Advances in Korea in UHF Solenoids

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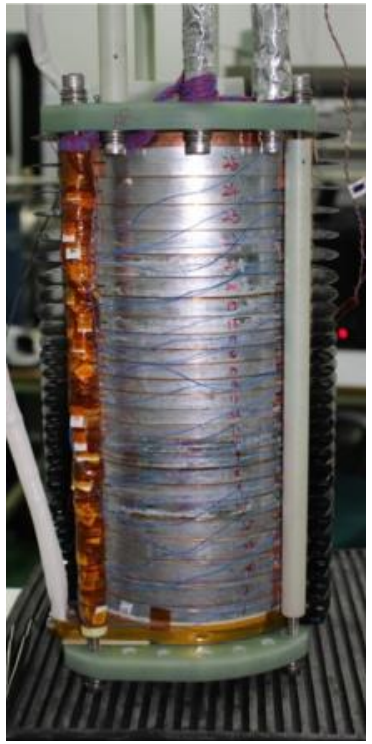
- *NI HTS Magnets Developed in Korea*
- *Overview of PRISM*
- *PRISM Alliance and Vision for Industrialization of HTS Magnet*

No-Insulation High Temperature Superconductor Magnets Developed in Korea

(2015) 26.4 T All-REBCO Magnet



- Highest field achieved by all-REBCO magnet in 2015
- Initiation of a compact tokamak concept in fusion (presented by Prof. Dennis Whyte, MIT)

(2015) NI HTS Magnet for Hyperloop

- First HTS magnet for rail transportation
- Development ongoing to apply the magnet to an actual Hyperloop system (Hypertube)

(2017) 18 T Magnet for Axion Detection

- First commercial HTS magnet fabricated and sold in Korea
- Long-term continuous operations (>2 years)
- Still in operation

(2017) Sextupole Magnet (MI) for Accelerator

- First HTS magnet for an actual accelerator
- Still in operation

(2018) 9.4T Magnet for 400 MHz NMR

- State-of-the-art HTS Magnets selected by Continuum in 2018
- Still in operation

Need for more systematic, collective, and detailed R&D to achieve higher fields and make breakthroughs for various applications

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"PRISM (Project for Research & Innovation in Superconducting Magnet)" in Korea ($36M/2022-2026, MSIT)

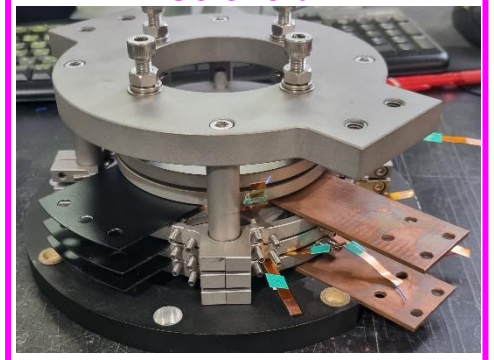
Key Philosophies: 4 Major Types of Coils & 7 Core Component Technologies for Reliability and Mass Production

Manufacturing Industry based on High Magnetic Field and High Current Technology

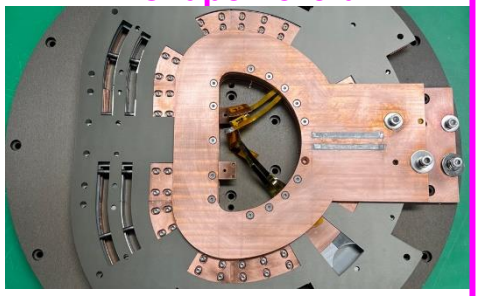
Trans-portation & Mobility	Electric Vehicle
	Railway • Hyperloop
	Ship • Aircraft
Energy & Environ-ment	Nuclear Fusion
	Magnetic Separation
	High Efficiency Industrial Machinery
Bio & Medical	Diagnostic MRI
	NMR for Drug Discovery
	Cancer Treatment Accelerator
Power System	Renewable Energy (Wind Power)
	Energy Storage
	High Power Cable
Defense & Weapons	Stealth Propulsion
	Railgun
	Electromagnetic Pulse (EMP)
Advanced Science	New Materials Development
	Particle Accelerator
	High Energy Physics

4 Major Types of HTS Magnet

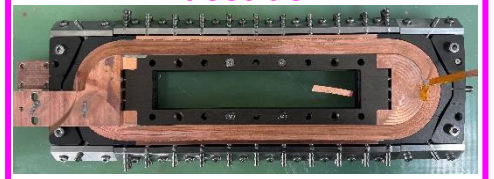
Solenoid



D-shape Toroid



Racetrack



Saddle

PRISM: Core Technology Research Team dedicated to HTS Magnets

Motto: **One nation, one laboratory, one university** (27 research groups, 220 researchers)

