UNIVERSITY OF TWENTE.

High Current Superconductivity in Fusion Applications

Hans van Oort & Arend Nijhuis

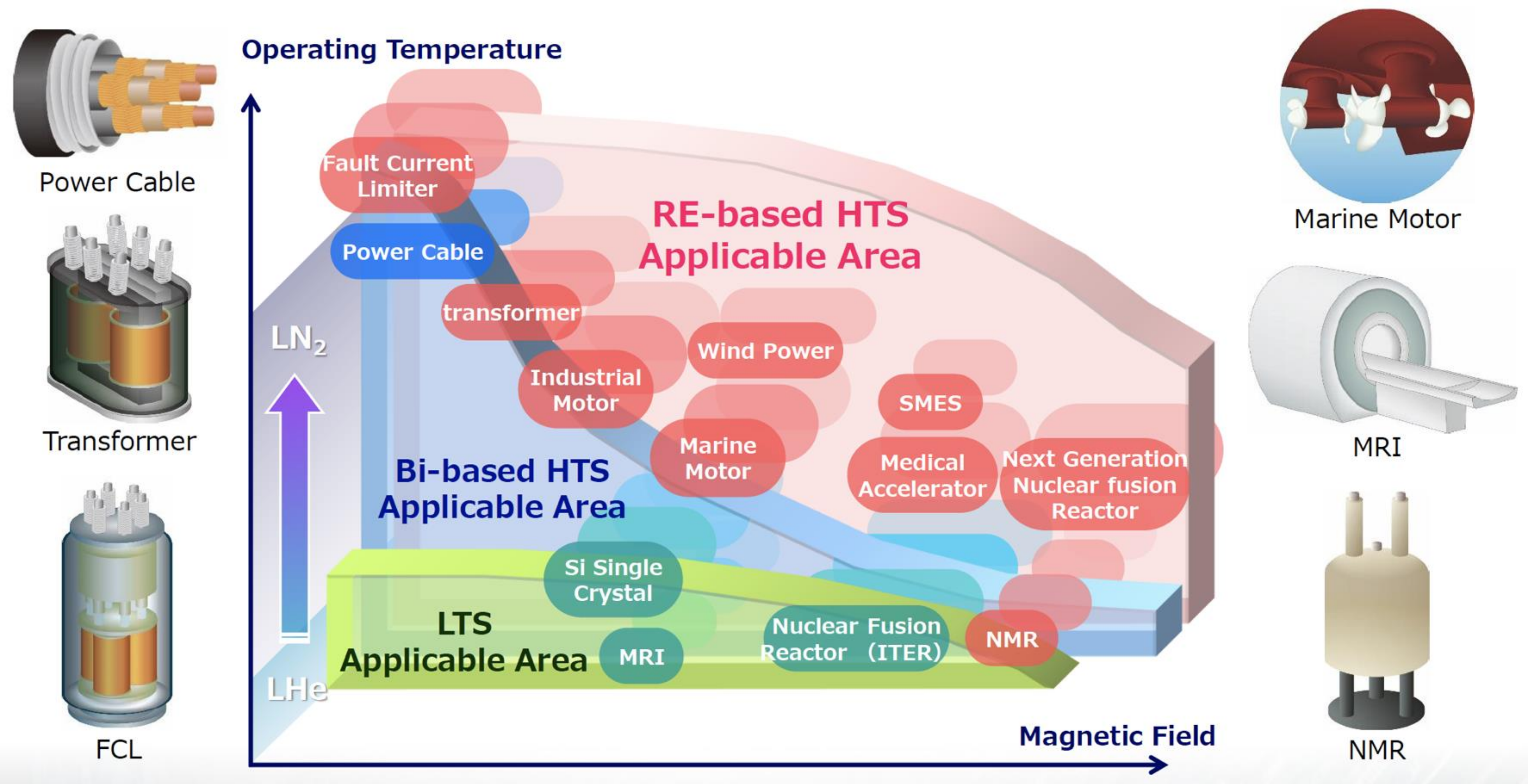
University of Twente
Faculty of Science & Technology
Enschede, Netherlands

Dutch Fusion Day, Eindhoven, 3 May 2024

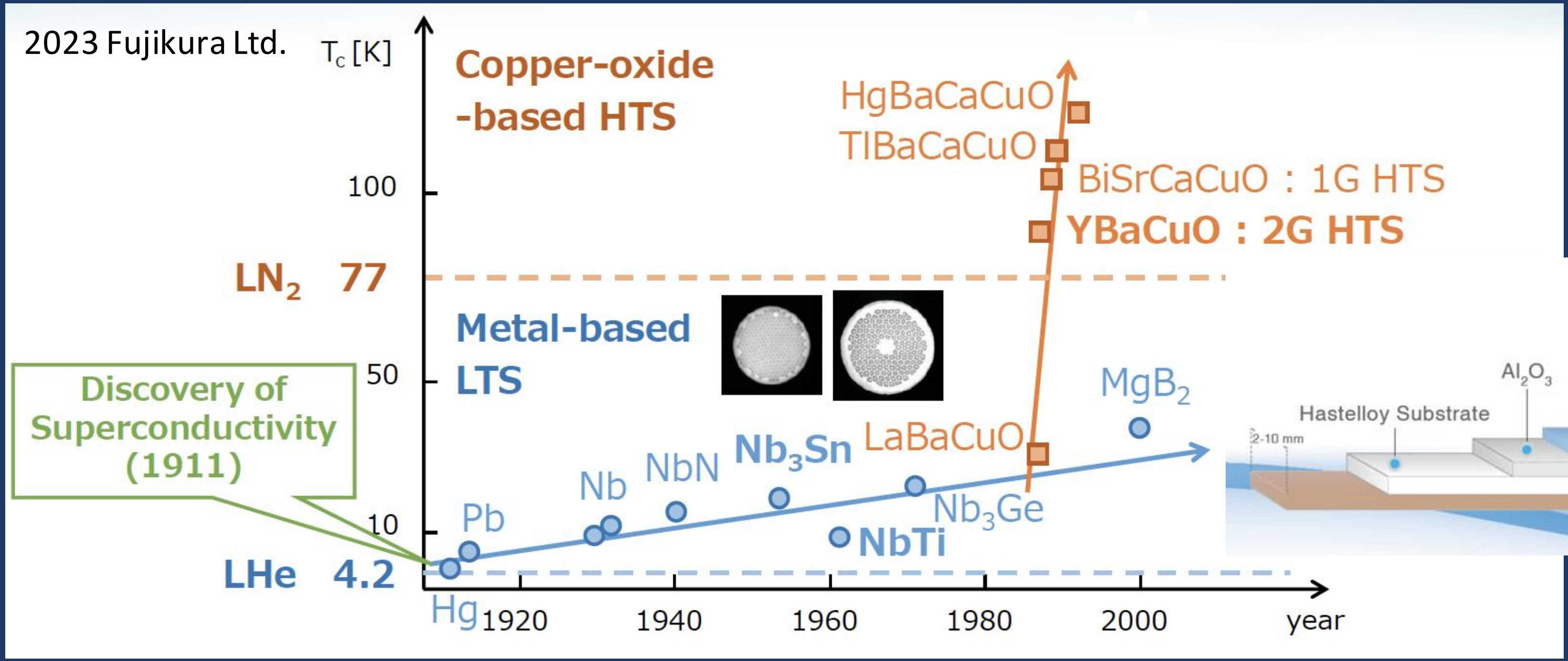
Content

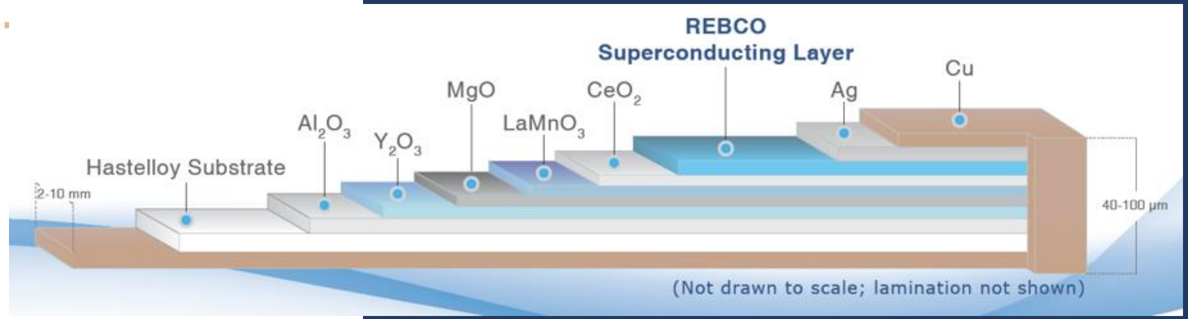
- Introduction
- Low Temperature Superconductors
- High Temperature SC-CICC technology

