Catch-22 of Nuclear Energy

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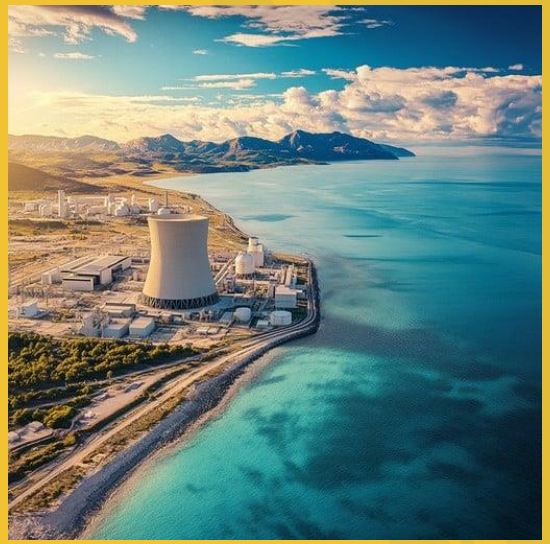

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Why has Nuclear energy failed in the west?

Safety?
Waste?
Public opinion?
Proliferation risk?

Three-mile Island?
Chernobyl?
Fukushima?

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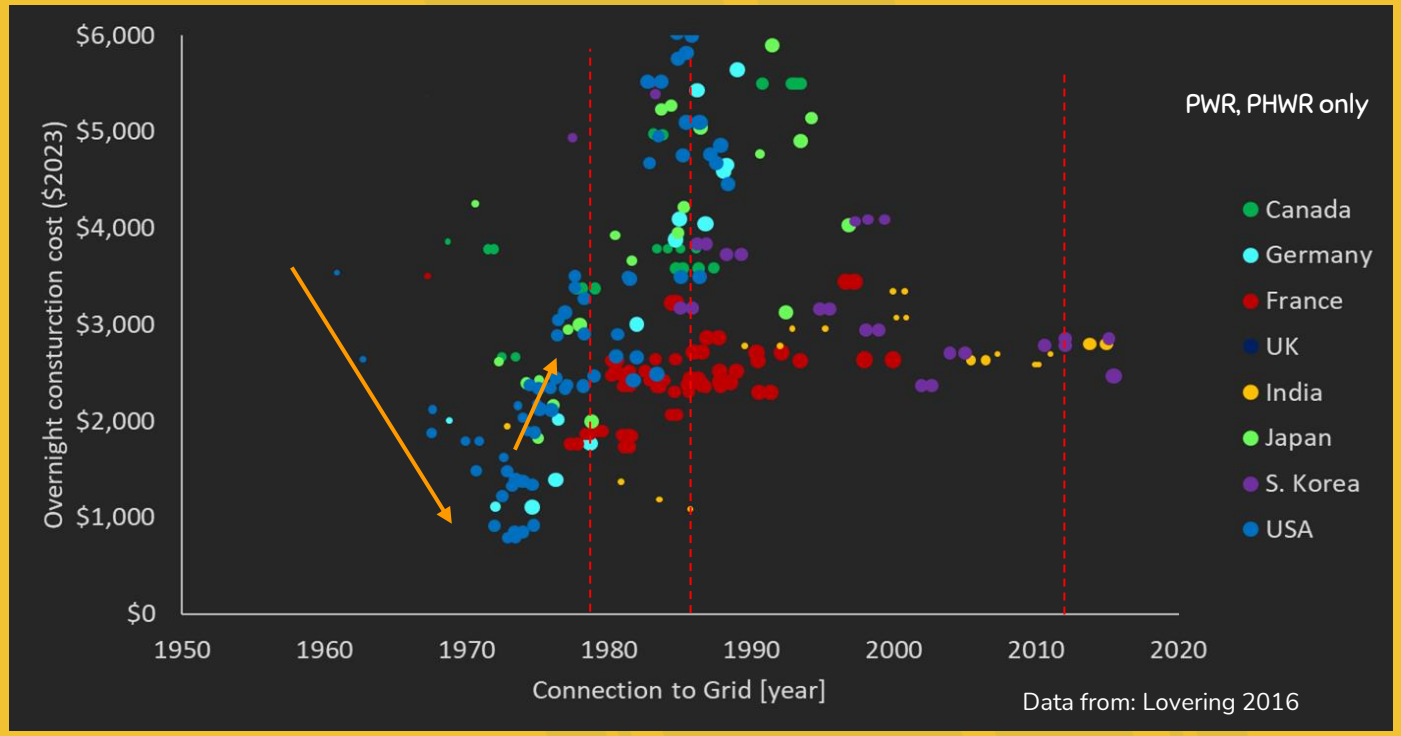
As usual, Follow the money

US Nuclear stopped being competitive around 1975

Mechanism: Regulatory ratchet

Only state programs in recent decades



Missing from graph: China, Russia (no cost data)

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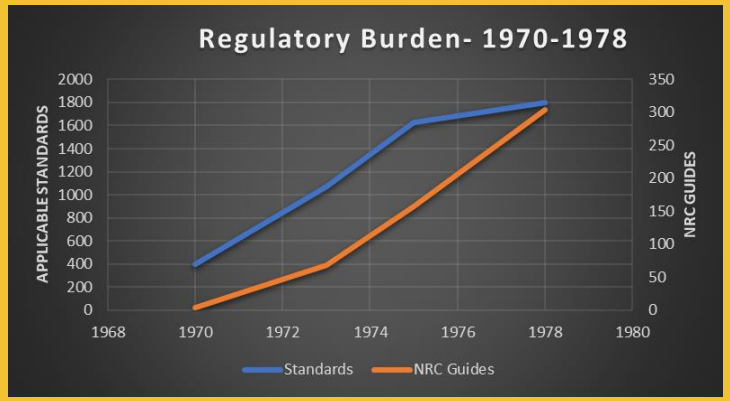
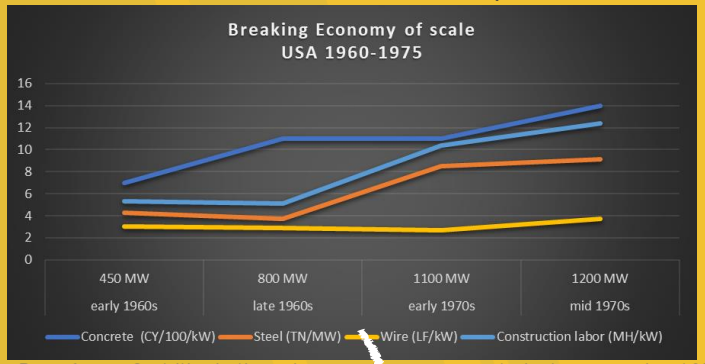
US mid 70s: Regulation Breaking Economy of Scale

