Energy for the future – making the right choice

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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

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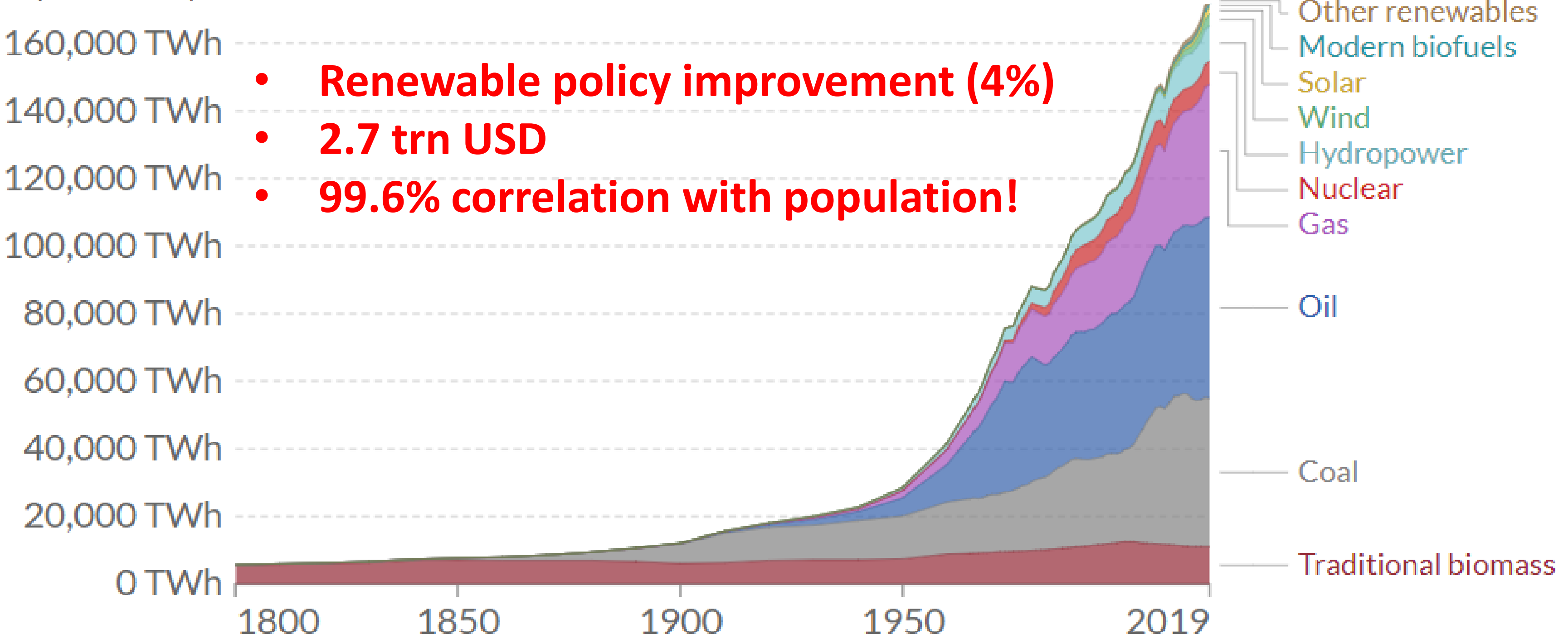
Energy transition is at risk!

