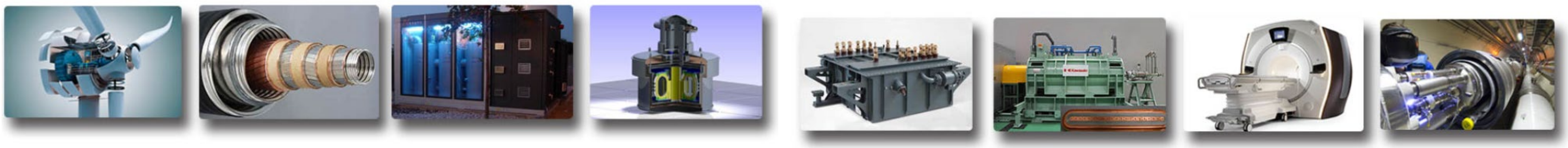

Process Innovations for High Temperature Superconducting (HTS) Wire Manufacturing

DE-EE0007871

Superconductor Technologies Inc., TECO-Westinghouse, & M.I.T.

6/1/2017-9/30/2020

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Superconductor Technologies Inc.

U.S. DOE Advanced Manufacturing Office Program Review Meeting

Washington, D.C.

June 12, 2019

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Title: Process Innovations for High Temperature Superconducting (HTS) Wire Manufacturing

Timeline:

Project Start Date: 06/01/2017

Budget Period#1 End Date: 09/30/2018

Budget Period#2 Start Date: (TBD)

Project End Date: 09/30/2020

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$4,497,115	$1,124,279	$5,621,394	20.00%
Budget (BP-1&2)	$3,803,979	$950,995	$4,754,974	20.00%
Costs as of 3/31/19	$2,120,857	$530,214	$2,651,071	20.00%

Barriers and Challenges:

- Quantity of process runs for Ic improvement. Failures & process tuning when trying new things
- 77K vs. 65K cryogenic electrical, magnetic metrology, & mechanical testing
- In-Situ (vacuum & 800oC) metrology for ReBaCuO compositional controls is extremely difficult. Yields are sensitive to <1%Atomic composition shifts.

AMO MYPP Connection:

Next Generation Electric Machines

Project Team and Roles:

Superconductor Technologies Inc:

Lead-R&D to enhance superconducting wire, new manufacturing techniques & metrology.

TECO-Westinghouse:

Commercial Partner-Wire specifications, Electric machine design, magnetic field analysis, testing & qualification.

M.I.T.:

R&D Partner- 2G HTS superconducting wire metrology & cryogenic/HTS applications engineering

Project Objective(s) – Start Year #2

<u>Annual USA energy savings >6,000 GWh</u>

Use of High Temperature Superconductor (2G HTS) wires in large (Mwatt) motors and generators can reduce U.S. annual electricity consumption by 0.2% @ >96% efficiency

<u>(3)-Year Program OBJECTIVES:</u>

#1: *Improve 2G High Temperature Superconducting (HTS) wire performance & Mfg.*

Start: 180A/cm-width (65K, 1.5T) → Goal: 1440A/cm-width Ic_{min} , 65K/1.5 Tesla

Use renewable Liquid Nitrogen as 65K cryo-coolant.

#2: *Reduce manufactured costs of 2G HTS wires with better; Ic, yield, & process controls*

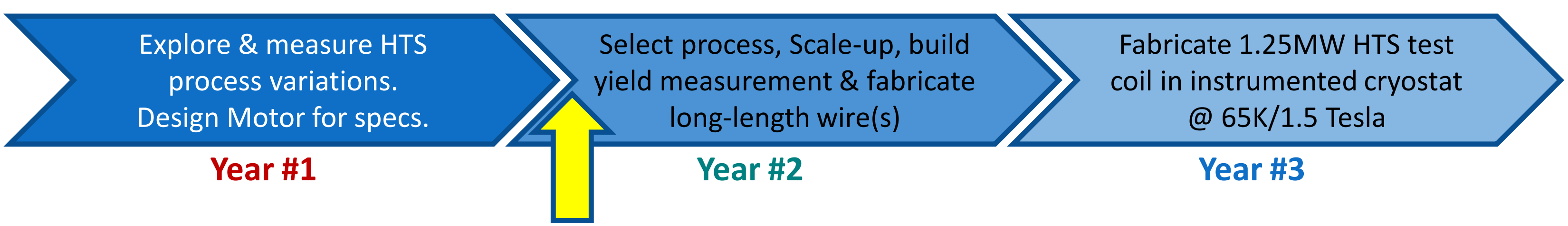
Cost/performance EQUAL to -or- BETTER than copper magnet wire.

