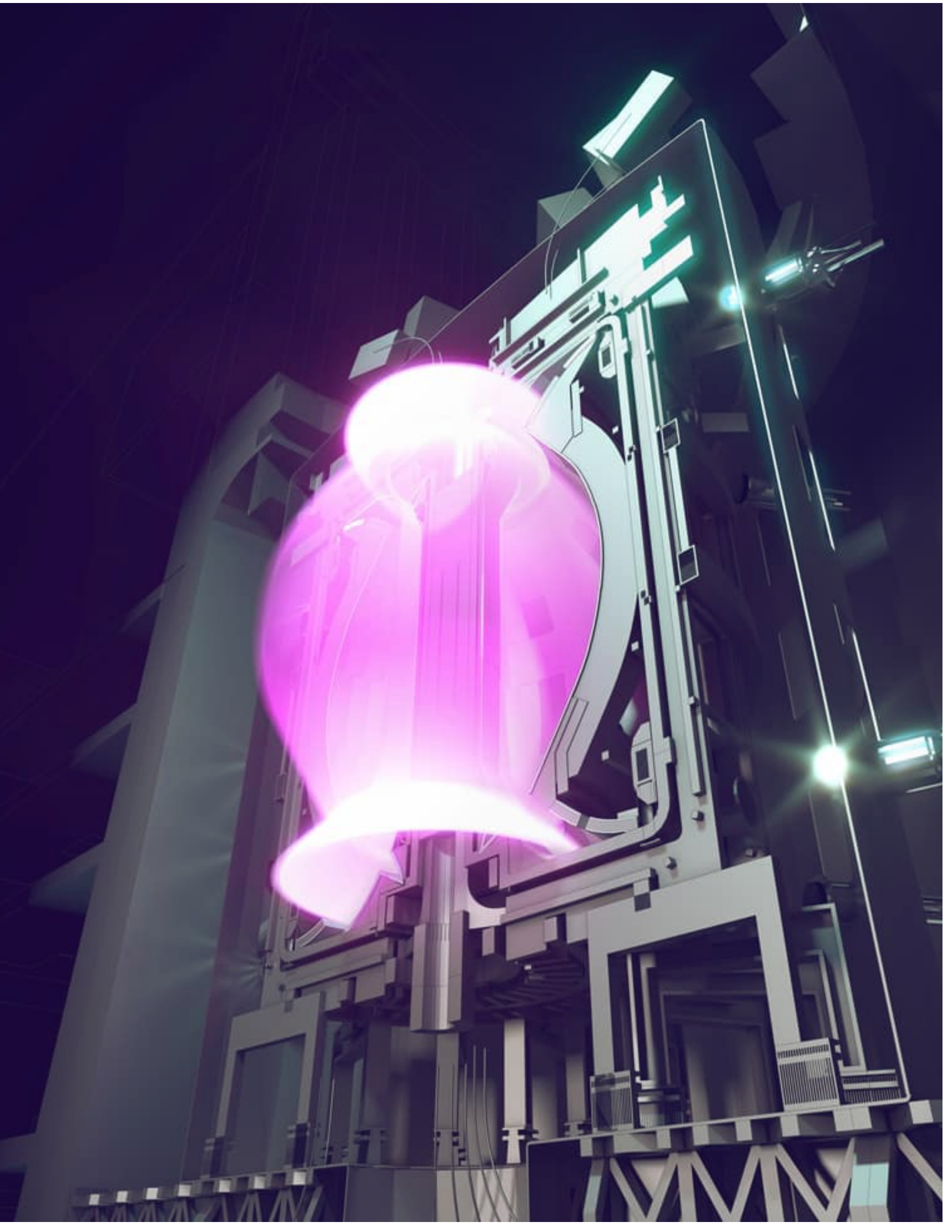
STEP FUSION

STEP: Driving a pathway to accelerated fusion delivery

Howard Wilson for the STEP Team

30TH IAEA FUSION ENERGY CONFERENCE

13-18 OCTOBER, 2025



STEP: Accelerating fusion delivery

- Climate change and energy security drive **urgency** in the delivery of a sustainable, reliable, independent means to power our industry and society

- Raises a key and fundamentally important question:

STEP: Accelerating fusion delivery

- Climate change and energy security drive **urgency** in the delivery of sustainable, reliable, independent means to power our industry and society

- Raises a key and fundamentally important question:

Can we accelerate the delivery of fusion energy?

- The STEP programme is designed to provide an answer

Commercially viable pathway to fusion delivery contains three key elements

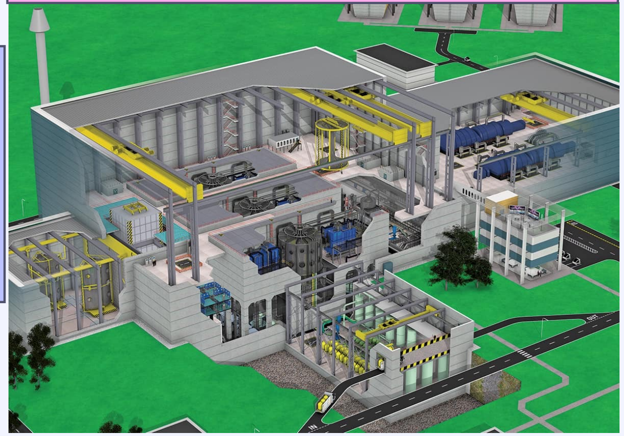
Near term benefits for stakeholders and investors