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

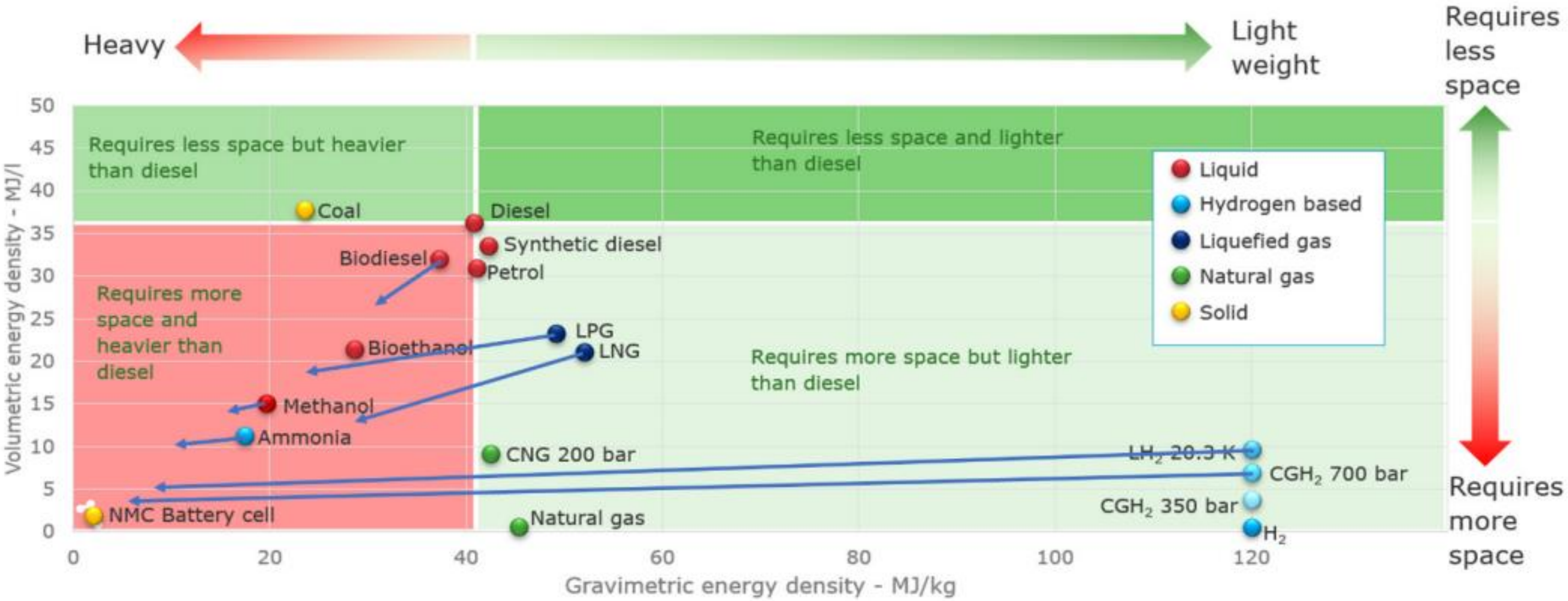
Electricity is easy – fuels are hard

Unrealistic and unsustainable

- 300 million tonnes HFO per year f[illegible]ping
- HFO has 11 MWh/tonne, h[illegible]n ammonia has only 5 MWh/tonne – more [illegible] twice the volume is needed
- Green ammoni[illegible]res 9 – 15 MWh/tonne
- To supply [illegible] shipping with green fuels will require twice the total EU power production



