The Risks of Nuclear Energy

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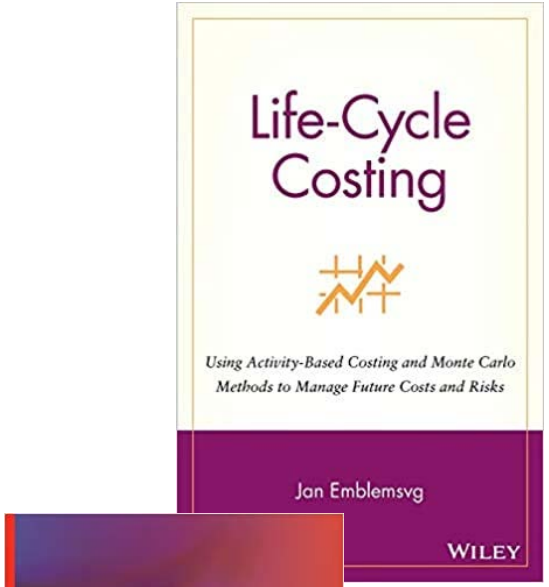
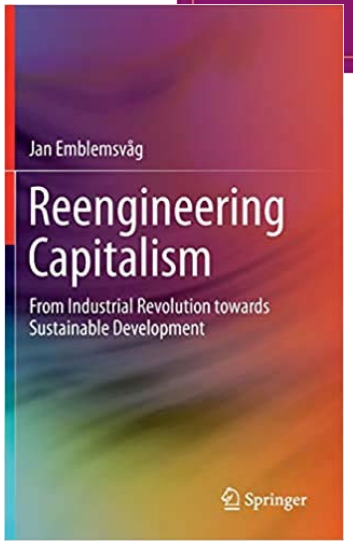
2022-05-04

A few words about myself

- 20 years in top management positions primarily in maritime industry
- Professor at NTNU
- Written several books and about 40 journal papers
- Hold a PhD (99) and M.Sc. (95) at Georgia Institute of Technology and a ‘Sivilingeniør’ from Norwegian Institute of Technology (NTH) (94)





NTNU

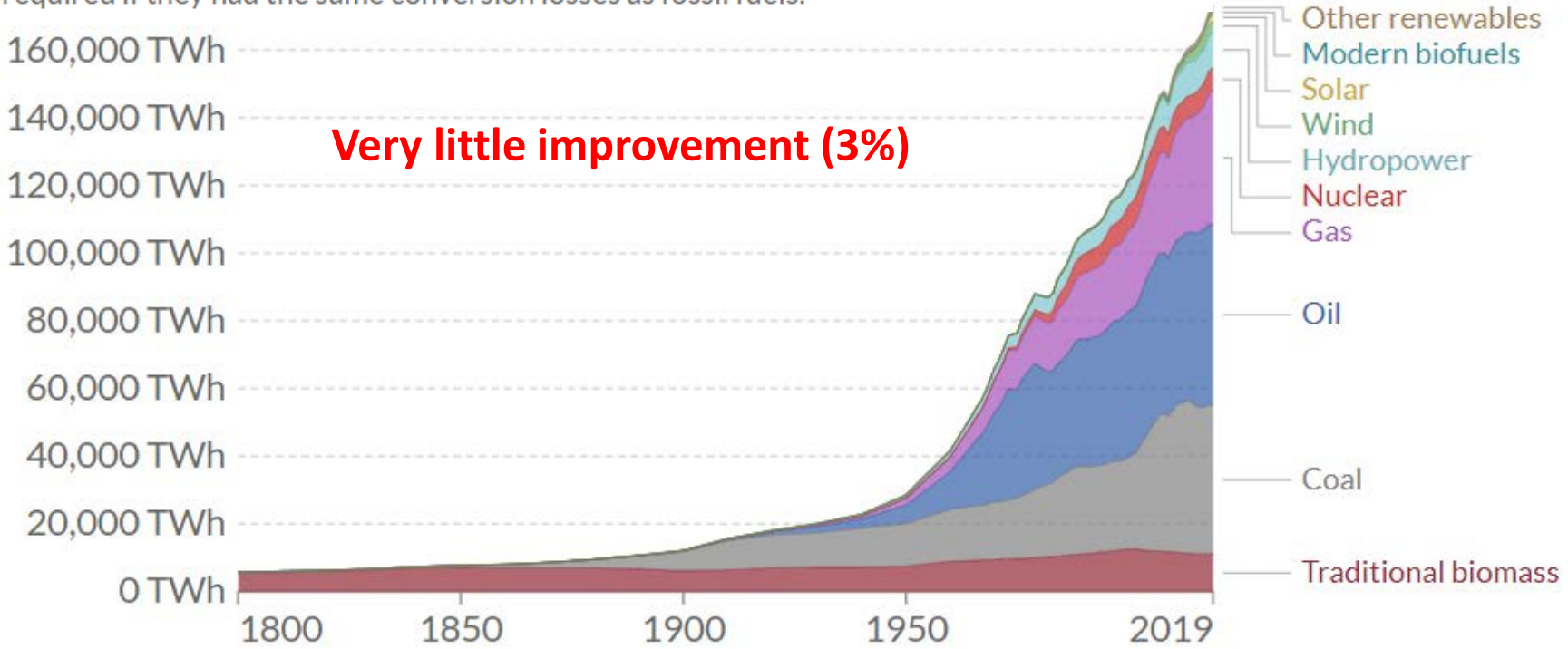
Risks are not just bad things happening, but also good things not happening.

Typical risks

1. Radiation – potential radiation excludes nuclear energy
2. Waste – the waste issue is huge and long-lasting
3. Costs – the technology is very expensive
4. Time –
   a) 4th generation nuclear technology takes too much time to develop
   b) Nuclear power plants take too long time to build
   c) We do not have time!

BUT – this is the real risk!

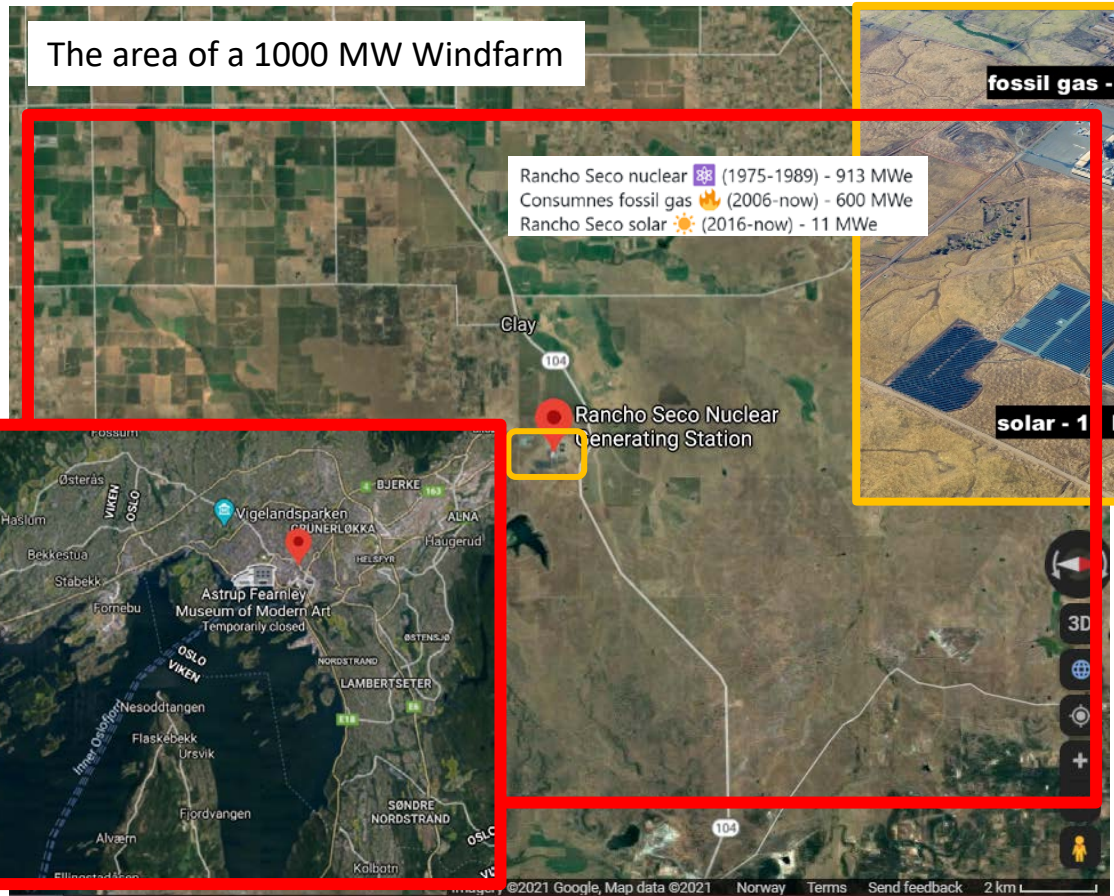
Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.