Superconductor technology



High & Low Temperature Superconductors



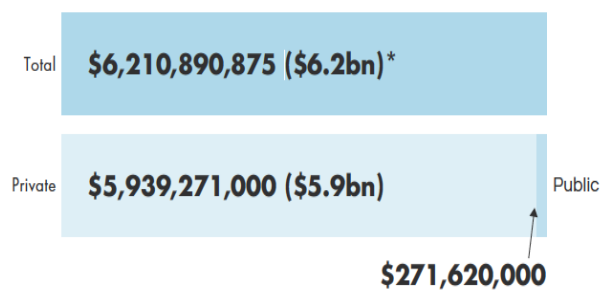


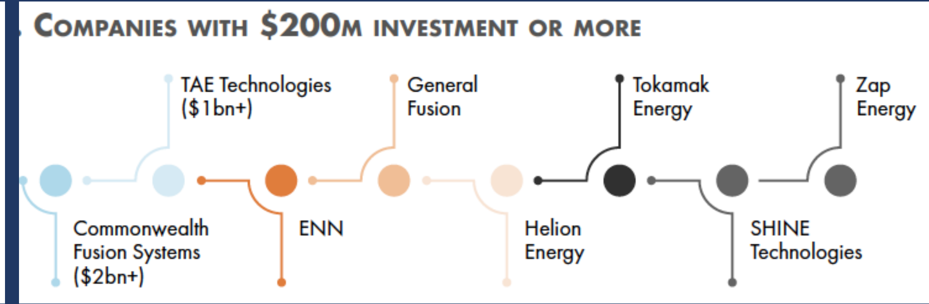
Low Temperature Superconductors (Metal-based)	Cooling below LHe temperature required Practical use in conventional superconducting applications
High Temperature Superconductors (Copper-Oxide-Based)	Critical temperature higher than LN2 temperature Verification stage for practical use in industrial applications Bismuth (Bi) : 1st generation (1G) Yttrium (Y) or Rare-Earth : 2nd generation (2G)

Fusion industry supply chain

Key findings fusion developers

- Spent > $500 m on supply chain in 2022.
- Spending growth > $7 bn, when "First of a Kind" power plant.
- Potentially trillions in mature fusion industry (2035-2050).
- Existing supply chains (concrete, steel, power electronics, etc.).
- Limited set of supply chain needs that are unique to fusion (high-powered magnets, laser components, heat management technologies, advanced materials, high powered semiconductors, and fusion fuel.
- Longer term needs: Engineering, Procurement and Construction (EPC) for transition from fusion technology into factories and power plants.





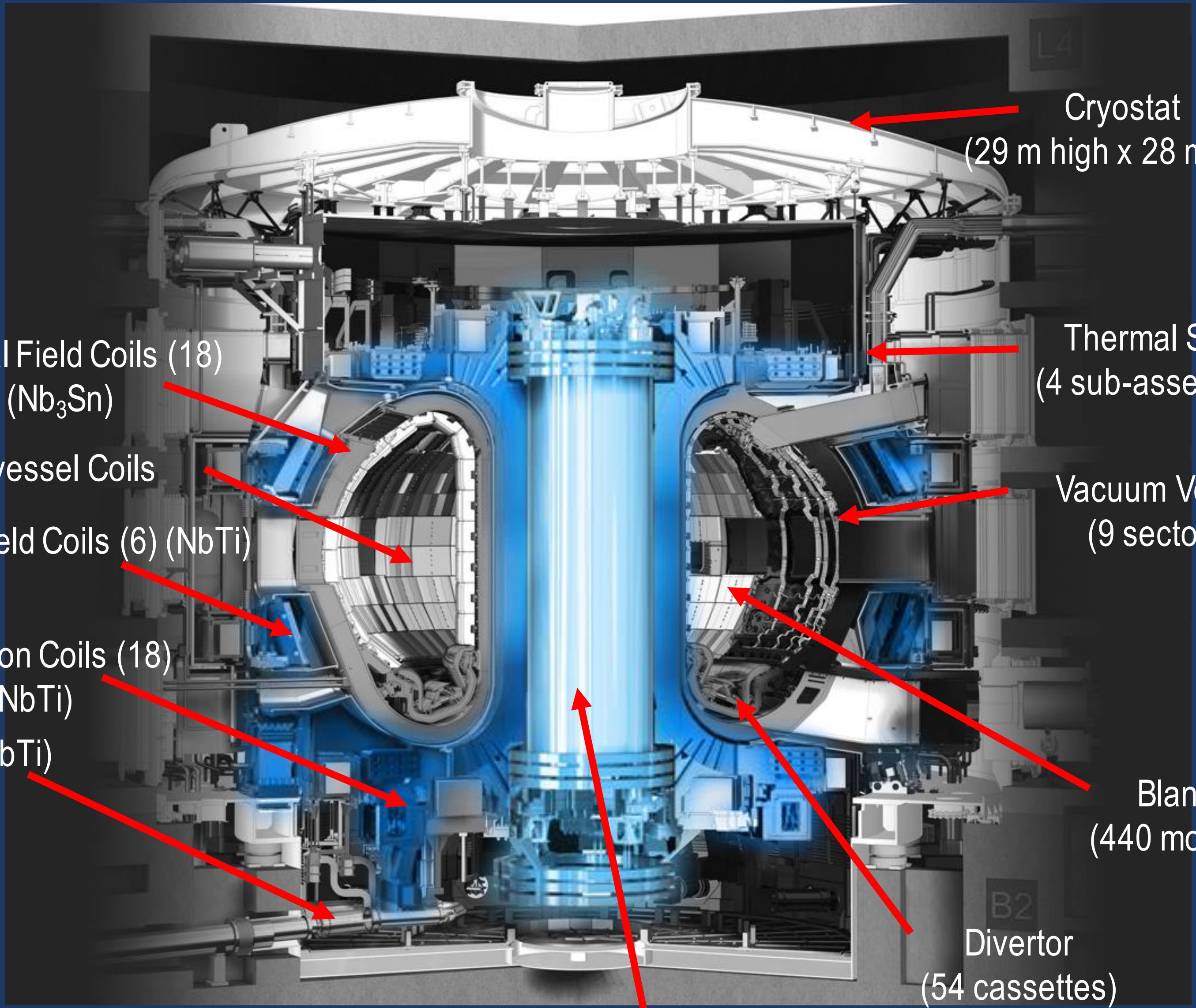
Vacuum pumps
Precision engineering and manufacturing services
Control Software
Power semiconductors
Deuterium, tritium, or other gaseous fusion fuels
Recruitment
Specialized metals, e.g. high-grade steel
Common metals, e.g. nickel, copper
Engineering, Procurement and Construction Firms
Heat management technologies
Natural Lithium
First wall materials
Legal services
Cryogenic devices
Magnets
RF heating
Lithium (enriched)
High Temperature Superconducting (HTS) Tape
Lasers (assembled)
Rare earth metals
Laser components, eg. diodes, laser glass

https://www.fusionindustryassociation.org/fusion-industry-association-releases-supply-chain-report/
https://www.fusionindustryassociation.org/wp-content/uploads/2023/07/FIA–2023-FINAL.pdf

