Nuclear power for a sustainable world

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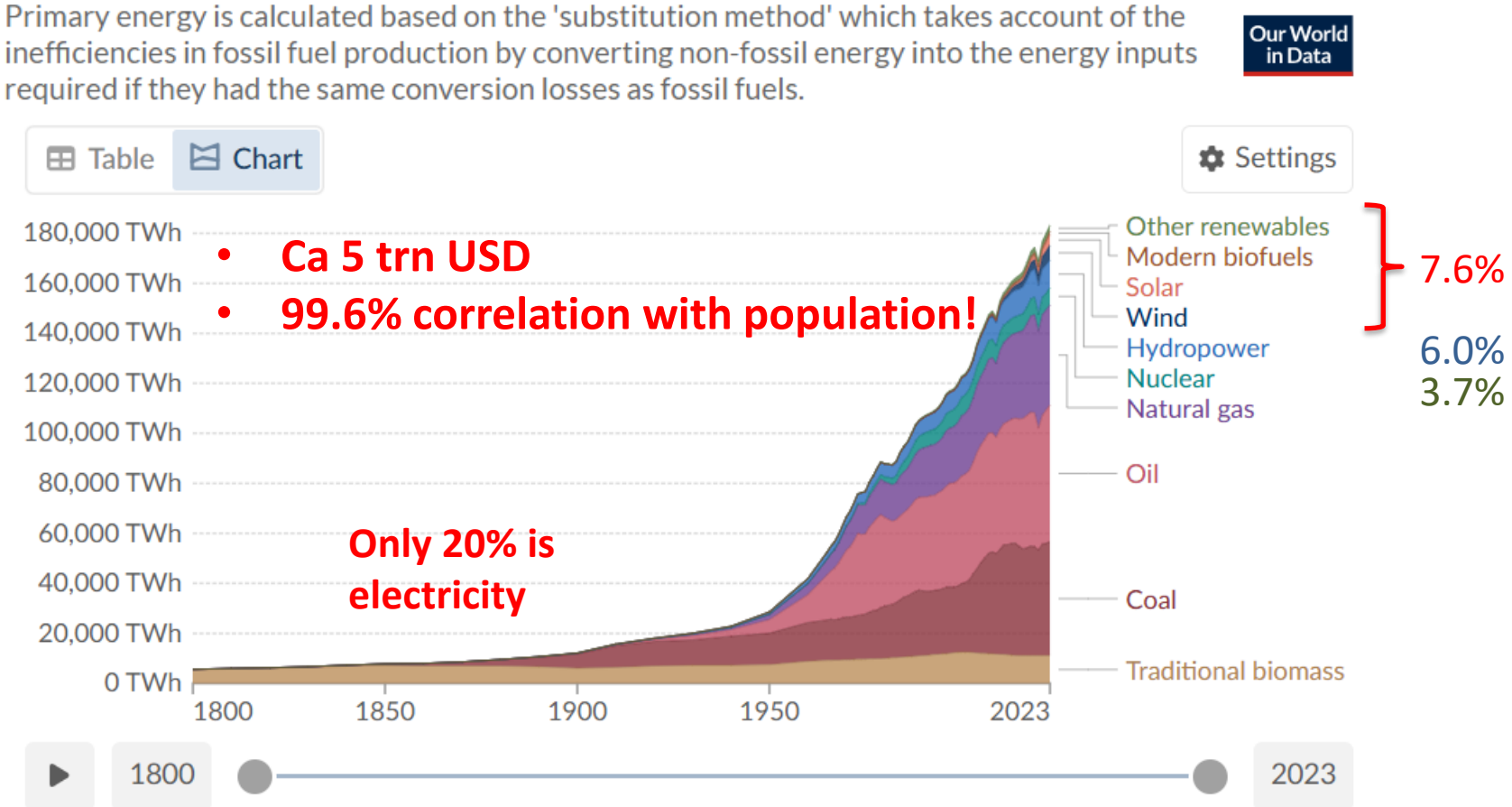
2025-01-30

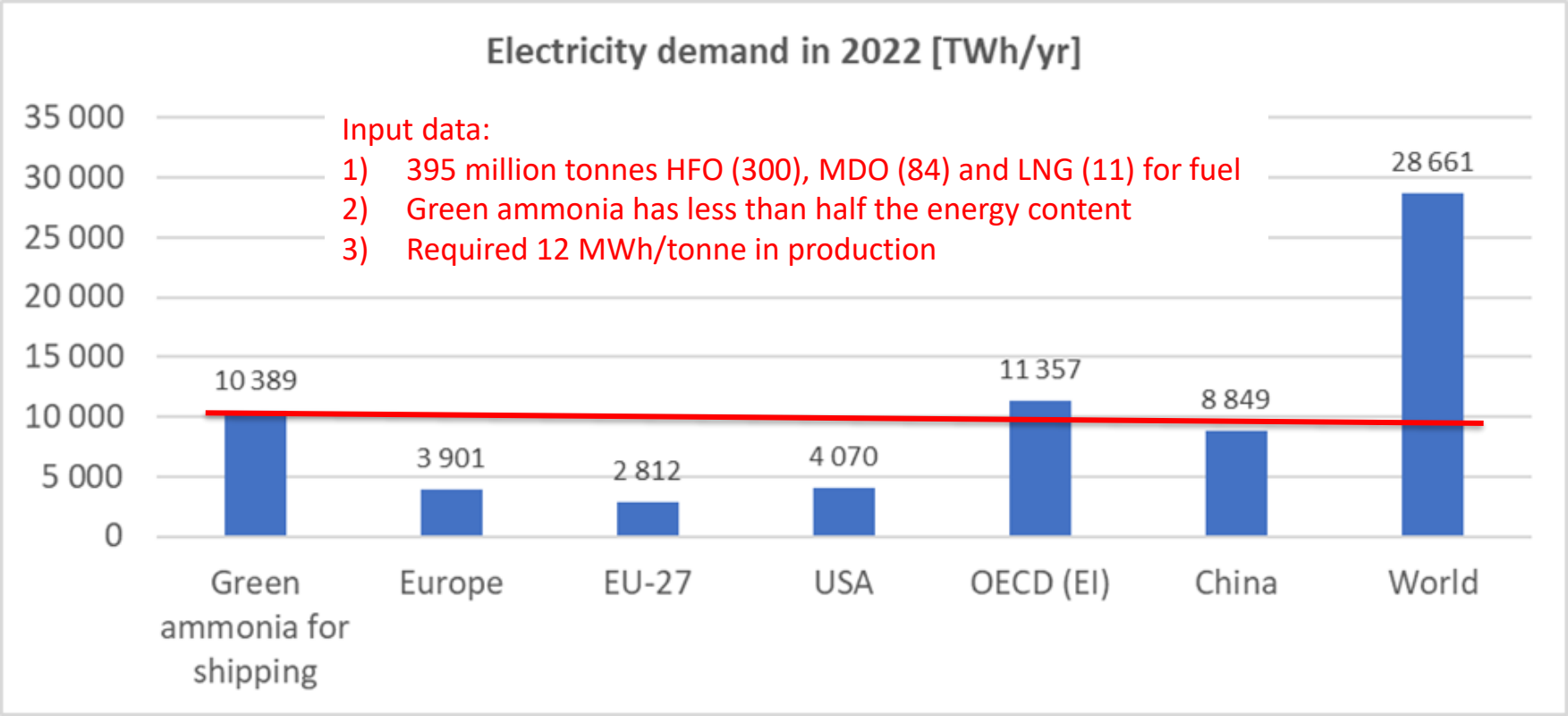
Content

1. Understanding the challenge
2. Myths and facts about nuclear
3. Generation IV nuclear reactors
4. The way forward

Energy transitions are all about scale



Fossil or nuclear is the choice for ships!

