STEP FORWARD TO FUSION

IAEA-CN-316/ #2872

STEP: NOVEL POWER INFRASTRUCTURE FOR FUSION POWERPLANTS

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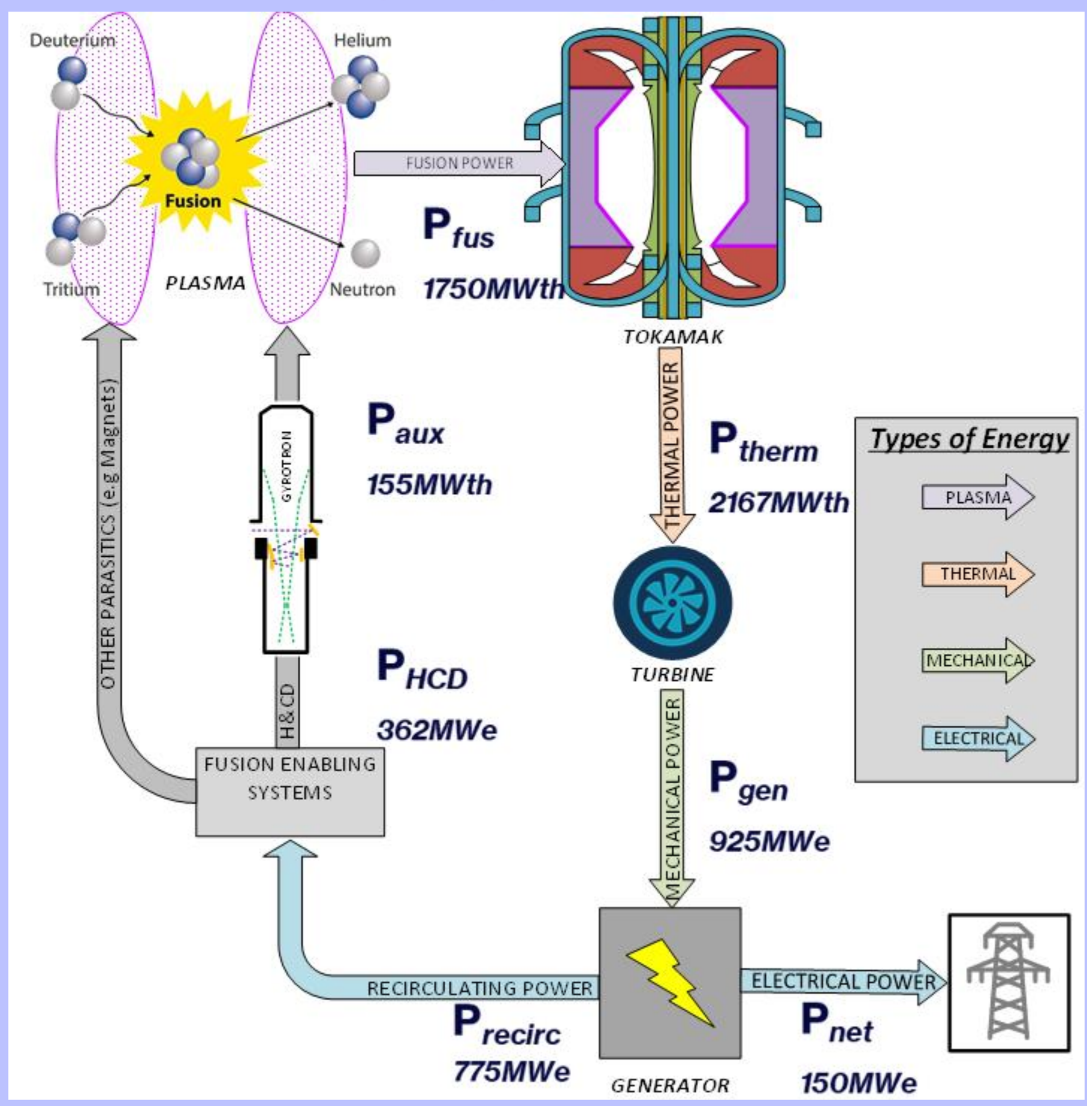
EFFICIENCY DRIVER



The SPP must demonstrate generation of at least 100 MWe net power [1] to the national electrical grid network (in the UK: the *National Grid*).

As many fusion powerplants, the SPP is notoriously "power hungry" meaning that the majority of the power generated is required to sustain the internal recirculating power.

