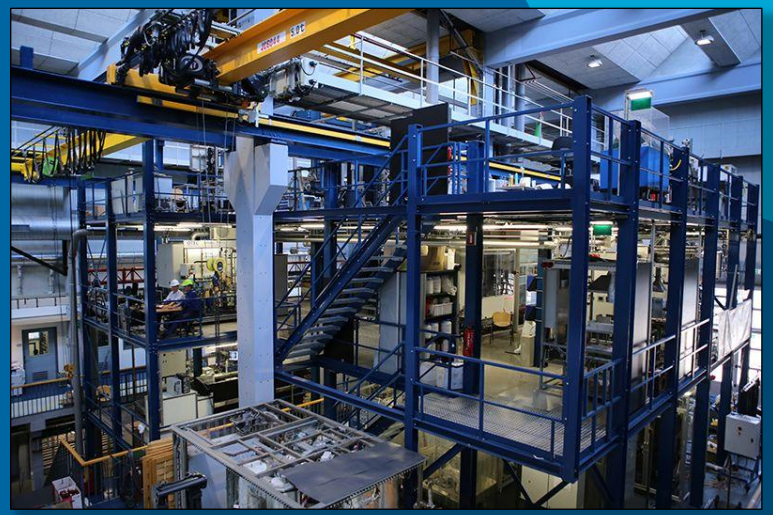
Nuclear renaissance: new opportunities, new challenges