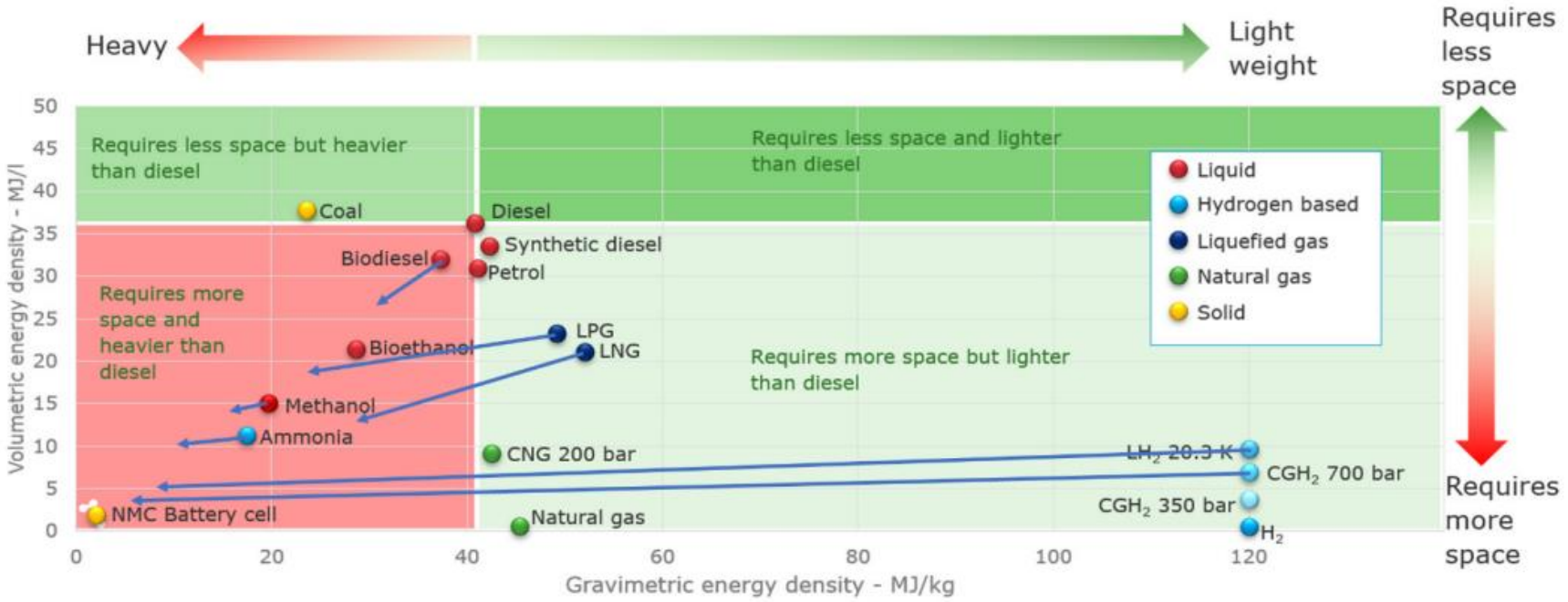


All marine fuels are included in these figures

Norwegian energy transition

- 1.1 million tonnes of diesel oil for local shipping
- Green fuels will require 30 TWh/year for production
- Add population growth (20 TWh), current shortages, aviation fuel, new industries to replace oil- and gas, etc
- A doubling of the energy production is probably necessary

Energy density is the key



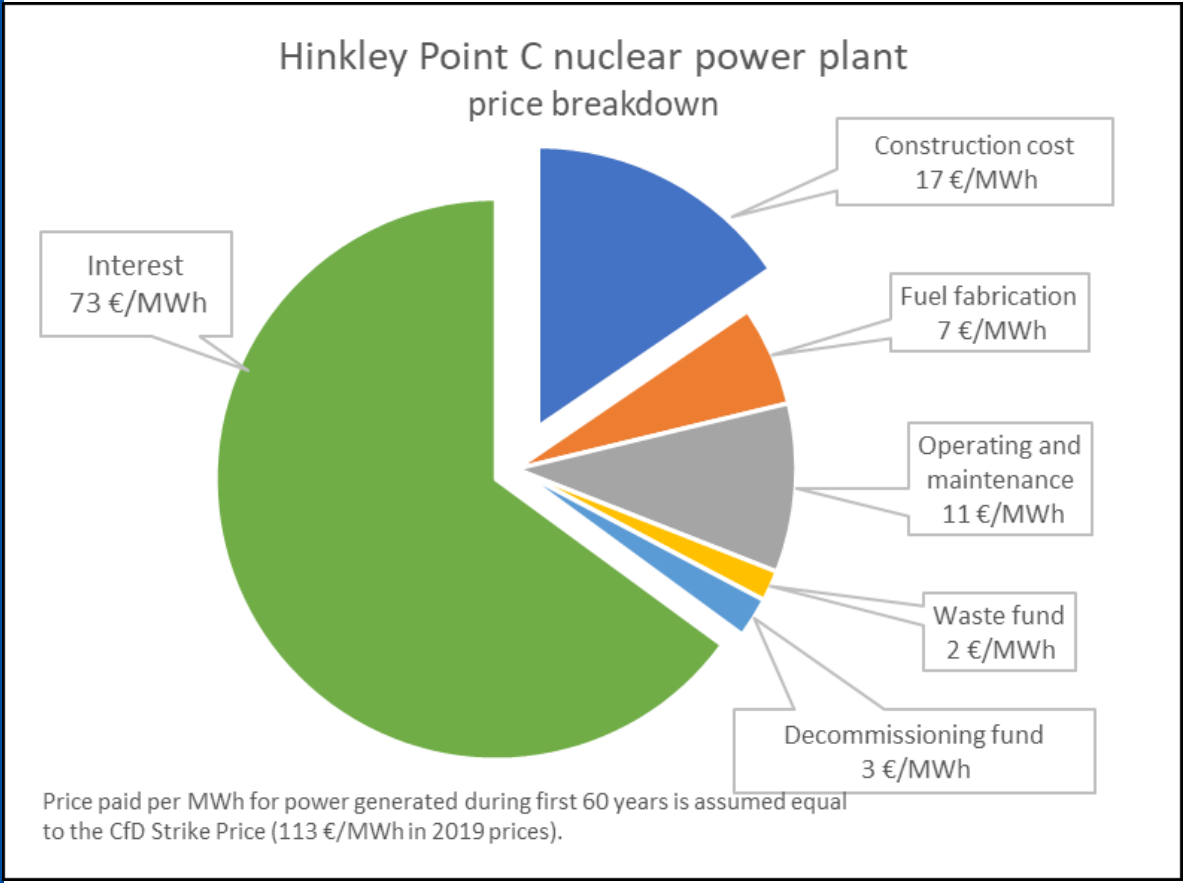
If H2 is 1 meter on this scale, Uranium would be 32 km away from this venue and Thorium 38 km away

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

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) Nuclear power plants take too long time to build
   b) 4th generation is too far ahead

The cost of ‘the worst’ – GBP 44 bn



- 26 TWh/yr in 65 years
- Expensive financing
- New reactor design (2x EPR 1650)
- Lack of experience
- 7000 changes (politics)
- EUR 100 bn in profit!
- EU annual subsidy of renewables EUR 85 bn

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

APR 1400 offered to Turkey

KEPCO submitted February 1st 2023 a preliminary proposal to build 4 APR 1400 worth about $30bn (€27bn);

- 5,6 GW / 45 TWh per year
- 80 TWh per year thermal energy

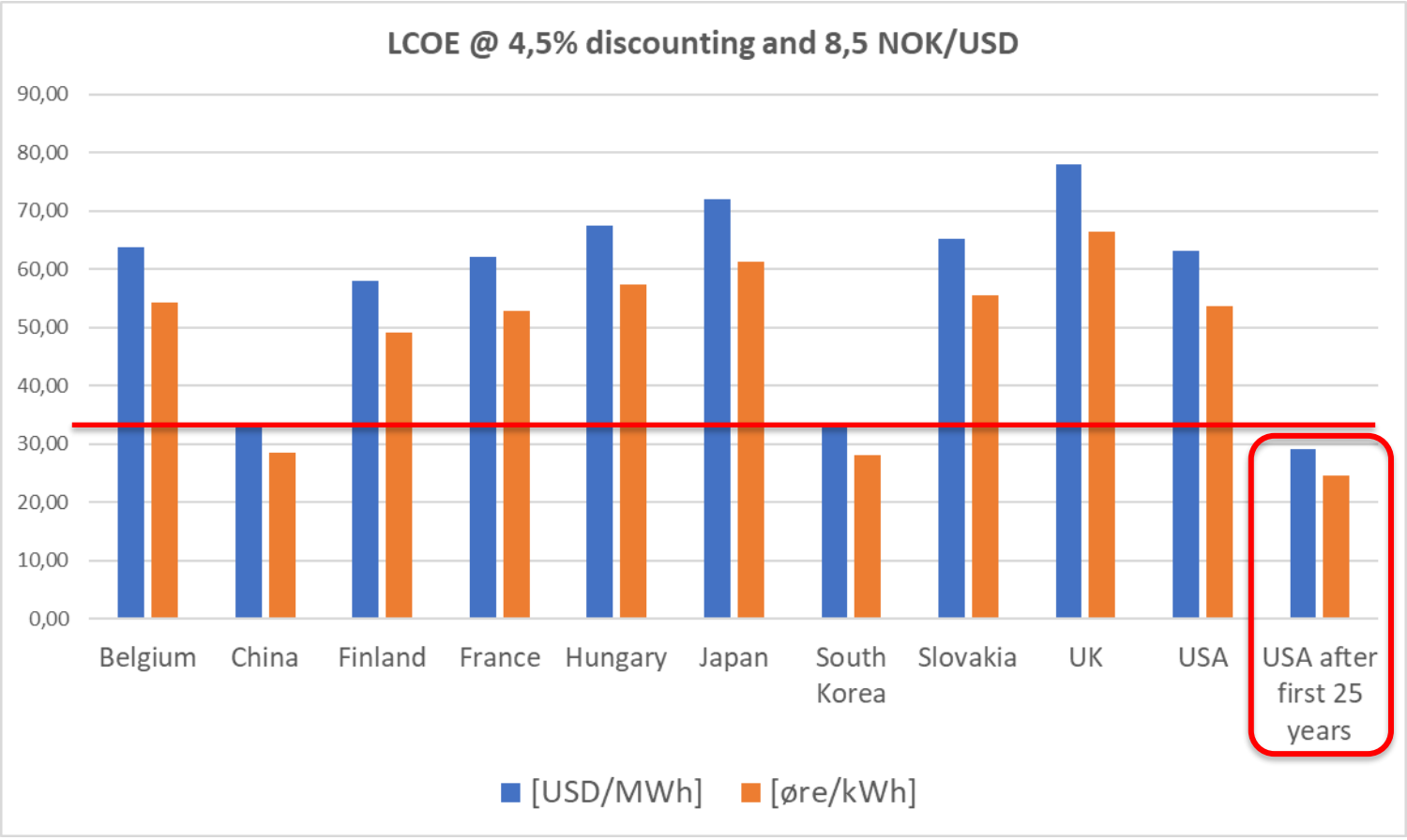
South Korea would offer the same APR1400 technology used for four units at the Barakah nuclear power station in the United Arab Emirates.

