The Fork in the Road to Electric Power From Fusion

Helion Energy, Inc.

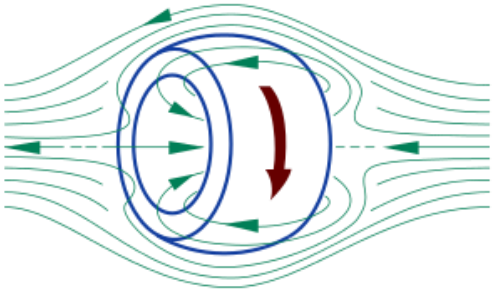
Peter Lobner, 1 February 2021

Helion Energy is a privately held firm founded in 2013 in Redmond, WA as a spin-off of MSNW LLC, also located in Redmond. Helion Energy is focused on developing pulsed magneto-inertial fusion (MIF) power technology. Their website is here: https://www.helionenergy.com

Their Fusion Engine is a pulsed, accelerator-driven, colliding beam fusion reactor with magnetic compression of field-reversed configuration (FRC) targets. The Fusion Engine is designed for deuterium-helium-3 (D-He3) fusion. Helium-3 sometimes is called "helion." This fusion reaction has the lowest energy threshold for an aneutronic fusion reaction, occurring a temperature of about 800 million °C. This is an intermediate temperature range between deuterium-tritium (D-T) fusion at about 100 million °C and aneutronic hydrogen-boron-11 (p-B11) fusion at about 3 billion °C. One problem with D-He3 fusion is the rarity of helium-3 on Earth.

Stray D-D reactions also will occur and will generate some neutrons and tritium.

The Helion Fusion Engine is based on the magnetic compression of colliding field reversed configuration (FRC) deuterium-helium-3 plasma targets. A plasma gun creates each FRC plasma target in the form of a self-stable, rotating plasma torus, similar to a smoke ring.



FRC: a toroidal electric current is induced inside a cylindrical plasma, making a poloidal magnetic field, reversed in respect to the direction of an externally applied magnetic field. The resultant high-beta axisymmetric compact toroid is self-confined. Source: Wikipedia

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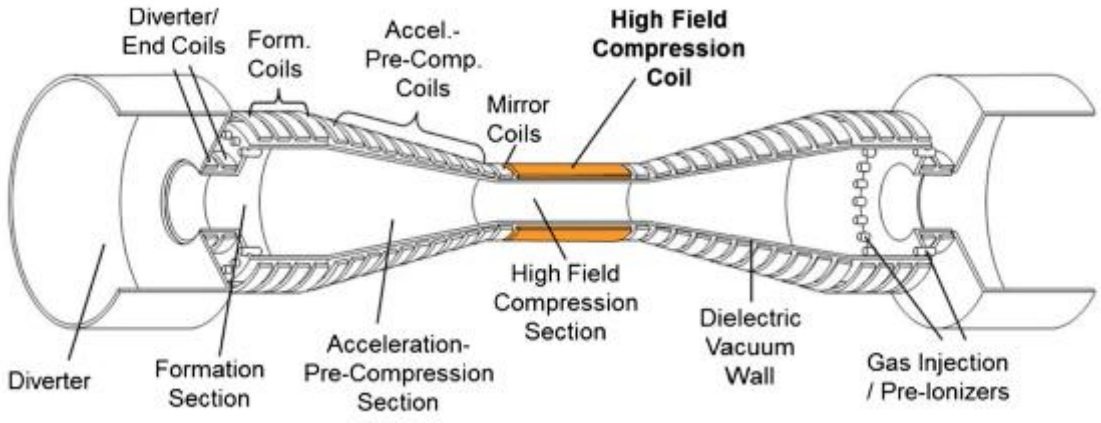
The general arrangement of the Helion Fusion Engine is shown in the following diagram.