Supported by the Korea Government MSIT 2022-2026 (46.9 bn KRW/5years)

4 National Labs (5 Research Groups): KERI, KBSI, KIMM, PAL

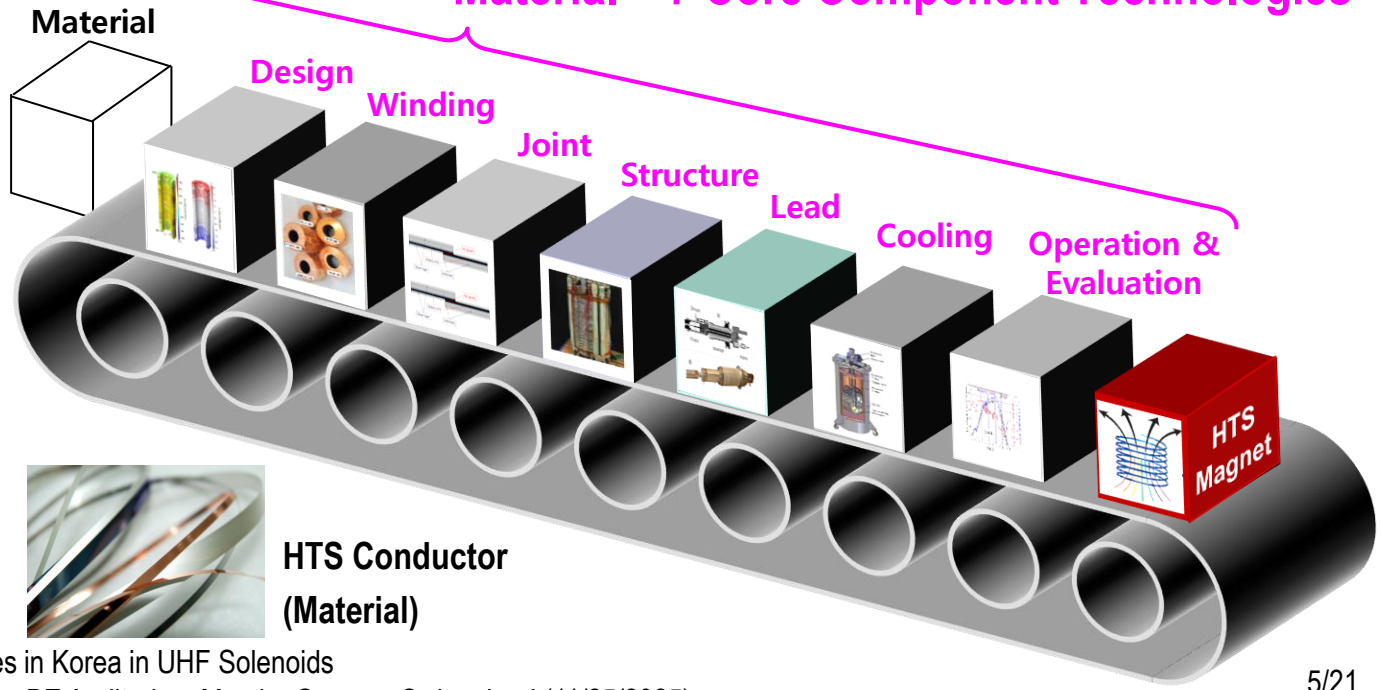
14 Universities (17 Research Groups)

5 Companies: STANDARD MAGNET, SuNAM, Sam Dong, SUPER GENICS, PowerNix Co., Ltd.

Director

Prof. S. Lee (SNU)

Material + 7 Core Component Technologies



HTS Conductor (Material)