KIVI-NT, Den Haag 6-2-2026

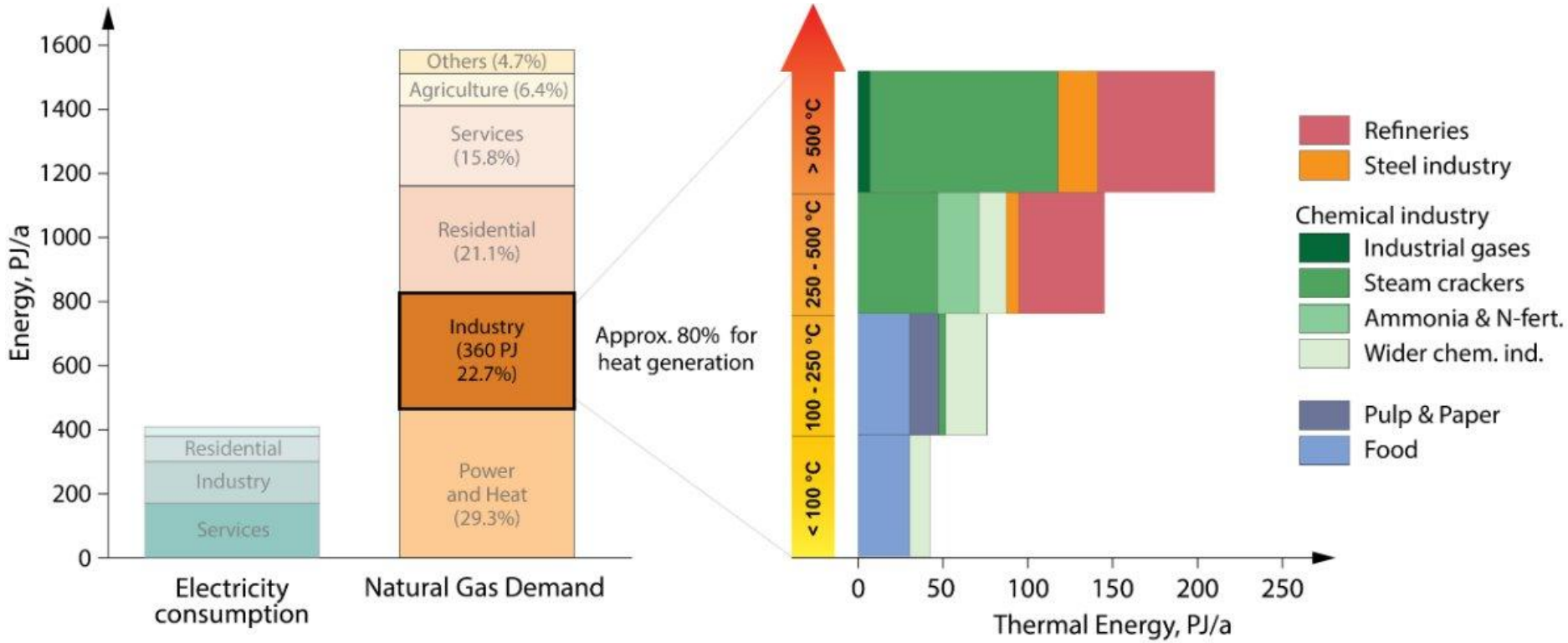
J.W.R. Peeters

Reactor Institute Delft



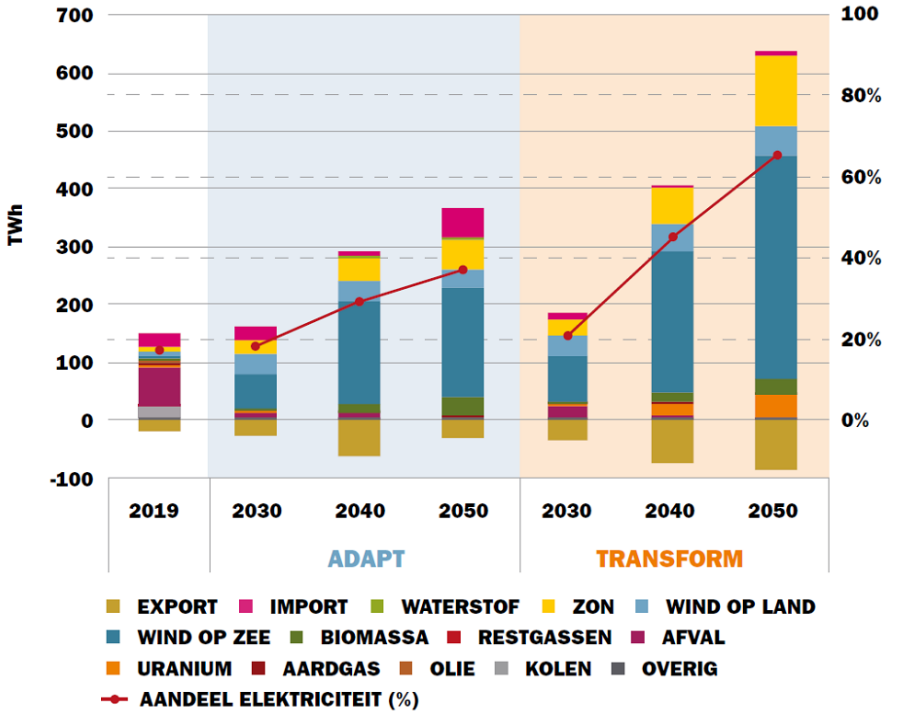
Process & Energy laboratory

The Dutch energy landscape in 2020



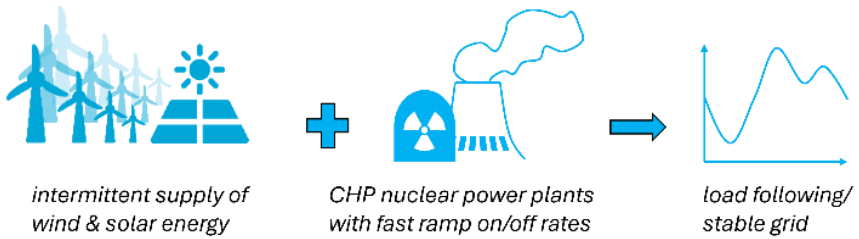
The Dutch energy landscape in 2050

- The EU & NL is committed to become climate-neutral by 2050
- Large increase in renewable energy foreseen in the Netherlands
- Intermittency of solar and wind energy poses serious problems for the electrical grid
- Currently, over 40% of Dutch energy is provided by gas power plants
- In parallel, electricity demand increases by a factor 3 – 5
- Load following of other energy sources is necessary

