한국의 KSTAR, ITER 건설 경험과 EnableFusion의 역할과 도전

2024. 5. 24.

Gyung-Su LEE

EnableFusion Inc.

EnF

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

Global and National Risks in middle of the 21st Century

Washington Times (January 2009)

Snow of Kilimanjaro (2005)

Strategic Competition, New Cold War

Climate Crisis, Net-Zero with Energy Crisis

Low Carbon Energy Options

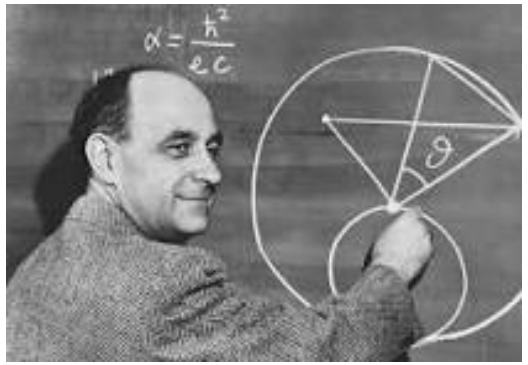
RE100 or CF100 ?

Toward Commercialization of Fusion Energy in 2040s

Quest for Holy Grail (1945-2045?)

$$^{2}D + ^{3}T \rightarrow n + ^{4}He + 17.6\ \text{MeV}$$

$$^{2}D + ^{3}He \rightarrow ^{1}H + ^{4}He + 18.3\ \text{MeV}$$

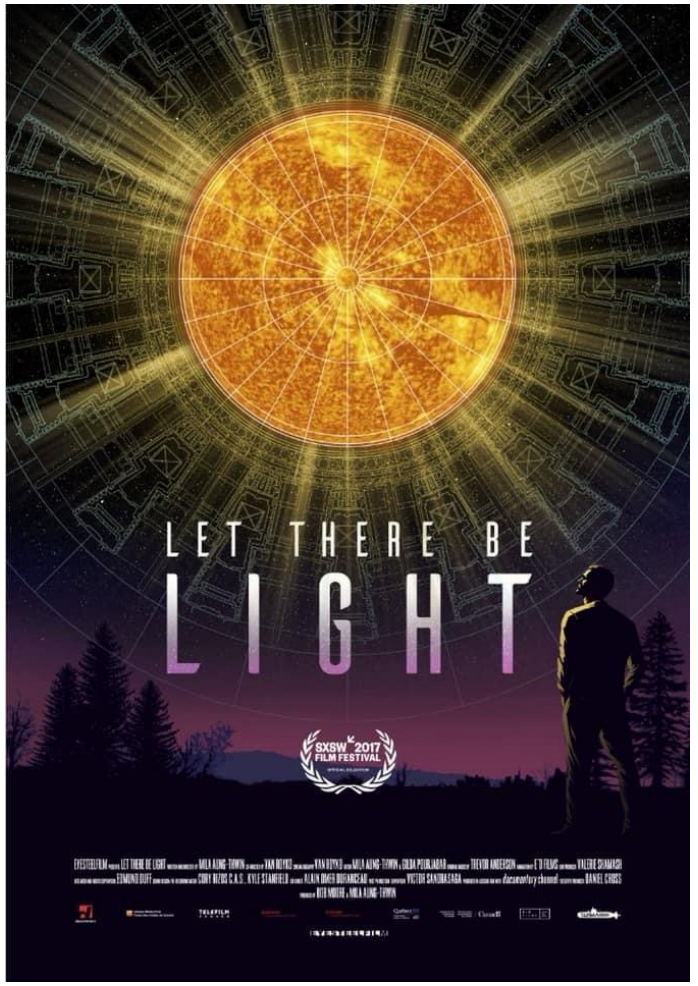


Enrico Fermi (Chicago)

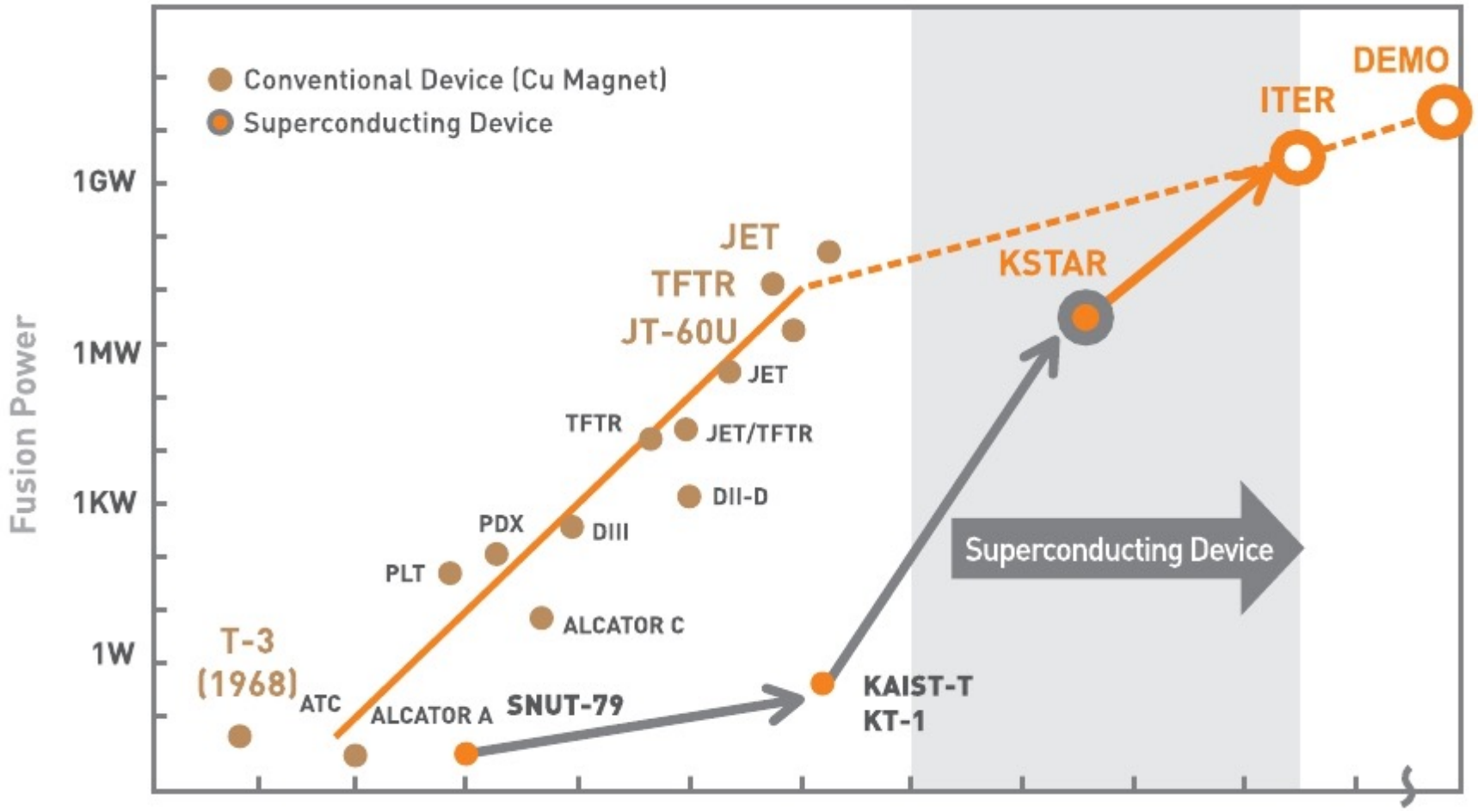
Eugene Parker (Chicago)

Edward Teller (LLNL)

Marshall Rosenbuth
(Chicago, Princeton & Austin)

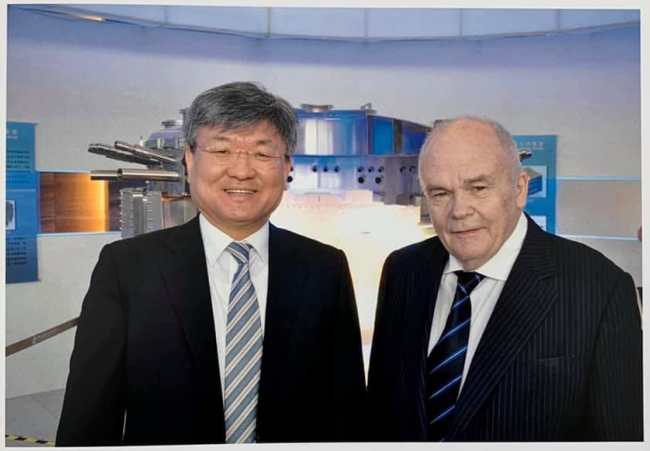


National Fusion Energy based on “Mid-entry Strategy”



핵융합 에너지
상용화 50년 계획
(1995~2045)

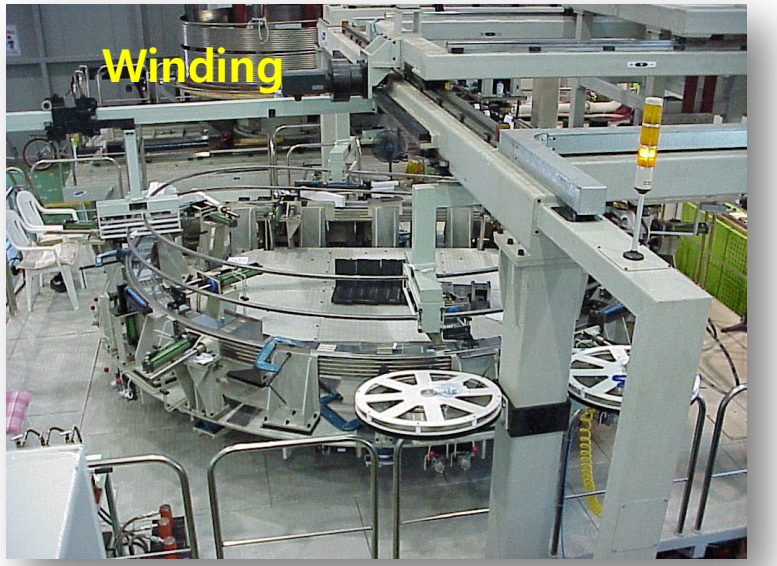
KSTAR Construction start, ITER Negotiation… (1995~2007)

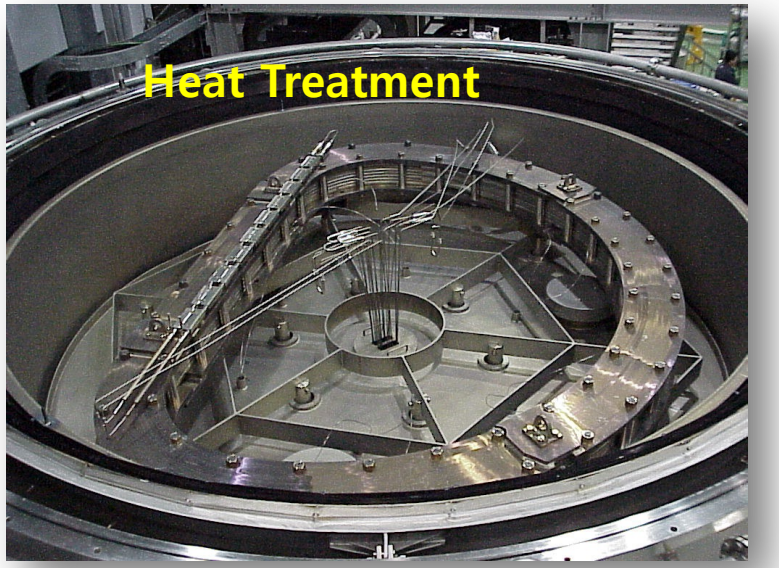


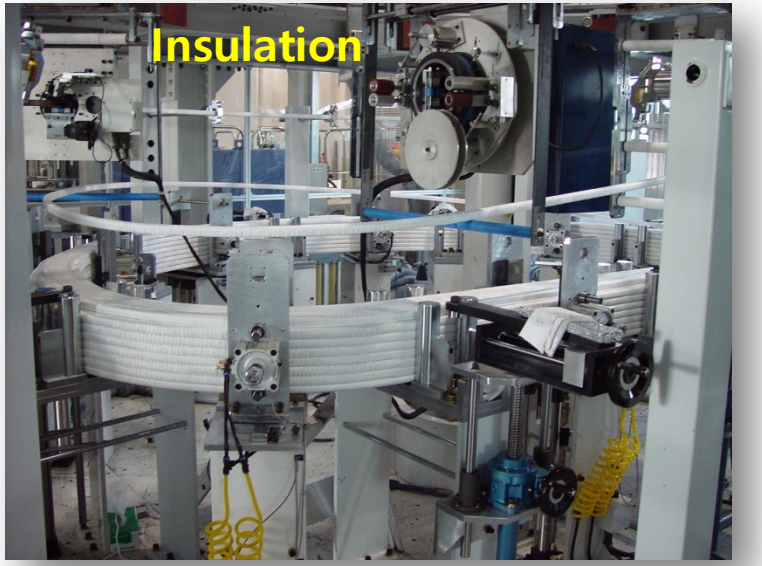
Posing for the history books:
MAC Chairman Gyung Su Lee and the Chairman of the ITER Council, Academician Evgeny Velikhov.