Increased regulatory requirements



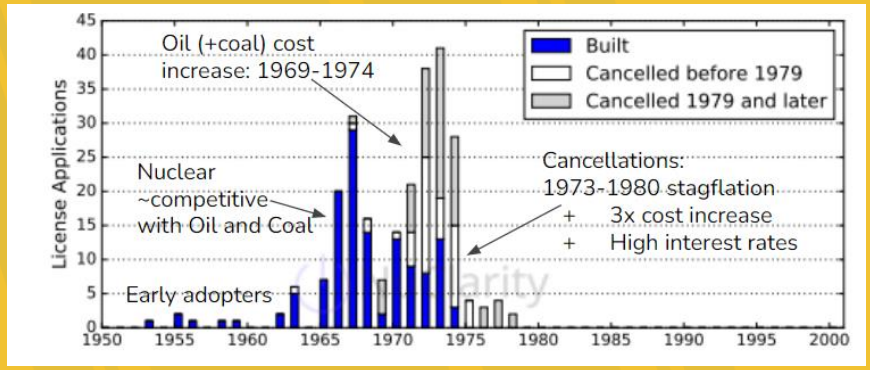
Data from: Stability in licensing requirements : technical perspective 1978

More materials and labour per kW



Data from: Stability in licensing requirements : technical perspective 1978

3x more expensive



Graph From: why has nuclear Energy been a flop p. 204

Most plants canceled in 70's
no new plants

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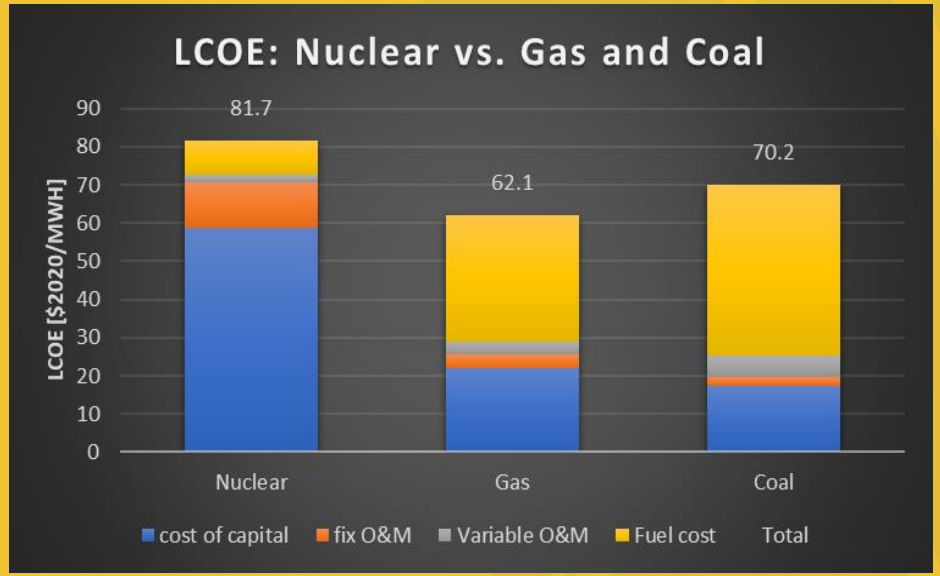
Nuclear can be successful only if it is price competitive in the energy market and investible

Nuclear cost structure (Large Water Reactors)



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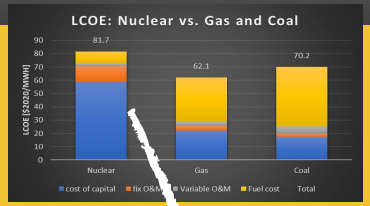
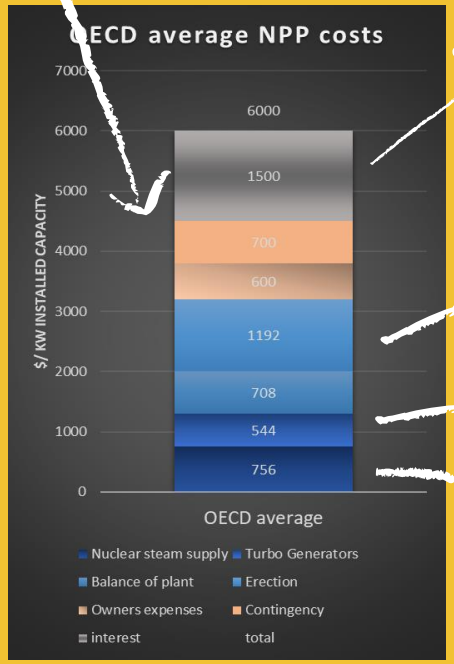
What drives the LWR cap cost?