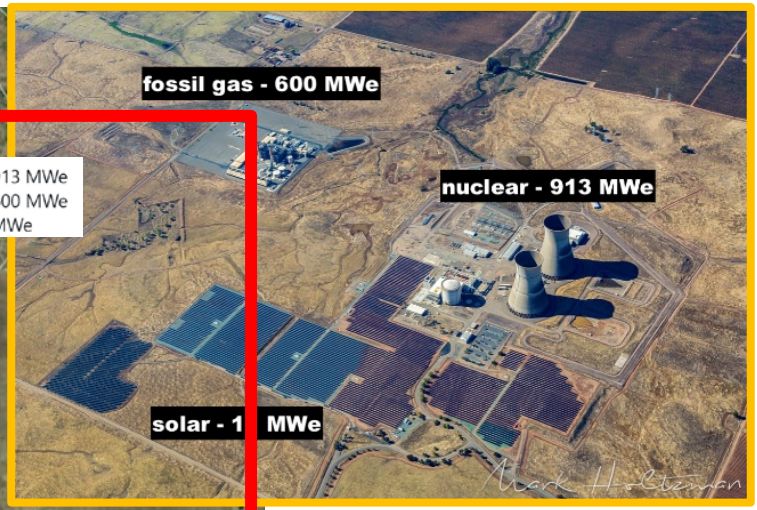


Source: Vaclav Smil (2017) & BP Statistical Review of World Energy

OurWorldInData.org/energy • CC BY

High energy intensity is key



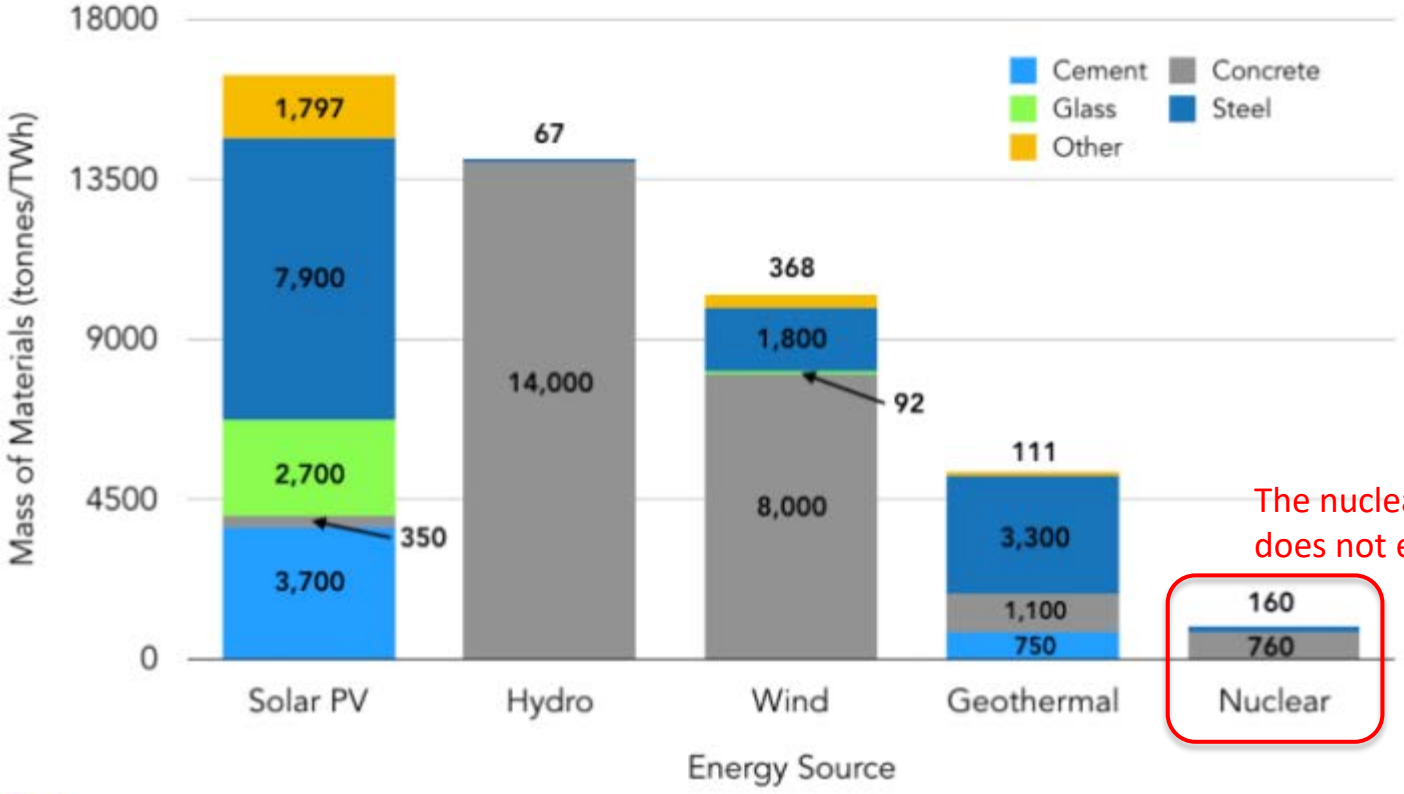


BUT we need min 4 such areas or balancing power

250-350 tonnes HFO per day

- 580 large container vessels globally
- They alone would consume half of Europe's total electricity production

