Comparative assessment of SMR technologies

28th January 2020

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TRACTEBEL ENGIE

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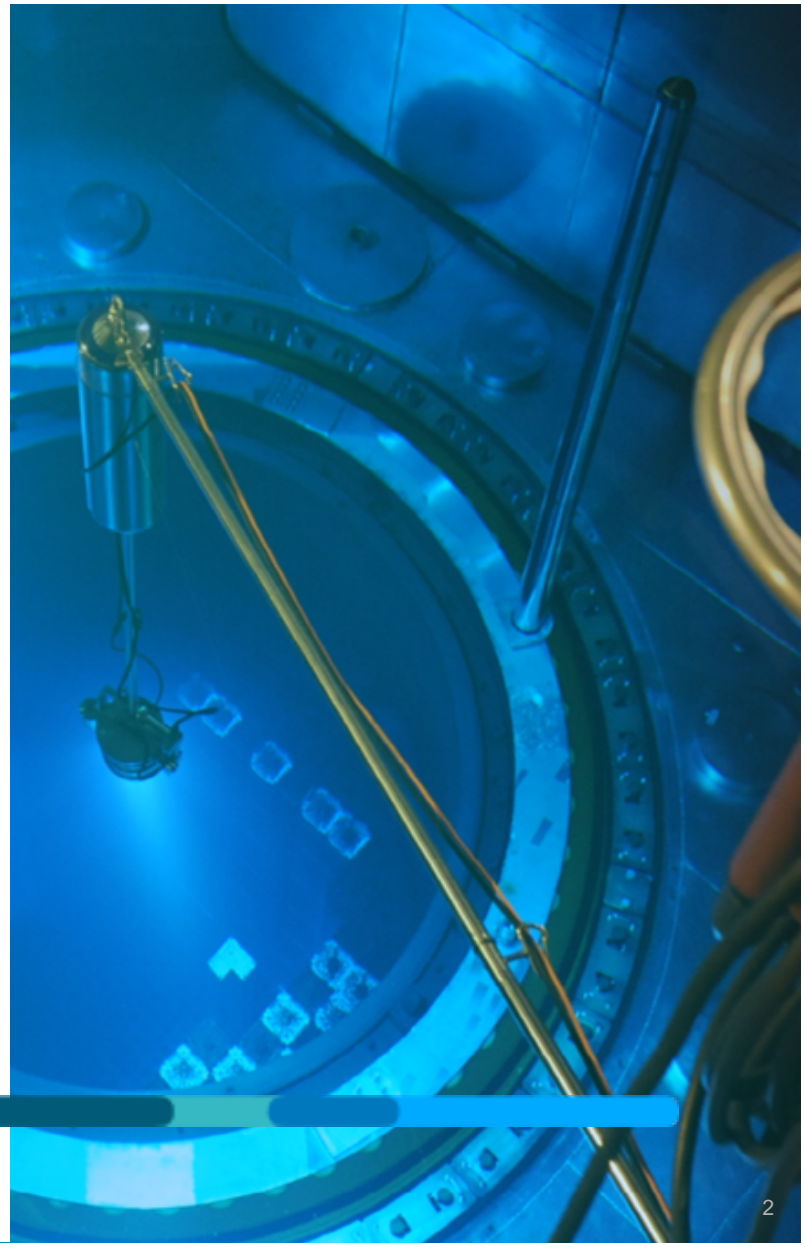
Context & introduction



Decarbonization is the challenge of this decade!

Generation III nuclear reactors are not the best fit for Estonia

- Huge Capital cost
- Construction delays and cost overruns
- Not adapted to smaller grids

Olkiluoto Unit 3 EPR (1650 MWe)

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Why are SMRs different?
A business model that contrasts with GenIII challenges in the West

The **challenges**	The **context**	The SMR **answers**
Foster nuclear investments?	Construction issues	Standardized modules
	Financial burden	Reduced project size
Recreate trust in nuclear safety?	Post-Fukushima concerns	Passive & inherent safety Extended grace period Limited EPZ
Role in zero-carbon transition?	Intermittent renewables	Flexibility
	Climate change	Non-electric applications
Concern of nuclear waste?	Political & public opinion	Reduction of nuclear waste through fast-spectrum SMRs

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Resilience to Severe Accidents
Example: Nuscale Triple Crown Safety

wnn world nuclear news

Energy & Environment | New Nuclear | Regulation & Safety | Nuclear Policies | Corporate | Uranium & Fuel | Wa

NRC agrees NuScale SMR needs no back-up power

10 January 2018

Share

The US nuclear regulator is satisfied that NuScale Power's small modular reactor (SMR) design can operate safely without the need for safety-related electrical systems. The reactor uses passive safety features, such as relying on convection, not pumps, to circulate water in the primary circuit.

Source: world-nuclear-news.com

No Operator Action

No AC or DC Power

No Additional Water

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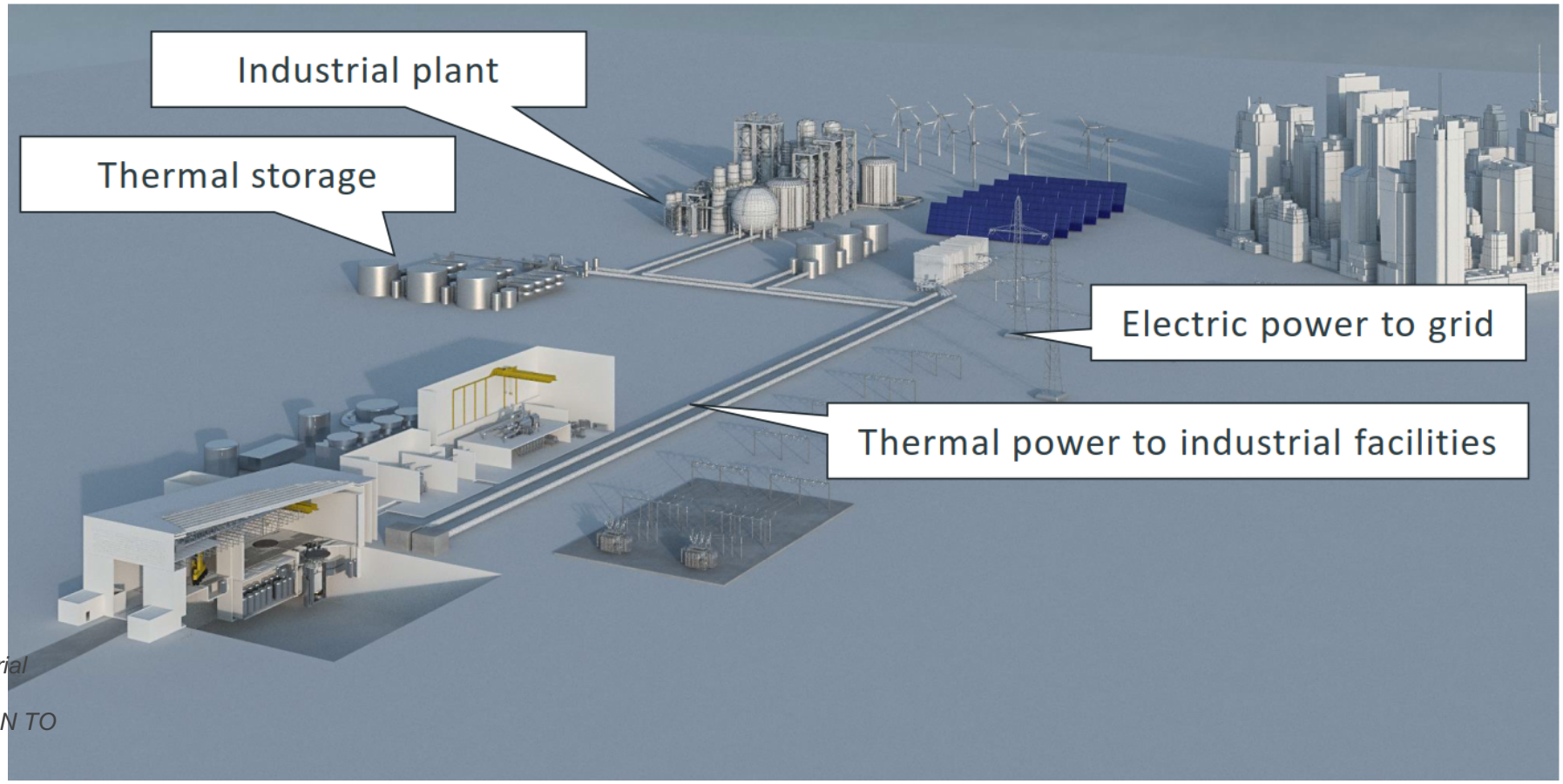
Flexibility & industrial heat
Terrestrial example



