ENN Fusion Technology Overview

Hebei Key Laboratory of Compact Fusion, Langfang, China

ENN Fusion Technology R&D Center (ENN-FTRC)

Minsheng Liu (刘敏胜)，July 12, 2022

WHO WE ARE

Established in 1989, ENN Group is a Chinese conglomerate committed to establishing modern energy systems and improving quality of life.

Employees:

40,000+

3 In-House Institutes

- ★ Energy Research Institute
- ★ Digital Research Institute
- ★ Institute of Life S&T

4 Publicly Traded Companies

- ★ ENN Energy Holdings 新奥能源（02688.HK）
- ★ ENN Ecological Holdings 新奥股份（600803.SH）
- ★ ENC Digital Technology 新智认知（603869.SH）
- ★ Tibet Tourism 西藏旅游（600749.SH）

ENN Energy Research Institute (EERI)

The ENN Energy Research Institute is ENN's innovation engine that is committed to addressing humanity's energy challenges.

Team

500+ Researchers

Partners

MIT
UCLA
University of Tokyo
Tsinghua University
Peking University
……

Intellectual Properties

Issued Patents 1600+
Utility Patents 800+

Innovation Platform

State Key Laboratory for Coal-based Low Carbon Energy
Hebei Key Laboratory of Compact Fusion
International Scientific and Technological Collaboration Base
Post-Doctoral and Academician Work Station
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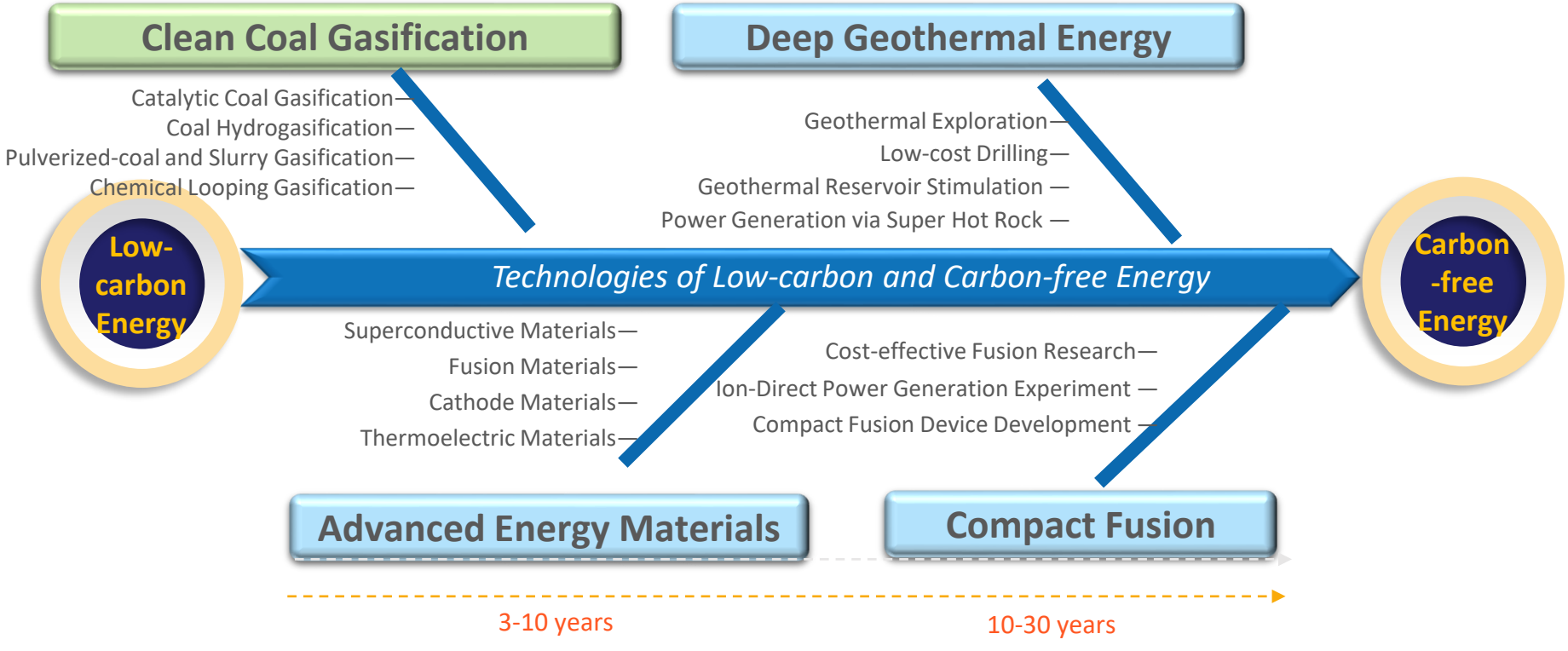
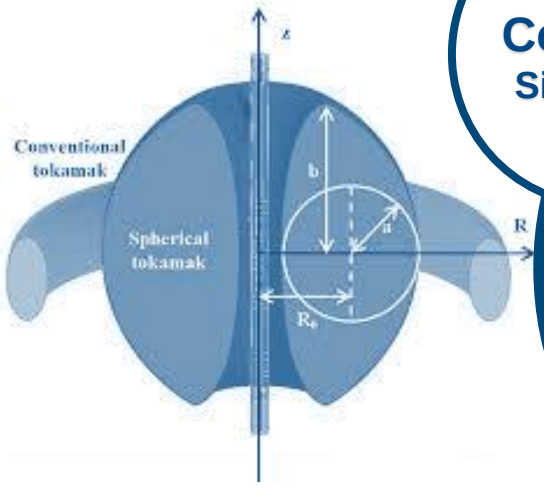
Research Areas

