COPYRIGHT NOTICE

This original [Publication/Work] was created by Dhinesh Thanganadar, Advanced Cycles Lead, on 24 Feb 2026.

STEP

POC DEMONSTRATION OF A CLOSED LOOP CO_2 POWER CYCLE FOR STEP

THE 9TH INTERNATIONAL SCO_2 ENERGY TECHNOLOGIES SYMPOSIUM

Dhinesh Thanganadar Ph.D., Jacob Connors, Jack Acres

SPHERICAL TOKAMAK FOR ENERGY PRODUCTION

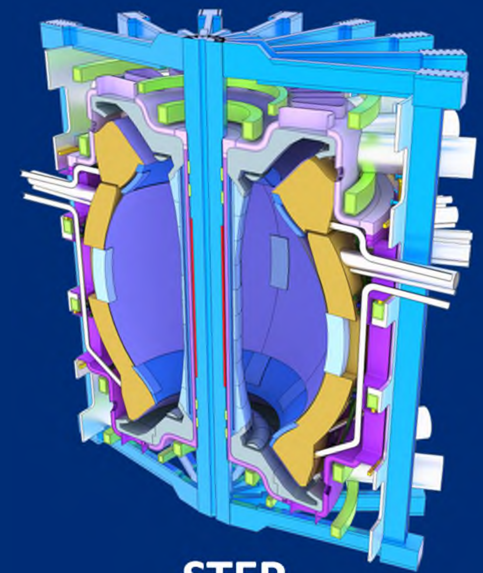
A pioneering, prototype fusion powerplant that will demonstrate:

- Net energy
  100 MWE
- Fuel self-sufficiency
  TBR > 1
- Maintainability of fusion powerplants –
  MAINTAINABLE & AVAILABLE
- A route to the commercial viability of fusion
  £££

STEP has progressed through five Concept Maturity Level reviews and three independent Fusion Technical Advisory Group reviews.

STEP will be delivered in 3 phases:
Phase 1 – develop concept design and select a site
Phase 2 – detailed engineering design and permissions and consents as well as pre-construction works by early 2030s
Phase 3 – manufacturing and construction – targeting operations around 2040.