Efficiency and developing highly efficient systems is therefore key in both minimising the recirculating power (P_{recirc}) while maximising the power generated (P_{gen}).

STEP POWER AND COOLING

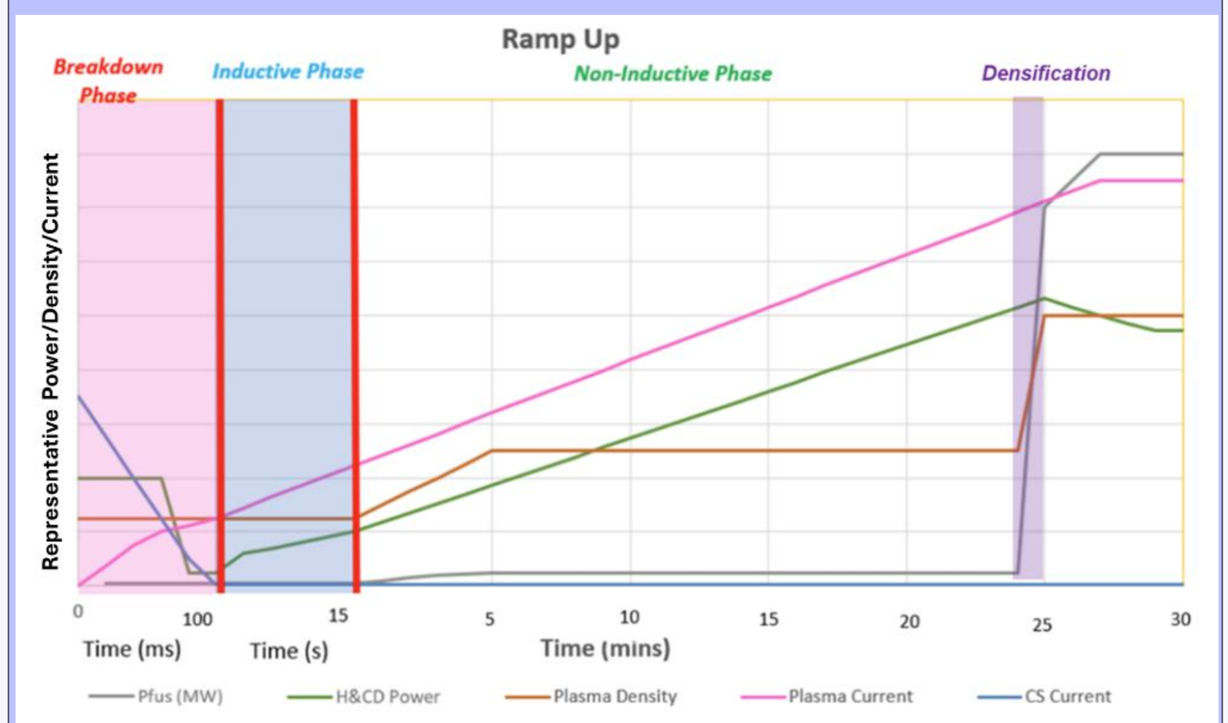
The Spherical Tokamak for Energy Production (STEP), a programme pioneered by the United Kingdom Industrial Fusion Solutions (UKIFS), seeks to develop a first of a kind demonstration fusion pilot plant based on a spherical tokamak: the STEP Prototype Powerplant (SPP). The SPP must develop, not only a novel tokamak core, but a much wider holistic and integrated powerplant. The powerplant design must include the extraction and conversion of fusion energy, which is delivered by the *Power & Cooling (P&C)* systems and sub systems.

The P&C Systems must enable two key elements:

- **EFFICIENCY:** Ensuring highly efficient *P&C* systems is vital in achieving STEP's primary 100 MWe goal. driven by the power balance previously established [1]
- **FLEXIBILITY:** A requirement to match the dynamics of a fusion heat source. For the SPP, these flexibility requirements are challenging when considering its scale and prototypic nature. P&C systems must have the ability to switch on and off, or ramp up and down, in similar timescales as the sudden generation and extinguishing of thermal power from the tokamak; even at unexpected times.

STEP has made key decisions which has heavily influenced the integrated powerplant design to meet both elements.

FLEXIBILITY DRIVER



The ST offers a particularly attractive pathway to steady state operation. The bootstrap current, self-driven by the plasma, is optimised for the SPP [2], greatly reducing the need for external current drive. As a result the SPP will not need to pulse on a frequent basis to recharge a central solenoid.