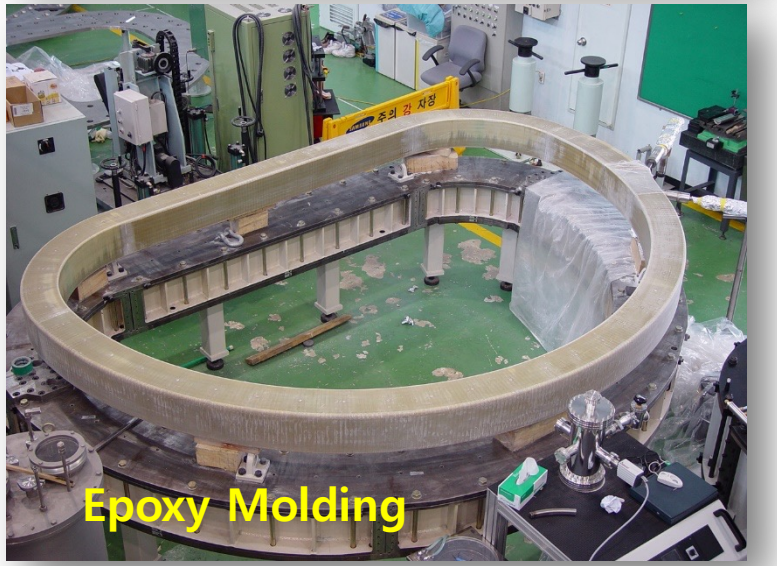
KSTAR Construction Experience with Korean Industries

KSTAR Nb_3Sn SC Magnet (Samsung, Kiswire, Doosan, …)

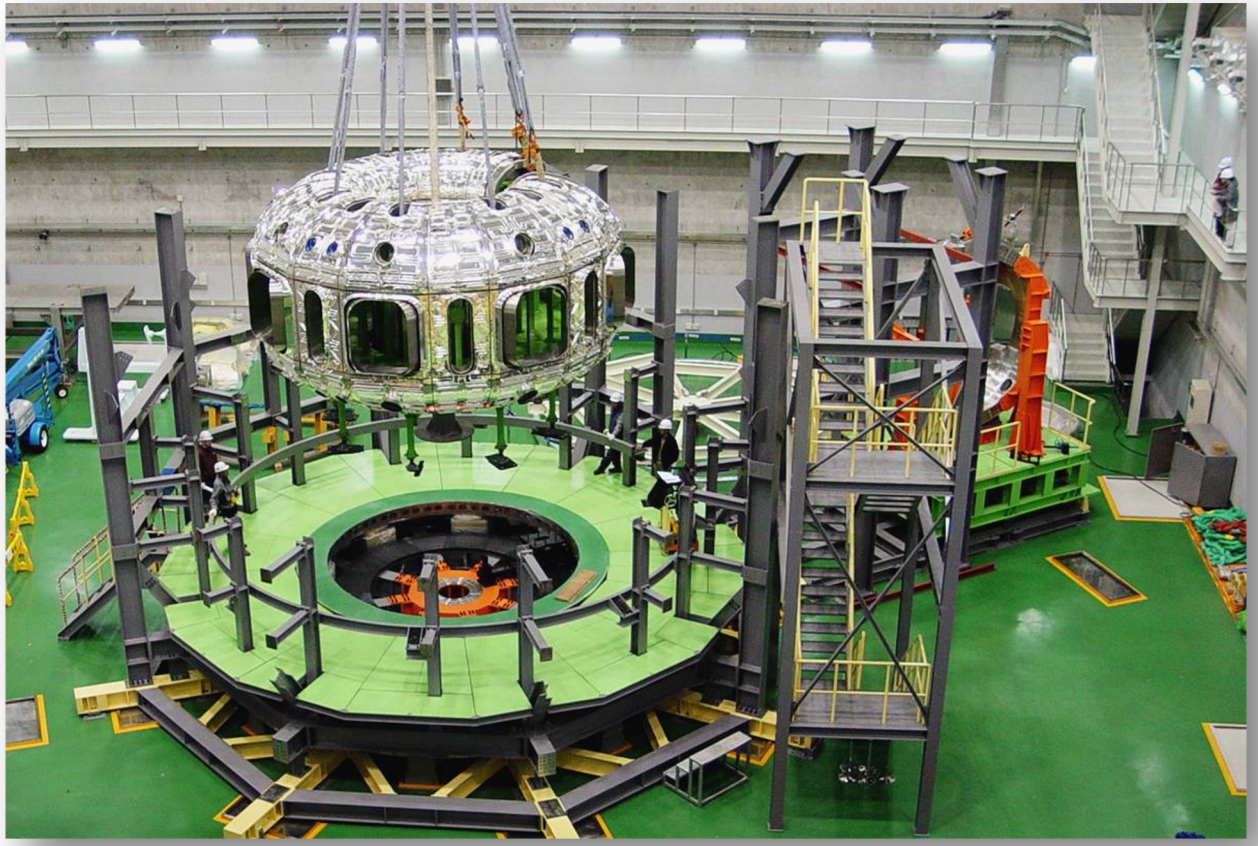




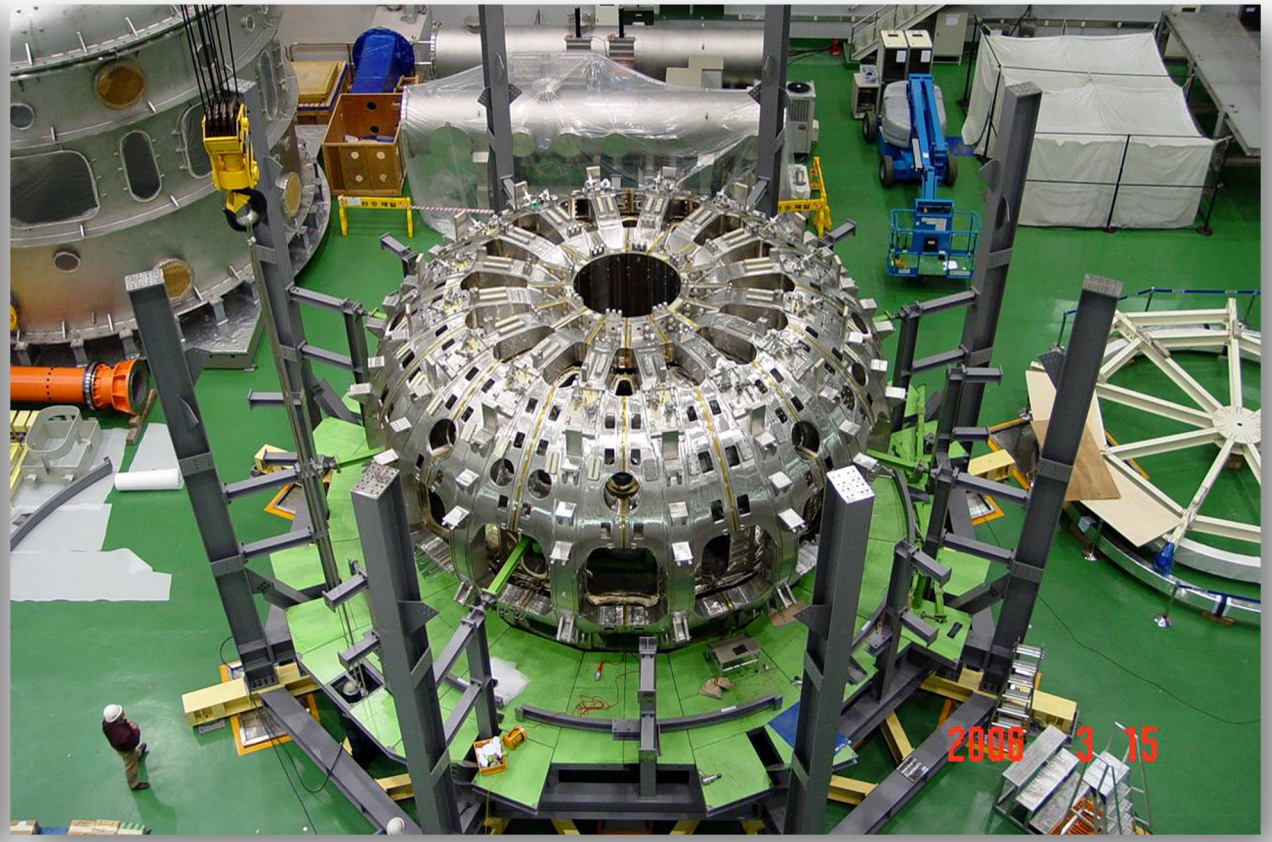




KSTAR Assembly (Hyundai, Doosan, SFA, …)