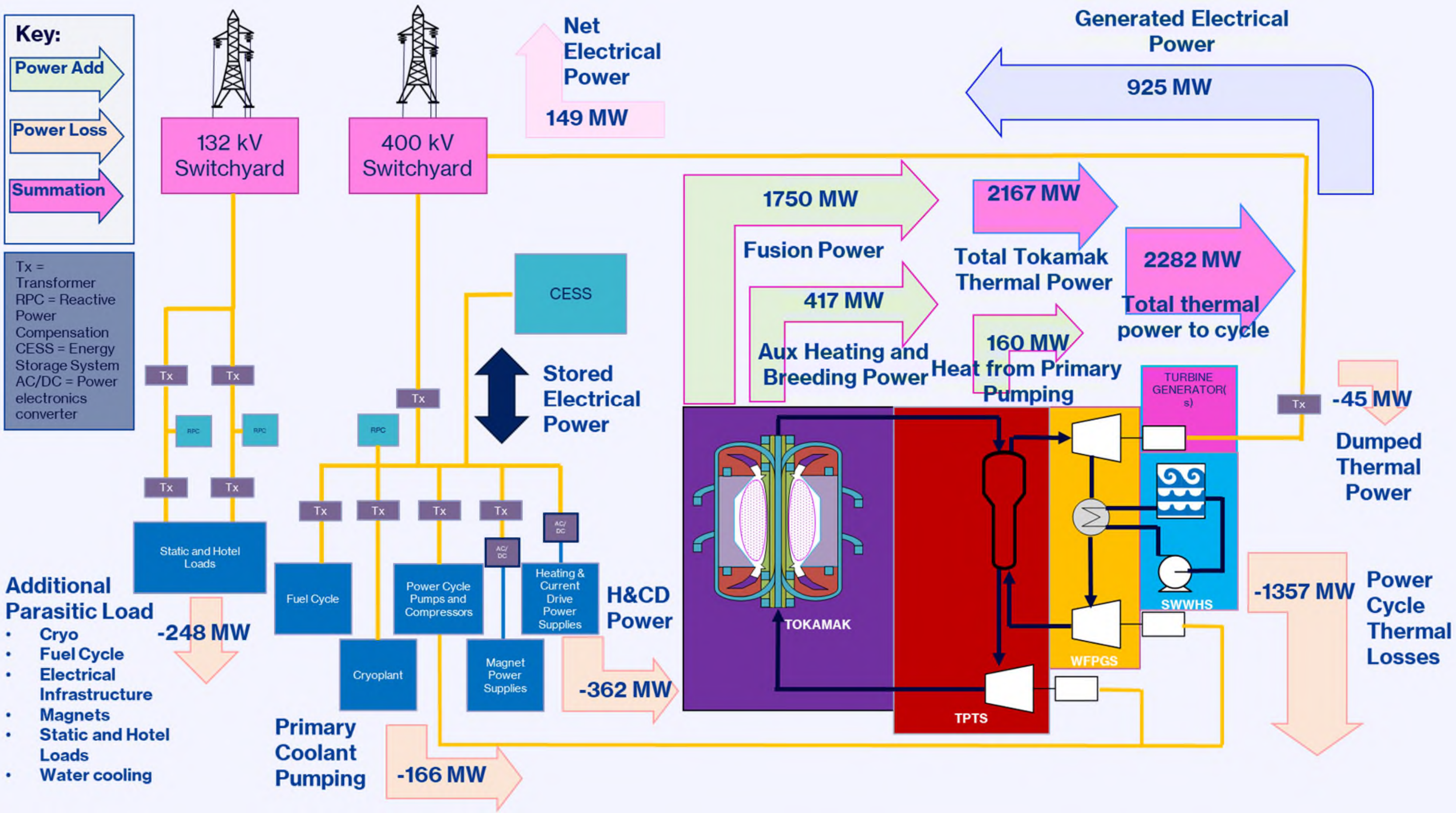
SPHERICAL TOKAMAK BASIS



STEP

- Cored apple shape
- Novel exhaust options – Super-X Divertor
- Fewer, smaller magnets
- Smaller buildings
- Lower costs due to compact nature

REPRESENTATIVE POWER BALANCE



Staying Positive: Producing Net Power, https://doi.org/10.1098/rsta.2023.0404

POWER CYCLE REQUIREMENTS - RECAP

4 KEY CHALLENGES UNIQUE TO FUSION POWER GENERATION:

Challenge 1: Need for efficiency

Challenge 2: Need for heat integration

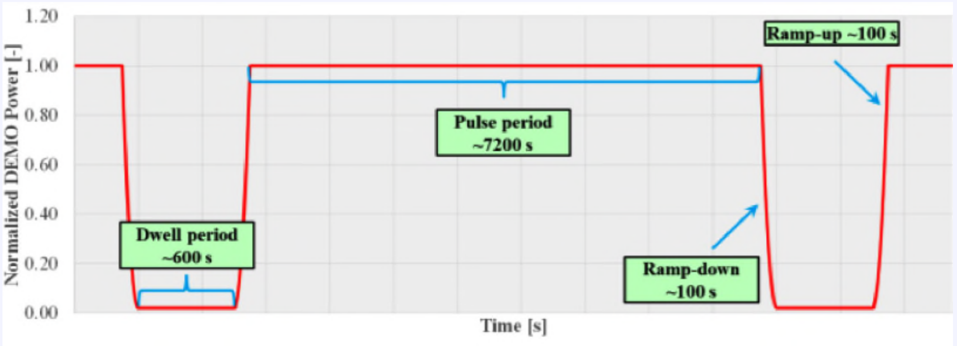
Challenge 3: Need for flexibility

Challenge 4: Need for viability

Plasma starts/ stops very rapidly → Operational Flexibility

Pulse mode of operation of prototypic plant

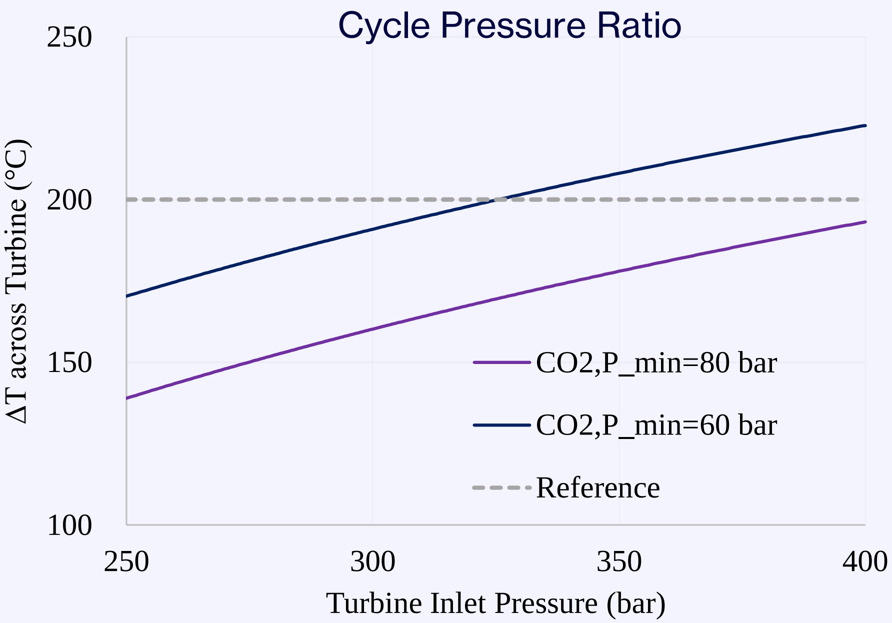
Conventional Tokamaks are Inherently pulsed



Maturation of critical technologies for the DEMO balance of plant systems, Fusion Engineering and Design, Volume 179, 2022; L. Barucca et al.

