



Magnet Technology Advances at CFS

Workshop on ultra-high-field solenoids

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Commonwealth Fusion Systems

Agenda



- Quick introduction to Commonwealth Fusion Systems (CFS)
- Overview of CFS magnet technologies
- Overview of CFS HTS magnet capabilities
 - Magnet design
 - Magnet manufacturing
 - Magnet testing
 - Magnet integration
- CFS public knowledge disclosures
- Questions and potential next steps



Quick Introduction to CFS

- CFS was founded in 2018, spinning out of MIT with the goal of commercializing fusion energy
- CFS' approach to commercial fusion was to build a high field compact tokamak
 - To accomplish this, CFS always planned to use high temperature superconducting (HTS) magnets
 - CFS believes that tokamaks represent the surest path to a commercially relevant fusion device
- CFS is now a leading private fusion company
 - CFS has raised approximately **\$3B** of private capital from investors
 - The CFS team has grown to over **1000** folks supporting a broad range activities from magnet R&D to integrated power project development
- CFS is building **SPARC**, a proof-of-concept fusion gain device outside Boston expected to demonstrate net gain in 2027
- CFS has done early work developing **ARC**, its first commercial power plant in Virginia, which it hopes to deploy in the early 2030s



SPARC TFMC 2021 – Previously World's Largest Highest Field Pure HTS Magnet (20T)

