Small Modular Reactors

Common and Unique Challenges

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ČEZ, a. s.

Small Modular Reactors

- **Opening session**
  - SMR – what is it?
  - Do we need SMRs?
- **Common challenges of Nuclear projects**
- **SMR Unique and Innovative technology**
  - Technical features
  - History vs. SMR
  - SMR programme in ČEZ
- **Discussion**
  - Why to become a nuclear guy?
  - Discussion / controversial topics

SMR technology

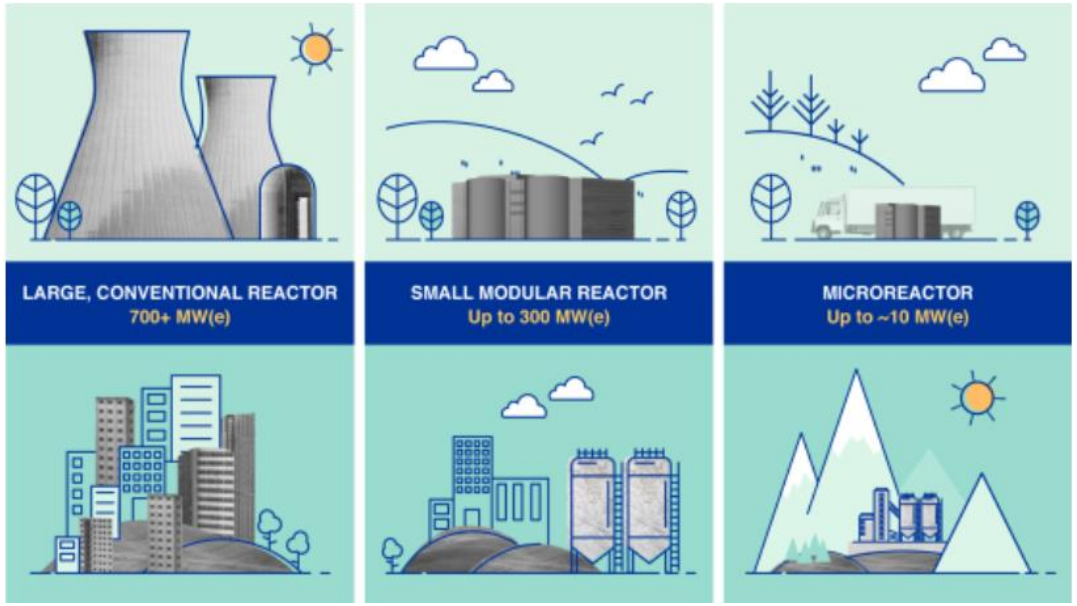
…what the hell it is?

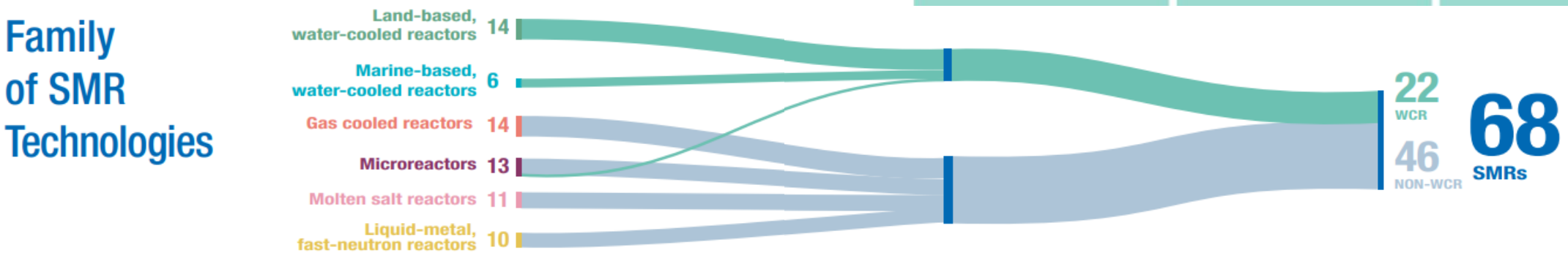
IAEA definition

Small modular reactors (SMRs) are advanced nuclear reactors that have a power capacity of up to 300 MW(e) per unit, which is about one-third of the generating capacity of traditional nuclear power reactors. SMRs, which can produce a large amount of low-carbon electricity, are:

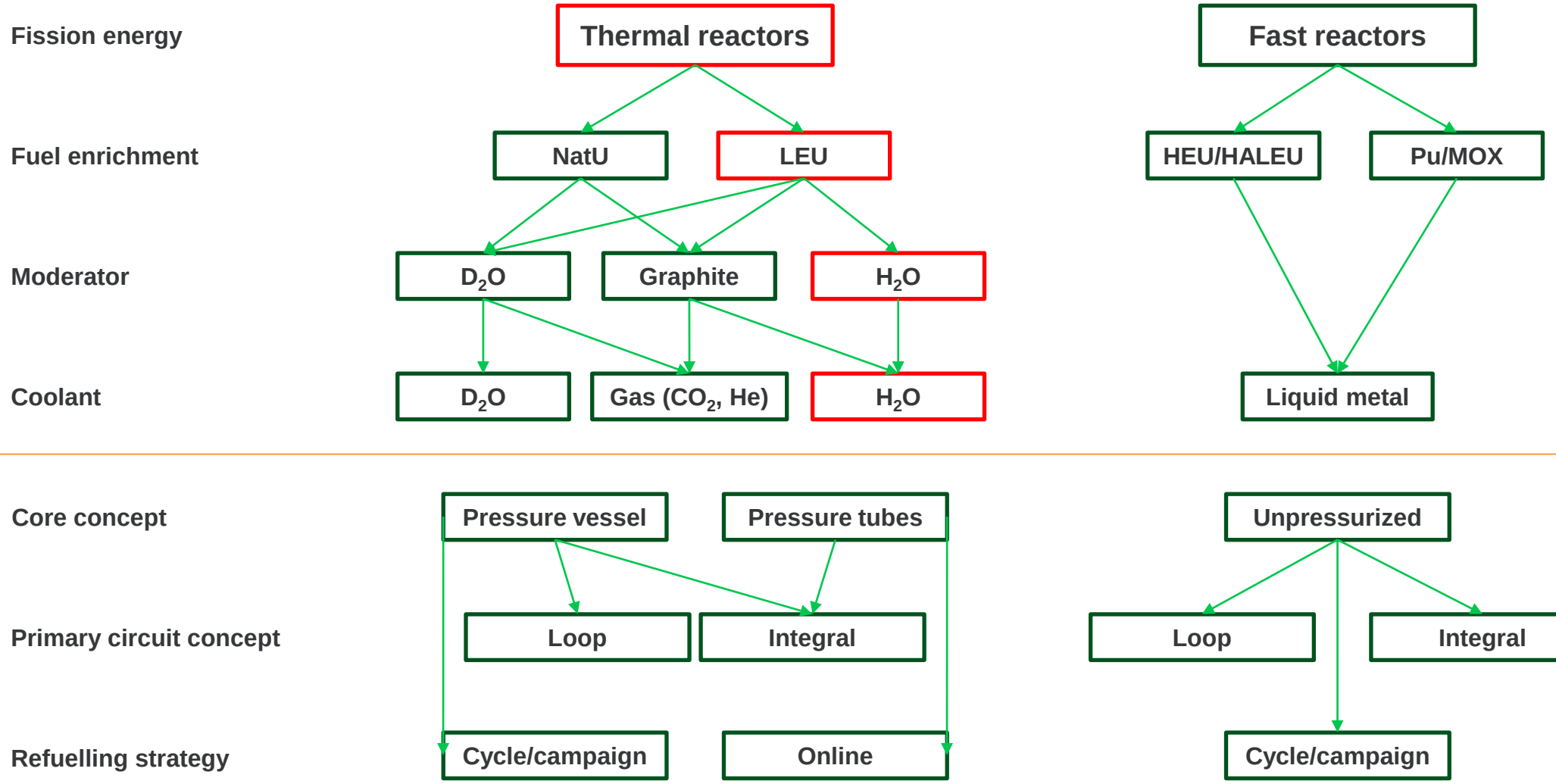
- **Small** – physically a fraction of the size of a conventional nuclear power reactor.
- **Modular –** making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation.
- **Reactors –** harnessing nuclear fission to generate heat to produce energy.

ČEZ definition: Small modular reactors (SMRs) are light water nuclear reactors of at least generation III+ with an installed electrical output in the range of 100 to 520 MWe.



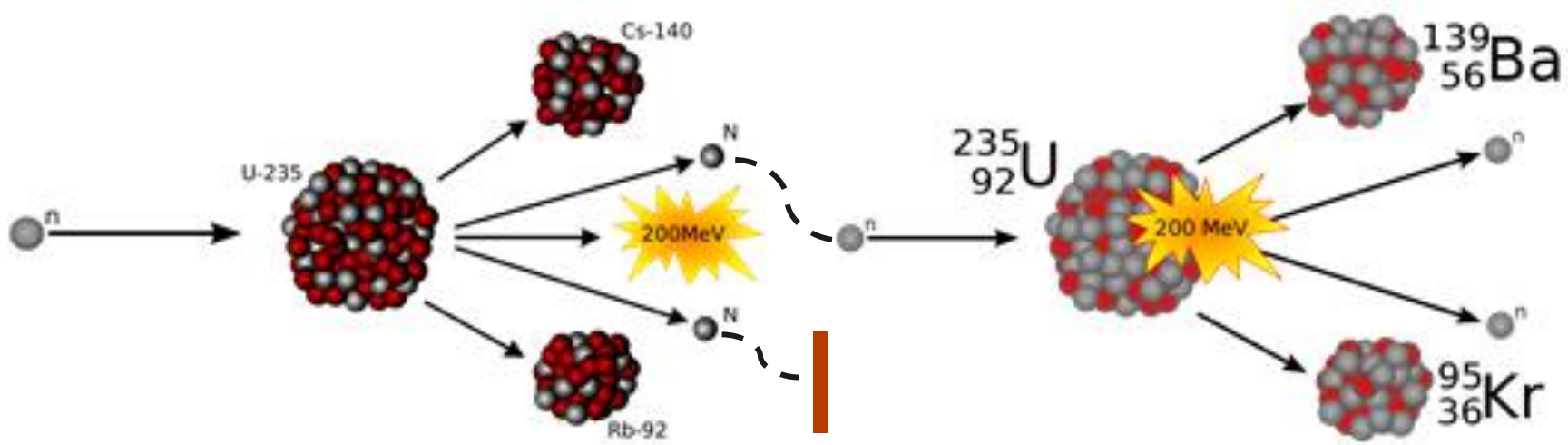


SMR Technologies



SMReactor

Reactors – harnessing **nuclear fission** to generate heat to produce energy.



Nuclear fission:

- Thermal neutron
- Collision
- 2 fission products
- 2-3 released fast neutrons
- **Energy (ca 200 MeV, cca 83 TJ/kg)**

- Which nuclei are suitable for fission?

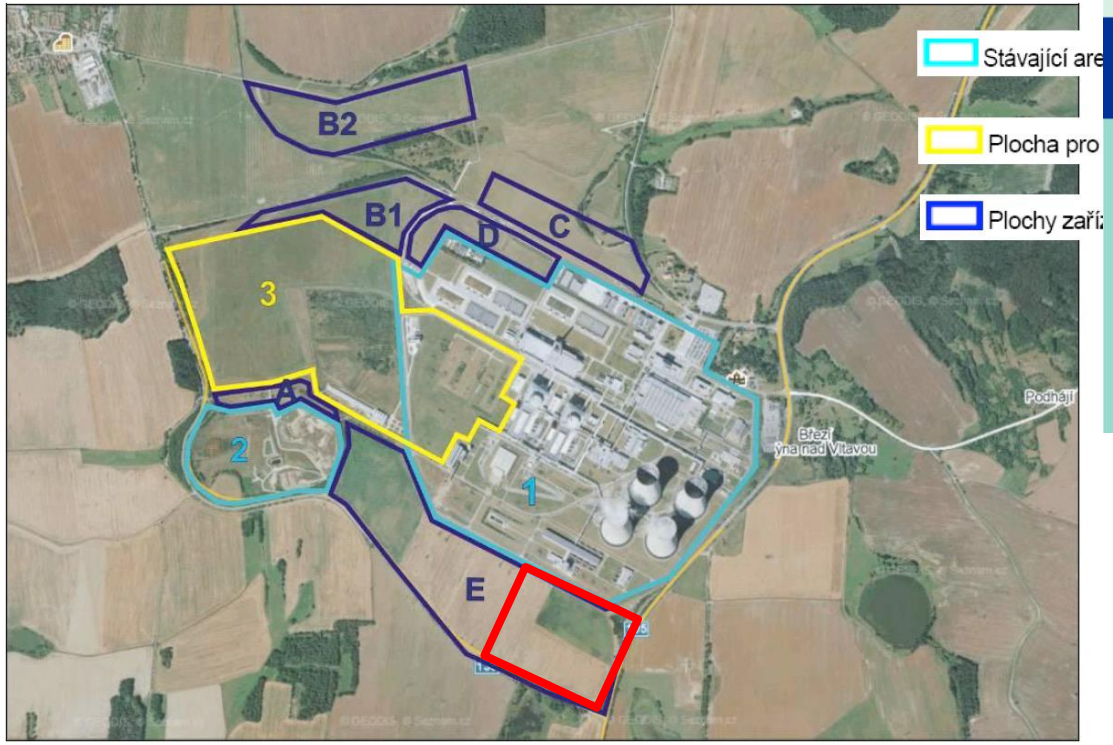
$$D\Delta\emptyset - \sum_{a} \emptyset + S = \frac{\partial n}{\partial t}$$

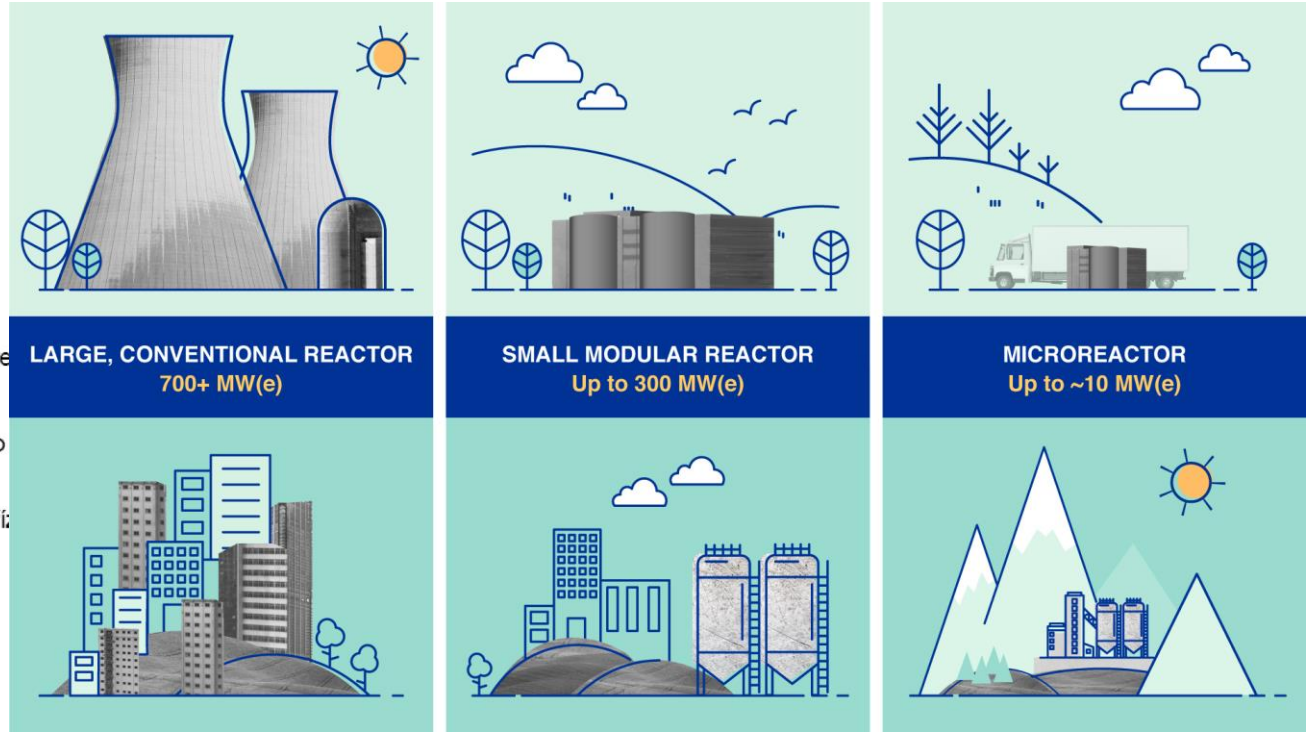
SmallMR

Small – physically a fraction of the size of a conventional nuclear power reactor.