To Embrace a Carbon-free Future with Disruptive Innovations



Compact Clean Commercial Power, Starting with Spherical Tokamak

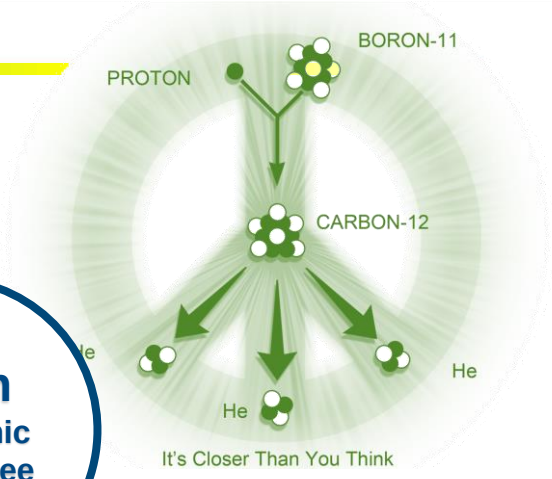


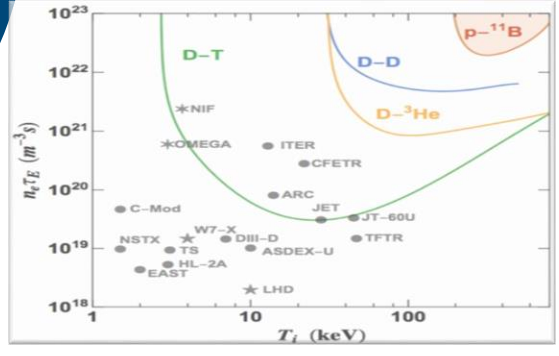
Compact
Simplified

Fusion
ENN

Clean
Aneutronic
Tritium-free

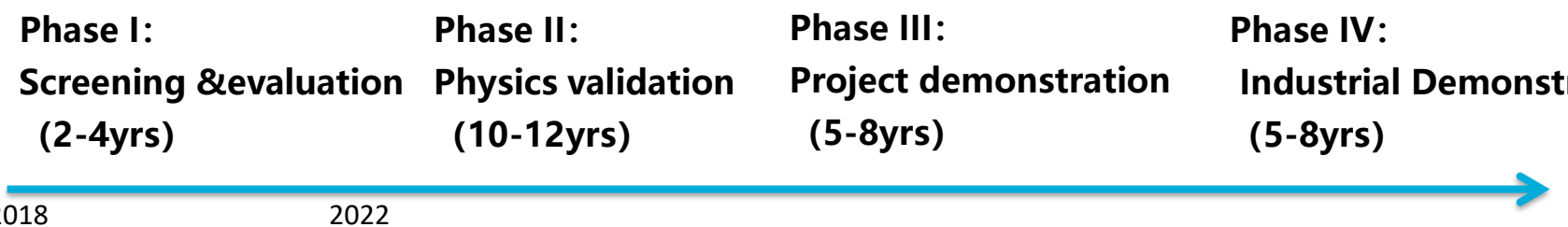
Low Unit Cost
Mass Produced



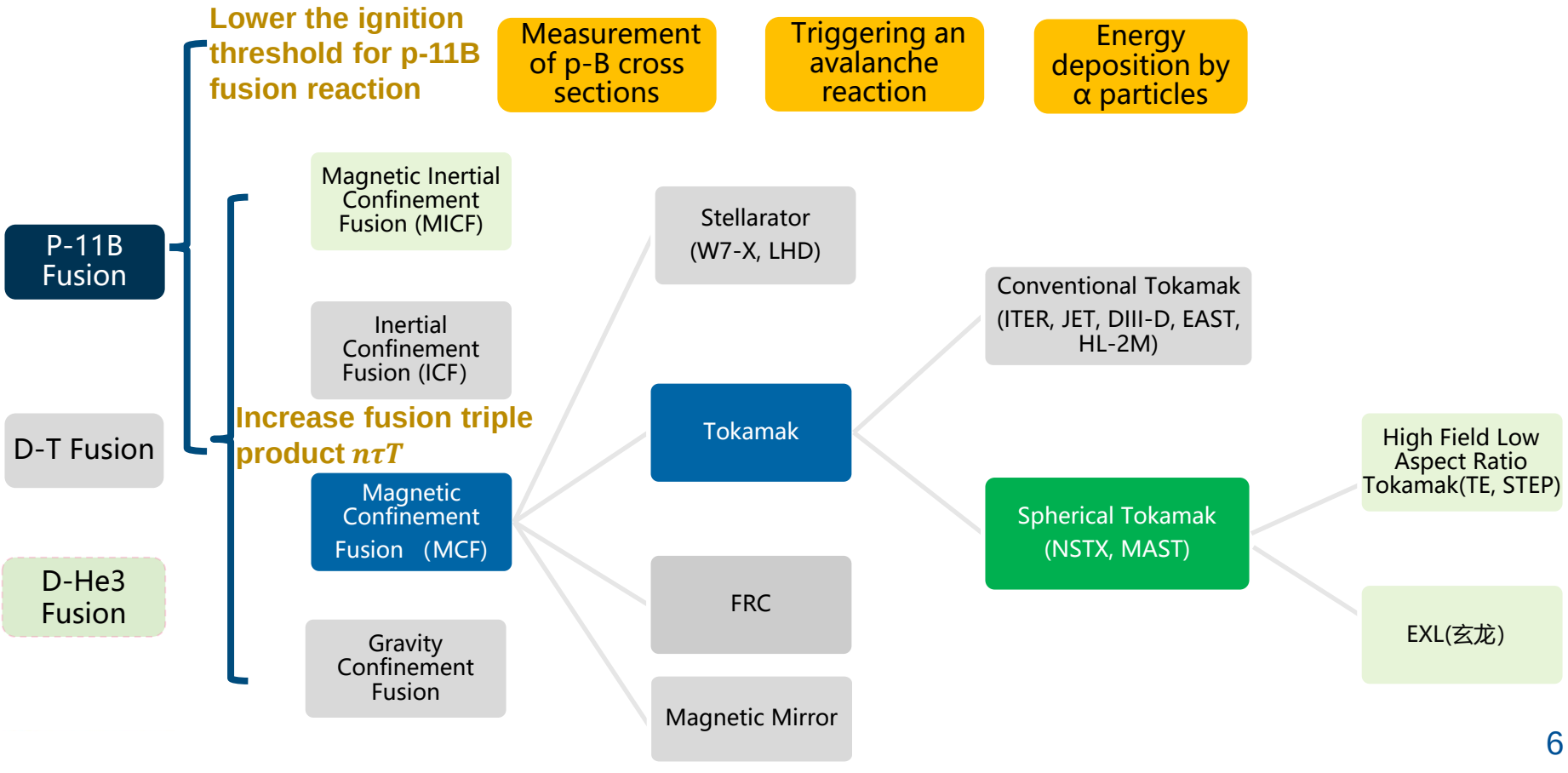


ENN Compact Fusion Timeline

Conduct Scientific Feasibility Study | **Address Engineering Challenges** | **Improve Cost Effectiveness**



