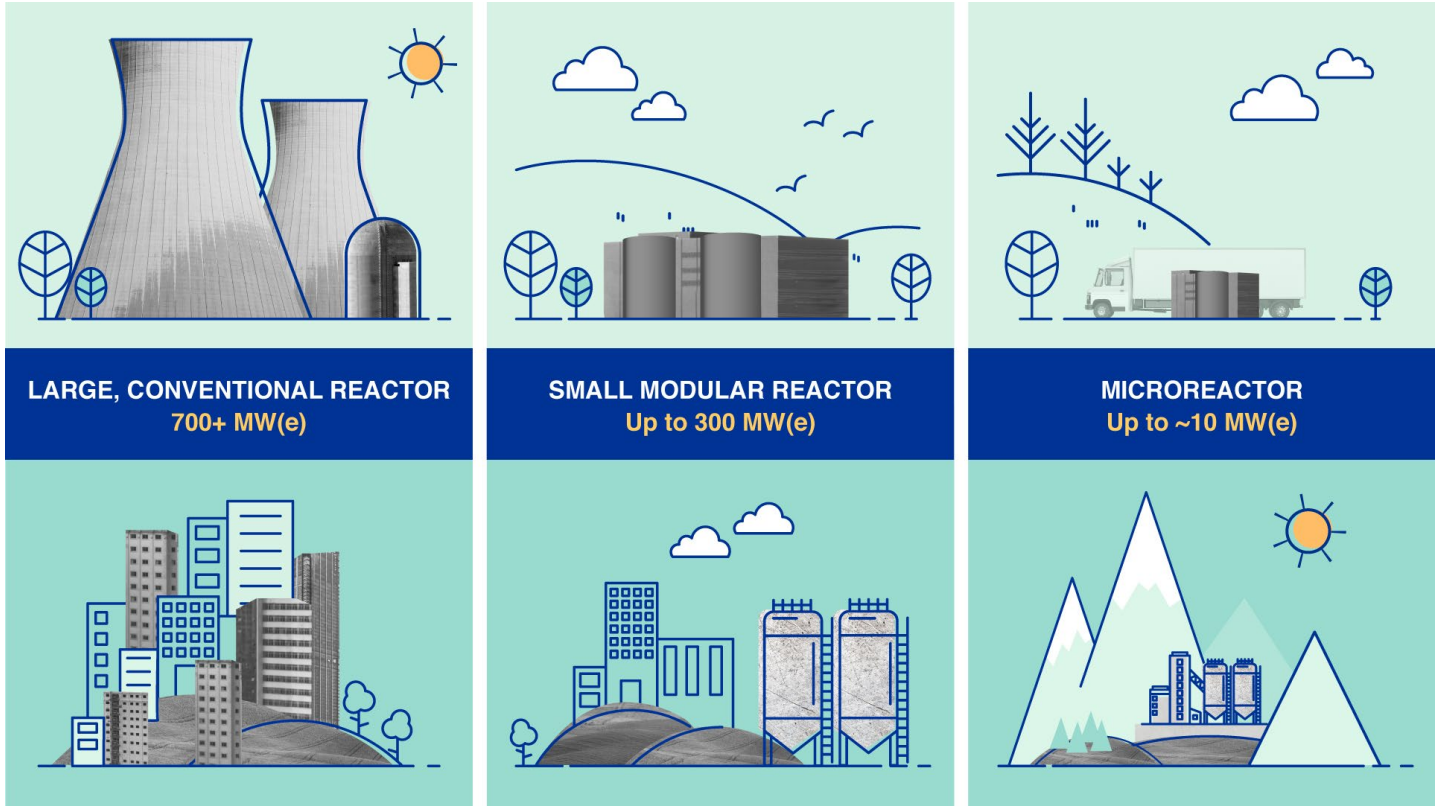
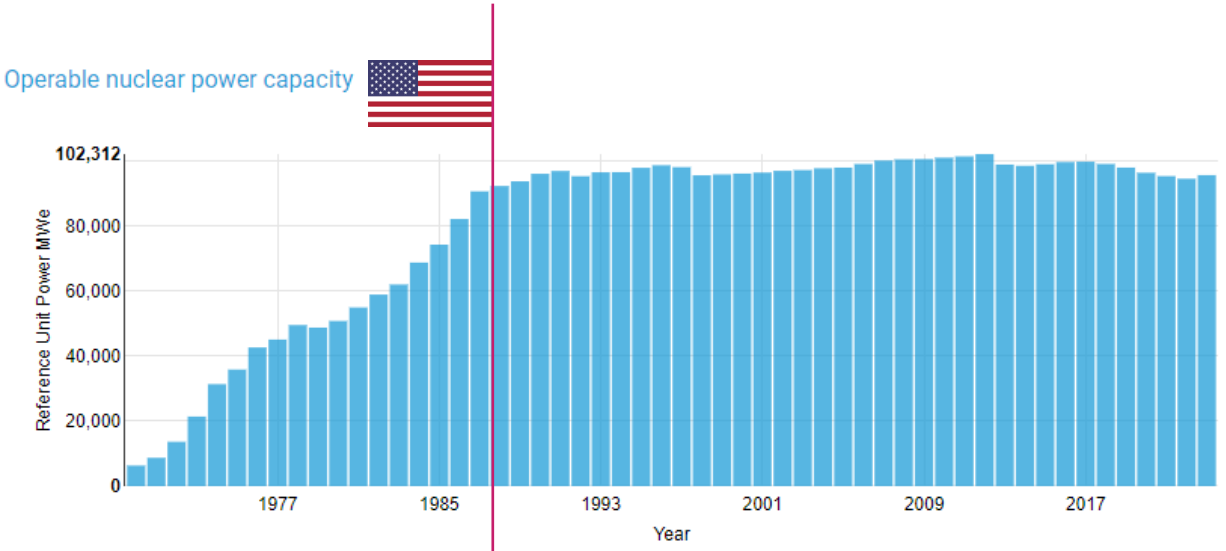
SMRs: Tendências Internacionais

