

Accelerated Fusion Energy Development by Private-Public Partnership in Korea

June 14, 2024

Gyung-Su LEE

EnableFusion Inc.

EnF

EnF (Energy and Fusion)
<http://EnableFusion.com>

Global Risks in middle of the 21st Century



■ Washington Times (January 2009)

Strategic Competition, New Cold War

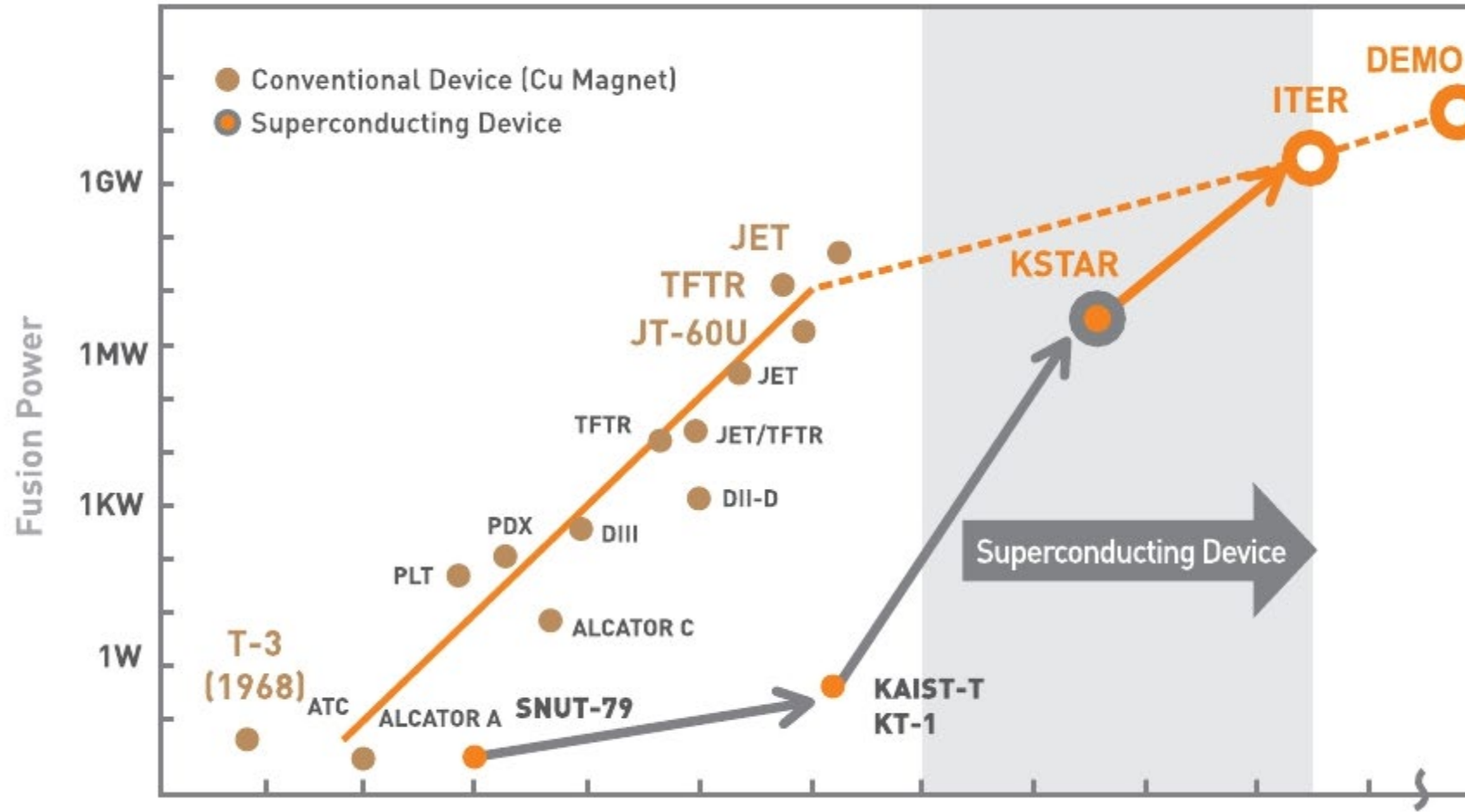


■ Snow of Kilimanjaro (2005)

Climate Crisis, Net-Zero with AI Energy Needs

BIG Question : Will Fusion Energy contribute Net-Zero 2050?

Fusion Energy Plan based on “Mid-entry Strategy”



**Korean National
Fusion Energy
Development
Plan (1995~2045)**

Fusion Energy Development in Korea

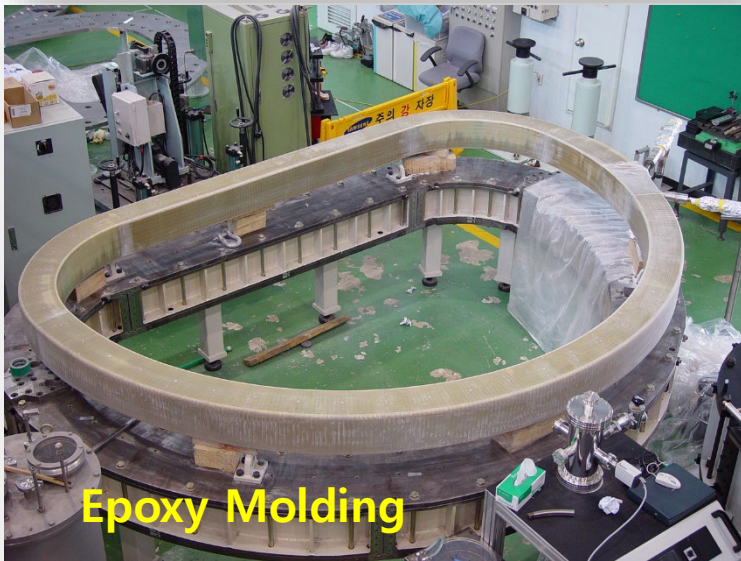
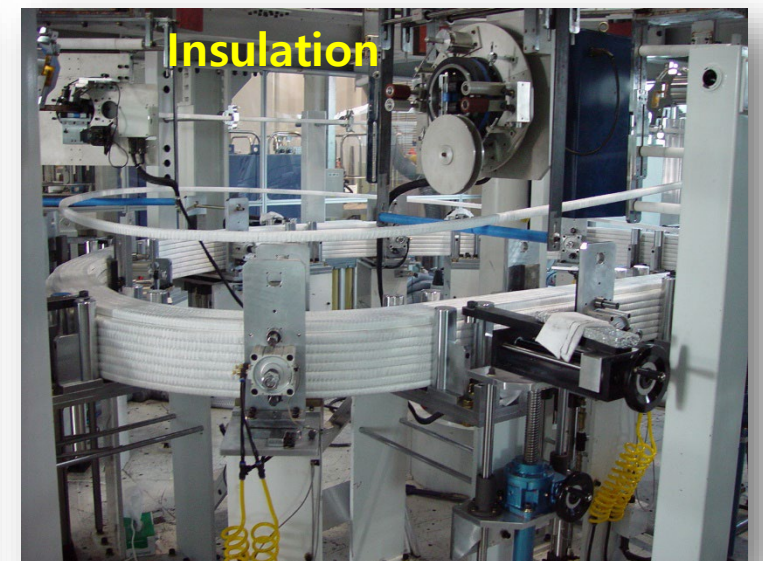
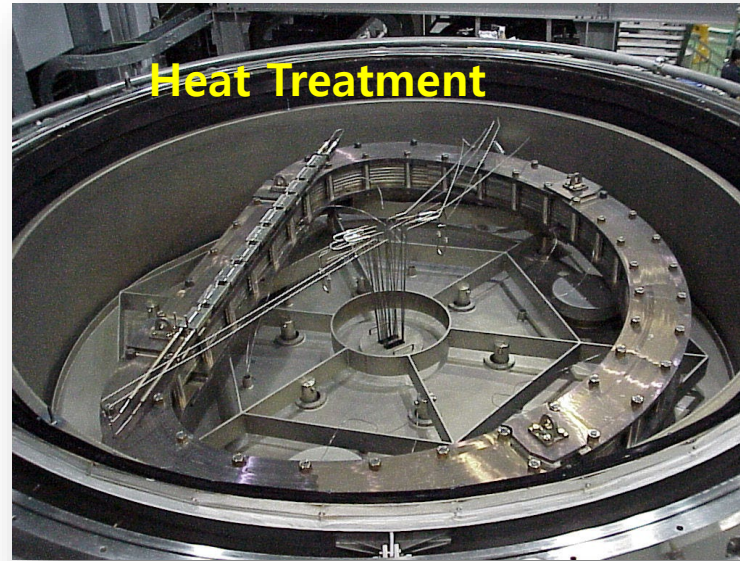
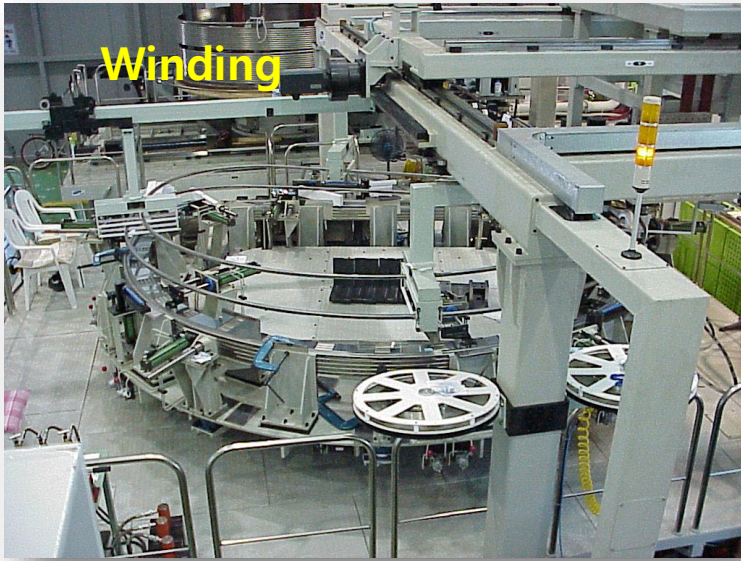
- Based on the **Korean National Fusion Energy Promotional Law**
 - Succeed the KSTAR Project (1995-2007 Construction; 2008~ Operation)
 - Joined Member of the ITER Project (since 2007 for Construction)
 - Initiated Korean Fusion DEMO Plant Design Activities (2023~ present)
- Korean Industries participated in Publically Funded Fusion R&D
 - **Major Korean Industries (e.g. Samsung, Hyundai, Doosan, etc.)**
 - **Mid-size Korean Industries (e.g. KAT, DawonSys, etc.)**
 - **Many Medium & Small Scale Businesses**
- Formed a **High Quality, Cost Competitive and Field Experienced “Fusion Supply Chain Platform”** for **Fusion Energy Commercialization by Private Sector**
- **EnableFusion Mission** : Bringing clean, safe, and sustainable fusion energy to the world as a **digitally-driven platform for innovative fusion engineering and industrial solutions**



KSTAR Construction, ITER Negotiation... (1995~2006)



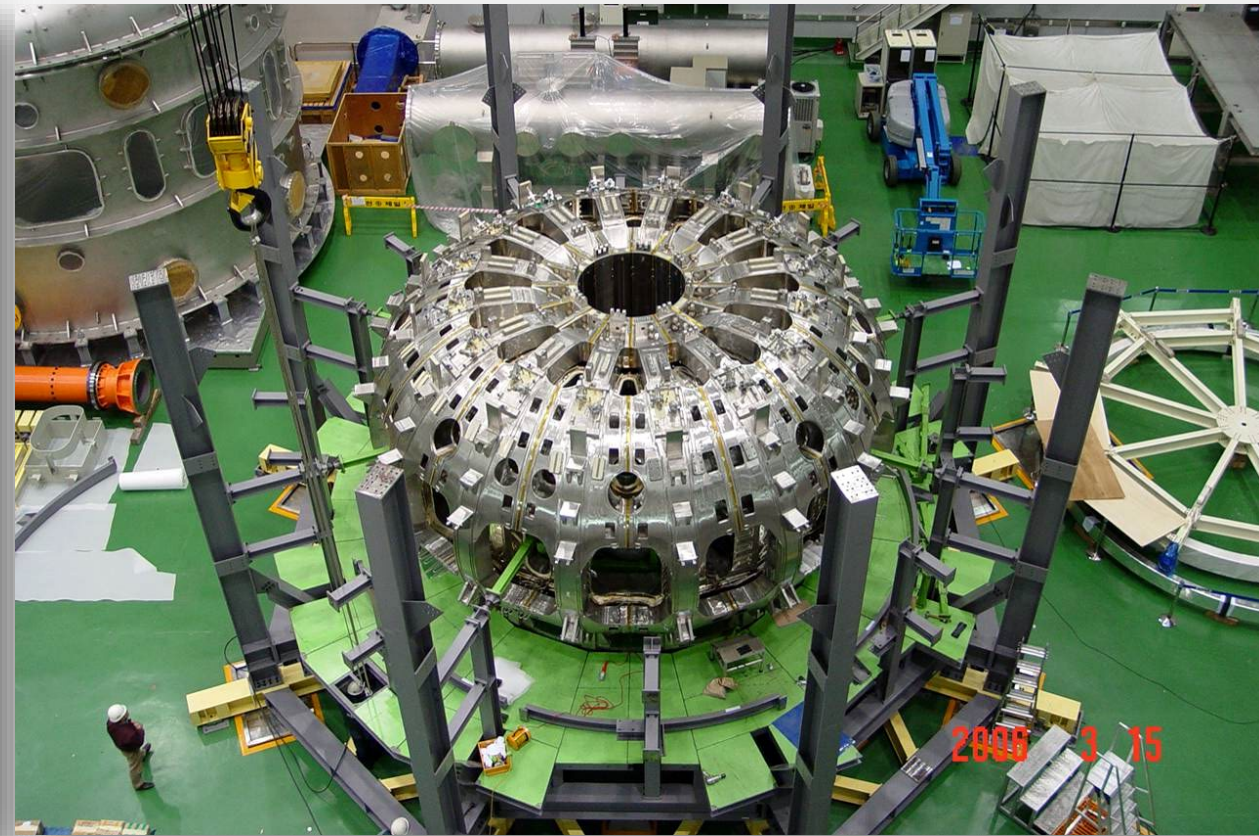
KSTAR Nb₃Sn SC Magnet (Samsung, Kiswire, Doosan, ...)