KSTAR VV and VVTS are installed in TKM Pit

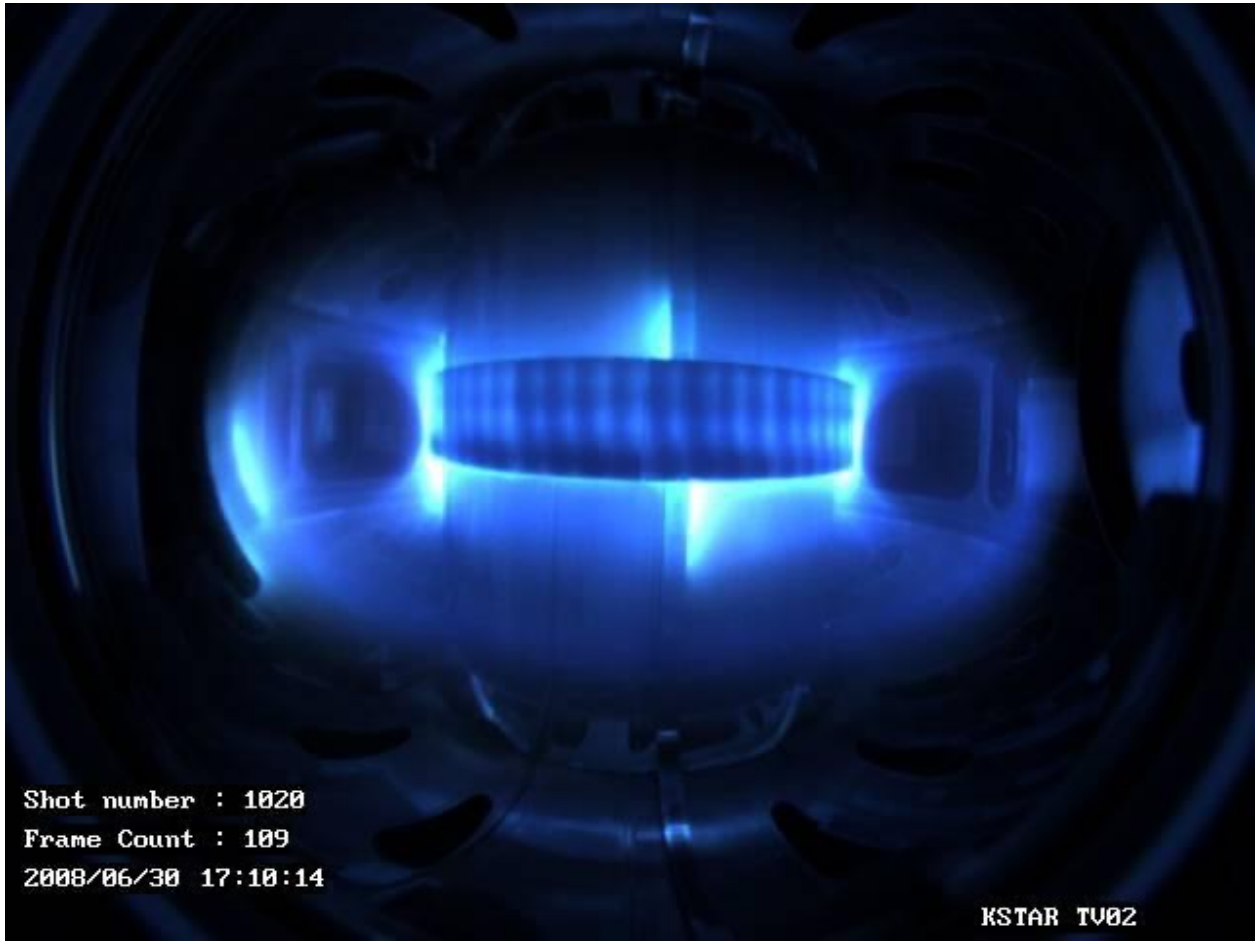


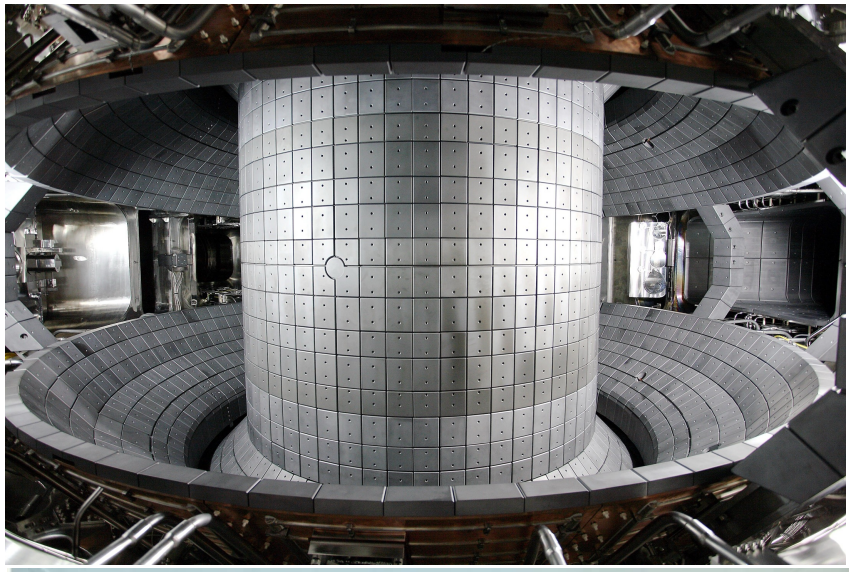
KSTAR TF magnet are installed

KSTAR Construction completed in 2007

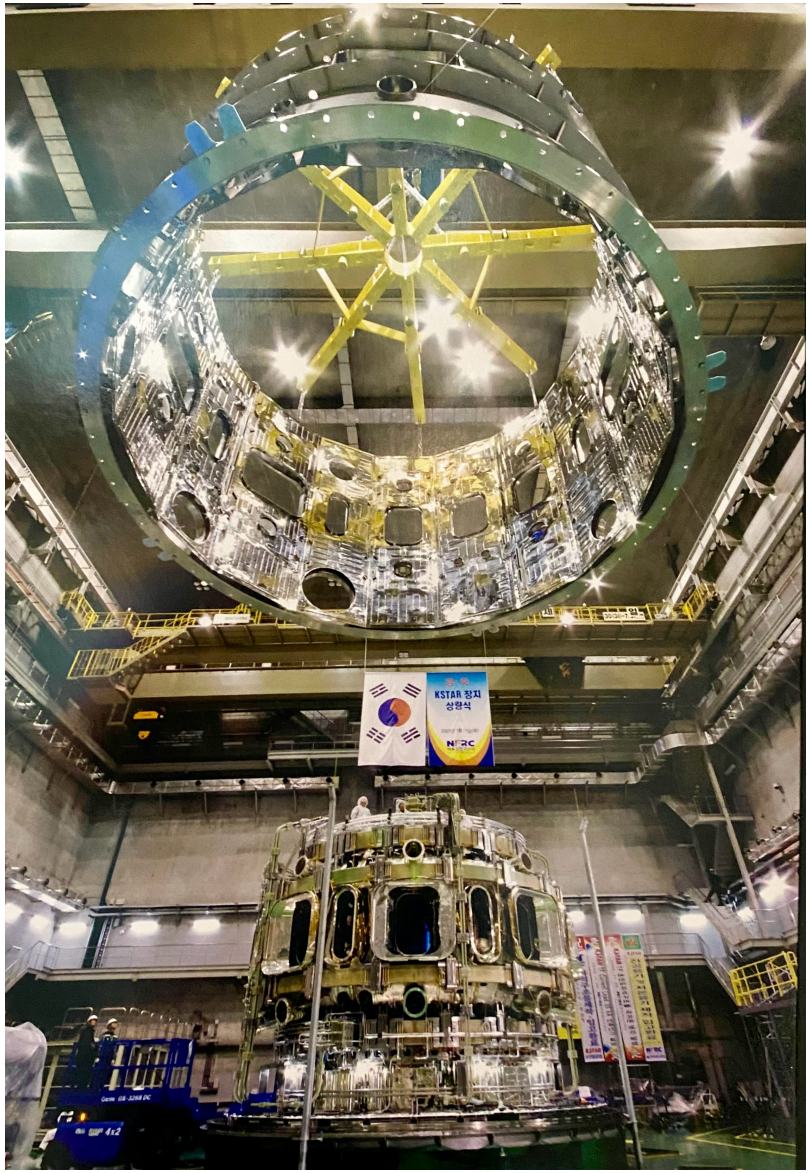
KSTAR succeeded Construction: First Plasma in 2008

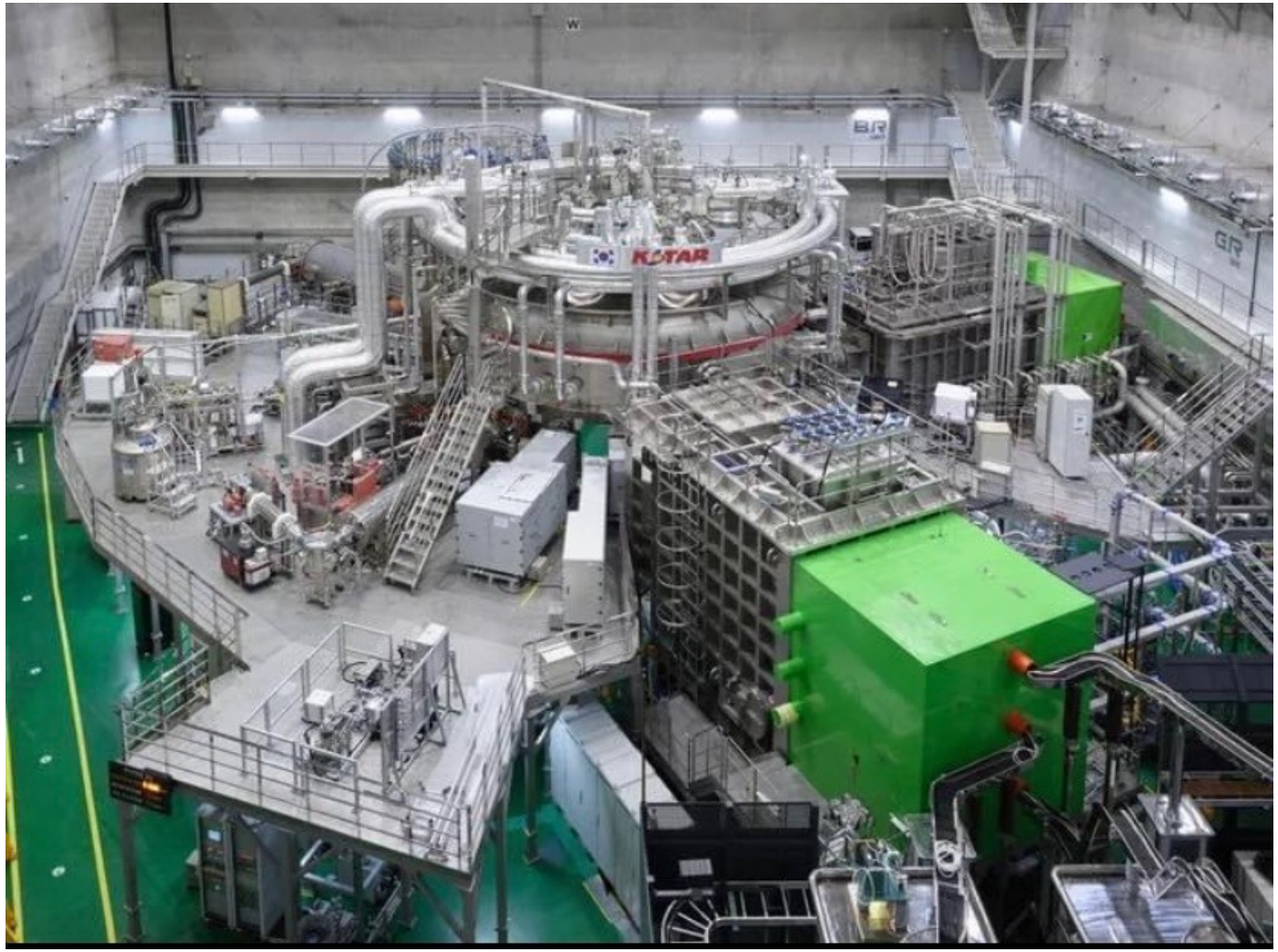
KSTAR First Plasma in 2008



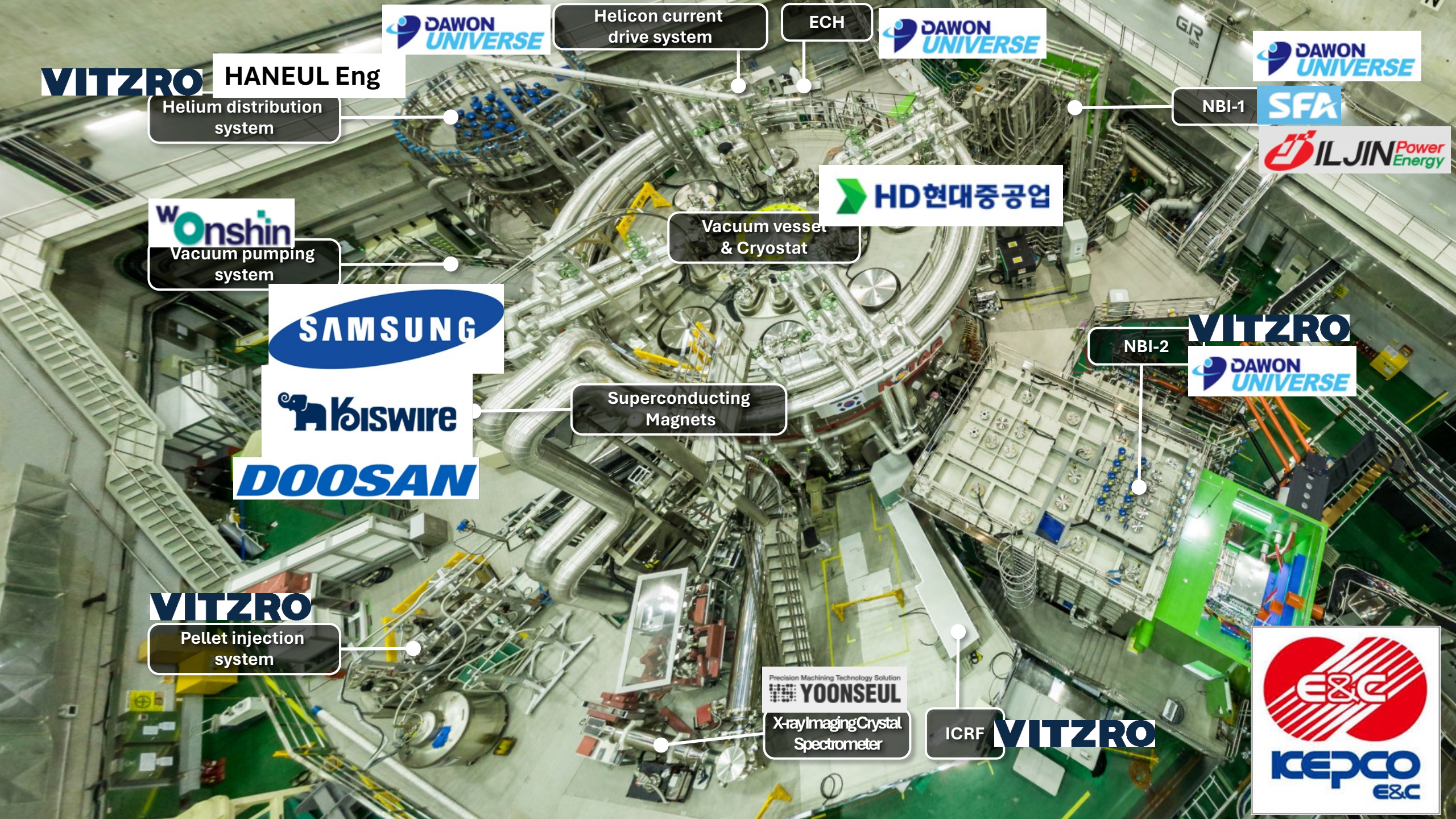


KSTAR Operation 15-years from First Plasma in 2008





No Machine Faults for 15 Years of Operation!