National skills and industrial capability to deliver fusion

Demonstration of technical and commercial viability

Requirements

Commercial Fusion Power



STEP: An Integrated Multi-pronged pathway to commercial fusion delivery

Drive near term economic and societal benefits

Grow a skilled and capable fusion industry

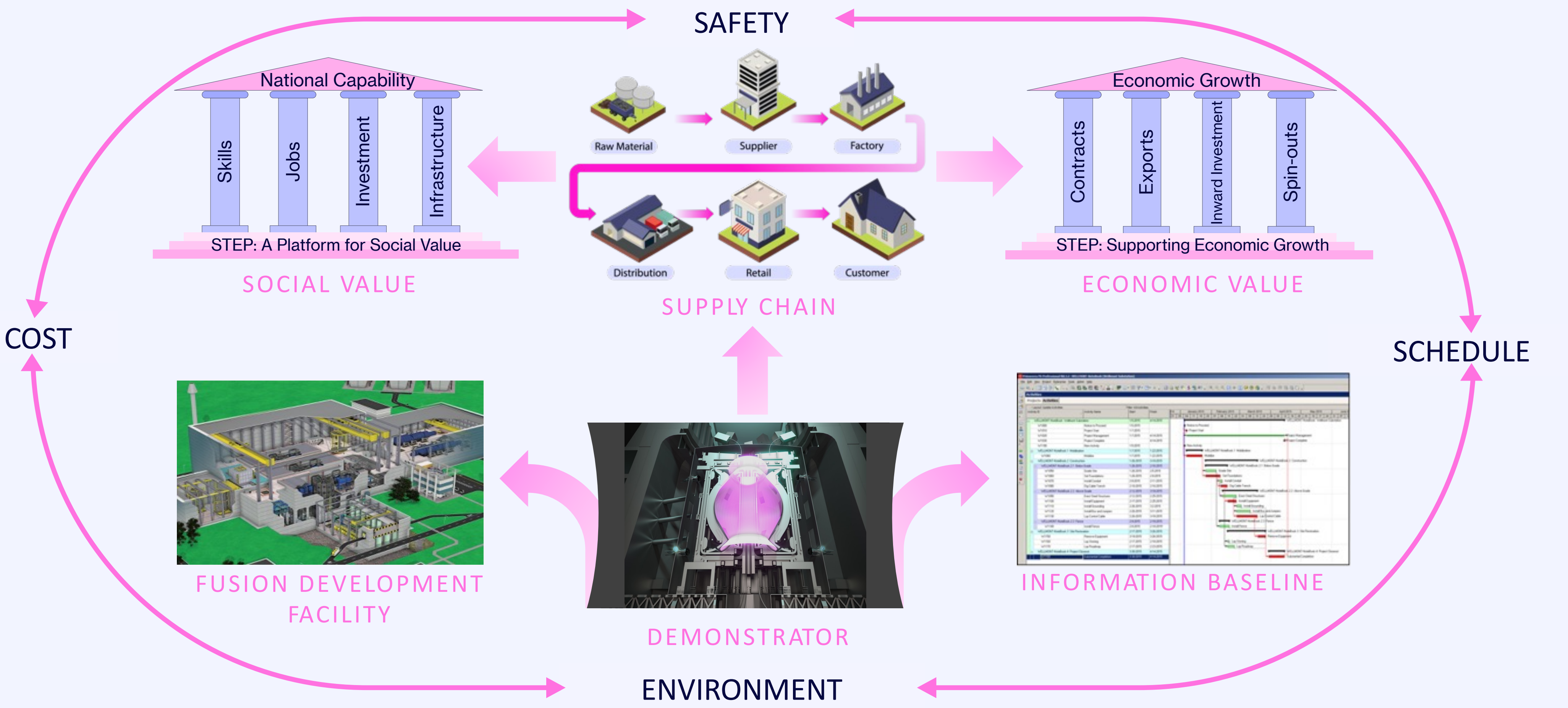
Demonstrate commercial viability through prototype

STEP

Commercial Fusion Power

- STEP: Spherical Tokamak for Energy Production
  - STEP Prototype Plant (SPP) is the key vehicle to drive delivery
    - *Net electrical power to the grid at the 100MW level*
    - *Demonstrate fuel self-sufficiency*
    - *Targeting operation in the 2040’s*

STEP: more than just a pilot plant



STEP Prototype Plant (SPP) Timeline

2020 2025 2030 2035 2040

Concept

- Concept/reference design
- Site Selection
- Operating model

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- Concept/reference design
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Detailed Design and Mobilisation

- Build partnerships
- Engineering design
- Test rigs
- Early manufacture
- Site Development