Fact; Low footprint and no emissions

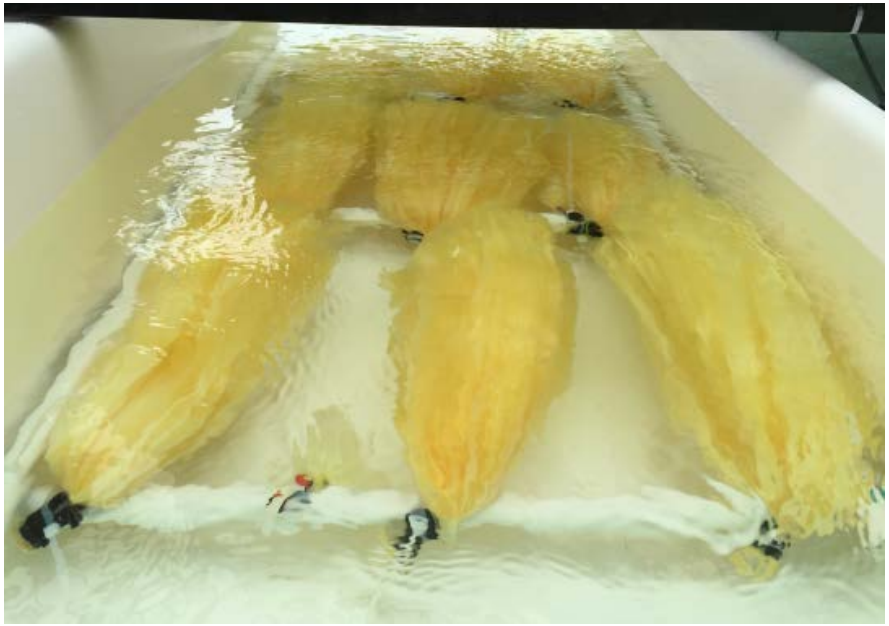


The nuclear materials does not even show up!

"Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities." Table 10. September 2015. United States Department of Energy. Nuclear and hydro require 10 tonnes/TWh and 1 tonne/TWh of other materials, respectively, but are unable to be labeled on the graph.

Fact; Nuclear is renewable!

- There is ca 4.6 bn tonnes (3.3 ppb) uranium in seawater
- The earth rocks contain ca 100,000 bn tons uranium which replenish the oceans at 16,000 tonnes per year

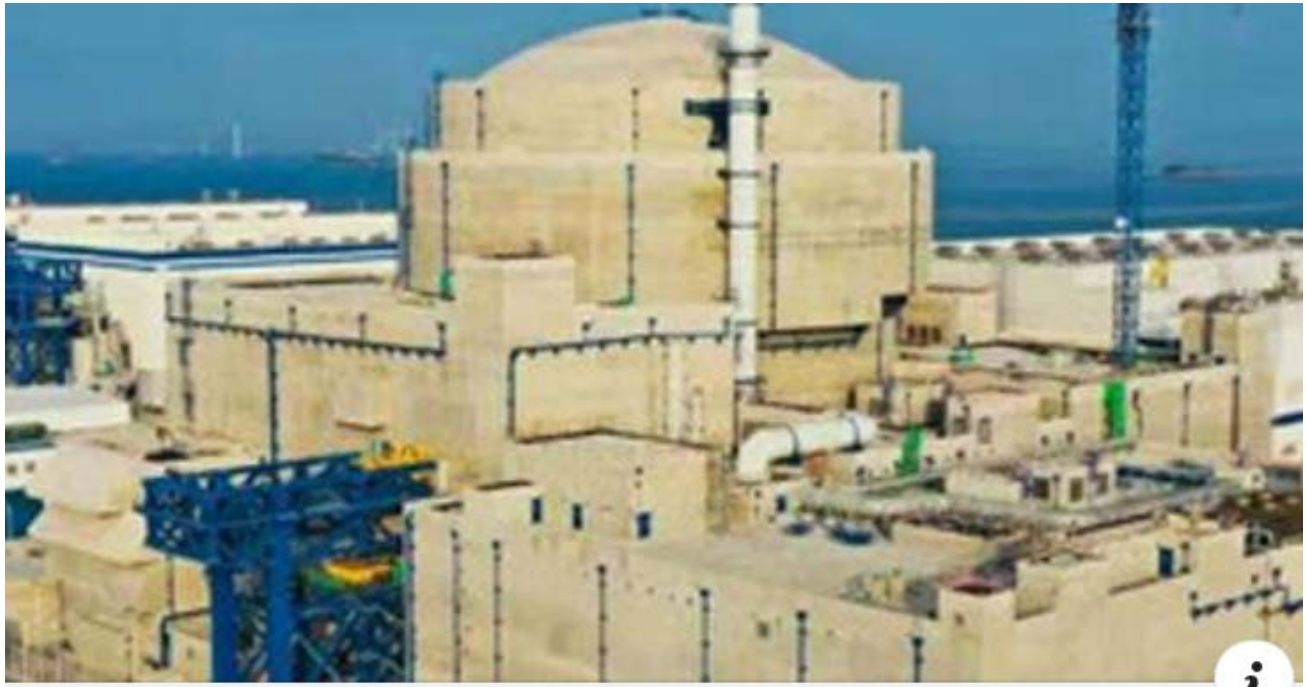


Extraction using old yarn

Source: https://www.forbes.com/sites/jamesconca/2016/07/01/uranium-seawater-extraction-makes-nuclear-power-completely-renewable