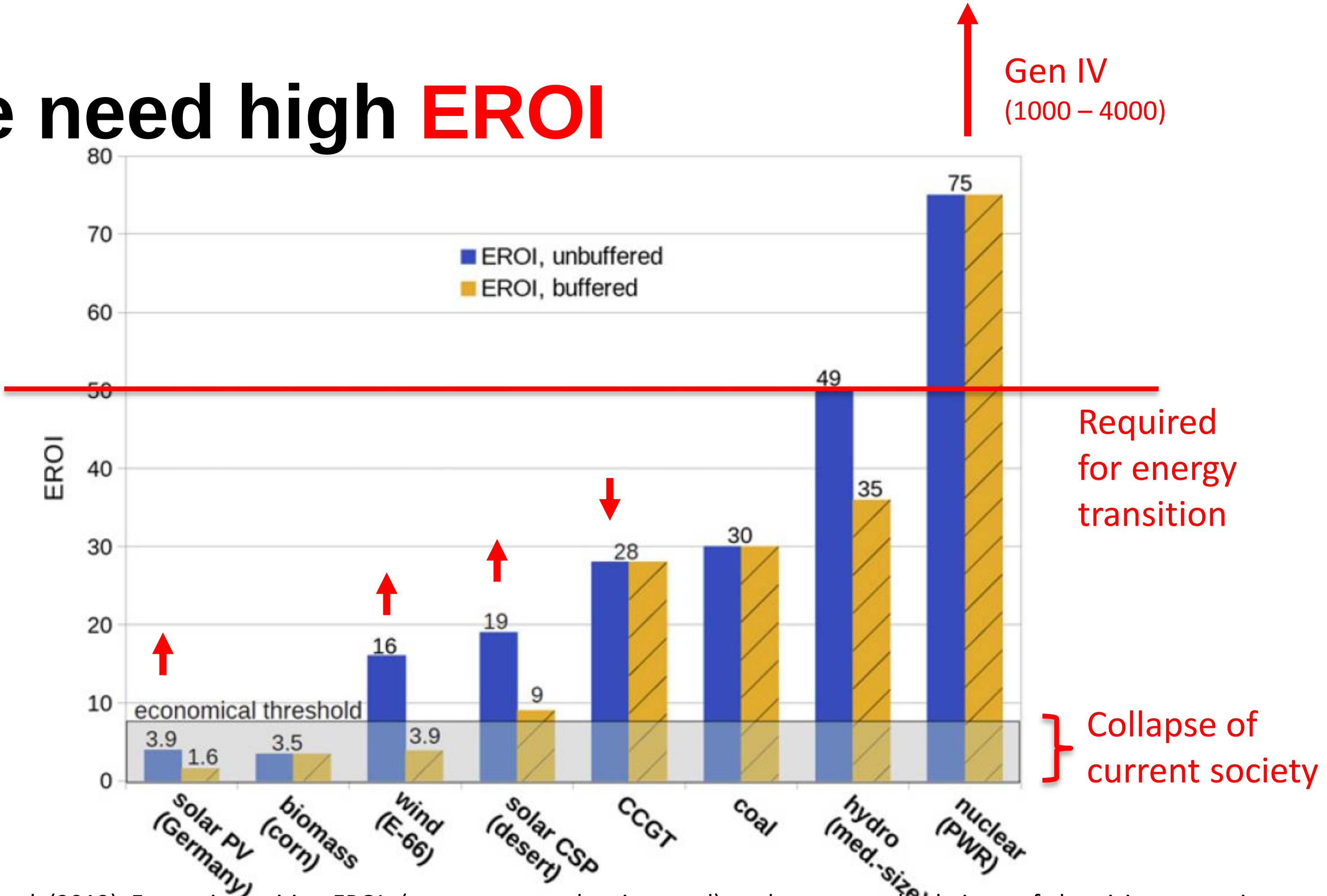

Energy density is the key



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

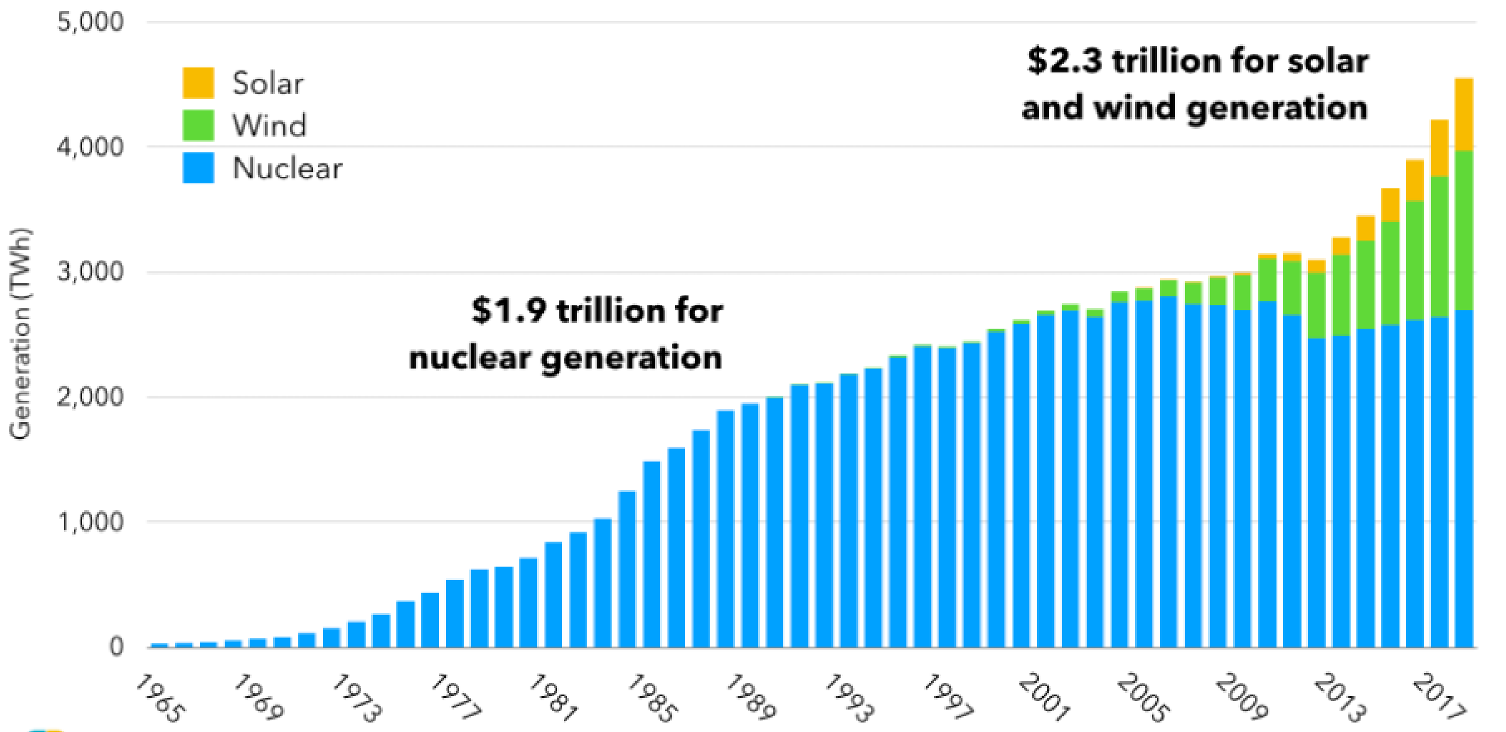


Source: Weißbach et al. (2013). Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. Energy, Vol 52, pp. 210-221.

