Nuclear power for a sustainable world

JAN EMBLEMSVÅG

GUNNERUSFORELESING 2023-03-02

The story

- The challenge
- Myths and facts
- New reactor designs
- What the future holds

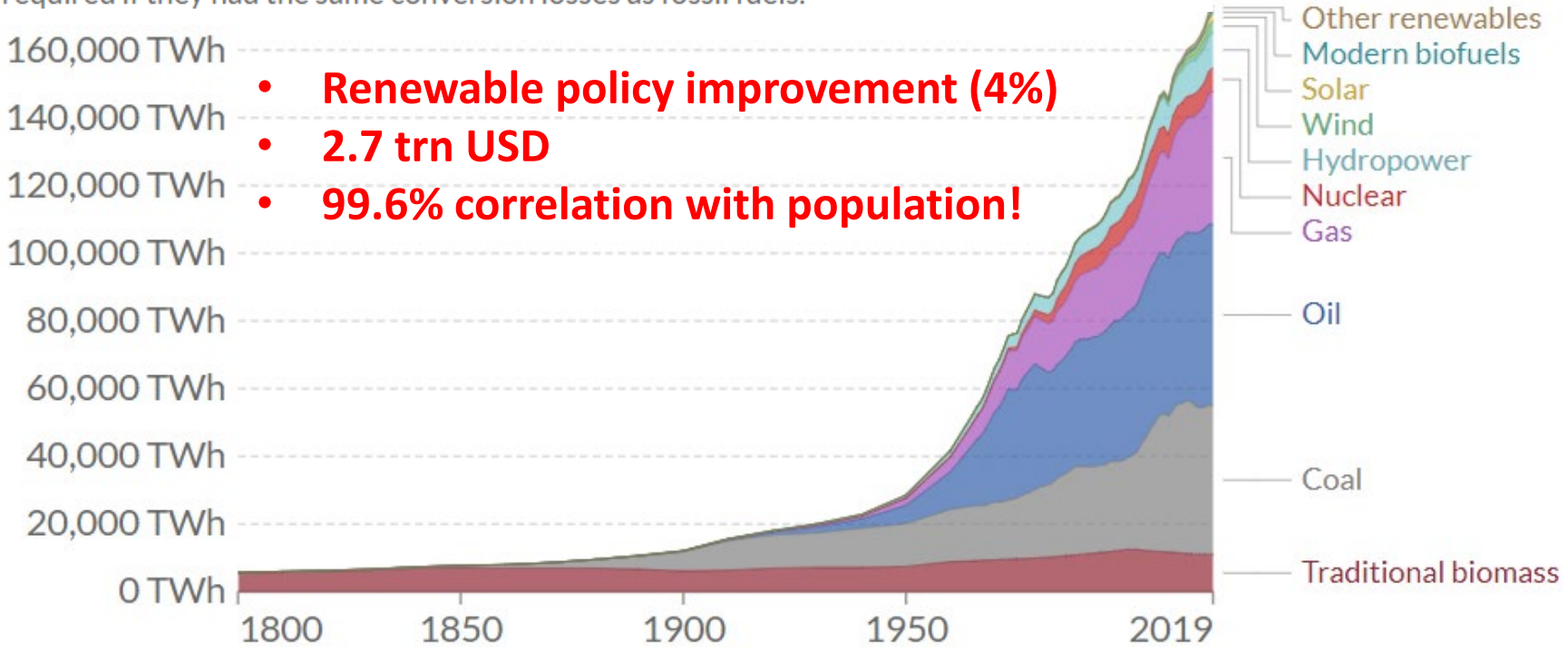
This Thorium ball hold enough energy to supply you for your entire life!

Based on today's average use per person in USA

Energy transition is at 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.

- **Renewable policy improvement (4%)**
- **2.7 trn USD**
- **99.6% correlation with population!**



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

OurWorldInData.org/energy • CC BY

250-350 tonnes HFO per day

- 580 large container vessels globally
- Large bulkers and tankers
- Large cruise ships