Source: Terrestrial Energy - IMSR PRESENTATION TO ICEF 2017

TRACTEBEL ENGIE market and technology watch for Small and Advanced Nuclear

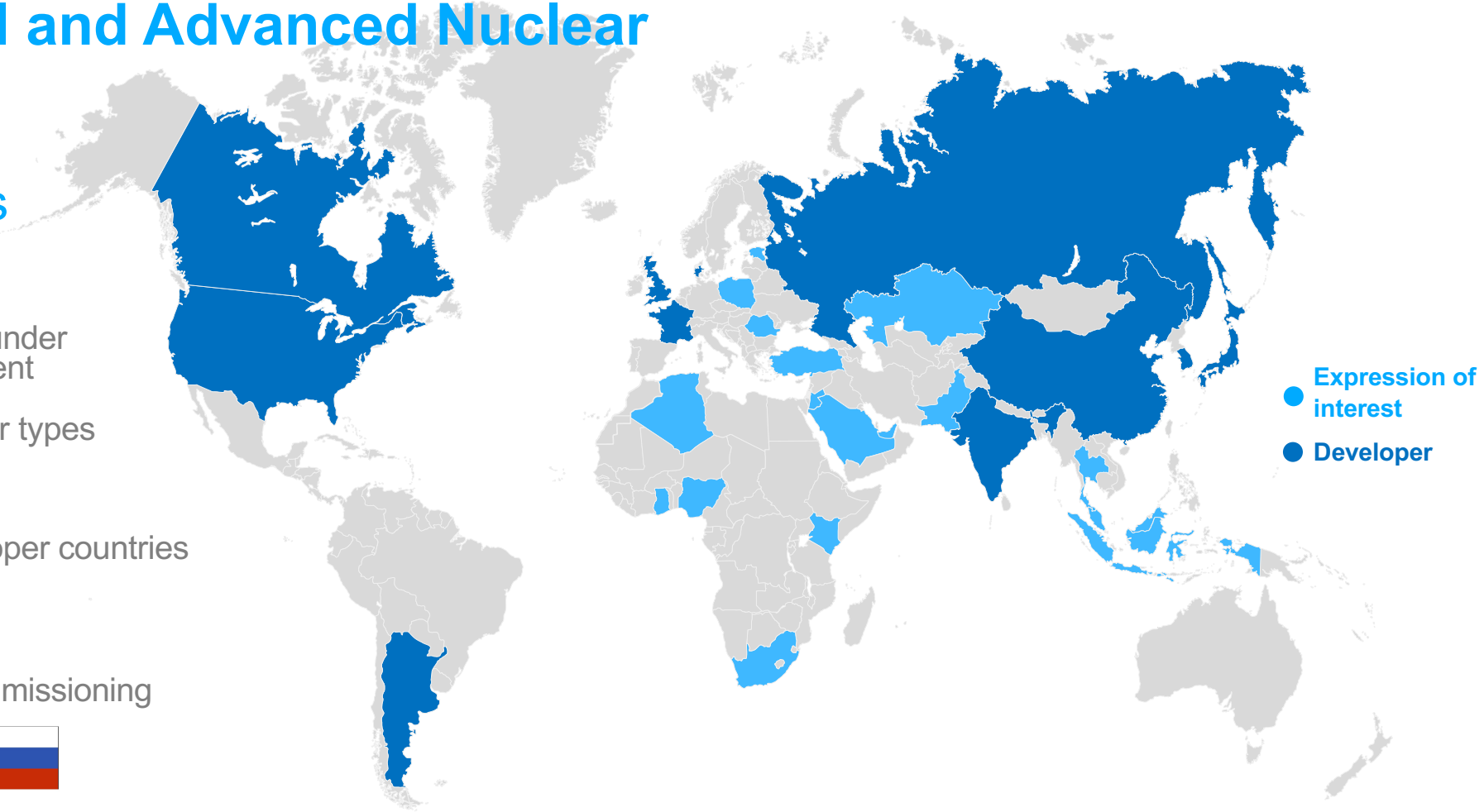
Key figures

+50 Products under development

+6 reactor types

10 developer countries

2 designs under commissioning



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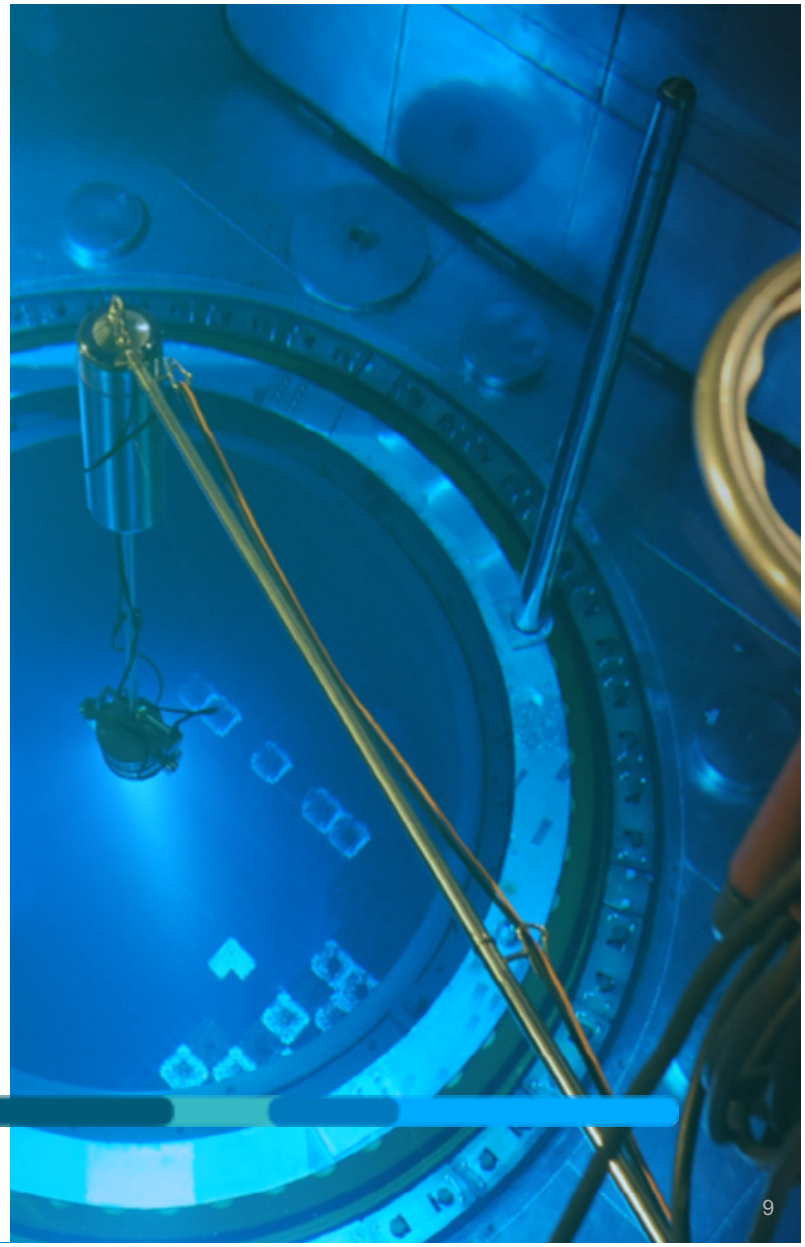
Comparative assessment



Survey of most promising technologies for Estonia

- +50 advanced reactor design initiatives
- Which ones will emerge?
- What are the critical success factors?
- Which ones are the most suited for Estonia energy future?

