Nuclear Co-Generation Opportunities

Bill Lee and Michael Rushton

Nuclear Futures Institute, Bangor University.

Nuclear Academics Meeting, Sept 8th 2021.

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Undeb Ewropeaidd European Union
Llywodraeth Cymru Welsh Government
Cronfa Datblygu Rhanbarthol Ewrop
European Regional Development Fund

https://nubu.nu/

Nuclear Lab Technicians Group

Creating a Community for Technicians

- Close communication between labs
- Social events
- Workshops
- Webinars

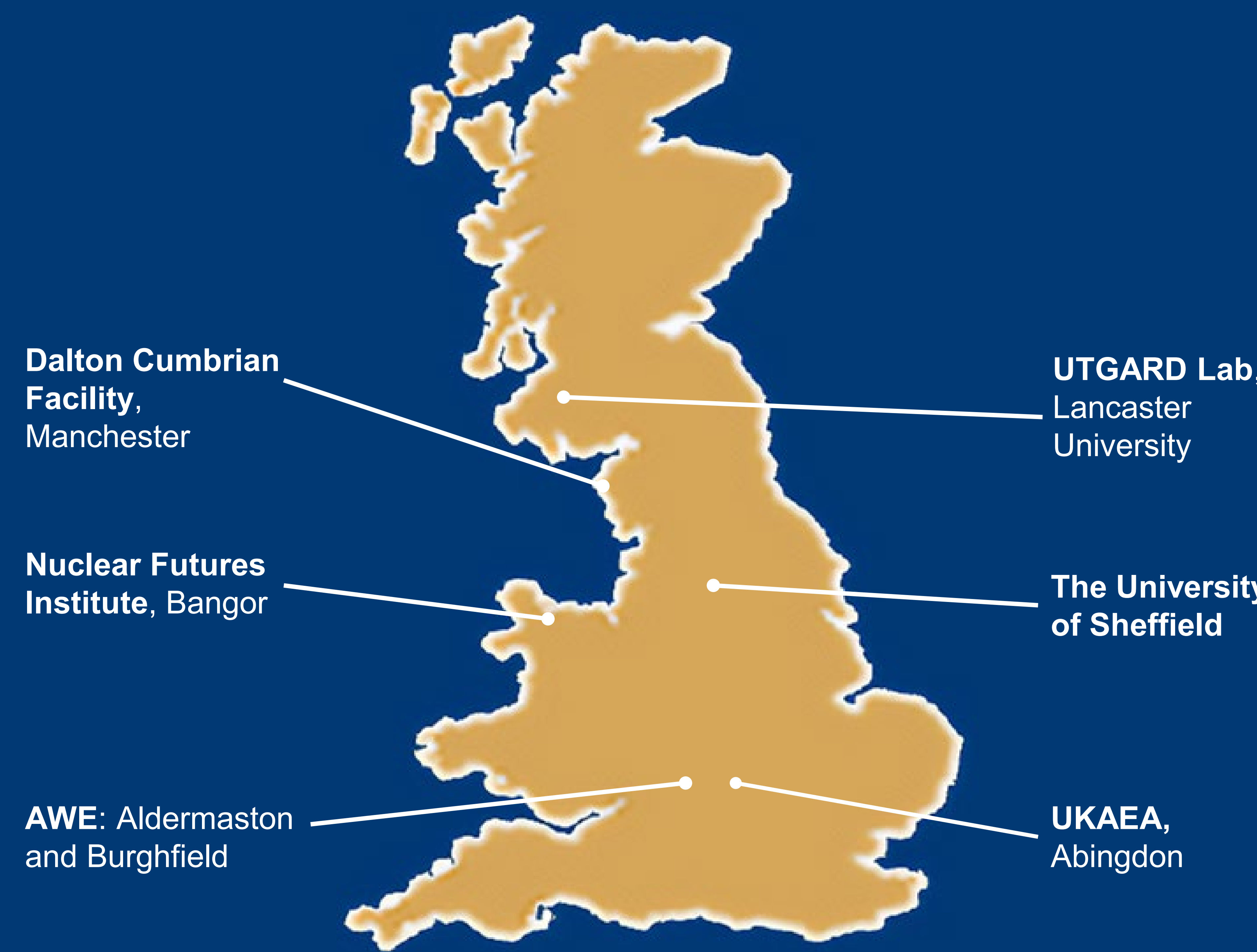
Improving Nuclear Lab Safety

- Accident case studies
- Lab visits
- Harmonisation of working practices

File and Document Sharing

- Upload documents to the NLT website
- View and download documents from other labs
- Leave comments on documents for future revisions
- Best practises , COSHH forms, Risk Assessments

