ENN 新奥

Overview of ENN Fusion

1. Hebei Key Laboratory of Compact Fusion
2. ENN Energy Research Institute

1. About ENN Group

新奥集团
ENN GROUP
https://www.enn.cn

ENN Group is a Chinese conglomerate that was founded in Langfang, Hebei Province in 1989 with **a mission to establish modern energy systems and improve the quality of life**. Starting as an urban gas provider, ENN gradually expands its business to cover the entire natural gas industry chain, including distribution, trade, transportation and storage and production, providing intelligent, low-carbon integrated energy solutions. ENN has also expanded into sectors such as real estate, tourism, culture, and healthcare, creating quality living habitats. In the age of digital intelligence, ENN continuously upgrades its smart city services for both households and businesses, including advanced security and carbon management solutions.

40,000+ employees

Revenue of 2023: $22.3bn

4 publicly traded companies

ENN Energy（02688.HK）

ENN Digital Technology（603869.SH）

ENN Natural Gas（600803.SH）

Tibet Tourism（600749.SH）

2.1 About ENN Energy Research Institute(EERI)

EERI was established in 2006, focusing on innovation in clean energy technology.

R&D Platforms

- State Key Laboraroty of Coal-based Low-carbon Energy
- Hebei Key Laboratory of Compact Fusion
- Internatioanl Science and Technology Cooperation Base

Team

- 300 staff members

State-funded projects

- Domestic R&D projects 20
- International R&D cooperation programs 10

Intellectual Properties

- Patents Filed 2400+
- Patents authorized 1900+

Partners

- Chinese Academy of Sciences
- Southwest Institute of Physics
- Peking University
- Tianjin University
- University of Science and Technology of China
- Xi'an Jiaotong University

（As of December 2023）

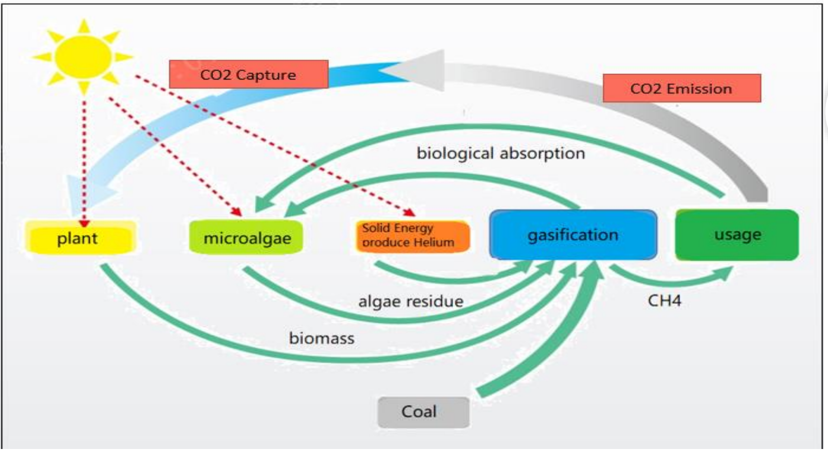
2.2 Research Areas

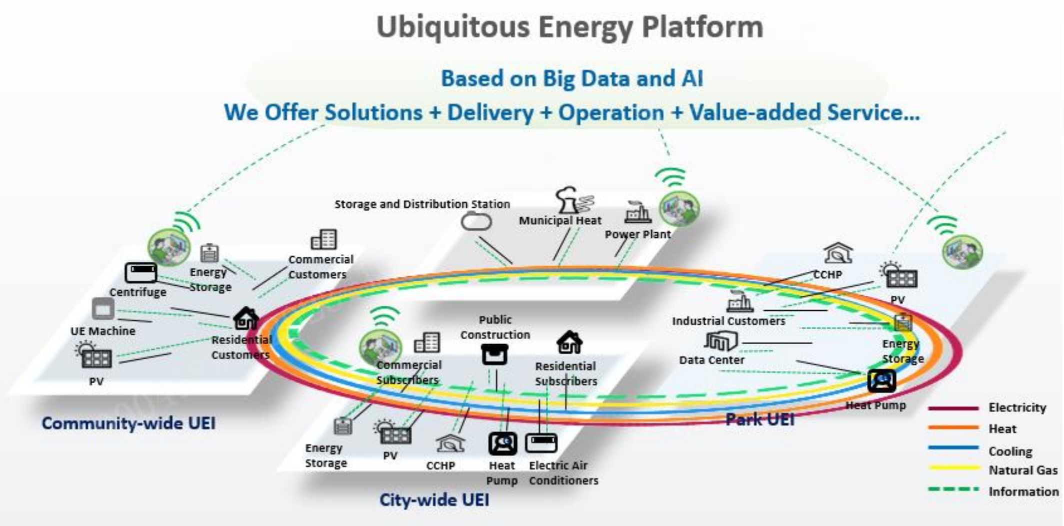
EERI 1.0 （2006-2017）

Low-carbon energy and system efficiency improvement

Clean energy/carbon recycling

- PV
- Microalgal bio-tech
- Underground coal gasification
- Catalytic coal gasification
- Coal hydro-gasification





Carbon-free

Emerging

EERI 2.0 （since 2018）

Carbon-free technology

Offer large-scale carbon-free energy production in order to decrease both energy and social costs.

Digital intelligence and carbon neutrality”

