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SAS / ELSTOR AT LUT

SMALL MODULAR REACTORS

November 4, 2021

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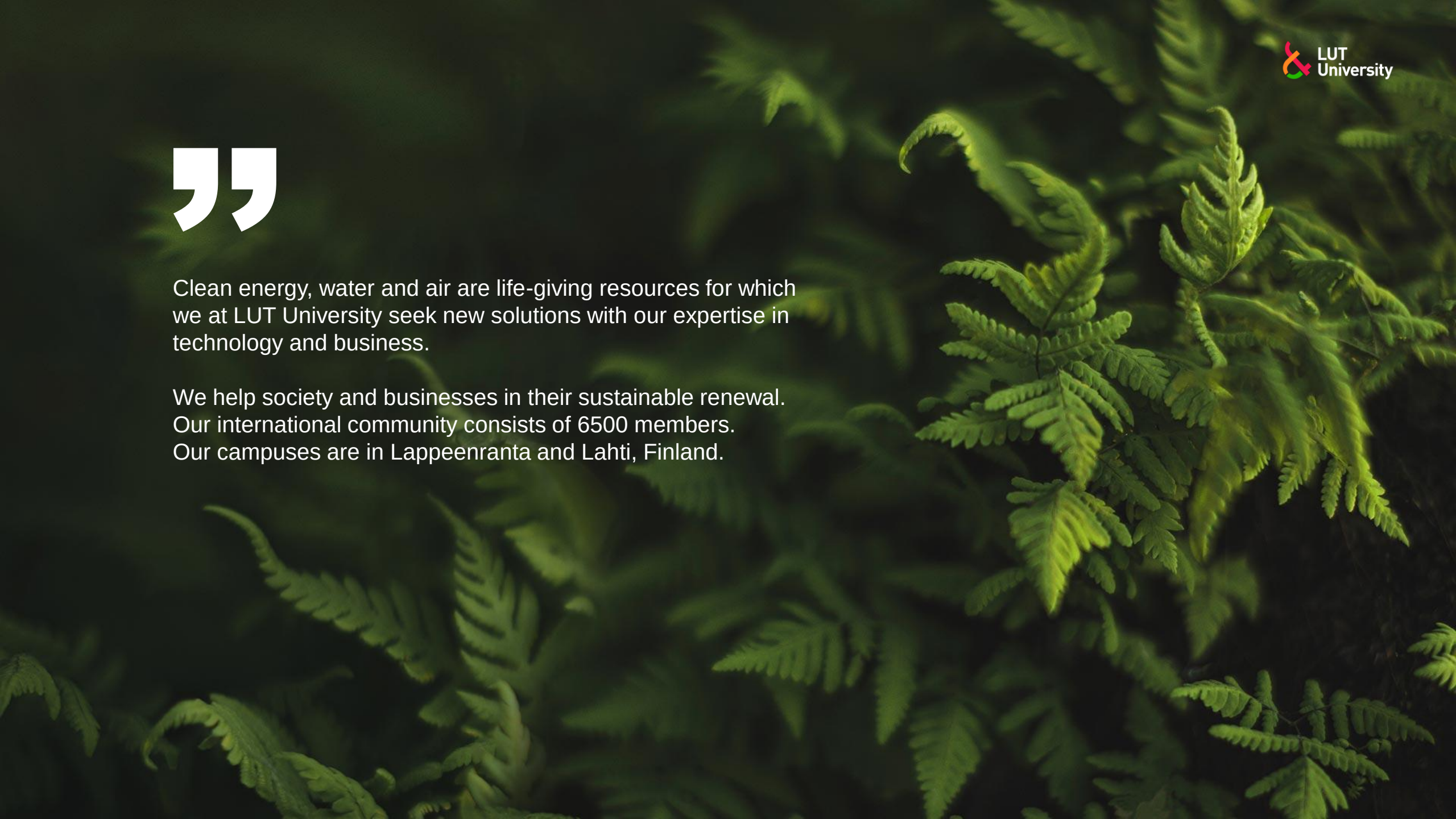


Clean energy, water and air are life-giving resources for which we at LUT University seek new solutions with our expertise in technology and business.

We help society and businesses in their sustainable renewal.
Our international community consists of 6500 members.
Our campuses are in Lappeenranta and Lahti, Finland.


LUT University
SYSTEM
EARTH
AIR
Turning emissions into opportunities
BUSINESS
Sustainable renewal of business and industry
WATER
Refining sidestreams into value
ENERGY
Transition to a carbon-neutral world
LUT UNIVERSITY STRATEGY 2030 • TRAILBLAZERS – Science with a Purpose

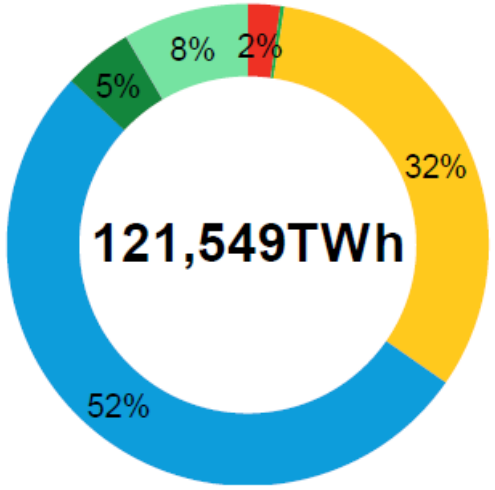
OUTLINE

- Why nuclear?
- ”Small” ”Modular” Reactors – examples
  - Use cases: electricity, heat and both
  - Technologies
- Cost and availability
- Siting and licensing
- LUT research into SMRs
- Conclusions

GLOBAL SCENARIOS FOR NET-ZERO 2050

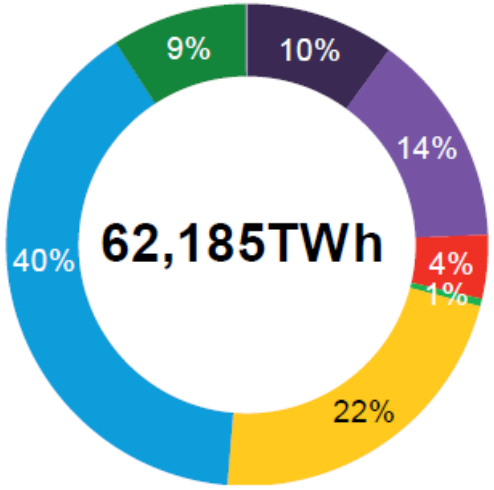
[Bloomberg New Energy Outlook 2021]:

Figure 4: Electricity generation by technology in the *Green Scenario*, 2050



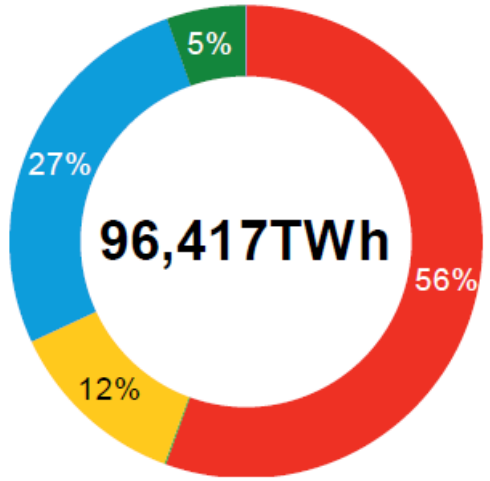
Source: BloombergNEF Note: includes both power for end-use economy and hydrogen manufacturing.

Figure 5: Electricity generation by technology in the *Gray Scenario*, 2050



Source: BloombergNEF

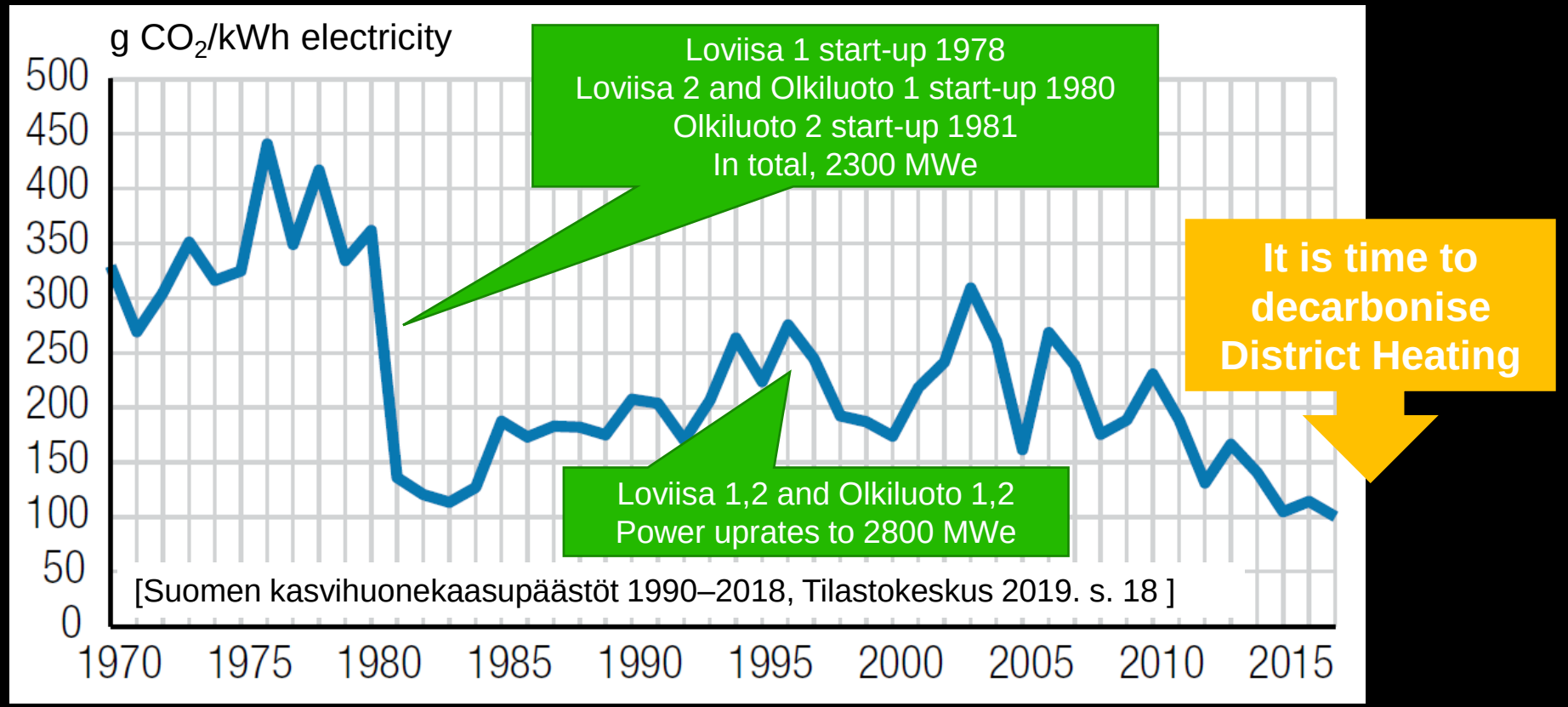
Figure 6: Electricity generation by technology in the *Red Scenario*, 2050



Source: BloombergNEF Note: includes both power for end-use economy and hydrogen manufacturing.