Explore P-11B Fusion based on Spherical Tokamak

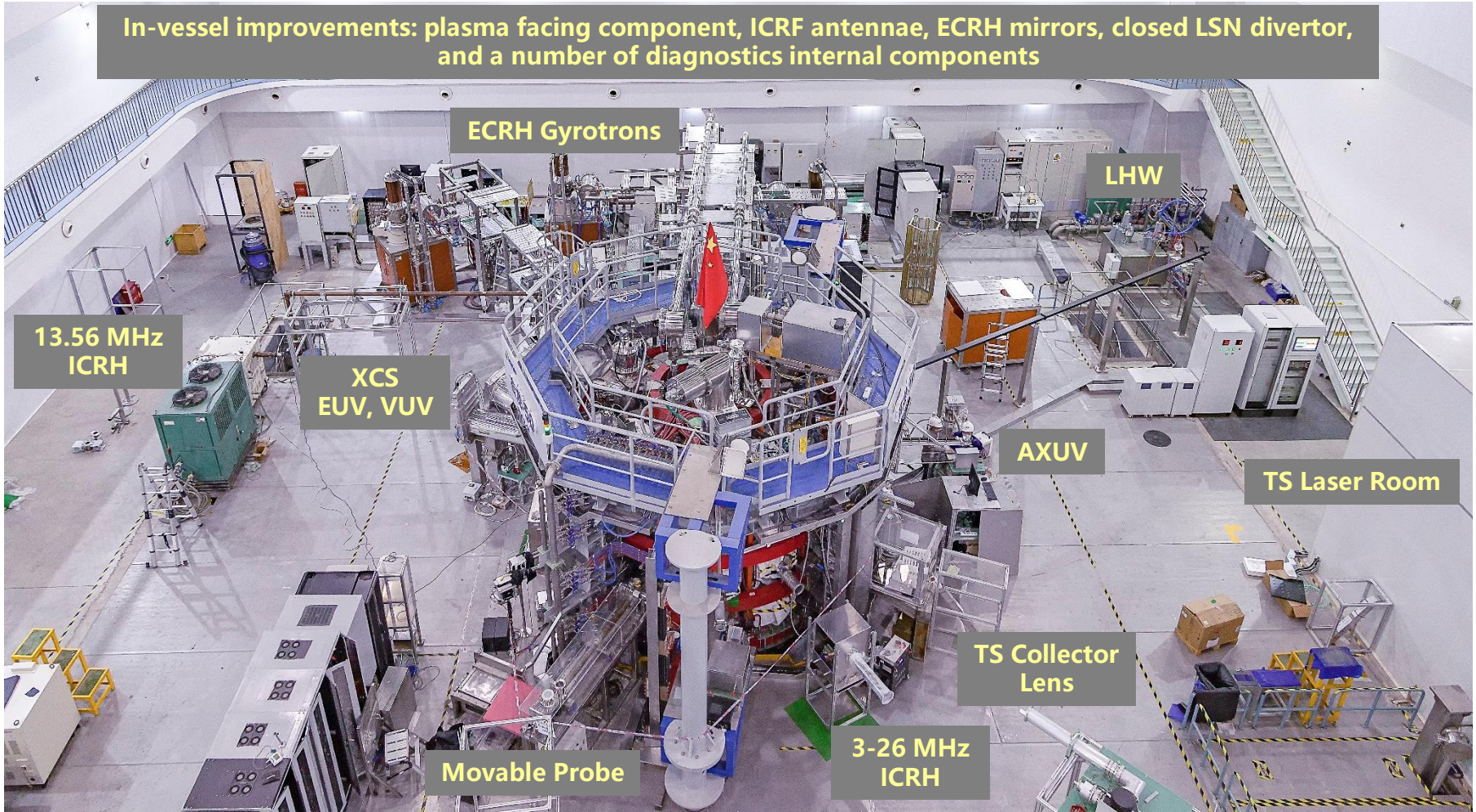


EXL-50 Proof-of –Principle Experimental Platform

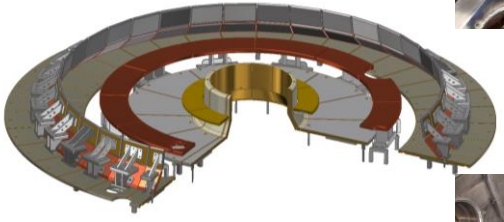
Parameters	Technical Goals
Plasma Current I_p	500 kA
Toroidal Field B_T	0.46 T
Major Radius R	0.58 m
Minor Radius a	0.41 m
Elongation k	1.8-2.2
Triangularity δ	0.1-0.4
Plasma Density	10^{19} m^{-3}
Ion Temperature T_i	1 keV
Pulse Length t_d	5 s

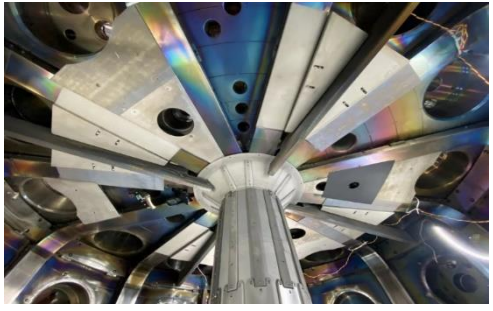
ENN has designed and built the first medium-scale Spherical Tokamak experimental device EXL-50. On August 8, 2019, the first solenoid-free plasma discharge was produced on "EXL-50 ".

EXL-50 Experimental Platform following April Vessel Opening



Full Metal Tungsten-coated Wall



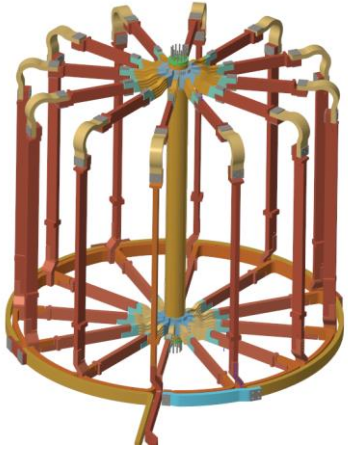


Tungsten-coated upper-plate

Tungsten-coated divertor