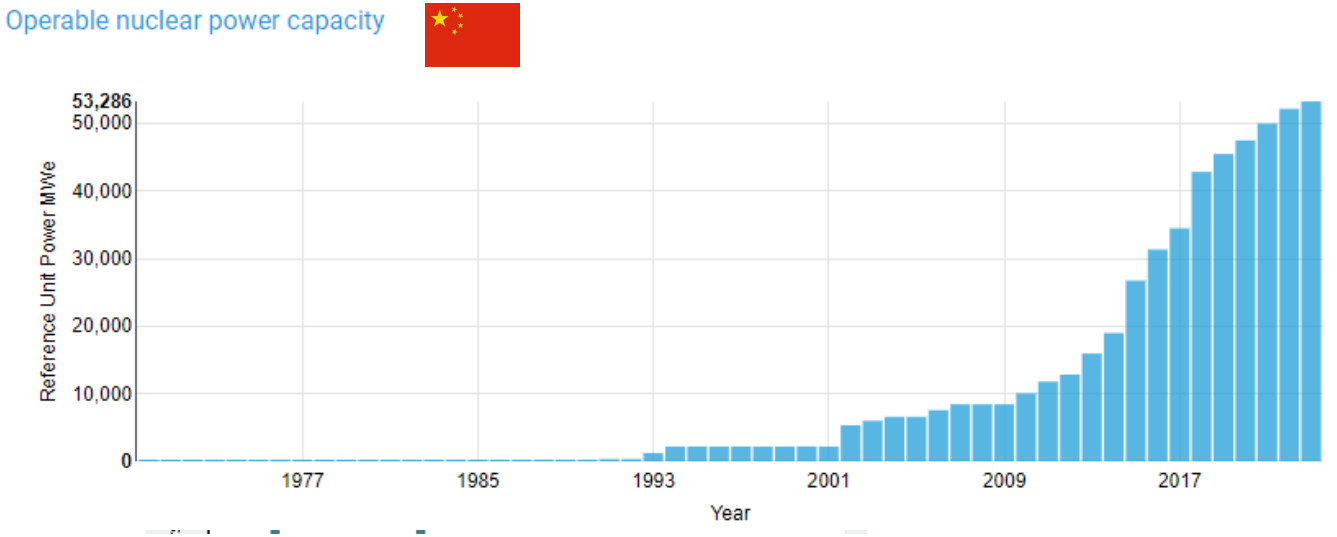
Miguel Sousa – Nuclear Safety Engineer

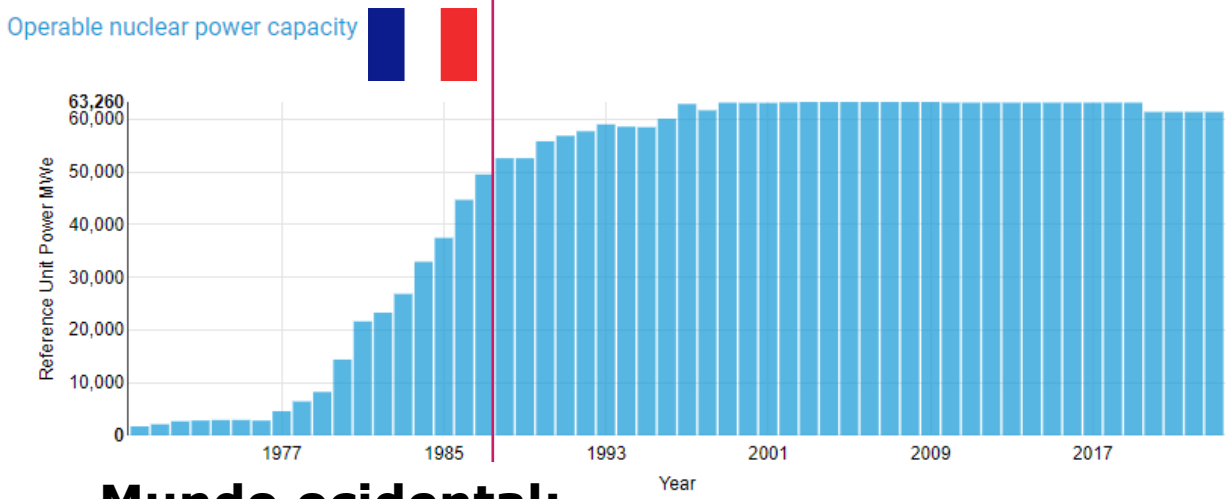


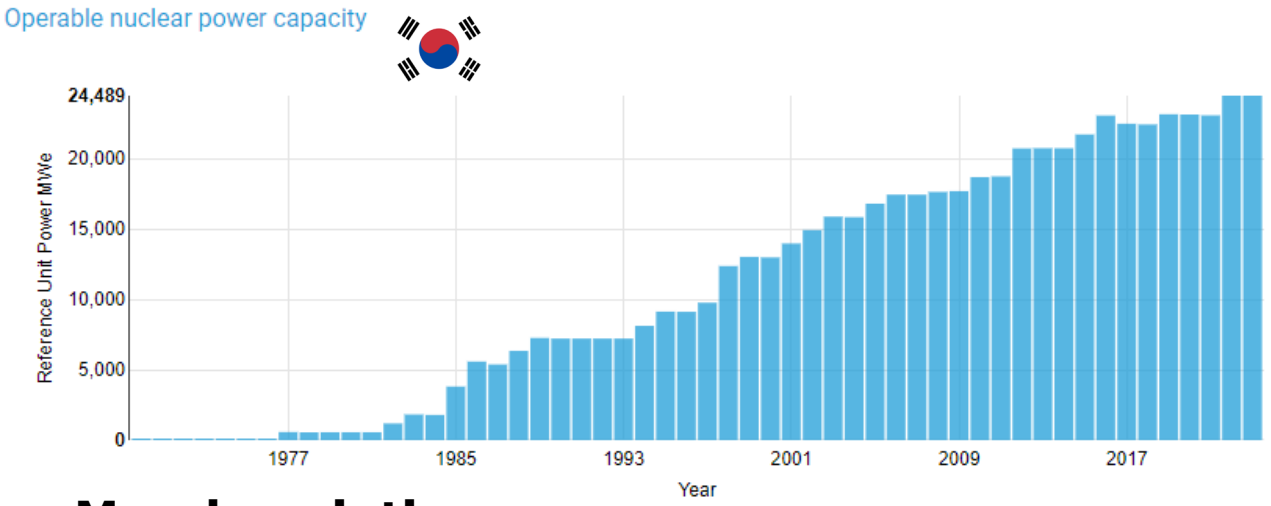
Porquê SMRs?

História do desenvolvimento nuclear









Mundo ocidental:

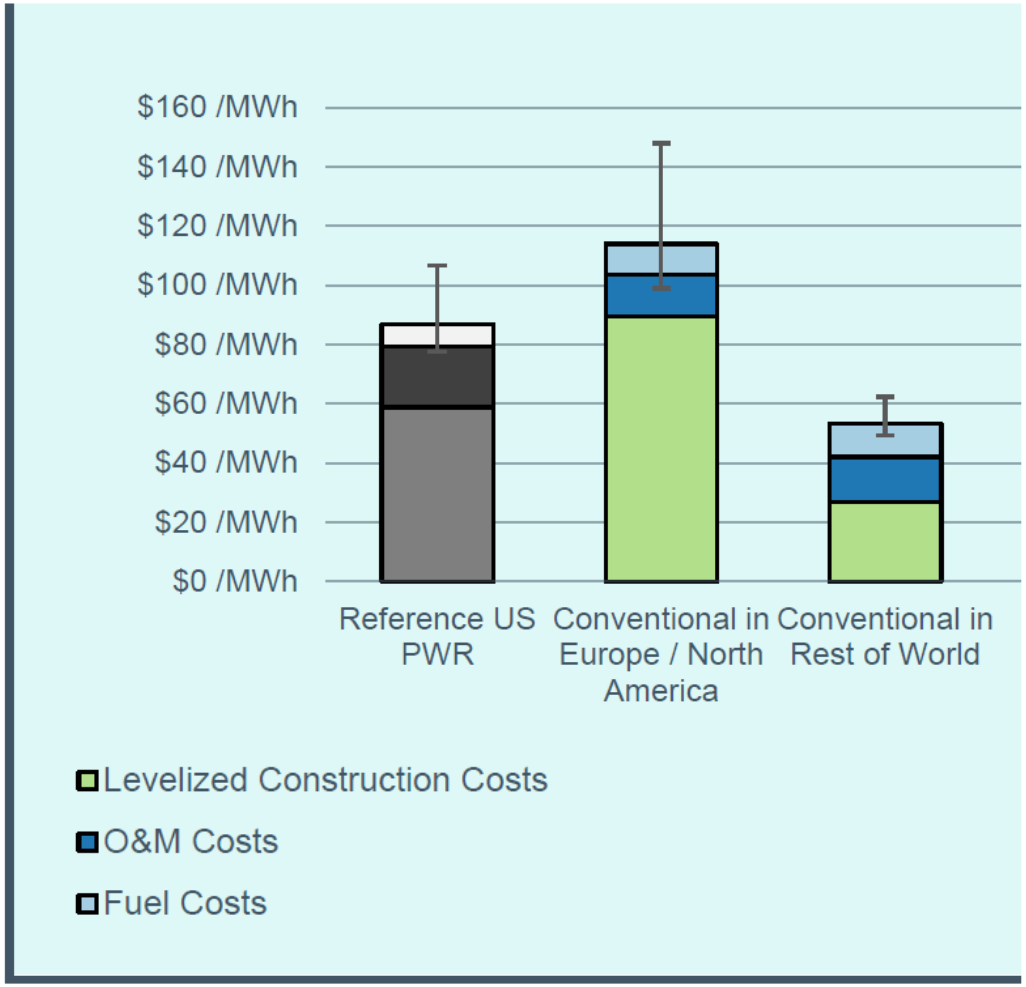
Sucesso entre 1960-1980, mas depois parou.
Medo de Chernobyl, Three-Mile Island, Opposition.
Aquecimento global não era preocupação
Gás barato.
Perdeu experiência a construir (décadas!)

Mundo asiatico

Copiar sucesso do mundo occidental
Nunca parar de construer
Desejo intenso por mais energia
Gás não é solução tão viável
Ganhou experiência a construir (décadas!)

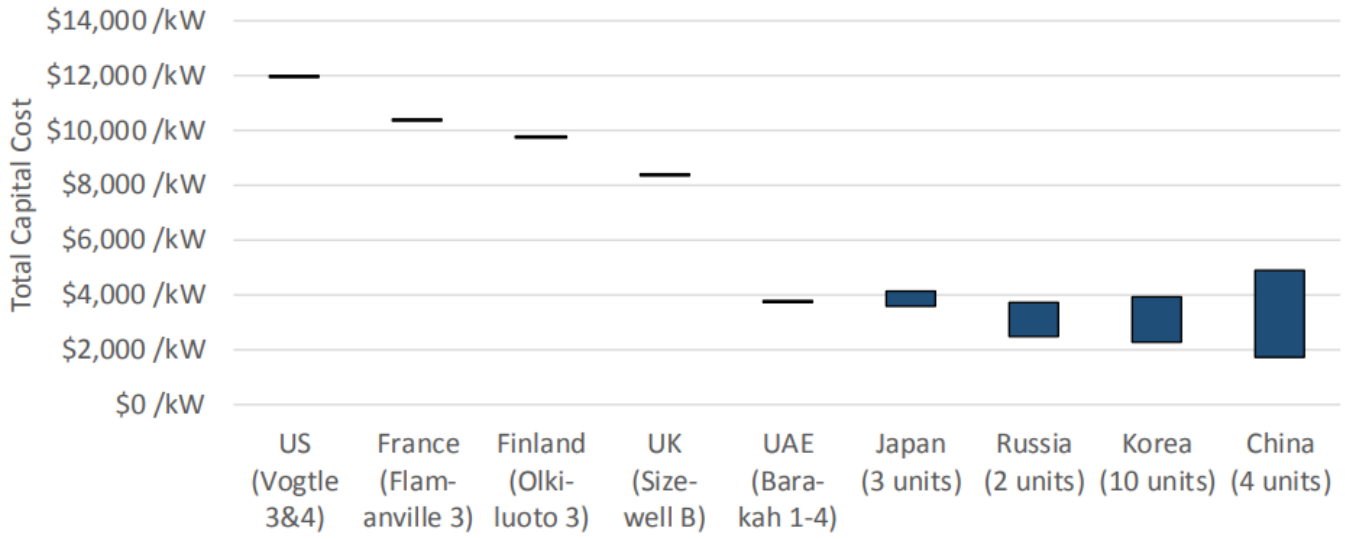
Custos Nucleares

Figure 19. **Comparison of LCOE Costs Across All Genres**



- Reatores de EU-NA **35% mais caros** que o previsto
- Resto do mundo a metade do custo, e nao se atrasam
- *Resto do mundo inclui Rússia, China, Japão, Coreia do Sul*