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

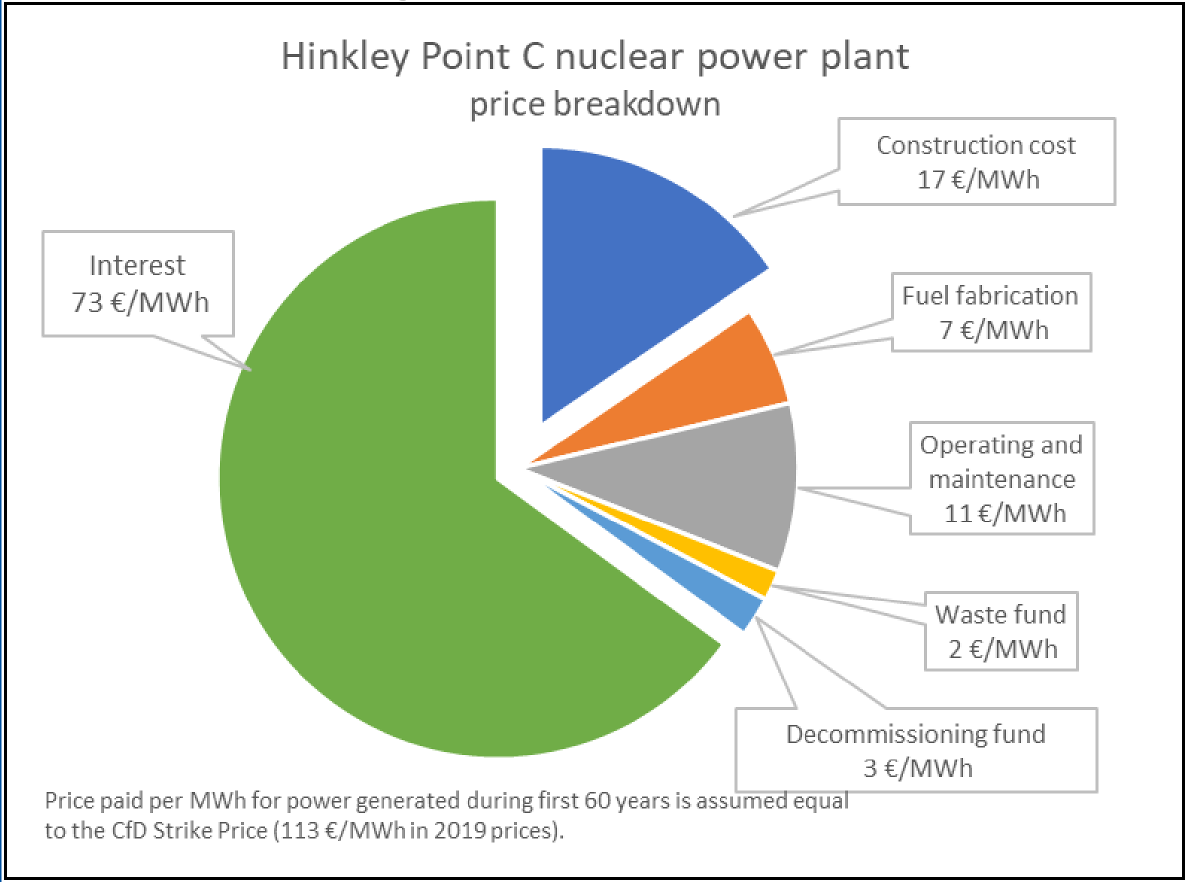
Myth; Nuclear is costly



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

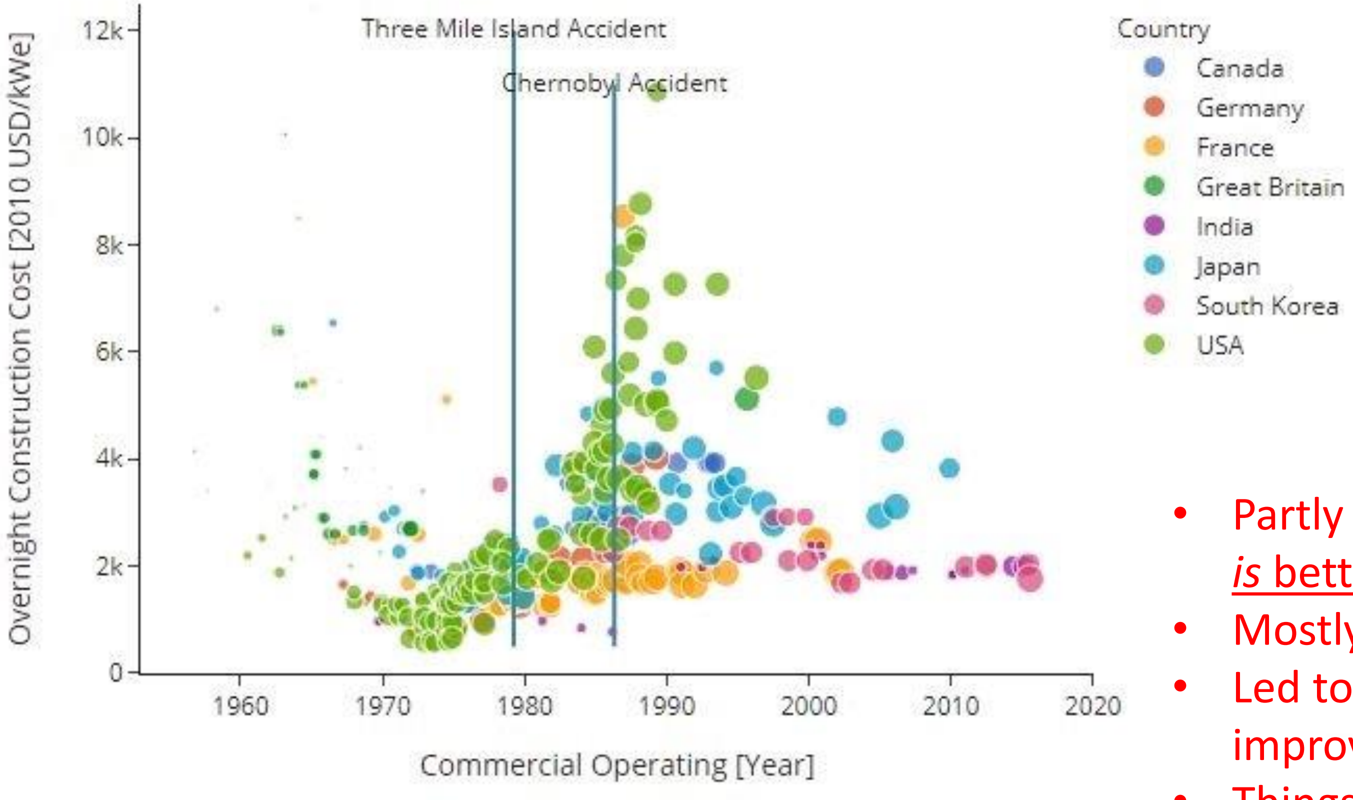


- Expensive financing
- 100 bn Euros in profit!
- Prototype reactor
- Lack of experience

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

Regulations drive costs



Overnight Construction Cost for nuclear power plants. (Lovering, 2016)

- Partly science – Gen III *is* better than Gen II
- Mostly politics
- Led to very slow improvement tempo
- Things may change…?