Footprint vs installed capacity:

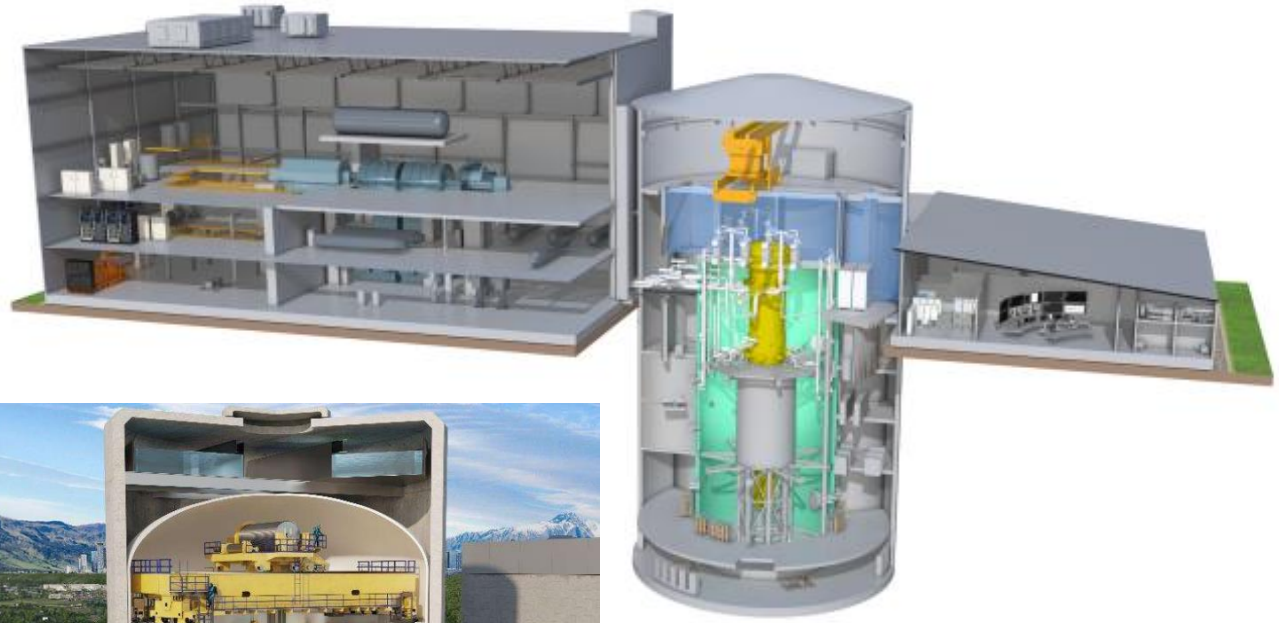
- <1ha vs < 20 ha vs 123 ha
- ~10 MWe vs ~300MWe vs 1 000 MWe

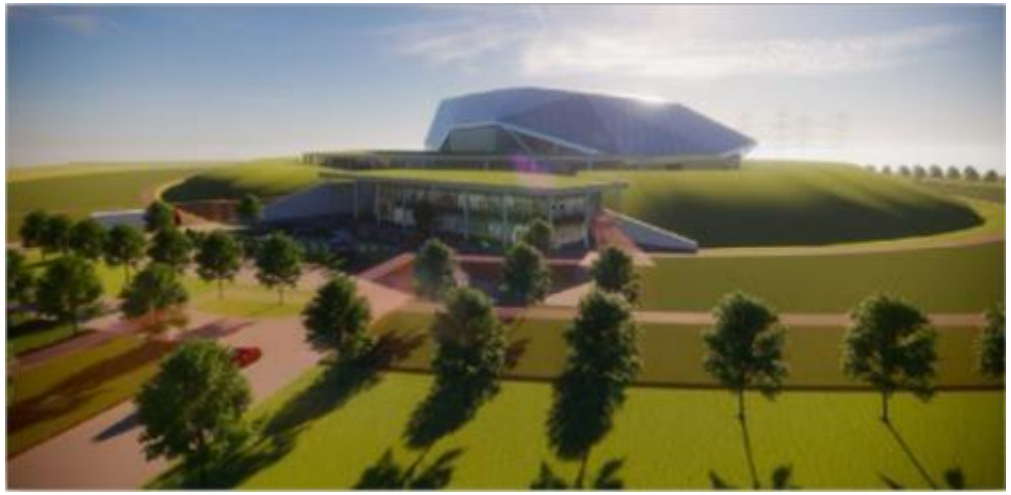


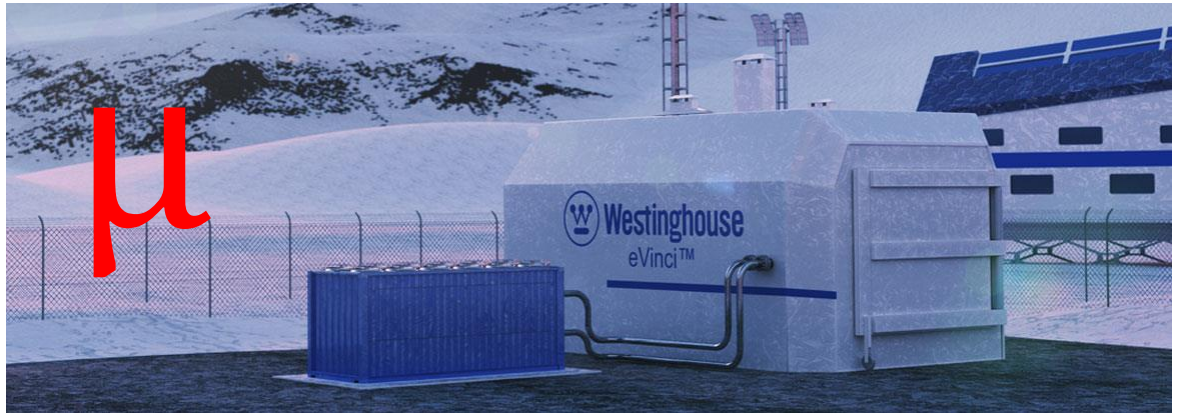


SmallMR

Small – physically a fraction of the size of a conventional nuclear power reactor. **..some of them!**





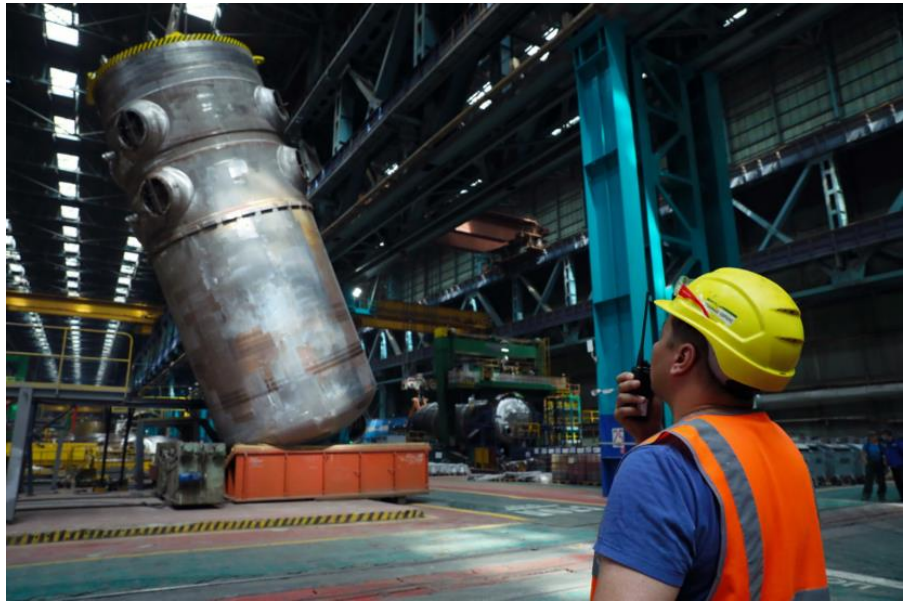


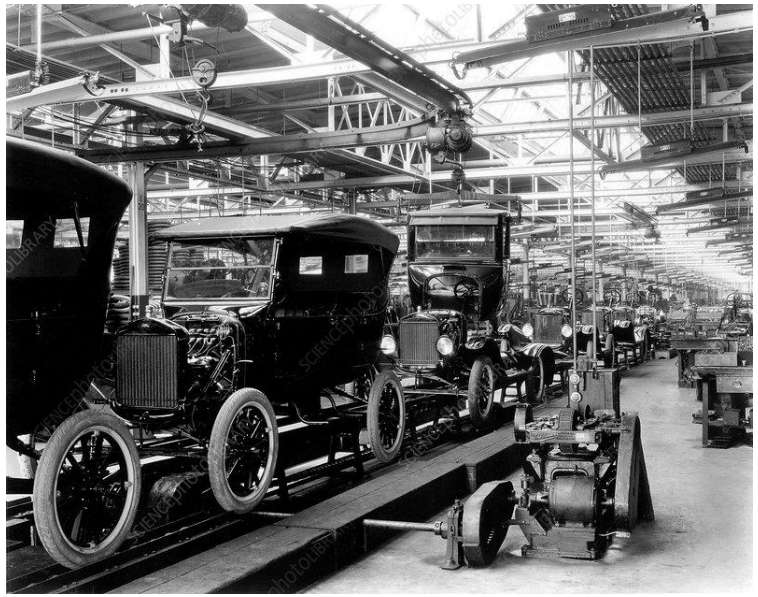
SModularR

Modular – making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation.

Modularity:

- Each design is unique in the modularity concept
  - Module as one „part“ of NPP (several components)
  - Module as independently operable part of NPP
  - Module as entire NPP
- Supplier may benefit from factory „mass“ production

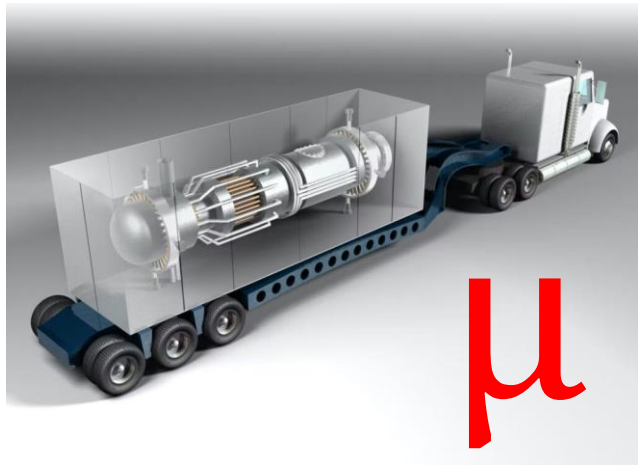


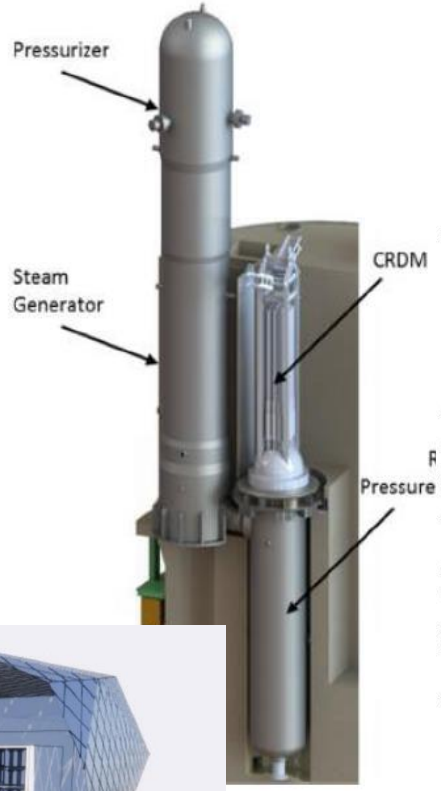


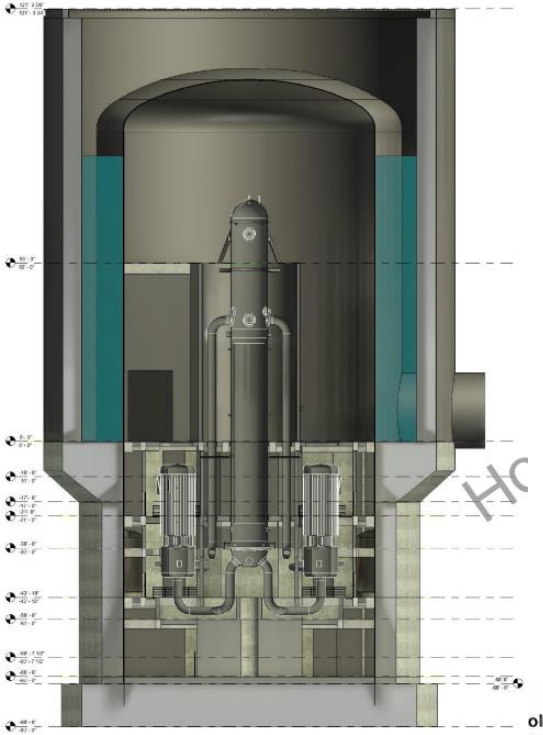
SModularR

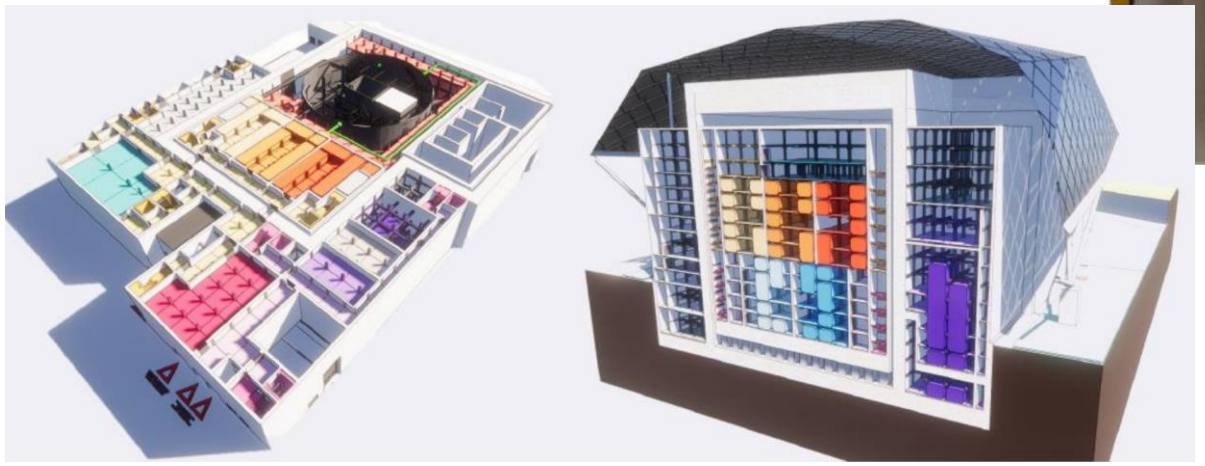
Modular – making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation.

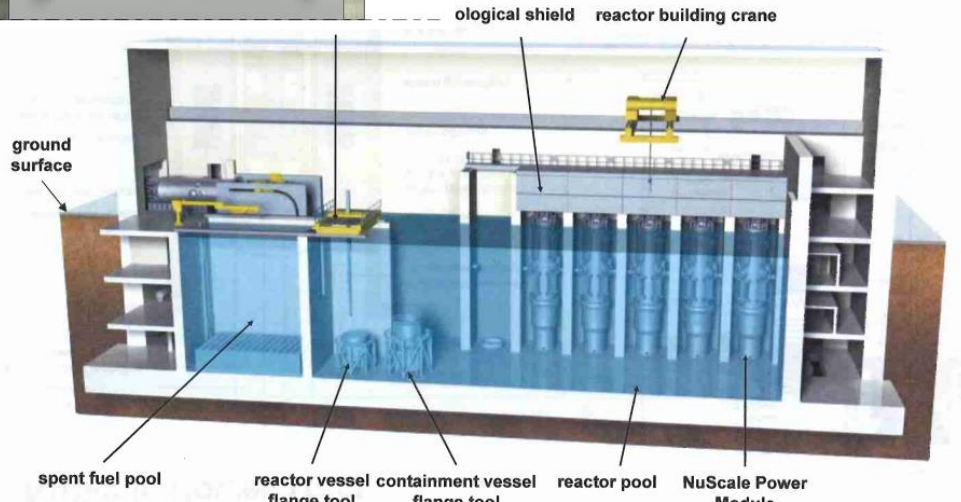
Modularita:











IAEA SMR Booklet

- ca 80 SMR designs
- 5 categories:
  - Water cooled SMR
  - High temperature gas cooled SMR
  - Liquid metal cooled SMR
  - Molten salt SMR
  - Microreactors (< 10 MW_e)
- One Czech project in 2024 edition

Are there all SMR designs?

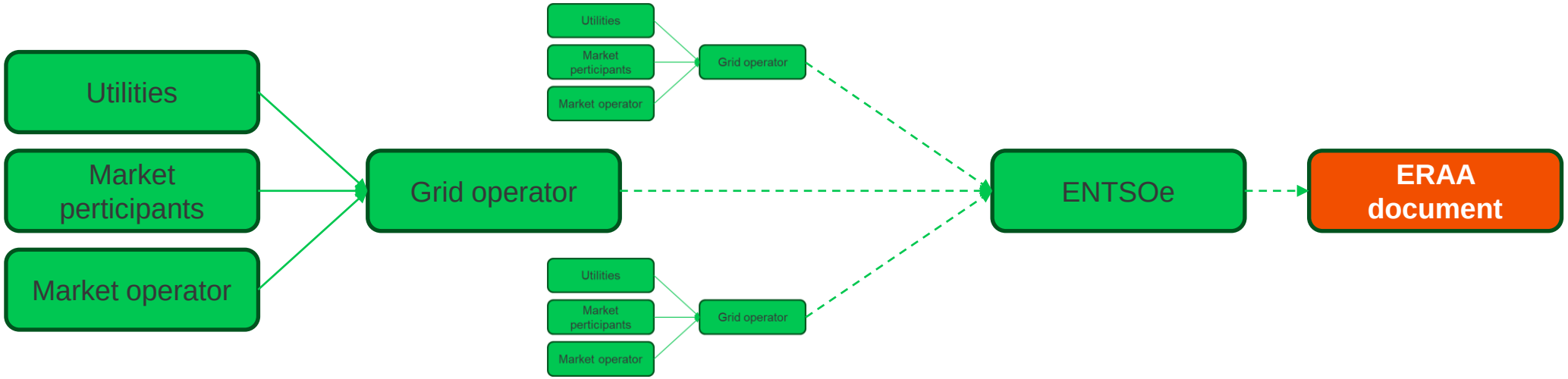
Do we need SMRs?

SOS!