Figure 1. Total Capital Costs for Historical and Ongoing Nuclear Projects in Database

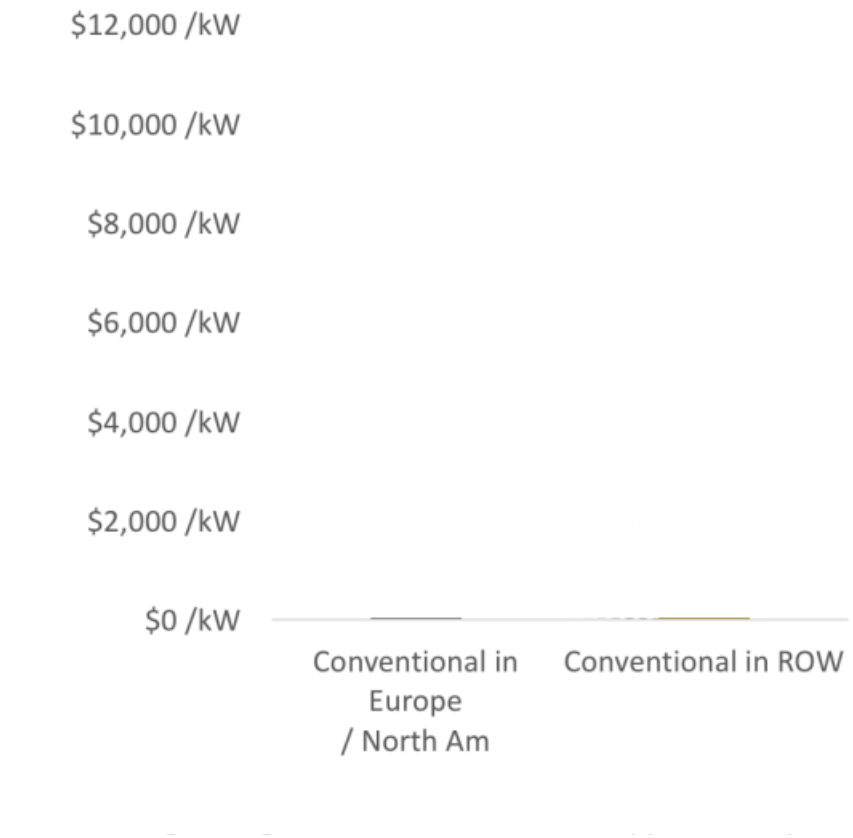


Ref: ESC, Lucid Catalyst: The ETI Nuclear Cost Drivers Project – Full Technical Report, Sept. 2020

Custos Nucleares: CAPEX

Custo de um projeto nuclear

Figure 9. "Genre" Cost Comparison: Europe/North America and ROW Costs

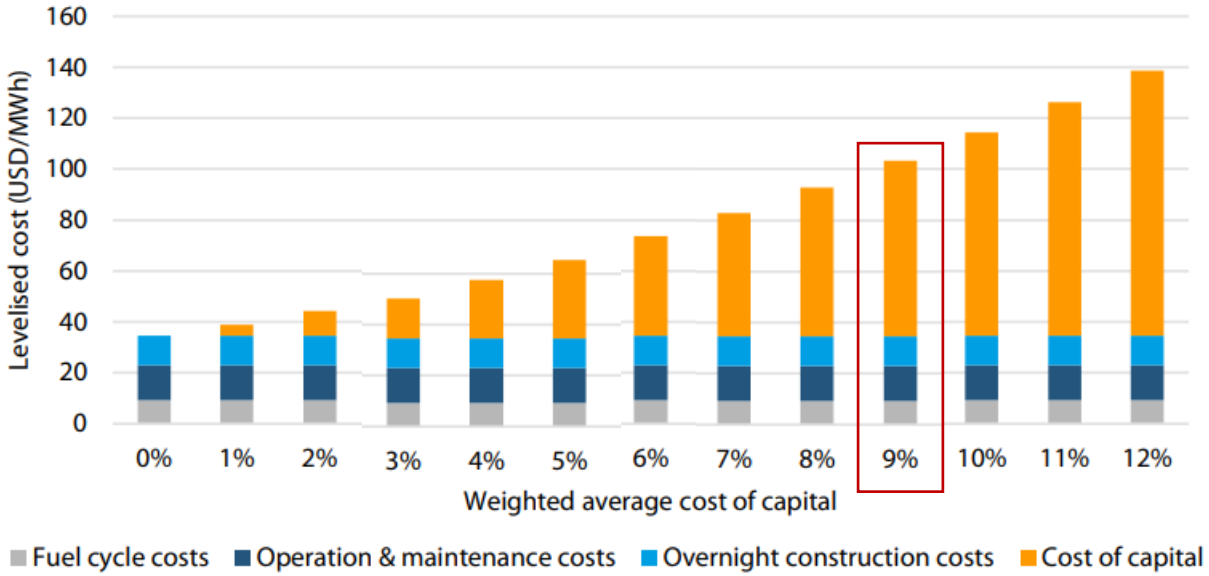


Pontos negativos de EU/USA

- Demasiados gastos indiretos
- Mão de obra pouco experiente
- Inexistência de supply-chain (incl/ consultorias)
- Pouca confiança financeira nos projetos

Custos Nucleares: Custo de Capital

Figure 37: **LCOE of a new nuclear power plant project according to the cost of capital**

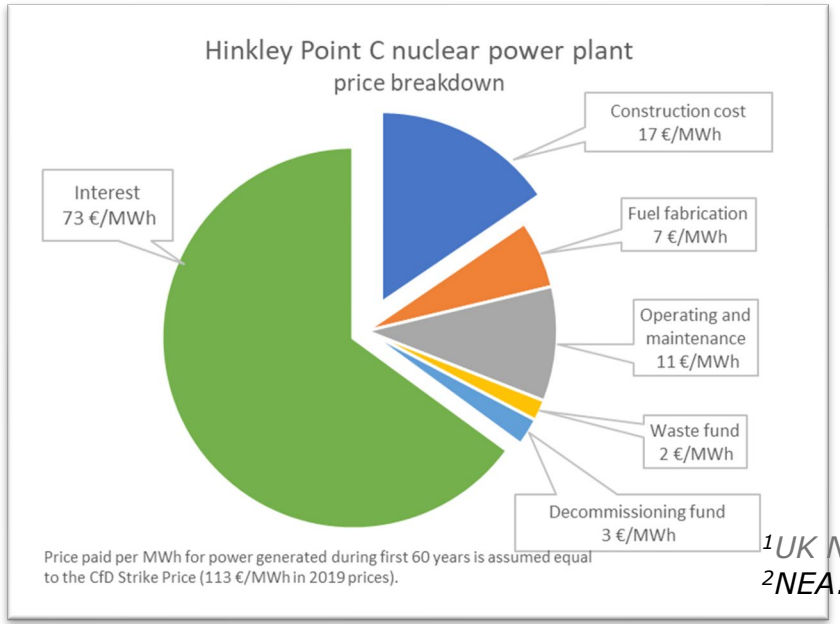


WACC (nuclear, IEA) = 7-8%
Hinkley Point C (em 2018): WACC = 9%

Para o mesmo CAPEX:
LCOE (WACC=7%): 81$ / MWh
LCOE (WACC= 9%): 102$ / MWh

Aumento de 25% no LCOE!

HPC (WACC= 9%): 121$ /MWh

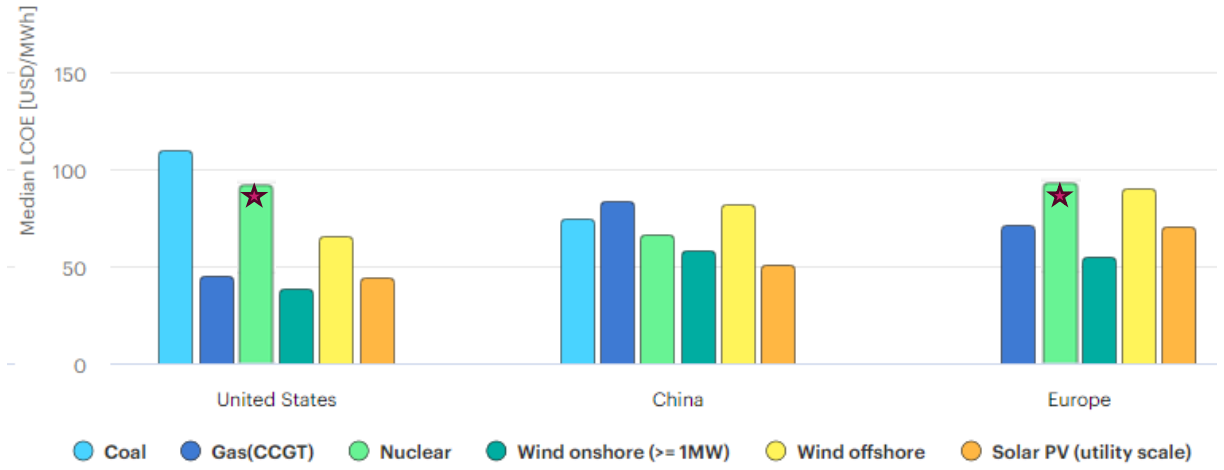


Custo de capital reflete economia no momento,
Mas tambem risco do projeto e maturidade da Industria.