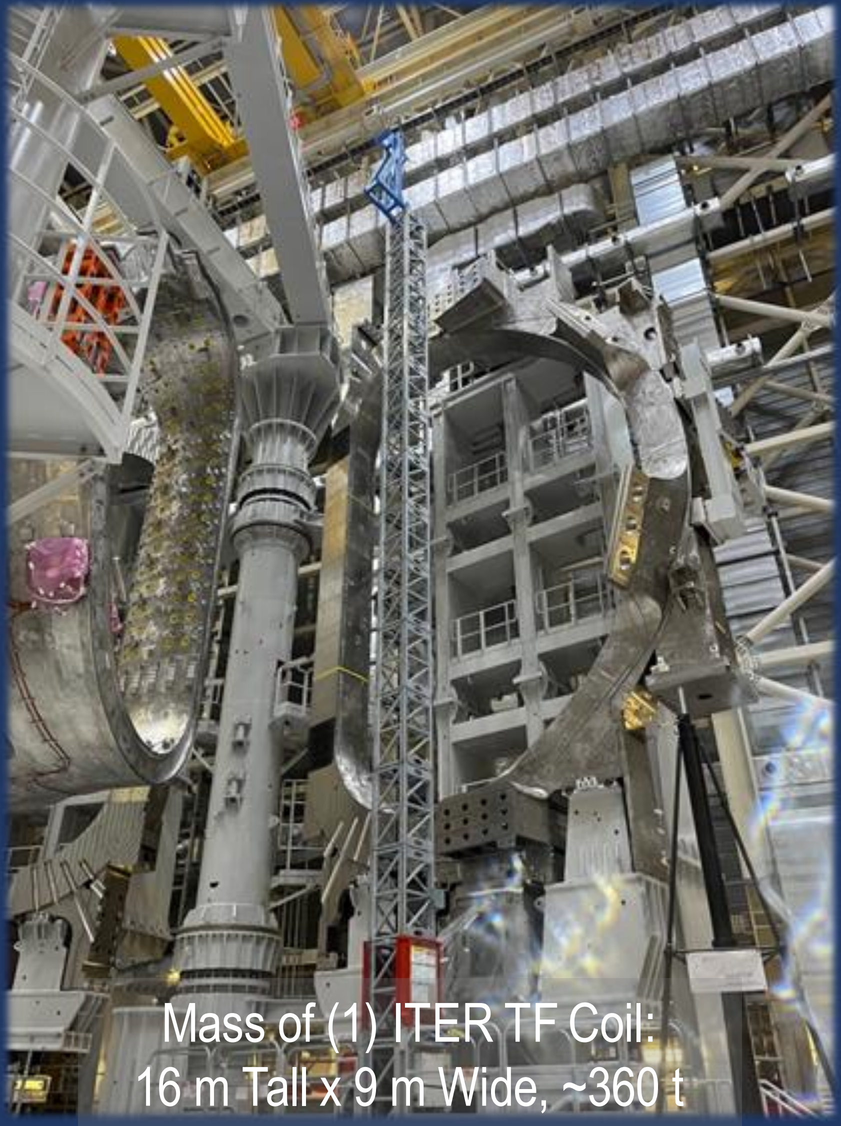
ITER under construction (LTS)

29 m high x 28 m diam. & ~23,000 t
Major plasma radius 6.2 m
Plasma volume: 840 m^3
current: 15 MA
Fusion power: 500 MW

Technical challenges
- Highly integrated design
- Large scale up of many systems
- High quality components
- Manufacturing around the world
- >100,000 km Nb_3Sn strand



Large superconducting magnets (ITER)

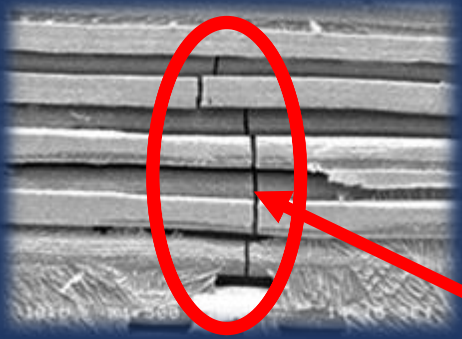


Mass of (1) ITER TF Coil:
16 m Tall x 9 m Wide, ~360 t

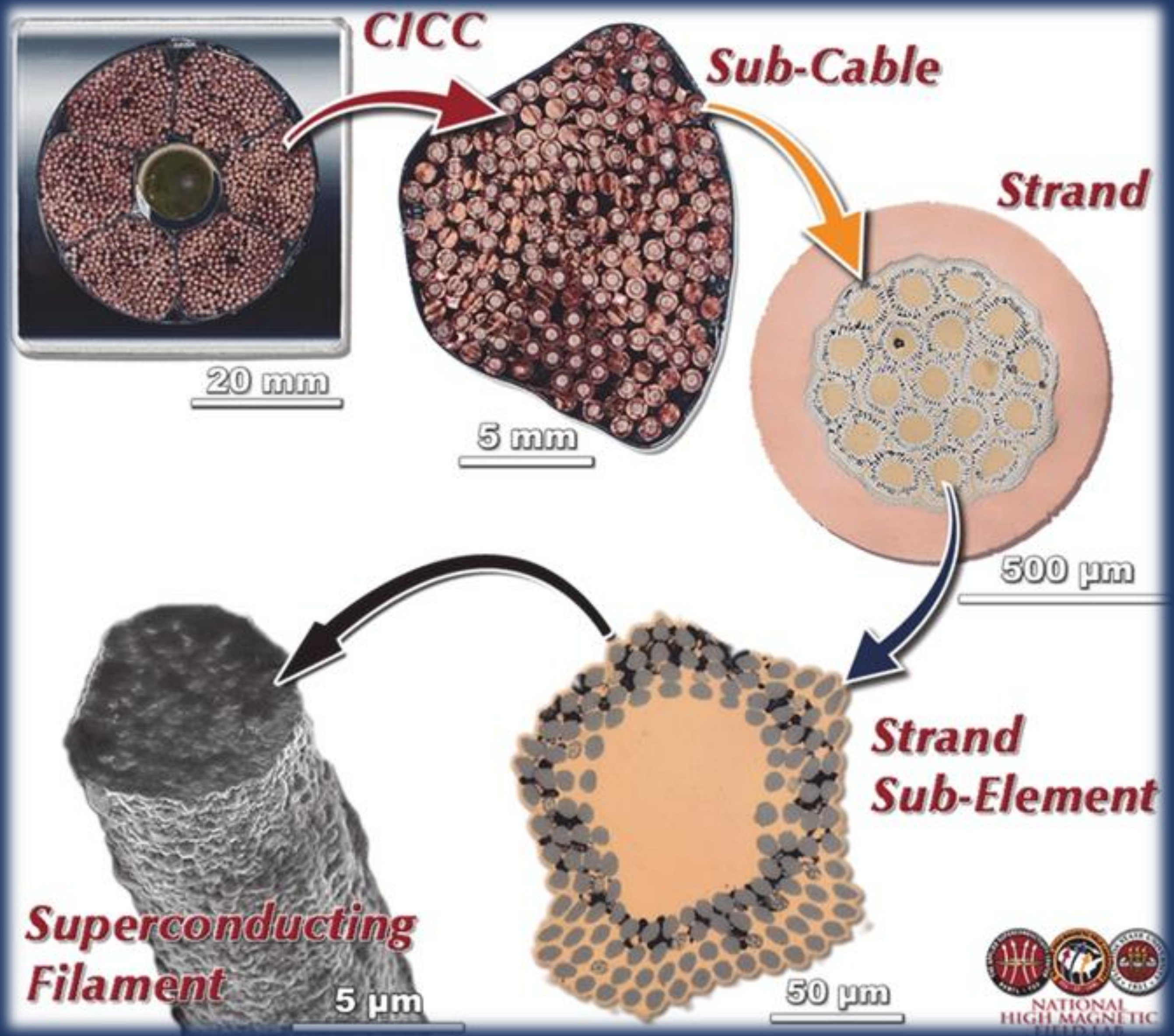
Boeing 747-300
(Maximum takeoff weight) ~377 t

Pre-ITER world production of Nb_3Sn was ~15 t/year;
scaled up to ~100 t/year.