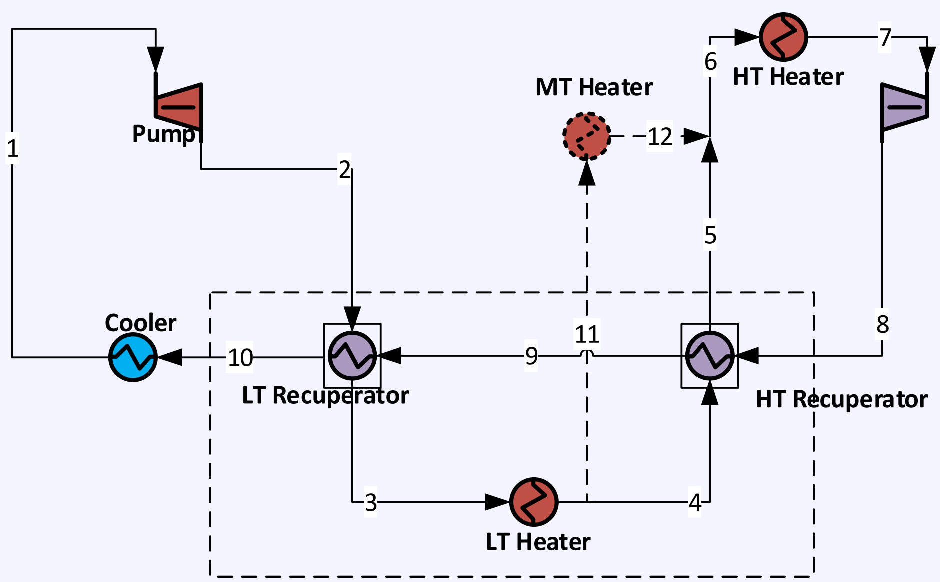
TRANSCRITICAL CO_2 POWER CYCLE

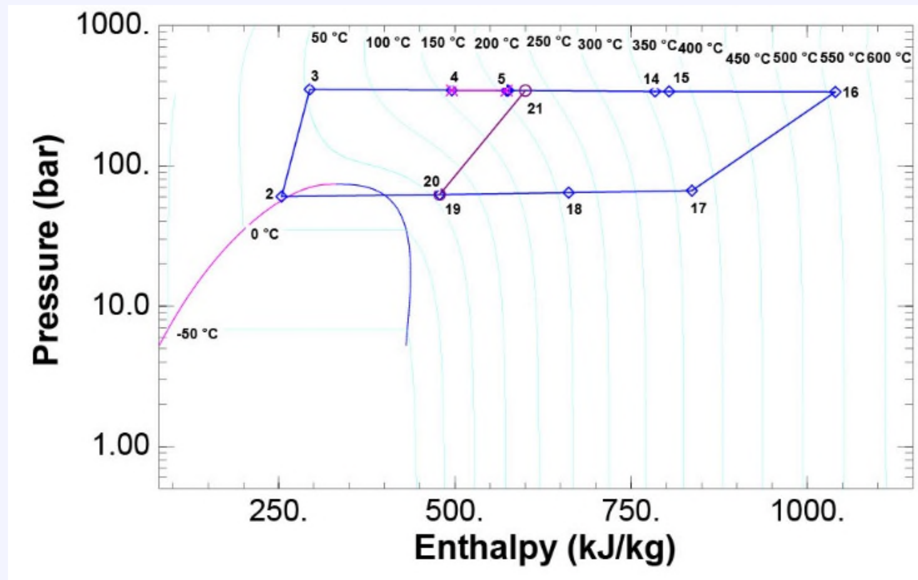
HEAT INTEGRATION (HT, MT, LT) - SIMPLIFIED



Parameters	IVC	Heat Split (%)	Supply Temperature (°C)	Return Temperature (°C)
HT Heat Source	Blanket, Outboard first wall	65	600	400
MT#1 Heat Source	outboard limiter	10	450	250
MT#1 Heat Source	Divertor cassette	5	500	350
LT Heat Source	Diverter and inboard components	20	213	200