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Detailed LCOE per reactor type

Country	Technology with 60 year life times	Size	Refurbishment and D&D costs			Fuel and waste costs	O&M costs	LCOE			
			3%	7%	10%			3%	5%	7%	10%
		MWe	USD/MWh			$/MWh	$/MWh	USD/MWh			
Belgium	Gen III	1 000-1 600	0.46	0.08	0.02	10.46	13.55	51.45	66.13	84.17	116.81
Finland	EPR	1 600	0.44	0.06	0.01	5.09	14.59	48.01	66.52	81.83	115.57
France	EPR (2030)	1 630	0.40	0.06	0.01	9.33	13.33	49.98	64.63	82.64	115.21
Hungary	AES-2006	1 180	1.59	0.26	0.06	9.60	10.40	53.90	70.08	89.94	124.95
Japan	ALWR	1 152	0.42	0.07	0.02	14.15	27.43	62.63	73.80	87.57	112.50
Korea	APR 1400	1 343	0.00	0.00	0.00	8.58	9.65	28.63	34.05	40.42	51.37
Slovakia	VVER 440	535	4.65	1.50	0.83	12.43	10.17	53.90	66.68	83.95	116.48
UK	Multiple PWRs	3 300	0.54	0.09	0.02	11.31	20.93	64.38	80.88	100.75	135.72
US	ABWR	1 400	1.26	0.52	0.26	11.33	11.00	54.34	64.81	77.71	101.76
Non-OECD members											
China	AP 1000	1 250	0.23	0.04	0.01	9.33	7.32	30.77	34.57	47.61	64.40
	CPR 1000	1 080	0.16	0.03	0.01	9.33	6.50	25.59	33.05	37.23	48.83

Source: The Full Costs of Electricity. Provision Nuclear Energy Agency International Workshop 2016, OECD, Paris

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

- 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

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Decommissioning is NOT difficult