Interested Organisations



First meeting to be held on the 30th September 2021

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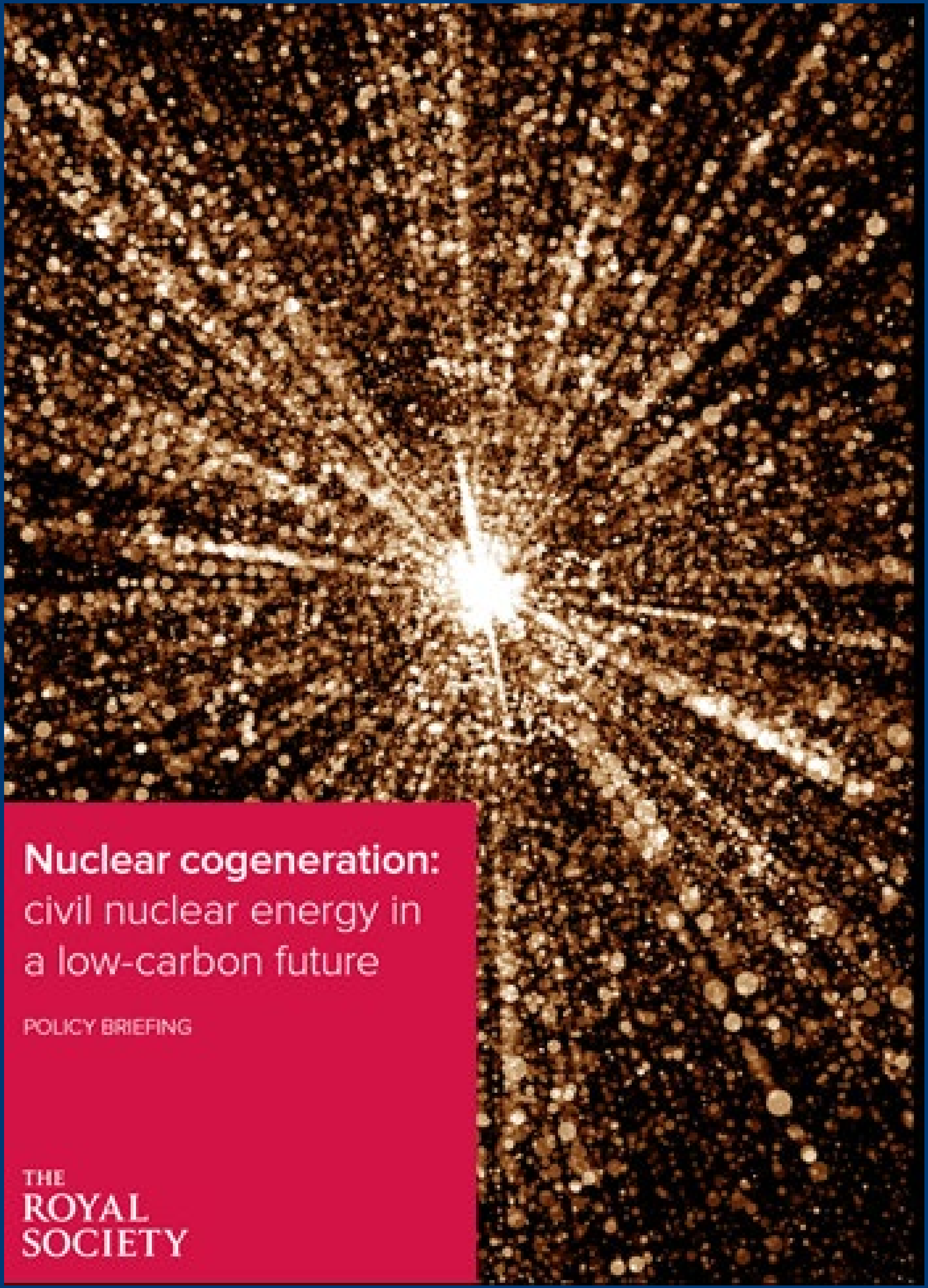
Outline

- Royal Society Policy Briefing Report main findings
- Opportunities and Progress



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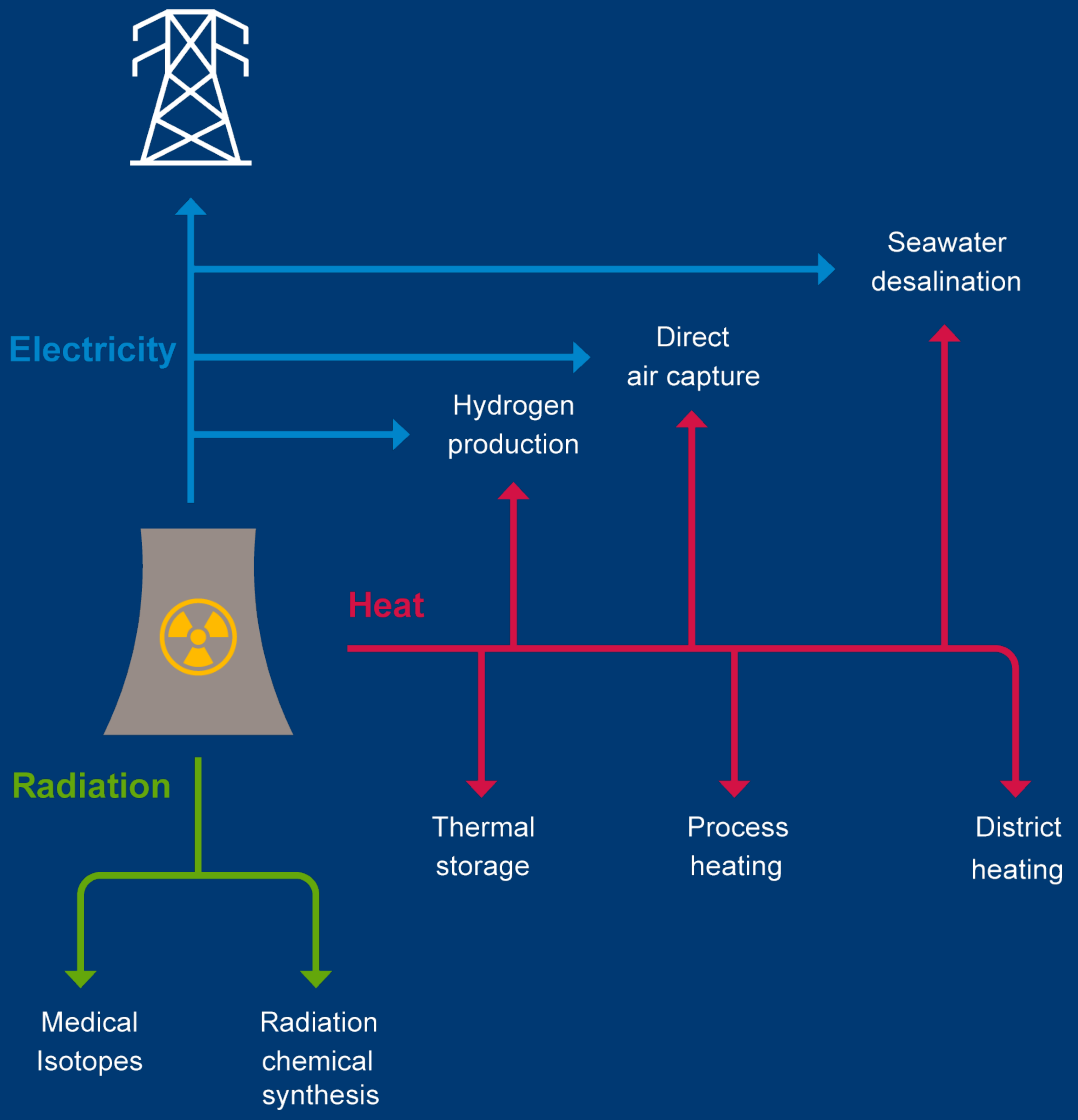
Nuclear Co-generation

- Options available depend on reactor type.
  e.g. some routes for hydrogen production need >800°C so limited to High Temp Gas Reactors (HTGR) or fusion.



