SuperOx

S Innovations

Advanced second generation high temperature superconductor wire for fusion

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SUPERCONDUCTOR TO THE FUTURE

IAEA FEC 2020

Credits

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Outline

SuperOx
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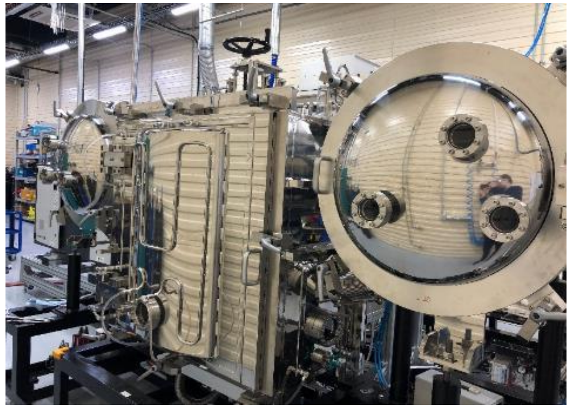
- The SuperOx group
- High temperature superconductors (HTS) enable compact fusion
- Challenges to HTS for fusion---being resolved

1. High J_e in magnetic field
2. Consistent quality
3. Production capacity and cost
4. Cable technology

The SuperOx group

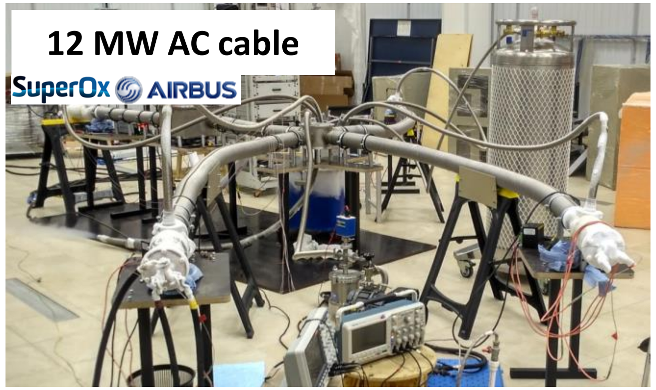
S Innovations (Moscow) and SUPEROX JAPAN (Tokyo)

- 2G HTS wire production and development
  - Supply wire to SuperOx projects
  - Supply wire to customers worldwide

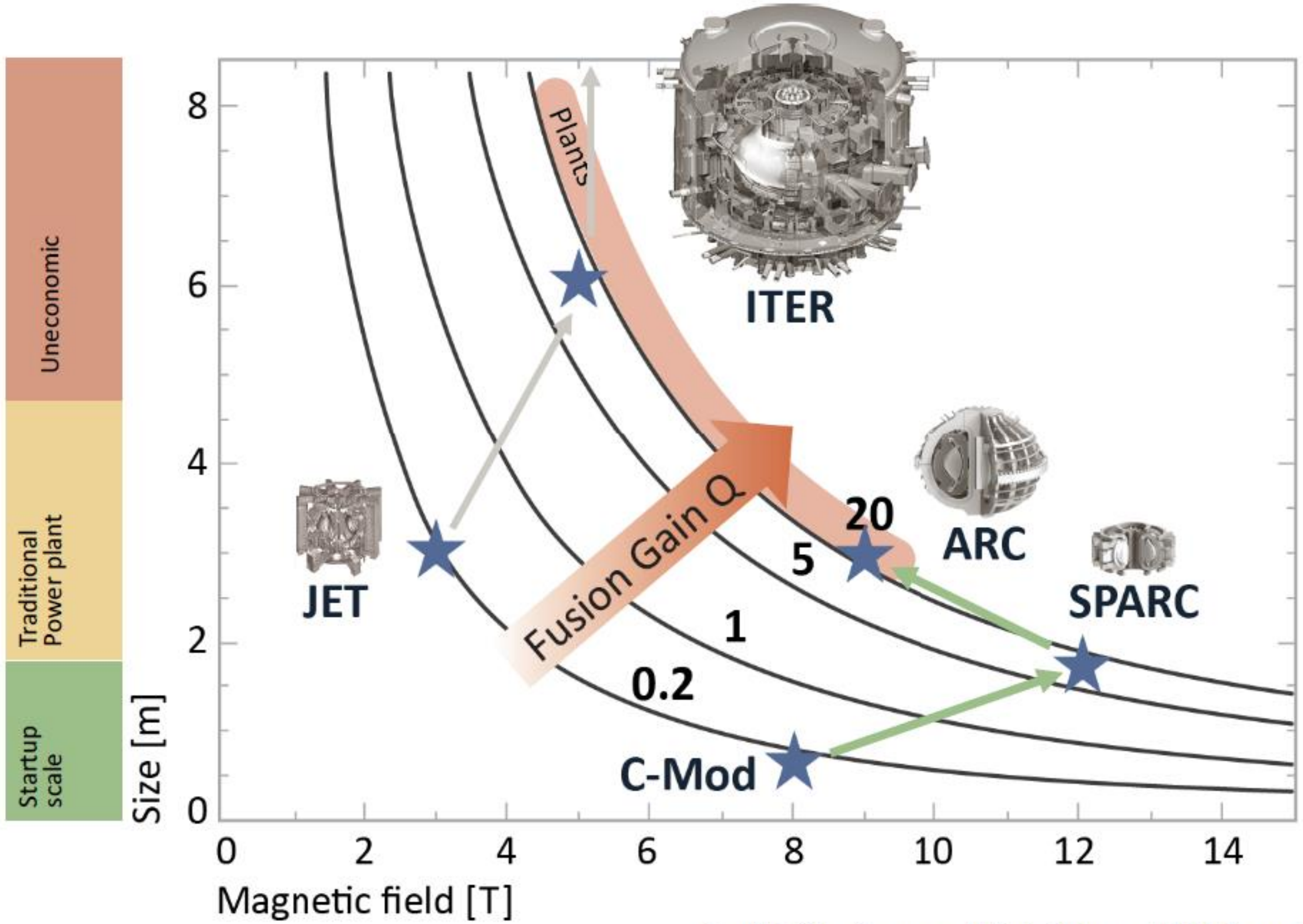
SuperOx (Moscow)

- HTS Applications development and commercialisation
  - Fault Current Limiters: 220 kV FCL in Moscow city grid in 2019
  - Coils: 0.5 MW motor for aircraft
  - AC/DC cables: 12 MW AC cable system for aircraft



Commonwealth Fusion Systems' high-field path to fusion

Commonwealth Fusion Systems



The CFS plan to get to clean fusion energy will use a lot of HTS

Commonwealth Fusion Systems

COMPLETED:
Proven science
Alcator C-Mod

IN PROGRESS for Summer 2021
Demonstrate Groundbreaking HTS magnets

Demonstrate magnet technology

500 km ordered, delivered, characterized, and put into a magnet

CONSTRUCTION PLANNING UNDERWAY for 2025 LAUNCH
Achieve net energy from fusion
SPARC, Q>2

Value inflection from showing net energy

Requires **~10,000 km** of HTS.