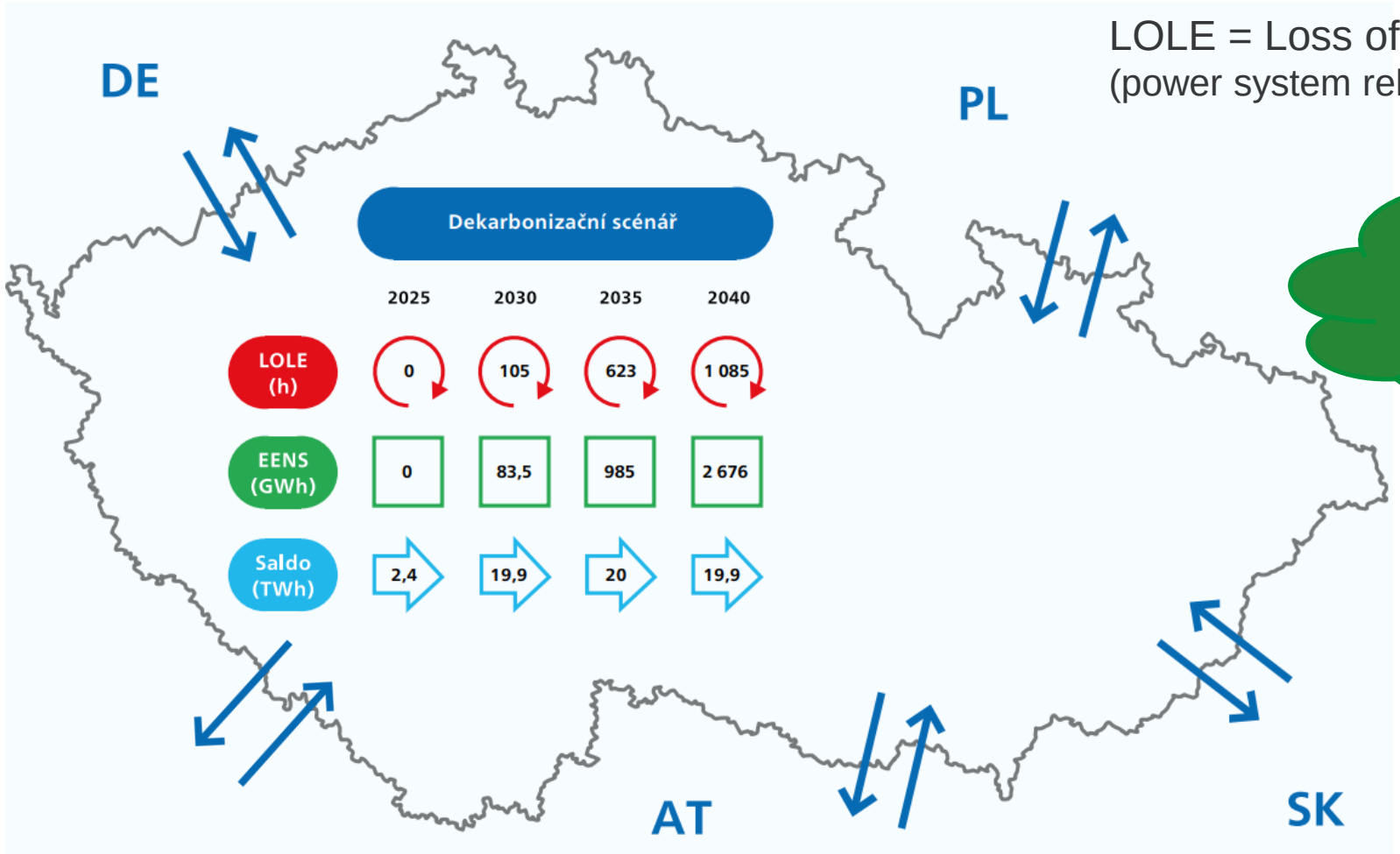
(Security Of Supply)

Quo vadis, security of supply?

- Outlook of the security of supply on the European level is assessed by the ENTSOe (European Network of Transmission System Operators)
  - SOAF, MAF, ERAA
- **Grid operators provide ENTSOe with data every year** based on the requirements of EU Regulation 2019/943, Art. 23, par. 4:
  - **ENTSO performs the European assessment of resource adequacy annually**.
  - Utilities and other market participants provide grid operators with data on the expected utilization of sources taking into account the availability of primary sources and expected supply/demand scenarios

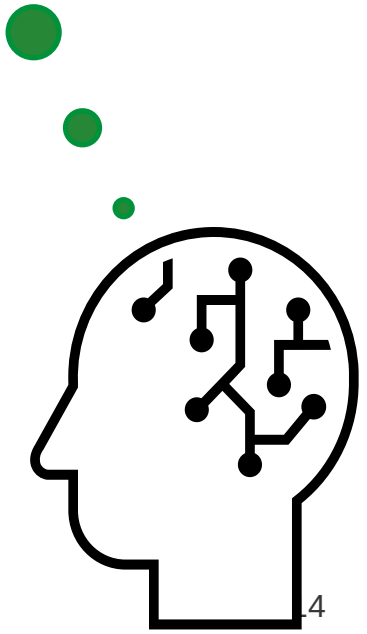


SECURITY OF SUPPLY FORECAST

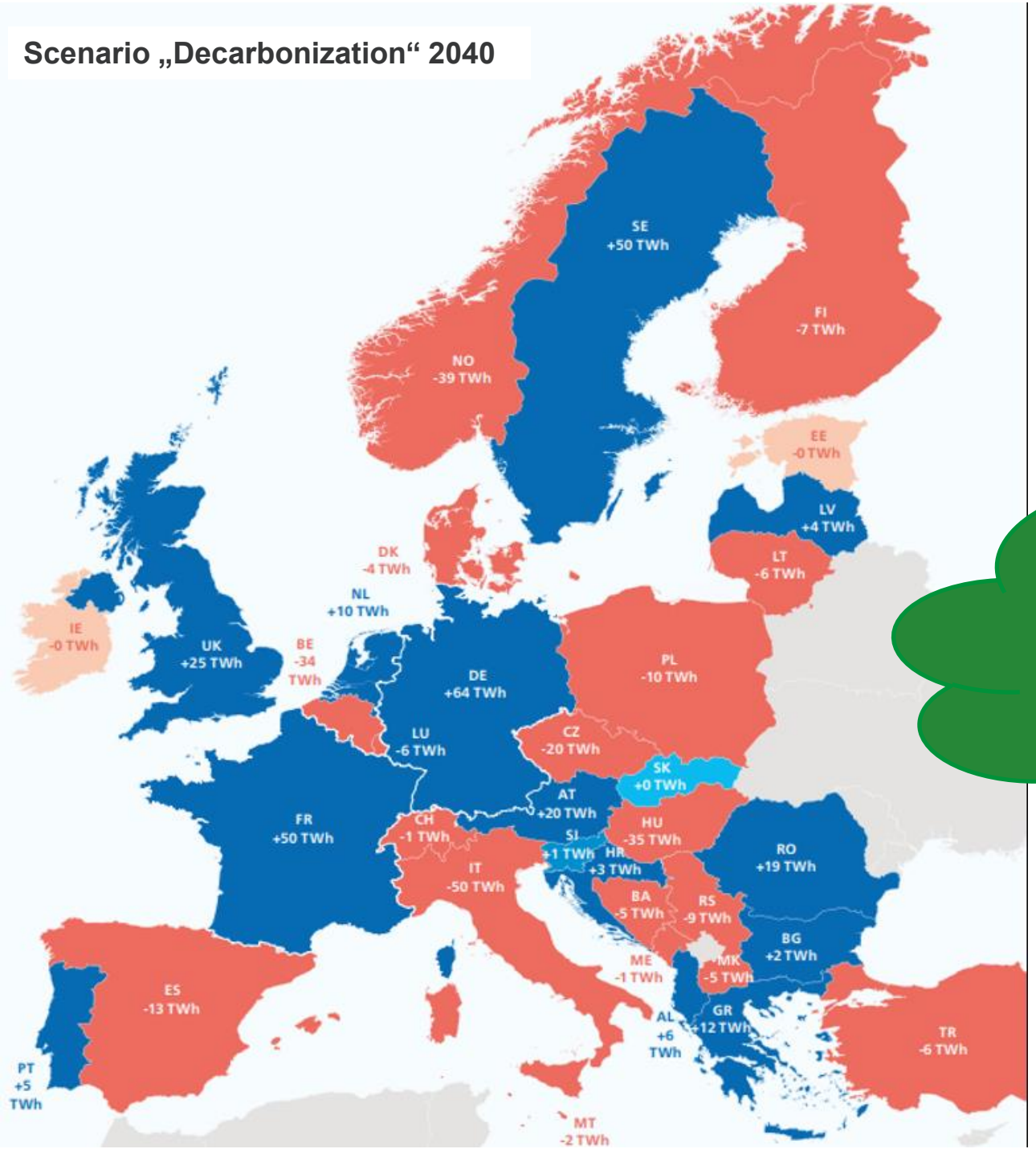


LOLE = Loss of Load Expectation
(power system reliability indicator)

When will the „Loss of load“ occur??



Source: MAF CZ 2022 – ČEPS, a.s.



Decarbonization via intermittent RES

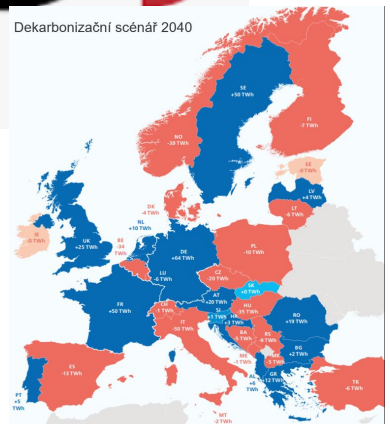
- Baseload sources are forced into semi-peak operation
  - Ruined economics –> going offline
- Peak sources are becoming semi-peak as well
- Reserve sources are becoming peak sources
- Dependency on peak sources increases (gas, fuel oil..)

After the disturbing results published in MAF 2022, „MAF 2023“, which was published in 2024, was delayed by more than half a year.

Why?

Politicians and experts

We are sorry that you don't trust us at all.

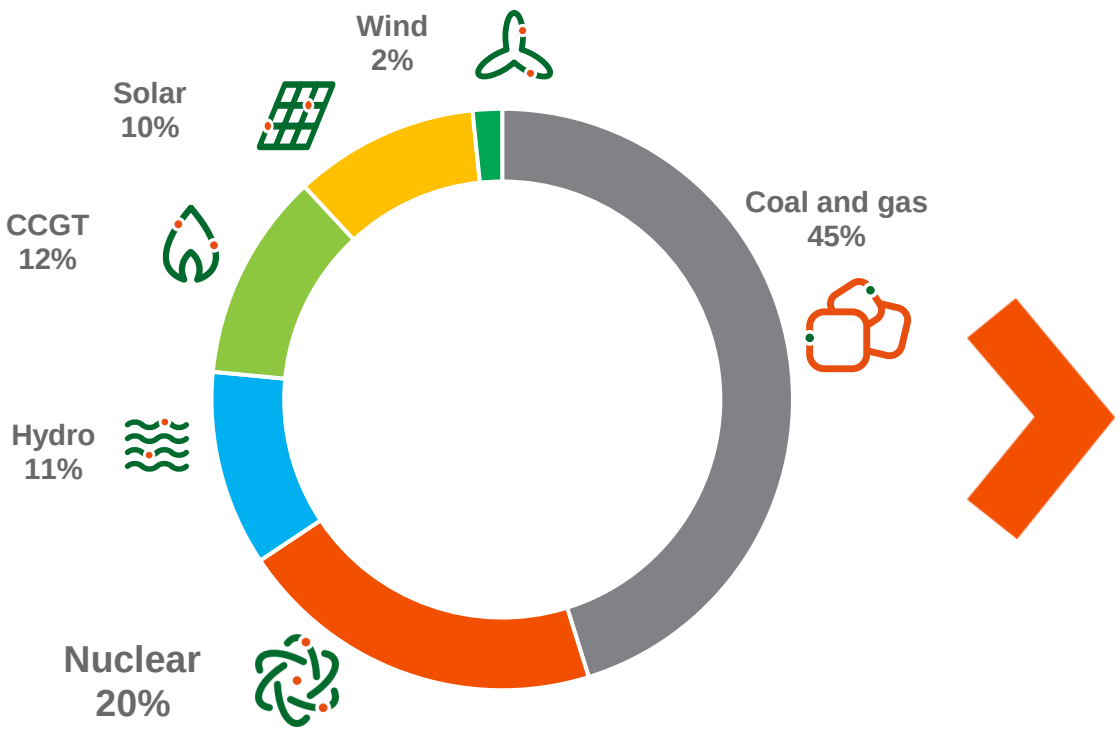


No way, you're misunderstanding, you have to trust us.

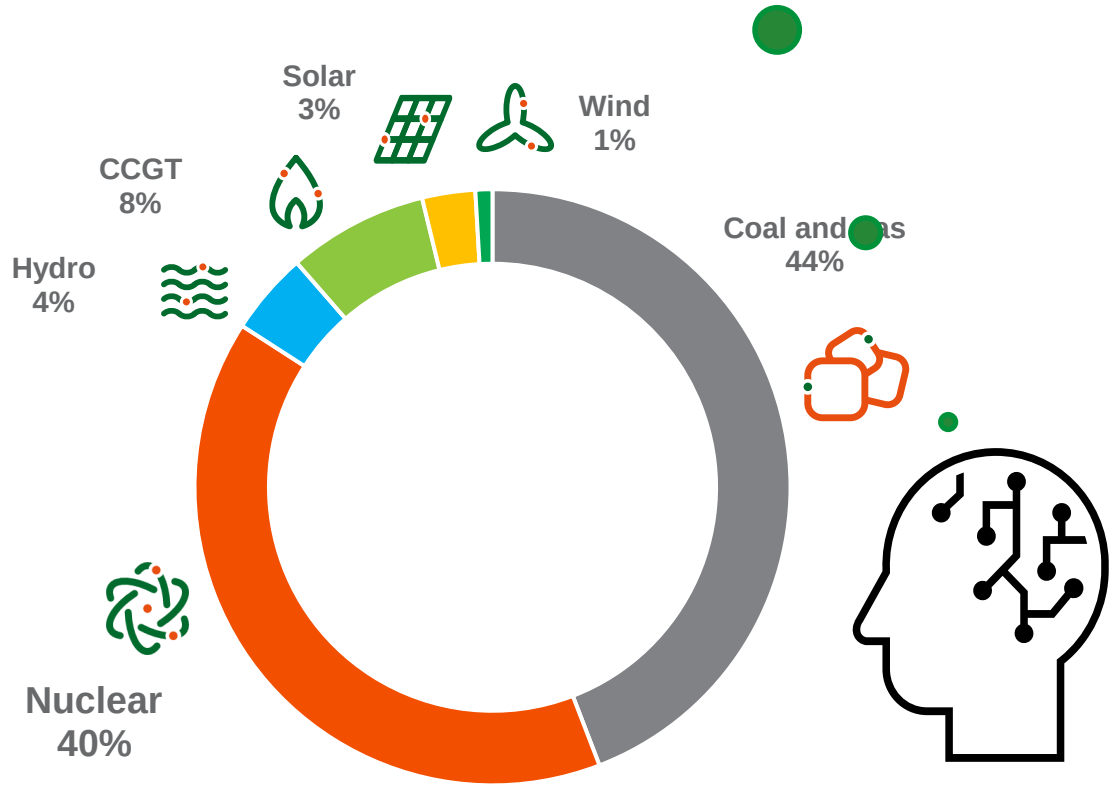
ELECTRICITY GENERATION CZECH REPU

Say a few words about this power system?

Installed capacity CZ 2023



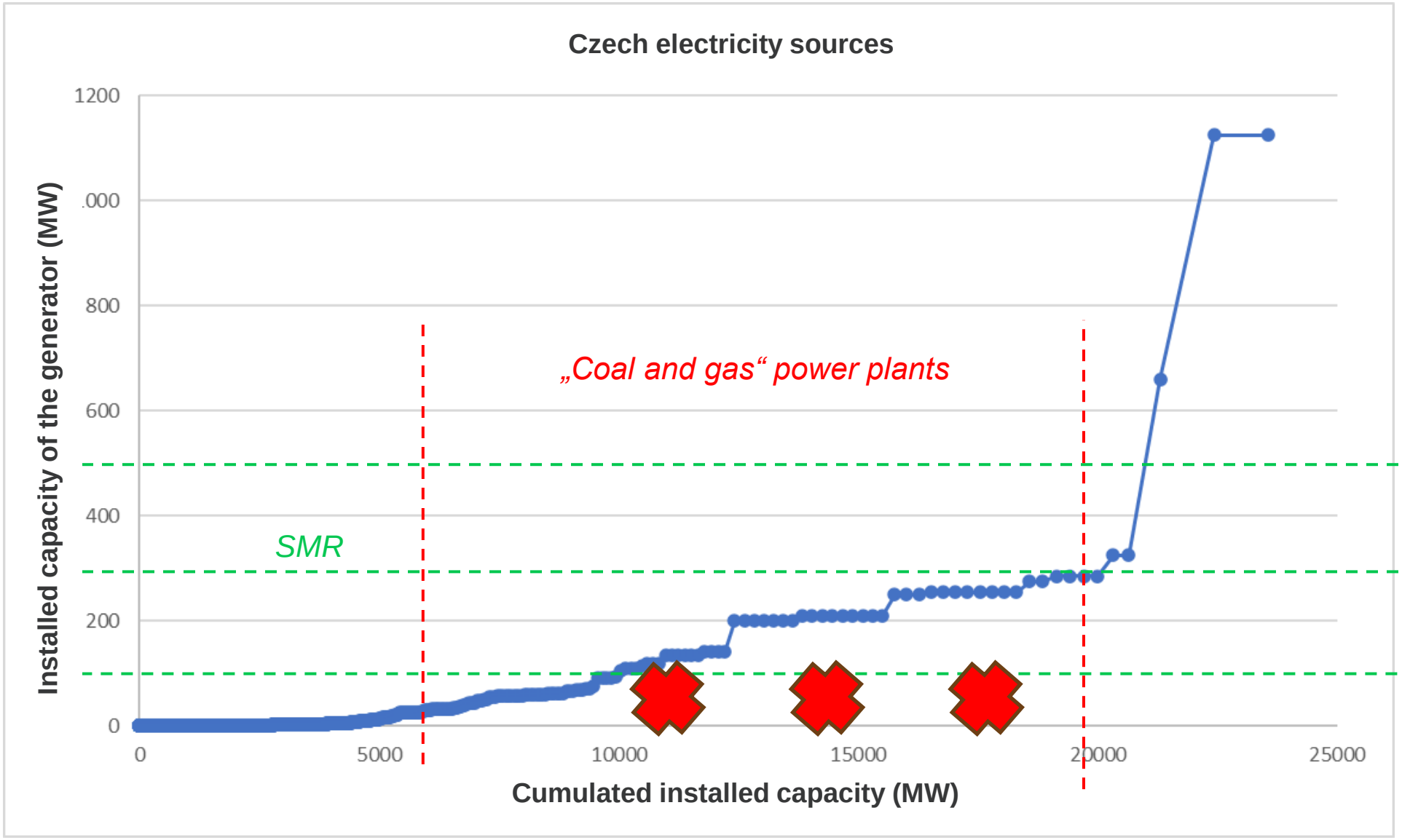
Electricity generation 2023 (brutto)