Shanghai – Amsterdam

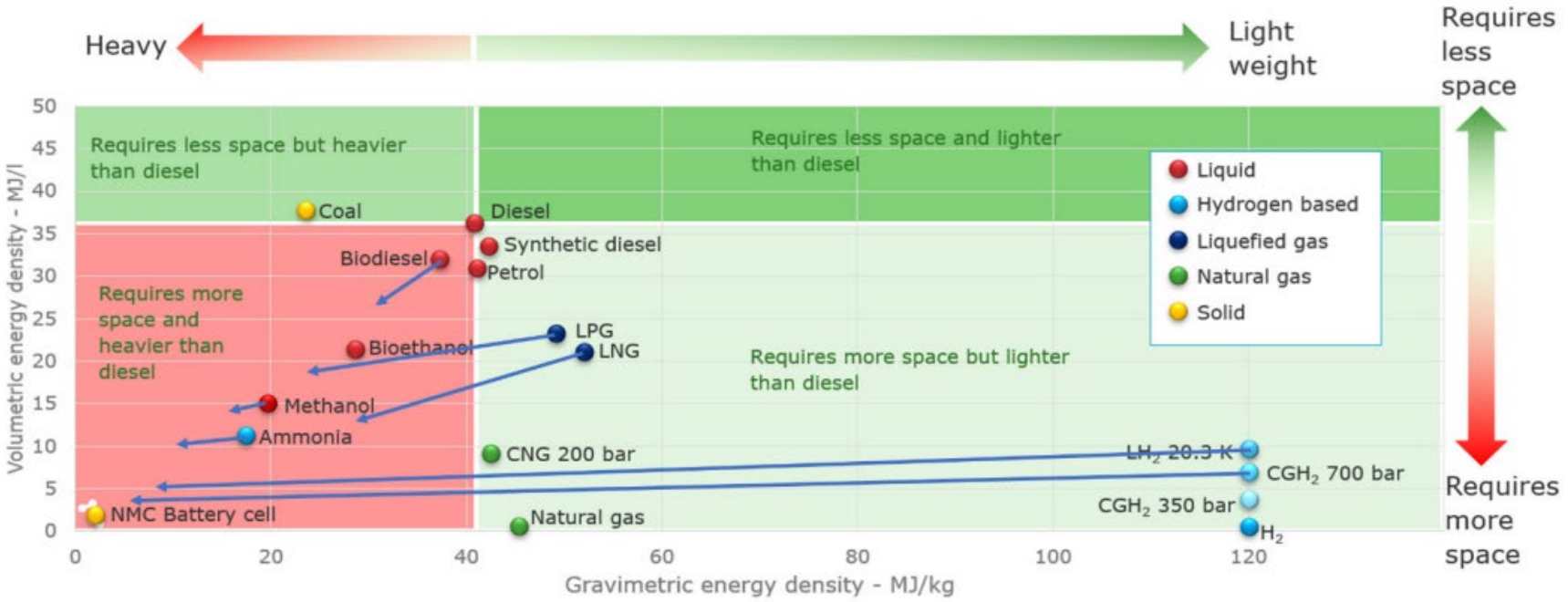
- 3350 MWh per day requirement
- HFO;
  - At 11 MWh/tonne, this gives 350 tonnes
  - 3900 tonnes each way
- Green ammonia;
  - 5 MWh/tonne
  - 8425 tonnes each way
  - Green ammonia via electrolysis requires 9-15 MWh/tonne
- 80% utilization of ships gives 12 trips per year

Shanghai – Amsterdam (2)

- HFO – 1 TWh/year thermal power
- Green ammonia – 2.2 TWh/year elec[illegible] power for each ship plus losses in grid, ba[illegible]g power, etc.
- The1164 windmills in Nor[illegible]oduced 9.9 TWh in 2020 or almost enou[illegible] ships
- The 580 large c[illegible]er vessels will require 1,280 TWh per y[illegible] almost half of Europe's total electricit[illegible]oduction in 2019 of 2,780 TWh