DAWON UNIVERSE
Helicon current drive system
ECH
DAWON UNIVERSE
DAWON UNIVERSE
VITZRO
HANEUL Eng
Helium distribution system
NBI-1
SFA
ILJIN Power Energy
HD현대중공업
Vacuum vessel & Cryostat
Wonshin
Vacuum pumping system
SAMSUNG
KISWIRE
DOOSAN
Superconducting Magnets
NBI-2
VITZRO
DAWON UNIVERSE
VITZRO
Pellet injection system
Precision Machining Technology Solution
YOONSEUL
X-ray Imaging Crystal Spectrometer
ICRF
VITZRO
E&C
KEPCO E&C

ITER Project Experience as a Member State

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

Past and Present Status of ITER

[2009]

Leading World-wide Fusion thru KSTAR & ITER (1995~2015)

ITER Nb_3Sn Superconducting Strands (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.

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).

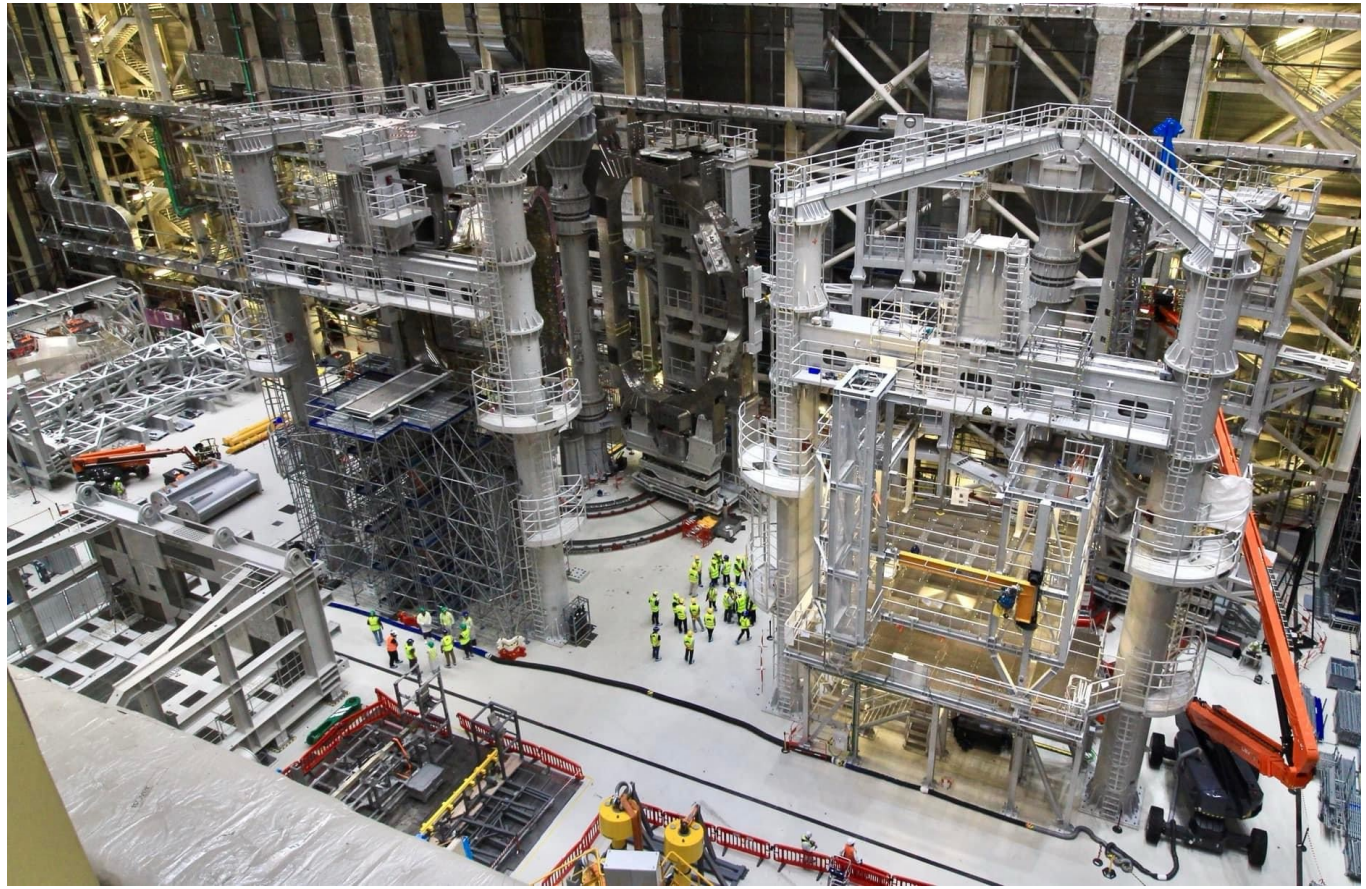
Recognized for the quality of their manufacturing contributions to ITER were: Kiswire Advanced Technology (KAT); Nexans Korea; and the Italian Consortium for Applied Superconductivity (ICAS).
KAT, who was awarded the manufacturing contract for 93 tonnes of niobium-tin (Nb3Sn) superconducting strand for 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.

ITER-CERN Collaboration with World-wide Suppliers

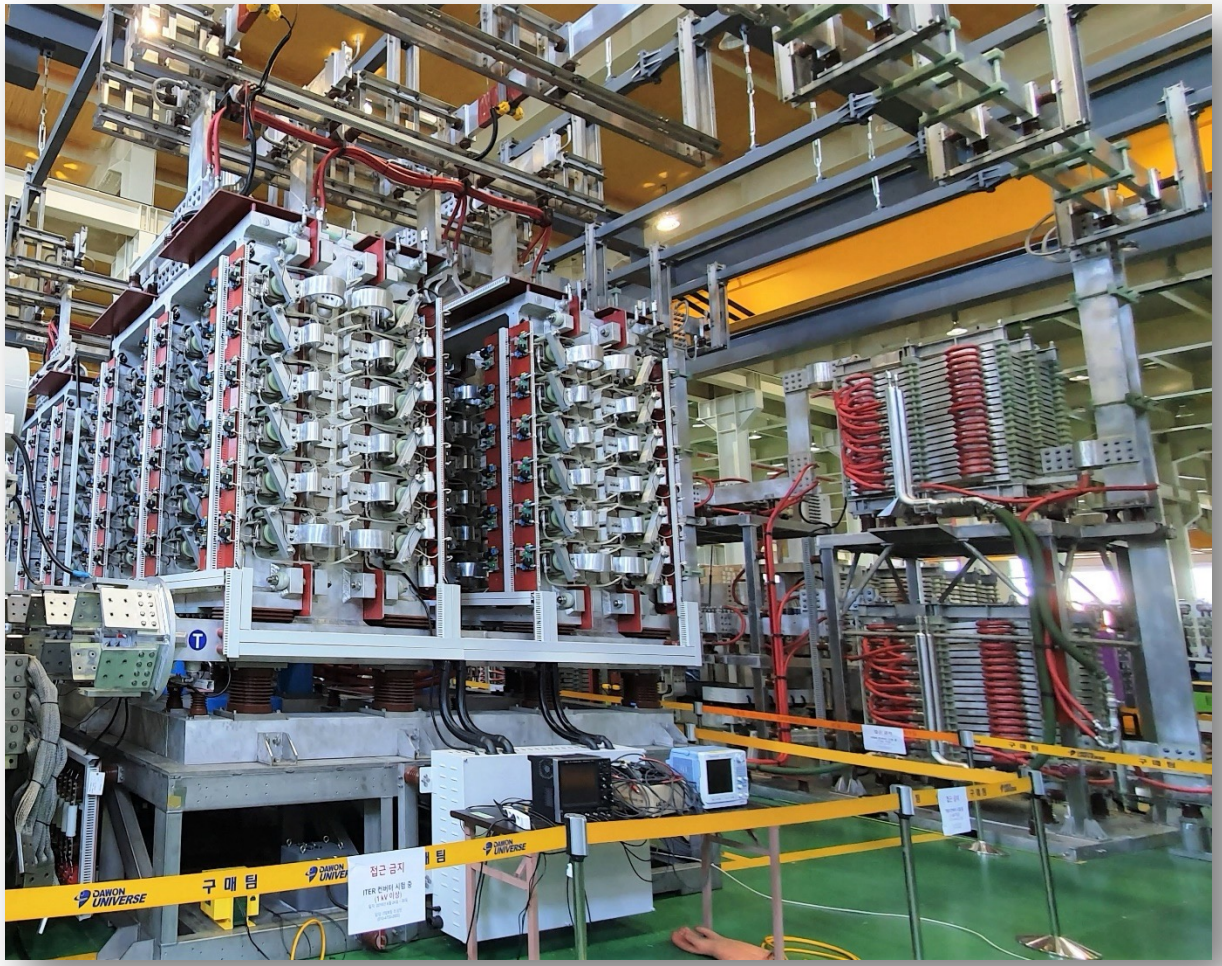
Valued at more than EUR 600 million, the 11 conductor Procurement Arrangements signed by the ITER Organization between 2007 and 2010—covering the procurement of conductors for the large toroidal field, poloidal field and central solenoid magnets as well as correction coils and feeders—represent one of 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 (KO)

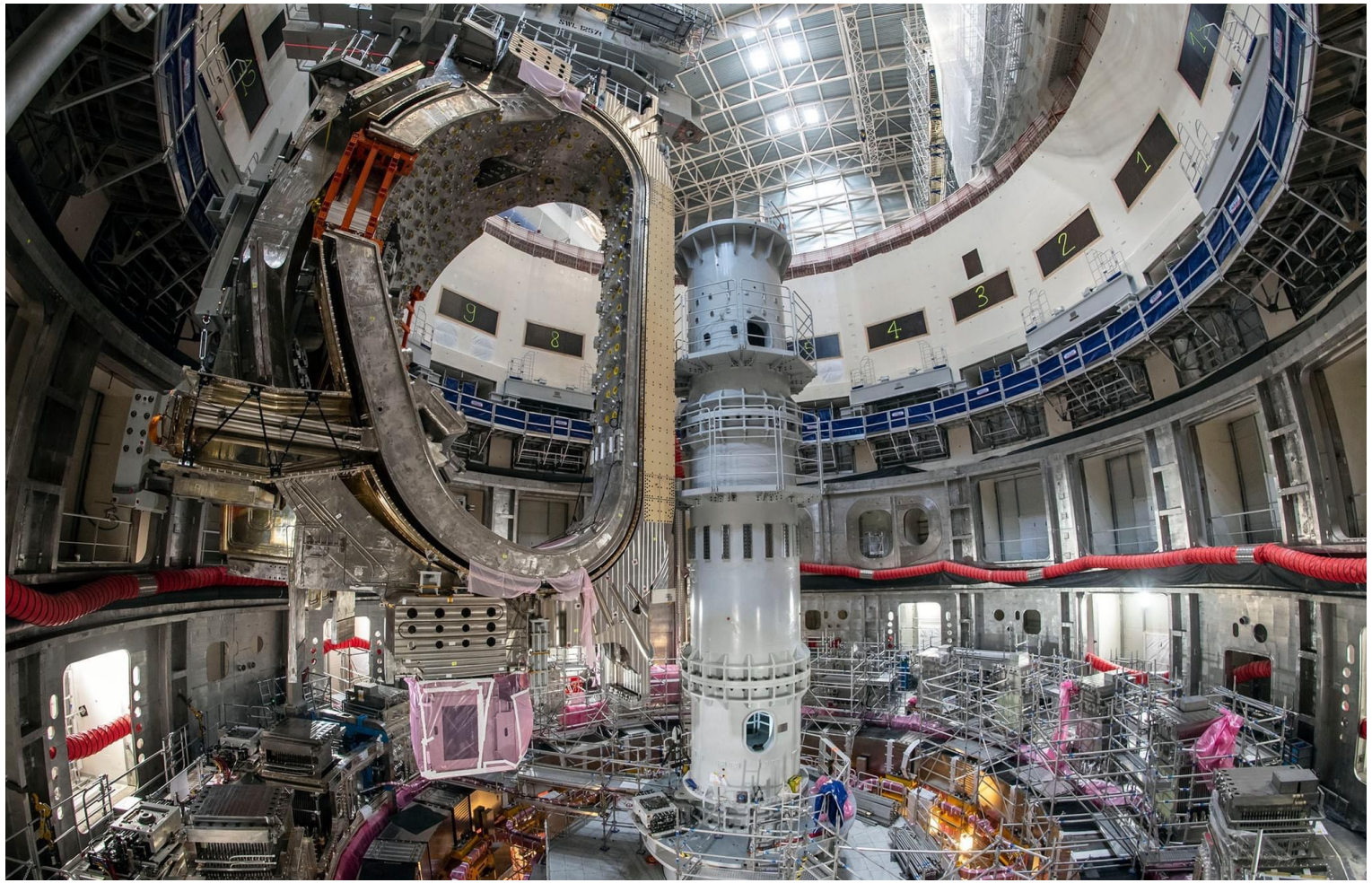


ITER Thermal Shield (KO)