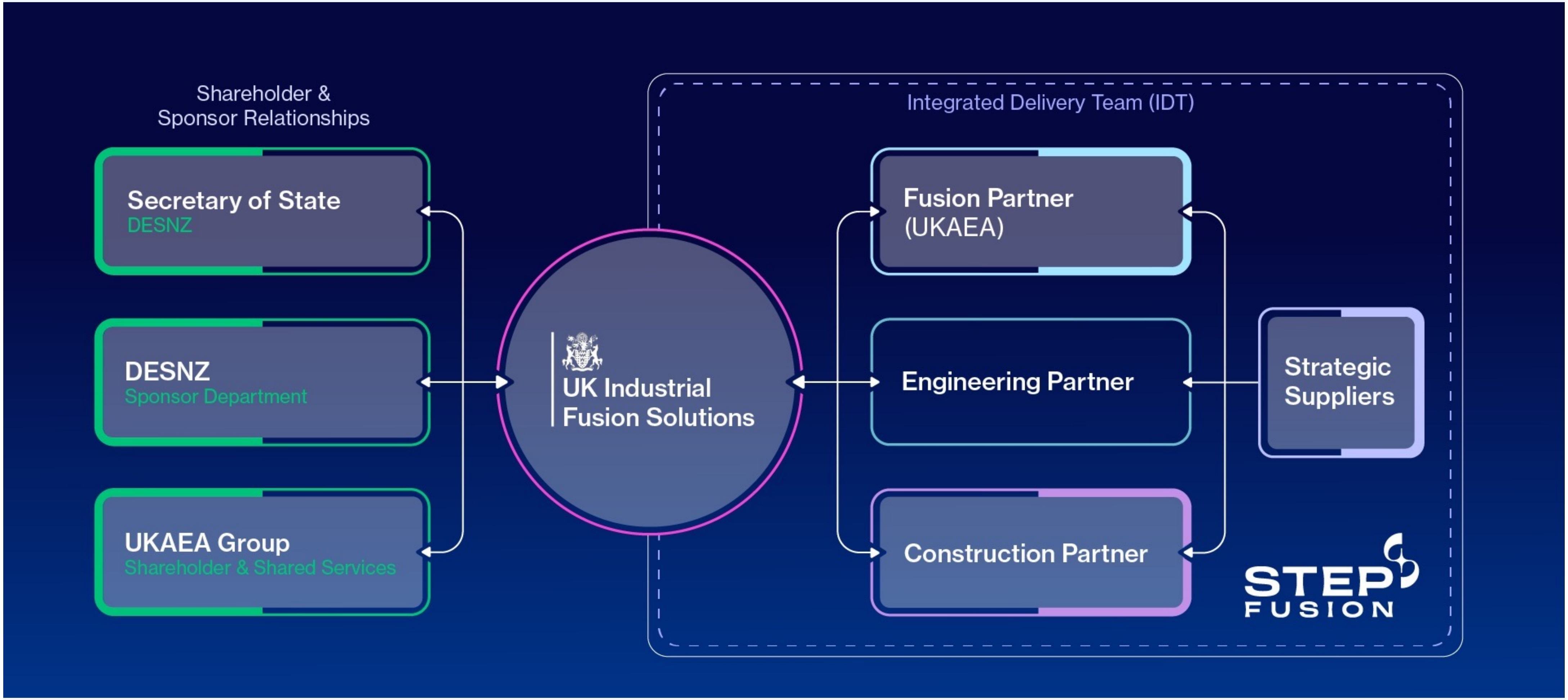
Main Construction

- Full plant manufacture & assembly
- Full site development
- System testing

Commission and operate

- Commissioning
- Prototype operations
- Commercial plant design

STEP operating model: Achieves its objectives through partnerships



STEP Prototype Plant: Why a spherical tokamak?

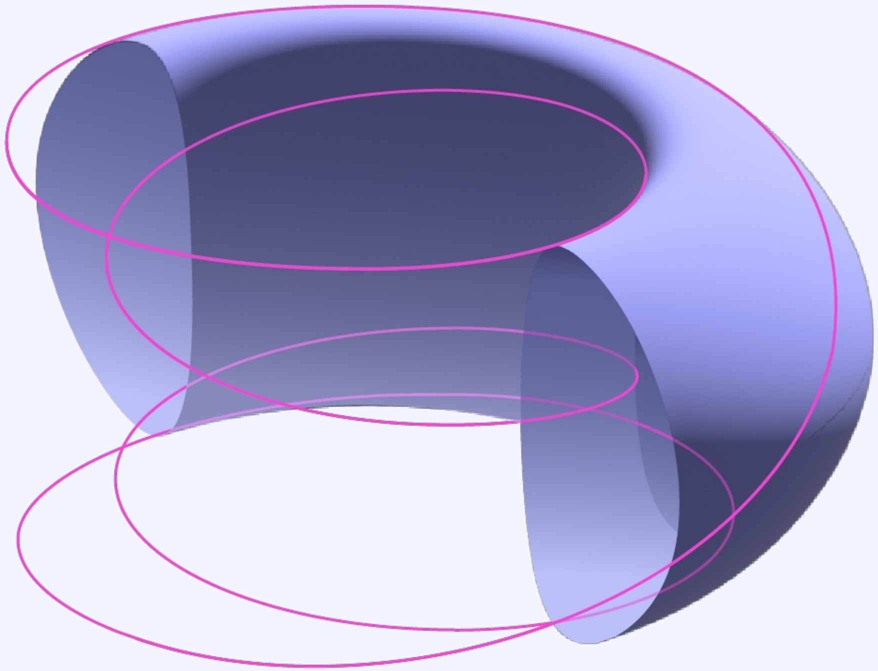
1) Compact radial build

2) High current-carrying capacity

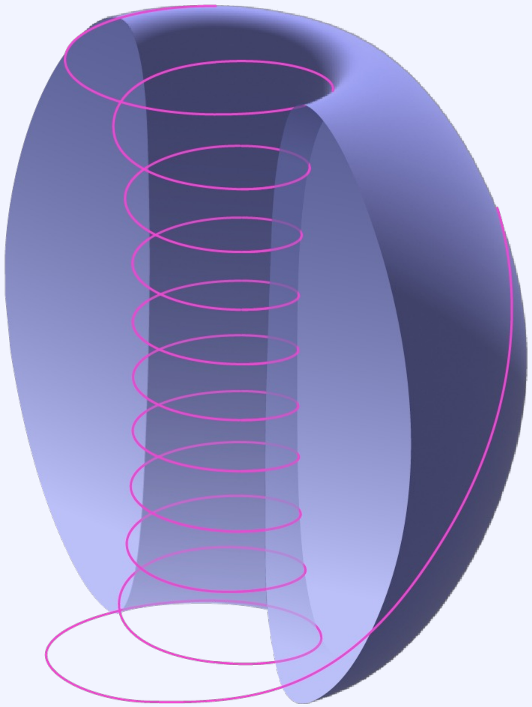
3) Pathway to steady state operation

4) Novel, simplified maintenance options
    - No requirement for inboard breeding