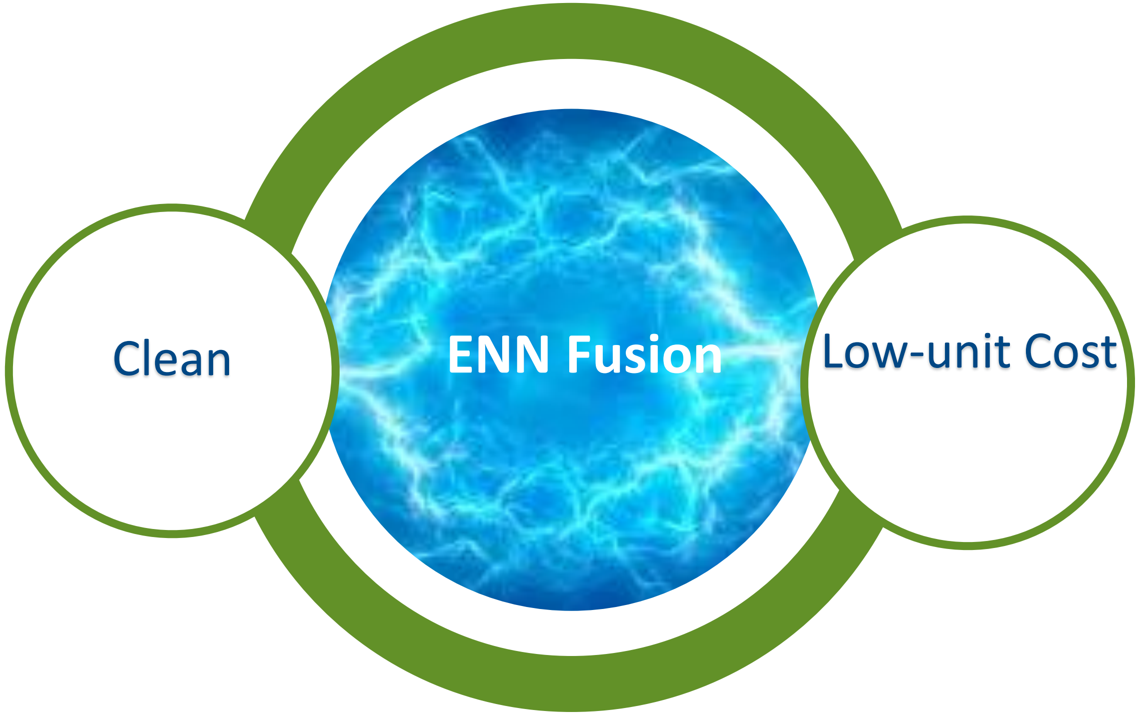
Integrate digital technology to accelerate innovation breakthroughs

In October 2018, ENN initiated the design and construction of China's first medium-sized spherical torus experimental device, known as "EXL-50" (Xuanlong-50), successfully achieving its first plasma in August 2019.

In 2022, ENN embarked on the upgrade of the device to "EXL-50U" (Xuanlong-50U) and concurrently commenced the design phase for "EHL-2" (HeLong-2).

3.1 Our goal: commercially-viable fusion

- Aneutronic
- Eco-friendly



- ✓ Low cost power generation (cheaper than wind and PV)
- ✓ Abundant and accessible fuel
- ✓ High energy conversion rate
- ✓ Suitable for distributed energy market

3.2 Fusion fuel of great promise and challenge: proton-boron

Assuming full-scale deployment in 2050 to help realize carbon neutrality

Nuclear reaction	Advantages	Challenges	Fuel Price (USD/g)	Proved Reserves
1. D-T	Lowest threshold	High energy neutron material damage, tritium processing	Tritium: 30,000	25 kg
2. D-D	Next lower threshold, low fuel cost	High energy neutrons, lower reaction cross sections	Deuterium: 4	45 trillion tons
3. D-^{3}He	Higher reaction threshold, further reduced neutron production	^{3}He expensive if mined on the Moon	^{3}He: 15000	10kg
4. p-^{11}B	Cheap fuels, photon shielding only, high leverage of direct conversion	Highest reaction threshold, highest plasma heat flux, direct conversion innovation leverage	^{11}B: 4	1 billion metric tons

- High world R&D resources allocated for fusion energy: materials, tritium management, large complex fusion core equipment
- T and ^{3}He fuels are materials controlled by governments.

3.3 ST can boost p-B potential for fusion commercialization with challenges

ST features high beta and potentially high confinement

Tokamak beta 1-2%

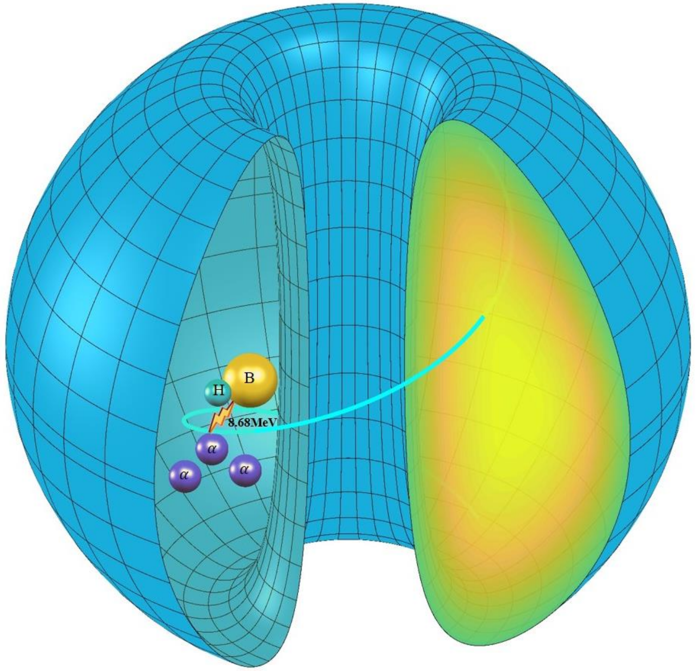
$$\tau_E^{IPB98\mathbf{y2}} = 0.0562 I^{0.93} B^{0.15} P^{-0.69} n^{0.41} M^{0.19} R^{1.97} \varepsilon^{0.58} \kappa_a^{0.78}$$

