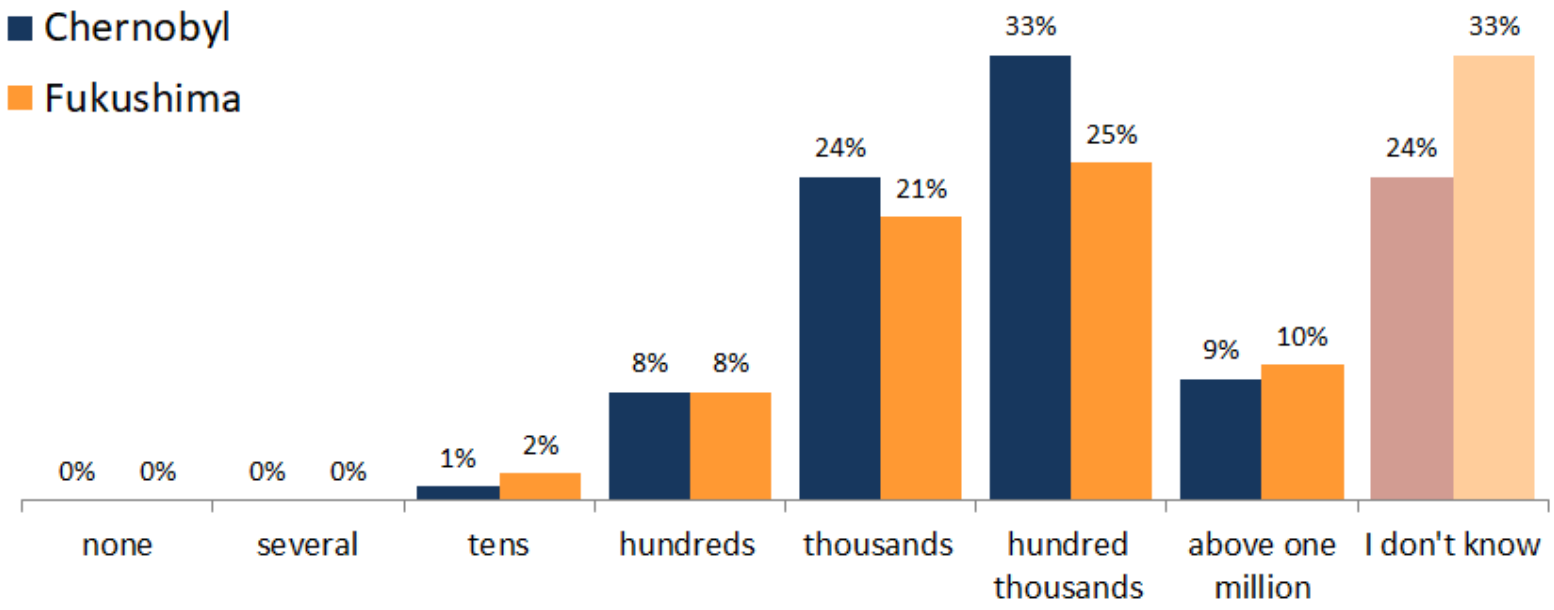
What are the safest and cleanest sources of energy?



*Life-cycle emissions from biomass vary significantly depending on fuel (e.g. crop resides vs. forestry) and the treatment of biogenic sources.
*The death rate for nuclear energy includes deaths from the Fukushima and Chernobyl disasters as well as the deaths from occupational accidents (largely mining and milling).
Energy shares refer to 2019 and are shown in primary energy substitution equivalents to correct for inefficiencies of fossil fuel combustion. Traditional biomass is taken into account.
Data sources: Death rates from Markandya & Wilkinson (2007) in *The Lancet*, and Sovacool et al. (2016) in *Journal of Cleaner Production*;
Greenhouse gas emission factors from IPCC AR5 (2014) and Pehl et al. (2017) in *Nature*; Energy shares from BP (2019) and Smil (2017).
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Public perception of radiation

Survey of opinions on numbers of radiation-related deaths from Chernobyl/Fukushima

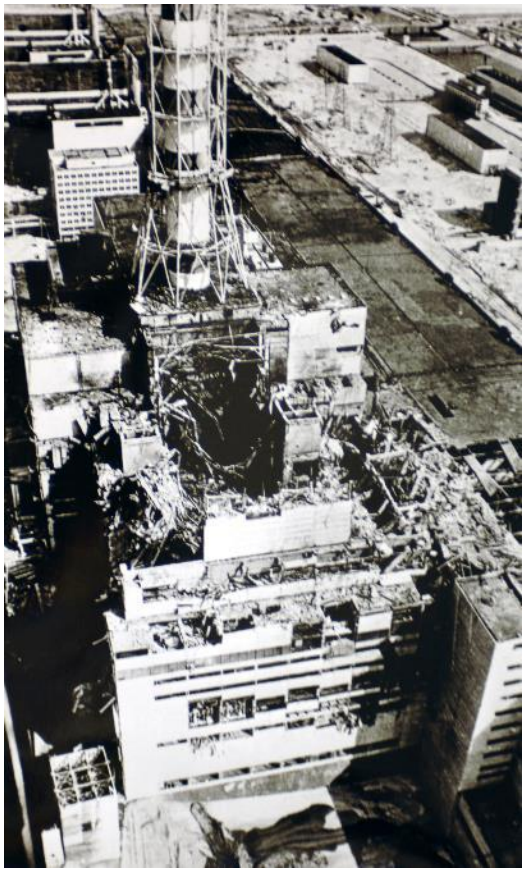


Russia Omnibus 2012, G. Thomas 2014

Nuclear accidents: what we know

Chernobyl

- 28 deaths from acute radiation sickness
- 4000 cases of thyroid cancer leading to ~60 deaths
- No effects on malformations,
  infant mortality and no heritable effects