Spherical tokamak offers advantages:
1) Compact radial build



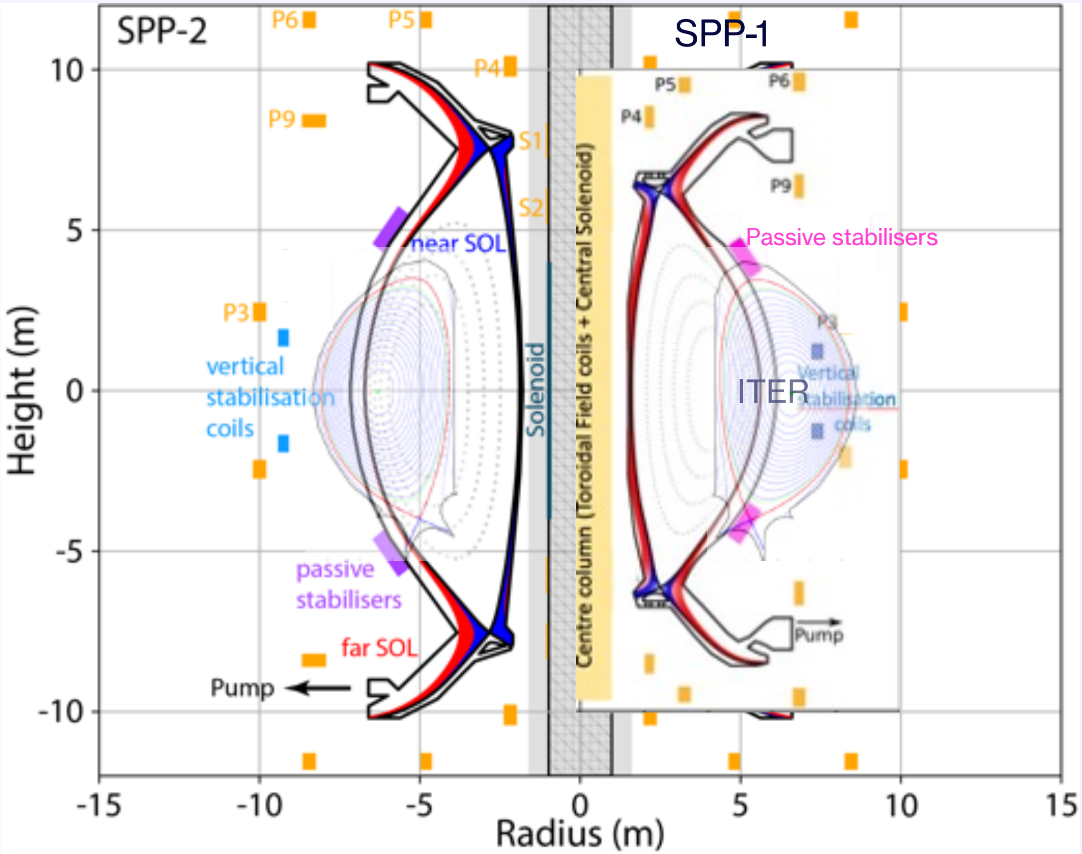
Conventional Tokamak



Spherical Tokamak

Spherical tokamak offers advantages:

1) Compact radial build

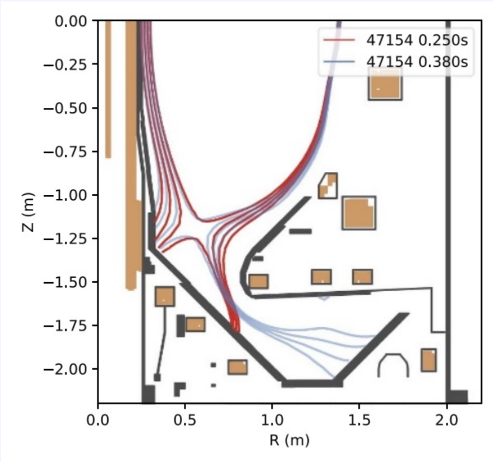


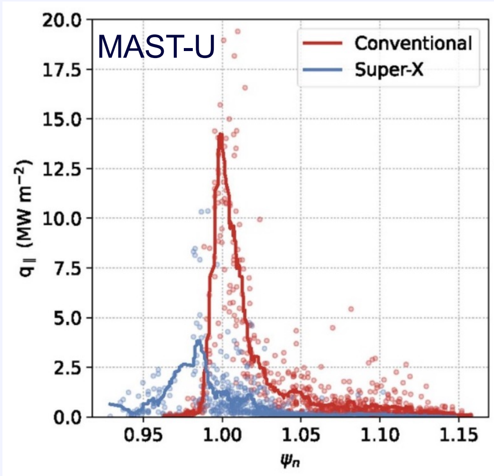
- Radial build of SPP is below that of ITER
- High SPP elongation means plasma volumes are similar
- SPP has ~3 times the fusion power of ITER

Spherical tokamak offers advantages:

1) Compact radial build

- Managing the exhaust in compact geometry requires a novel approach
- MAST-U has demonstrated beneficial properties of Super-X, which SPP exploits
- Acceptable power loads predicted for SPP with:
  - Double null; balanced X-points
  - Super-X outboard leg
  - Extended inner leg
  - Ar divertor gas seeding to drive detachment
  - ~70% core radiation through Xe pellets
- Further modelling/optimisation seeks to:
  - Reduce core radiation requirement to access lower P_{fus} solutions
  - Manage transients
  - Quantify/reduce uncertainty in SOL width





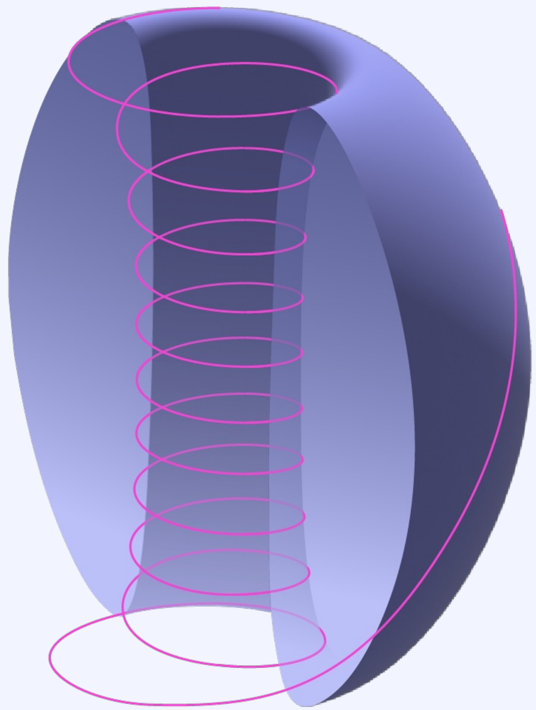
Harrison et al, PPCF **66** (2024) 065019

(H. Meyer, TH/6-2 ; J. Harrison OV/4-5; S Wang Poster 2813; E. Tholerus, Poster 2899; D. Moulton Poster 3044; M.J. Kryjak)

