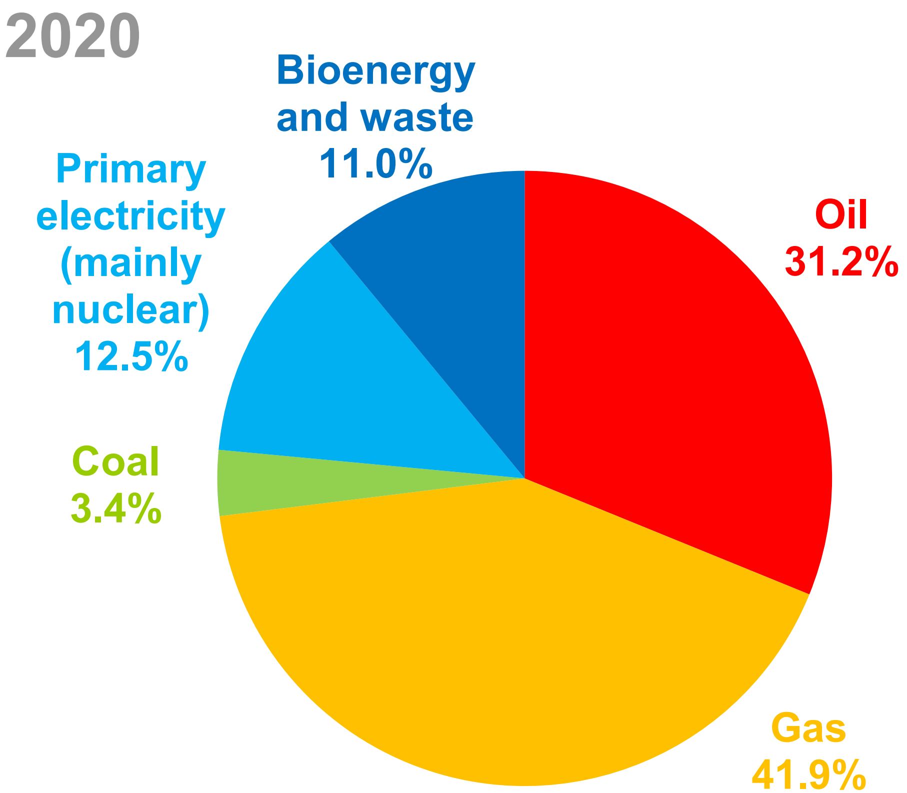
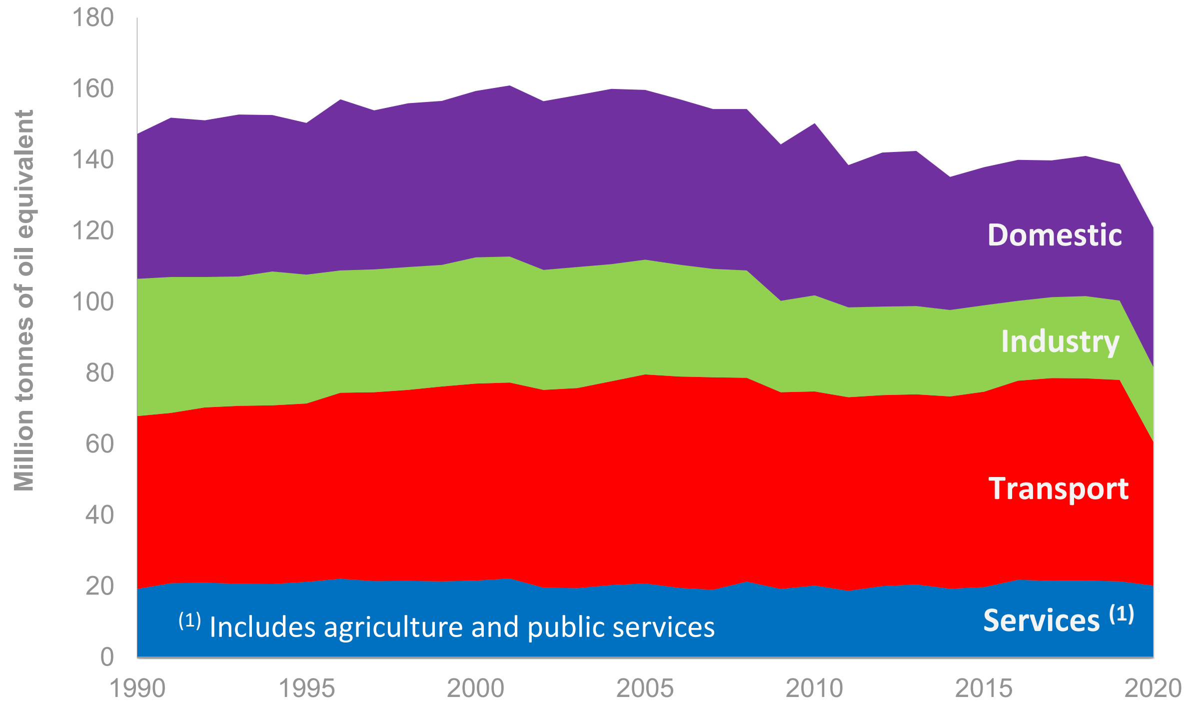
U-Battery® Technology and Development Status

