SuperPower® Inc.
A Furukawa Company

superior performance. powerful technology.

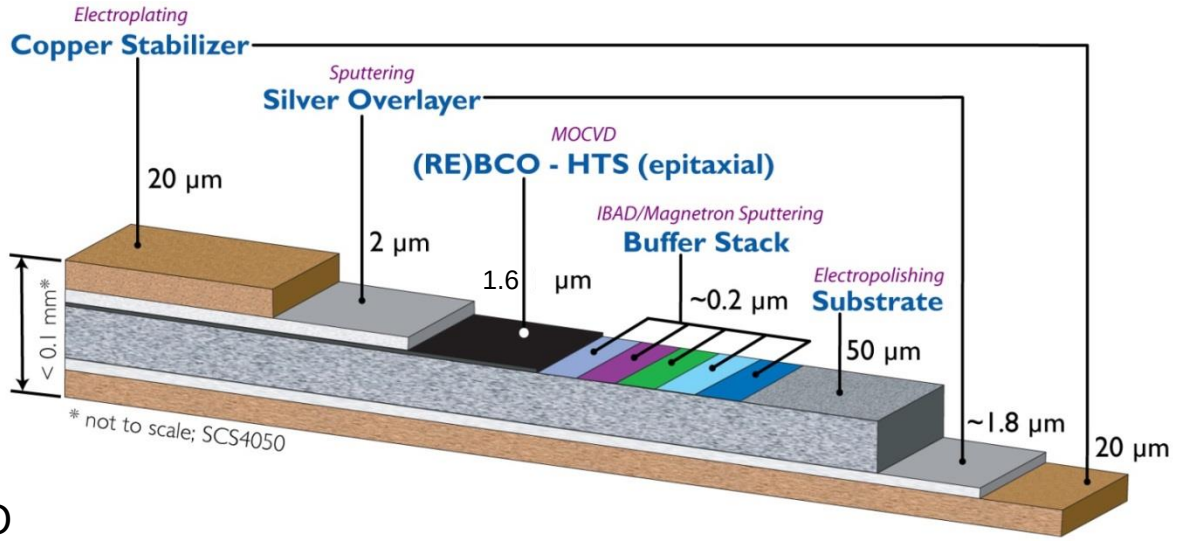
Magnet conductor development at SuperPower

DW Hazelton

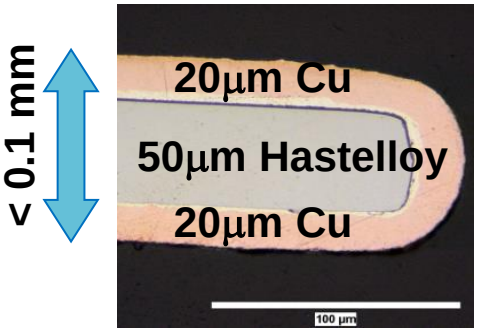
US MDP virtual workshop
March 3, 2021

FURUKAWA ELECTRIC GROUP

SuperPower's (RE)BCO superconductor with artificial pinning structure provides a solution for demanding magnet applications



- Hastelloy® C276 substrate
  - high strength
  - high resistance
  - non-magnetic
- Buffer layers with IBAD-MgO
  - Diffusion barrier to metal substrate
  - Ideal lattice matching from substrate through REBCO
- MOCVD grown (RE)BCO layer with BZO nanorods
  - Flux pinning sites for high in-field I_c
- Silver and copper stabilization



In order to meet rising demand, our efforts are focused on…

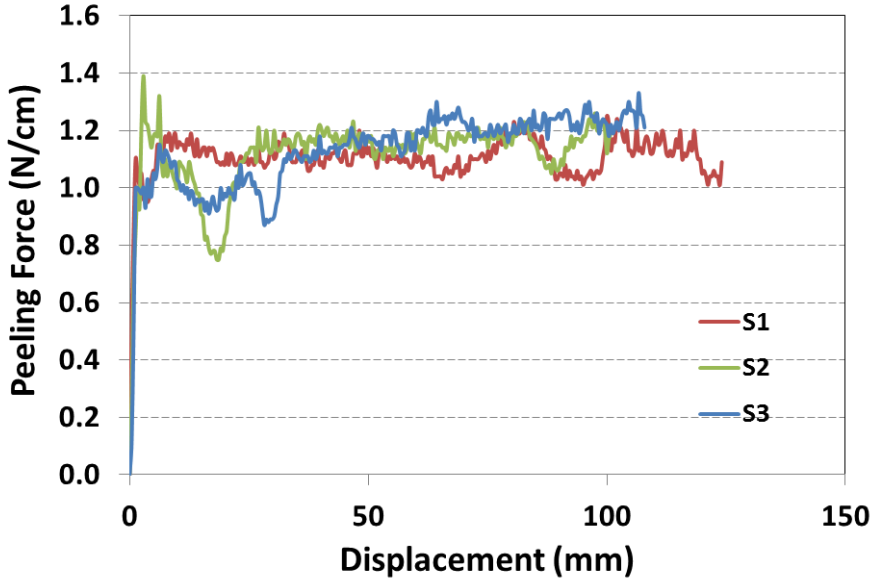
1. Stable wire production especially for lower temperature, high field performance
2. Longer piece length with homogeneous quality
    - 1000+ m charge lengths for MOCVD production runs are now being routinely run
3. Achieve larger production MOCVD and lower cost by
    - stabilizing the whole process
    - bringing all processes in house
    - while adding new equipment to expand capacity