Pareto estimates that to provide 40 TWh with the current policy in Norway will cost 420 bn NOK

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

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

Myth: Nuclear waste is a problem

- All civilian nuclear waste in the US fits on a football field, 10 yards deep
- 29,847 TWh produced by 2022 at 0.49% burnup
- Over 95% of the energy is left
- Gen IV reactors can extract it
- 986,778 TWh at 18% burnup
- Can power the US for 260/60 years
- Over 6000 years @ 160 TWh/yr

Value of 49,000 bn USD
@ 0.05 USD/kWh

Decommissioning is NOT difficult

Oyster Creek 650 MW

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

Pilgrim 677 MW

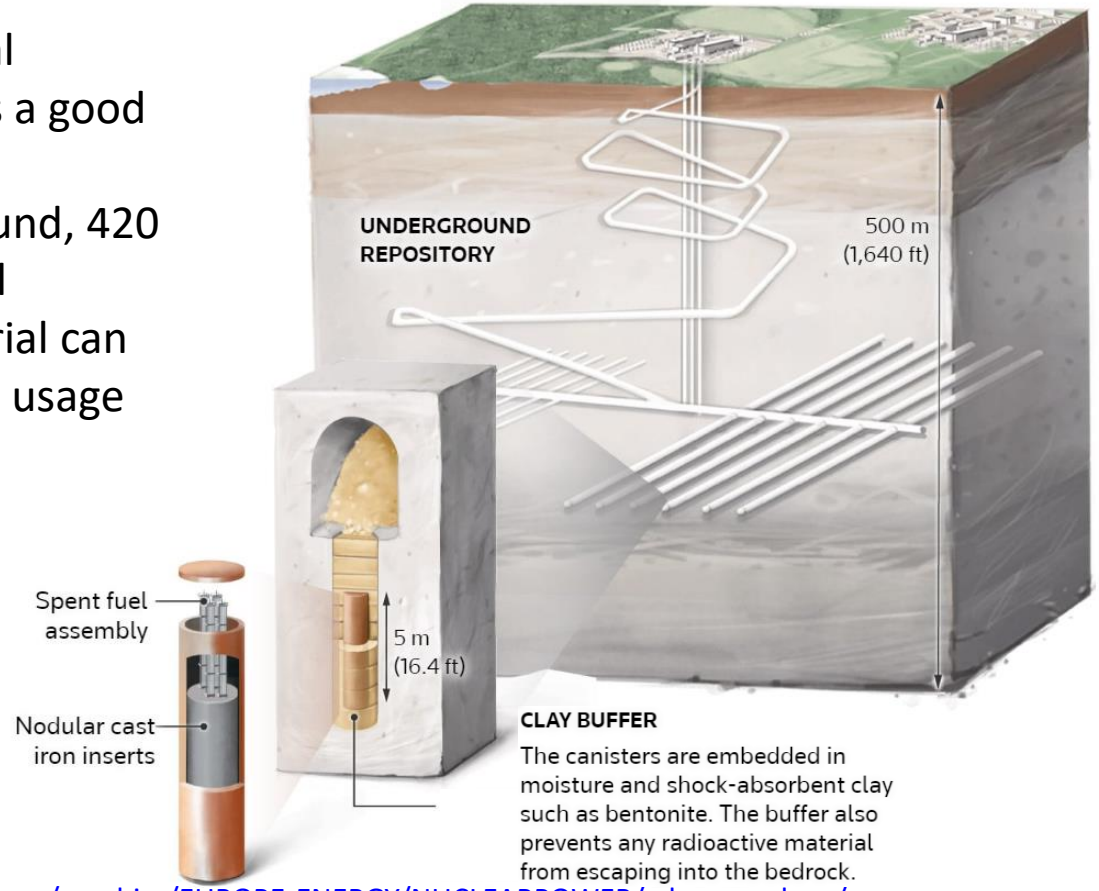
- 8 years by Holtec
- 2100 tonnes
- 1130 MUSD
- Back to nature by 2080

Storage canisters/caskets

Source: Reuters, https://www.reuters.com/graphics/EUROPE-ENERGY/NUCLEARPOWER/gdvzwweqkpw/

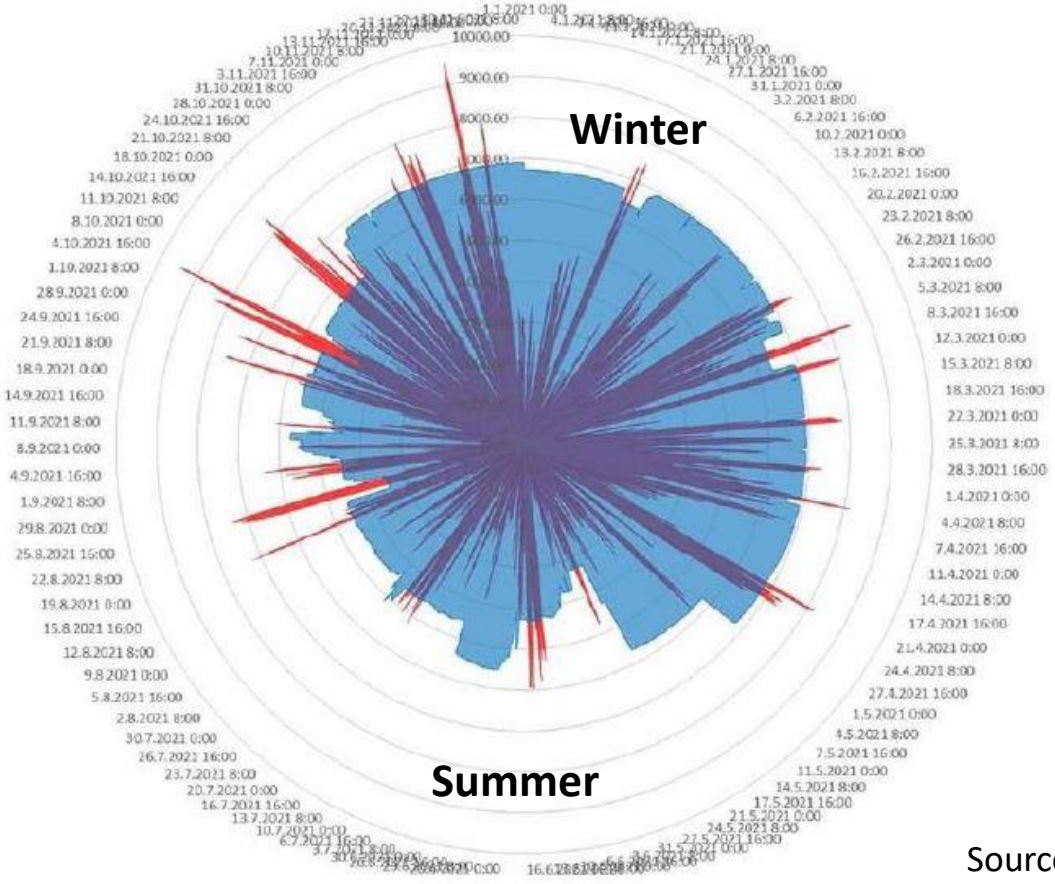
Deep geological repository

- Onkalo deep geological repository in Finland is a good example
- 430 meters below ground, 420 meters below sea level
- The nuclear rest material can be retracted for future usage



Source: Reuters, https://www.reuters.com/graphics/EUROPE-ENERGY/NUCLEARPOWER/gdvzwweqkpw/

