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Nuclear to X

Developing capability to support the application of advanced nuclear to support a low-carbon energy transition.

The potential role for AMR in industrial decarbonisation

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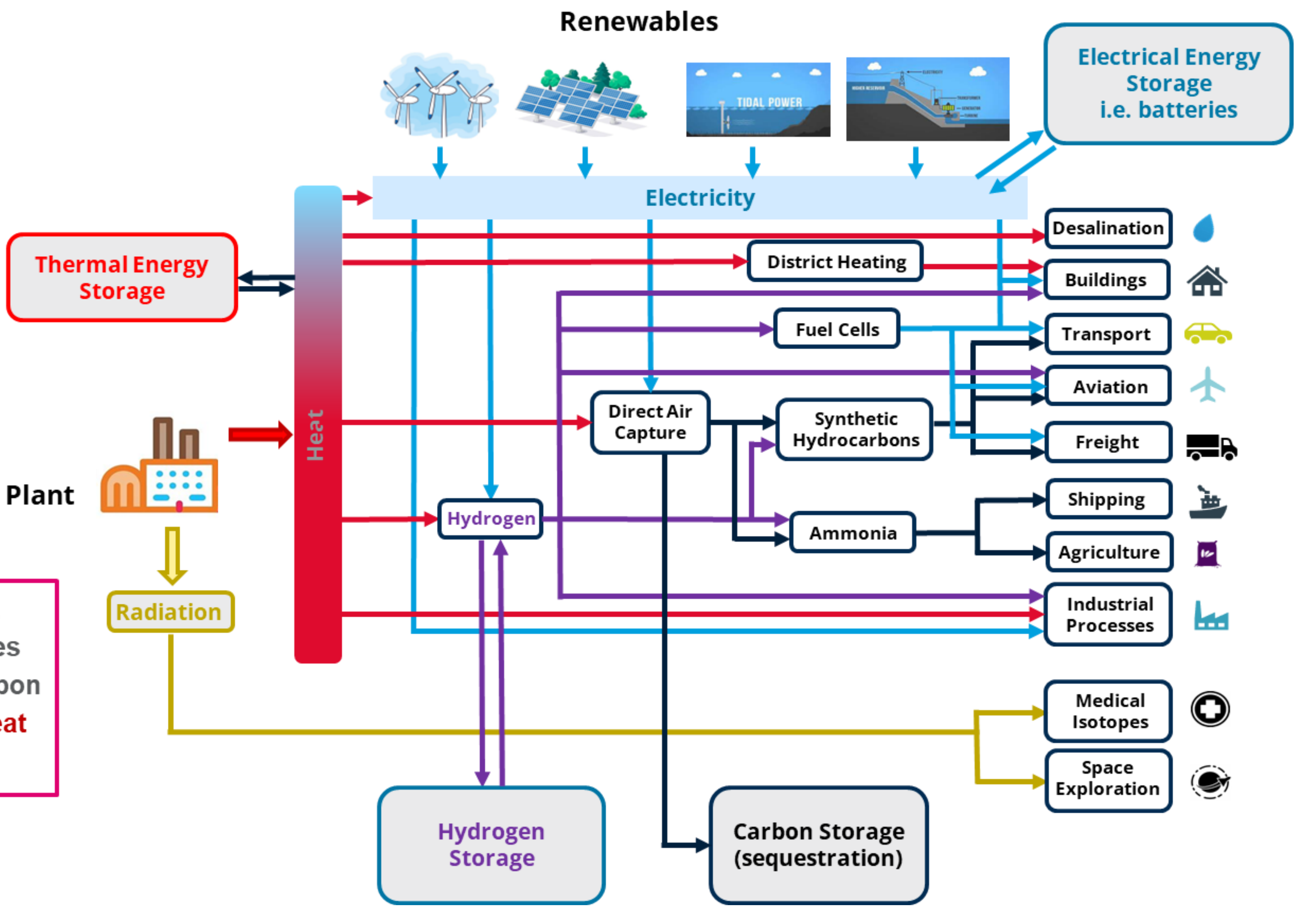

Nuclear power, uniquely provides access to low carbon electricity and heat and at scale

What is Nuclear to (X)?

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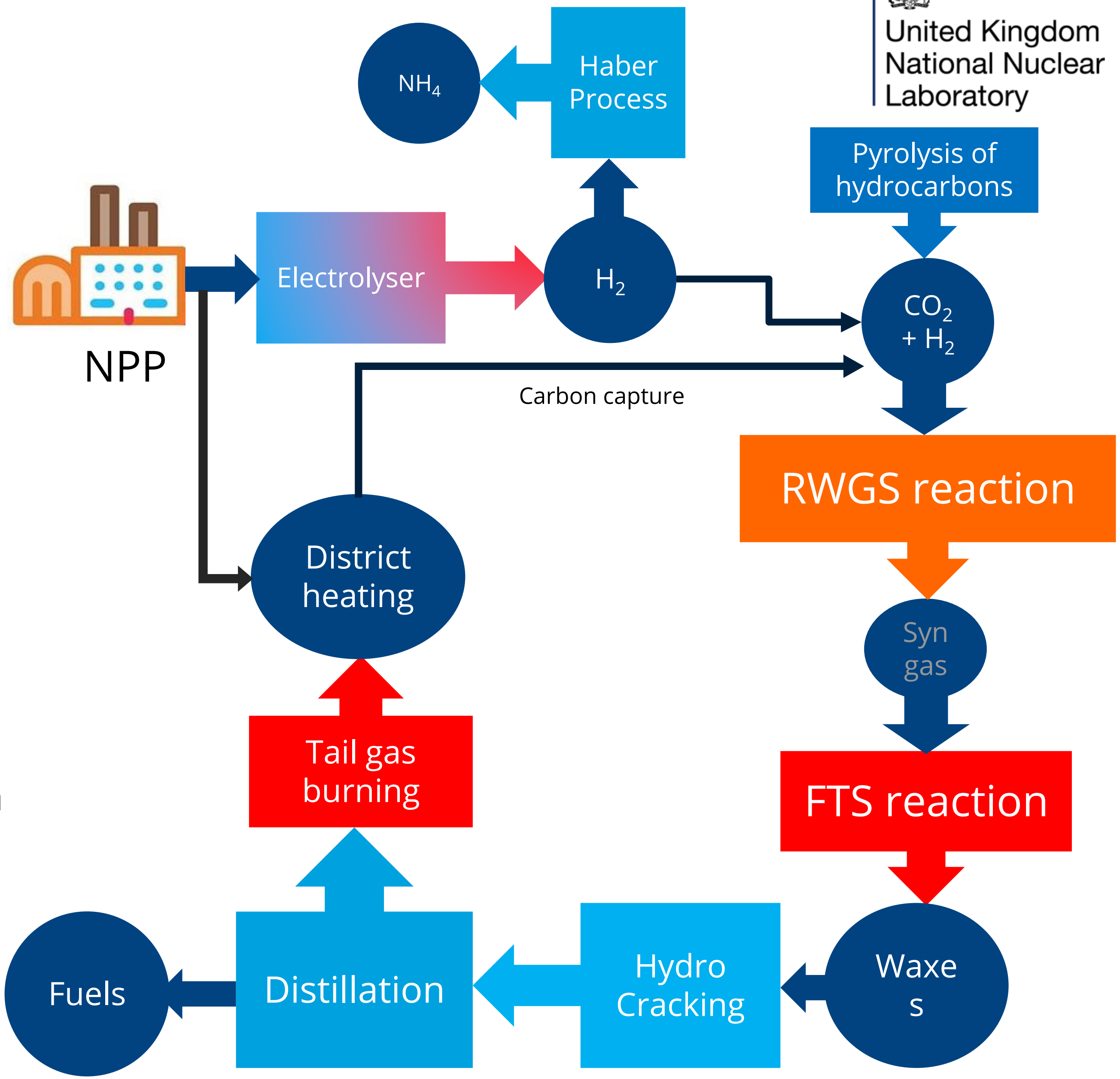
(X) is generic term commonly used to represent liquid products or fuels (hydrogen, ammonia, synthetic hydrocarbons). Transition to net-zero production of these important substances is seen as an important step in the transition to net-zero.