SIMPLIFIED CYCLE CONFIGURATION

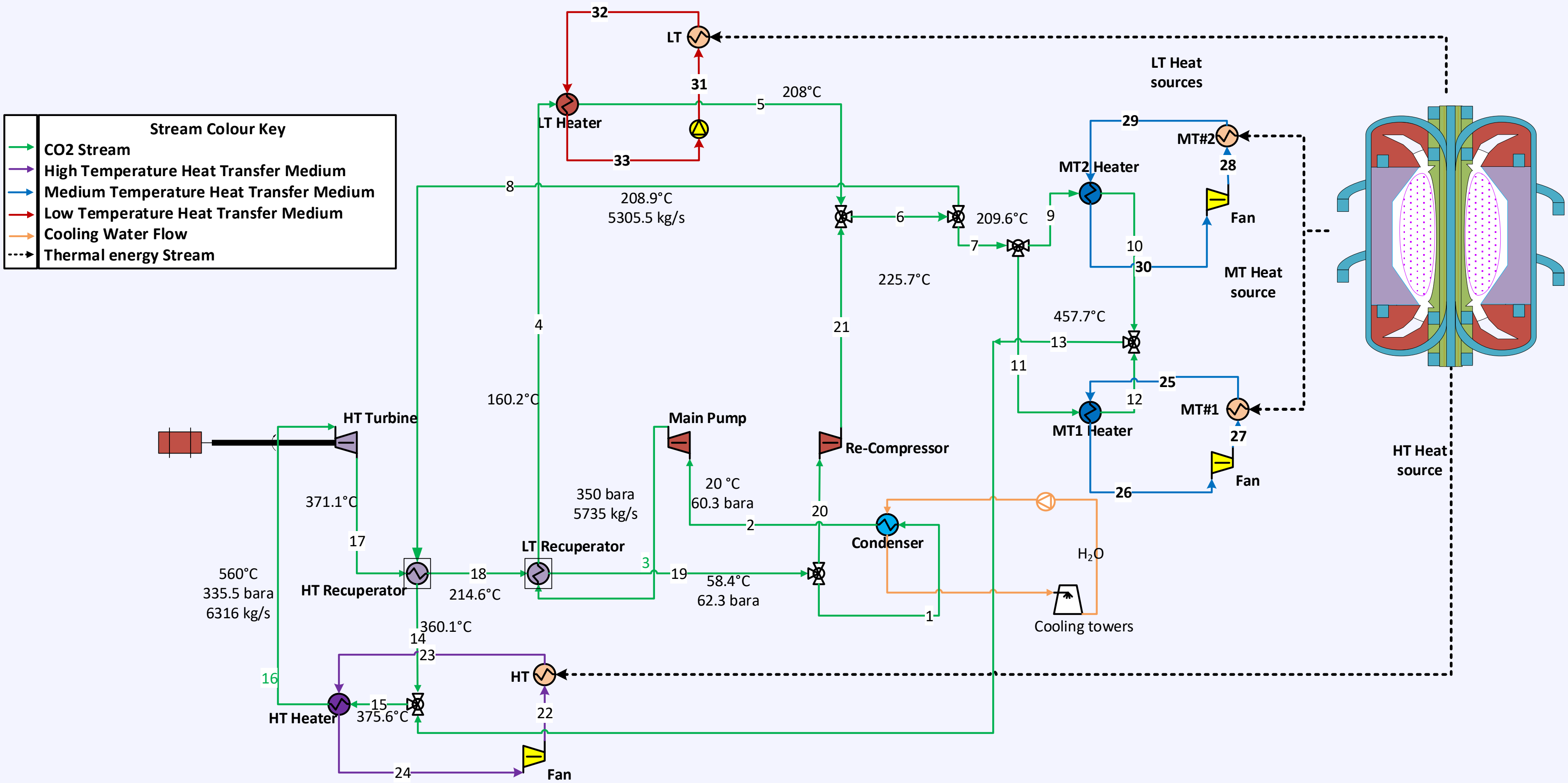




- **Enthalpy gap**
- **ΔT**

DOI: 10.17185/duepublico/83288

CYCLE CONFIGURATION



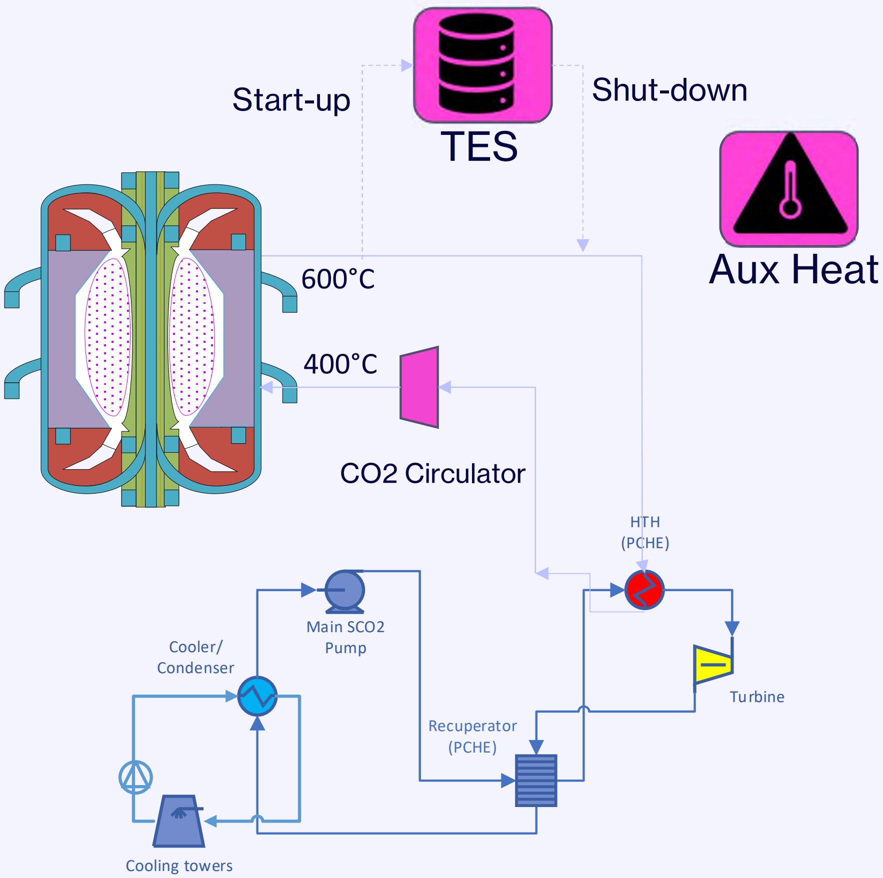
DOI: 10.17185/duepublico/83288

AUX HEAT SOURCE

+

TES FOR RAMP MISMATCH

WHY DO WE NEED?