Unrealistic and unsustainable

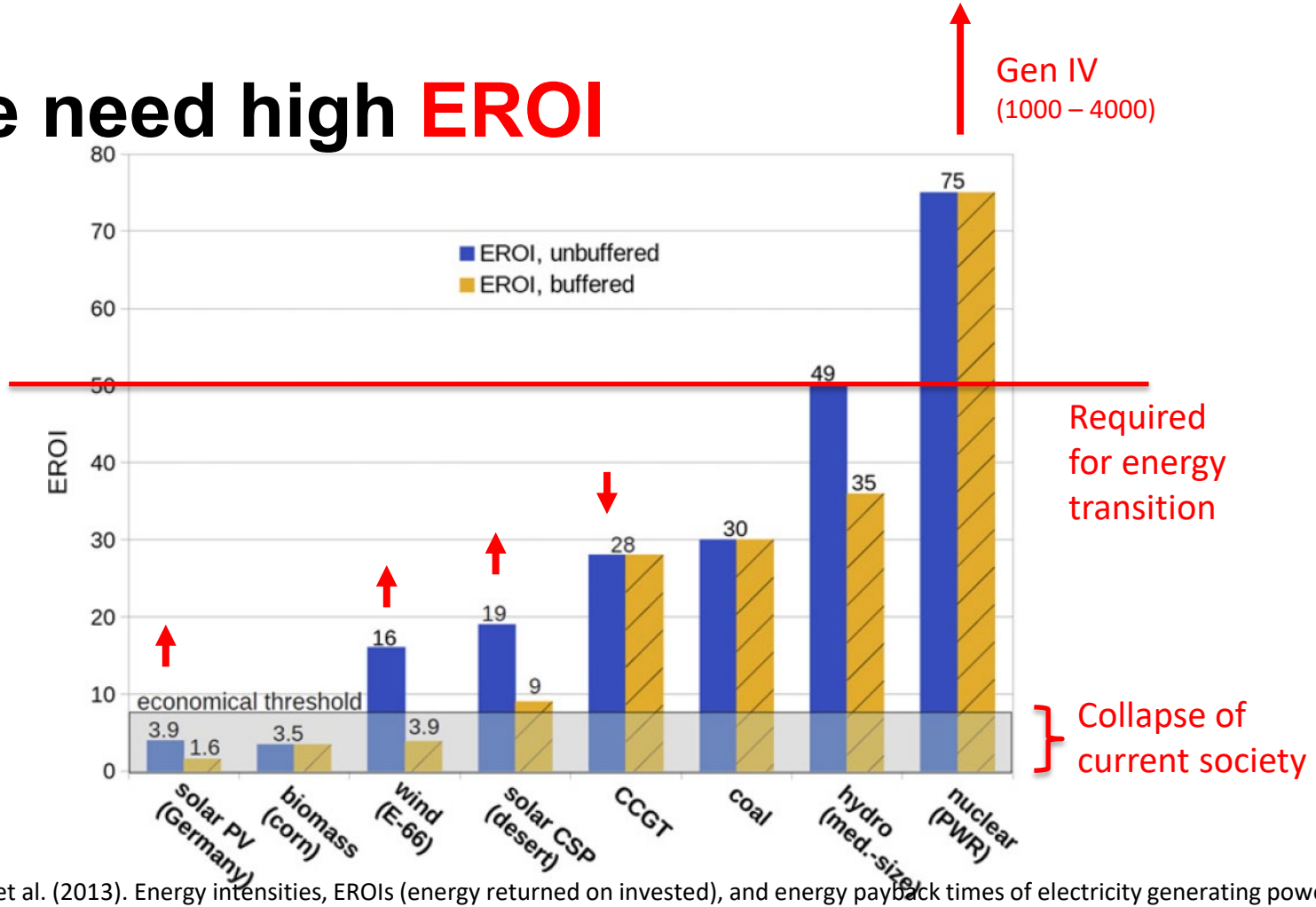
Energy density is the key



If H2 is 1 meter on this scale, Uranium would be 32 km away from this venue and thorium 38 km away

Source: DNV GL – Report No. 2019-0567, Rev. 3

We need high EROI

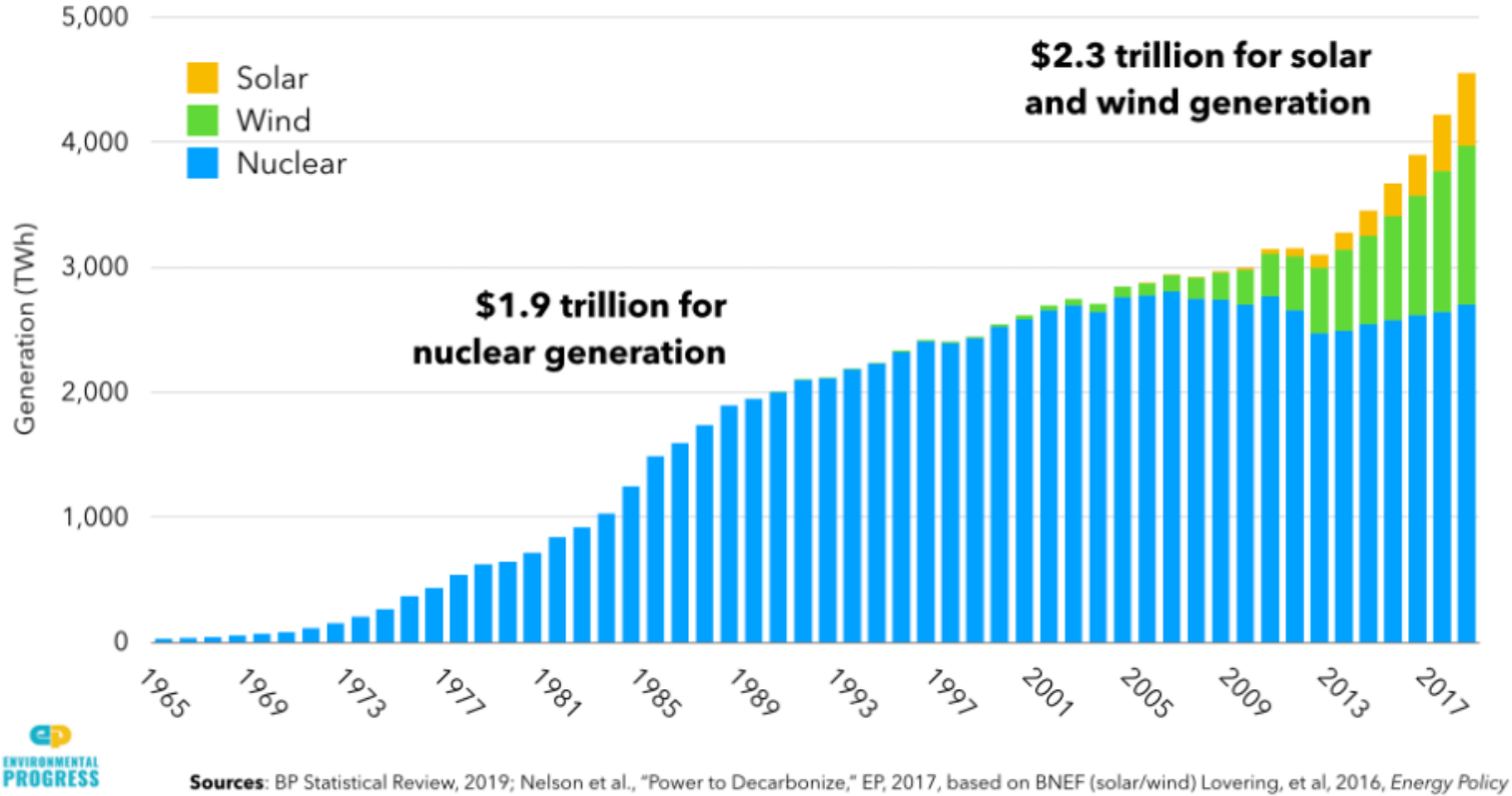


Source: Weißbach et al. (2013). Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. Energy, Vol 52, pp. 210-221.