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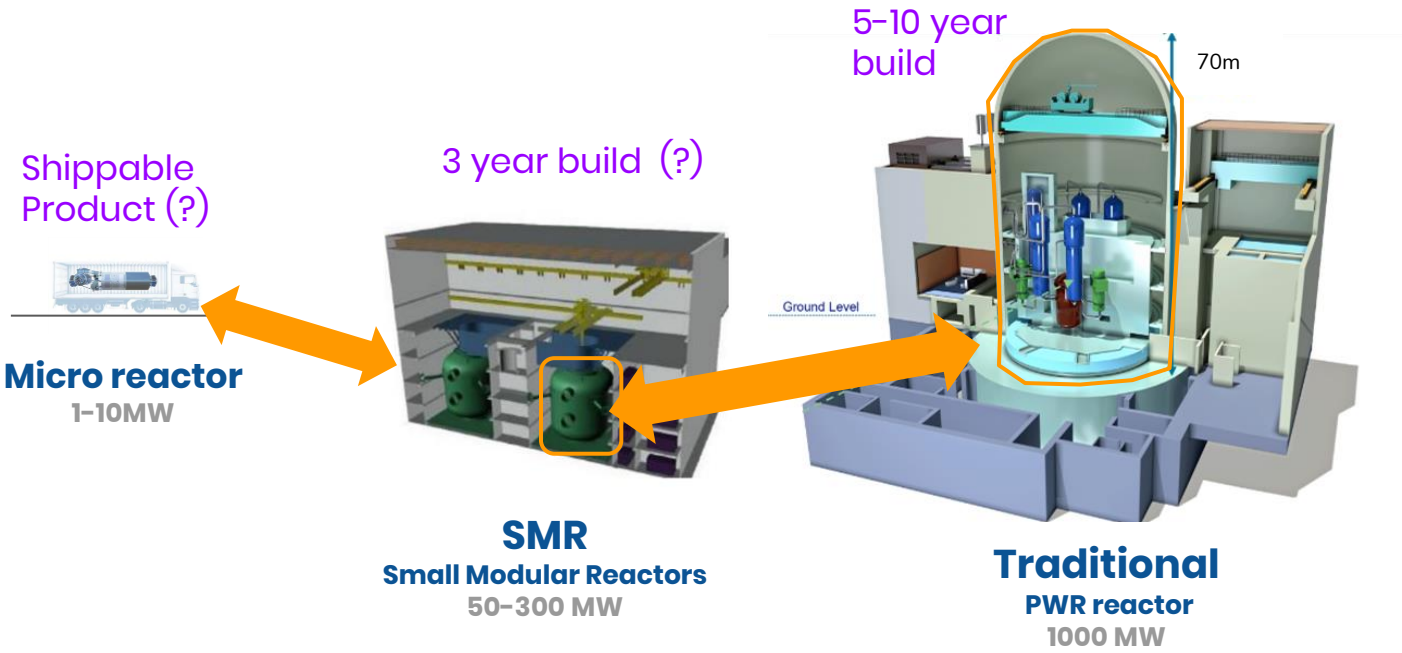
SMRs and advanced Nuclear

Paradigm shift in nuclear?



Images to scale

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PWR: pressurized water reactor

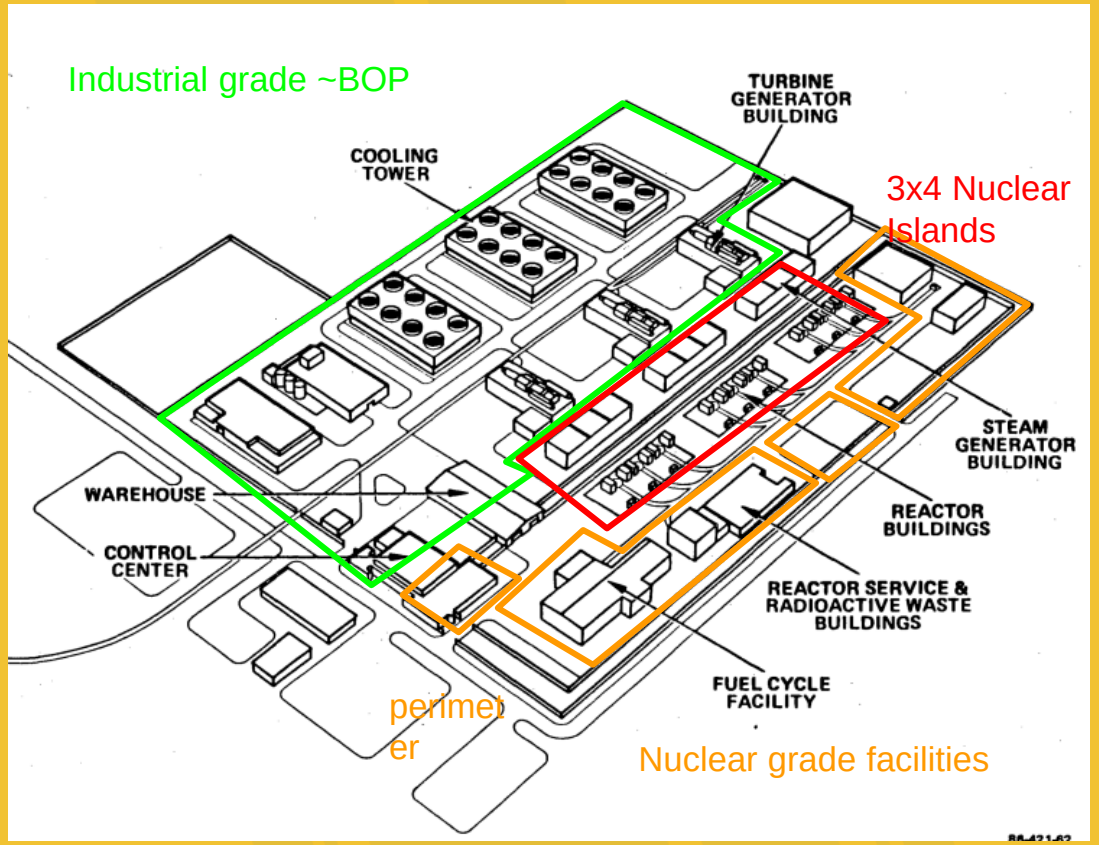
SMR Reactor vs. everything else

3100MW Gen IV NPP layout

3x4 GE Prism SFR reactors

Can you spot the reactor?

We tend to concentrate on the Nuclear island.
It is only a fraction of the cost.



