SEABORG

making nuclear sustainable

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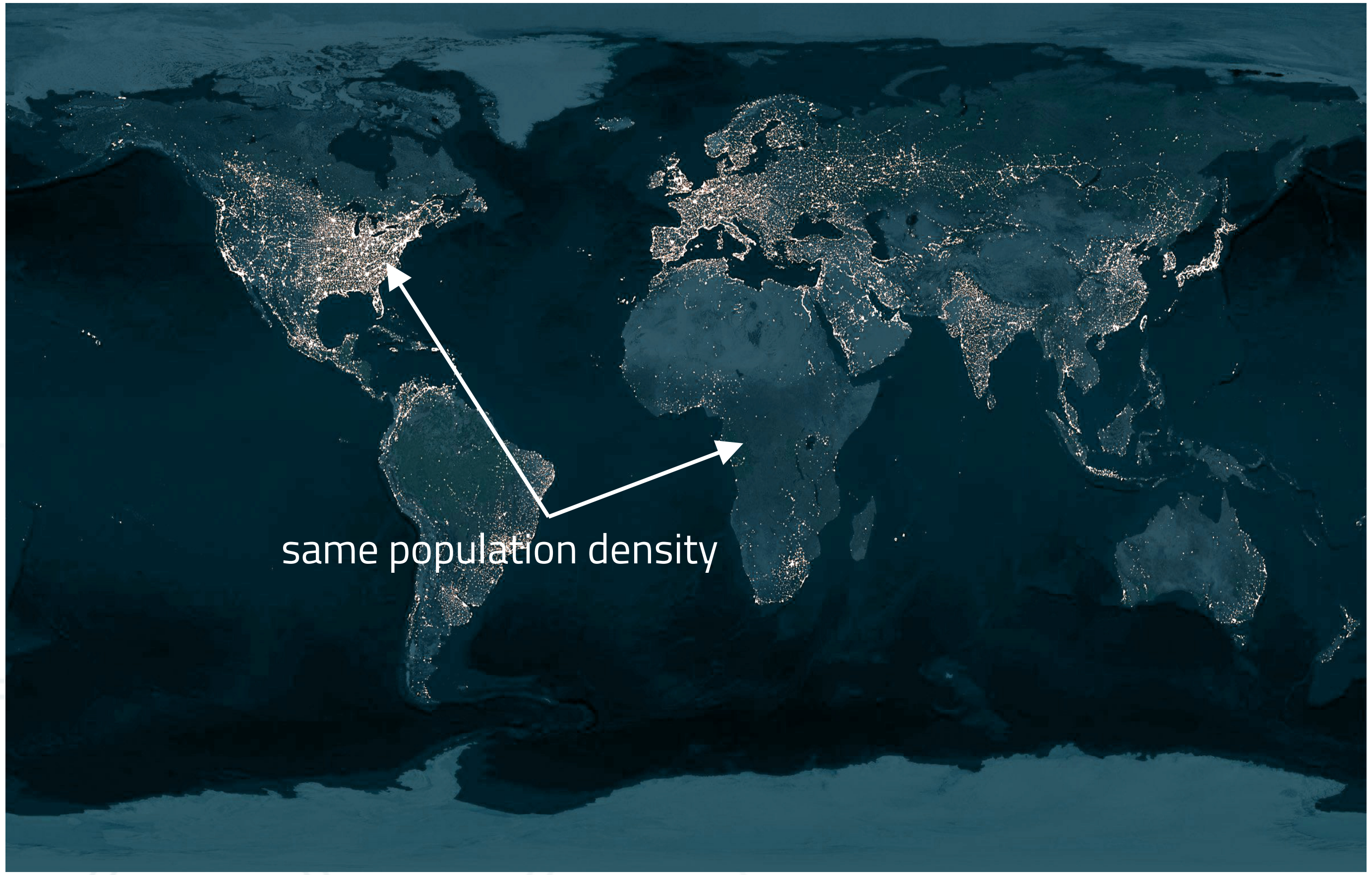
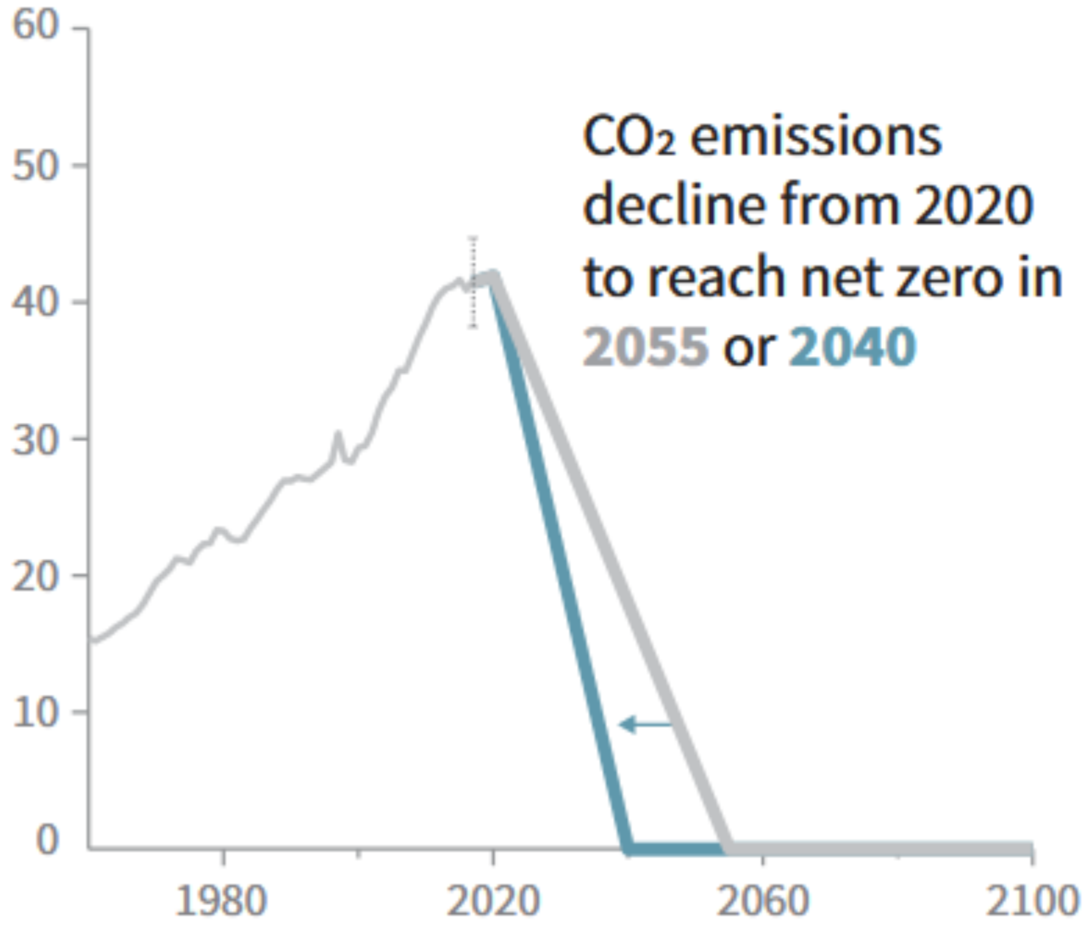
The dilemma



Satellite image of poverty
7 billion people today - 9 billion in 2050



Despite serious efforts
global CO_2 emissions continue to rise

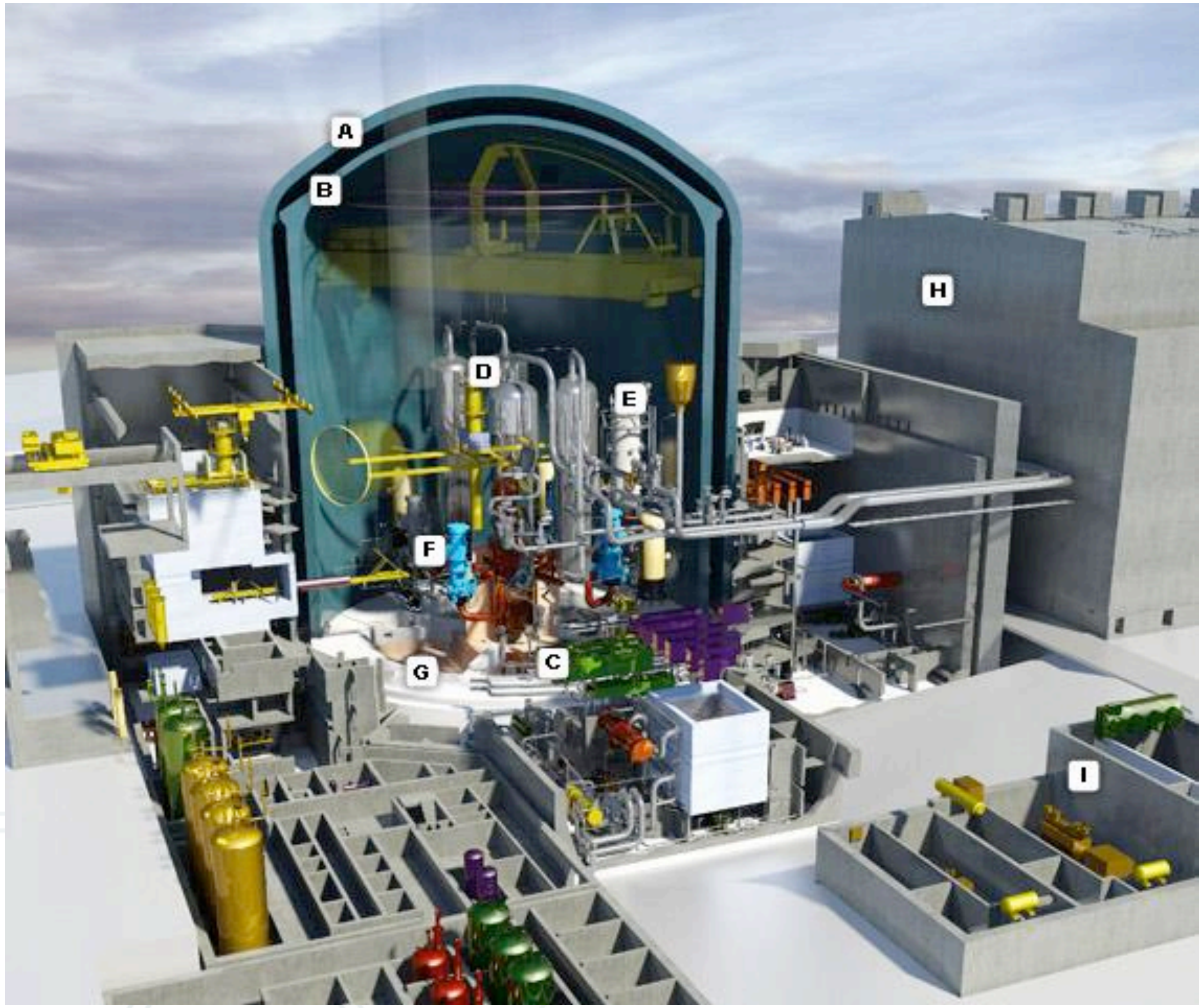
We will:

Enable the free market to fight the runaway GHG emission and eliminate energy poverty.

By:

Commercializing a scalable, cheaper-than-coal, dispatchable energy source (by the mid-2020s)

Setting the scene:
Conventional nuclear = Safety-by-engineering



Severity of accidents and inherent system instability

=> Safety-by-engineering.

Mainly innovation in safety => complexity

=> Costs, risk and delays.