Early 2030s
Fusion power on the grid
ARC, Q>10, $P_{electric}$~200MW

Carbon-free fusion energy

Requires **~20,000 km** of HTS per fusion device.

SuperOx 2G HTS wire: Technology

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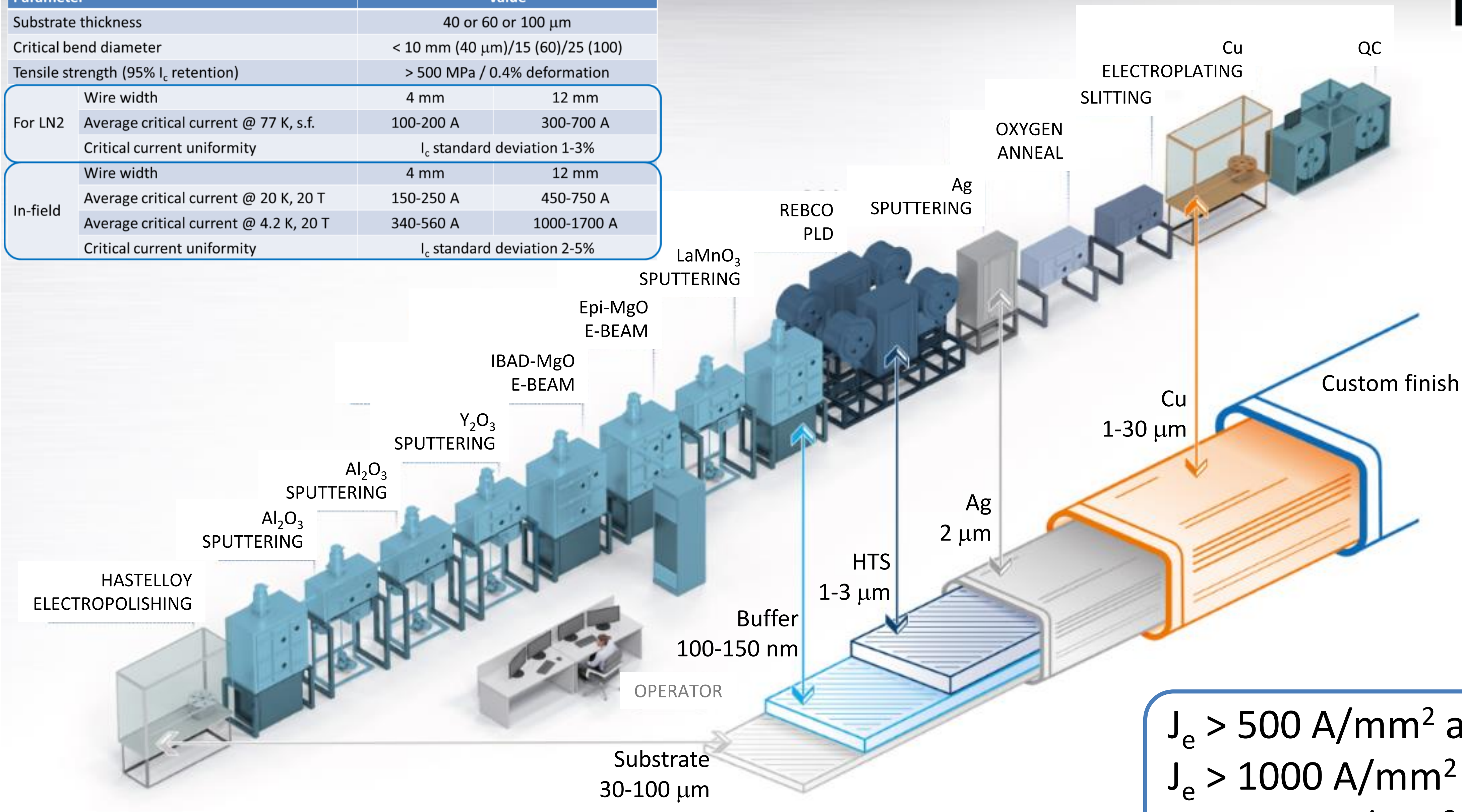
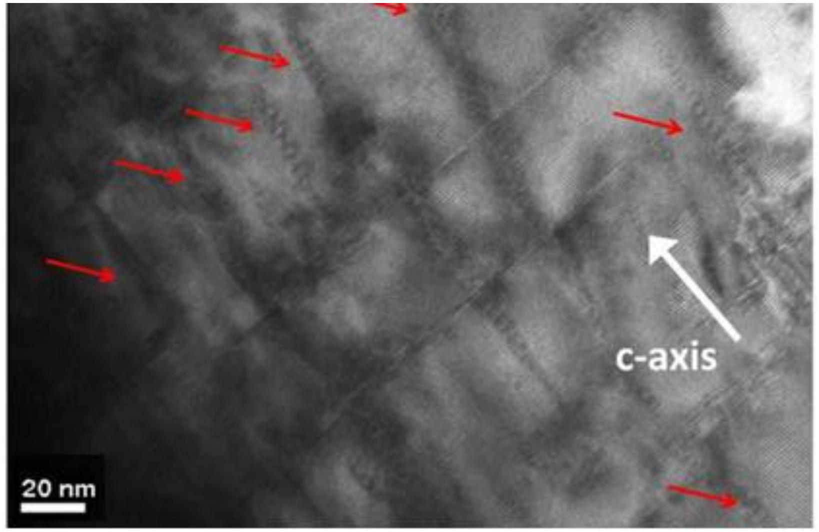
Parameter		Value	
Substrate thickness		40 or 60 or 100 µm	
Critical bend diameter		< 10 mm (40 µm)/15 (60)/25 (100)	
Tensile strength (95% I_c retention)		> 500 MPa / 0.4% deformation	
For LN2	Wire width	4 mm	12 mm
	Average critical current @ 77 K, s.f.	100-200 A	300-700 A
	Critical current uniformity	I_c standard deviation 1-3%	
In-field	Wire width	4 mm	12 mm
	Average critical current @ 20 K, 20 T	150-250 A	450-750 A
	Average critical current @ 4.2 K, 20 T	340-560 A	1000-1700 A
	Critical current uniformity	I_c standard deviation 2-5%	



J_e > 500 A/mm^2 at 77 K, s.f.
J_e > 1000 A/mm^2 at 20 K, 20 T
J_e > 2000 A/mm^2 at 4.2 K, 20 T