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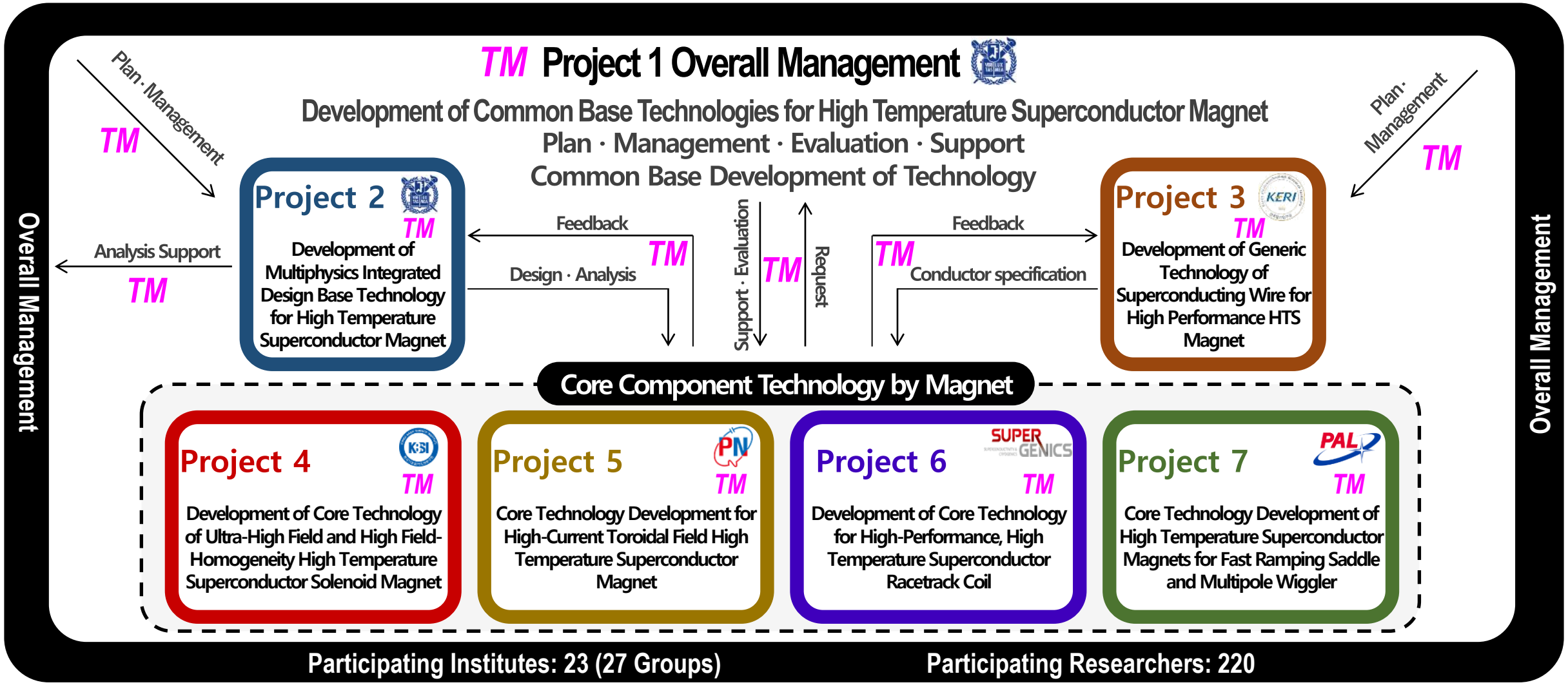
"PRISM (Project for Research & Innovation in Superconducting Magnet)" in Korea ($36M/2022-2026, MSIT)

Technical Manager (TM) key operational lead in organizing, coordinating, and managing the PRISM team



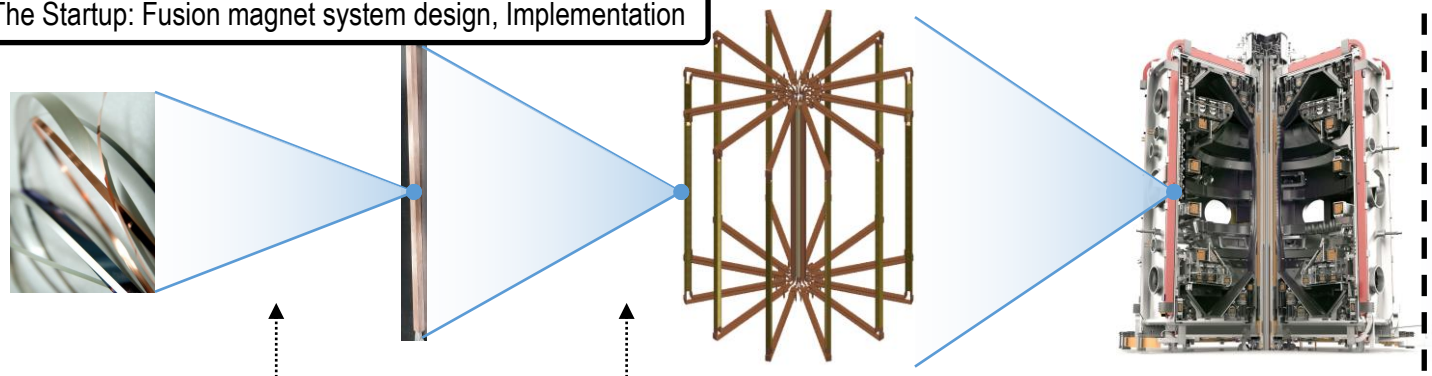
Research Group Objective: Develop fundamental HTS magnet technology