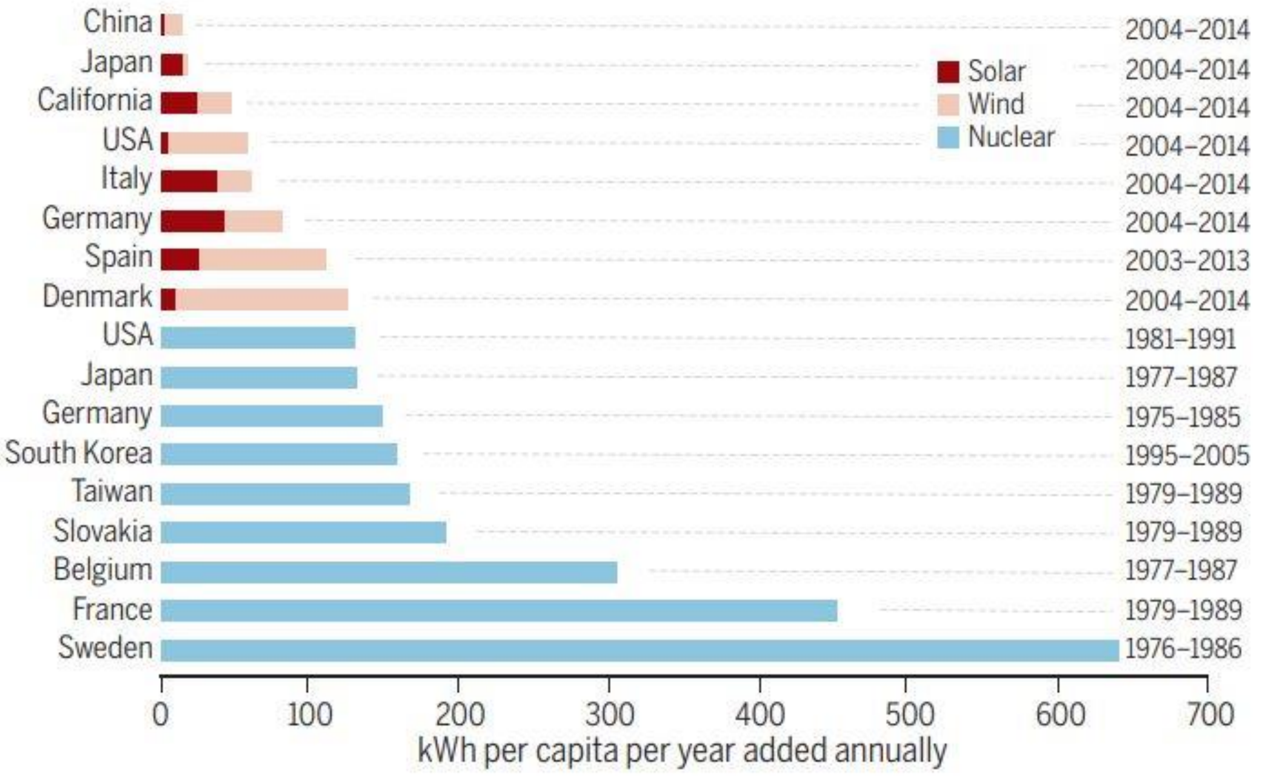
Oyster Creek 650 MW

- 8 years by Holtec
- 2300 tonnes
- 884 MUSD
- Back to nature by 2080

Pilgrim 677 MW

- 8 years by Holtec
- 2100 tonnes
- 1130 MUSD
- Back to nature by 2080

Myth: Nuclear takes too much time



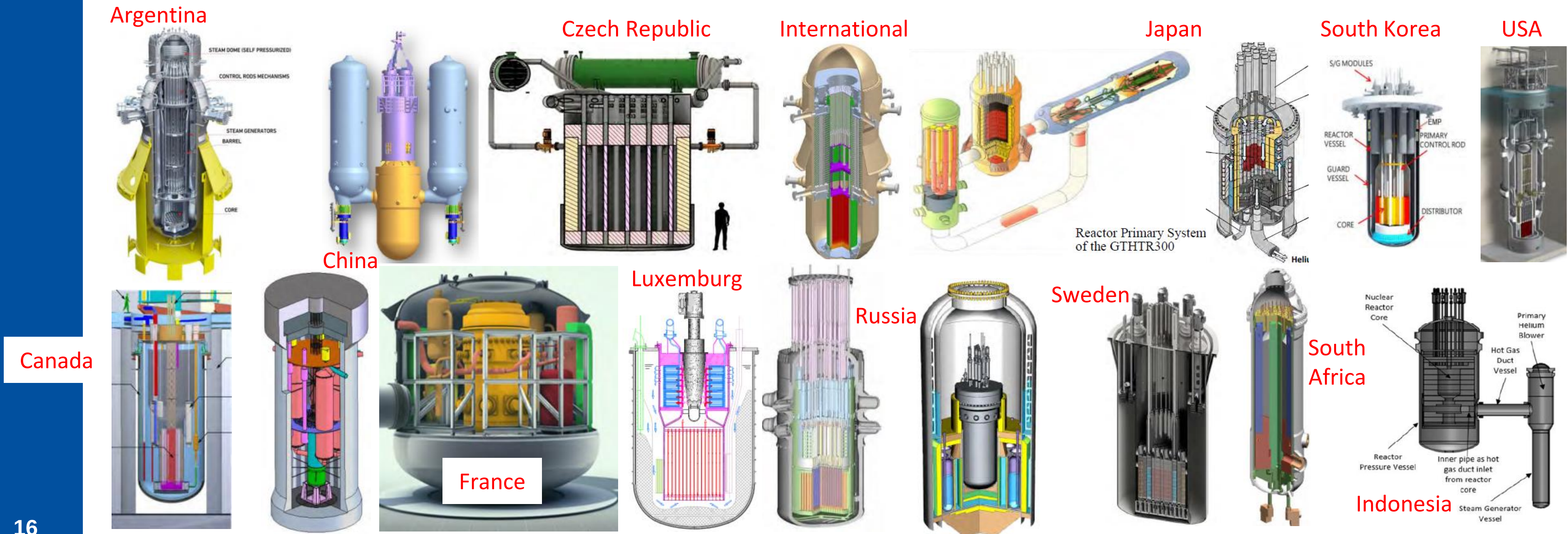
Average annual increase of carbon-free electricity per capita during decade of peak scale-up. Energy data from (6) except California renewables data from (7). Population data from (8). See supplementary materials.