Synthetic hydrocarbon production from Reverse Water Gas Shift (RWGS), Fischer Tropsch synthesis (FTS).

Some of these processes are **endothermic** (require heat from the nuclear reactor) and some are **exothermic** (generate heat that **must be recycled**). As a result, it is important to understand the heat integration of the system (*complicated*).

More importantly we identify the potential to produce a **diverse range of products** from chemicals to energy that can be powered by HTGR (optimisation and control of this system-of-systems).



Low-carbon Hydrogen production from nuclear energy

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Low Temperature-Electrolysis

Low Temperature Water Electrolysis (TRL 9)

- Same as planned for use with renewables such as wind & solar
- Perceived USP of nuclear energy are the capacity (high GW) and ability to produce constant output
- Deployable today using nuclear generated electricity

High Temperature-Electrolysis

High Temperature Steam Electrolysis (TRL 7)

- Thermoelectric process that utilises reactor heat and electricity
- Can utilise low grade heat from nuclear electricity production to vaporise feed water
- Potential advantages when coupled to AMR and SMR designs (higher efficiencies)

Thermochemical Cycles

(e.g. S-I, Cu-Cl)

Multi-step and hybrid cycles (TRL <<5)

- Theoretically sound approaches, but with large technical challenges to overcome
- Limited research in UK, unlikely to make much impact in short/near term due to technical ‘dead ends’
- Difficult to reliably determine the potential with nuclear derived energy due to low-TRL

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Heat Exchange System Digital Twin

How do we utilise nuclear heat?

Technology development under UK-AMR programme (TD1).

Nuclear is…

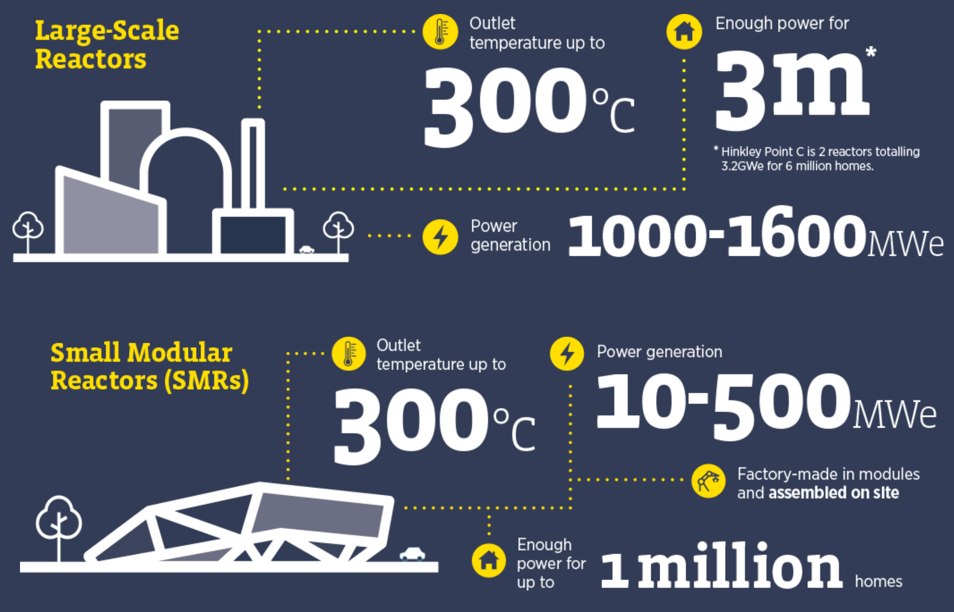
among the lowest carbon emitters of all energy-producing technologies, across its full life cycle

amongst the safest forms of energy, equivalent to wind and solar

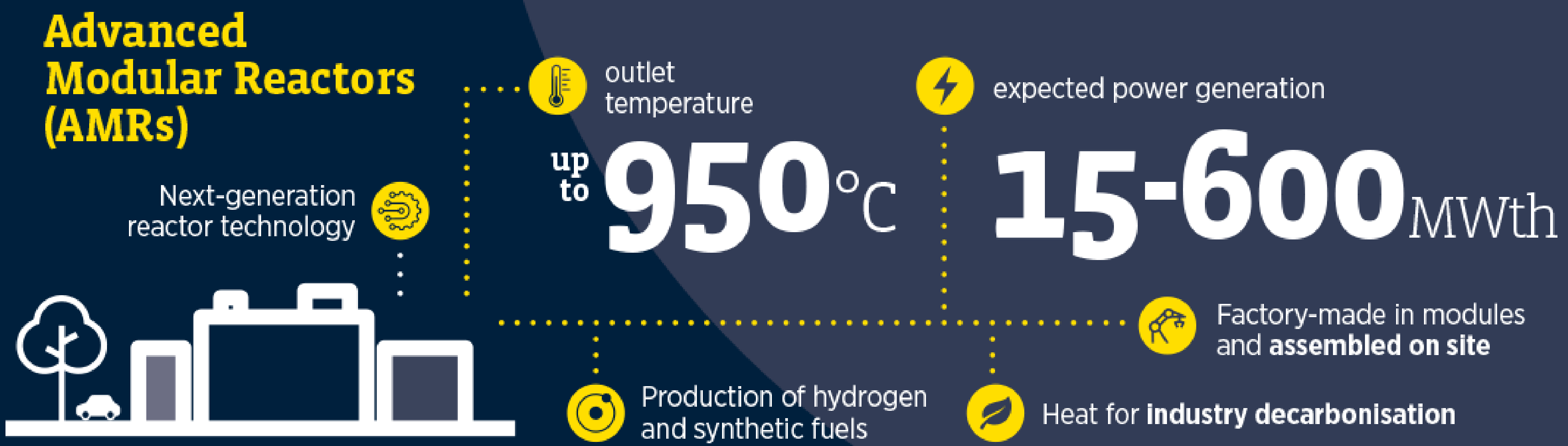
the most energy dense i.e. the least space for the most electricity produced