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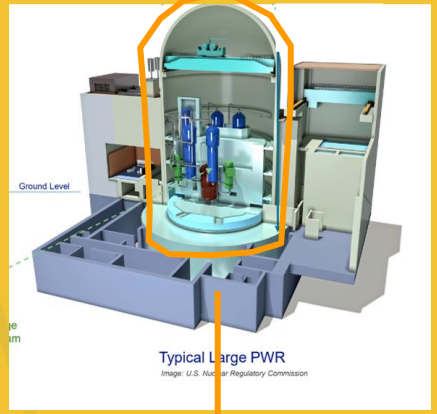
Deep dive: NuScale (Voygr)

- Integrated passive design- no pumps

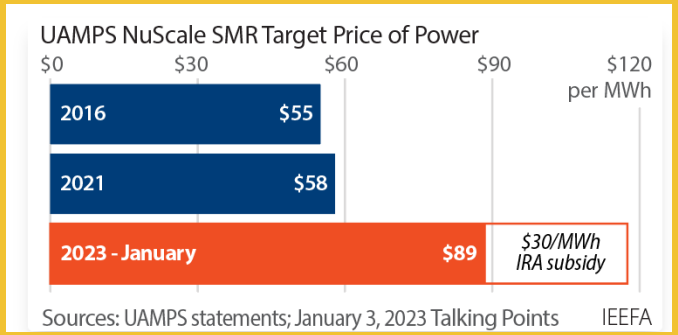
<u>But:</u>

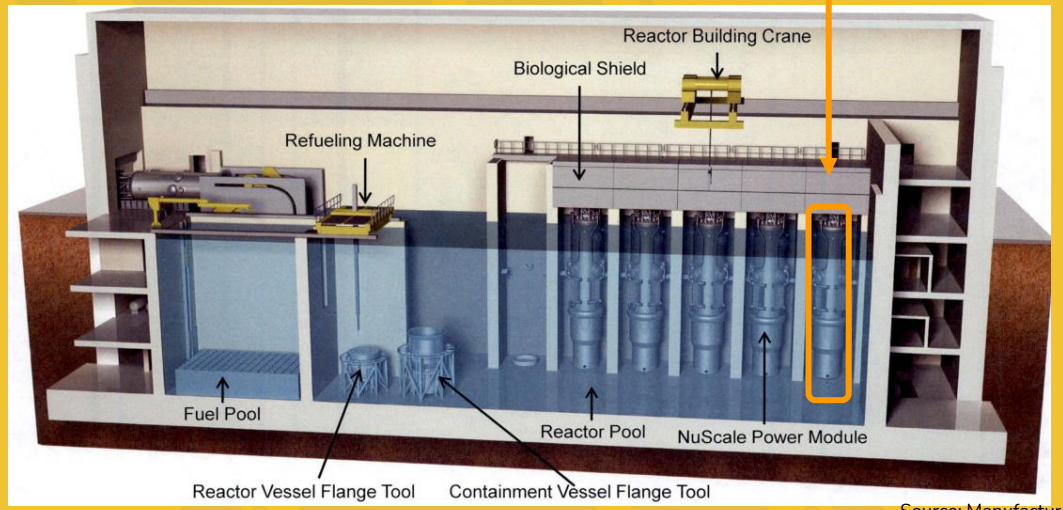
- 10x lower power- 3x more expensive than LWR
- Each 77MW module has its own steam turbine generator (=$$)
- Huge pool building- 100x50x45 m^3



Cost Estimation:

3,000→ ~15,000 $/kW





Source: Manufacturer

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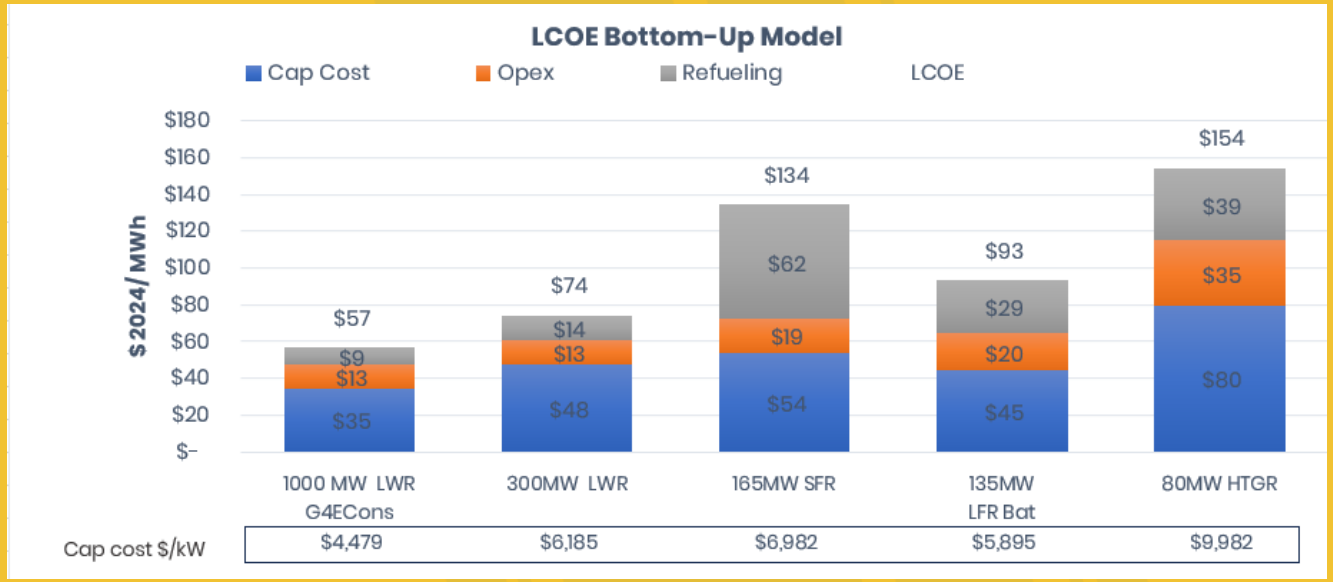
Source: Nuscale

NuClarity bottom-up cost model

Detailed accounting of full cost of nuclear power plant.

All models are wrong; some are useful...