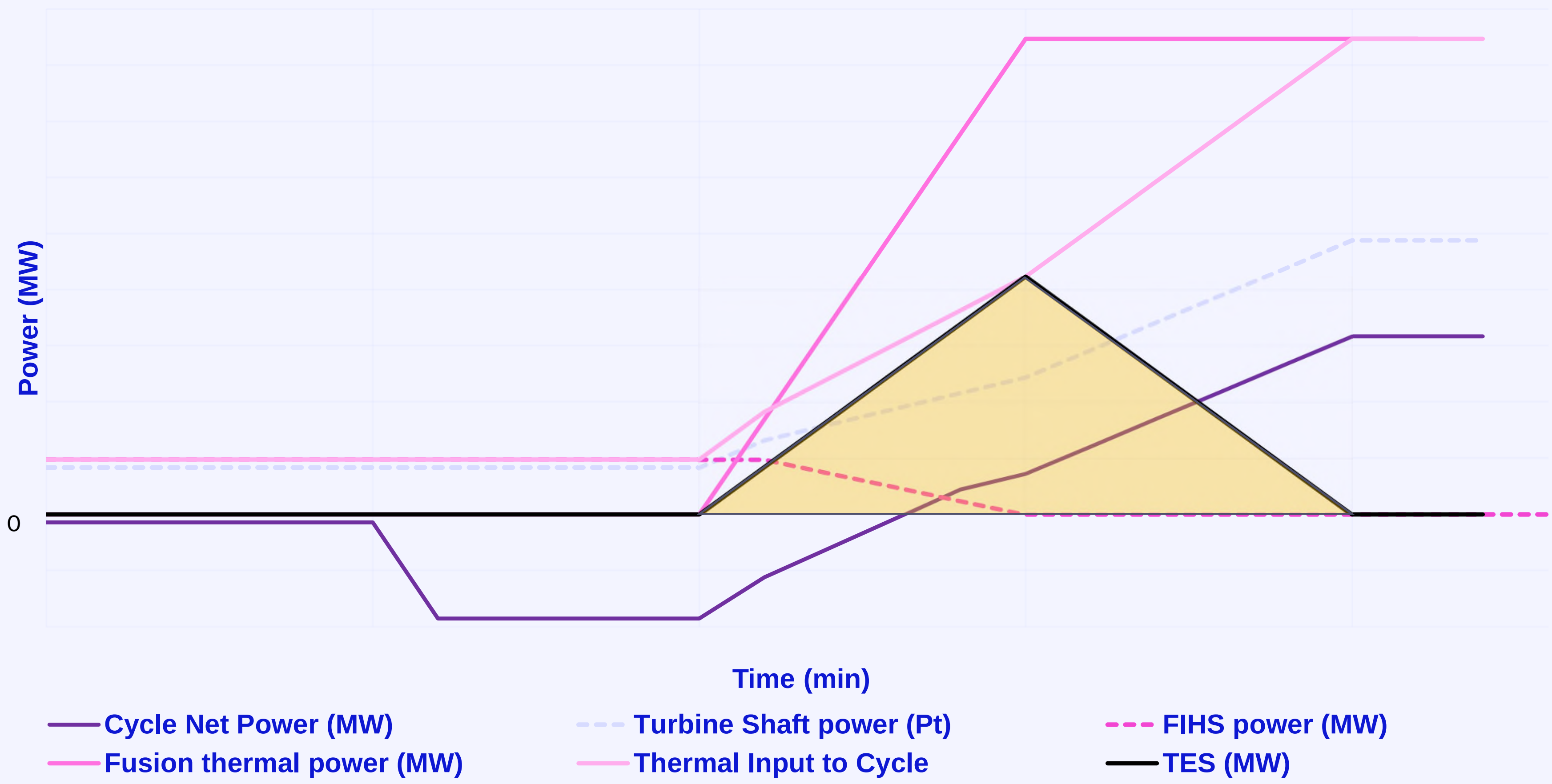
AUX HEAT SOURCE

1. Supporting cold start-up and maintaining the power cycle at its minimum stable load to enable a smooth transition to fusion heat source
2. Maintain Temperature profile close to fusion mode
3. Facilitating controlled shutdowns when required