2007: "EDF irá ligar a sua primeira central nuclear na Inglaterra **antes do Natal de 2017!** - Vincent de Rivaz, EDF's UK CEO

[1] *UK National Audit Office: Audit on HPC, 2019*
[2] *NEA: Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders, 2020*

E se WACC = 7%?



★ **Nuclear com WACC=9%**

EU e USA:

- 2.5%-5% solar+eolica
- 4%-7% eolica offshore
- **7%-9% nuclear!**

Imaturidade da industria nuclear.
Falta de suporte constante.
Dificuldades em executar mega-projetos

China tem WACC= 5.5% em VRE e nuclear!

Maturidade global das industrias.

Diferença nas plantas OECD vs ROW

Bruce Lee: "I fear not the man who has practiced 10,000 kicks once, but I fear the man who has practiced one kick 10,000 times."

É necessário não só repetir design, mas **repetir a maneira de como se entrega as centrais.** Repetição leva a perfeição! Back to the 60s and 80s!

Prioridades:

1. **Supply-Chain**
2. Mao-de-obra
3. Governanca e Desenvolvimento de Projetos
4. Construcao
5. Contexto Politico e Regulatorio
6. Equipamento e Materiais
7. Design do Reator

Estabelecer uma industria constante, não mega-projetos esporádicos em regimes diferentes

Table 9. Relative importance of cost drivers in dataset

Cost Driver	Relative Importance
Supply Chain	High
Labour	High
Project Governance and Project Development	High
Construction Execution	Med
Political and Regulatory Context	Med
Equipment and Materials	Med
Vendor Plant Design	Med
Operations	-

China restarts Taishan 1 after a year of repairs

18 August 2022

Tentou-se fazer isto com EPR, mas...

BANKING

REU

Finlan

delay

NEW BUILD

Flamanville-3 / EDF Announces Further Delay And €500 Million Cost Overrun

Hinkley Point C delays raise 'big questions' about nuclear power, says RWE chief

Britain's flagship nuclear power station will not open until 2027 at the earliest

2007: "EDF irá ligar a sua primeira central nuclear na Inglaterra **antes do Natal de 2017!** - Vincent de Rivaz, EDF's UK CEO

China restarts Taishan 1 after a y
repairs

Hinkley Point C delays raise
about nuclear power, says R
Britain's flagship nuclear power station will not open until 2027 at the earliest

BANKING

REUTERS

Finland's OL3 nuclear power plant again
delays restart

BUILD

amanville-3 / EDF Announces
urther Delay And €500 Million
Cost Overrun

EPR foi bom na teoria. No entanto:

- 4 países, 4 designs diferentes
- Começou construção antes de design estar acabado
- Industria de construção nuclear a ganhar experiencia (e de repente, 4 projetos duma só vez)
- Mercado Europeu desfavorece múltiplos GW de nuclear num só país

- Consequências
- Confiança em nuclear reduzida
- Ideia "mal implementada". E se agora for bem implementada, não será tarde demais?
- **Mesmo que governo queira nuclear, é dificil dar apoio necessário.**

Sizewell C faces funding challenges as two pension funds back out

01 FEB, 2023 | BY CATHERINE MOORE

Proposed Sizewell C nuclear plant seeks outside investment 19th SEP 2023

<u>É preciso tornar o método de repetição mais fácil!</u>

Tornar investimentos mais atrativos

- Reduzir custos iniciais, Reduzir tempo de entrega
- Aumentar previsibilidade de projetos
- Reduzir o quanto o governo tem de suportar

Arranjar maneira de construir vários em sequência, não esporádicos.
Repetir, Repetir, Repetir.

Muitos destes problemas estão associados mais a caracteristicas de Mega-Projetos.
E é dificil repetir mega-projetos…

Mas nuclear não tem de ser mega-projeto….

Possivel solução

Small
Modular
Reactor

- **Easier to invest**
- **Quicker to build**
- **More passive safety – easier to regulate**

- **Repetition of parts of the plant (like modules)**
- **A lot can be done in factories!**

- **Nuclear!**

Beneficios extra:

- Melhor implementação de nuclear noutras industrias (e.g industry heating)
- Menor investimento é mais atraente para novos países “experimentarem” nuclear

