The Fork in the Road to Electric Power From Fusion

Zap Energy

Peter Lobner, 1 February 2021

Zap Energy was founded by Benj Conway, Brian Nelson, and Uri Shumlak in 2017 in Seattle, WA, as a commercial spin out from the FuZE (Fusion Z-pinch Experiment) research team at the University of Washington (UW). This spin out was aided by seed money from Strong Atomics, a venture fund managed by Malcom Handley. Zap Energy and UW are collaborating on the development of a sheared flow stabilized (SFS) Z-pinch fusion reactor.

The Department of Energy's (DOE) Advanced Research Project Agency – Energy (ARPA-E) reported the following history related to the Zap Energy spin out from UW:

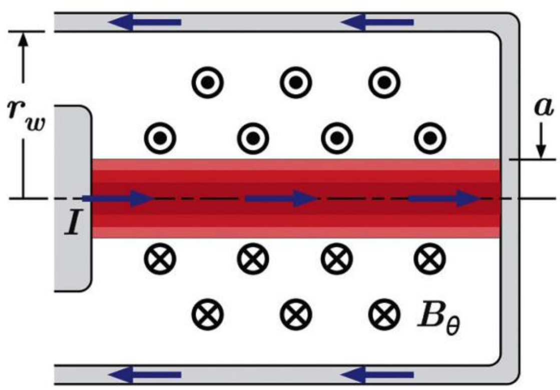
> "Prior to spinning out, the FuZE team received funding from several U.S. Department of Energy programs, dating back to 1998. While the FuZE team had been working on the science of plasma stabilization of their fusion concept for decades, ARPA-E began supporting the FuZE team in 2015 on advancing the fusion performance of their concept, as part of the Accelerating Low-Cost Plasma Heating and Assembly (ALPHA) program."
>
> "Through ALPHA, the University of Washington received $6M in funding to advance the performance of the sheared flow stabilized (SFS) Z-Pinch approach for simultaneously heating, confining, and compressing plasma by applying an intense, pulsed electrical current that generates a magnetic field. Their design simplifies the engineering required for a fusion system through a reduced number of components and increased efficiency, thus enabling research to progress faster through lower costs and more rapid experimentation."
>
> "The FuZE team at the University of Washington was one of the most successful performers in ALPHA, and in 2017 spun out to create a new private fusion startup Zap Energy."

The Zap Energy website is here: https://www.zapenergyinc.com

SFS Z-pinch basics

Z pinch is one of the simplest configurations for a controlled fusion machine. This approach does not require magnetic coils or any external heating systems other than the source to drive a powerful electrical current.

Following is a schematic diagram showing a simple Z-pinch machine at equilibrium. The machine is comprised of two electrodes (the gray center electrode and a surrounding can), a conducting gas, and a powerful current source. A large axial current (I) is driven between the two electrodes along a plasma column, producing an azimuthal magnetic field B_θ, which radially compresses the plasma to a smaller radius (a) where the magnetic pressure gradient balances the Lorentz force. With sufficient current, the compressed plasma can be heated to fusion conditions. The current loop is completed by an electrical return path through the surrounding wall (the can of the Z-pinch machine) located at radius r_w from the centerline of the machine.



Simple Z-pinch schematic. Source: U. Shumlak (2020)

In the past, Z pinch has been troublesome because of fast growing instabilities that limited plasma lifetimes. In recent years, two notable solutions have been developed:

- SFS Z-pinch being developed by UW and Zap Energy
- Staged Z-pinch (SZP) being developed by the University of California Irvine and Magneto-Inertial Fusion Technologies, Inc. (MIFTI).