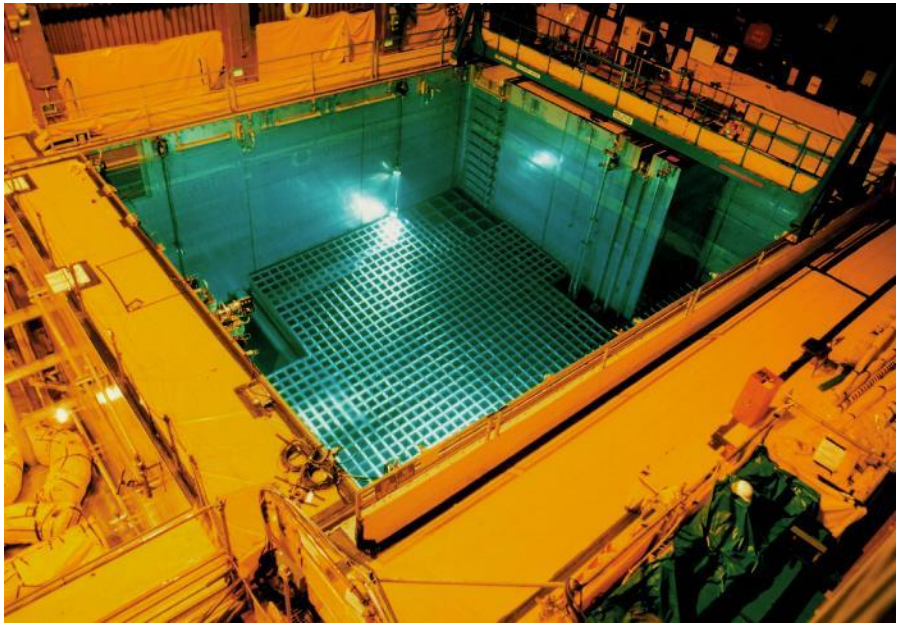
Fukushima

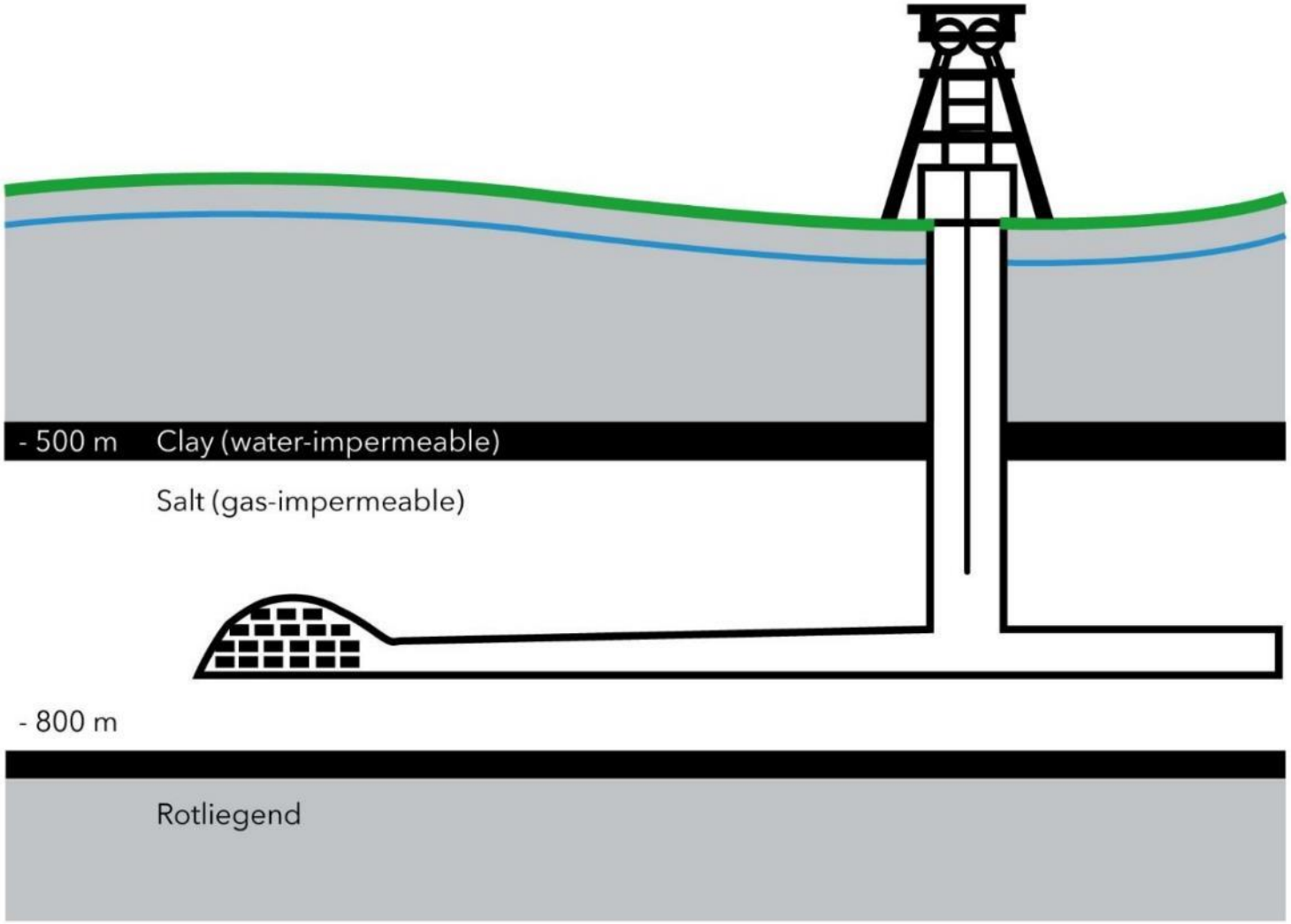
- No radiation related health effects

Waste

Waste

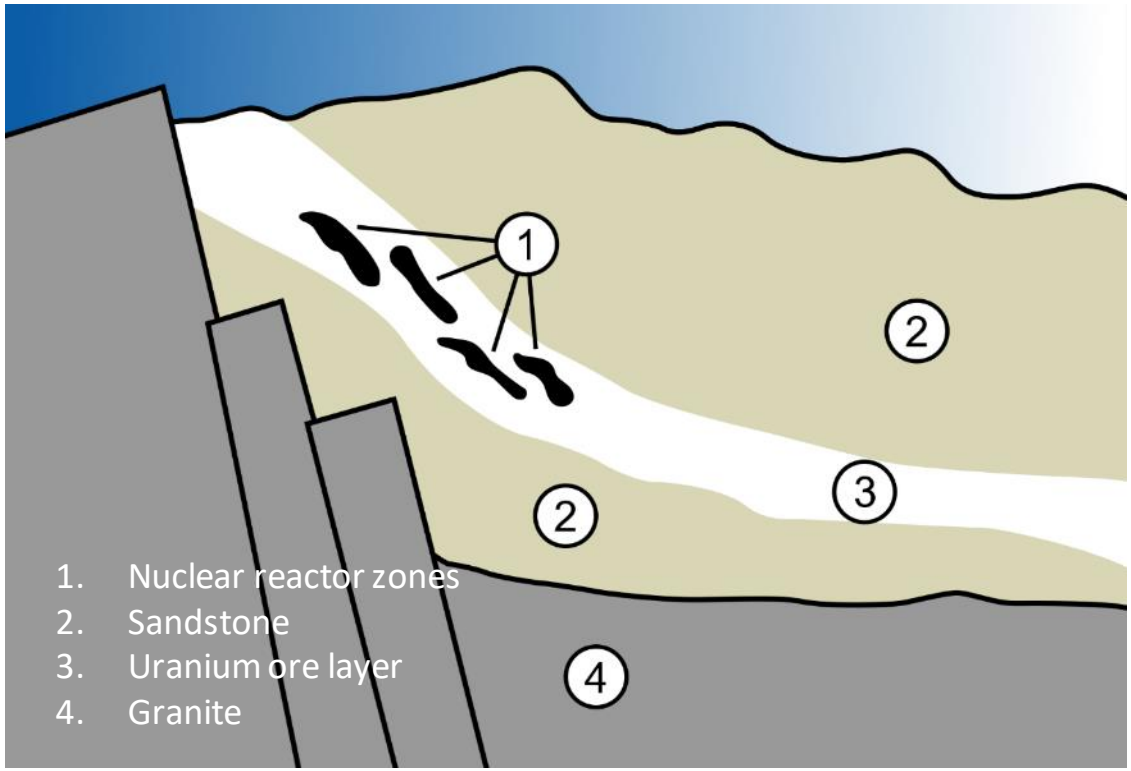
- Lifetime waste per capita
- Fully internalised
- Paid for by the industry
- Progressively benign
- Cooling/storage is cheap and safe
- Can be recycled to max energy value
- Final disposal is a technically sound solution