PRISM ALLIANCE: Industrial Partnership for Fusion and Beyond

- Specialized Company for Compact Fusion HTS Magnet Systems ➔ PRISM ALLIANCE
  - Goal1: Develop fusion magnet systems based on the PRISM research program in collaboration with domestic SC* related companies
  - Goal2: Establish supply chain for HTS magnets and respond to other future application markets

*SC: superconductor

The Startup: Fusion magnet system design, Implementation



(1) Conductor (2) Cable (3) Magnet (4) Magnet System

Fusion System Advisory

Fusion Magnet System

(Experimental or Power plant)

8 Key Challenges in Fusion
(Defined by Korea Institute of Fusion Energy, KFE)

SC conductor delivery → **SC material** specialized company

SC cable delivery → **HTS cable** specialized company

Magnet technology support → **SC magnet** specialized company

Cryogenic system delivery → **Cryogenics** specialized company

SuNAM · Sam Dong · KISWIRE · PowerNix Co., Ltd. · STANDARD MAGNET · SUPERGENICS

"PRISM ALLIANCE"

EnF · Eterna Fusion

Collaboration in conductor, material: PPPL PRINCETON PLASMA PHYSICS LABORATORY · ENEA

Collaboration in cable, magnet: UK Atomic Energy Authority

Superconducting team at overseas national fusion research institutes collaborating with Seoul National University


Dr. Gyung-su Lee
CSO


Dr. Doohwan Choi
CEO


Prof. Yong-Seok Hwang
CSO


Taekyoung Kim
CEO

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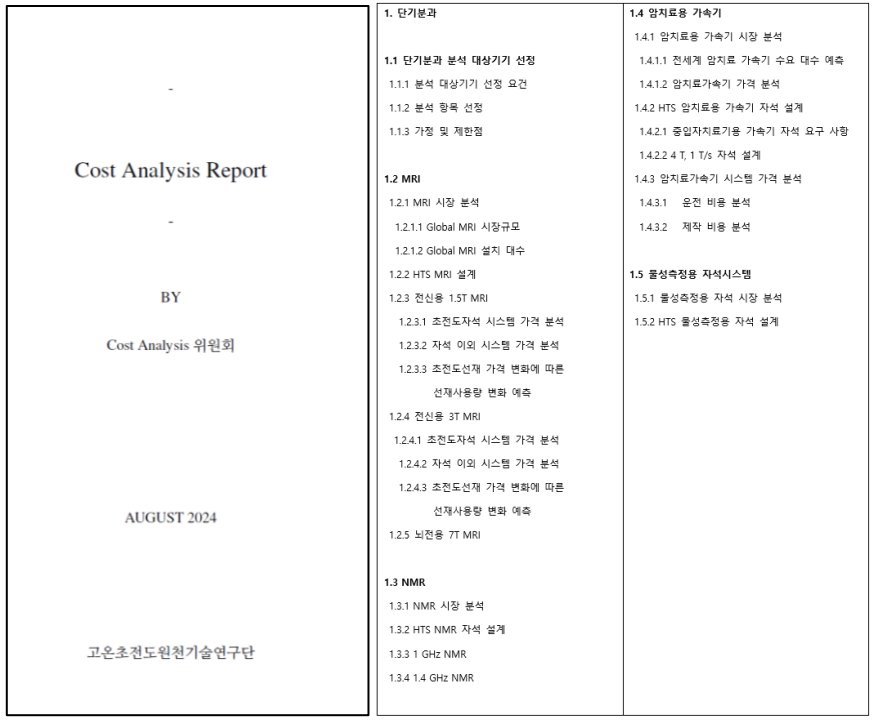
"3-Step Industrialization Strategy" to Build the HTS Magnet Industry Ecosystem

■ Cost Analysis Committee of PRISM

- ☐ Analyze and forecast prices according to the market size of key HTS application devices
- ☐ Analyze and forecast prices according to the production volume of high-temperature superconducting wires