KSTAR Assembly (Hyundai, Doosan, SFA, ...)



KSTAR VV and VVTS are installed

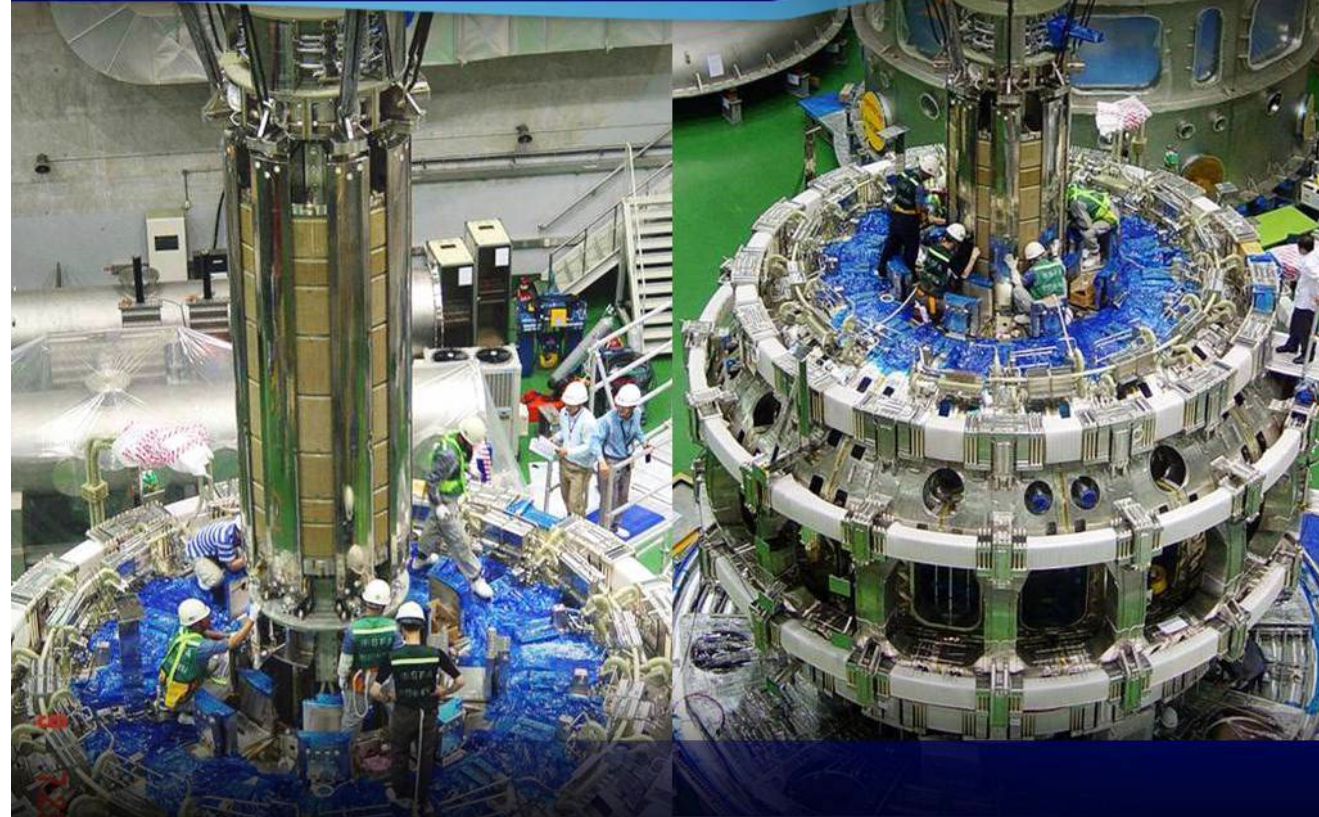


KSTAR TF magnet are installed

KSTAR Construction completed in 2007

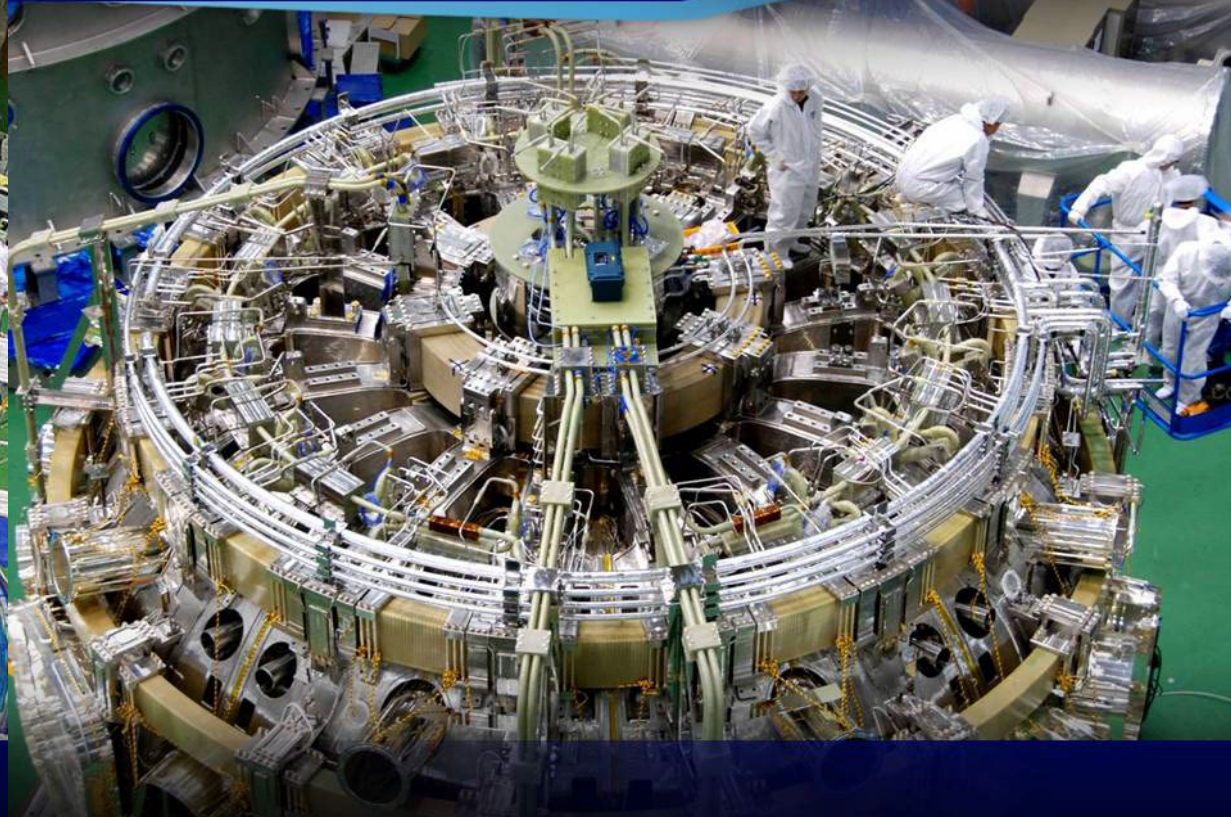
2006. 10

중심 솔레노이드 자석(CS) 조립 완료



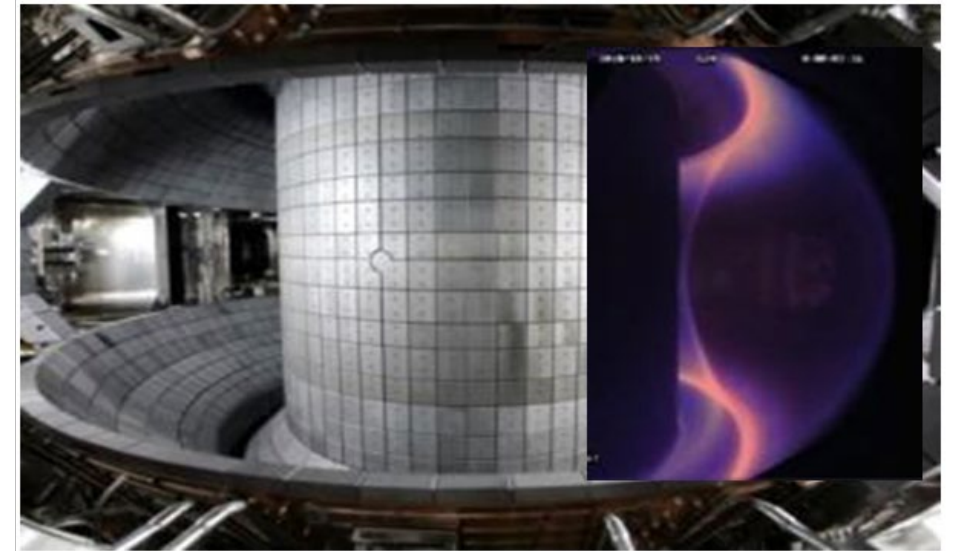
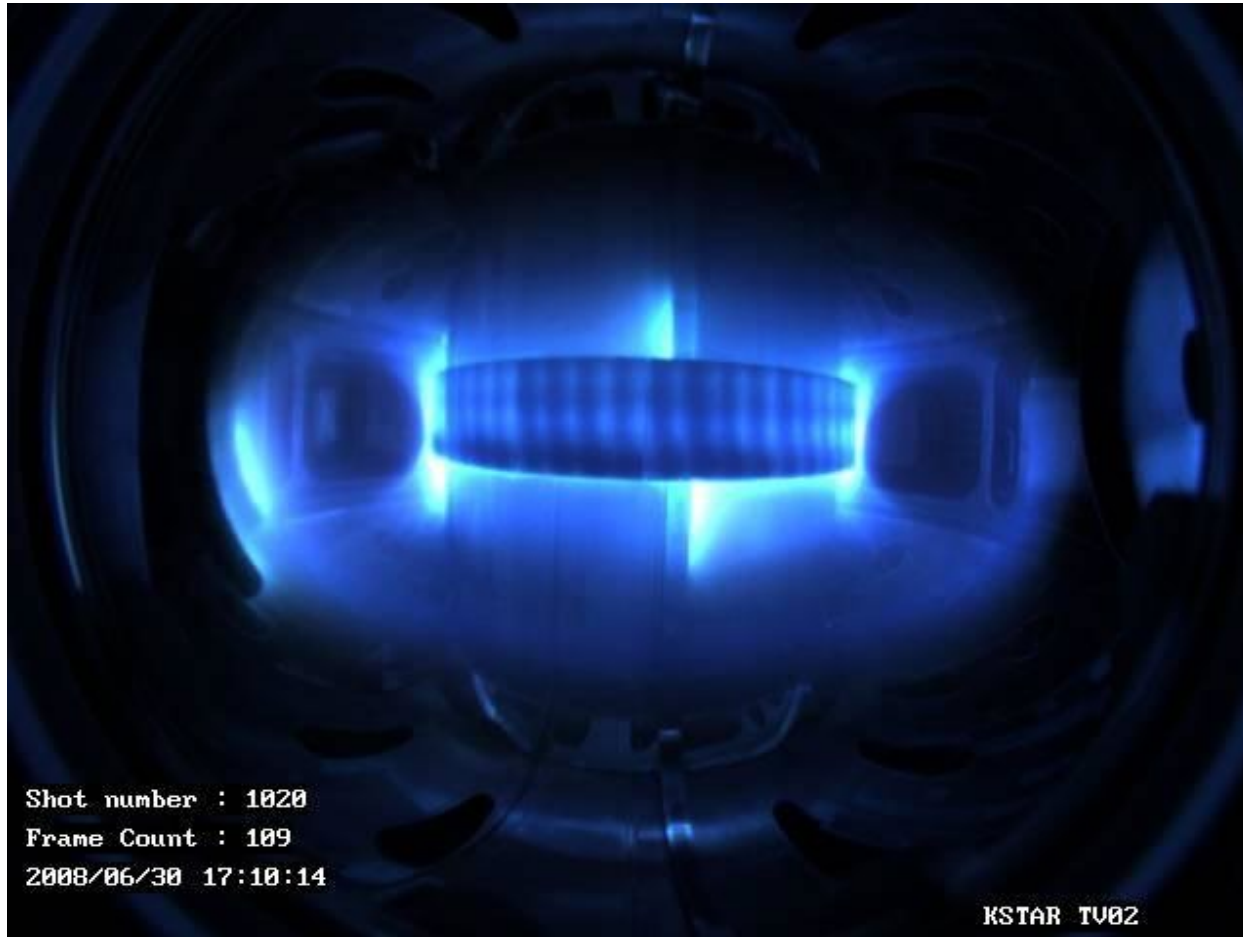
2006. 12