The key risks people think of

1. **Costs** – the nuclear technology is very expensive
2. **Waste** – the waste issue is huge and long-lasting
3. **Time** – we do not have time;
    a) Too long building-time
    b) Generation IV is too far ahead

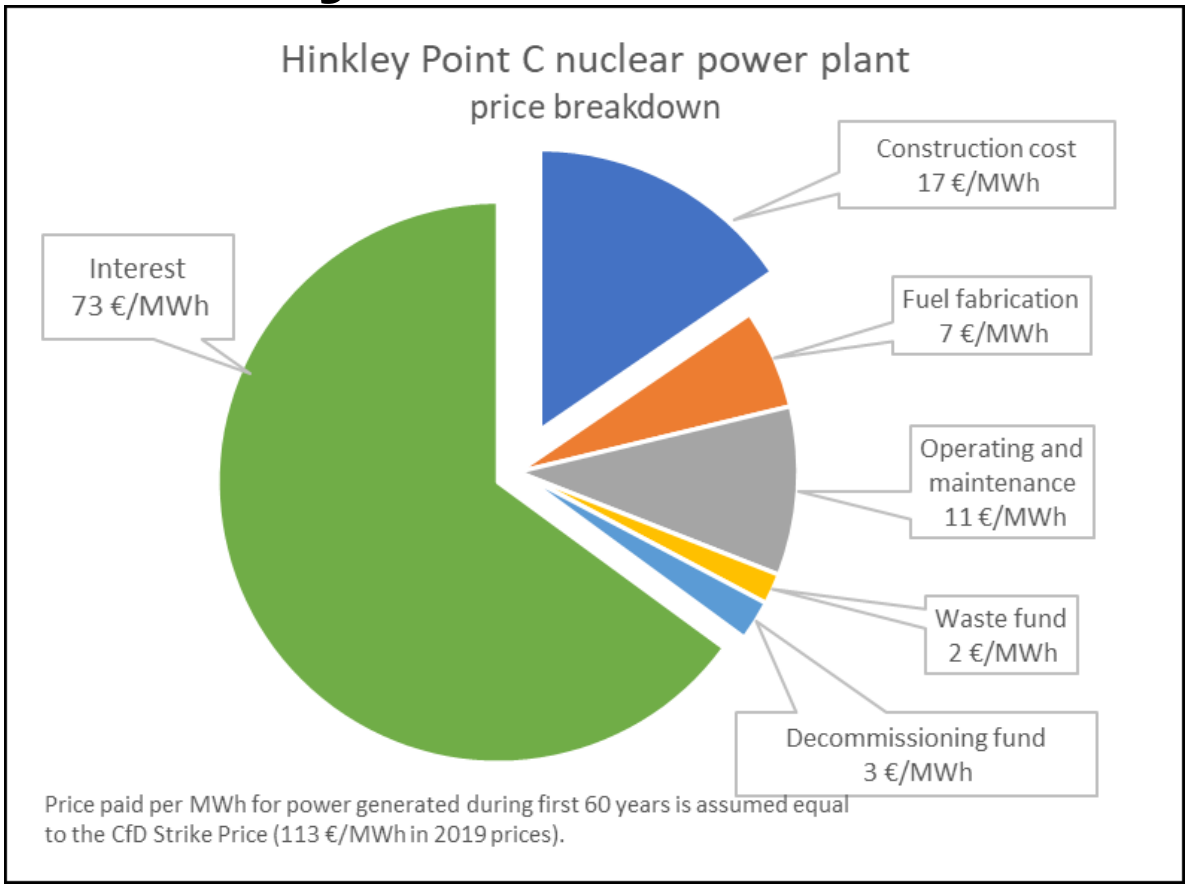
Myth; Nuclear is costly



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*

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 or Nuclear?

Offshore wind;

- 1500 MW capacity
- 8 years construction time
- CAPEX is 30 MNOK/MW
- Ca 45 bn NOK
- 7.0 TWh/year for 25 years
- Requires balancing
- LCOE target is 60 USD/MWh

Nuclear (APR1400);

- 1400 MW capacity
- 5 years construction time
- CAPEX is 25 MNOK/MW
- Ca 40 bn NOK
- 11 TWh/year for 60 years
- No balancing needed
- LCOE is ca 30 USD/MWh

APR 1400 offered to Turkey

Kepco submitted February 1st 2023 a preliminary proposal to build 4 APR 1400 (5,6 GW / 45 TWh per year) worth about $30bn (€27bn)

South Korea would offer the same APR1400 technology used for four units at the Barakah nuclear power station in the United Arab Emirates.