GIF Industry Forum, Non-electric Applications of Nuclear Heat Workshop
Toronto, Canada
October 3, 2022

Prof. Tim Abram, Head of Engineering

Energy supply and demand in 2020





2020 Primary energy consumption: 163.3 MTOE

Source: *www.gov.uk/government/statistics/uk-energy-in-brief-2021*

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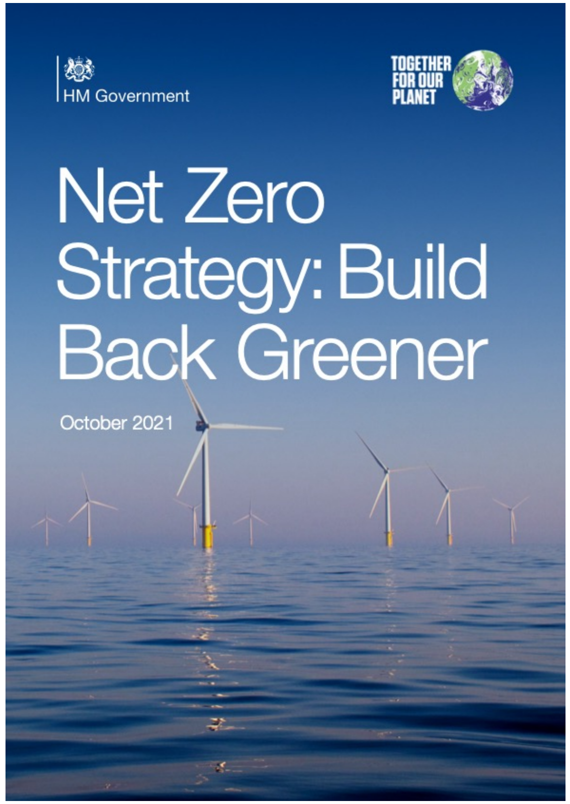
Energy strategy

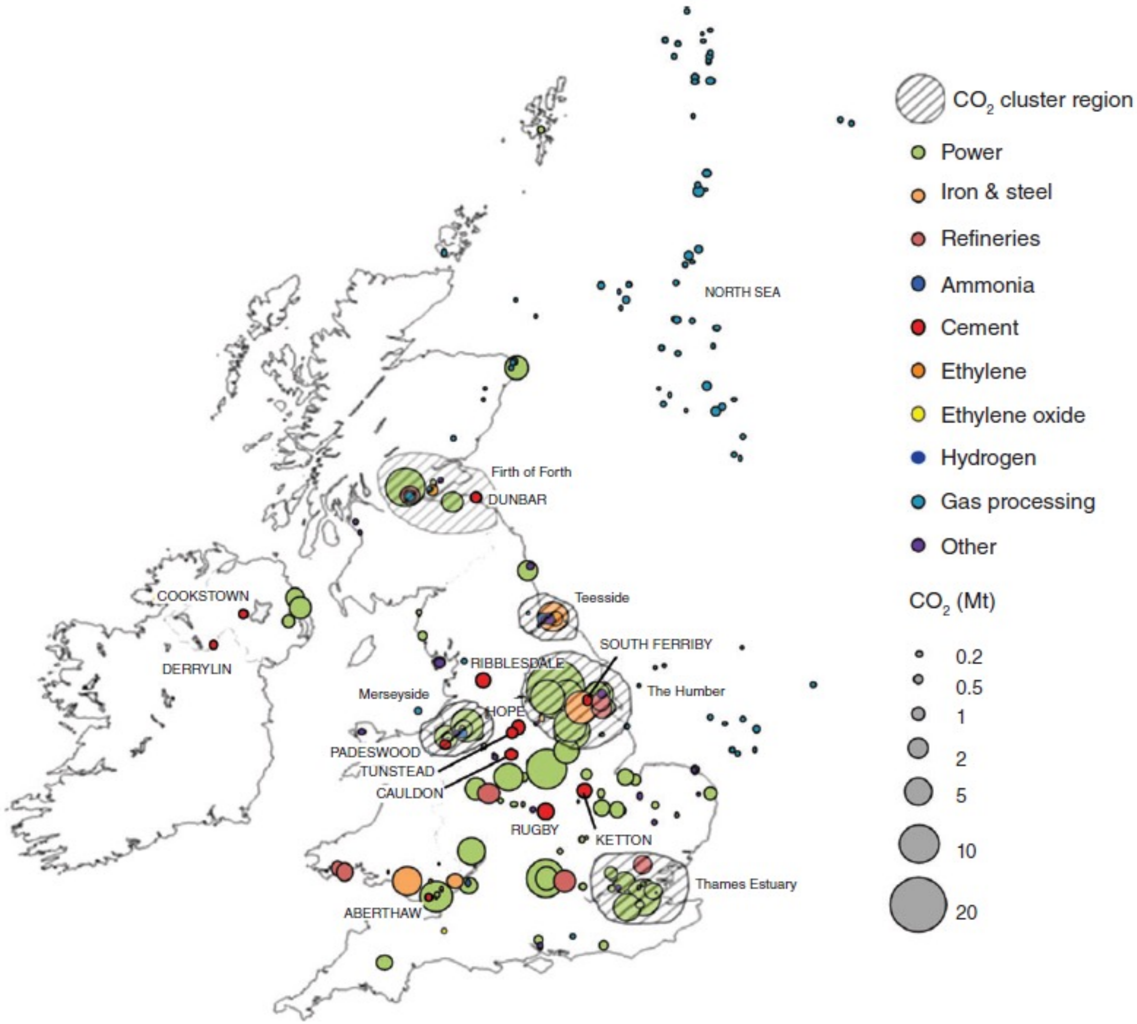
UK committed to achieving Net Zero Carbon Emissions by 2050 with important interim steps:

- End the sale of fossil fuelled cars by 2030
- 5 GW of hydrogen production capacity by 2030
- End the sale of gas-fired domestic heating systems by 2035
- Decarbonise all power systems by 2035
- Govt. support for new nuclear
  - EDF's Sizewell C project (£700m contribution to 2 EPRs)
  - Support to SMR and AMR developments



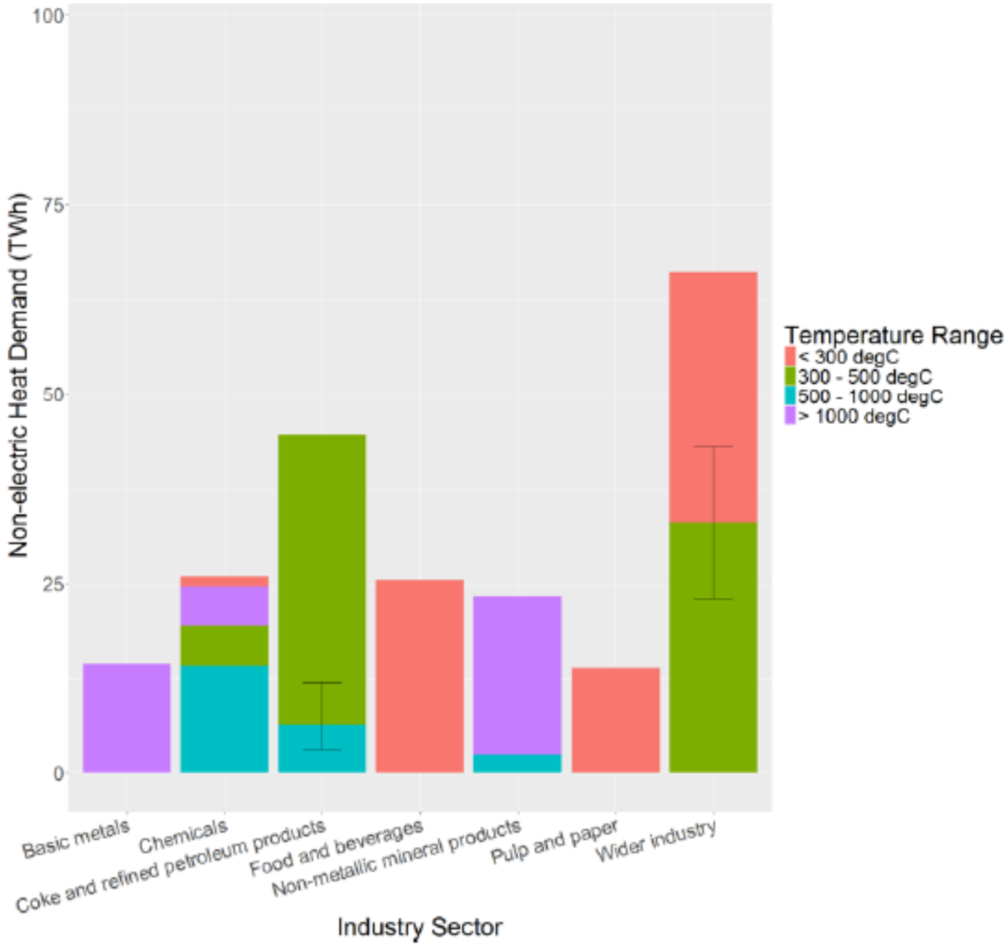
Decarbonising UK industry

- UK industrial energy usage is ~400 TW·h/yr of which ~300 TW·h/yr used for process heat
- "Foundation industries" (glass, steel, petro-chemicals, paper, etc.) are worth around £52 billion/year **but** they the UK's biggest polluters: ~50 Mt CO_2/year (10% of total CO_2)