Fuel cost is very important in Gen IV SMR design cost



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Deep dive: X-Energy (Xe-100)

- 80MW
- Gen IV: High temp gas cooled
- TRISO fuel
  - Safe and 10x more expensive vs. PWR fuel
- Standard very small off the shelf steam turbine

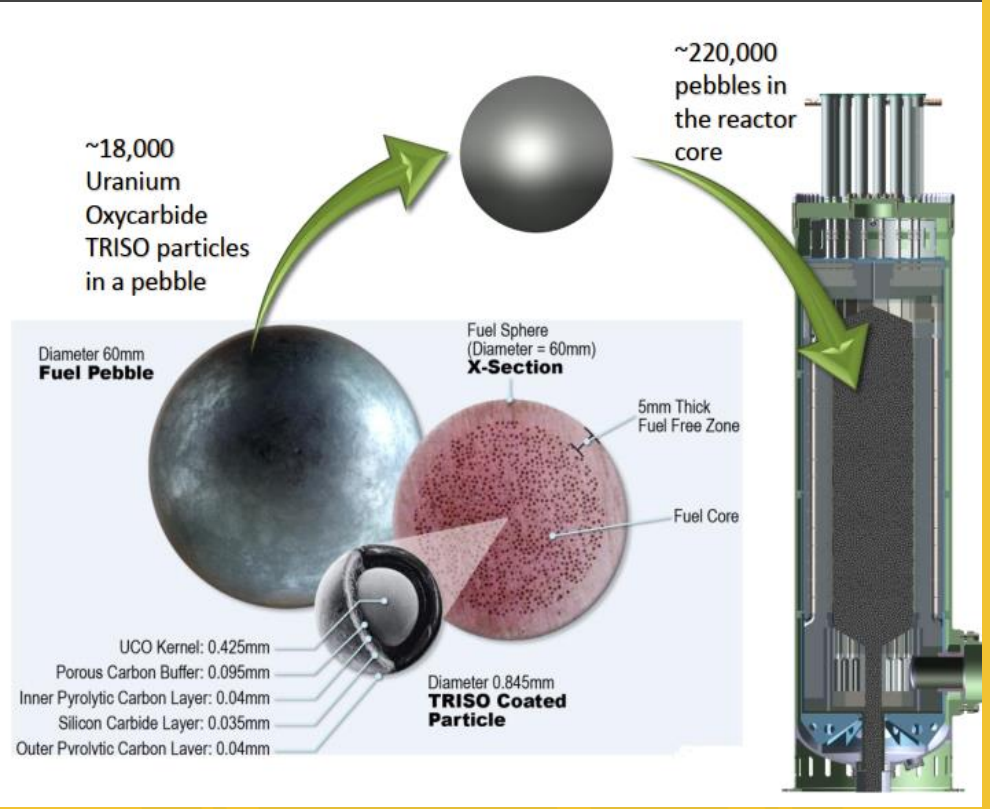
Vendor estimation:

7,500$/kW

Our estimation: 9700$/kW

Chinese HTGR : ~6000$/kW

@200MW reactor



Source: Manufacturer

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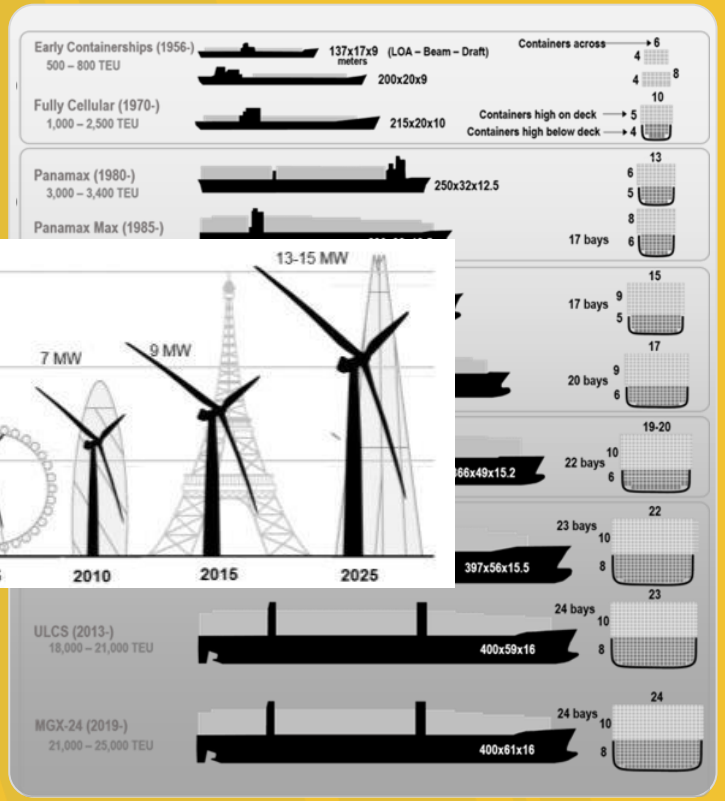
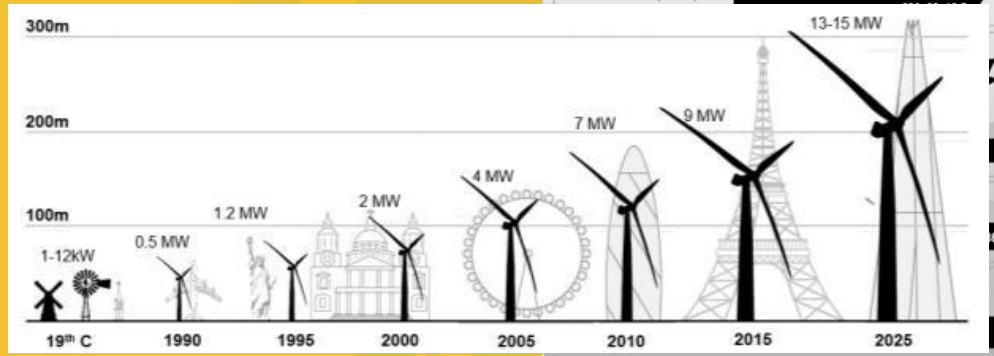
Economy of scale