Source: https://www.pnnl.gov/news/release.aspx?id=4514

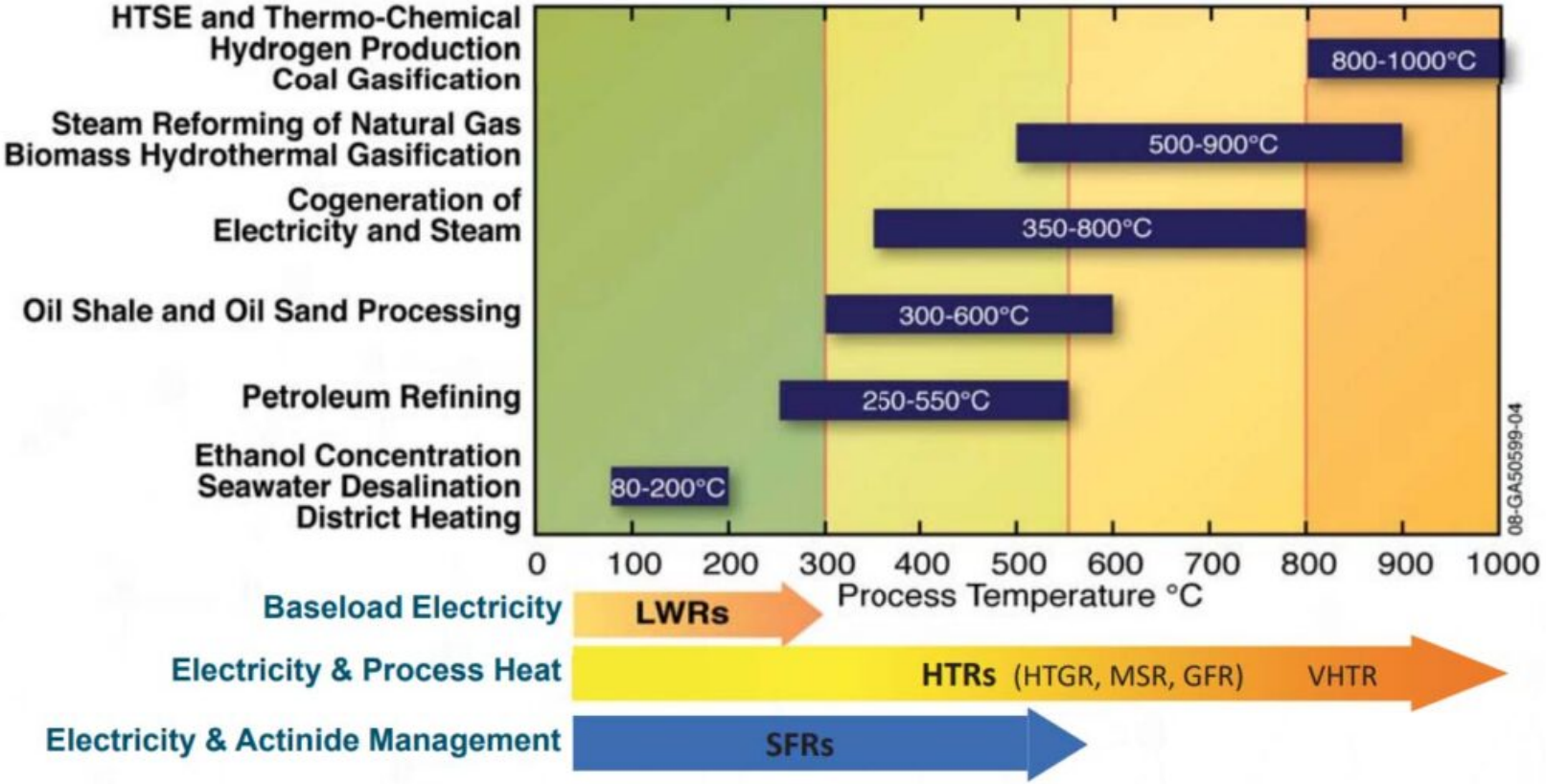
China plans to build 9 GW/year



NUCNET.ORG

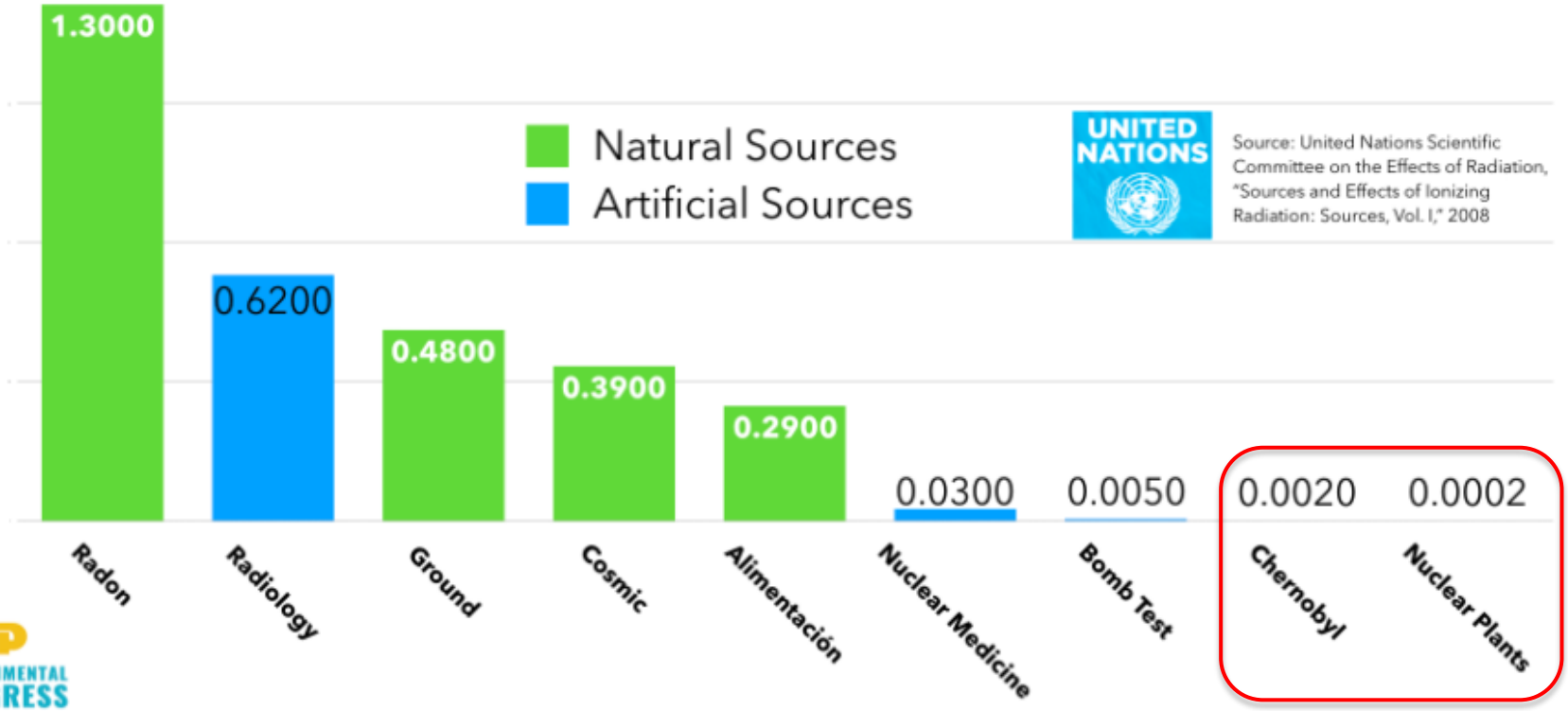
China / Beijing 'To Start Construction' Of Facility For Extracting Uranium From Sea :: NucNet | The Independen...

Different reactor for different usage



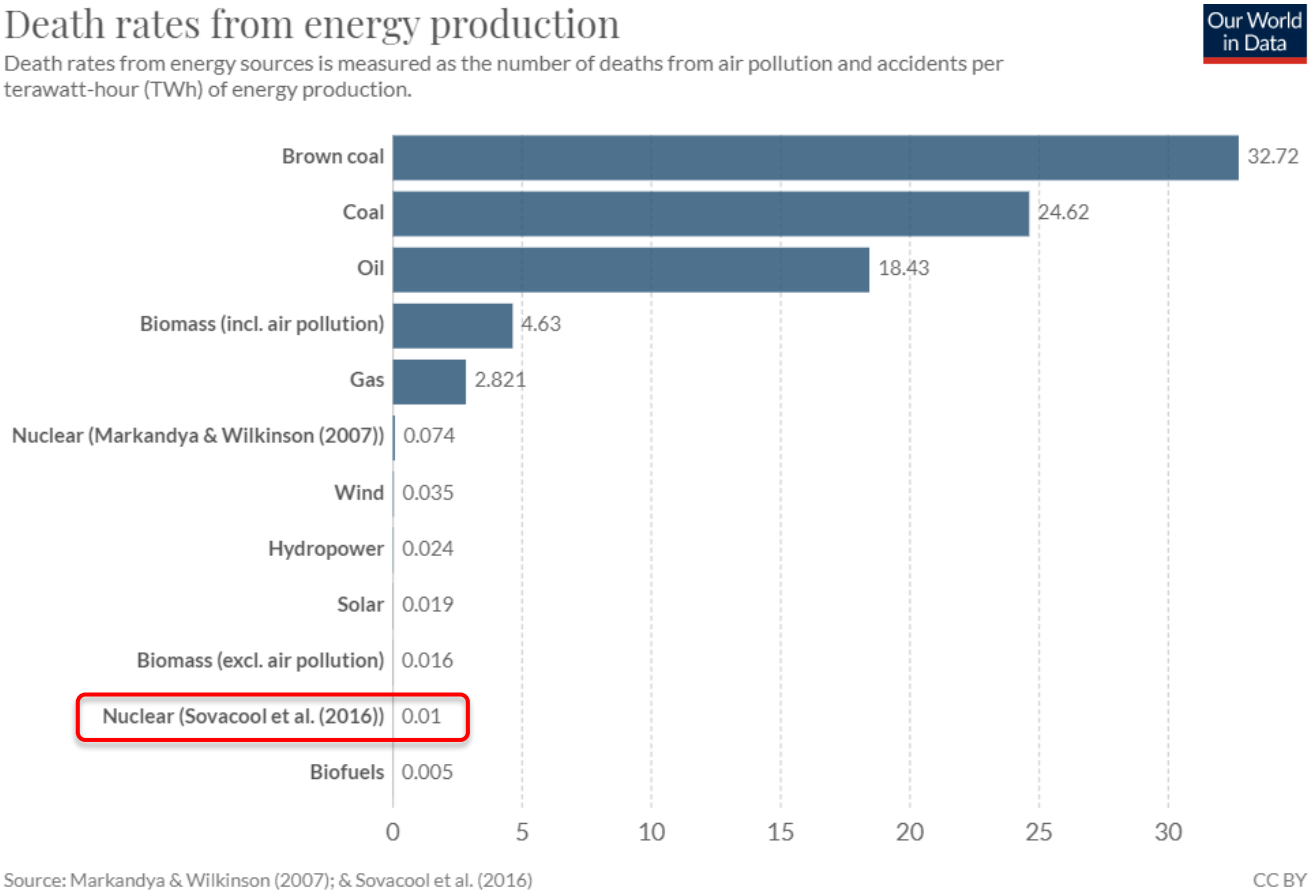
Source: Idaho National Laboratory, 2019, see https://www.nrc.gov/docs/ML1921/ML19214A096.pdf