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

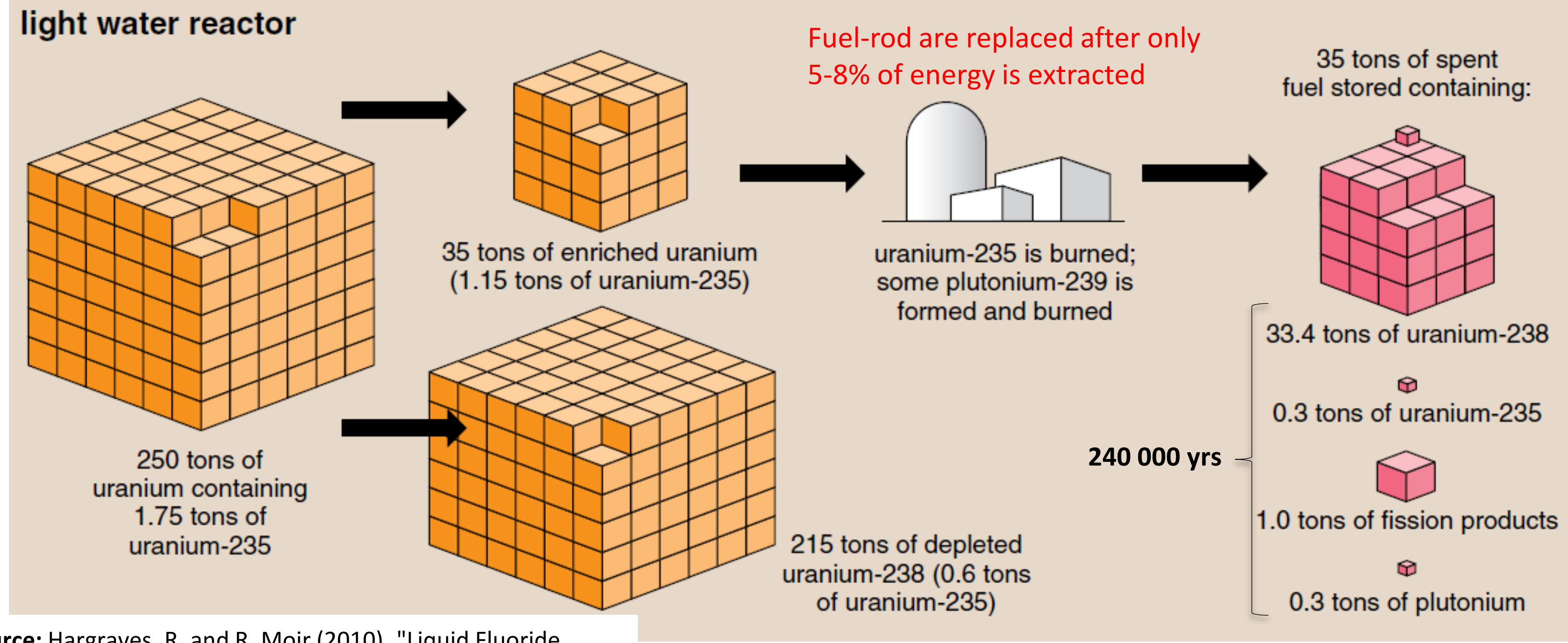
Nuclear innovations are many

Not in scale

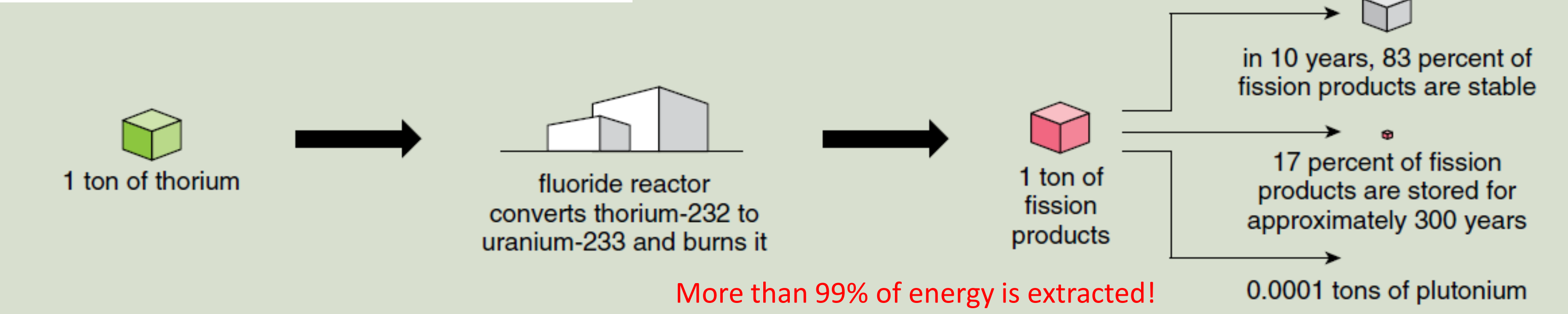
67 different Small Modular Reactors (SMR) under development in 2020… here are 17;



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.



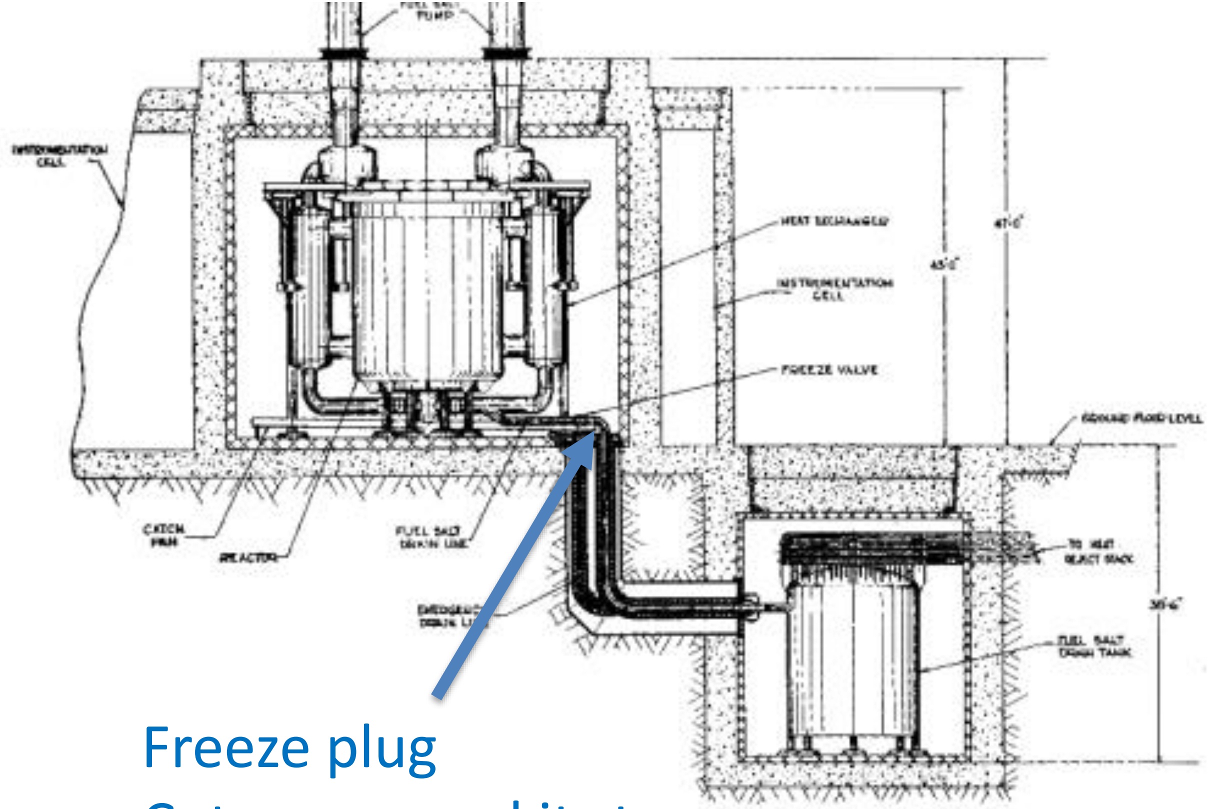
Introducing the Molten Salt Reactor (MSR)