non-stop and reliable, **operating 24/7**

offers **cogeneration**



It is AMRs this programme of work with the EUAB is primarily focused on



Advantages of HTGR for Industrial decarbonisation

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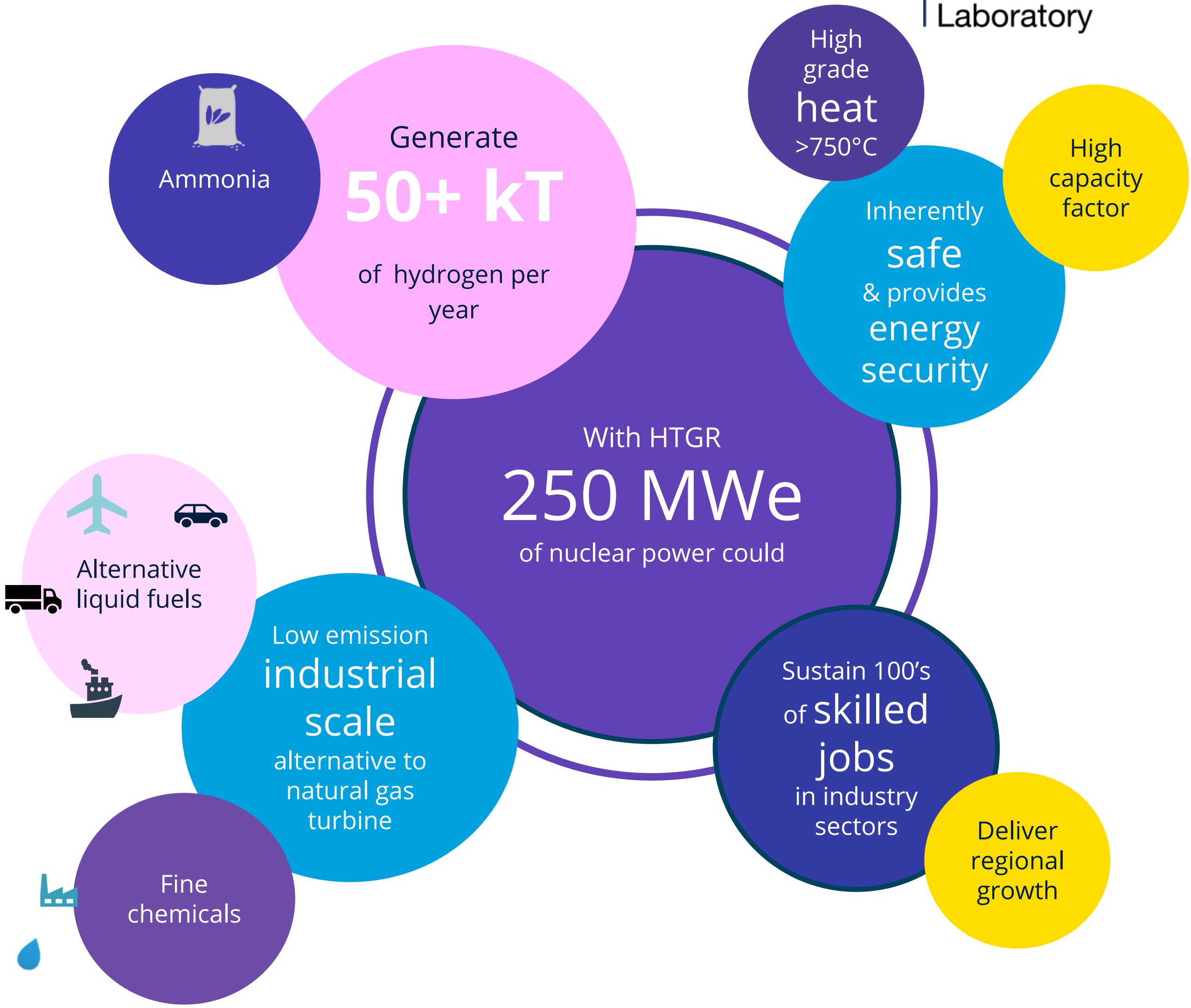
In the area of applications for nuclear heat we are researching the potential benefits of HTGR technology to aid industrial decarbonisation.

HTGR produces high-grade heat above 750ºC which can be utilised by several downstream processes to produce industrial products, some of which are low-carbon energy vectors.