Fact; Nuclear gives stability – also prices

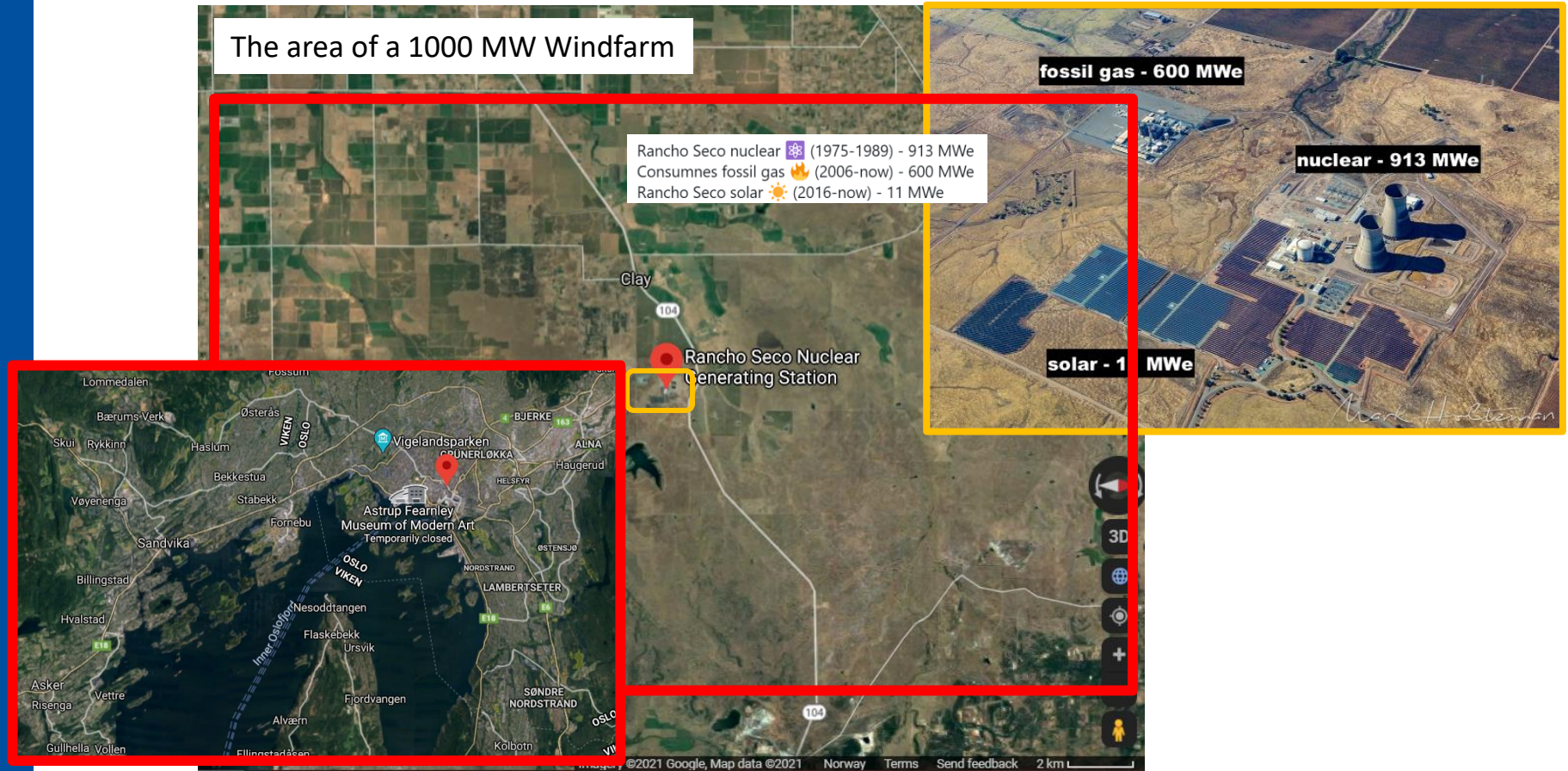


Production of effect in Sweden, 2021:

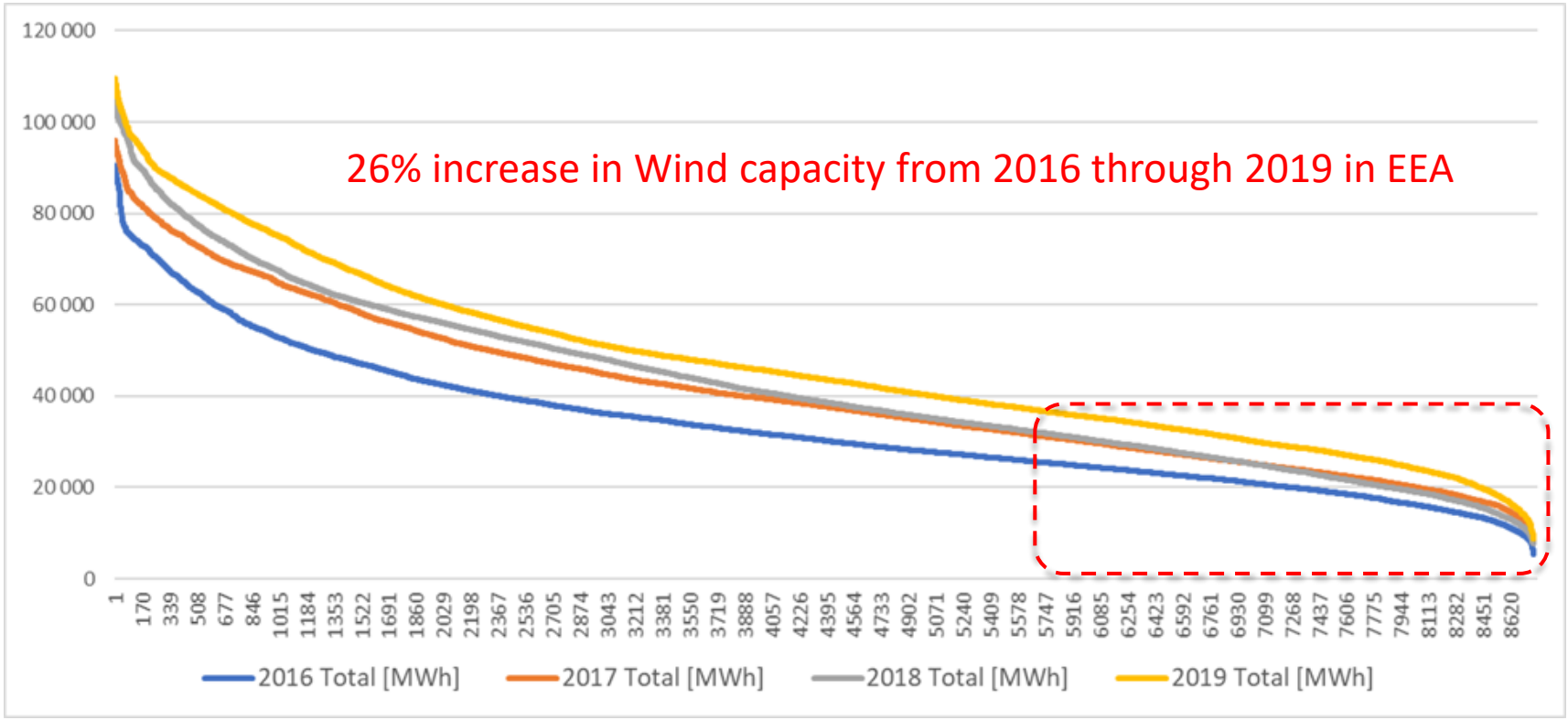
- Production volume aggregated to 3-days intervals
- Blue is nuclear
- Red is wind