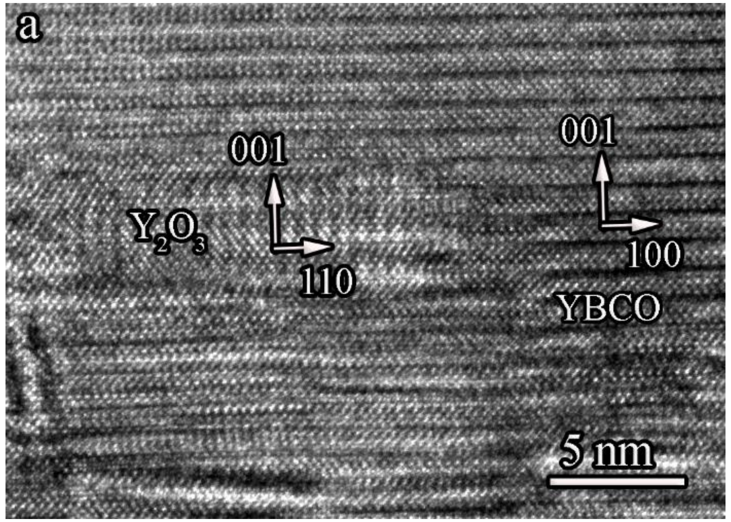
SuperOx wire for in-field use:
Simple and amenable to industrial production

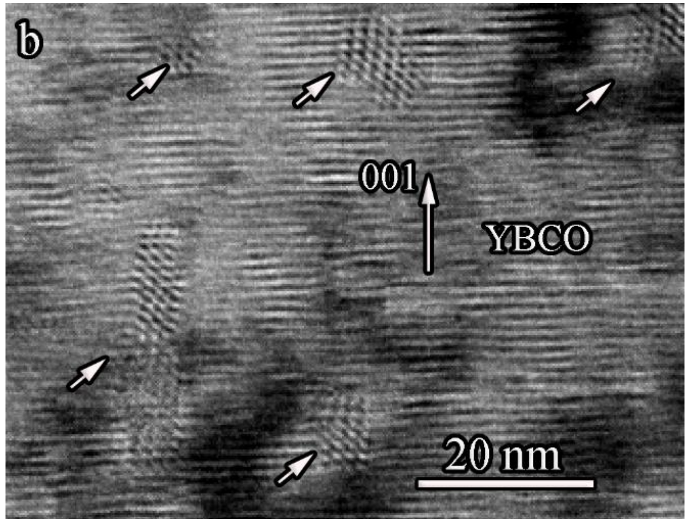
Conventional approach to pinning in HTS wire:
c-axis correlated extrinsic defects (e.g. $BaZrO_3$)



Wee, S. et al. Sci Rep 3, 2310 (2013)
doi.org/10.1038/srep02310

SuperOx 2G HTS wire for in-field use:
Uniformly distributed intrinsic Y_2O_3 nanoparticles in YBCO





Molodyk, A. et al. Sci Rep 11, 2084 (2021)
doi.org/10.1038/s41598-021-81559-z

- x Complex composition and nano-structure
- x Difficult to control
- x Issues with reproducible manufacturing

- ✓ Simple composition and nano-structure
- ✓ Easy to control
- ✓ Good reproducibility in manufacturing

Challenge 1: High performance SuperOx wire for in-field use
Best commercial wire for magnets today

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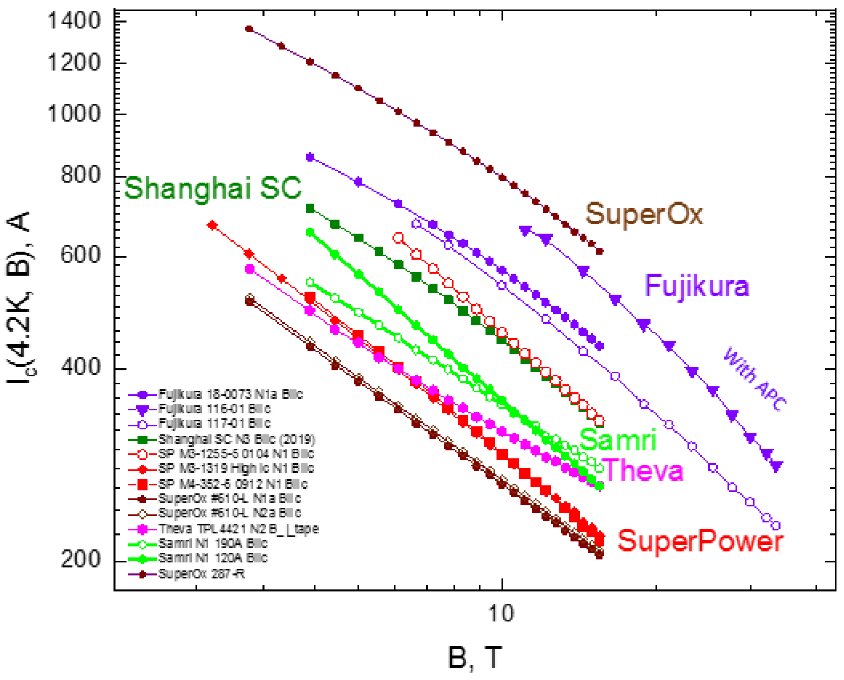
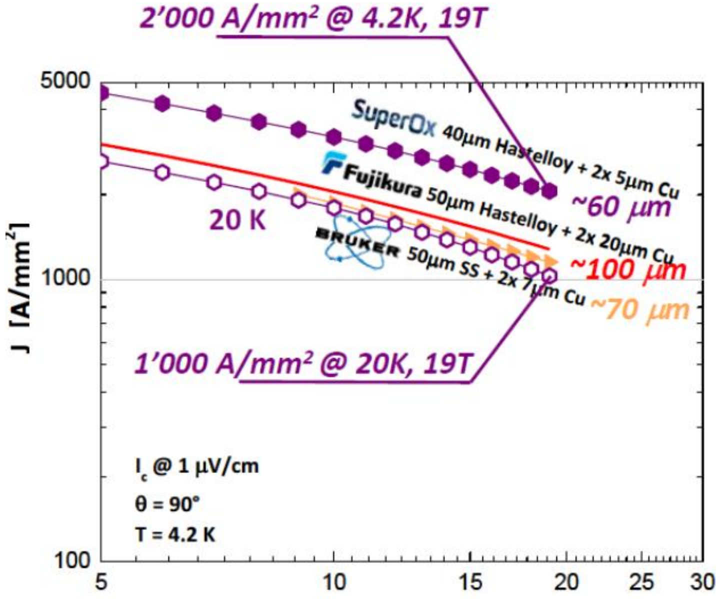