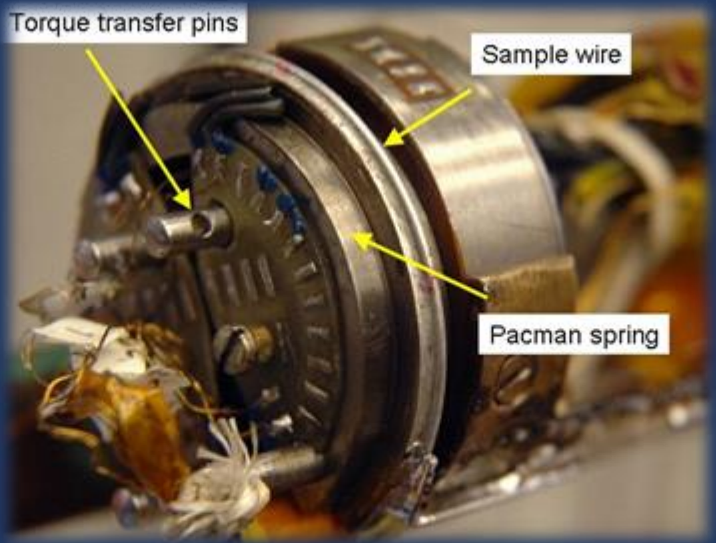
Low Temp Superconductors (ITER)

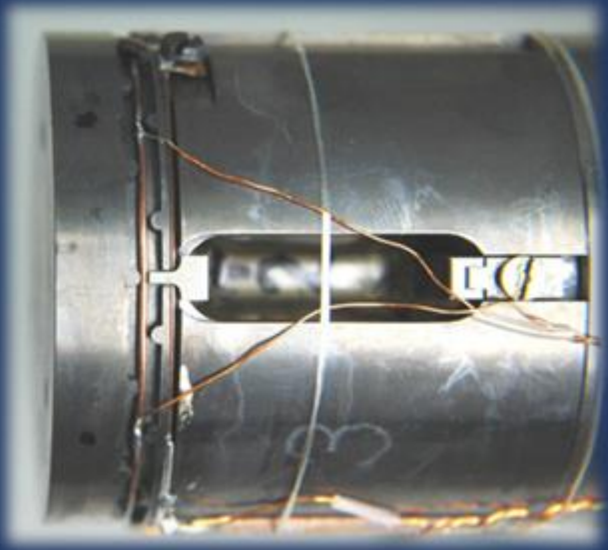


Electromagnetic Lorentz force:
68,000 A times 11 T:
700 kN/m, or
70 tons/m cable with very brittle Nb_3Sn.



UT - Low Temp Superconductor testing

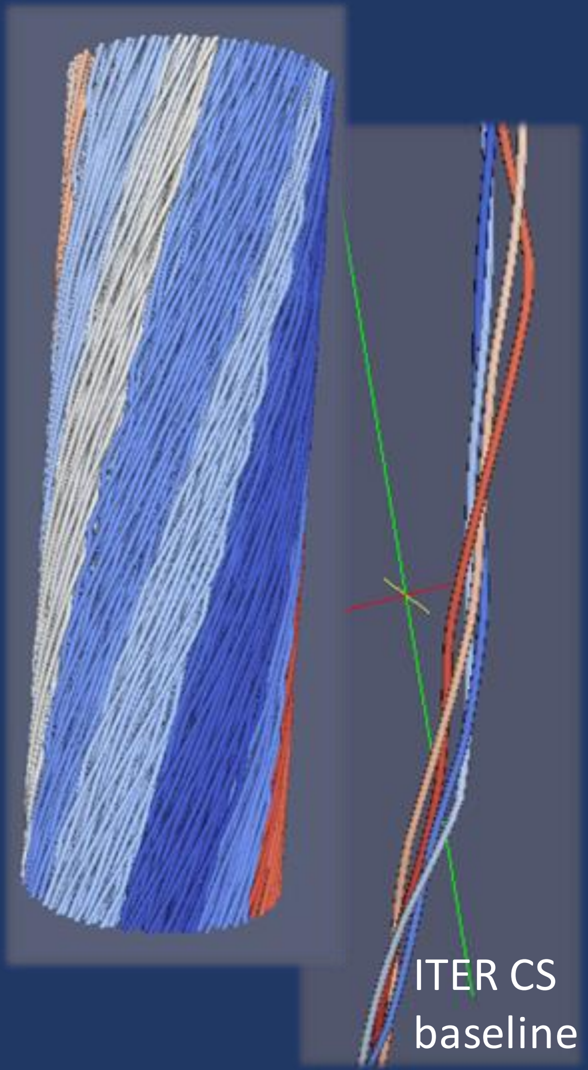




LTS strands and conductors for ITER, CRAFT & BEST performance (2008)

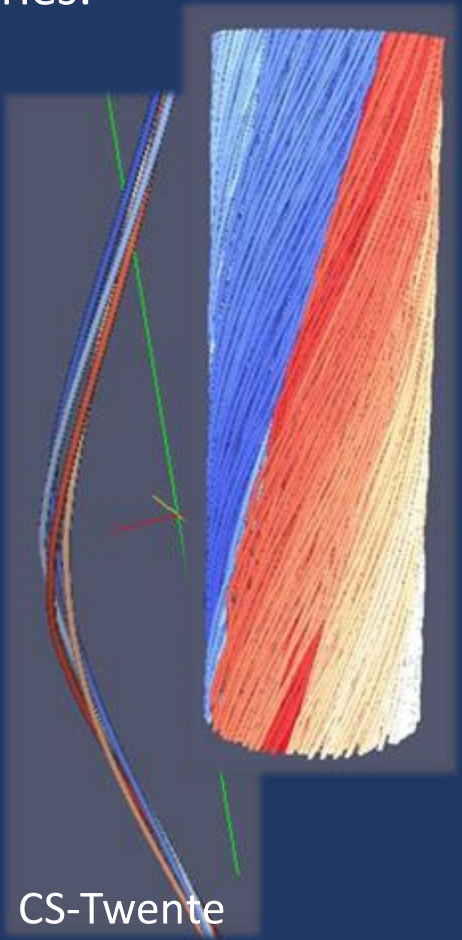
- Electromagnetic-Mechanical behavior superconducting wires
- Mechanical properties measurement and analysis of full-size superconducting cables
- AC loss (heat dissipation) and contact resistance measurement of full-size conductors

UT - Detailed modeling of ITER cables & joints

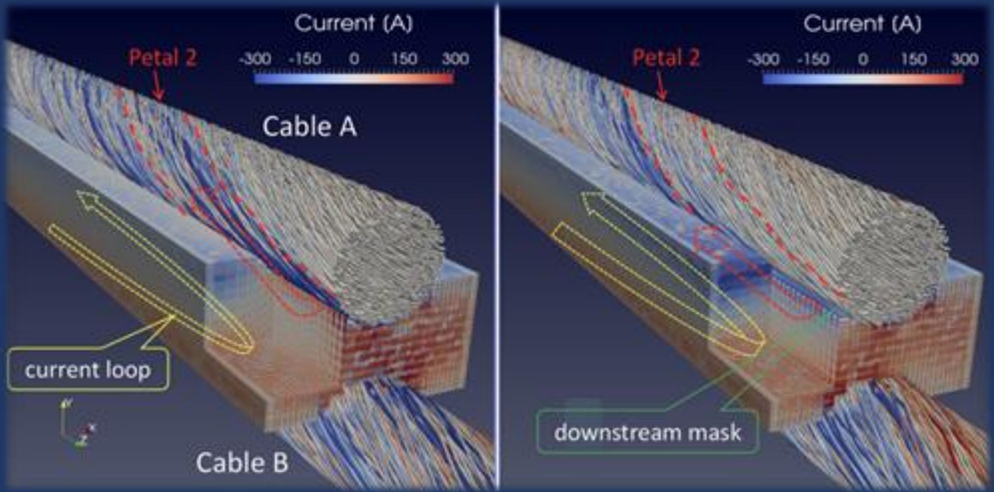


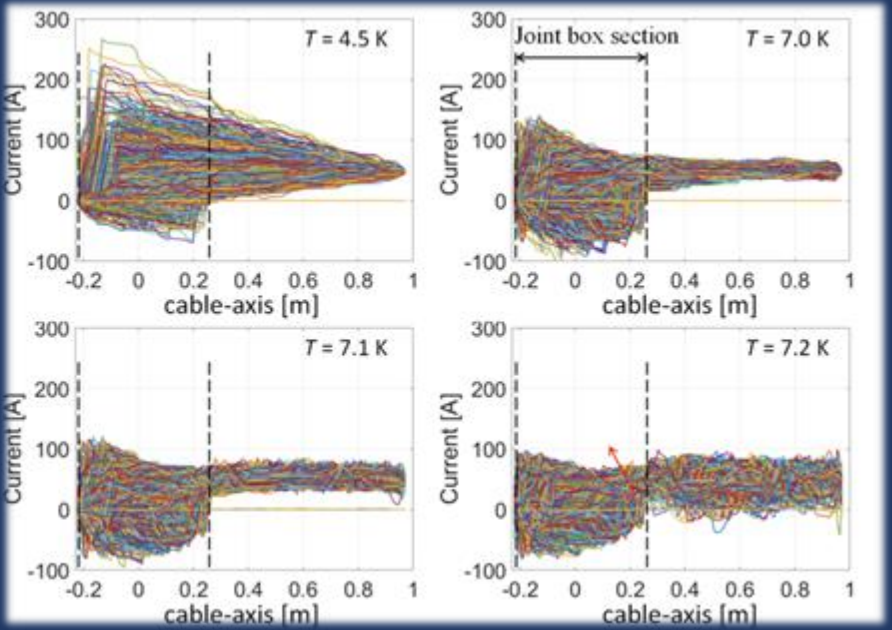
ITER CS baseline

Maximizing mechanical stability and minimizing coupling loss by optimizing cable strand trajectories.