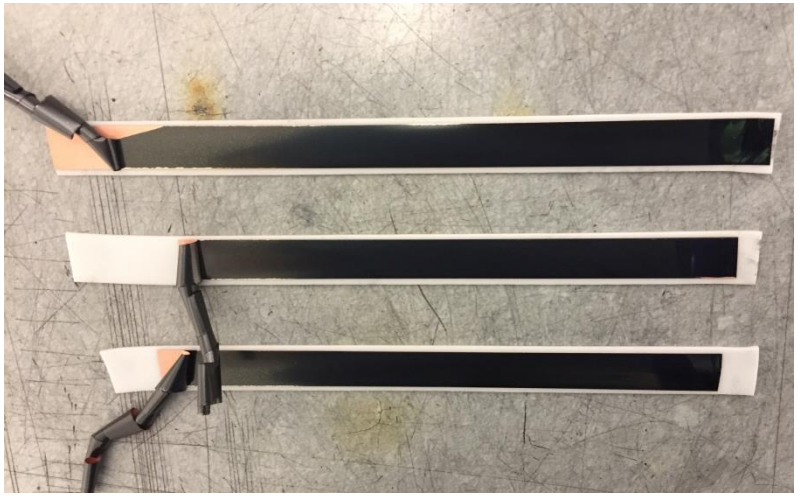
R&D work for improved wire performance moving into production

- Film optimization for target operating range
  - Multiple Ic measurement sites
  - Internal (SuperPower, FEC-Nikko)
  - Collaborations (Tohoku Univ, NHMFL……..)
- Higher current density by thinner substrate (50, 30 μm std)
  - 25 μm under development
- Higher current density by thicker film (1.6 >1.9 μm)
- Narrower 1.5 mm tapes for CORC cable use
- Improved processing for delamination mitigation

Peel test result of M3-1337-3

- Production manual peel test result: Passed.
- Observation: the qualitative manual peel test showed a normal peeling. behavior of the sample tape, peeling within REBCO. No bubbling observed.
- R&D instrumented peel test result: average peel strength = 1.13 N/cm (minimum peeling force = 0.75 N/cm).
- Three samples were prepared from this section and tested at the 90° peeling configuration.
- Peeling force vs. displacement curves shown below. Normal peeling behavior, good peel strength, peeling within REBCO, and clean edges.





Comprehensive testing capabilities for mechanical and electromechanical properties

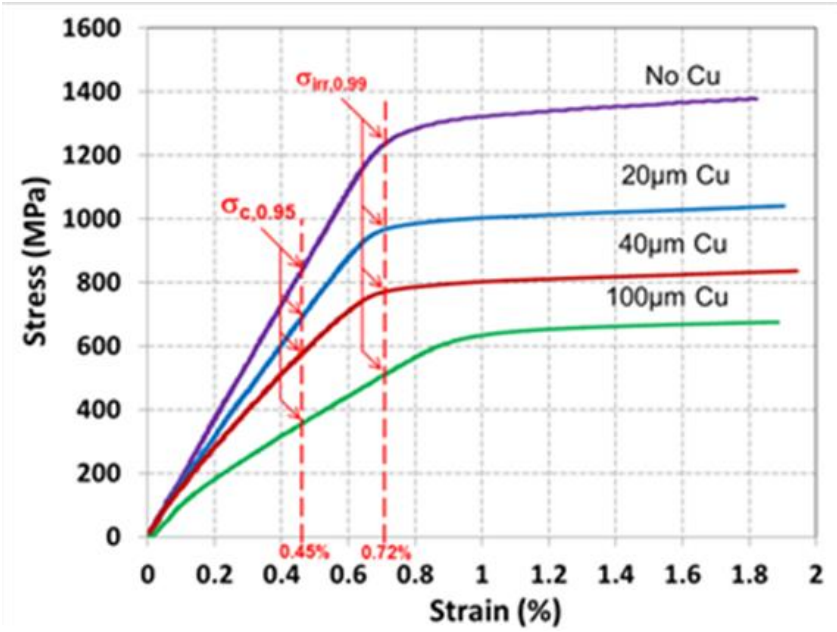
- Axial tensile test at room temperature or at 77K (with I_c)
  - Measurement of elastic modulus and yield stress
  - Determination of critical stress and irreversible stress (strain)
- Measurement of delamination strength – various testing methods
  - Peel test: at room temperature and with varying peeling angle
  - Pin-pull (c-axis tensile) test: at room temperature
  - Anvil (c-axis tensile) test: at room temperature or at 77K (with I_c)
- Transverse (c-axis) compressive test at 77K (with I_c)
  - Measurement of critical compressive stress
- Torsion-tension test at 77K (with I_c)
  - Measurement of critical tensile stress under twist
- Fatigue testing of conductor under development

Studies on mechanical/electromechanical properties

- Mechanical behaviors under various stress conditions at RT and/or 77K
- Electromechanical testing for stress (strain) dependence of I_c at 77K
- Electromechanical strength determined by critical stress with 95% I_c retention