Size becomes the economy of scale

=> Poor market fit and massive upfront investments

Larger reactors means increased severity

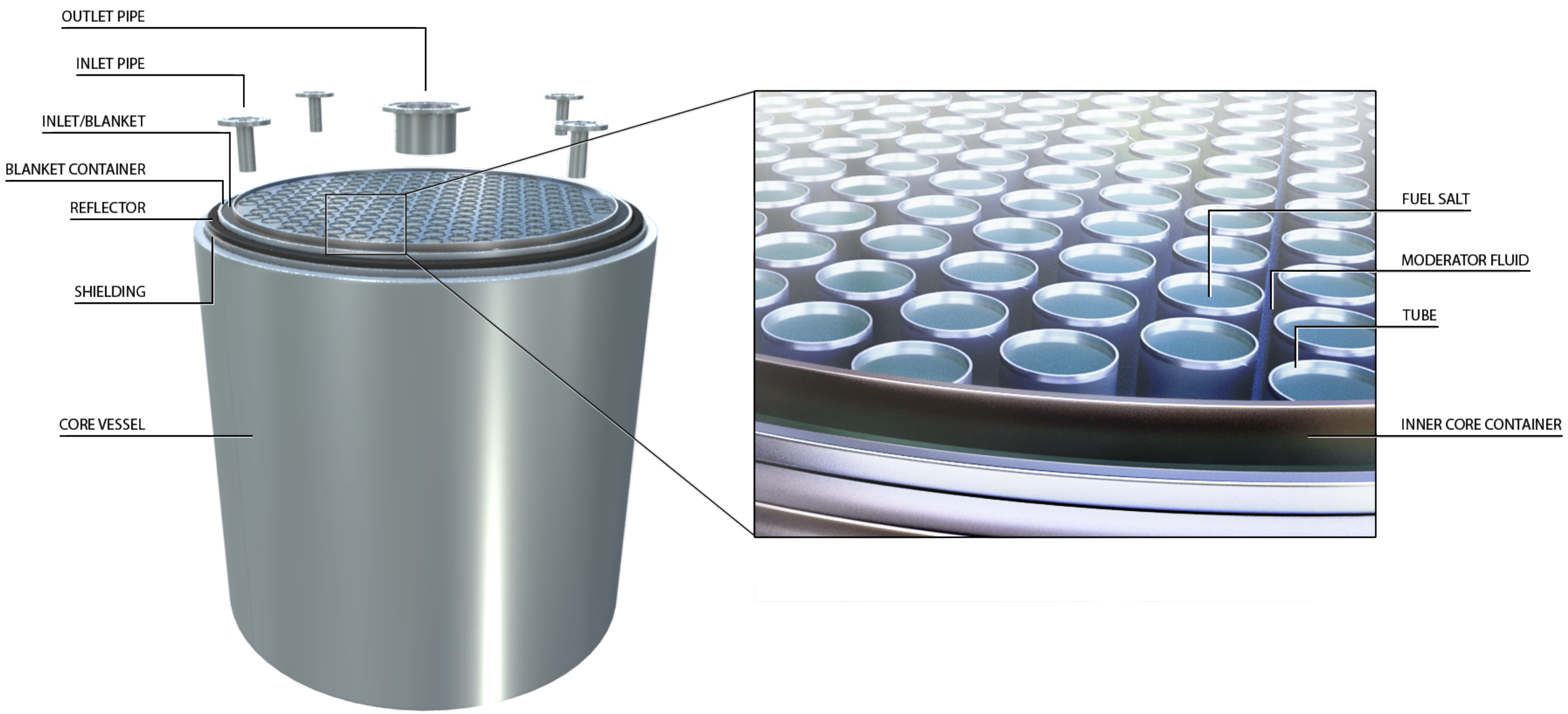
=> Even more focus on safety

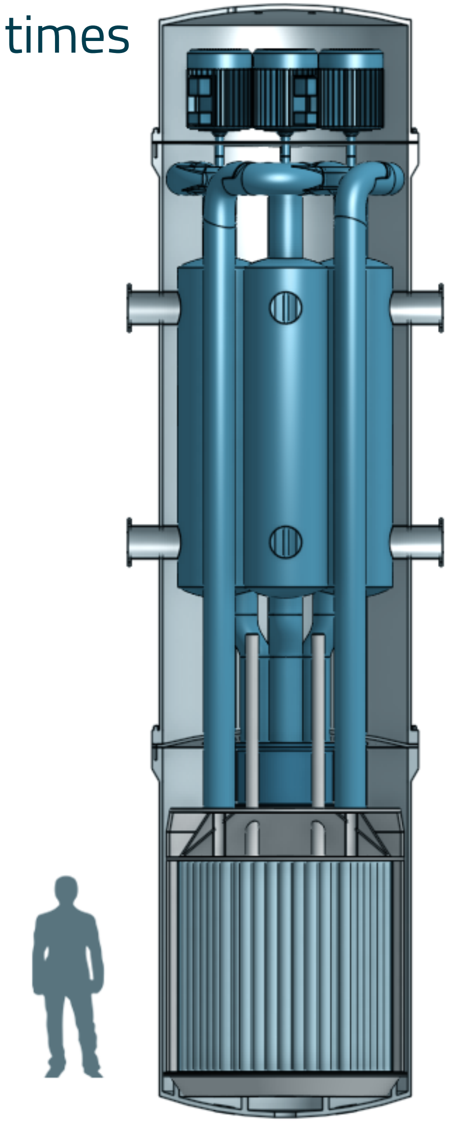
Molten Salt Reactor (MSR)

A fundamentally different class of nuclear reactor which has been built and operated 3+ times

Our design:

1. **CANNOT** be used for nuclear weapons
2. **Burns waste** from conventional reactors
3. **CANNOT** meltdown or explode





Safety-by-physics rather than safety-by-engineering

Fuel and coolant is the same, i.e. loss of coolant = loss of power

⇒ Cannot meltdown

Atmospheric operating pressure

⇒ No risk of pressure explosions

No explosive gas production

⇒ No risk of gas explosions

Chemical stability in liquid

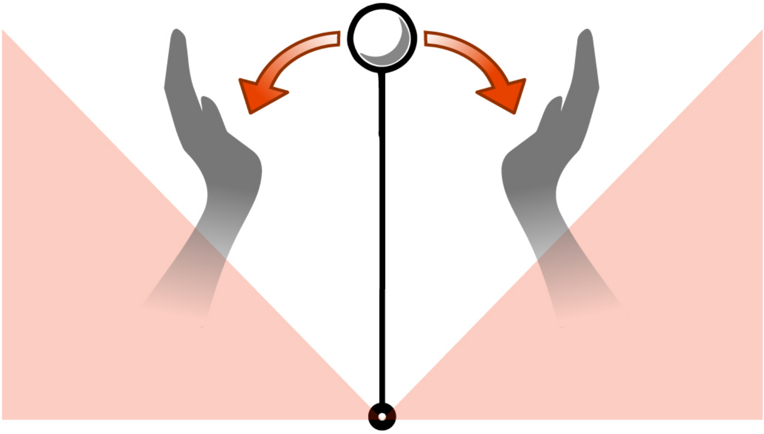
⇒ No dangerous radioactive gasses

Thermodynamic equilibrium control

⇒ Walk-away safe

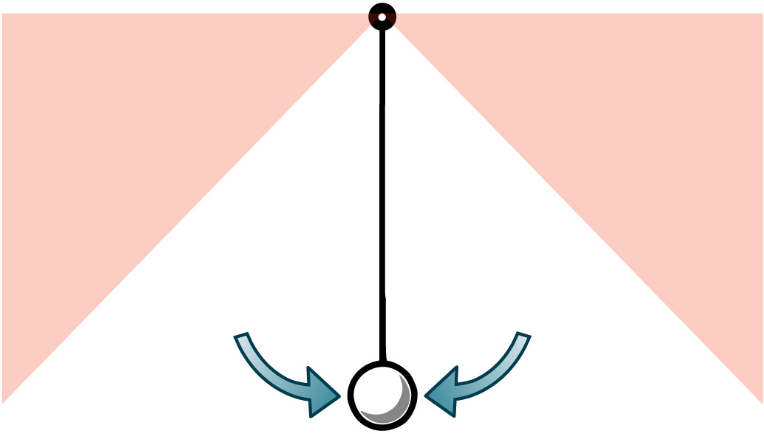
Due to the inherent safety, MSRs are economically superior to conventional nuclear

CONVENTIONAL NUCLEAR



SAFETY SYSTEMS - SAFETY BY ENGINEERING

MOLTEN SALT REACTORS



INHERENT SAFETY - SAFETY BY PHYSICS

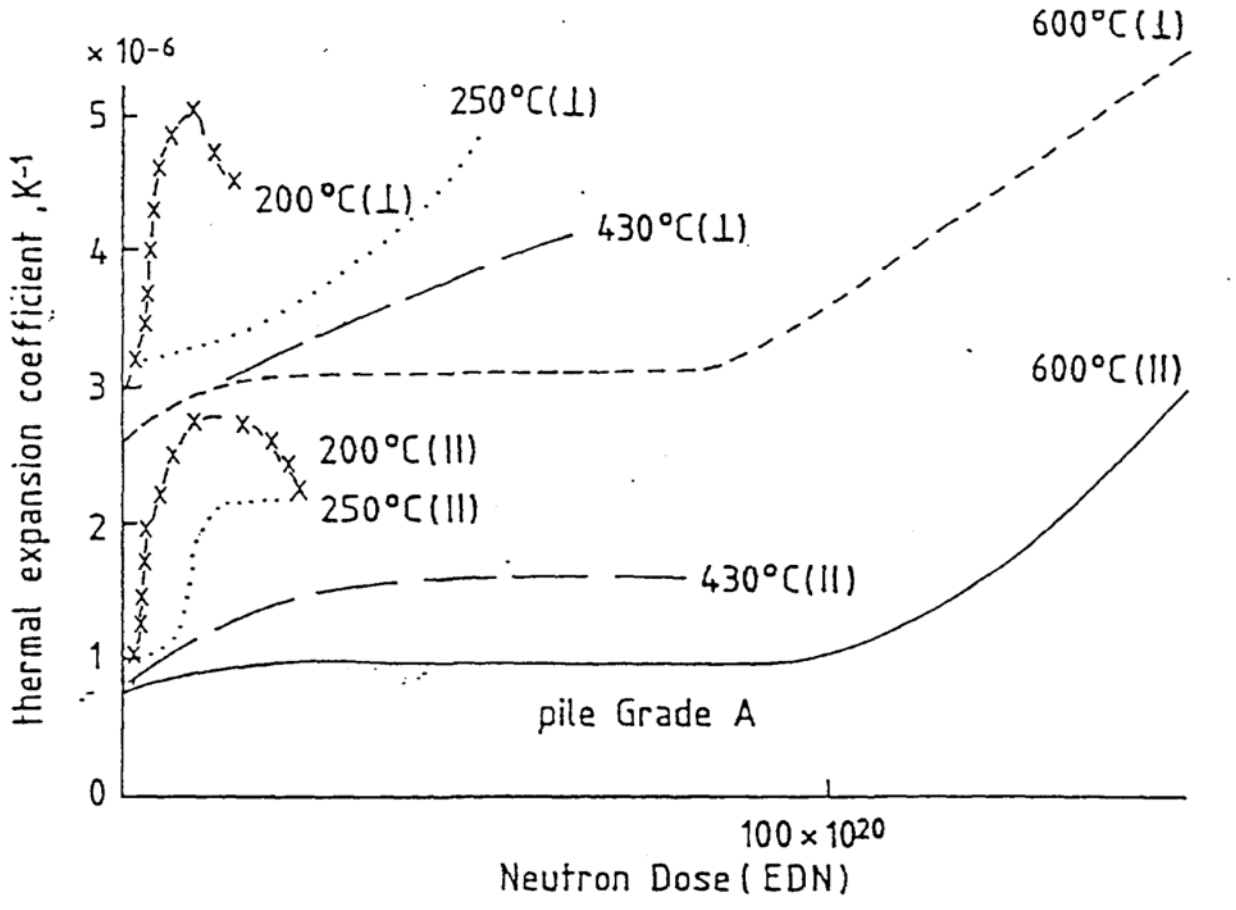
Moderator

- Graphite exhibits complicated changes with irradiation, temperature and stress that are not yet well-understood
  - Swelling/contraction
  - Thermal expansion coefficient, and thus fuel tube dimensions