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

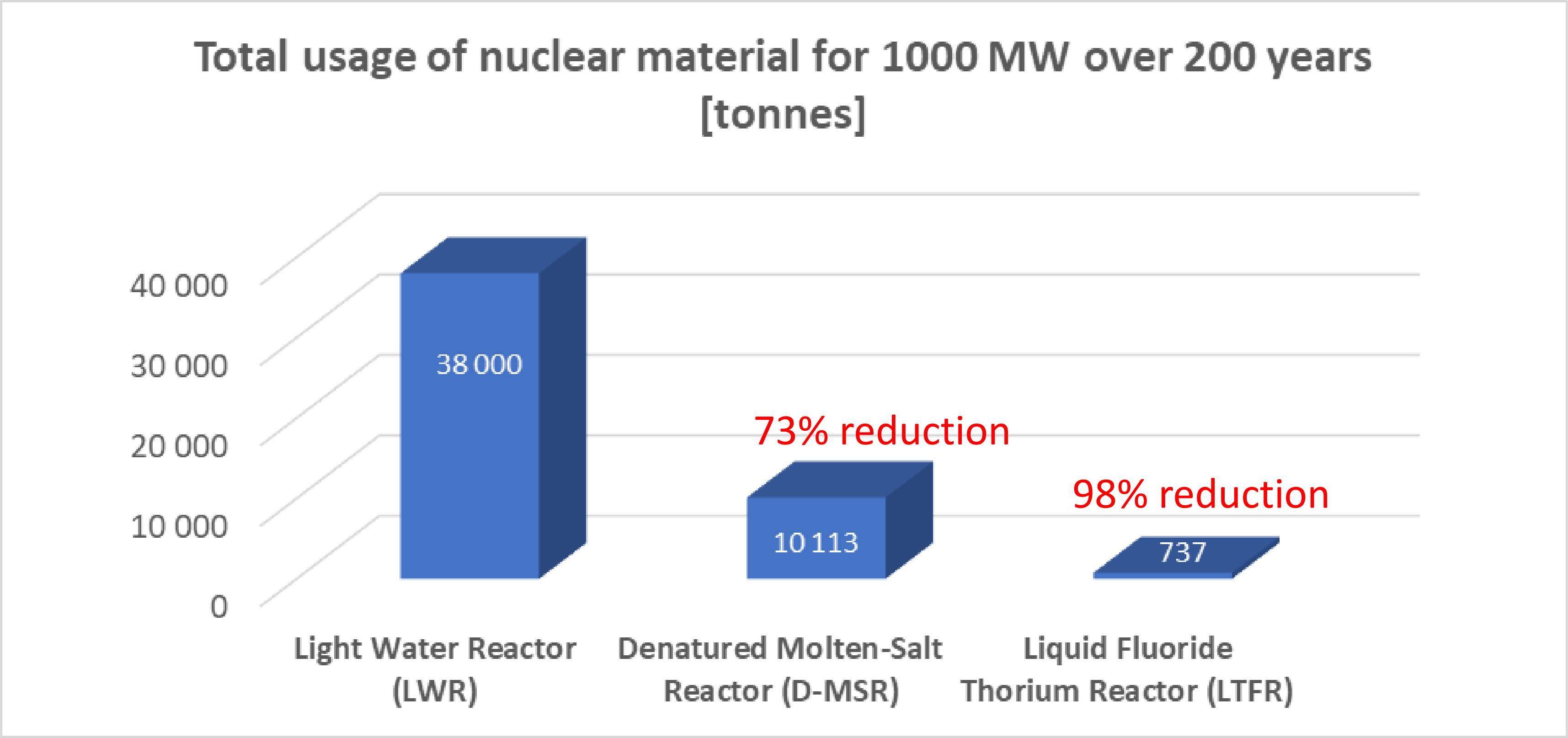
All MSRs are walk-away safe!

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.

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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

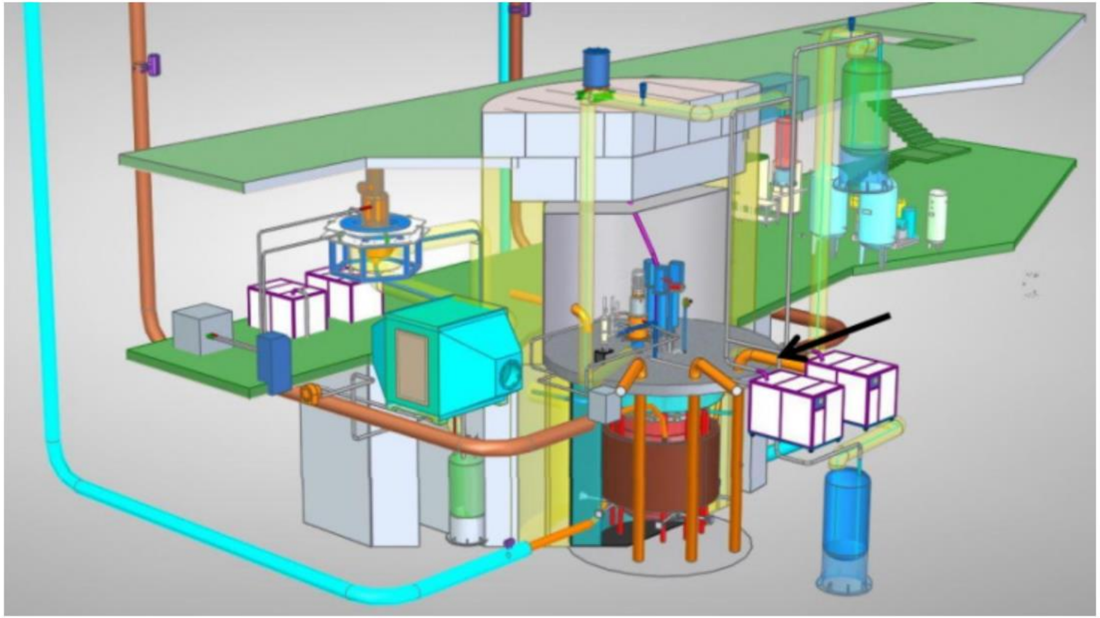
The thorium-based MSR is also here

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

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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
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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

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Question and Answer