<Cost Analysis Report>



Cost Analysis Report

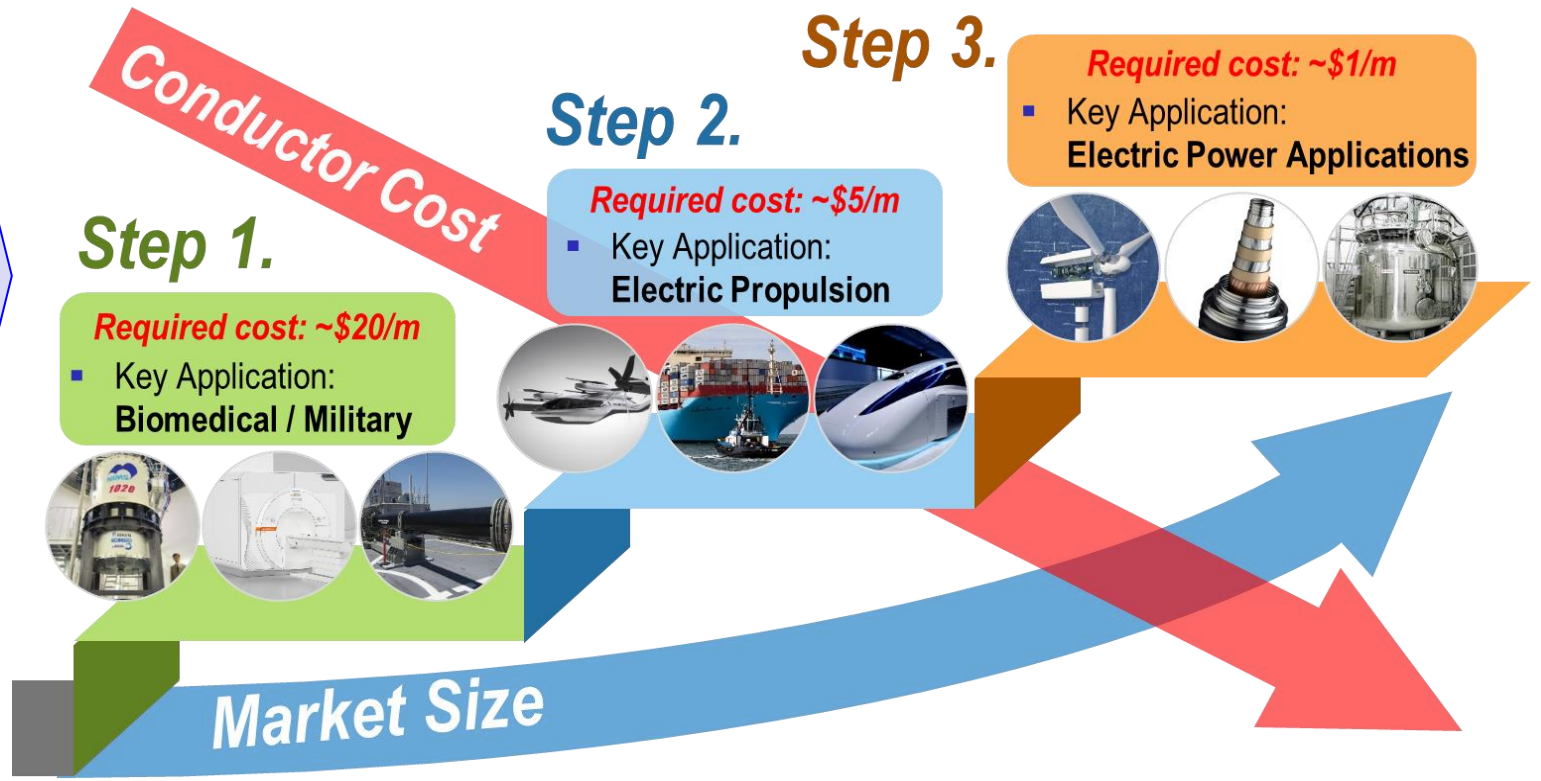
BY

Cost Analysis 위원회

AUGUST 2024

고온초전도원천기술연구단

<3-Step Industrialization Strategy>



- ☐ Secure endorsement of the industrialization strategy from domestic and international HTS communities
- ☐ Formulate national R&D and private-sector business promotion strategies for HTS magnet based on the established industrialization roadmap

Part2. PRISM's "Master Coil" Development and Its Recent Achievements

- *Concept of Master Coil*
- *Potential of "Complete Reliability" of REBCO magnet*
- *Problems, Solutions and Results for Solenoid Master Coil*

4 Types of "Master Coil" to Resolve Challenges in 7 Core Technologies

- Key R&D Philosophies: (1) Mass Production; (2) Reliability (Premium Quality)

1. Design
2. Winding
3. Joint
4. Structure
5. Lead
6. Cooling
7. Op./Eval.

Master Coils
Integration of Core Technologies

4 Major Types of Superconductor Magnets

Solenoid

Toroid

Racetrack

Saddle

Mass Production & Premium Quality of Superconductor Magnets

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Part3. Ongoing PRISM Research on Selected Topics

- Towards Better Estimation of Magnet Critical Current (feat. Lighthouse Project)

- Seeking Solutions for Robust Supporting Structure

- Unraveling the Mechanism of Magnet Degradation

Towards Better Estimation of Magnet Critical Current: "Lighthouse Project"

- Lighthouse #3: Consistency Factor – A New Measure to Define "Consistency"
  - To enhance consistency of REBCO tapes by commercial manufacturers
  - Definition of 'consistency factor (*CF*)' (if perfectly consistent, *CF* equals 100):

$$CF_{T,\boldsymbol{B}} = \frac{100}{1 + \frac{\sigma}{\mu}}$$

T: temperature
$\boldsymbol{B}$: magnetic field
σ: standard deviation of measured $I_c(B,T)$
μ: average of measured $I_c(B,T)$