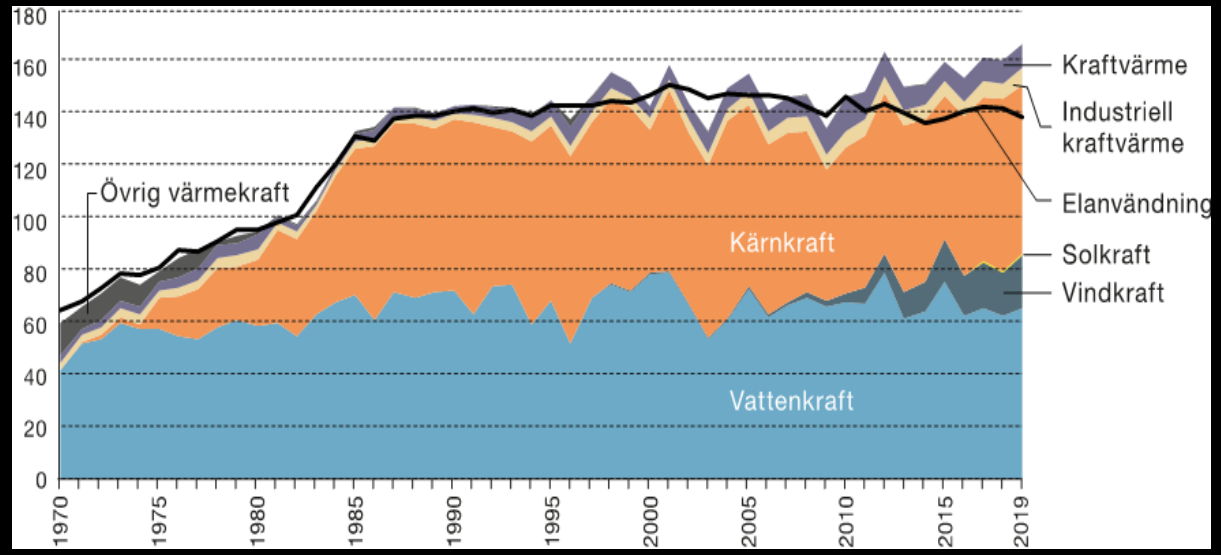
Other · Wind · Solar · Other renewables · Bioenergy
Nuclear · Hydrogen · Oil with CCS · Gas with CCS · Coal with CCS
Oil · Gas · Coal

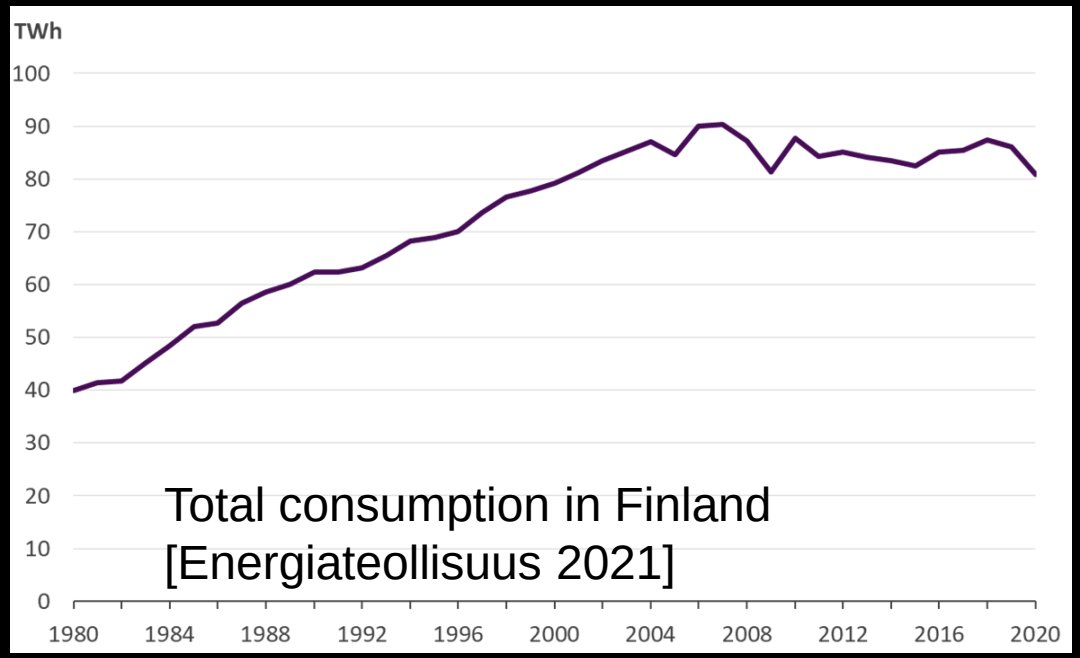
NUCLEAR – PROVEN EMISSIONS REDUCTION



ELECTRICITY CONSUMPTION IN NORDICS IS STABLE

- Annual consumption grew until ca. 1985 in Sweden, until 2005 in Finland
- **Thereafter, plateau.**
- Will there be an energy system transition to materially change this? If yes, how fast?

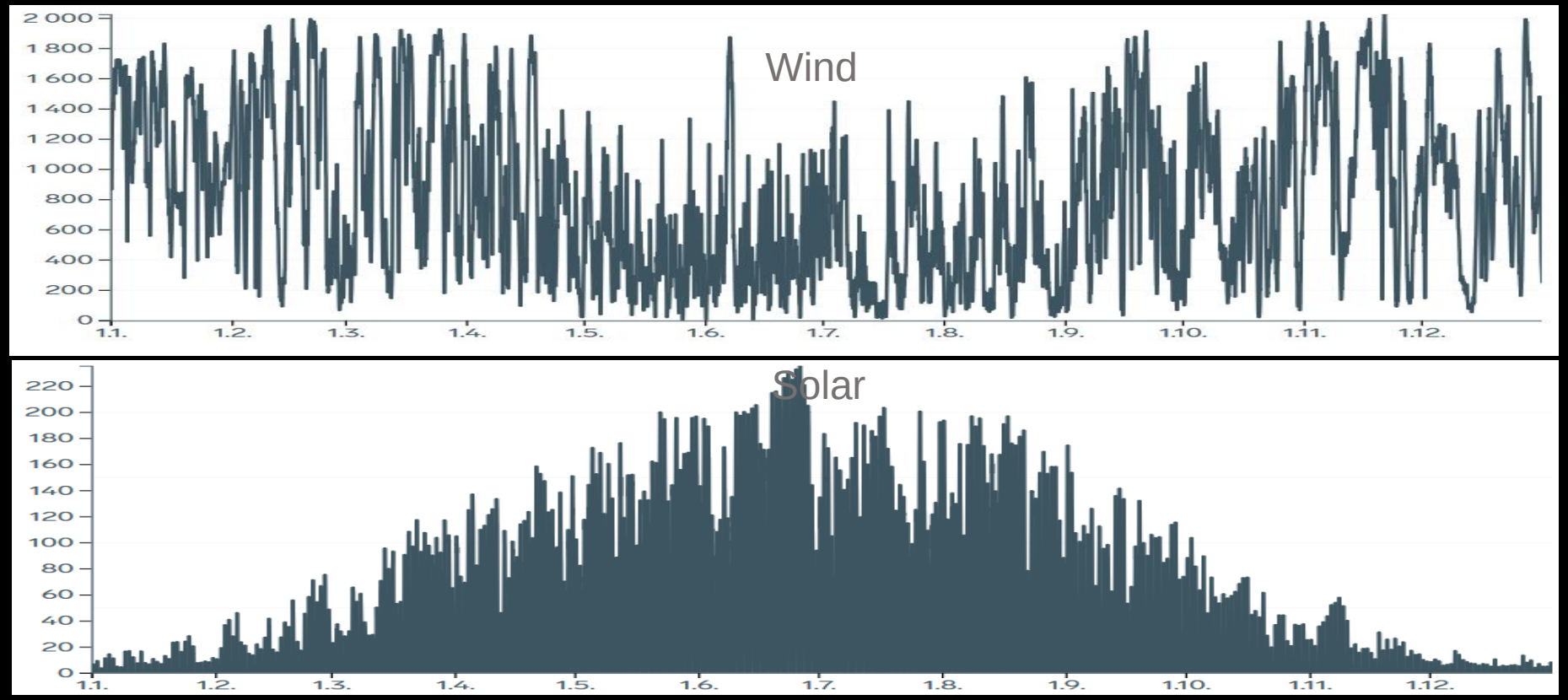




FINNISH ELECTRICITY DEMAND AND SUPPLY IN 2020

[https://www.fingrid.fi/sahkomarkkinat/sahkomarkkinainformaatio/kulutus-ja-tuotanto/]