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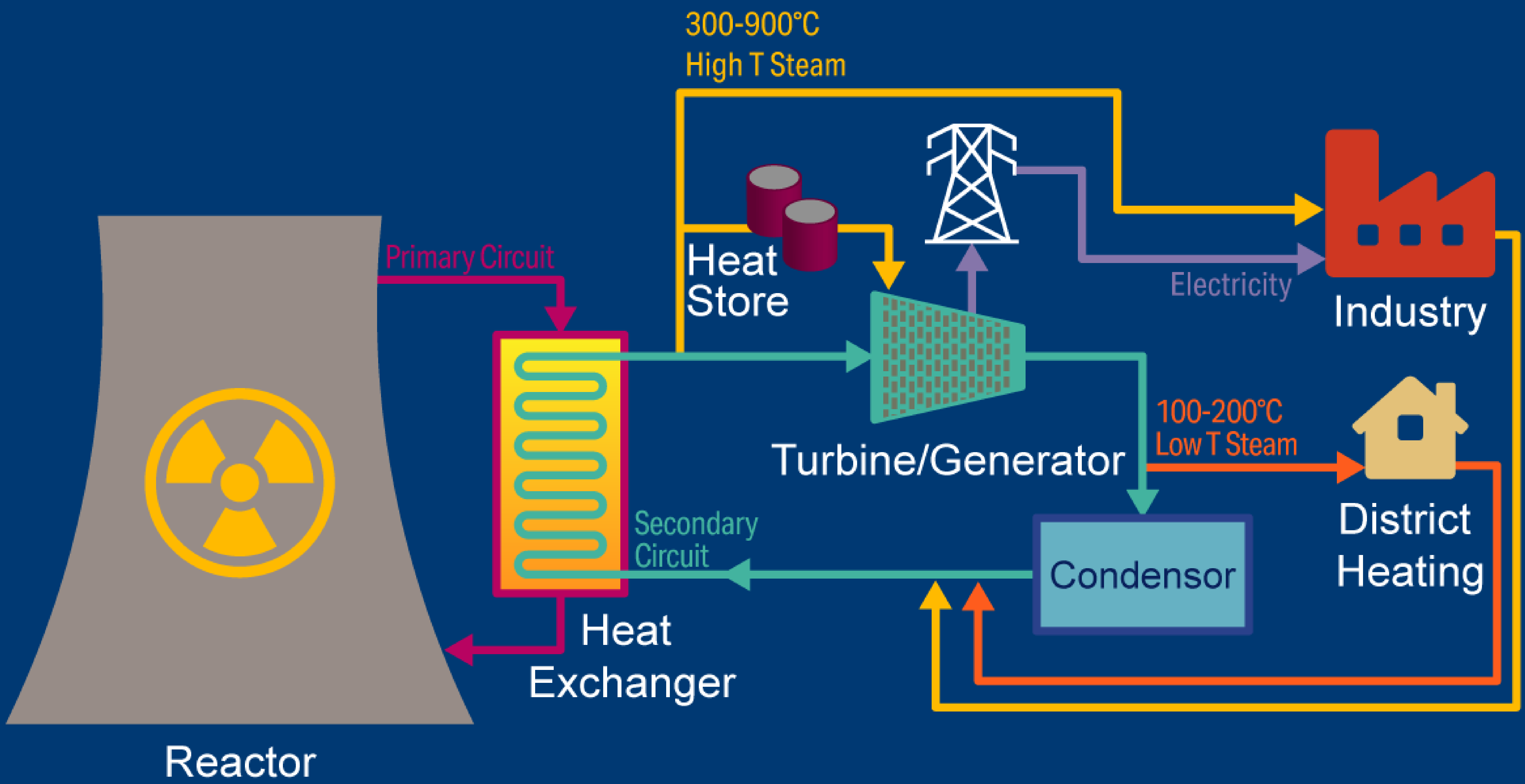
Co-Generation Potential Applications

- **Low-temperature co-gen:**
  - District heating
  - Seawater desalination
- **High-temperature co-gen:**
  - Decarbonising industry through nuclear process heating
  - Hydrogen production
  - Sustainable synthetic fuel
  - Direct Air Capture of CO_2
  - Thermal energy storage
- **Medical Isotope production**