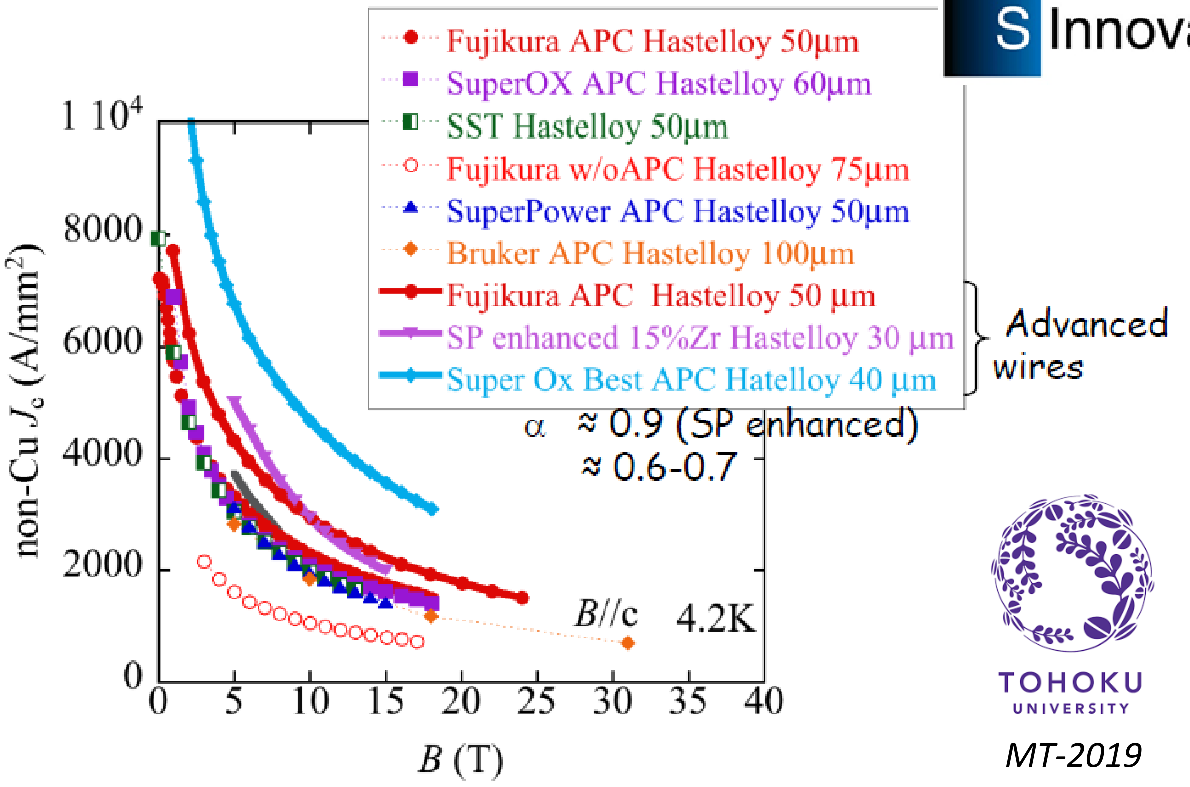
NATIONAL MAGLAB

EUCAS-2019



UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

FCC Week 2019



TOHOKU UNIVERSITY

MT-2019

I_c 30% higher than competition

Challenge 2: Consistent quality

SuperOx wire for in-field use: 2G HTS wire is becoming industrial

300+ km of 4 mm wire delivered to customers in 9 months

300+ km more in another 6 months; 3,000 km in 2022

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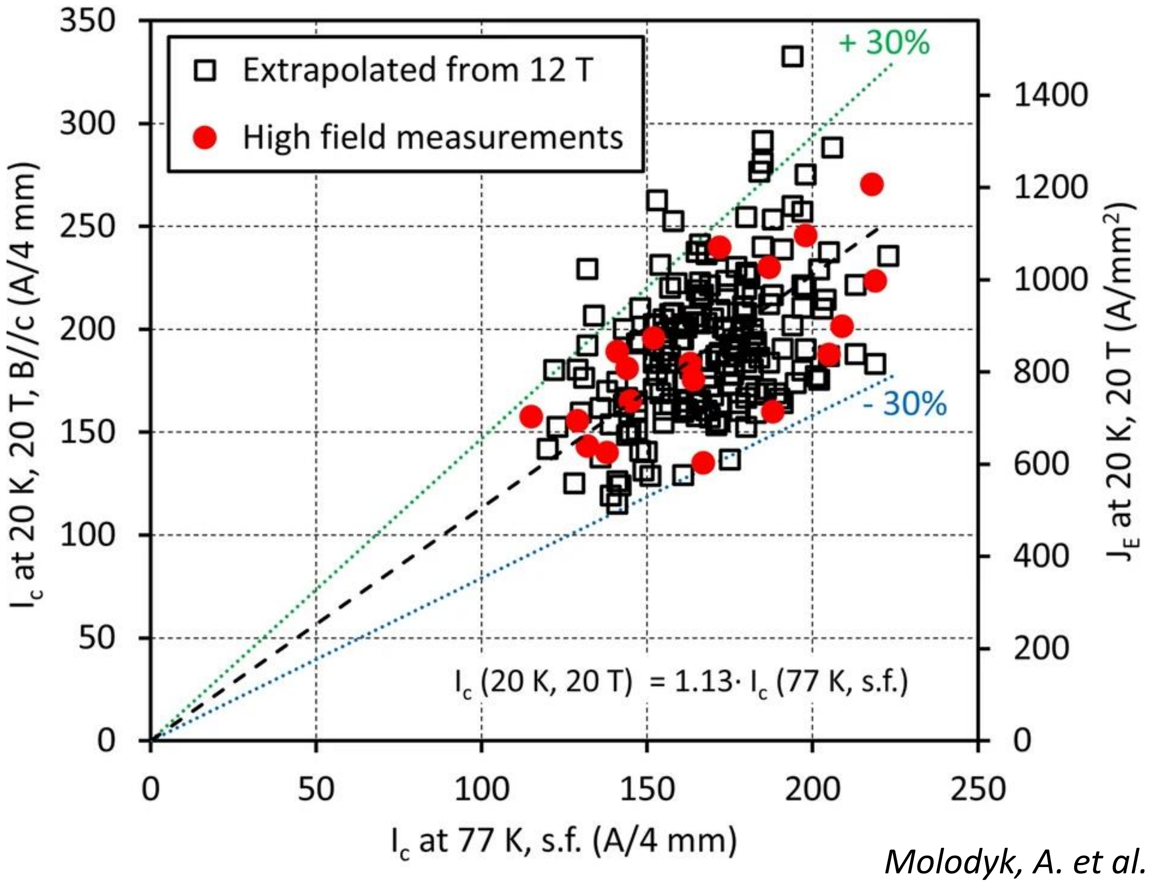