FINNISH WIND AND SOLAR PRODUCTION IN 2020

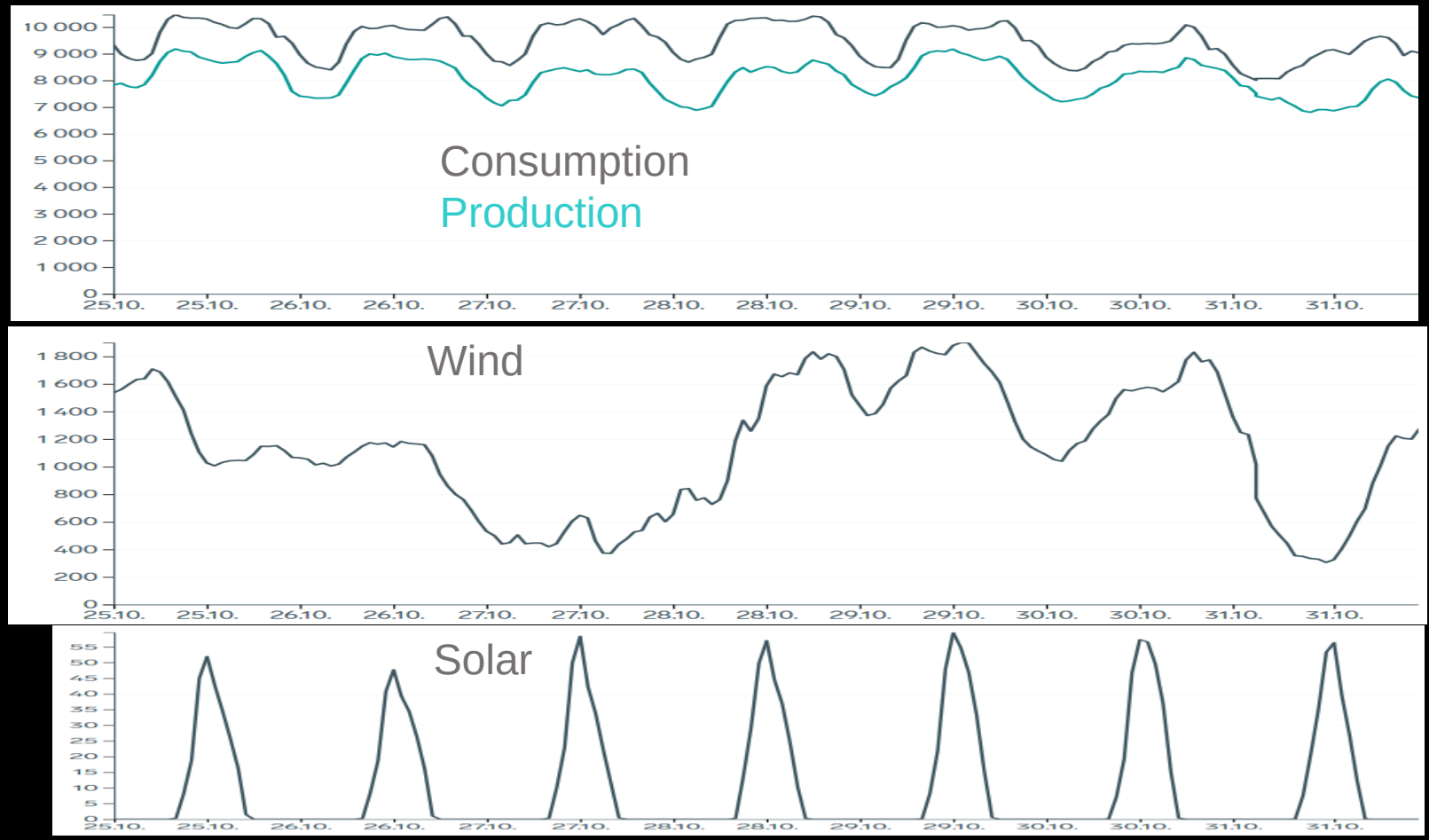


Wind and solar **fail to meet seasonal demand.**

Solar mirrors the seasonal demand profile.

[https://www.fingrid.fi/sahkomarkkinat/sahkomarkkinainformaatio/tuulivoiman-tuotanto/ ja …aurinkovoima/]

Last week (25.-31.10.2021) status



Wind and solar **fail to meet daily demand** → system cost due to buffering. Therefore, proposals for

- Electric vehicles (batteries)
- Hydrogen economy

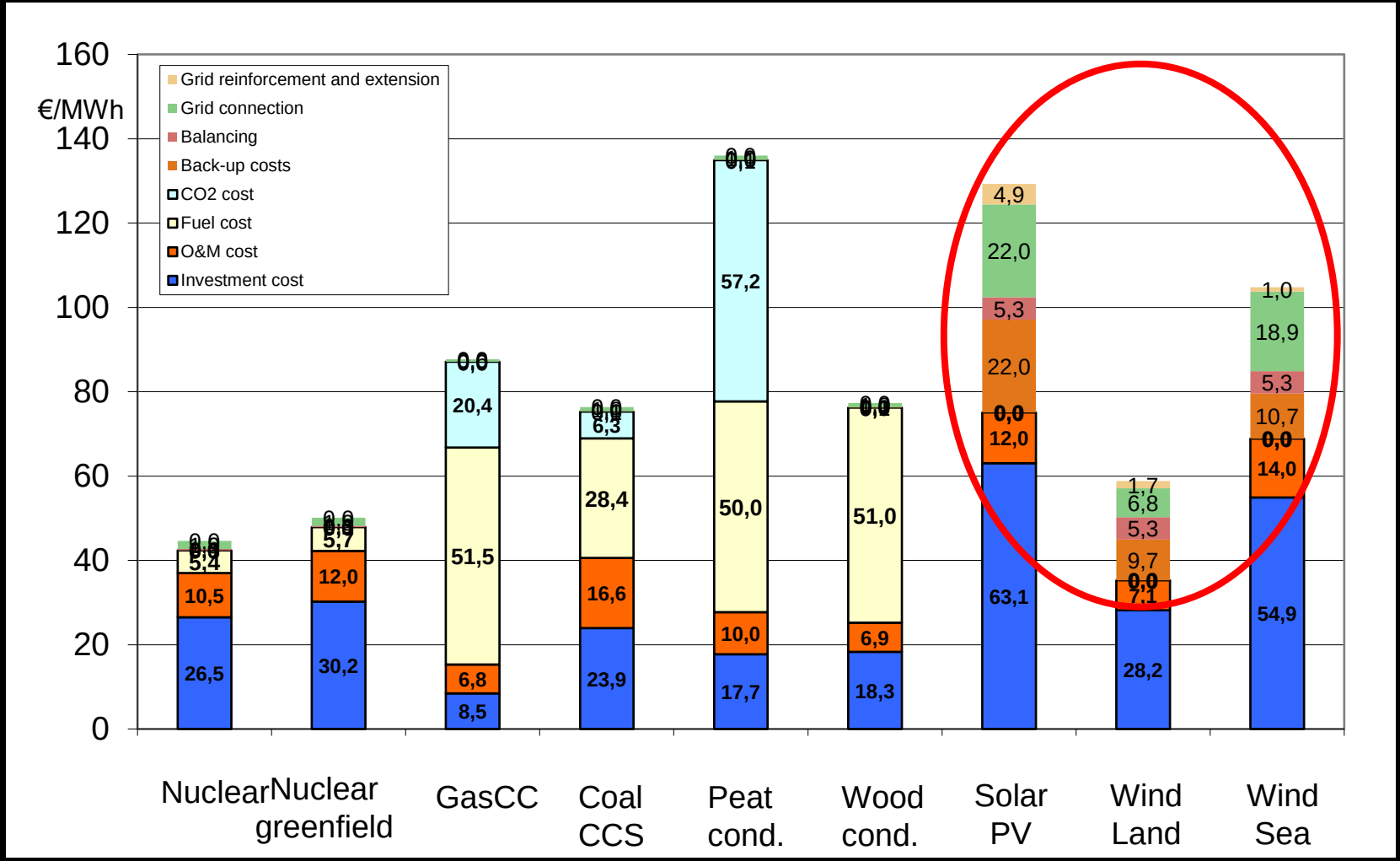
	Wind	Solar
Nominal	2585	278
Max (actual)	2025	235
Ave	823	32
Ave/Nom	**32 %**	**12 %**

[https://www.fingrid.fi/sahkomarkkinat/sahkomarkkinainformaatio/tuulivoiman-tuotanto/ ja …aurinkovoima/]

Systeemihinta – huomioitu järjestelmäkustannus

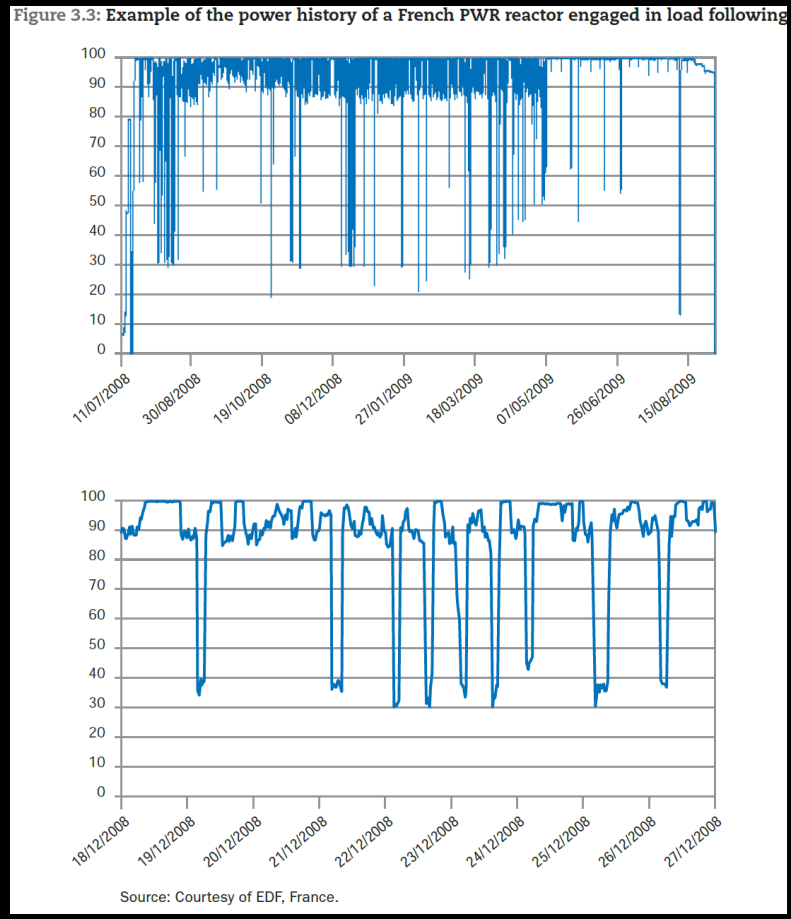
Järjestelmäkustannus VTT:n mukaan. Kuka maksaa? Asiakas maksaa.