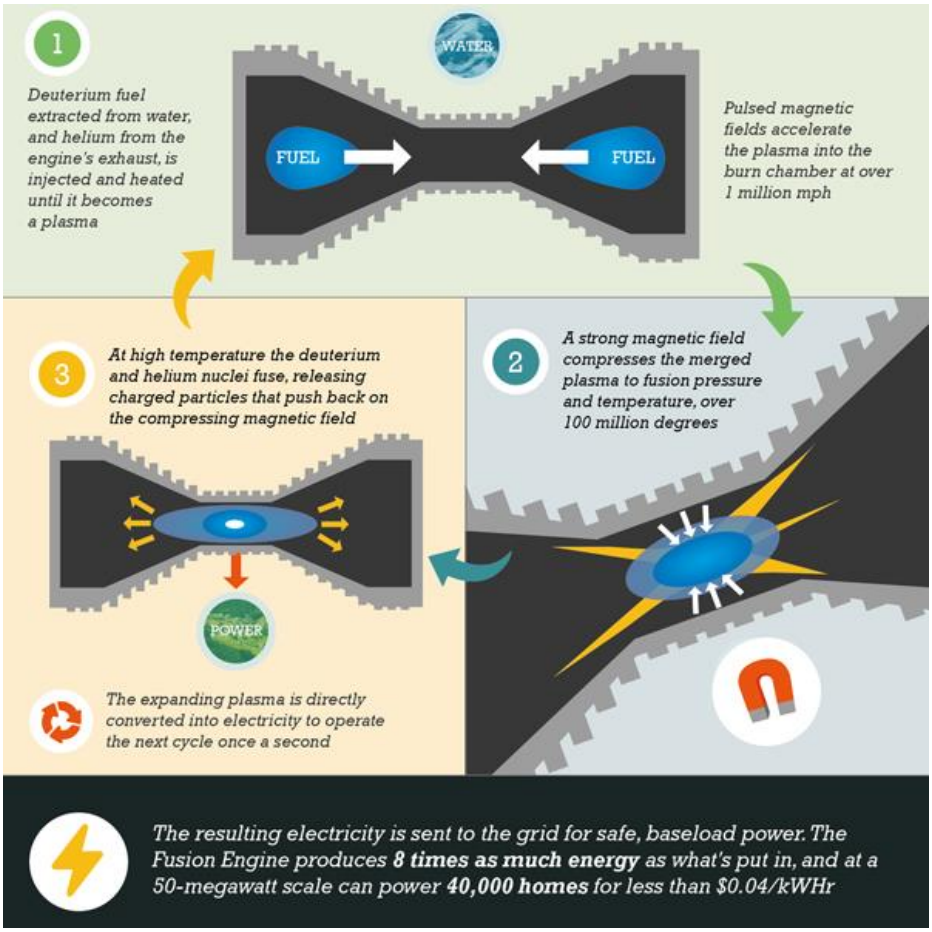
Source: J. Slough, et al., (2011)

The physical layout of the Helion Fusion Engine bears a general resemblance to TAE's pulsed, accelerator-driven, FRC colliding beam fusion reactor. One big difference is in the choice of fuel. The TAE machine is designed for p-B11 fusion while the Helion Fusion Engine is designed for deuterium-helium-3 (D-helium-3) fusion at much lower temperatures.

There are five steps in each Fusion Engine pulse cycle:

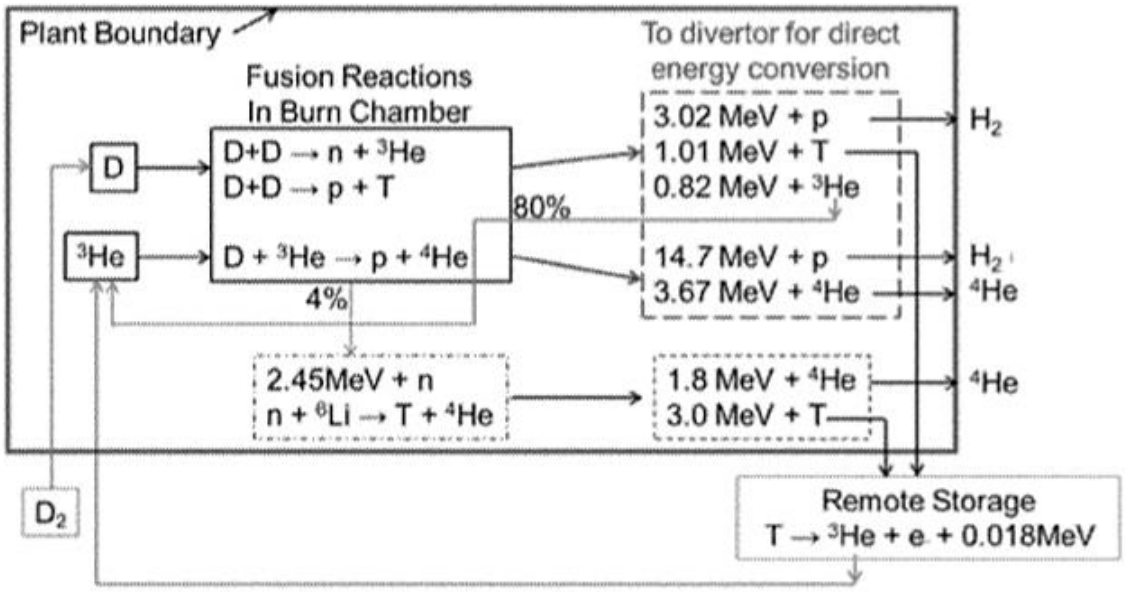
- **Target formation:** FRC plasma targets are created by plasma guns in the "Formation Sections" at each end of the machine.
- **Acceleration:** The FRC plasma targets are magnetically accelerated to high velocities (>300 km/sec / 186 miles/sec) through the "Acceleration-Pre-Compression Sections."
- **Merging:** The FRC targets collide and merge in the small-diameter, central "High Field Compression Section."
- **Adiabatic Compression & Burn:** The FRC is magnetically compressed to fusion conditions. Two different types of fusion reactions occur: D-helium-3 and D-D.
- **Energy Generation, Pumpout & Recovery:** High-energy expanding plasma and fusion ions are converted directly to electricity and fusion neutrons are absorbed in a lithium blanket.