ITER Magnet Power Supply (KO)



ITER VV & Tokamak Assembly (KO)



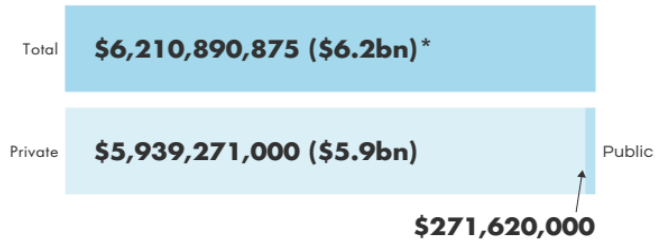
World-wide Accelerated Fusion Energy Commercialization Progress

Startup: 북미, 英, 日, 中 등 50여개 회사

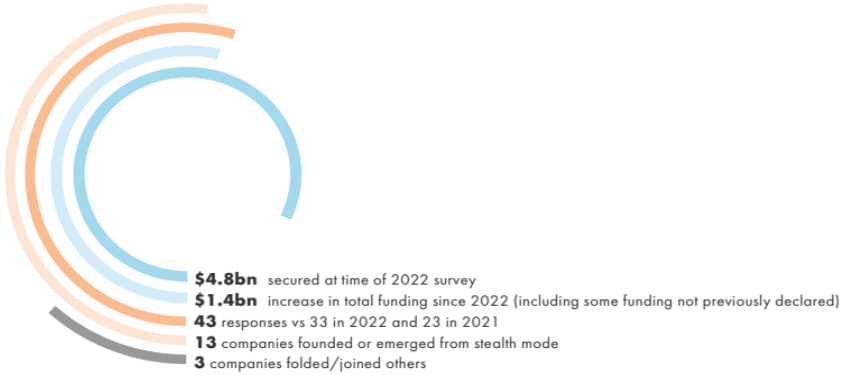
- FIA(Fusion Industry Association) “The global fusion industry in 2023”

HIGHLIGHTS TO DATE

1. Funding for fusion companies

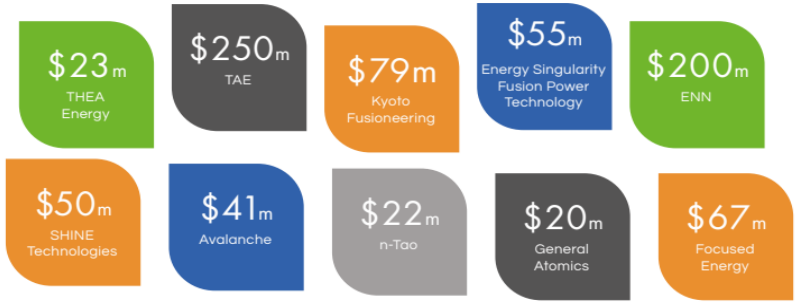


2. Change since 2022 survey

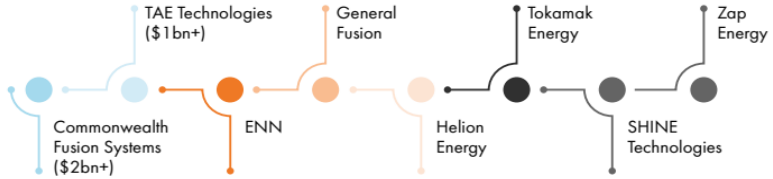


* Some figures have been rounded. Some funding was declared privately, hence total figure here is higher than combined figures stated in company profiles.

3. Notable investments since the last survey



4. Companies with $200m investment or more

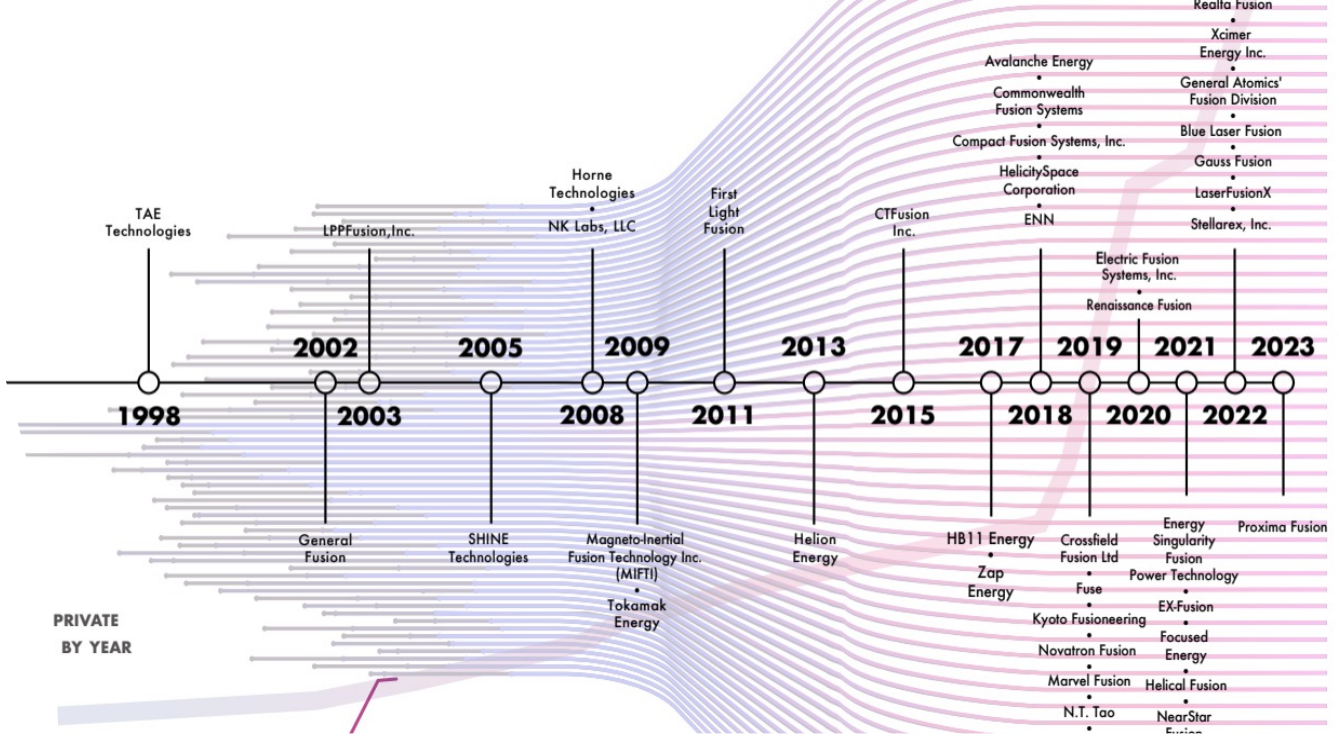


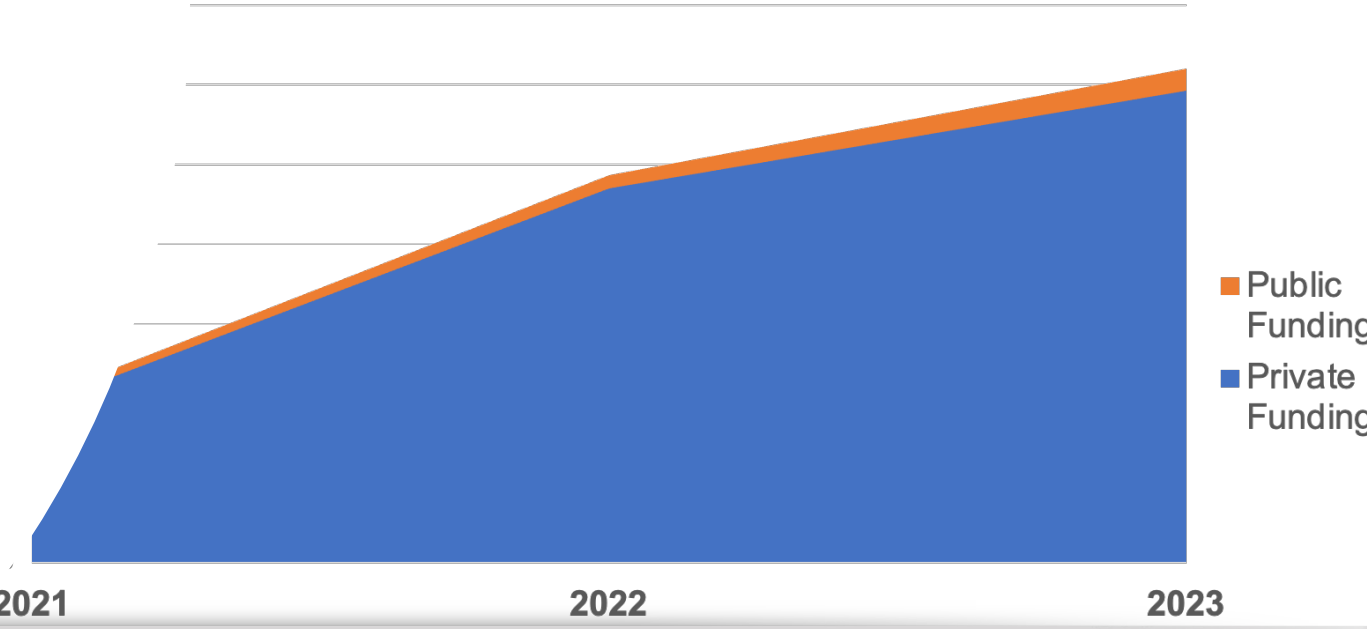
5. Location

By primary HQ

Startup: 2016년 이후 스타트업 수가 급증

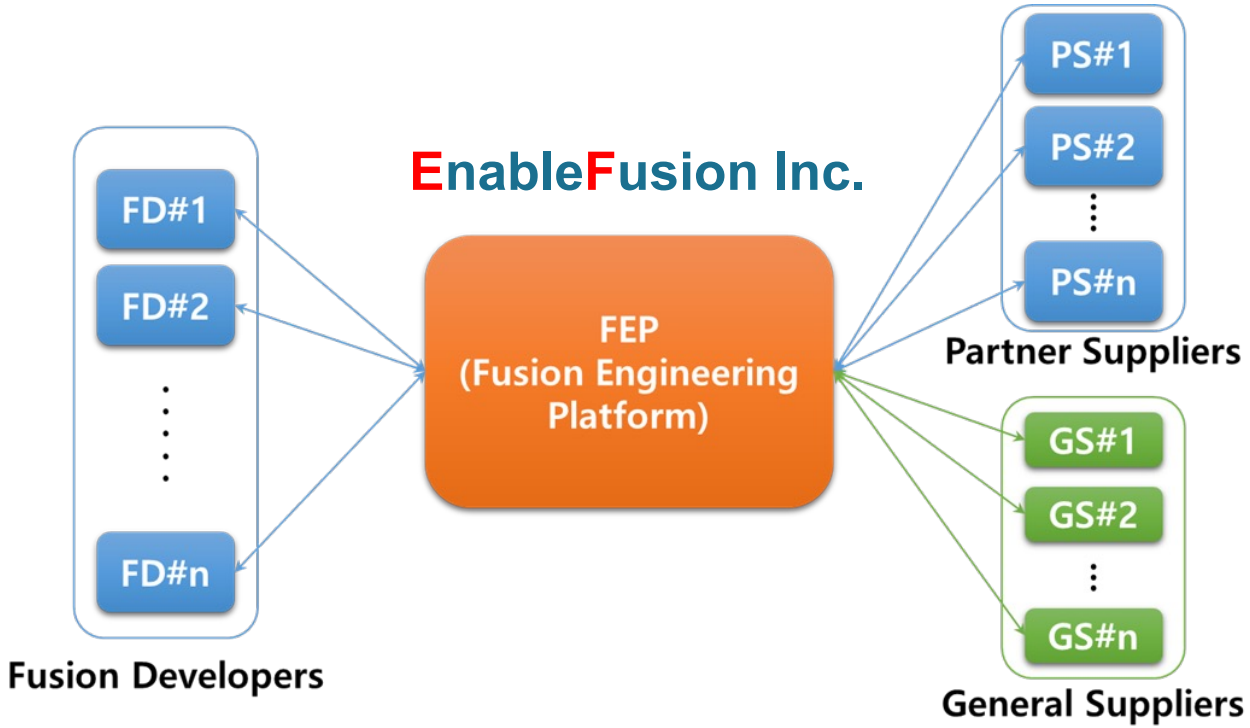
- Tokamak Energy, TAE, General Fusion, Commonwealth Fusion (CFS), Helion 등이 주요기업
- 민간투자도 급증 : 8조원 수준