[OECD, 2012, Nuclear Energy and Renewables : System Effects in Low-carbon Electricity Systems. OECD - NEA, Report NEA No. 7056, Paris, France, December 2012, 252 p. ISBN 978-92-64-18851-8.



NUCLEAR – RESOURCE EFFICIENT & SECURE

- A **3000 MWth / 1000 MWe** nuclear power plant consumes about **22 tn** of fresh fuel **annually**
  - Same fuel as operating reactors
  - Same waste management procedures
- Controllable output ("**dispatchable**"), helps maintain electric grid balance and stability
- **Secure** supply, fuel easy to store
- Cogeneration feasible if heat customers nearby



NEA 7056, 2012

NUCLEAR – HIGHLY ACCEPTED NATIONALLY

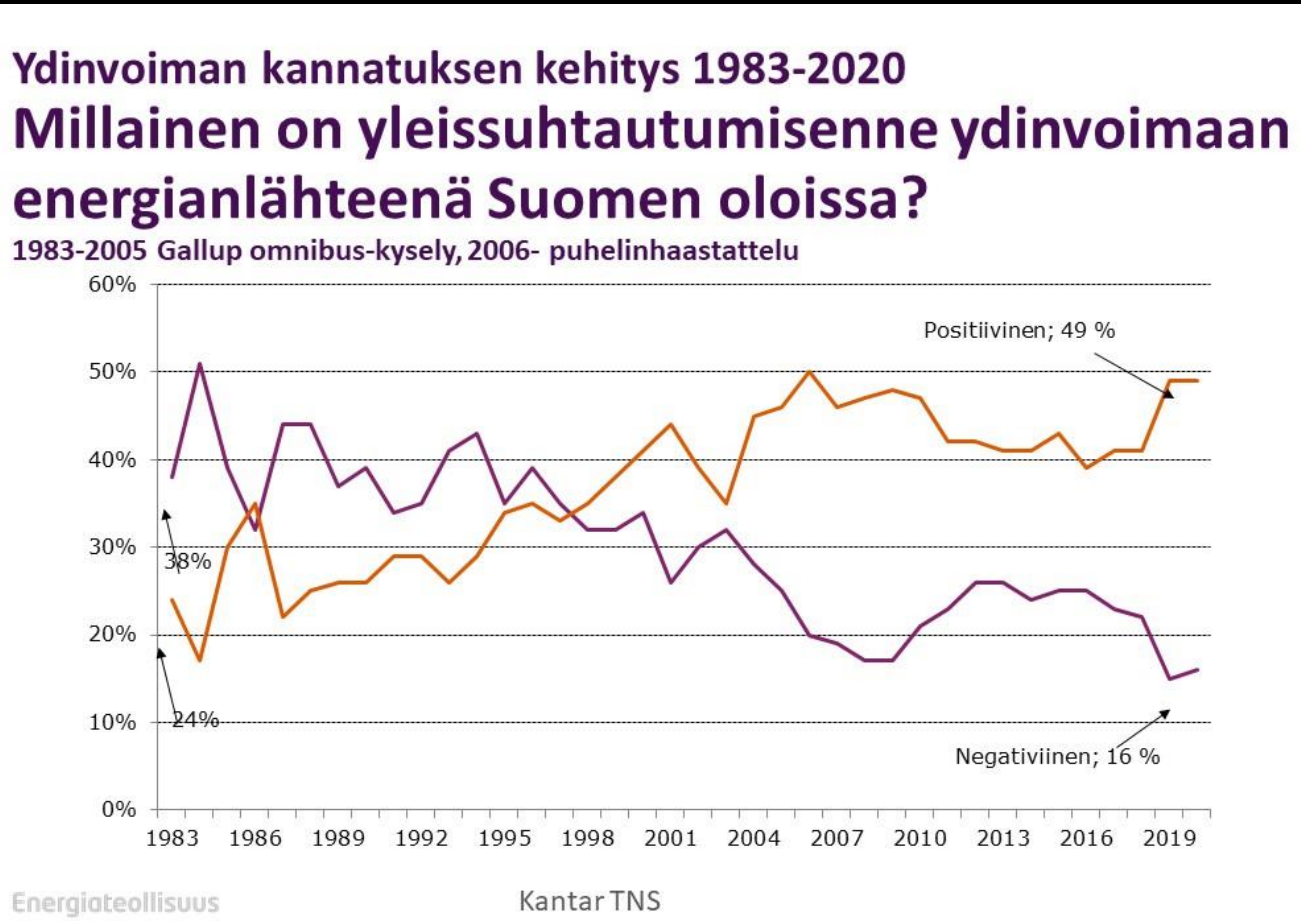
What is your general attitude to nuclear power in the Finnish conditions?

2020 response:

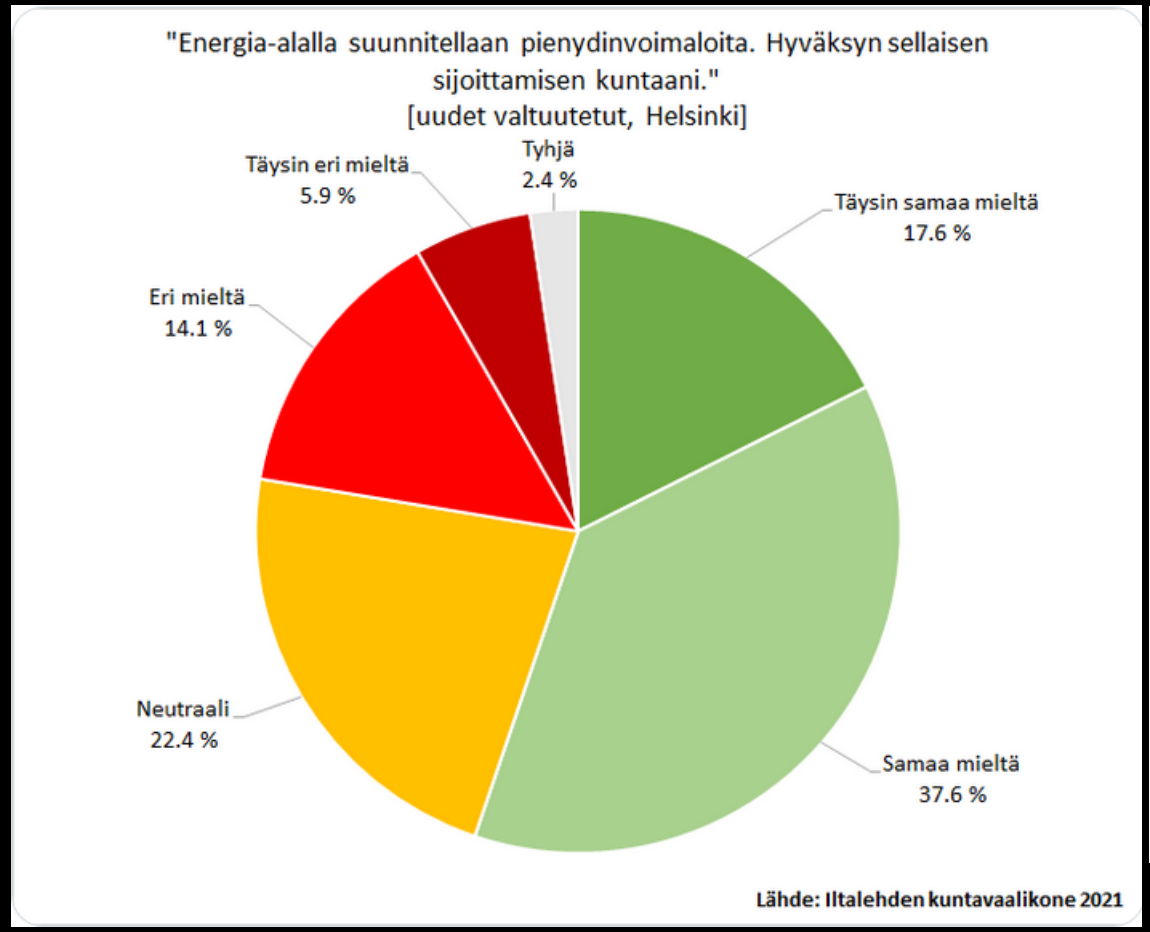
- 49 % in favour
- 16 % against

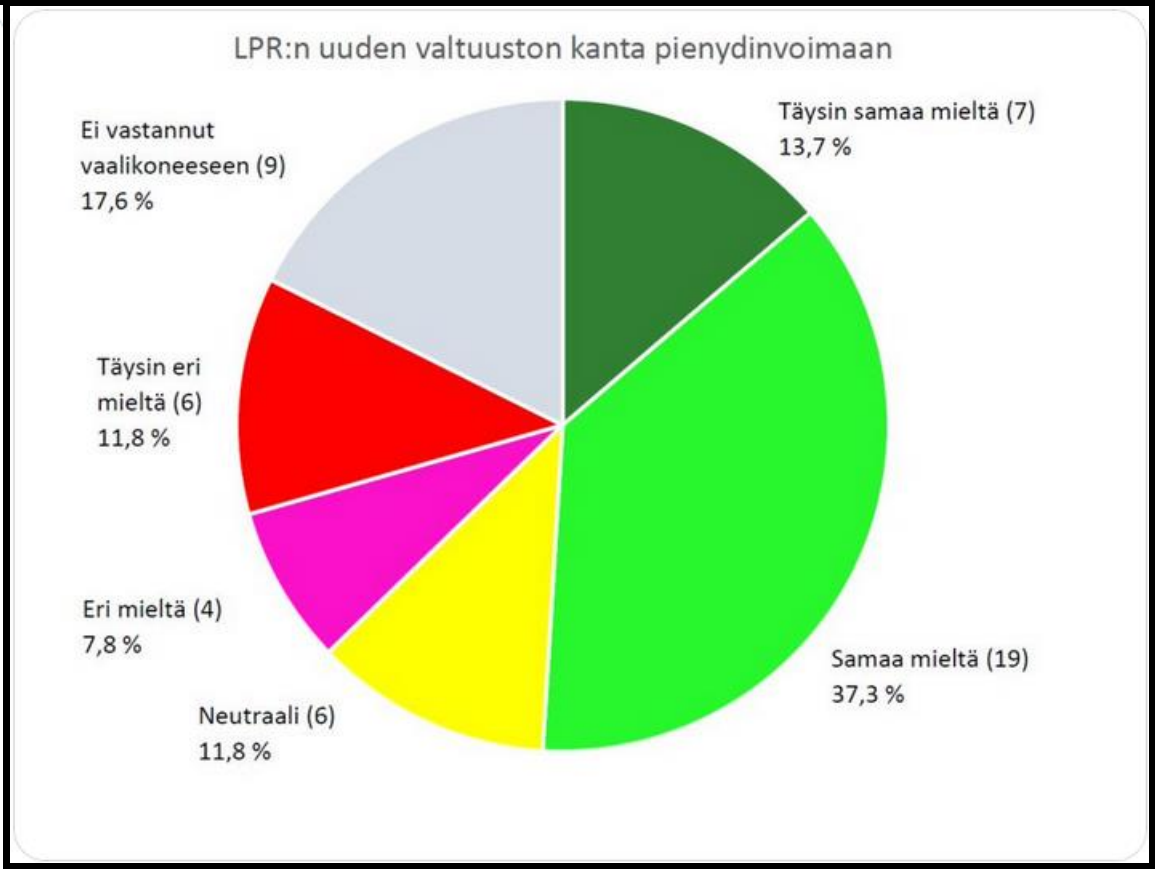
More than 3:1 in favour!

Rapid increase among the young.



NUCLEAR – HIGHLY ACCEPTED LOCALLY, TOO





SMR POWER RANGES AND USE CASES

- “SMR” is a broad notion; generally, < 1000 MWth; feasible for many applications

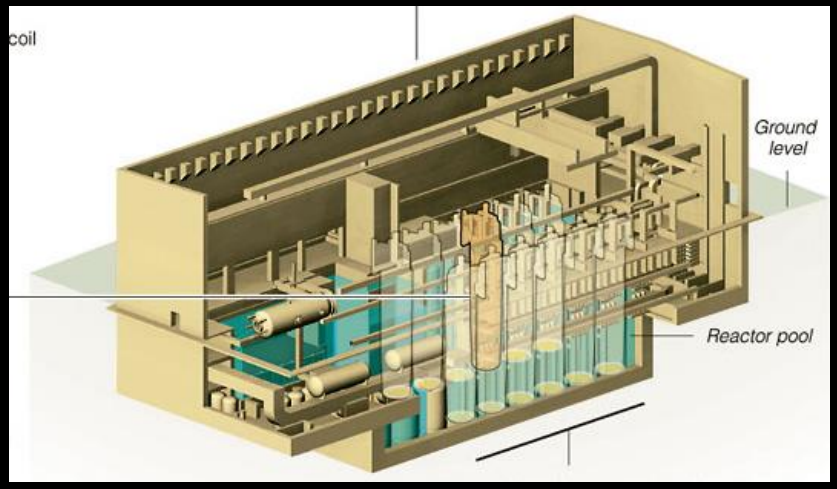
Use →	**Electricity**	**Co-generation / Desalination**	Naval	**District heat / Desalination**	Direct Hydrogen (non-LWR)
Thermal power (MW)	1000..10	1000..100	200.. 100	100..10	~500
Max temp (°C)	300	300	300	120	900
Units / installation	1..12	1..12	1..2	2..4	1..few
Nature of application	Traditional	Heat new	Movement	New	New, material production
TRL	8	8	9	6	5

COMMERCIAL SMRS – GENERIC POWER PLANTS

GE Hitachi BWRX-300
870 MWth / 300 MWe

Cost target 2250 $/kWe

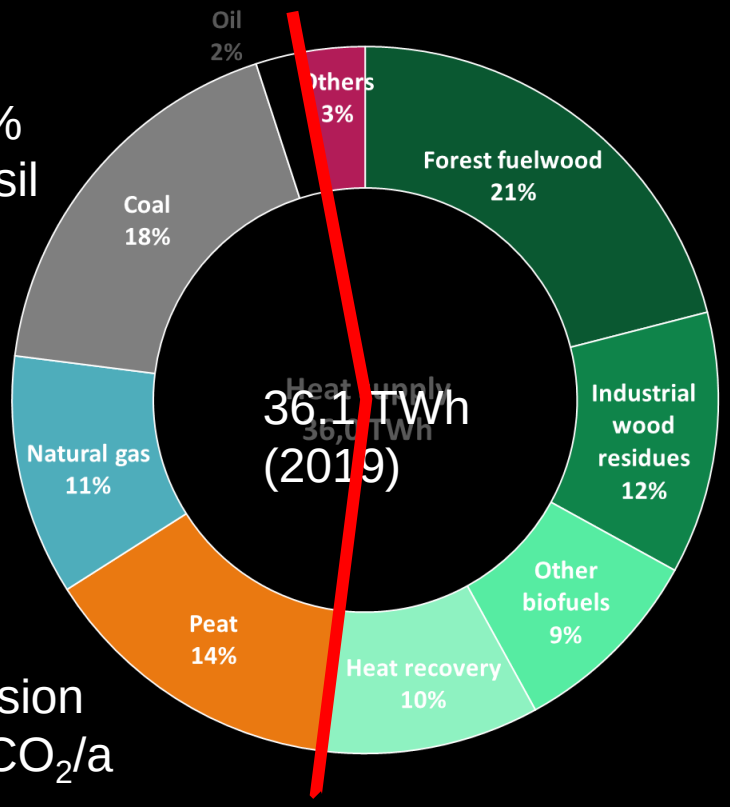
NuScale: 4..12 modules / plant
200 MWth / 60 MWe per module