Then the next pulse cycle is ready to begin. This pulse cycle is shown in the following Helion Energy graphic.



Helium-3 is a rare form of helium, extracted from natural gas fields in trace amounts and formed from tritium β-decay, which has a 12.3-year half-life. Once operating, a Helion fusion reactor will produce more helium-3 than it uses as fuel. However, accumulating the initial inventory of helium-3 needed for Helion reactor operation may prove to be challenging.

The fuel cycle for the Helion Fusion Engine is described in patent US2017/0011811A1, “Advanced fuel cycle and fusion reactors utilizing the same.” Treating the fusion fuel cycle as a black box, the inputs are deuterium (D) and helium-3. The outputs from the black box are stable, common hydrogen and helium-4 gases and tritium (T), which is stored and allowed to decay into helium-3 for recycling later in the reactor.



Helion fuel cycle. Source: US2017/0011811A1, Figure 3

Helium-3 produced directly from D-D fusion is recycled immediately within the black box to sustain operation of the Fusion Engine.

While the D-helium-3 fusion reaction is aneutronic, one of the D-D fusion reactions produces relatively low energy 2.45 MeV neutrons that are used to breed tritium (T) in a lithium shielding blanket. In comparison, D-T fusion produces 14 MeV neutrons that require much more shielding.

In patent US2017/0011811A1, Helion explains their direct energy conversion process as follows:

> "With primarily all of the fusion energy in the form of fusion particle energy, a high net plant electrical generation efficiency can be obtained from direct conversion of both the fusion product and fusion plasma particles in some examples. This may be accomplished through the electromagnetic compression and expansion cycle employed to create the fusion conditions and thus may avoid the low efficiency and waste heat issues typically found in the usual thermal cycle employed by other nuclear and carbon based power sources."

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During their participation in the ARPA-E ALPHA program from 2015 - 2018, the Helion team achieved a 6 Tesla (T) magnetic field in the central section and observed D-D fusion neutrons.

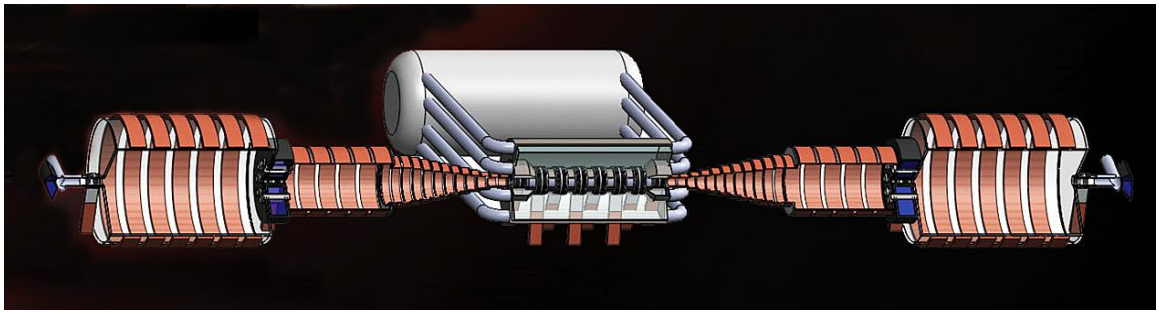
Helion's fifth-generation plasma machine, Venti, went into operation in 2017. Its performance targets are to generate a 20 T magnetic field and compress targets to fusion temperatures.

Helion's path to a small fusion power plant involves at least three additional iterations:

- The sixth-generation machine was in the design stage in 2018.
- The seventh-generation machine is expected to achieve a net energy gain (Q > 1.0) in the 2020s.
- The prototype production device is expected to be a shipping container-sized 50 MWe module with an net energy gain of 8 (Q = 8), for use in base load power generation.

As of January 2021, Helion has demonstrated compression fields of greater than 100 Tesla, achieved fusion temperature plasma and full-scale plasma lifetimes greater than 1 microsecond.

The general configuration of a power-producing helion Fusion Engine is shown in the following graphic.



Source: adapted from Helion Energy

Helion Energy was launched with $1.5 million in private funding from Y Combinator and Mithril Capital Management (Peter Thiel). Capricorn Investment Group is another known investor. In 2015, Helion also received $3.97 million funding under the DOE ARPA-E ALPHA program. In July 2015, Helion reported $10.6 million in new

private funding. In April 2018, Helion CEO David Kirtley reported that the firm had raised $30 million in the past three years, which he expects will be enough to get Helion through the debut of its 50 MWe prototype. The total value of private investments is not publically available.

The FRC target technology embodied in the Helion Fusion Engine for electric power generation also has applications for spacecraft fusion propulsion, as described in patent US9082516B2, which was granted on 14 July 2015.

For more information

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