Possivel solução

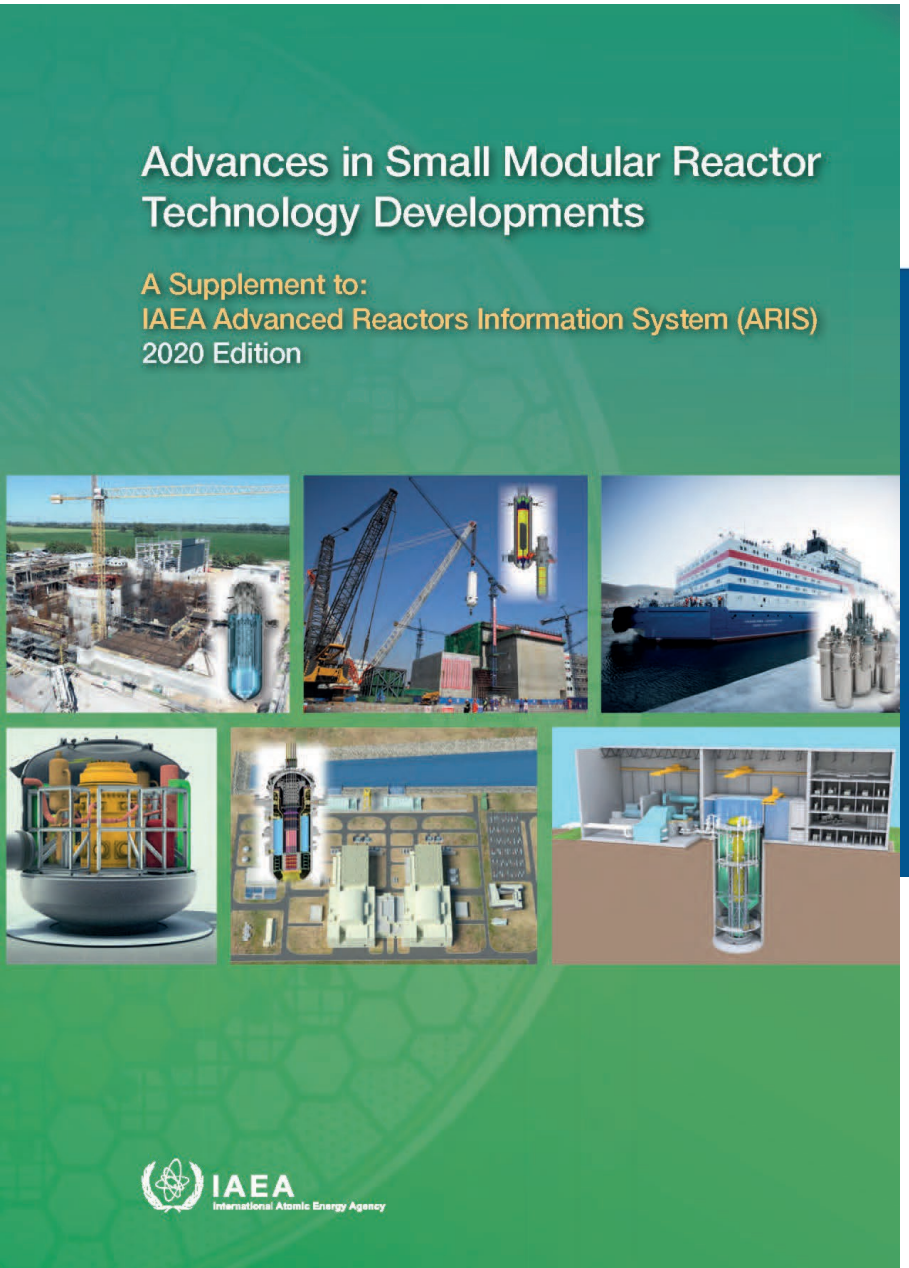
Small
Modular
Reactor

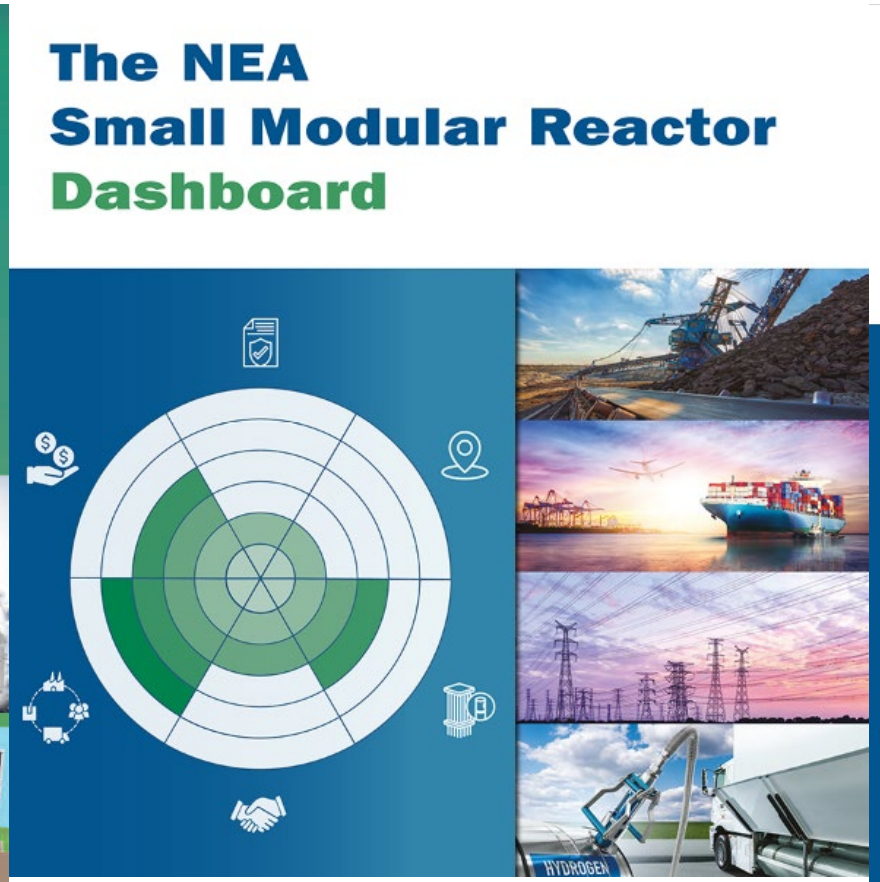
Não é nova tecnologia.

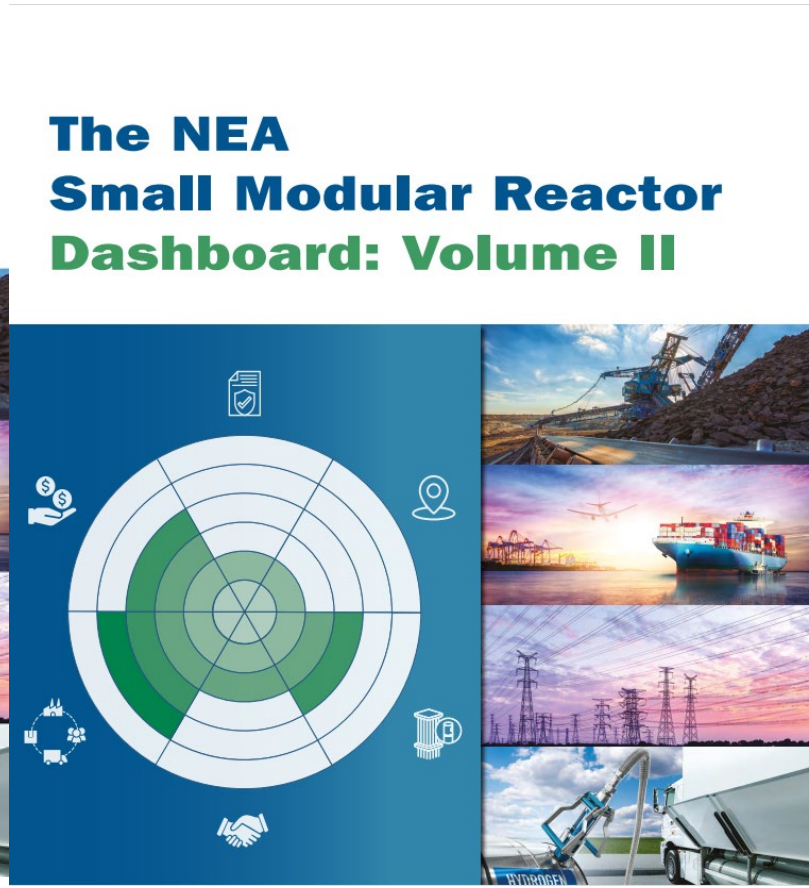
É um Business Model

Por agora, quanto mais estabelecido e menos inovador, melhor!
Problema nuclear é socio-económico, não técnico!

Reference Documents: IAEA & NEA

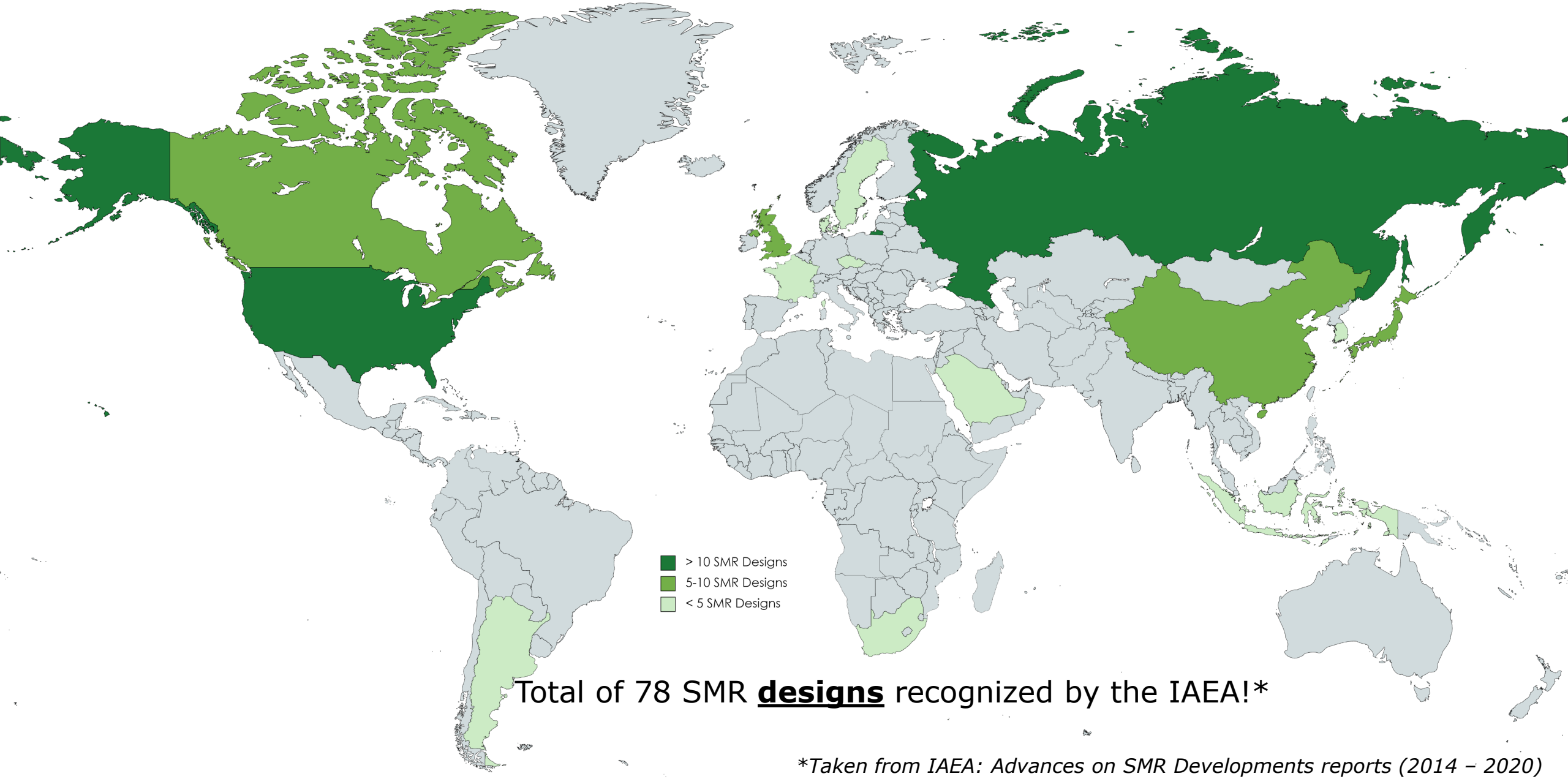






Each document provides more details on each SMR development.