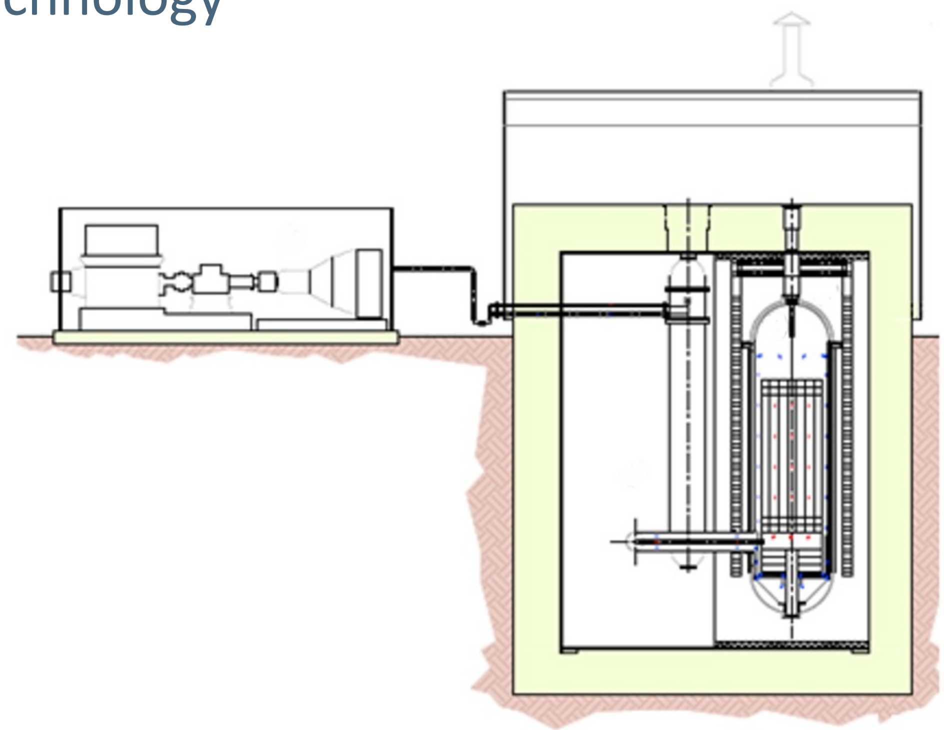
Prospects Advanced Modular Reactors

- Govt.preference for high-temperature gas-cooled reactor technology
- AMRs likely to focus on **non-electricity applications**
- Industry temperature needs are beyond LWR capabilities, but 80% of heat is ≤ 1000°C: potentially achievable by HTRs
- BEIS funded a 2-year programme to develop a UK HTR: the U-Battery



U-Battery HTGR: an overview

- Concept first developed by the Universities of Manchester and TU-Delft to address combined heat and power needs of small industries and off-grid communities using demonstrated technology
- 10 MWth prismatic core HTGR
- He-cooled, graphite moderated
- 750°C outlet temp.
- 30 year design life
- Modular factory build
- Standard reactor island
- Multiple power conversion options
- Capable of autonomous operation



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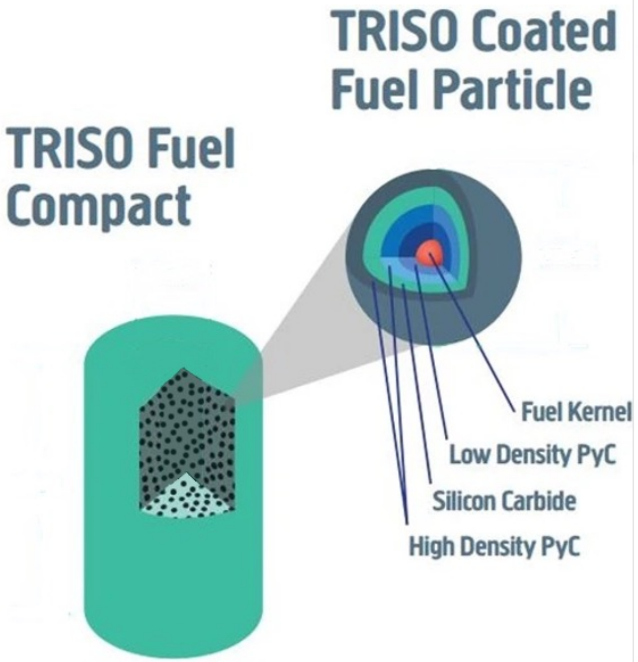
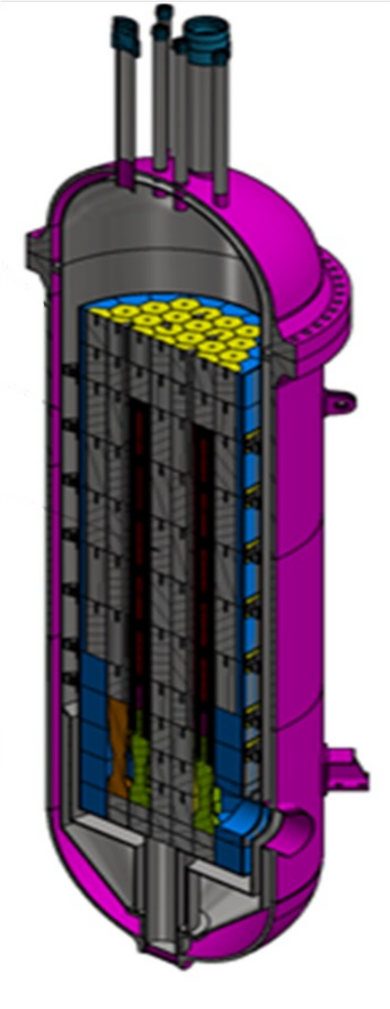
A demonstrated technology delivered by a world-class team

Dragon 1966 → Peach Bottom 1 1966 → AVR 1966 → Fort St Vrain 1974 → THTR 1983 → HTTR 1998 → HTR-10 2000 → HTR-PM 2021 → U-Battery 2028?