Myth; Nuclear radiation is a problem



ENVIRONMENTAL PROGRESS

Myth; A lot of people has died



Myth; Nuclear generates a lot of waste

- All nuclear waste ever produced in the US fits on a football field, 50 feet high
- Over 90% of the energy is left
- Ca 250,000 TWh
- Ca 300 years of production with the current mix of the US grid

Waste storage

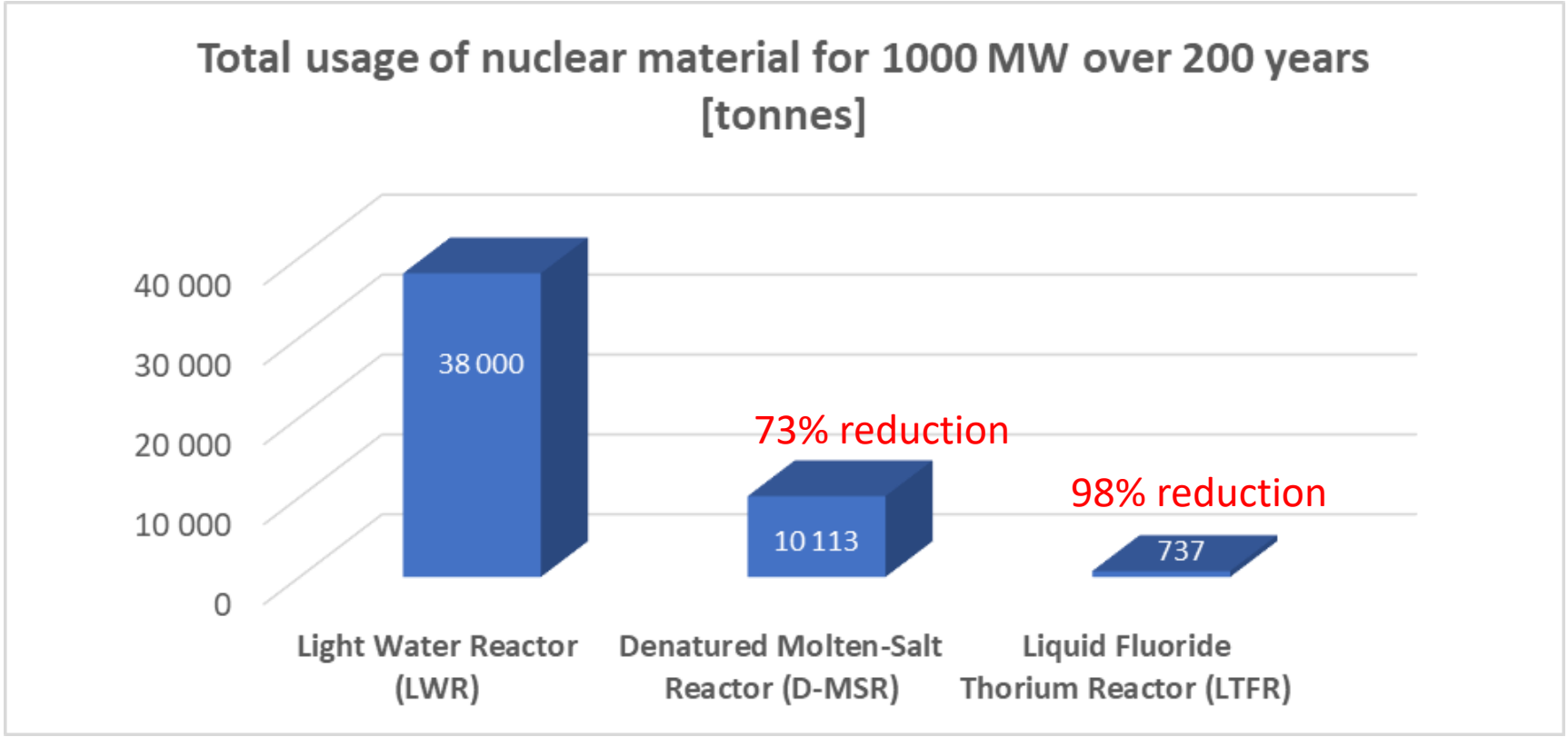
Zwilag in Switzerland

- 99.5% of the radiation in only 10.2% of the material
- By yearend 2018, there was 2,355 m^3 material from which Switzerland had generated 2,667 TWh
- Gen IV would have given 100,000 TWh
- With Gen IV, 17% of the material must be stored for 300 years and the rest for only 10 years

Waste storage (2)