4. Rapid cut-in during plasma shutdowns to sustain minimum cycle load – thus reducing number of shutdowns/ start-ups

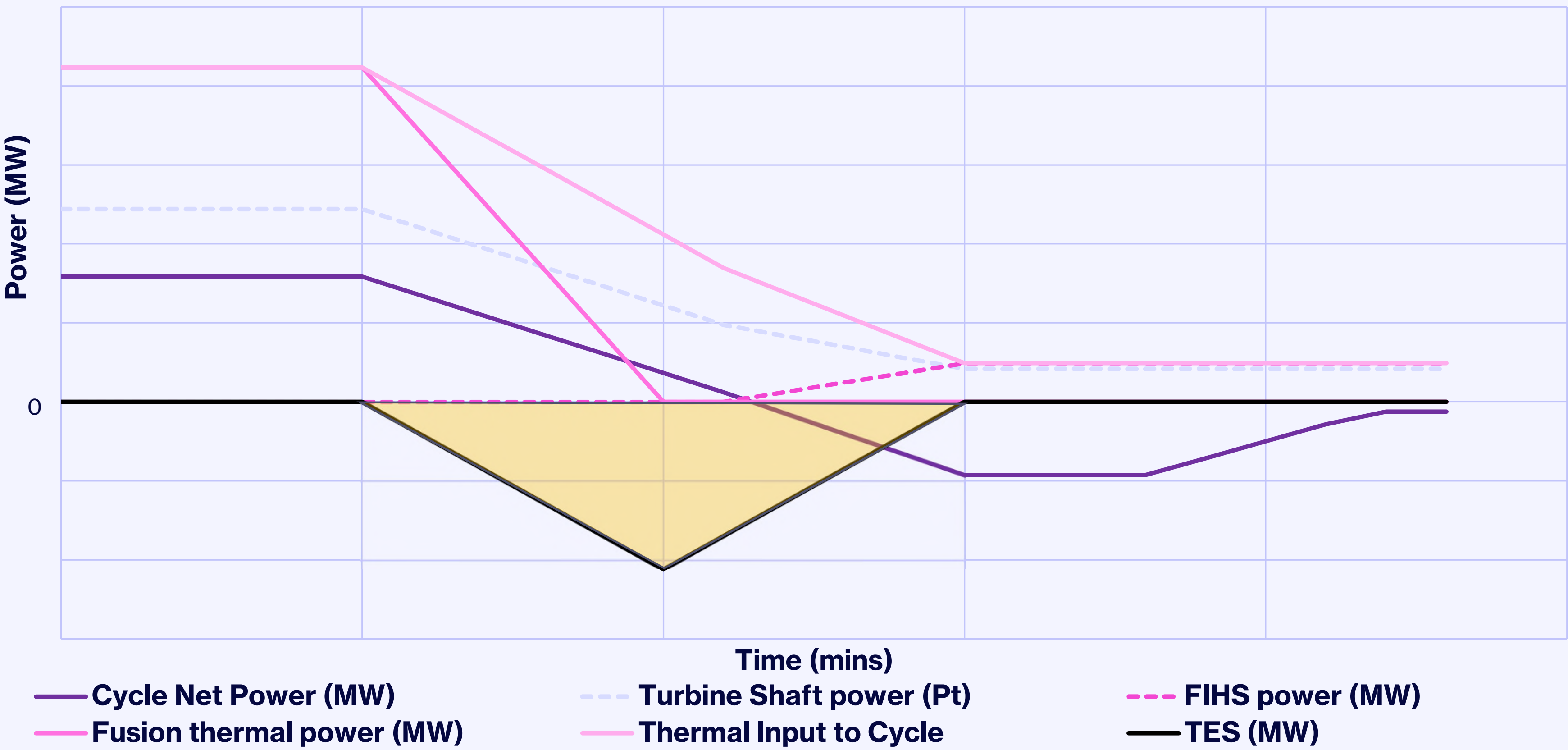
TES

1. Bridge the thermal ramp mismatch between the plasma, and the thermally constrained systems e.g., large heat exchangers, pipe(s), and turbomachinery