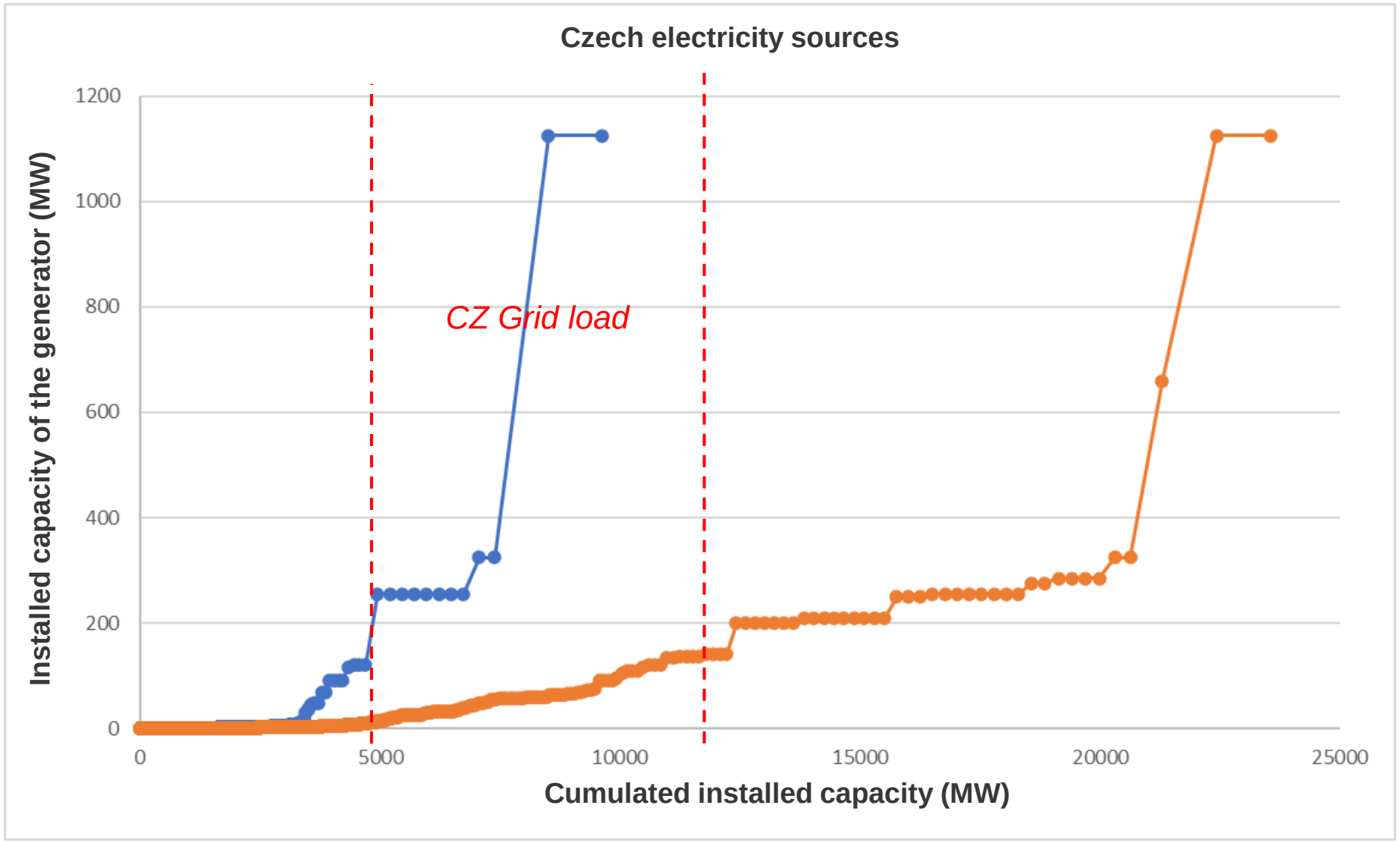
Electricity generation (netto):	71 TWh
Consumption:	57 TWh

Source: ERÚ

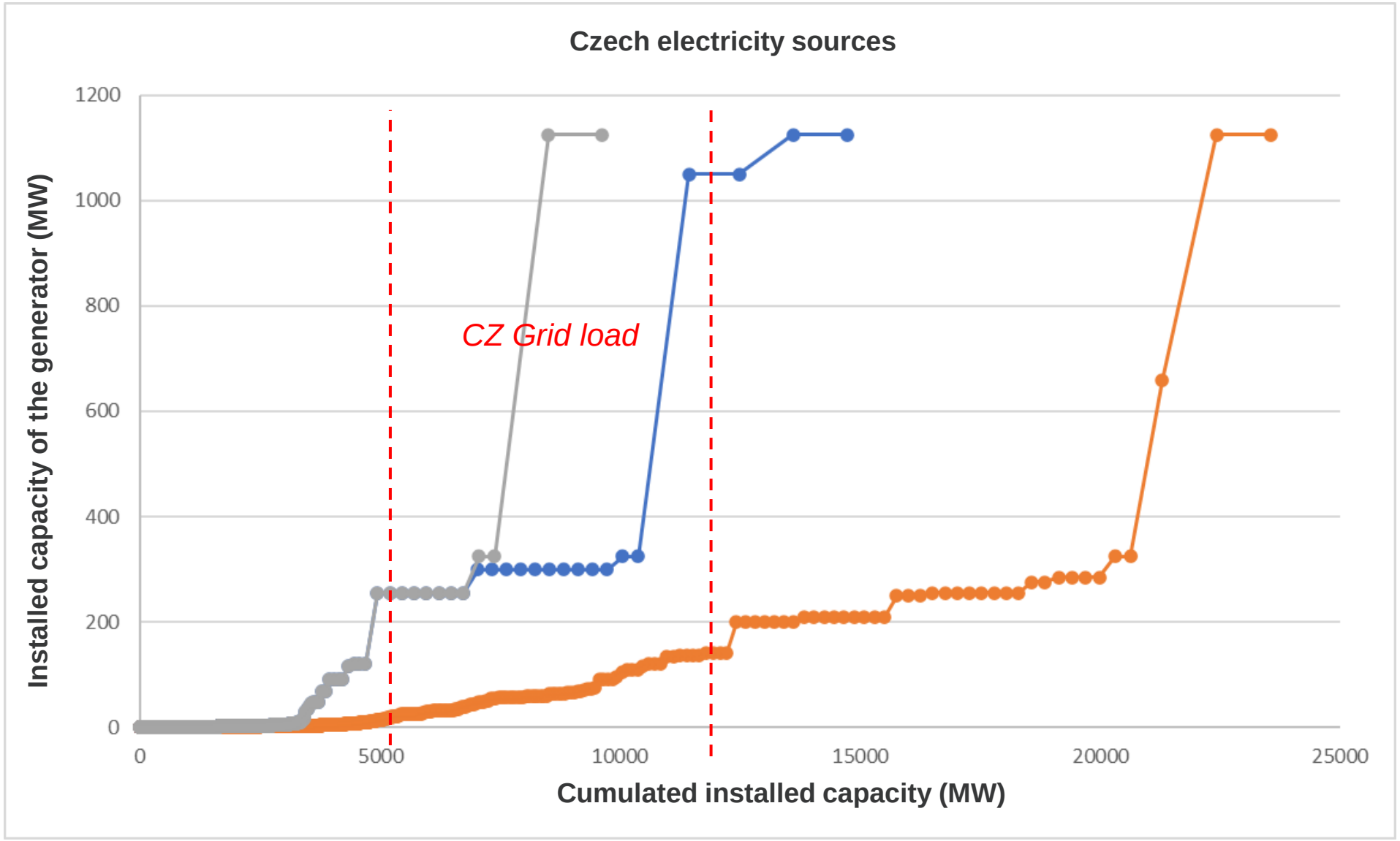
CZECH ELECTRICITY SOURCES



CZECH ELECTRICITY SOURCES TODAY AND TOMORROW



ZDROJOVÁ ZÁKLADNA ČR – DNES A ZÍTRA (A S JÁDREM)



So, do we need SMRs?

- In the Czech republic…

YES!!!

Common Challenges of Nuclear Projects

..and nuclear advantages as well

Nuclear facts and myths

- **Emission intensity - The Intergovernmental Panel on Climate Change, OSN**

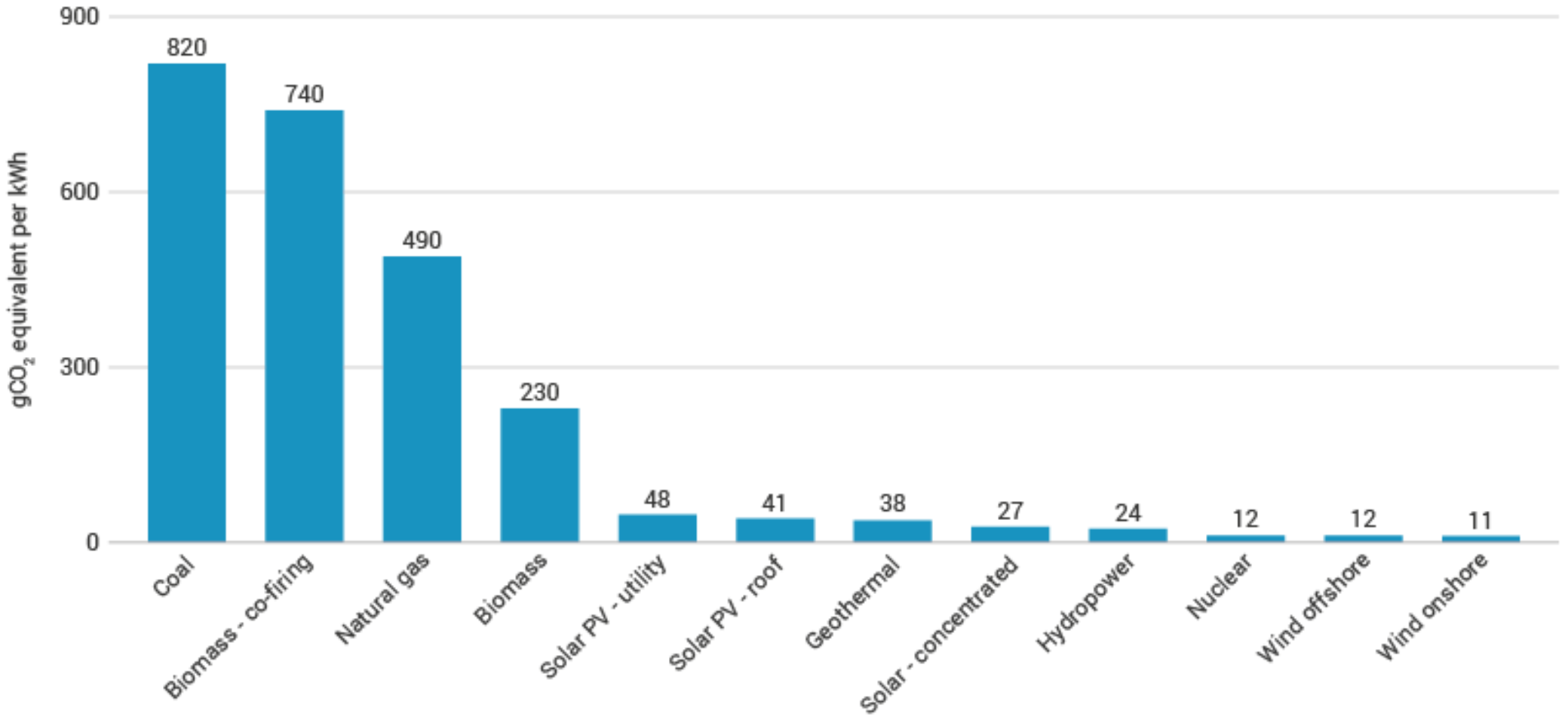
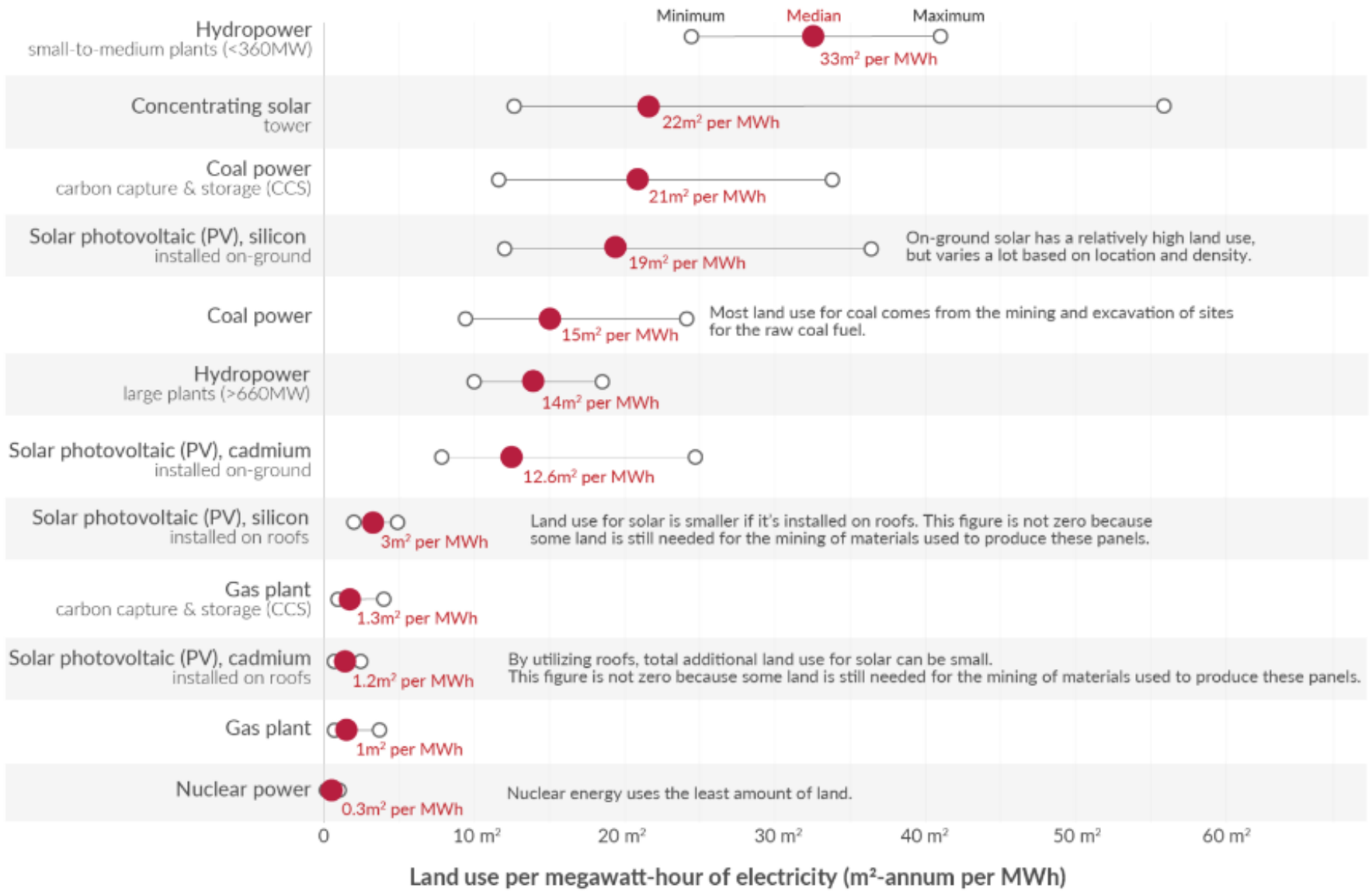


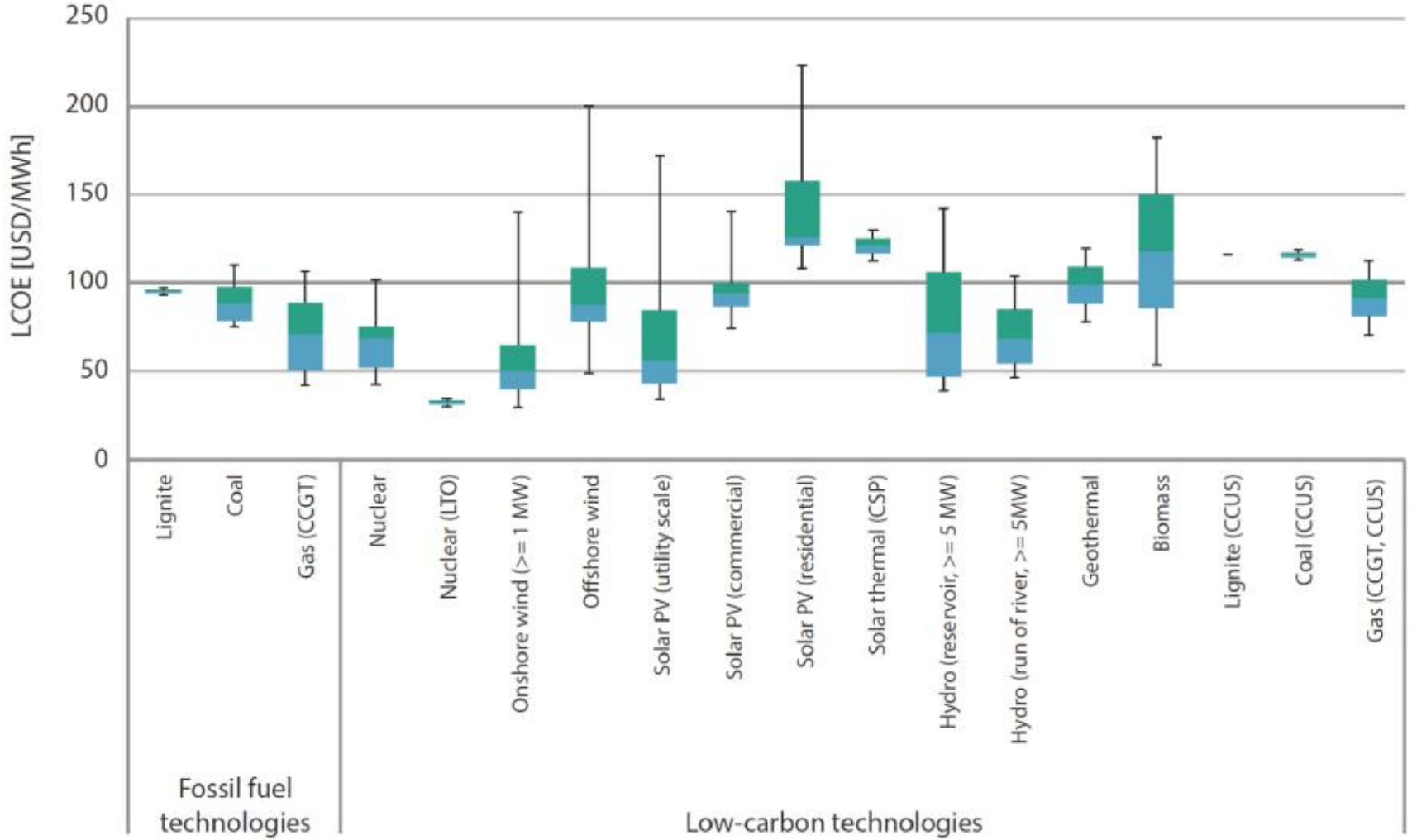
Figure 1: Average life-cycle CO_2 equivalent emissions (source: IPCC)

Land needed for generation of one megawatt-hour of electricity p.a.