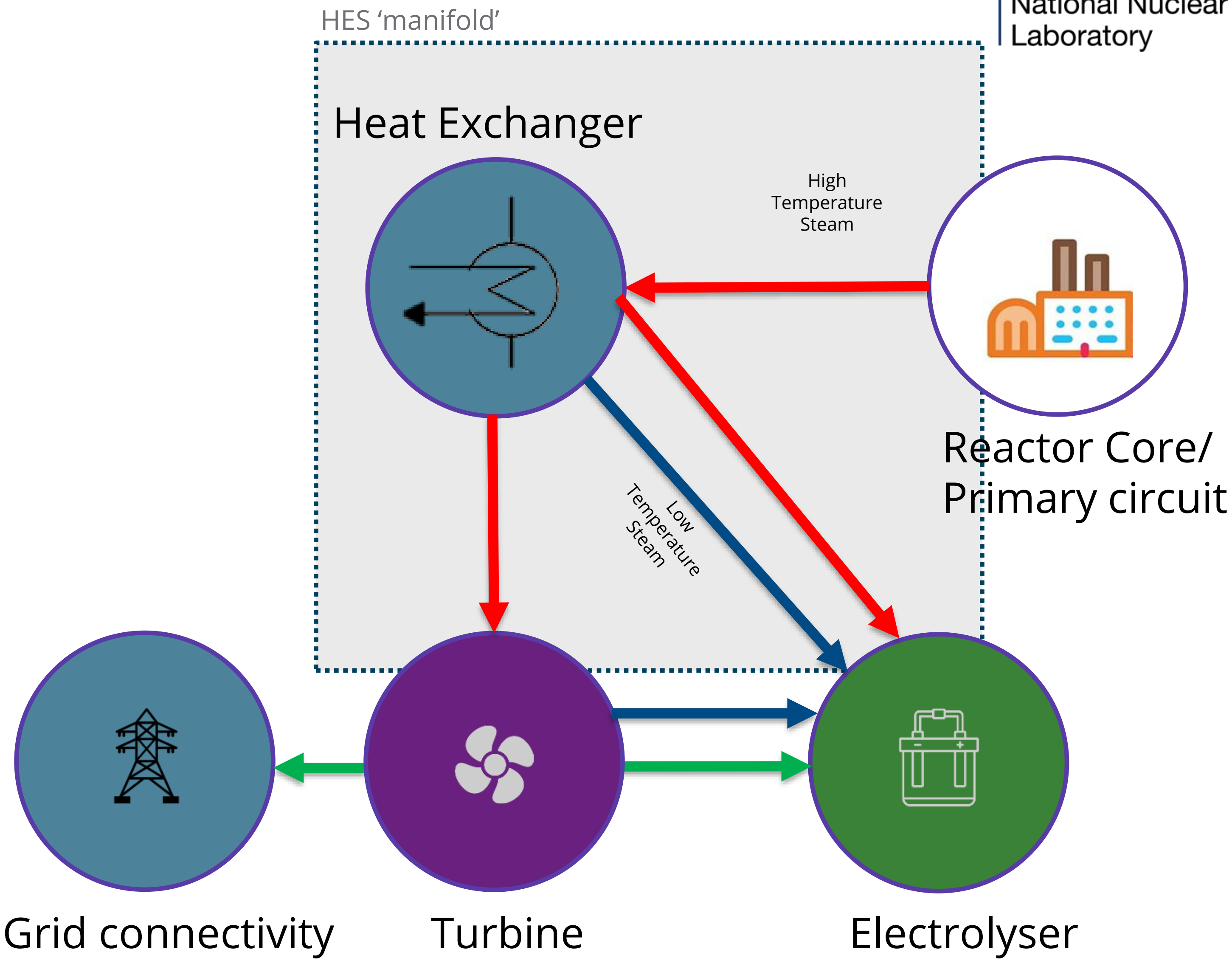
Text and image slide

Similar in concept to a domestic central heating system, we want to have the ability to divert steam to different applications

This will not be a single item of plant, but more a series of interconnected manifolds, heat exchangers and valves.

Also important is that the system as a whole will need to be controlled to ensure that any feedback does not lead to unsafe shutdowns of the reactor core.

The ‘smart’ feature is the way the control systems of individual plants will interact within the energy production ‘system’.



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Developing the scope for the Digital Twin

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Epics

Optimize the Heat Exchange System manifold design by understanding the impact of demand on design

Unique Selling Point (USP) is hydrogen or derived products, the project must focus on delivery of heat optimization for this process

Digital Twin will enable the exploration of deployment scenarios to optimise deployment and design

Features

- Optimisation capability
- Modular software/ hardware components
- Represent a range of possible use-cases
- Integrate with a wide range of data sources
- Collaborative
- Open architecture

Model Based Systems Engineering

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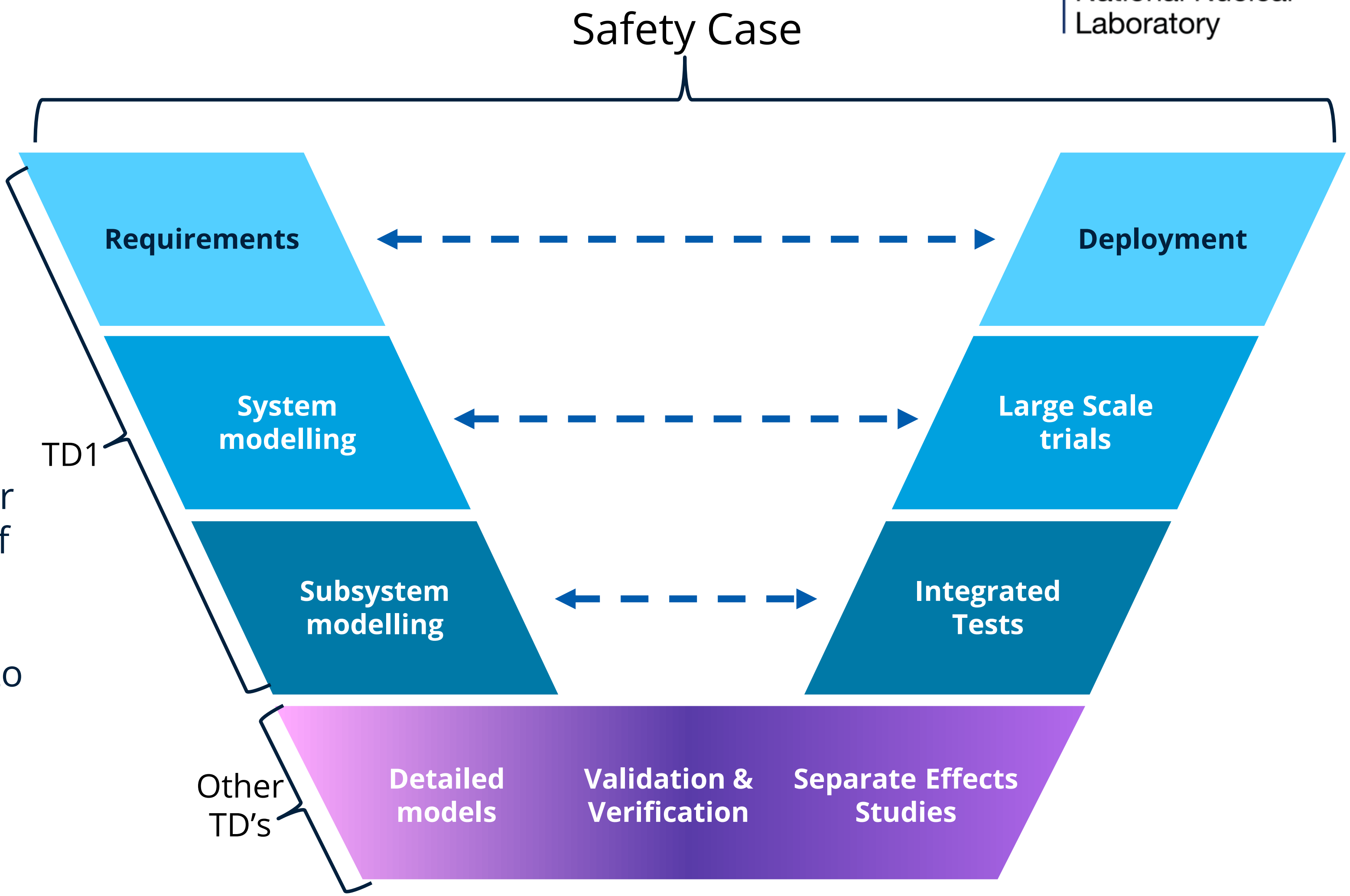
MBSE is an engineering concept to aid with the design of complex plants.

Model based not document based to overcome the handover (biggest factor in cost and schedule overruns) in complex engineering projects.

Working with the Centre For Modelling & Simulation, we are developing a roadmap for the implementation of MBSE in the design of heat applications for HTGR.

This will be important in future phases due to the high-level of integration of the nuclear system with several conventional systems (complex system-of-systems).



Digital Twin

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A digital twin is a digital representation of a real-world asset that features a live two-way coupling to assess its performance.