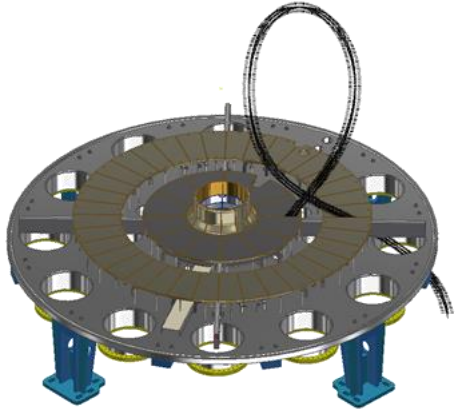
Pure tungsten limiter

Flexible Magnetic Configuration



Toroidal field coils

Poloidal field coils



Divertor target plate

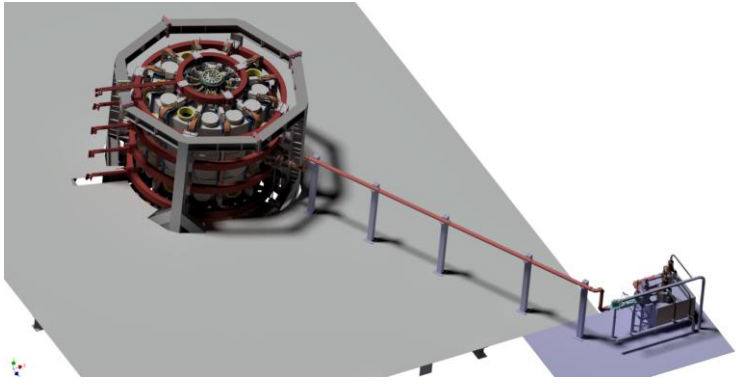
Parameter	Value
Turn	12
Current	100 kA
Magnetic field	0.41 T (at R=0.58m)
Materials	CuZr, CuAg
Weight	13 t
Cooling	water
Ripple	<1.6% (at R=1.51m)
Temperature rise	70 °C
Pulse flattop time	5 s

Coils	R, m	Z, m	dR, m	dZ, m	Turns	Current, kA
PF1 PF2	1.908	± 0.963	0.147	0.224	22	17.3
PF3 PF4	1.335	± 2.107	0.147	0.224	22	17.3
PF5 PF6	0.445	± 2.107	0.147	0.224	22	17.3

Lower Hybrid Current Drive (LHCD) System

- The 2.45GHz/15kW RF system produced the first plasma in 2019 and then was used for discharge cleaning, ECR boronization, and pre-ionization at full field.
- Now the 2.45GHz/200kW RF heating system is used as Lower Hybrid Current Drive System.