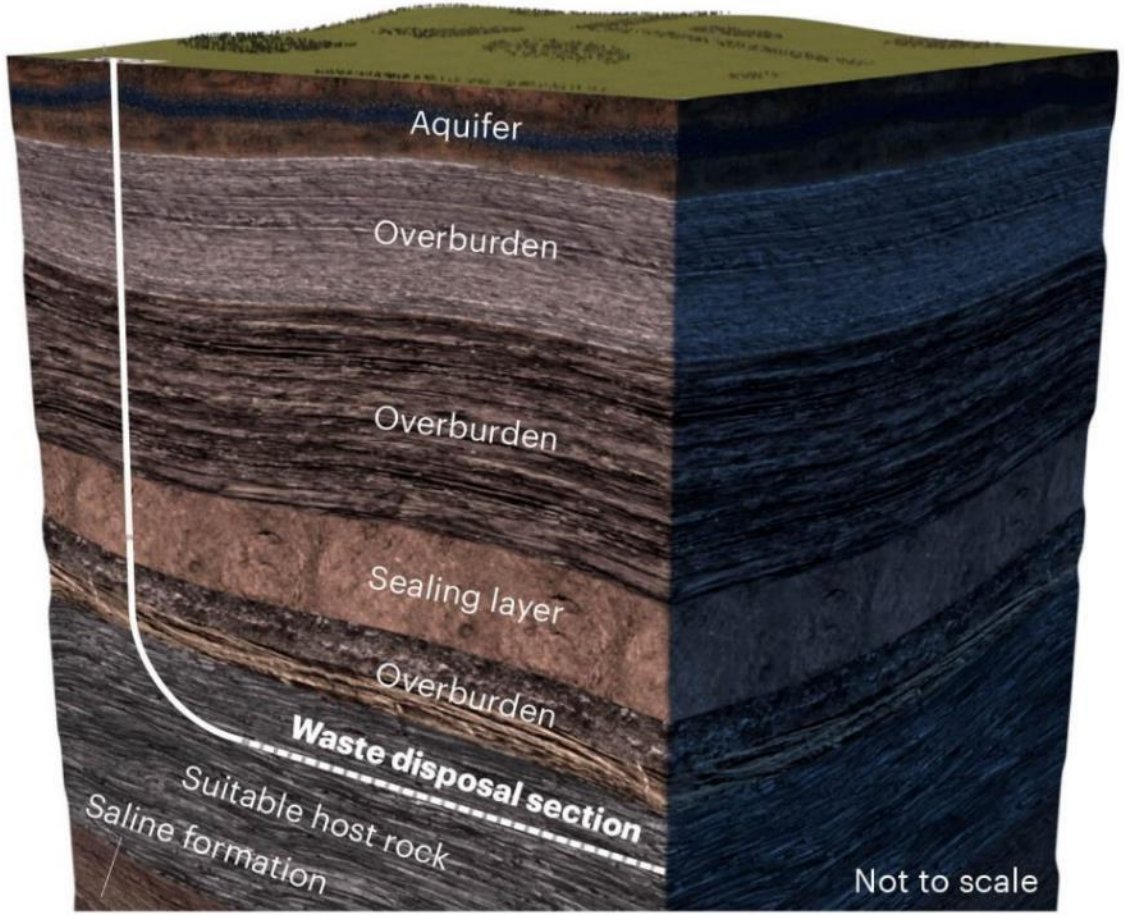



- 500 m
Clay (water-impermeable)
Salt (gas-impermeable)
- 800 m
Rotliegend


33
33

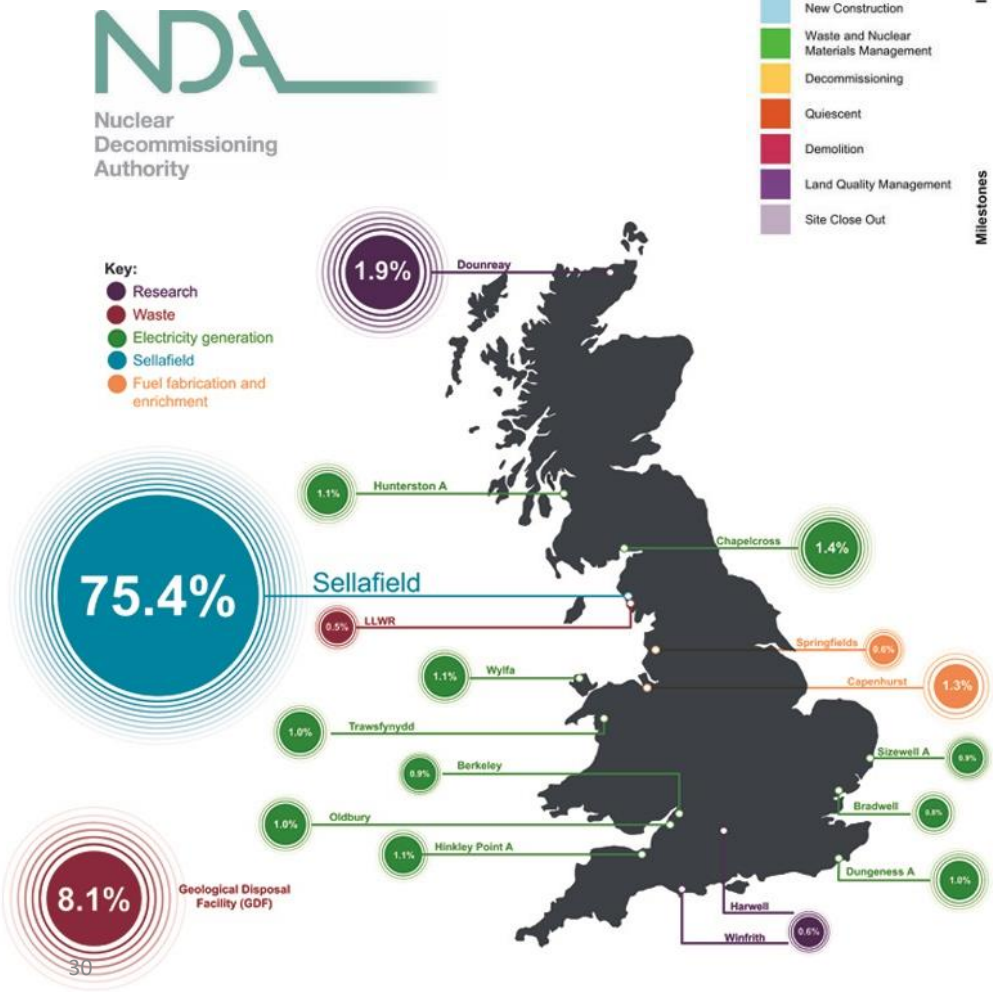
- Geology of spent fuel repository is not speculative
- We can be informed by natural analogues
- Natural reactor in Oklo, Gabon, shows how radionuclides travel over time

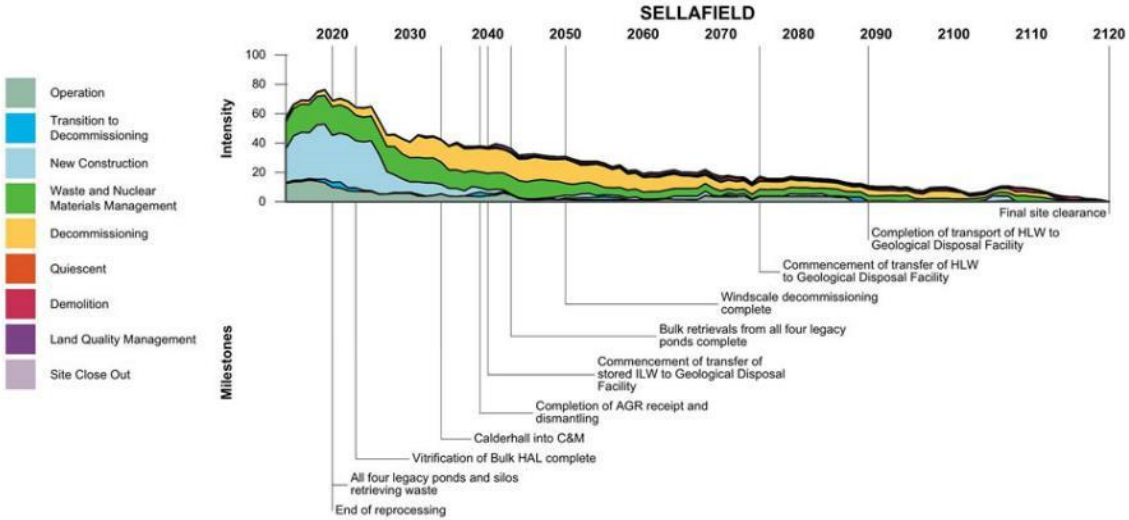




Deep Isolation Inc.