Kurskiev22

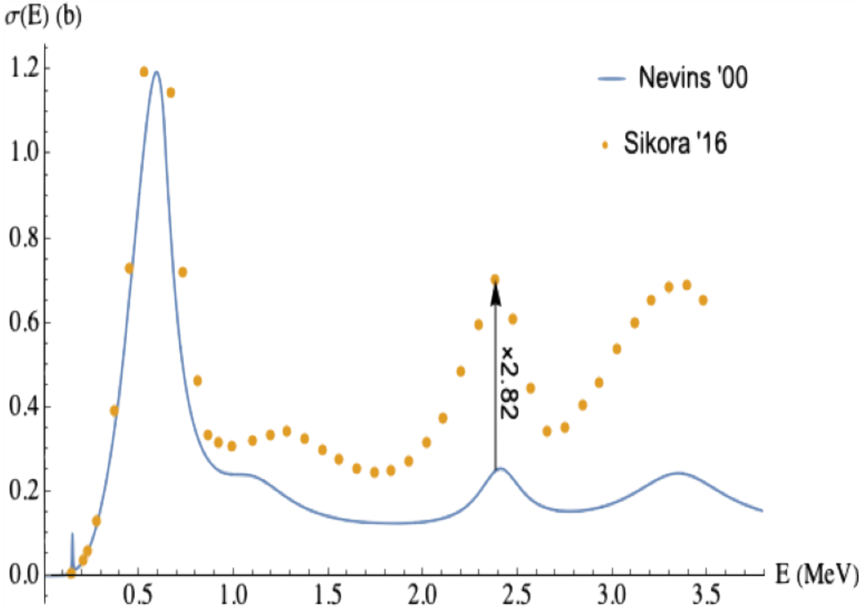
ST beta 20-40%

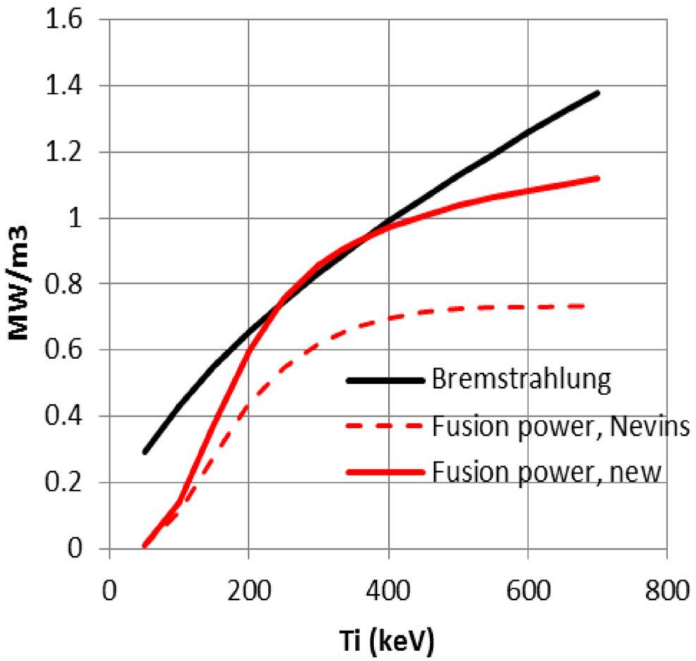
$$\tau_{\mathrm{E}}^{ST} = 0.066 I_{\mathrm{p}}^{0.53} B_{\mathrm{T}}^{1.05} P^{-0.58} n^{0.65} R^{2.66} \kappa^{0.78}$$

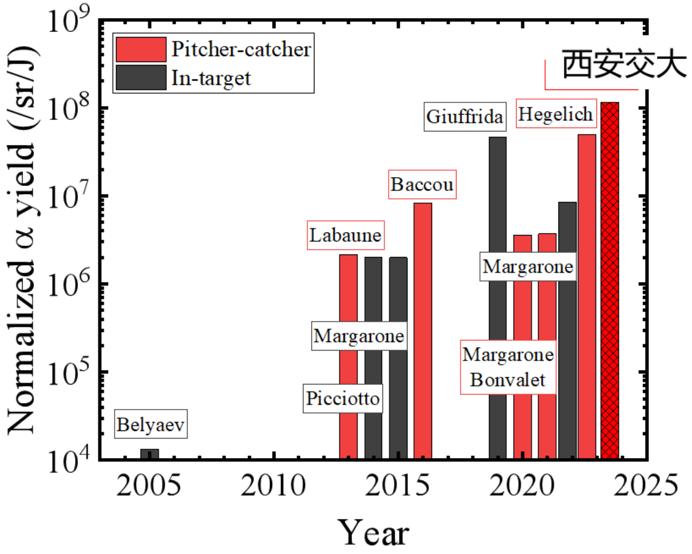
	p-B fusion	**ST**
Challenges	High fusion triple product High radiation loss	Limited central post space
Advantages	No need for neutron shielding and fuels breeding	Higher confinement Lower magnetic field lower radiation loss



3.4 Recent experiments improve prospect for magnetic p-^{11}B ignition



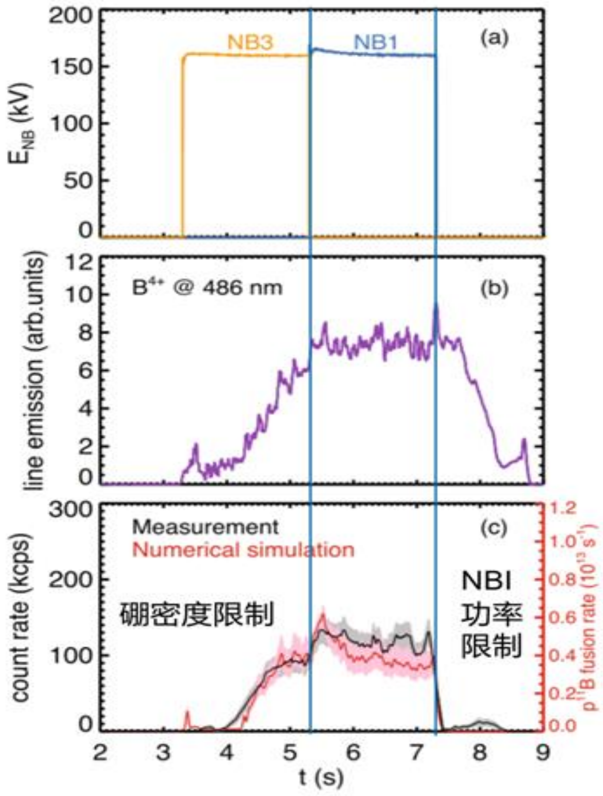




- ➢ Cross section remeasured within 0.14 MeV < E_{cm}<3.5 MeV shows a significant higher result (50%-200%) than previous at E > 400keV.
- ➢ Updated cross-section measurements provide new insight into p-^{11}B fusion ignition conditions. [Putvinski, 2019]
- ➢ In laser driven p-^{11}B experiments, nonlinear increase of α particle yield verse proton beam current has been observed, indicating a possible new mechanism for improving reaction rate.

3.5 NBI based on negative ion sources have been used on LHD to achieve hydrogen-boron fusion reactions

- **Positive result supporting the viability of ST p-B fusion approach.**
- **An essential prerequisite to designing higher performance magnetic confinement p-B systems.**



- Tri Alpha Energy proposed the LHD hydrogen-boron reaction experiment plan, with feasibility evaluation in 2021 and results published in Nature Communications in 2023.
- The paper presents first measurements of p11B fusion in a magnetically confined plasma. The yield of the hydrogen-boron reaction increased with rising boron ion density while maintaining NBI power, and terminated quickly when NBI was turned off, verifying the realization of p-B fusion reactions.
- Time coincidence consistent with theoretical expectations.

