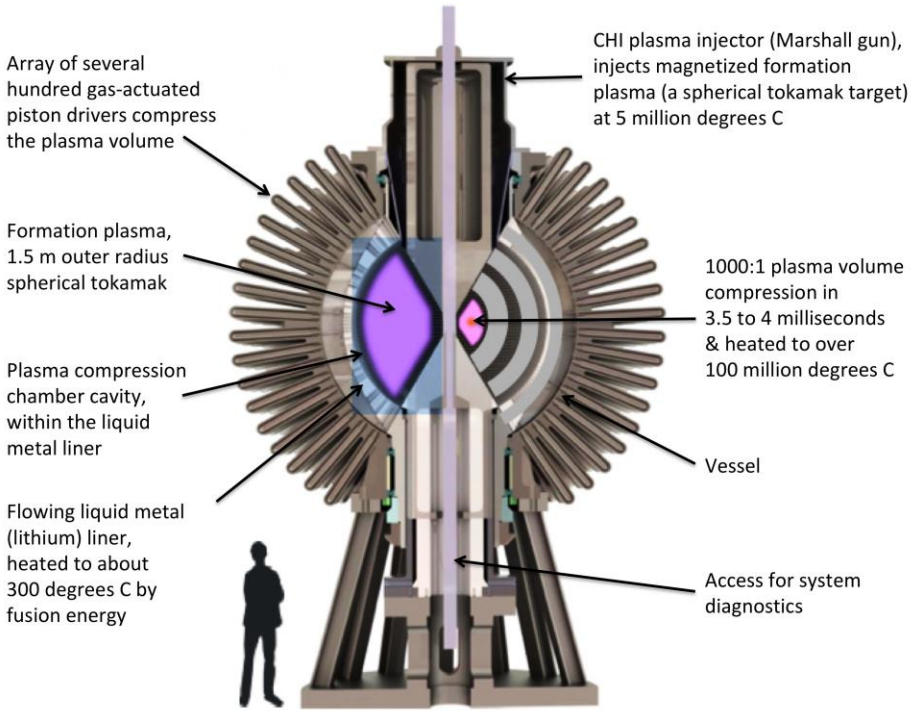
The Fork in the Road to Electric Power From Fusion

General Fusion, Inc.

Peter Lobner, 1 February 2021

General Fusion, Inc. was founded in 2002 in Vancouver, Canada by Michael Laberge. The firm is focusing on the development of a fusion power reactor based on magnetized target fusion (MTF) in a spherical, liquid metal liner implosion machine known as a "stabilized liner compressor" (SLC). Their website is here: https://generalfusion.com

The General Fusion SLC reactor is comprised of a spherical reactor vessel, a magnetized target plasma injector known as a Coaxial Helicity Injection (CHI) Marshall gun, and an array of piston drivers on the outer surface of the vessel to mechanically compress and heat the target plasma to conditions needed for fusion. A key to this approach is that plasma lifetime must be long enough to allow for mechanical compression (several milliseconds). This factor led to General Fusion's initial choice of spherical tokamak targets over field reversed configuration (FRC) and spheromak targets (tested on PI-1 and PI-2), which would have needed faster compression.



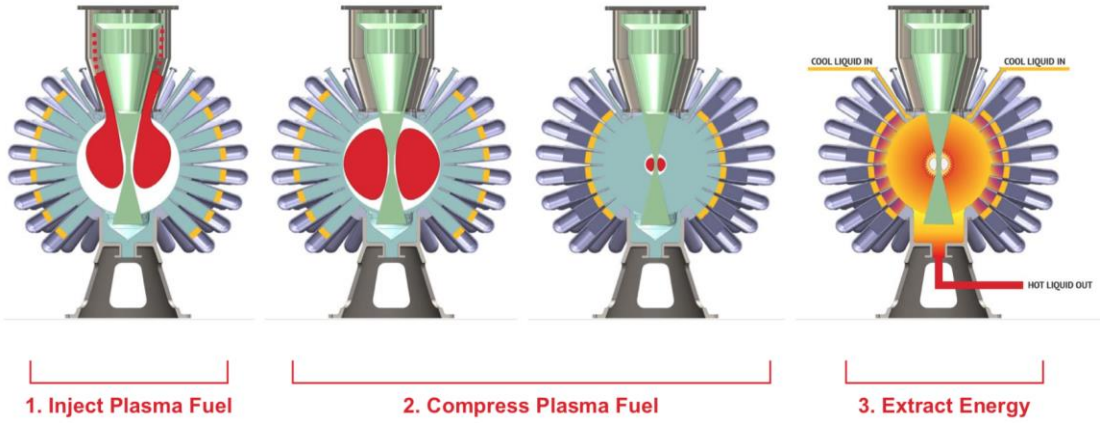
General Fusion integrated large-scale prototype concept drawing. Source: adapted from General Fusion

