The Fork in the Road to Electric Power From Fusion

Commonwealth Fusion Systems (CFS)

Peter Lobner, 1 February 2021

Introduction

CFS was founded in 2017 in Cambridge, MA, as a commercial spinoff from the Massachusetts Institute of Technology's (MIT) Plasma Science and Fusion Center. With Bob Mumgaard as CEO, CFS's goal is to leverage decades of MIT's fusion-related research into a near-term, compact commercial fusion power plant financed largely by the private sector and public-private partnerships. The CFS website is here: https://cfs.energy/technology

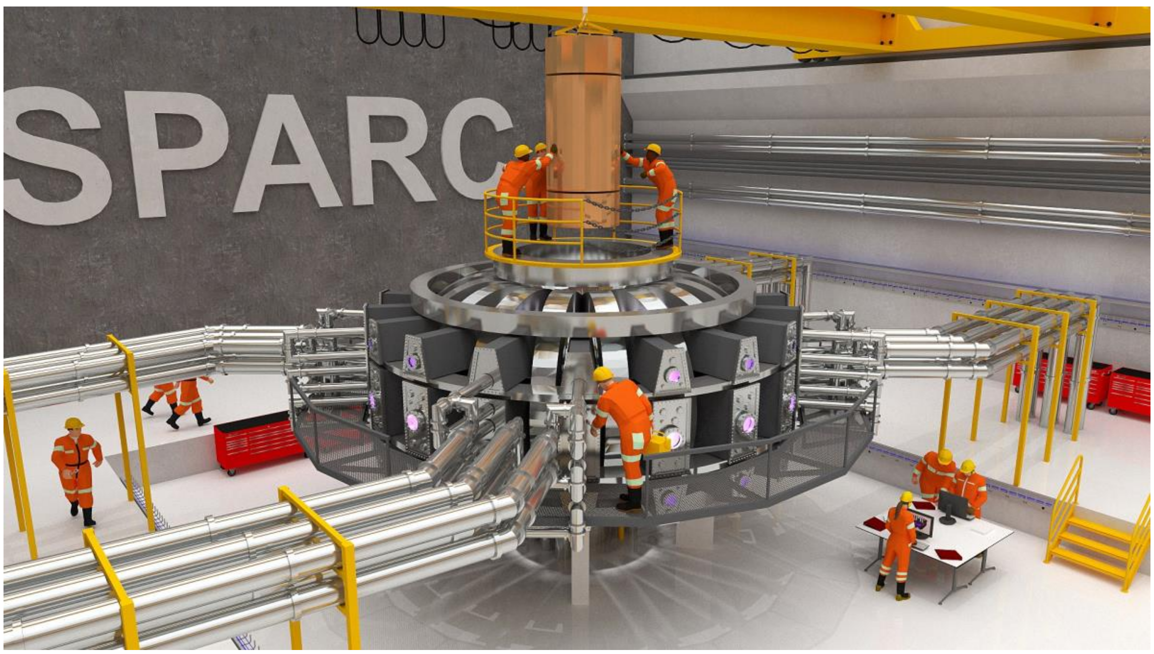
CFS builds on operational experience with MIT's Alcator C-Mod tokamak fusion machine and recent advances in the development of high-temperature superconductors (HTS), specifically a rare-earth (yttrium)-barium-copper oxide (ReBCO or YBCO) superconducting tape that can operate at 90 °K (-297 °F), which is above the temperature of liquid nitrogen (77 °K; −320 °F). Use of the HTS tape to produce magnets and other components will enable stronger magnetic confinement fields in a more compact fusion machine.

In 2021, CFS and MIT expect to test a full-scale demonstration HTS magnet with a field strength of 20 Tesla. The magnet is a key component of their SPARC tokamak net fusion energy experimental machine, which CFS and MIT will begin constructing later in 2021.

SPARC (Soonest / smallest Private-funded Affordable Robust Compact) tokamak

SPARC will be a pulsed D-T fusion compact tokamak, intended to produce a fusion reaction with a net energy gain (Q > 1.0) after it begins operation in 2025. SPARC's performance goal is to achieve at least Q = 2.0 and fusion power of about 50 MWt. Many peer-reviewed papers published in 2020 supported the SPARC design and some suggested that a higher net energy gain may be possible, perhaps even reaching the ITER performance target of Q ≥ 10. SPARC will have cooling systems to remove heat generated from operation, but it will not have a power conversion system for generating electricity from fusion energy.