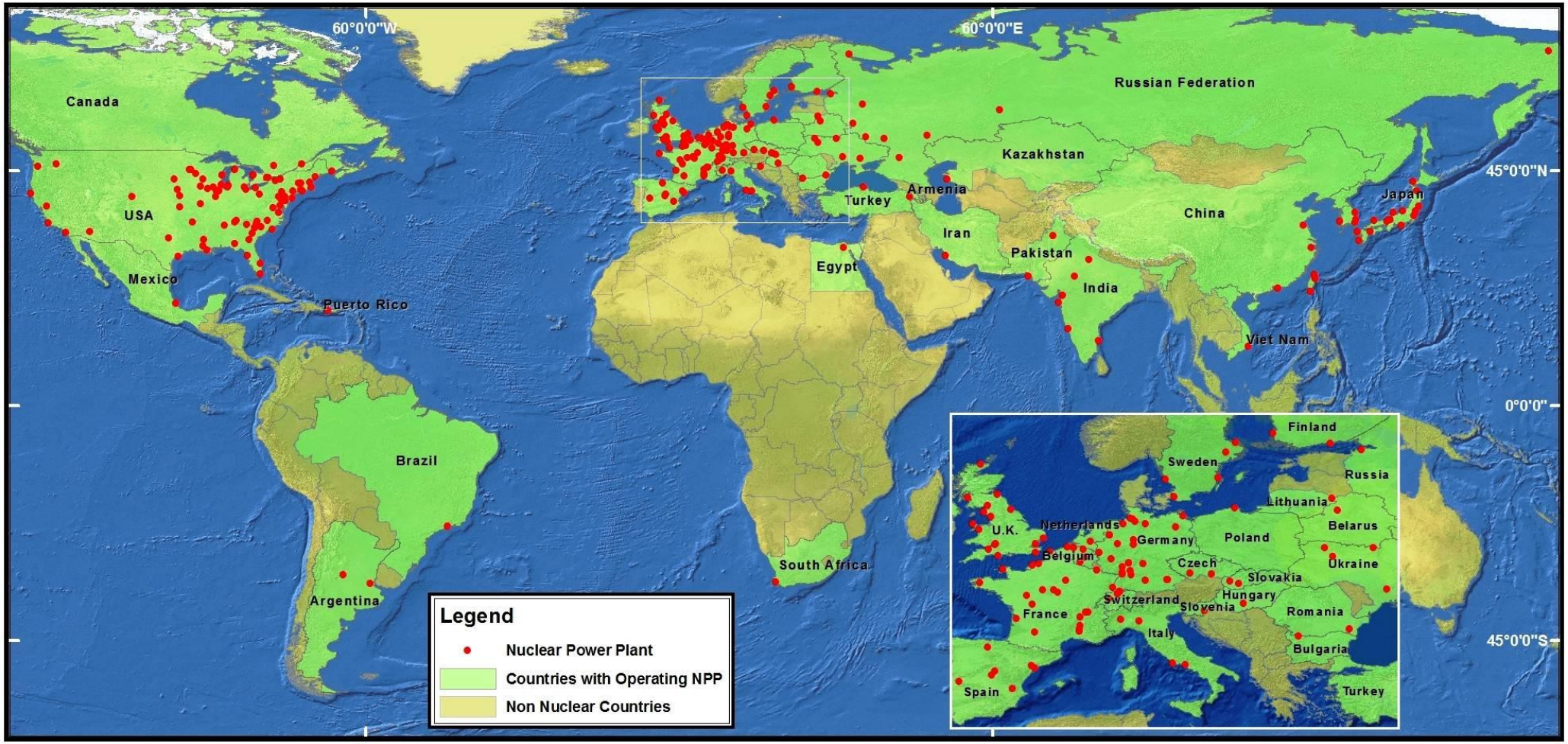
Production costs

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}}$$



Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

Nuclear Power Plant = reliable source



- Ca 440 nuclear reactors in 33 countries
- More than 20,000 reactor-years of experience with power reactors

Nuclear Power Plant = reliable source

107 decommissioned and
100 commissioned reactors
within last 20 years

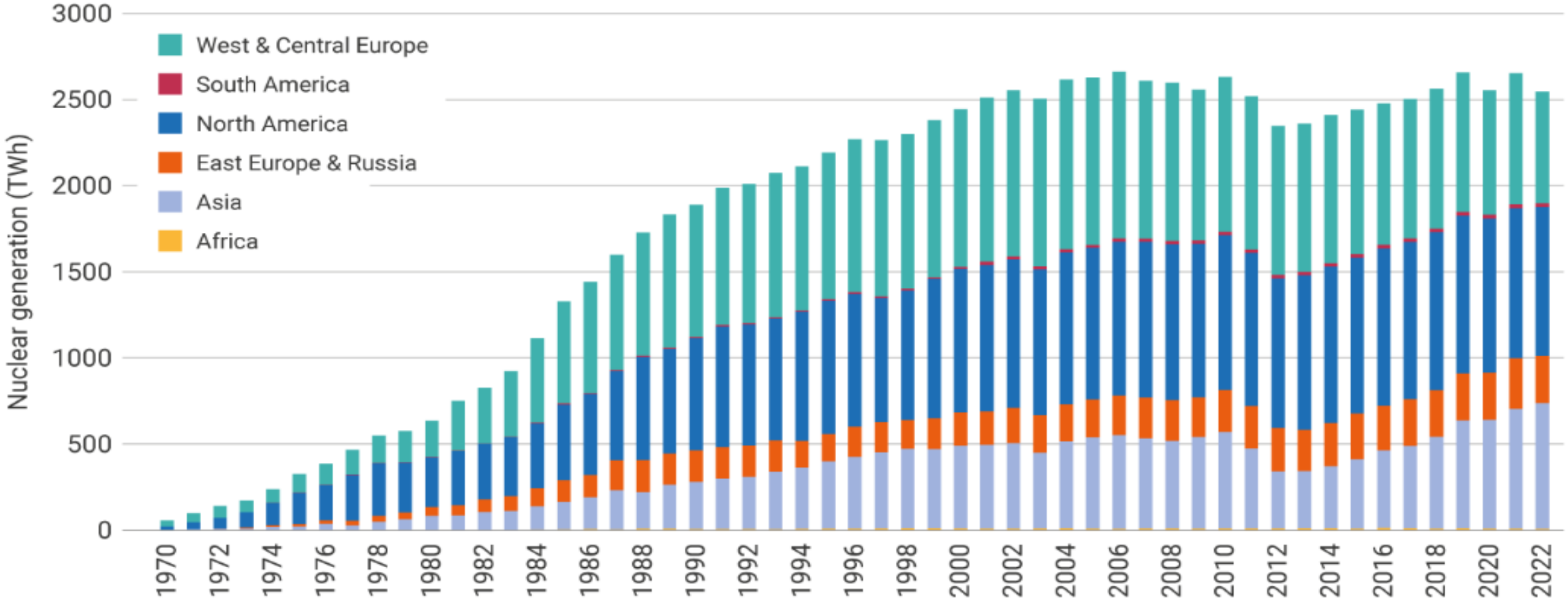


Figure 1: Nuclear electricity production (source: World Nuclear Association, IAEA PRIS)

Nuclear Power Plant = reliable source

We are increasing the capacity factor of the operating NPPs

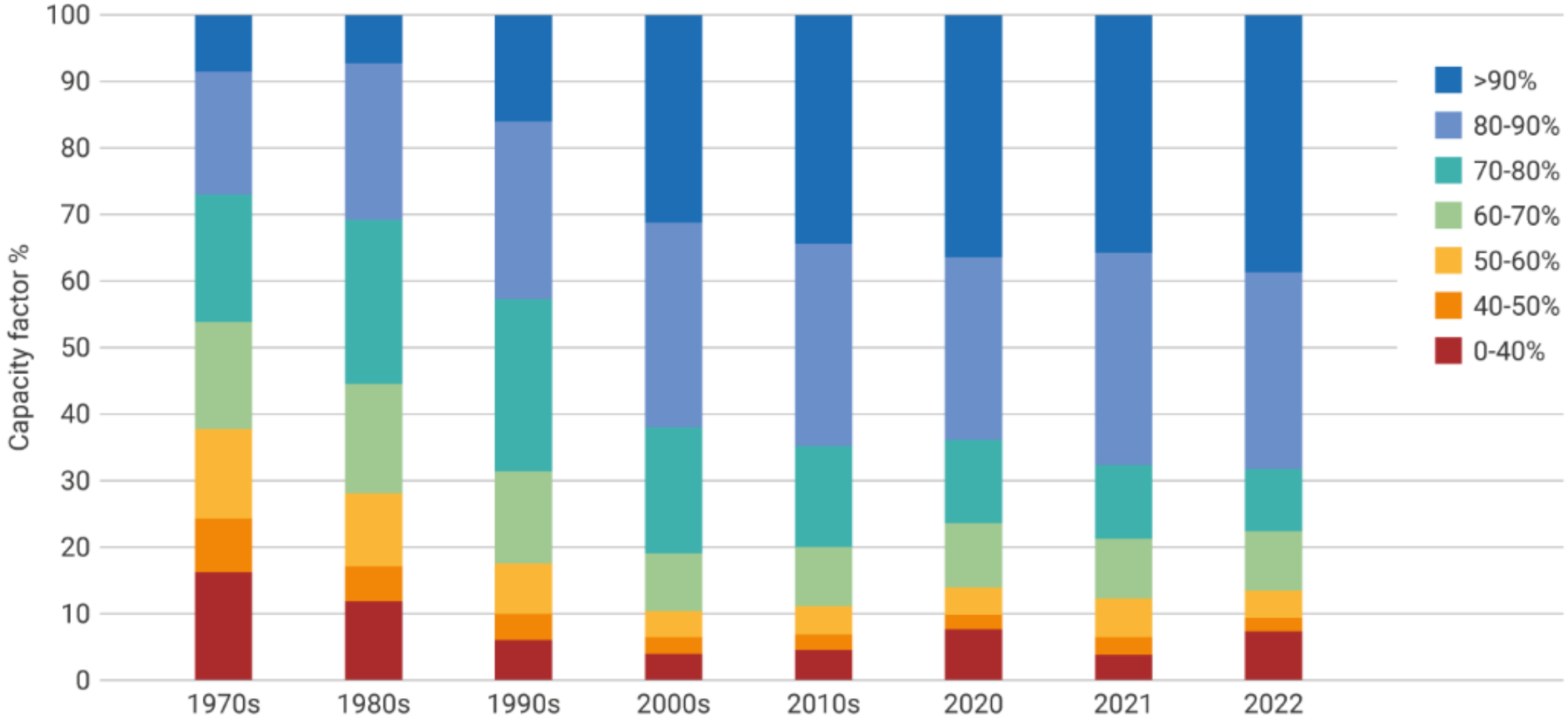


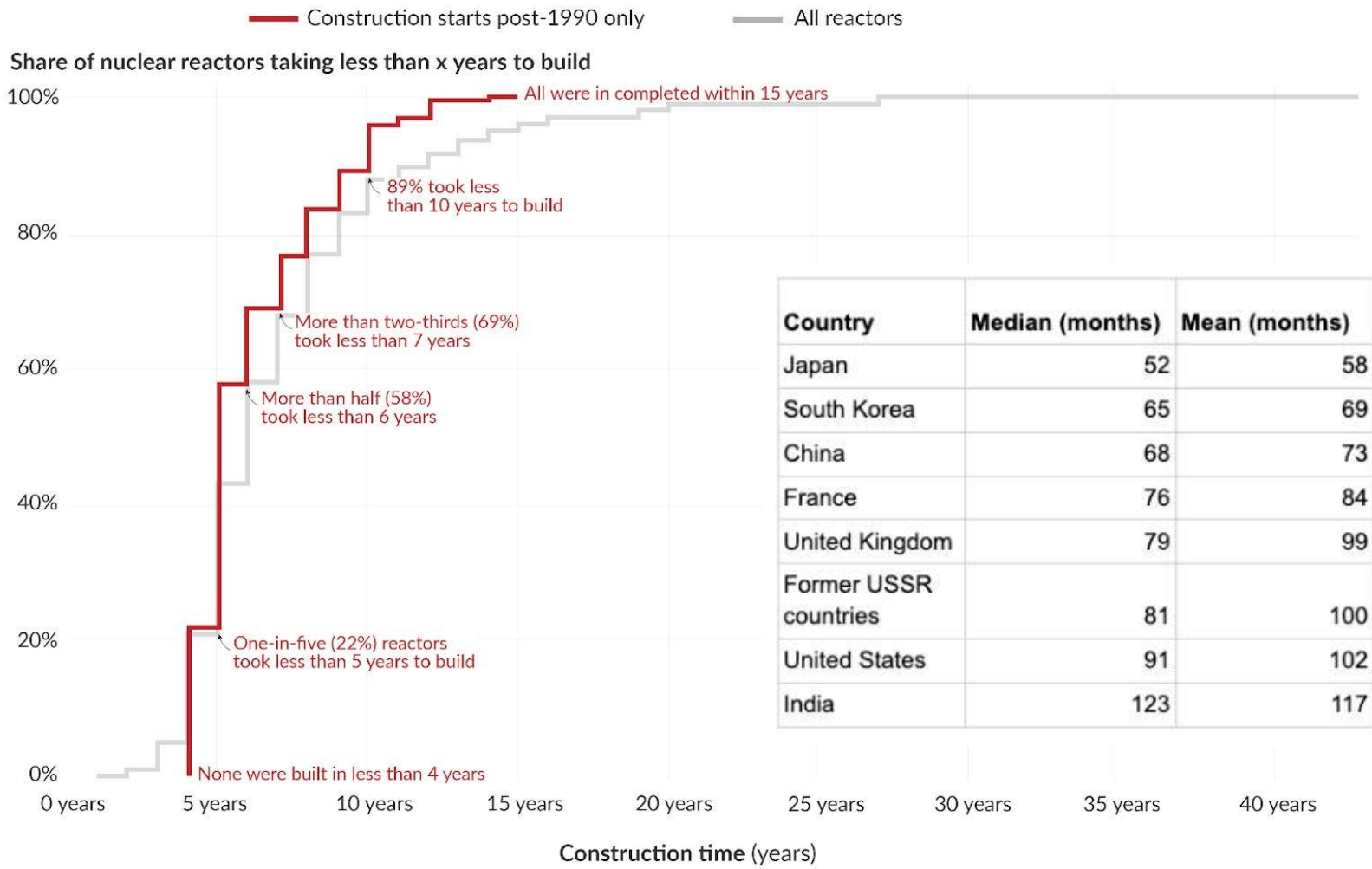
Figure 4: Long-term trends in capacity factors (source: World Nuclear Association, IAEA PRIS)

So where is the **problem** with large nuclear power plants?

Construction time of Large NPPs

How long does it take to build a nuclear reactor (post-1990)?

Construction time of nuclear reactors that were operable by March 2023. This includes reactors still in operation, plus those that had been shut down or decommissioned.

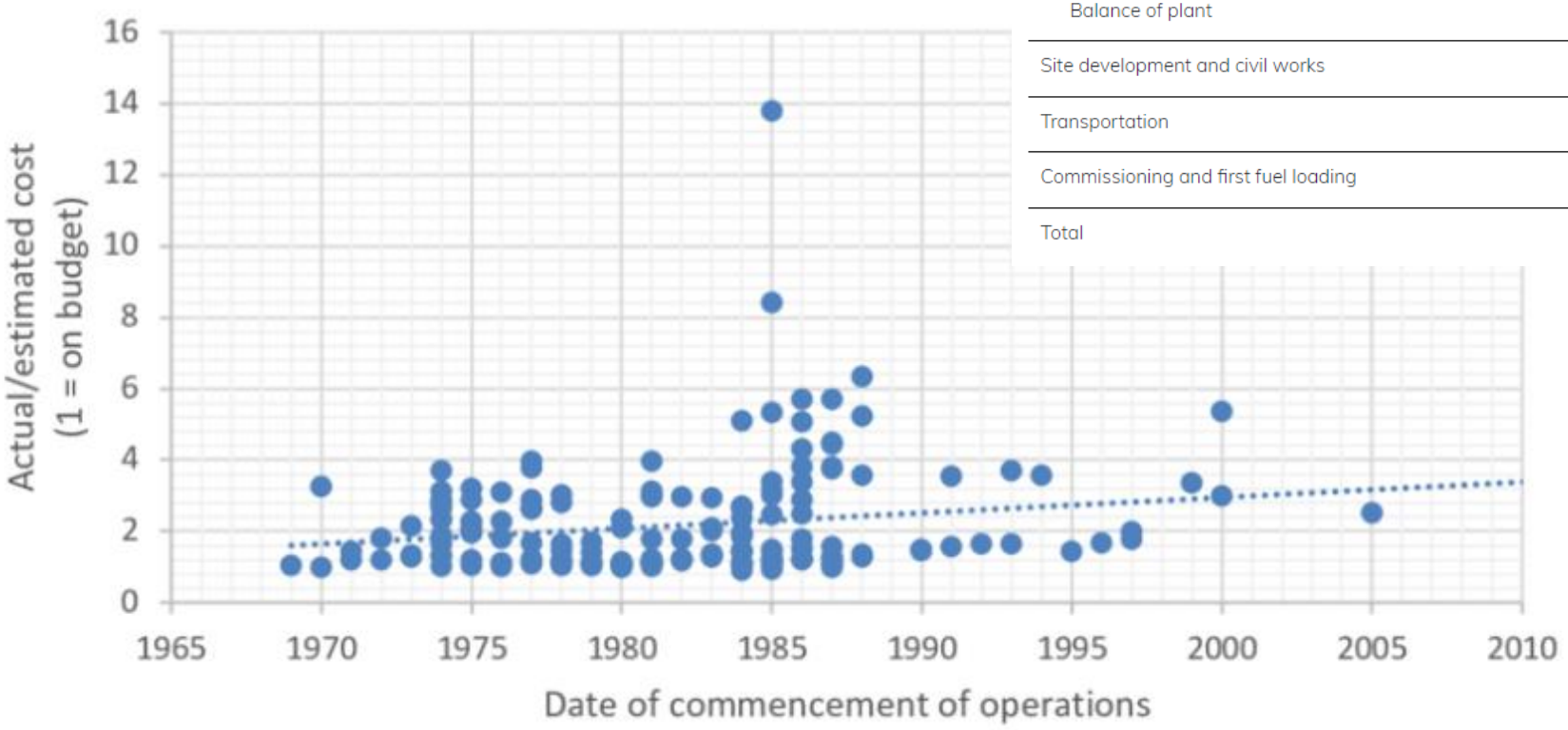


Country	Median (months)	Mean (months)	Minimum (months)	Maximum (months)
Japan	52	58	39	111
South Korea	65	69	51	124
China	68	73	51	113
France	76	84	59	196
United Kingdom	79	99	33	282
Former USSR countries	81	100	43	331
United States	91	102	21	513
India	123	117	60	176

Note: Construction time is measured from the first day that building begins (not the first day of planning) and ends when commercial production begins.
Data source: IAEA Power Reactor Information System (PRIS) and Wikipedia.
Author: Hannah Ritchie.