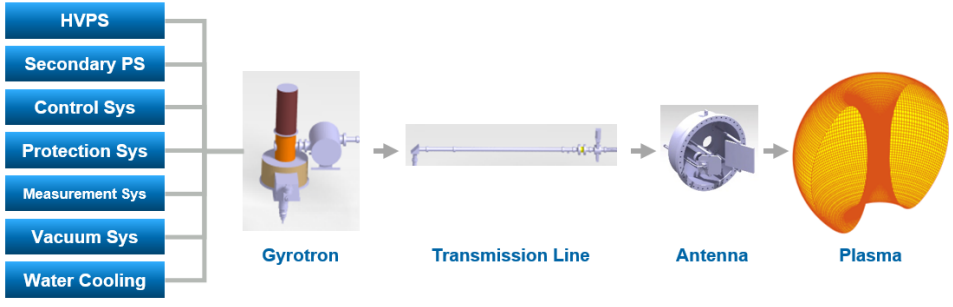
2.45GHz/15kW RF heating systems



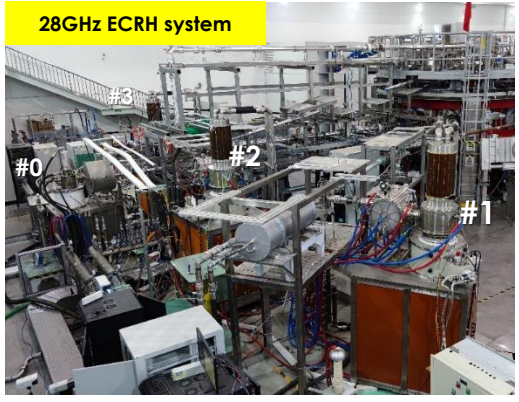
2.45GHz/200kW LHCD systems

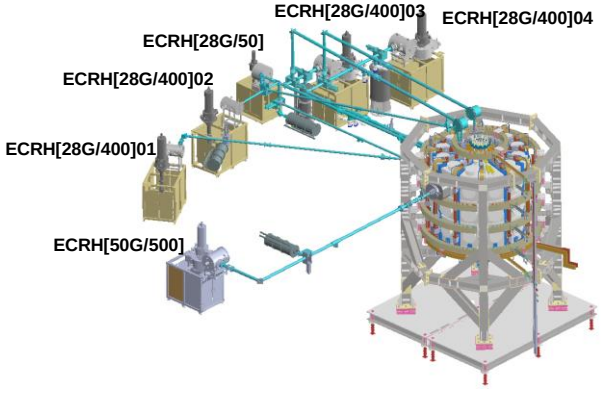
Electron Cyclotron Resonance Heating(ECRH) System

- The ECRH system is used for plasma start-up, heating and current drive.
- The EXL-50 device will be equipped with one 28GHz/50kW/30s system, four 28GHz/400kW/5s systems and one 50GHz/500kW/2s system by the end of 2022, when the total gyrotron output power is expected to reach 2.9 MW.
- The installed systems have delivered up to ~500kW/3s.
- One equatorial, three upper and two top launchers have been equipped for flexible position and injection angle control.
- A 50GHz ECRH system is being prepared to produce high density discharge, thus overcome the cut-off density of 28GHz($9.7\times10^{18}/m^3$) ECW.



Architecture of the ECRH System





2.9MW ECRH System Layout

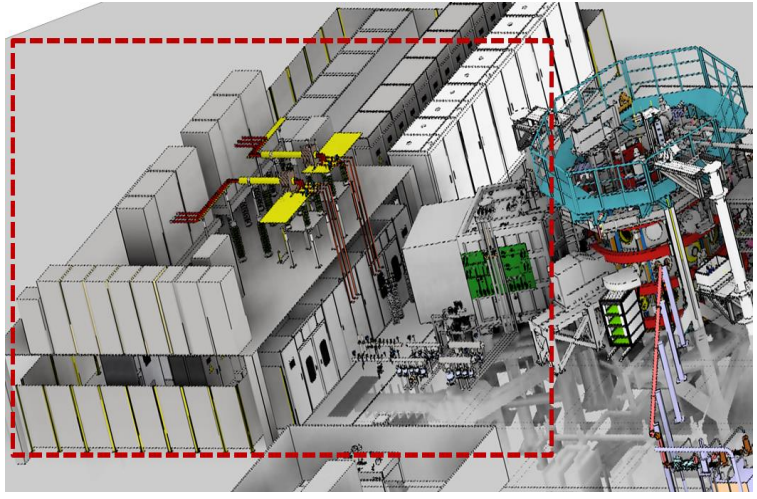
Ion Cyclotron Range of Frequency (ICRF) System

A 13.56MHz/40kW system with one 40kW solid-state generator and a 3-26MHz/100kW system with a 100kW broadcast transmitter has been installed in the EXL-50.

