The Fork in the Road to Electric Power From Fusion

Tokamak Energy Ltd.

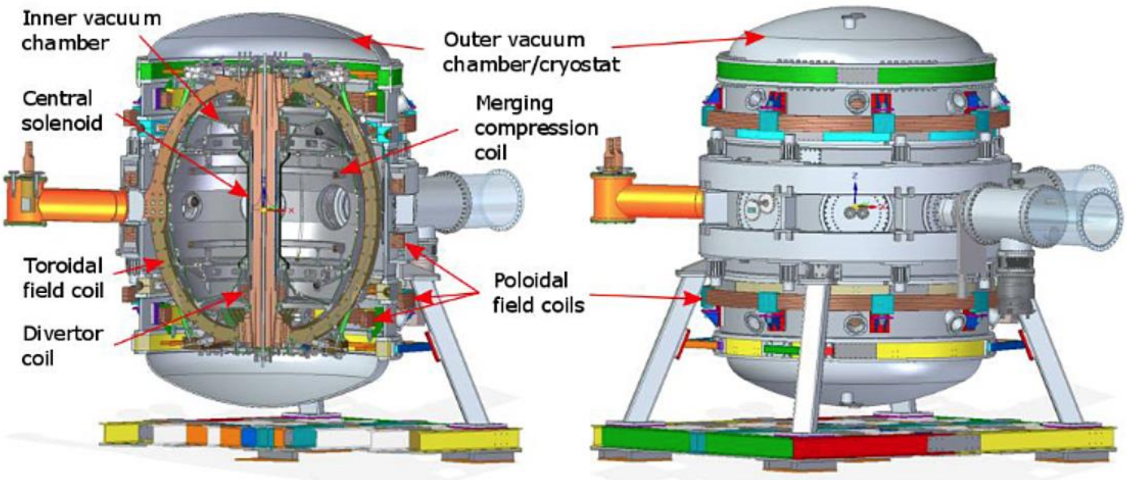
Peter Lobner, 1 February 2021

Tokamak Energy Ltd. (formerly Tokamak Solutions) is a private firm founded in 2009 in Milton Park, Oxfordshire, UK as a spinoff from the nearby Culham Center for Fusion Energy. Their current focus is on developing a scalable, high-field, compact spherical tokamak (ST) power reactor using high-temperature superconducting (HTS) magnets. The firm's website is here: https://www.tokamakenergy.co.uk

In 2013, Tokamak Energy built the ST25 as a proof-of-concept device with a 25 cm (10 inch) outside radius of the plasma. Rebuilt in 2015 with HTS magnets made from with yttrium-barium-copper oxide (YBCO) tape, the ST25 HTS became the world's first tokamak to operate exclusively with HTS magnets, which can operate at 77 °K, cooled by liquid nitrogen. Operating experience demonstrated better performance when the HTS magnets were cooled by liquid helium and operated at about 30 °K. The ST25 HTS demonstrated 29 hours of continuous hydrogen plasma during the Royal Society Summer Science Exhibition in London in 2015.

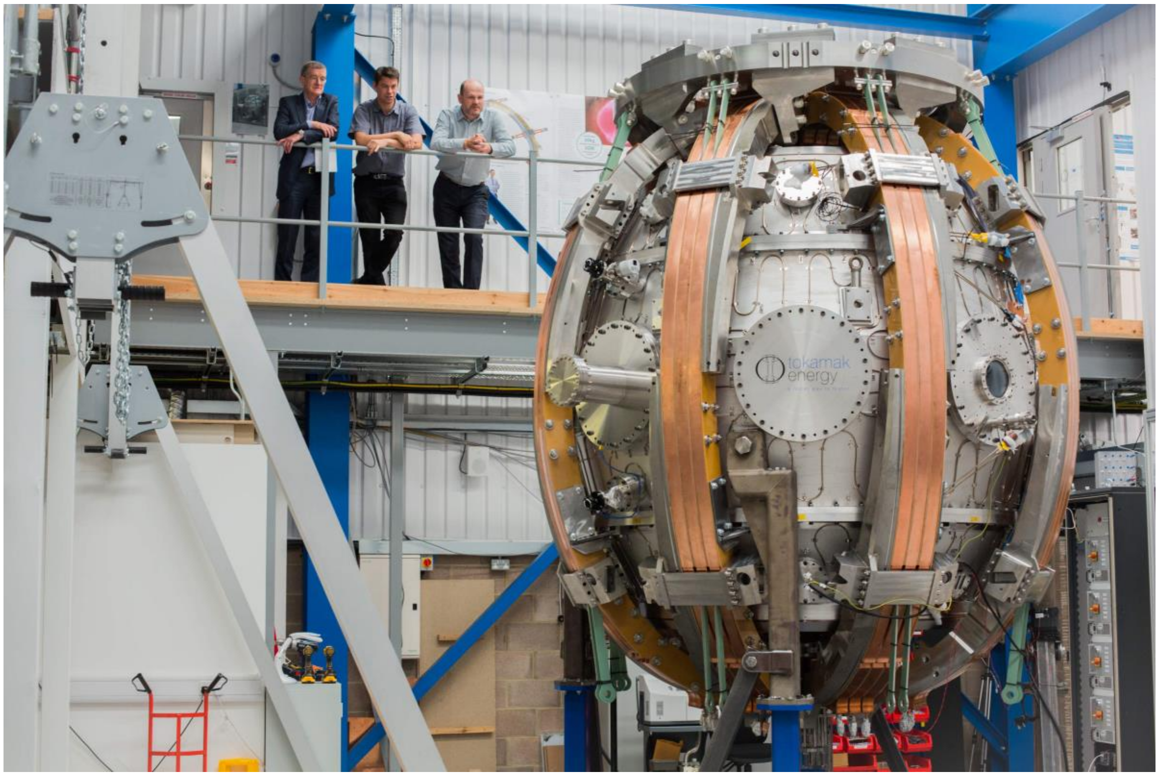
The ST25 in operation. Source: Tokamak Energy