Problem1: Inconsistency within Single REBCO Conductor

Problem2: Uncertainty in Current Distribution Under High Magnetic Fields

Problem3: Widthwisely Bent Conductor

Problem4: Critical Current Estimation from Limited Dataset

Problem5: Champion Sample v.s. Regular Sample

Problem6: I_c(77 K, self-field)-basis Lifting Factor

Problem7: I_c and n defined in Limited Operating Region

Problem8: Variations in Critical Electric Field (E_c)

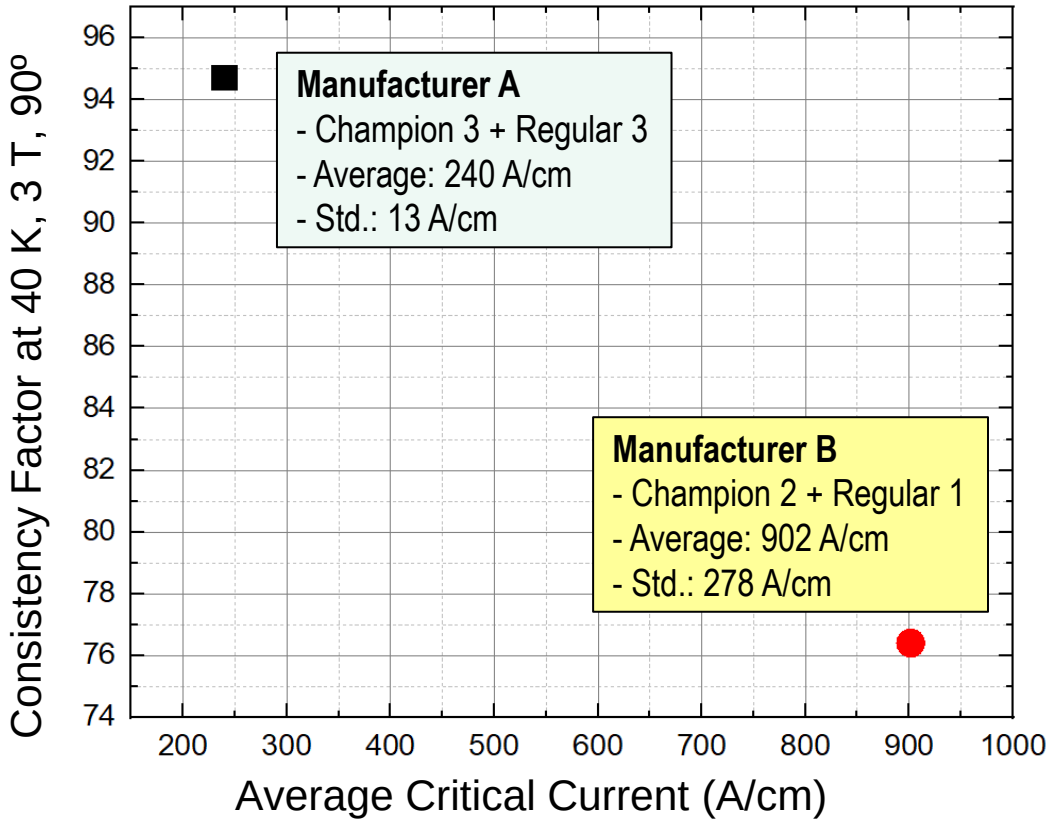
Lighthouse #1: Pinpointing "Representative" Magnetic Field Angles

Lighthouse #2: Redefining Lifting Factor to Reduce Uncertainty

Lighthouse #3: Consistency Factor – A New Measure to Define "Consistency"

Lighthouse #4: "Basis" $I_c(T, |\boldsymbol{B}|, \theta)$ Data

Lighthouse #5: "Prototype" Sample and Measurement "Standard"



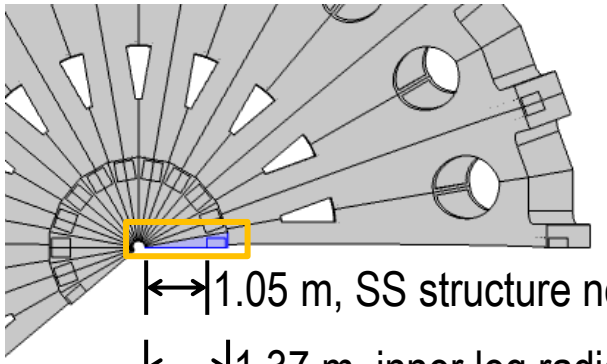
Seeking Solutions for Reliable Mechanical Support: Large and Robust Supporting Structures