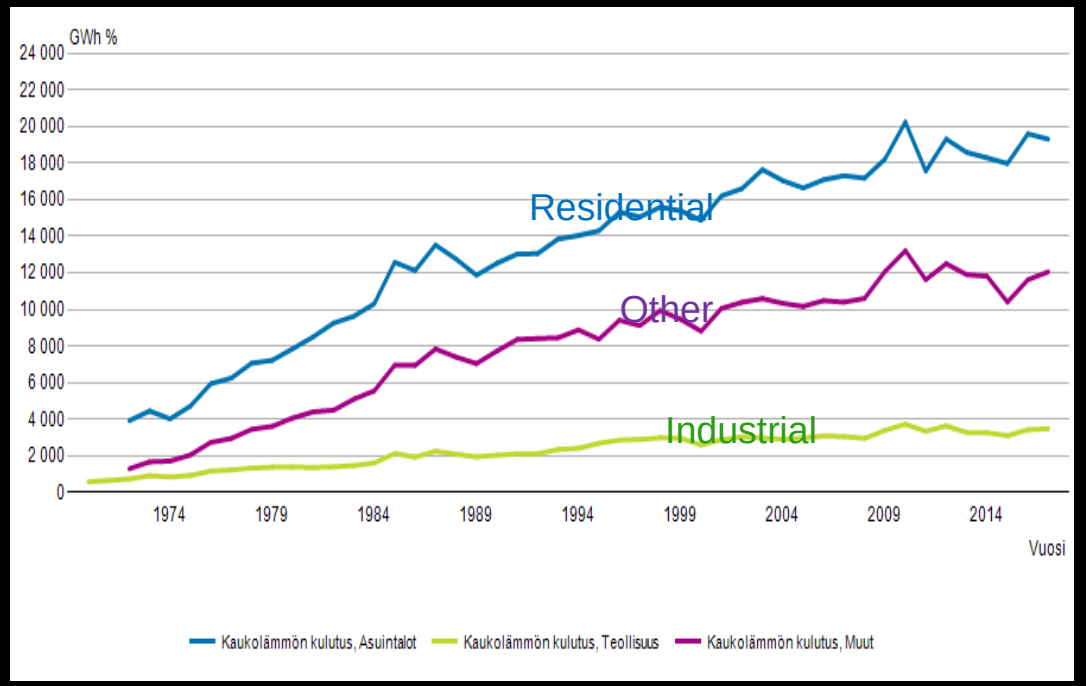
Cost estimate 4200 $/kWe

NUCLEAR DISTRICT HEATING = GHG REDUCTION

47 %
Fossil

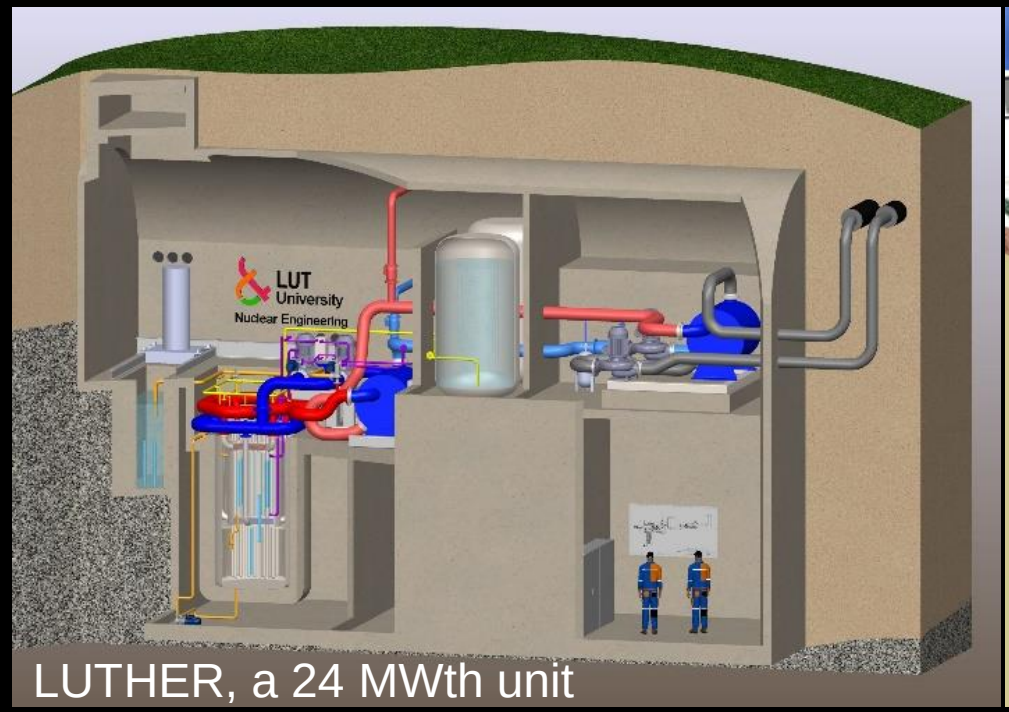


Emission
5 $MtCO_2/a$



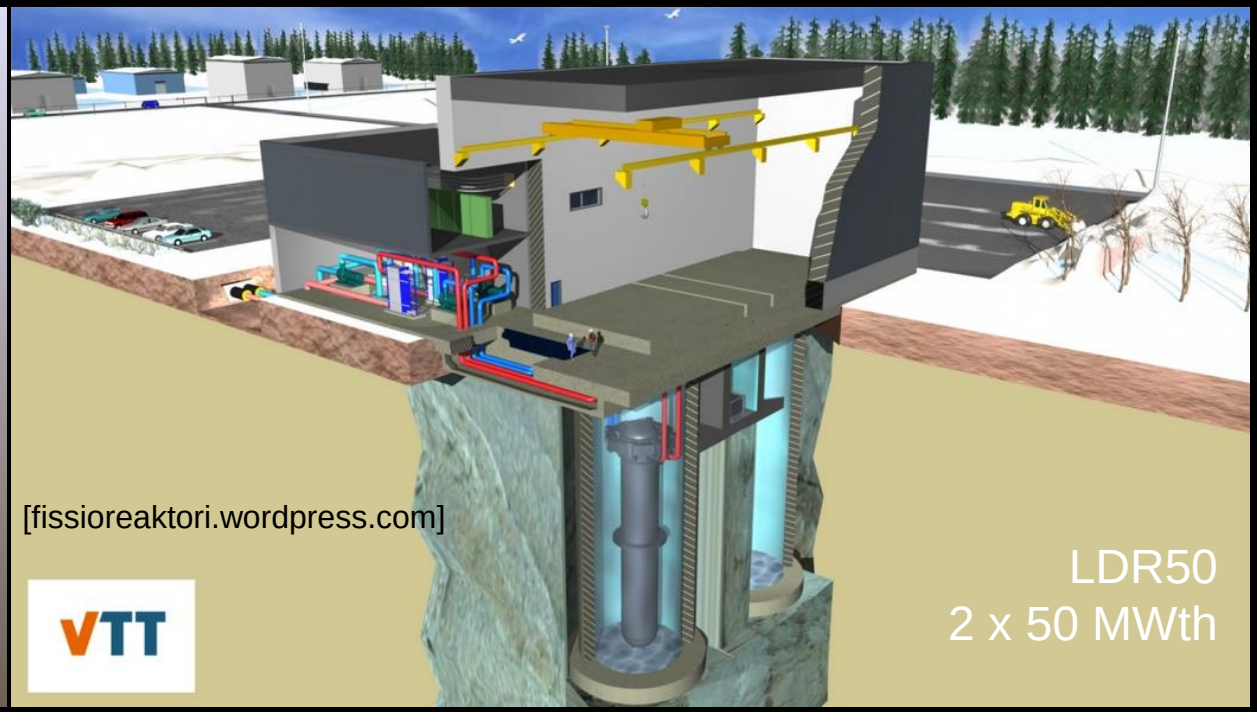
[Finnish Energy 2020]

FINNISH DISTRICT HEATING REACTOR CONCEPTS



LUTHER, a 24 MWth unit

LUT HEating Reactor



[fissioreaktori.wordpress.com]

VTT

LDR50
2 x 50 MWth

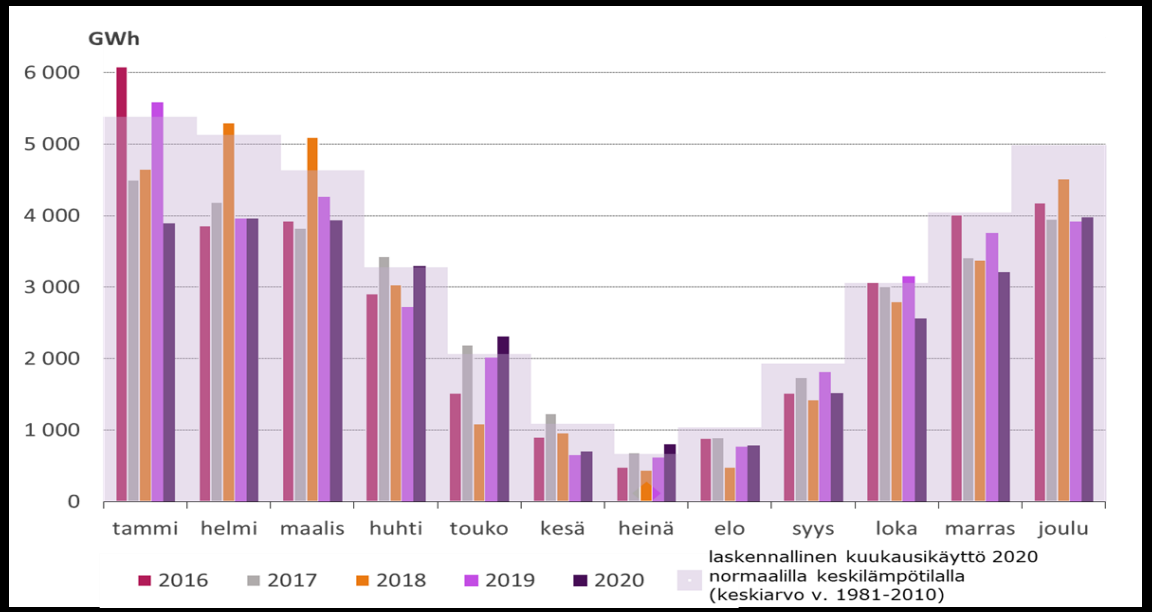
COST AND AVAILABILITY

	Type	Thermal MW	Electric MW	Cost of one, M€	Conv. eff.	€/kWe	€/kW -heat	Availability
Olkiluoto 3	EPR	4300	1600	9 000	37 %	5 600	2 100	On sale
Barakah	APR1400	4000	1400	6 100	35 %	4 400	1 530	On sale
SMRs	BWRX-300	870	300	1 000	34 %	3 300	1 150	Coming soon
	NuScale	200	60	250	30 %	4 200	1 250	Certified in US
District heating	LUTHER	24	N/A	50		N/A	2 100	Concept