- MSRs require higher flux because fissile density is lower

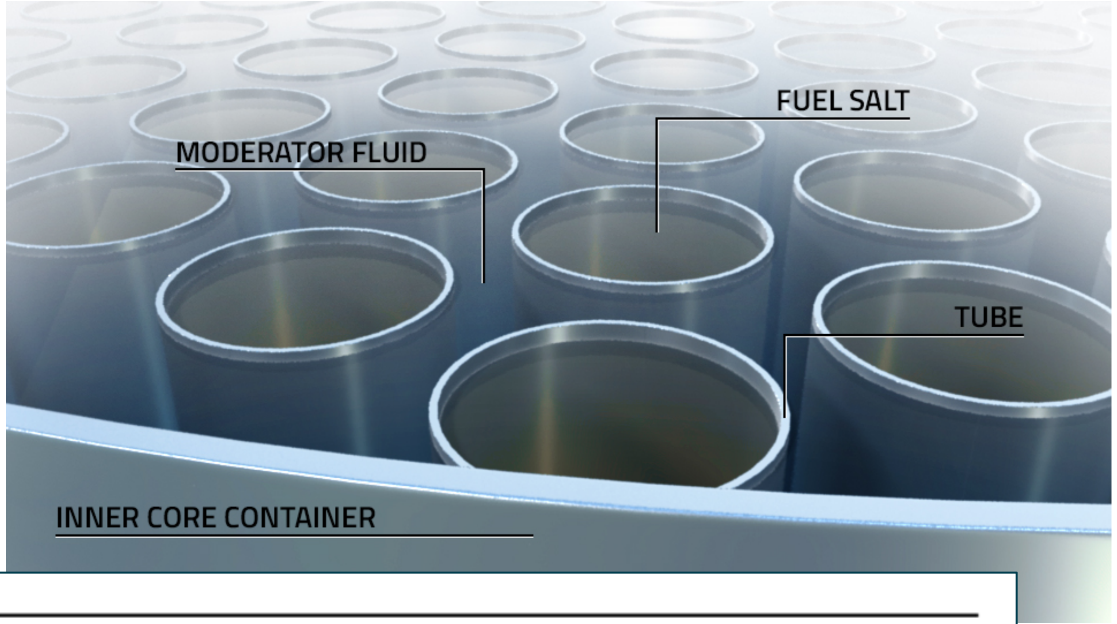
- Past graphite reactors were generally low power density
  - MSRE, Gas-cooled reactors

- Four alternatives:
  1. Overcome graphite challenges (Chinese approach)
  2. Avoid graphite tubes (e.g. pebble bed)
  3. Non-moderated design – fast reactors (MSFR, Terrapower)
  4. Adopt novel moderator material



Seaborg solution - liquid moderator

- NaOH melts at 318 C, boils at around 1400 C
- Efficient moderator with 10 times slowing down power of graphite, about half of water
- Very affordable and long-lasting
- **Enables the ultra-compact design**
- Poses little long-term disposal problem
- Enables diverse reactivity control and residual heat removal
- There are also challenges:
  - Corrosion/material concerns
  - Degraded neutronics performance compared to graphite



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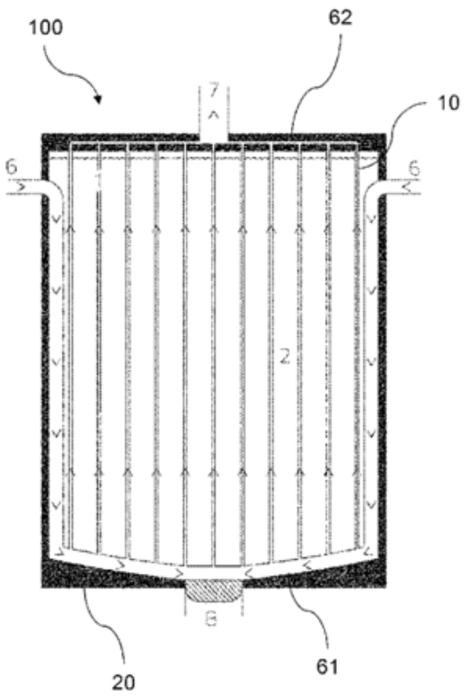
(54) Title: MOLTEN SALT REACTOR



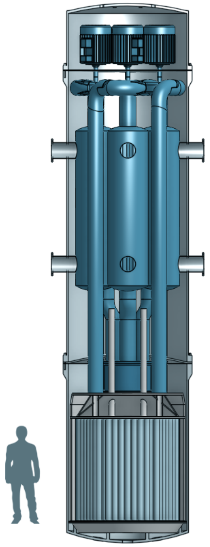
(57) Abstract: A device adapted for producing energy by nuclear fission, the device comprising a core container of a core container material, which core container encloses an inner tubing of an inner tubing material, the inner tubing and/or the core container having an inlet and an outlet, the device further comprising a molten fuel salt with a fissionable material and a molten moderator salt comprising at least one metal hydroxide, at least one metal deuteroxide or a combination thereof and a redox-element having a reduction potential, which is larger than that of the inner tubing material or of the inner tubing material and the core container material, wherein the molten moderator salt is located in the core container and the molten fuel salt is located in the inner tubing, or wherein the molten fuel salt is located in the core container and the molten moderator salt is located in the inner tubing. The invention also relates to methods of controlling nuclear fission processes using the device and to the use of a molten salt comprising at least one metal hydroxide, at least one metal deuteroxide or a combination thereof and a redox-element for moderating fission neutrons created in a fission reaction process.

patent published

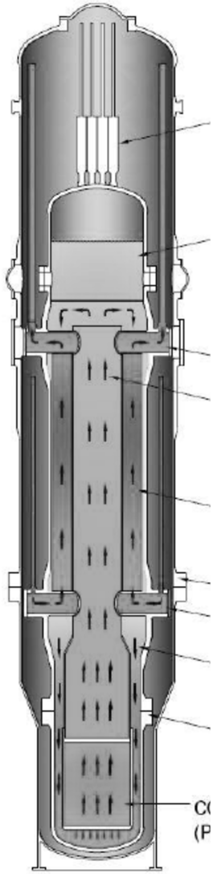
Proprietary ultra compact design

Most importantly our proprietary moderator avoids the use of graphite. Additionally it gives us three unique advantages:

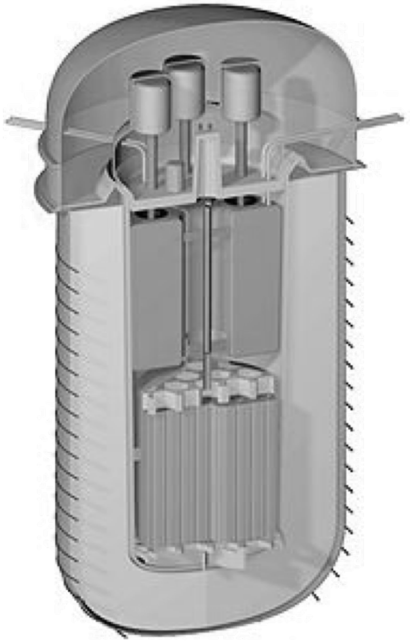
1. 12 years of operation without refueling
2. Economical at low power (100MW).
3. **Unprecedented compactness (container-sized reactor module)**



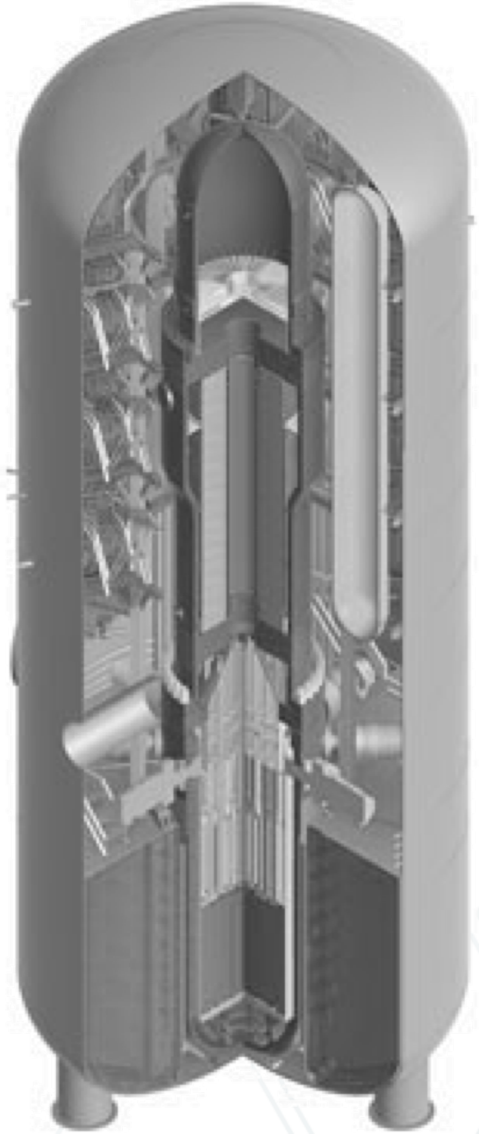
Seaborg CMSR
250/100 MW



NuScale LWR
160/70 MW



Downscaled IMSR
300/125 MW



Westinghouse LWR SMR
600/225 MW

Small and modular means factory production

Nuclear modules are assembled in a factory like wind turbines or planes and shipped to the site of the power plant