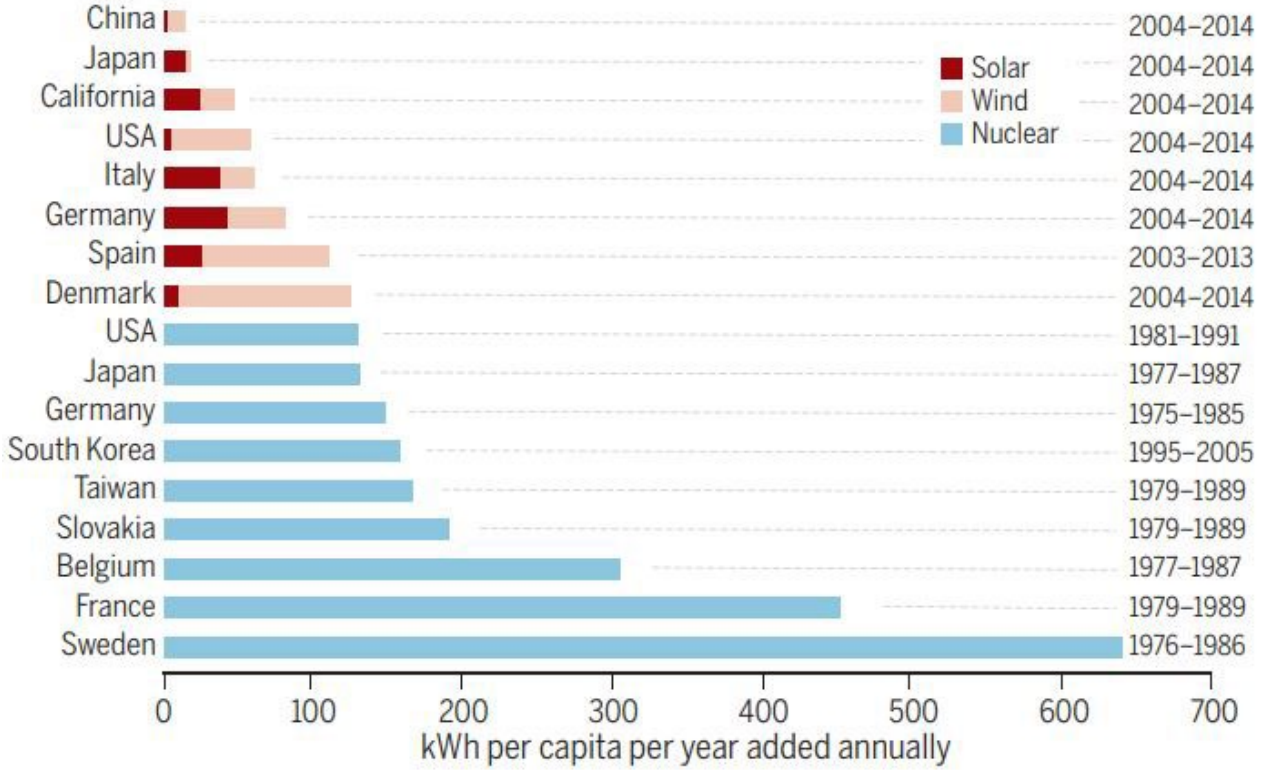
Source: https://www.nucnet.org/news/south-korea-s-kepco-launches-bid-to-build-four-new-nuclear-reactors-2-4-2023

Myth; Nuclear generates a lot of waste

Zwilag in Switzerland

- 99.5% of the radiation is found in 10.2% of the material
- After 40 years, only 1 permille of radioactivity is left
- In 2018, there was 2,355 m^3 material from which Switzerland had produced 2,667 TWh by the end of 2018
- Gen IV would have given 100,000 TWh

Myth: Nuclear takes too much time



Average annual increase of carbon-free electricity per capita during decade of peak scale-up. Energy data from (*6*) except California renewables data from (*7*). Population data from (*8*). See supplementary materials.

Source: Cao J. et al. (2016). China-U.S. cooperation to advance nuclear power. Science, 353 (6299). DOI: 10.1126/science.aaf7131.

The reactor design is key

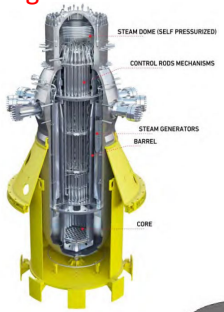
- Nuclear power is 95% nuclear engineering and 5% nuclear physics (H. Rickover)
- Fuel;
  - Uranium
  - Thorium and uranium
  - TRU (trans-uranium elements) – nuclear rest material (waste)
- Major reactor design types;
  - Once through fuel cycle – chemical (re)processing offline
  - Closed loop fuel cycle – chemical (re)processing online