Bigger production capacity=
cheaper per unit produced*

*assuming every else stays the same





That's why

planes, ships, hotels, oil refineries and wind turbines
tend to get bigger (and bigger)

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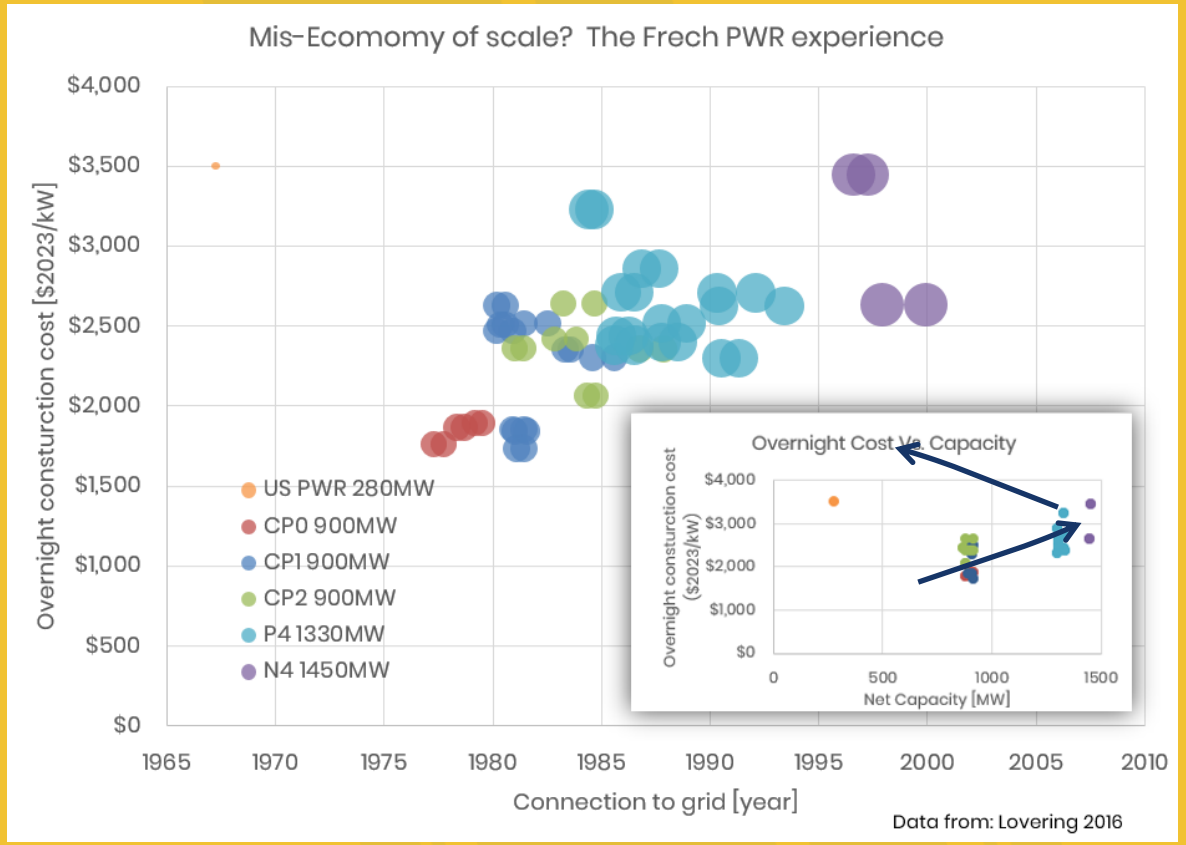
Nuclear: Broken economy of scale?

- It is very hard to find examples where economy of scale seems to work in Nuclear
- Going smaller today -> expected to be more expensive