Most testing & QA is on the factory floor

Educated work force stationary – learning

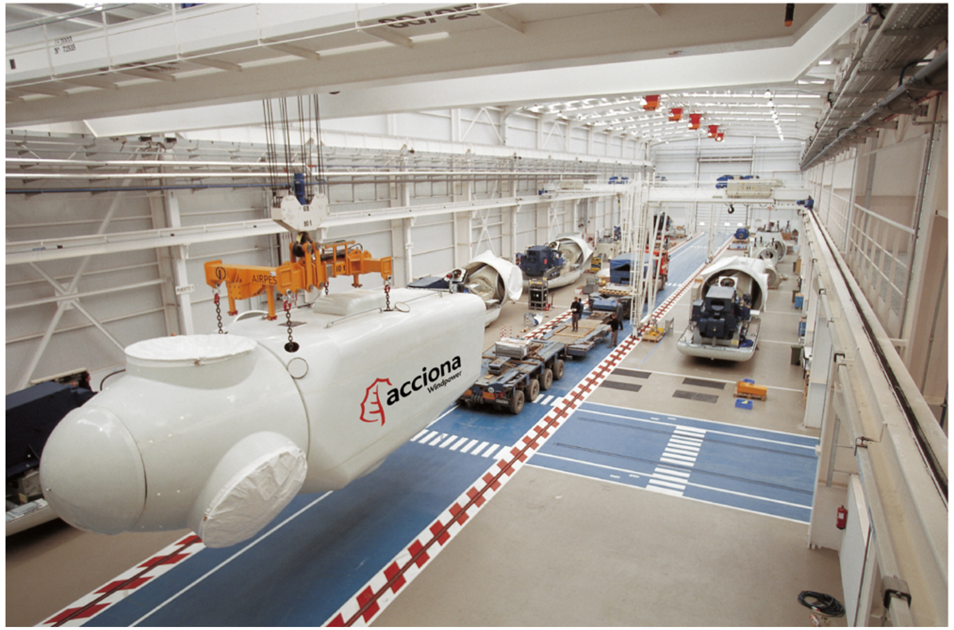
Economy of scale in serial production

Stationary supply chain

Shorter plant build time

Smaller project risk

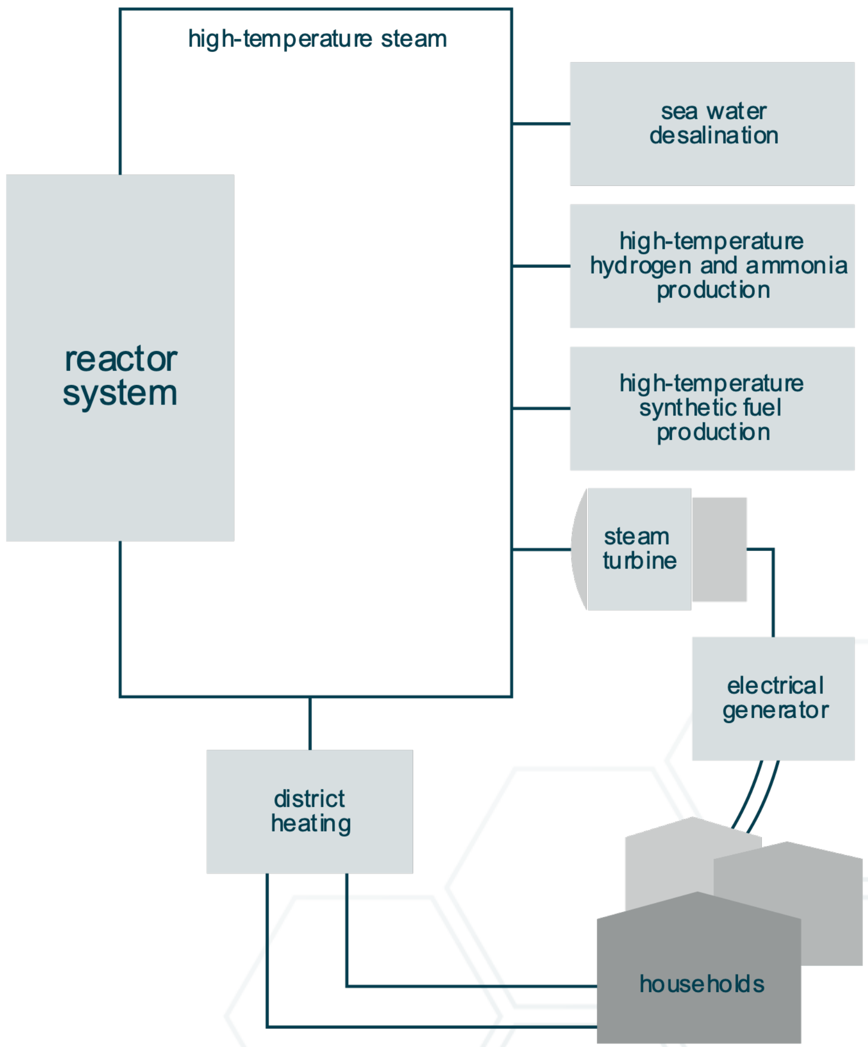
Reduced financial risk



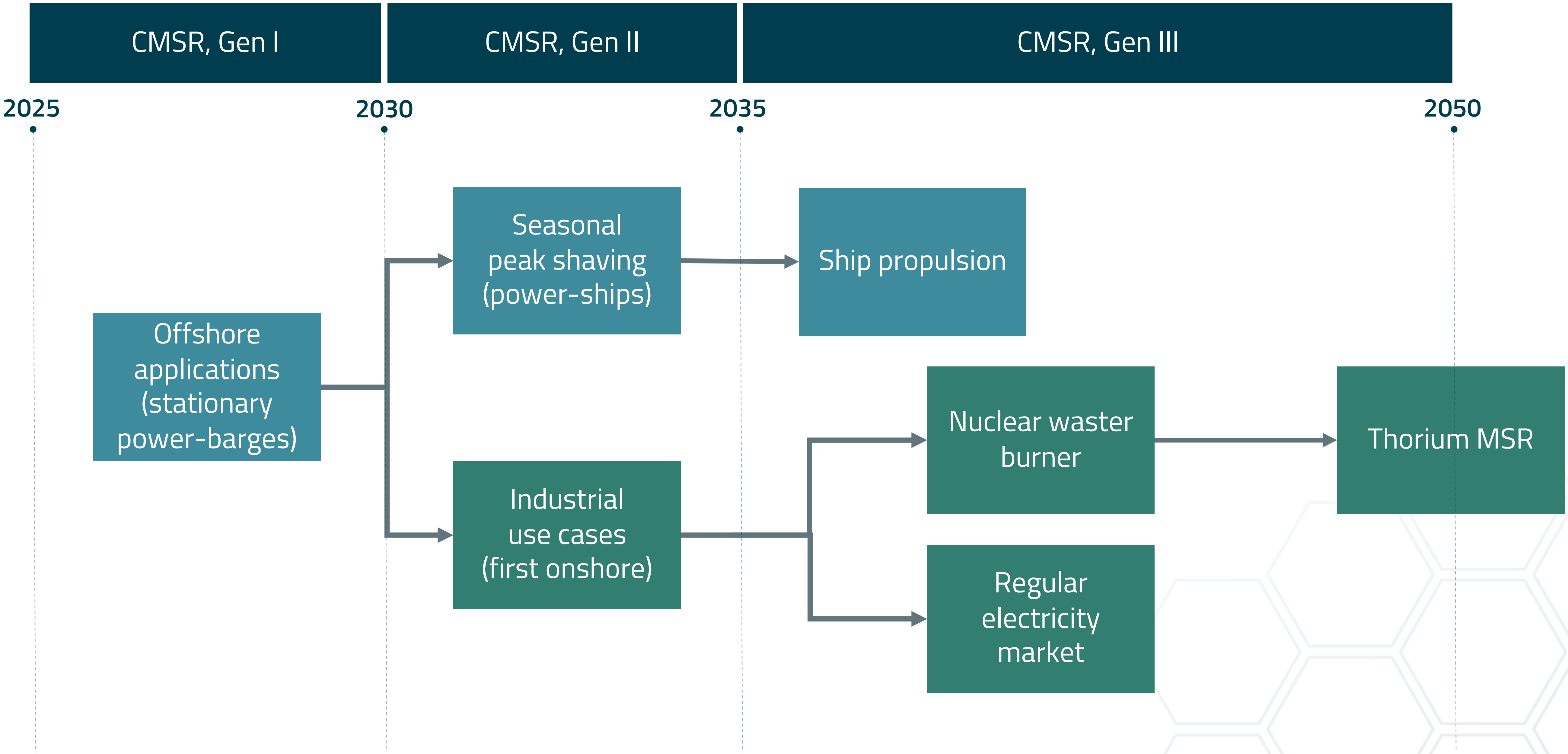
- A UK study into the costs of small modular reactors has estimated that the efficiency lost due to the small size is made up for in the gains from serial production - for conventional reactors.
- Molten salt reactors are cheaper to make than conventional reactors due to simpler design
- Seaborg's compact molten salt reactor reduces the costs further due to its smaller size

Applications

- The Seaborg CMSR **power** plant can produce 250MWt/100MWe (power for 200,000 homes)
- This can be coupled with 125MW district **heating**/cooling, **desalination** ⇒ increasing revenue stream
- Excellent load following capabilities – as fast as natural gas
- Can be deployed decentral or with several power units linked to replace a coal plants.
- Excellent for high temperature applications, e.g. production of: **synthetic fuel**, **hydrogen**, **ammonia**, fertilizer, medical, etc.
- Small enough to fit in the larger cargo- (and tanker) ships



Reactor Markets



Propulsion

- The CMSR is the worlds smallest at it’s power capacity - fits engine room in vessels.
- Provides electricity and heat (cooling - e.g. reefers)
- Several financing models could be deployed – the power train could be bought with the vessel but could also be licensed at fixed yearly rate
  - Current CAPEX and OPEX estimates puts the yearly cost **including fuel** below $30m.
  - This includes all systems to 100MW electric output (steam generator, turbine + generator) and it includes the price of refuelling that will happen every 10 years and the consumed fuel.
- Fuel is in core and storage tanks – no need for fuel tanks increasing container storage
- Many ships today are already diesel-electric
- Higher speed
- Challenge: legislation and public concerns!

Seaborg Technologies

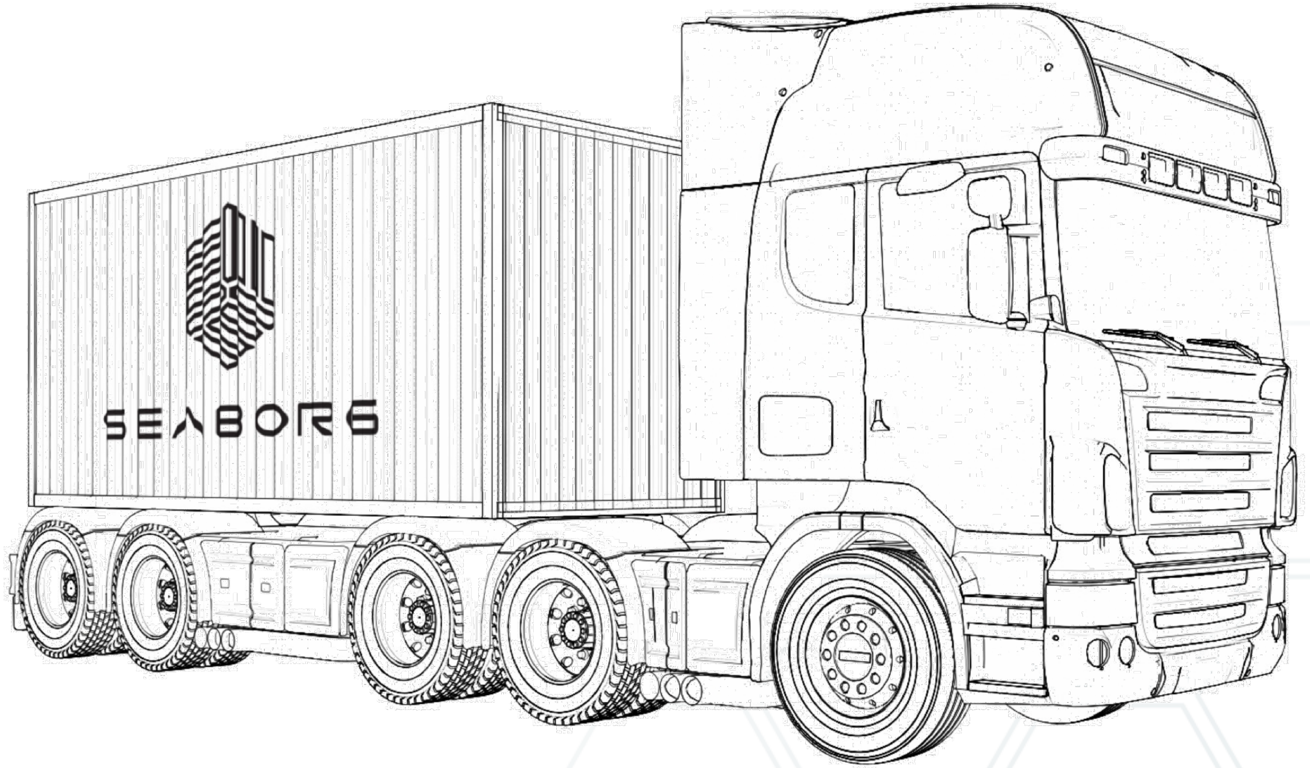
19 employed – with 8 PhDs and people from 4 continents
(plus students and interns - BSc, MSc and PhD) and 7 planned hires
Korea , US and Polish office opening

Leading tech contester (outside the Great Wall):
- World leading in MSR physics
- Chemical **experiments started**
- Technical design phase and licensing process initiated (ABS)

We are engaged with the East Asian **supply chain and shipyards**:
- "To jointly Develop, License and Manufacture Seaborg's CMSRs"