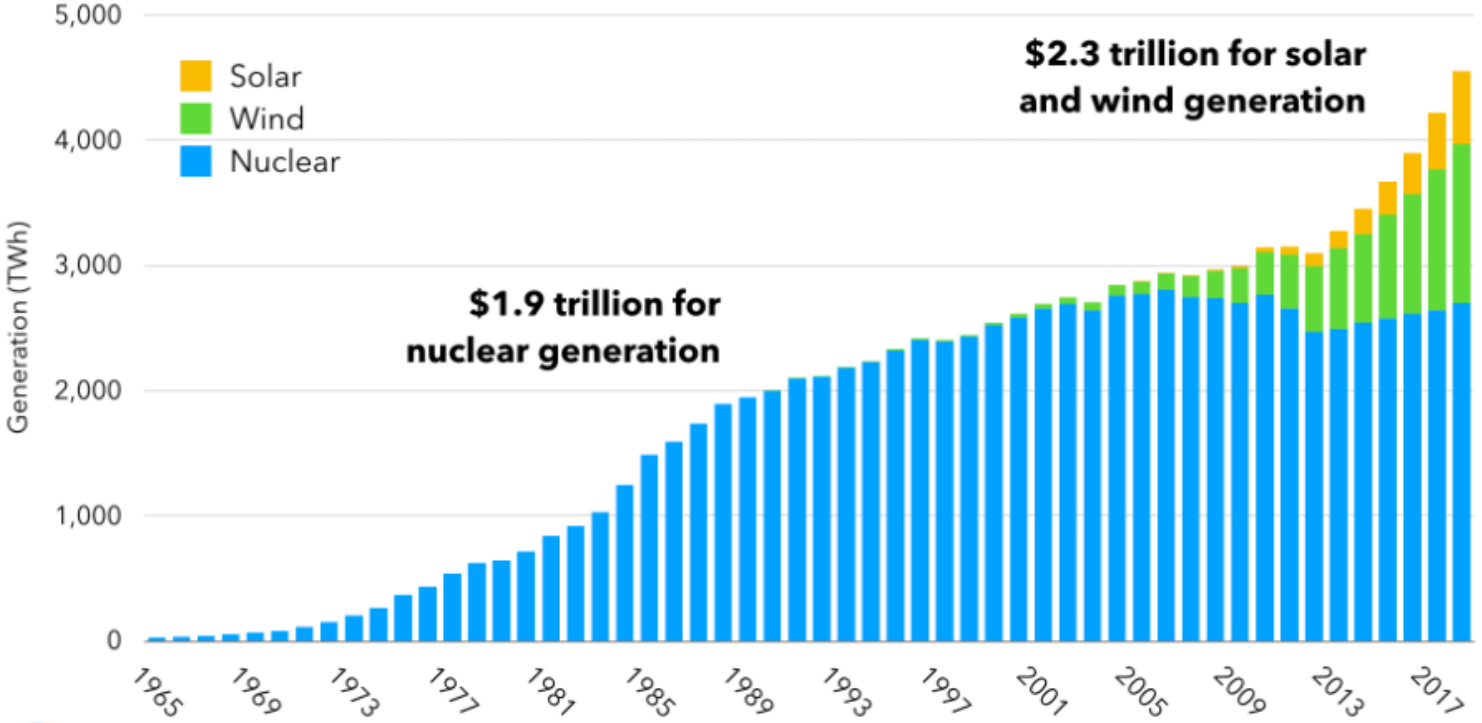
- After 40 years, only 1 permille of radioactivity is left
- Yet, rules mandate storage for thousands of years
- The cost is included in the production costs of nuclear power plants
- Nuclear waste is extremely valuable, which is why intermediate storage is used
- Gen IV reactors can use this ‘waste’

Dramatic reduction of waste



Source: Moir, R. W. and E. Teller (2005). "Thorium-Fueled Underground Power Plant based on Molten Salt Technology." Nuclear Technology 151(9):pp.334-340.

Myth; Nuclear is expensive

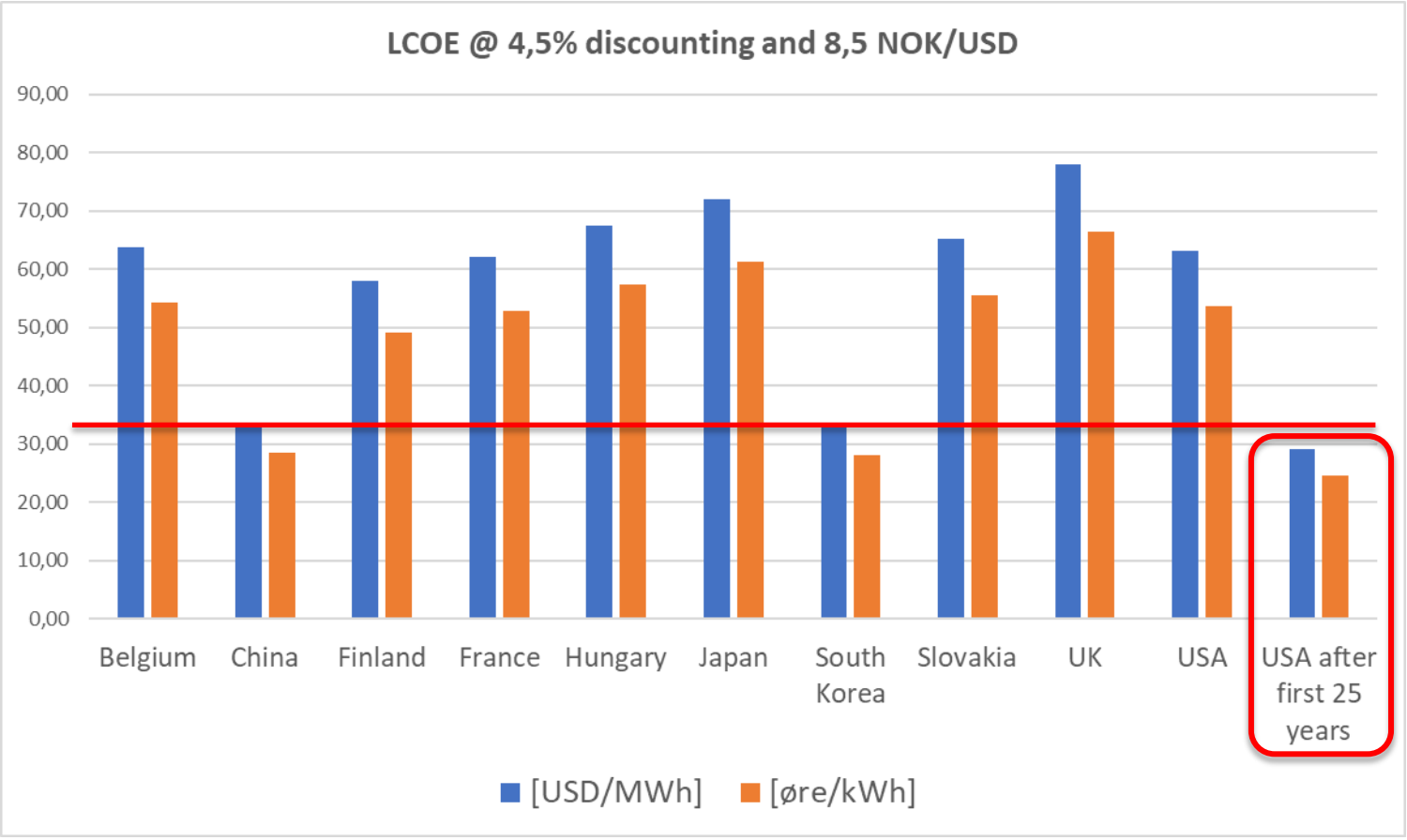


ENVIRONMENTAL PROGRESS

Sources: BP Statistical Review, 2019; Nelson et al., "Power to Decarbonize," EP, 2017, based on BNEF (solar/wind) Lovering, et al, 2016, *Energy Policy*