***all things being equal**



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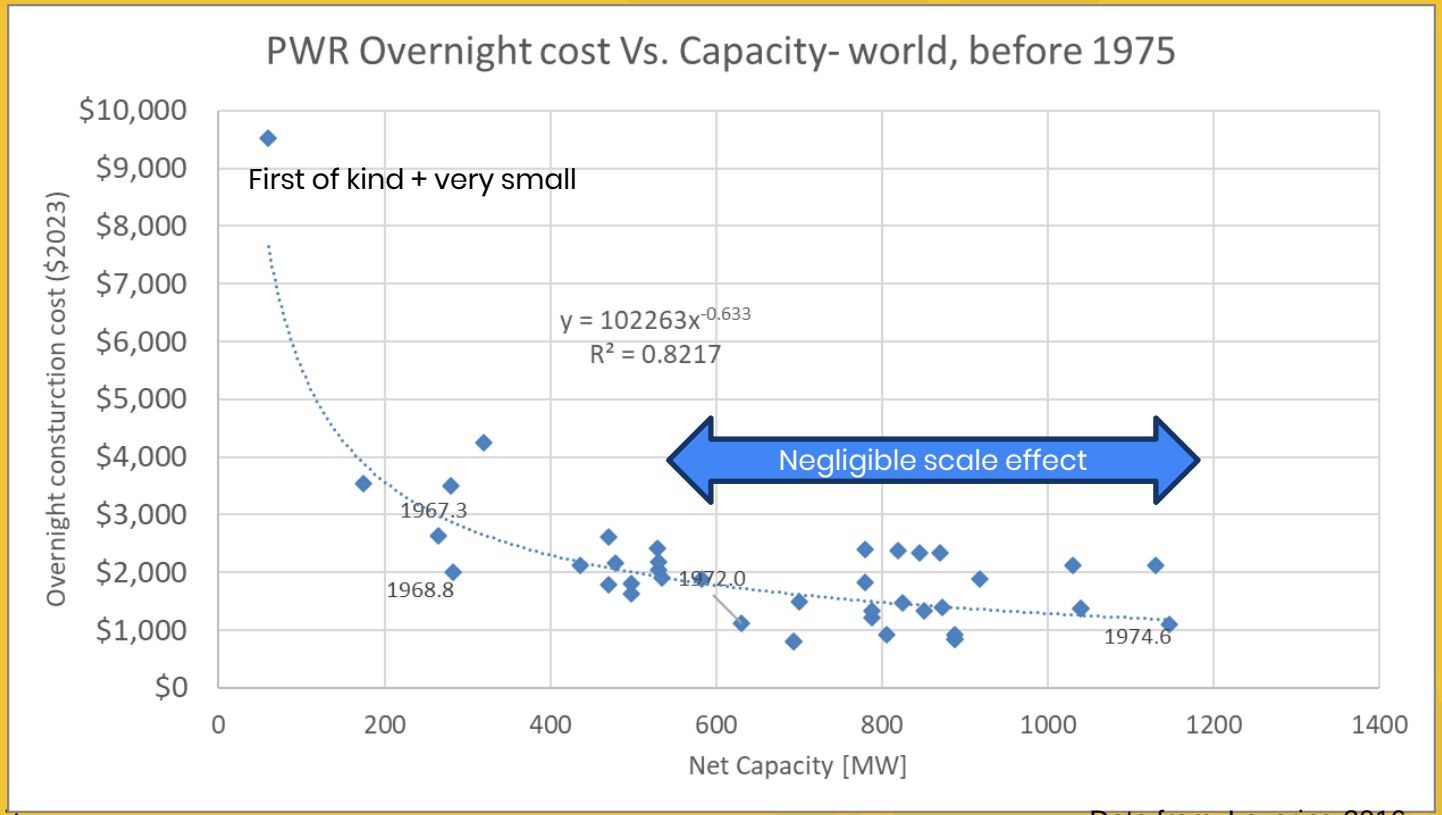
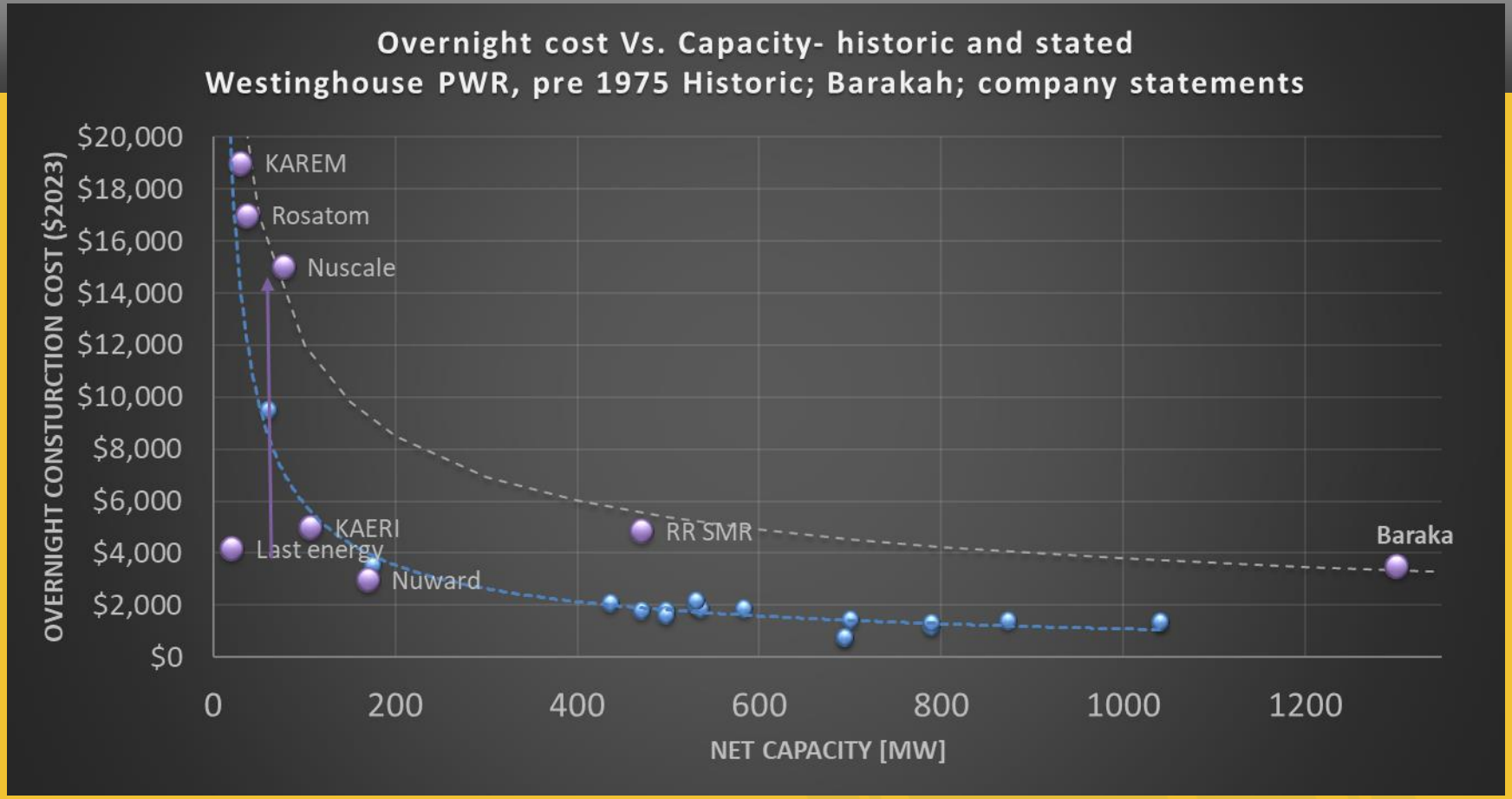
Nuclear: economy of scale “below 500MW”...