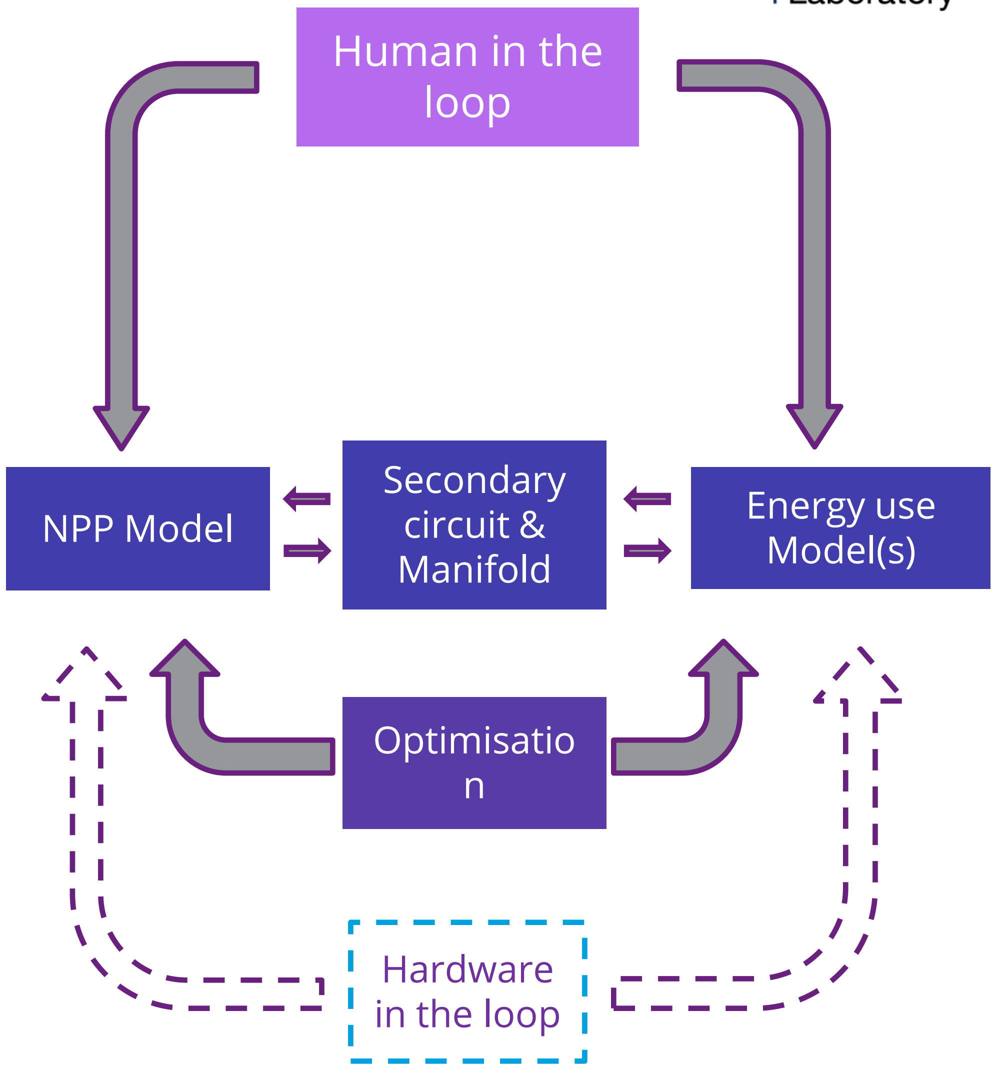
The goal of a digital twin is to improve through life-cycle performance and optimisation of a physical asset. Areas for study include:

- Process control and throughput optimisation
- Safe operation and asset management

We are developing a prototype digital model of the systems that could form a digital twin of a future demonstrator facility.

MBSE is an important component of digital twin.

We are developing skills in key areas of digital technology in preparation for the future demonstrator.



Secondary Circuit & Manifold Modelling

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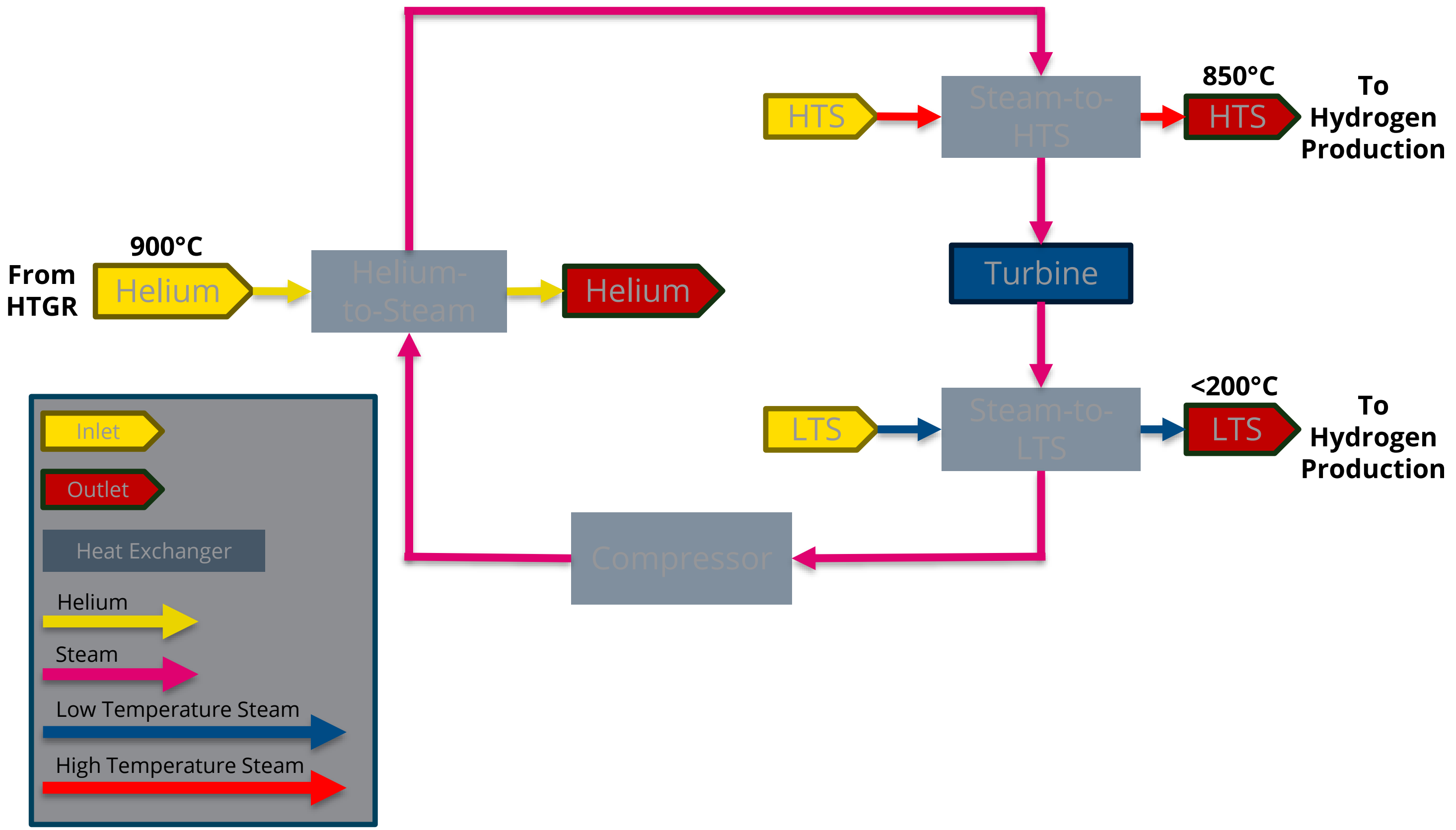
We are developing a series of custom models of the reactor core, secondary circuit and steam turbine circuits to represent the reactor and its integration with downstream processes.