Fuel and core concept

- Reference fuel is BWXT-supplied UCO TRISO – demonstrated excellent performance, validated by an extensive irradiation and PIE programme
- Novel fuel block and core design provides 5-year cycle length
- Removable graphite reflector blocks surrounded by a fixed graphite reflector
- Six B_4C primary control/shut-down rods, three secondary shut-down channels (B_4C spheres).
- Core restraint system based on bimetallic tension elements (used in Magnox reactors)
- Acceptable fuel temperatures maintained entirely by passive cooling – no safety claims on any engineered cooling or reactivity control systems
- No demands on operator action





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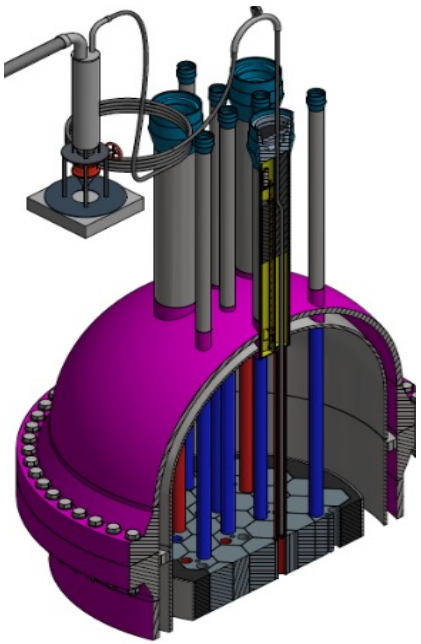
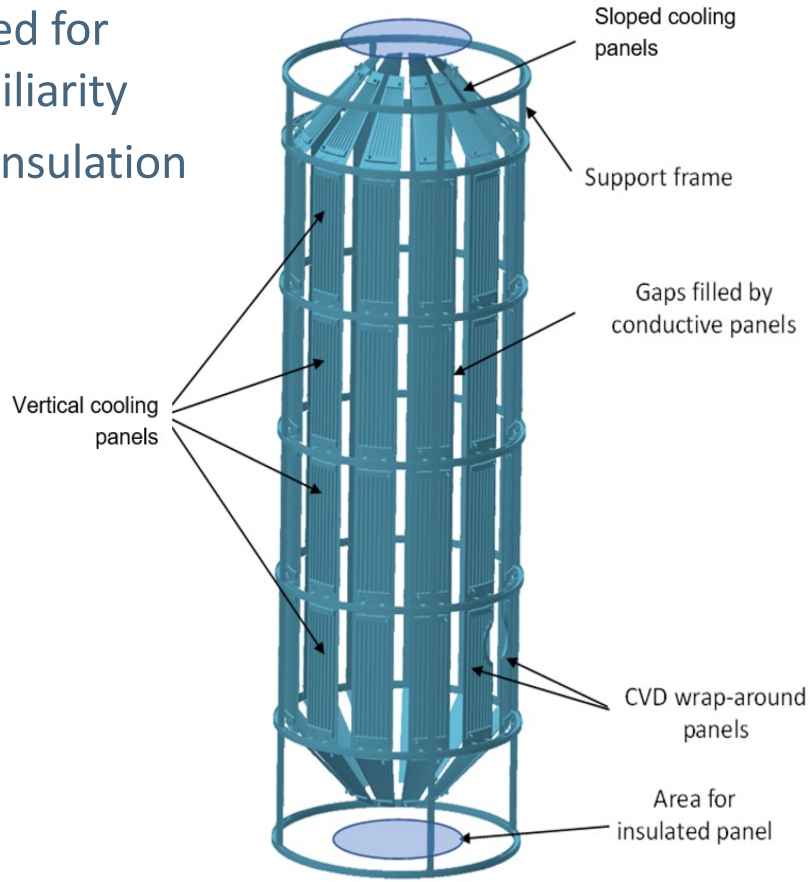
RPV and IHX arrangement