저온용기 내부 헬륨배관계 설치

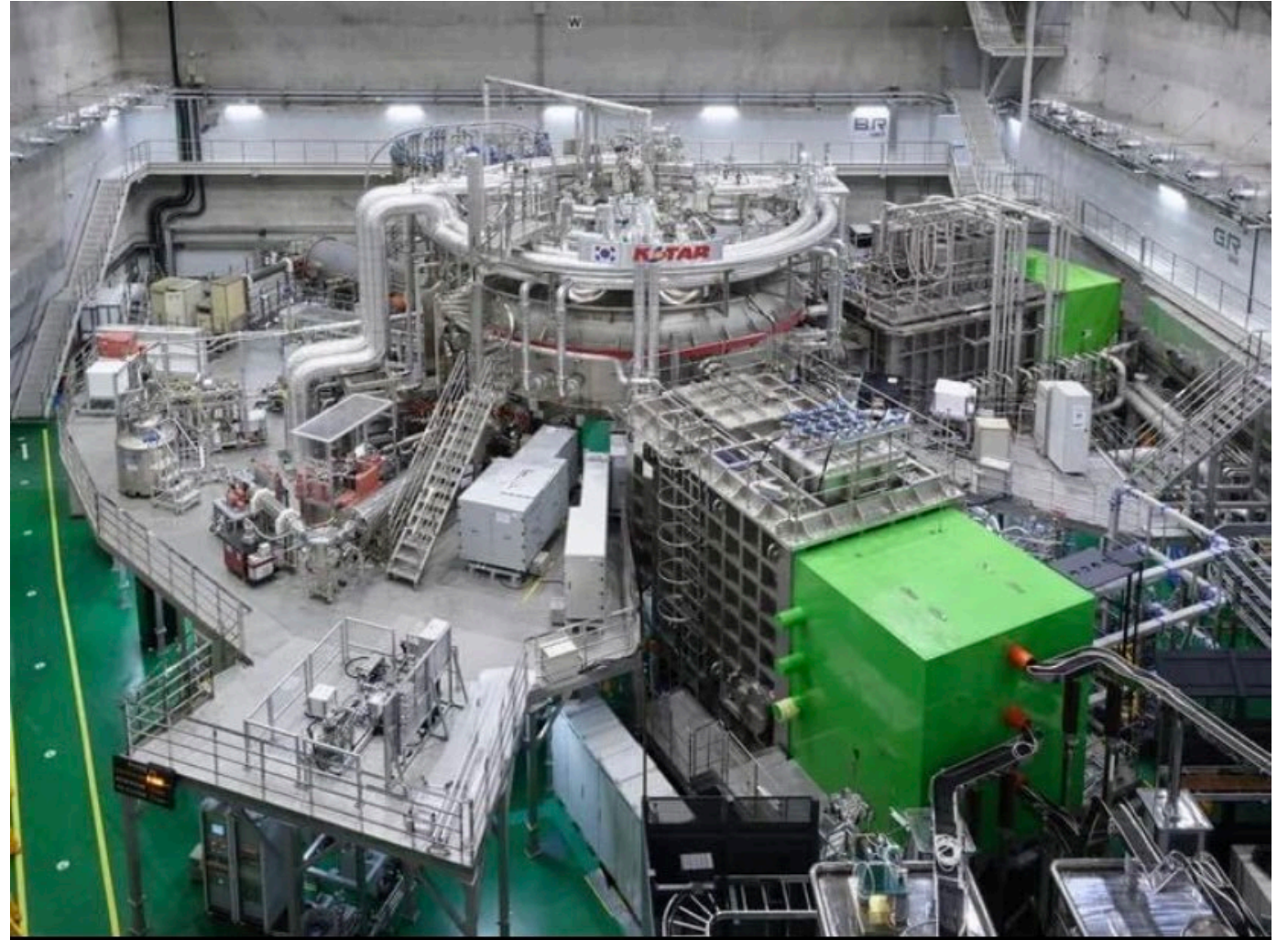
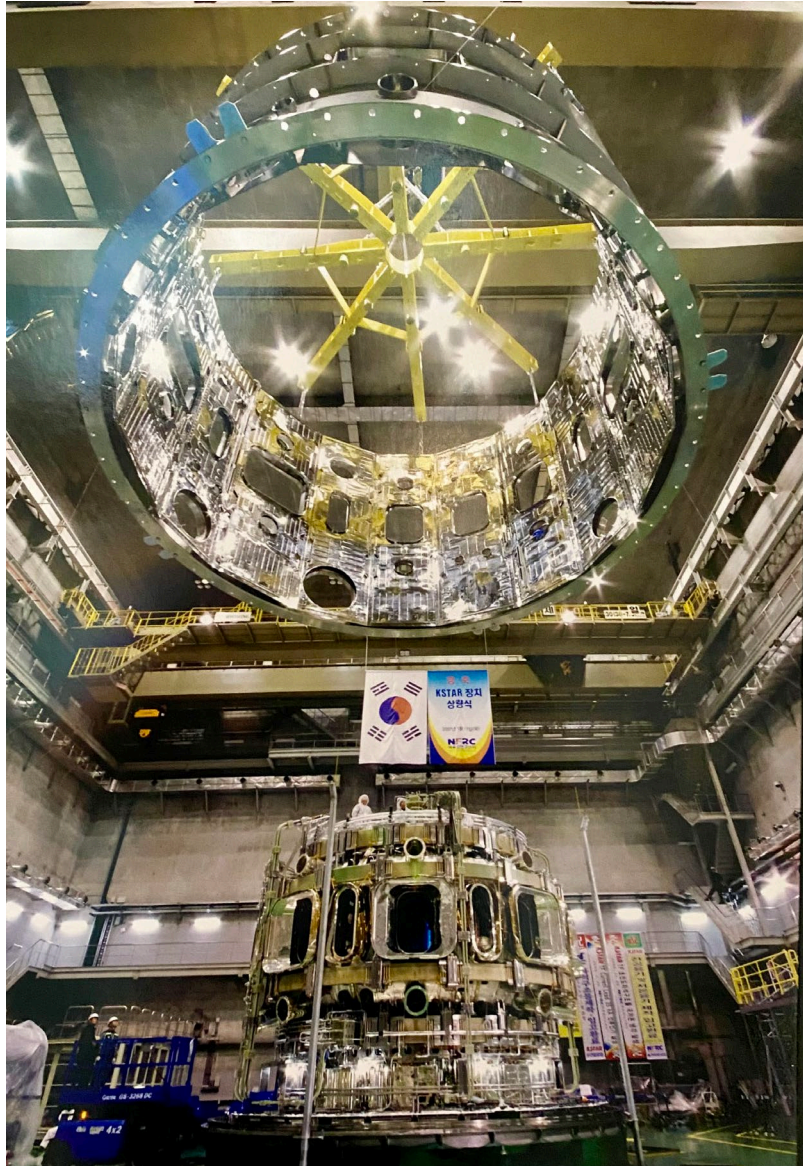


KSTAR succeeded Construction: First Plasma in 2008

KSTAR First Plasma in 2008



KSTAR Operation from First Plasma in 2008



No Machine Faults for 16 Years of Operation!

VITZRO

HANEUL Eng

Helium distribution system



Helicon current drive system

ECH



NBI-1



Vacuum vessel & Cryostat

wonshin
Vacuum pumping system



Superconducting Magnets



NBI-2

VITZRO



VITZRO

Pellet injection system



XrayImagingCrystal Spectrometer

ICRF

VITZRO



ITER

Global challenge, global response



On 28 June 2005, the ITER Members unanimously agreed to build ITER at Cadarache, France.

On 21 November 2006, the ITER Agreement was signed at the Élysée Palace, in Paris.

The seven ITER Members represent more than 50% of the world's population and about 80% of the global GDP!

China EU India Japan Korea Russia USA

ITER Project Participation (2007~)



Past and Present Status of ITER

[2009]



ITER Nb₃Sn Superconducting Strands (Kiswire-KAT, KO)

SUPPLIER EFFORTS RECOGNIZED IN KOREA

Ji-Min Song, ITER Korea

In recognition of and in gratitude for outstanding contributions to the ITER Project, the National Fusion Research Institute (NFRI) in Korea presented three of its suppliers with plaques of appreciation on 4 November 2014.

Recognized for the quality of their manufacturing contributions to ITER were: Kiswire Advanced Technology (KAT); Nexans Korea; and the Italian Consortium for Applied Superconductivity (ICAS).

KAT, who was awarded the manufacturing contract for 93 tonnes of niobium-tin (Nb₃Sn) superconducting strand for ITER toroidal field conductors in 2009, completed the procurement last year. "To have completed the manufacturing in four years is impressive," stressed the head of the Korean Domestic Agency Kijung Jung, "especially considering that the worldwide rate of Nb₃Sn strand production before ITER did not exceed 15 tonnes per year."

The cabling contract for the toroidal field conductors was awarded to Nexans Korea, also in 2009. From the superconducting strand produced by KAT, Nexans manufactured 27 superconducting cables and 2 qualification dummies—the entire Korean share of toroidal field cable procurement. Production was successfully completed and all the authorization to proceed points (ATPP) were cleared by the ITER Organization in May 2014.