Spherical tokamak offers advantages:
2) High normalised current

- ST geometry has high q for given $I_N = I_p/aB$
  - Provides access to high plasma current, I_p
- High normalised current gives:
  - High confinement time
  - High $\beta < \beta_N I_N$
- Puts STEP plasma in new regimes
  - Turbulence and transport, for example

(D. Kennedy, TH/6-3; L. Zanesi, Poster 2936)

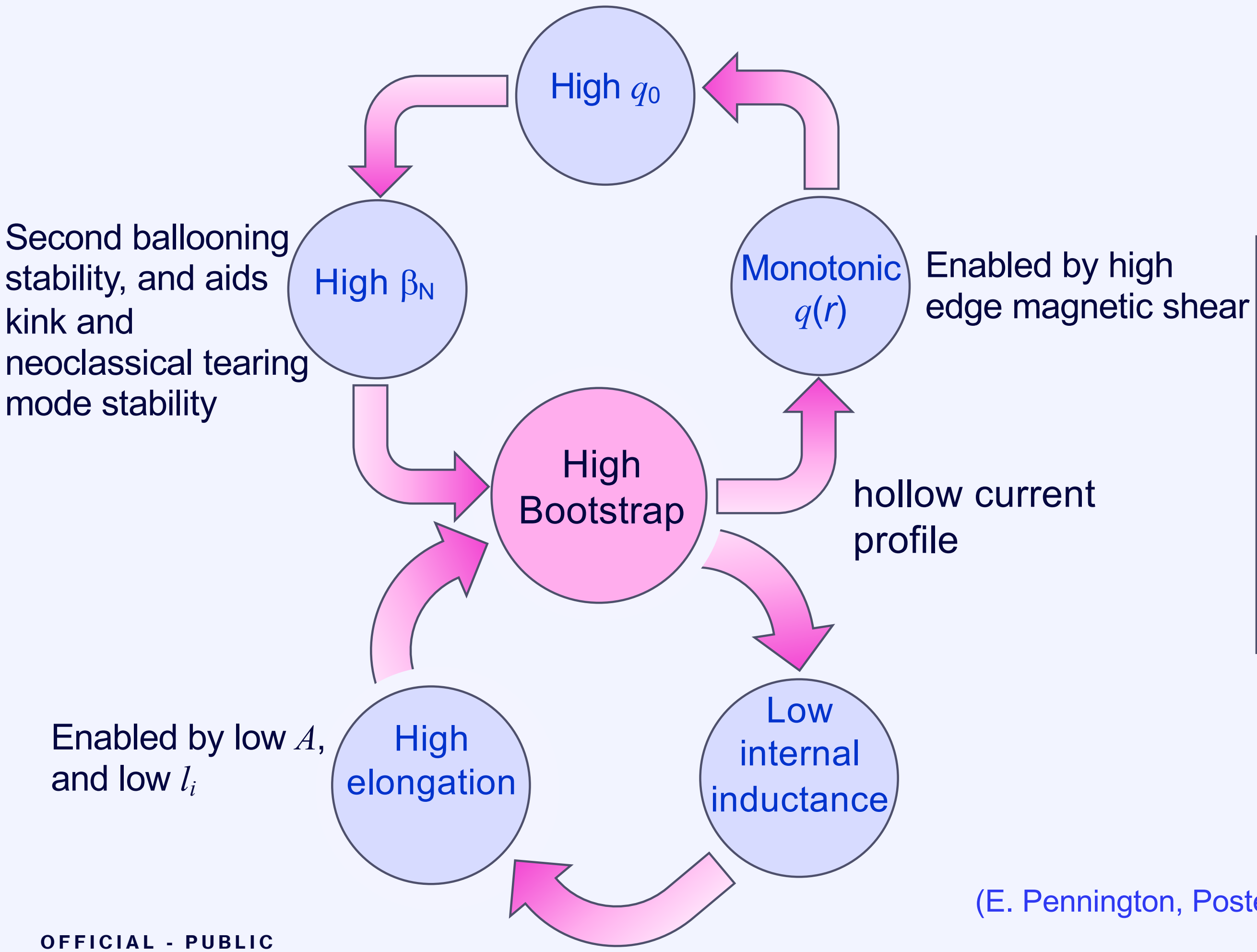


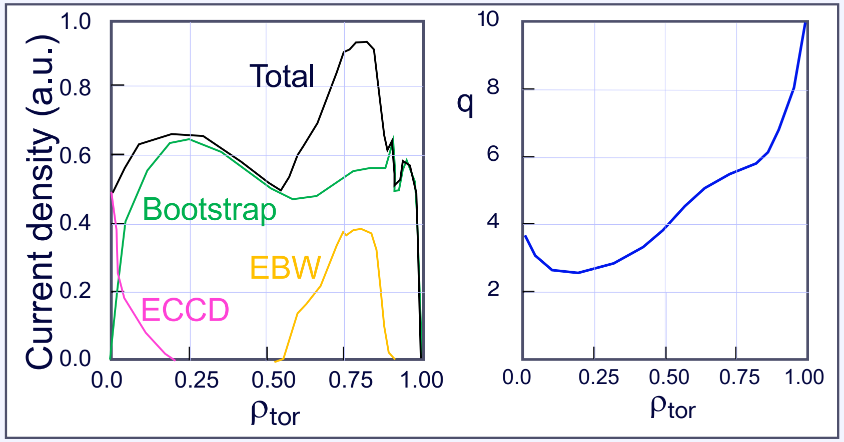
High ratio of toroidal to poloidal magnetic field on inboard side creates high q

Spherical tokamak offers advantages:
3) Steady state with ~90% bootstrap

$\propto \kappa \rightarrow \kappa^2$

$$\frac{I_{boot}}{I_p} \sim \beta_N \frac{I_{rod}}{I_p} h(\kappa)$$





- Large edge current density can be accommodated, keeping q(r) monotonic
- Remaining current can be provided by microwaves