3.6 Roadmap for p^{11}B fusion power based on spherical torus

Commercial Demonstration Reactor 2035-

2035 **Fusion power generation**

- **Achieving cost-effectiveness to drive commercialization**
  - ➢ Leveraging technological innovations
  - ➢ Ensuring operational stability and reliability

Engineering Validation Platform (EHL-3A&3B) 2027-

- **Achieving p^{11}B combustion and demonstrating power generation**
  - ➢ Optimizing parameters to address engineering scale-up challenges
  - ➢ Attaining an energy gain in p^{11}B fusion (Q>3)

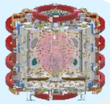
Thermonuclear Physics Experimental Platform (EHL-2) 2023-

- **Comprehensively validating the feasibility of p^{11}B thermonuclear reaction**
  - ➢ Validating key technologies with high ion temperature
  - ➢ Assessing the viability of increasing p^{11}B fusion reaction rates

✓ **EXL-50U 2022-**

- **Exploring key technologies for ST p^{11}B fusion**
  - ➢ Enhancing Plasma Parameters
  - ➢ Achieving Stable Control of Plasma

✓ **EXL-50 2018-2023**

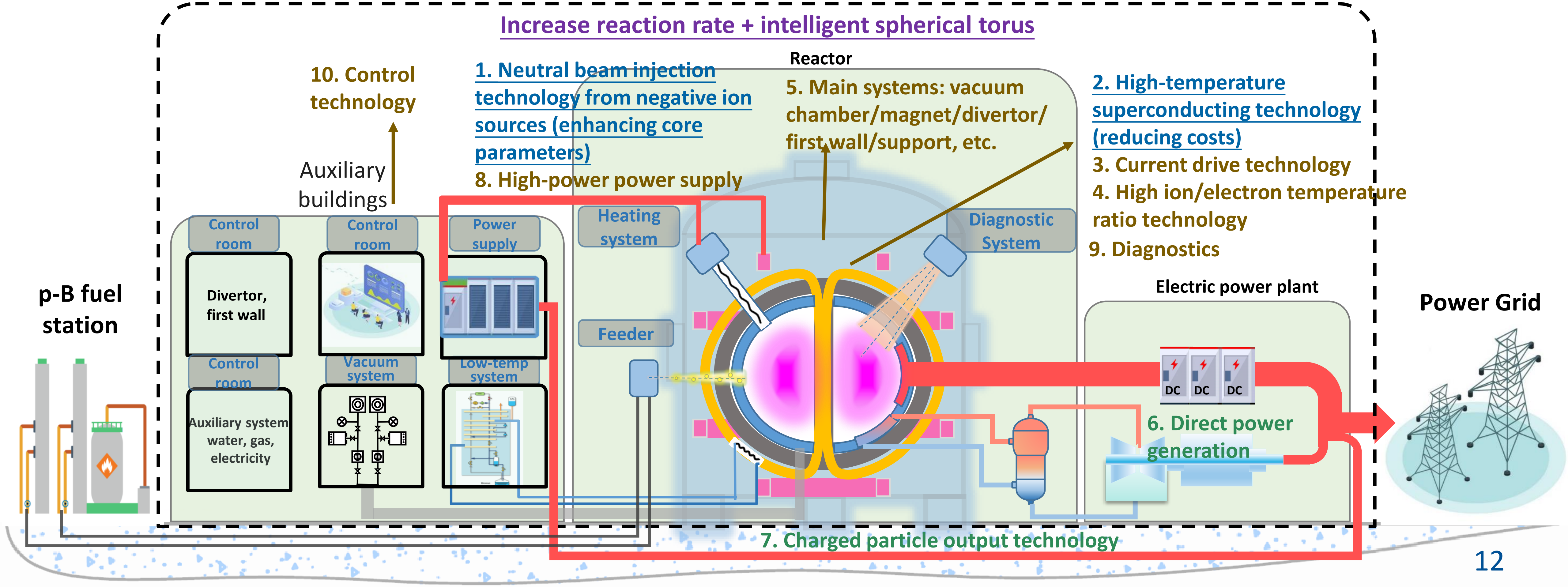


- **Established the basis of ST p^{11}B fusion**
  - ➢ Comprehending p^{11}B fusion process
  - ➢ Cultivating skills in experimental device assembly

3.7 Core technologies to be explored

- ➢ Purple-core technologies for the commercialization route.
- ➢ Blue color-key technologies that need to be launched in advance
- ➢ Brown-main technologies for the construction and operation of each generation of fusion device.
- ➢ Green-future product-end technologies