Waste and Decommissioning in the UK





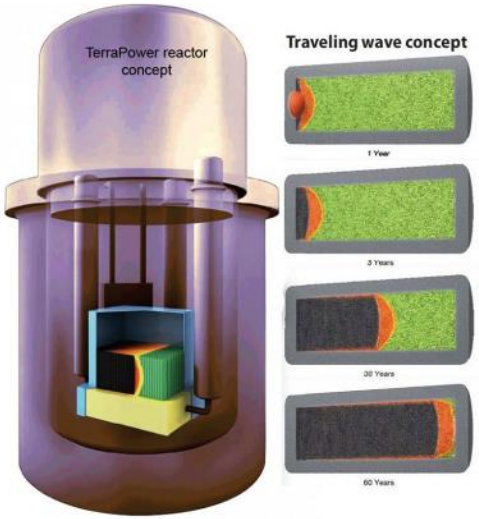
- ~ 100 years of clean-up
- ~ 90 - 200 B£ in liabilities

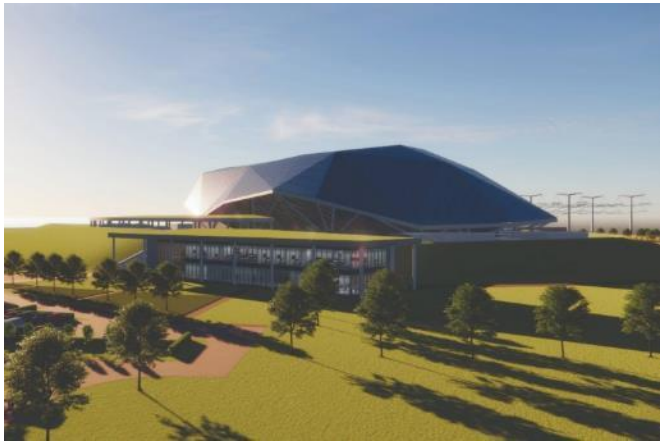
Nuclear Provision: the cost of cleaning up Britain's historic nuclear sites, NDA (2018)

The Future

Technological developments

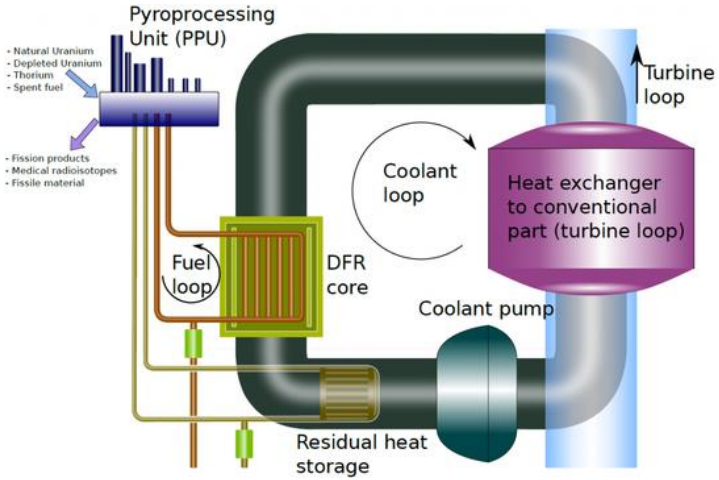
- Nuclear is a growing industry
- $B's of recent private investments
- Numerous start-ups
  - Fission, fusion, molten salts, high T gas-cooled, etc
- Many governments provide backing
  - US, UK, Canada, Japan, S. Korea, China, Russia, India, Bangladesh, some EU

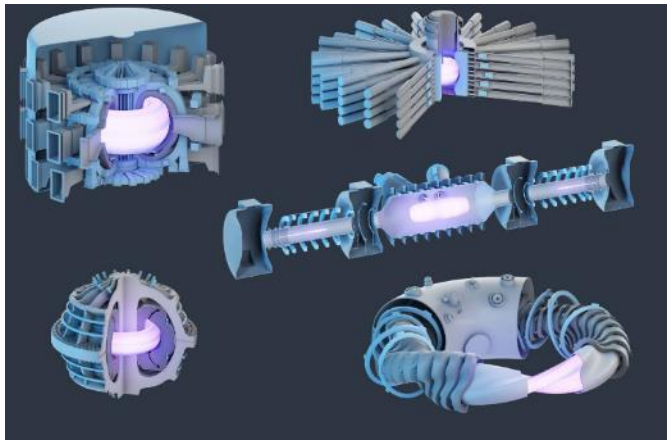




Thorium, fusion, molten salt…

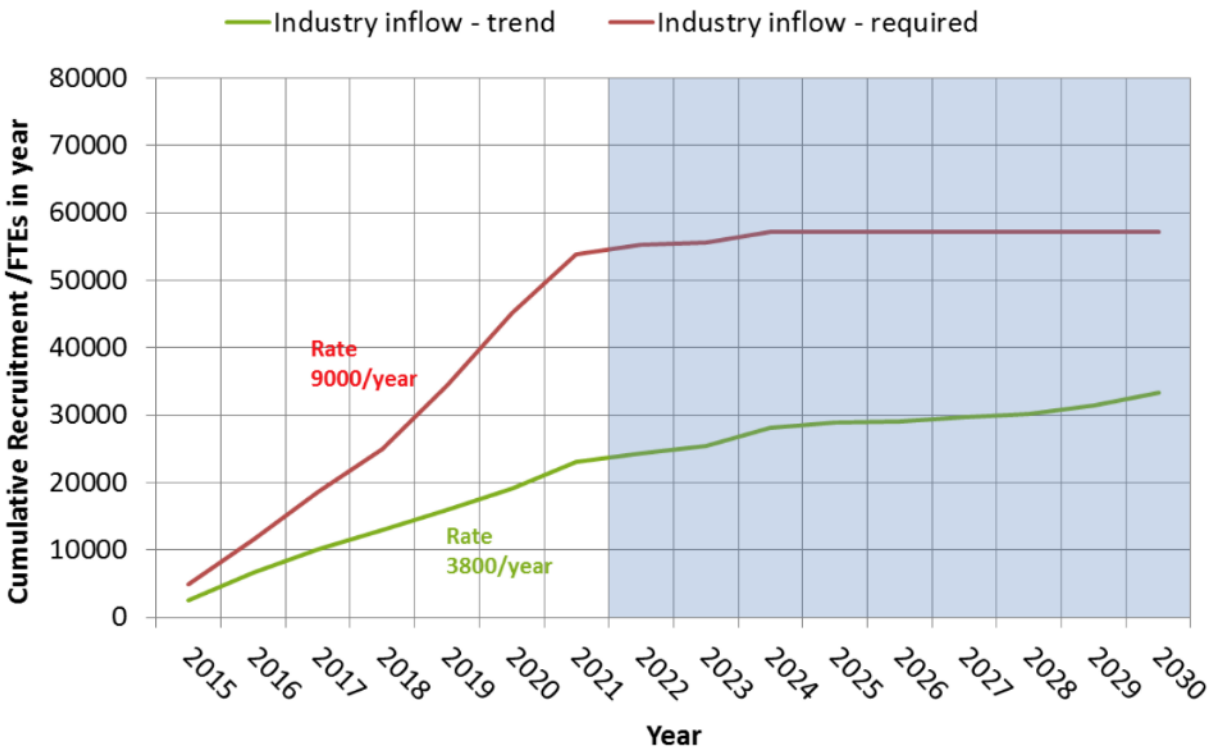
- There are many exciting and promising technologies – none are a silver bullet
- All have their own strengths, limitations and technological readiness
- Current decision making on what to pursue is suboptimal
- We need people who can tell the difference between hype and real promise