Doubling yields @200-meter lengths, and/or reducing components costs by 50%

#3: *Demonstrate HTS progress in a >1.25MW motor test coil @ 1.5T/65K*

<u>Challenge Areas:</u>

- Thin film stack: Growing & measuring each HTS combination & comparing to best performers.
- High-Yield: New mfg. techniques must work for high-performance & long-length HTS Wires
- In **B**-Field 65K Cryo Measurements: Slow measurement feedback slows-down process feedback
- Demonstration Project: Multiple competencies required to build/test motor coil w/ enhanced HTS wires.
  {Electrical, Mechanical, Magnetic, Thermal/Cryogenics, Software}



Technical Innovation

Copper (incumbent magnet wire) vs. HTS

-HTS has Higher Performance, yet with much higher costs

-HTS enables new machines & new technologies;

Smaller, Higher Power & Field (Tesla), more Efficient

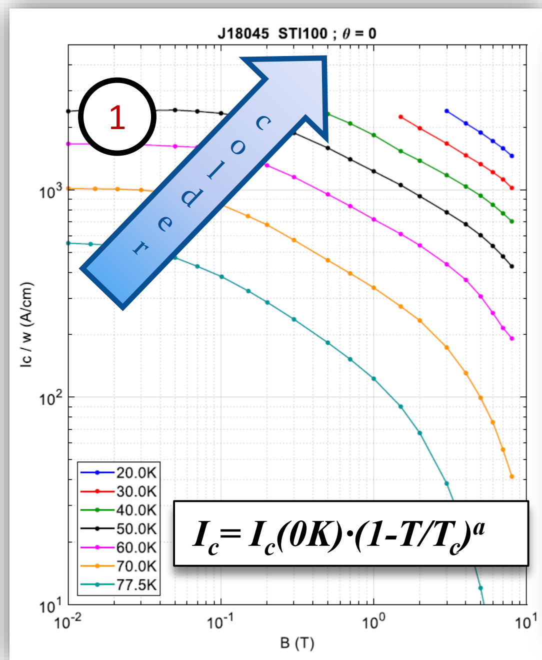
	CONDUCTUS® Superconducting Wire	Conventional Copper
Capacity	100X Greater	Low
Efficiency	Extremely High	Poor - Signifigant Heat Loss
Size, Weight	Compact, Light Weight	Large and Heavy
Economics	Improving	Static, Limited
Design	Enabling New Devices	Limited

(4) Levers to improve HTS Cost/Performance Ratio

Lower Temperature

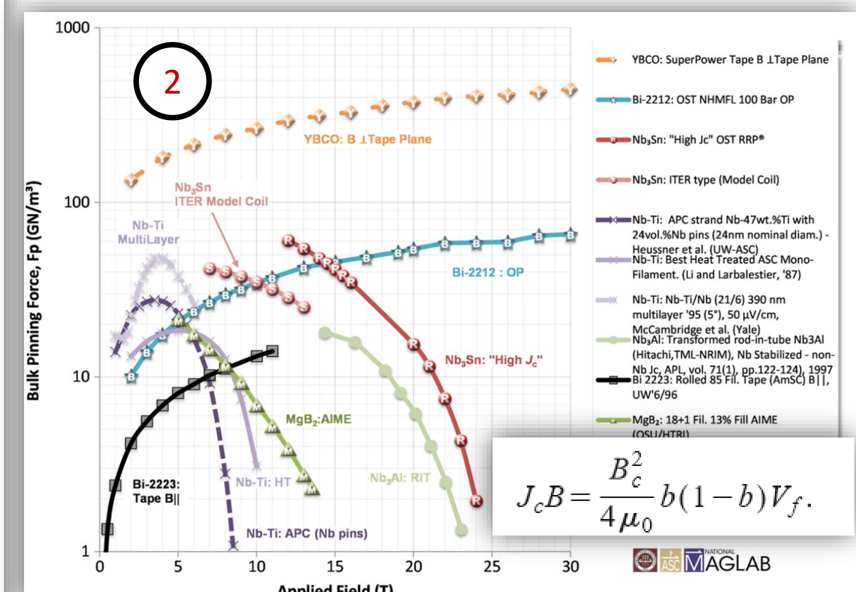
Raises current-carrying capacity

65K Liquid Nitrogen lower limit



Increasing Pinning Forces:

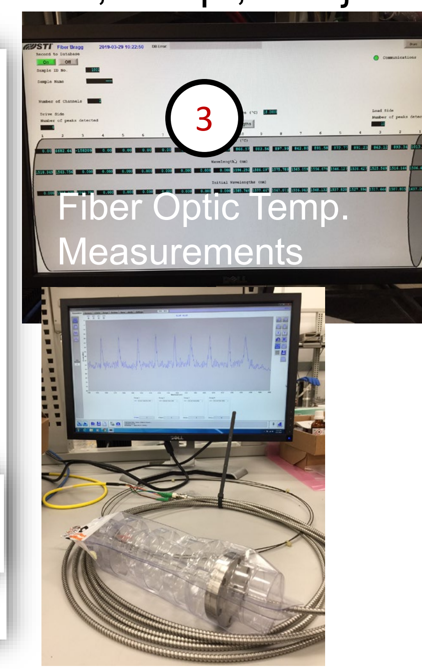
Lowers in B-Field thermal (Lorentz) losses but also disrupts crystal lattice & can lower Ic.



https://nationalmaglab.org/magnet-development/appliedsuperconductivitycenter/plots#ybco

Increase Mfg. Yield:

Improve process Controls {In-Situ, Temp., Flux}



Technical Approach

(4) Levers to enhance HTS Cost/Performance Ratio:

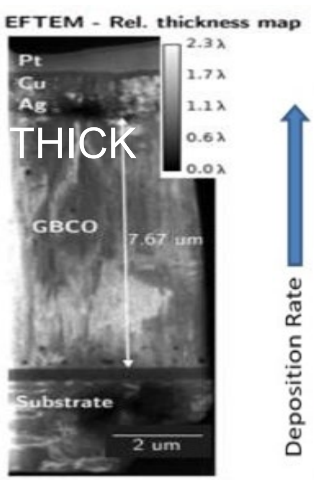
1. Ic Lift vs. Temperature (composition control)
2. Increase Pinning forces w/ minimal lattice distortion (an optimization for 1.5T/65K)
3. Increase Mfg. Yields (process controls, run-to-run yield enhancement)

(4) Combined enhancement of 2G HTS: $Re_1Ba_2Cu_3O_{7-d}$

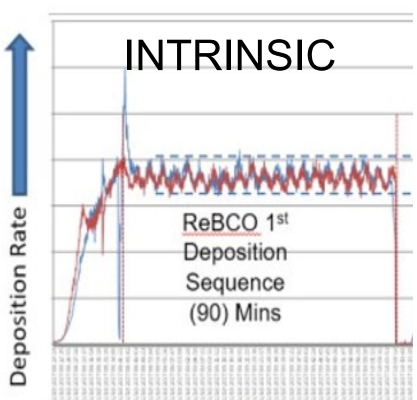
a. Increased Film Thickness (2→7 μm)
b. Intrinsic Pinning (gradient concentrations of Re/Ba/Cu atoms)
c. Extrinsic Pinning (add dopants; Zr, Hf, others)
d. Insertion of Superlattices

STI®

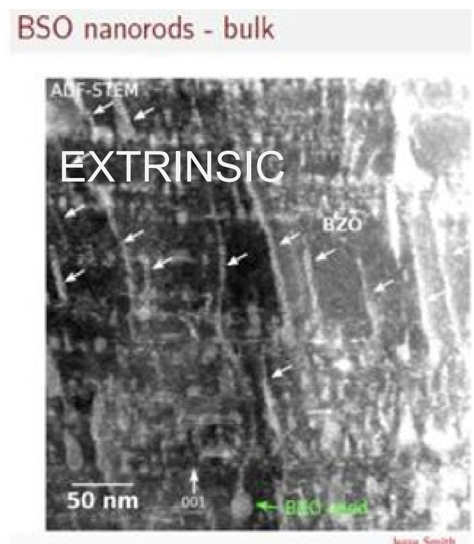
a. X-section Area
b. Diffusion
c. Column Defects
d. Planes