We are working with the other TD areas to cross-validate these high-level models against physics-based simulations.



Why is High Temperature Steam Electrolysis More efficient?

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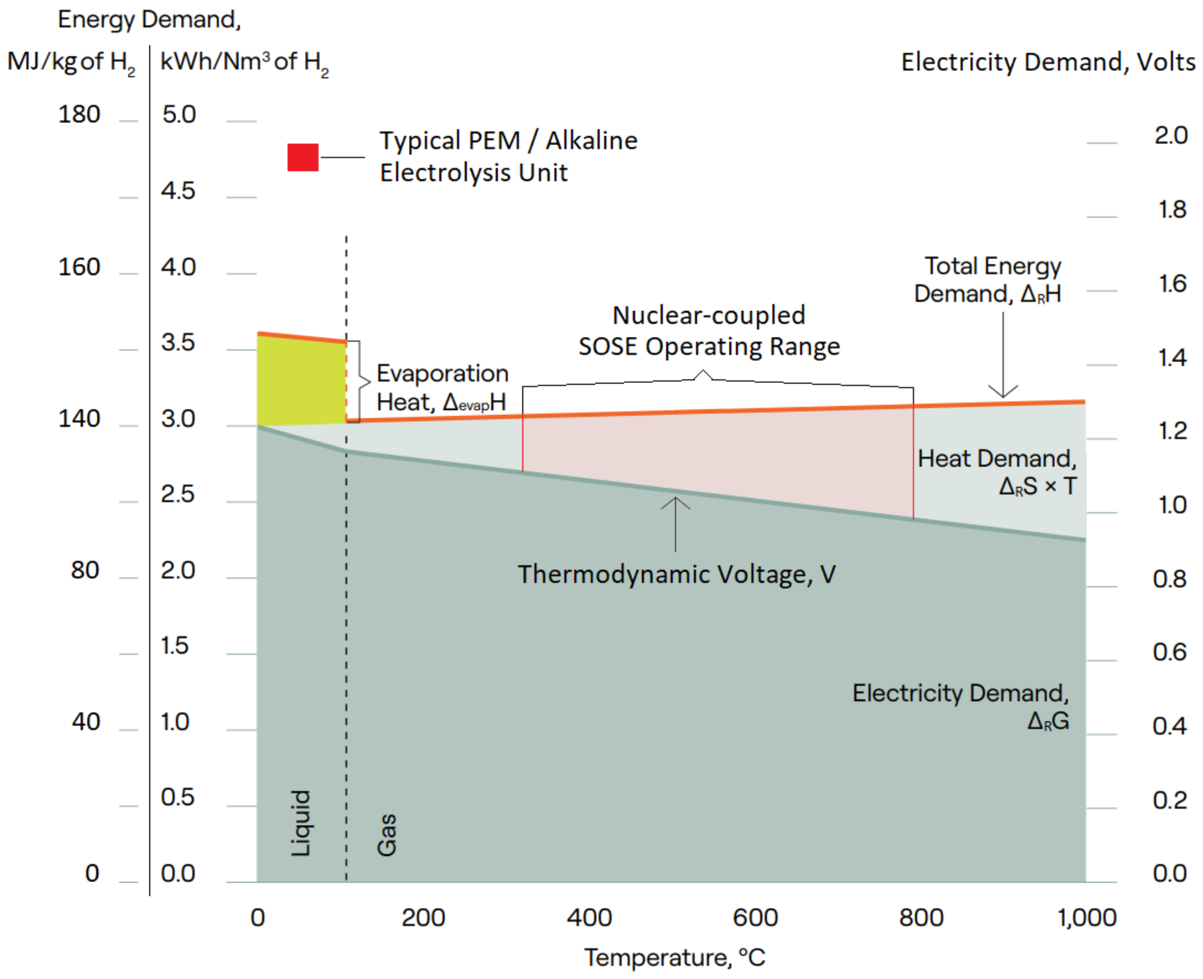
Firstly, cell components have lower resistances and higher performance at higher temperatures.

However, It’s mostly down to thermodynamics. Hydrogen production from water via electrolysis is an **endothermic** process, that means you need to put energy into the process to produce the product.

- The **thermoneutral voltage** is proportional to the electricity needed to sustain the temperature during the reaction. It is lower for steam.
- Nuclear produces heat with a near **100% efficiency**, but electricity at **~40% efficiency**.

Thus, using heat from HTGR with HTSE we can **sustain** hydrogen production more efficiently.



High Temperature Steam Electrolysis model

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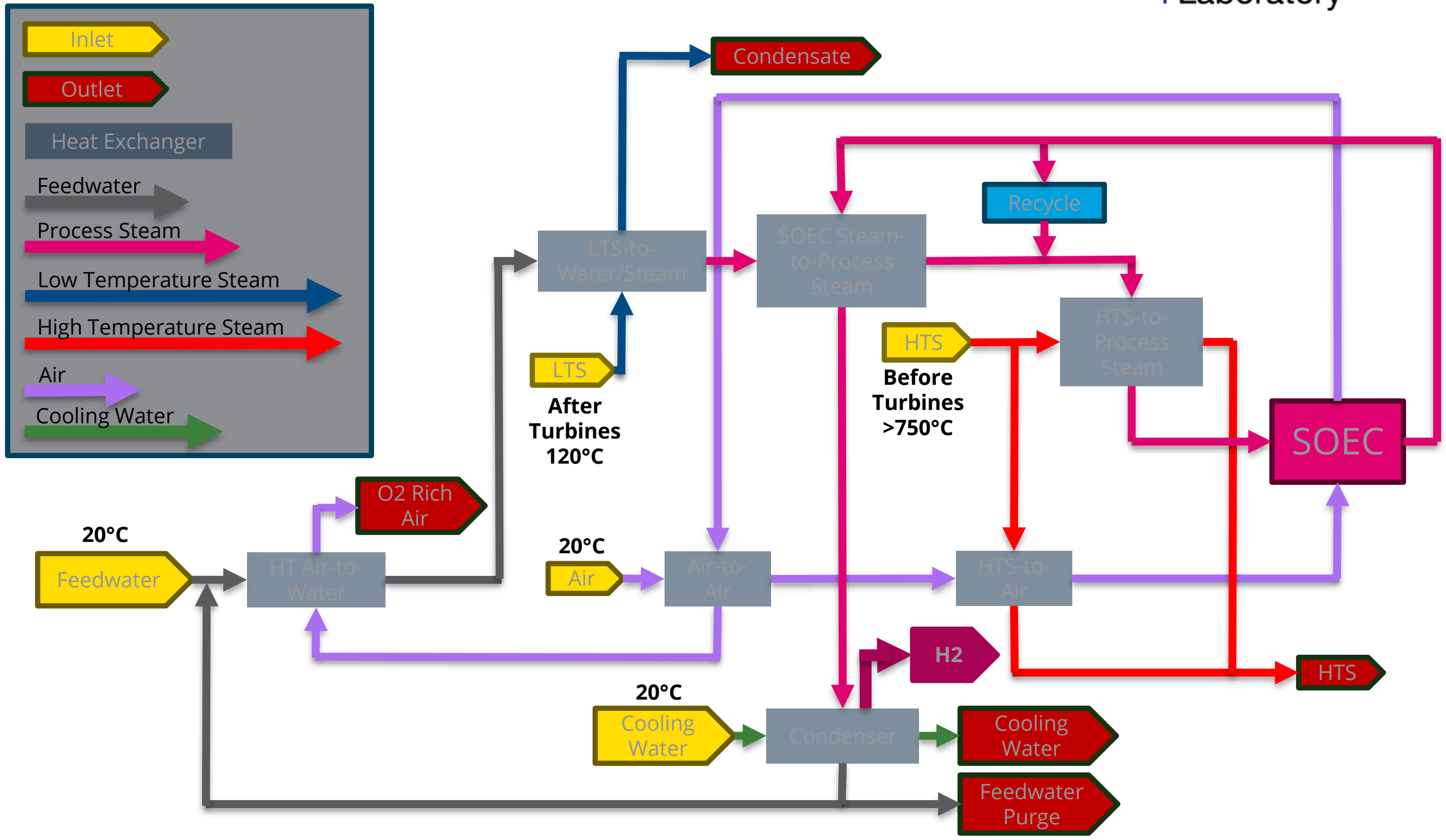
Our current concept for the secondary circuit involves two heat exchanger systems providing high temperature steam (>750ºC) to pre-heat feed to the HTSE stack and low temperature steam (<200ºC) which vaporises feed water.