CS-Twente



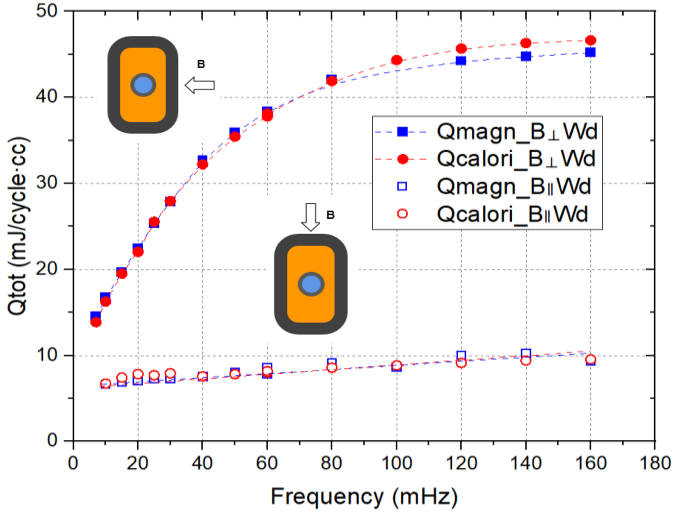


UT - Low Temp Superconductors optimization

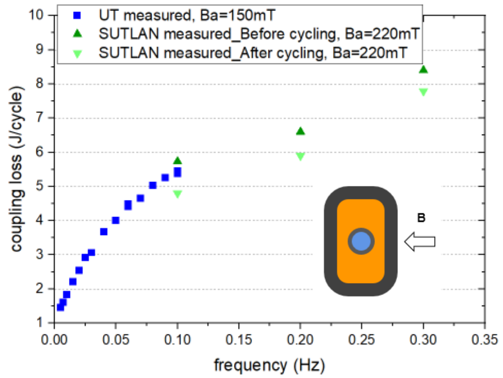
4th Technical Exchange Meeting on CFETR and EU-DEMO Fusion Reactor Design, 20-21 March 2024
Joint work ASIPP and University of Twente on Nb_3Sn CICC for Chinese BEST tokamak.

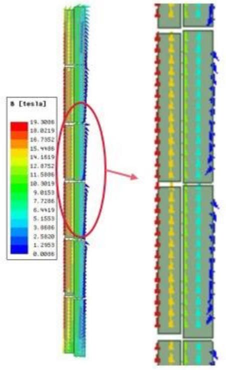
CICC technology: LTS conductors

- Nb_3Sn CICC – AC coupling loss



	ntau (ms)
B ⊥wide side	1700
B ∥ wide side	36





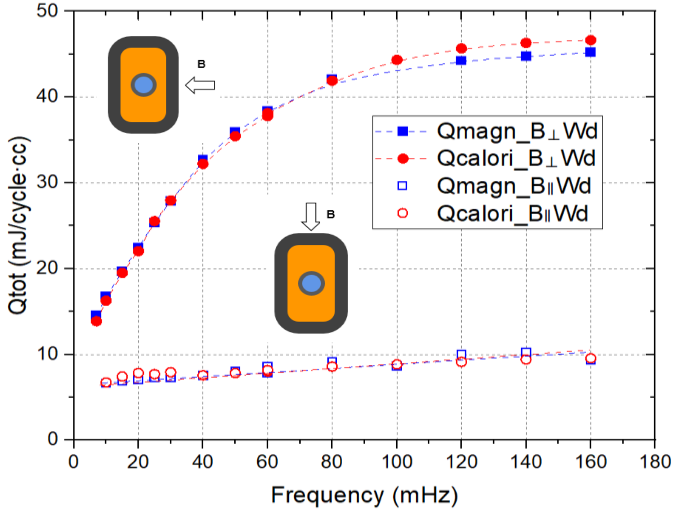
- AC loss was measure in both UT and SULTAN.
- SULTAN result and UT result show good agreement.
- The coupling loss with B ∥ wide side is much lower than that with B ⊥wide side of the conductor.
- This is beneficial for CS coils due to the magnetic field in CS coil is parallel to wide side of the conductor during operating.

UT - Low Temp Superconductor optimization

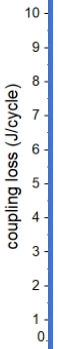
4th Technical Exchange Meeting on CFETR and EU-DEMO Fusion Reactor Design, 20-21 March 2024
Joint work ASIPP and University of Twente on Nb_3Sn CICC for Chinese BEST tokamak.

CICC technology: L

■ Nb_3Sn CICC – AC coupling loss



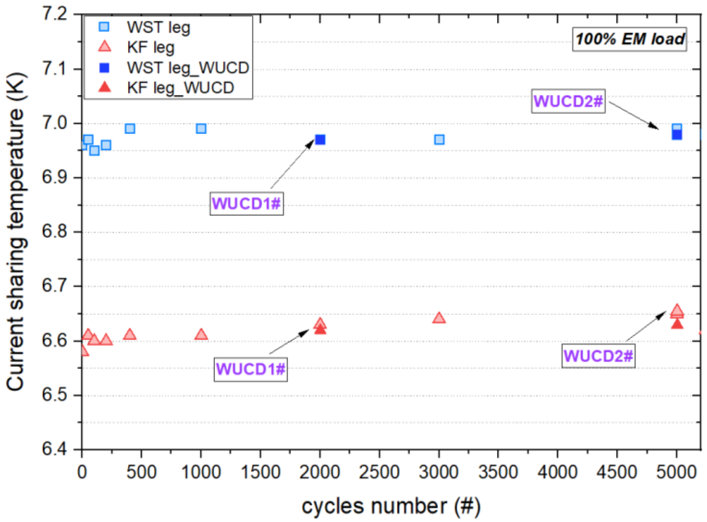
	ntau (ms)
B ⊥wide side	1700
B ∥ wide side	36

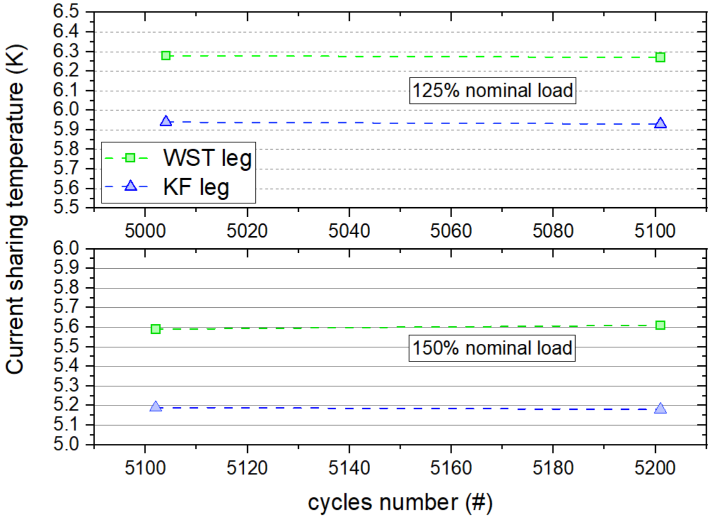


CICC technology: LTS conductors

■ Nb_3Sn CICC – DC performance

- Nb_3Sn strands for SULTAN sample were from two suppliers, which are WST and KuaFu.
- Both legs show stable performance, no visible degradation were observed under the maximum 150% nominal load.