13.56MHz/40kW/5s ICRF system

3~26MHz/100kW/5s ICRF system

1.5MW Neutral Beam Injection System



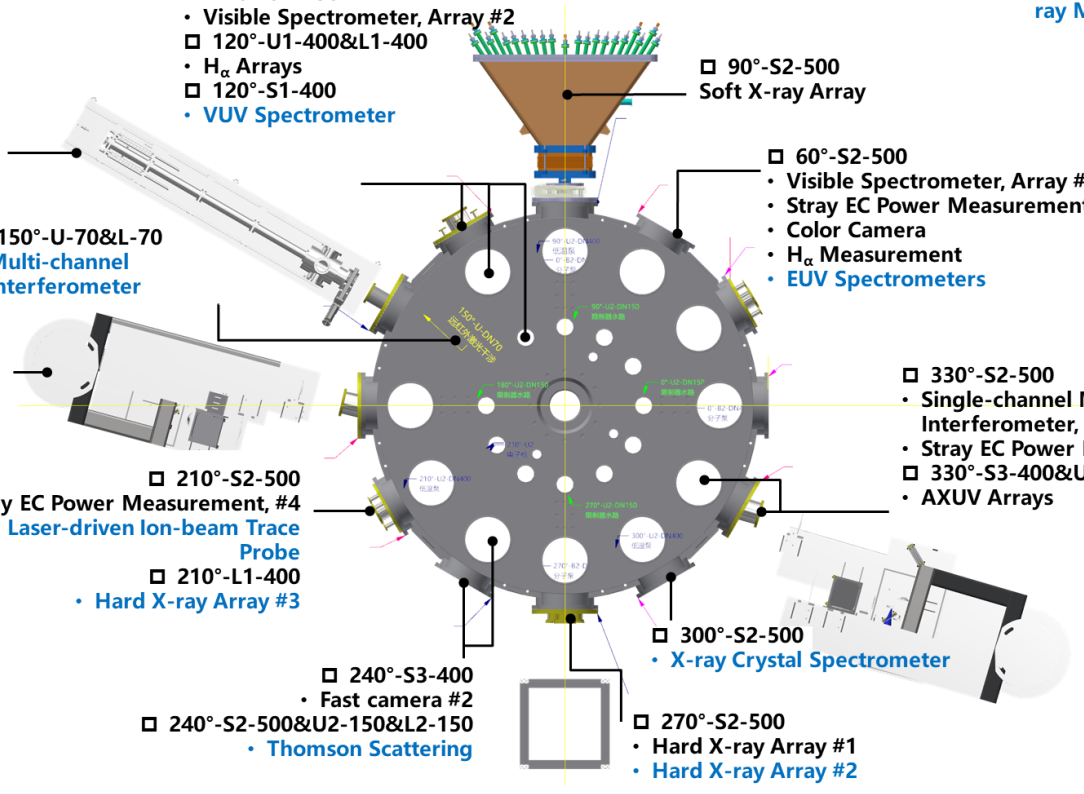
View of NBI on EXL-50

Main Parameters of 1.5MW NBI for EXL-50 Tokamak

- Ion source type: Multi-cusp bucket ion source
- Number of grids: 3
- Number of ion sources: 2
- Acceleration parameters: 50kV/40A/5s
- Beam Convergence angle: 2×3.2°
- Grid convergence angle: 178°
- Beam focal length: 5366mm
- Neutralization efficiency: > 55%
- Proton ratio: > 70%
- Pumping speed: 1×10^6 l/s
- Residual ion deflection: magnetic deflection
- Injection angle: 55.3 °
- Number of filaments: 16

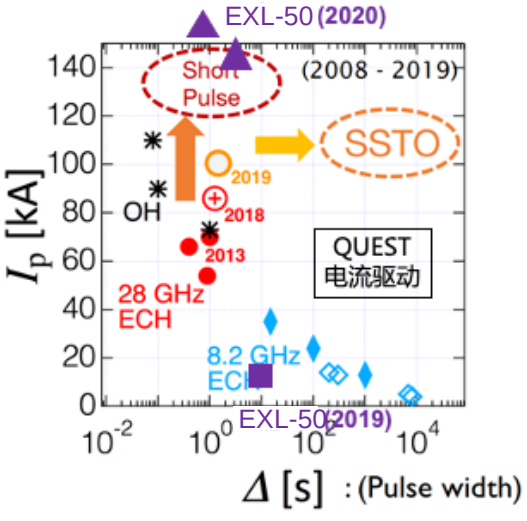
Present and Planned Diagnostics on EXL-50

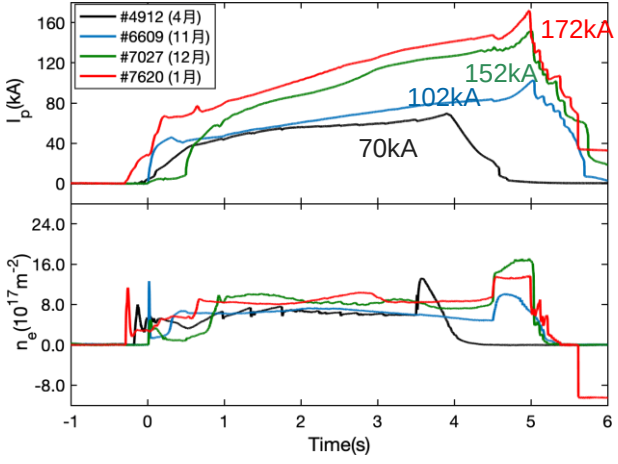
- Black: Installed
- Blue: Under Construction

