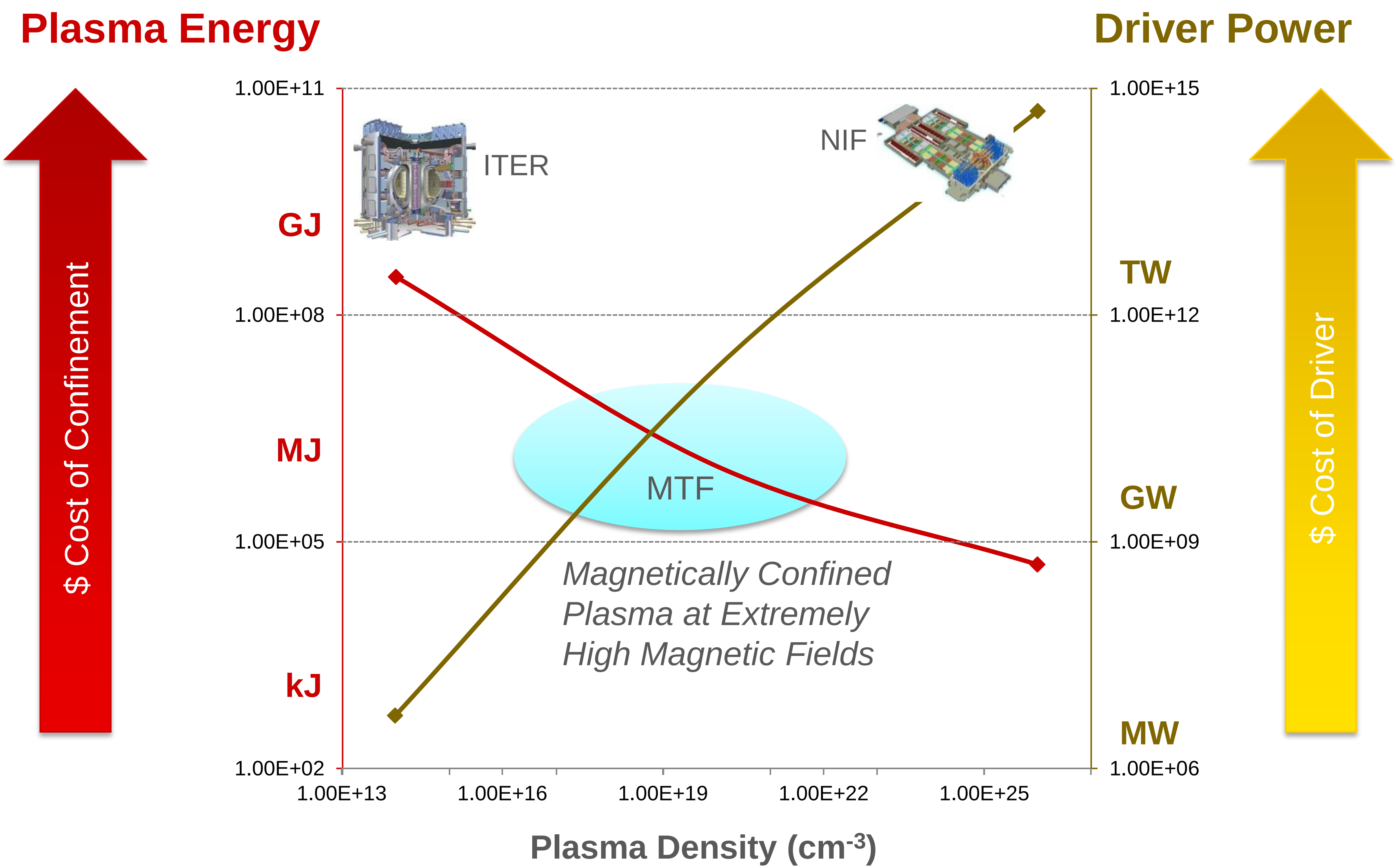
generalfusion

Overview

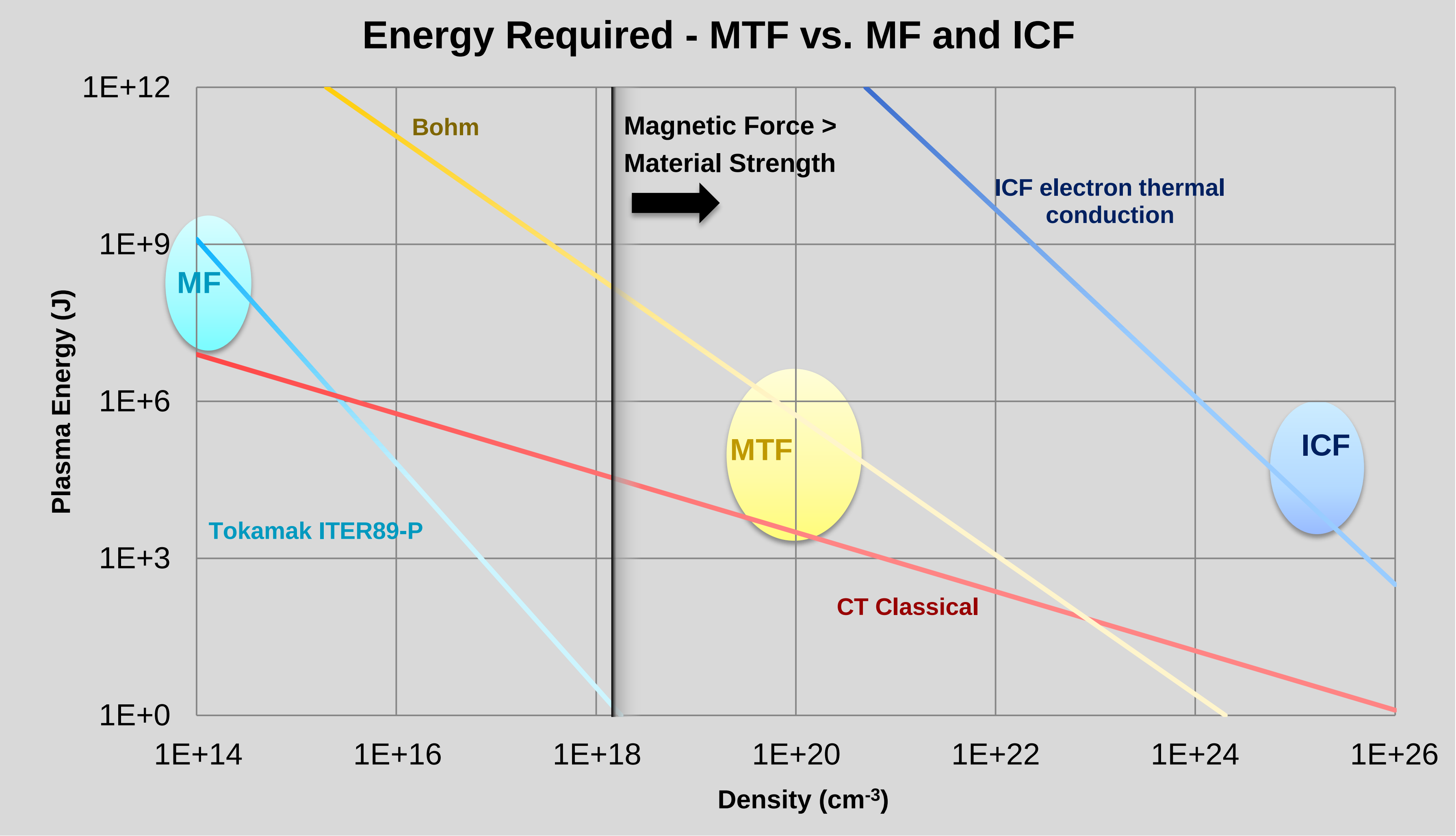
Why this Middle Region is Attractive

generalfusion