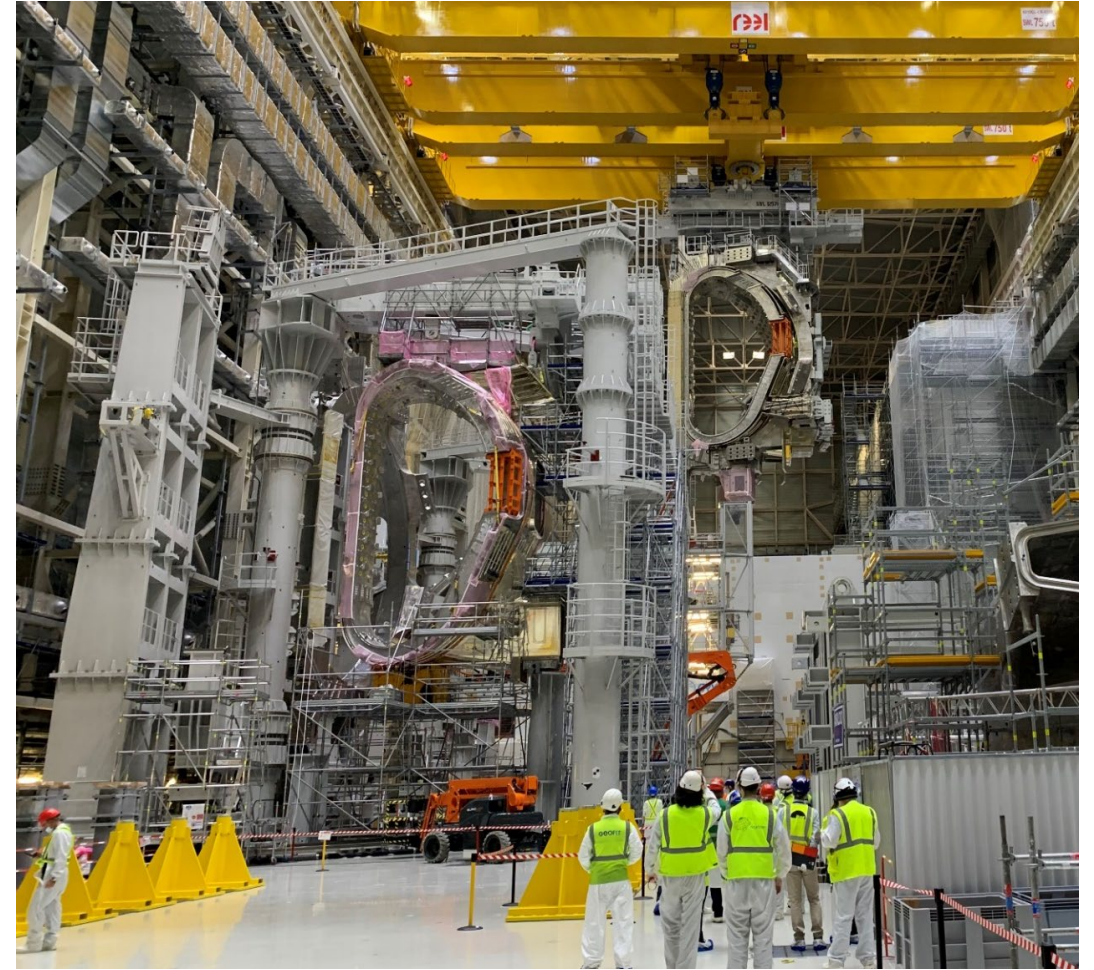
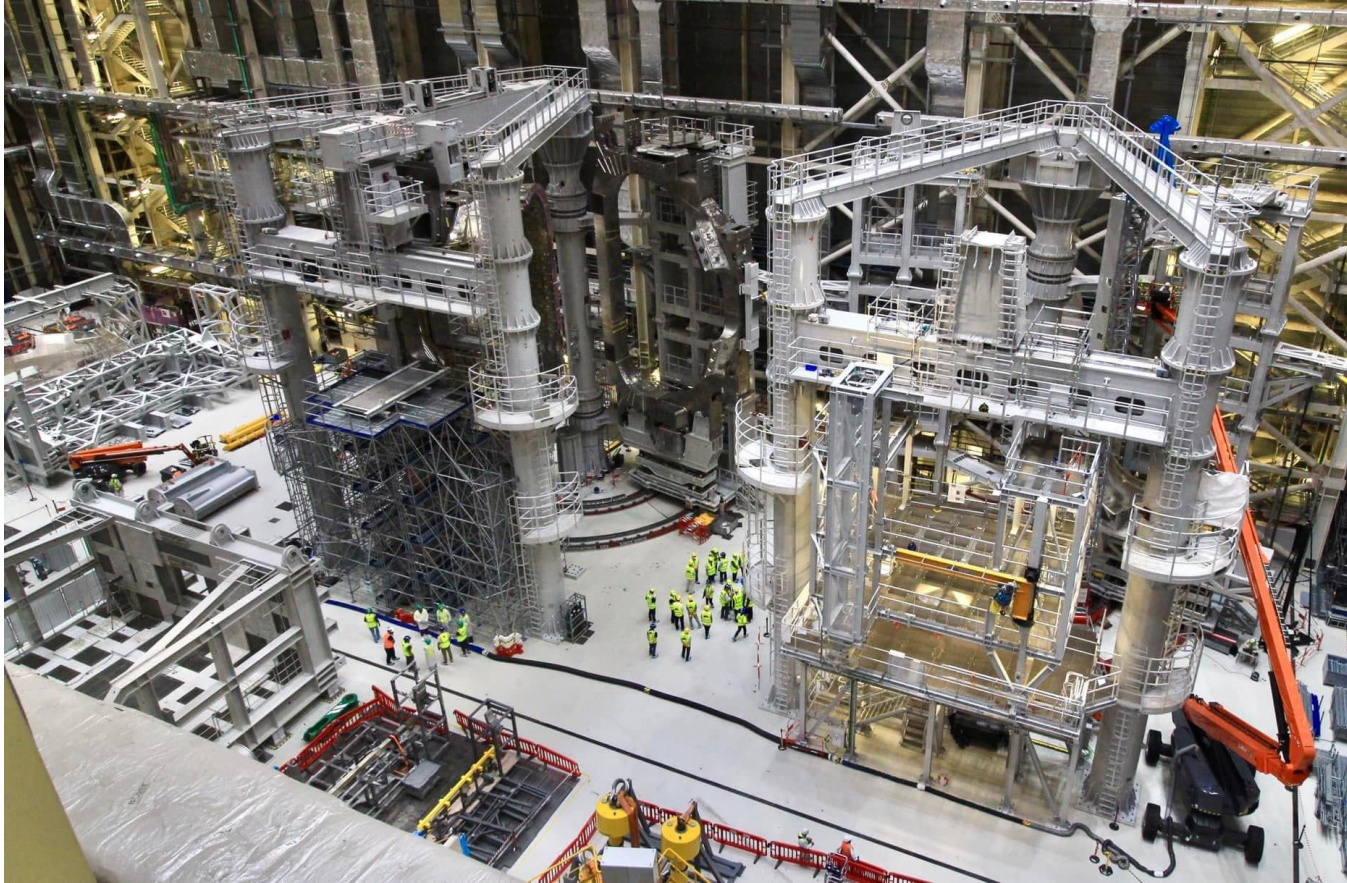
From left to right: Lee Jun-Seg (Nexans Korea), Guido Roveta (I.C.A.S), Antonio Della Corte (I.C.A.S), Kwon Myeun (NFRI), Han Il-Young (Nexans Korea), Park Soo Hyeon (NFRI), Jung Ki Jung (NFRI), Lee Hyeon Gon (NFRI), Ahn Hee-Jae (NFRI).

ITER-CERN Collaboration with World-wide Suppliers



Valued at more than EUR 600 million, the 11 conductor Procurement Arrangements signed by the ITER Organization between 2007 and 2010—covering the procurement of conductors for the large toroidal field, poloidal field and central solenoid magnets as well as correction coils and feeders—represent one of the project's largest in-kind procurement packages. Six out of the seven ITER Members (China, Europe, Japan, Korea, Russia and the United States) have taken part.

ITER Assembly Tools (SFA-Taekyung HI, KO)



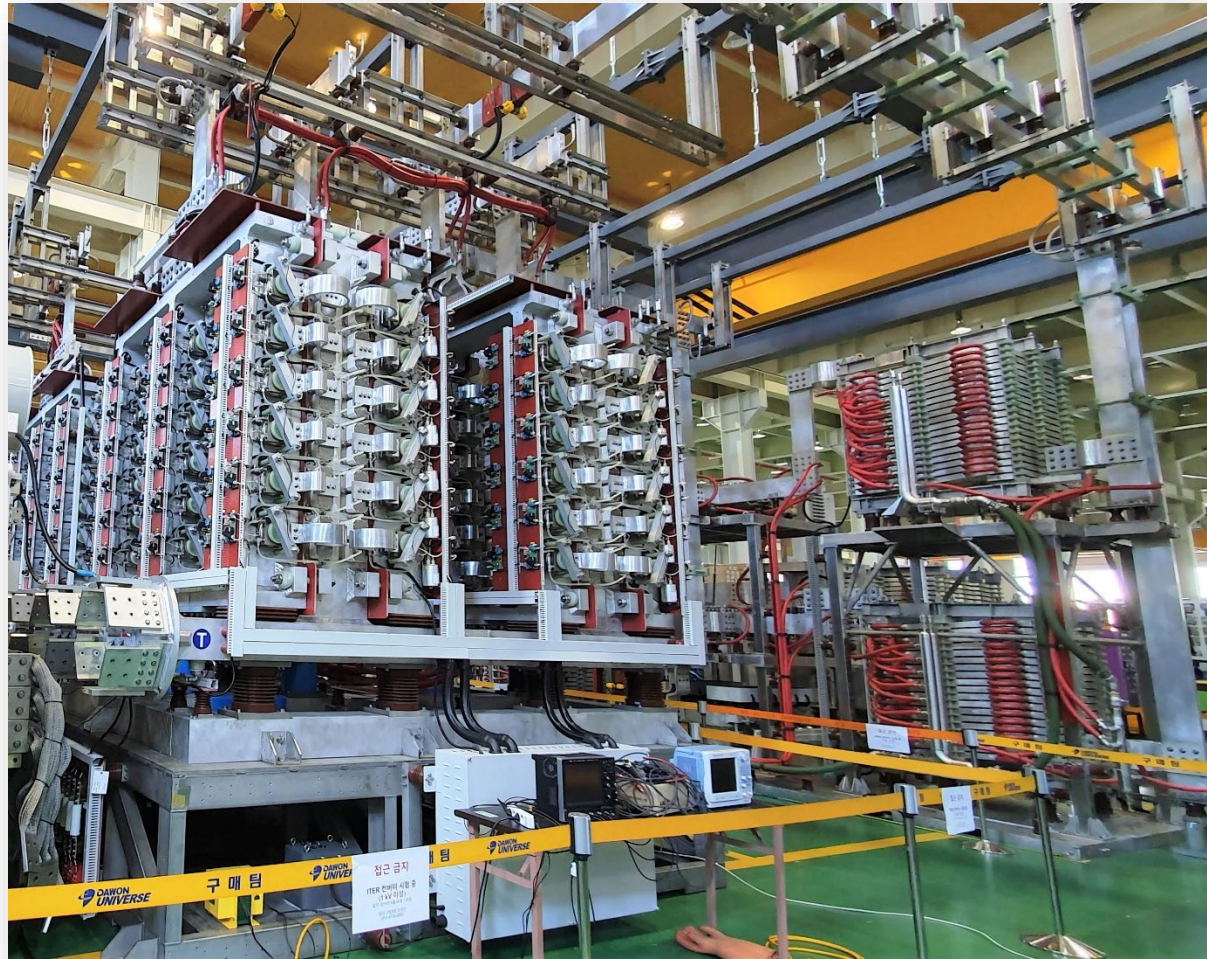
ITER Vacuum Vessel (HD Hyundai, KO)



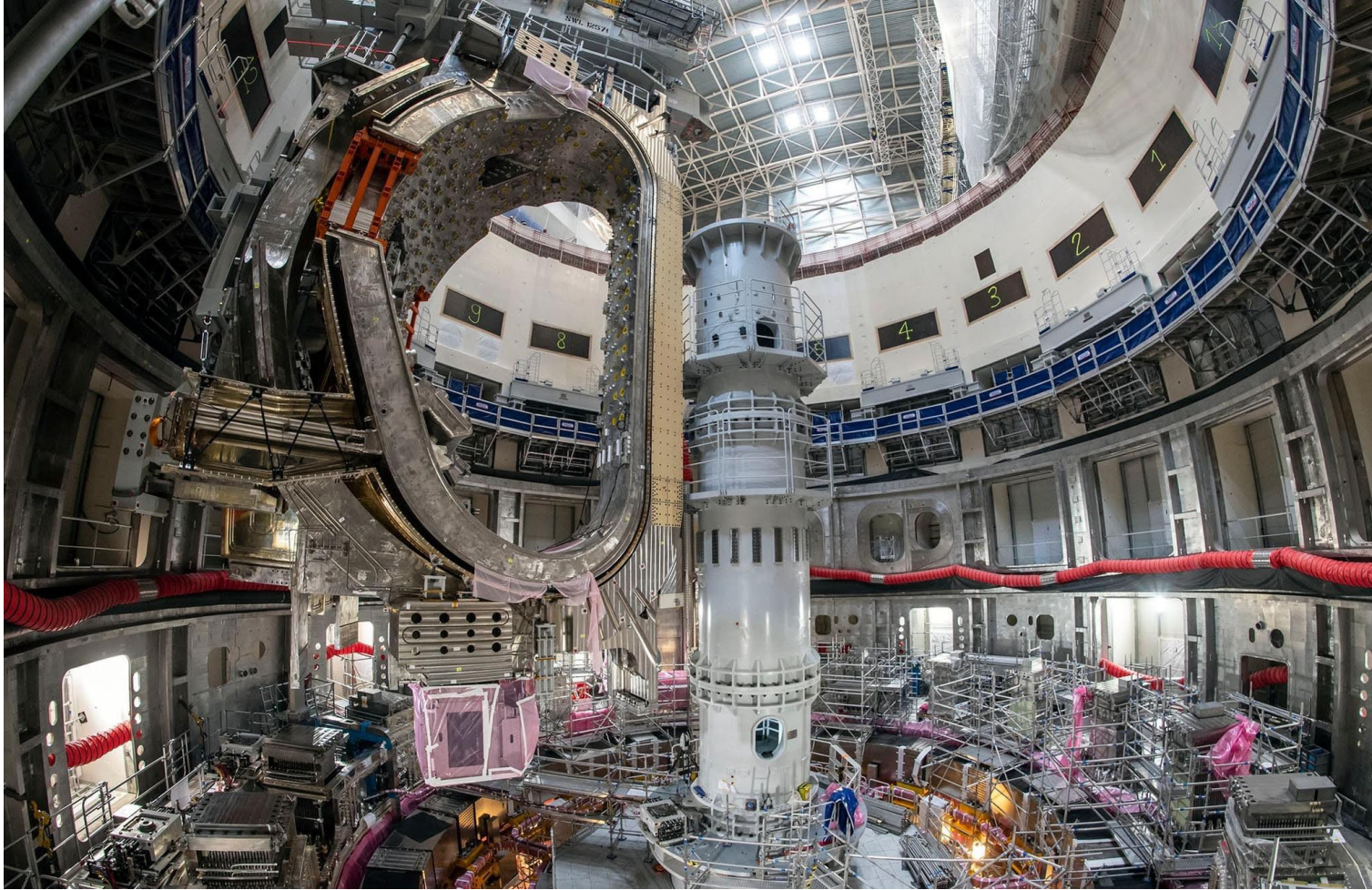
ITER Thermal Shield (SFA-Samhong HI, KO)



ITER Magnet Power Supply (DawonSys, Hyosung, KO)