Source: www.svk.se

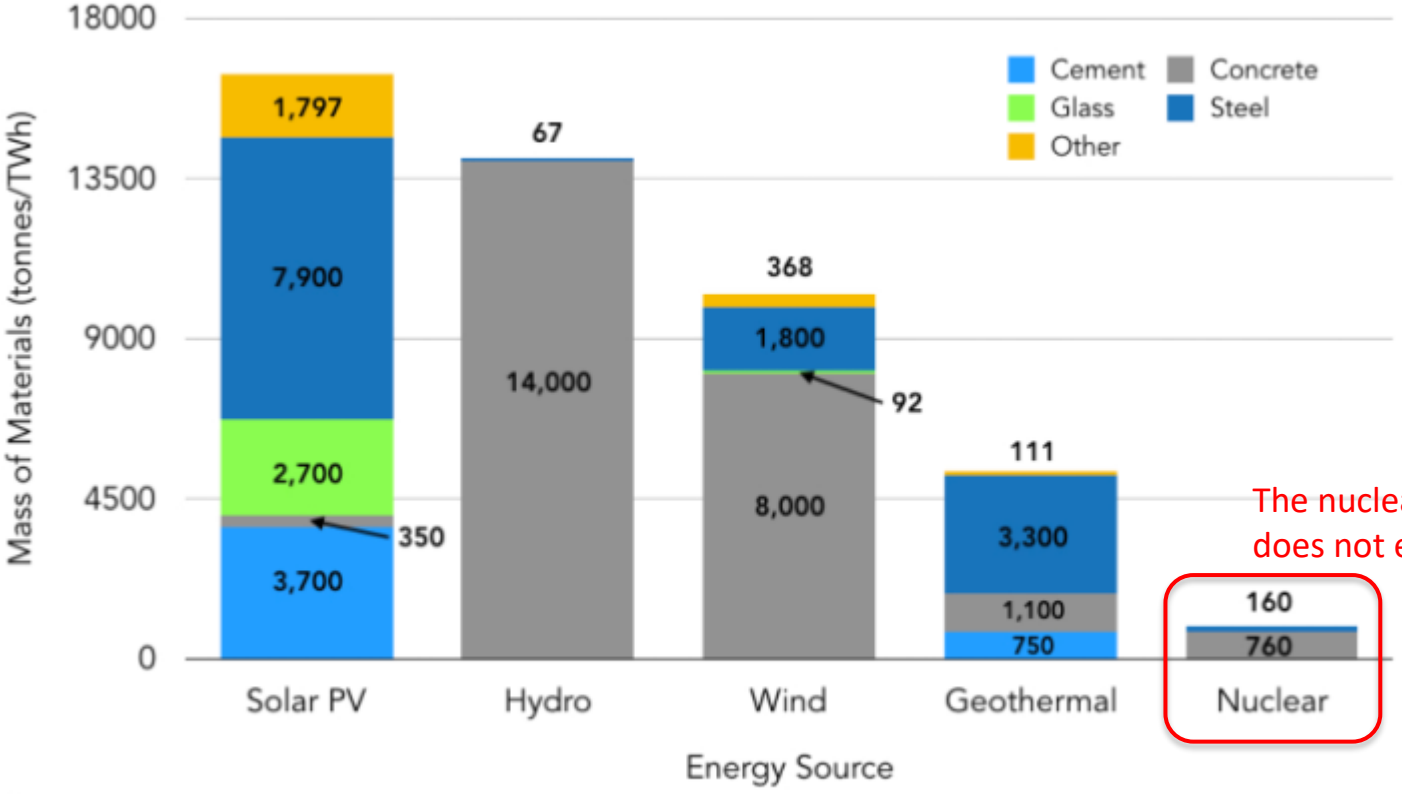
Area: Wind and Solar PV vs Nuclear



Expansion of Wind does not help



Fact; Low footprint and no emissions

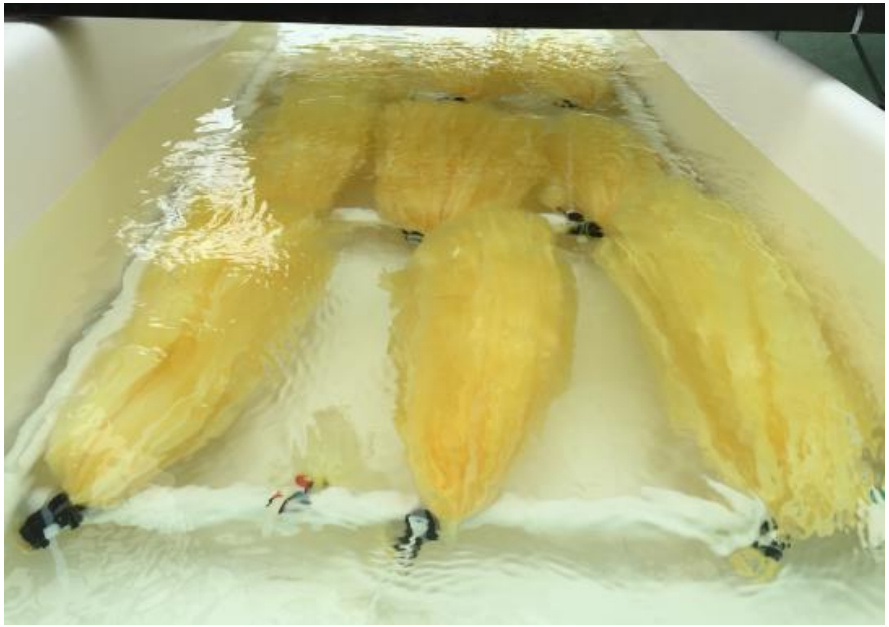


The nuclear materials does not even show up!

"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
- Can power humanity for 4 bn years



Extraction using old yarn

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

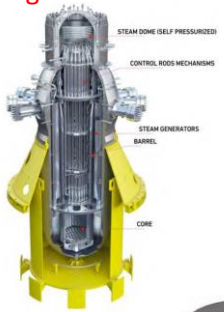
Source: https://www.pnnl.gov/news/release.aspx?id=4514