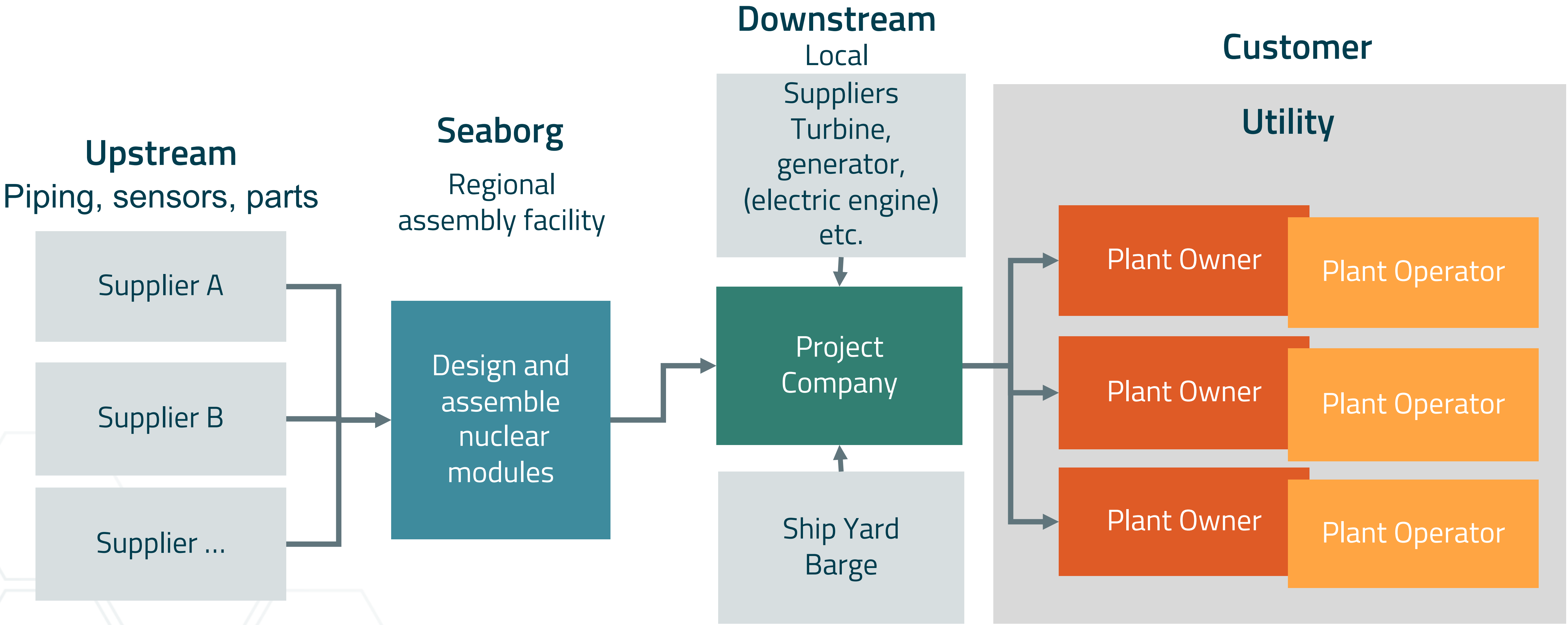
We are in dialogue with a potential **customer**:
- Interested in 10-15 units by the late 2020s

Funding sources:
- Mainly from **private investors**
- Geared by public funding (both DK and EU)
- Some revenue



Bonus Slides

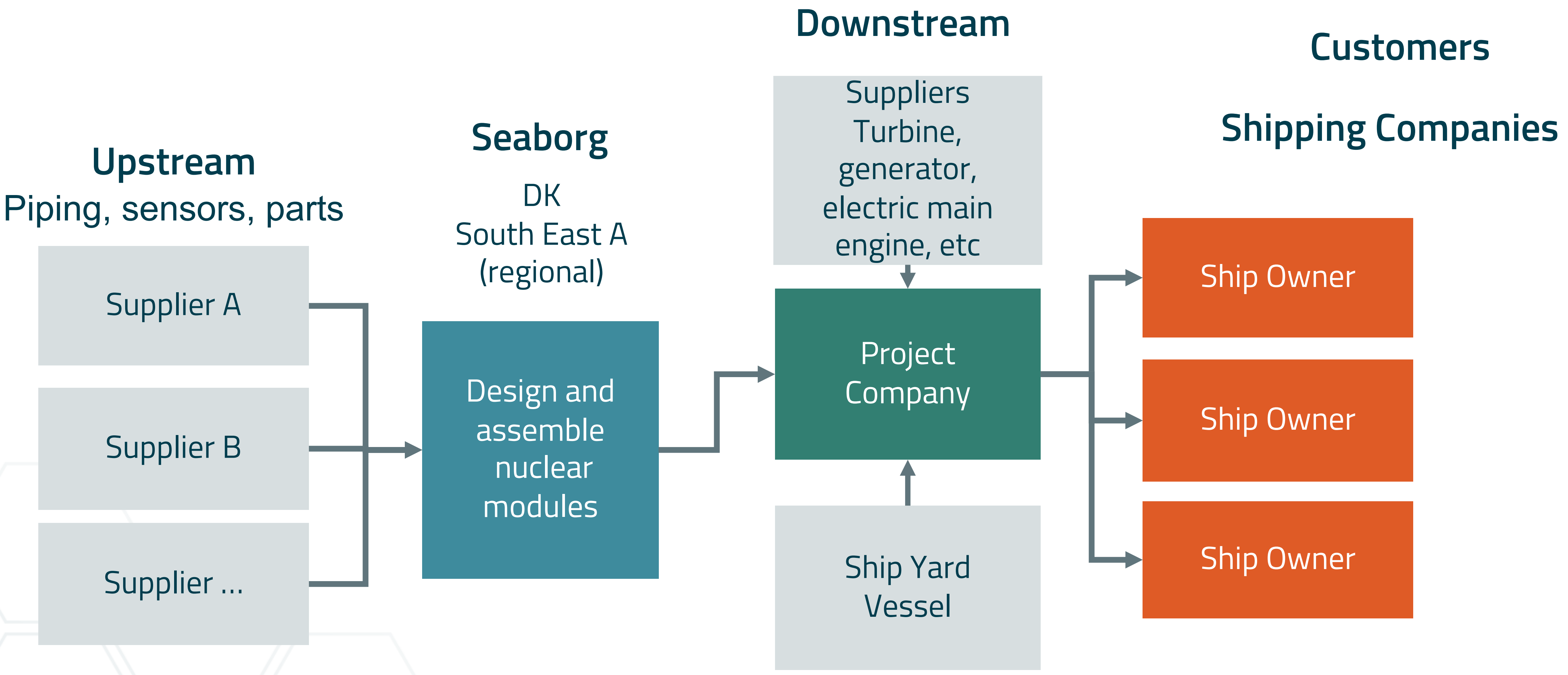
Supply Chain Setup



Nuclear island and supporting systems → Turn-key project → Complete Power Plant

Seaborg role is to design and manufacture the Nuclear Steam Supply System

Supply Chain Setup – Maritime propulsion



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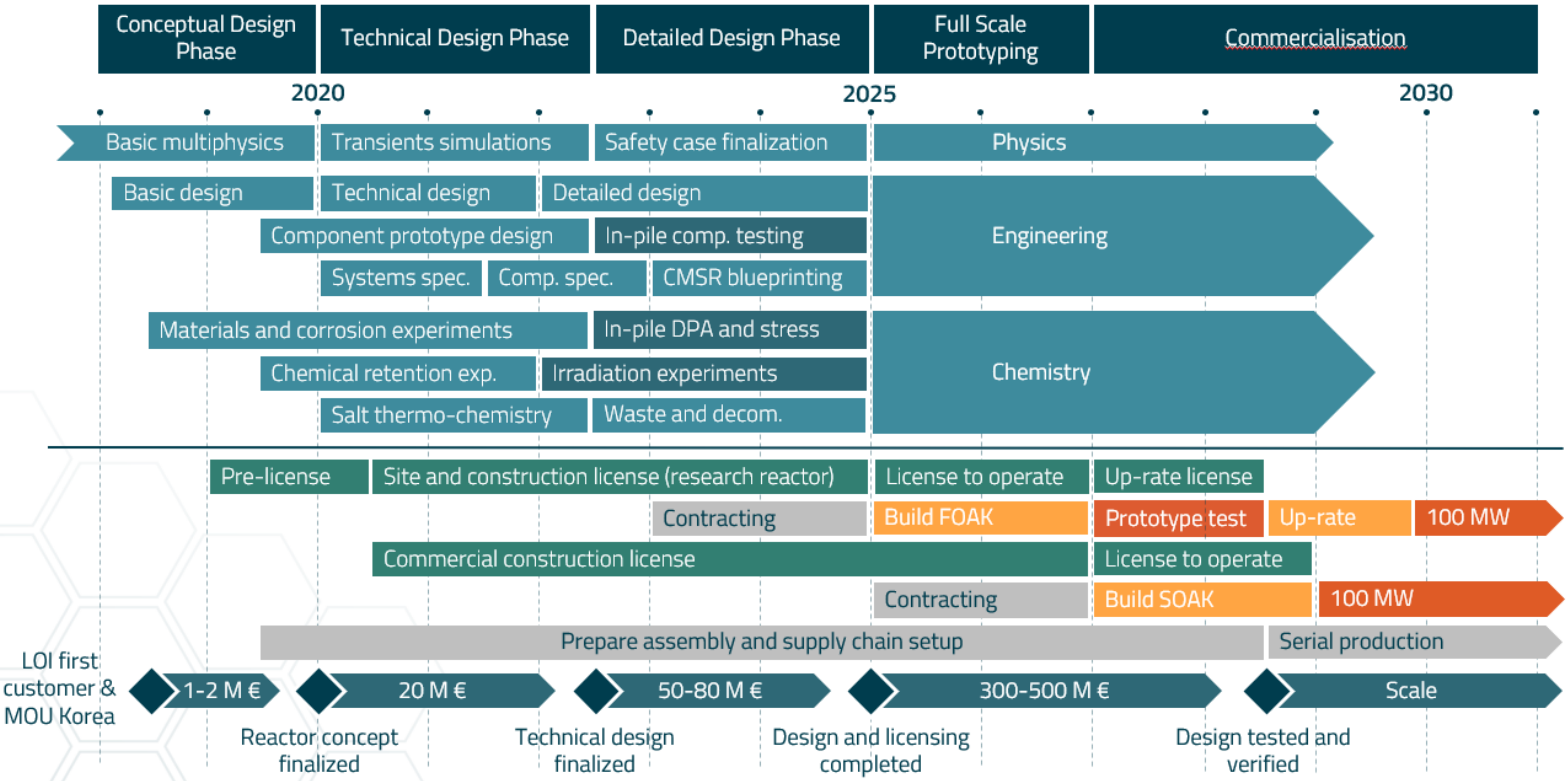
Master Plan