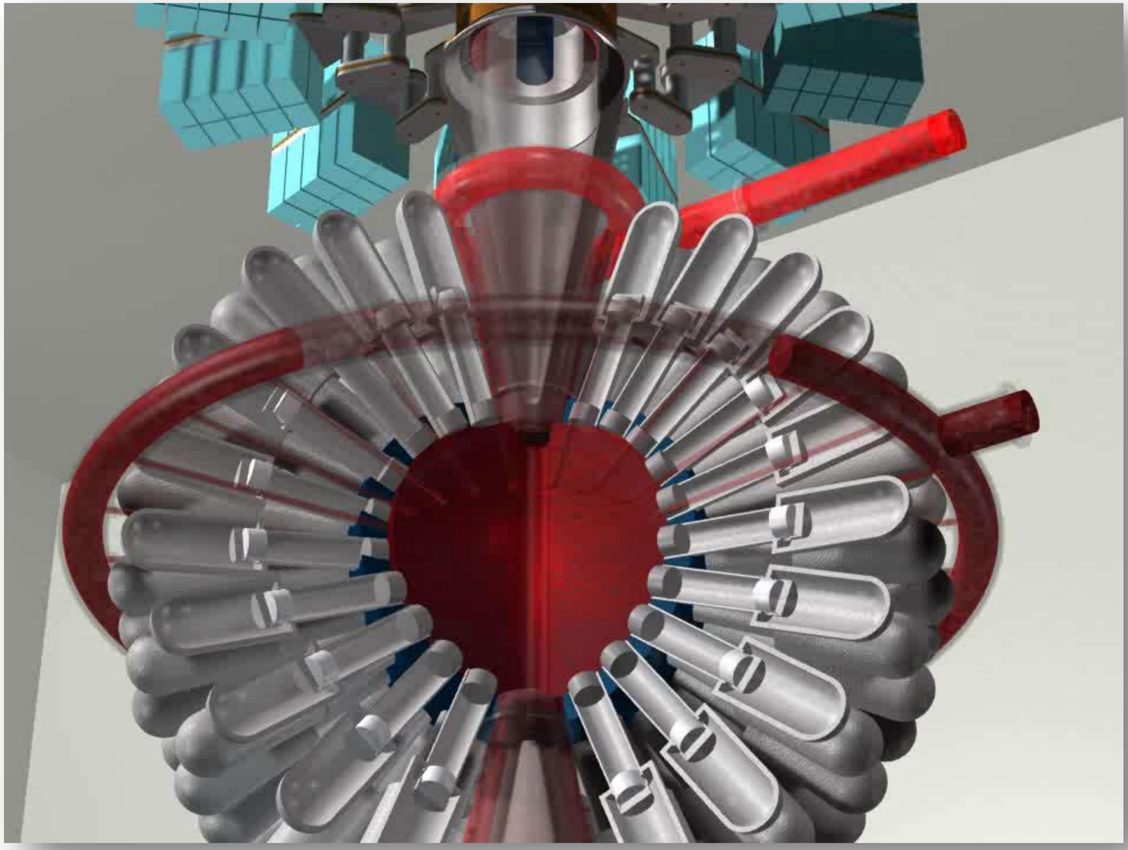
Energy Required: MTF vs. MF and ICF

generalfusion



Source: LANL MTF Group. Assumes $n\tau_E = 3\times10^{14}\ cm^{-3}s$, $T_i = 10$ keV, and poloidal β~1.