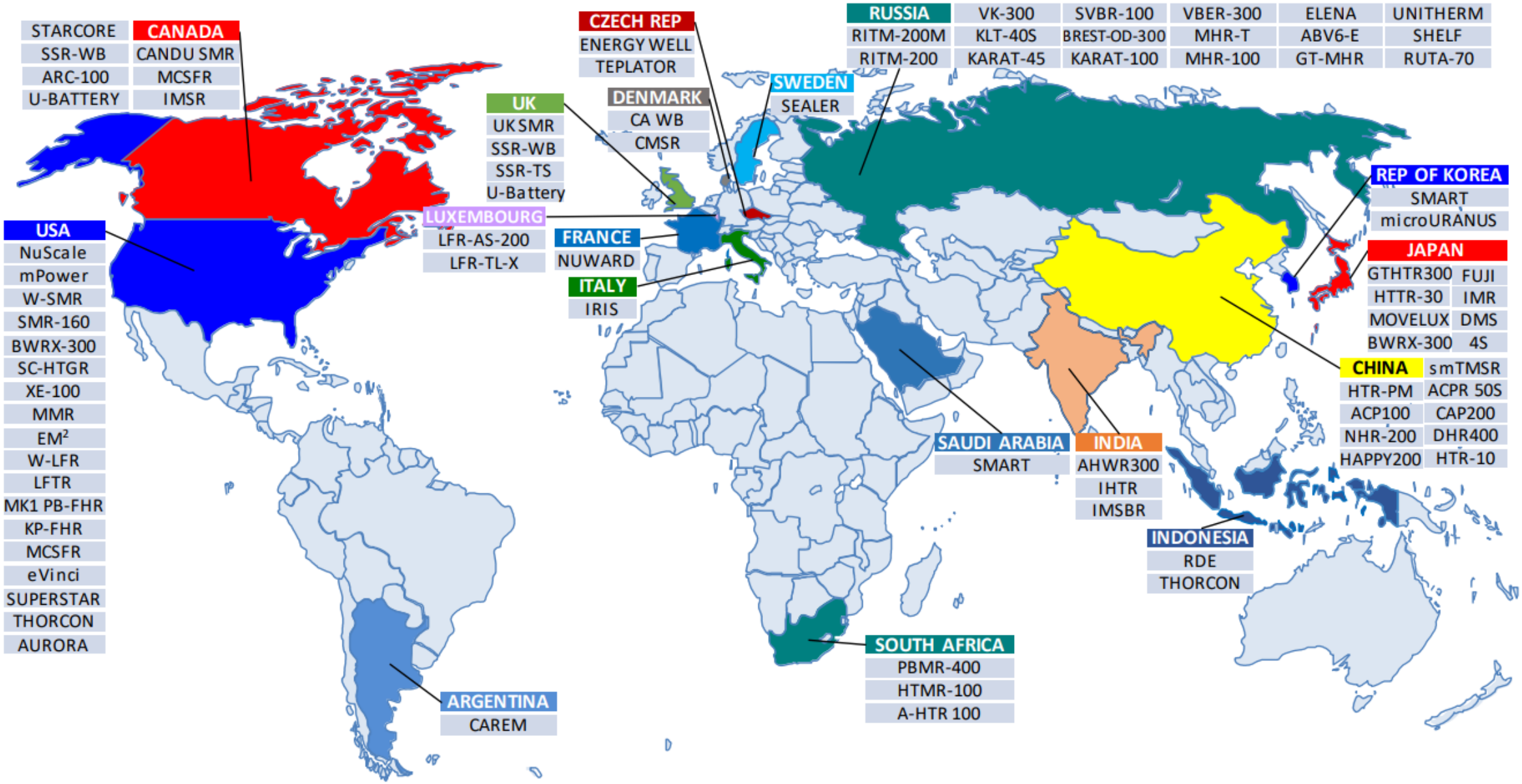
SMR Being Developed Worldwide



Total of 78 SMR **designs** recognized by the IAEA!*

**Taken from IAEA: Advances on SMR Developments reports (2014 – 2020)*

SMR Status and Development Worldwide



*Taken from IAEA: Advances on SMR Developments reports (2014 – 2020)

USA – Water based Reactors

- BWRX-300 – 300MWe BWR
- SMR Vendor with the most experience
- Nothing new, but leading the way!

- **Status: Contracts with Canada, Eastern EU, Estonia, ….**

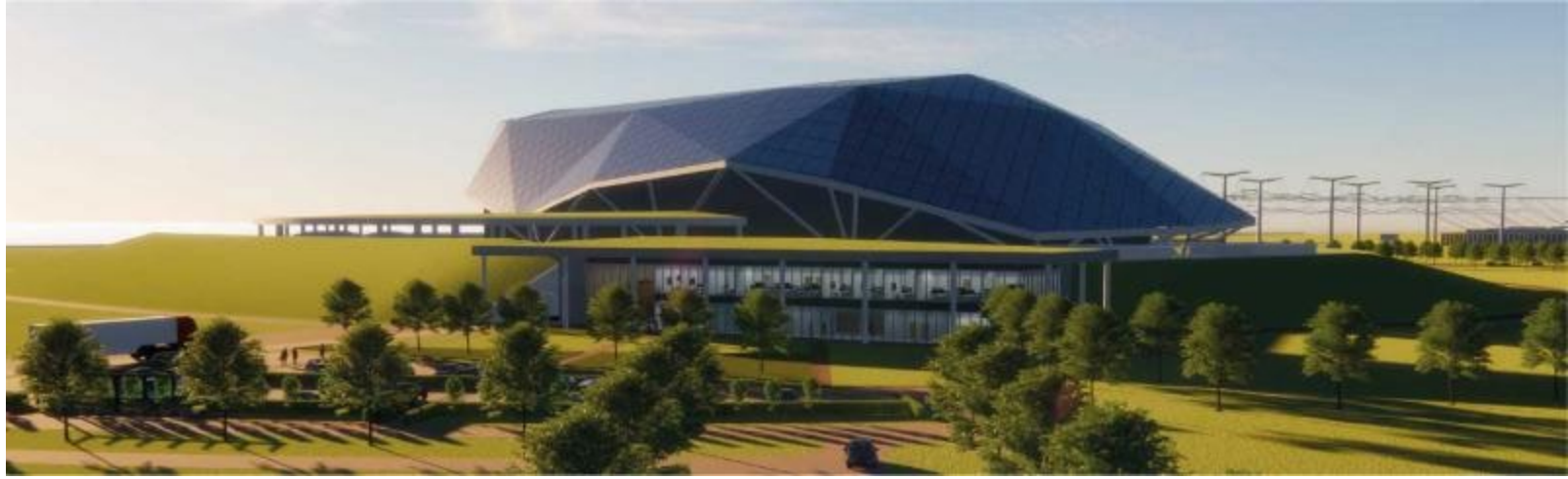
- VOYTGR - 77 MWe PWR, **scalable up to 12 units**
- 1billion USA funding
- NSC design approved, factory started.
- Public company

- **Status: Looking to build (Poland, Romania, Czech Republic, Ukraine).**

- Westinghouse SMR – AP300
- Scaled-down version of AP1000

- SMR-160
- 300MWe, air-cooled

UK

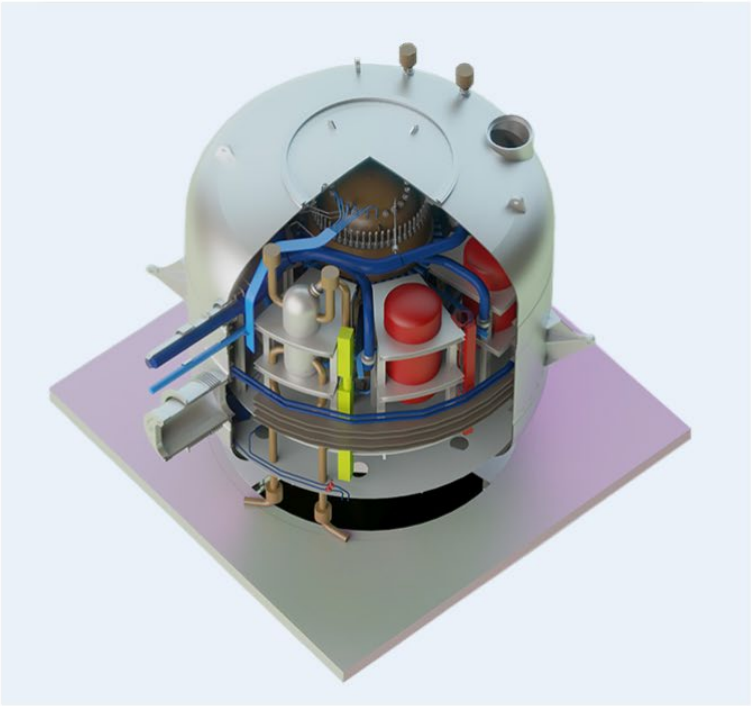


- Rolls-Royce “SMR” - 470 MWe PWR
- Main SMR of UK, had initial funding
- Entire Power Plant, not only reactor, on “island” platform!
- Very fabric focused

- **Status: Getting it licensed and built in the UK, while building connections internationally (Czech Republic, Estonia, Sweden, Netherlands, ….).**

France – Going big, small AND New

nuward
EDF GROUP



Key Milestones

- Conceptual design + preparation to pre-licensing 2019-2022
- Basic design + pre-licensing 2023-2025
- Commercialisation as early as 2025
- Detailed design + licensing 2025-2030
- Safety options validated + First Concrete in France by 2030

- **340 Mwe (2x 170MWe) PWR, based on EDF experience.**
- **Standardisation, simplicity for mass-production**
- **Load follow, and adaptable for industrial use**
- **Aimed at replacing coal plants.**
- **European approach** to foster regulation harmonization and to promote partnerships for successful deployment of EU SMR technology (Joint Early Review (JER) of design by 3 regulators).

asn AUTORITÉ DE SÛRETÉ NUCLÉAIRE
nuward
STUK
SÚJB

Reference Plant in France in 2030, **bolstered by 500M€ of financial support** to accelerate France's efforts to export its SMR model.

China

Multiplos investimentos!