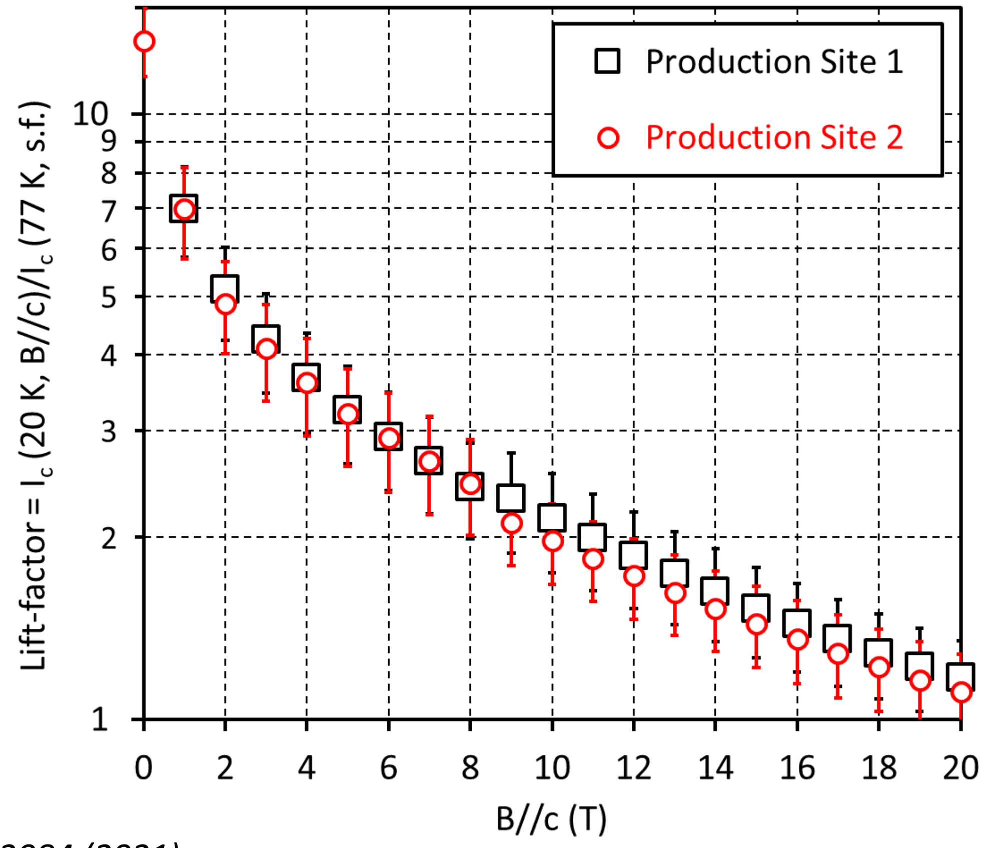

Molodyk, A. et al. Sci Rep 11, 2084 (2021)
doi.org/10.1038/s41598-021-81559-z

- Reasonable statistical spread of in-field properties. StD ~ 15%
- Wires fabricated at different sites are identical

SuperOx 2G HTS wire: Specifications

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Parameter		Value	
Substrate thickness		30 or 40 or 60 or 100 μm	
Critical bend diameter		< 10 mm (30 & 40 μm)/15 (60)/25 (100)	
Tensile strength (95% I_c retention)		> 500 MPa / 0.4% deformation	
For LN2	Wire width	4 mm	12 mm
	Average critical current @ 77 K, s.f.	100-200 A	300-700 A
	I_c uniformity along wire	I_c standard deviation 1-3%	
In-field	Wire width	4 mm	12 mm
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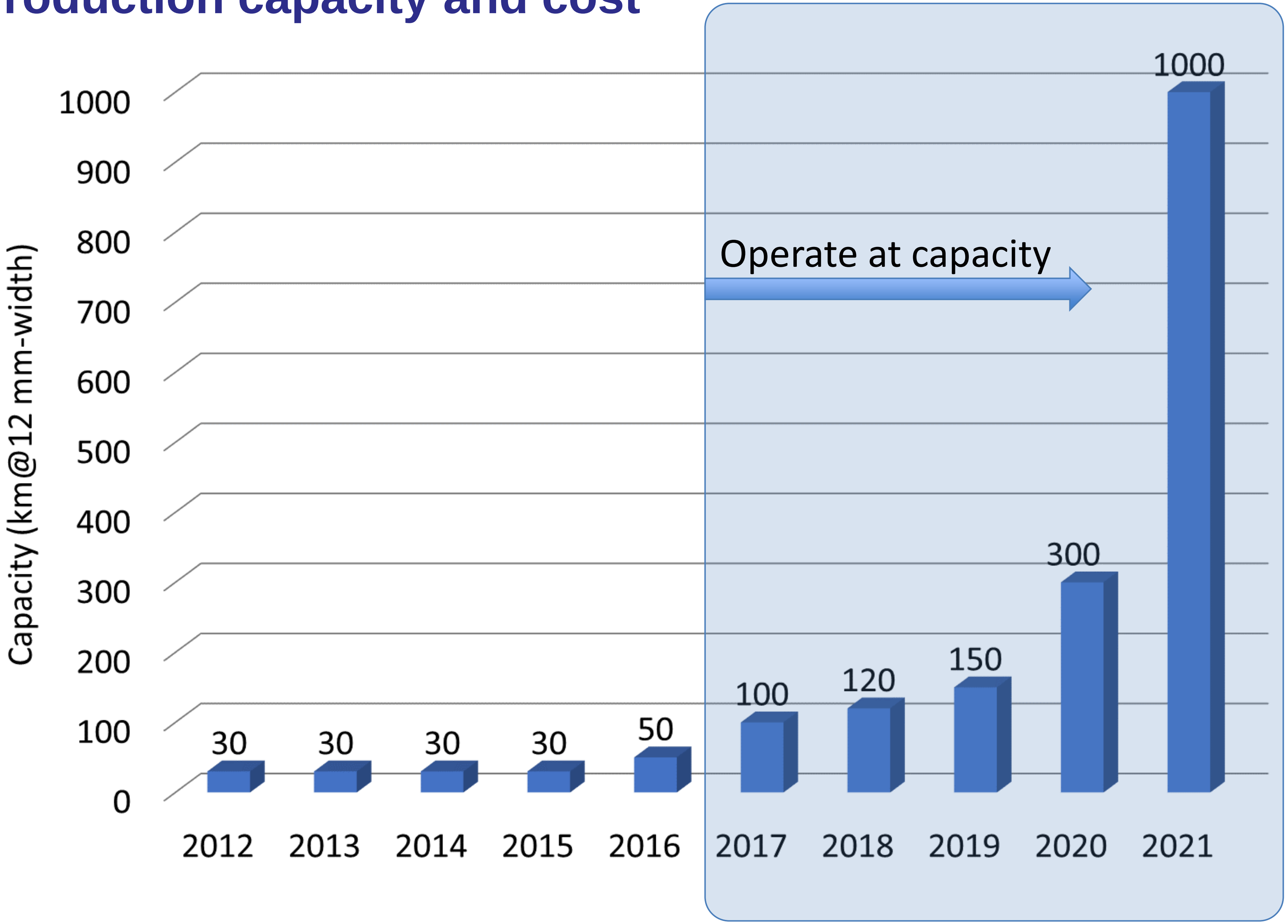
	I_c uniformity along wire	I_c standard deviation 2-5%	

Customisation:

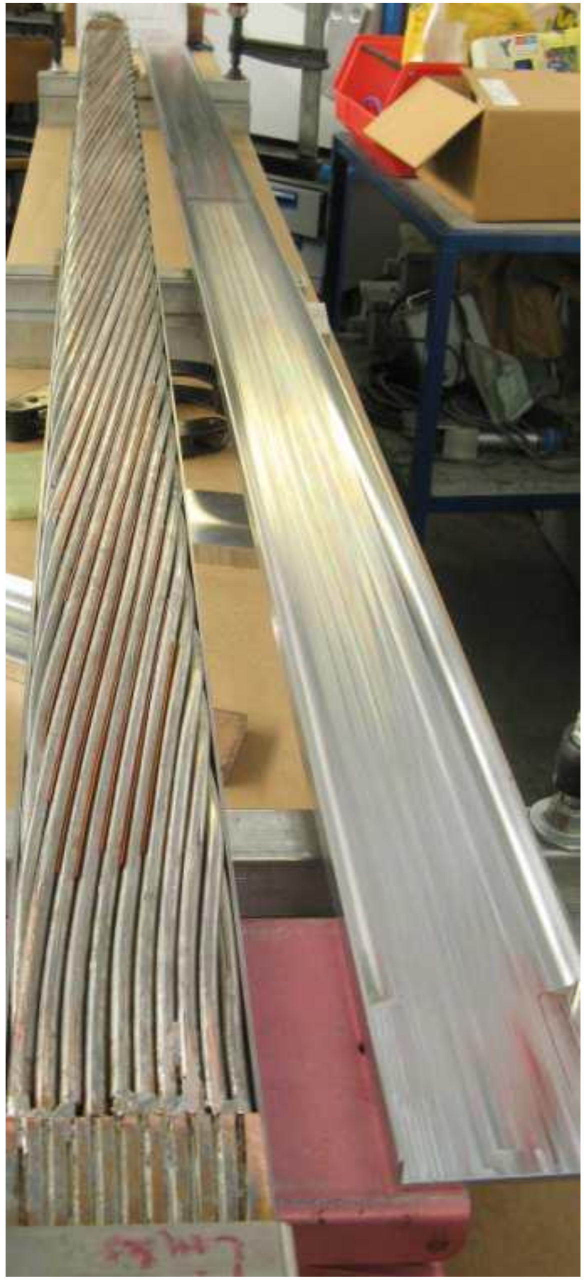
+ Variable copper thickness
+ Insulation: 10-20 μm thin polyimide varnish
+ Solder plating
+ Lamination
+ Low resistance splices
+ … just ask

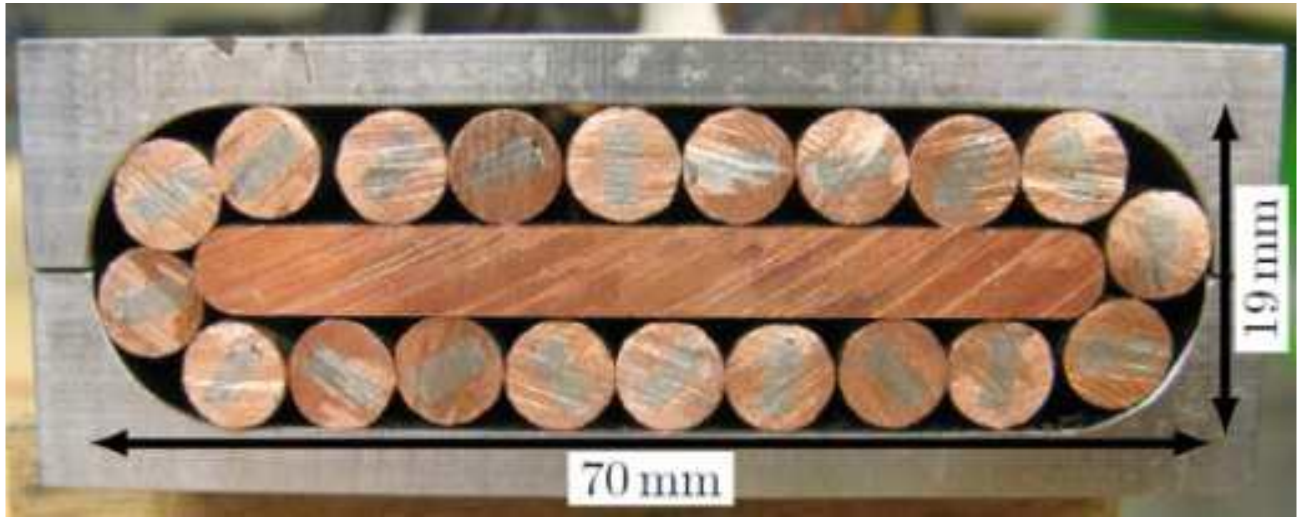
Challenge 3: Production capacity and cost