General Fusion's Acoustically Driven MTF



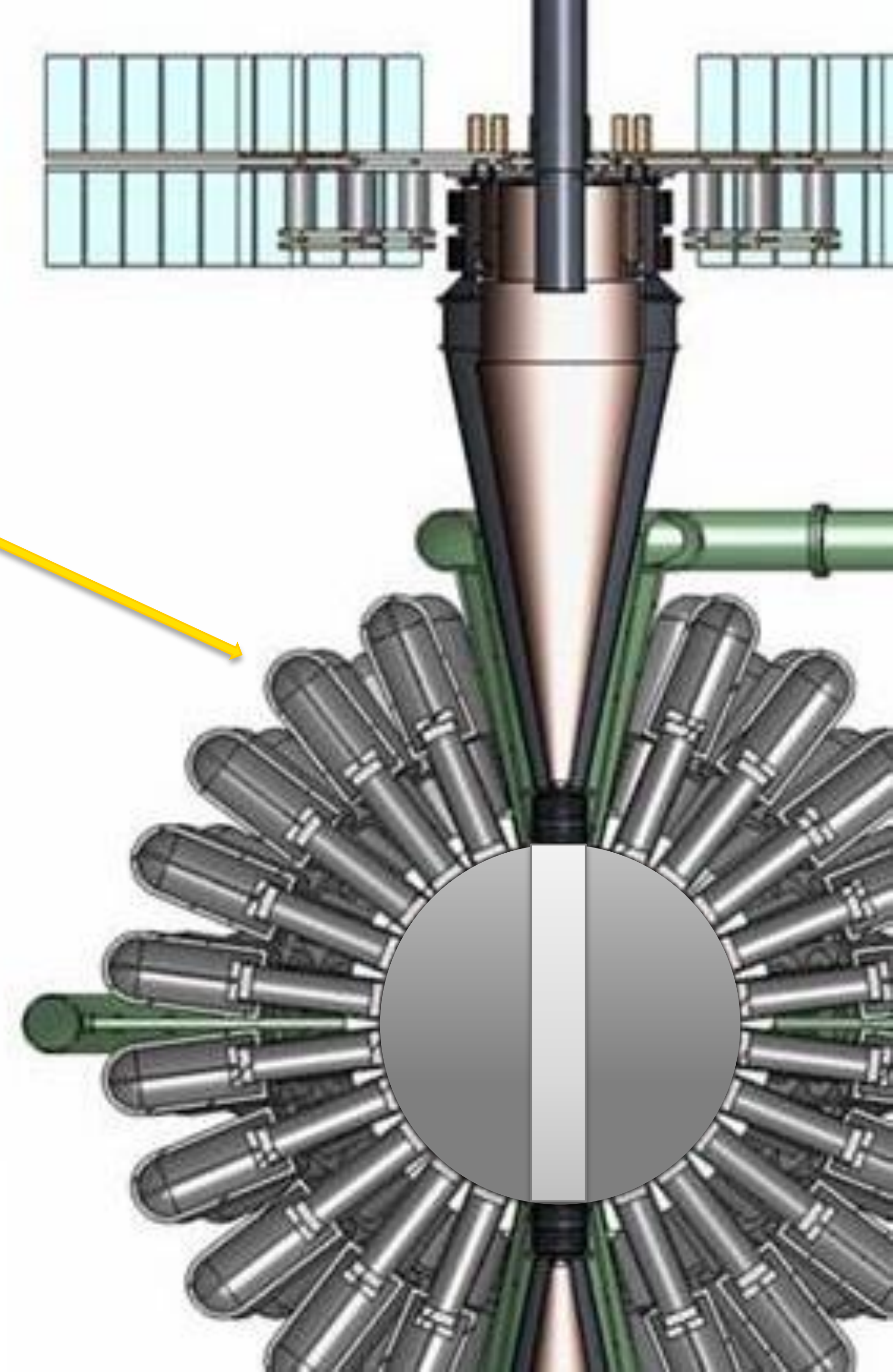
Practical

Low cost compressed gas driver

Liquid absorbs most neutron energy, low dpa

High breeding ratio, 1.5 with natural lithium

No target destroyed



Plasma Injector

5×10^{16} cm^{-3}

300 eV

20 μs

3 T

Accelerator current damages plasma magnetic structure