Axial tensile
RT or 77K w/ I_c

Transverse tensile
Stud method
RT or 77K w/ I_c



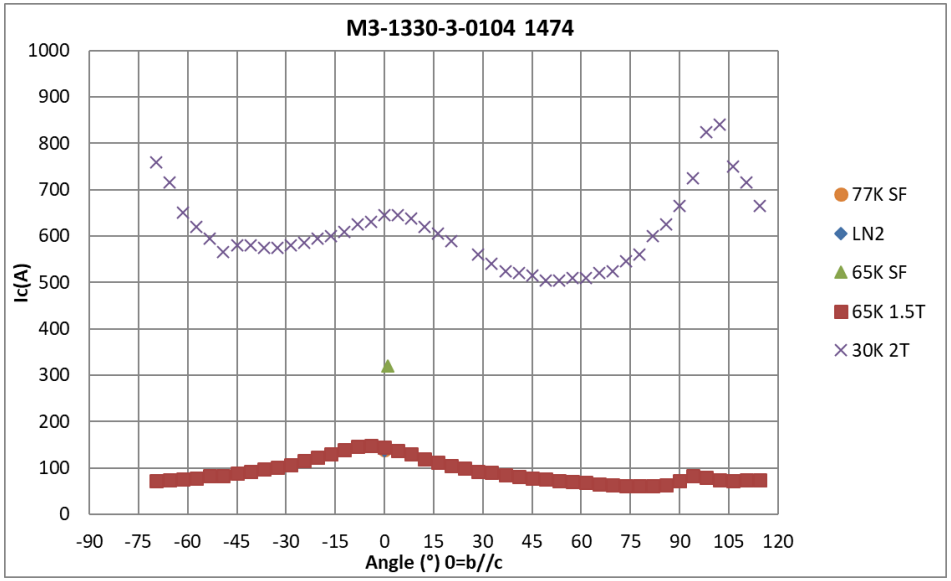
Stress-strain relationship curves of four different SCS4050 wires

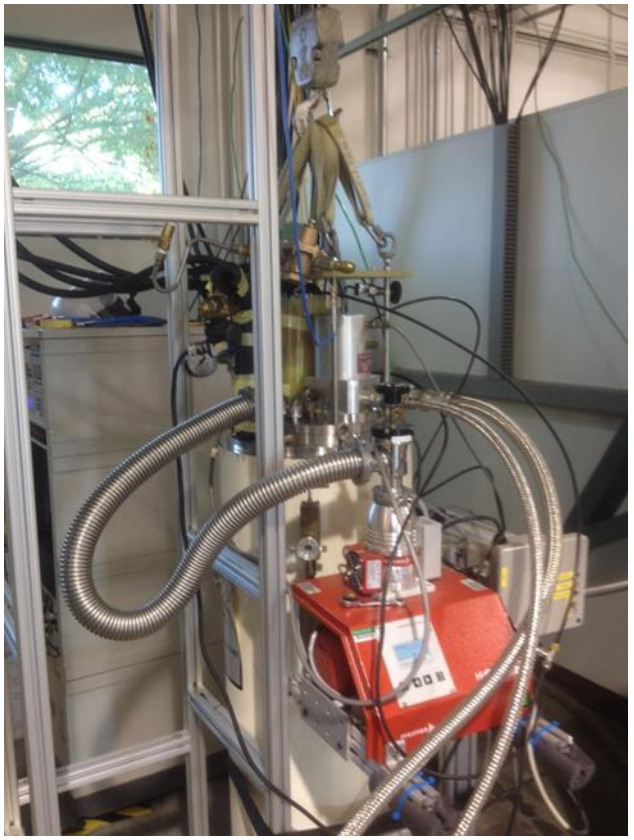
Fixture for mechanical/electromechanical testing

Ic-B-T-Θ measurement systems available to SuperPower

System at SuperPower Inc. (Ic-B-T-Θ)

- Cryo-cooled
- Operating condition is down to 30K
- Field strength is up to 2.5T
- Field angle can be rotated 180 degrees
- ~1000A can be applied to a sample