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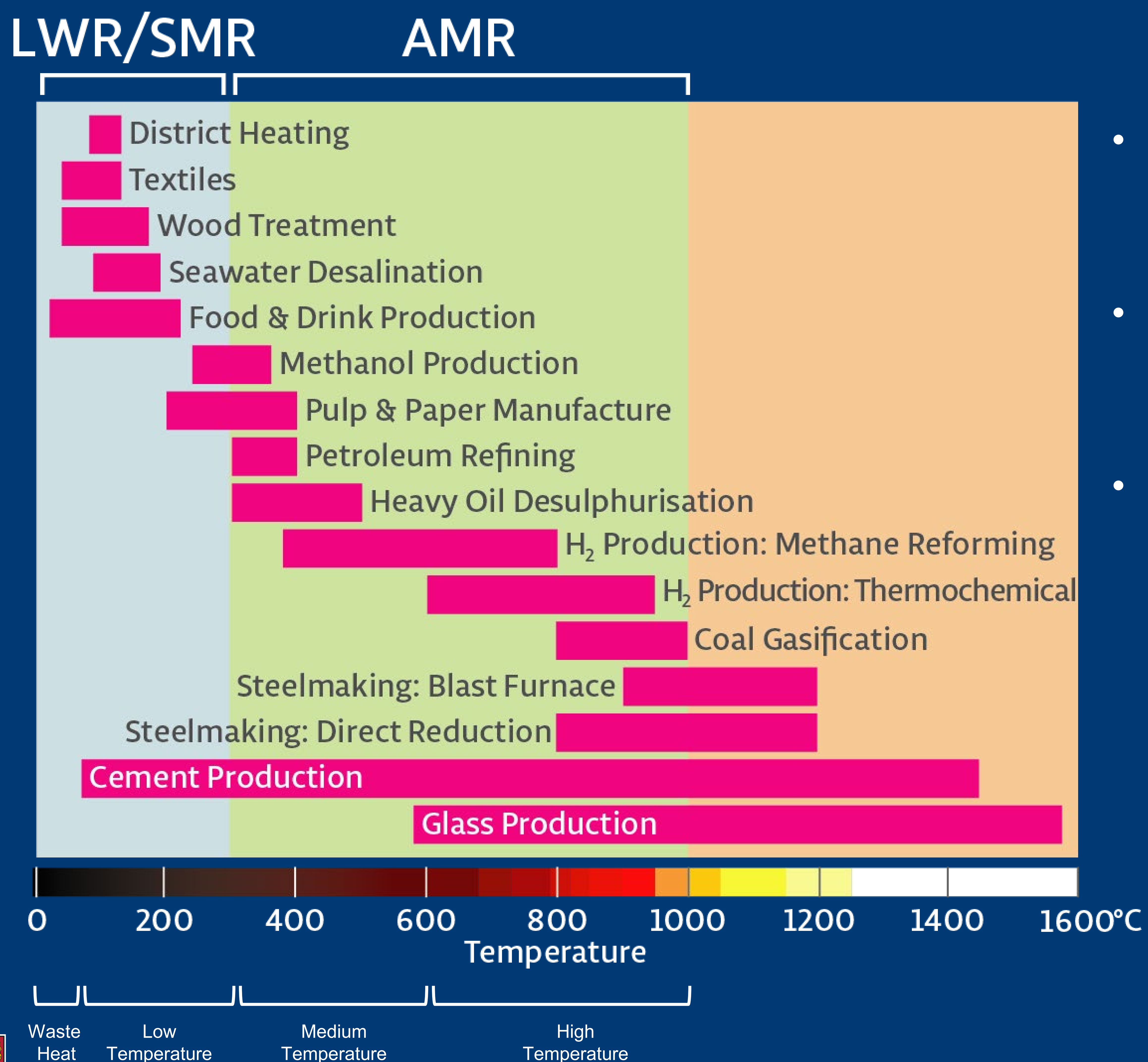
Industrial Processes



- Electricity when electricity is needed – e.g. when renewables generate less.
- Other 'products' when electricity needs are met by renewables.
- But products that contribute to those 'hard to reach' areas of decarbonisation.
    - Ammonia, direct air capture, synthetic fuels, hydrogen.

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Low-temperature Co-Gen: District Heating

- 18% of UK carbon emissions from home heating
- Nuclear experience mainly in cold climates (Russia, Ukraine, Slovakia, Switzerland, China etc.)
- Could be considered in UK with SMRs.

District heating used from Haiyang NPP in Shandong province, China eventually will heat all houses in city (population 300,000).

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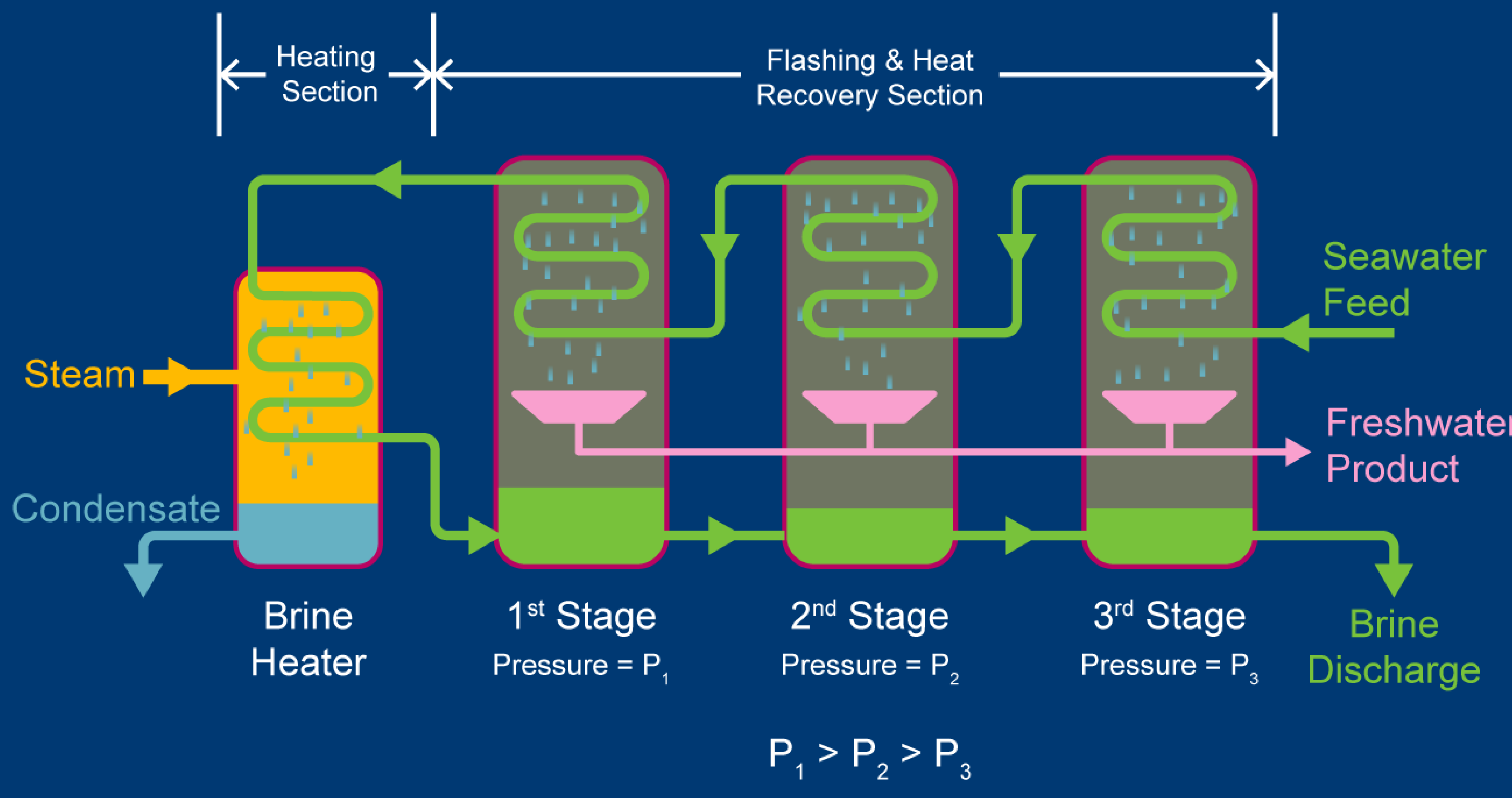
Low-Temperature Co-Gen: Seawater Desalination