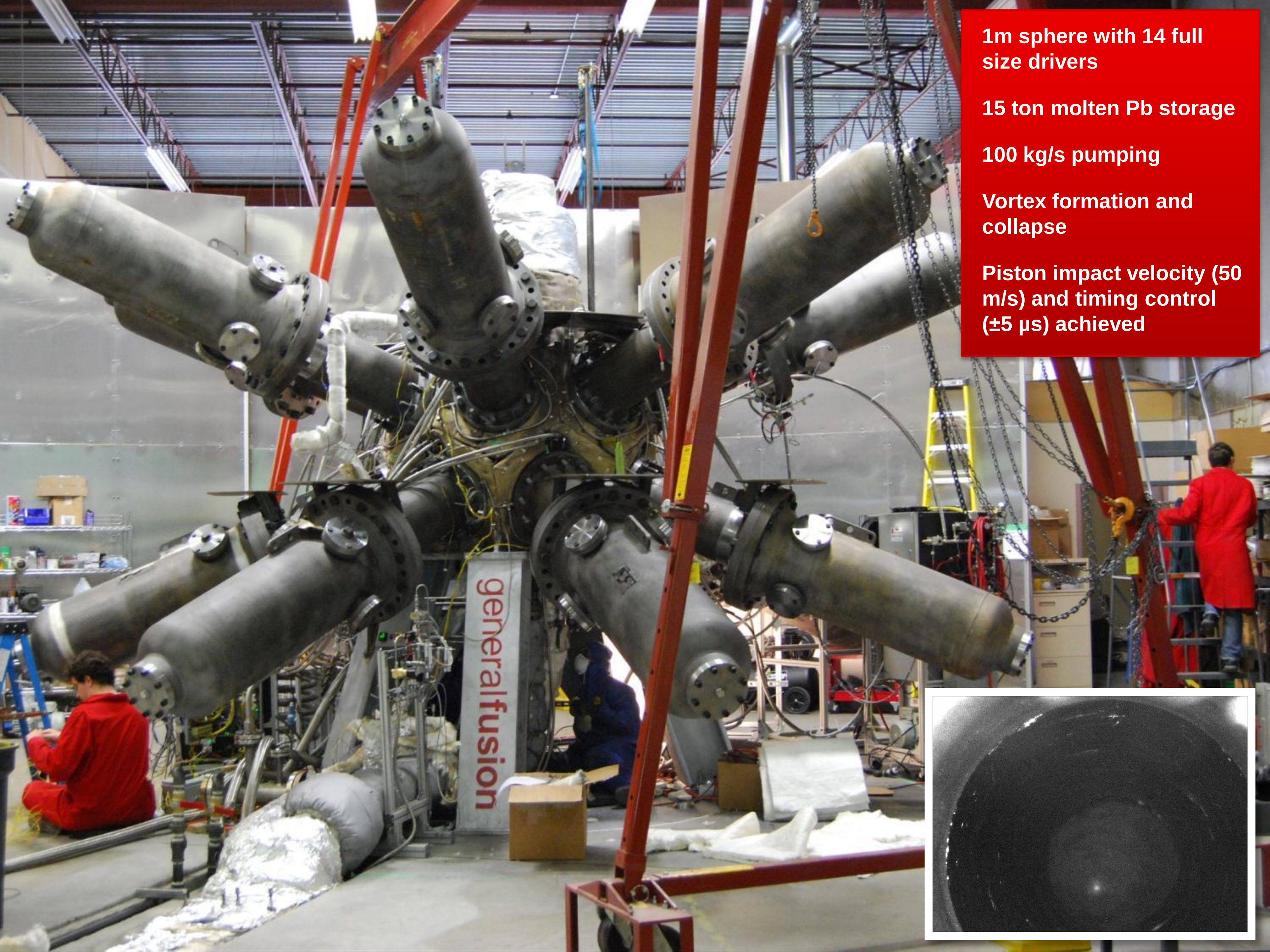
1m sphere with 14 full size drivers

15 ton molten Pb storage

100 kg/s pumping

Vortex formation and collapse

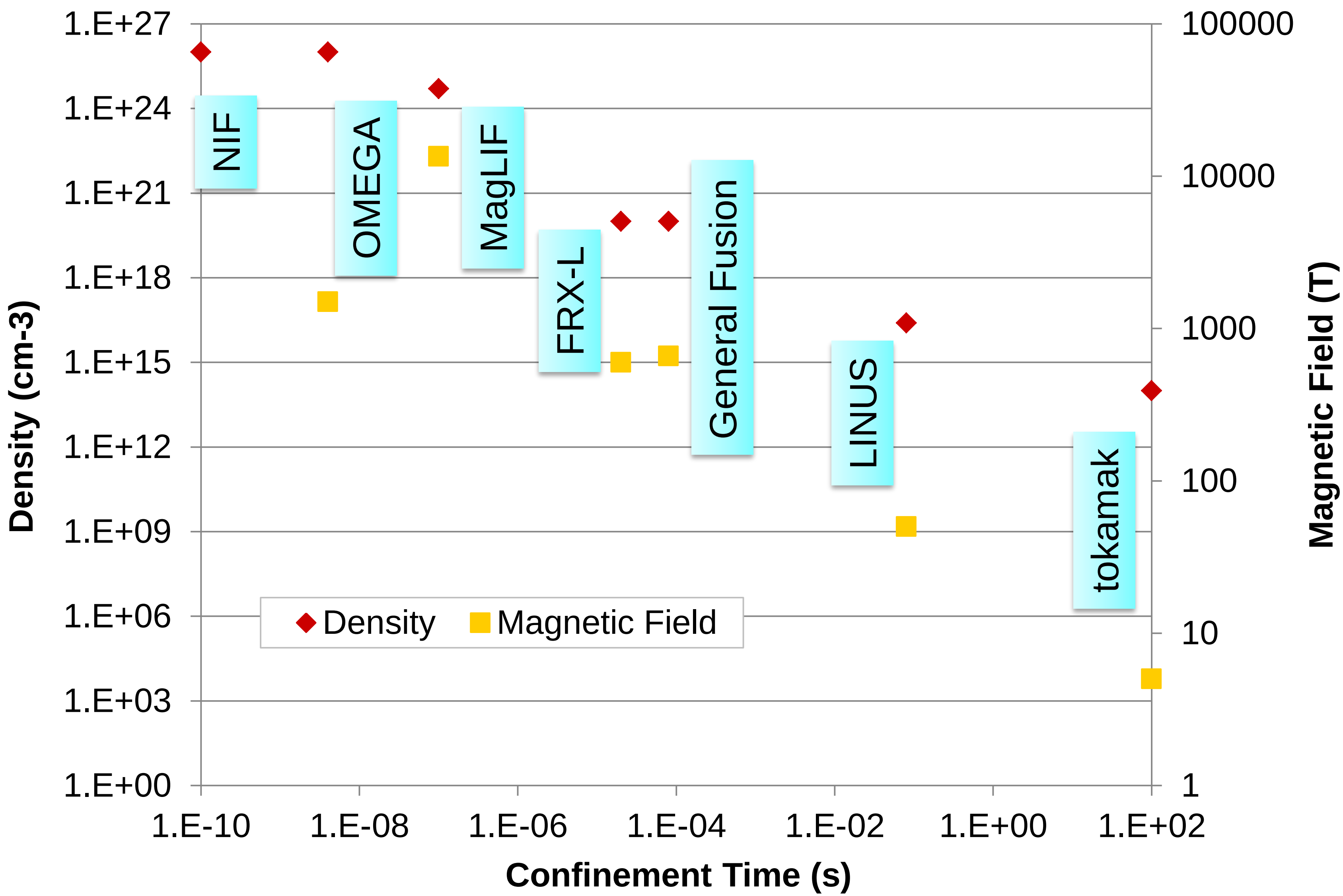
Piston impact velocity (50 m/s) and timing control (±5 μs) achieved

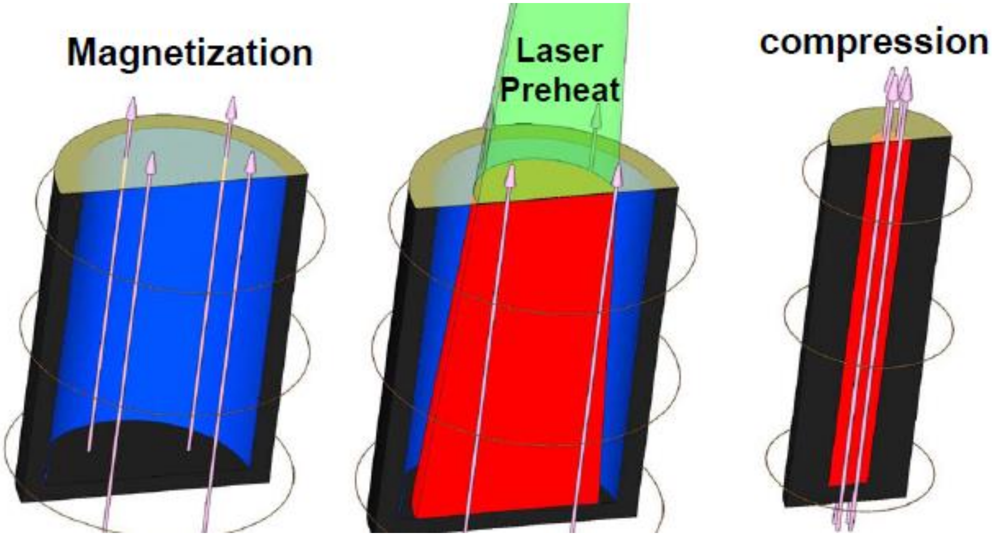