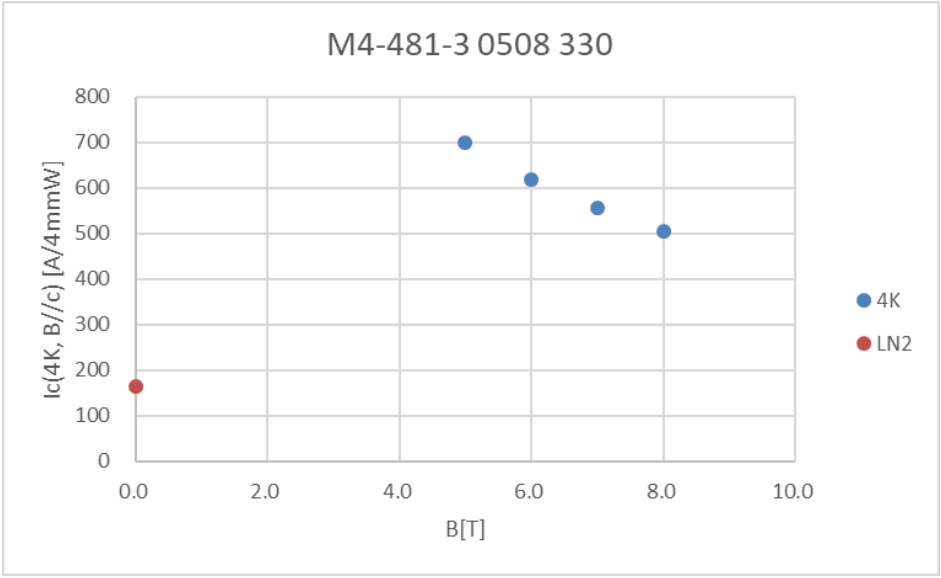


- 2T-77/65K reel-to-reel local transport Ic measurement system under development

Ic-B-T-Θ measurement systems available to SuperPower

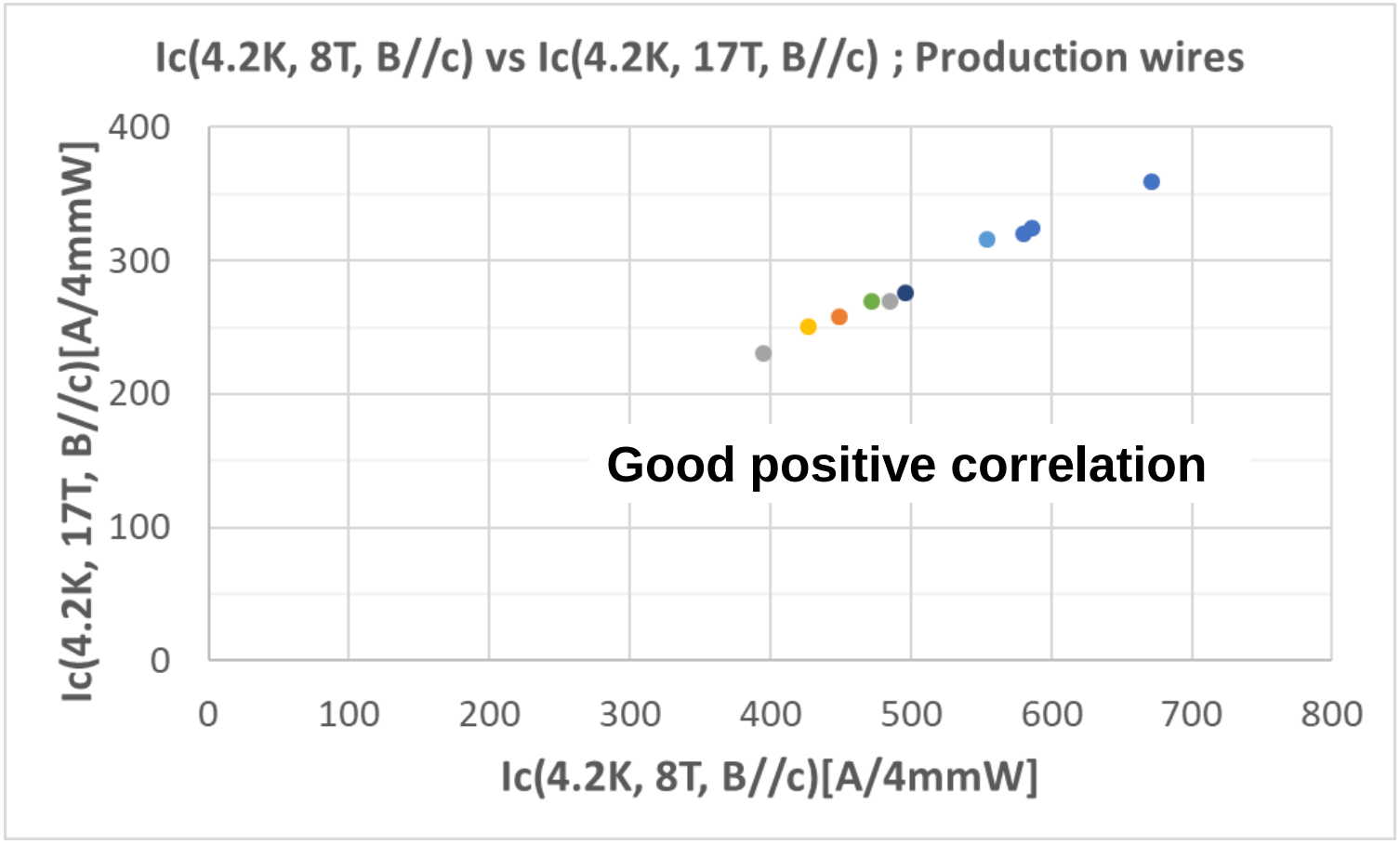
System at Furukawa Electric Co.,Ltd. (NIKKO)(4K-B)

- LHe cooled
- Field strength is up to 8T or 17T (depending on test magnet types)
- Field direction is fixed (B⊥Tape surface)
- ~1000A can be applied to a sample