- ACP100 – Multi-purpose PWR, 125MWe
- Based on previous PWR experience. More reactors being investigated.
- **Status: Construction on-going of Linglong One, for electricity, heating, steam production or seawater desalination**

Russia

ROSATOM

- ***Floating Nuclear Power Plant (PWRs)***

Innovate on already-known designs

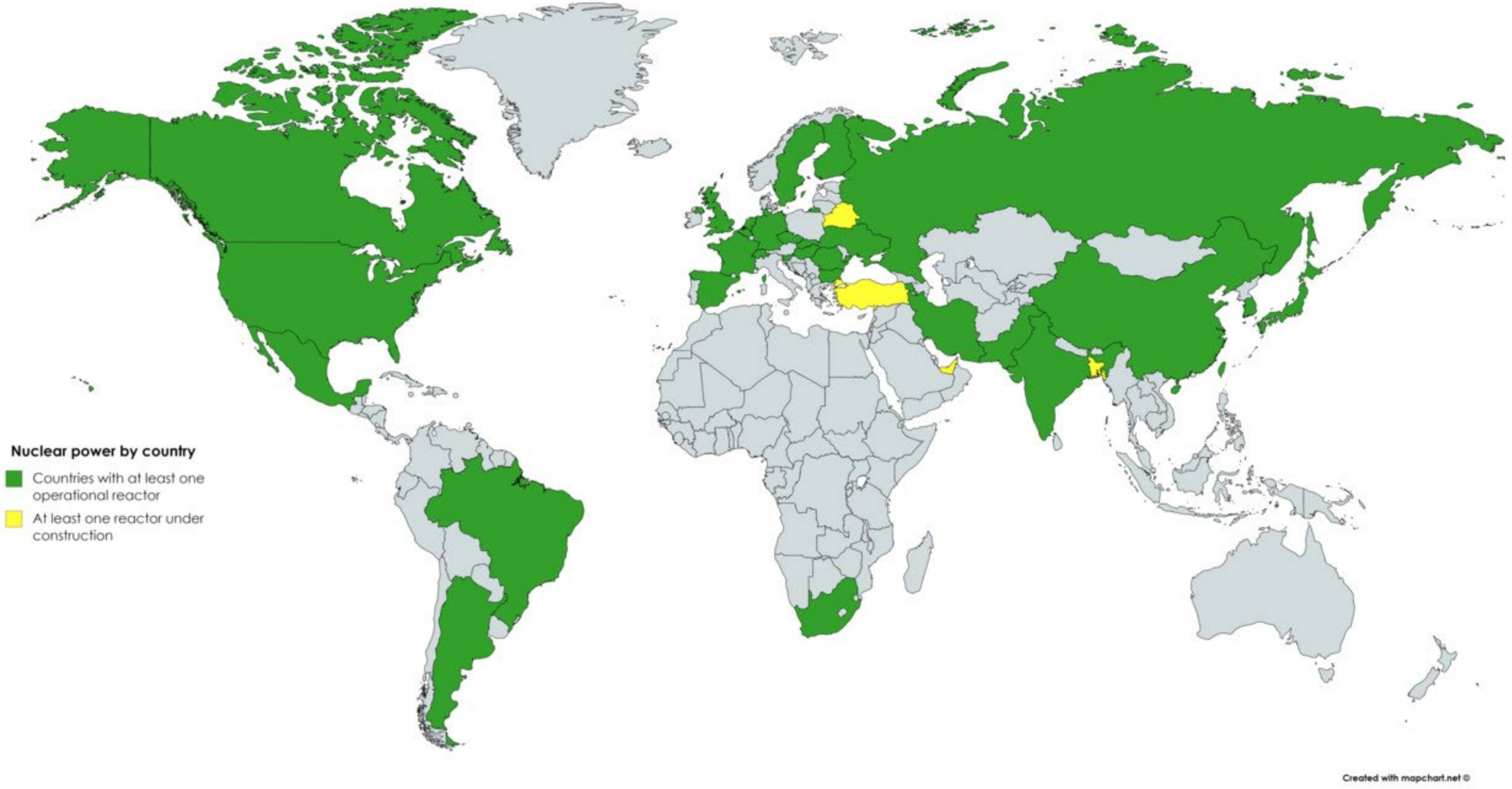
ABV-6E: micro-reactor, 9MWe (Final design)
VBER-300: large reactor, 325MWe (Licensing)

- ***Export Nuclear Power Plant***

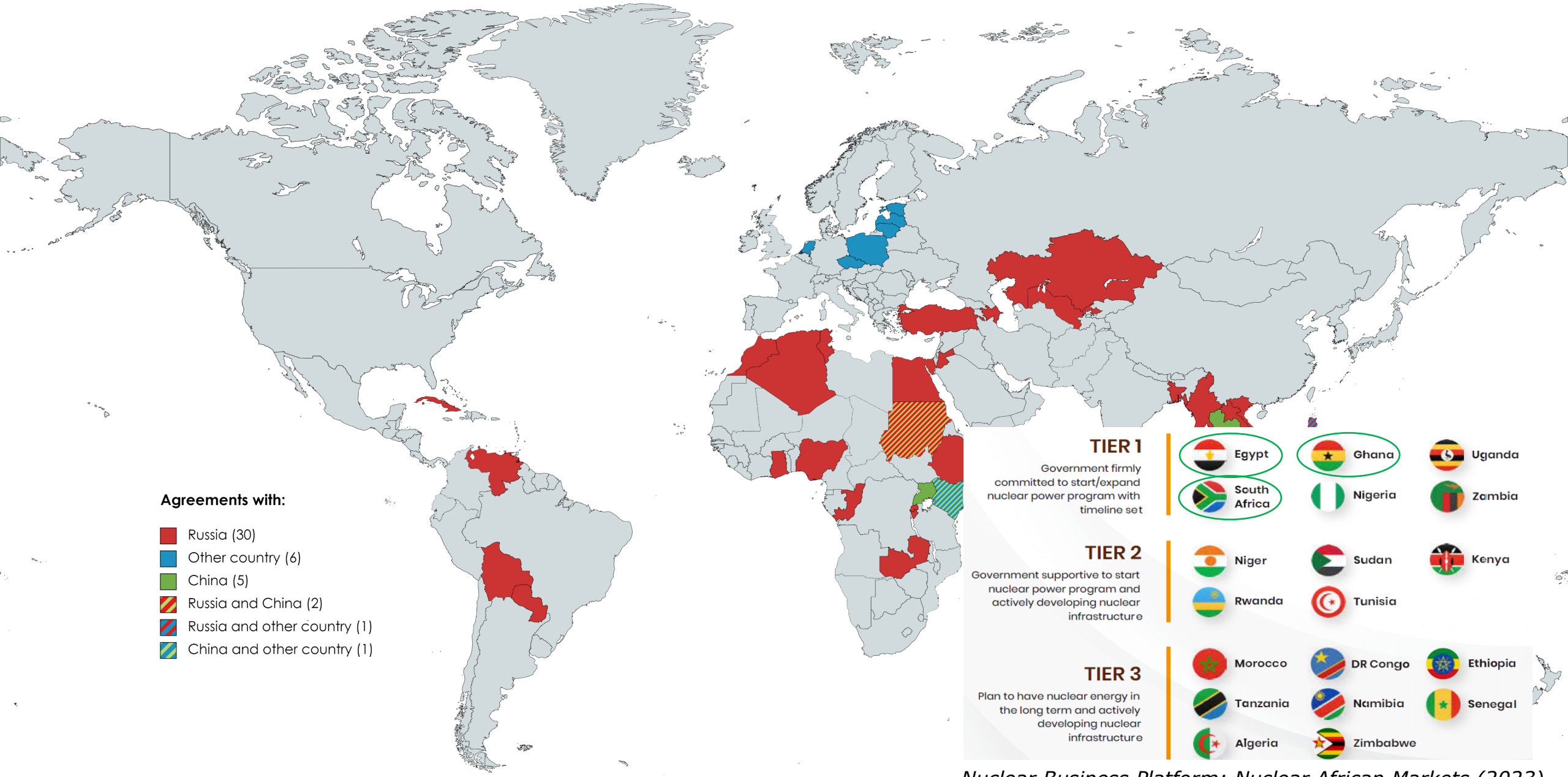
A lot of reactors for export reasons

VK-300: BWR, 250MWe (detailed design)
RITM-200: iPWR, 2x50MWe (under development)

Nuclear Countries



Emerging Nuclear Countries



Nuclear Business Platform: Nuclear African Markets (2023)

Tecnologias mais inovadoras - AMRs

Tipo de Reactor	High / Very High Temperature Gas Reactors	Molten-salt / Lead-cooled / Sodium-cooled Reactors
Diferença	Uso de gás como arrefecimento Uso de TRISO Fuel Potencial de usar Pebble-Bed Design	Uso de um material fundido como arrefecimento Potencial de misturar fuel com o sal (MSR)
Objetivo	Atingir T até 1000$^{\circ}C$. Aplicações industriais dificeis de descarbonizar Se for Pebble-Bed, nunca ultrapassa 1600$^{\circ}C$ – **impossivel ter acidente nuclear.**	Funcionar a pressões ambiente Produção flexível Possibilidade de serem Fast-Reactors (consumo de U238, Torium, **e residuos nuclear**)

UK + Japan – Partnership to develop HTGR

FRANCE2030 → Objective 1: To bring out small, innovative nuclear reactors with better waste management in France. (**1 BILLION euros**).