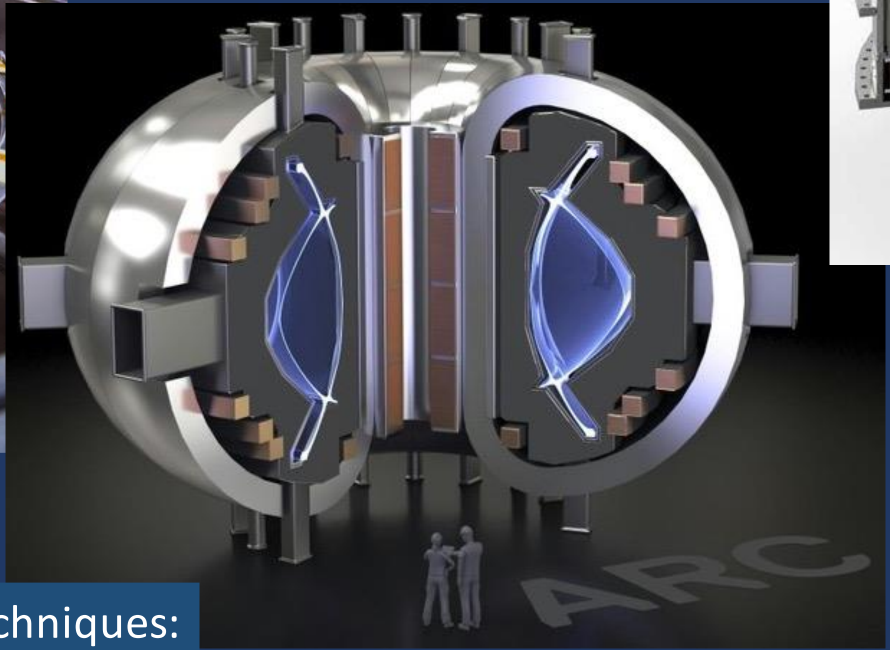




Fusion magnets based on HTS ReBCO tape

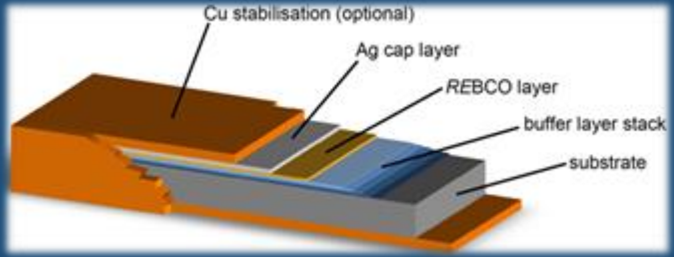
20 T world record HTS large coils

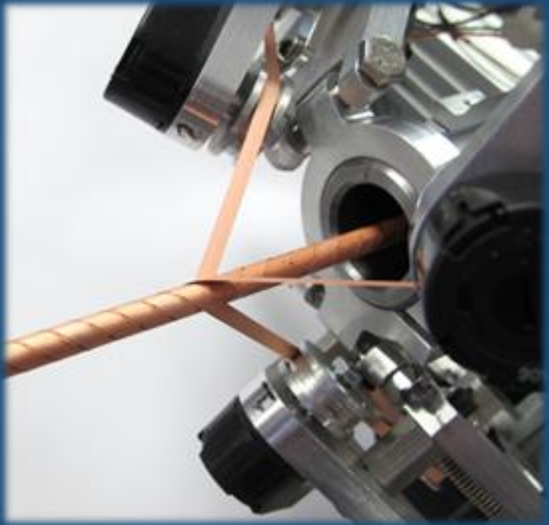
tokamak
energy
a faster way to fusion

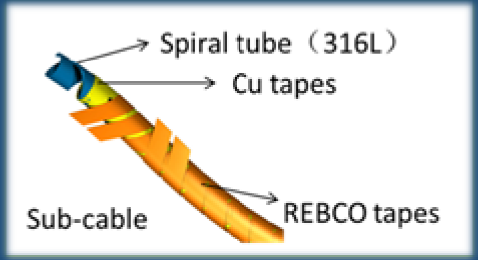


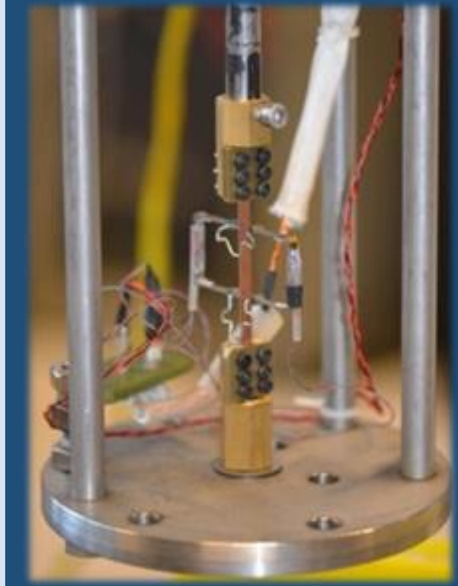
Different coil winding techniques:
Non-insulated tape
Stacked Tape cables
Cable On Round Core

UT - ReBCO tape & cable testing (EUROfusion)