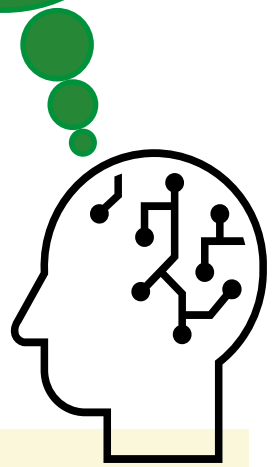
Large NPPs costs and overruns

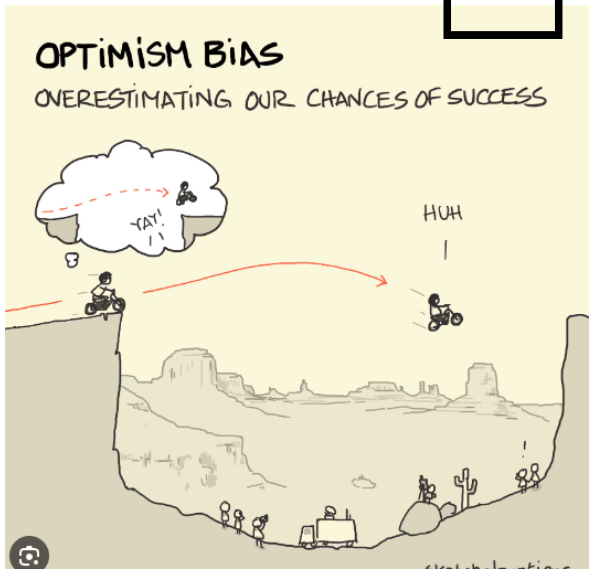
- Olkiluoto 3 – 2005 - 2023, 18 years, 4x budget
- Flamanville 3 – 2007 – 2024, 16 years, 4x budget
- Vogtle 3,4 – 2013 - 2023, 10 years, more than 2x budget
- Mochovce 3,4 – 1987 - 1992 + 2008 - 2023; 3x budget
- Hinkley Point C – 2017-2030; at least 13 years; at least 3x budget



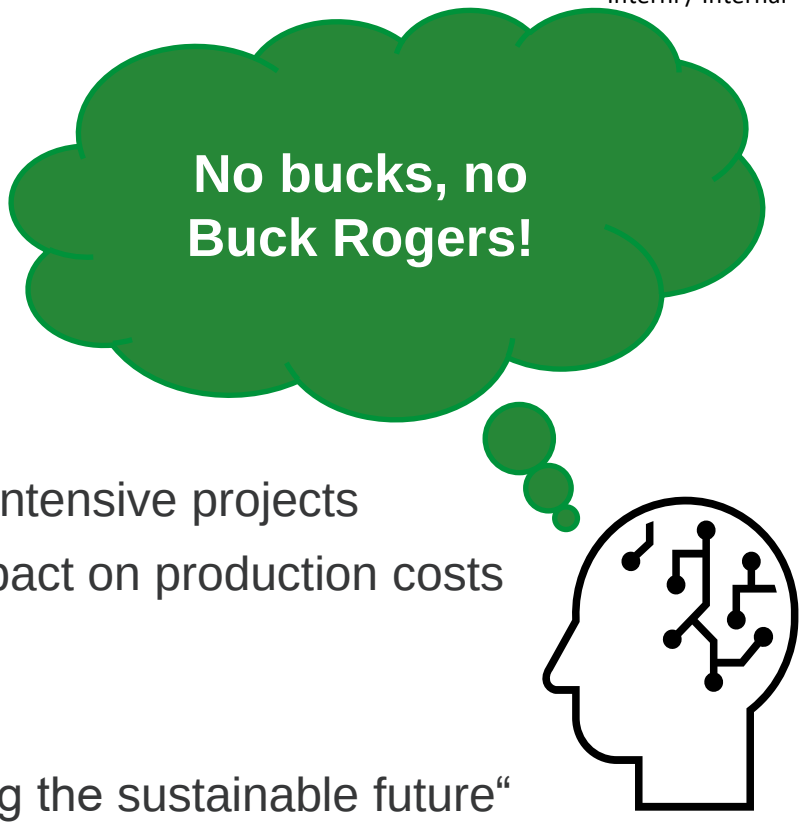
Design, architecture, engineering and licensing	5%
Project engineering, procurement and construction management	7%
Construction and installation works:	
Nuclear island	28%
Conventional island	15%
Balance of plant	18%
Site development and civil works	20%
Transportation	2%
Commissioning and first fuel loading	5%
Total	100%

What is the contribution of optimism bias to overruns?





Economics and financing



Economic efficiency

- NPP Economics is **„controversial“** topic
  - Strategic project for a country or region
  - Long-term project
    - 10y preparation,
    - 5y construction
    - 18y loan repayment
    - …and only then making money
- **Due to the high risks, NPP projects need state aid!!**

Financing

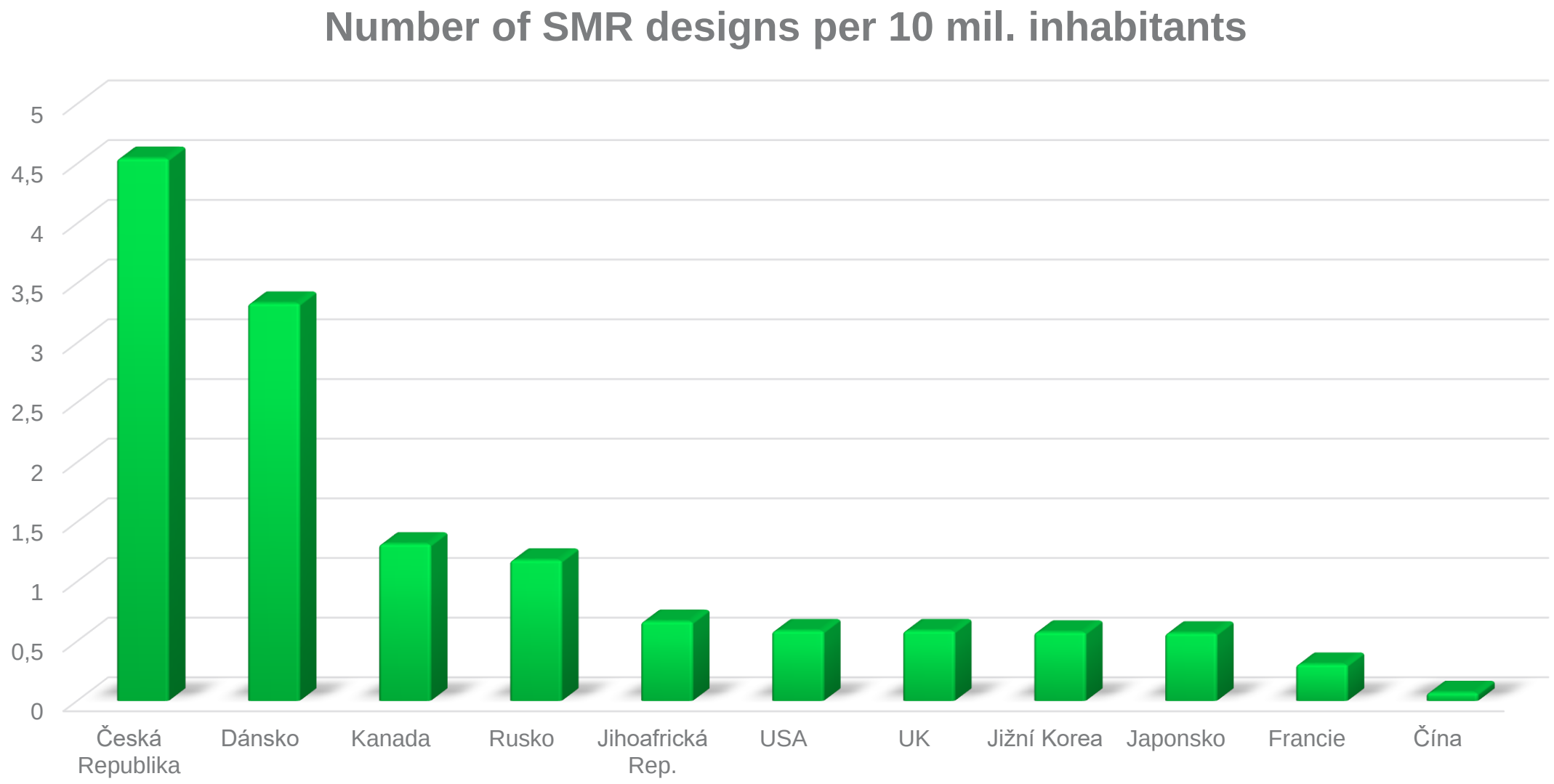
- Extremely capital-intensive projects
- Has significant impact on production costs
- EU financing rules
  - Taxonomy
    - „Financing the sustainable future“
  - Notification of the state aid
    - Treaty on Functioning of EU art. 107, 108
- **May apply special regulation on the projects!!**

NPPs and water, locality…

Unique Challenges of SMRs

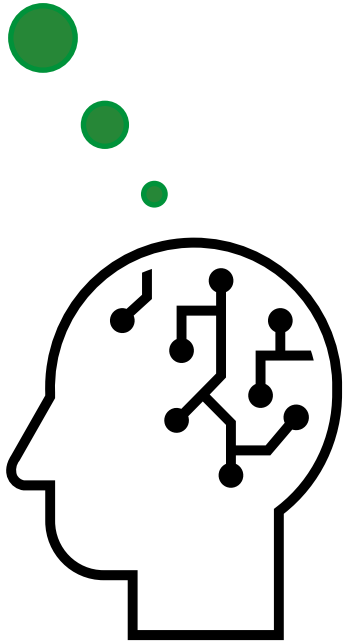
..and advantages as well

SMR designers in the Czech Republic are quite …fertile ☺



Innovative technical features of SMR projects

To what extent is it reasonable to innovate at the nuclear industry?



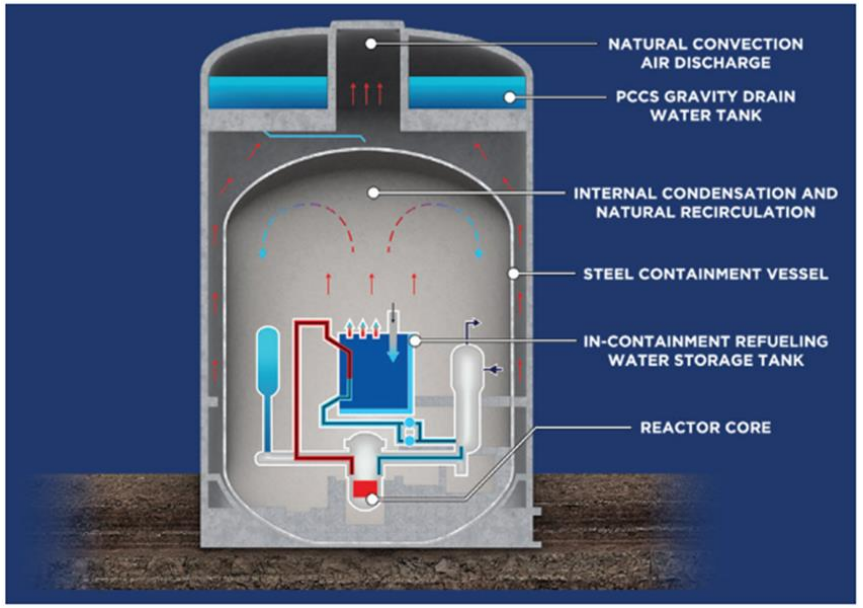
Innovative technical features of SMR projects?

- Passive safety systems
- Boron free operation
- Natural circulation
- Integral design

Passive safety systems

Active systems into passive systems

- **Pros**
  - No electricity needed
- **Cons**
  - Huge amount of energy carried away with a small driving force
  - Sensitivity to containment and structural integrity



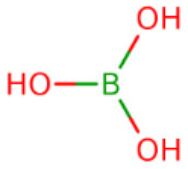
Boron free operation

Substance identity

EC / List no.: 233-139-2

CAS no.: 10043-35-3

Mol. formula: BH3O3



Hazard classification & labelling

Danger! According to the **harmonised classification and labelling** (ATP17) approved by the European Union, this substance may damage fertility and may damage the unborn child.

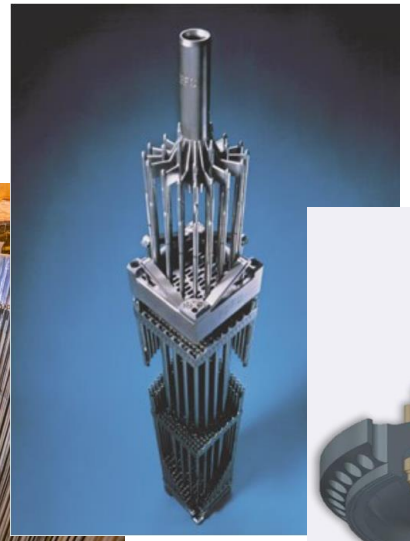
Additionally, the classification provided by companies to ECHA in **REACH registrations** identifies that this substance may damage fertility or the unborn child.

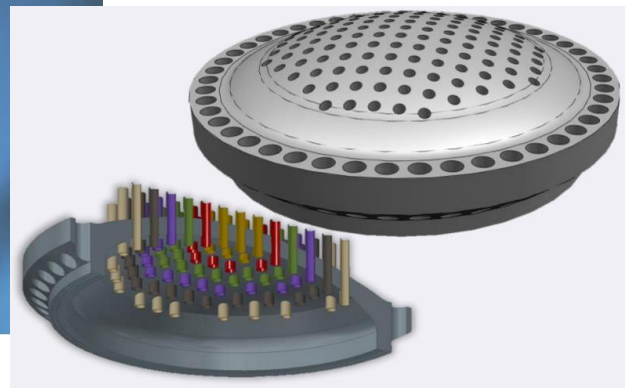
Important to know

- Substance of very high concern (SVHC) and included in the candidate list for authorisation.

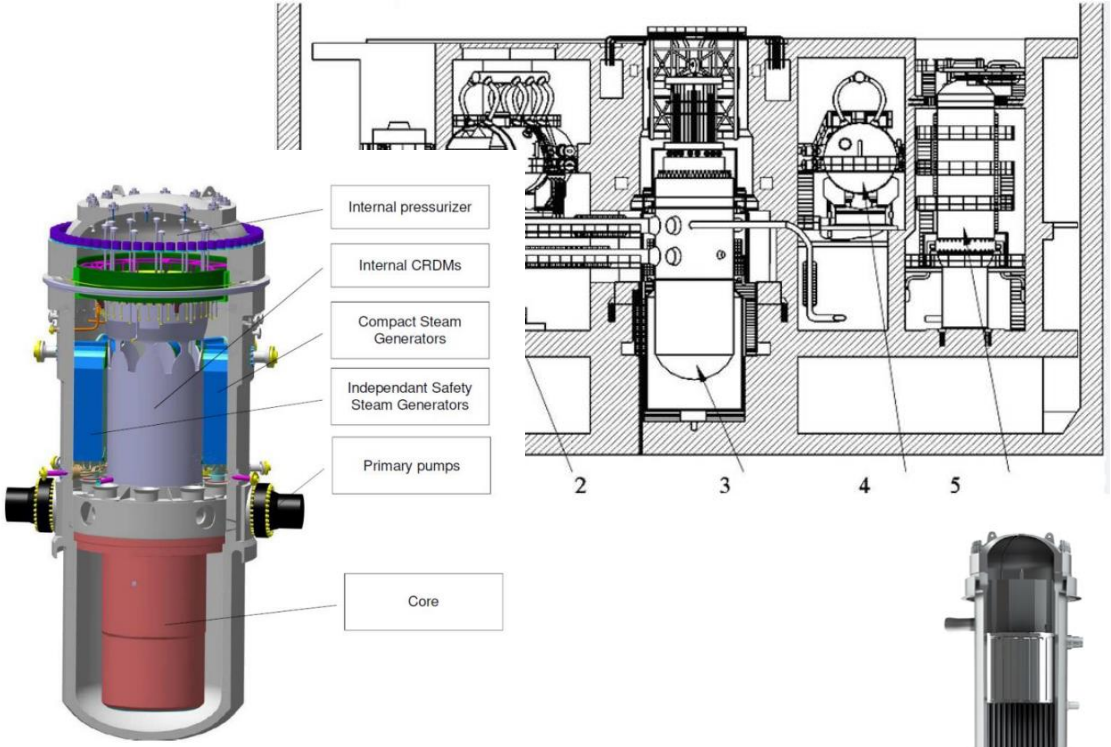
- **Pros**
  - Simpler coolant purification and regeneration system
- **Cons**
  - Loss of diverse reactivity control system
  - Large number of control & compensation rods
  - Burnable absorbers
  - Expensive operation