Inside the vessel, a rotating layer of flowing liquid metal forms the "stabilized liner" that establishes an evacuated cavity (a vortex cavity) along the centerline of the plasma compression chamber. The flowing liquid metal also serves as a "first wall" neutron blanket / radiation shield, a tritium breeding medium and a heat transfer medium. Details on how the vortex cavity is established inside the reactor vessel are provided in Patent CA2969934A1.

At the start of a cycle, a magnetized target plasma is formed by the Marshall gun and injected at about 5 million °C into the vortex cavity in the plasma compression chamber. The array of precisely synchronized, gas-driven pistons pushes symmetrically and rapidly on the liquid metal layer, compressing the plasma to 1/1000th of its original volume in several milliseconds. This heats the confined, compressed plasma to more than 100 million °C to initiate deuterium – tritium (D-T) fusion.

The fusion energy rapidly heats the liquid metal to about 300 °C (572 °F), which is comparable to the "hot leg" coolant temperature in a modern pressurized water reactor. The liquid metal in the compression chamber is drawn off at a controlled rate in a closed-loop primary system that establishes the heat transfer path to a secondary saturated steam and power conversion system outside of the reactor. This is where electric power will be generated.

This fusion cycle is illustrated in the following graphic sequence.

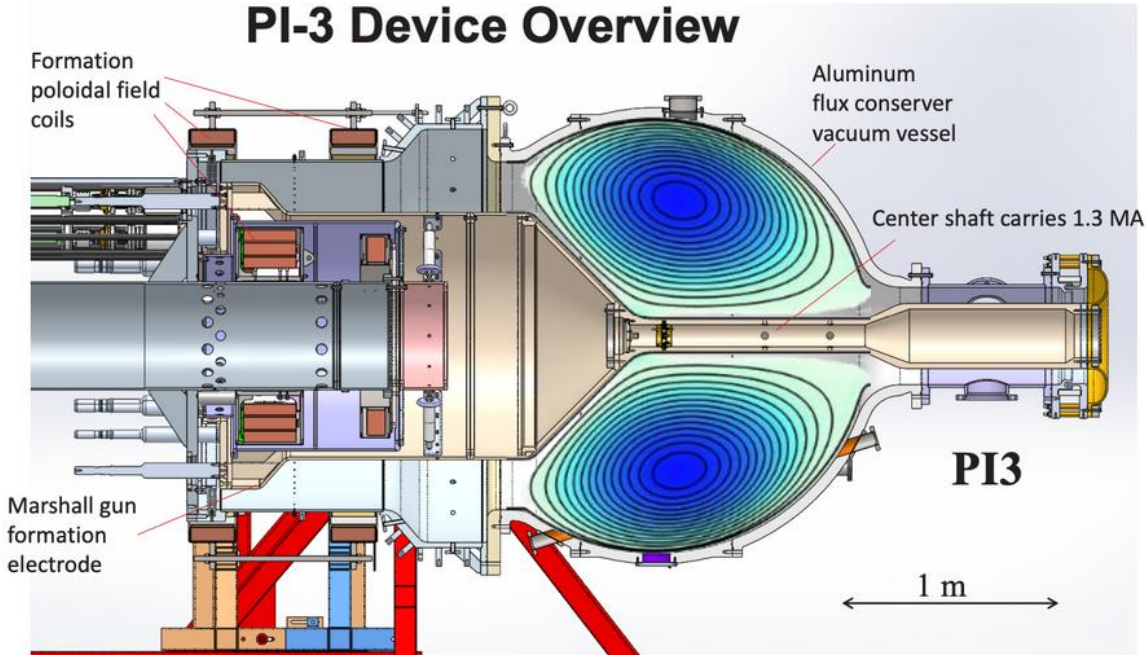


Source: General Fusion (2017)

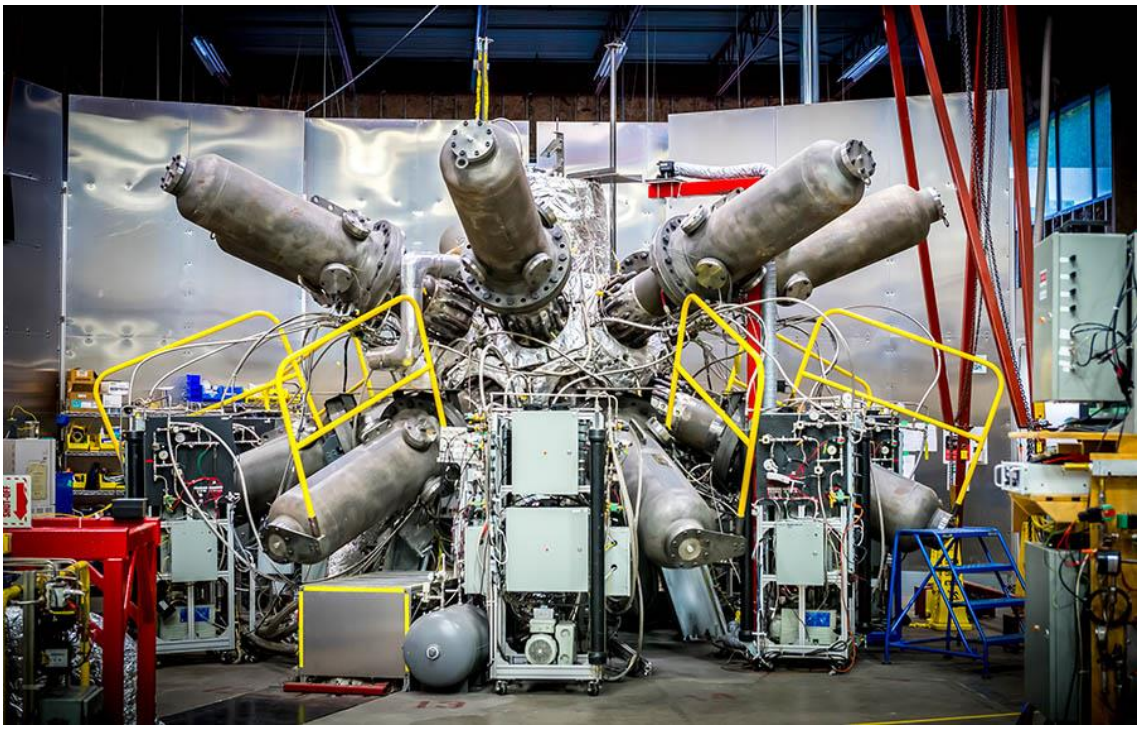
General Fusion has been focusing first on the development on the major subsystems of their fusion reactor.