Why now?

- New built, legacy clean up, defence
  - Skilled workers to construct, commission, operate and decommission reactors
  - Many of current nuclear staff in UK are approaching retirement
  - Many other developments around the world require well-trained nuclear engineers



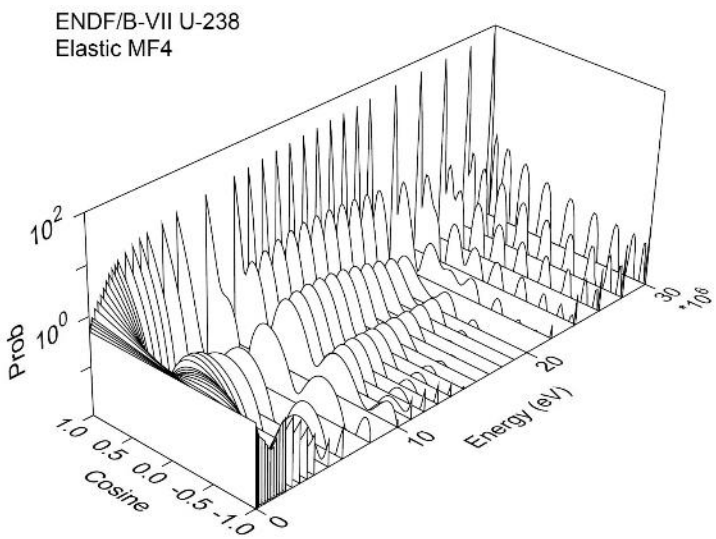
National Nuclear Skills Strategic Plan, Cogent Skills, 2016

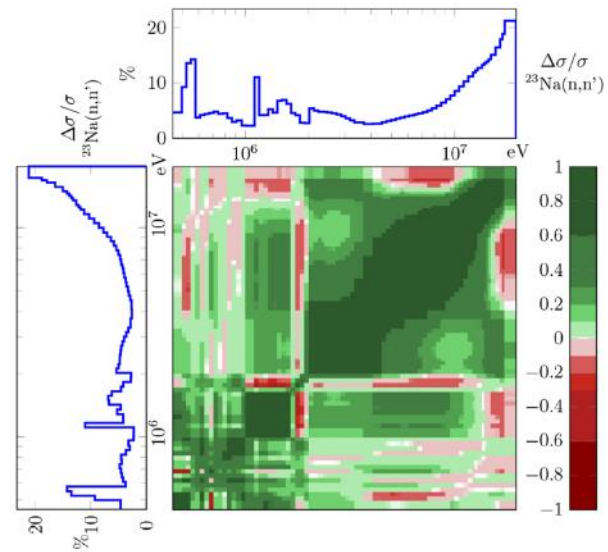
UK Plans

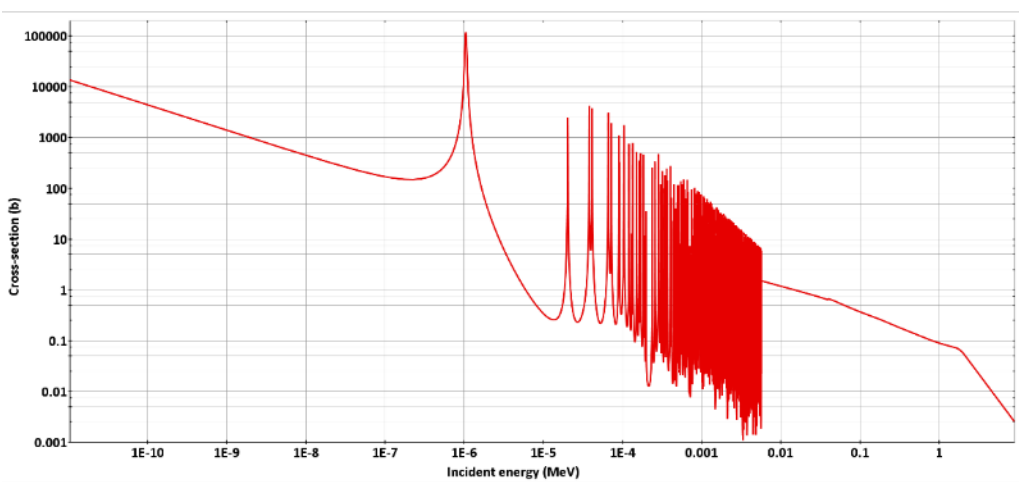
- Climate change is a problem, recognition that nuclear can help
- Electricity market reform, mechanisms for supporting low carbon technologies (CfD, RAB)
- Direct government investment and R&D support
  - Nuclear Sector Deal
  - 10 Step Net-zero Plan
  - Fusion (STEP) program
  - Rolls-Royce SMR
  - Fission energy is UKRI priority area