Fusion Engineering Platform for Fusion Energy Development

Fusion Engineering Platform (FEP), which connects Fusion Developers and Fusion Manufacturers through a **digitally-driven platform** to solve mutual problems in Fusion Energy Commercialization



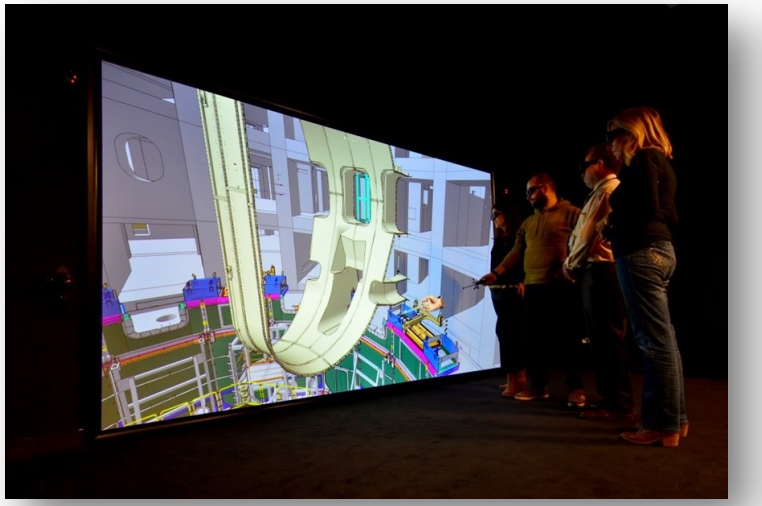
Asset Leveraging Structure in the EnableFusion

Additional Business Areas

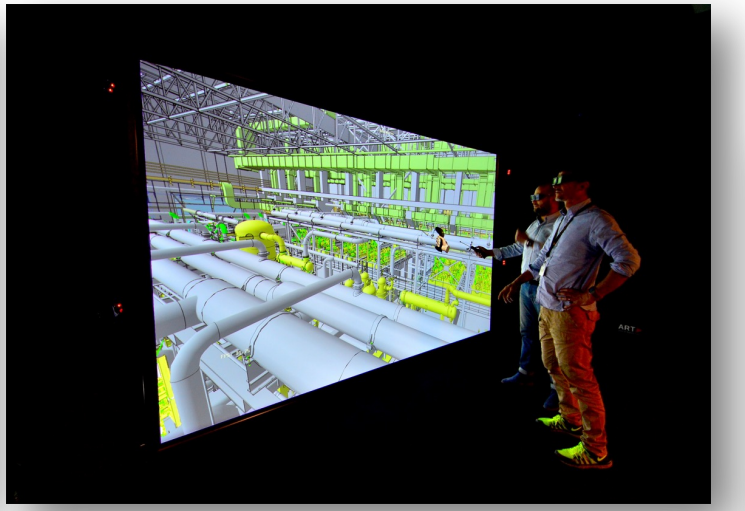
- New Major Accelerator Projects
- 4th Generation SMR…

Digital Innovation Platform for Fusion Engineering and Design

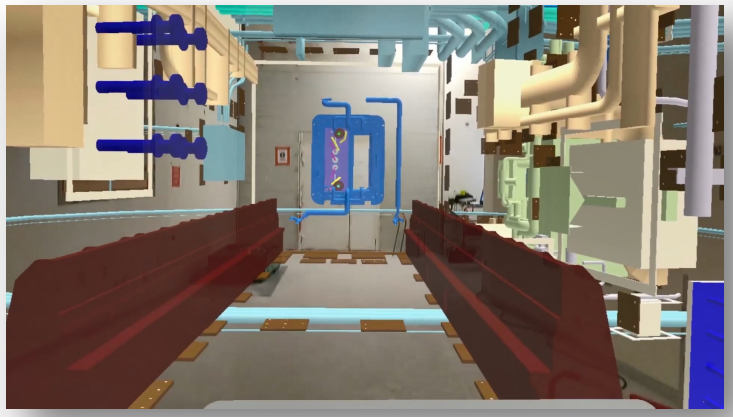
- ITER case exemplifies the potential of **digitally-driven manufacturing** and, when paired with Korea's robust high-quality manufacturing, the resulting synergies could be significantly advantageous.



Virtual Room → VR +



AR → MR + Robotics



Korean ICT High-tech with AI / GPTs

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

KISWIRE KAT

LS ELECTRIC

SeAH 세아창원특수강

SOLiD

posco 포스코DX

DAWONSYS

mobiis

VITZRO NEXTECH

삼홍기계

(주)스타웰즈 STARWELDS Inc.

[주]유진엠에스 MECHATRONICS

EMK 이엠코리아주식회사 ENERGY&MACHINERY KOREA CO.,LTD.

HANEUL HANEUL ENGINEERING CO., LTD.

HIGH VALUE CONSULTING

• • •

EnableFusion Opening (April 17, 2024)

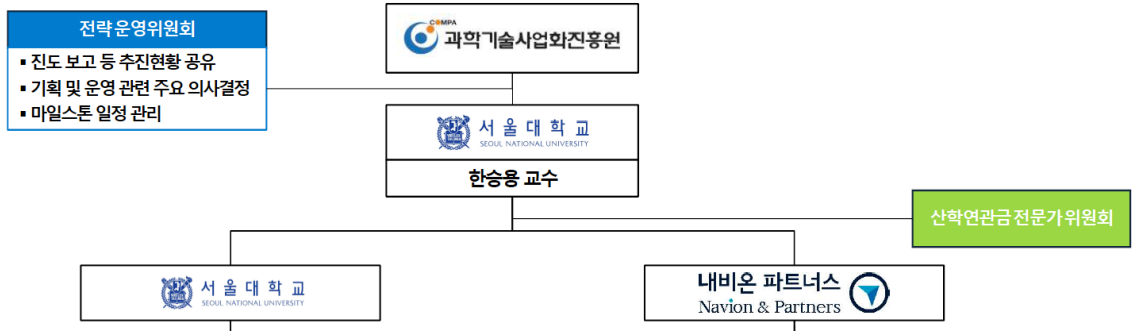
EnF Future Partners (핵융합분야 딥사이언스 창업기업)

소형핵융합용 고온초전도 자석시스템 전문기업 창업

서울대학교 공과대학 전기·정보공학부 한승용
주식회사 내비온 조성한

2024 딥사이언스 창업 활성화 지원사업 선정평가(발표평가)

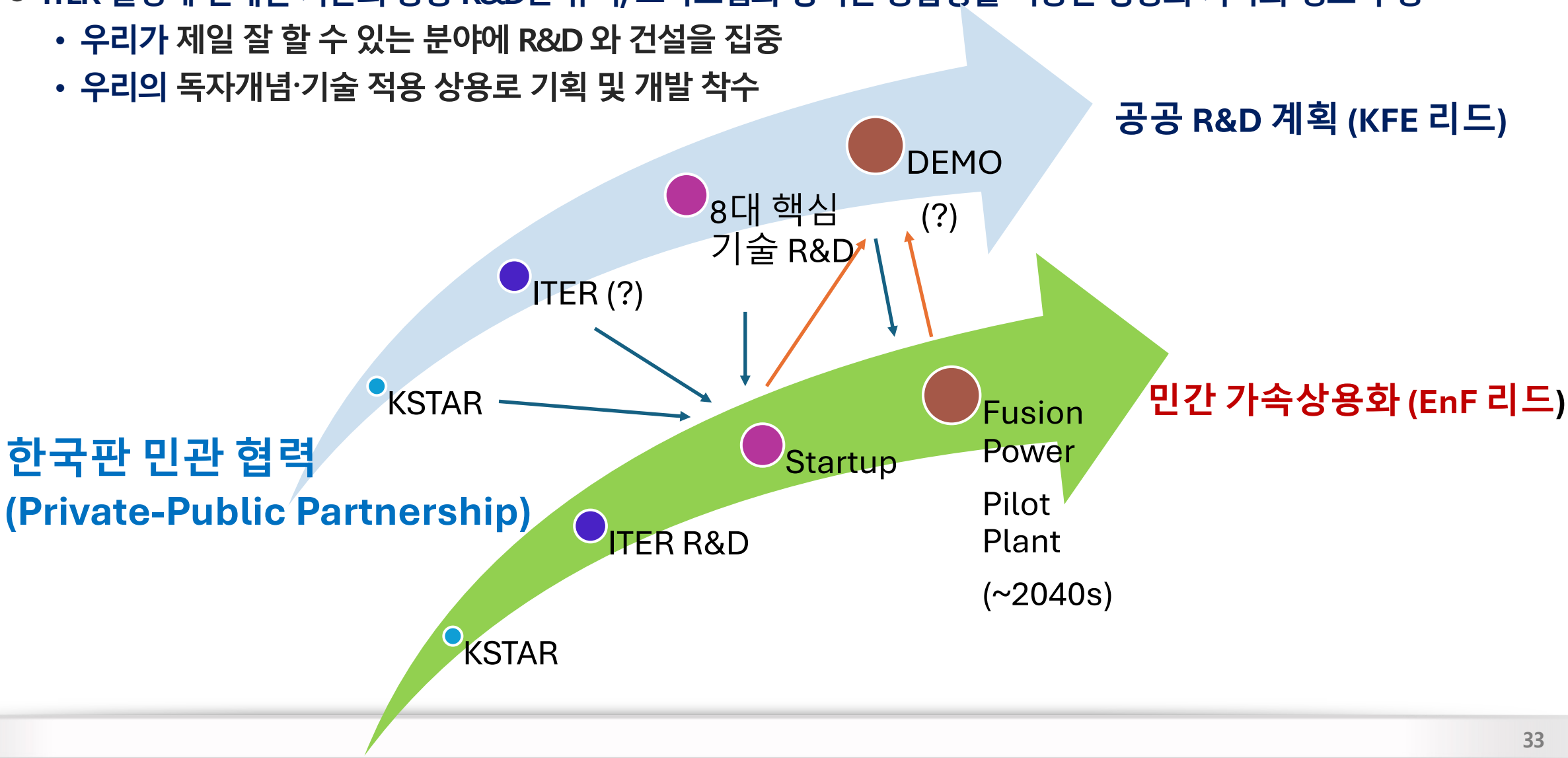
	1단계(9개월) 창업 준비 및 기획	2단계(3년) 기술고도화 + 창업	3단계(2년) 시장지향R&D + 초기성장
서울대 핵융합 연구팀	- 소형 핵융합로 기술 동향 분석 - 창업 유망 기술 검증	- 연속 운전을 위한 전류 구동 방식 기술 고도화 - VEST 초전도화 계획 수립	- VEST의 초전도화 진행 - 소형 ST 성능 검증 - 에너지 순생산 장치 설계 데이터 확보
블루 포인트 파트너스	- 예비 창업팀 구축 지원 - 경영자 창업 교육과 멘토링 - 사업 모델 타당성 검토와 시장 분석 - 장단기 사업 모델 구축	- 창업준비 - 투자 유치 지원	- 후속 투자 유치
경영자 & 창업팀	- 서울대 대학원생 3명을 주축으로 구축 - 내부적으로 예비 경영자 발굴 - 외부 경영자 추가 고려	- 핵심 기술 공동 개발 및 사업모델 고도화 - 창업 기업 설립 - 특허 포트폴리오 구축	- 시장지향 R&D 지원 - 시제품 제작 및 실증 지원 - 후속 투자 유치



핵융합 가속상용화 추진 (Two-track Approach)