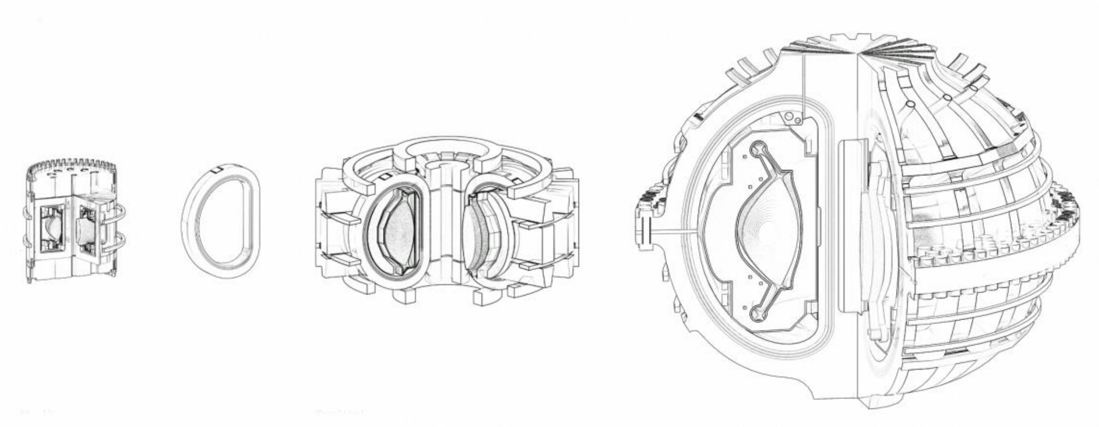
CFS estimates that SPARC will cost about $400 million. Dale Meade, former deputy director of the Princeton Plasma Physics Laboratory (PPPL), has expressed skepticism of the CFS cost and schedule estimates for SPARC. Based on his experience with PPPL's D-T burning Tokamak Fusion Test Reactor (TFTR), Mead suggested a SPARC cost in the range of $1.5 – 2.0 billion and readiness for tritium experiments possibly in 2033.



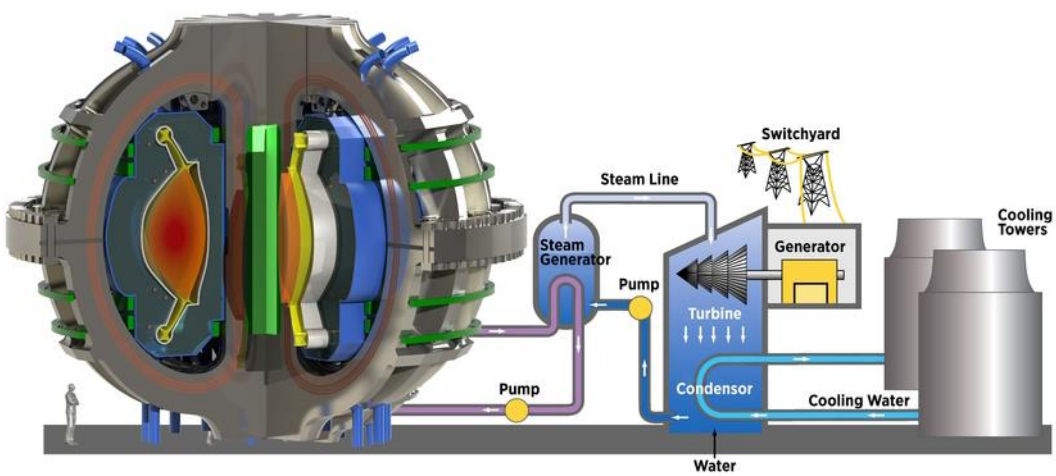
CAD concept drawing of SPARC. Source: Ken Filar via HandWiki

ARC (Affordable, Robust, Compact) tokamak

After SPARC, CFS plans to construct the considerably larger ARC fusion power plant, which will have a fusion power rating of about 500 MWt and a power conversion system for delivering 200 MWe electric power to the grid. ARC also will have tritium breeding and extraction systems, which are needed for a sustainable fuel cycle in a D-T fusion machine.