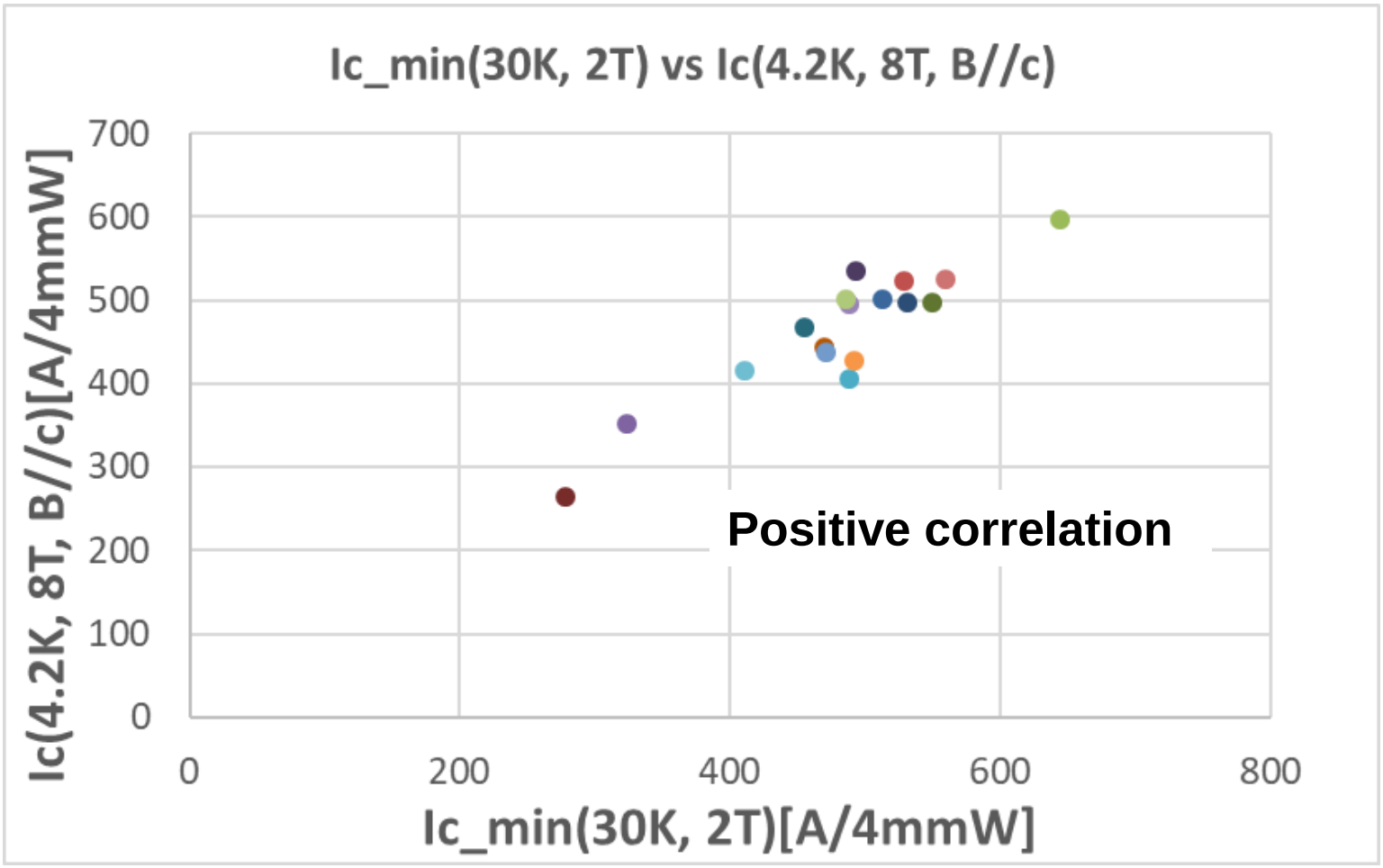
Measurement conditions to evaluate production wires

Currently we are choosing 30K-2T-Θ and 4K-8T(B//c) as representative measurement conditions to confirm the wire performances.

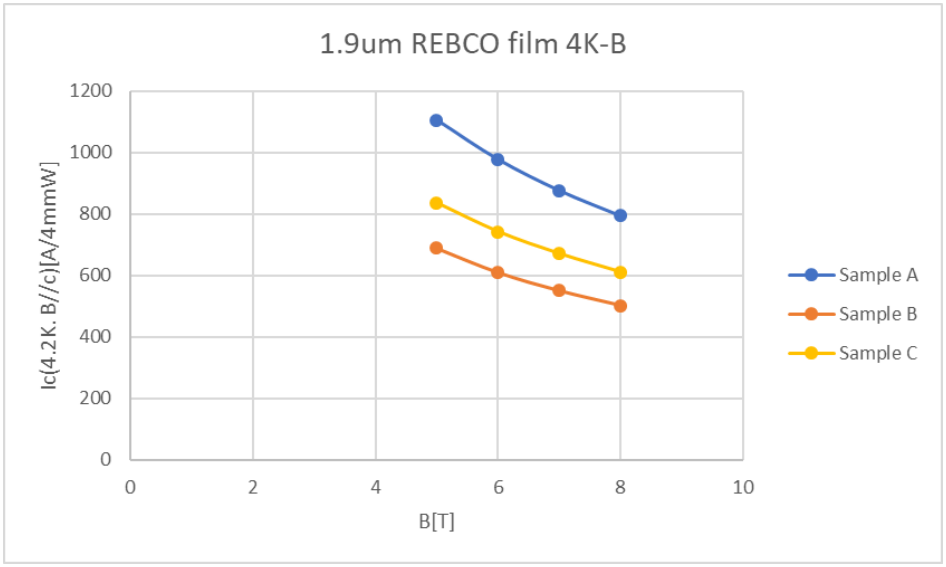


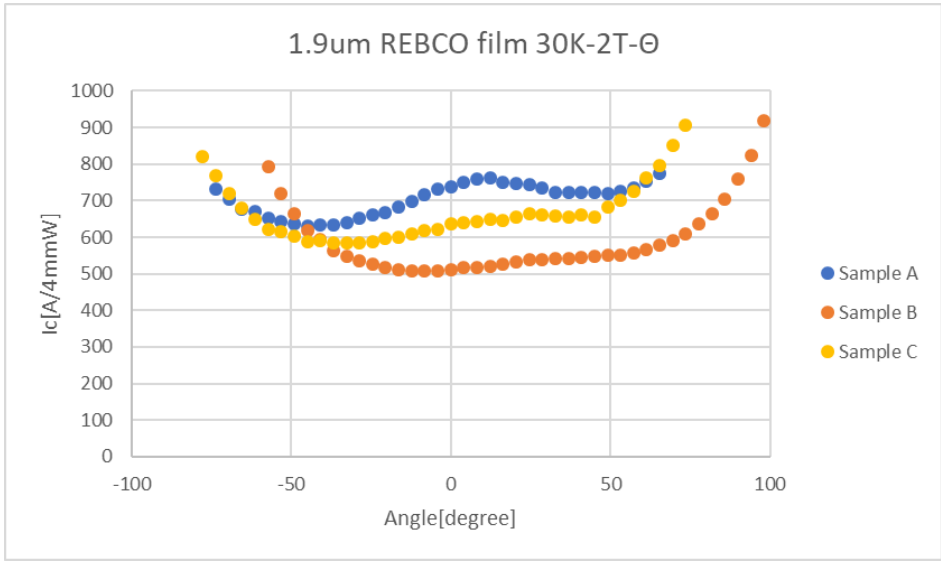
Measurement conditions to evaluate production wires