Nuclear innovations are many

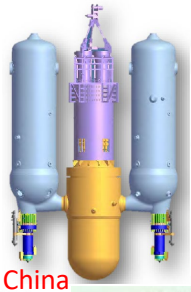
Not in scale

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

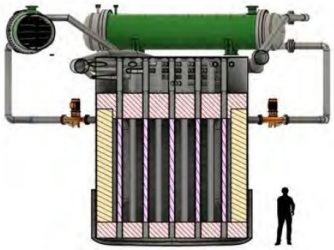
Argentina



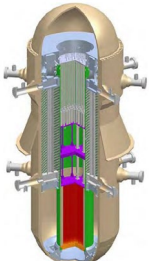
China



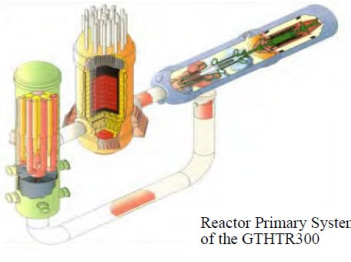
Czech Republic

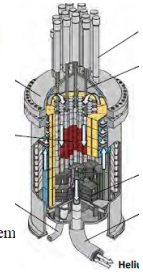


International

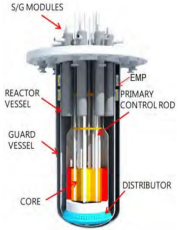


Japan



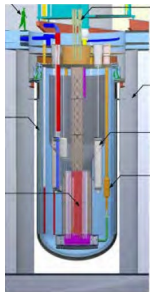


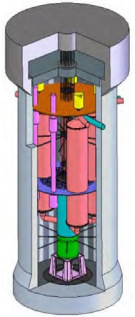
South Korea



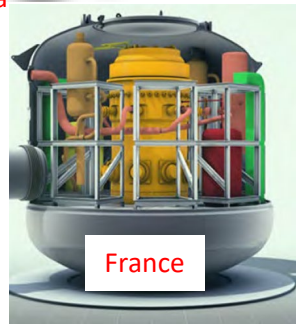
USA

Canada

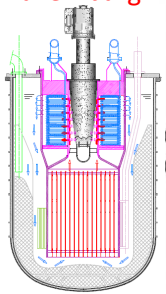


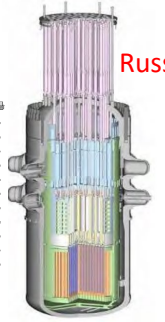


France

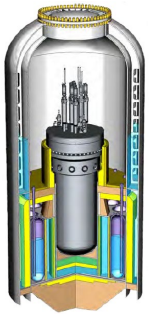


Luxemburg

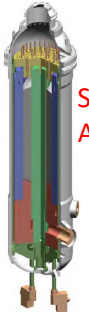




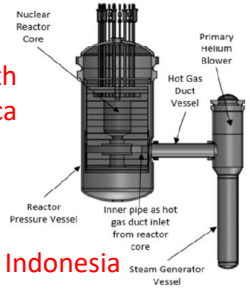
Russia



Sweden

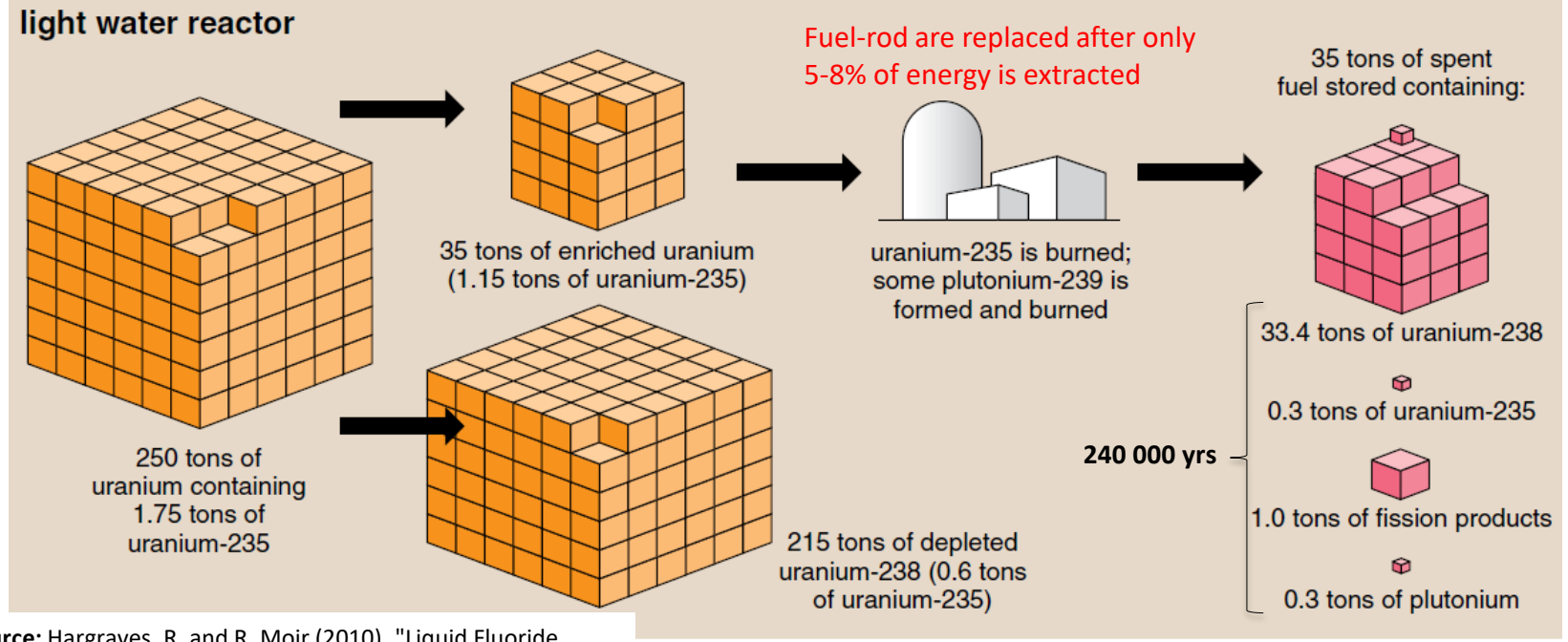


South Africa



Indonesia

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



Source: Hargraves, R. and R. Moir (2010). "Liquid Fluoride Thorium Reactors: An old idea in nuclear power gets reexamined." American Scientist 98 (July-August):pp.304-313.