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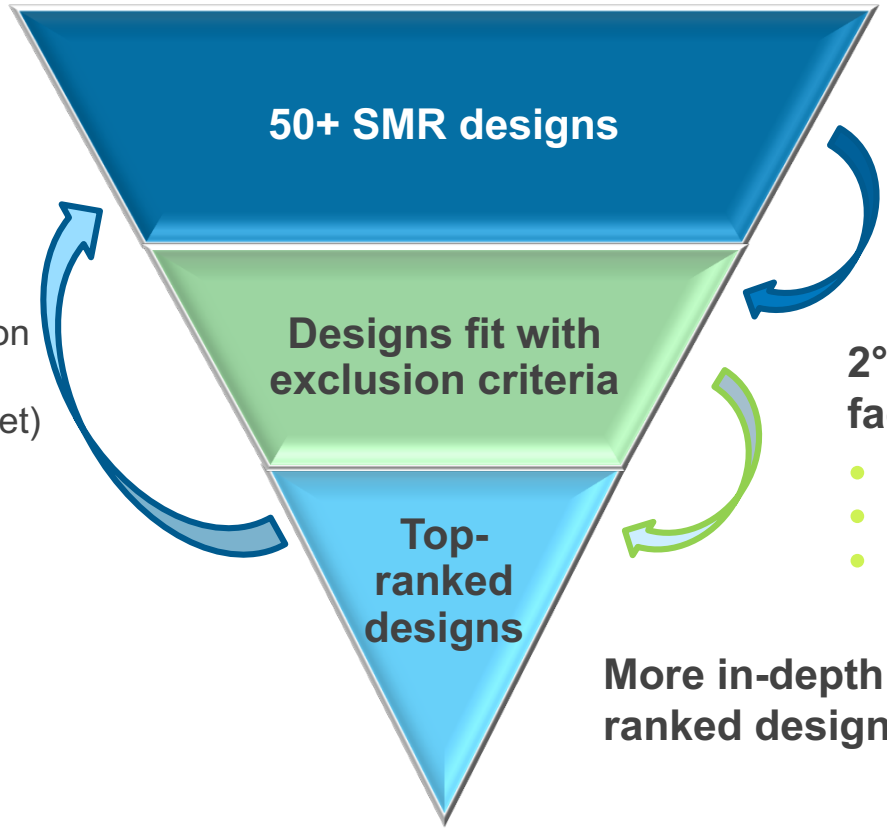
Down-selection Methodology



1° Exclusion of

- Very small reactors (<25MWe)
- Active safety systems required
- Time to FOAK > 2035
- Developers that are not likely partners for Fermi Energia

2° High-level assessment of critical success factors

- 1 to 5 scoring for each criteria
- Global score for each design by weighted sum
- Weight according to preferences profile

More in-depth assessment of top-ranked designs

2°bis Continuous market watch

- Periodic re-evaluation
- News follow-up (fast changing market)

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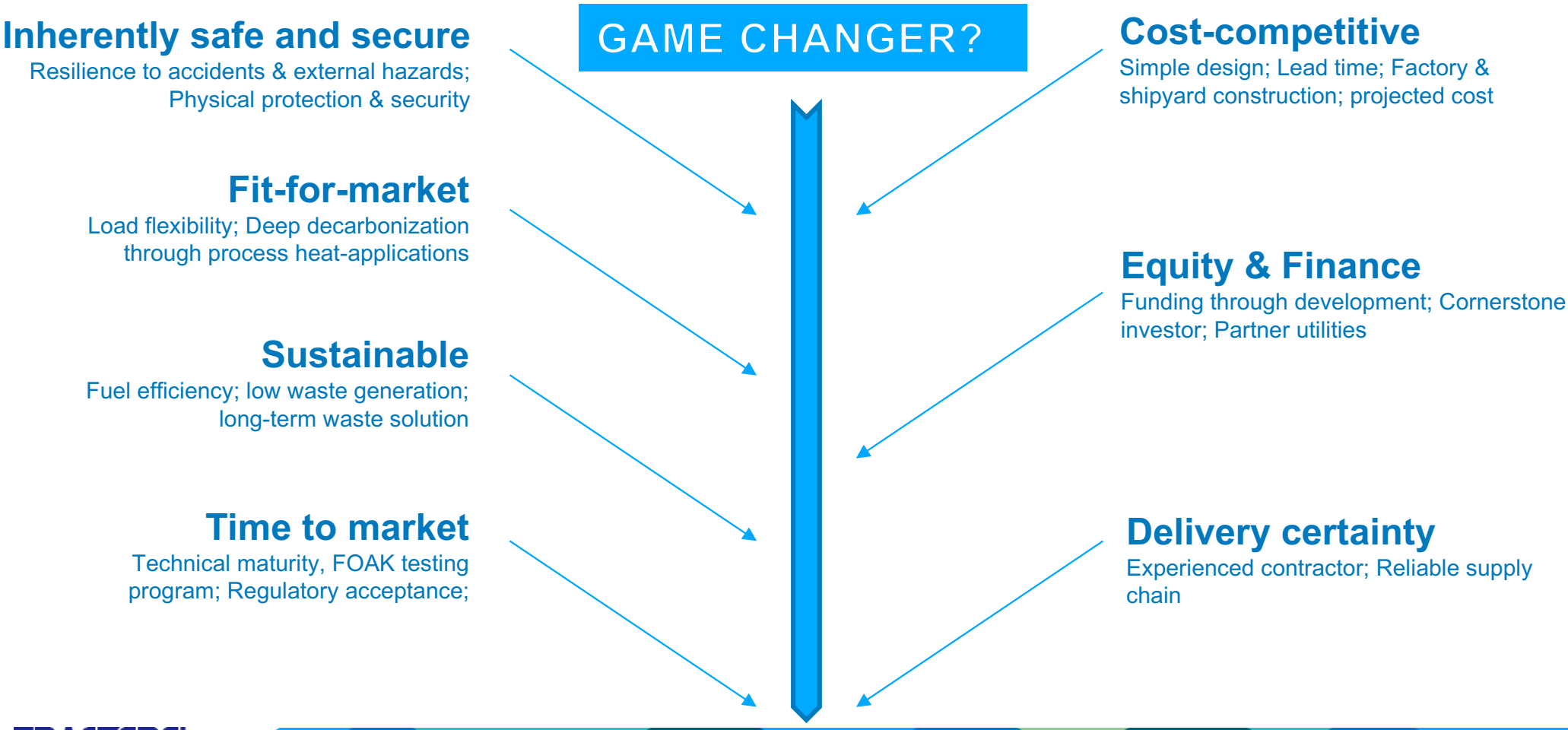
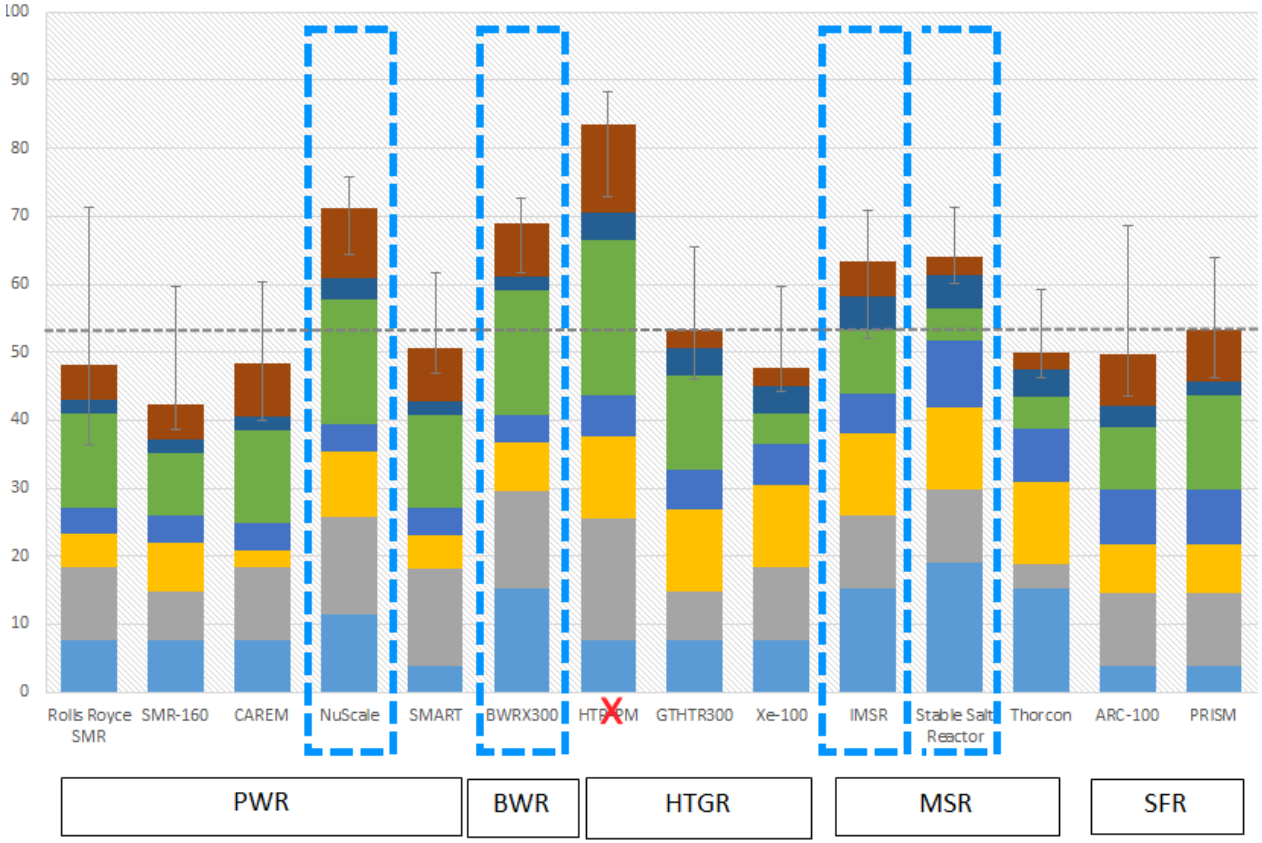
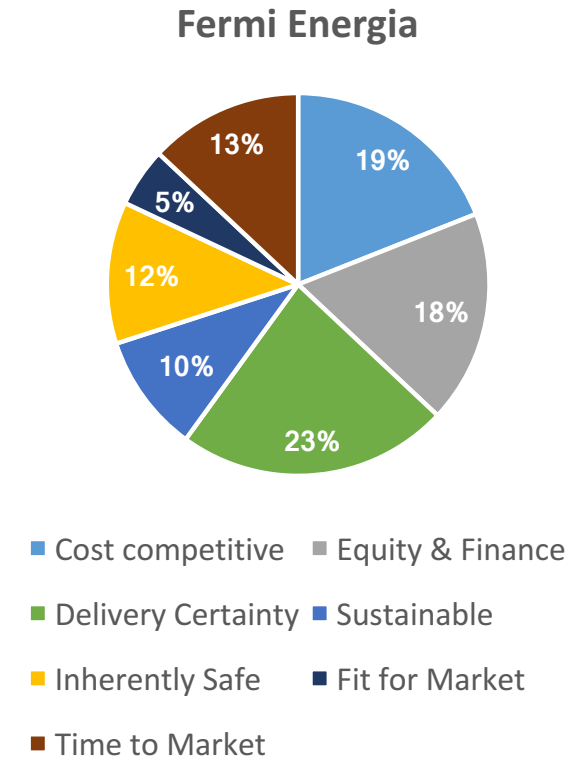
Assessment through Critical Success Factors