Significant fusion power (Pfus) will only be generated from the period starting from the rapid density rise phase ("densification") towards the end of the plasma ramp, lasting ca. 100 seconds. From a thermal power perspective this is an effective ramp of 2GWth generated from the tokamak, during these 100 seconds. Prolonging this densification time frame is undesirable. For similar reasons a 100 sec period is also targeted for shut down, where the thermal power generated by the tokamak drops from 2 GWth to almost 0.

Managing this very sudden ramp up and ramp down of tokamak heat is a difficult engineering feat. This challenge is further exacerbated when considering the prototypic nature of the SPP.

POWER & COOLING DYNAMIC NEEDS

Due to the unique operations and dynamic profile of the SPP, the following needs must be met by the P&C systems to ensure flexible operations that can be adapted:

Need for pre-heat: pre-heating of key equipment is required (eg turbomachinery) to ensure integrity during rapid ramp phases.

Need for thermal energy storage: Thermal storage may meet several functions in a design. As a minimum it is needed to extend the thermal inertia of the TPTS to enable a rapid thermal power ramp from the tokamak, allowing the power cycle to "catch up"

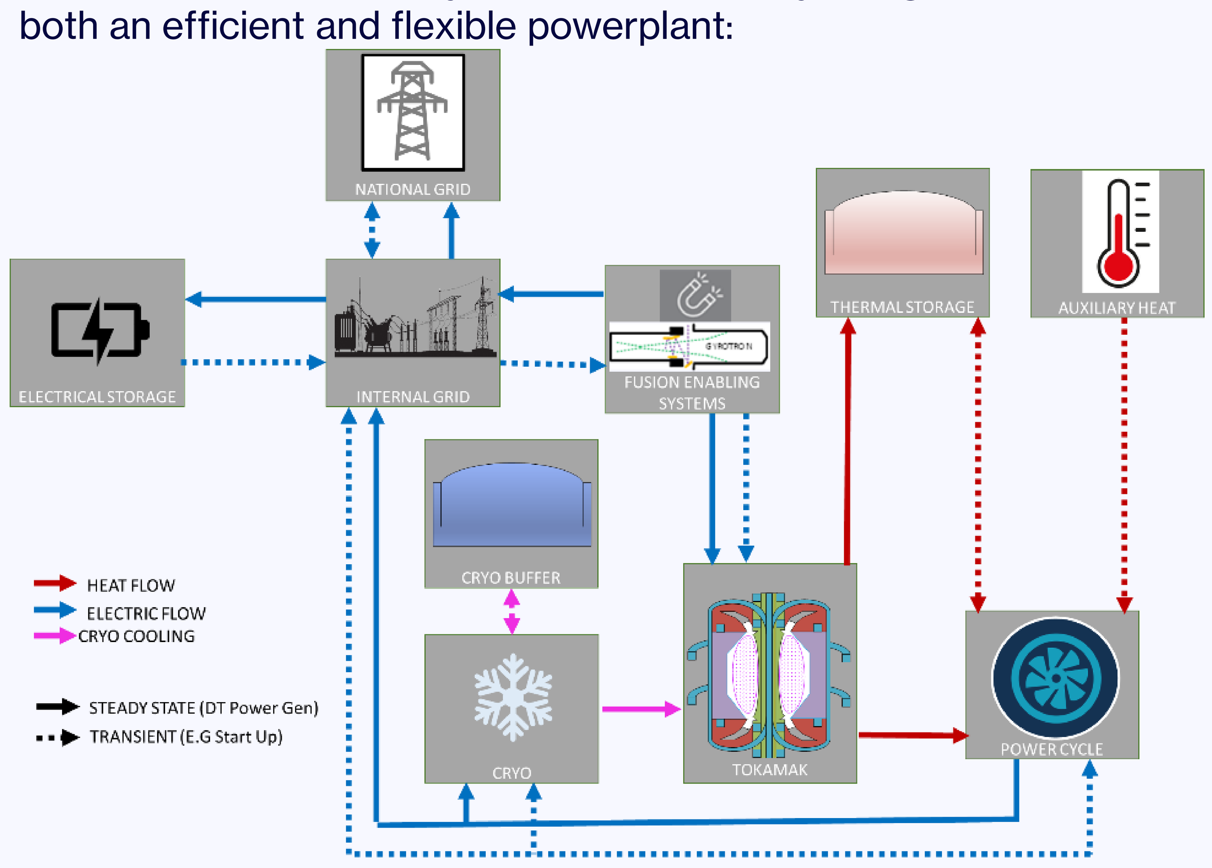
Need for electrical energy storage: The electrical infrastructure must cope with rapid dynamics and must sustain the fusion enabling systems; during the ramp up and ramp down periods when power generated from the turbine is not available.