ITER VV & Tokamak Assembly



World-wide Accelerated Fusion Energy Commercialization Progress

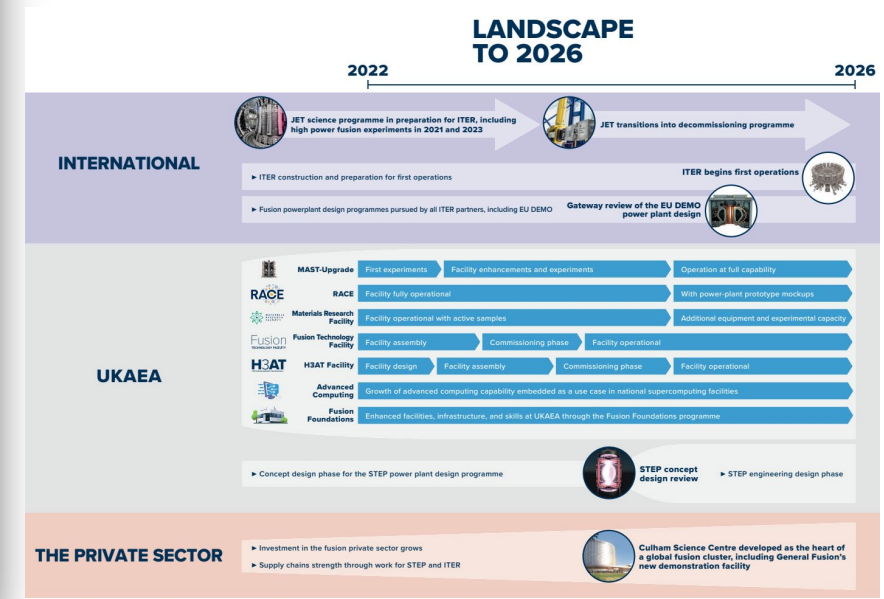
UK PPP Plan towards Fusion Energy

Nuclear fusion: Five sites shortlisted for UK energy plant

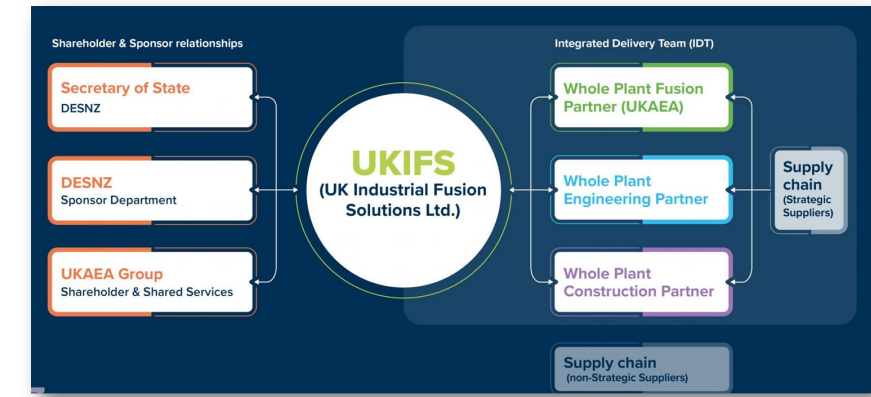
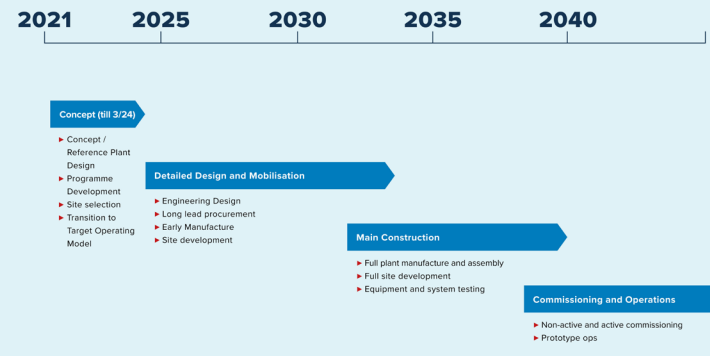
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A final decision on the chosen site is due at the end of 2022
Five sites in England and Scotland are in the final running to be the home of the UK's prototype fusion energy plant.



STEP high-level schedule



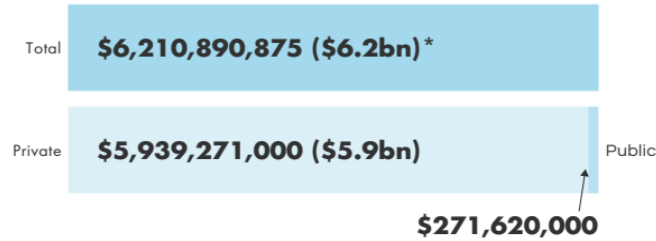
World-wide Fusion Startups

FIA(Fusion Industry Association) "The global fusion industry in 2023"

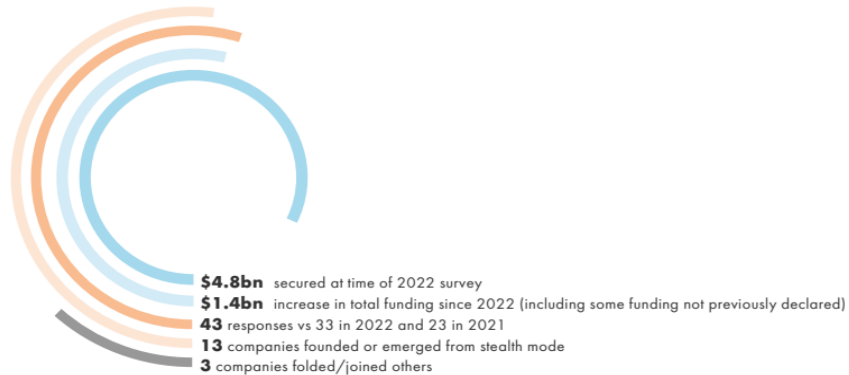


HIGHLIGHTS TO DATE

1. FUNDING FOR FUSION COMPANIES

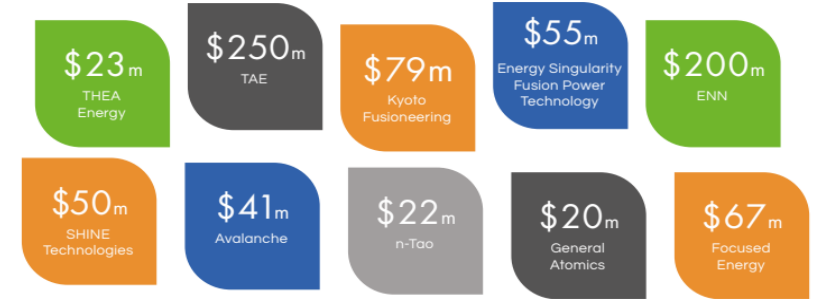


2. CHANGE SINCE 2022 SURVEY

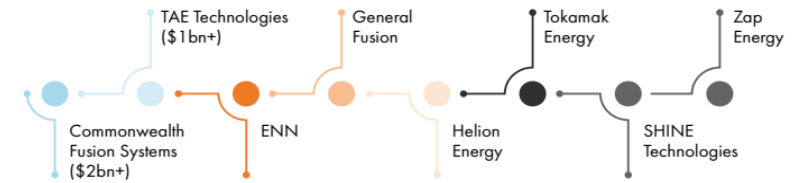


* Some figures have been rounded. Some funding was declared privately, hence total figure here is higher than combined figures stated in company profiles.

3. NOTABLE INVESTMENTS SINCE THE LAST SURVEY



4. COMPANIES WITH \$200M INVESTMENT OR MORE



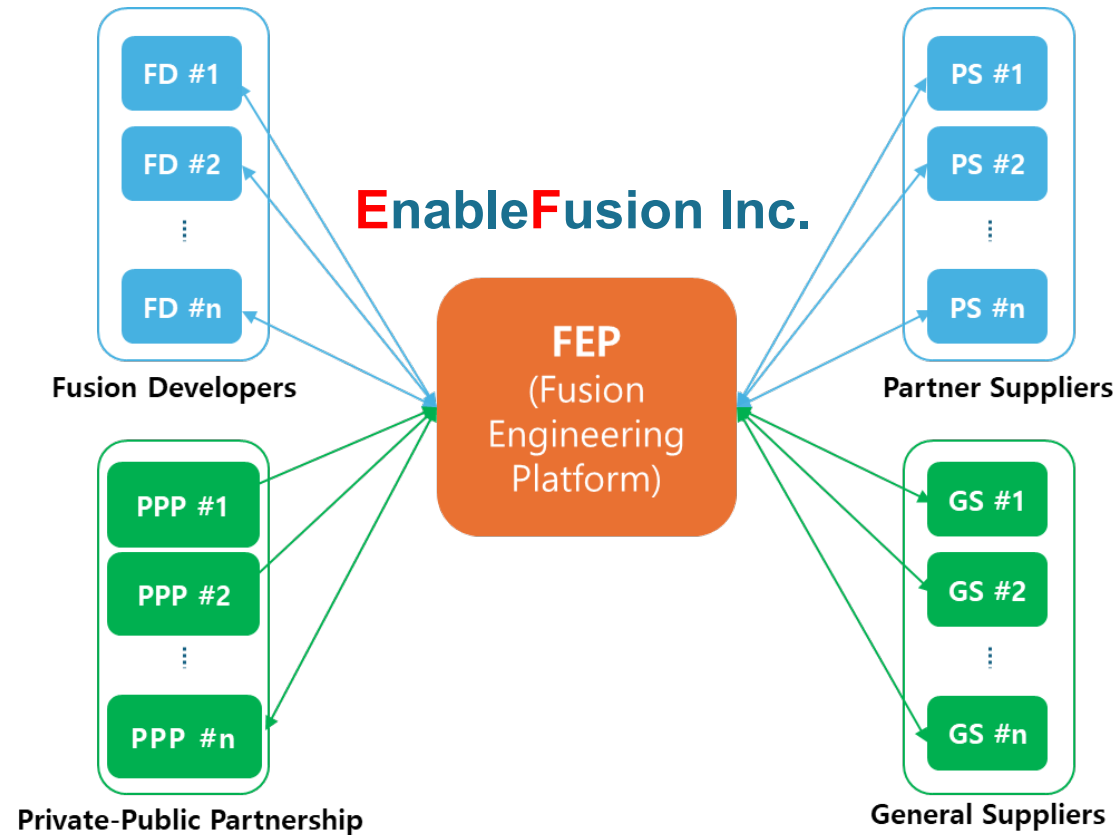
5. LOCATION

By primary HQ



First Korean Fusion Startup : EnableFusion as Fusion Engineering Platform

- Fusion Engineering Platform (FEP) connects Fusion Developers and Fusion Manufacturers through a **digitally-driven platform** to accelerate Fusion Energy Commercialization.



Asset Leveraging Structure in the EnableFusion

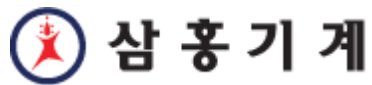


Korean Industry in Fusion Supply Chain

Major Participating Companies in ITER and KSTAR Projects (a few examples)

	Company	Field
1	HD Hyundai Heavy Industries	Structure Design & Fabrication (Vacuum Vessel, Magnetic Structure, Cryogenic Vessel...)
2	Doosan Enerbility	Design and manufacture of Superconducting magnet structures
3	Samsung SDS	Plant operation system design and manufacturing
4	Mobiis	Device operation system design and manufacturing
5	KAT	Superconducting strands and conductor design and manufacturing
6	Dawonsys	Power supply design and manufacturing
7	Wonshin Industrial	Auxiliary equipment design and manufacturing (heating equipment)
8	Haneul Engineering	Auxiliary equipment design and manufacturing (medium-sized structures)
9	BITZTROTECH	Auxiliary equipment design and manufacturing (electromagnet, plasma facing wall...)
10	EM KOREA	Assembly equipment design and fabrication
11	Eugene MS	Assembly equipment design and manufacturing
12	SamHong Machinery	Thermal shield and medium-sized structure design and manufacturing
13	SeAH CSS (POSCO SM)	Special material production
14	KEPCO E&C	Design integration, quality and project management