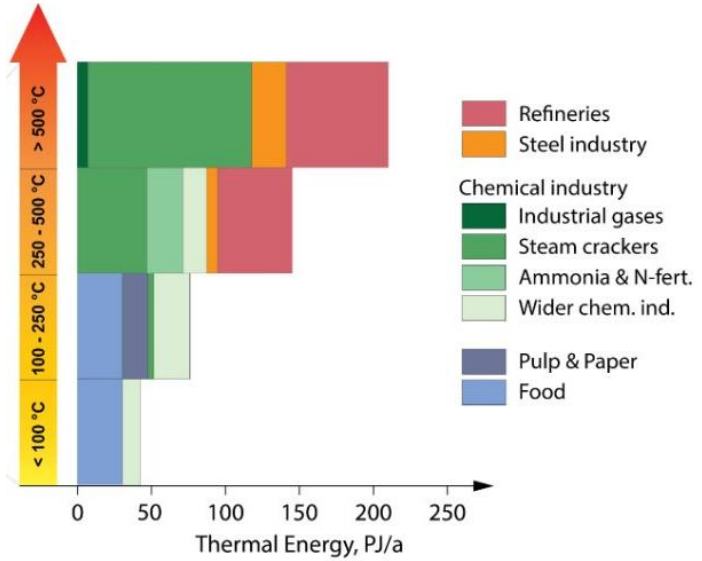


https://www.tno.nl/en/sustainable/system-solutions-environment/transition-pathways/scenarios-climate-neutral-energy-system/

New roles for nuclear power



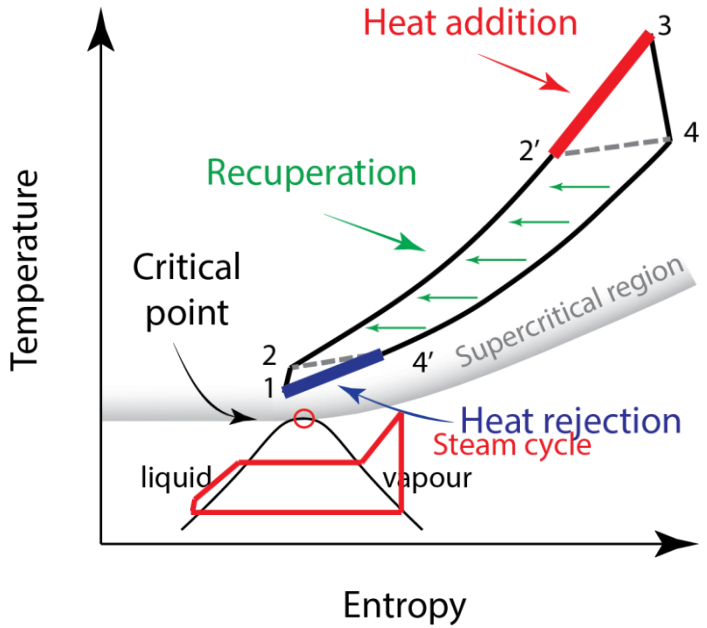
Load following

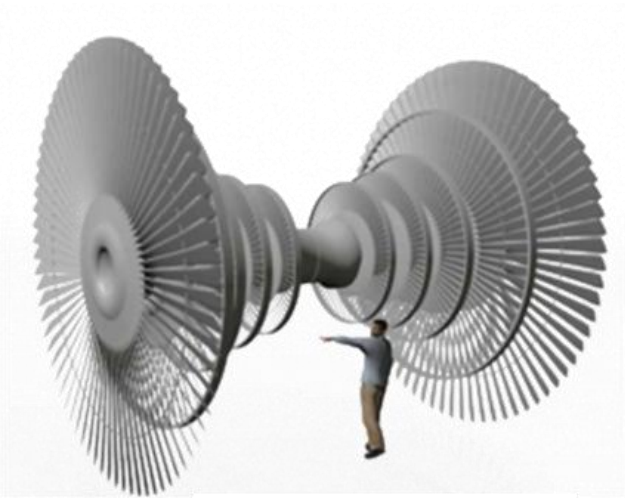


Industrial process heating

Advantages of CO_2 Brayton cycles

- Thermal efficiency is potentially higher than steam cycles
- Tiny turbomachinery