START-UP PROCEDURE



SHUTDOWN PROCEDURE



POC RIG

SUB HEADING

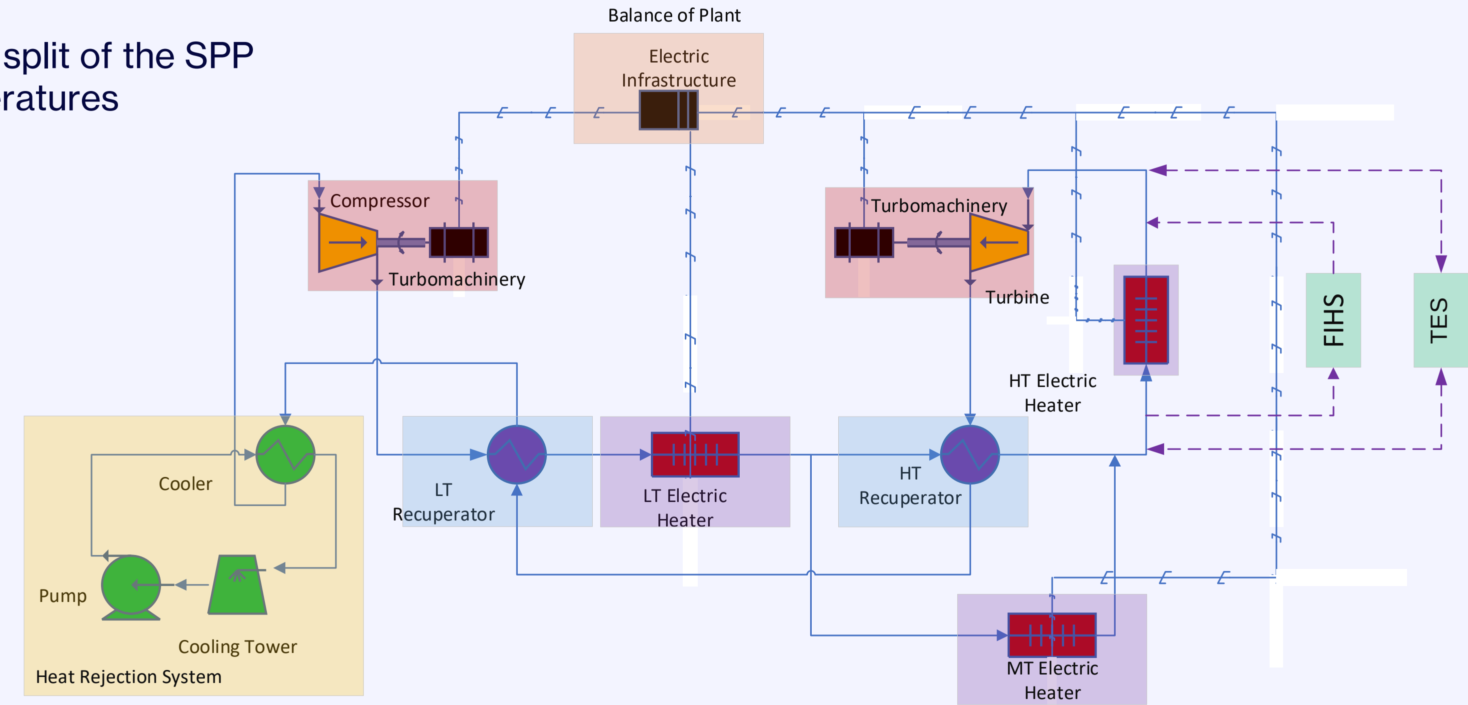
OBJECTIVES

Demonstrate stable operation across fusion-relevant operating modes and transition between them, while generating data to support component model validation, control system development, and scale-up toward the STEP prototypic powerplant.

- Verify integrated operation of the complete CO2 closed loop, e.g., start-up, shut-down, trips.
- Demonstrate steady-state operation in both fusion heat and auxiliary heat modes, and mode transitions.
- Evaluate operability of the candidate FIHS during low load operation, and rapid ramping.
- Assess the thermal-mechanical and control performance of the TES, verifying component limits during fast transients.
- Validate steady-state, and transient performance of TES, FIHS, heat exchangers, turbomachinery, and component interactions.
- Acquire operational experience with a closed-loop CO_2 cycle