Diagram of p-B fusion power plant



Increase reaction rate + intelligent spherical torus

10. Control technology

Auxiliary buildings

1. Neutral beam injection technology from negative ion sources (enhancing core parameters)

8. High-power power supply

Reactor

5. Main systems: vacuum chamber/magnet/divertor/ first wall/support, etc.

2. High-temperature superconducting technology (reducing costs)

3. Current drive technology

4. High ion/electron temperature ratio technology

9. Diagnostics

Electric power plant

Power Grid

p-B fuel station

Control room

Divertor, first wall

Control room

Auxiliary system water, gas, electricity

Control room

Vacuum system

Power supply

Low-temp system

Heating system

Feeder

Diagnostic System

DC

DC

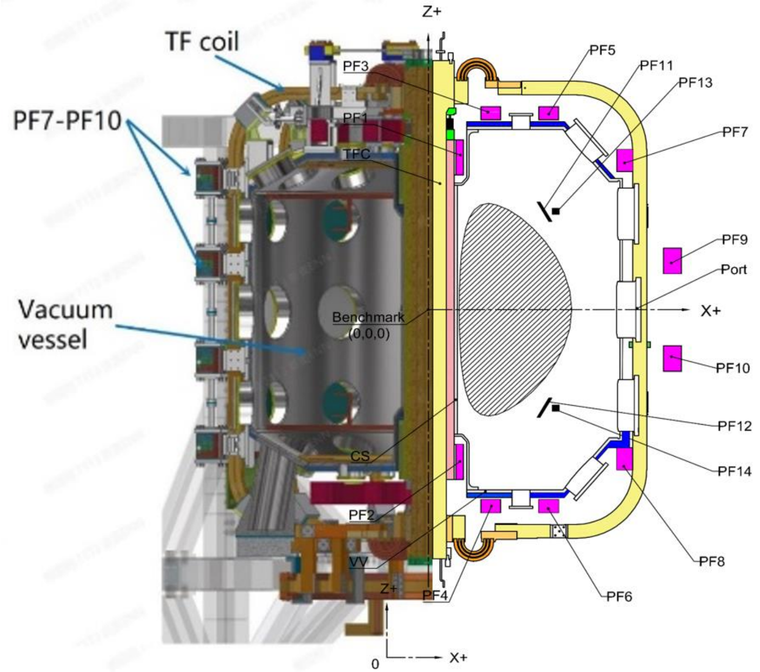
DC

6. Direct power generation

7. Charged particle output technology

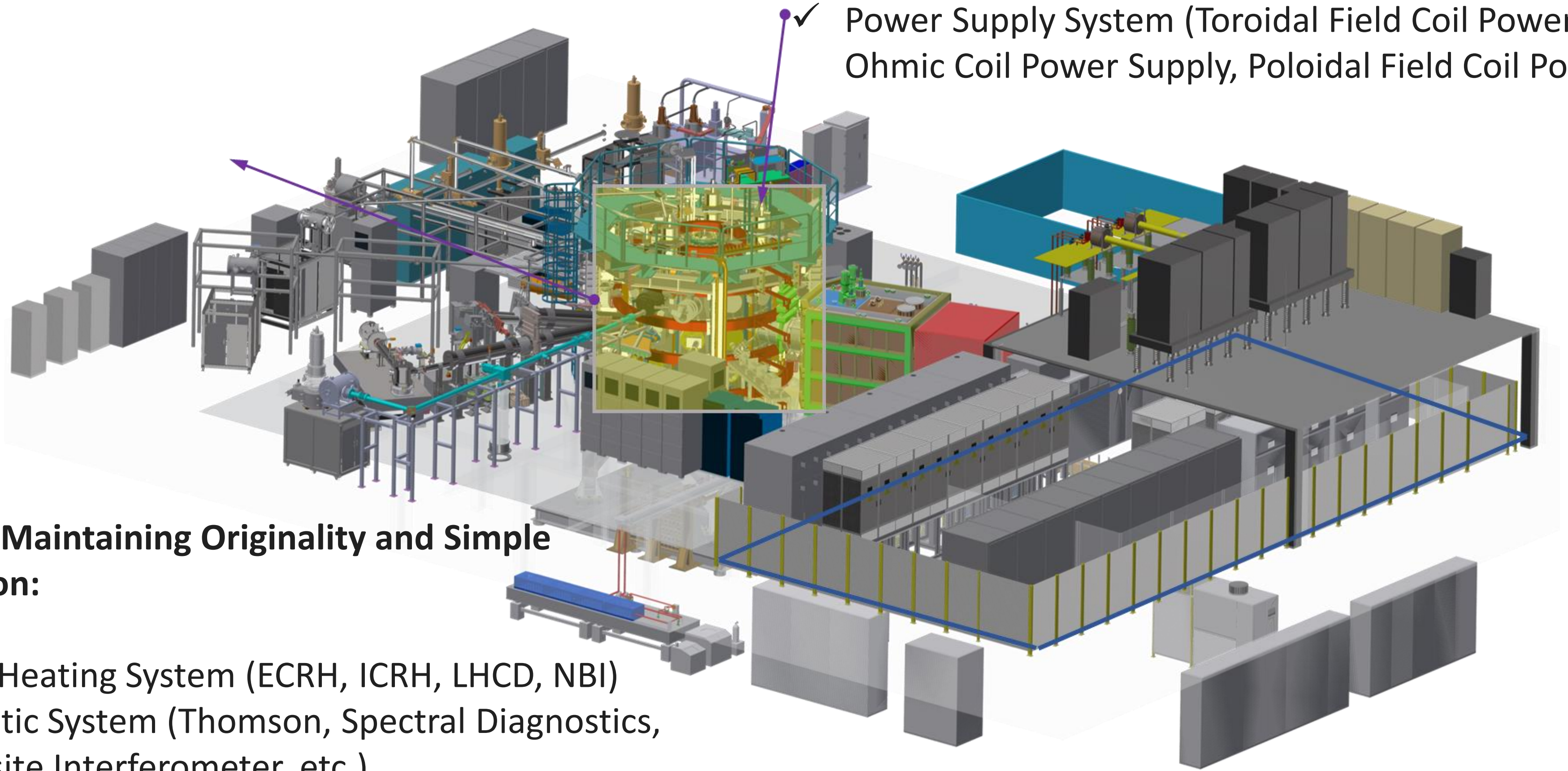
4.1 EXL-50 upgrades

Parameters	EXL-50	EXL-50U
R (m)	0.5	0.6~0.8
a(m)	0.32	0.32~0.5
R/a	1.5	1.4~1.85
k	2.0	2.0
Ip （MA）	0.2	0.5~0.7
B_T (T)	0.5@R=0.5m	1.2@R=0.6m
Heating Power (MW)	1.5	7
Discharge time t_d （s）	5@0.5T 10@0.3T	2@1.2T
n_{e0} ($10^{19}m^{-3}$)	1	8
T_{i0} (keV)	0.3	5



First wall:
Phase 1: W limiter & Diverter +SS vacuum
Phase 2: Carbon limiter after July. 2024

4.2 Schematic diagram of EXL-50U fusion device (Dec. 2023)



Replacement or Addition of Systems:

- ✓ Primary System (Magnetic Coil, Vacuum Chamber & Support)
- ✓ Power Supply System (Toroidal Field Coil Power Supply, Ohmic Coil Power Supply, Poloidal Field Coil Power Supply)

System for Maintaining Originality and Simple Optimization:

- ✓ Plasma Heating System (ECRH, ICRH, LHCD, NBI)
- ✓ Diagnostic System (Thomson, Spectral Diagnostics, Composite Interferometer, etc.)
- ✓ Control System
- ✓ Auxiliary System (Vacuum Pumping, Cooling, Heating)