The resulting configuration is mid-TRL but delivers a more efficient configuration than others.

We believe that development of this technology should proceed in parallel to HTGR to ensure we have a **low carbon** demonstration of HTGR technology to drive industrial investment.



Early phase concept for integrated power and high temperature hydrogen synthesis via electrolysis

Optimisation

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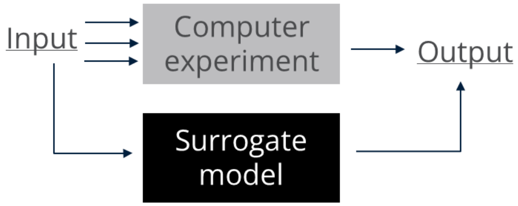
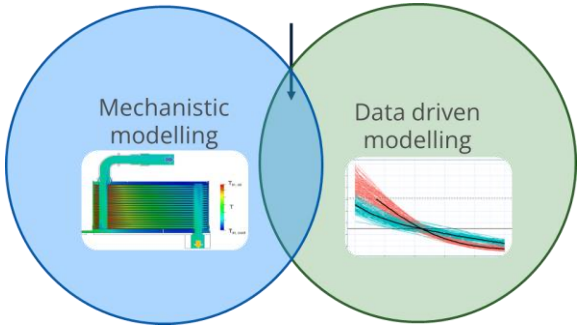
We are developing an approach combining AI and Statistics to develop methods for optimising heat application designs.

- Sensitivity analysis to identify the most important input variables.
- Minimise the complexity of the problem (smaller dimensions).
- Build surrogate models that can be used to explore sensitivities quickly.
- Add uncertainty in the predictions to assist informed decision making.

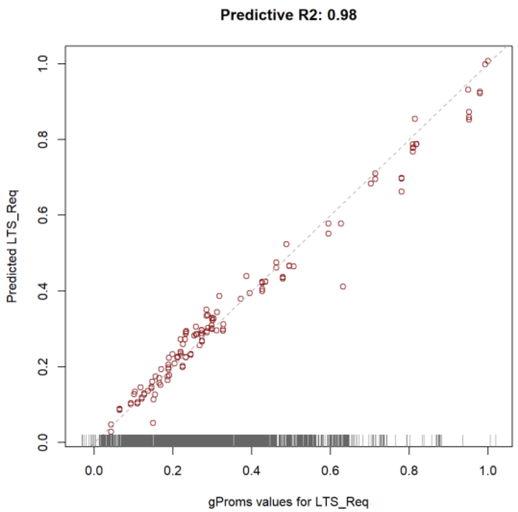
Develop transferable skills that can be applied across nuclear problems.

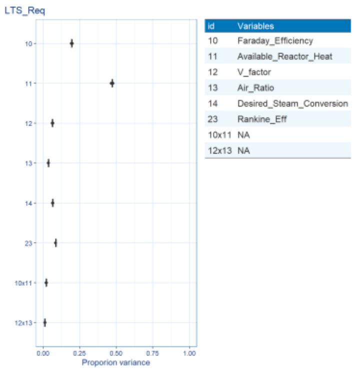


Bridging the gap



- Global Sensitivity Analysis
- Surrogate Modelling
- Model Calibration
- Model Uncertainty





Analysis of SOEC model identifying areas for stability/ optimisation improvements

Direct air capture, Pyrolysis and SAF production

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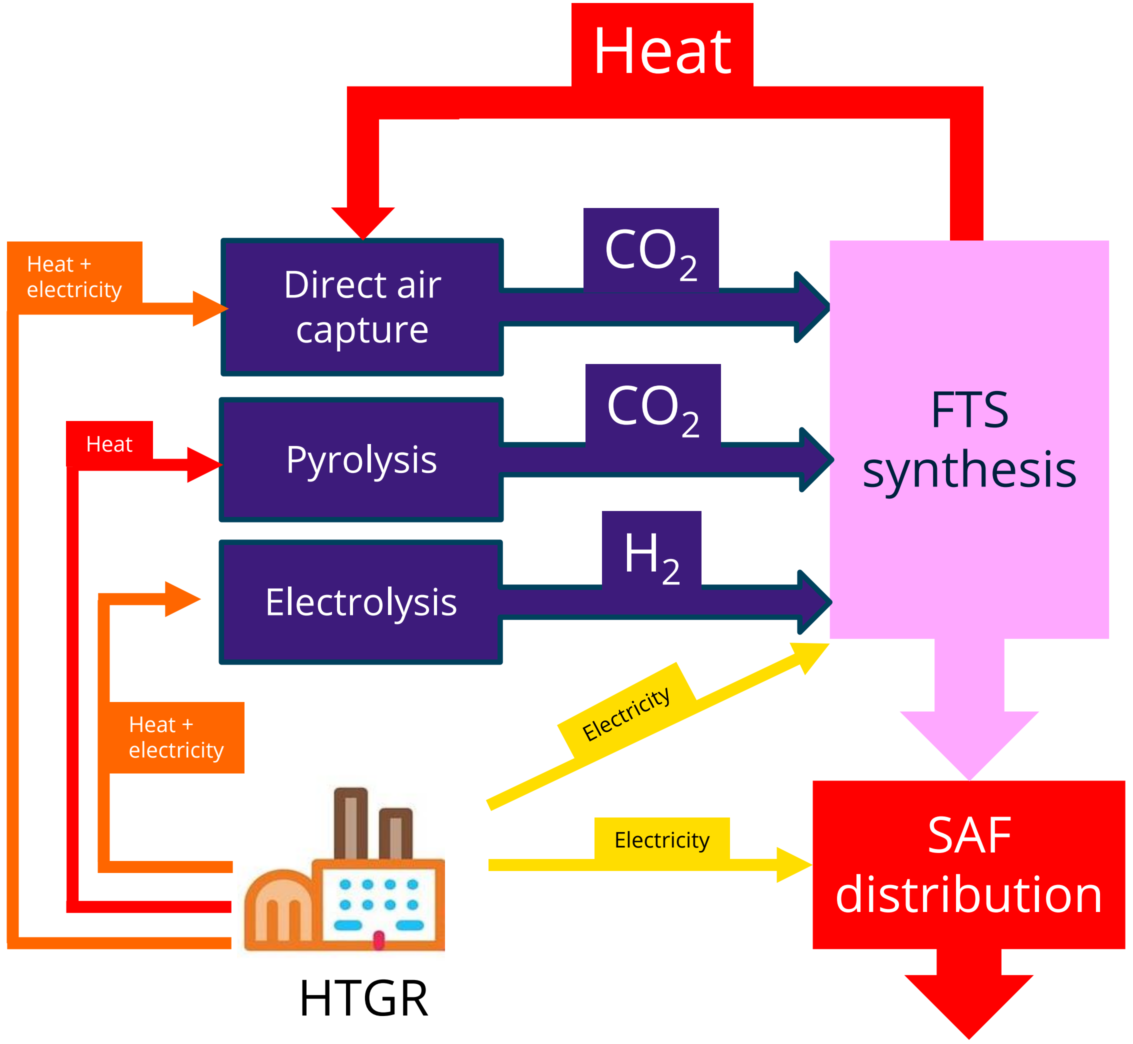
Direct air capture is important technology for net-zero (it's not zero-carbon). It removes excess CO_2 from the atmosphere allowing it to be stored or re-used to manufacture synthetic hydrocarbons.