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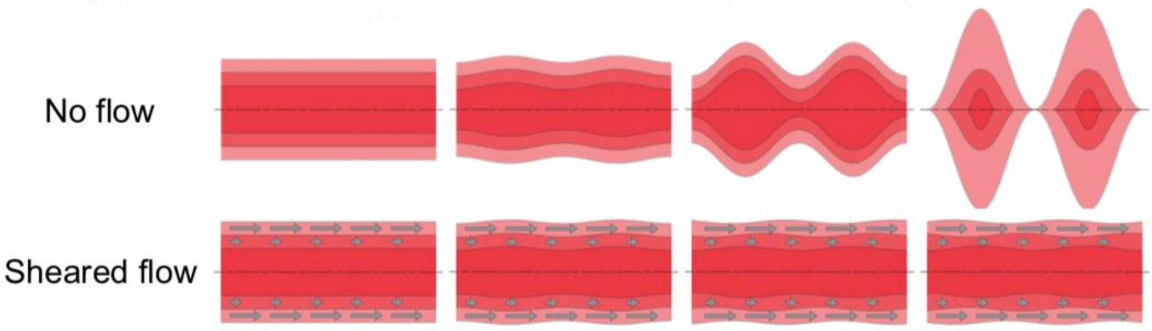
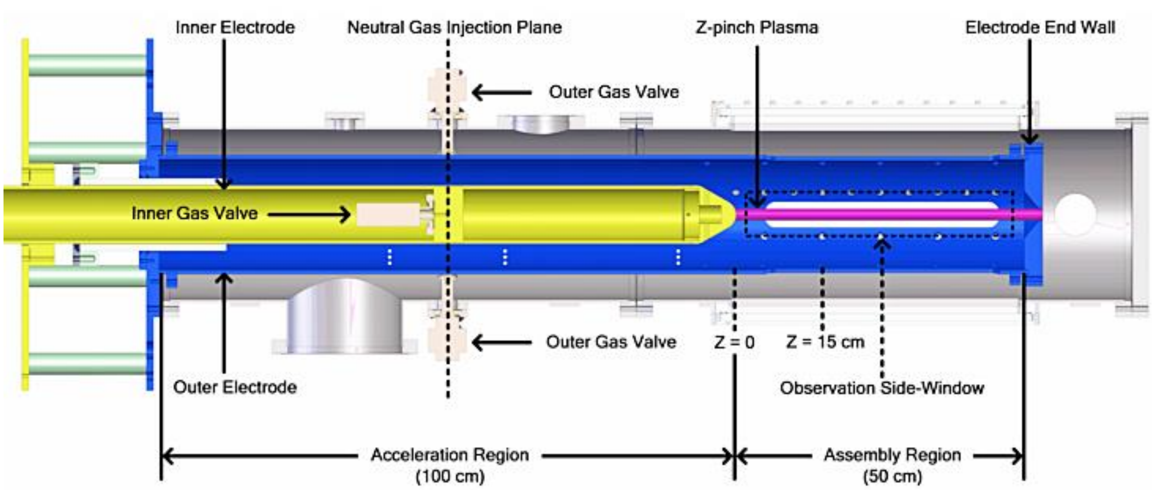
In 1995, researchers at the Philips Laboratory (Kirtland Air Force Base, NM) and Lawrence Livermore National Laboratory (LLNL) theoretically demonstrated that a Z-pinch could be stabilized by inducing a low-speed sheared axial flow along the pinched plasma. The relative effects of no sheared flow and SFS are shown in the following diagrams.



From 1998 to 2014, DOE-funded experimental projects at UW to investigate the use of SFS in a Z-pinch machine. This led to the development of the Fusion Z-pinch Experiment (FuZE) machine.

The FuZE machine at UW

The general configuration of the FuZE machine is shown in the following diagram. Compare the FuZE diagram to the simple Z-pinch schematic above.