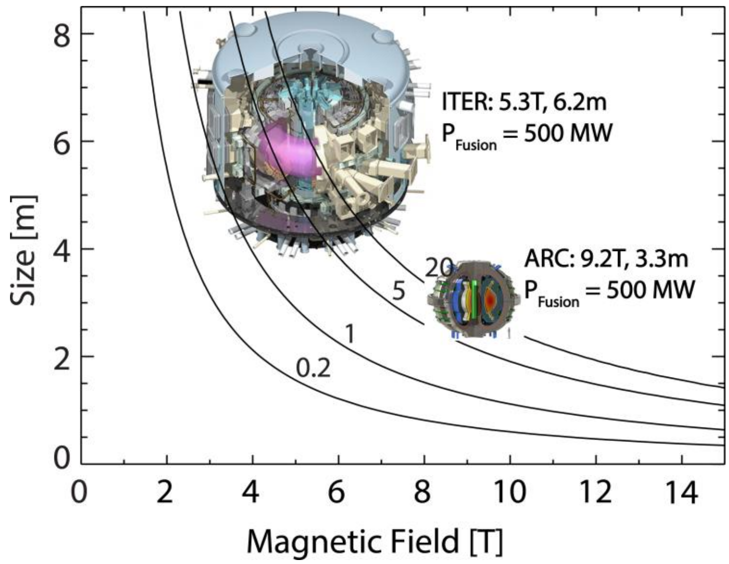
Relative scale: Alcator-Mod C (left), HTS demo magnet & SPARC (middle), ARC (right). Source. Adapted from CFS



CFS ARC fusion power plant concept drawing showing the addition of a steam and power conversion system for generating electricity. Source: MIT News

ARC (Affordable, Robust, Compact) tokamak

A 2019 paper by Martin Greenwald describes the relationship of constant fusion gain ($Q = P_{fusion} / P_{input}$) to magnetic field strength (B) and the radius (R) of a tokamak device. As it turns out, Q is proportional to the product of B and R, so, for a constant gain, there is a tradeoff between the magnetic field strength and the size of the device. This can be seen in the comparison between the relative field strengths and sizes of ITER and ARC, which are drawn to scale in the following chart.



Contours of constant fusion gain (Q) plotted against magnetic field strength and device size: Source: Greenwald (2019)

CFS plans to start work on the ARC fusion power plant in 2025, with the first commercial system appearing in the early 2030s. This ARC prototype could become the world's first fusion power plant and play an important role in the development of future economically competitive fusion power plants.

Funding

In October 2020, *Physics Today* reported that CFS had raised about $200 million in funding for their fusion program.

There have been two big rounds of private and institutional investments:

- 2019: $115 million from a large group of investors, including Kolsla Ventures, Breakthrough Energy Ventures (Bill Gates), Future Ventures, Lowercase Capital, Safar Partners, Schooner Capital, Moore Strategic Ventures, Starlight Ventures, Italian energy company ENI, and The Engine
- 2020: $84 million from Temasek and Equinor SA

In addition, CFS has received significant public-private partnership funding from the Department of Energy (DOE):

- A $2.39 million cooperative agreement awarded under the ARPA-E BETHE program in April 2020

- Eight projects awarded under the FES INFUSE program from 15 October 2019 to 3 December 2020.

CFS expects that a successful fusion demonstration with SPARC will attract investments from utility companies to finance the follow-on electricity-generating ARC fusion power plant.

For more information

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- Peter Dunn, "On the right path to fusion energy," MIT News, 21 December 2018: https://news.mit.edu/2018/nas-report-right-path-fusion-energy-1221
- Martin Greenwald, "Fusion Energy: Research at the Crossroads," Joule, 3, pp. 1172 – 1179, 15 May 2019: https://www.sciencedirect.com/science/article/pii/S2542435119301254
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- Leda Zimmerman, "Superconductor technology for smaller, sooner fusion - MIT-Commonwealth Fusion Systems demonstration of new superconducting cable is a key step on the high-field path to compact fusion," MIT News, 13 October 2020: https://news.mit.edu/2020/superconductor-technology-smaller-sooner-fusion-1013
- David Chandler, "Validating the physics behind the new MIT-designed fusion experiment," MIT News, 20 October 2020: https://news.mit.edu/2020/physics-fusion-studies-0929

- Poster, “Innovative Technology Pathways to Commercial Fusion Power,” CFS & MIT: https://arpa-e.energy.gov/sites/default/files/Soensen_MIT%20CFS.pdf

Videos

- “SPARC IAP Talk, January 14 2016” (56:14 minutes), MIT Plasma Science and Fusion Center, 2016: https://www.youtube.com/watch?v=fKREB8IvCbs
- “ARC: The Smaller, Faster, Cheaper Fusion Reactor” (4:14 minutes), MIT Plasma Science and Fusion Center, 29 October 2015: https://www.youtube.com/watch?v=4ao24BhgBKc
- “ARC — putting it together” (3:43 minutes), MIT Plasma Science and Fusion Center, September 2016: https://www.youtube.com/watch?v=efOlmF3wjJE