Construction of their larger prototype, the ST40, with a 40 cm (15.7 in) plasma radius, began in 2016. This machine uses conventional copper magnets cooled to liquid nitrogen temperatures and operate at fields up to 3T. The ST40 started its first experimental campaign in January 2018. The ultimate goal for the ST40 is to reach a temperature of 100 million °C and to demonstrate a net energy gain from deuterium – tritium (D-T) fusion by 2025 in ST40.



Cutaway view (left) and outside view (right) of the ST40.
Source: M. Gryaznevich & O. Asunta (Feb 2017)

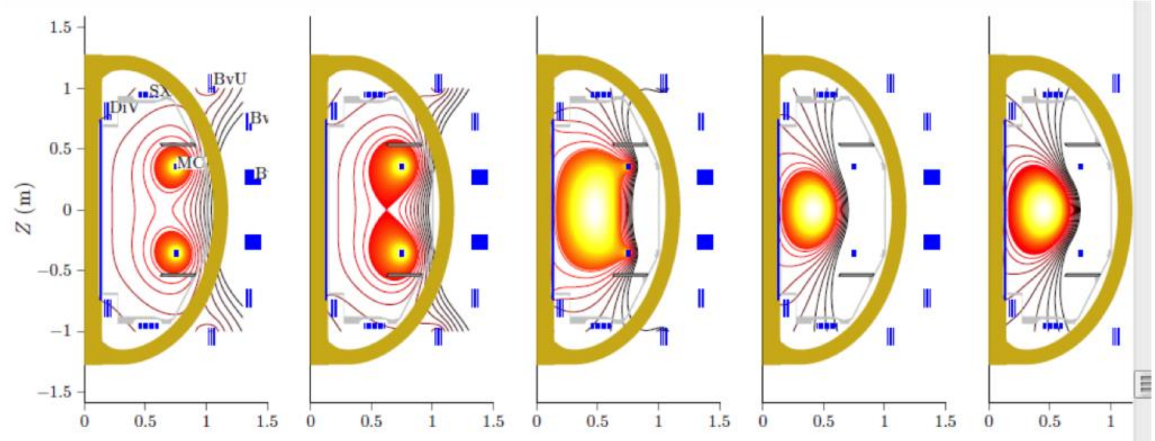
External view of the inner vacuum vessel for the ST40 spherical tokamak. Source: Tokamak Energy



External view of the partially assembled ST40 spherical tokamak. Source: Tokamak Energy

Tokamak Energy’s spherical tokamak uses a technique called “merging-compression” for enhanced plasma heating. They explain the process as follows:

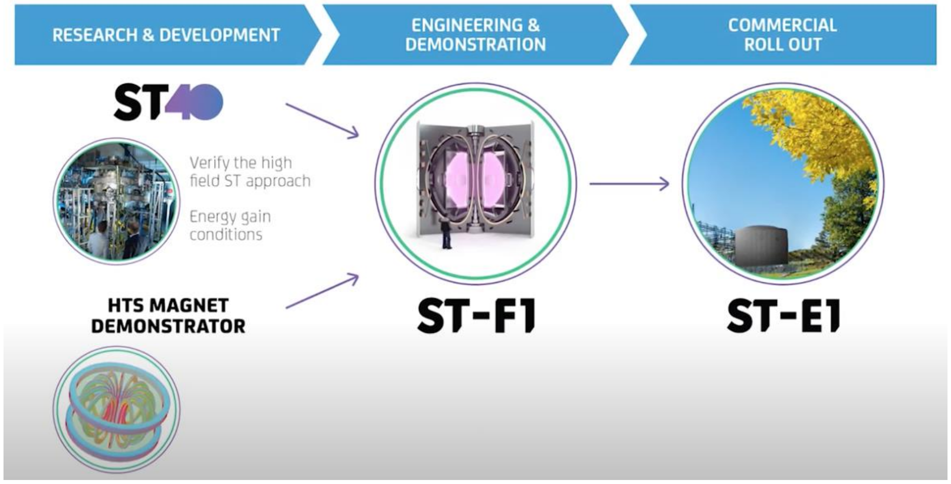
> “For merging compression, two symmetric magnet rings are constructed inside the torus chamber. Running high currents through these magnetic coils creates two rings of plasma around them, and as the coil current is reduced to zero the plasma rings attract and combine. When the rings combine, their magnetic fields reconfigure in a process called “reconnection”. Stretched field lines break and release huge amounts of energy, in the same way that a stretched catapult releases enough energy to launch a missile. This energy heats the plasma.”