FuZE SFS Z-pinch machine schematic. Source: LLNL-JRNL-811187

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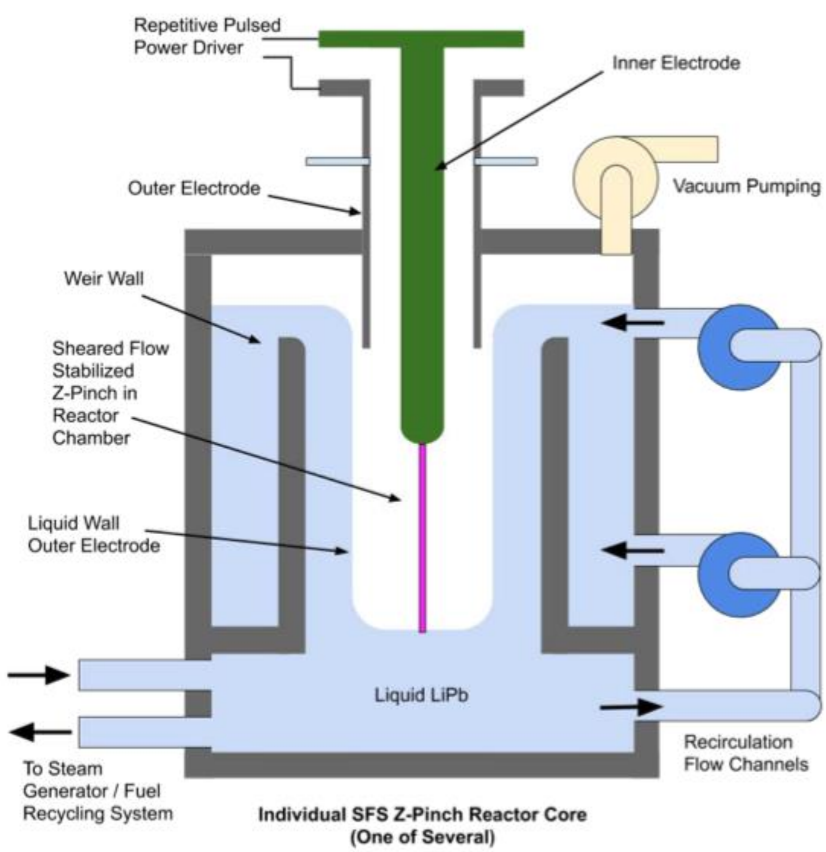
Under the ARPA-E ALPHA and OPEN 2018 programs, the SFS Z-pinch machine demonstrated a fusion triple product ($nT\tau_E$ = ion density x ion temperature x energy confinement time) exceeding 10^{17} keV s/m^3. The ARPA-E BETHE project will enable Zap Energy to implement an upgrade to their SFS Z-pinch device to allow independent control of the plasma formation and acceleration stages. They will use the upgraded device to advance their triple product toward breakeven conditions, which, by the Lawson criterion, traditionally is defined as $nT\tau_E > 10^{21}$ keV s/m^3, with T between 10 to 20 keV. Just four orders of magnitude to go.

Concept for a SFS Z-pinch commercial power plant

The team of Zap Energy, UW and LLNL developed the following design concept for an SFS Z-Pinch power reactor.