Nuclear innovations are many

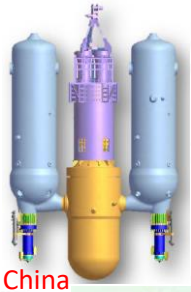
Not in scale

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

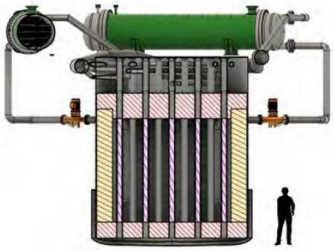
Argentina



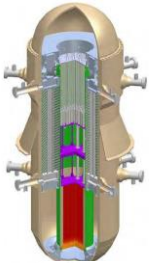
China



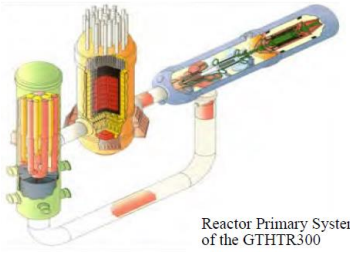
Czech Republic

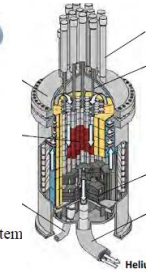


International

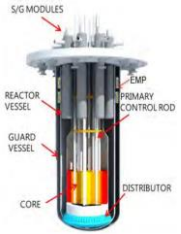


Japan



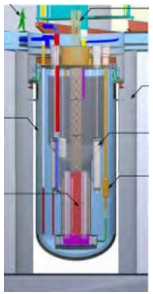


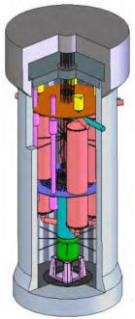
South Korea



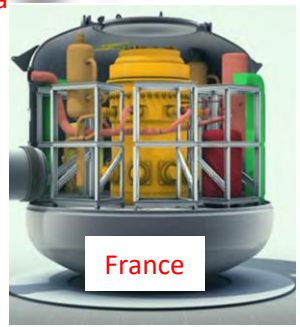
USA

Canada

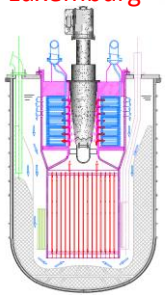




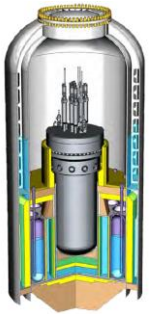
France



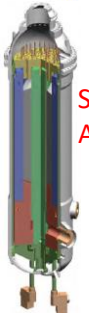
Luxemburg



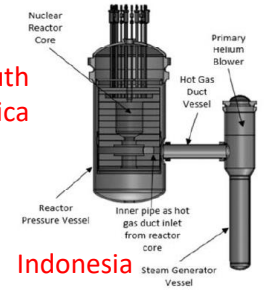
Russia



Sweden

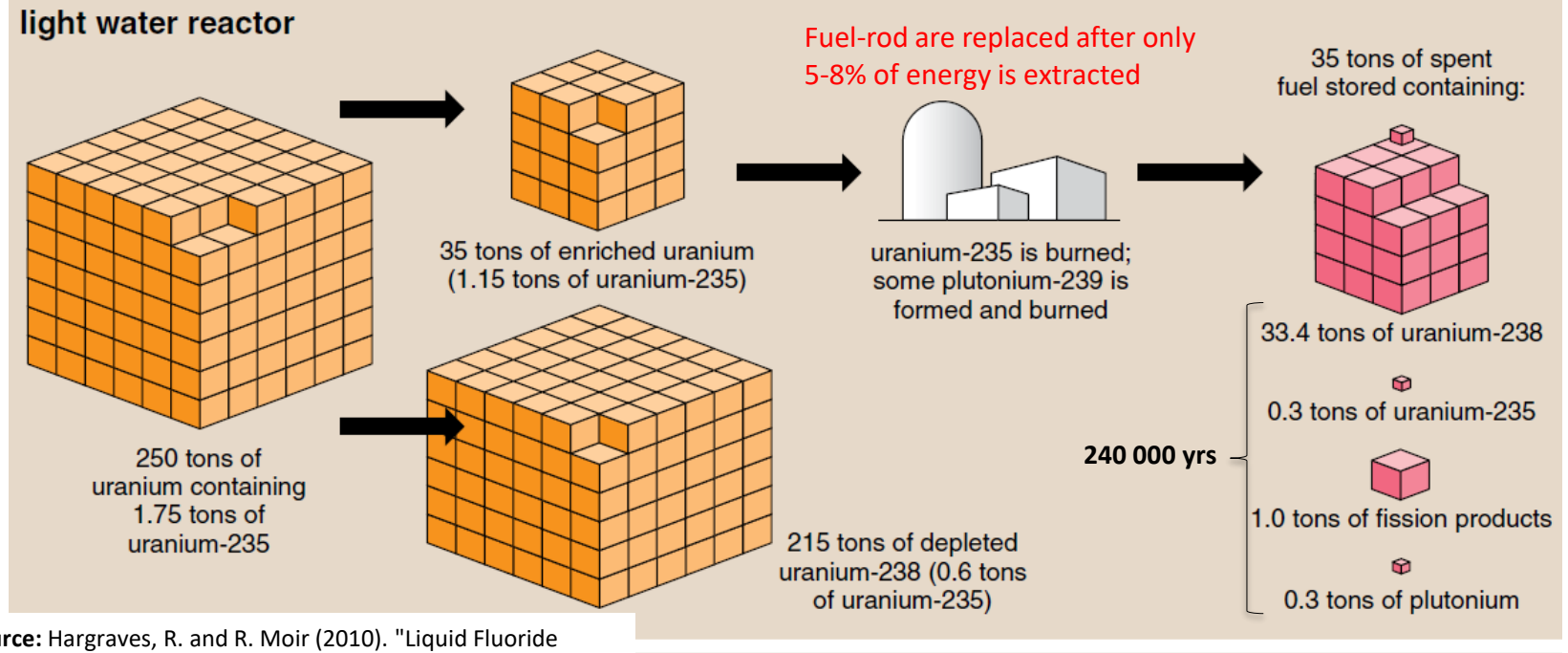


South Africa

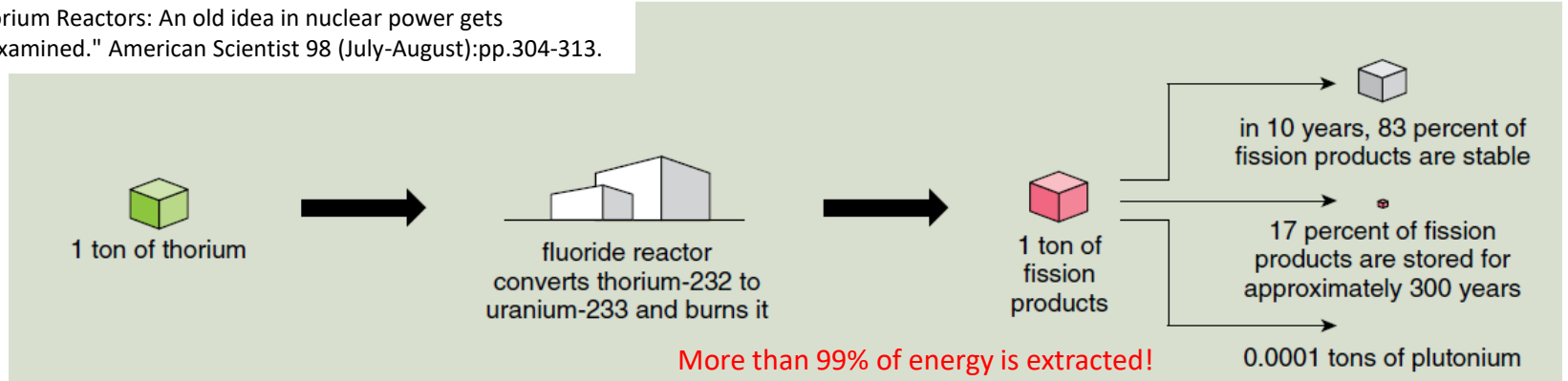


Indonesia

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.



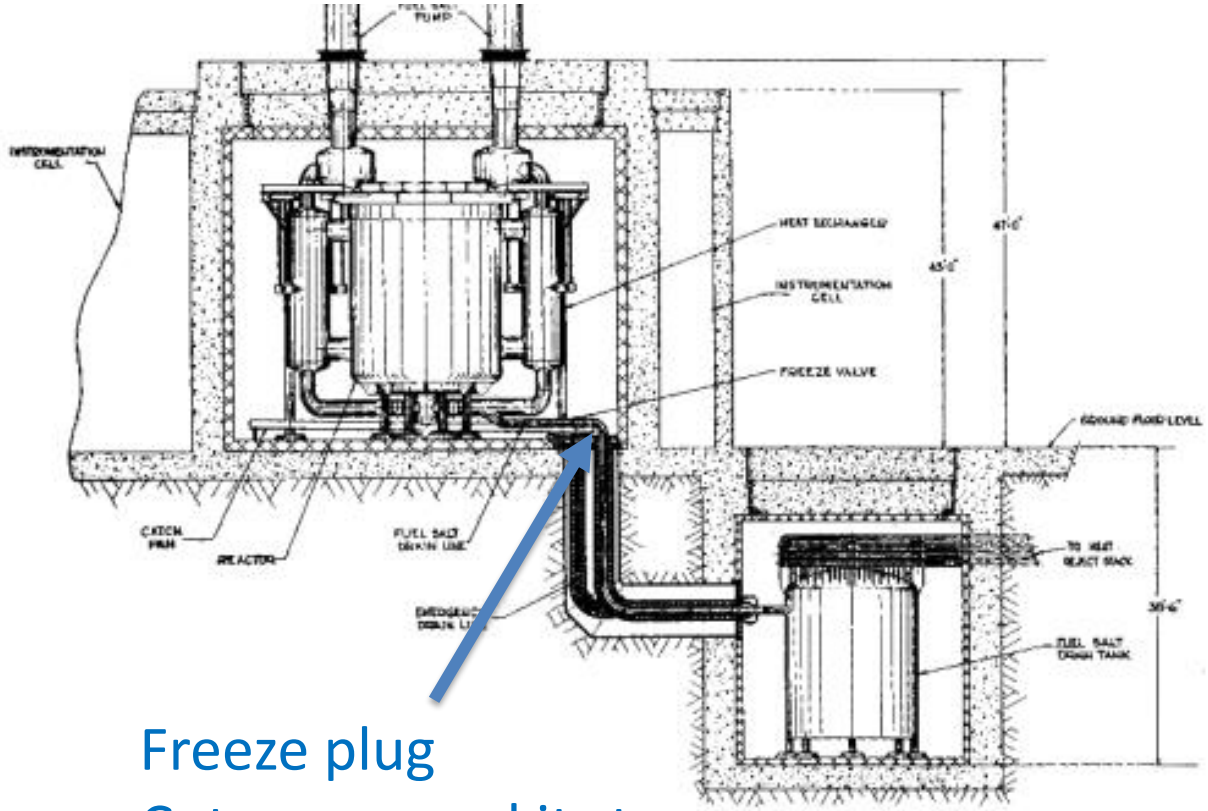
Introducing the Molten Salt Reactor (MSR)

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!

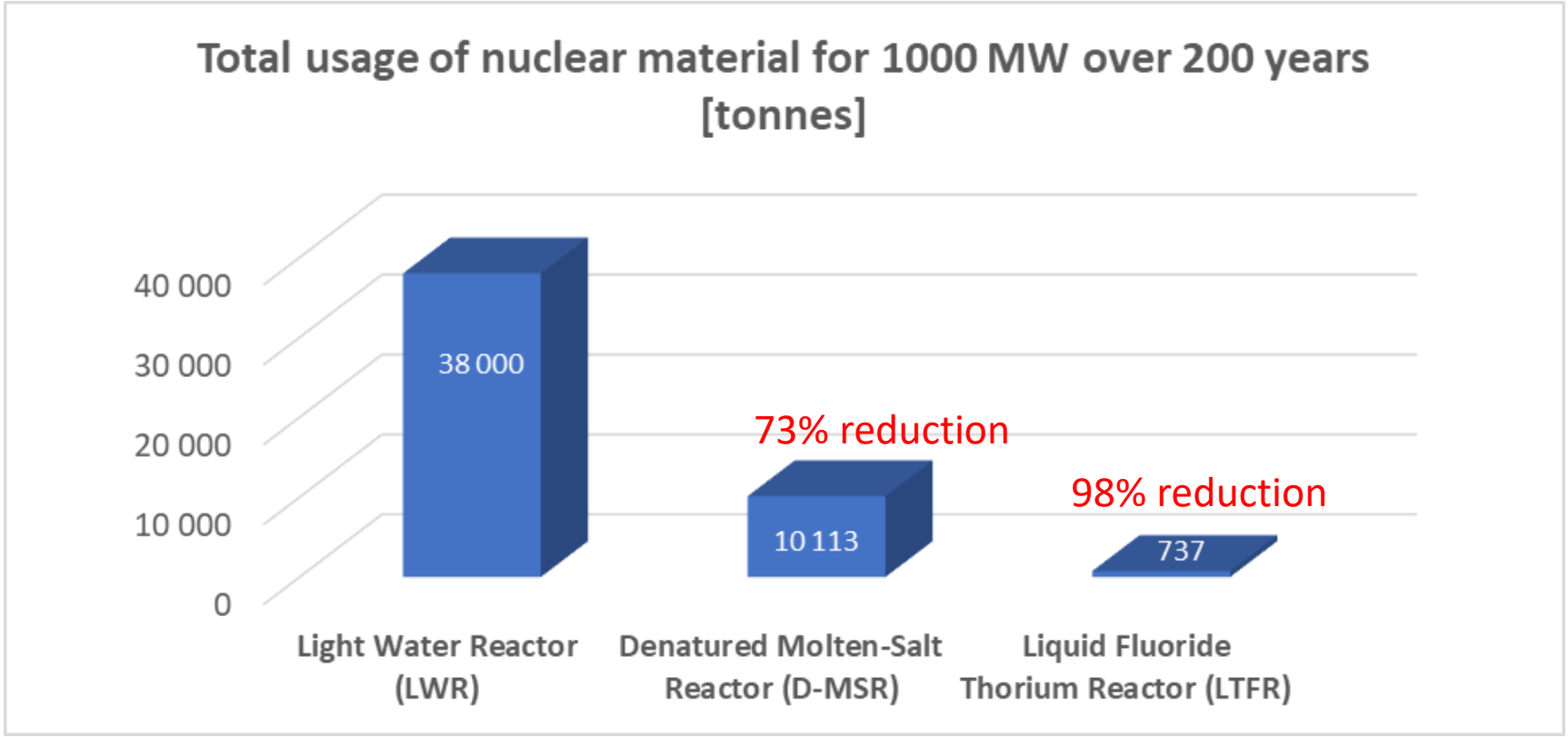
1. Inherently stable (negative reactivity)
2. Fuel is already melted – cannot boil
3. Atmospheric pressure prevents explosions