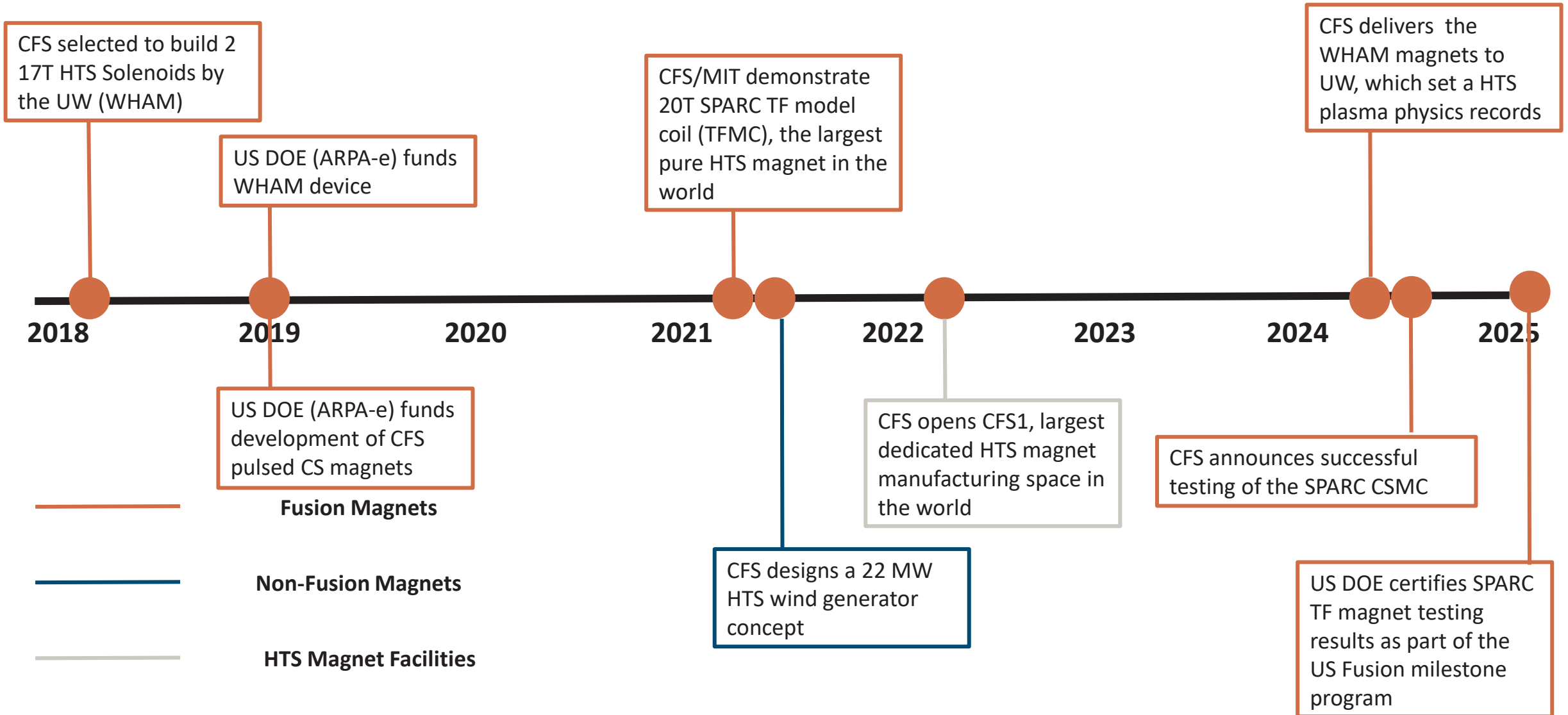


SPARC TF Assembly Line



Time of CFS' HTS Magnet Activities

- CFS has been developing HTS magnet technology for almost 10 years



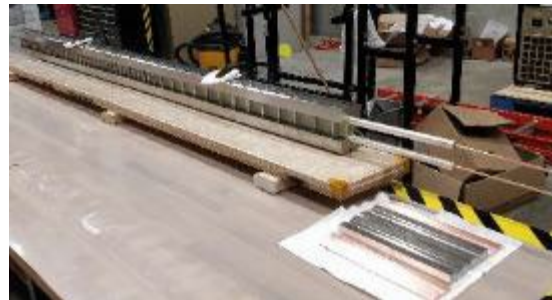
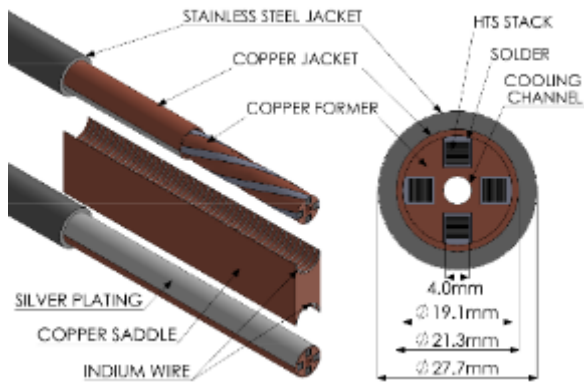


CFS Works With Non-Insulated and Cable Magnets

Starting in 2017, both technologies were built on HTS magnet work pioneered at MIT

VIPER/PIT-VIPER HTS cables

- Based on traditional SC CICC cables using the TSTC architecture for REBCO tapes [1]
- Demonstrated high $I \times B$ robustness, fiber optic quench detection, $\sim n\Omega$ joints [2,3]
- Developed for *multiple* SPARC applications:
 - **High current FEED cables**
 - **AC magnets: SPARC CS, PF -> The CSMC**



VIPER SULTAN assembly (2018)

[1] M. Takayasu *et al.*, IEEE Trans. Appl. Sup., **21** (2011) 2340
 [2] Z. S. Hartwig *et al.*, SuST, **33** (2020) 11LT01
 [3] E. E. Salazar *et al.*, SuST, **34** (2021) 035027
 [4] Sanabria *et al.* SuSt, **37** (2024) 115010

No Insulation No Twist (NINT) Coils

- HTS cable-based adaptation of single tape NI coils [4] with innovations to enable large-scale fusion magnets
- Advanced EM modeling capabilities, low voltage operation
- Developed for a *specific* SPARC application:
 - **DC magnet: SPARC TF magnet -> The TFMC**