Scan the qr code to see the facility

4.3 Timeline of EXL-50U

Launch the EXL-50U Project

Physics Design

Manufacture of Main Components

Vacuum Pumping and Baking

First Plasma

2022.07 2022.12 2023.10 2023.12.31 2024.01.20

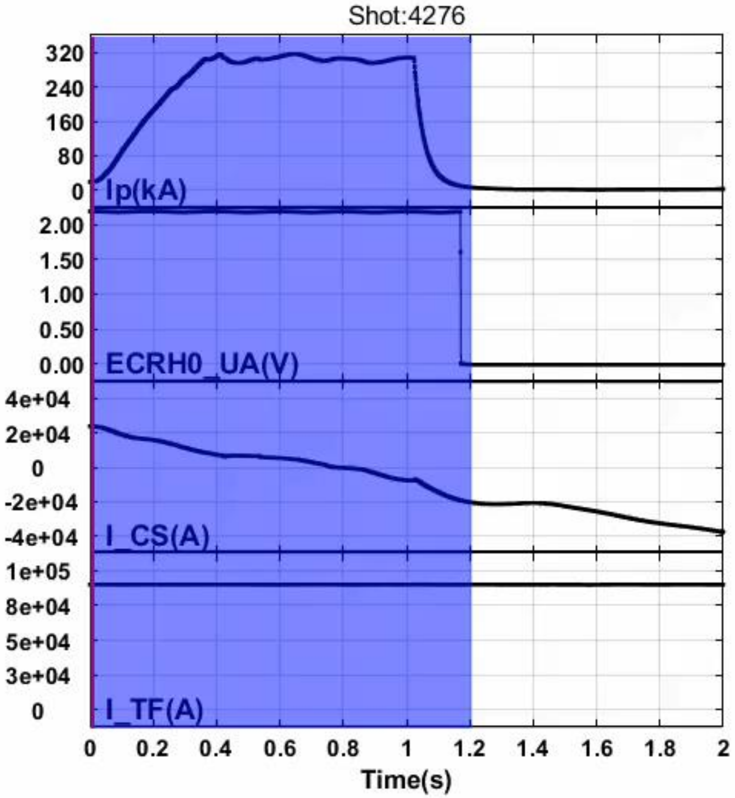
Engineering Design

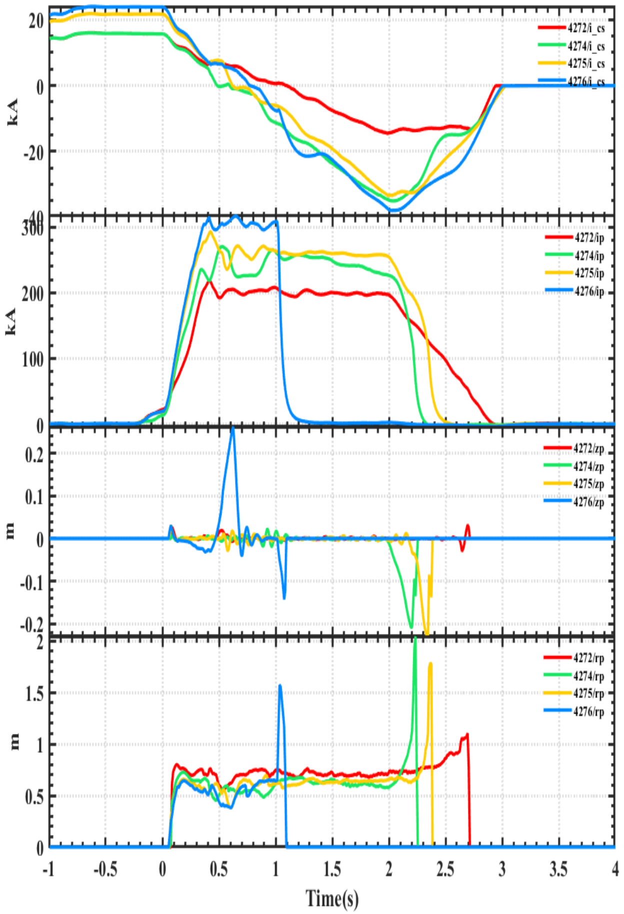
Upgrade of Power Supply, Heating and Diagnostics

Machine Assembly

Testing of Power Supply

4.4 Experiment progress of EXL-50U (May 2024)



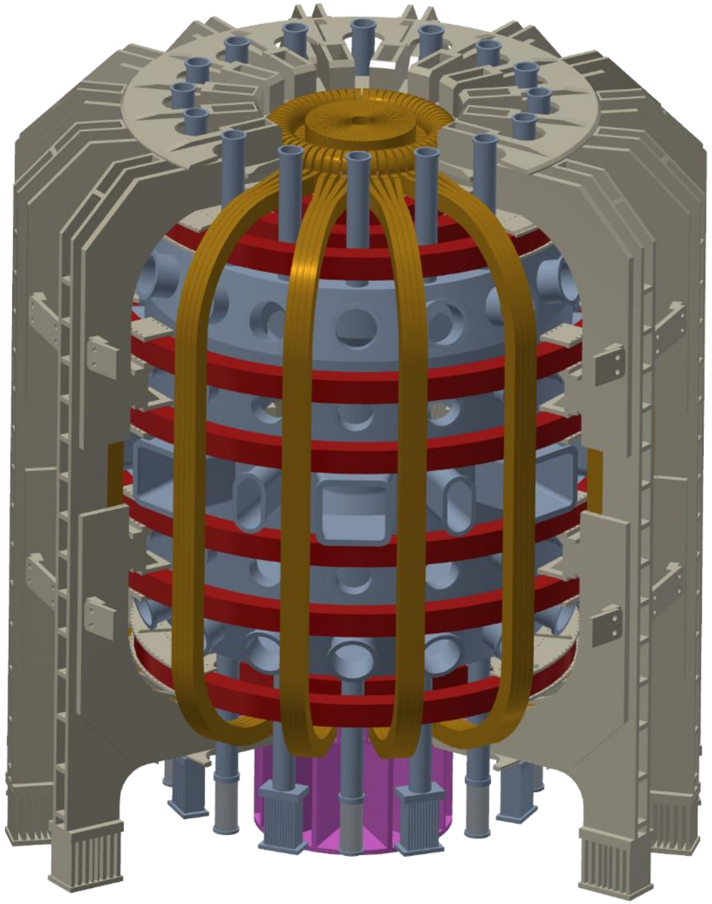


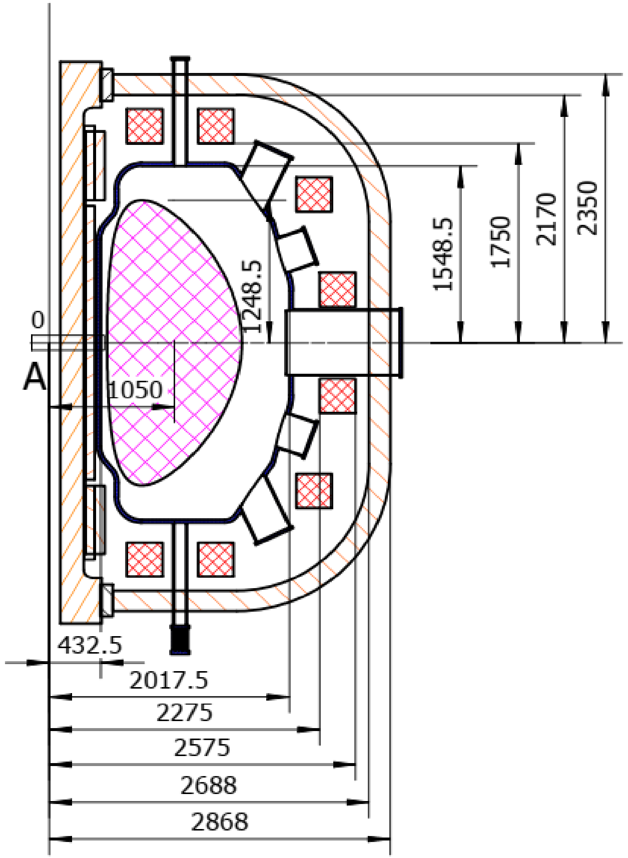
- Start-up with EC+ CS
- Plasma current 150~300kA with stable Ip-RZ feedback control
- Max Ip=316kA for 500ms
- Typical density $0.5\times10^{19}m^{-2}$, Temperature Ti~300eV, Ti~1keV
- NBI in recent weeks