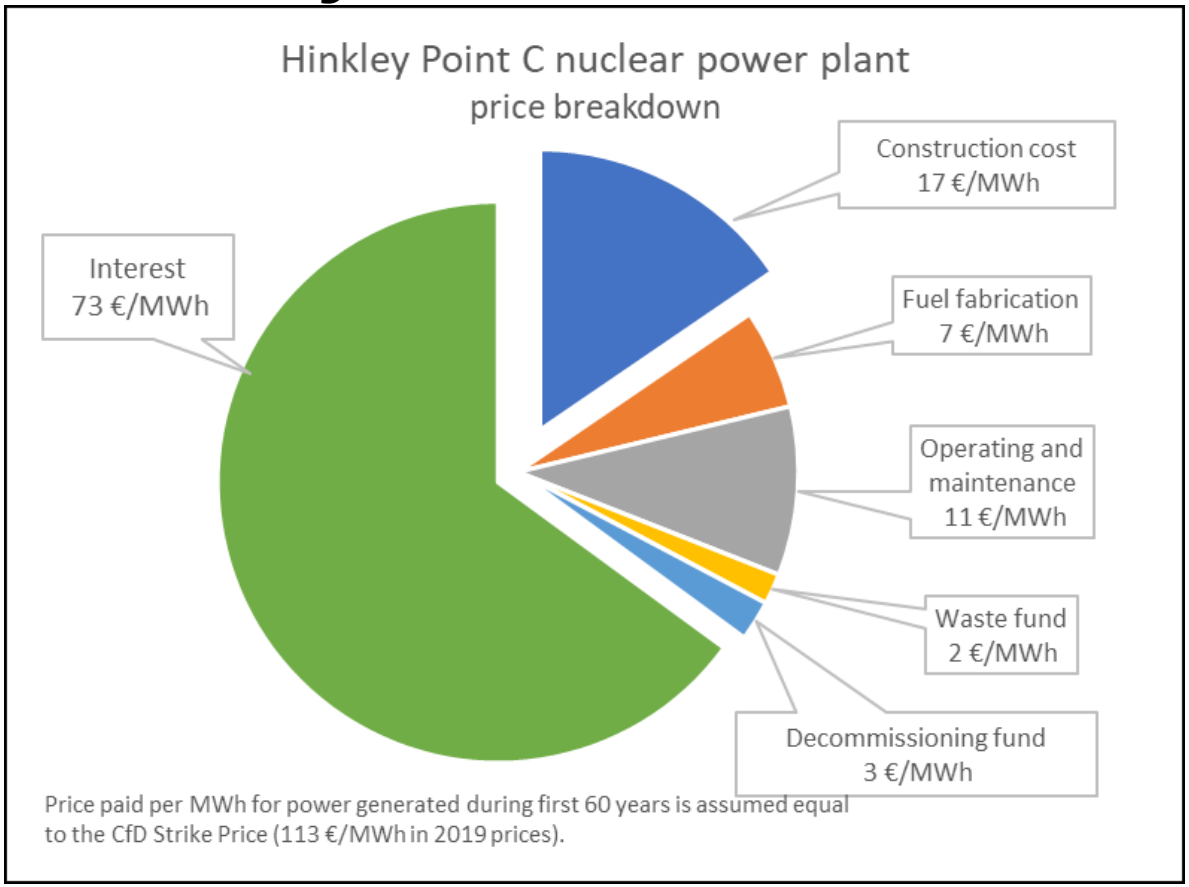
Levelized Cost Of Energy

Source: Emblemsvåg, Jan. (2021) Safe, Clean, Proliferation Resistant and Cost-Effective Thorium-based Molten Salt Reactors for Sustainable Development. International Journal of Sustainable Energy.



Norwegian Hydro power

Hinkley Point C is instructive



- Expensive financing
- 100 bn Euros in profit!
- New reactor design (EPR)

Source:

- National Audit Office (2017). Hinkley Point C
- Joris van Dorp; https://medium.com/generation-atomic/the-hinkley-point-c-case-is-nuclear-energy-expensive-f89b1aa05c27

Offshore wind vs Nuclear

Offshore wind;

- 8 years construction time
- CAPEX is 30 MNOK/MW
- Ca 50 bn NOK per offshore wind power plant
- 7.0 TWh/year for 25 years

Nuclear (AP1000);

- 5 years construction time
- CAPEX is 19 MNOK/MW
- Ca 30 bn NOK per nuclear powerplant
- 8.5 TWh/year for 60 years
- Up to 200.000 tonnes hydrogen per year from waste heat

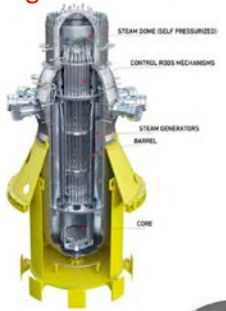
Further information: https://www.aftenbladet.no/meninger/debatt/i/dn9dWO/kjernekraft-noedvendig-for-groenn-omstilling

Development – innovations are many

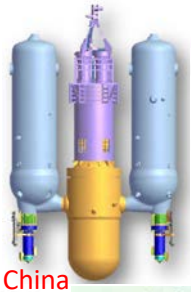
Not in scale

67 different Small Modular Reactors (SMR) under development in 2020… here are 17;

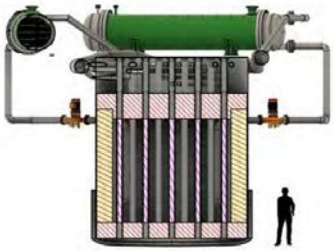
Argentina



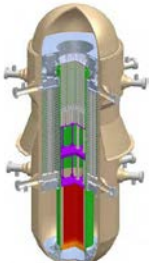
China



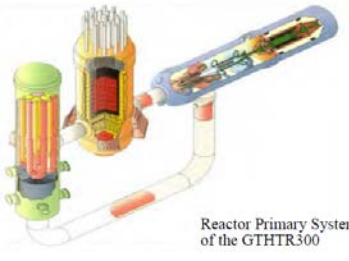
Czech Republic

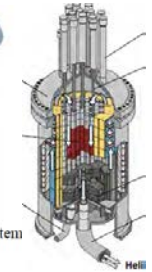


International



Japan

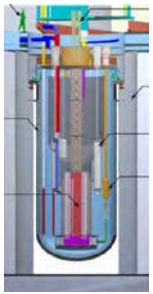


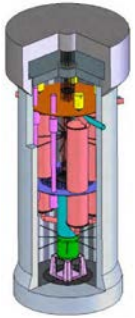


South Korea

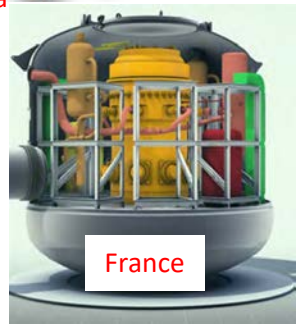
USA

Canada

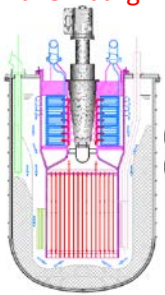




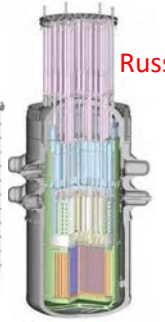
France



Luxemburg

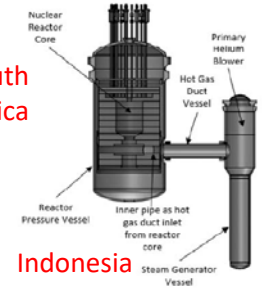


Russia



Sweden

South Africa



Indonesia

Source: Advances in Small Modular Reactor Technology Developments. A Supplement to: IAEA Advanced Reactors Information System (ARIS). 2020 Edition