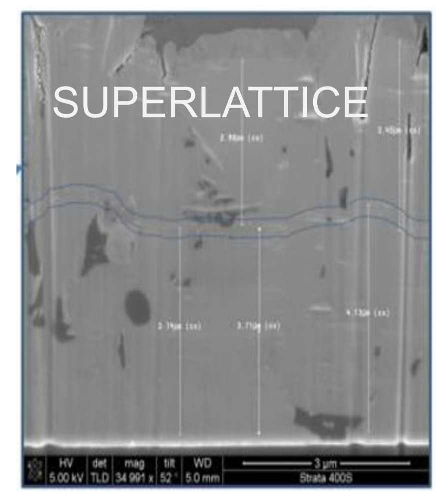
a. Increased Area (μm^2)



b. Controlled Gradients Re/Ba/Cu elements

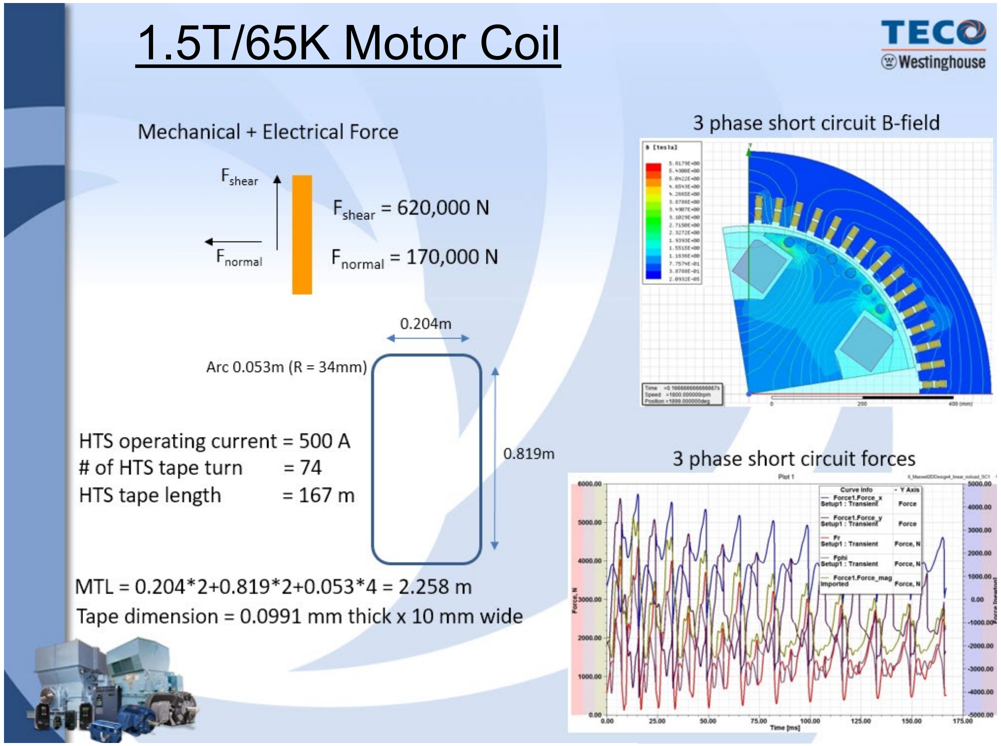


c. Adding dopants



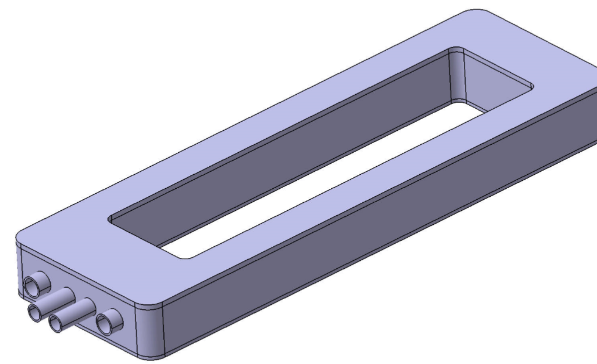
d. Adding ‘reset’ layers for fixed pinning planes

Technical Approach

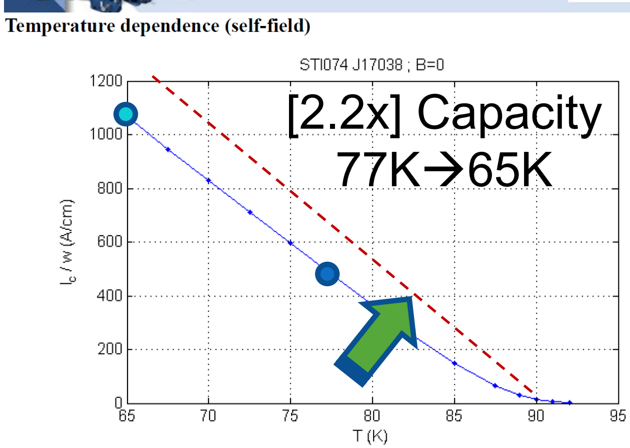


Motor Coil Analyses Completed:

Electrical: s.s. & transient short-ckt.
Magnetic: Motor torque
Mechanical: thermal (cte), Lorentz



Motor Pole Coil in Cryostat

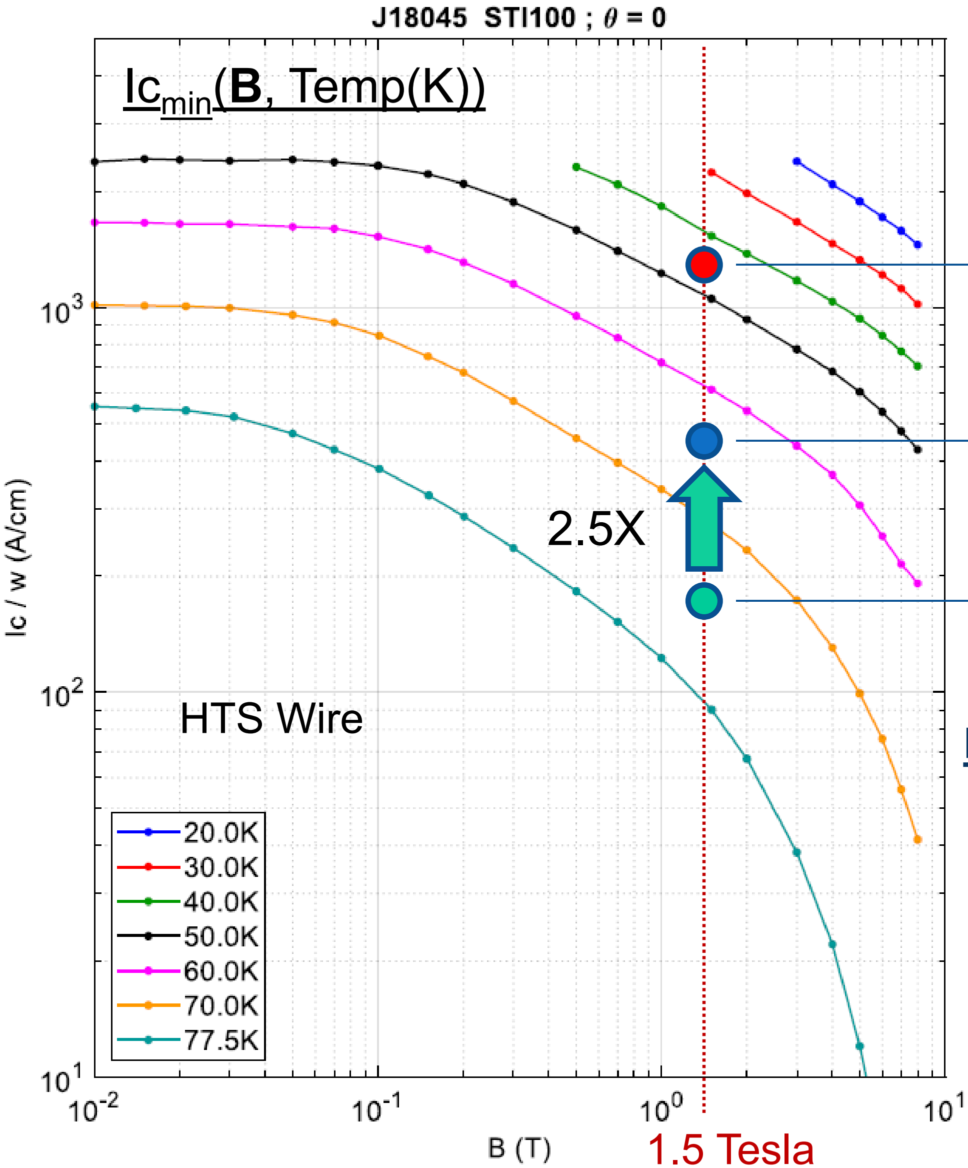


Enhancing Thermal Lift:
Composition Controls
<1% Atomic

Massachusetts Institute of Technology

- Cryogenic engineering
- Coil winding
- Instrumentation
- HTS metrology

Results and Accomplishments



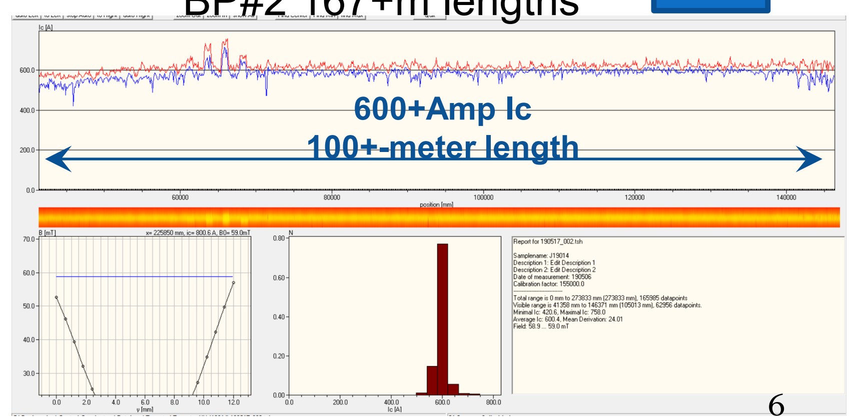
1440 A/cm @ 65K, 1.5T — GOAL: BP#3 End

470 A/cm @ 65K, 1.5T — NOW: BP#1 Ended

180 A/cm @ 65K, 1.5T — START: of Program

LENGTH: BP#1 (2x) 15m lengths
BP#2 167+m lengths

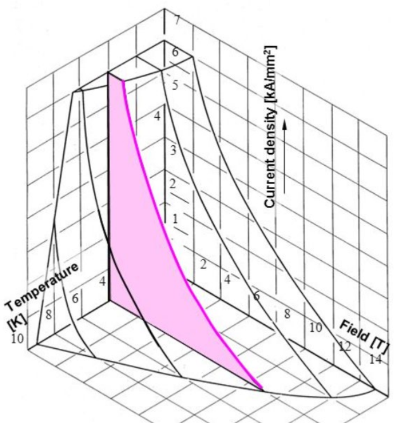
10X



Transition

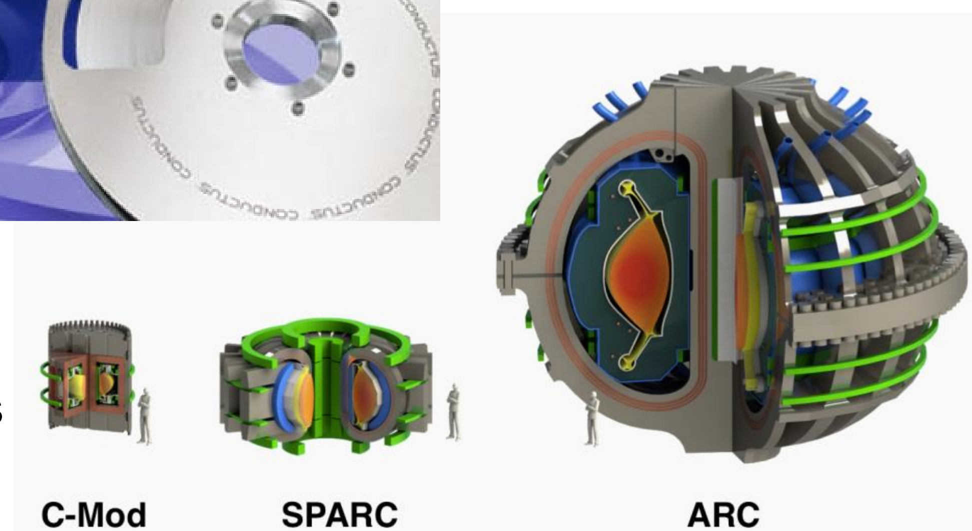
TECO-Westinghouse:
Commercial partner for Next Gen electric machines
Active participant in this program.

Reel-to-Reel In-Field Metrology:
- Per Wire Spec Sheet (dataset)
- Defines minimum performance Ic_{min} (B, Angle, Temp) vs. Length (mm)



Critical surface plot Vs. Reel Position

Future Work:
Higher B-field applications
-Scientific (accelerator, NMR) Magnets
-Fusion containment electromagnets



https://qz.com/1402282/in-search-of-clean-energy-investments-in-nuclear-fusion-startups-are-heating-up/

Questions?

Thanks for your time, attention, the opportunity to continue 2G HTS wire development

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