Discharge Video

5. Next generation ST device for p-B plasma research (EHL-2，ENN Helong 2)

A high-performance ST p-B fusion device EHL-2 is expected to achieve its first plasma in around 2027.





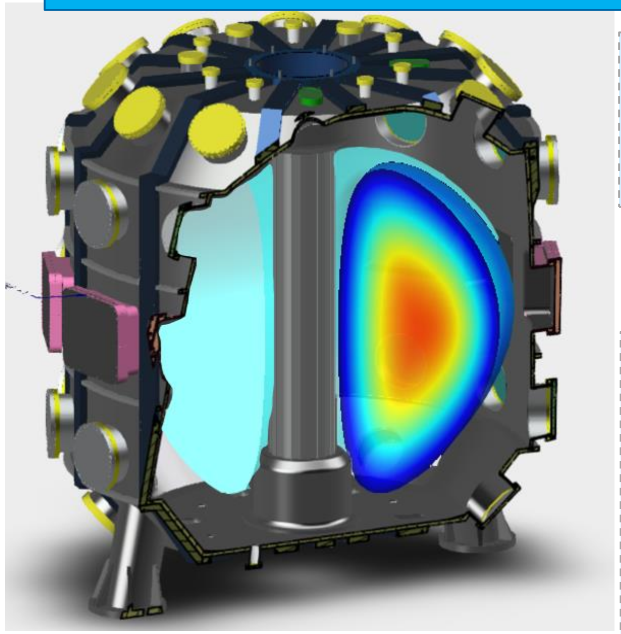
Parameters	EHL-2 (Ver0)
Avg./Peak ion temperature T_i(keV)	-/30
Avg./Peak density n_e(m^{-3})	-/1.3e20
Confinement time τ_E(s)	0.5
Beta β	0.11
Magnetic field B_0(T)	3.0
Major radius R_0(m)	1.05
Aspect ratio A	1.85
Heating power P_{heat}(MW)	17
Plasma current I_p(MA)	3.0
Hot ion mode T_i/T_e	3

6. Advance fusion power with digital intelligence

To realize intelligent simulation design, operation control, and experimental analysis of the spherical torus device, integrating physics, diagnosis, and control.
To expedite device design, enhance device design reliability, accelerate analysis and comprehension of experimental results, and accomplish intelligent device control.

Digitize actual experiments and perform them on the computer

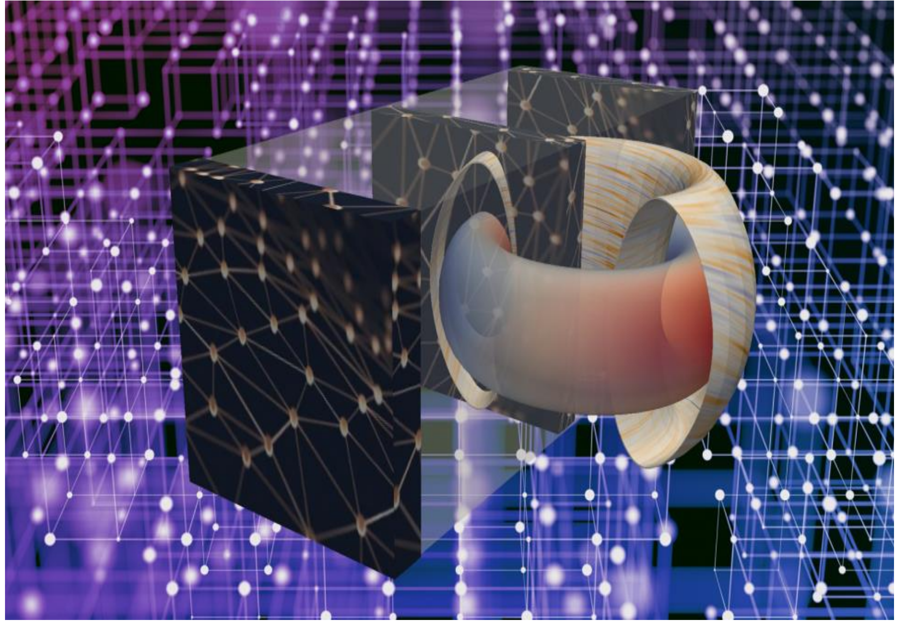
Construction, operation, and maintenance of these systems are time-consuming, labor-intensive, and constrained by current engineering technologies.



ST experimental platform (Real scenario)