- Use low temperature steam/heat in thermal processes:
  - Multi-Stage Flash (MSF),
  - Multiple Effect Distillation (MED).
- Use electricity to drive membrane processes:
  - Reverse Osmosis (RO).
- Most current desalination plants use fossil fuels so contribute to global warming.
- Currently used by NPP in Japan, Pakistan, India, Kazakhstan and planned in UAE and Saudi Arabia.
- Key driver for Australia to pursue nuclear technologies.
- Small and medium sized nuclear reactors are suitable for desalination, often with cogeneration of electricity.
- Not needed in UK.



Multi-Stage Flash Distillation

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High-temperature Co-Gen: Industrial Process Heating

- Contributes 14% UK carbon emissions
- 50% of UK industrial process heat used by energy intensive users (e.g. iron and steel, ceramics, cement, lime etc.).
- Typically need high temperature heat (>400˚C) so favours HT reactors (and UK has good experience with AGRs).
- Could cluster industry around the reactors in areas with energy intensive industries e.g South Wales, Hartlepool, Deeside.
- Costs competitive but issues with
  - Cross sector regulation of nuclear and energy intensive industries
  - Ideally use proven nuclear technology
  - Need sound, long term investment case.
- Research opportunity e.g. safety and regulation.

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High-temperature Co-Gen: Hydrogen Production

- Moving towards hydrogen economy
- Hydrogen from nuclear via
  - Water electrolysis
  - Steam (600-1000°C) electrolysis more efficient than water
  - Thermochemical (e.g. S-I, Cu-Cl and hybrid S cycles) using nuclear heat.
  - Steam reform fossil fuels using nuclear heat – hydrogen from methane and need CCS.
- Research opportunity e.g. materials for high temperature and corrosive environments, improved catalysts, electrolyte and electrode materials.

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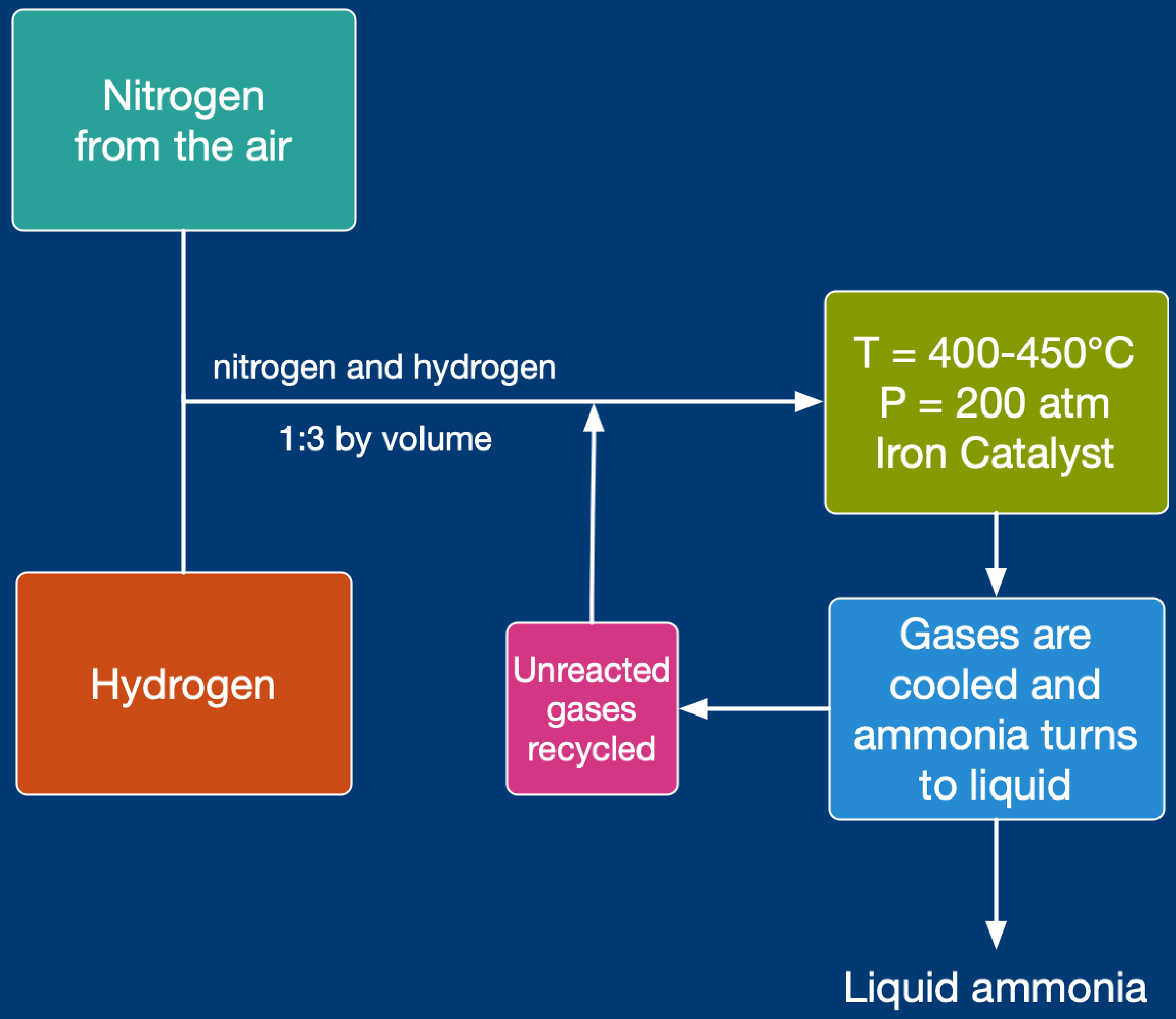
High-temperature Co-Gen: Synthetic Fuel Production