Assessment results
Fermi Energia weighting profile





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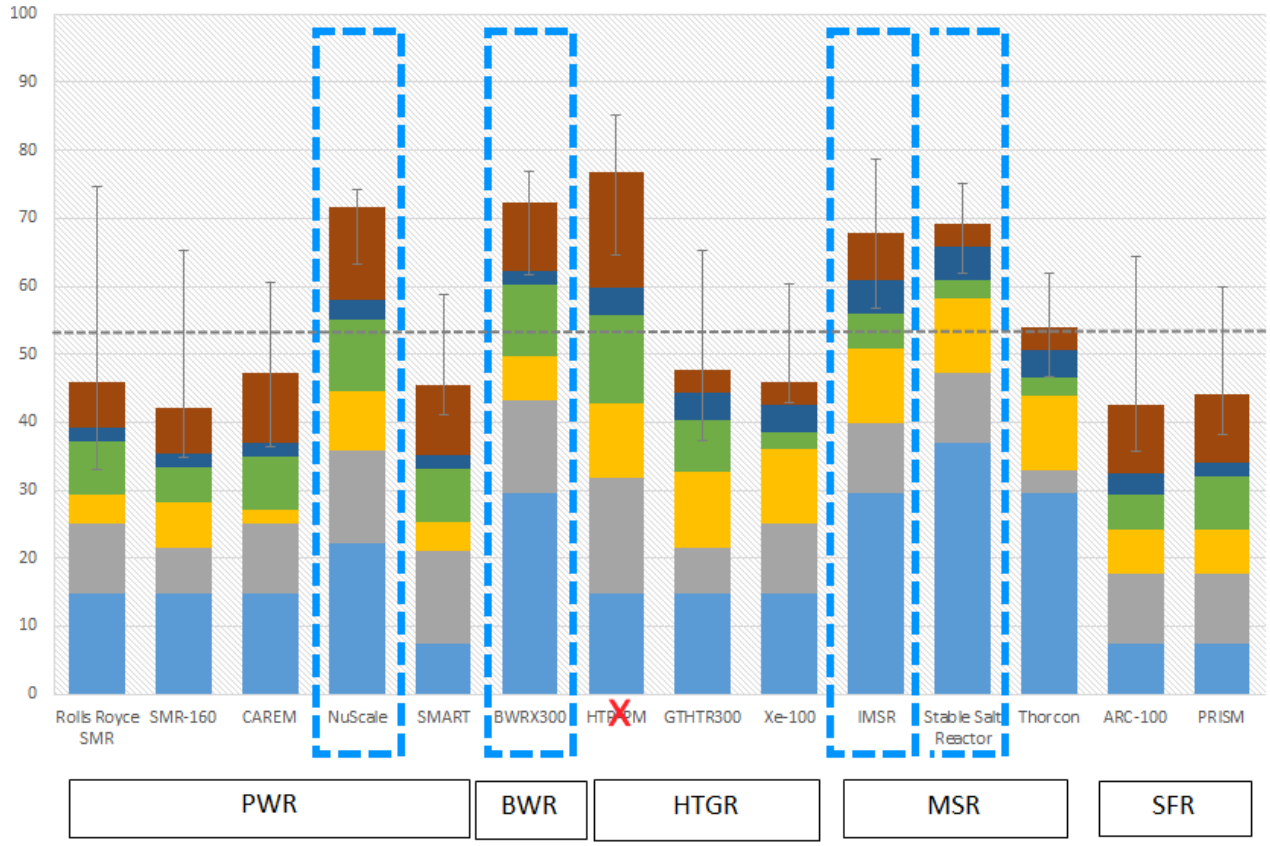
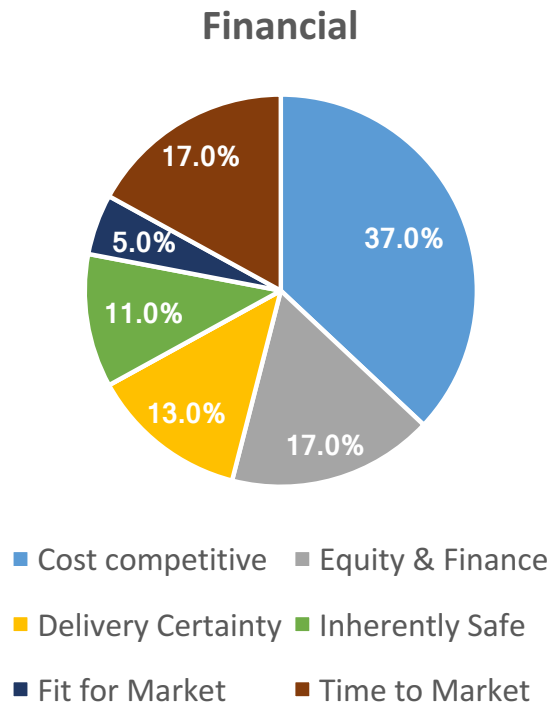
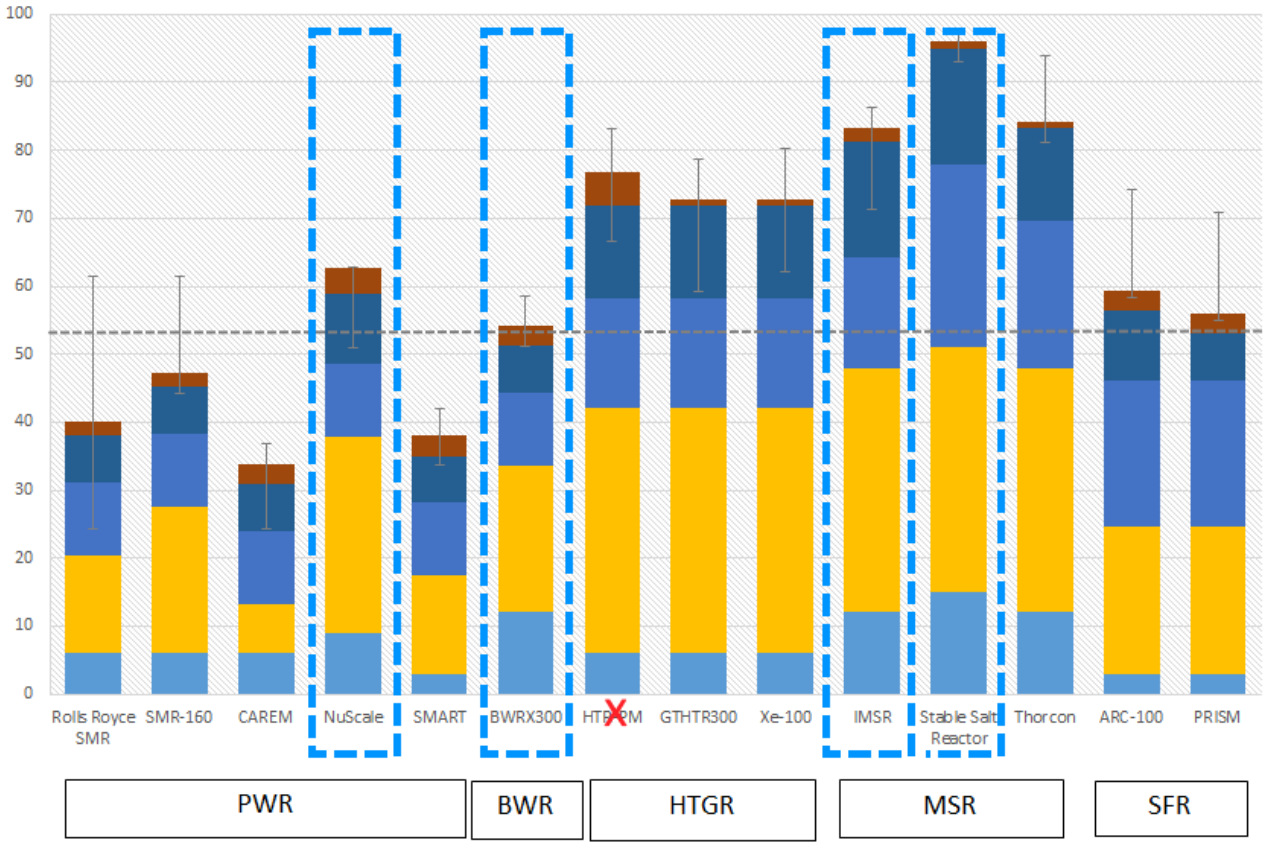
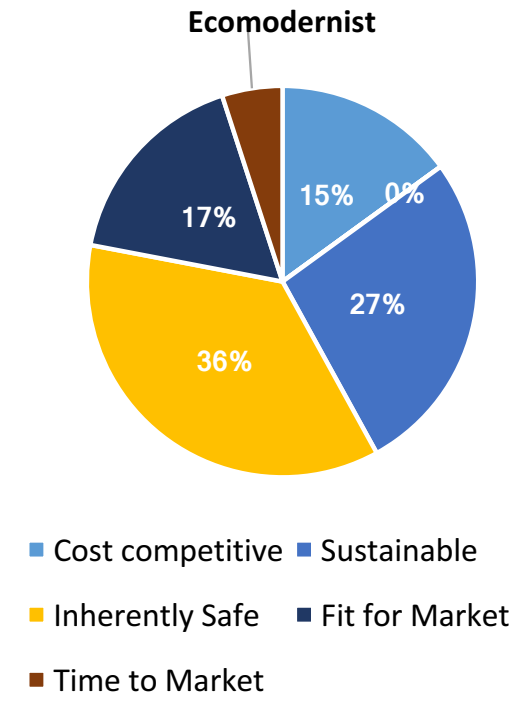
Assessment results
Financial weighting profile