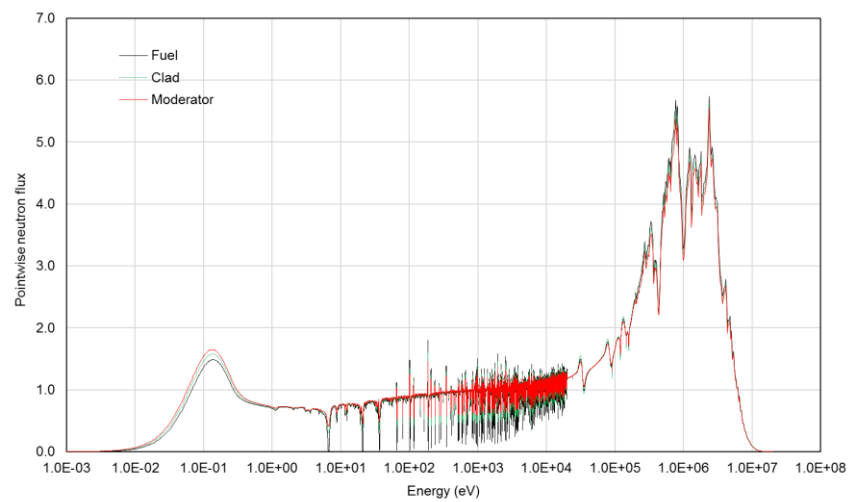
Nuclear needs phyicists!