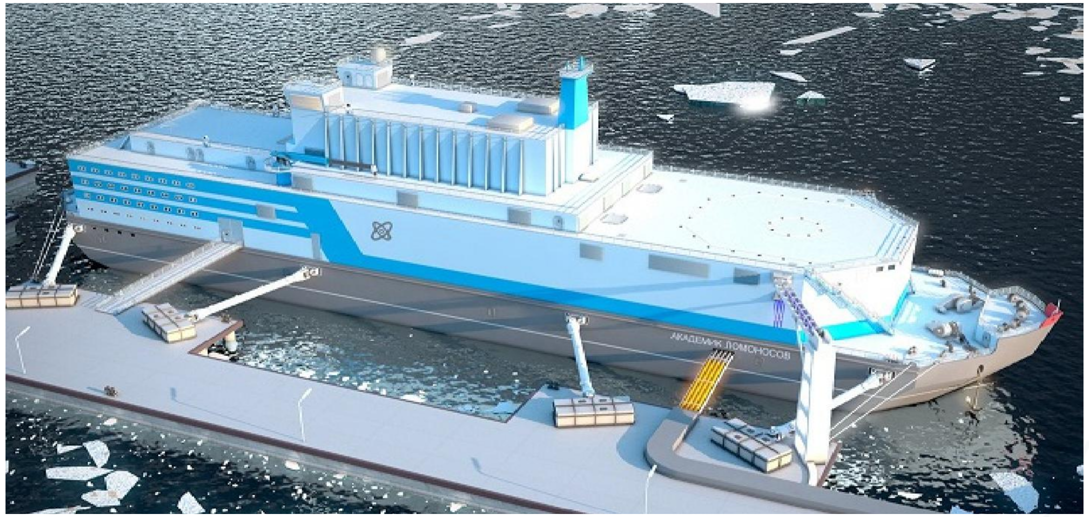

Conceptual Design Phase
Technical Design Phase
Detailed Design Phase
Full Scale Prototyping
Commercialisation
2020
2025
2030
Basic multiphysics
Transients simulations
Safety case finalization
Physics
Basic design
Technical design
Detailed design
Component prototype design
In-pile comp. testing
Systems spec.
Comp. spec.
CMSR blueprinting
Engineering
Materials and corrosion experiments
In-pile DPA and stress
Chemical retention exp.
Irradiation experiments
Salt thermo-chemistry
Waste and decom.
Chemistry
Pre-license
Site and construction license (research reactor)
License to operate
Up-rate license
Contracting
Build FOAK
Prototype test
Up-rate
100 MW
Commercial construction license
License to operate
Contracting
Build SOAK
100 MW
Prepare assembly and supply chain setup
Serial production
LOI first customer & MOU Korea
1-2 M €
20 M €
50-80 M €
300-500 M €
Scale
Reactor concept finalized
Technical design finalized
Design and licensing completed
Design tested and verified

Floating Nuclear Power Plants

- Utilize the ship yards effectiveness of manufacturing
- Pre-commission in port
- Turn key delivery
- Moveable asset

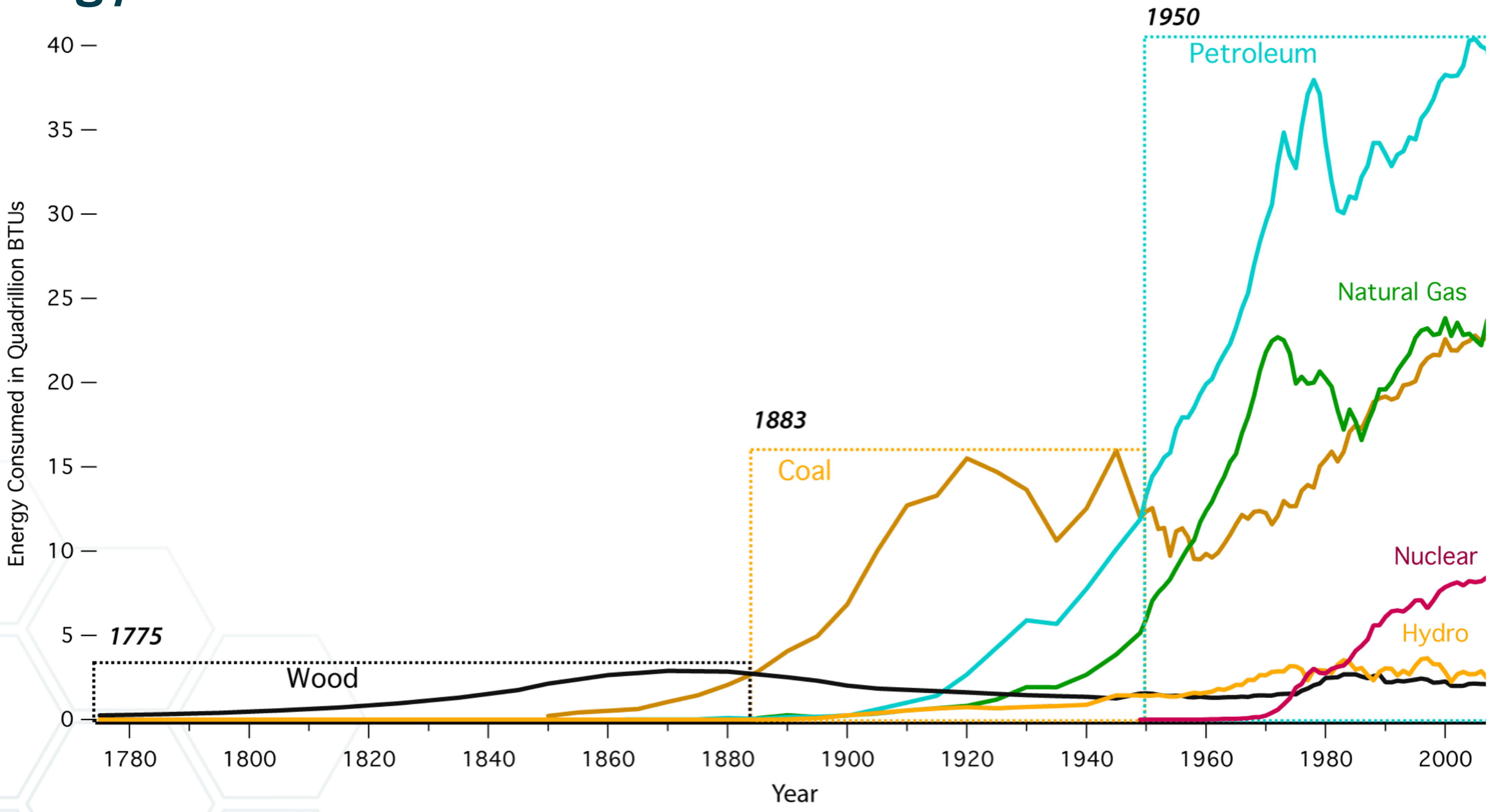
- Russia has build one 70 MWe (and have gotten 70 orders within 3 months)
- China plans 20 FNPPs

- For remote communities and mining operations in the beginning

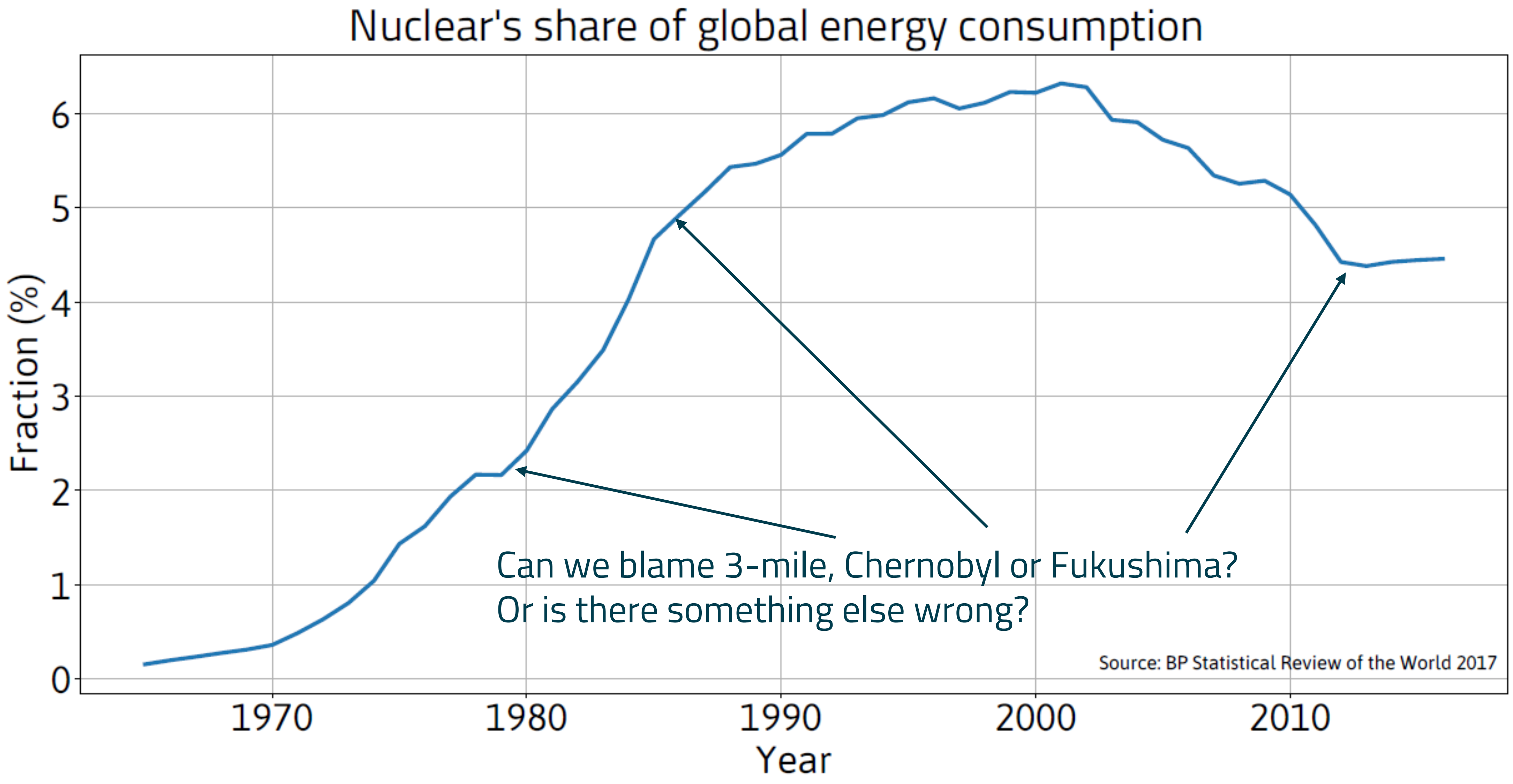


Why conventional nuclear failed

Energy revolutions



But why?


Nuclear's share of global energy consumption
Fraction (%)
0
1
2
3
4
5
6
1970
1980
1990
2000
2010
Year
Can we blame 3-mile, Chernobyl or Fukushima?
Or is there something else wrong?
Source: BP Statistical Review of the World 2017

1: LWRs

1: Inherently unstable systems

- 300 °C liquid water at 300 bar pressure
- 2500 °C in fuel center
  - Cooling MUST never fail
- Zirconium cladding
  - high temperature catalyst
- H_2 gas from hydrolysis
- Control very operator dependent
  - Balancing act