Merging compression sequence from formation (left) to reconnection (middle) and final ST plasma (right). Source: Tokamak Energy.

In a 2015 paper, A.E. Costley examined the technical feasibility of small tokamaks and concluded that "lower power, smaller, and hence potentially lower cost, pilot plants and reactors than currently envisaged may be possible. The main parameters of a candidate low power (~180 MW), high Q fus (~5), relatively small (~1.35 m major radius) device are given." The paper provided an important validation of the physics behind Tokamak Energy's compact spherical tokamak concept.

Following success with the ST40 and the HTS magnet demonstrator, Tokamak Energy plans to develop the ST Pilot Plant (ST-F1) and then the Power Plant module (ST-E1), which will be designed to deliver about 150 MWe to the grid.



Source: Screenshot from "Tokamak Energy Update: August 2020,"

Funding

The UK Innovation & Science Seed (UKI2S) Fund was the founding investor in Tokamak Energy Ltd. In late 2020, UKI2S reported that Tokamak Energy Ltd. had raised £123 million (about USD $166 million) to date, on top of a recently awarded grant of £10 million (about USD $13.5 million) from the UK Department for Business, Energy & Industrial Strategy (BEIS) to advance work on their next generation device.

Under the US Department of Energy's (DOE) INFUSE program, TAE received three awards in 2019 and three more awards in two rounds of 2020 funding.

For more information

- A.E. Costley, et al., "On the power and size of tokamak fusion pilot plants and reactors," Nuclear Fusion, 55, 033001, 2015: https://www.researchgate.net/publication/271649804_On_the_power_and_size_of_tokamak_fusion_pilot_plants_and_reactors
- M. Gryaznevich & A. Sykes, "Merging-compression formation of high temperature tokamak plasma," Nuclear Fusion, 57, 072003, 2017: https://iopscience.iop.org/article/10.1088/1741-4326/aa4ffd/meta
- M. Gryaznevich & O. Asunta, "Overview and status of construction of ST40," Fusion Engineering and Design, 123, February 2017: https://www.researchgate.net/publication/315349402_Overview_and_status_of_construction_of_ST40
- David Kingham, "Spherical Tokamaks With High Temperature Superconducting Magnets," presentation to DOE ARPA-R, August 2017: https://arpa-e.energy.gov/sites/default/files/2_KINGHAM.pdf
- A. Sykes, et al., "Compact fusion energy based on the spherical tokamak," Nuclear Fusion, 58, 016039, 29 November 2017: https://iopscience.iop.org/article/10.1088/1741-4326/aa8c8d
- M. Gryaznevich, et al., "Faster fusion: ST40, engineering, commissioning, first results," AIP Conference Proceedings,

2019, 26 November 2019: https://aip.scitation.org/doi/pdf/10.1063/1.5135481
- "Merging compression," Tokamak Energy: http://www.100milliondegrees.com/merging-compression/

Videos

- "Ten years of Tokamak Energy: the rapid progress of a private fusion company" (18:13 minutes), Tokamak Energy, 17 June 2020: https://www.youtube.com/watch?v=hWYnbYsp3i8&feature=emb_title
- "The Holy Grail of Clean Energy" (9:04 minutes), Bloomberg, 2019: https://www.youtube.com/watch?v=l50ZUdGeRlI

Patents

- Patent WO2011/154717A1, "Compact fusion reactor," filed 26 May 2011, published 15 December 2011: https://patents.google.com/patent/WO2011154717A1/en?oq=tokamak+energy
- Patent WO2016/009176A1, "Shielding materials for fusion reactors," filed 7 July 2015, published 21 January 2016: https://patents.google.com/patent/WO2016009176A1/en?oq=tokamak+energy
- Patent EP2752099A1, "Efficient compact fusion reactor," filed 24 August 2012, granted 5 July 2017: https://patents.google.com/patent/EP2752099A1/en?oq=tokamak+energy
- WO2015/036749A1, "Toroidal field coil for use in a fusion reactor," filed 10 September 2014, published 19 March 2015: https://patents.google.com/patent/WO2015036749A1/en?oq=tokamak+energy