Need for auxiliary heat: Auxiliary heat can be used to ensure: Availability of the power cycle, Independence of the power cycle and Variation handling. Auxiliary heat enables a power cycle that can receive fusion heat rather than depend on it.

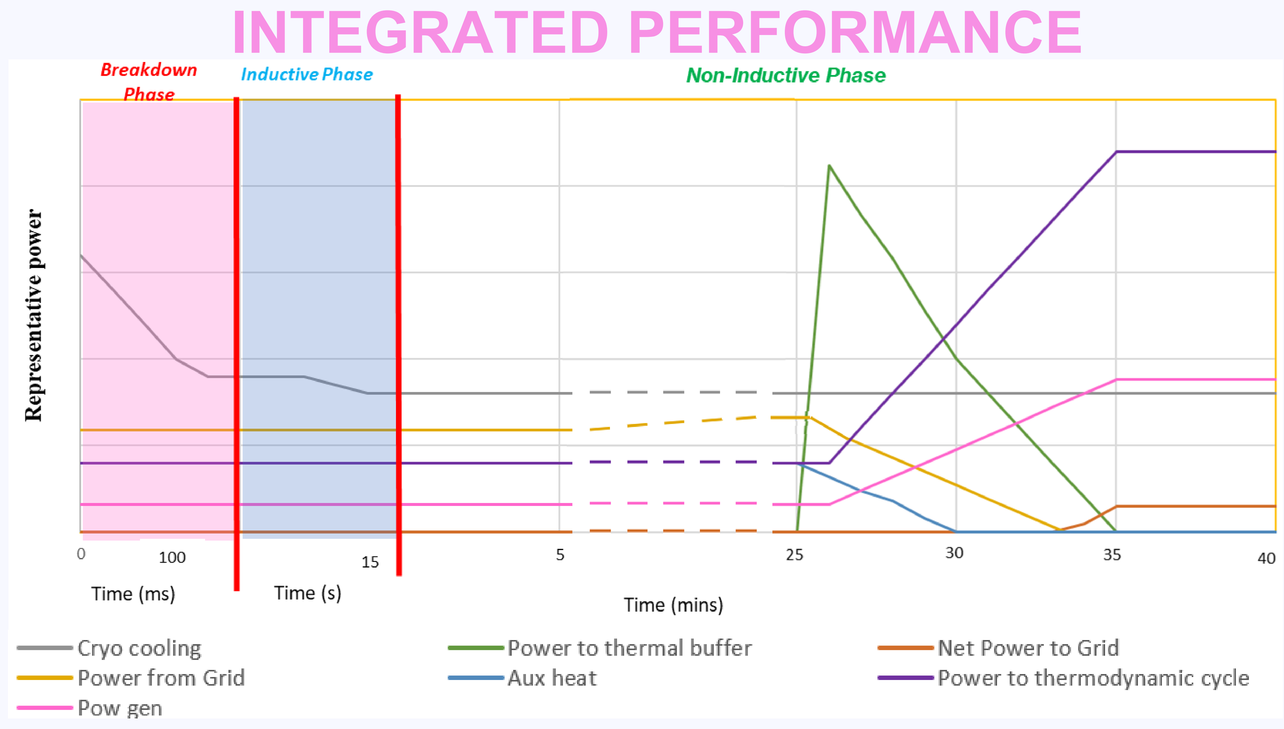
Need for cryo-storage The main cryogenic user is the magnets and operates in a dynamic manner around the plasma breakdown. Cryobuffers are needed to manage these dynamic scenarios.