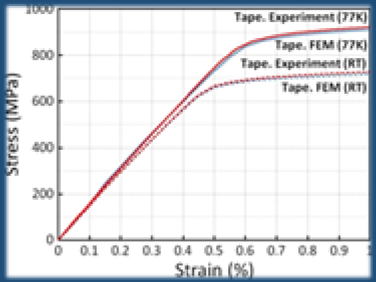




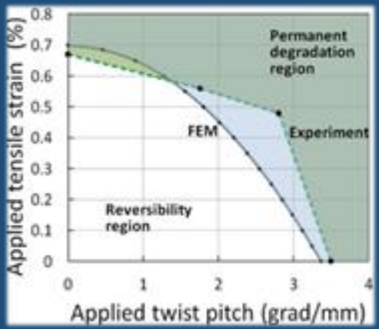


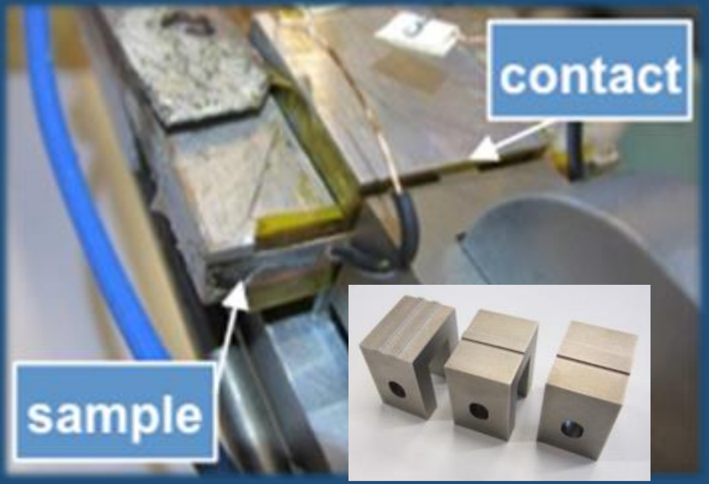


Tensile axial stress-strain

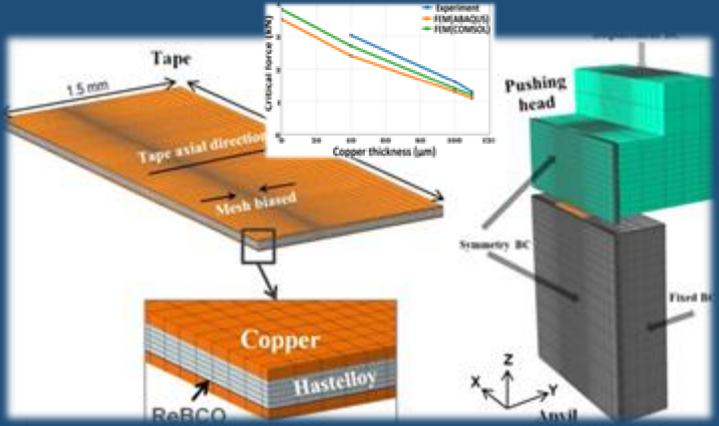


Combined torsion + tensile axial stress

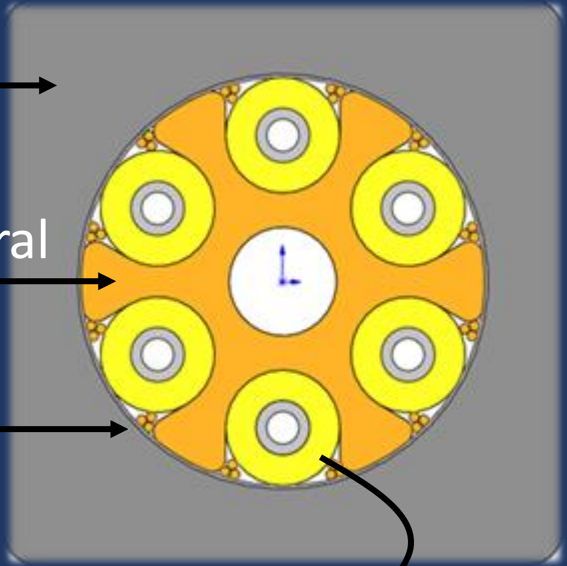


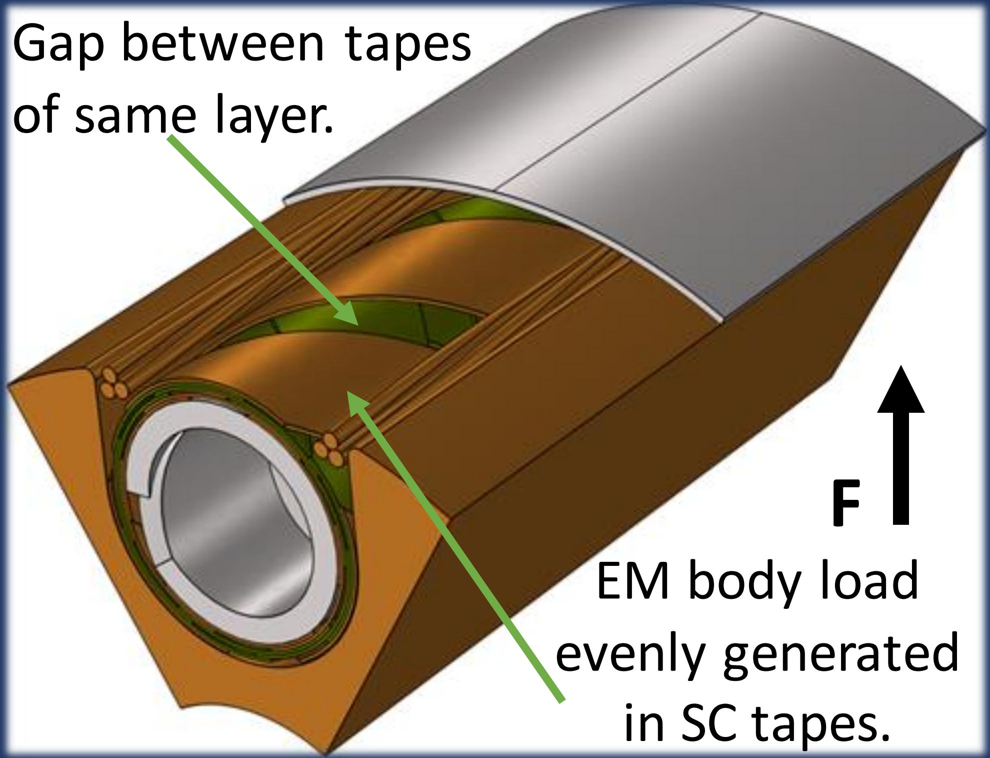


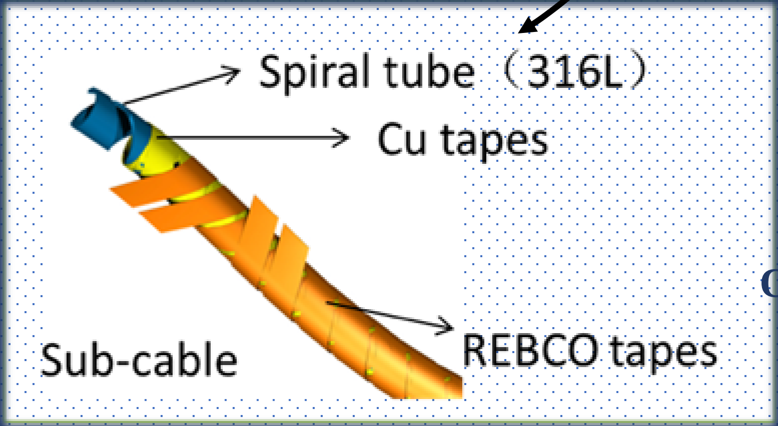
Transverse stress with different loading profiles



UT-ASIPP CORC-CICC: Mechanically decoupled

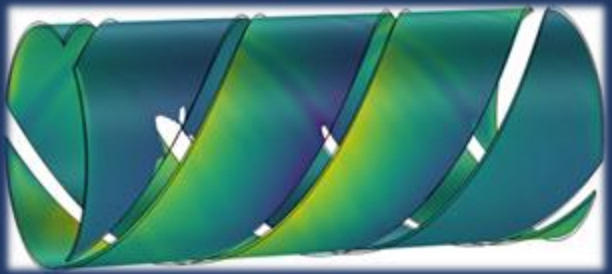


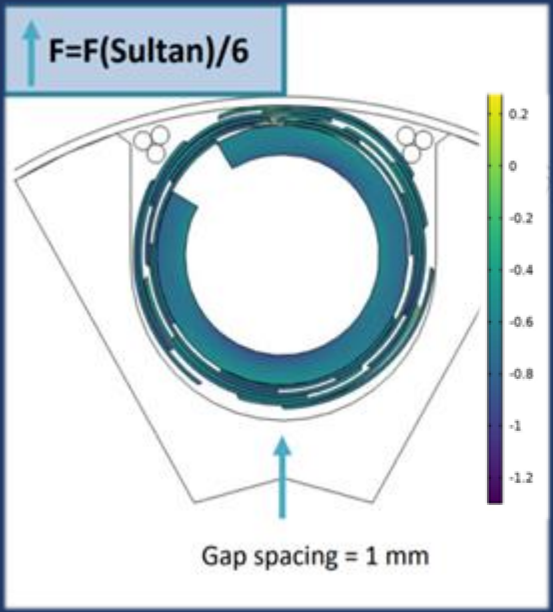


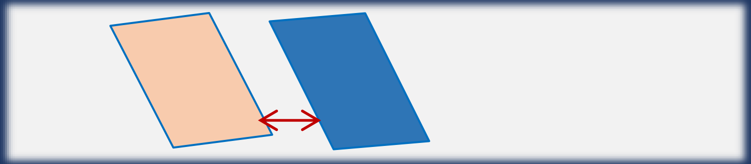


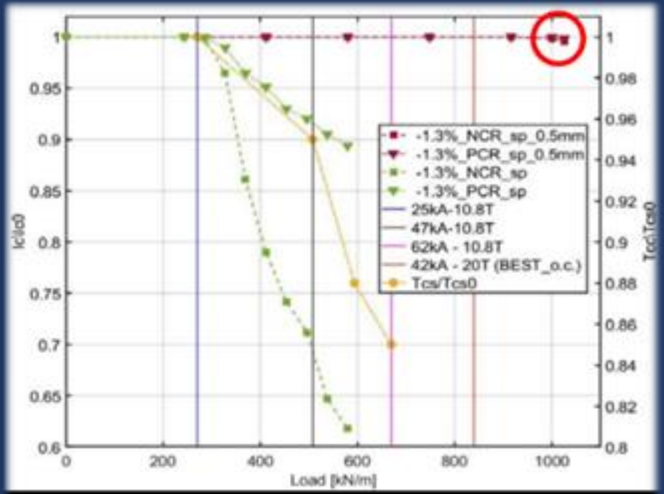
High Temp SC-CICC technology (CORC)

- **Established a partnership on HTS CICC technology development since 2019**
  - Contact resistance and AC loss analysis and testing of ReBCO CORC-like cable
  - Modelling analysis provide references for HTS CICC design optimization to improve its operation stability under high EM load



