# COMMONWEALTH FUSION SYSTEMS' HIGH-FIELD PATH TO FUSION ENERGY

[1]D. BRUNNER FOR THE TFMC, SPARC, AND ARC TEAMS

[1]Commonwealth Fusion Systems, Devens, MA, USA

Email: dan@cfs.energy

Commonwealth Fusion Systems (CFS) has demonstrated high-field superconducting magnets at the performance and scale needed for fusion energy, has raised over $2B in private capital, is building a high-field tokamak to demonstrate net energy, and is laying the technical foundations for a fusion industry. This paper will cover CFS' achievements to date and its plans for getting to a fusion pilot plant.

CFS, in collaboration with the MIT Plasma Science and Fusion Center, built and operated the Toroidal Field Model Coil (TFMC), a 20.3 T magnet with high-temperature superconductor (HTS) in the summer of 2021 [1]. HTS, in contrast to the low-temperature superconductors (LTS) being used in ITER and other major superconducting tokamaks, can go to much higher magnetic fields, allowing for smaller machines that have lower capital cost and shorter construction times. The mission of the TFMC (Fig. 1) was to retire the major risks in using HTS in fusion-relevant magnets, including developing scalable manufacturing techniques, standing up a reliable HTS supply chain, and engineering relevant cryogenic coolant, current leads, and structural support of the immense forces. While smaller HTS magnets have been operated at comparable fields, the TFMC was ~100 times larger in size and stored magnetic energy (110 MJ). The TFMC was brought up to full performance on its first test run, Fig. 2, demonstrating the great potential of the new technology. The initial magnet R&D behind the TFMC was carried out in 12 months and the TFMC went from a "blank sheet" through design, manufacturing, assembly, and testing in only 27 months.



Figure 1 TFMC being assembled in its test stand at MIT.

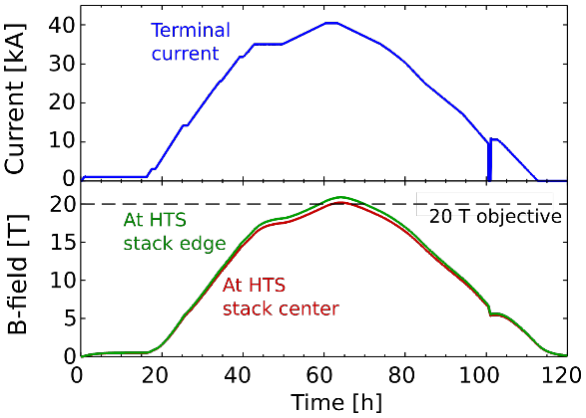



Figure 2 Top: Time-trace of the TFMC terminal current. Bottom: Calculation of the peak magnetic field on the superconductor in the TFMC based on magnetic sensors.

In parallel with the TFMC program, CFS and its collaborators developed the conceptual design for SPARC, a compact ($R_0$=1.85 m), high-field ($B_0$=12.2 T) deuterium-tritium burning tokamak, to use the TFMC magnet technology. The physics basis for SPARC was published [2,3] demonstrating that the machine could achieve a scientific gain of Q=11 using the same conservative assumptions as ITER (i.e., $H_{98}$=1.0 in ELMy H-mode), giving confidence that it can meet its mission of Q>1 with margin. The empirical performance predictions were backed up by first-principles modeling indicating similar levels of gain [4]. SPARC will be heated with 25 MW of ICRF at 120 MHz, ensuring there's enough power to enter into H-mode in deuterium plasmas. The small size results in short current relaxation times and short total pulse length (~10 s); this enables SPARC to operate with an inertially-cooled tungsten



Figure 3 The CFS campus in Devens, MA, with the SPARC facility in the foreground and the engineering offices and magnet factory in the background; the latter of which were moved into in December 2022.

divertor. The SPARC team is aiming for first plasma in mid-2025 with a sprint to demonstrate Q>1 as soon as possible thereafter. Subsequent experimental campaigns will focus on raising the machine performance to higher power and higher gain to study and retire risks for high-field tokamak fusion, including burning plasmas and high-power exhaust in advanced divertors. The SPARC facility is presently being constructed at the CFS campus in Devens, MA (Fig. 3). The concrete pour for the tokamak hall is complete and the majority of the support buildings have been erected. Purchase orders are out for over one third of the SPARC equipment and CFS is ramping up to produce the HTS magnets for SPARC (Fig. 4).

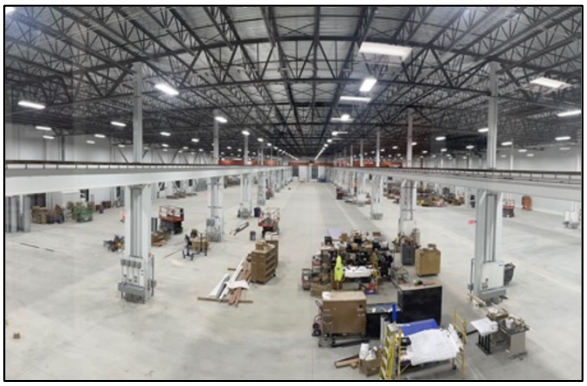


Figure 4 Interior of the CFS Magnet Factory being prepared to build the SPARC HTS magnets.

With SPARC well underway, CFS and its collaborators are laying the groundwork for the ARC fusion pilot plant. CFS' ARC concept has grown out of the ARC-class devices developed at MIT [5,6]. Like SPARC, it is a compact, high-field deuterium-tritium burning tokamak. However, ARC must be larger to include sufficient blanket to shield the HTS magnets, enabling an economic lifetime, and breed tritium. SPARC will be a critical part of the R&D for ARC, both demonstrating the HTS magnets integrated into a high-performance fusion machine as well as closing gaps in tokamak physics. CFS is ramping up R&D for ARC on systems not included in SPARC; including demountable HTS magnets, remote maintenance, fusion nuclear materials, high-temperature FLiBe molten salt, and high throughput tritium processing.

## ACKNOWLEDGEMENTS

Work supported by Commonwealth Fusion Systems. Parts of this work was funded under the INFUSE program – a DOE SC FES public-private partnership – and ARPA-E.

## REFERENCES

[1] HARTWIG, Z.S., et al. "Overview of the SPARC Toroidal Field Model Coil Project, presented at the Applied Superconductivity Conference", Honolulu, 2022.

[2] GREENWALD, M.., Status of the SPARC physics basis, J. Plasma Phys., 86(5) (2020) 861860501.

[3] CREELY, A.J., et al., Overview of the SPARC tokamak, J. Plasma Phys., 86(5) (2020) 865860502.

[4] RODRIGUEZ-FERNANDEZ, P., et al., Predictions of core plasma performance for the SPARC tokamak, J. Plasma Phys., 86(5), 865860503.

[5] SORBOM, B.N., et al., ARC: A compact, high-field fusion nuclear science facility and demonstration power plant with demountable magnets, Fusion Eng. Des., 100 (2015), 378-405.

[6] KUANG, A.Q., et al., Conceptual design study for heat exhaust management in the ARC fusion pilot plant, Fusion Eng. Des., 137 (2018) 221-242.