Detailed assessment results
Ecomodernist weighting profile





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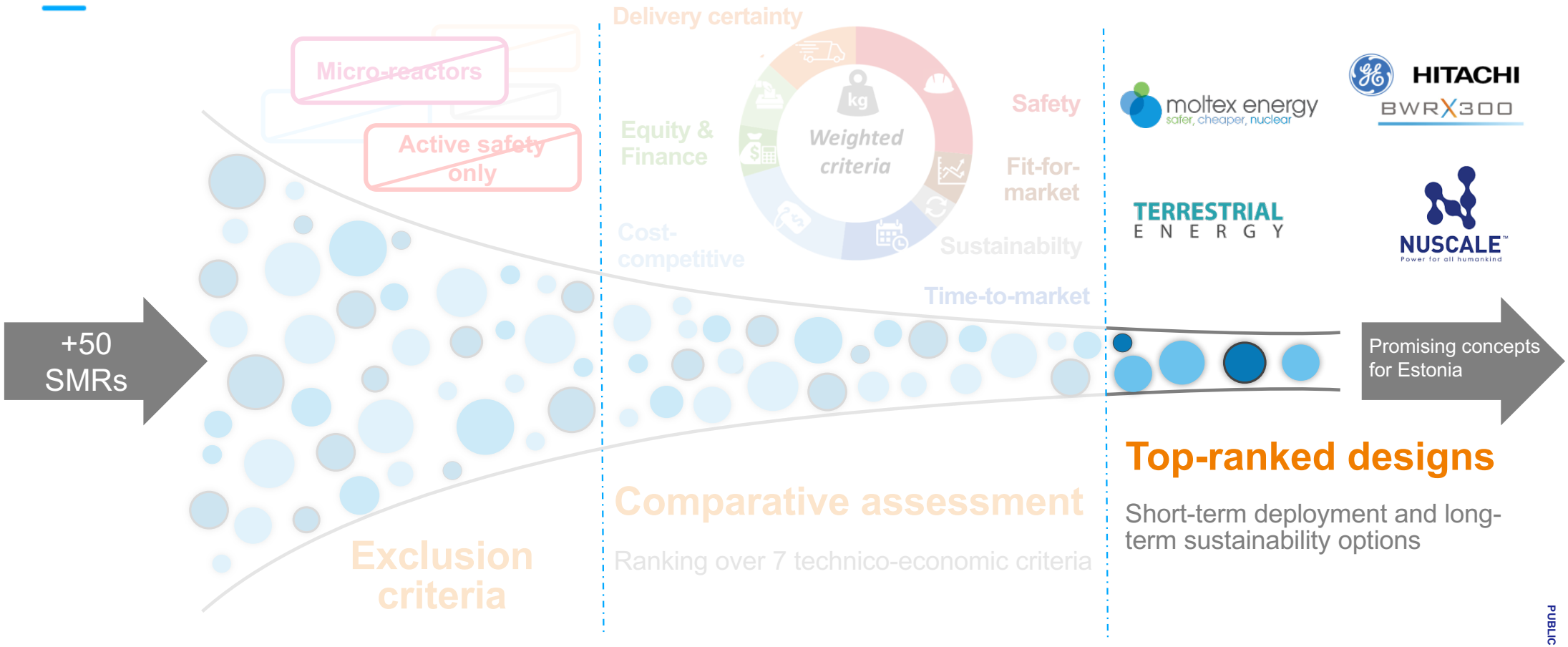
TRL= Technology Readiness Level

Overview of SMR technologies

Light Water Reactor	Molten Salt Reactor	High Temperature Gas-cooled Reactor	Sodium Fast Reactor
Mid-2020s	Early 2030s (low TRL)	Under commissioning	Late-2020s
Excellent passive safety No backup power	Inherent passive safety High simplicity systems	Excellent passive safety Elimination of core melt	Excellent passive safety But sodium reactivity & void coefficient
Possible load-following & desalination	Load-following & heat applications	Load-following & high T° applications	Medium T° applications
Not a long-term waste solution	Prospects for waste solution	Higher burn-up Not a long-term solution	Closed fuel cycle and transmutation
Good cost-competitiveness: 40 – 90$/MWh	Excellent expected competitiveness: 30 – 65 $/MWh	Lower competitiveness: 80 – 120$/MWh	Operational complexity

Results summary



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Focus on preferred technologies

Short-term deployment

- Well-established nuclear technologies
- Deployment at the end of this decade

Long-term Sustainability

- Deep decarbonization of energy sector
- Reduction of nuclear waste with Advanced Reactors