Shift to boron free operation



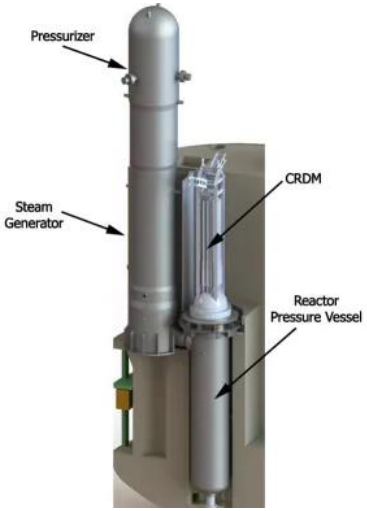


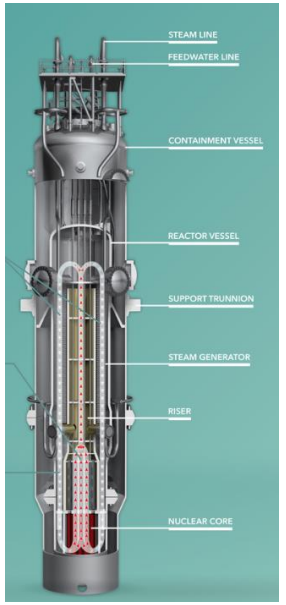
Natural circulation



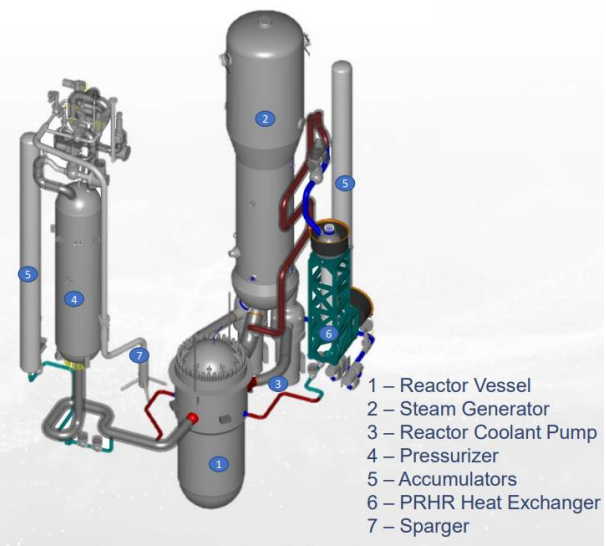
From forced to natural circulation

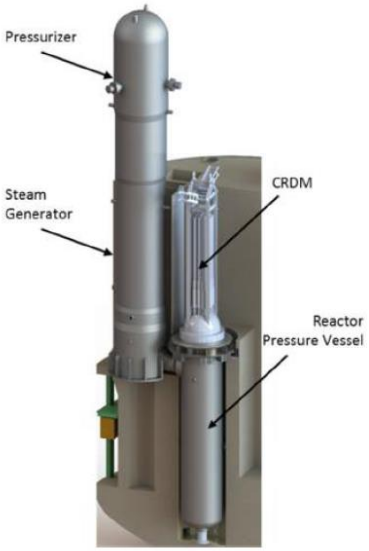
- **Pros**
  - Lower maintenance costs
  - Lower operational costs
- **Cons**
  - Limits the thermal power/enlarges the core
  - Larger Δ T (up to 80ºC)
  - Must have the „auxiliary“ pumps for lower thermal power
  - Worse maneuverability



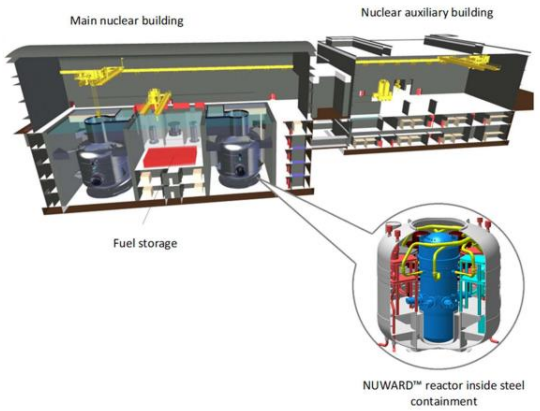


Integral design

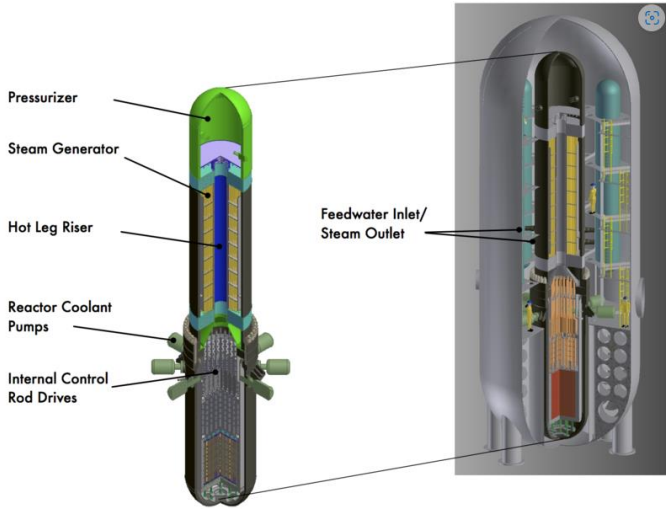




From loop design to integral design

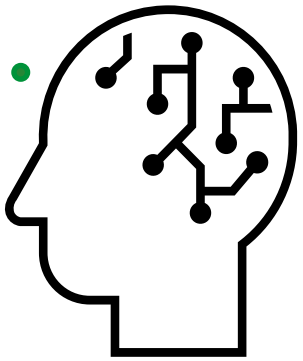


- **Pros**
  - LB LOCA practically eliminated
  - Primary circuit and „radioactive water“ within one pressure vessel
  - Smaller containment
- **Cons**
  - Transportability
  - Operation & Maintenance



History vs. SMR

What is the real motivation..?

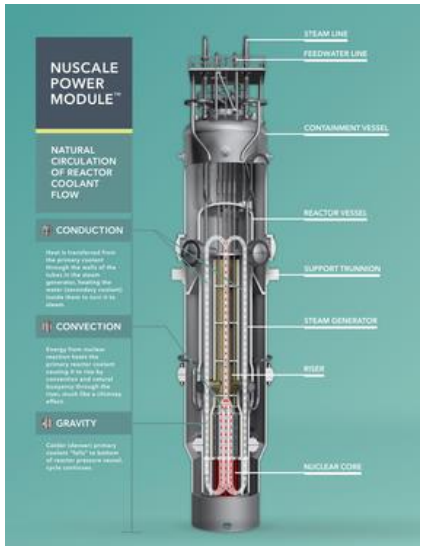


Prehistoric nuclear age

- 1932 Chadwick
- 1938 Strassmann, Hahn
- 1942 Fermi
- 1945 Oppenheimer
- 1954 Obninsk
- 1956 Calder hall

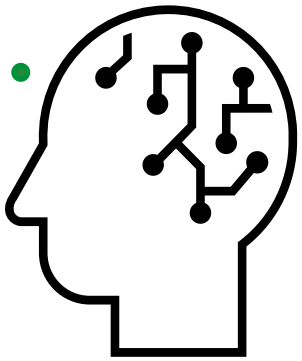
Modern era (NuScale)

- 2002 DOE grant for SMR development
- 2007 NuScale company founded
- 2017 SDA application submitted (50 MWe)
- 2020 Design change (uprate to 77MWe)
- 2022 Stock market entry
- 2023 Production of LLI
- 2025 ….???



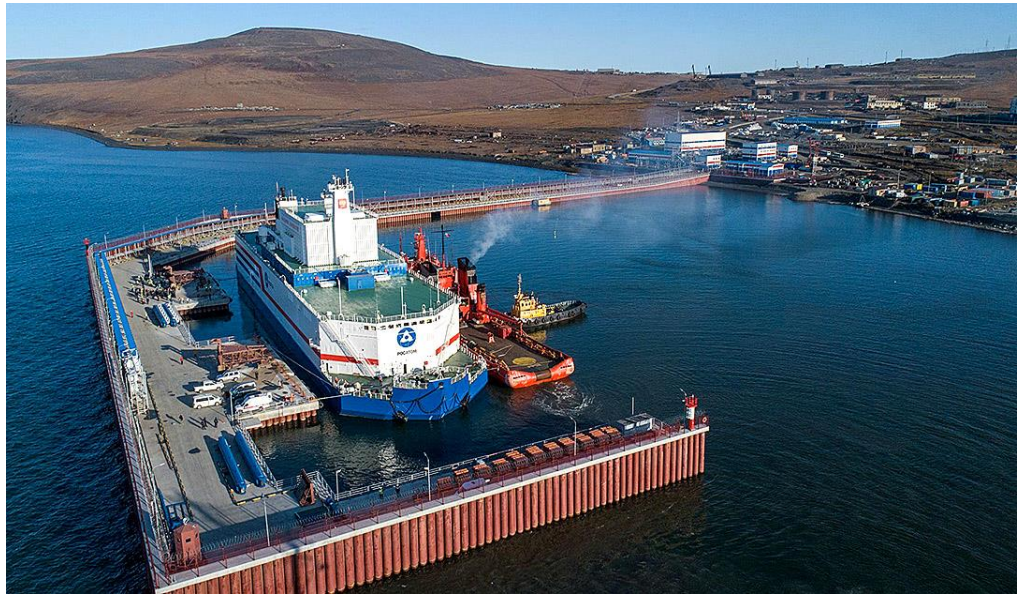
SMRs in operation

Where are western types?



Akademik Lomonosov

- Russian PWR (KLT-40S)
- 2 x 35 MWe (2 x 150 MWt)
- Grid connection 19.12.2019



Shidao Bay-1

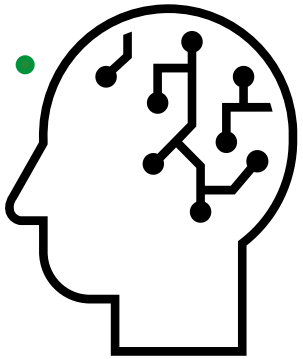
- Chinese HTGR (HTR-PM)
- 2 x 105 MWe (2 x 250 MWt)
- Grid connection 14.12.2021

SMR projects within ČEZ

..why should we have the interest?

Introduction

What is the real motivation..?



„The construction of small modular reactors* (SMRs) represents an interesting development opportunity for CEZ Group to replace coal and gas energy sources for electricity generation and heating use without emissions. “

(SMR opportunity study approved by BoD 12. 4. 2022)

* Small modular reactors (SMRs) are light water nuclear reactors of at least generation III+ with an installed electrical output in the range of 100 to 520 MWe.

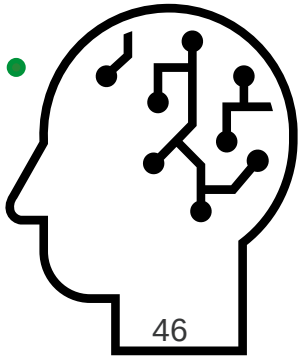
Opportunity study - Technologies

SMR technologies of higher potential were analyzed (RFI, vendor visit)

Preferred technologies (LWR)		Perspective technologies (HTGR)
• **NuScale (IPWR; NuScale Power; USA),** • **SMART100 (IPWR; KAERI, KHNP; S. Korea),** • **SMR-160 (PWR; Holtec International; USA).** • **BWRX-300 (BWR; GE Hitachi; Japan, USA),** • **UK SMR (PWR; Rolls-Royce; UK),** • **Nuward (IPWR; CEA, EdF, Naval Group, Francie; Westinghouse, USA),**	• ACP100 (IPWR; CNNC; China)* • ACPR50 (PWR; CGN; China)* • RITM-200 (IPWR; OKBM Afrikantov; Russia)*	• GTHTR300 (HTGR; JAEA; Japan), • HTR-PM/HTR-200 (HTGR; INET, CNNC; China).

* Russian and Chinese technologies were eliminated from the selection process due to the law on transition to the low-carbon economy

Why do we prefer designs of more than 100 MW?



Preferred SMR designs

AP 300 (USA, 300 MWe), PWR
Westinghouse

BWRX-300 (USA, 300 MWe), BWR
GE Vernova

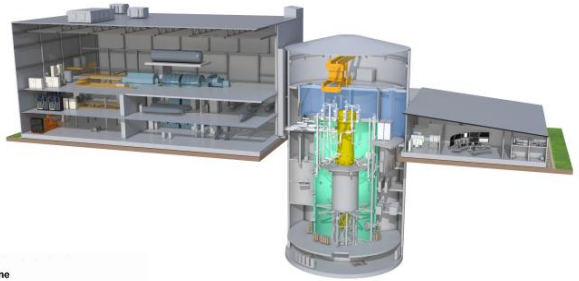
NuScale (USA, 12 modulů – 924 MWe), PWR
NuScale Power

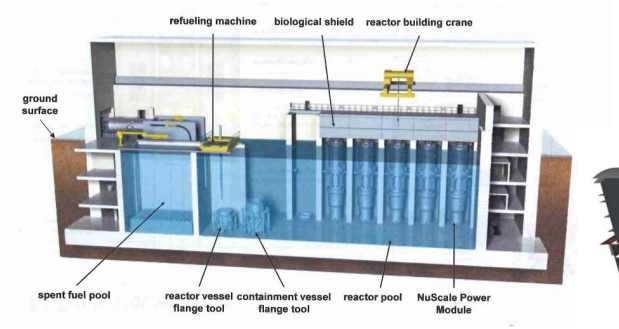
Nuward (France, 2 x 170 MWe), PWR
EDF

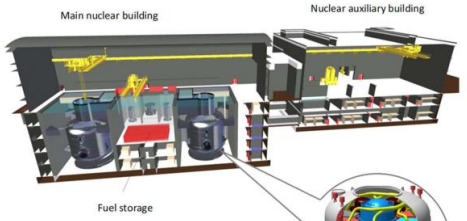
SMART100 (S. Korea, 2 x 107 MWe), PWR
KHNP

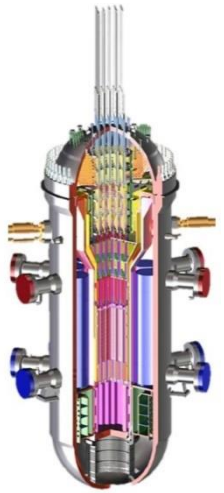
SMR-300 (USA, 300 MWe), PWR
Holtec

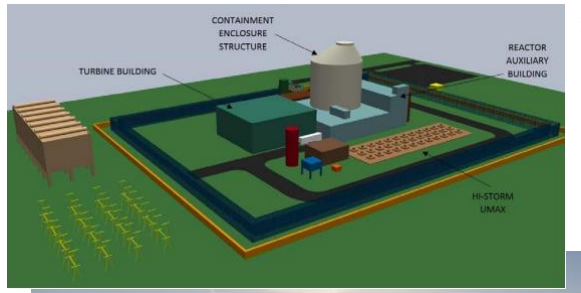
UK SMR (UK, 470 MWe), PWR
Rolls Royce SMR

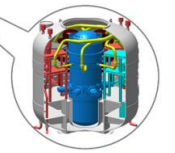












Innovative non-technical features and other circumstances of SMR projects?

- Minimized Emergency Planning Zone
- Economy of numbers
- Graded approach
- **Siting (opening new sites)**

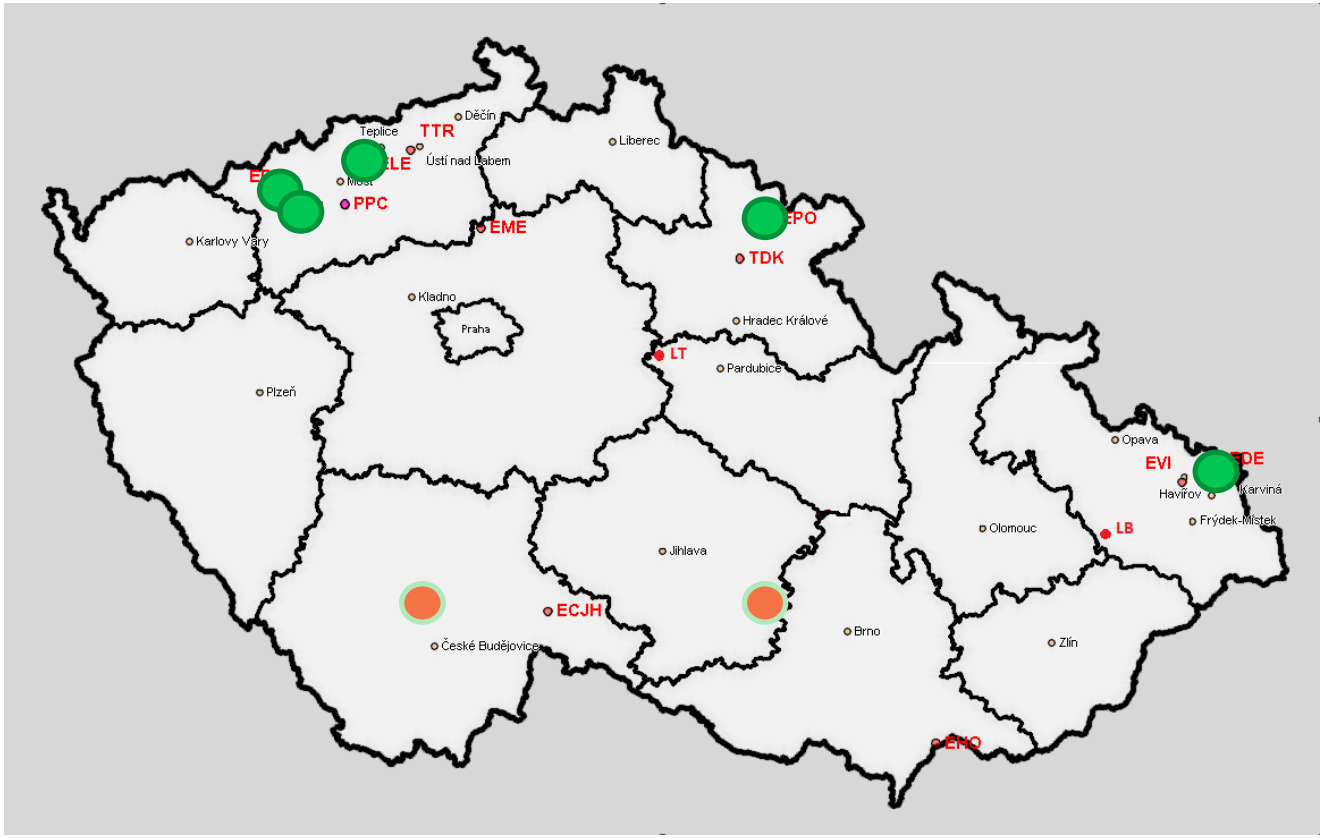
SELECTION OF THE MOST SUITABLE SITES FOR SMR SITING OWNED BY ČEZ

Lokalita/ Parametr	Jevy vyluč. umístění	Plocha	Strategie SKČ	Dostupnost vody	Vyvedení výkonu	PÚR	CZT v lokalitě	Vodní cesta	Silniční napojení	Železniční napojení	Plocha (typ)	Bezpečnostní omezení	Blízkost sídel	Ověřená lokalita	Body celkem	Pořadí lokality	Další posouzení
Prunéřov	-	5	A	5	5	5	2	0	2	2	2	0	1	3	32	1	A
Tušimice	-	5	A	5	5	5	2	0	2	2	2	0	1	3	32	1	A
Ledvice	-	0	A	5	5	5	2	2	2	2	2	2	1	3	31	3	A
Dětmarovice	-	5	A	3	3	5	2	0	2	2	2	2	0	3	29	4	A
Poříčí	-	0	A	3	3	0	2	0	2	2	2	2	0	1	17	5	A
Vítkovice	-	0	A	5	3	0	2	0	2	2	2	0	0	0	16	6	N
Tetov	-	3	A	5	0	0	0	2	0	0	0	2	3	0	15	7	N
Blahutovice	-	5	A	3	0	5	0	0	0	0	0	0	1	0	14	8	N
Dvůr Králové	-	0	A	3	0	0	2	2	2	2	2	0	0	0	13	9	N
Otín	-	0	A	0	0	0	2	0	2	0	2	2	3	0	11	10	N
Mělník	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N
Počerady	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N
Hodonín	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N
Trmice	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N