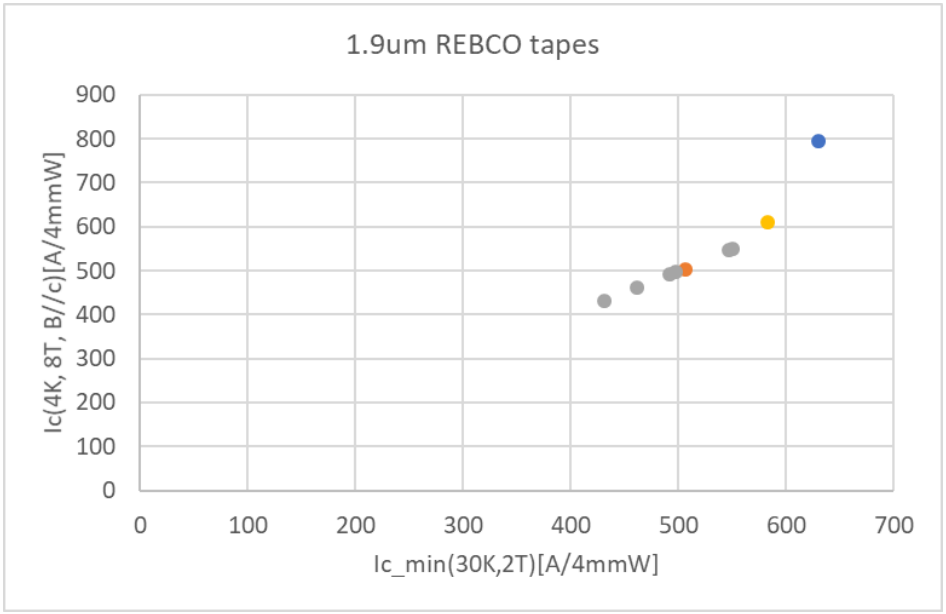
Correlation between Ic_min(30K,2T) and Ic(4K,8T, B⊥Tape surface)