Data from: Lovering 2016


Overnight cost Vs. Capacity- historic and stated
Westinghouse PWR, pre 1975 Historic; Barakah; company statements
OVERNIGHT CONSTURCTION COST ($2023)
$20,000
$18,000
$16,000
$14,000
$12,000
$10,000
$8,000
$6,000
$4,000
$2,000
$0
KAREM
Rosatom
Nuscale
KAERI
Last energy
Nuward
RR SMR
Baraka
0
200
400
600
800
1000
1200
NET CAPACITY [MW]

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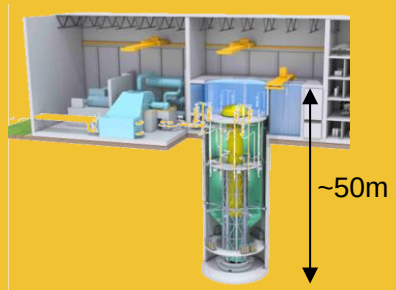
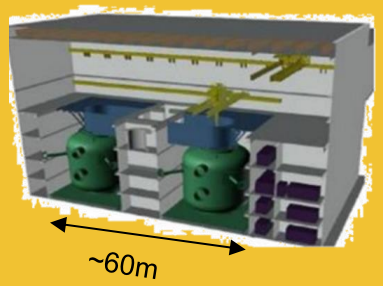
Water cooled SMR's buildings are not small

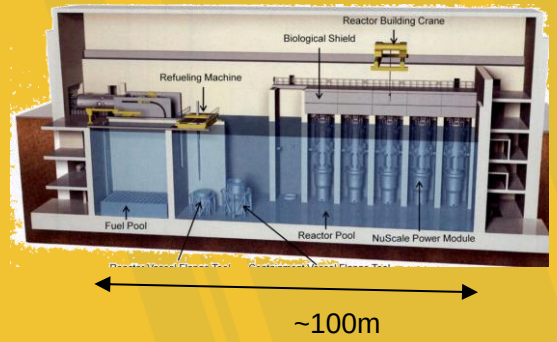
GE BWRX-300
300 MWe



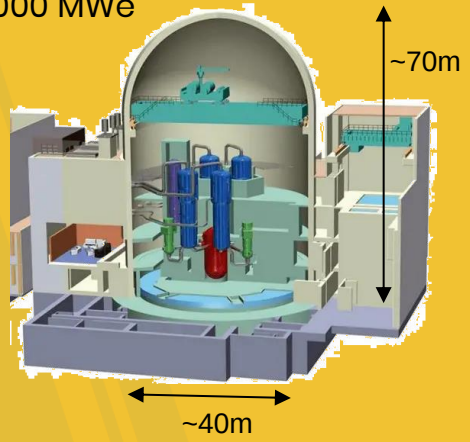
Nuward
340 MWe



NuScale Voygr
6-12 NPV=450-900 MWe



LWR
1000 MWe



Images ~to scale

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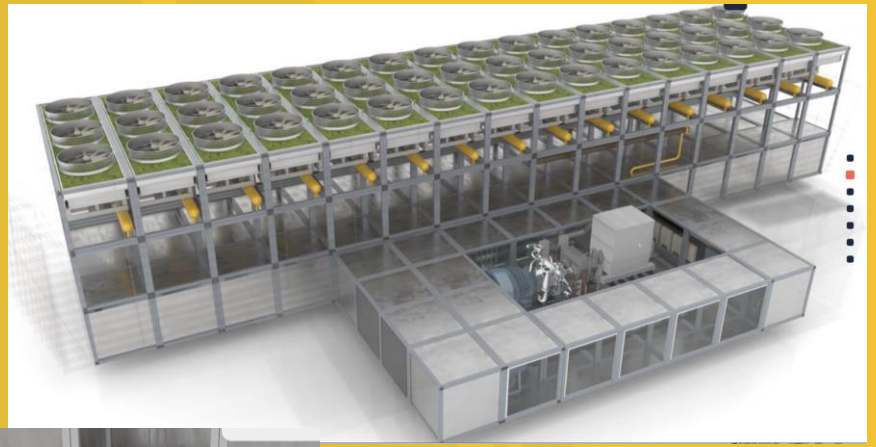
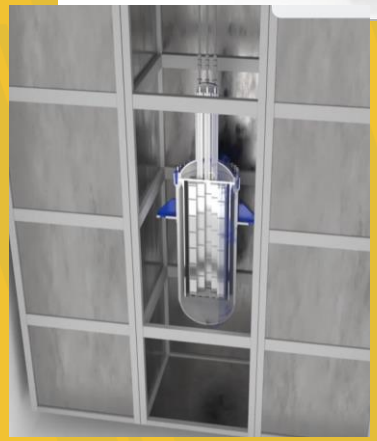
Deep dive: Last energy (SMR-20)

- "No new tech"- old school
- size, modularity
- 20MW- 50x smaller , 7x cost increase

Claiming 5,000$/kW!

2024 update:
claiming 70$ per MWh opex
(i.e. very expensive)





Source: Manufacturer

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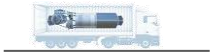
Catch 22 of advanced Nuclear

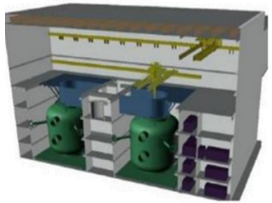


Micro reactor

1–10MW

Low risk, <0.2B$

Very high LCOE



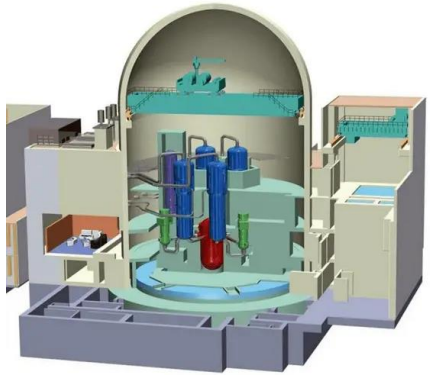
Small Modular Reactor

50–300 MW

“Lower risk”, <1B$

“Market investible”

High LCOE, probably



Large PWR reactor

~1000 MW

High Risk, multi B$

Only governments

Lower LCOE

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Where do we go from here? (For SMR developers)

- **Optimize for cost** from ideation and in every step
- Size matters: Aim for a bigger SMR if possible
- Minimize Nuclear fuel costs
- Fight over-design by engineers
- Fight expensive unjustified regulatory bloat (ALARA)
- Think about the plant as a whole
  – minimize overheads, share auxiliaries