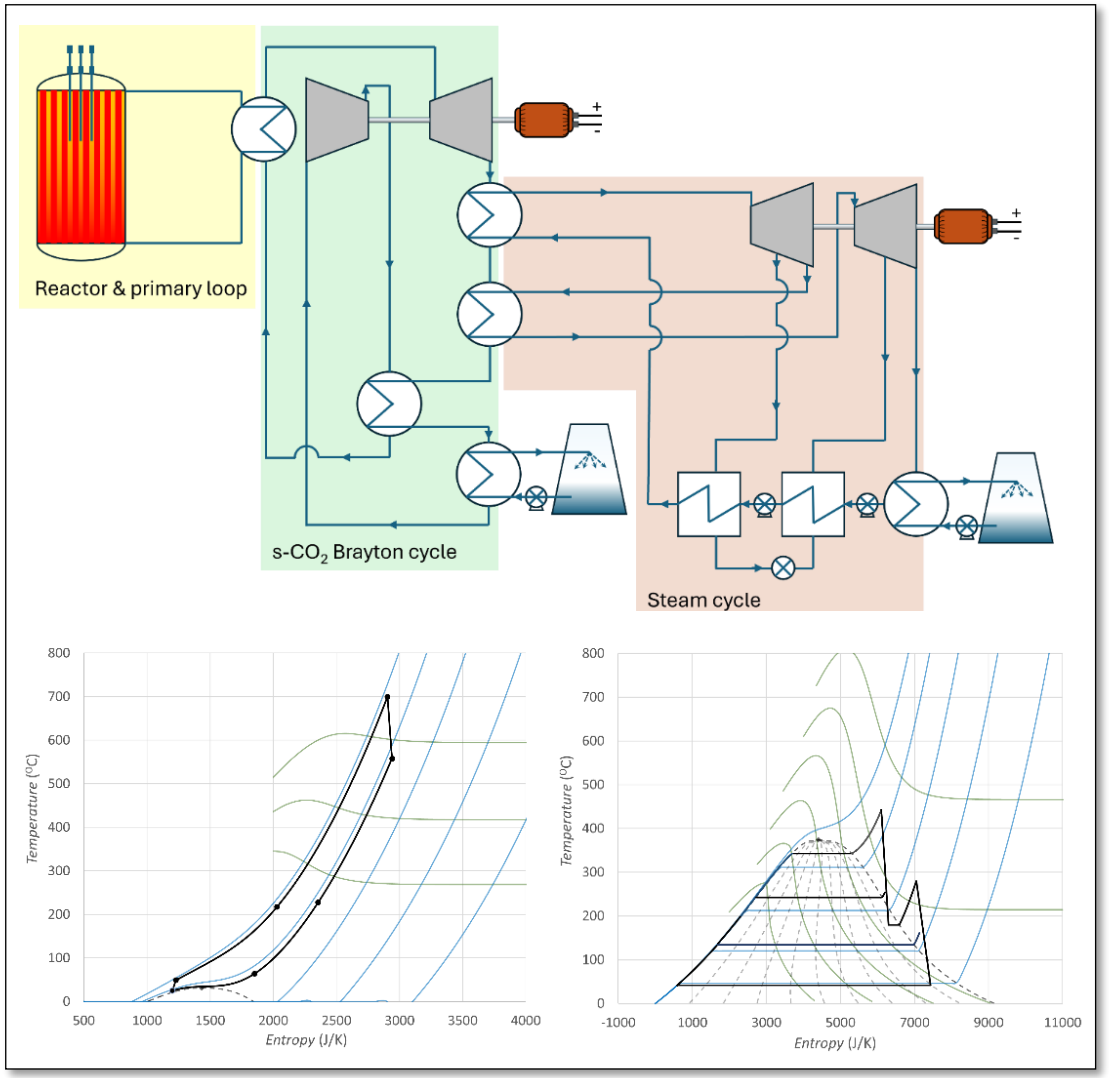
steam turbine

supercritical CO_2 turbine

small & cost-effective systems

Nuclear – sCO_2 on land

- Current NPP (3rd gen.) are limited to efficiencies of ~ 35 %.
- Advanced reactor designs allow for much higher efficiencies when considering combined cycles.
- Reactor conditions crucial for power cycle design
    1. *HTGR reactor suited to combined cycle as temperatures are between 250 and 750 °C.*
    2. *Molten salt reactor is ideal with a recompression sCO_2 Brayton cycle*
- sCO_2 power cycle well-suited for load-following owing to its compact design
- Potential student project: modern NPP design