EnF Partner Suppliers

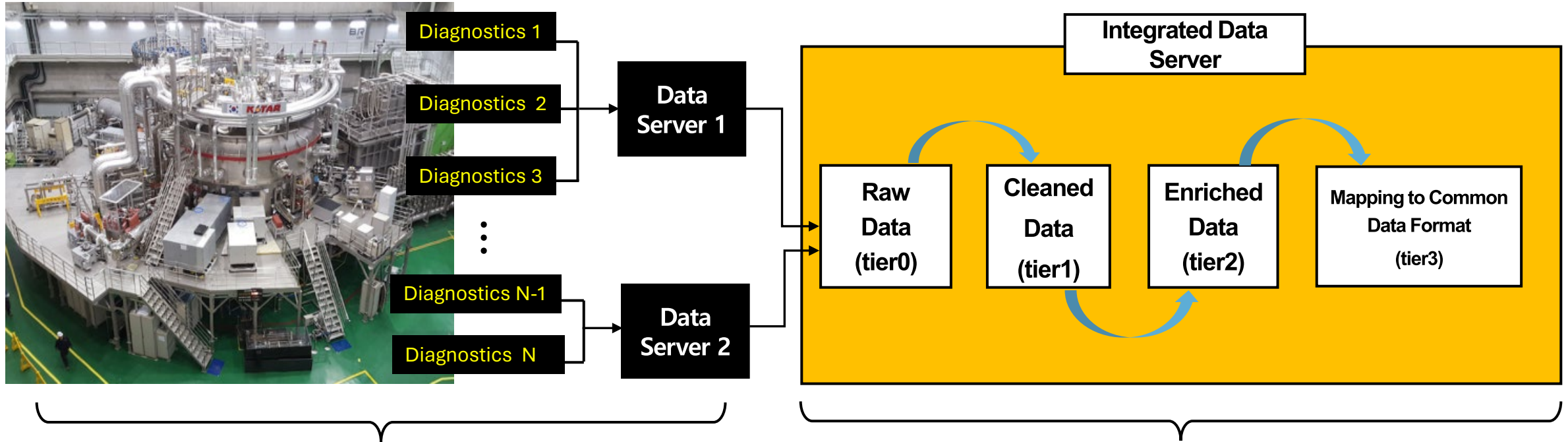




EnableFusion Opening (April 17, 2024)

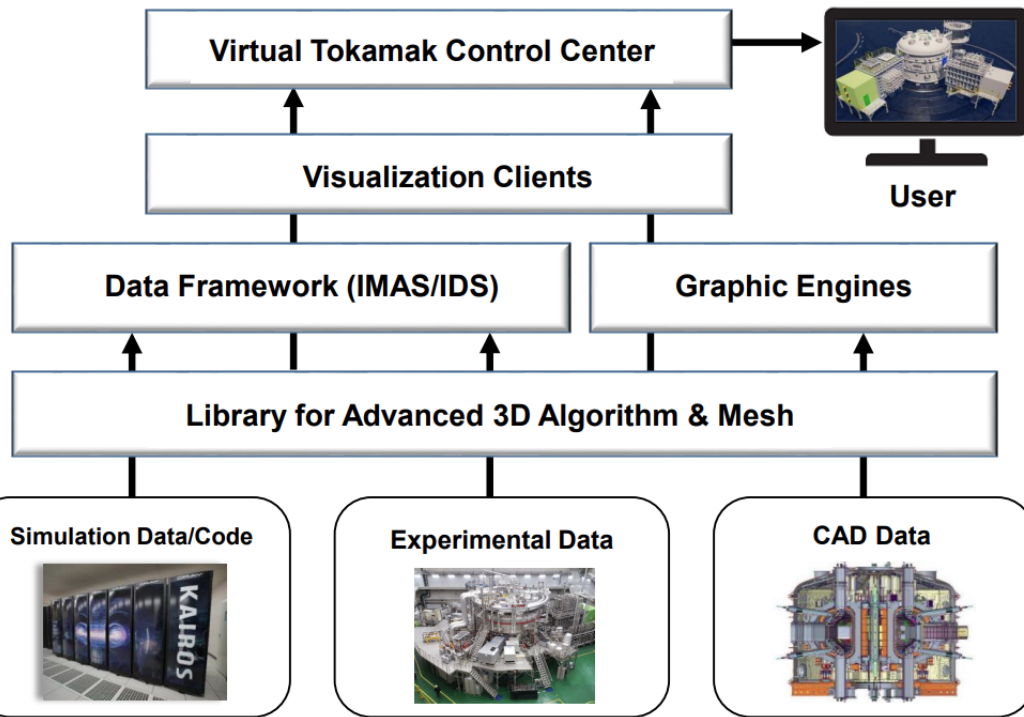
Additional Development Area with Korean Institutions

Build LLM-based Fusion Expert System

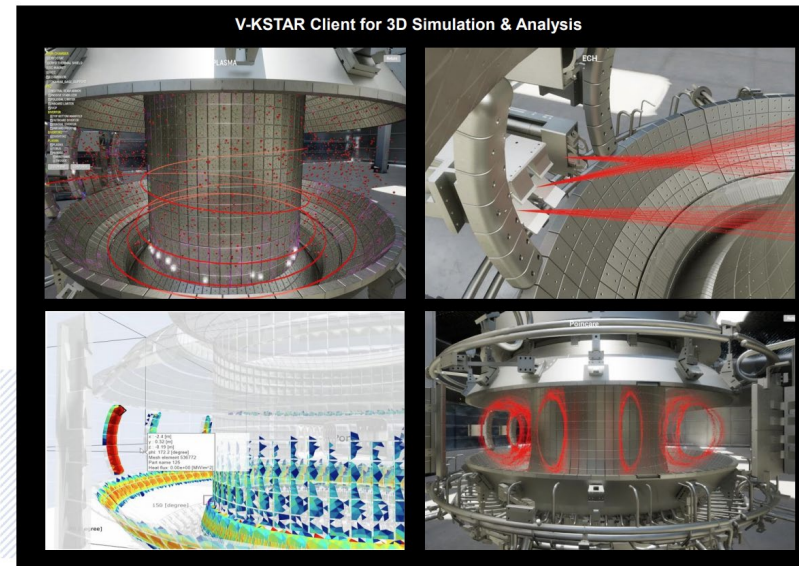
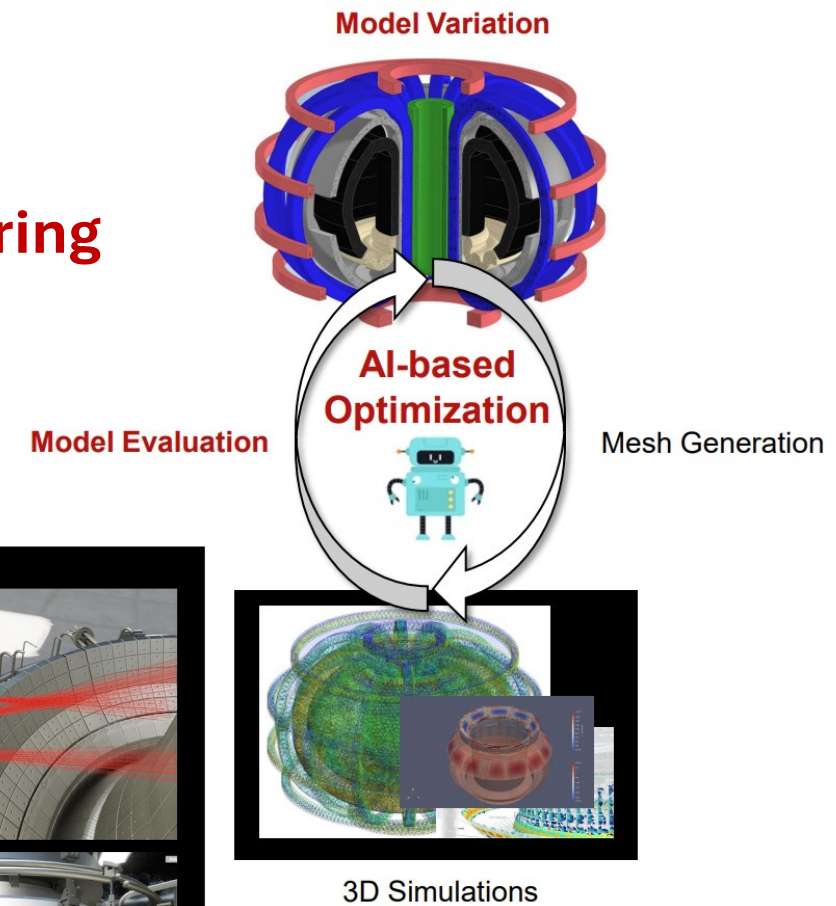


Develop Flexible and Learnable AI-based Control System

AI and Digital Twin based Fusion Design & Engineering Platform

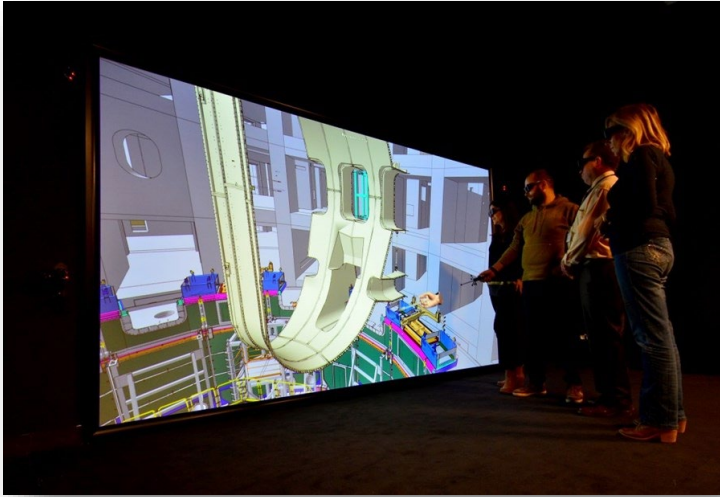


Virtual Tokamak & Digital Engineering

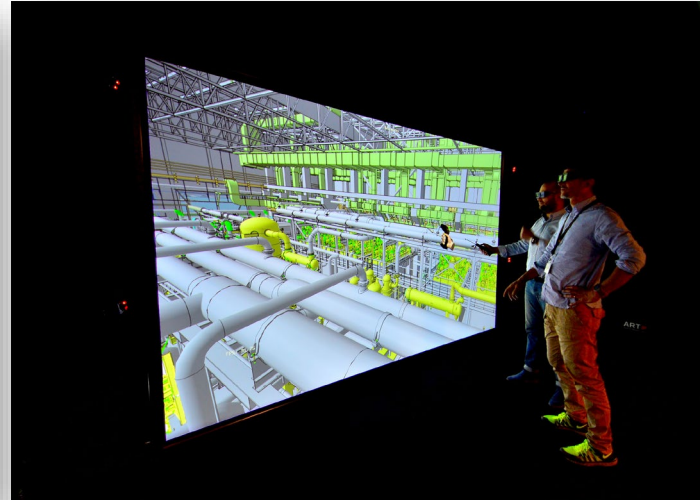


Digital Innovation Platform for Fusion Engineering and Design

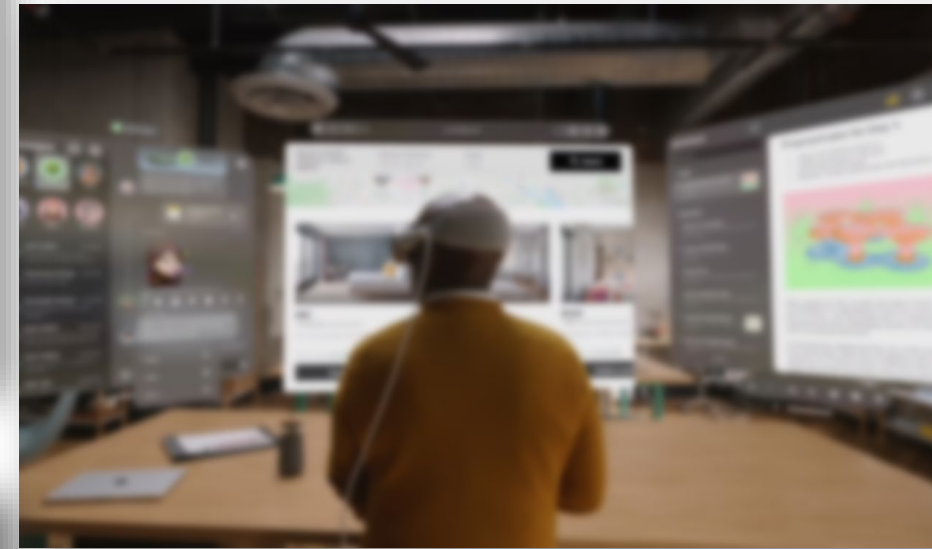
- ITER case exemplifies the potential of **digitally-driven manufacturing** and, when paired with Korea's robust high-quality manufacturing, the resulting synergies could be significantly advantageous.



Virtual Room → VR +



AR → MR + Robotics



Korean ICT High-tech
with AI / GPTs

Fusion HTS Magnet R&D and Manufacturing

➤ Fusion Magnet Requirements (e.g.)