Recent R&D ; Optimization for 1.9um REBCO film production

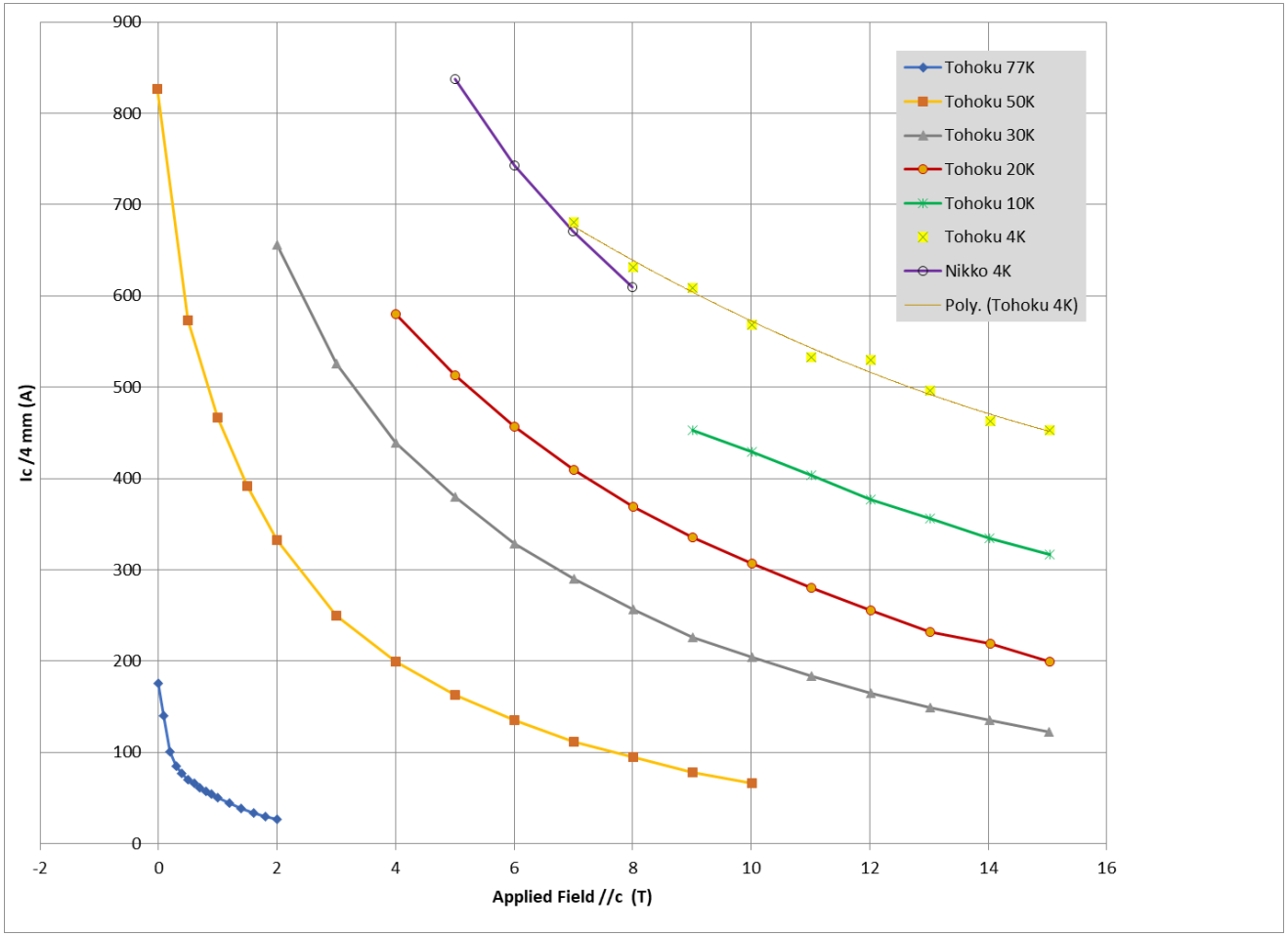




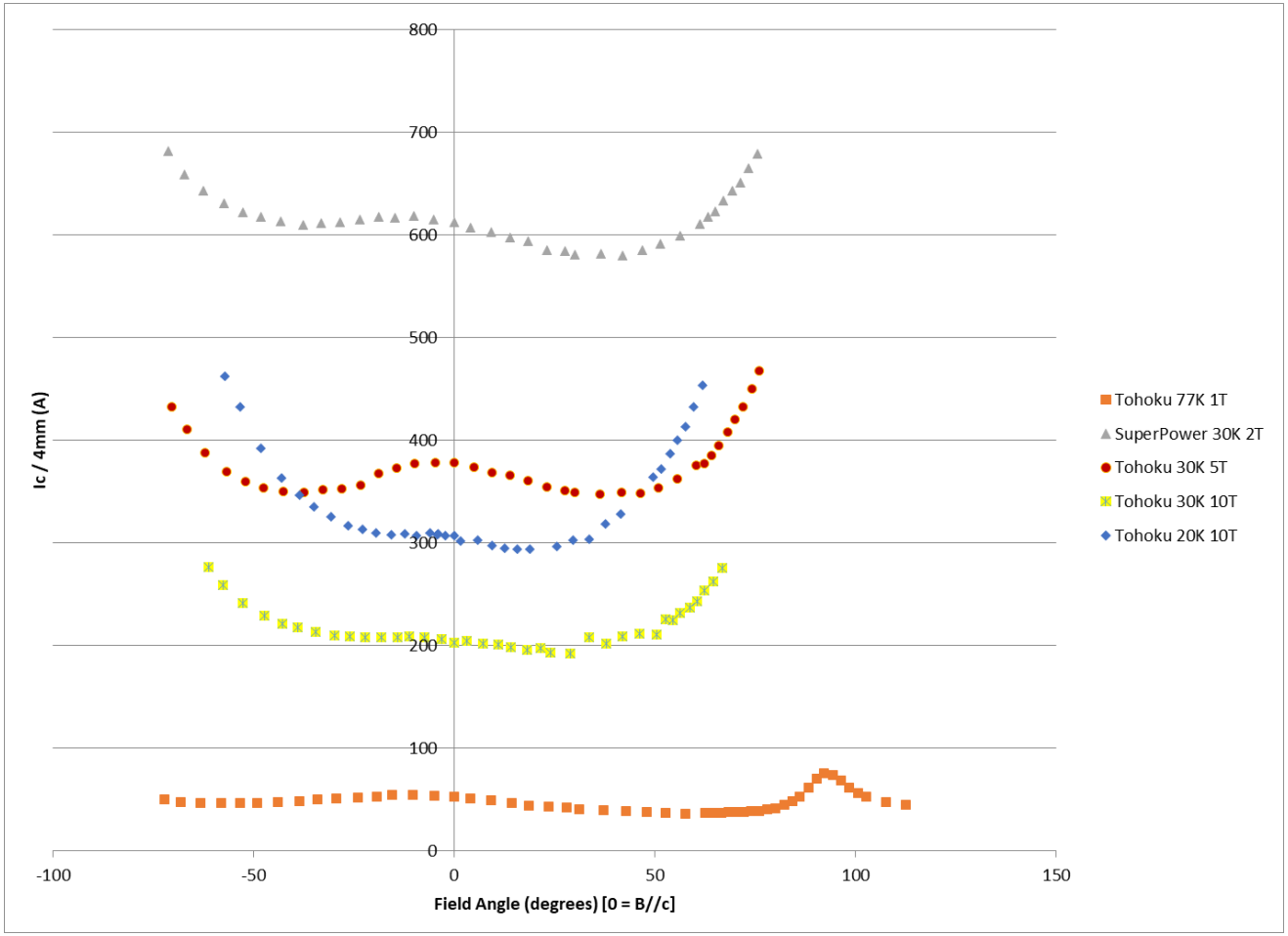


- Working on optimization for 1.9um production.
- Directions to improve In-field performance noted.
- Confirmed good correlation between Ic(30K, 2T, min) and Ic(4.2K, 8T, B//c).