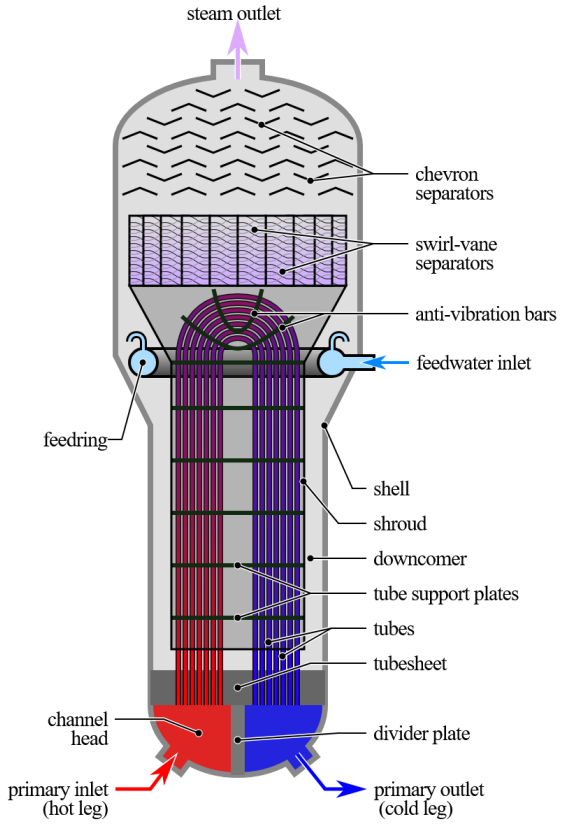


Other options for load-following

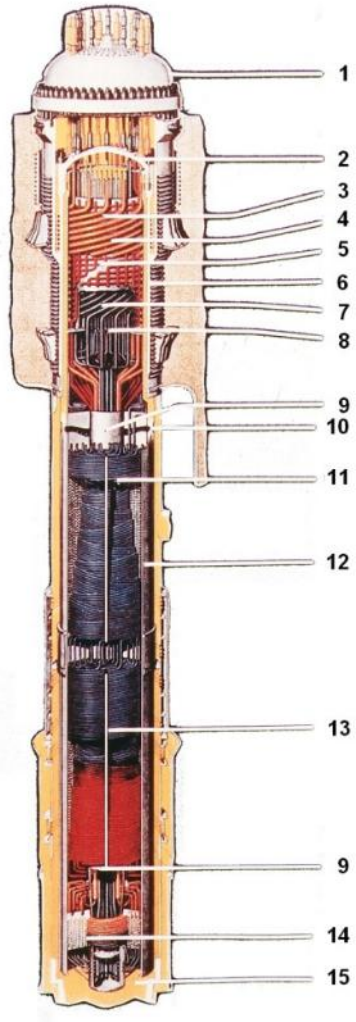
- Novel reactor designs allow for enhanced ramping compared to older generations
- Combine reactor with molten salt storage and a steam cycle
- Small modular reactors have less inertia
- Enhanced nuclear load-following will lead to new engineering challenges

New nuclear steam generator designs

- To utilize the high temperature heat of novel reactors, U-tube is replaced with once-through SG
- Helical coil OTSG is most often mentioned
- OTSG allows for superheating of vapour, while U-tube doesn't



source: wikipedia



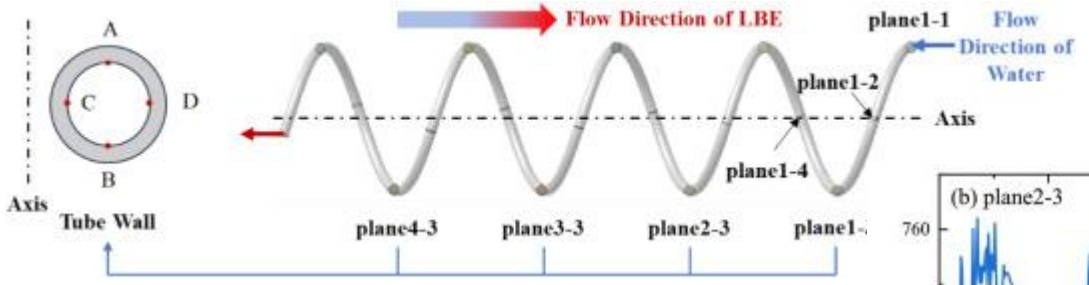
Esch et al., proceedings of HTR 2010, paper 267