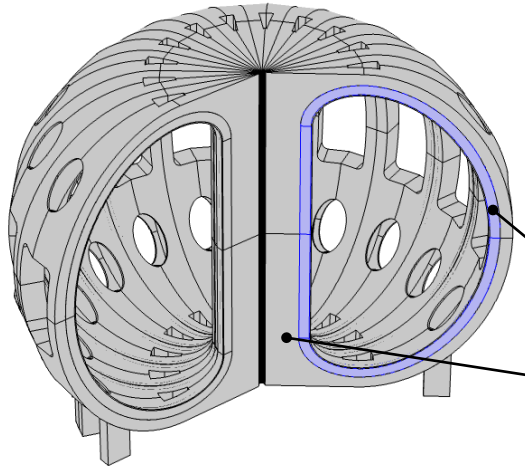
- Marginal Effect of Screening Current-induced Stress calculated in Large/Well-supported Magnets

  - Toroidal field coil inner leg designed by SNU, D-shaped coil for a large toroid
    → Large supporting structure

    REF: J. T. Lee, PhD Thesis, Seoul National University, 2025.

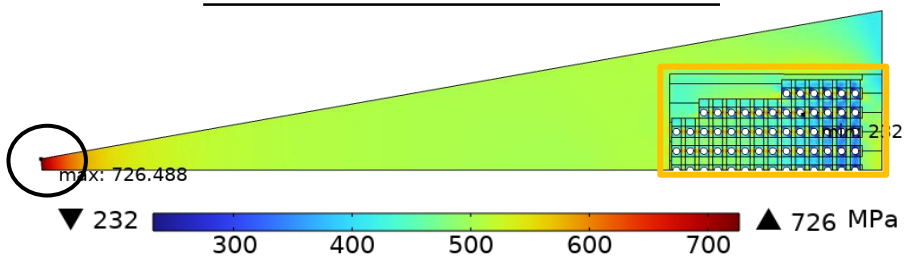
    Zoom 1) 3D model of toroid
    (midplane cross-section view)

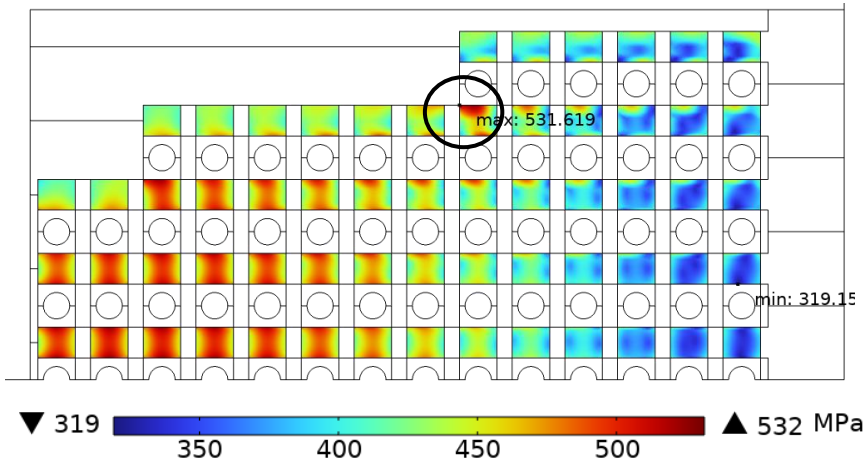
    

    Major radius (R_0): 3.3 m
    Toroidal field @R_0: 9.2 T
    Peak field on coil: 24 T

    Zoom 2) Inner leg (midplane cross-section),
    Peak Tresca stress: **726 MPa**

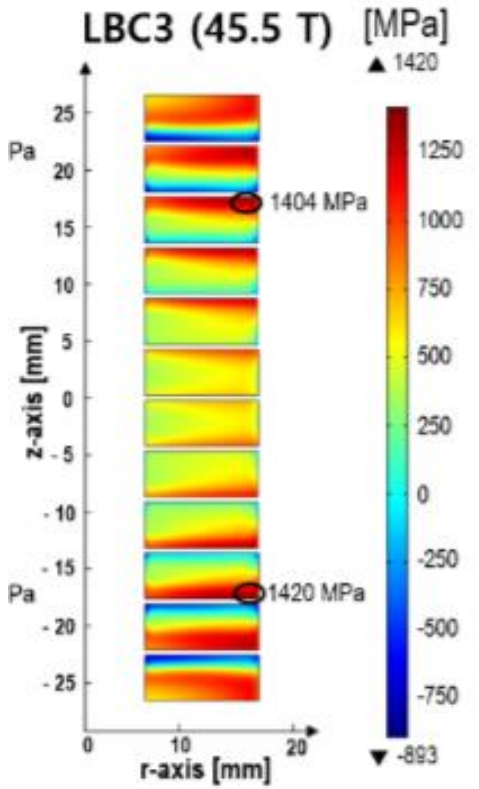
    

    Zoom 3) REBCO, Peak Tresca stress: **532 MPa**

  - LBC3, a small solenoid
    → Small supporting structure

    Peak hoop stress: **1420 MPa**

    REF: Hu, Xinbo, *et al*. "Analyses of the plastic deformation of coated conductors deconstructed from ultra-high field test coils." *Supercond. Sci. Technol.*, vol. 33, no. 9, 2020.