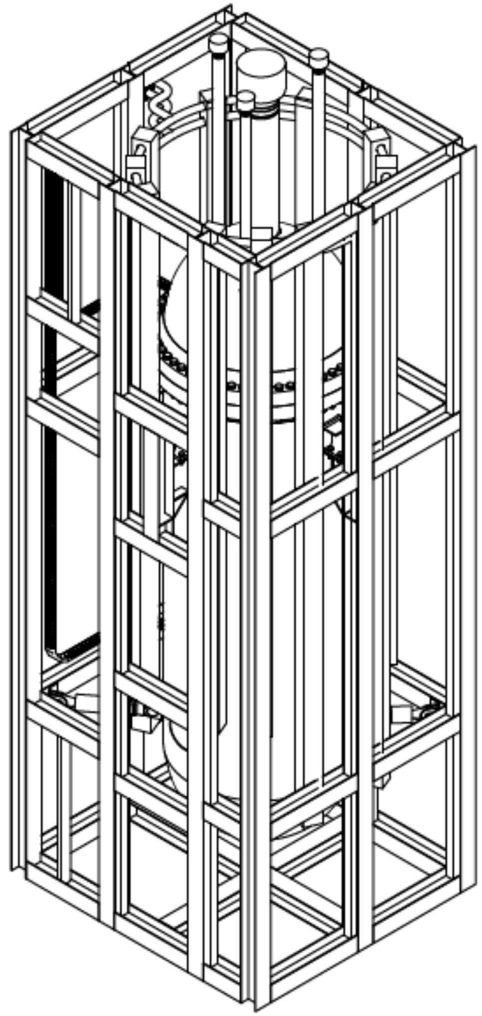
- RPV utilises proven low-carbon SA-508 forgings and is designed for compliance with ASME BPVC Part III to ensure regulatory familiarity
- Only ‘new’ material is fused silica insulation blocks: superior insulation to traditional carbon blocks
- RPV wall temperature maintained ≤ 370°C using a passive reactor cavity cooling system
- Co-axial cross-vessel duct designed to be removable for inspection / replacement without moving the RPV or IHX
- Helium circulator incorporated into IHX head: simplifies access and allows IHX tube bundle removal





Simplicity and flexibility

- Constructed as three road-transportable modules
- Module manufacture, assembly & testing in a factory environment
- Civil construction methods based on recent large projects provide cost savings (e.g. standardised circular ground socket)
- Full life cycle: modular construction facilitates decommissioning
- Small core inventory results in low spent fuel decay heat: allows discharge straight to spent fuel storage/transport flasks
- Standard reactor island that can support multiple applications



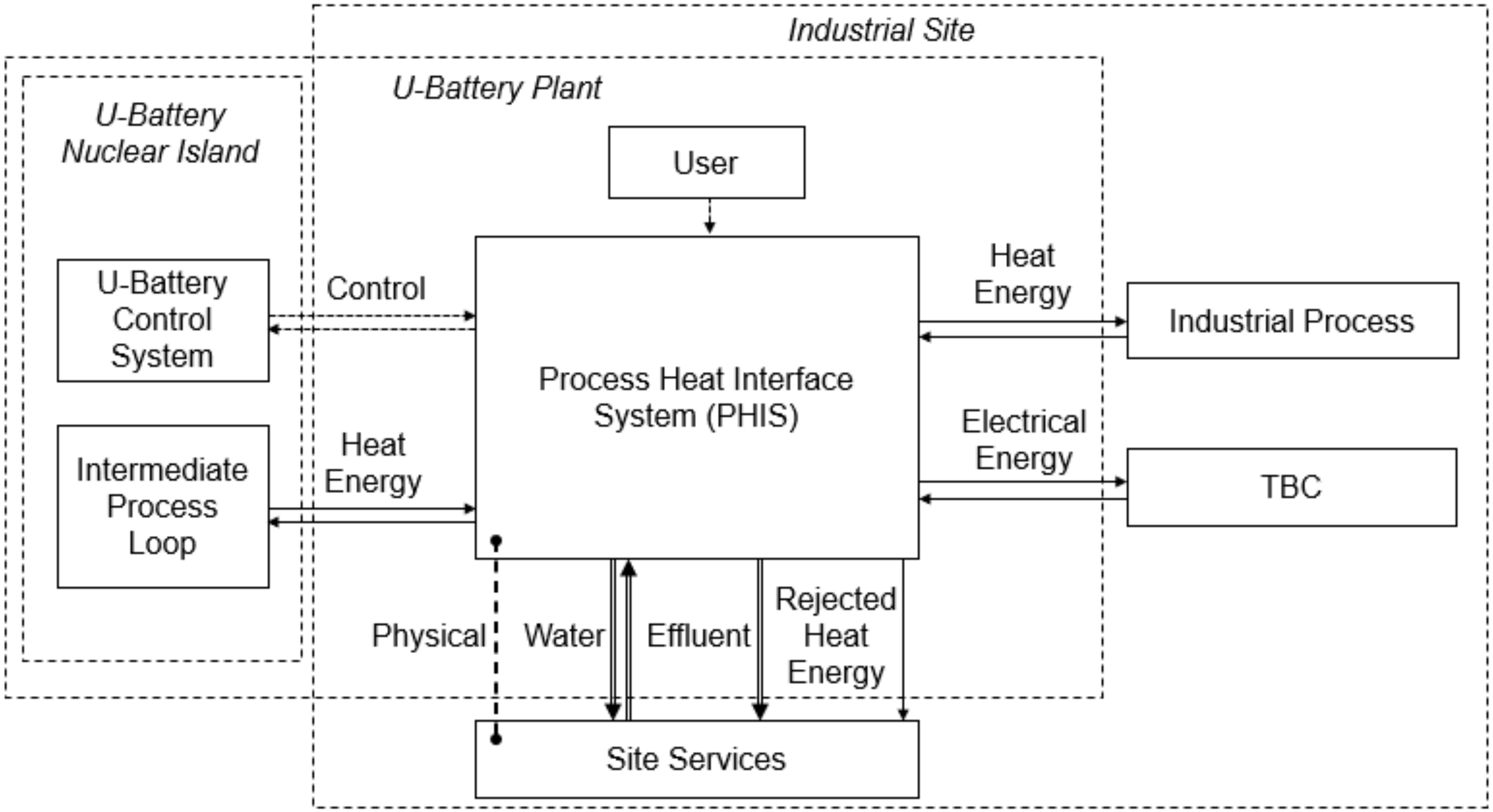
U-Battery full scale reactor cavity mock-up