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)

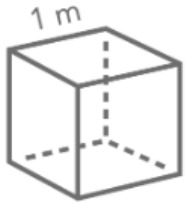
Item	1978$			2000$		
Direct costs, M$	MSR	PWR	Coal	MSR	PWR	Coal
	Cost/kWh, ¢/kWh					
Capital	0.83b	0.85b	0.65b	2.01b	2.07b	1.58b
O&M	0.24c	0.47d	0.33d	0.58c	1.13d	0.80d
Fuel	0.46c	0.31e	0.71f	1.11c	0.74e	1.72f
Waste disposal	0.04g	0.04g	0.04d	0.10g	0.10g	0.09d
Decom	0.02c	0.03d	--	0.04c	0.07d	--
Total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

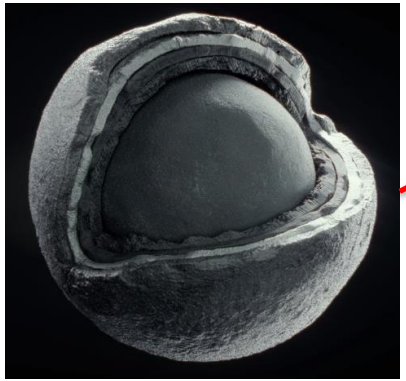
Helium Gas-cooled Reactor with TRISO

- Up to 50 MWth/15MWe depending on enrichment
- 300 MWyr core energy
- Test units are scheduled for 2026
- TRISO fuel:



2000 kg

SPENT FUEL PER CORE



Commercial deals are made on SMRs

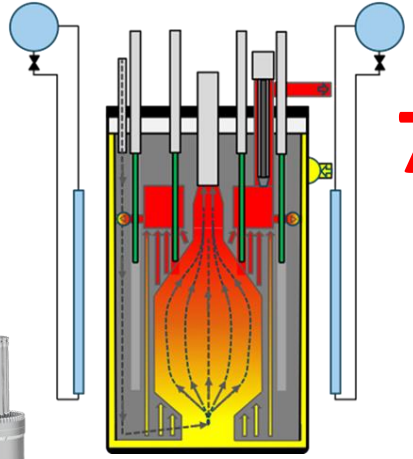
world-nuclear-news.org/Articles/Agreement-signed-for-planned%C2%A0UK-fleet-of-AP300-rea

Agreement signed for planned UK fleet of AP300 reactors

08 February 2024

Share

Westinghouse has signed an agreement with Community Nuclear Power Limited (CNP) for the construction of four AP300 small modular reactors (SMRs) in the North Teesside region of northeast England. It would be the UK's first privately-financed SMR fleet.



7 x Google

Kairos Power

amazon

4 x

energy

world-nuclear-news.org/Articles/Alliance-signs-Canadian-SMR-contract

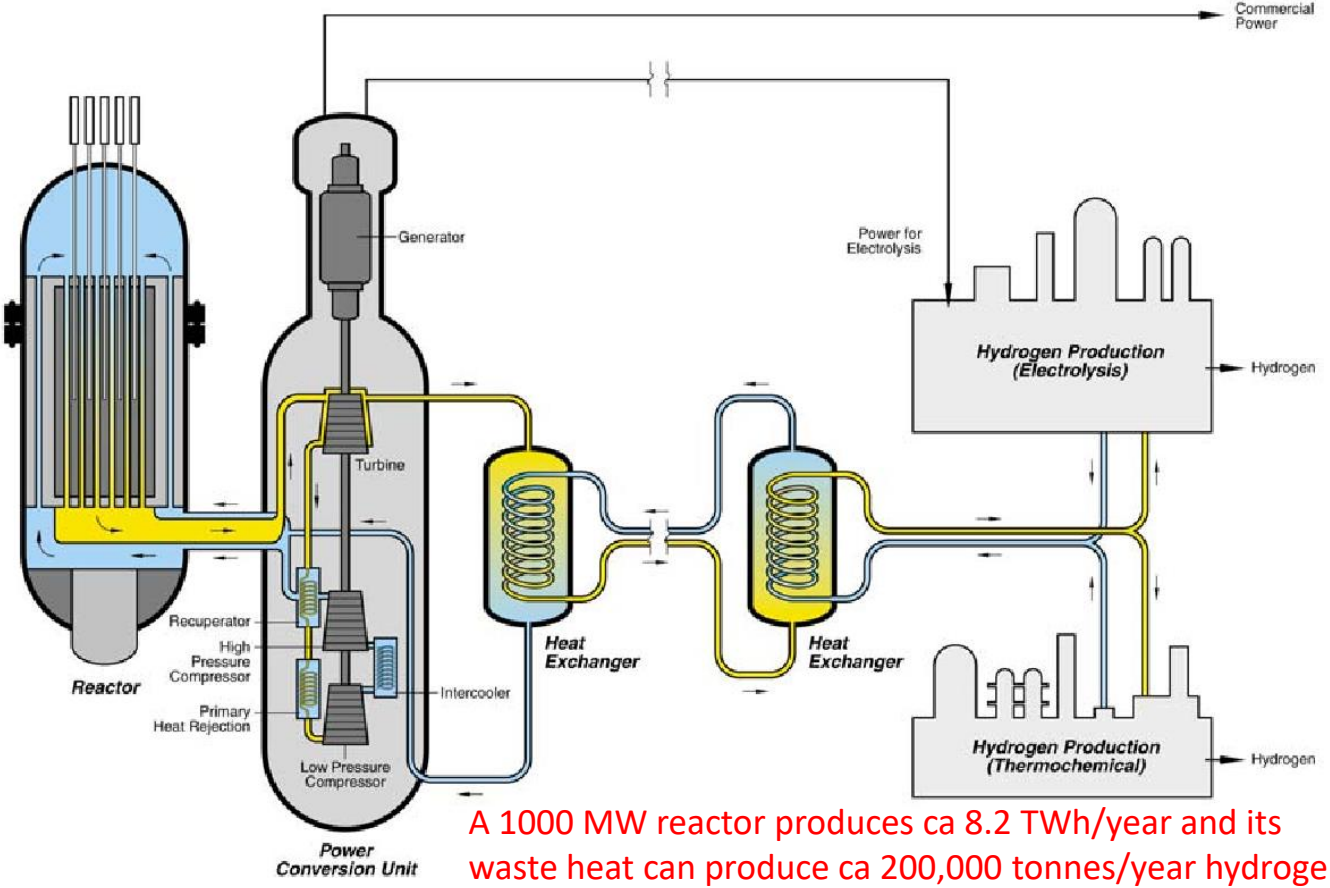
Alliance signs Canadian SMR contract

30 January 2023

Share

The first commercial contract for a grid-scale small modular reactor (SMR) in North America sees Ontario Power Generation (OPG), GE Hitachi (GEH), SNC-Lavalin and Aecon team up in an innovative integrated project delivery model to develop, engineer and construct a BWRX-300 at OPG's Darlington New Nuclear Project.

Nuclear gives electricity and heat



A 1000 MW reactor produces ca 8.2 TWh/year and its waste heat can produce ca 200,000 tonnes/year hydrogen