Test plasma compression with explosive

generalfusion

Fusion Parameter Space



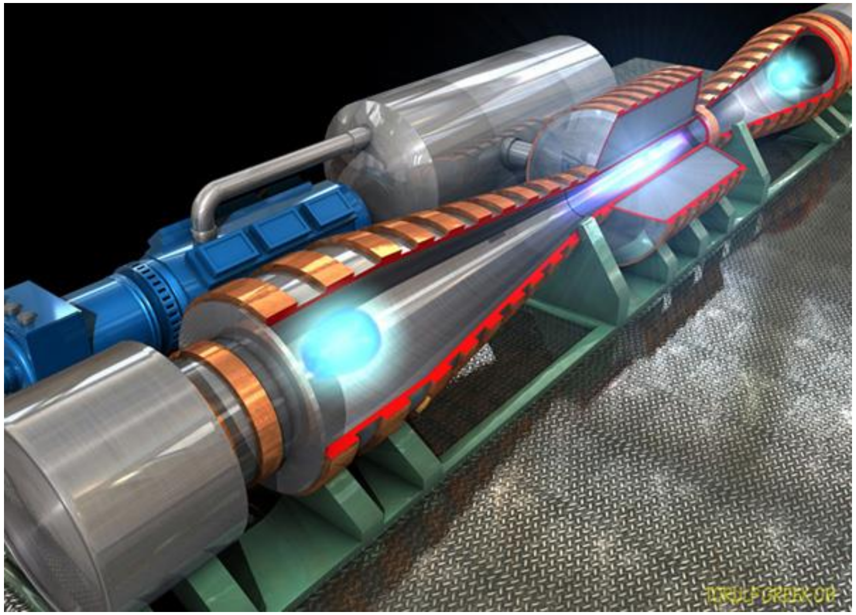


- Open field lines
- Z-pinch: faster compression, smaller plasma compared to General Fusion
- Government research
- Impressive neutron yield in 2013
- Poor / impractical reactor prospects, unfortunately