- **High-temperature heat to produce feedstocks:**
  - Single molecule e.g. ammonia via Haber-Bosch process which uses N from the air and H from natural gas at 400-450°C with iron catalyst at 200 atm.



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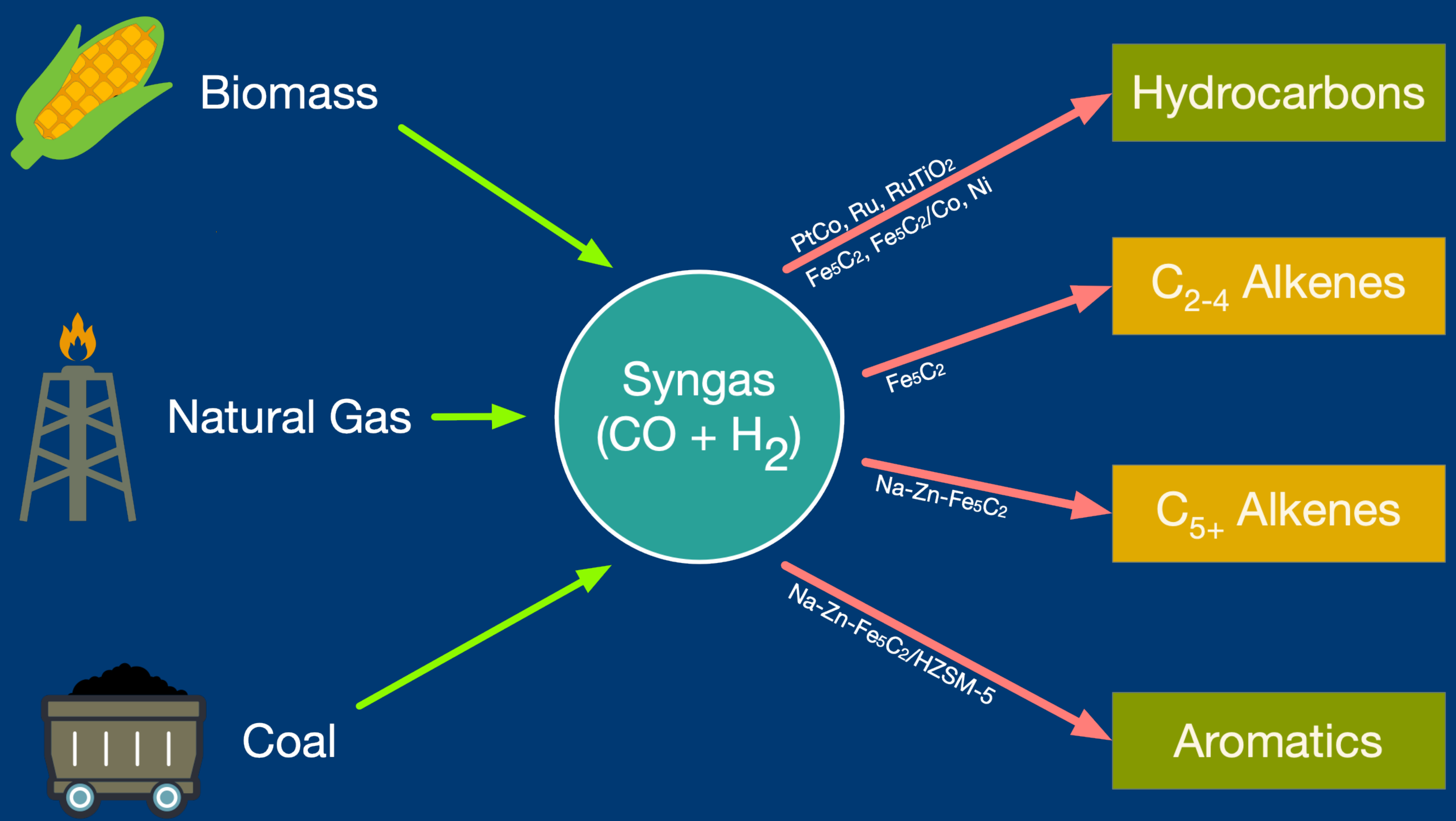
High-temperature Co-Gen: Synthetic Fuel Production

- **High-temperature heat to produce feedstocks:**
  - Complex molecules e.g. synthetic fuels for transportation (shipping, aircraft) via Fischer-Tropsch process which converts CO + H_2 to liquid hydrocarbons at 150-300°C in presence of metal catalyst at ~20 atm.