New nuclear steam generator designs

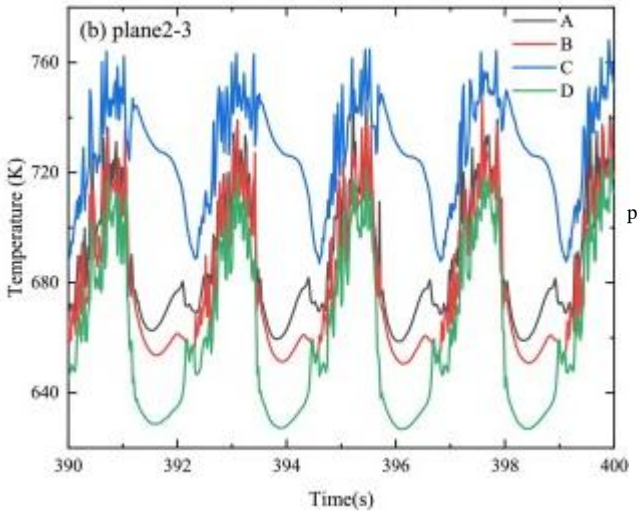
- Helical coil OTSG

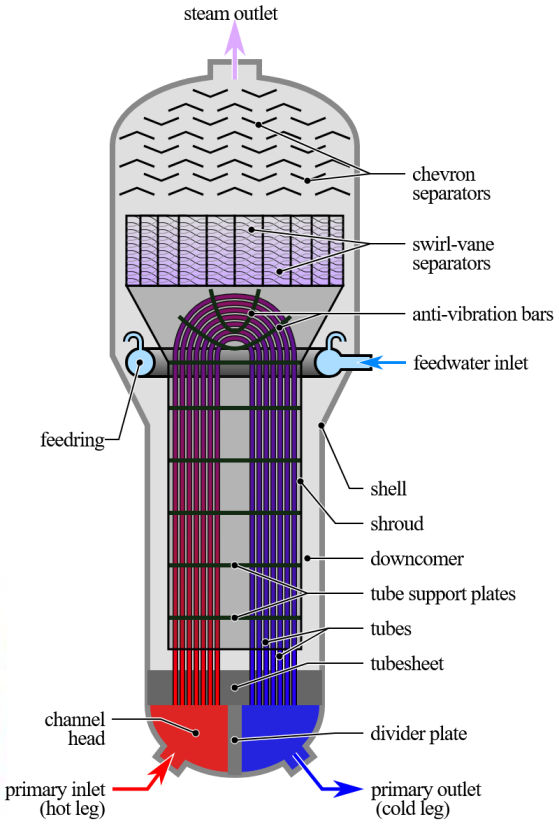
  a) Inherently flexible towards thermal stresses due transients
  b) more prone to two-phase instabilities
  c) instabilities affect reliability/safety

- Flow instabilities lead to local variations in mass flow rate, pressure, temperature, heat transfer rate

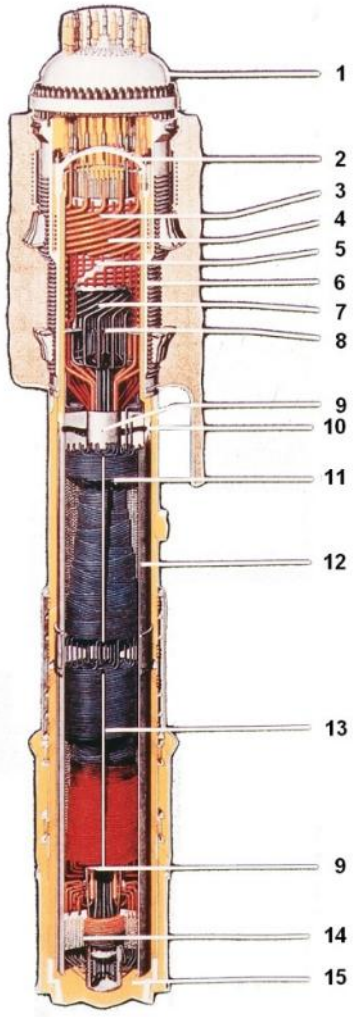


Lai et al., International communications in heat and mass transfer, 2025, 109354.