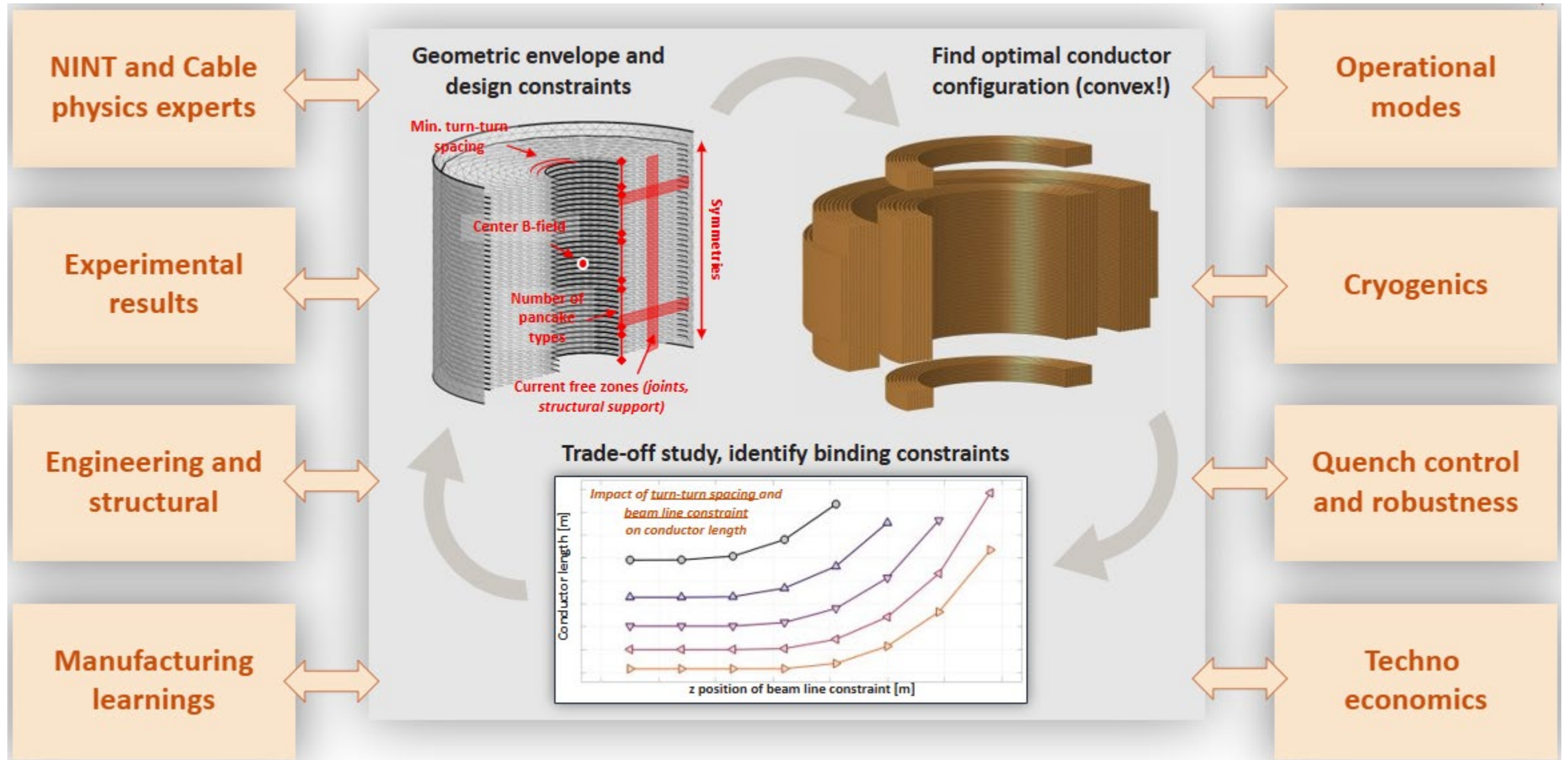


EM simulation of a NINT coil

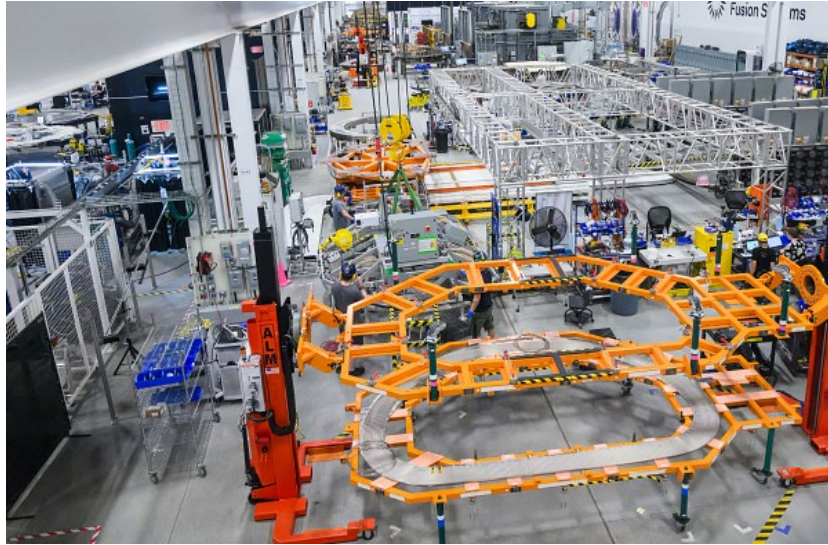


[5] S. Hahn *et al.*, IEEE Trans. Appl. Sup., **21** (2011) 1592
 [6] Z. S. Hartwig *et al.*, "The SPARC toroidal field model coil program," IEEE Trans. Appl. Supercond., early access, Nov. 13, 2023, doi: 10.1109/TASC.2023.3332613.

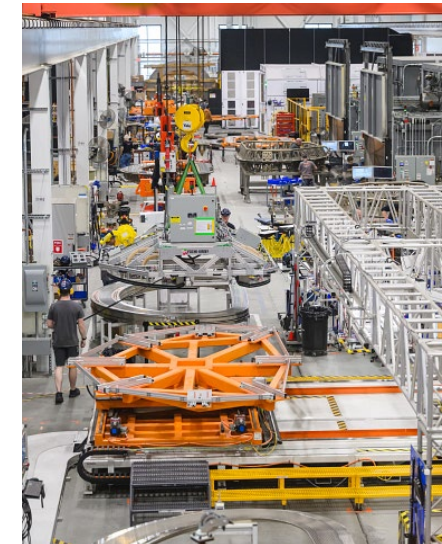
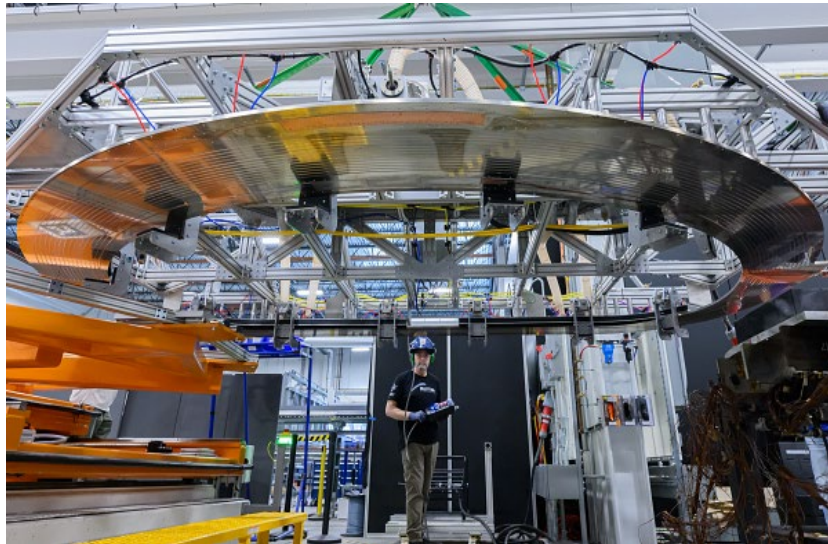
CFS Has HTS Design Tools That Leverage its Experience



CFS Has the Largest HTS Magnet Manufacturing Facility



- CFS has 108k square feet of HTS magnet manufacturing space today, a magnet facility at scale needed to make the next generation muon collider magnets
- **CFS has processed 10,000 km of HTS tape, of which over 7,000 km are already in magnets**
- We currently operate 24/7 building and testing fusion magnets; Our factory is fully supported by an integrated organization (procurement, logistics, quality, etc.)