China já demonstra um pouco de tudo

Russia já tem vários demonstrados, comercialização em 2030

USA – HTGR/TRISO fuel Reactors

X energy

- Xe-100, HTGR 80MWe, TRISO-X particle fuel, scalable up to 4 units
- Completed basic design of the reactor
- Completed fabrication of its first TRISO (tristructural isotropic)

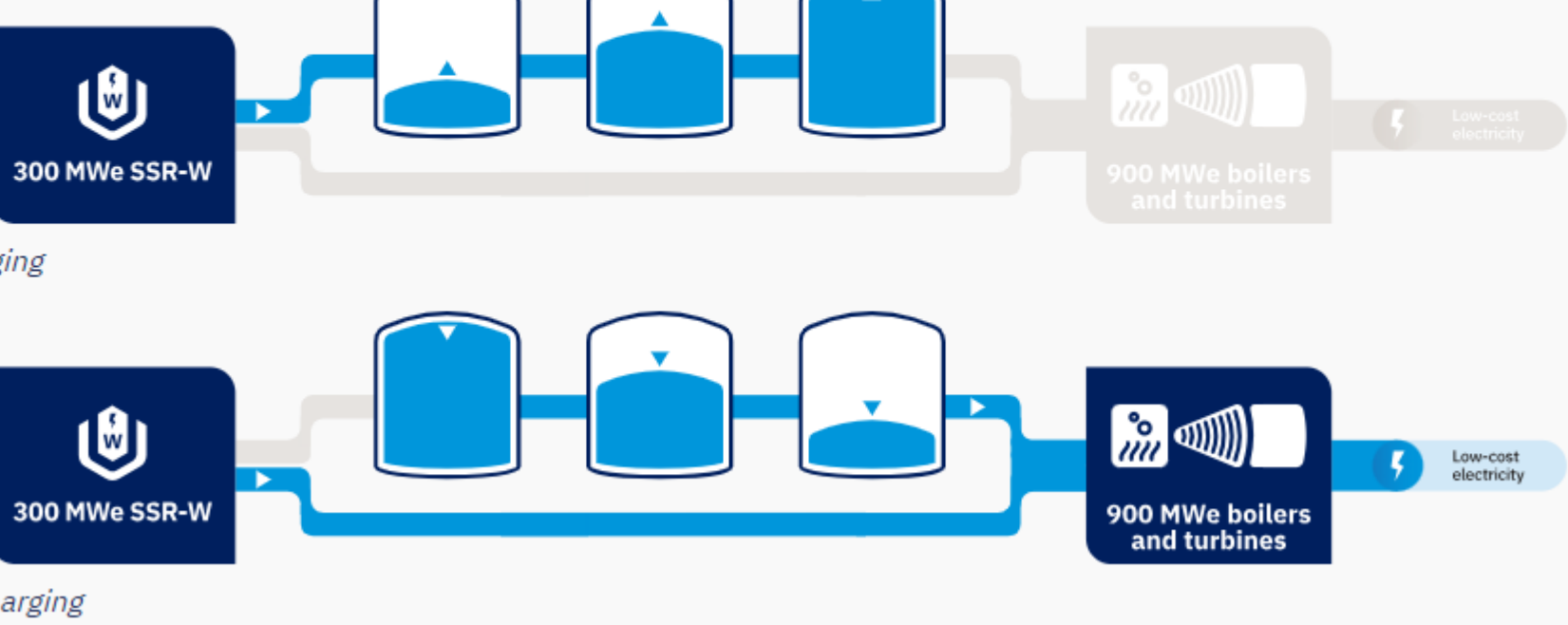
- **Status: Working to get NSC license, presence in the UK**

USNC
ULTRA•SAFE•NUCLEAR

- MMR, HTGR, micro-reactor, 5MWe, TRISO particle fuel
- Completed basic design

- **Status: Plans to begin operations of Pilot Fuel Manufacturing**

- *(Also present in the UK AMR programme!)*



e 2 (VDR2) with CNSC
License
use
e coal furnaces directly with nuclear!

moltex clean energy

- 300 MWe Stable Salt Reactor – Wasteburner (**SSR-W**)
- Uses nuclear waste as fuel
- Use of *GridReserve* (salt storage) allows flexibility
- No pumps (only small impellers in the secondary salt bath)

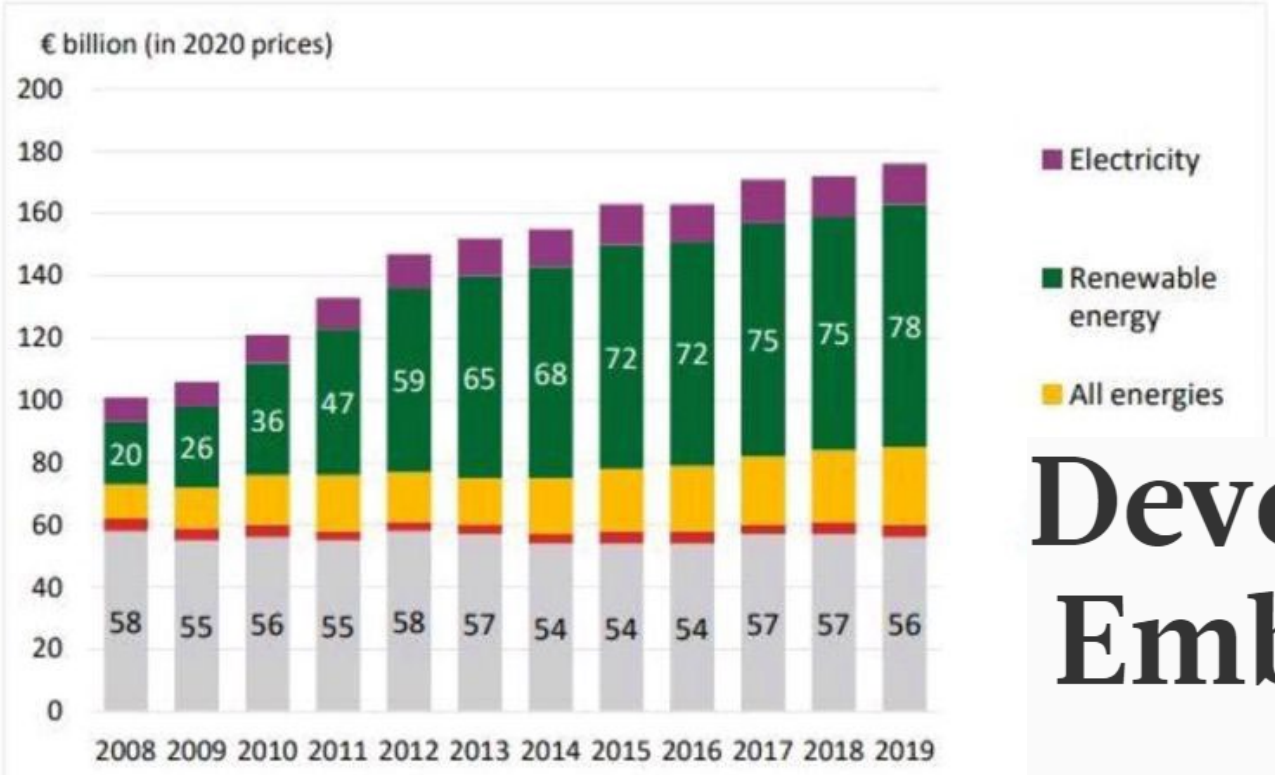
Status: In VDR2 with CNSC.

arc CLEAN TECHNOLOGY

- 100 MWe Sodium Coolant Salt Reactor – Wasteburner (**SSR-W**)
- Based on EBR-II, a tried and tested Sodium-Cooled Reactor in the USA.
- EBR-II demonstrated inherent safety, load following and waste recycling!
- **Status: In VDR2 with CNSC.**

- **Both reactors selected by NB Power to be build at the Point Lepreau site, New Brunswick**

Figure 10 – Energy subsidies by category between 2008 and 2019



Source: ECA based on the *Study on energy subsidies and other government interventi Union*, October 2021.

Condições não são ideais...

Development Banks Must Embrace Nuclear Energy

Feb 28, 2023 | **HÅVARD HALLAND** and **JESSICA LOVERING**

Multilateral development banks' refusal to support nuclear power plants has enabled Russia and China to become the world's leading providers and funders of such projects. To accelerate the net-zero transition and reduce these countries' global influence, shareholder governments must reconsider their outdated stance.

PARIS/SANTA BARBARA – Multilateral development banks (MDBs) have historically been reluctant to invest in nuclear energy, and the World Bank has not financed a nuclear power plant since 1959. In the absence of MDB funds, the majority of international financing for

Recent advances in technology and the energy crisis have sparked new interest in nuclear power across Europe.

Mas o desejo está cá, e hoje!

Lawmakers reintroduce nuclear in EU's net-zero

By Paul Messad | EURACTIV France | translated by Anna Martino and Daniel Eck **Est. 5min**

Jul 20, 2023 (updated: Sep 27, 2023)

Europe: Denmark, Norway, Italy Reconsider Nuclear

Sweden / Government Planning To Build At Least 10 New Nuclear Reactors

By David Dalton
11 August 2023

Country needs 'all the power it can get' as demand set to double, minister says

Poland insists on nuclear's role in green transition