- Full-scale replica of RPV, cross-duct and IHX (14 m high, 4x5 m footprint)
- Facilitated design optioneering, construction sequencing, maintenance and inspection planning, etc.

Heat application study: Urenco's Capenhurst site

- Located in the north-west of England, 8 km north of Chester
- Three enrichment plants, total capacity of 4,500 tSW/year
- Urenco ChemPlants operates the Tails Management Facility for deconversion of depleted UF_6 to U_3O_8
- Two kilns with a nameplate capacity of 7000 t/yr
- Major on-site demand for electricity (~25 GWe) and process steam for TMF

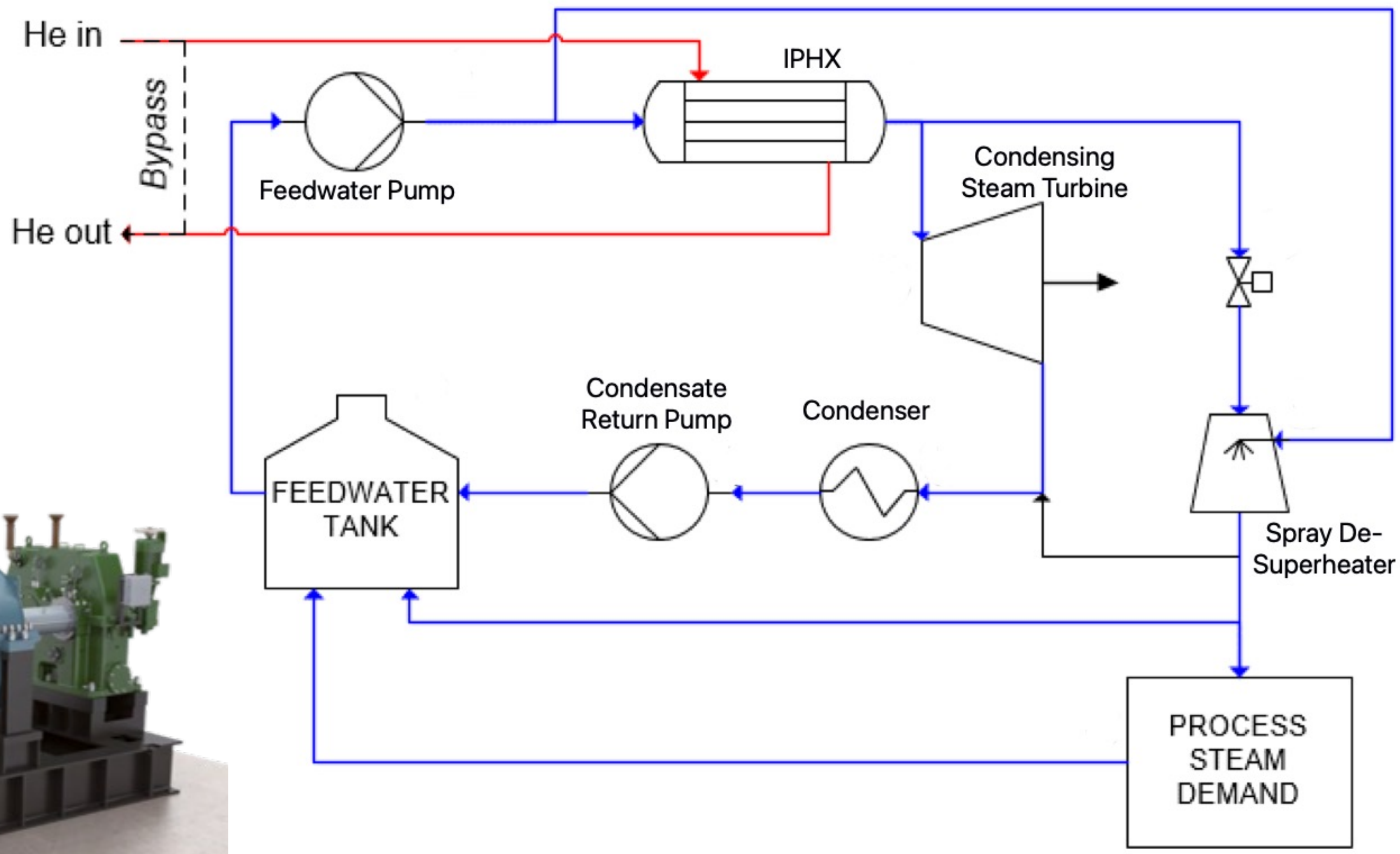
Process Interface Identification Diagram