RIG LAYOUT

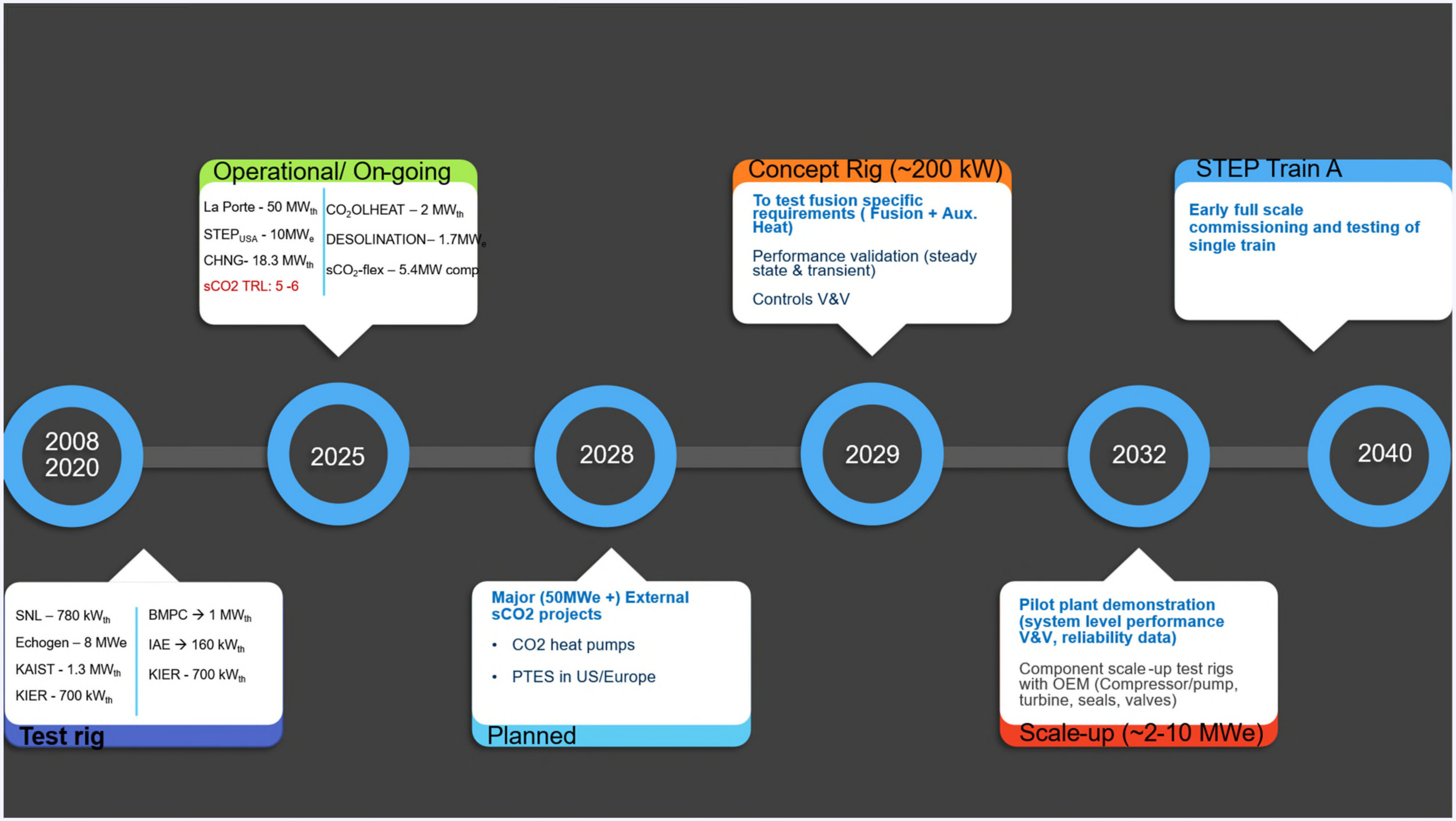
- Size : ~200kWe
- replicate the representative heat split of the SPP
- equivalent maximum cycle temperatures
- Includes FIHS & TES
- Operate in cyclic condition
- recompressor is omitted



Limitations:

- dynamic response, characteristic time constants, and thermal inertia observed in the small-scale test rig will not fully replicate those of the SPP

ROADMAP



Operational/ On-going
La Porte - 50 MW$_{th}$
STEP$_{USA}$ - 10MW$_{e}$
CHNG- 18.3 MW$_{th}$
sCO2 TRL: 5 -6
CO_2OLHEAT – 2 MW$_{th}$
DESOLINATION– 1.7MW$_{e}$
sCO_2-flex – 5.4MW comp
Concept Rig (~200 kW)
To test fusion specific requirements (Fusion + Aux. Heat)
Performance validation (steady state & transient)
Controls V&V
STEP Train A
Early full scale commissioning and testing of single train
2008
2020
2025
2028
2029
2032
2040
SNL – 780 kW$_{th}$
Echogen – 8 MWe
KAIST - 1.3 MW$_{th}$
KIER - 700 kW$_{th}$
BMPC → 1 MW$_{th}$
IAE → 160 kW$_{th}$
KIER - 700 kW$_{th}$
Test rig
Major (50MWe +) External sCO2 projects
• CO2 heat pumps
• PTES in US/Europe
Planned
Pilot plant demonstration (system level performance V&V, reliability data)
Component scale-up test rigs with OEM (Compressor/pump, turbine, seals, valves)
Scale-up (~2-10 MWe)

THANKS
ANY Q'S?

END SLIDE