- Plasma injectors:
  - MRT (Magnetized Ring Test): spheromak plasma injector experiment
  - PI-1 & PI-2: full-scale spheromak target injectors
  - SPECTOR (Spherical Compact Toroid): small-scale spherical tokamak plasma injector experiment
  - PI-3: reactor-scale spherical tokamak target injector

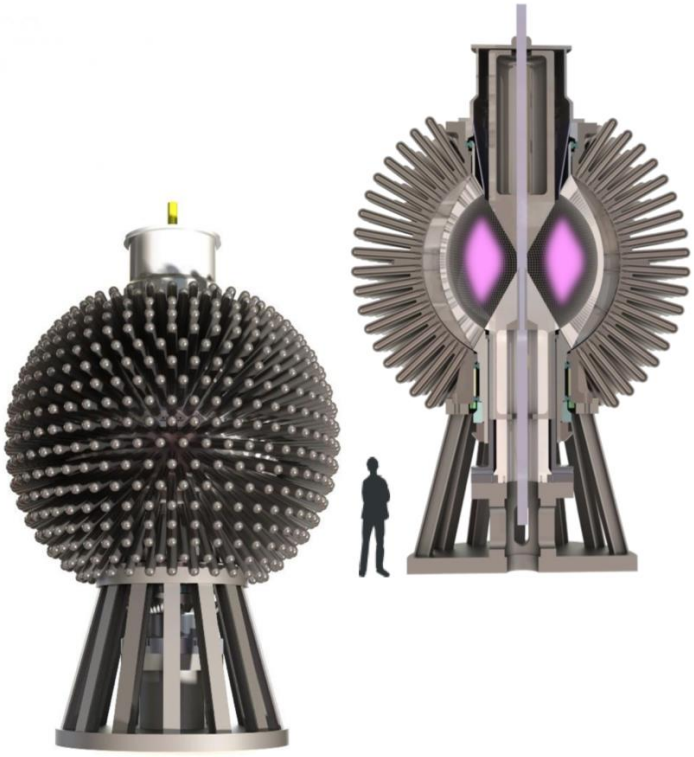
- Compression experiments:
  - Mini-sphere: test vortex generation in a subscale sphere with 14 full-scale pistons
  - SWC: 1/10th scale spherical liquid compression experiment
  - PCS (Plasma Compression Small): chemical implosion experiment to study the physics of compact toroid (CT) compression



The PI-3 plasma injector is a magnetized target plasma injector known as a Coaxial Helicity Injection (CHI) Marshall gun. Source: General Fusion



General Fusion's sub-scale "Mini-Sphere" liquid metal compression experiment has a 1-meter (3.28-ft) inner diameter sphere, 14 pneumatically driven pistons, and a molten lead liquid metal loop. Source: General Fusion



The planned integrated large-scale prototype concept will use liquid lithium coolant. The fusion cycle will be repeatable about once a day.

Source: General Fusion

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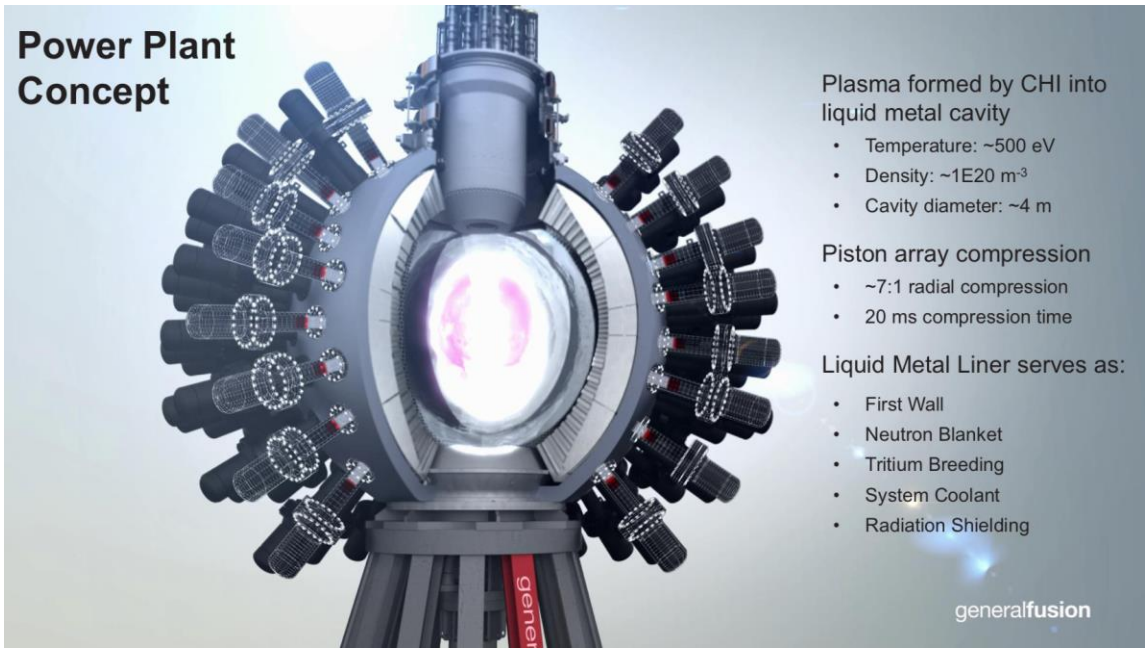
In 2017, General Fusion estimated the cost to develop the integrated large-scale prototype at about $100 million for a 3 - 5 year development effort. The machine would have high performance, but not reach breakeven (Q = 1).