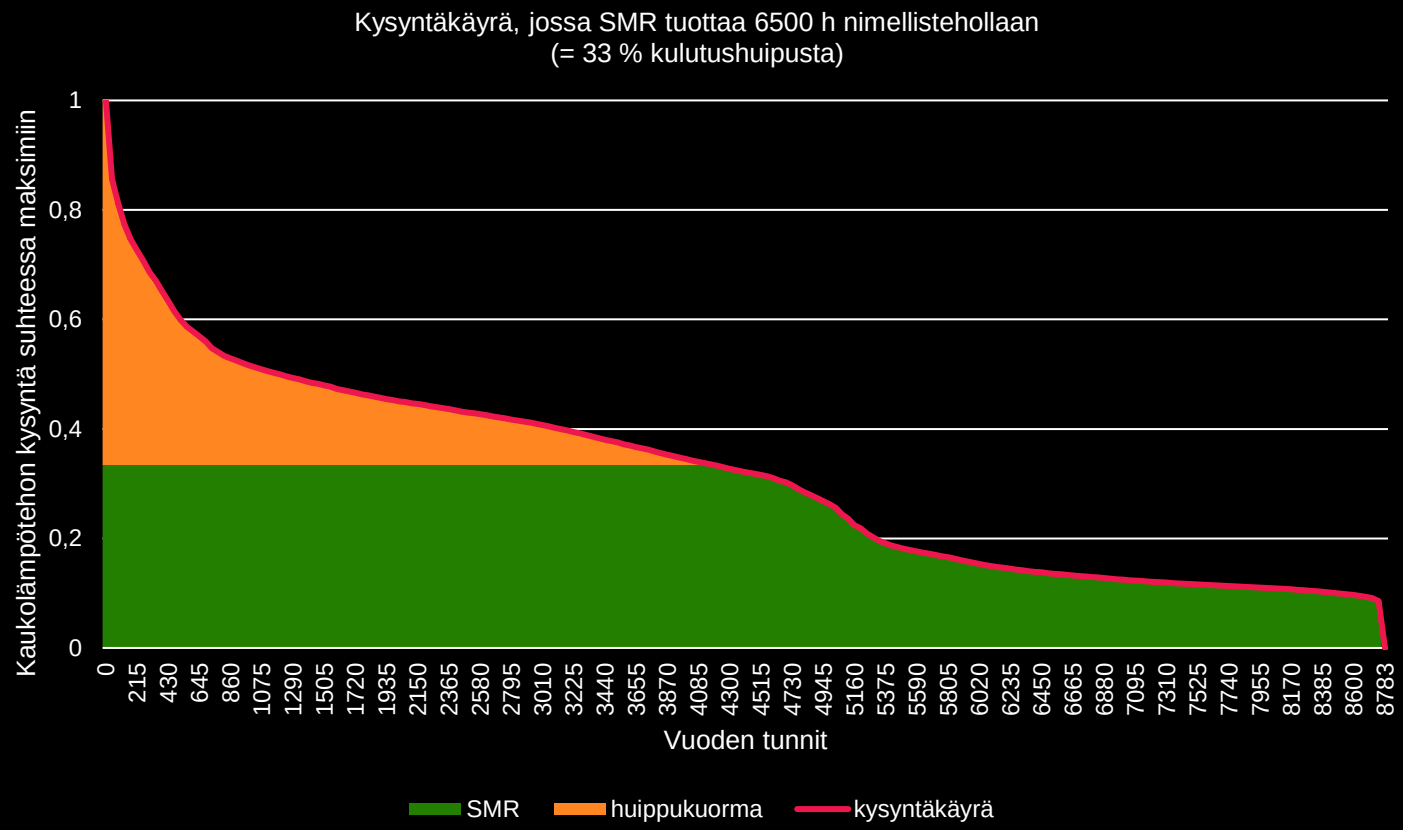
YDINKAUKOLÄMPÖ

- LUTissa kehitellään puhdasta kaukolämpöreaktoria, kokoluokkaan 24 MWth
  - voidaan monistaa helposti,
  - sijoittaa mahdollisimman moneen isoon tai keskikokoiseen kaupunkiin,
  - haastaa optimoimaan valvontamenettelyt (kustannusrakenne).

- Kaukolämmön tarve kesällä on pieni
  - Reaktorin aikakäytettävyys rajoitettu, n. 9 kk / a eli 6500 h



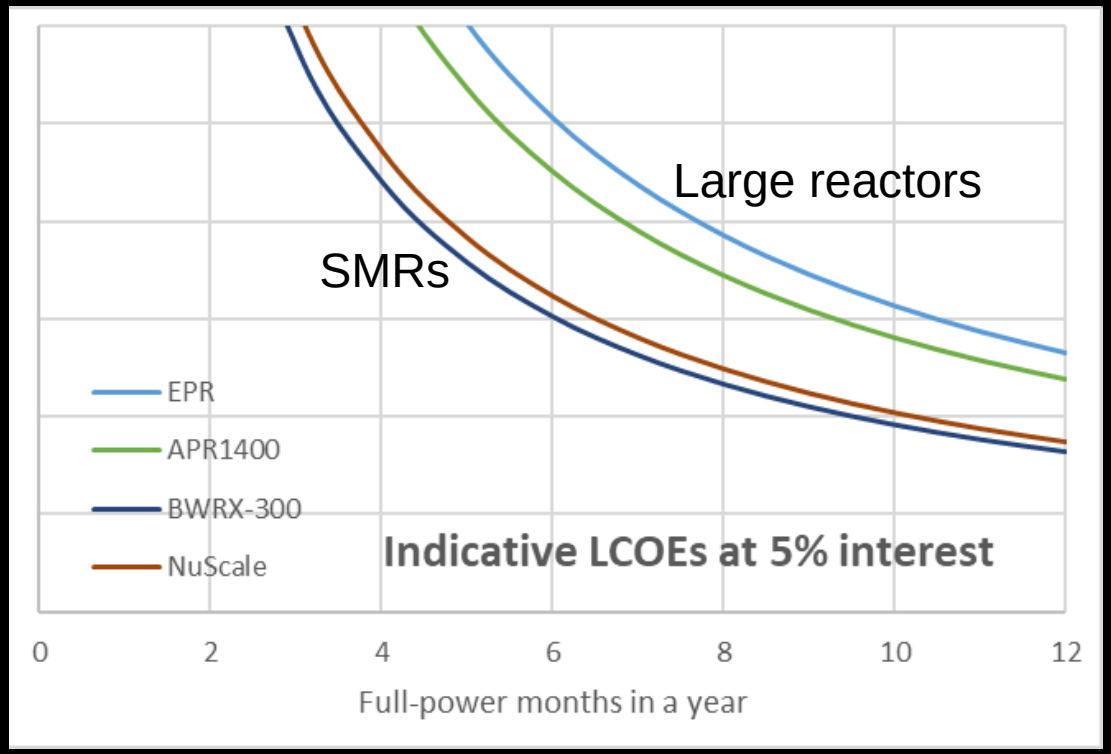
KAUKOLÄMMÖN KYSYNNÄN PYSYVYYSKÄYRÄ

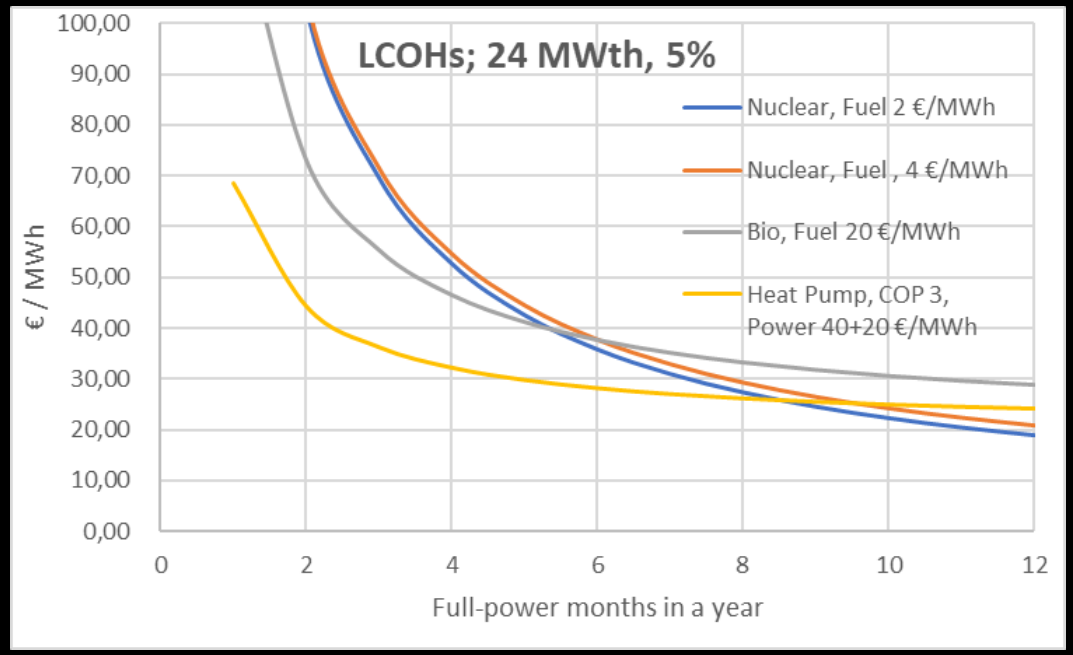


Perustuu Helenin vuoden 2016 tuntikohtaiseen dataan.

SMR-lämmitystehoksi voidaan ottaa n. 1/3 huippuarvosta ja silti kattaa puolet energian tarpeesta... se fossiilinen osuus ☺