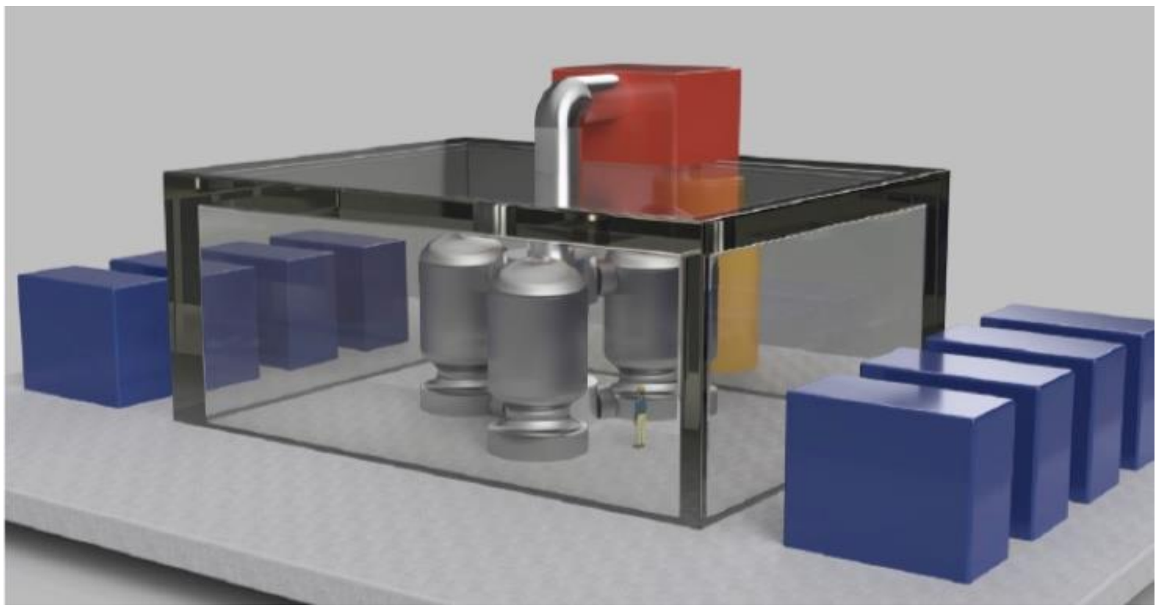


Vertically oriented, 50 cm-long SFS Z-pinch (pink) is the "reactor core." It impinges on a flowing metal blanket (light blue). Source: LLNL-JRNL-811187

Basic reactor features include:

- D-T fusion
- 190 MWt per reactor
- Pulsed at 10 Hz
- Liquid LiPb eutectic mixture (17% lithium and 83% lead) serves as outer electrode, primary heat transfer medium, biological shield & tritium breeding medium
- Tritium breeding ratio of 1.1

As part of a 2017 cost study for ARPA-E, Bechtel and Woodruff Scientific developed a conceptual design for an SFS Z-pinch power plant. The concept, shown below, included three reactor modules (silver), a shared power conversion system (yellow) and pumping and tritium systems (red). The power supplies (blue) are outside of the biological shield building (clear).



Source: Bechtel and Woodruff Scientific (2017)

A summary of that cost study is available here: https://nucleus.iaea.org/sites/fusionportal/Shared%20Documents/Enterprises/2018/Presentations/14.06/Woodruff.pdf

Funding

The Department of Energy (DOE) has been an important source of funding for Zap Energy.

- November 2018: $6.77 million under the DOE ARPA-E OPEN 2018 program for electrode technology development from 2019 to 2022.
- April 2020: $1 million under the ARPA-E BETHE program to incorporate more flexibility in their SFS Z-Pinch experiments for advancing toward energy breakeven from 2020 to 2023.

In addition to the DOE funding, Zap Energy raised $6.5 million in July 2020 from Chevron Technology Ventures and Lowercarbon Capital (Chris Sacca).

For more information

- "Electrode Technology Development for the Sheared-Flow Z-Pinch Fusion Reactor," ARPA-E OPEN 2018 program: https://arpa-e.energy.gov/technologies/projects/electrode-technology-development-sheared-flow-z-pinch-fusion-reactor
- "Roadmap to a Compact Fusion Device based on the Sheared Flow Stabilized Z-Pinch," Zap Energy (and others) presentation for ARPA-E Fusion Workshop, 13 to 14 August 2019: https://arpa-e.energy.gov/sites/default/files/Shumlak_arpae2019_compressed.pdf
- "Sheared Flow Stabilized Z-Pinch Performance Improvement," ARPA-E BETHE program, 2019: https://arpa-e.energy.gov/technologies/projects/sheared-flow-stabilized-z-pinch-performance-improvement
- U. Shumlak, "Z-Pinch Fusion," Journal of Applied Physics, 127, 200901, May 2020: https://aip.scitation.org/doi/10.1063/5.0004228
- E.G. Forbes, U. Shumlak, et al., "Progress Toward a Compact Fusion Reactor Using the Sheared-Flow-Stabilized Z-Pinch," LLNL-JRNL-811187, Lawrence Livermore National Laboratory, 4 June 2020: https://www.osti.gov/pages/servlets/purl/1632373

- "ARPA-E Investor Update Vol. 2 - Zap Energy and the Pursuit of Lower-Cost Fusion Energy," DOE ARPA-E, 28 October 2020: https://arpa-e.energy.gov/news-and-media/blog-posts/arpa-e-investor-update-vol-2

Patents

- Patent EP3586575A1, "Plasma confinement system and methods for use," filed 23 February 2018, published 1 January 2020: https://patents.google.com/patent/EP3586575A1/en?inventor=brian+a.+nelson&oq=brian+a.+nelson