Accelerating advanced reactor demonstration and deployment

2030

Natrium Reactor
TerraPower & General Electric
2028
TerraPower
HITACHI

Hermes
Kairos
Kairos Power 2026

MCRE
Southern Co. & TerraPower
2025
TerraPower
Southern Company

Project Pele Microreactor
DoD
2023-2024

MARVEL
DOE
2022-2023

Xe-100
X-energy
2027
energy

SMR
UAMPS &
NuScale
2029
UAMPS
NUSCALE

Aurora
Oklo Inc.
TBD
OKLO

LOTUS Test Bed
NRIC
2024

DOME Test Bed
NRIC
2023-2024

NRIC National Reactor Innovation Center

IES Integrated Energy Systems

Advanced Reactor Development

1 DEMONSTRATION

GOAL: *Test, license and build operational reactors within 5 - 7 years.*

- 345 – 1000 MW
- 5 – 33X
- Load following
- Once-through

Natrium Reactor

Sodium-cooled fast reactor + molten salt energy storage system

TERRAPOWER

- 76 MW
- Full burn-up (100X)
- Load following
- Closed loop

Xe-100

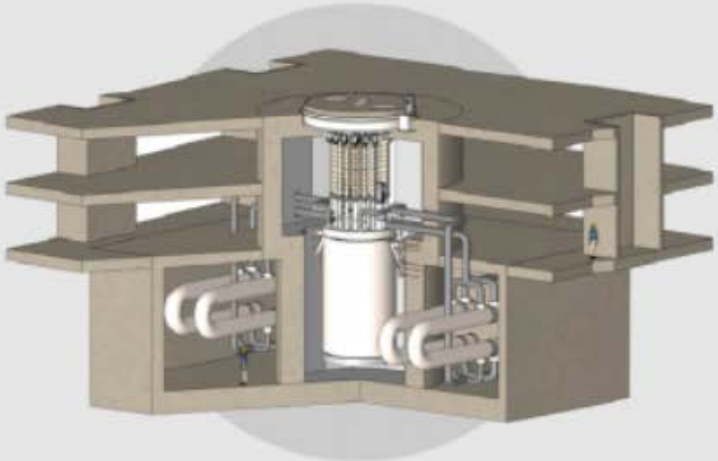
High-temperature gas reactor

X-ENERGY

Advanced Reactor Development (2)

2 RISK REDUCTION

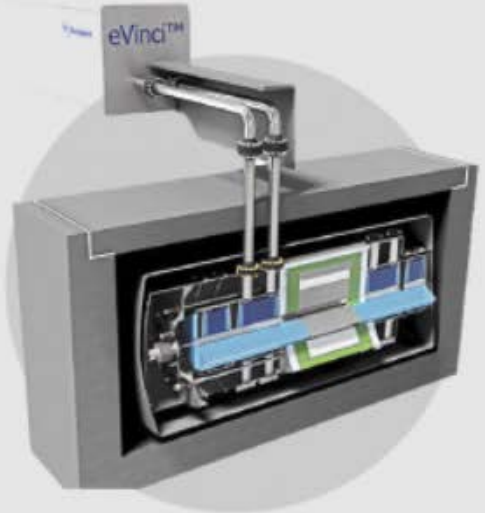
GOAL: *Solve technical, operational and regulatory challenges to support demonstration within 10 - 14 years.*



KP-FHR

Fluoride salt-cooled high-temperature reactor

KAIROS POWER

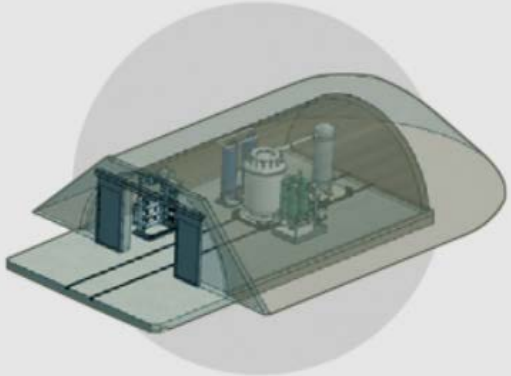


eVinci

Heat pipe-cooled microreactor

WESTINGHOUSE NUCLEAR

Advanced Reactor Development (3)



BWXT Advanced Nuclear Reactor (BANR)

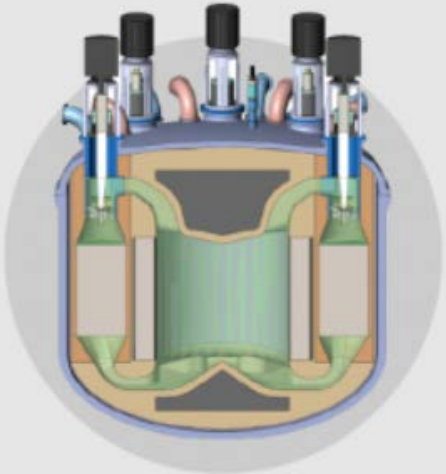
High-temperature gas-cooled microreactor

BWX TECHNOLOGIES

SMR-160

Advanced light-water small modular reactor

HOLTEC INTERNATIONAL



Molten Chloride Fast Reactor

SOUTHERN COMPANY

MSR – Molten-Salt Reactor
PWR – Pressurized Water Reactor

MSR is cheaper than coal

(before CO_2 taxes)

Item	1978$			2000$		
Direct costs, M$	MSR	PWR	Coal	MSR	PWR	Coal
Cost/kWh, ¢/kWh						
Capital	0.83b	0.85b	0.65b	2.01b	2.07b	1.58b
O&M	0.24c	0.47d	0.33d	0.58c	1.13d	0.80d
Fuel	0.46c	0.31e	0.71f	1.11c	0.74e	1.72f
Waste disposal	0.04g	0.04g	0.04d	0.10g	0.10g	0.09d
Decom	0.02c	0.03d	--	0.04c	0.07d	--
Total	1.58	1.69	1.73	3.84	4.11	4.19

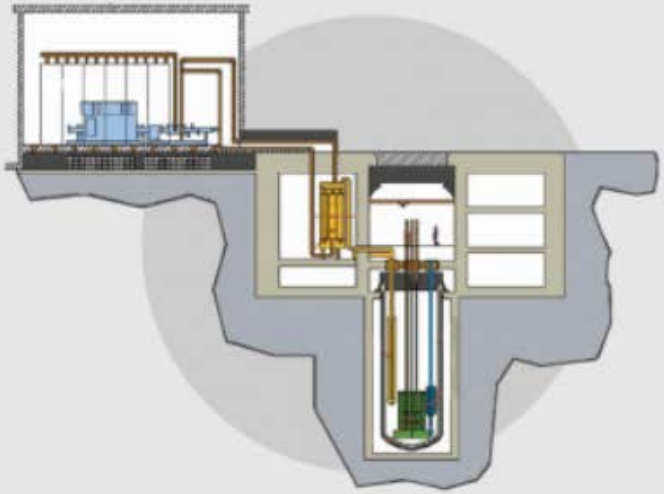
Ca 30 øre/kWh

Source: Moir, R.W. (2002). "The cost of electricity from Molten Salt Reactors (MSR)." Nuclear Technology 138(1):93-95.

Advanced Reactor Development (4)

3 CONCEPT DEVELOPMENT

GOAL: *Solidify concept to mature technology for potential demonstration by mid-2030s.*



Advanced Sodium-Cooled Reactor Facility

ADVANCED REACTOR CONCEPTS

Fast Modular Reactor

GENERAL ATOMICS

The pebble-bed reactor is here…

The demonstration high-temperature gas-cooled reactor pebble-bed module (HTR-PM) at the Shidaowan site in Shandong Province of China was connected to the grid in December 2021. Courtesy: China Nuclear Energy Association

BUT; we need to act

Takk for meg ☺

Question
and
Answer