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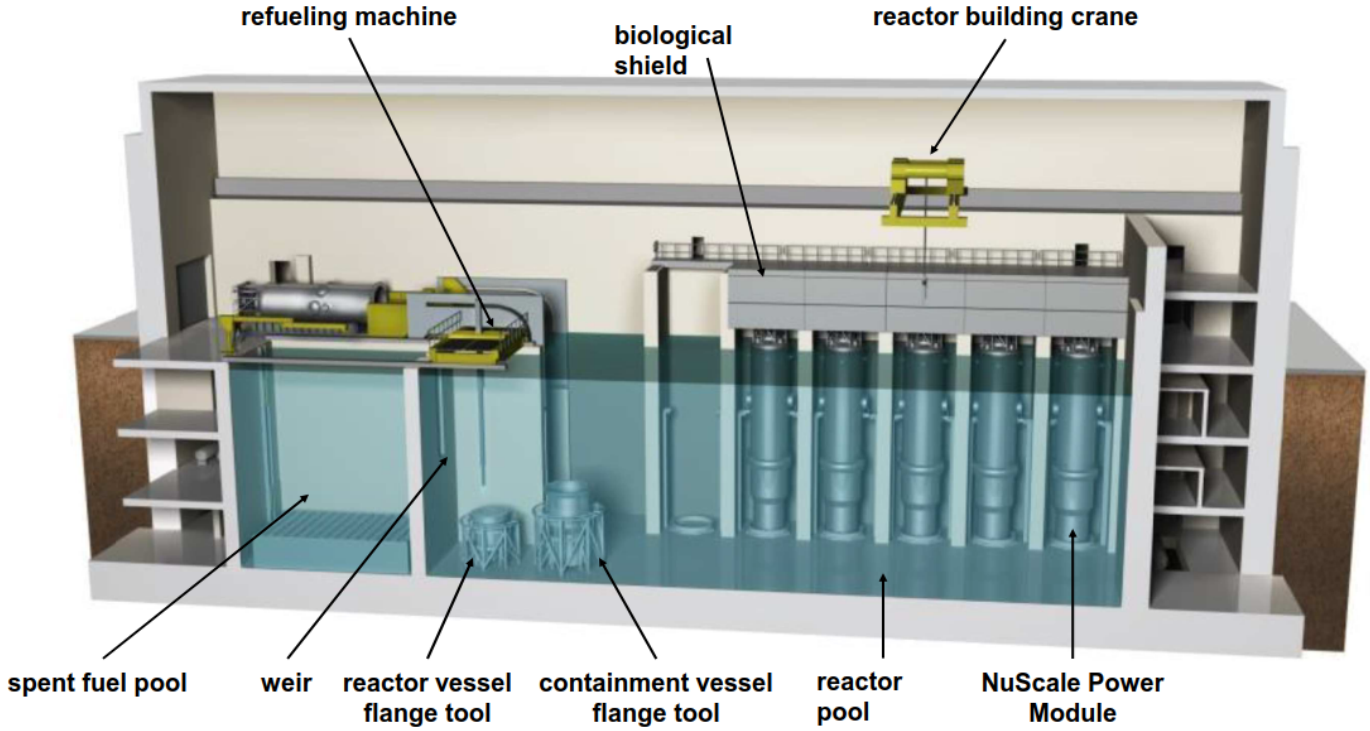
Short-term deployment options
Top-ranked designs

Short-term options:
Promising and mature LWRs

	NUSCALE™ Power for all humankind	HITACHI BWRX300
TECHNOLOGY	Integral Pressurized Water Reactor	Boiling Water Reactor
REFERENCE POWER	12x 60 MWe	300MWe
CAPEX	**4000 - 5000$/kW**	**3000 - 4000$/kW**
FIT FOR MARKET	Enhanced load-following & low T° process heat	Daily cycle load-following & low T° process heat
DISTINGUISHING FEATURES	**Triple Crown Safety**: extended grace period > 30days 1mile EPZ	Safety: extended grace period > 7days **Proven technology** – Evolved from ESBWR **Cost**
LICENSING	**2020 , US NRC**	**Pre-licensing US and Canada**
FOAK	**2026, Idaho - US**	Not yet announced

NUSCALE Integral PWR

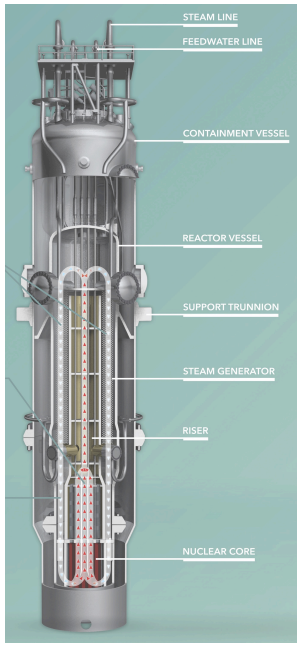


Source : NuScale SMR Overview at INPRO dialogue forum – July 2019

Status

Under licensing

FOAK at Idaho site



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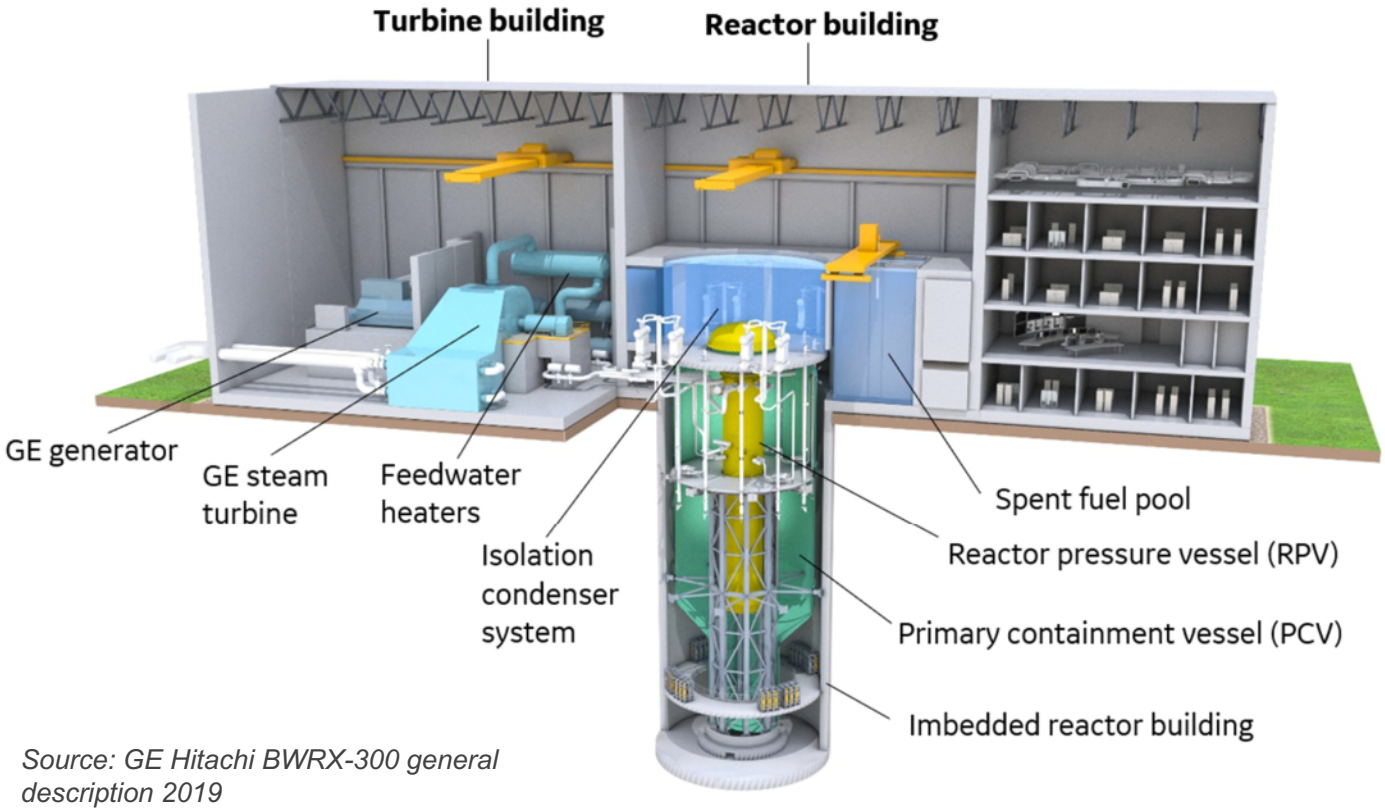
BWRX-300



Source: GE Hitachi BWRX-300 general description 2019

Status

Pre-licensing U.S.NRC

Design vendor review **phase 1** CNSC CCSN Canada

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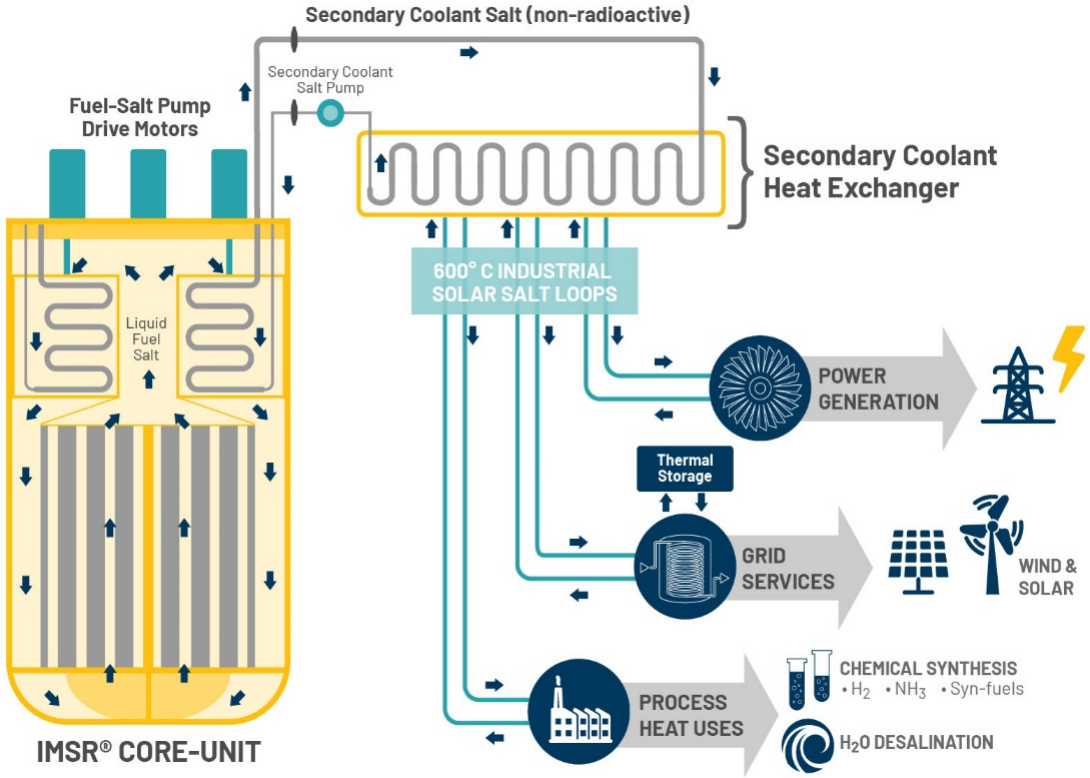
Long-term sustainability options
Top ranked designs