In 2020, General Fusion received two awards from the Department of Energy's (DOE) INFUSE program managed by the Office of Science, Fusion Energy Sciences (FES). These awards fund work on advanced stability analysis for magnetized target fusion and ion temperature diagnostic improvements.

In a commercial fusion reactor, the fusion cycle will be repeated at 1-second intervals.



Commercial power plant concept with 4-meter (13.12-ft) cavity diameter and liquid lithium coolant. Source: General Fusion

The short (1:17 minutes) 2018 video, "Inside a General Fusion Power Plant," at the following link, will give you a better understand of how this fusion power plant concept would work:
https://www.youtube.com/watch?v=k3zcmPmW6dE&list=LLUYKvLtd_1P1sXoXRXDyDPA&index=4274

Funding

General Fusion has an established track record of fund raising dating back to 2009, when it raised $9 million from Entrepreneurs Fund, Braemar Energy Ventures, and PenderFund Capital Management. Major investment rounds with private and institutional investors include:

- 2011: $19.5 million from Bezos Expeditions (Jeff Bezos) and Cerovus Energy
- 2015: $19.4 million from Khazanah Nasional Berhad (Malaysian Sovereign Wealth Fund) and GrowthWorks
- 2018: $37.5 million from Canada's Strategic Innovation Fund
- 2019: $65 million from a large group of investors

As noted previously, General Fusion received two awards in 2020 from the DOE-FES INFUSE program.

In October 2020, *Physics Today* reported that the firm had raised $200 million for their fusion program, about 80% of that from private sources.

For more information

- Michael Laberge, "Fusion Update," General Fusion presentation for ARPA-E, 2017: https://arpa-e.energy.gov/sites/default/files/11_LABERGE.pdf
- S. Howard, et al., "Physics Objectives of PI3 Spherical Tokamak Program," General Fusion, 2017: https://generalfusion.com/wp-content/uploads/2017/08/EPR2017-Howard-PI3-Physics-Objectives.pdf
- David Plant, "General Fusion Program," IAEA Workshop on Fusion Enterprises, 13 – 15 June 2018: https://nucleus.iaea.org/sites/fusionportal/Shared%20Documents/Enterprises/2018/Presentations/13.06/Plant.pdf
- P. O'Shea, et. al, "Magnetized Target Fusion At General Fusion: An Overview," General Fusion, Inc., 2018:

https://generalfusion.com/wp-content/uploads/2018/11/aps-2018-magnetized-target-fusion-overview.pdf

Patents

- Patent US8537958B2, “Systems and methods for compressing plasma,” filed 3 February 2010, granted 17 September 2013, assignee: General Fusion, Inc.: https://patents.google.com/patent/US8537958B2/en?oq=US+8537958+titled
- Patent CA2969934A1, “Apparatus and method for generating a vortex cavity in a rotating fluid,” filed 14 January 2016, granted 19 June 2018, assigned to General Fusion, Inc.: https://patents.google.com/patent/CA2969934A1/en?oq=general+fusion