source: wikipedia



Esch et al., proceedings of HTR 2010, paper 267

New nuclear steam generator designs

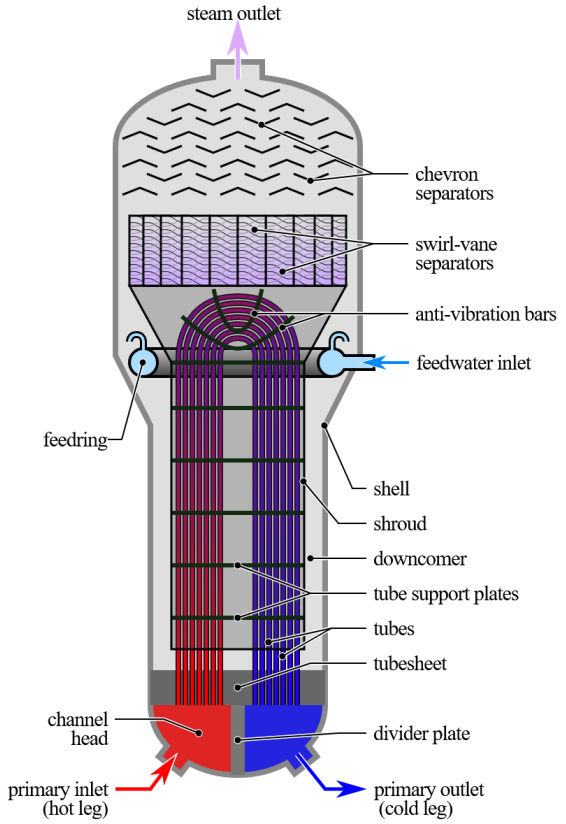
- Helical coil OTSG

  a) Inherently flexible towards thermal stresses due transients
  b) more prone to two-phase instabilities
  c) instabilities affect reliability/safety

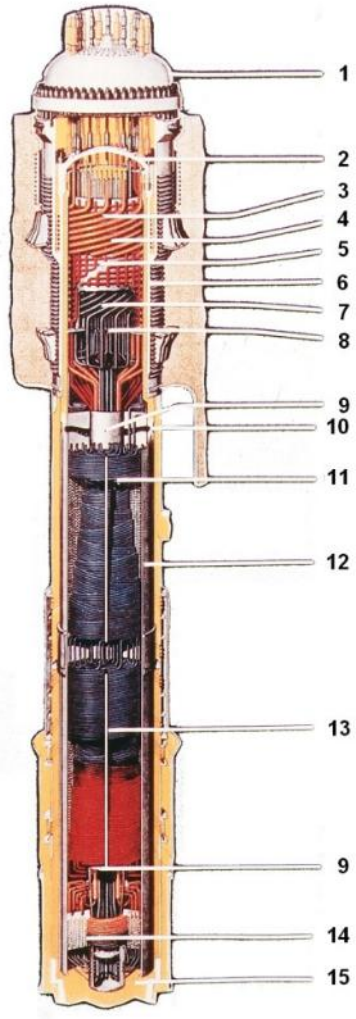
- Flow instabilities lead to local variations in mass flow rate, pressure, temperature, heat transfer rate

- ***Different reactor coolants – water, helium, molten salt, lead, may lead to different two-phase flow behaviour***