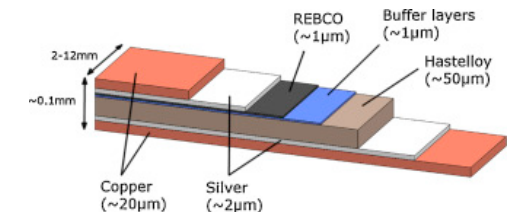
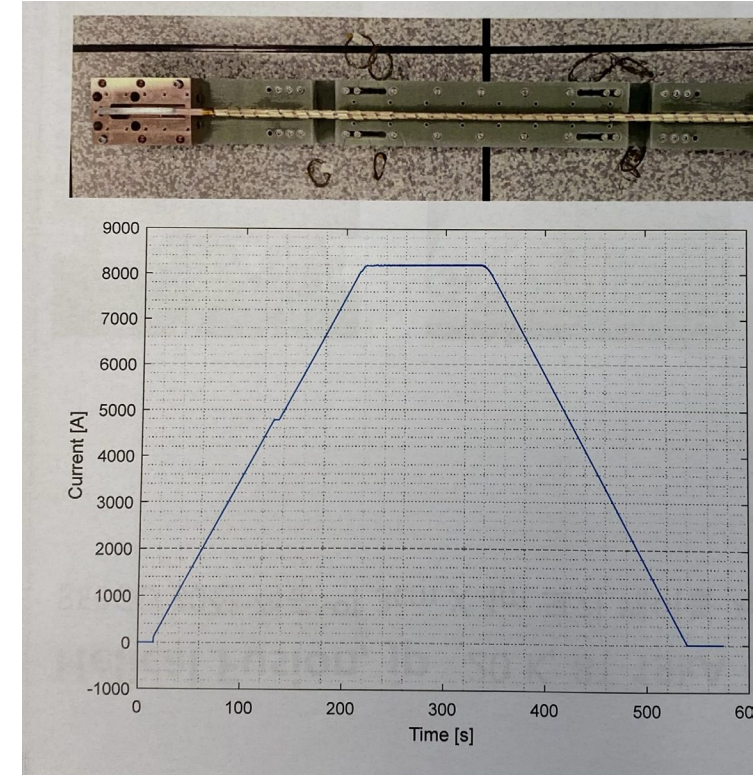
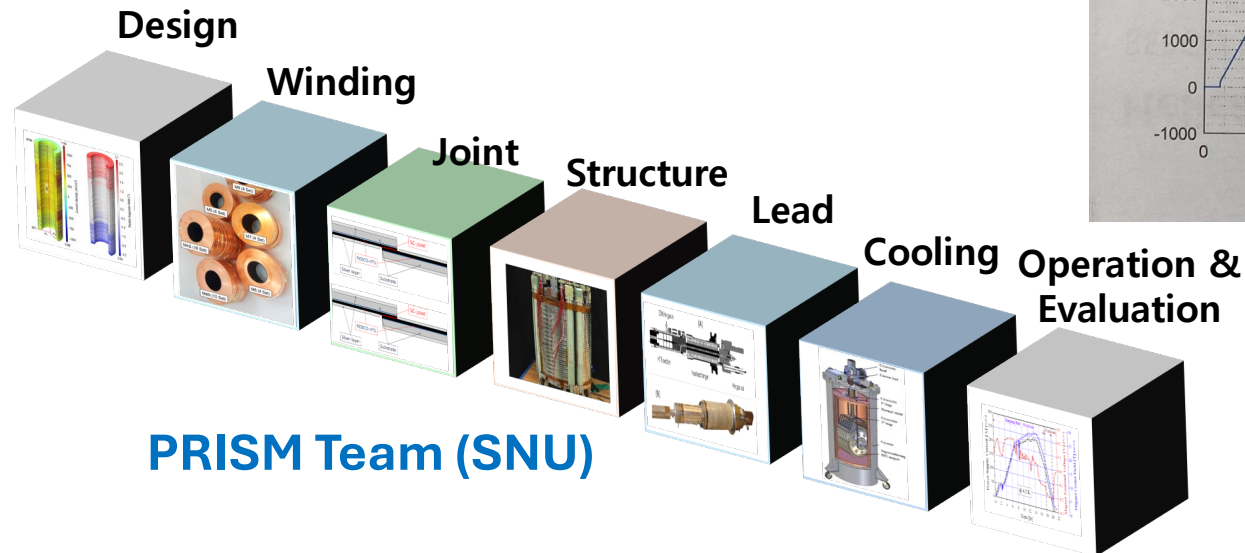
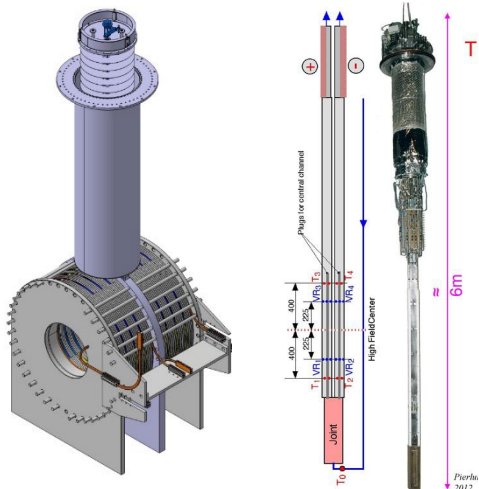
- TF Magnet (REBCO) :
 - $B_0 \sim 9 \text{ T}$, $B_{\text{peak}} \sim 22 \text{ T}$,

➤ HTS Fusion Magnet Cable Design and Optimization (with PRISM, KFE, Kentech, KAT)

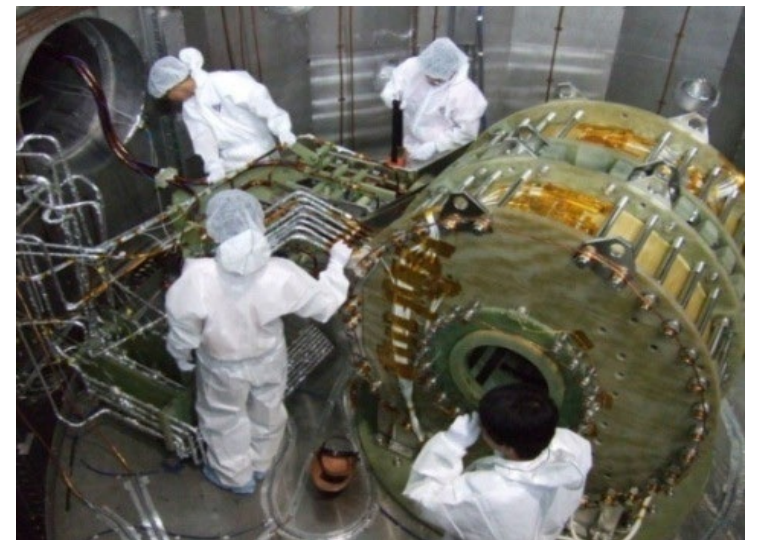
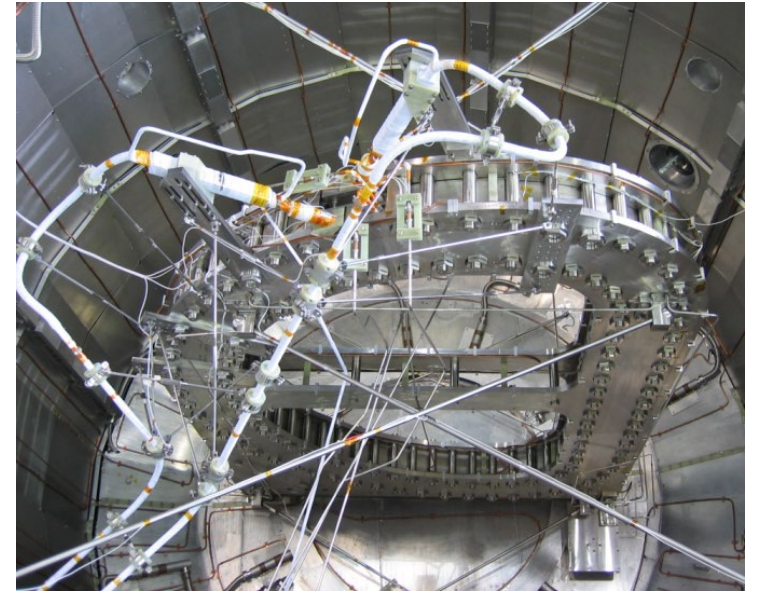
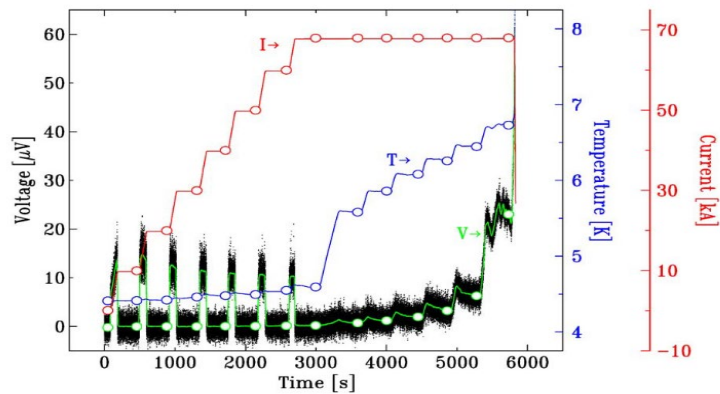
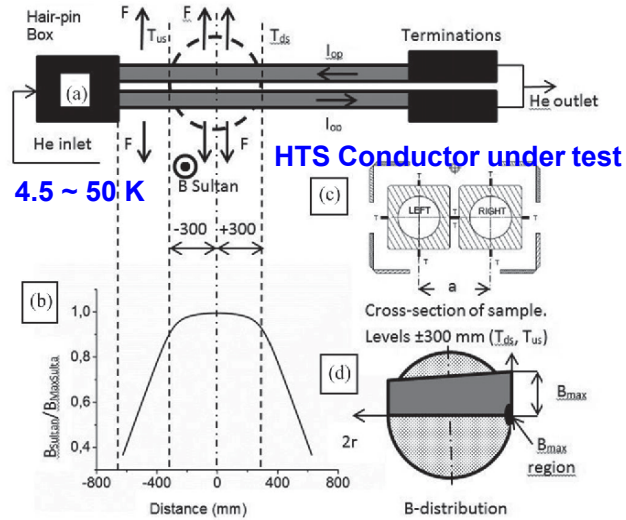
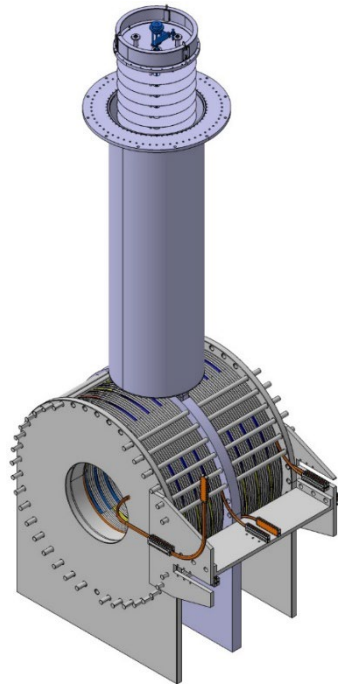
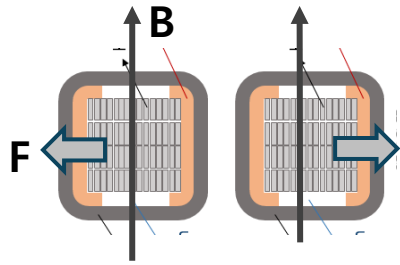
- Novel Conduit-based Design (SICC, 3D-bending)

➤ HTS Fusion Magnet Proto (with KFE, Kentech)

- D-shape Coil Fabrication & Test



Fusion HTS Magnet R&D and Test (KFE and KENTECH)



EnF Future Partners (New Korean Fusion Startups)

Spherical Tokamak Concept

HTS Fusion Magnet Compact Tokamak ...