- There are interesting things below 100 MeV

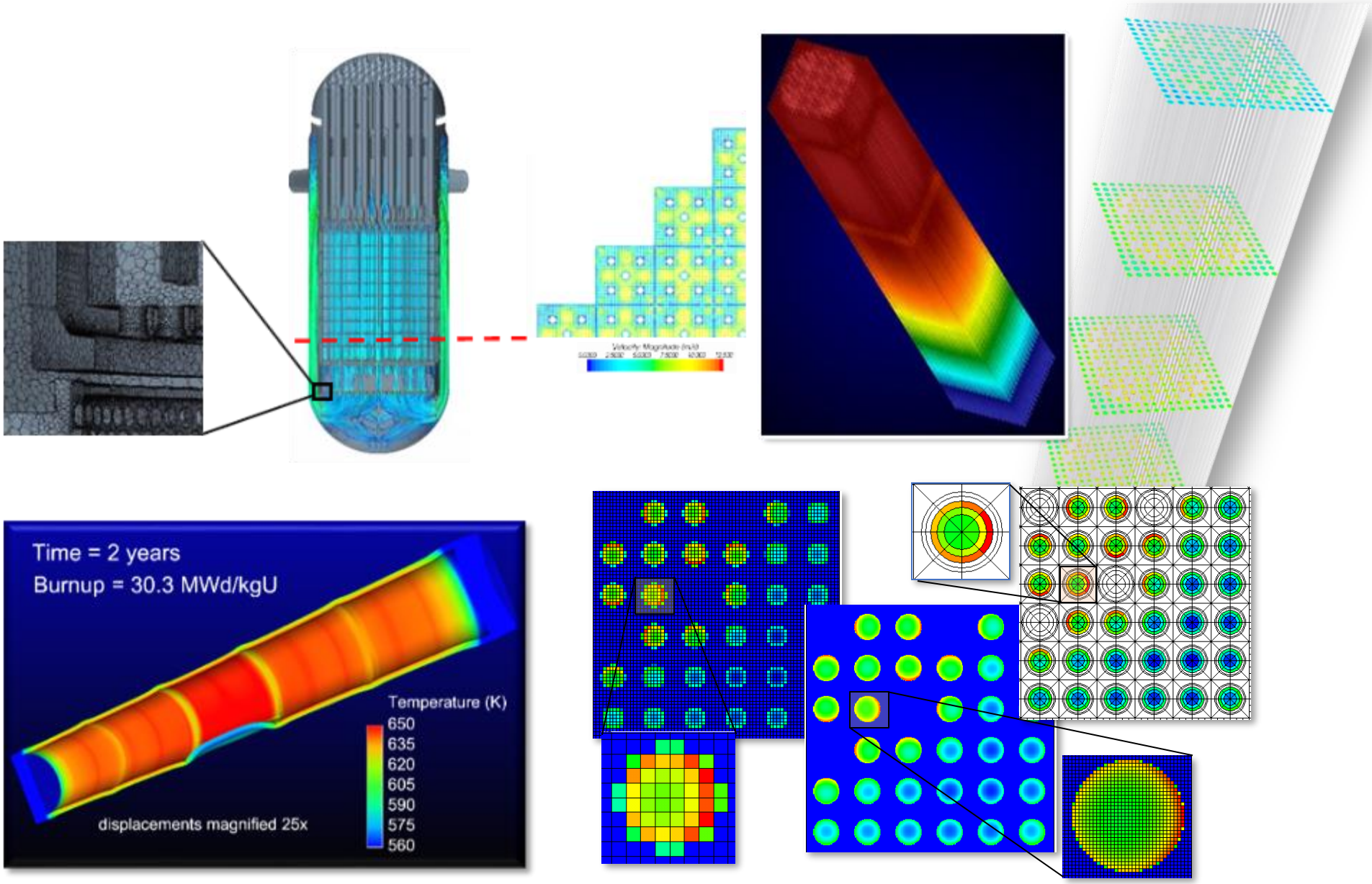




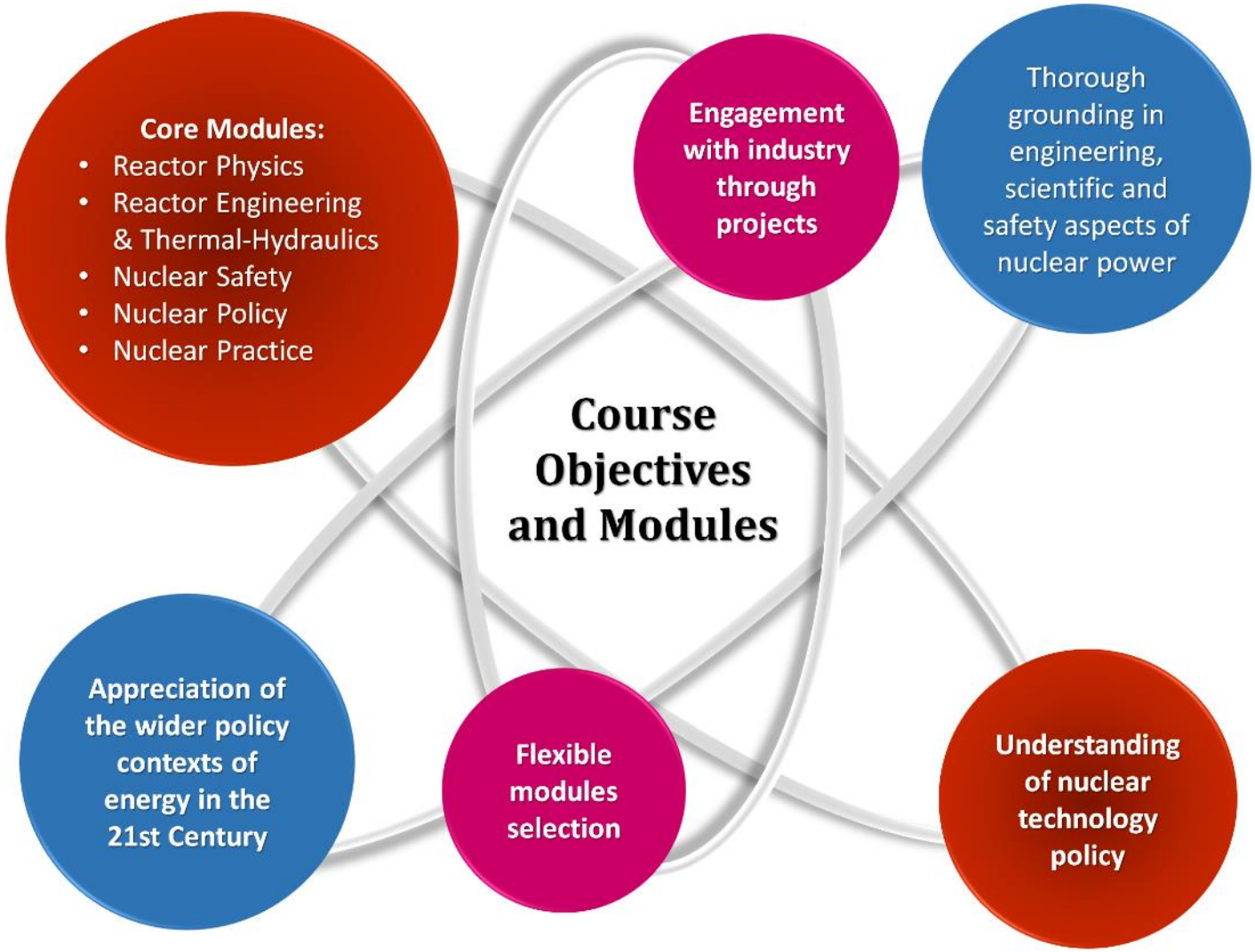




Predictive modelling challenges



MPhil in Nuclear Energy at Cambridge



MPhil in Nuclear Energy – Overview

- Taught 1 year MPhil in Nuclear Energy – October to August
  - Core nuclear technology modules (required equivalent of at least four credits)
  - One core nuclear policy module
  - One to four elective modules from masters teaching in Engineering, Materials Science, Chemical Engineering, Physics and the Judge Business School
  - Dissertation project – 4-months research in the Summer on either:
    - Cambridge research topic or
    - Industry partner research area

Westinghouse

NDA Nuclear Decommissioning Authority

AWE

framatome

urenco The Energy to Succeed

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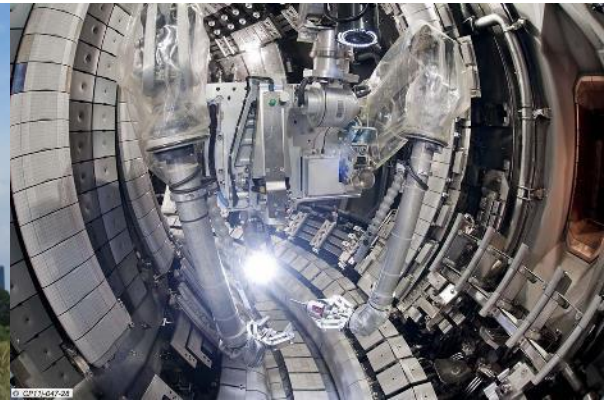
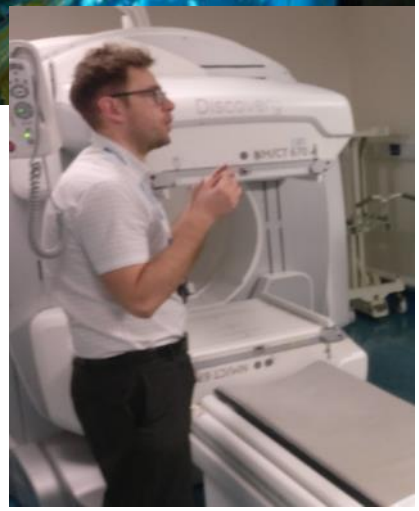
中广核 CGN

中广核研究院有限公司
China Nuclear Power Technology Research Institute Co.,Ltd.

Visits

- Department of Nuclear Medicine, Addenbrooke's Hospital
- Nuclear Research Centre, Romania
  - World-class research reactor, hot cell lab, fuel fabrication facility
- Sizewell B nuclear power plant
- Culham Centre for Fusion Energy
- Westinghouse-Springfields, Preston
- Sellafield, Cumbria





Seminars, prizes, social events

Summary

- Nuclear is back
  - Clean, sustainable, safe, scalable
  - Provides ultimate energy security
  - Engine of future economic growth
- Nuclear is a meaningful and impactful career choice
  - UK skills may be a bottleneck
- Physics is an ideal background
- MPhil is a gateway to careers in academia and industry
  - Accepting applications now

"As nuclear technology is special, the people who man and manage the technology must be special."

[A. Weinberg, Importance of an Engineer's Role in the Use of Nuclear Energy, 1972]

Thank you!

Questions?