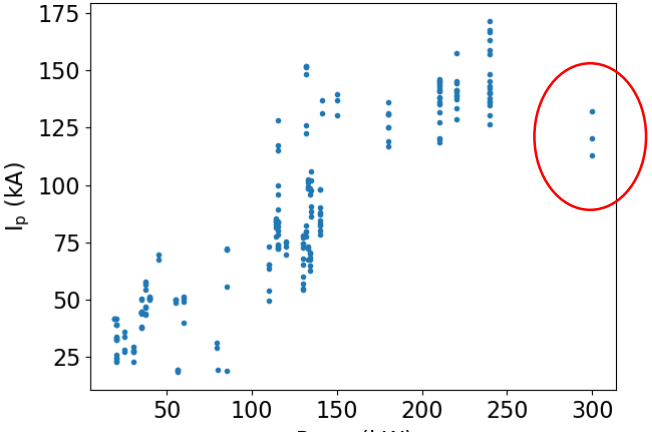


Progress in Current Drive

QUEST and EXL-50



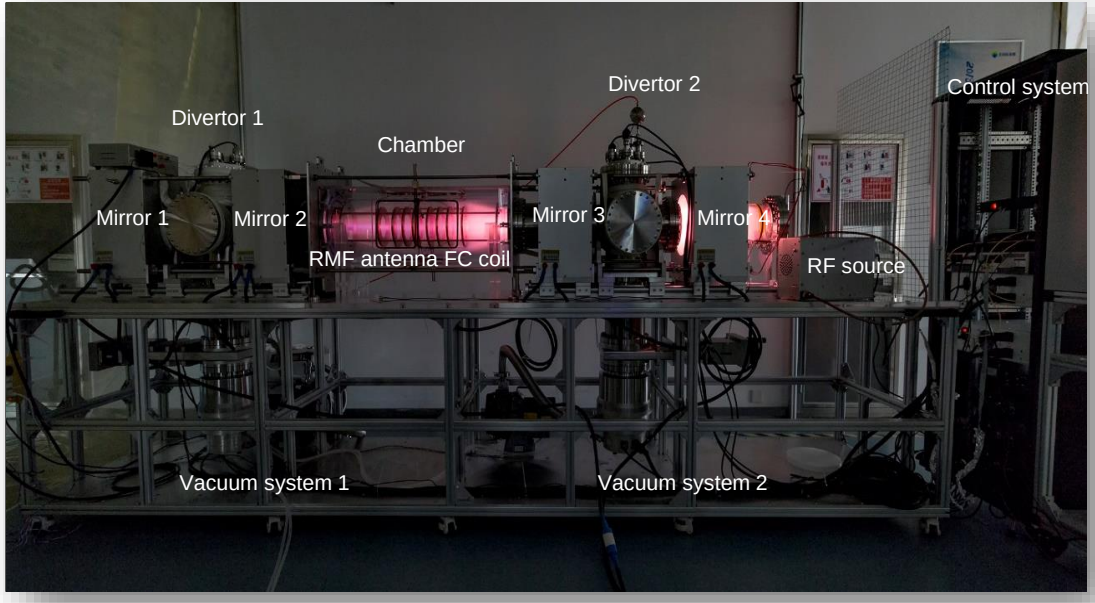




Microwave system output (kW)

- **Transient 172kA, quasi-stationary up to 150kA**

Field-Reversed-Configuration (FRC)