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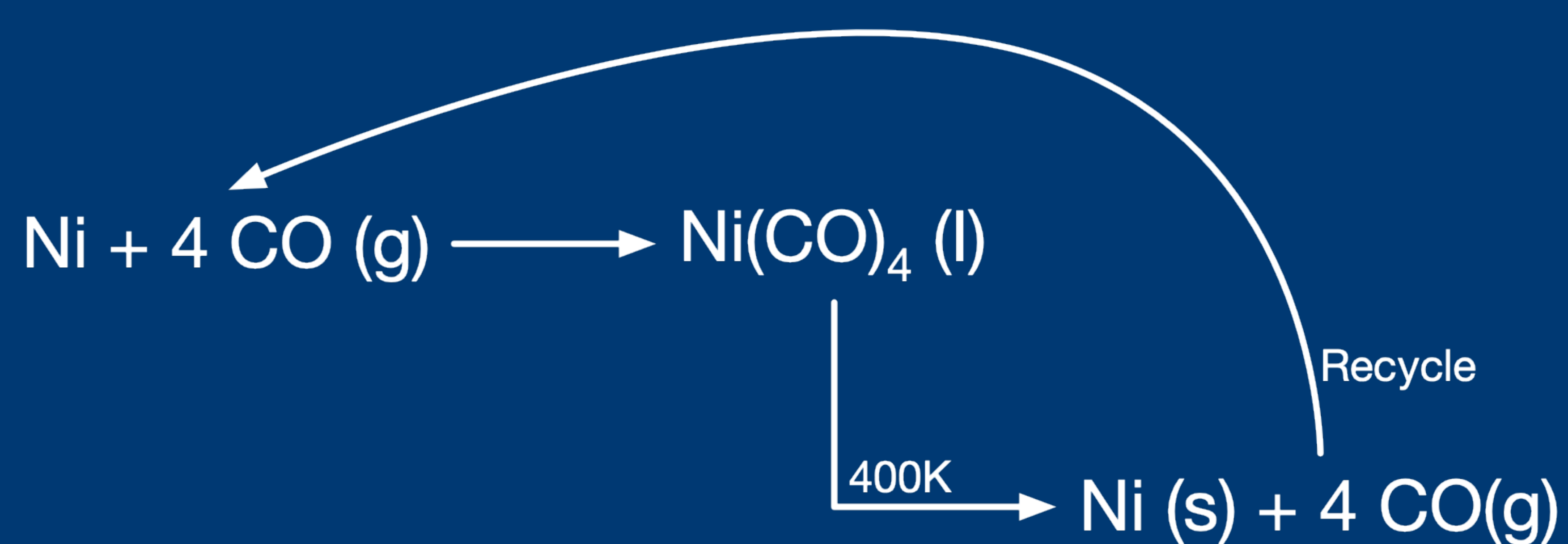
High-temperature Co-Gen: Direct Air Capture of CO_2

- Both liquid solvent and solid sorbent technologies are energy intensive requiring 80% thermal 20% electricity energy split.
- Liquid sorbent needs T up to 900°C, solid sorbent < 150°C.
- Sequester or reuse captured CO_2 e.g. as feedstock for polymers or convert to CO and use in Mond process to extract and purify Ni.



Ni reacts with CO (leaving the impurities behind), to form $Ni(CO)_4$.

The $Ni(CO)_4$ is passed through a tower filled with nickel pellets at a high velocity and 400K.

Pure Ni plates out on the pellets.

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High-temperature Co-Gen: Thermal Energy Storage

- Store thermal energy from NPP for later use or as buffer in Co-Gen applications.
- Already deployed alongside concentrated solar power stations but limited to sunny locations.
- Various storage media being examined e.g. clay-based refractory brick chequer work, concrete, molten salts, phase change materials etc.
- Research opportunity e.g. to assess potential and safety of operation.

FIRES – FIrebrick Resistance heated Energy Storage – Forsberg MIT

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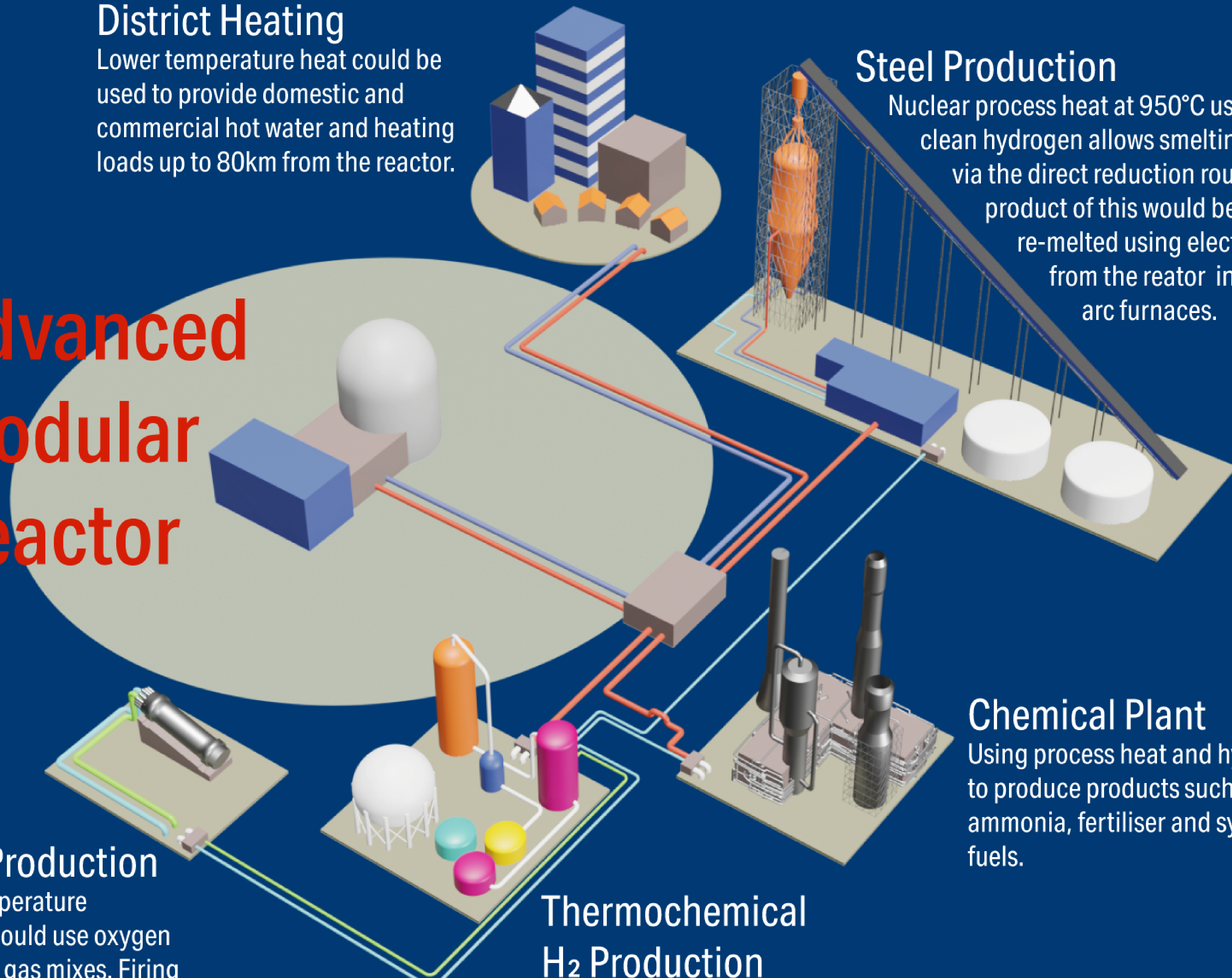
Industrial Heat Park