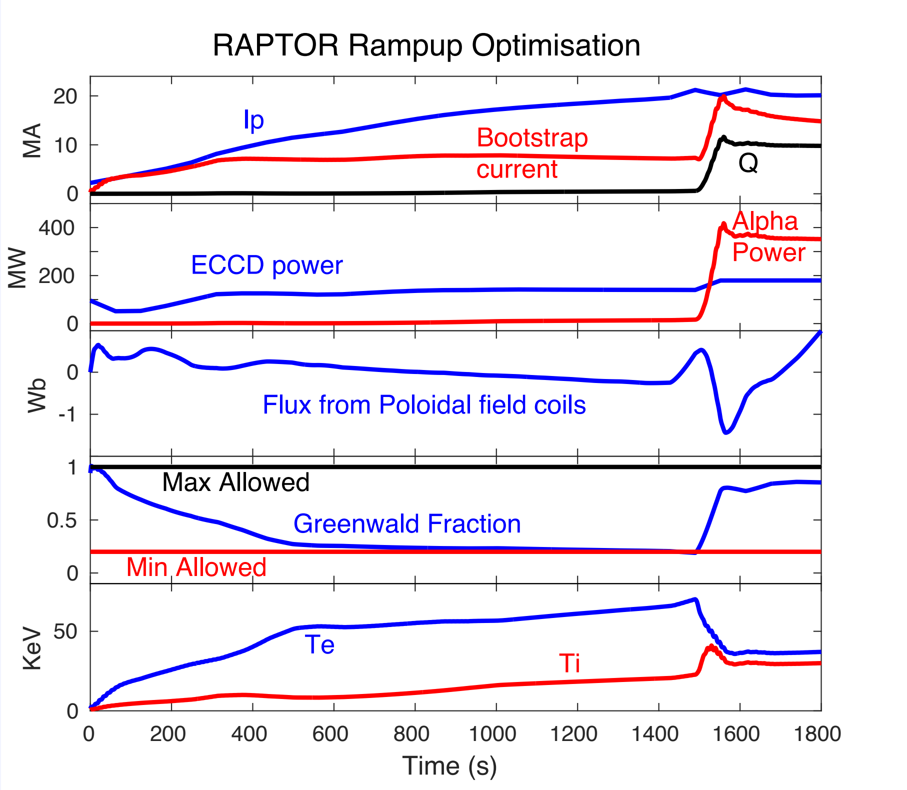
(E. Pennington, Poster 3068)

Spherical tokamak offers advantages:
3) Steady state with ~90% bootstrap

Two significant challenges with non-inductive

1. Microwaves planned for remaining 10% current is inefficient
    - Over 100MW required, driving up recirculating power
    - Electron Bernstein wave (EBW) predicted to be more efficient: validation on MAST-U planned
    - Drives R&D into higher efficiency gyrotrons
    - Improved efficiency will reduce recirculating power, opening pathways to lower P_{fus}

2. Non-inductive ramp-up is feasible, but uncertain:
    - Compact radial build leaves little room for solenoid
    - Seeking innovative ways to maximise solenoid flux swing available for initiating plasma



(H.T Kim, Poster 2754; P. Jacquet Poster 2867)

Spherical tokamak offers advantages:

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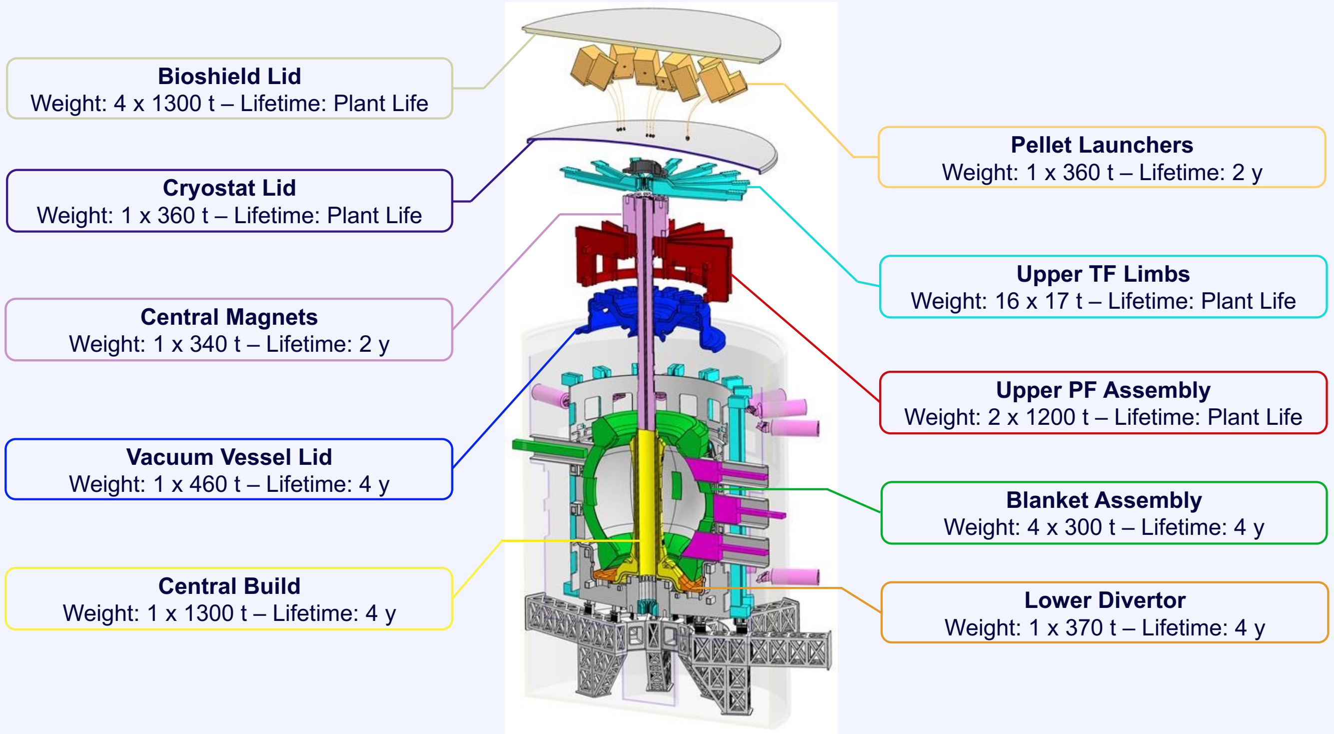
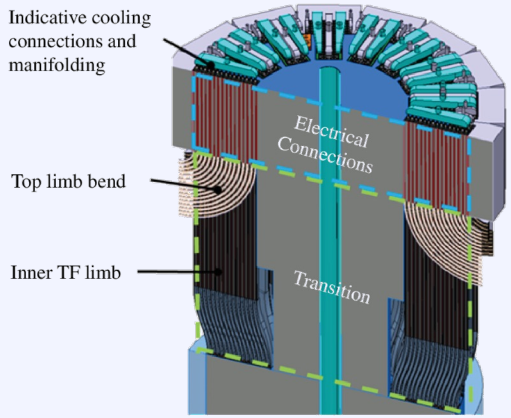
4) Novel simplified maintenance options