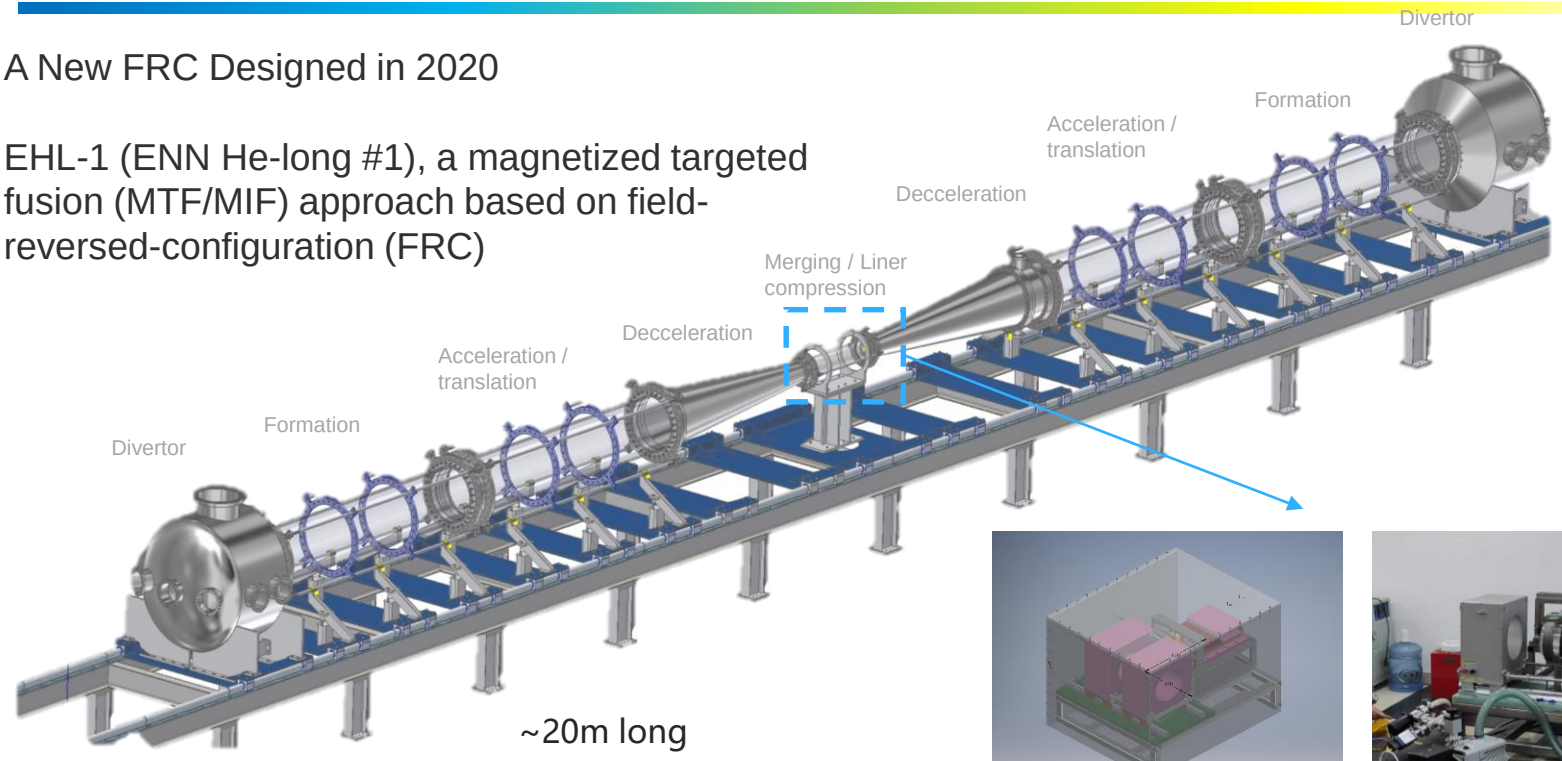


EFRC-0, July 2018
Uses Rotating Magnetic Fields (RMF)

Field-Reversed-Configuration (FRC)

A New FRC Designed in 2020

EHL-1 (ENN He-long #1), a magnetized targeted fusion (MTF/MIF) approach based on field-reversed-configuration (FRC)



~20m long

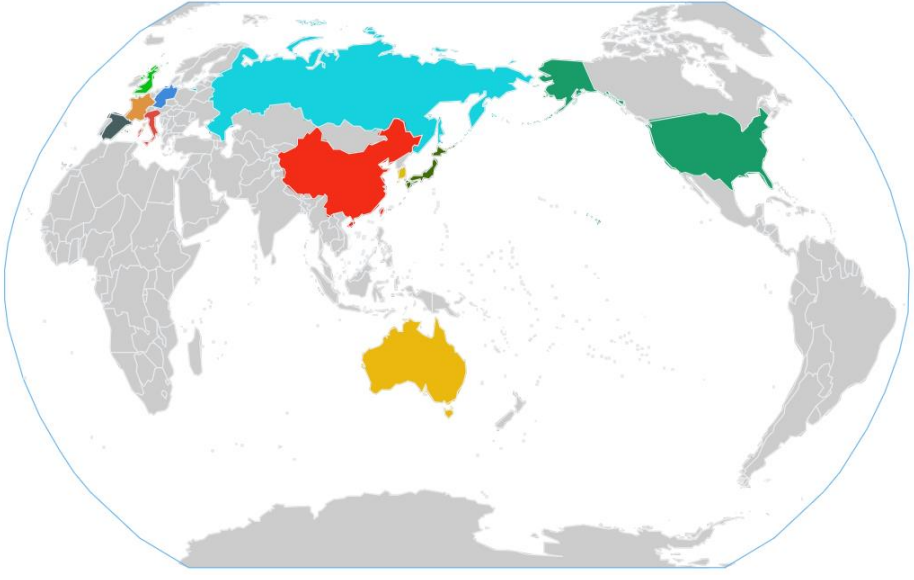
A Liner Compression experiment without plasma was carried out in June, 2020.

ENN Fusion Technology R&D Center (2022)

Founding time	Our people	Honor
Feb. 2018	Around 100 researchers with 40% holding PhD degree	Authorized as Hebei Key Laboratory of Compact Fusion

Cooperation, Contribution, Moving Fusion Energy R&D Forward

- Promote an efficient and agile p-B fusion R&D effort，be a member of fusion community
- Learning by doing, drawing from expertise in fusion, high-energy particles, laser, materials
- Engage experts from schools, laboratories, industries, power companies, private enterprises



北京大学 PEKING UNIVERSITY

ASIPP

中国科学院近代物理研究所 Institute of Modern Physics, Chinese Academy of Sciences

Conferences& Events

“Develop Fusion Energy, Benefit Mankind for Generations!”

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