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

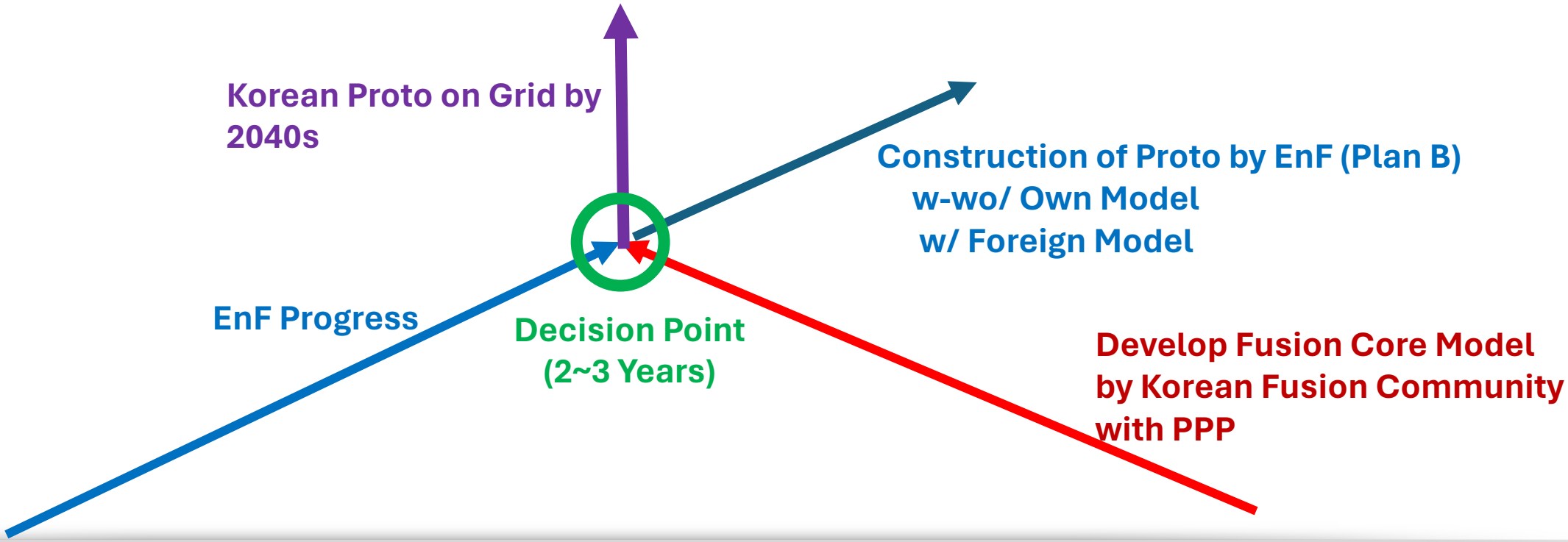
- ITER 일정에 연계된 기존의 공공 R&D는 유지, 스타트업과 강력한 공급망을 이용한 상용화 가속화 경로 수행
  - 우리가 제일 잘 할 수 있는 분야에 R&D 와 건설을 집중
  - 우리의 독자개념·기술 적용 상용로 기획 및 개발 착수



핵융합 가속상용화의 새로운 접근

- 지금의 Public-only Path 로부터, Private-Public Partnership (PPP)로 가속상용화 달성
  - EnableFusion Inc. : Leading Private Sector Engineering and Design Platform으로 발전
  - 동시에 세계 경쟁력을 가지는 독자 Fusion Core Model을 찾고, 기획하고, 설계

- 우리가 세계를 리드할 분야 기술 개발에 집중 (HTS SICC, AI+Robotics+MR, Digital Twin.. ?)
- 2030년대 우리나라 독자 Fusion Proto 건설 착수 : "Compact" Burning w/ New Edge Solution



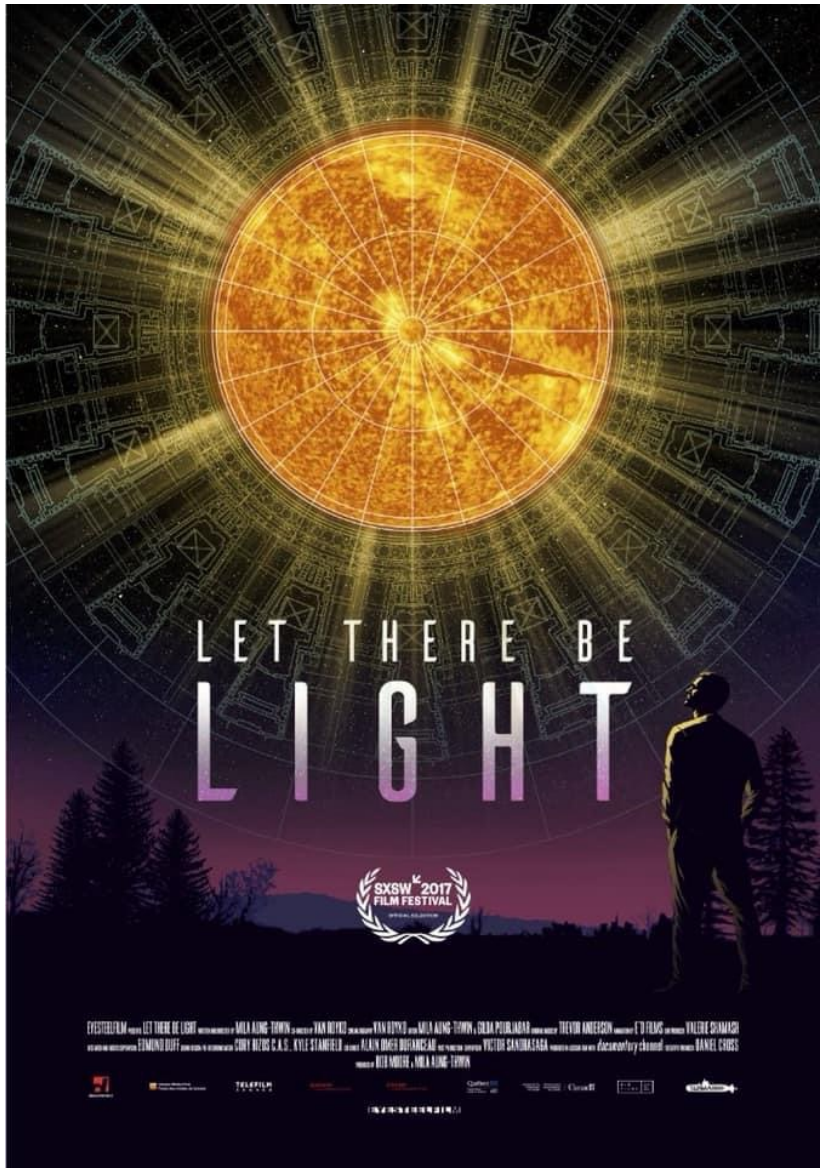
Let There Be Light...

EnF (주)인에이블퓨전 EnableFusion Inc. 기업부설연구소

Fusion Enabling R&D Center

$$^{2}D + ^{3}T \rightarrow n + ^{4}He + 17.6\ \text{MeV}$$

$$^{2}D + ^{3}He \rightarrow ^{1}H + ^{4}He + 18.3\ \text{MeV}$$



EnF Vision and Plan on World-wide Mega-Science Projects

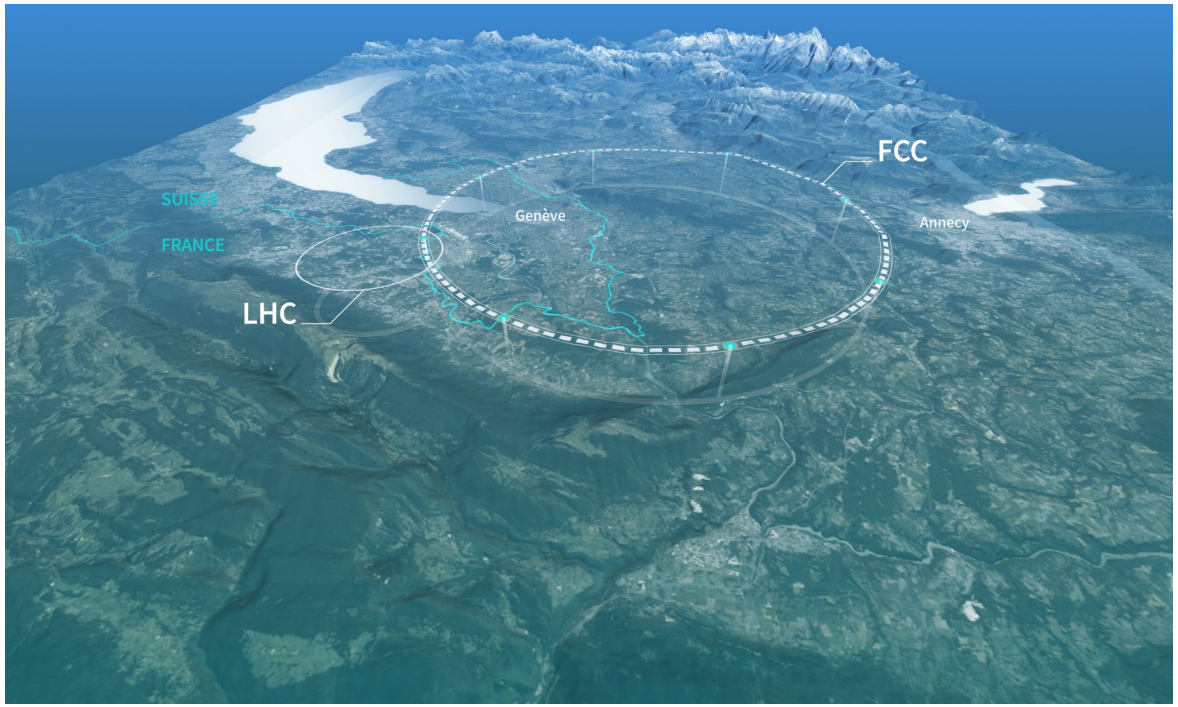
Future Circular Collider

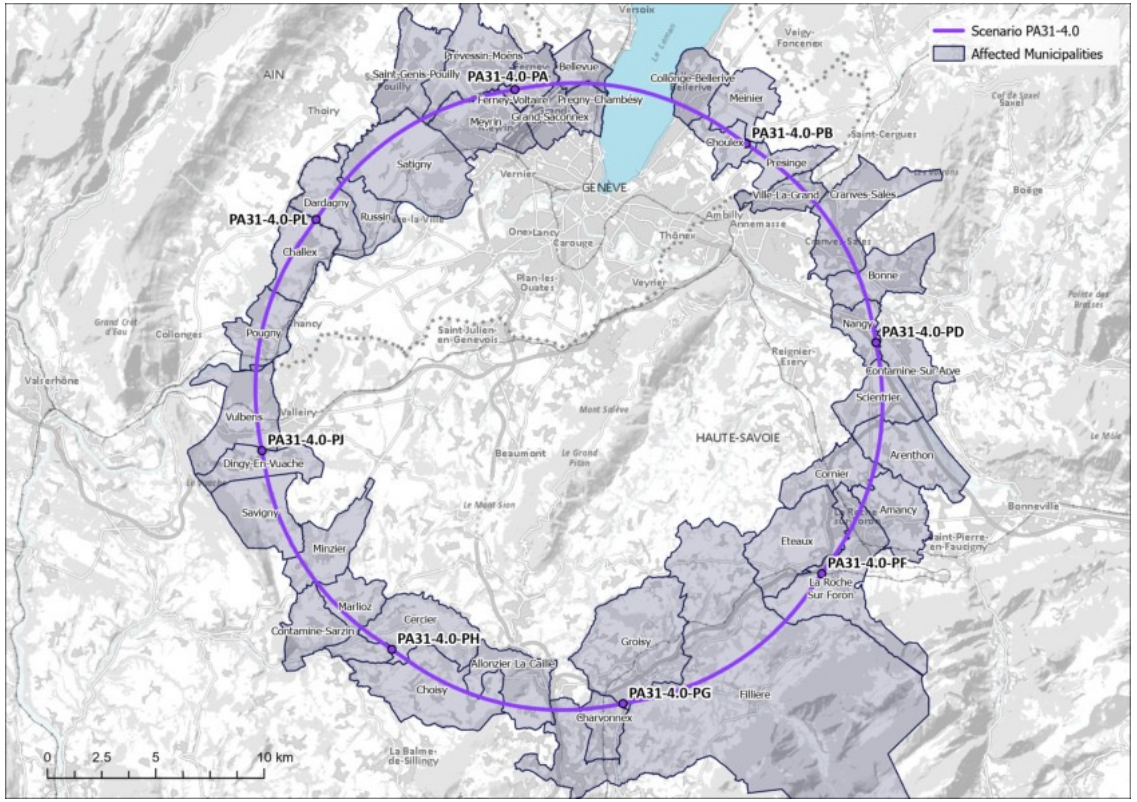
Europe is pushing forwards with plans to build a 91-kilometre-long, 15-billion-Swiss-franc (US$17-billion) supercollider underneath the French and Swiss countryside.

CERN Future Circular Collider

SUPERCONDUCTIVITY

Superconductivity is one of the key technologies for the efficient and reliable operation of particle colliders. Among the FCC core technologies are beyond-state-of-the-art 16 T dipole magnets, based on some 6000 tons of advanced Nb3Sn superconductor, as well as highly efficient superconducting radiofrequency systems for all collider scenarios.