CFS Magnet Factory is Used to Build HTS Magnets at Scale



- CFS is building MJs worth of fusion magnets each week
 - 2 – 4 m radii, 10s of tons each
- CFS is building magnets with very high stored energy
 - The WHAM solenoids are **3.2 MJ** each
 - SPARC TF magnet system will be **6 GJ**





CFS Can and Does Test HTS Magnets

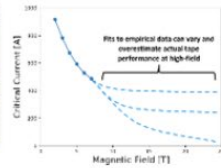
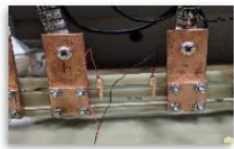
- For SPARC, CFS is characterizing all HTS tapes, testing multiple subassemblies and every finished magnet system
 - **We have done A LOT of testing over the last 8 years**
- This provides CFS a unique insight into the performance of HTS magnet systems
- To support this level of testing, CFS has had to scale its own internal testing operations
 - CFS has two full scale cryostat test stands capable of testing all CFS magnets

2x Magnet Test Stands	
Operating temperature	20 K
Operating current	50 kA
TF Coil tests	18
PF Coil tests	8
CS Coil tests	6
5x Subassembly Test Stands	
Operating temperature	77 K
Operating current	10 - 16 kA
TF Pancake tests	288
PF/CS Cable tests	140
FEED Cable tests	33

Tape Level

Component Level

Sub-scale Magnet Level



HTS tape I_c characterization and extrapolating to SPARC conditions



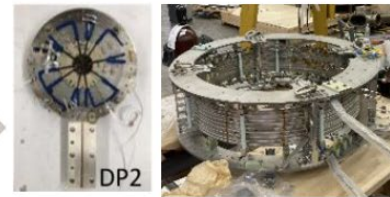
Testing turn insulation under SPARC loads



Testing turn insulation under SPARC loads



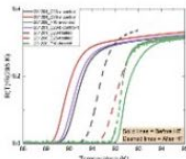
In-situ I_c test with transverse compression