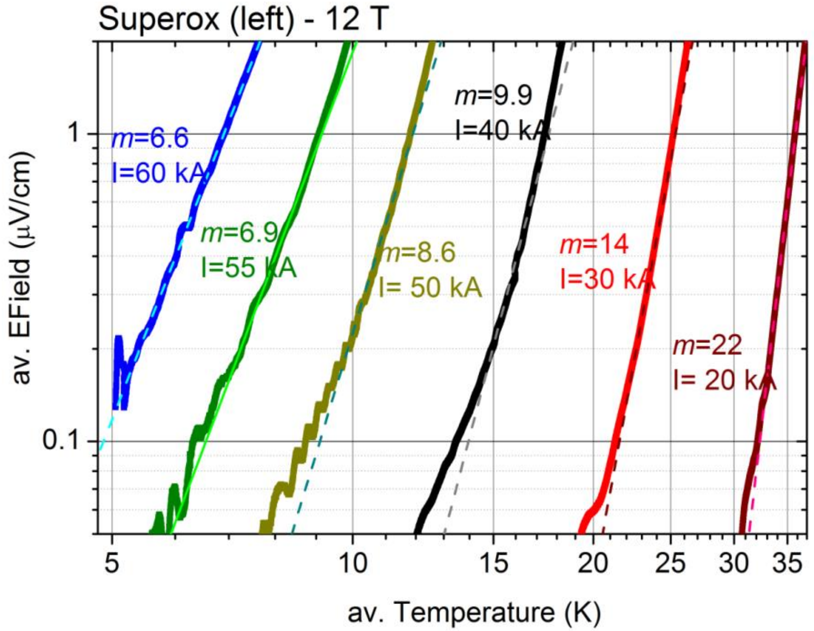


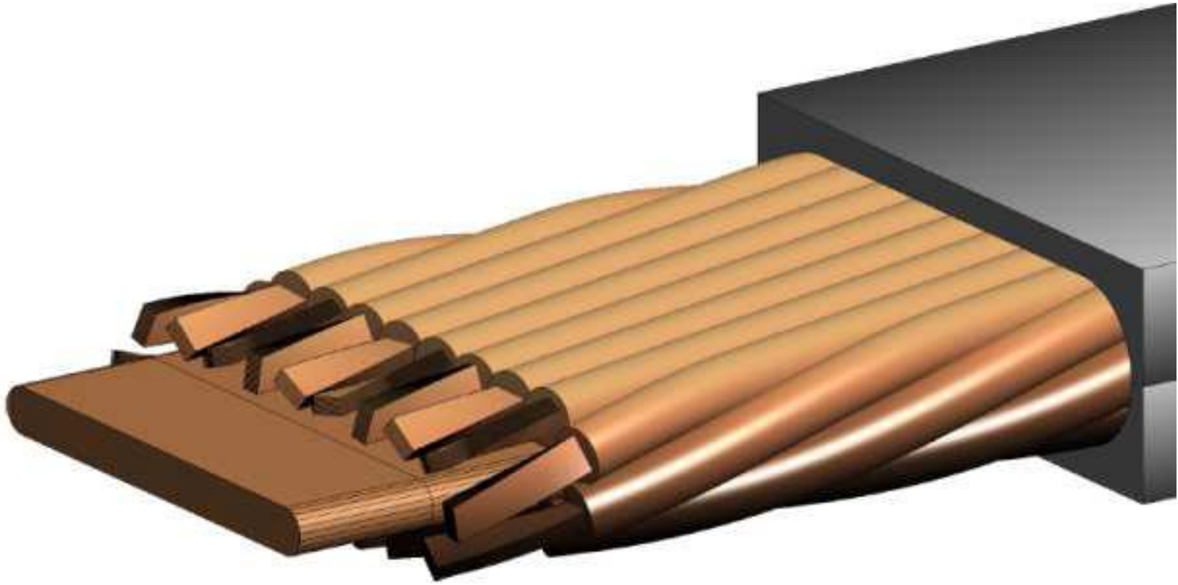
- Demand drives capacity scale-up
- Economies of scale bring the price down