Best sites for SMR construction owned by ČEZ

Results of the phase I of surveys and investigation

- Tušimice
- Prunéřov
- Ledvice
- Poříčí
- Dětmarovice



Nuclear sites (Temelín and Dukovany)

Compliance with requirements of the decree **no. 378/2016 Coll. to be performed in phase II.**

POTENTIAL SITES ASSESSMENT (DECREE NO. 378/2016 COLL. ON SITING)

Area of requirements	Tušimice	Prunéřov	Dětmarovice	Ledvice	Pořící
Seismicity	G	G	PY	G	R
Presence of active fault	PY	PR	PR	Y	B
Flooding	G	G	G	G	G
Underground water circulation	G	G	PG	PR*)	G
Volcanic and post-volcanic activity	G	G	G	G	G
Slope slides	G	G	G	G	G
Subsidence and terrain deformation	G	G	G	Y	G
Unsuitable properties of foundation soils	PY	PY	PY	Y	G
Meteorological phenomena					
Living organisms influence					
Natural fires					
Aircraft crashes					
Man induced explosions and fires					
Protective and safety zones collisions	G	G	G	G	G
Operated NPP in the vicinity					
Strong vibrations	G	G	PY	G	G
Electromagnetic interference					
Eddy currents					
Hazards of air, road, railroad and river traffic	G	Y	G	Y	G
Influence of product pipelines and power lines	G	G	G	G	G
Pollution of air, soils, surface and groundwater	G	G	G	G	G
Potentially dangerous factories	G	G	G	G	G
Other man-induced influence	G	G	G	G	G
Spread of RA substance through the environment and the food chain	PG	PG	PG	PG	PG
Population distribution and density	G	G	Y	G	G

Legenda:

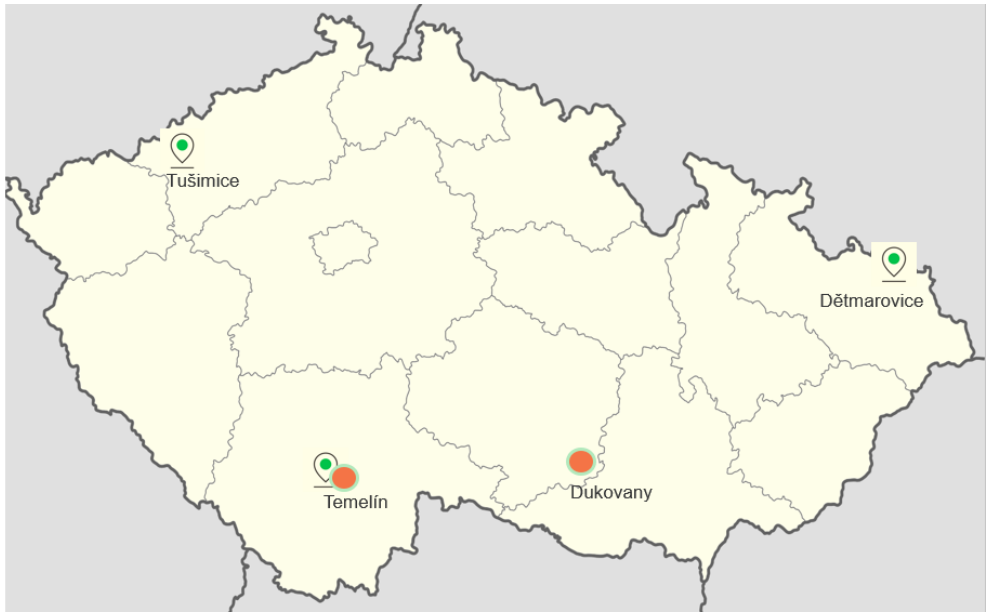
G	No risk, sufficient information
PG	No risk, partial information
Y	Low risk, sufficient information
PY	Low risk, partial information
R	Significant risk, sufficient information
PR	Significant risk, partial information
B	No-Go criterion
	Irrelevant requirements for this stage

Conclusions of the opportunity study:

- **Tušimice site is not threatened by any significant risk** and appears to be the most suitable for the siting.
- **Prunéřov, Dětmarovice and Ledvice sites are threatened by potentially significant risks** that need to be identified during the next phases of the surveys.
- **Pořící site is likely to conflict with the exclusion criterion of the presence of an active fault** (recommendation not to investigate the site further)

SUITABLE SITES FOR SMR SITING OWNED BY ČEZ

- Nuclear sites (SMR):
  - **Temelín**
- Non-nuclear sites:
  - **Tušimice**
  - **Dětmarovice**
- Nuclear sites (Temelín and Dukovany)



- 3 Potential sites
- 2 Living projects

- Main goals of the SMR Programme:
  - Put into operation one unit in Temelín by 2034
  - Commissioning of 3000 MWe in SMR in the Czech Rep. by 2050

Temelín SMR project in 2024

Project management

- Business plan approval (incl. budget for 2025)

Site surveys

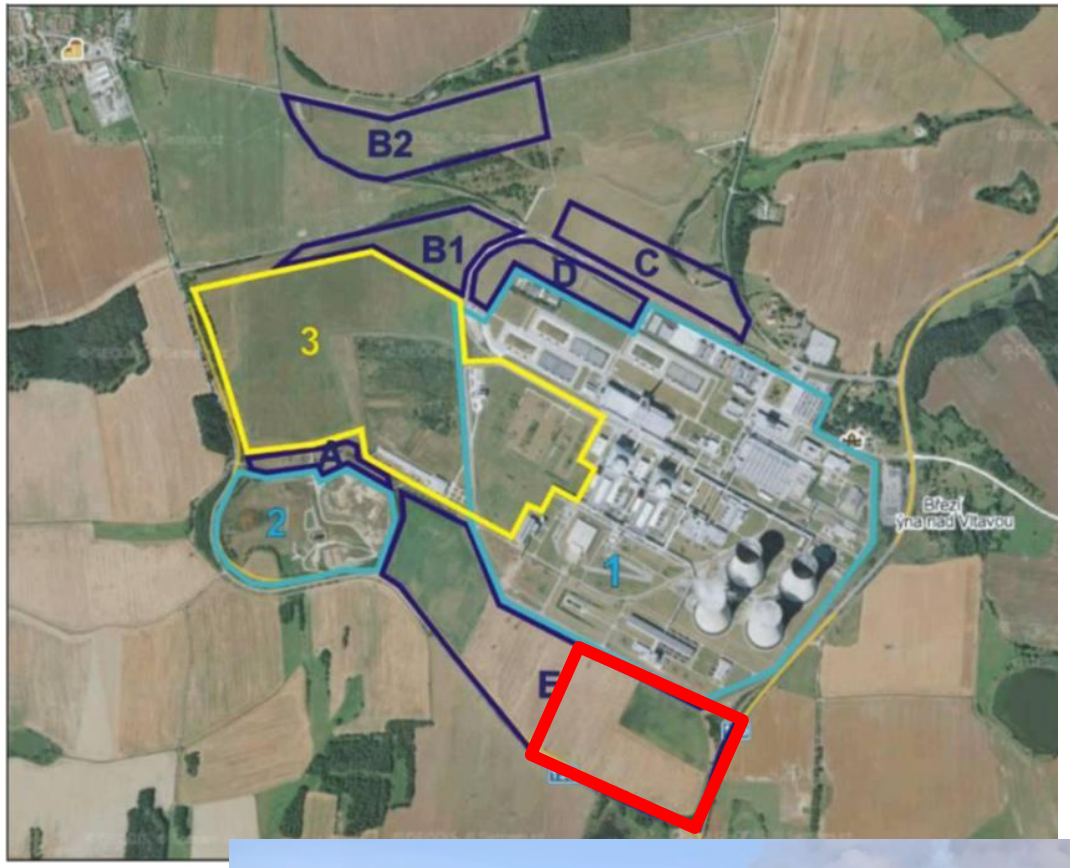
- Hydromonitoring

Permitting and licencing

- Tender for EIA documentation contractor
- EIA notification submitted

Engineering

- Design requirements
- Related and induced investments plan
- Grid connection application submitted



Tušimice SMR project in 2024

Project management

- Business plan approval (incl. budget for 2025)

Site surveys

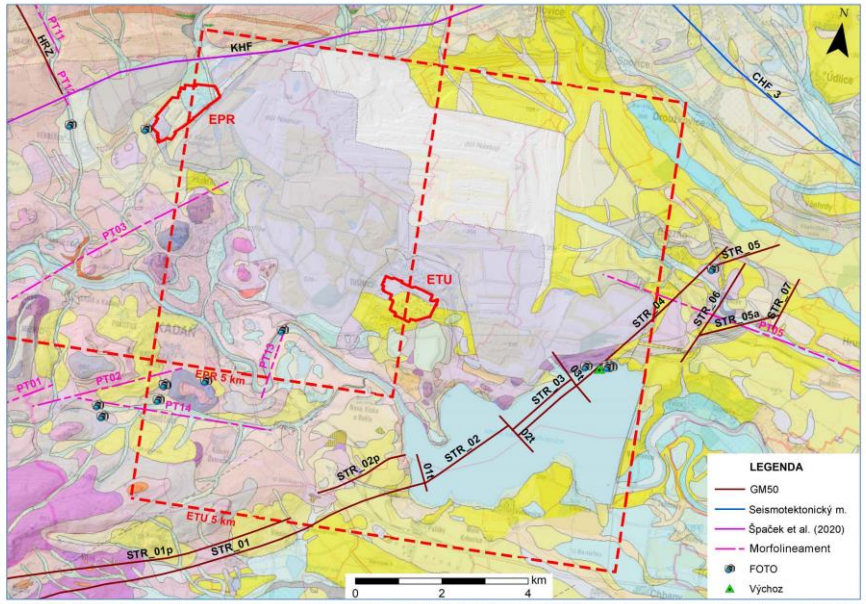
- Faults investigation
  - Střezovský fault
  - Krušnohorský fault
- Hydromonitoring
- RA monitoring of the environment

Permitting and licencing

- Tender for EIA documentation contractor
- EIA notification submission (spring 2025)

Engineering

- Inclusion into site strategy documentation

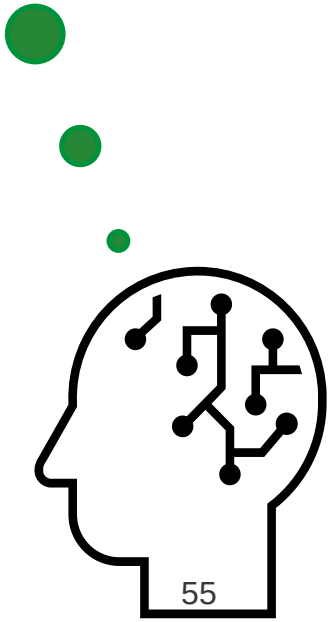


Obr. 14: Podezřelé zlomy v území ETU 5 km a vymezené morfolineamenty znázorněné na podkladu Geologické mapy 1 : 50 000 ČGS se zakreslením dokumentačních bodů vymezených při terénní rekognoskaci v červenci 2022. Legenda zkratek zlomů: HRF – zlom Hamry; KHF – krušnohorský zlom; CHF – zlomová zóna Chomutovky; STR – střezovský zlom. Zdroj: Databáze SMR v ČR ([Ref - 61]).

…from coal to atom

- Capacity of the coal fired unit is 100 – 250 MW

Where is the chimney?

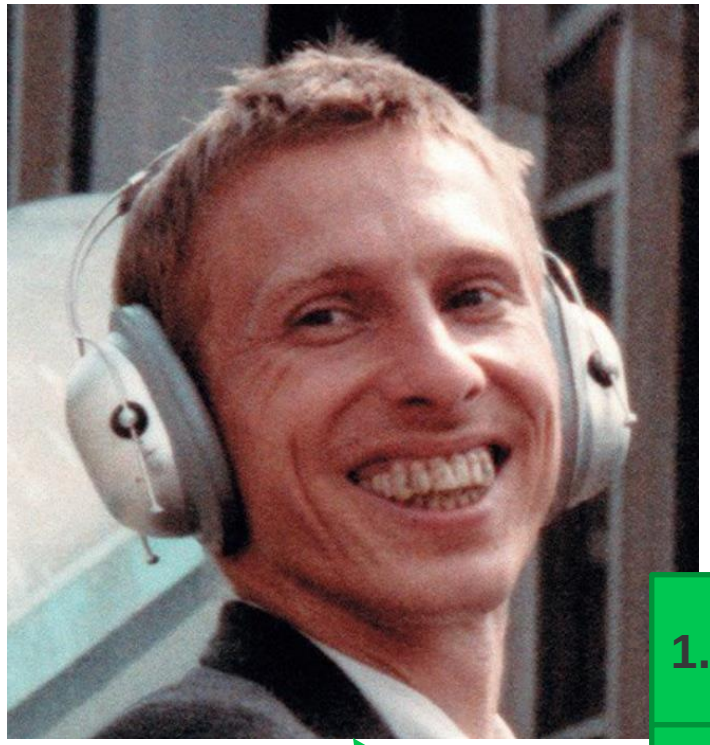


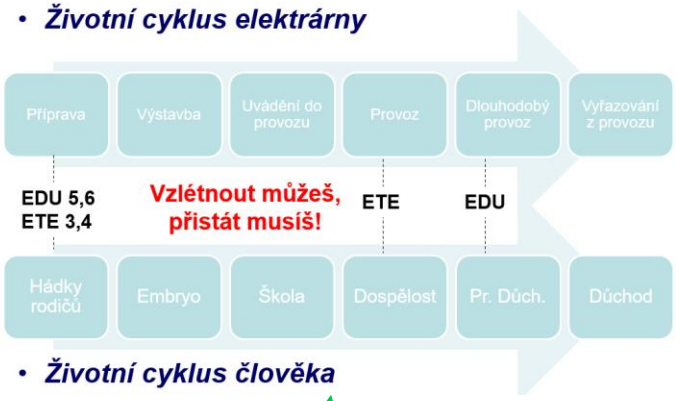
Conclusion

Small Modular Reactors

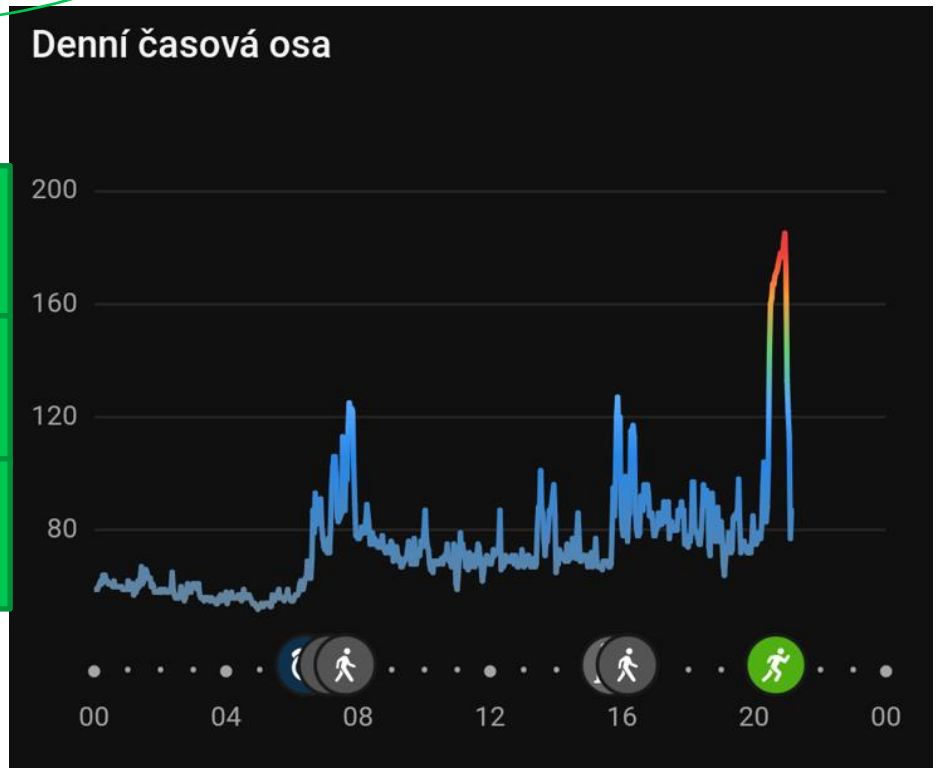
- **Closing discussion**
  - Why to become a nuclear guy?
  - Discussion / controversial topics

Why to become a nuclear guy?





1. Nuclear is future
2. Working with inspiring colleagues
3. It is almost the Zen garden



Controversial topics about nuclear…

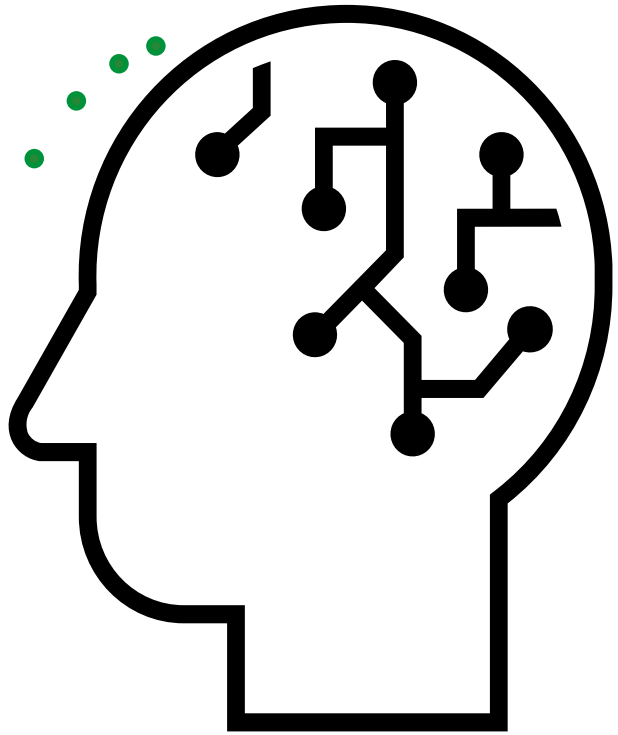
Energy market?

Hydrogen production?

Sustainability?

Clean energy?

Subsidies?



Thank you for your attention!
Questions?

(ask me whatever you want, I will answer whatever I want)

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+420 725 234 434