Pyrolysis is an important process in a future circular economy. It can convert difficult to recycle hydrocarbons into syngas from which synthetic fuels can be manufactured.

Work is ongoing to build techno-economic models of these processes that can integrate pyrolysis, direct air capture and synthetic hydrocarbon synthesis within a coupled system-of-systems to deliver fully integrated, carbon neutral Sustainable Aviation Fuel production.



Functional (digital) mock-up of the manifold system design, Current Status

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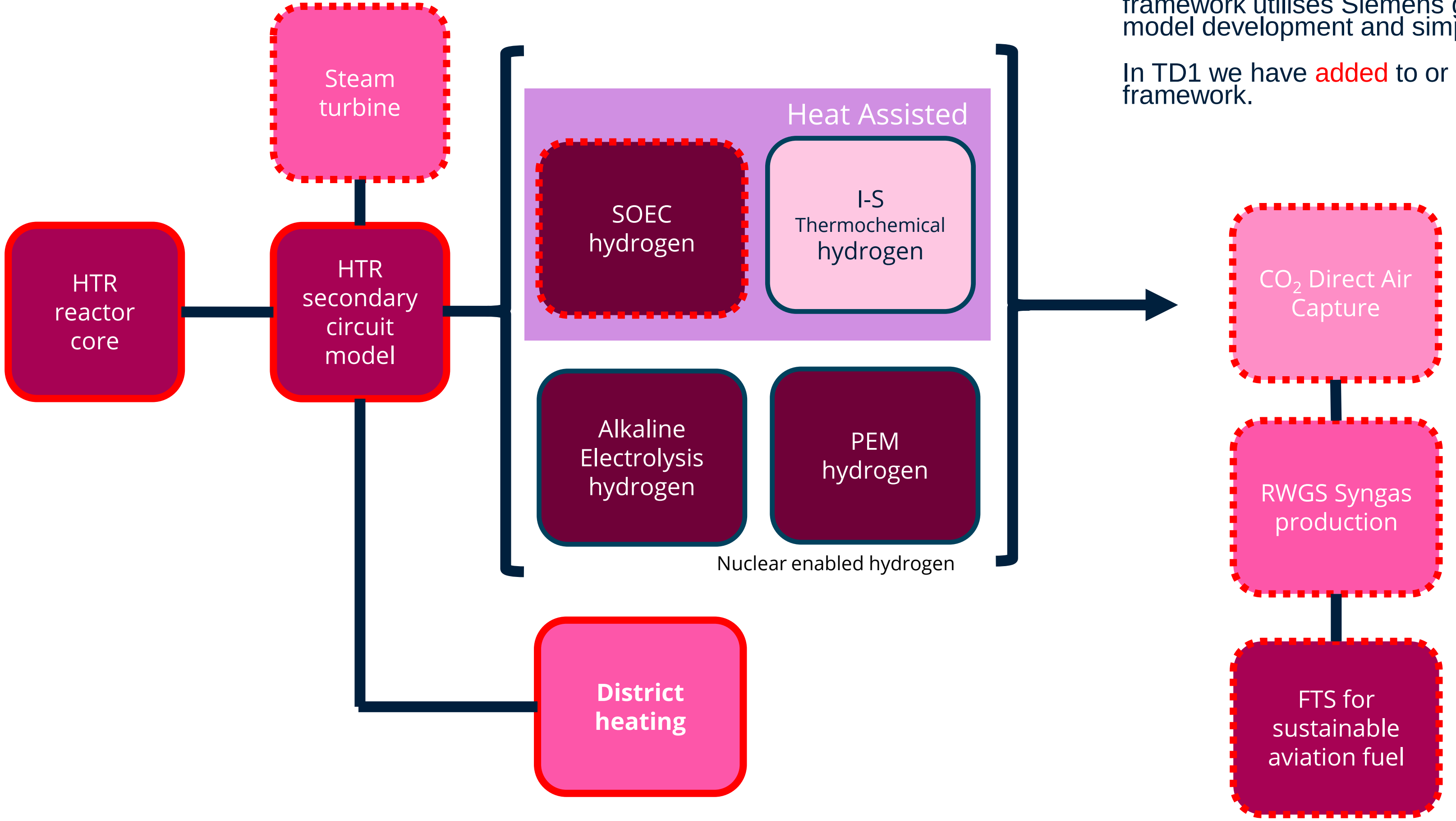
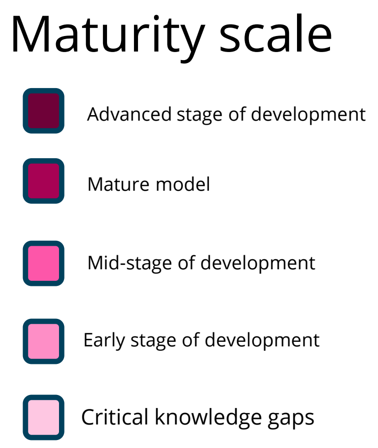
UKNNL have developed a modular framework of system level models for undertaking techno-economic assessments of nuclear cogeneration. The framework utilises Siemens gPROMS software to enable rapid modular model development and simplified model coupling.

In TD1 we have added to or improved a number of components to the framework.





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Thank you

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