**소형 핵융합로 실증 연구를 통한
한국형 상용 핵융합 발전 가속화**

황용석¹
 나용수¹, 김태경¹, 이영선¹, 정운호¹, 남건우¹, 전찬휘¹
 민남기², 최수임², 한정봉²

¹ Department of Nuclear Engineering, SNU
² BluepointPartners

답사이언스 창업 활성화 지원사업 대면 평가

소형핵융합용 고온초전도 자석시스템 전문기업 창업

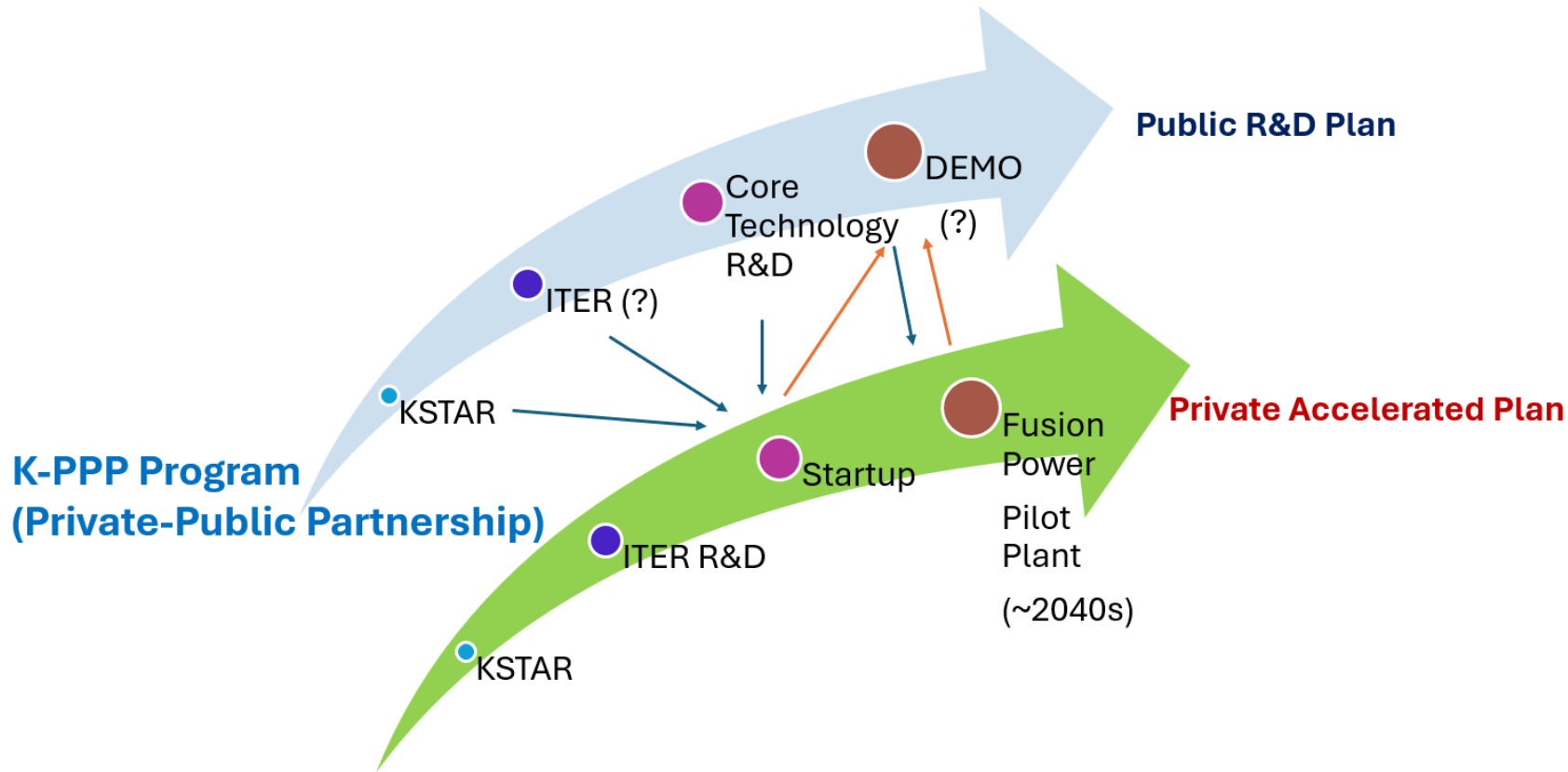
서울대학교 공과대학 전기·정보공학부 한승용
 주식회사 내비온 조성한

2024 답사이언스 창업 활성화 지원사업 선정평가(발표평가)



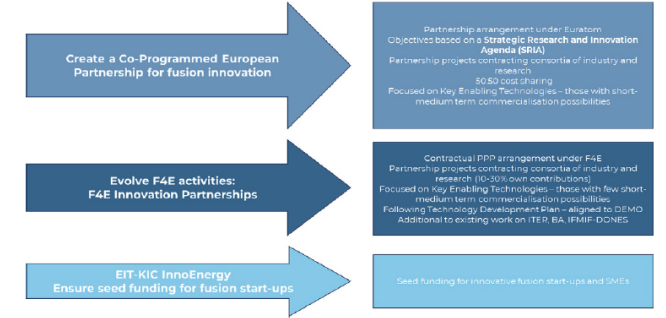
Accelerated Fusion Energy Commercialization (Two-track Approach)

Commercialize by Private-sector w/ Public R&D support @ Accelerated Path



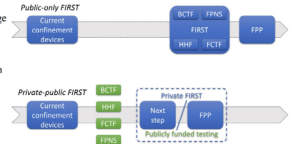
Recommendations for an EU PPP for fusion

Based on the analysis of the fusion funding landscape, the needs of different stakeholders, the main options available and the urgency for action the following overview approach to funding fusion innovation in the EU is proposed. The rationale and accompanying recommendations are detailed further below and fully in chapters 4 and 5.



Fusion Integration Research and Science Test Facility (FIRST) ²⁴

-Experimental facility, which integrates the combined effects of neutron damage from 14.1 MeV neutrons, fully operational blankets and their associated subsystems, and an at-scale fuel cycle.
 -Elucidate behavior and issues that may not appear in single-effects test stands.
 -Includes key capabilities of many single purpose facilities, and evaluated as an alternative to building those separate facilities.
 -Flexibility to explore multiple components and technology choices.



Connection to LRP & BDV, and ability to support/leverage private sector & partnerships

- Not called out directly, but would address numerous strategic objectives.
 - Not consistent with a decadal time frame as a public facility.

Potential to contribute to world-leading science &/or close fusion technology gaps

(b) important
 -Integrated testing in a nuclear fusion pilot plant is critically important to resolve science and technology gaps prior to a commercial fusion industry.
 -To rapidly accelerate towards a FPP, the single purpose facilities were deemed achievable on a more rapid time scale, although leaving a risk associated with integration.
 -An integrated facility requires a down selection of a fusion core and potentially the fusion technologies utilized

Readiness for construction

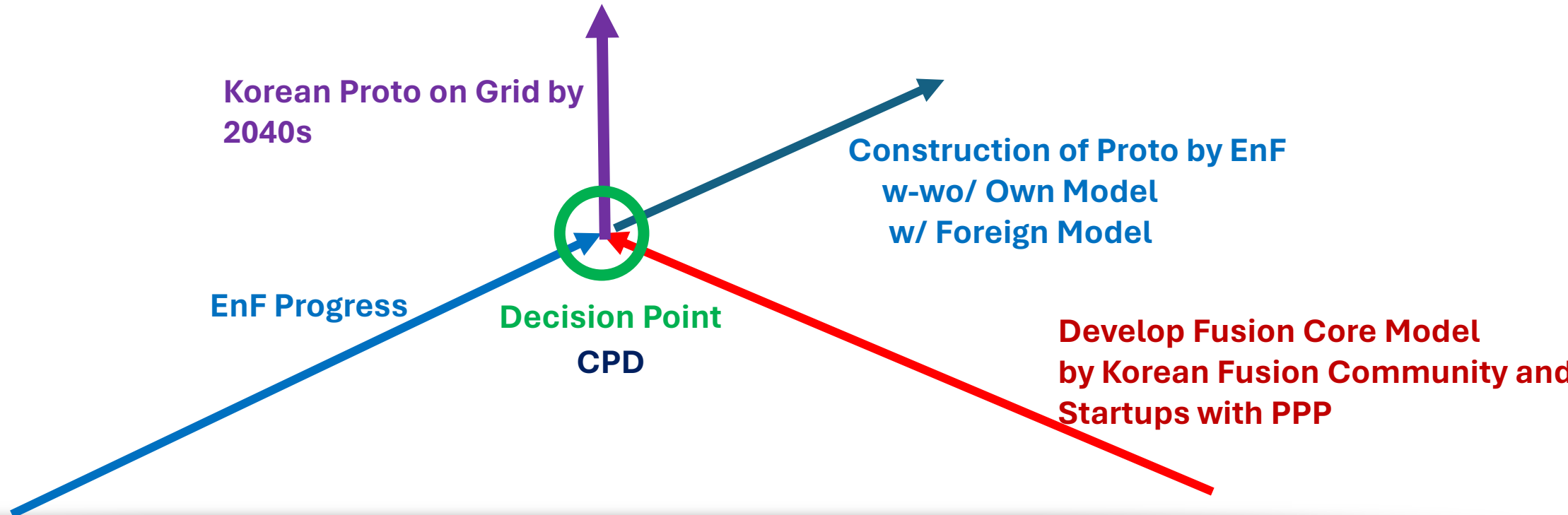
(c) mission and technical requirements not yet fully defined.
 -A FIRST that bypasses single-test facilities puts excessive risk on facility readiness for construction.
 -Privately funded, publicly supported FIRST-type facilities could provide integrated testing across multiple fusion concepts. That has the potential to accelerate readiness for construction and decrease public cost.

背景：各国政府は早期発電実証に向けた国家戦略を既に推進している

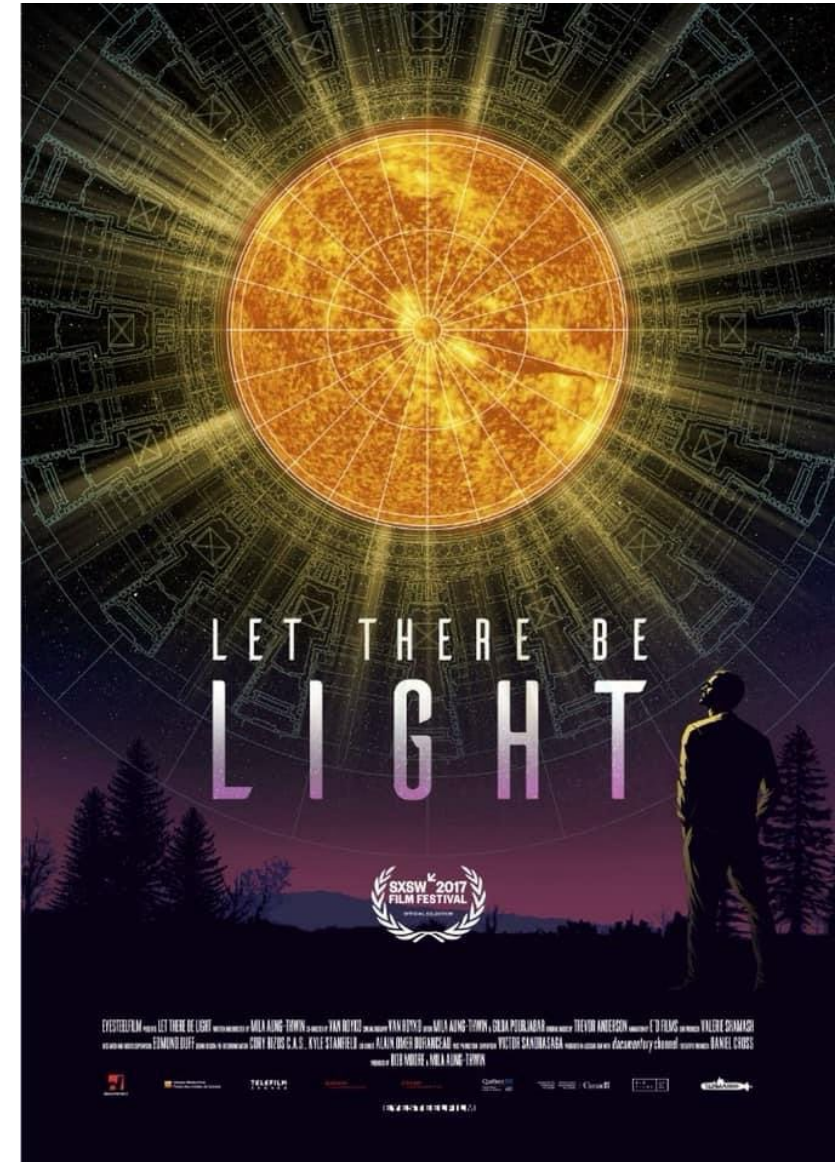
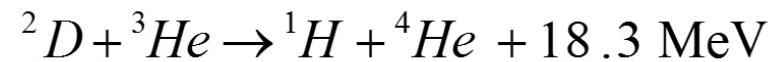
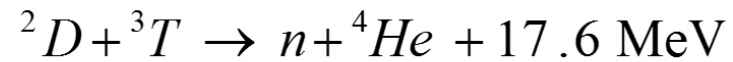
各国の打ち出すフュージョン早期発電戦略	先進実業技術	統合試験	発電実証	実施主体
多様な民間企業に補助金を付け競争させる (USA)	GAMOW (2020) / INFUSE (2023) 初資金 CHIMERA (2024年) 炉内環境模擬試験施設 H3AT (2024) / LIBRTI 燃料系試験施設 RACE (2024) 遠隔取り扱い試験施設	FIRST (2032年) 核融合総合実証試験施設 (計画段階) CRAFT (2025年) 核融合総合実証試験施設 M-ショット (2024) 研究費	2035~40年 競争により決定 2040年 STEPプログラム (球状トカマク) 2030年代 CFETR (従来型トカマク) 2045 or 50年 JA-DEMO (従来型トカマク)	民間主導による官民連携 政府主導による官民連携 中国政府 未定 (計画なし)

Korean Model for Accelerated Fusion Energy Commercialization

- From Public-only Path, to **Private-Public Partnership (PPP) Path**
 - **EnableFusion Inc.** : Leading Private Sector Engineering and Design Platform
 - Define **Commercialization Fusion Core Model** and Design & Engineering
- Focus Developing Korean Best Technology (**HTS SICC, AI+Robotics+MR, Digital Twin.. ?**)
- Build Korean Fusion Proto : **"Compact" Ignition & Burning w/ New Edge Solution**



Let There Be Light...



Commercialization ... (NASA/ESA vs. SpaceX)

EnableFusion Vision with K-PPP



**NASA R&D
(Public Fund)**

**PPP – Private-Public
Partnership Program**

**SpaceX to Mars
(New Space - Private)**