Modify the computational model

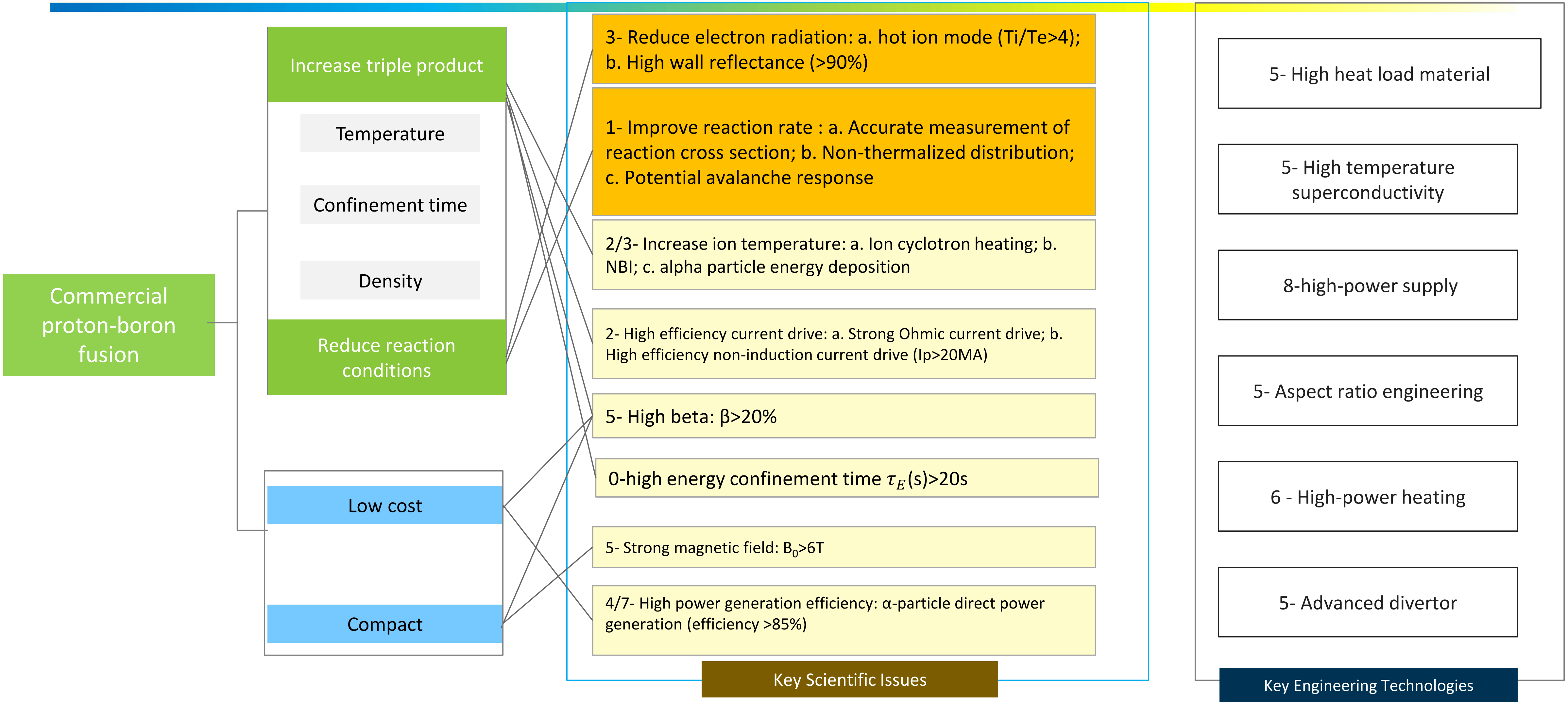
- Simulation design experiments
- Experiment analysis
- Intelligent control



Intelligent ST experimental platform (Virtual)

It is flexible, capable of intelligent evolution, and able to extrapolate and predict without being constrained by current engineering technologies.

7. Major technical challenges remain to be overcome



Commercial proton-boron fusion

Increase triple product

Temperature

Confinement time

Density

Reduce reaction conditions

Low cost

Compact

3- Reduce electron radiation: a. hot ion mode (Ti/Te>4); b. High wall reflectance (>90%)

1- Improve reaction rate : a. Accurate measurement of reaction cross section; b. Non-thermalized distribution; c. Potential avalanche response

2/3- Increase ion temperature: a. Ion cyclotron heating; b. NBI; c. alpha particle energy deposition

2- High efficiency current drive: a. Strong Ohmic current drive; b. High efficiency non-induction current drive (Ip>20MA)

5- High beta: β>20%

0-high energy confinement time τ_E(s)>20s

5- Strong magnetic field: B_0>6T

4/7- High power generation efficiency: α-particle direct power generation (efficiency >85%)

Key Scientific Issues

5- High heat load material

5- High temperature superconductivity

8-high-power supply

5- Aspect ratio engineering

6 - High-power heating

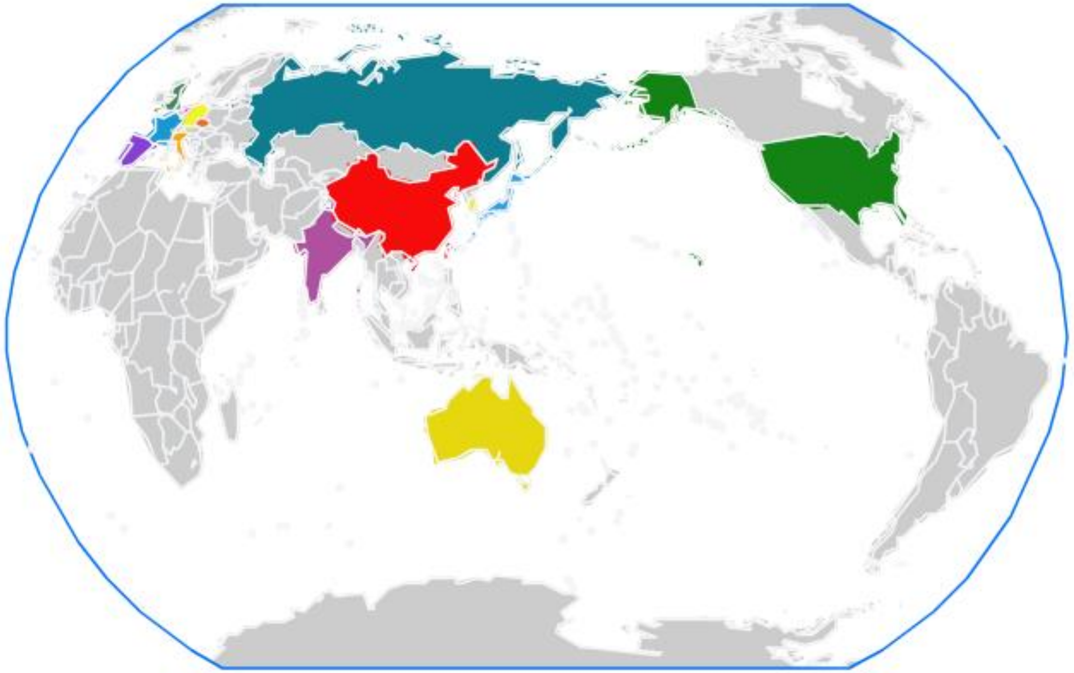
5- Advanced divertor

Key Engineering Technologies

- Primary factors are interactive. Achieving a technological breakthrough may lead to a reduction in other technical requirements accordingly.

8. Cooperation, Collaboration, Moving Fusion Energy R&D Forward

- Promote an efficient, cost-effective clean fusion R&D effort，as a member of fusion community
- Learn by doing, drawing from fusion, high-energy particles, laser and materials expertise
- Engage experts from universities, laboratories, industries, power companies and private enterprises



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9. ENN Fusion Team

Powering a Better Future

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