LEVELISED COST ESTIMATES, ELECTRIC & HEAT





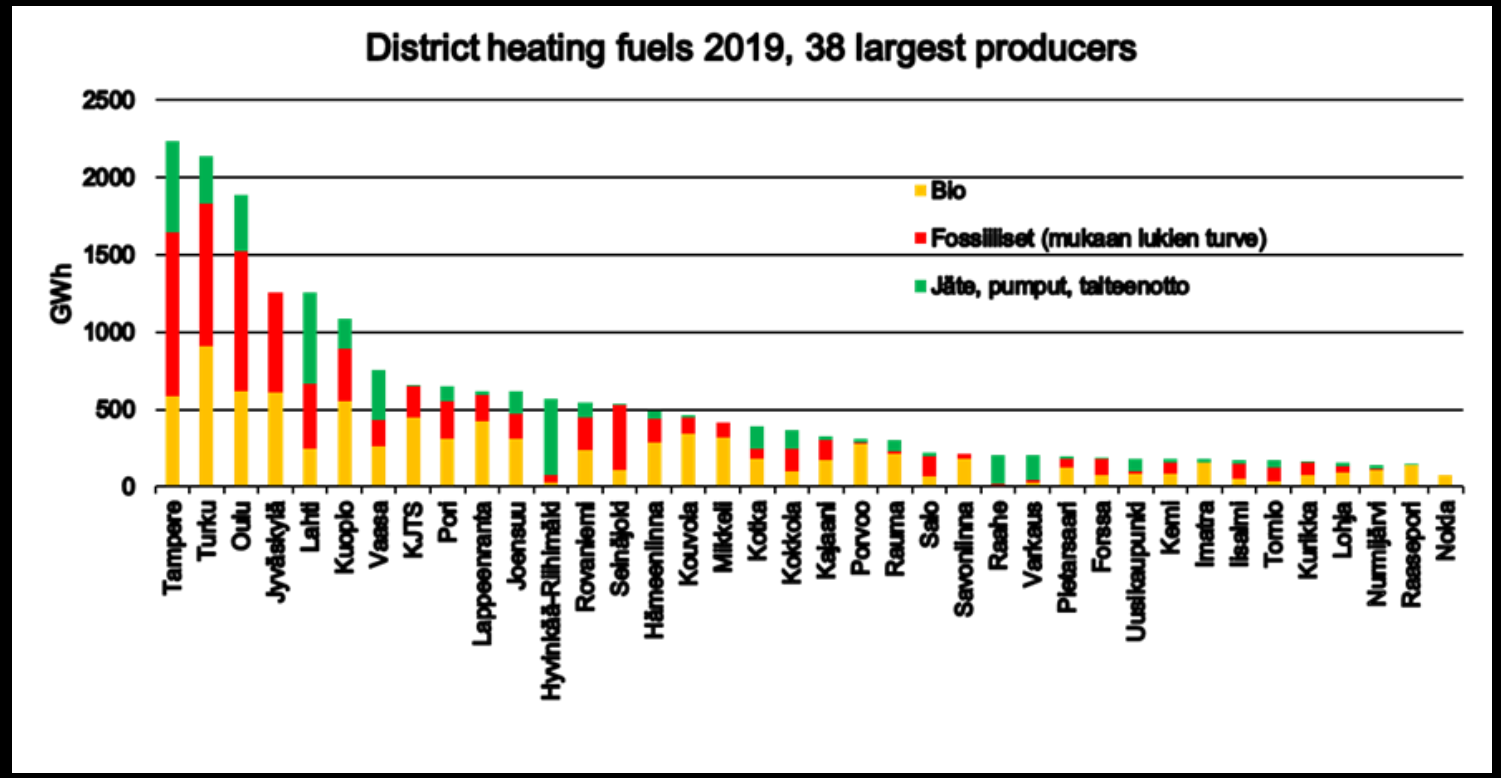
SITING AND LICENSING

- Electricity production: needs access to (national) power grid and heat sink
  - Distance from population centres is practical; few national sites
- Cogeneration and heat-only: needs access to district heat network or heat customer
  - Distance from population centres is i**mpractical; many sites all over the country**

- Traditional siting rules only consider large electricity producing plants
  - First codified in Guide YVL 1.10, 11.7.2000: 1 km site area, 5 km precautionary action zone and 20 km emergency planning zone
  - Currently promulgated in obligatory STUK Regulation Y/2/2018

- Siting rule revision for SMRs is being prepared for in VN-TEAS PIEMOS study by LUT
  - Risk ~ radioactive inventory; the smaller the reactor, the smaller risk

CANDIDATE CITIES FOR NUCLEAR HEATING



Big pressures to reduce fossil fuels

Coming pressure to reduce biofuels as well
- Habitat loss!

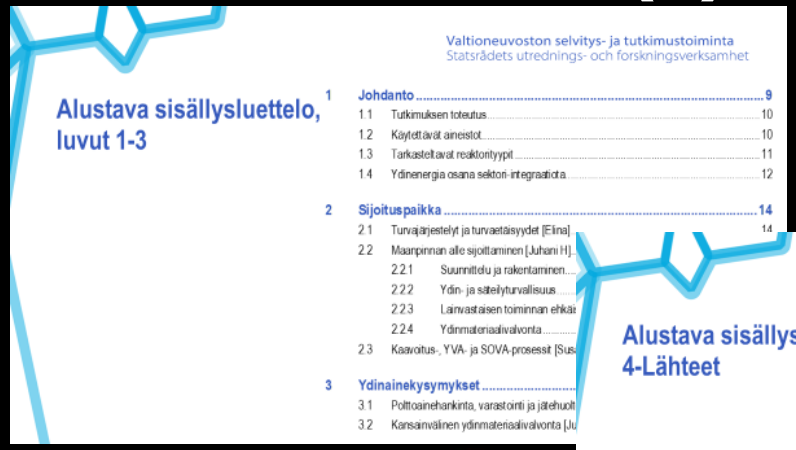
Nuclear heat would be economic for about 50 % of total energy demand

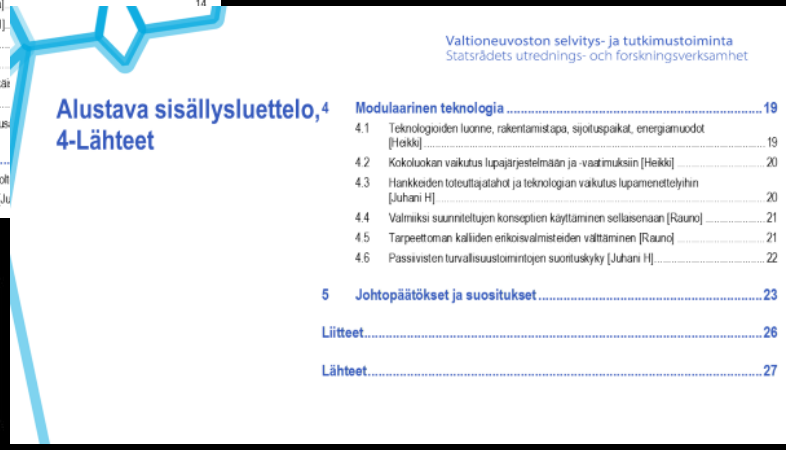
NEW BUSINESS MODELS AND OPPORTUNITIES

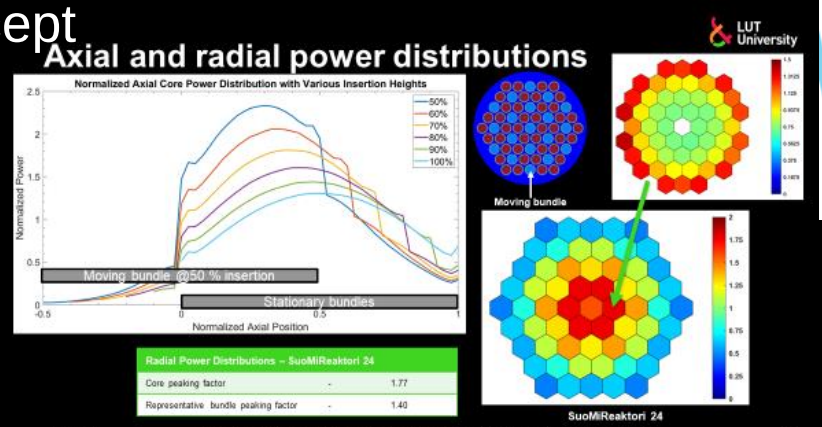
Present nuclear company Turnover > 1 Bn€/a	**An established large company becomes nuclear Turnover > 1 Bn€/a**	**An established mid-size company becomes nuclear Turnover ~100 M€/a**
Buys a few commercial SMR-plants for its current site, or	Buys a few commercial SMR-plants	Buys a few small reactors
Expands its activities by building small reactors *on new sites*	Builds on *new sites only*	Builds *on new sites only*

LUT ONGOING RESEARCH INTO SMRS (1)

- VN-TEAS funding to develop basis for new nuclear law (PIEMOS)
- LUTHER heating reactor concept development



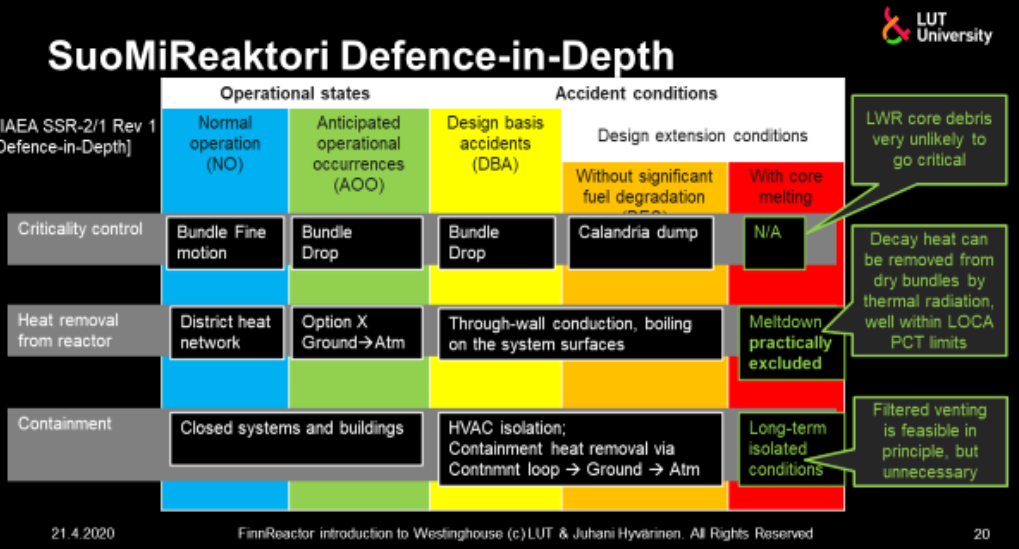




LUT ONGOING RESEARCH INTO SMRS (2)

- MOTEL test facility to study SMR architecture and key novel component behaviours
  - Operational since 2021

- OSAFE national nuclear safety research project to develop efficient safety assessment and licensing methods



CONCLUSIONS

- Nuclear power
  - \+ Climate friendly, resource efficient, secure dispatchable supply
  - \- Bad experience of large units: expensive, slow to license and build
- Small Modular Reactors contain a broad range of designs for electricity and heat production
  - Commercialisation beginning in the US and Canada
  - Promise faster and more cost efficient deployment
  - Finnish heating reactor development and deployment is totally realistic
- Siting and licensing
  - Heat supply requires siting closer to population centres. This will be safe
  - Licensing process updates will benefit all nuclear facilities
- LUT Nuclear Engineering is very active both on technology and regulations development

Thank you!

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