(R. Skilton, TEC/5-1; S. Kirk, Poster 2928)

- Removable centre stack opens up novel vertical maintenance options
- A challenge is remountable HTS joints
  - We have an encouraging solution in an advanced state of testing



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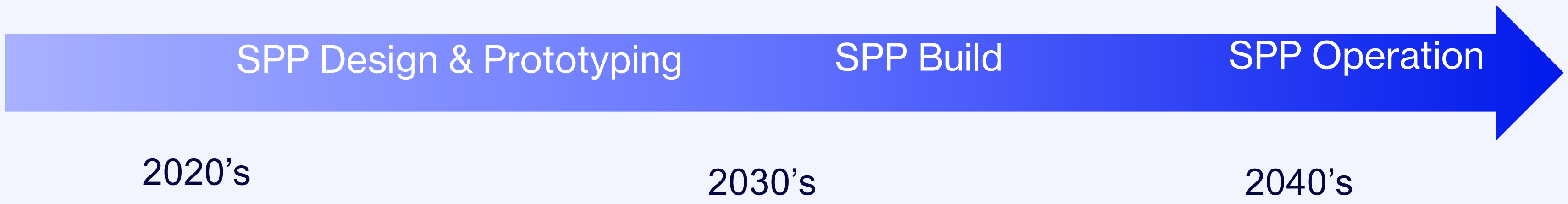
Managing Uncertainty: Science and technology advances inform design & operations



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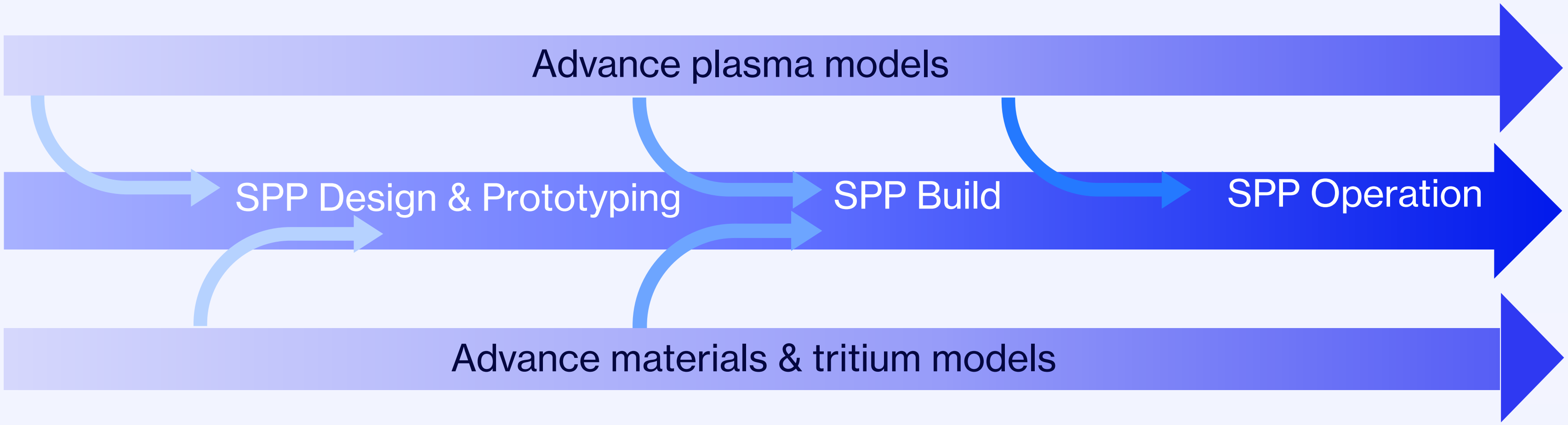
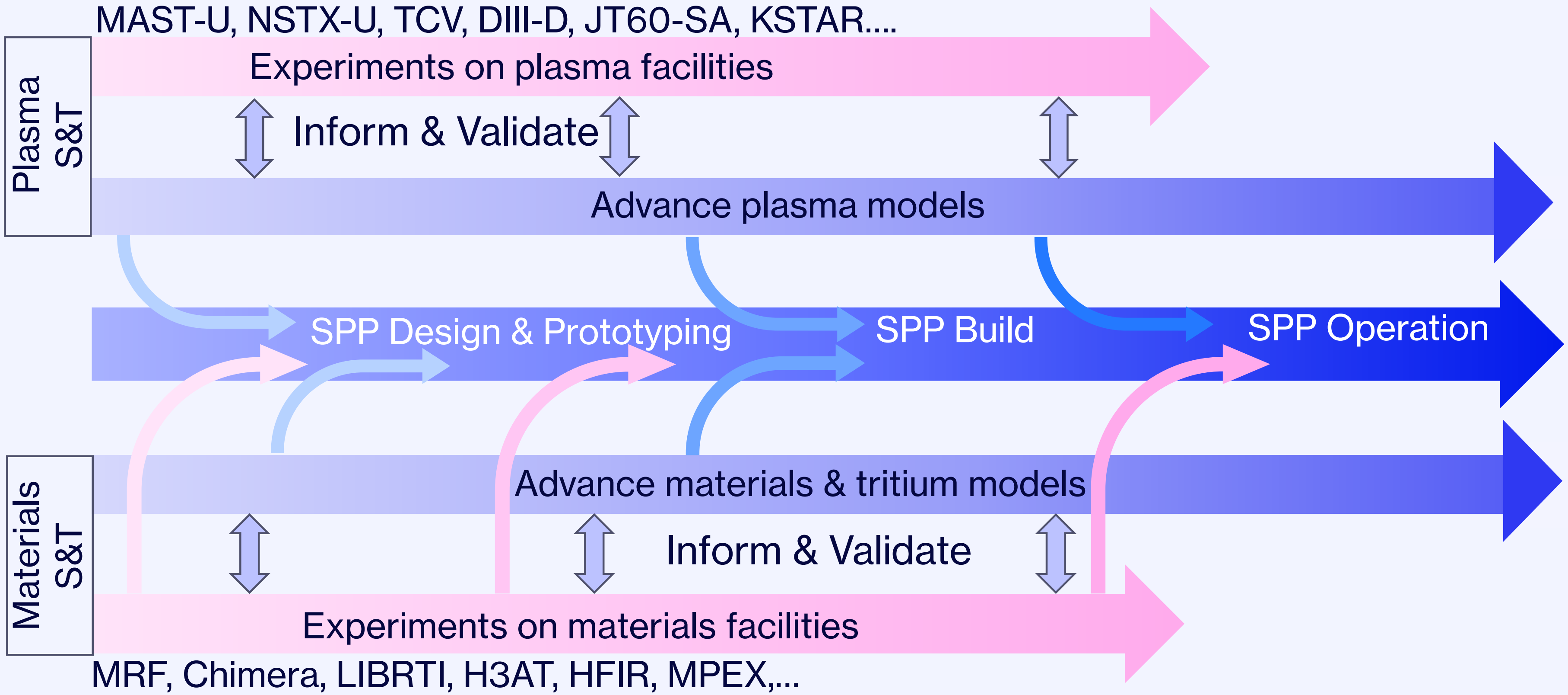