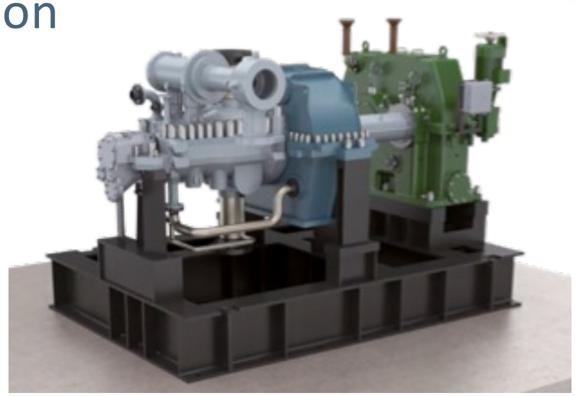


Demonstration process heat interface system

Developed to demonstrate:

- Power generation via a Siemens condensing steam turbine
- Supply of process steam to the Tails Management Facility
- Co-generation



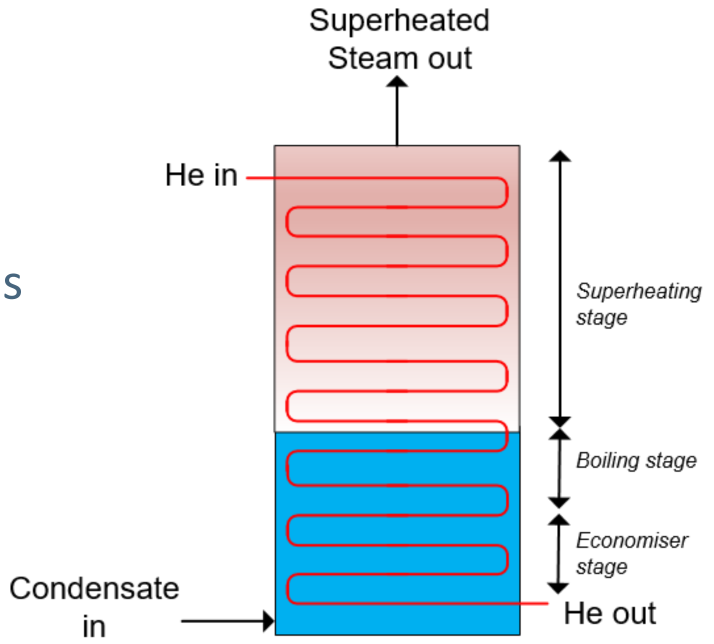


Siemens condensing steam turbine

Intermediate circuit to Process HX design

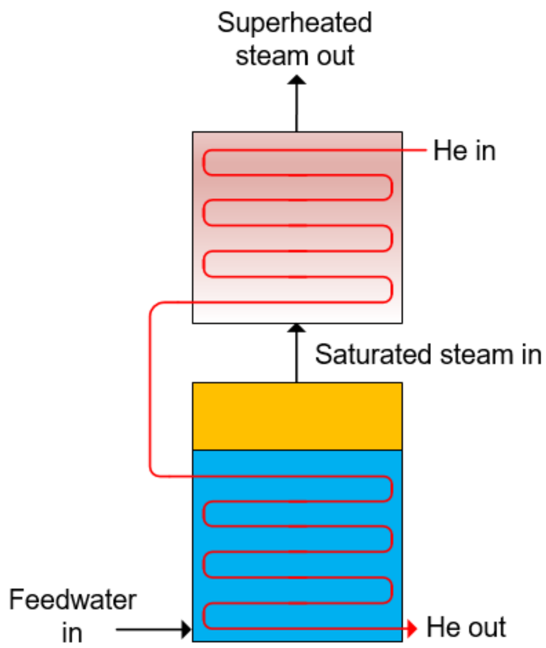
Different architectures explored:

- Once-through helical coil HXs widely used in previous HTGR projects
- Multi-stage HX used in HTTR: option to extract saturated steam before superheating improves efficiency of a co-generation cycle; single-phase fluid allows use of Printed Circuit HXs



Once-through single HX

- Fort St Vrain
- THTR
- HTR-10



Multi-Stage HX

- HTTR

Implementation timeline

U BATTERY
Local Modular Energy

2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030

Marketing | **Development** | **Deployment**

Activities	Building of consortium Marketing and opportunity assessment	Development of basic design Cost review Pre-Licensing, Safety and Security Commercial viability of fuel cycle*	Development of detailed design Licensing UK GDA plus site or Canada site	Construction of first-of-a-kind (FOAK)	Deployment of business in target geographies
Funding	Urenco Seed funding €5M	Urenco, Govt and Partners €20-25M	Phase 2 €20-30M	Phase 3 €80-100M	Project Financing

Total ~€120-160M (equity, debt, matched funding, grants)

** Fuel cycle means HALEU enrichment, working with partners on de-conversion and TRISO fuel fabrication, including transport packages*

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Thanks for your attention ☺

Any questions ?