MagLIF achieved good results in late 2013 with significant neutron production

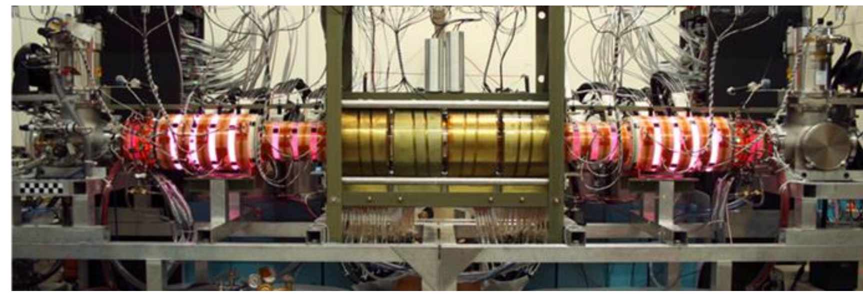
Helion Energy

generalfusion



Redmond, Washington

~20M invested



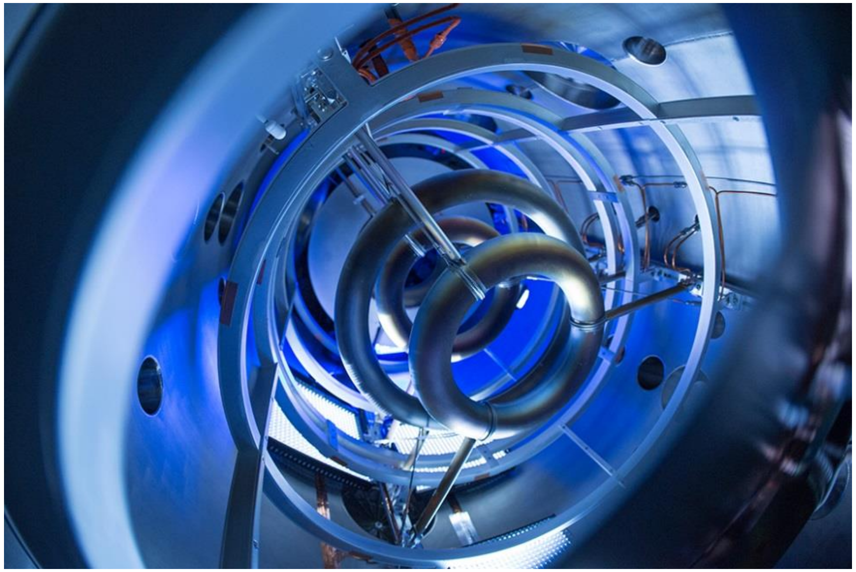
Technology Concept

- Merge compact toroids (FRC)
- Compress further with magnetic field
- Pulsed approach
- Fuel with deuterium-helium3
- Direct energy conversion technology required

Competitive Assessment

- Physics is sound and linear arrangement is attractive. Scientific lead is a recognized expert on FRC plasmas.
- FRC plasmas cannot achieve “ignition”, which limits the maximum gain possible.
- Low system gain requires very high efficiency power conversion and implies very high recirculated power (1 GW scale plant producing only 100 MW of electricity).
- Economics will be challenging.

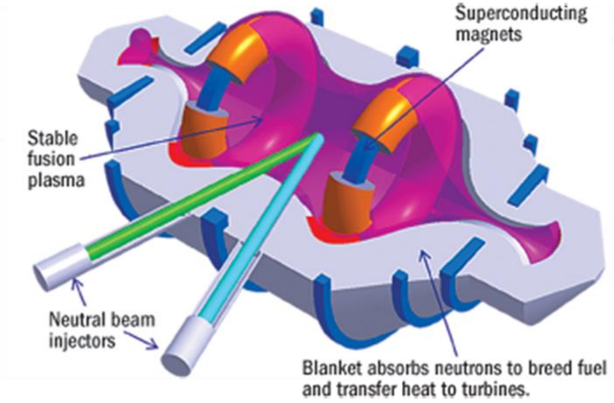
Lockheed Martin Skunkworks



Palmdale, California

~$30M invested

~15 staff



Technology Concept

- Encapsulated cusp combination of past cusp designs (e.g. polywell) and magnetic mirror machines. Goal is magnetic confinement with smaller scale and better geometry than tokamak.
- Steady-state system
- Fuel with deuterium-tritium
- Thick FLiBe blanket on outside to absorb neutrons and breed tritium
- Focus on naval and aviation applications

Competitive Assessment

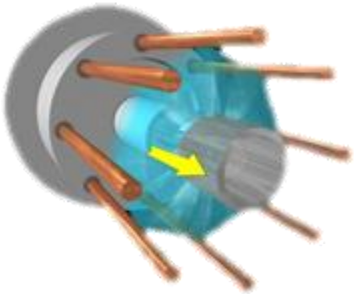
- Interesting twist on older concepts. L-M is currently assembling a prototype system which will provide first data on confinement quality and whether it matches simulation.
- Inner superconducting coils and supporting stalks will be subjected to very harsh neutron and energy fluxes, limiting life (hence focus on naval and aviation applications).
- Economics will be challenging for electricity generation.