2: Solid fuel

2: Severity of accidents

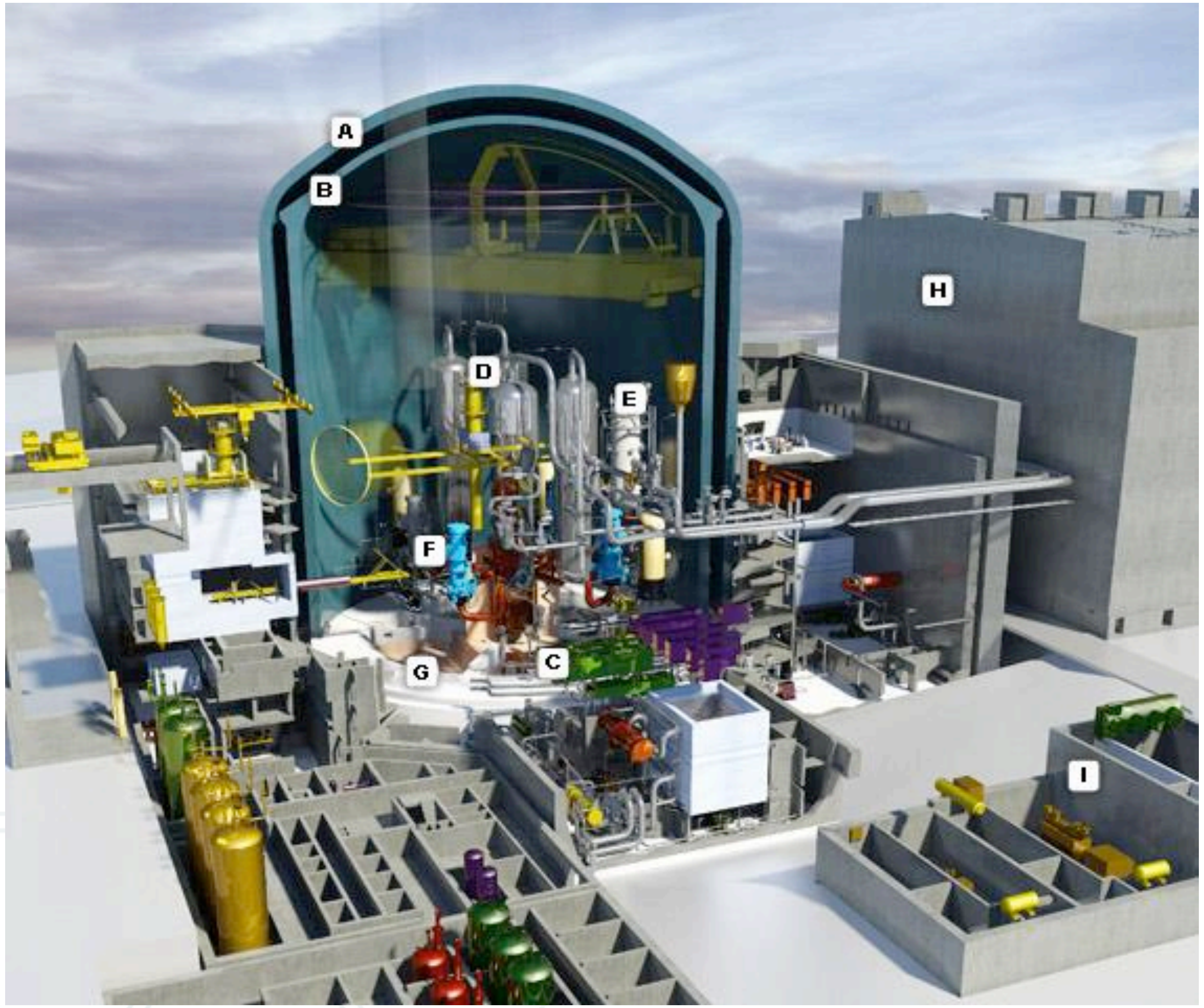
- Produces large amounts of TRUs
- Pu (and other TRU) and fission products are free radicals in the solid fuel

  (Easily reacts with atmosphere or water)
- Very volatile in environment

  - High solubility in water
  - Many are gasses
- Easily biologically consumed

  (cesium and iodine)

Solution: Safety-by-engineering



Severity of accidents and system instability
=> Safety-by-engineering.

Mainly innovation in safety => complexity
=> Costs, risk and delays.

Size becomes the economy of scale
=> Poor market fit and massive upfront investments

Larger reactors means increased severity
=> Even more focus on safety

In conclusion:

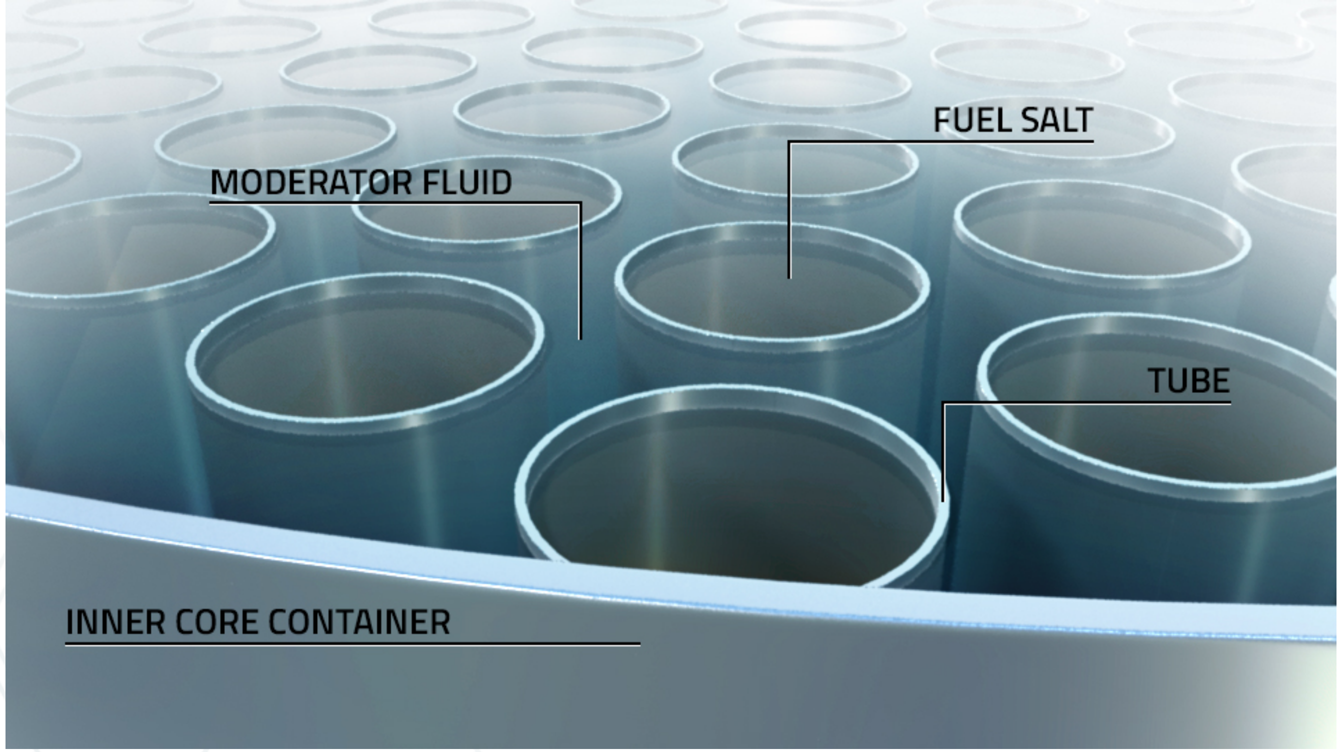
The nuclear industry did it wrong, and has become the largest barrier to worldwide deployment of nuclear power

A little bit of tech

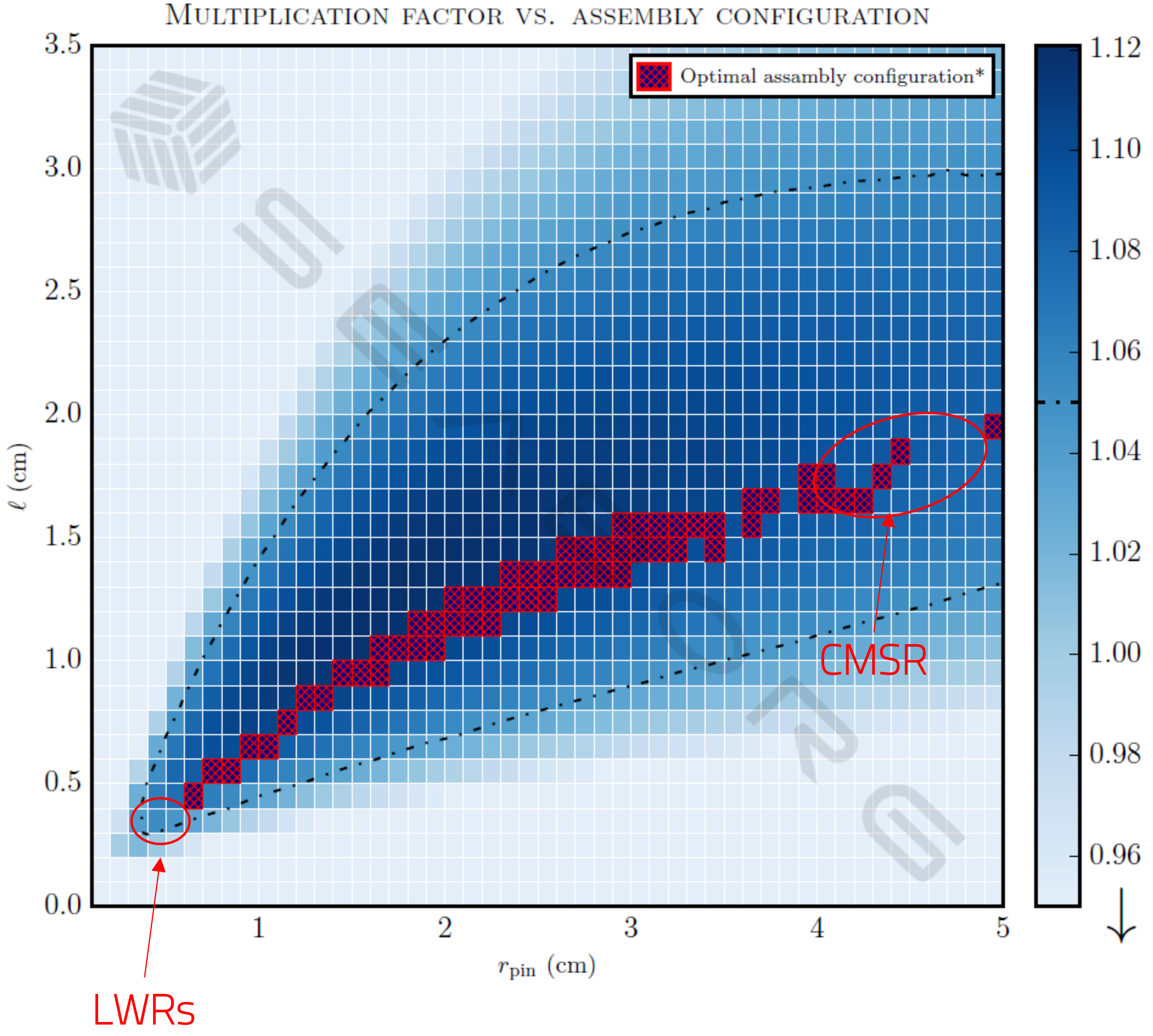
From vision to company

In 2014 **Reactive** was formed – working instead of talking
In 2015 we became **Seaborg Technologies ApS** and employed our first employee (plus 10ish volunteers)
In 2016 we doubled in size (First investment)
In 2017 we doubled in size, again (First grant)
In 2018 we doubled in size – twice (x4).
(If we keep it up, we will employ the world population by 2024)