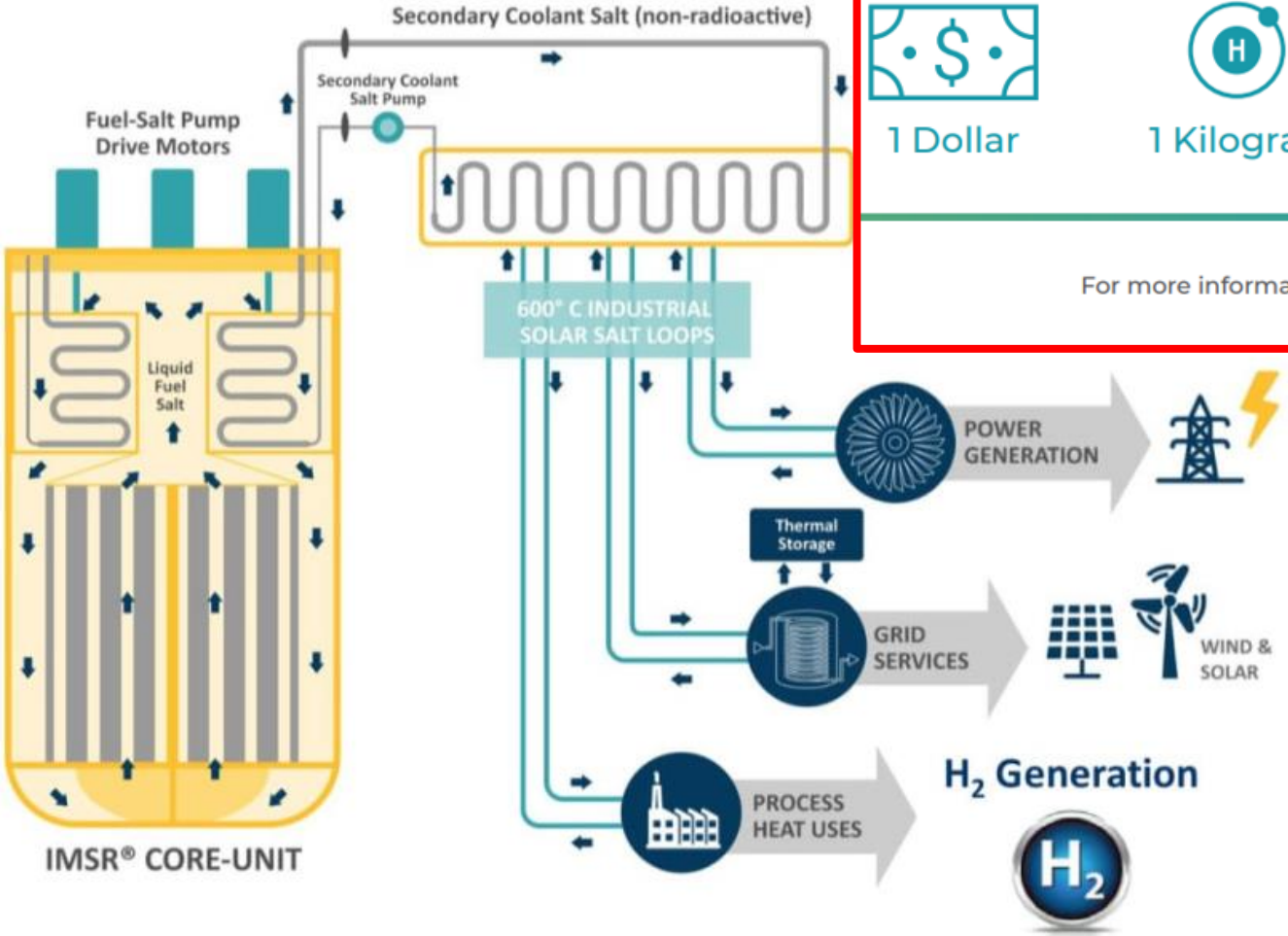
Electricity production for grid

AND/OR

hydrogen production

AND

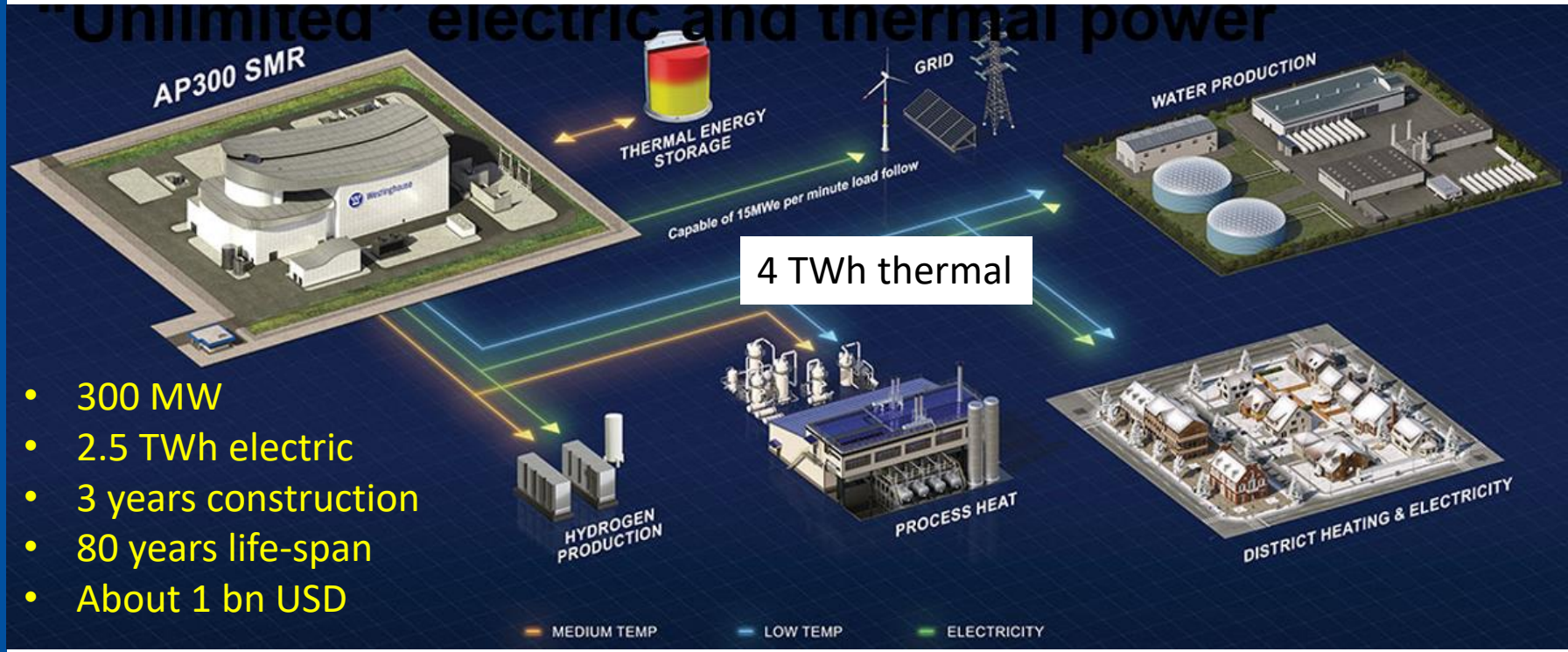
thermo-chemical hydrogen production



Integration of Hydrogen Generation with an Integral Molten Salt Reactor IMSR.

Courtesy: Terrestial Energy

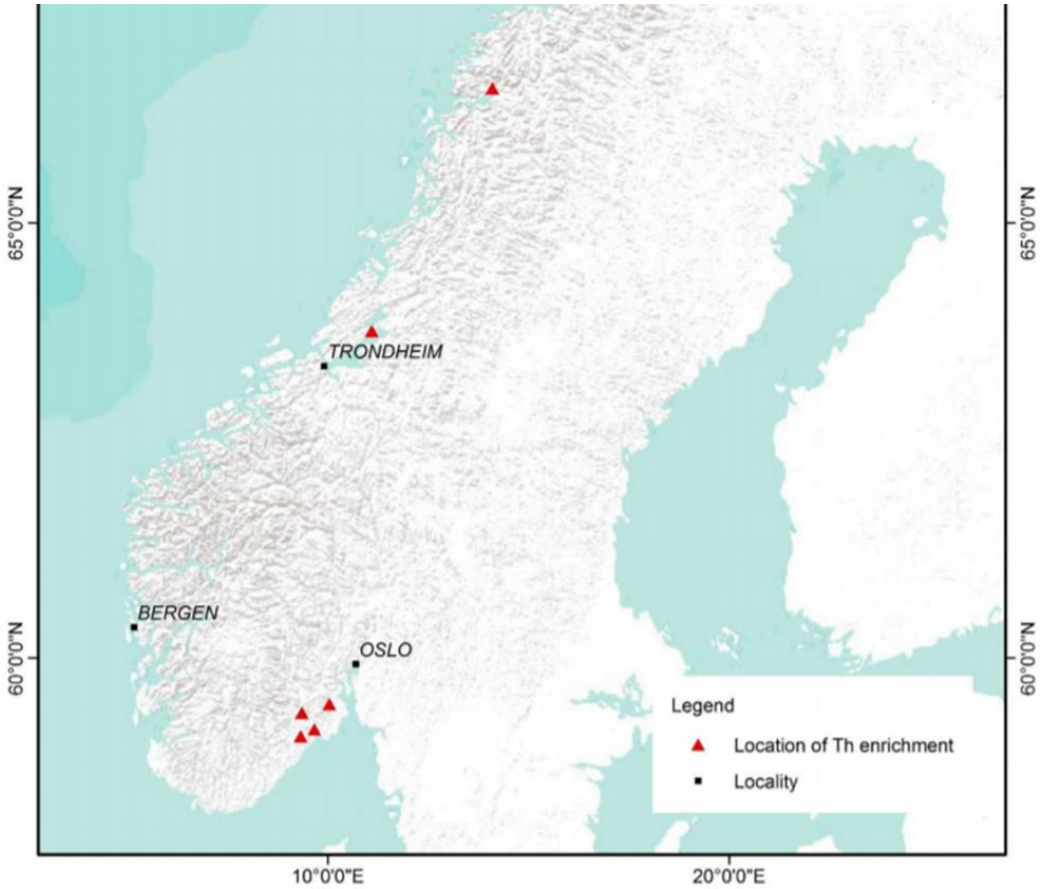
“Unlimited” electric and thermal power



- 300 MW
- 2.5 TWh electric
- 3 years construction
- 80 years life-span
- About 1 bn USD

Up to 80% of total energy output is possible to utilize with nuclear

We have Thorium and Uranium



- Estimates range from 87,000 tonnes to 320,000 tonnes
- 2,000+ years!
- Initial estimates are often wrong
- Extract Thorium + REE + phosphate
- Uranium from the sea

BUT; we need to act

Takk for meg ☺

Question
and
Answer

Further information

- Calabrese about radiation - https://hps.org/hpspublications/historylnt/episodeguide.html
- Popular science video about radiation around the world - https://www.youtube.com/watch?v=JpcUCo0ebNA
- The cost of the Energiewende https://www.tandfonline.com/doi/full/10.1080/14786451.2024.2355642
- About Chernobyl accident - https://www.universitetsavisa.no/energi-jan-emblemsvag-kjernekraft/hva-burde-vi-ha-laert-av-tsjernobylulykken/380904