Long-term options: Advanced reactors
Closing the fuel cycle

	moltex energy safer, cheaper, cleaner	TERRESTRIAL ENERGY
TECHNOLOGY	Molten Salt Reactor (fast spectrum)	Molten Salt Reactor (thermal spectrum)
REFERENCE POWER	300 MWe	200MWe
CAPEX	**~3000$/kW**	**<3500$/kW**
FIT FOR MARKET	Load-balancing with heat storage & high T° process heat	Load-balancing with heat storage & high T° process heat
DISTINGUISHING FEATURES	**Waste burner** **Walk-away safety** & site-boundary EPZ Load-balancing with **heat storage**	**Walk-away safety** & site-boundary EPZ **> 500°C process heat** (H2, petro-chemical, …)
LICENSING	**Pre-licensing CNSC**	**Pre-licensing CNSC**
FOAK	**~2030**, New Brunswick - **Canada**	**~2030, Canada** (site not announced)

Integral Molten Salt Reactor (IMSR)

TERRESTRIAL ENERGY



Source:
www.terrestrialenergy.com/

Status

Vendor Design Review **Phase 2**

CNSC CCSN Canada

Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

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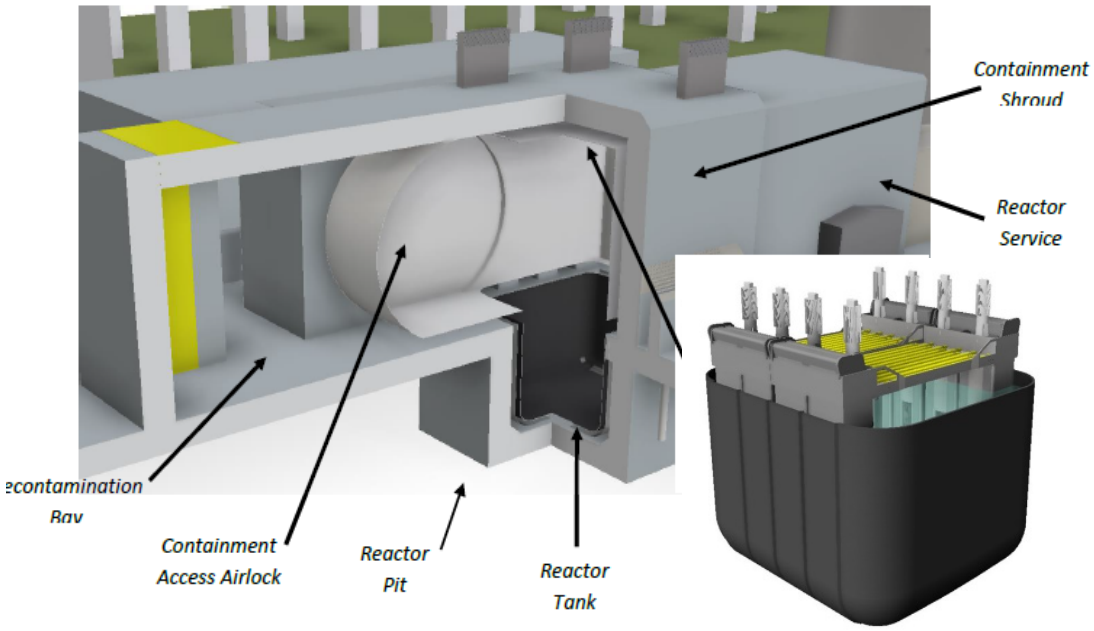
Integral Molten Salt Reactor (IMSR)

Source: www.terrestrialenergy.com/

Stable Salt Reactor (SSR-W)

moltex energy
safer, cheaper, cleaner



Status

Design vendor review
phase 1

CNSC CCSN
Canada

Énergie NB Power

FOAK in Point Lepreau

~2030

Pre-selected for the Advanced Modular Reactor (AMR) Feasibility and Development Project (40 M£)

Source: Moltex Energy – Introduction Portofolio 2018

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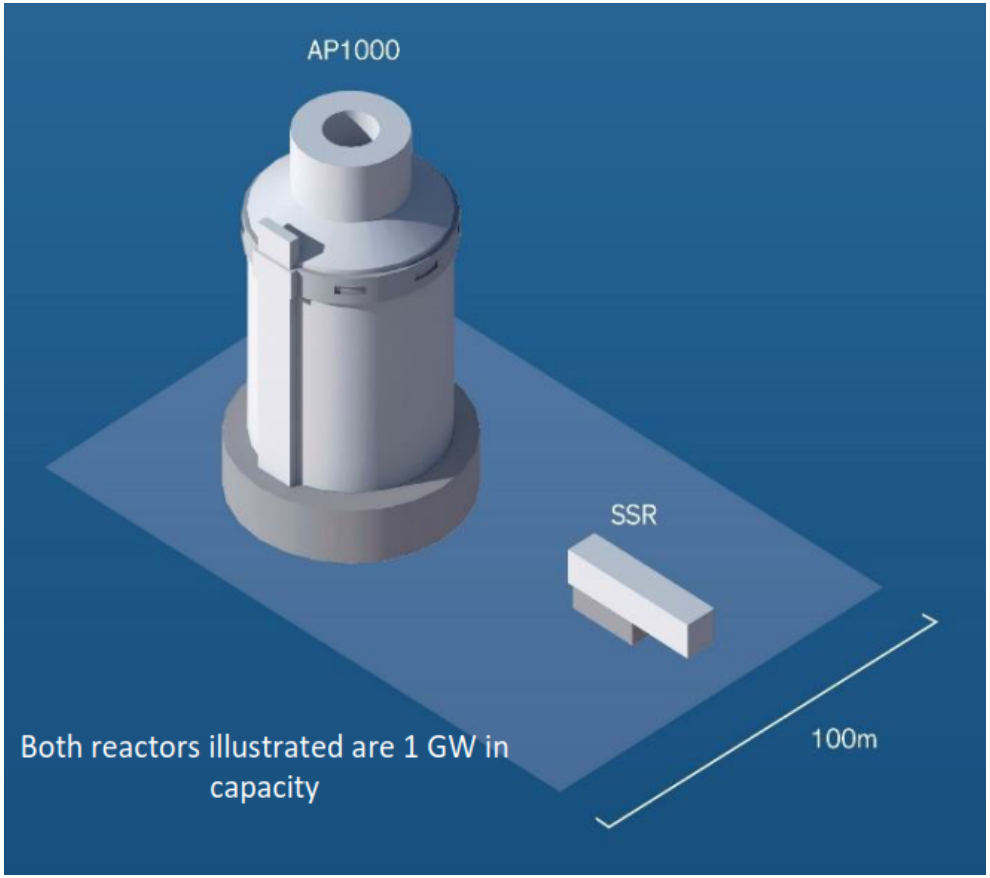
SSR-W
Footprint of 1GW reactor building