Quench testing of sub-scale NINT and cable magnets



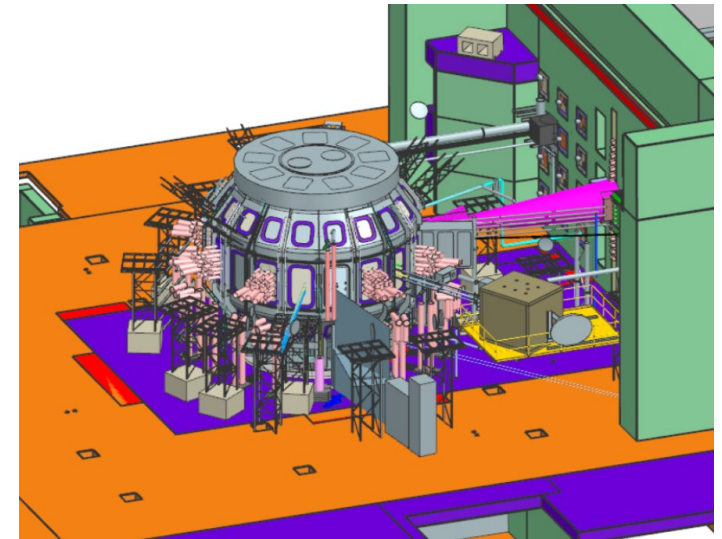
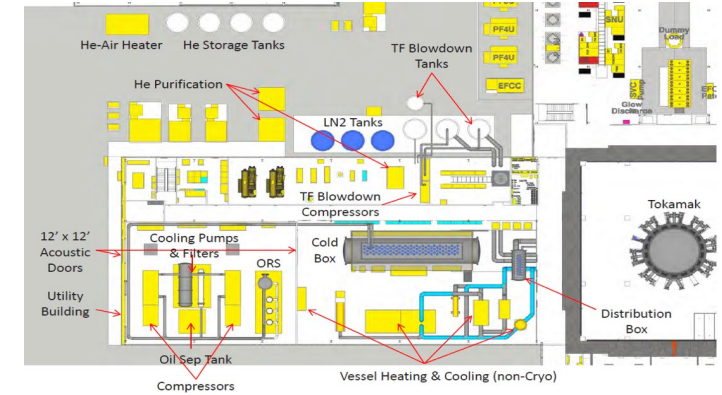
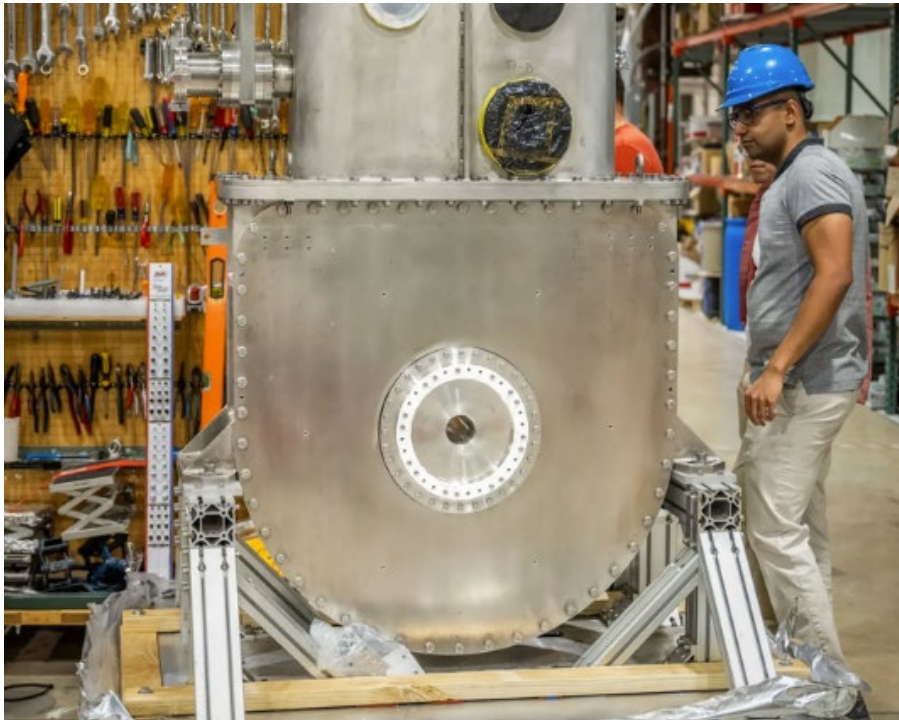
Early HTS tape heat treatment test rig and evolved tape heat treatment results



CFS Builds Integrated Systems, Not Just the Magnets



- CFS magnets are fully integrated with quench detection, controls, power supplies, cryogenics, and structural support
- For engagements with customers, we want to partner at the system level, where we can help integrate a full magnet system, including auxiliaries and structures, into a full device





CFS Public Knowledge Disclosures

- The capabilities that CFS has developed are derived from its staff of magnet technologists and engineers
- Our technologists often present at both fusion and magnet focused conferences (MT, ASC, SOFE, EUCAS, APS)
- Recently CFS has presented papers on the following topics:
 - HTS Characterization
 - SPARC Central Solenoid Model Coil Program (Pulsed HTS model magnet)
 - Quench Detection and Response
 - HTS Cable Manufacturing
 - Development of HTS Magnet Testing Programs





Questions and Next Steps

- CFS is interested in finding ways to support the Muon Collider
 - **This brief presentation focused on our capabilities and CFS has an active magnet business group open to providing these capabilities to other parties**
- We have HTS magnet capabilities that can support several different work scopes (design, build, test, etc.)
- CFS has an active fusion roadmap that we are executing against, we will continue to improve our capabilities
 - ARC magnet development will begin shortly, bigger magnets, more stored energy
 - **CFS (and many other fusion and non-fusion concepts) have an interest in improving HTS conductors and HTS magnet technology to drive to better performing fusion and non-fusion devices**
- We have already built solenoids with performance similar to some of the muon collider cooling channel specs (WHAM)

- Thank you and Questions