Lawrenceville, New Jersey

<$5M Invested: no institutional funds

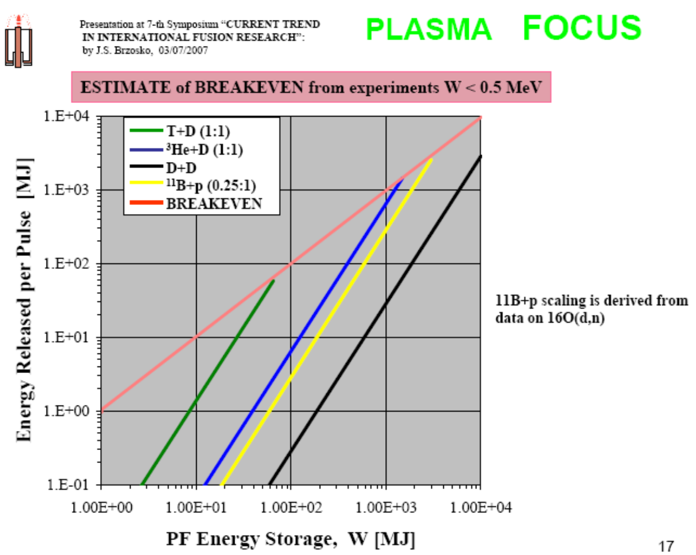
3-4 staff

Also known as “Focus Fusion”



Technology Concept

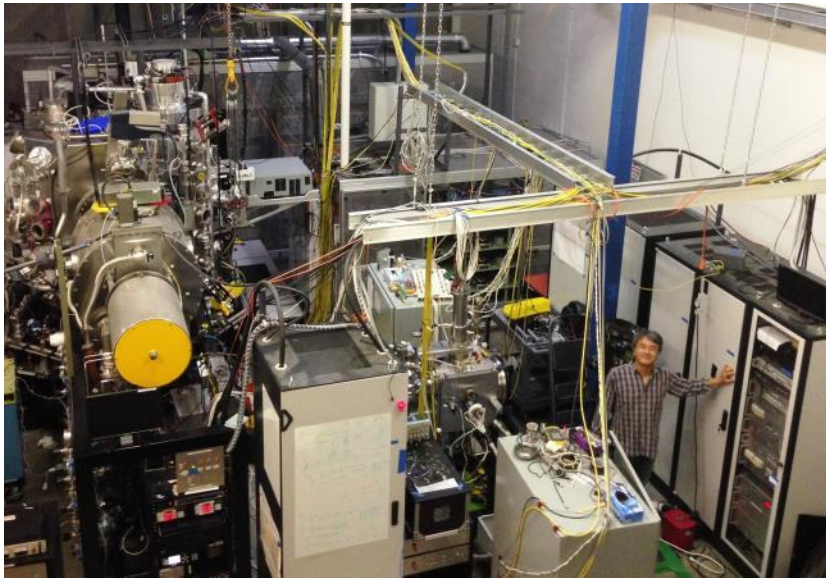
- Dense Plasma Focus. Energy discharge from electrodes causes a “pinch” which creates extremely high density and temperatures.
- Fuel with hydrogen-boron
- Collimate alpha particles, collect x-ray radiation direct to electricity.



Competitive Assessment

- Hydrogen-boron is extremely hard. Requires plasma performance 2000X better than deuterium-tritium.
- Dense Plasma Focus has been heavily researched. No evidence yet that LPP is on a different scaling law from previous experiments.
- Existing scaling laws indicate break-even system would be too large to be practical (need 3 GJ discharge!)
- Counting on theorized but undemonstrated quantum mechanical effect to break past scaling laws.
- Lack of neutrons is beneficial, but reverse particle accelerator and x-ray conversion are additional new technologies.

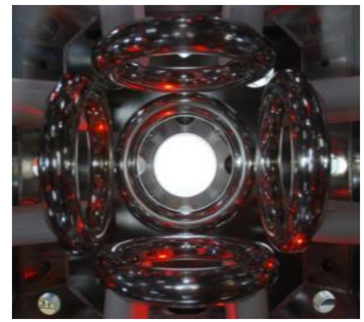
Energy Matter Conversion Corp (EMC2, or Polywell)

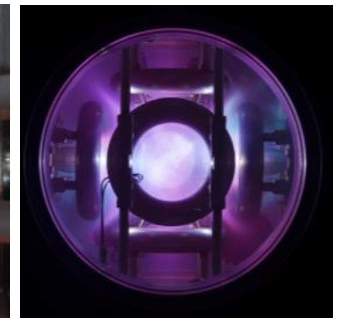


San Diego, California

~$12M? from US Navy. Funding now discontinued, seeking private investment.