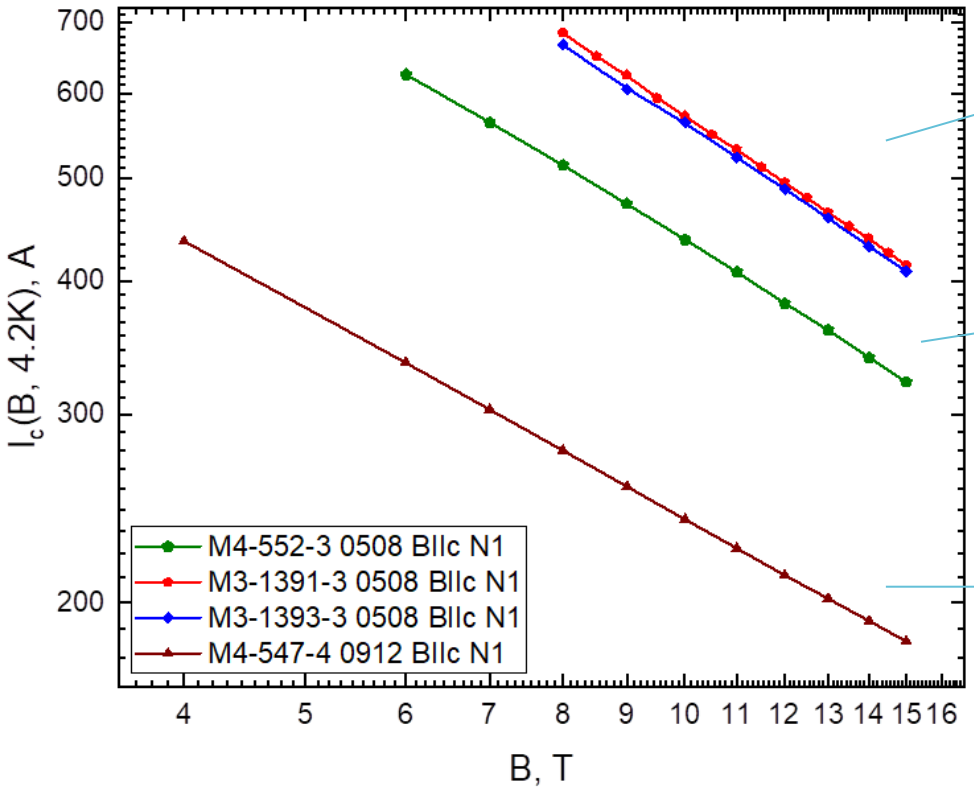
Production trial M4-508-4 0104 1.9 μm Ic vs. B, T



Production trial M4-508-4 0104 1.9 μm Ic, B, T,Θ



Recent NHMFL measurements on 1.9 um thick R&D tapes show excellent high field performance



1.9 um REBCO R&D trials optimized for high field

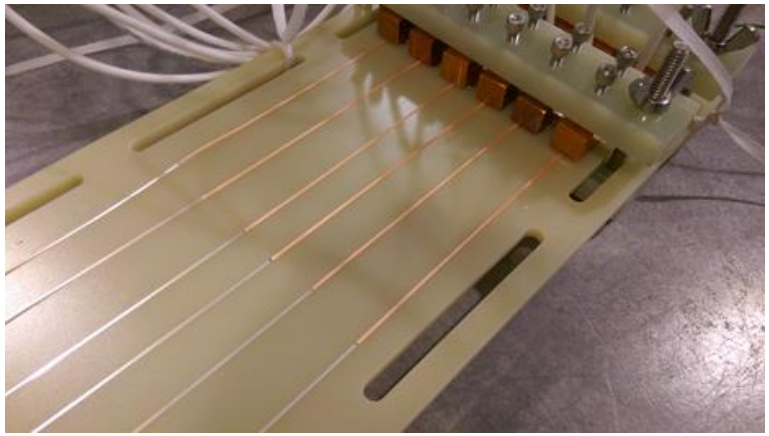
Standard 1.6 um REBCO optimized for high field

Standard 1.6 um REBCO not optimized for high field

Ongoing research initiatives

- Thinner substrates demonstrated
  - 25 μm process development demonstrated thru all production cells
- Narrower tapes (1.0, 1.5 mm) under development
  - More development work to do on slitting, tape handling and long length Ic measurement
- Process optimization windows for different operating conditions
  - High Ic at 77K, sf does not necessarily translate into high Ic at 4K, high field
- Thicker films (1.9 mm
- Solder coated tapes available

For use in higher Je cables (CORC, others)



Selective Cu plated 1mm tapes under Ic test

Relocation status

1/30/2020

Autumn 2020

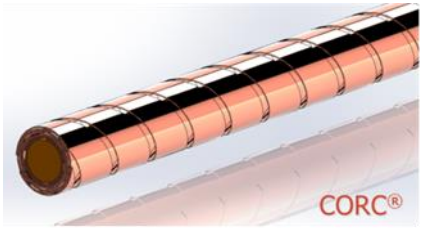
- Factory move now complete
- The factory space was available from Feb. 3, 2020. (Certificate of Occupancy)
- Equipment was fully moved over from old to new facility by end of May while coping with Covid-19 limitations.
- Production restart from middle of July, 2020.

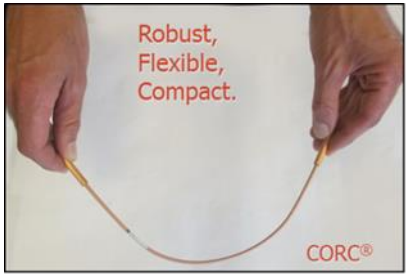
Production facility currently up and running with new equipment being brought online

Summary

- Strong focus on processing to improve uniformity, repeatability, piece lengths (currently up to 1 km) and yield.
- Maximize current capacity while implementing next generation equipment
  - Hardware and processing upgrades yielding benefits
  - Capacity upgrade underway
- R&D to enhance performance parameters for developing operating spaces
  - Thinner substrates
  - Narrower tapes
  - Optimized pinning

Ideal for cables such as CORC





- Further improve mechanical properties
  - Delamination mitigation demonstrated
- Ic (ε) with reinforcement
- Diverse market pull
  - Low temperature, high field
    - (Fusion, HEP, HF magnets)
  - Higher temperature, moderate field
    - Motors/generators
      - EERE NGEM (65K, 2-3 T)
    - Maglev
  - LN2 low field (Utility market)

Thank you for your attention