A HOLISTIC APPROACH

A holistic approach will address the unique P&C needs, integrating most of the P&C systems and functions, to enable the operation of the SPP. All of these systems are carefully integrated to ensure both an efficient and flexible powerplant:

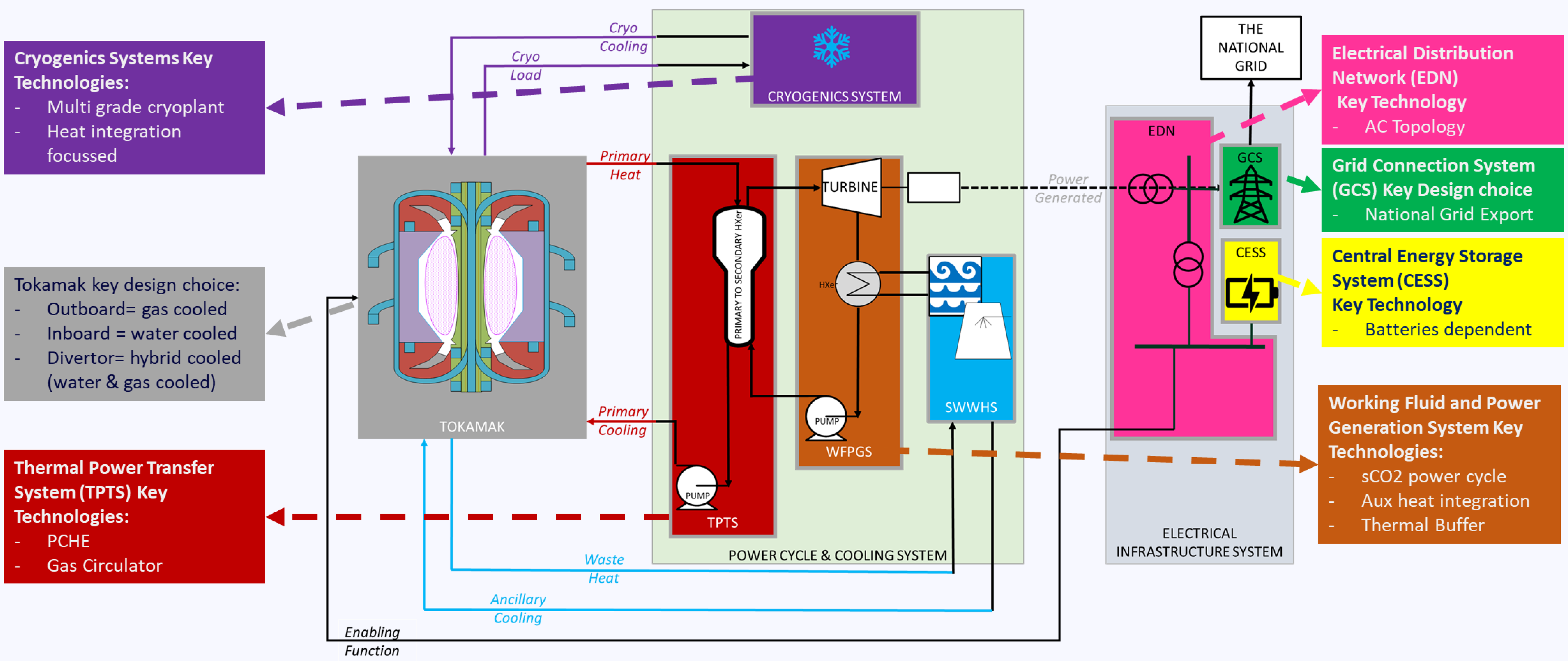


INTEGRATED PERFORMANCE



Integrating the systems together over a transient period must be carefully balanced ensuring time dynamics of the systems and technology within are respected. In turn this has led to a careful selection of the system technology which favours an adequate compromise between efficiency and flexibility, among other key parameters.

SYSTEM TECHNOLOGY



CONCLUSION

The overall technology of the P&C systems are predicated largely on incumbent technologies which are readily available, albeit with certain unique requirements incurring more bespoke componentry for select systems. Nonetheless a number of novel technologies, and novel applications, are discussed. As a result selective research and development is required to derisk these technologies in a timeline compatible with the SPP. Several technologies development programmes must therefore be started imminently to ensure project success.

REFERENCES
[1] Acres J., et al. Staying positive: producing net power, DOI: 10.1098/rsta.2023.0404
[2] H. Meyer, "Plasma burn – mind the gap," vol. 382, 2024.

ACKNOWLEDGEMENTS
This work has been funded by STEP, a major technology and infrastructure programme led by UK Industrial Fusion Solutions Ltd (UKIFS), which aims to deliver the UK's prototype fusion powerplant and a path to the commercial viability of fusion.