Source: Moltex Energy – Introduction Portofolio 2018

Stable Salt Reactor – Moltex Energy: GridReserve

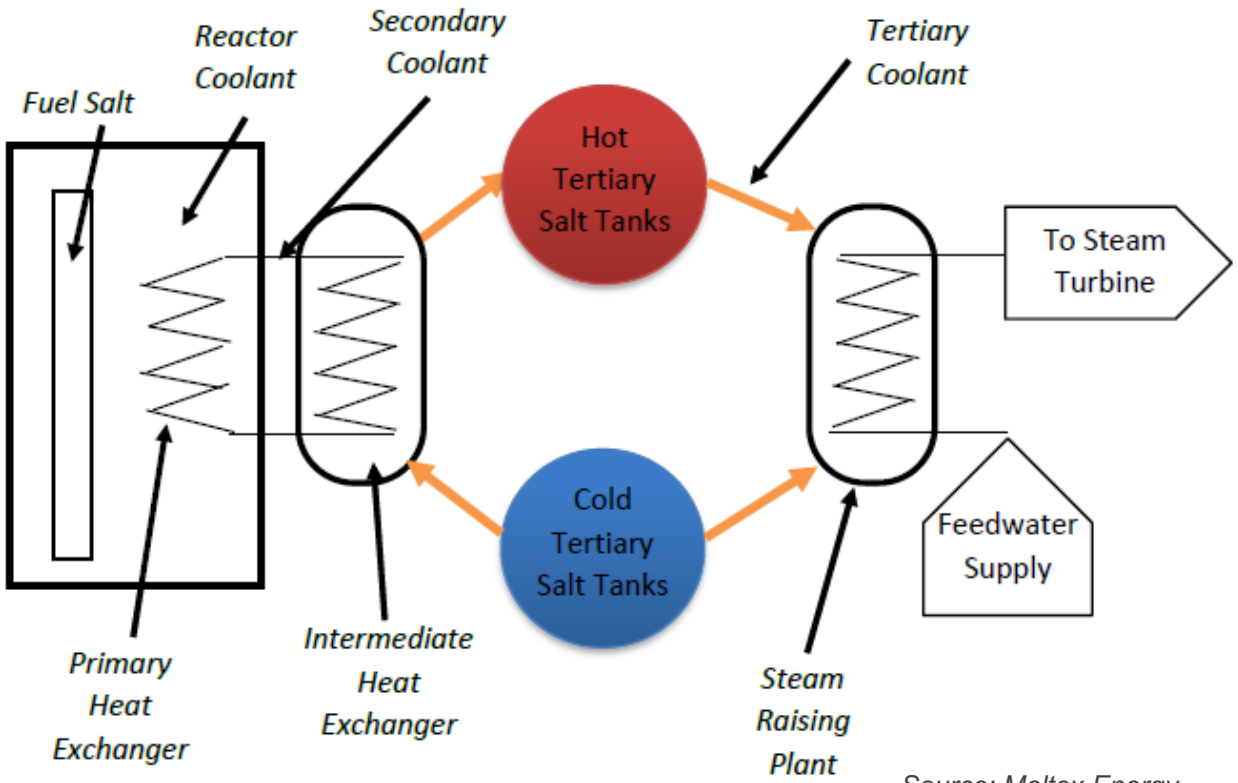


Figure 9: Overview of SSR Heat Transfer Loops

Source: Moltex Energy – Introduction Portofolio 2018

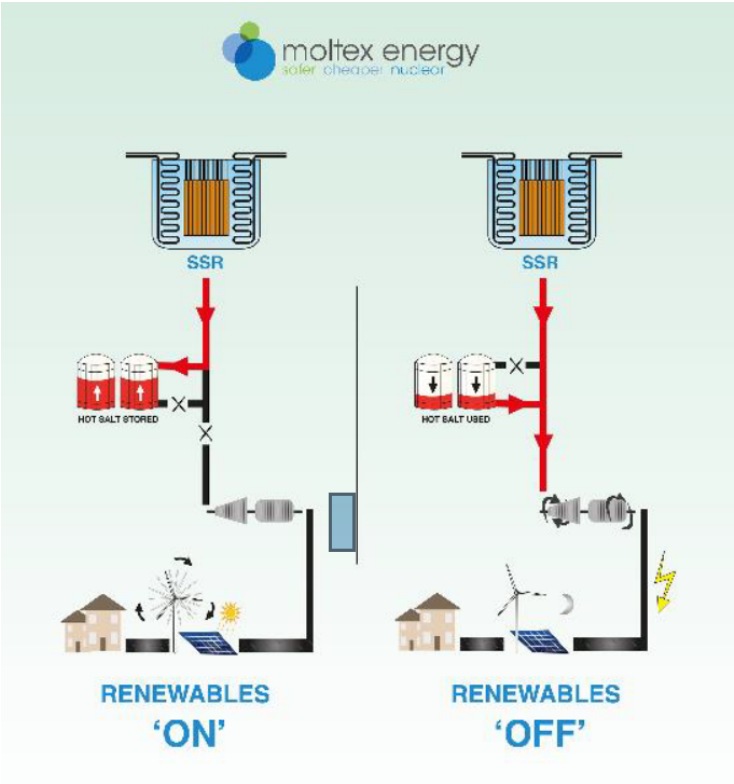


Figure 14: GridReserve to support intermittent renewables.

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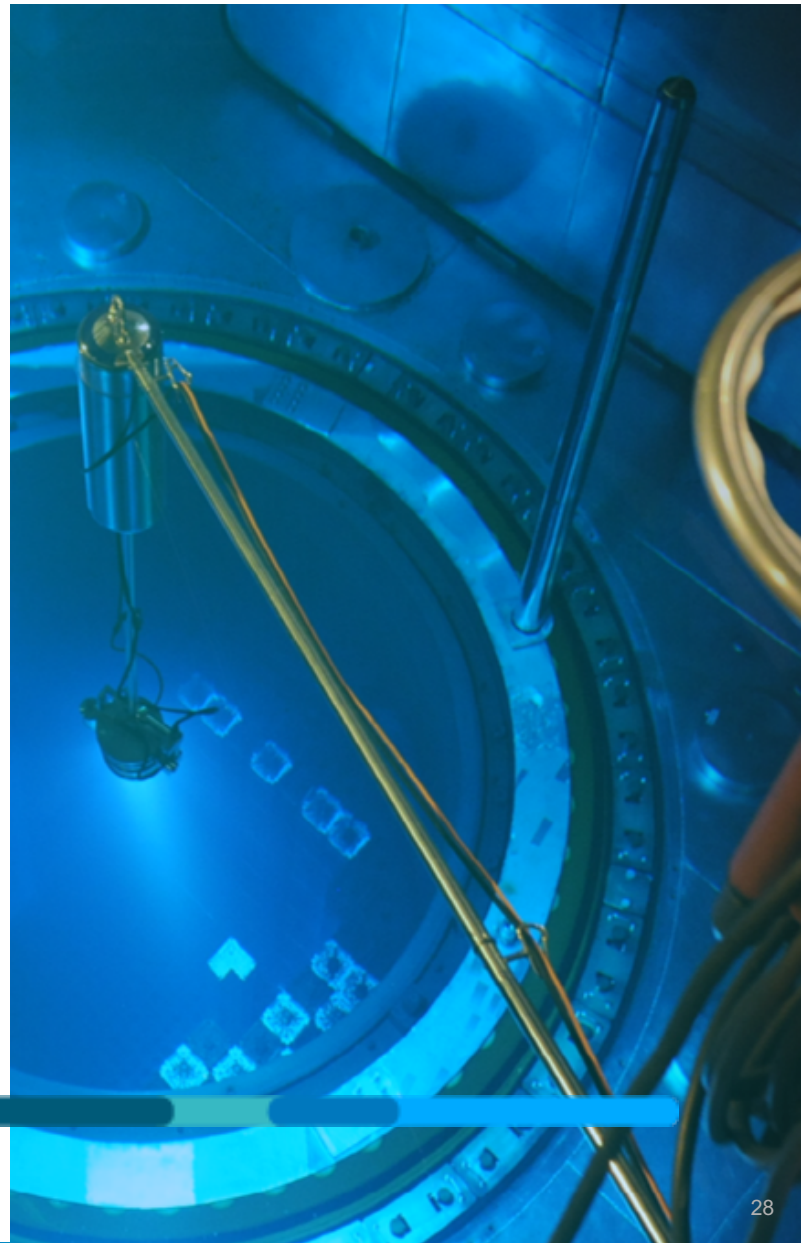
Conclusions



Conclusions

Strong international momentum

Nuclear industry is on the verge of launching SMRs demonstration projects in several parts of the world

Deployment of LWR within the decade

Chosen light-water SMR technologies rely on mature technology and would allow deployment within the decade

Long-term sustainability

Full potential of 'new nuclear' can be anticipated for the early to mid 2030s (deep decarbonization, H2, industrial use, waste reduction)

Synergy with renewables

SMRs should be promoted together with renewable energy, as synergetic means of achieving zero-carbon target by 2050

Fermi Energia leadership

Fermi Energia's ambitious goals and dynamic approach has drawn attention on the international scene and may become a trendsetter in the European nuclear industry

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“There is no sustainable energy future in the absence of nuclear energy.”
Fatih Birol,
Executive Director,
International Energy Agency