- Potential student project: NSSS design for novel reactors



source: wikipedia



Esch et al., proceedings of HTR 2010, paper 267

Nuclear powered process industry

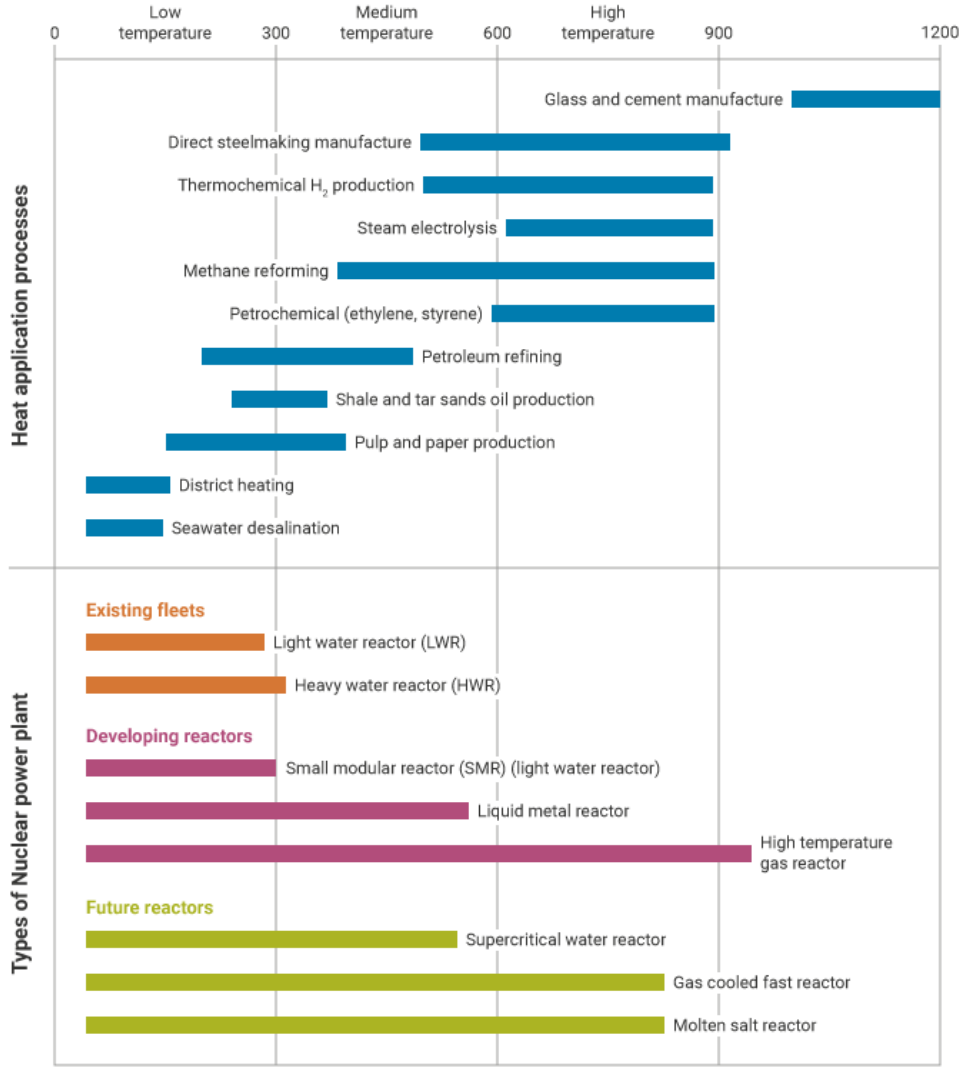
- For the coupling of Nuclear power and chemical process, look towards developments in chemistry

  a) *Nuclear industry looks for higher temperatures*
  b) *Chemical industry is looking to lower process temperatures*

- Example: reverse water gas shift reaction (currently 900 °C)
- Crucial step in the production of synthetic fuels

- Food & pulp process are also looking to lower temperatures & other technologies

- Potential student project: process design of nuclear- chemical plant



source: IAEA

Summary

- Load following & industrial process heating are potentially new opportunities for nuclear power
- Added complexity leads to engineering challenges – no dealbreakers

  a) sCO_2 cycles offer high efficiency, compact designs, but material choice & generator design are important

  b) helical coil OTSG is inherently flexible, but can show complex two-phase flow phenomena

  c) combination of nuclear and chemical process is alternative to fossil fuels, but it is much more complex than matching temperatures between technologies