District Heating

Lower temperature heat could be used to provide domestic and commercial hot water and heating loads up to 80km from the reactor.

Steel Production

Nuclear process heat at 950°C used with clean hydrogen allows smelting of iron via the direct reduction route. The product of this would be re-melted using electricity from the reator in electric arc furnaces.

Chemical Plant

Using process heat and hydrogen to produce products such as ammonia, fertiliser and synthetic fuels.

Cement Production

Very high temperature applications could use oxygen and hydrogen gas mixes. Firing cement kilns with low carbon oxyhydrogen mixtures could help decarbonise this industry.

Thermochemical H_2 Production

High-grade process heat allows efficient production of hydrogen through thermochemical routes.

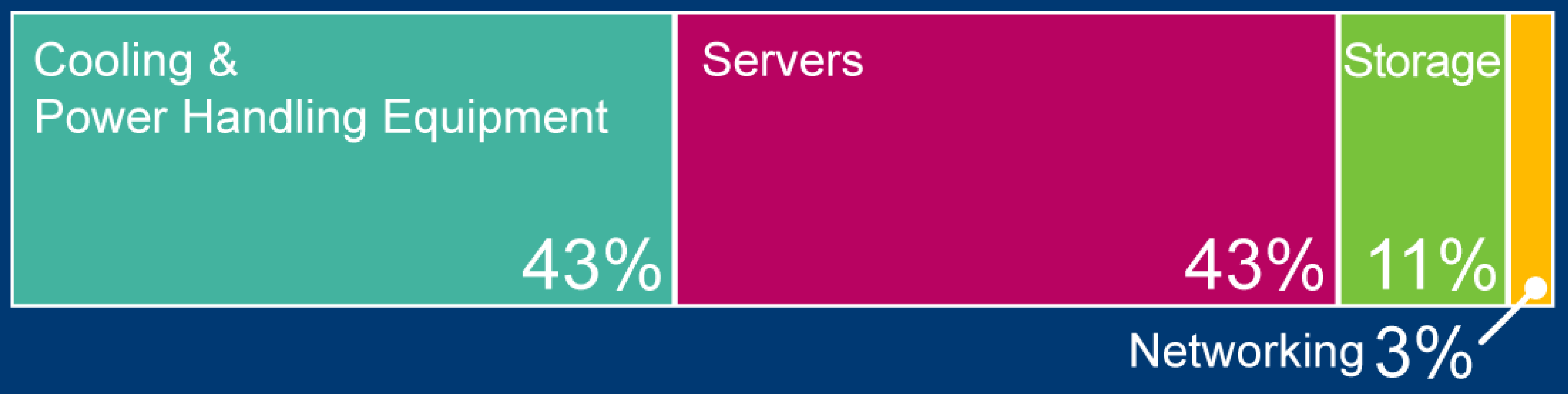
1 km
Hartlepool AGR
Redcar Blast Furnace
Venator TiO_2 Pigment Production
Oil and Gas Terminal
Ineos Nitriles (closed)
Huntsman Polyurethanes
BOC Hydrogen Teesside
NGA, GEBCO

Data Centres

- Consumed 1% of the World's electricity (205 TWh).
- It was 1% in 2010 too, despite:
  - Internet traffic ×10.
  - Storage ×25.
- Efficiencies of scale are partly responsible for this.
- Hyperscale data-centres (>40,000 sq ft, 3700 m^2) with power requirements above 100 MW are not unusual.

Data Centres

- Hyperscale computing is a good match for nuclear.
- High availability is essential.
- Share cooling infrastructure with nuclear plant?
- Nuclear heat used with absorption/adsorption chillers to cool data-centre – reducing electricity demand.



CWL1, Newport, Wales.
Europe’s Largest Data Centre Campus

270 MW available power.
72 MW already occupied.
2-125 kW per rack
400 kV Super-Grid connection.
134,500 m^2

Captive Power

- Privately owned power-stations.
- Electricity parks not unusual in developing countries with unreliable electricity grids.
- Ownership models for existing captive power or CHP, projects could be adopted for nuclear co-generation.
- Mechanisms are required to prevent power-station owners pulling the rug on viable companies that rely on their heat and power for existence.
- Could high levels of renewables introduce grid instability to the UK and make reliable, captive nuclear plants attractive to some large energy users?

Challenges

- Safety and Security.
- Regulation.
- Waste reuse, recycle and disposal.
- Economics and business model.
- Public attitudes and behavioural science opportunity.
- Need to coordinate UK Co-Gen R&D certainly via a coordinated Network+ and possibly via a Centre of Excellence.

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