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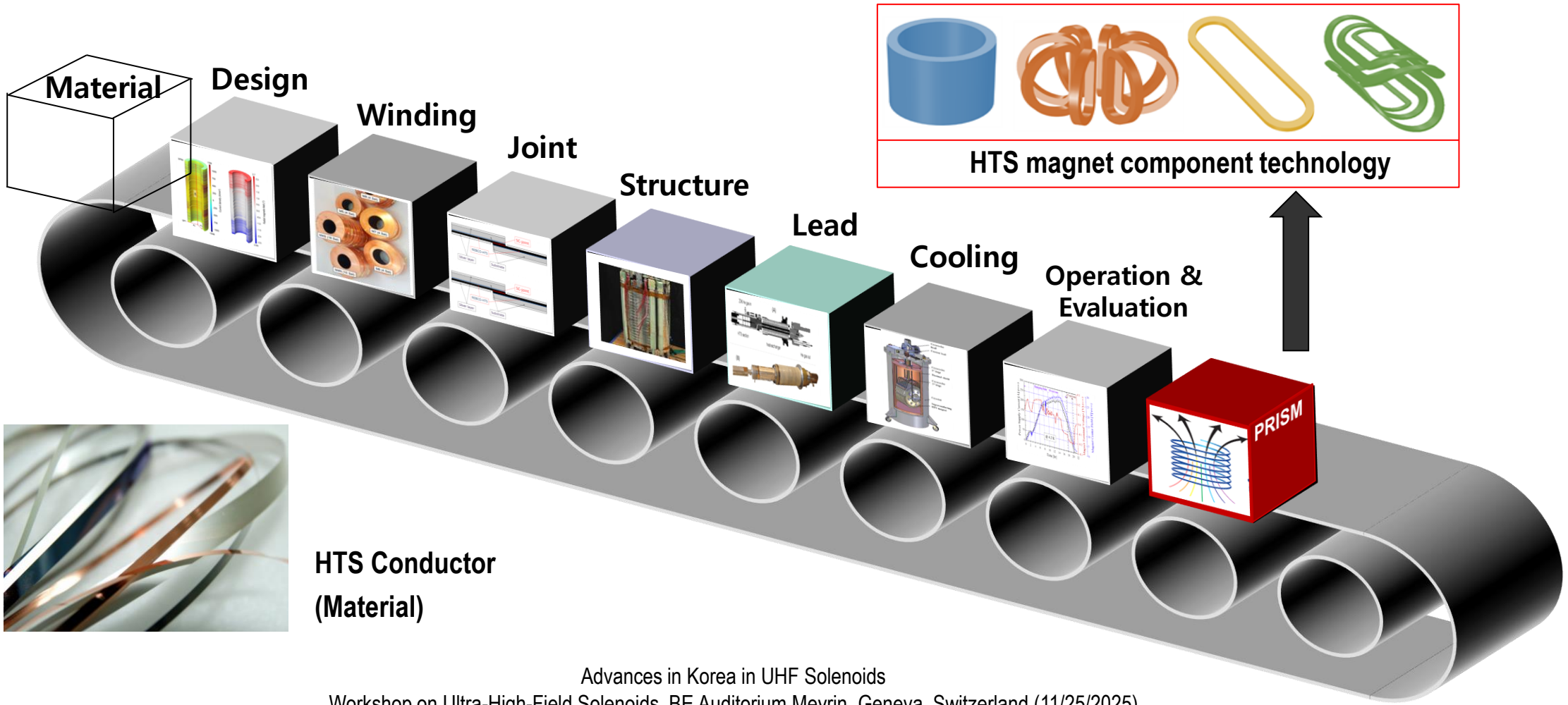
Summary and Conclusion

- PRISM (Project for Research & Innovation in Superconducting Magnet) is leading the HTS magnet R&D in Korea in collaborations with domestic and international partners
- Systematic, collective, and detailed R&D required, such as Master Coil development, to tackle the problems HTS magnet is facing to achieve reliable operation of UHF solenoids



Thank you for your attention

Q&A

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