Proto-typing for Future Circular Collider (HL-LHC Upgrade)

The cryo-assembly containing two MQXFA magnets was delivered to CERN in early December. (Image: CERN)

The magnet, named MQXFB03, is 7.2 metres in length. It is the first of ten that will be needed for the HL-LHC. (Image: CERN)

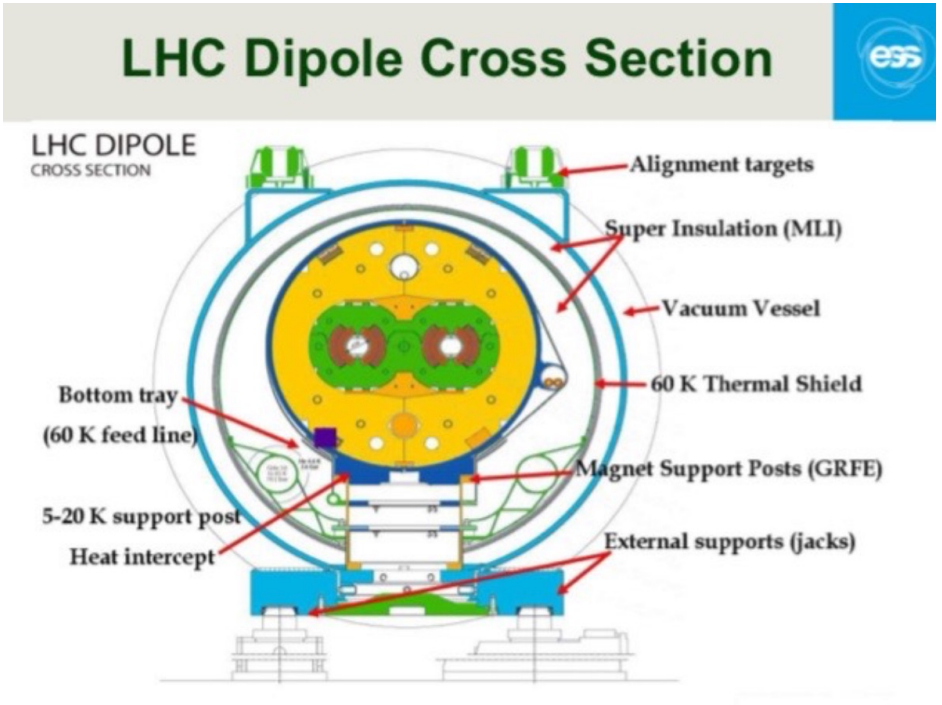
Unlike the LHC magnets, which are made from niobium–titanium (Nb–Ti), the new magnets are made from a more challenging material: **niobium–tin (Nb3Sn)**. The CERN Technology department is developing a series of ten magnets (eight, plus two spare), each 7.2 metres in length. This work builds on the **HL-LHC Accelerator Upgrade Project (AUP),** based in the USA, which is currently manufacturing 20 (16, plus four spares) quadrupole magnets, each 4.2 metres long.

Future Circular Collider Construction Opportunities

Superconducting Cryomodules :

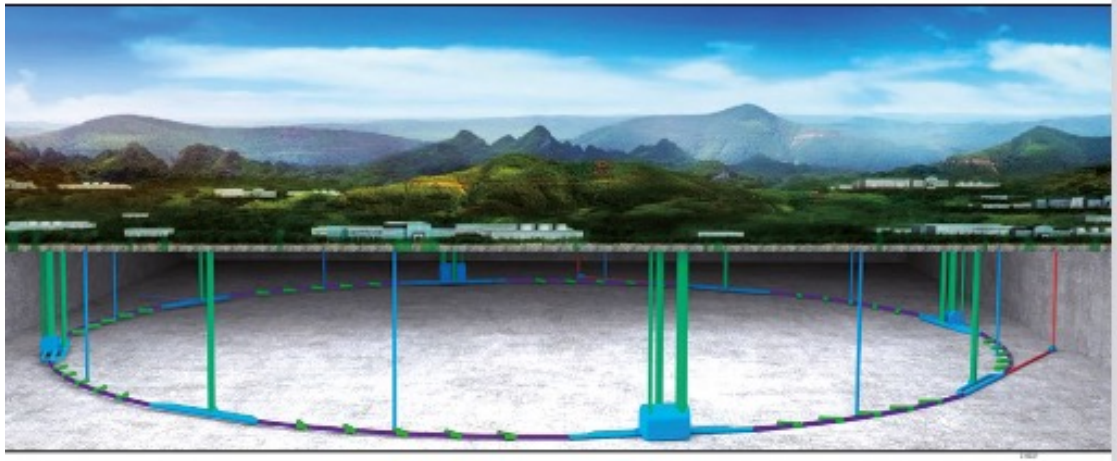
- Nb_3Sn Superconducting Strands : 6,000 tons
- 5,500+ Cryostats, Thermal Shields, Support Structures
- Magnet Power Supplies…

Detector Components, Sub-systems …



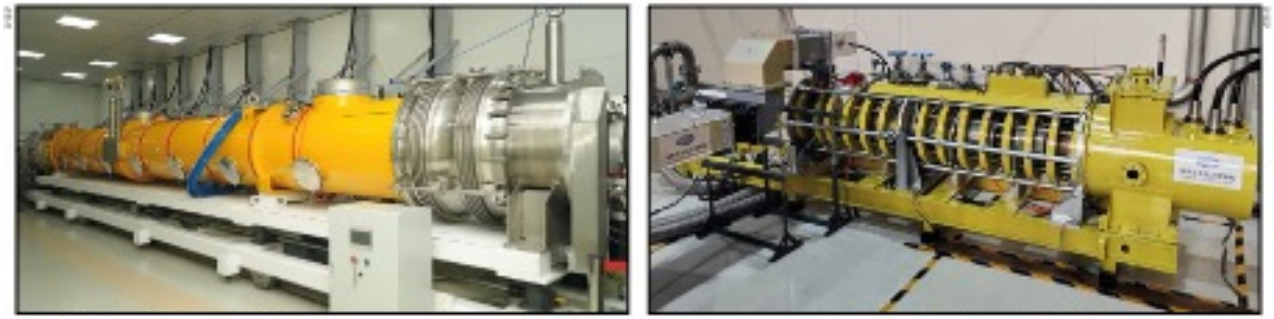
- Some key requirements
  - 1232 cryostats required
  - High reliability
  - 1.9 K (He II) cooled magnets
  - Low per unit heat leak
  - Minimize cost of materials & assembly

China Circular Electron-Positron Collider



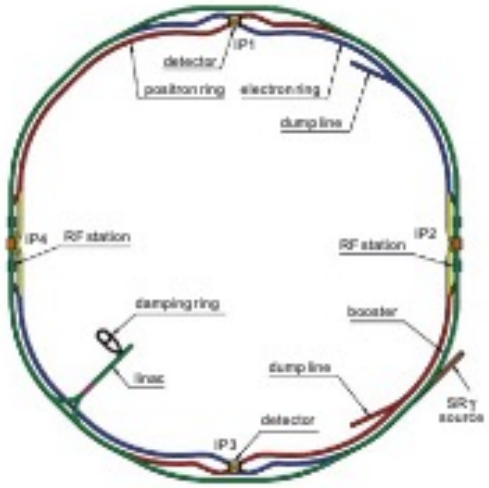
CHINA'S DESIGNS FOR A FUTURE CIRCULAR COLLIDER

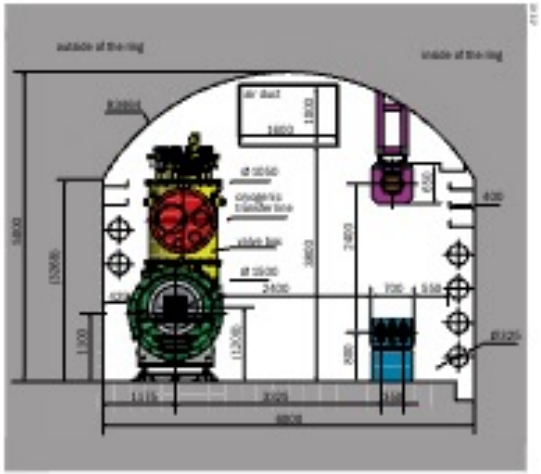
The completion of the accelerator technical design report for the proposed Circular Electron–Positron Collider in China marks a milestone towards construction, write Jie Gao, Yuhui Li and Chenghui Yu.



CEPC technologies *A 1.3 GHz 8 × 9-cell cavity cryomodule (left) and a 650 MHz 800 kW continuous-wavelength, high-efficiency klystron (right) developed and tested at IHEP in Beijing.*

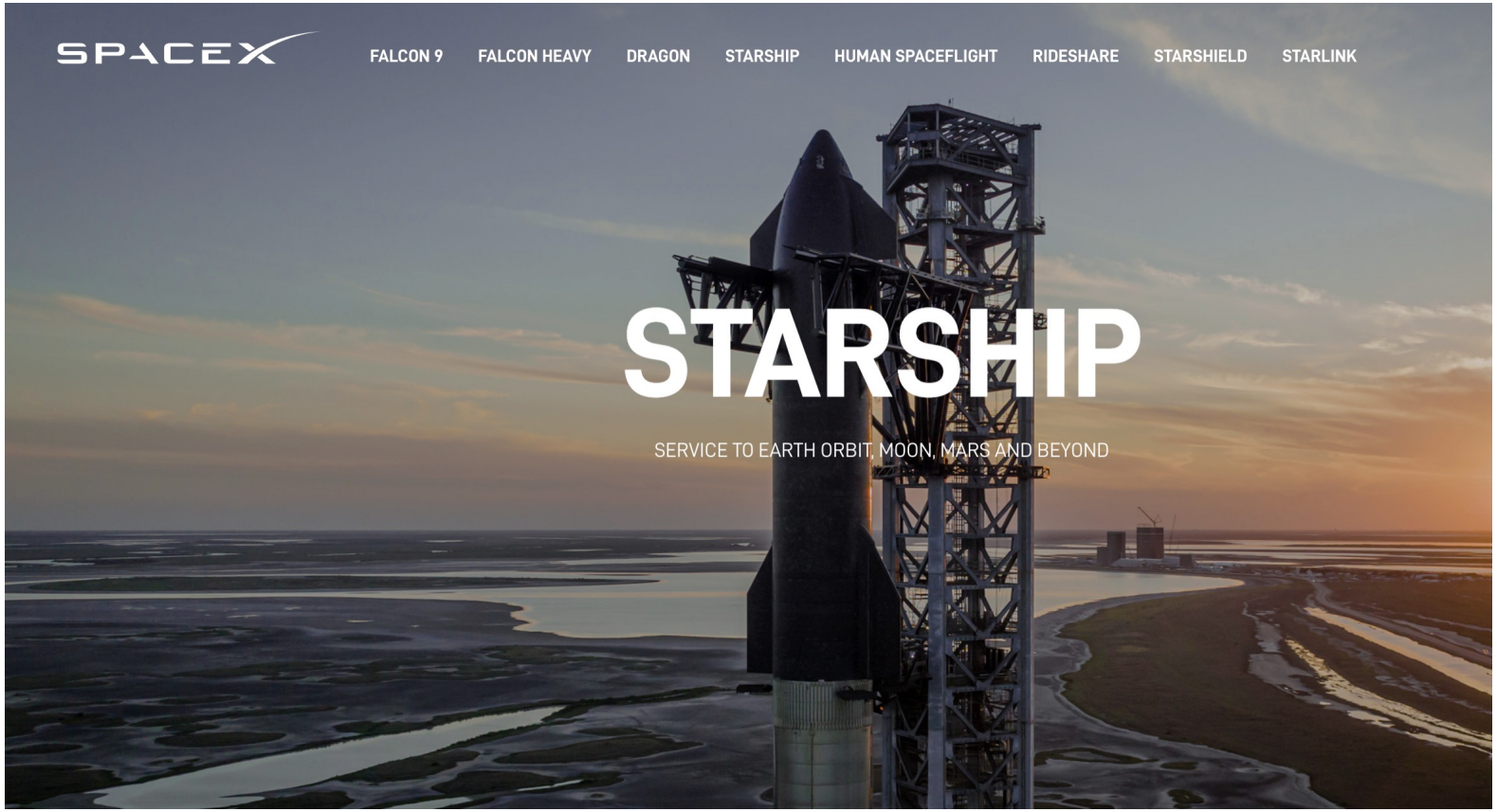
Going underground *The CEPC layout (left) and a cross section of the tunnel if drill-and-blast methods are used (right) showing the SppC ring and cryogenic modules (green and red) on the outer side and the CEPC booster (purple) and collider rings (blue) on the inner side.*





Commercialization … (NASA/ESA vs. SpaceX)

EnableFusion을
Fusion의 SpaceX로…



NASA R&D (Public Fund) → **PPP – Private-Public Partnership Program** ← **SpaceX to Mars (New Space - Private)**