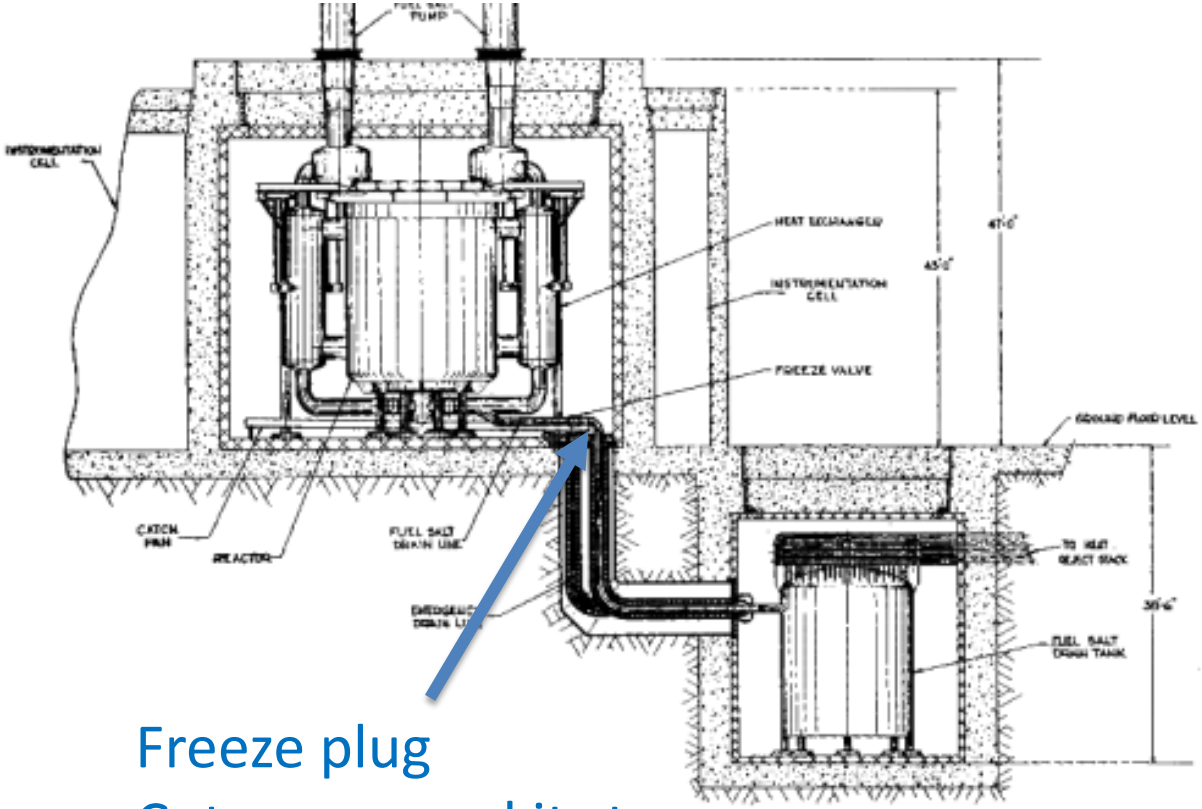
Introducing the Molten Salt Reactor (MSR)

Source: Haubenreich, P. N. and J. R. Engle (1970). "Experience with the Molten-Salt Reactor Experiment." Nuclear Applications and Technology 8(2):pp.118-136.
Support: https://energyfromthorium.com/pdf/

- The MSR is a liquid, chemical device and not a mechanical device based on fuel rods as in traditional nuclear reactors
- An MSR operated perfectly between 1965 and 1969 at 7 MWth
- 80% uptime!
- MSR is ideal due to scalability, safety, simplicity and costs
- The breeder versions can become almost 100 times more effective than current nuclear plants

All MSRs are walk-away safe!

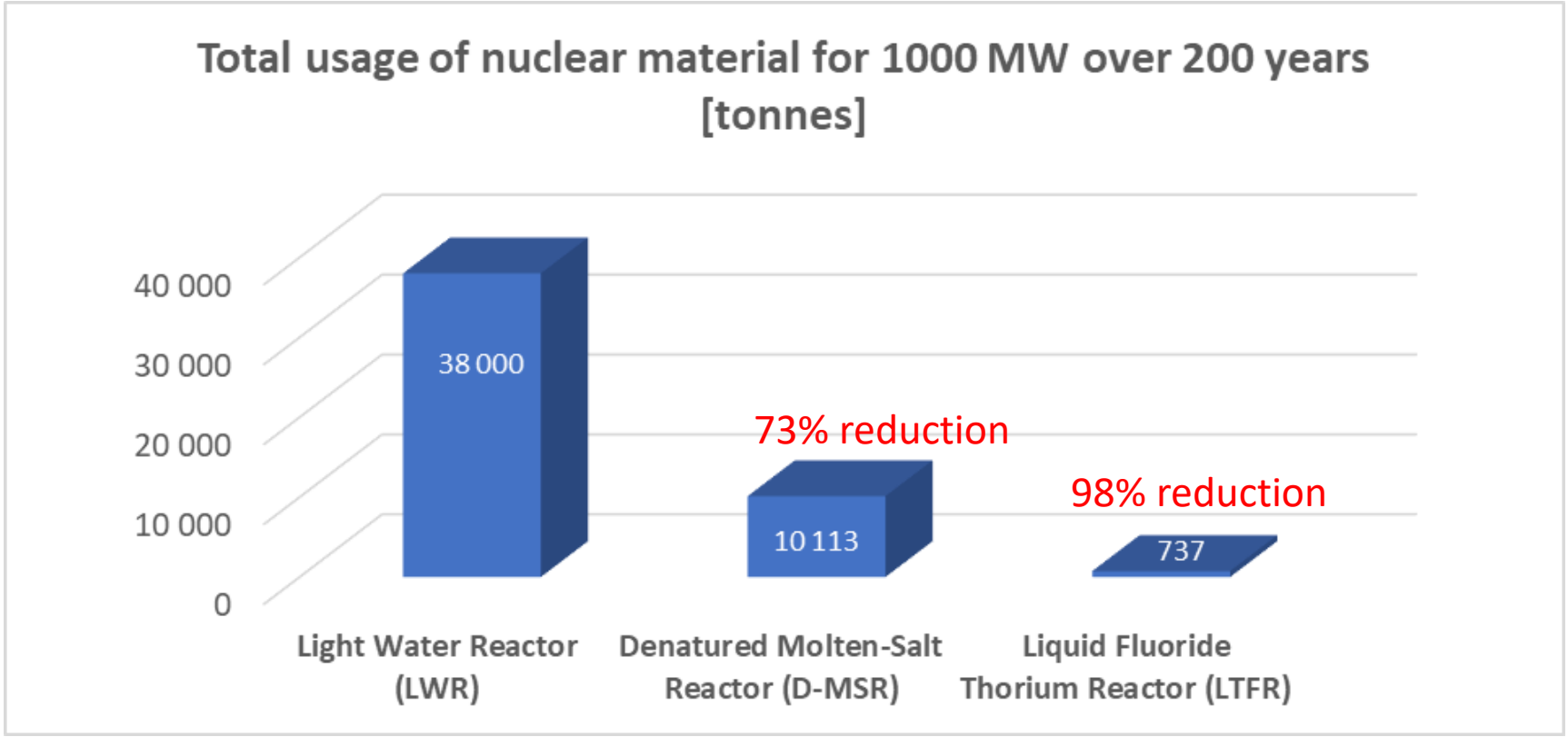
1. Inherently stable (negative reactivity)
2. Fuel is already melted – cannot boil
3. Atmospheric pressure prevents explosions