Managing Uncertainty: Science and technology advances inform design & operations



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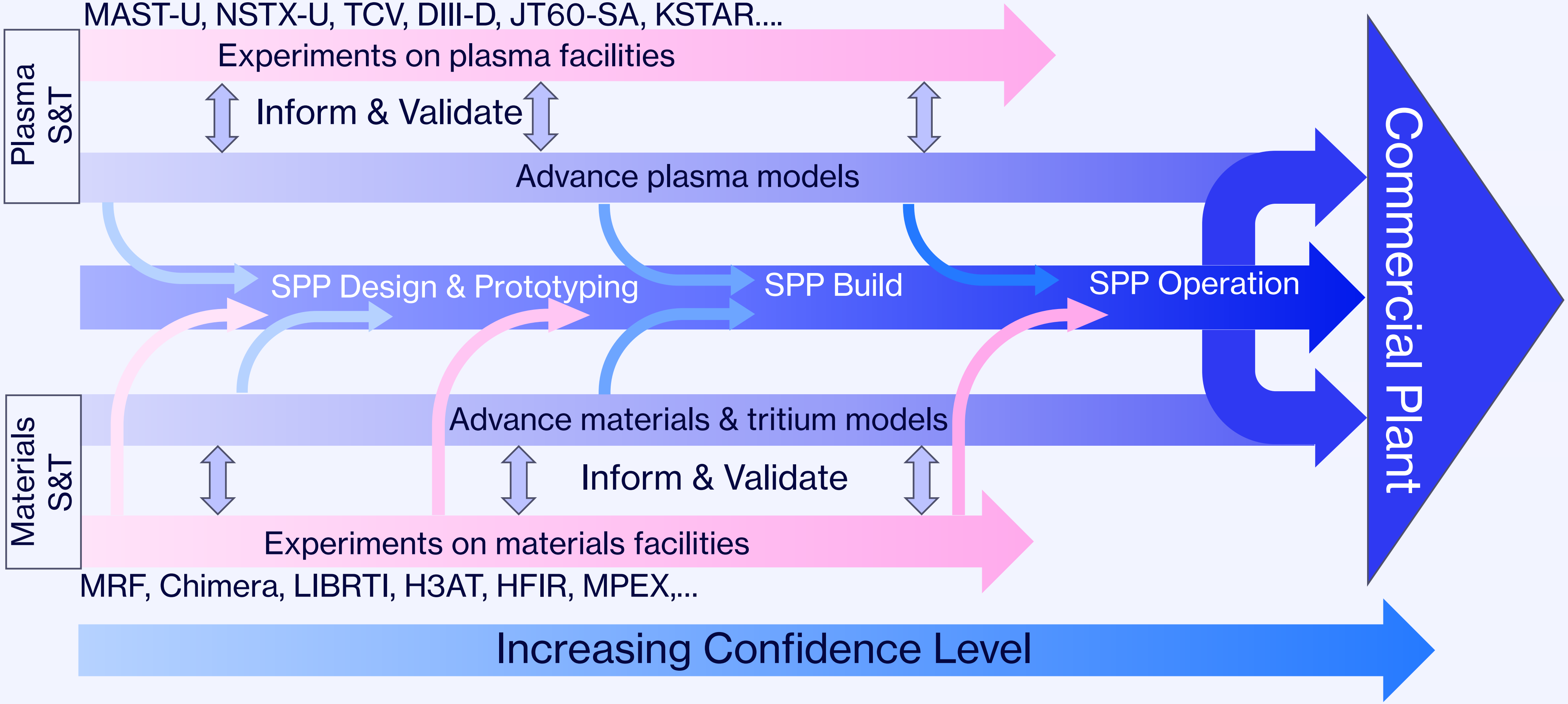

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(R. Lawless, OV/5-1)

Conclusions

- STEP adopts an holistic approach to fusion delivery
  - Delivering early benefits for stakeholders
  - Building a skilled fusion industry capability
  - Addressing technical challenges for fusion commercialisation
- The STEP Prototype Plant is the key vehicle to deliver all three
  - Exploits the advantages of the spherical tokamak
  - Will deliver 100MW net electrical power and demonstrate fuel self-sufficiency
- Meeting the 2040 timeline requires close integration between science & technology and design, engineering & testing to reduce technical risk