Challenge 4: HTS cables for fusion
Paul Scherrer Institute: 60 kA @ 4.2 K, 12 T





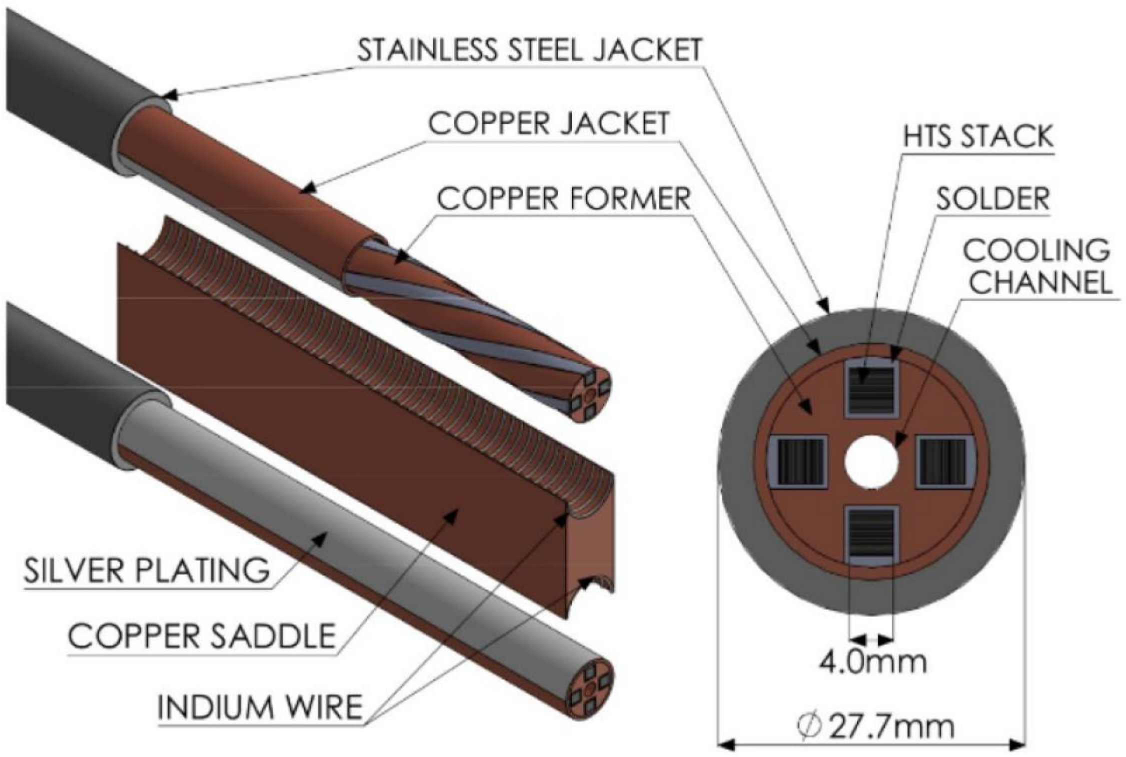


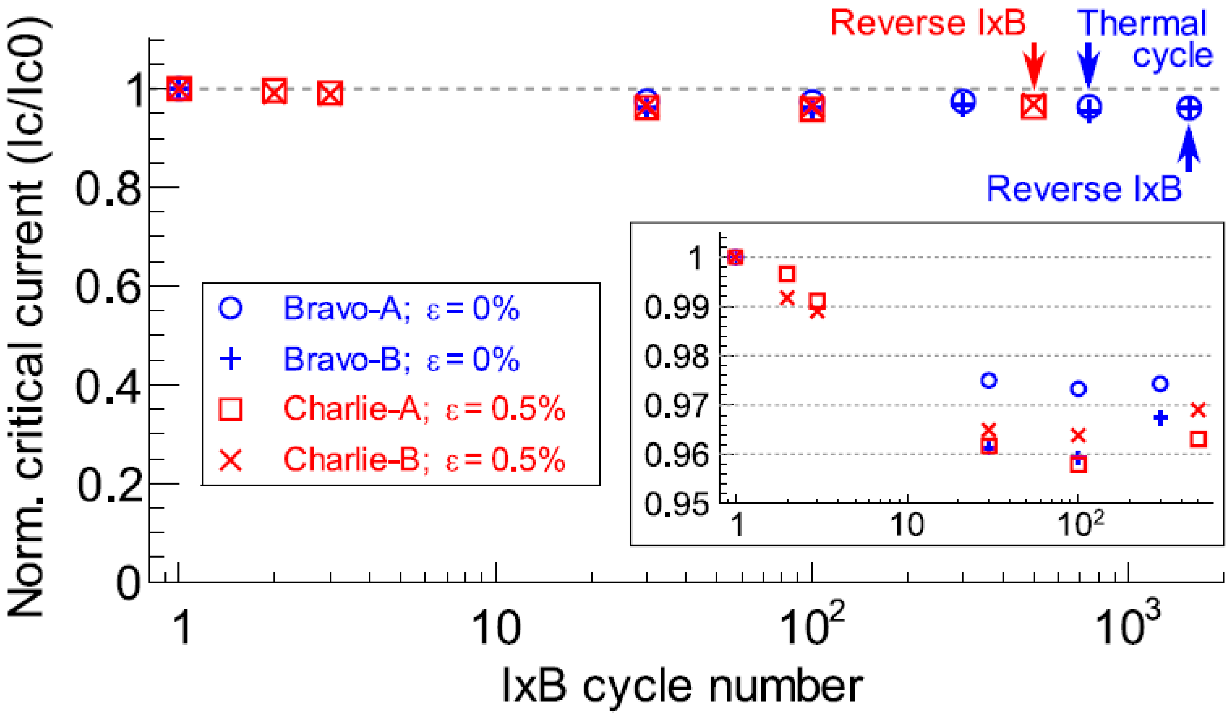


D. Uglietti et. al, 2015 Supercond. Sci. Technol. 28 124005

Challenge 4: HTS cables for fusion
MIT / CFS: VIPER design

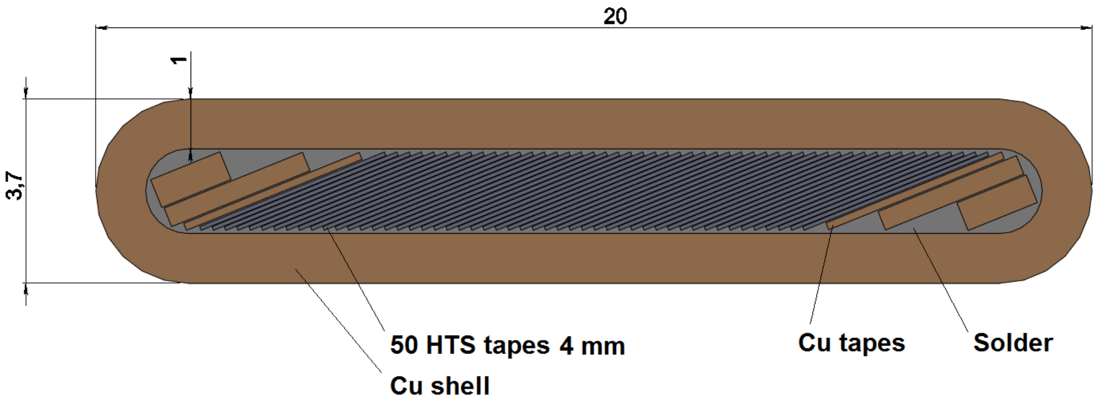
Massachusetts Institute of Technology
Commonwealth Fusion Systems

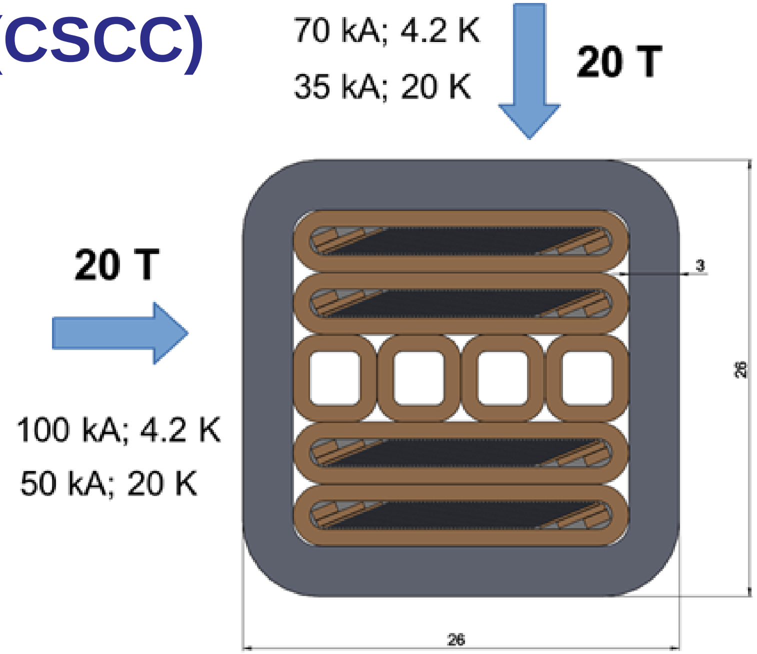




Zachary S Hartwig *et al* 2020 *Supercond. Sci. Technol.* **33** 11LT01

Challenge 4: HTS cables for fusion
SuperOx: Canted Stack in the Channel Conductor (CSCC)

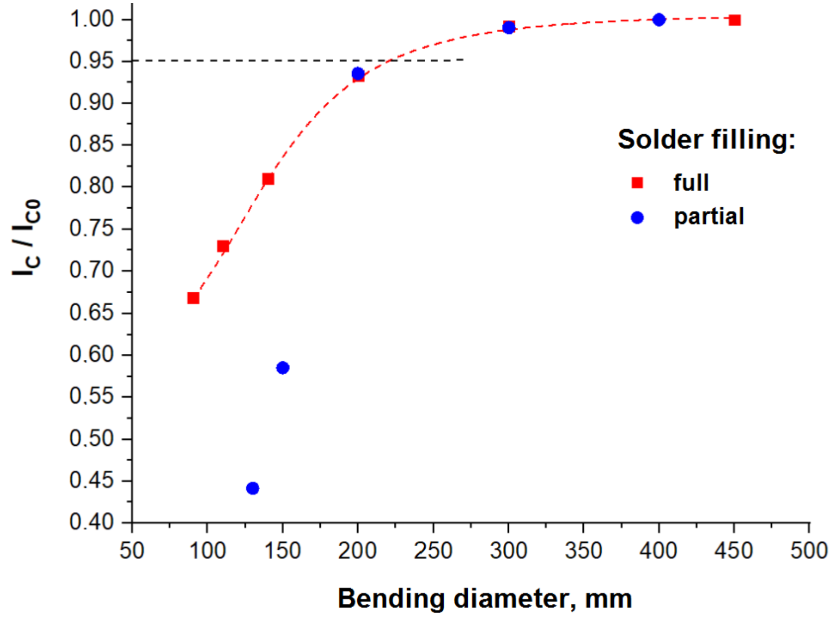




200 HTS tapes 4 X 0.06 mm

Cu: 245 mm^2

SS: 260 mm^2



Summary

- The SuperOx group:
  - Produce and sell 2G HTS wire
  - Commercialise HTS applications
- HTS will turn the fusion dream into reality
  - High magnetic field: path to compact commercial reactors
- Challenges to HTS for fusion---being resolved

1. High J_e in magnetic field: 1,000+ A/mm^2 (20 K, 20 T), 2,000+ A/mm^2 (4.2 K, 20 T)
2. Consistent quality: through simple superconductor
3. Production capacity and cost: tonne-scale projects two-digit $/kAm
4. Cable technology: choice among designs that work

Thank you for your attention

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