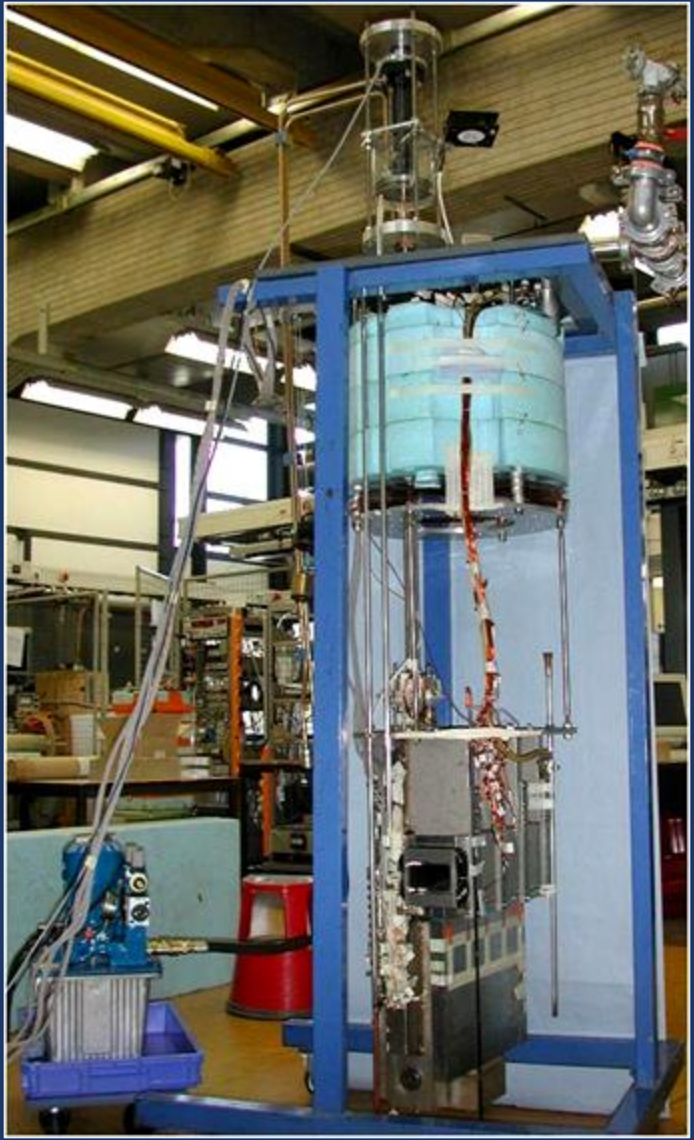


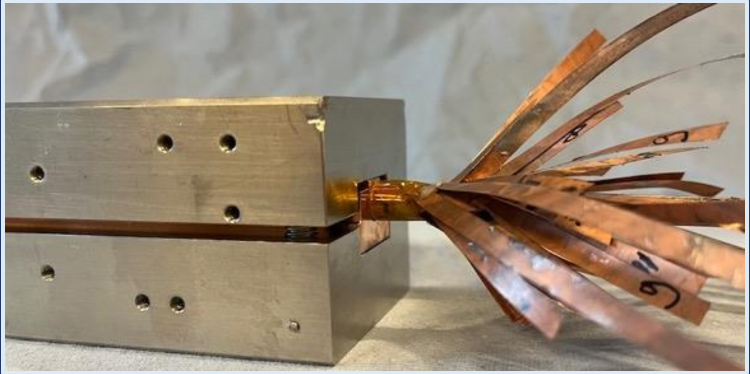


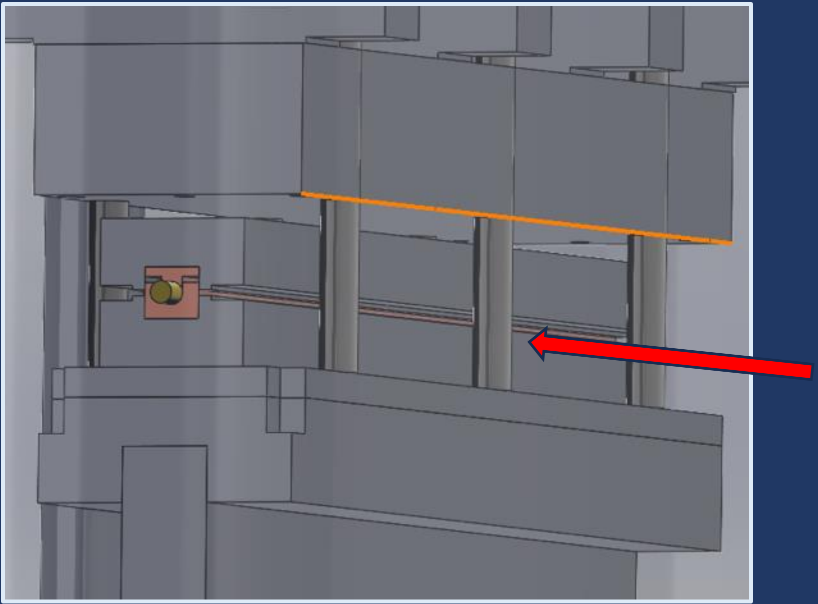


- NCR = no current sharing between tapes.
- PCR = perfect current sharing between tapes.
- Vertical lines: Sultan testing load levels (IxB).

Twente Press with transport current







ReBCO CORCs tested under cyclic transverse load CICC condition in Twente Cryogenic Press at 77 K for critical current and inter-tape contact resistance measurements.

First sample (ACT): cable used in ACT Sultan sample with 36 tapes and OD of 7.04 mm (~0.5 m) length (ID: 220922-SULTAN-07).
(I_c 6096 A).

Presently under test.

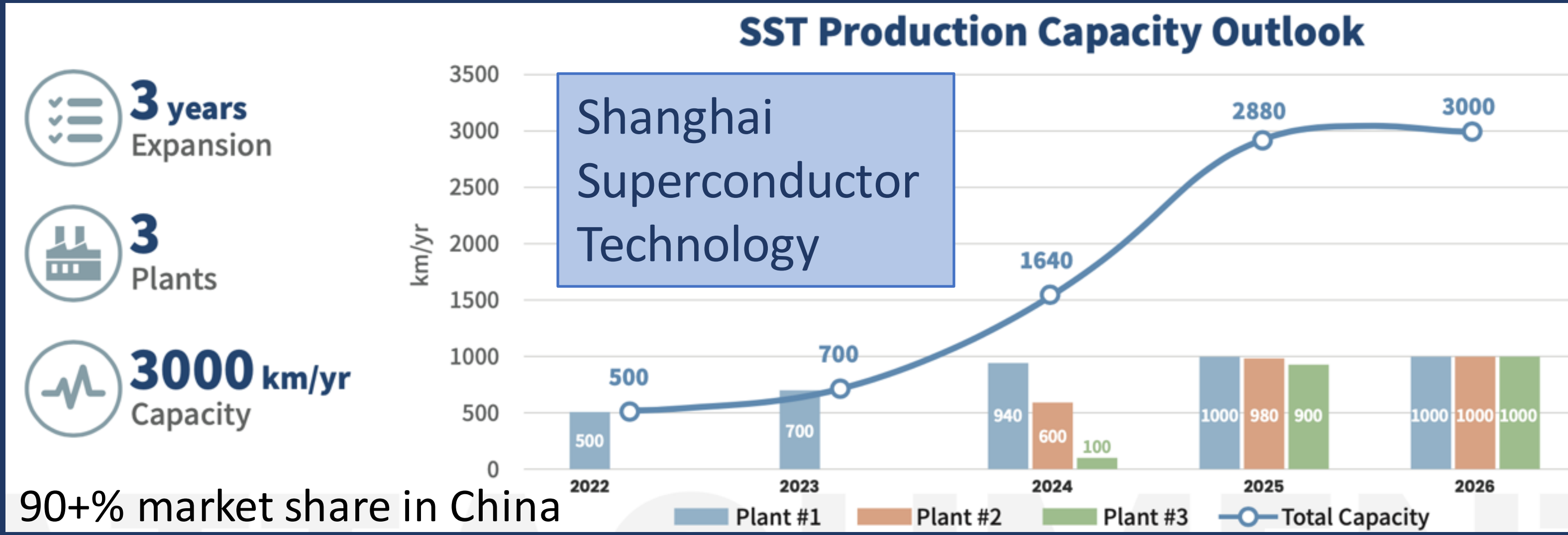
Advanced Conductor Technologies
www.advancedconductor.com

ReBCO tape production


Faraday Factory Japan
April 19, 2024, 00:00 GMT

Faraday Factory Japan gives a start to a new game-changing production facility to boost a global availability of high temperature superconductors

ZAMA, JAPAN, April 19, 2024 /EINPresswire.com/ -- Faraday Factory Japan LLC, the world's largest producer of high temperature superconductors (HTS), has announced today that it has started operations in its new production facility in Zama (Kanagawa, Japan). The factory will be making at least every second meter of HTS tape in the world significantly boosting global production of



90+% market share in China

2G HTS tapes commercialized

UT - ITER Reference Laboratory

XIVth and Final Conductor Meeting
15th - 17th September 2015
ITER Head Quarters