Freeze plug

Cut power and it stops

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.

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.

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

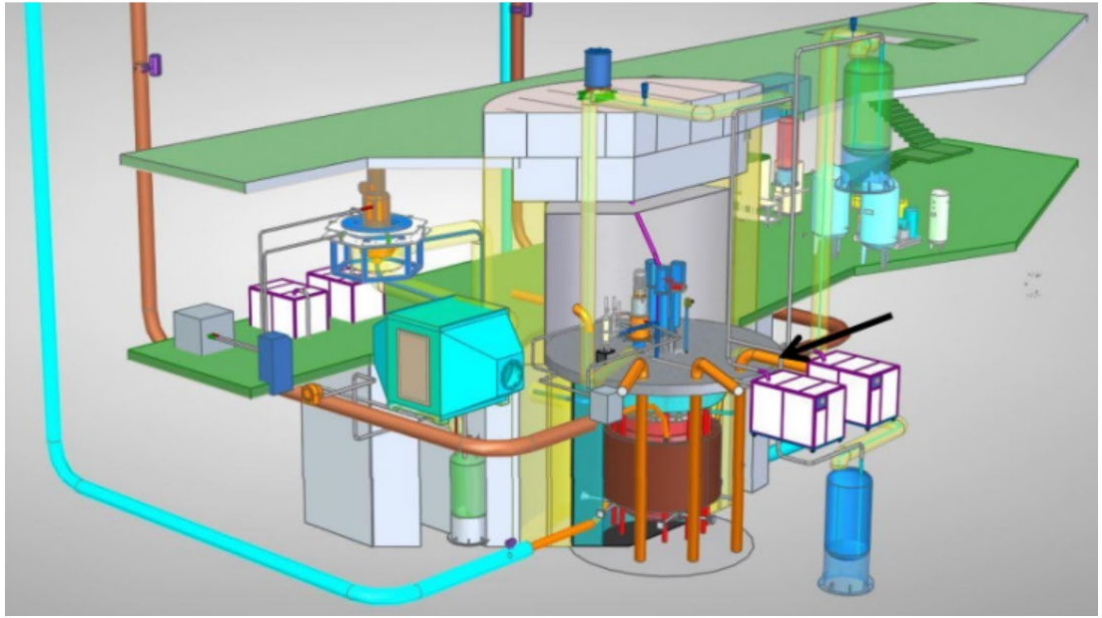
The thorium-based MSR is also here

Chinese molten-salt reactor cleared for start up

09 August 2022

Share

The Shanghai Institute of Applied Physics (SINAP) - part of the Chinese Academy of Sciences (CAS) - has been given approval by the Ministry of Ecology and Environment to commission an experimental thorium-powered molten-salt reactor, construction of which started in Wuwei city, Gansu province, in September 2018.



- 500 MUSD project
- Commercial versions ready before 2030
- 370 MW

NTNU

CNBC

WATCH LIVE

CLEAN ENERGY

Why Silicon Valley is so hot on nuclear energy and what it means for the industry

PUBLISHED FRI, DEC 2 2022 7:00 AM EST
UPDATED FRI, DEC 2 2022 4:39 PM EST

Catherine Clifford
@CATCLIFFORD
@IN/CATCLIFFORD/

WATCH LIVE

KEY POINTS

- From 2015 to 2021, the pace at which venture capitalists put money into private nuclear companies eclipsed the entire VC space and even the fast-growing climate tech space.
- That new money coming from new places is leading to smaller and more specific kinds of nuclear reactors.
- But some say all of this activity is overwrought and a sign that investors are forgetting the industry's long history of taking too long and being too expensive to be meaningful.

BUT; Norway also needs to act

NTNU

Question and Answer