Optimal configuration

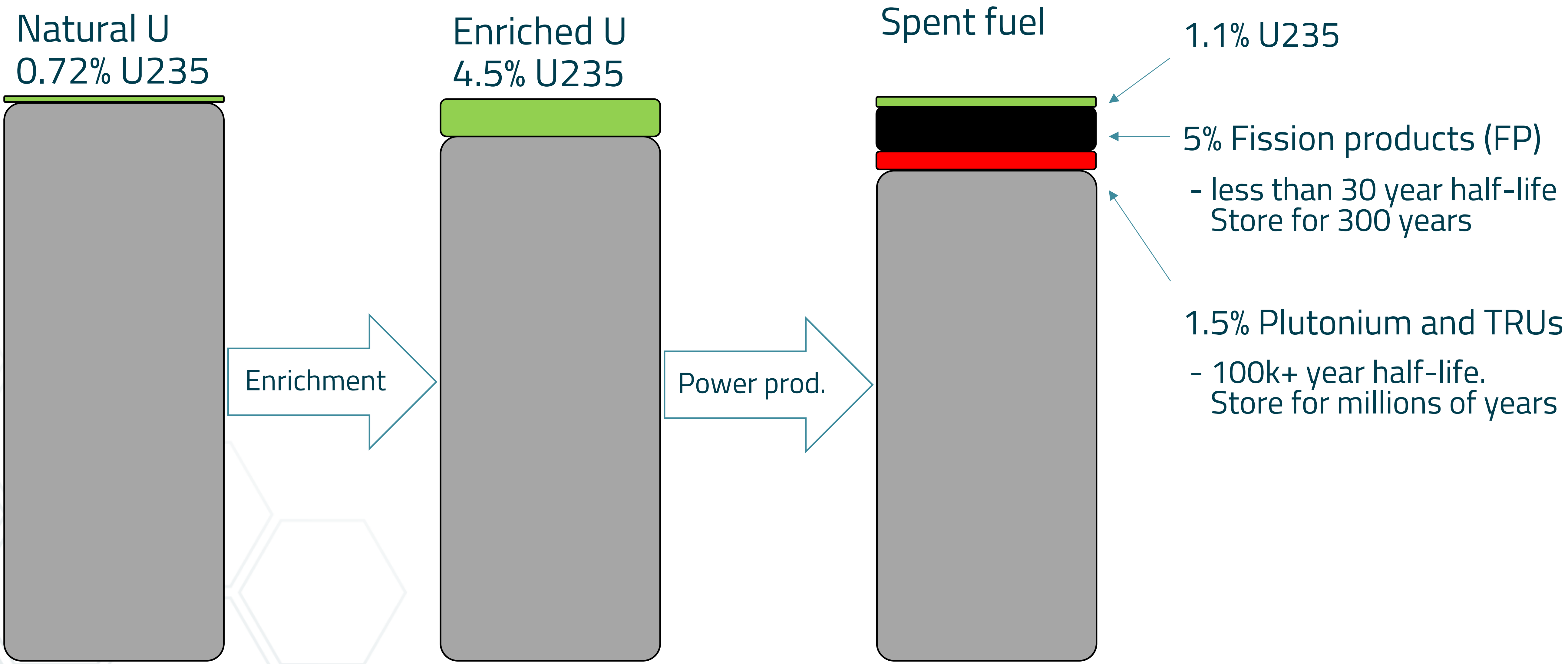


There are several upsides in our liquid moderator.
The most important one: **it's not graphite!**

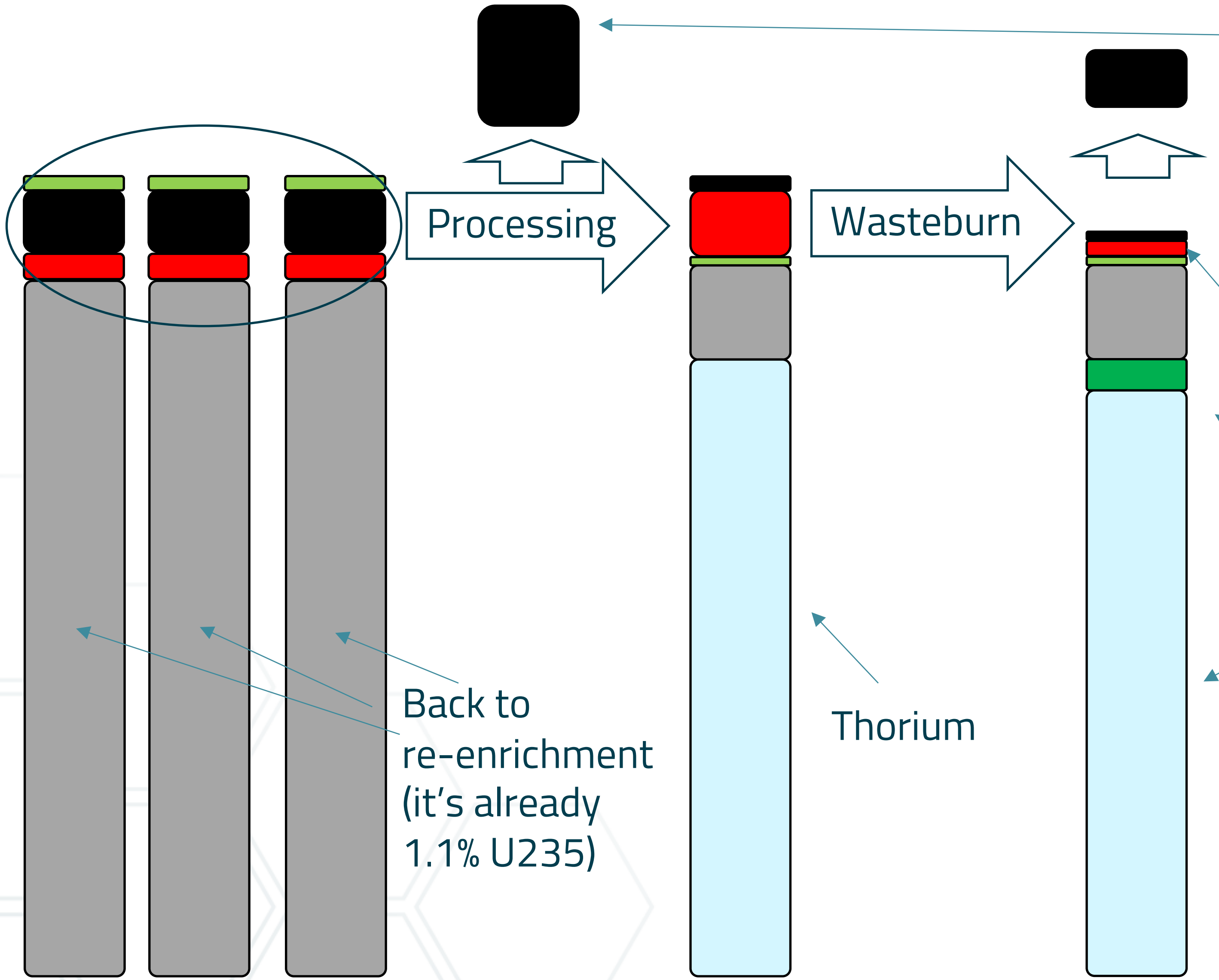


Nuclear waste,
waste-burning and thorium

Crash course in nuclear fuel and waste



Crash course in waste-burning



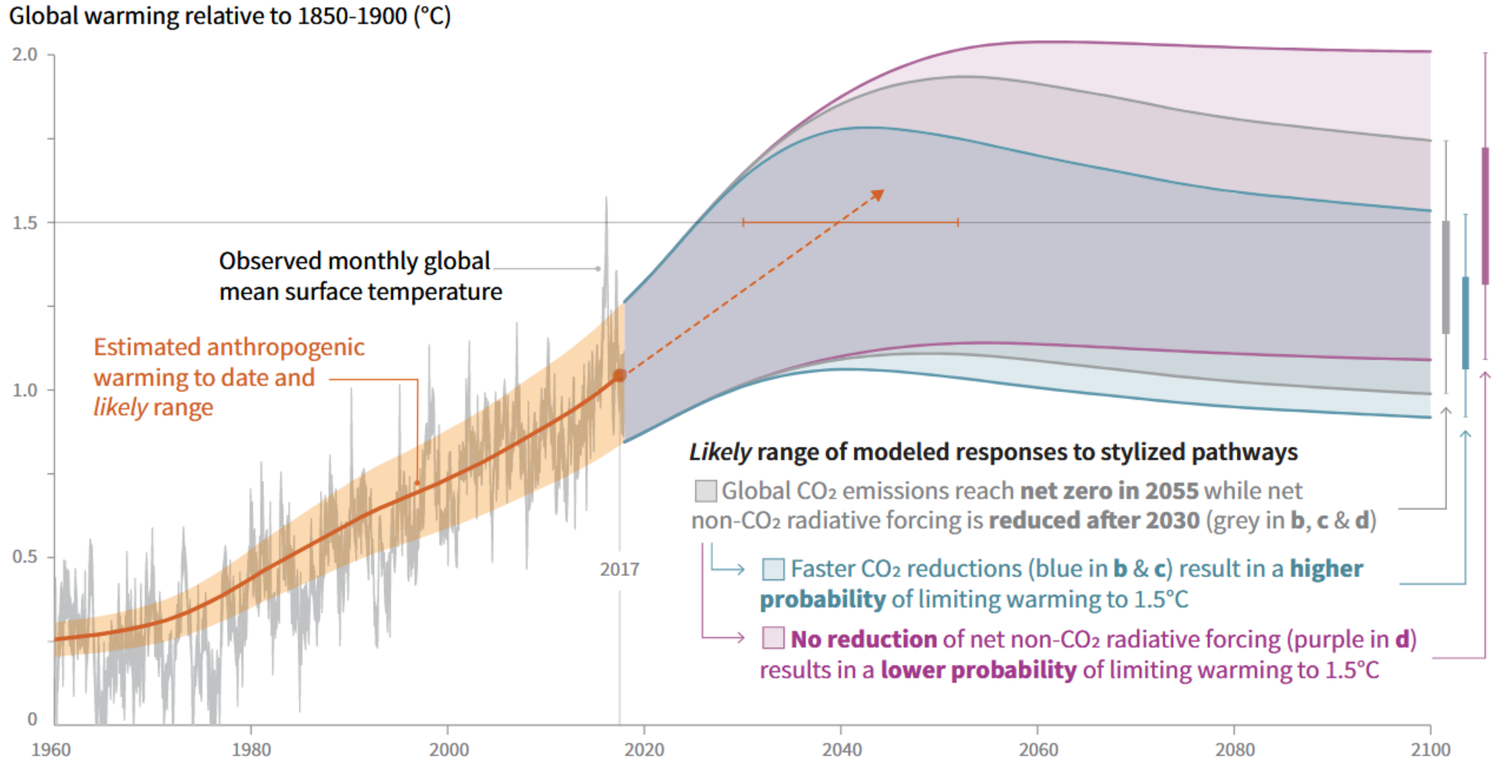
The **FPs** can be stored on a “intermediate” depot (a few hundred years).
This is **handled and stored routinely**, e.g in the medical sector. Some are valuable rare earth elements, others have important medical applications – these could be extracted.

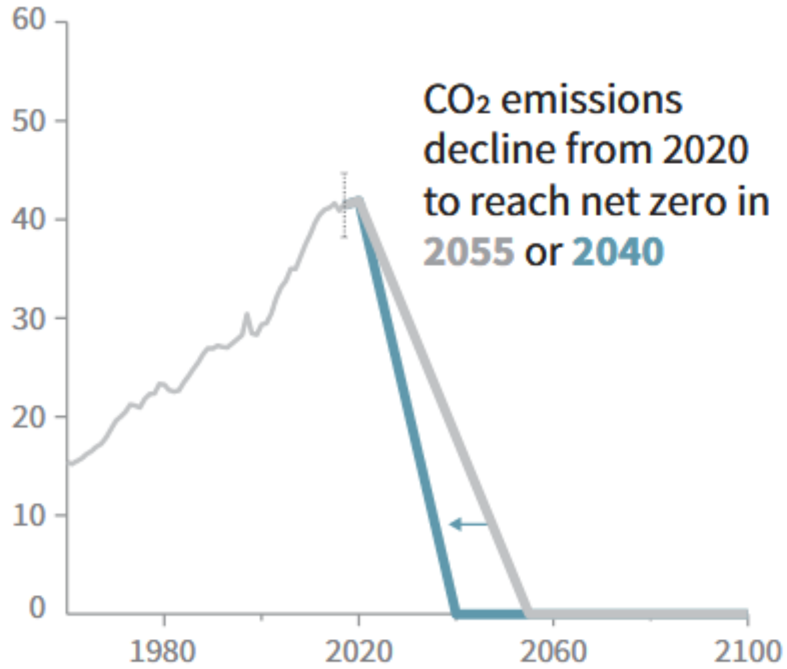
Pu and TRU can be reused in new Seaborg units.

U233 and Th is important to start future “thorium reactors”.

UN’s Climate Rapport – IPCC 2018

1.5°C will be disastrous – max. 35 years to fix it





Faster immediate CO_2 emission reductions limit cumulative CO_2 emissions