<10 staff





Technology Concept

- Polywell cusp confinement
- Evolution from inertial electrostatic confinement concepts (IEC), such as the Farnsworth fusor
- Steady-state system
- Fuel eventually with hydrogen-boron fuel
- Direct energy conversion
- Focus on naval and aviation applications

Competitive Assessment

- IEC devices such as the Polywell have a long history as being relatively easy to construct neutron sources (many “garage” systems built)
- Unclear scaling required for break-even level… Marginal data from recent EMC2 results show confinement may be better than projected. Further study is required.
- Deuterium-tritium fuel will quickly damage internal coils making D-T commercial operations unrealistic. Achieving the confinement required for hydrogen-boron fuel extremely hard.

Tri Alpha Energy

generalfusion

Irvine, California

~$300M invested: mix of HNW / VC / Private Equity

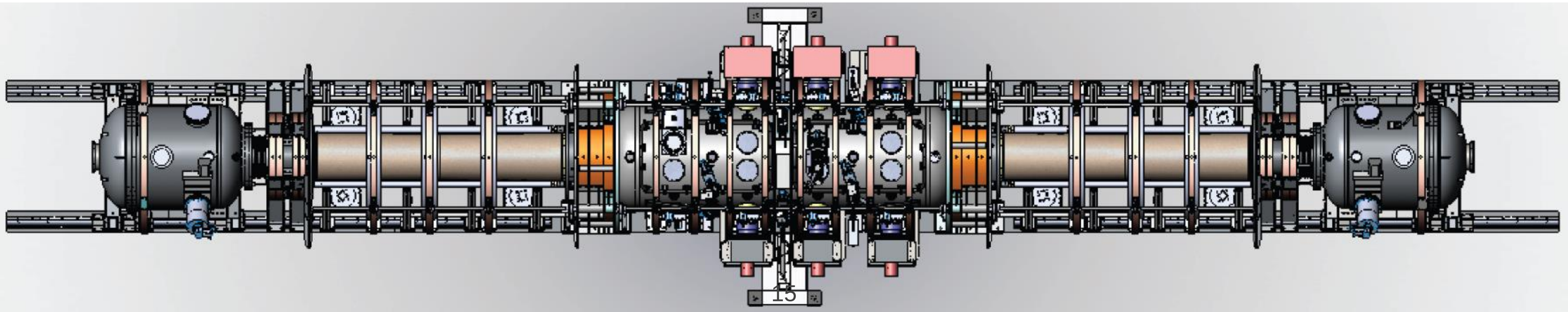
~100 staff

Technology Concept

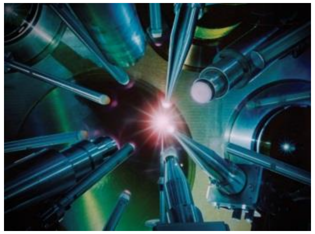
- Merge compact toroids (FRC)
- Sustain and fuel the low density plasma with neutral beams
- Fuel with hydrogen-boron, produces 3 charged alpha particles
- Collimate alpha particles, extract direct to electricity energy using novel reverse particle accelerator

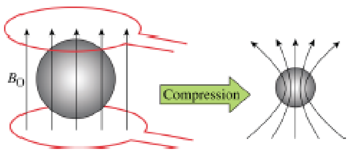
Competitive Assessment

- Hydrogen-boron is extremely hard. Requires plasma performance 2000X better than deuterium-tritium.
- Data to date does not demonstrate better energy confinement than a tokamak (tokamak is the leading steady-state fusion approach), and hydrogen-boron will require better than tokamak.
- Scale challenge: very large system needed (>$1B) to demonstrate break-even
- Lack of neutrons is beneficial, but reverse particle accelerator tech is an additional new technology

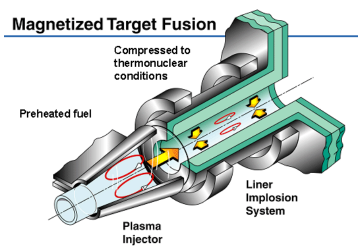


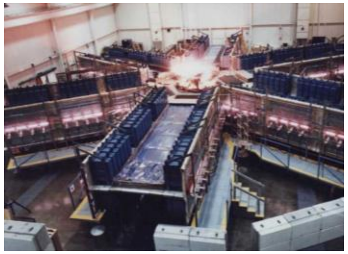
OMEGA: ICF research facility at the Laboratory for Laser Energetics (USA). Laser compression of magnetized pellets



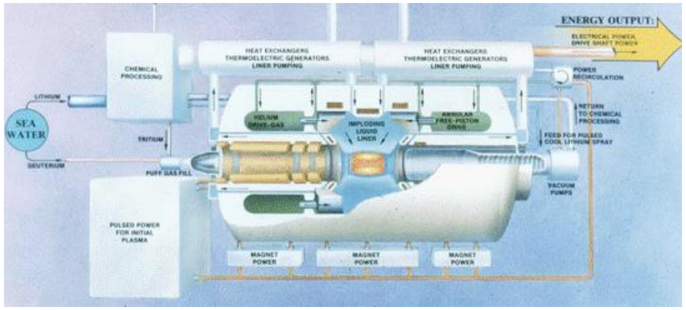


FRX-L: MTF research program at Los Alamos National Laboratory and Air Force Research Laboratory. Program completed in 2013.





LINUS: 1970s era Magnetized Target Fusion research program at Naval Research Laboratory

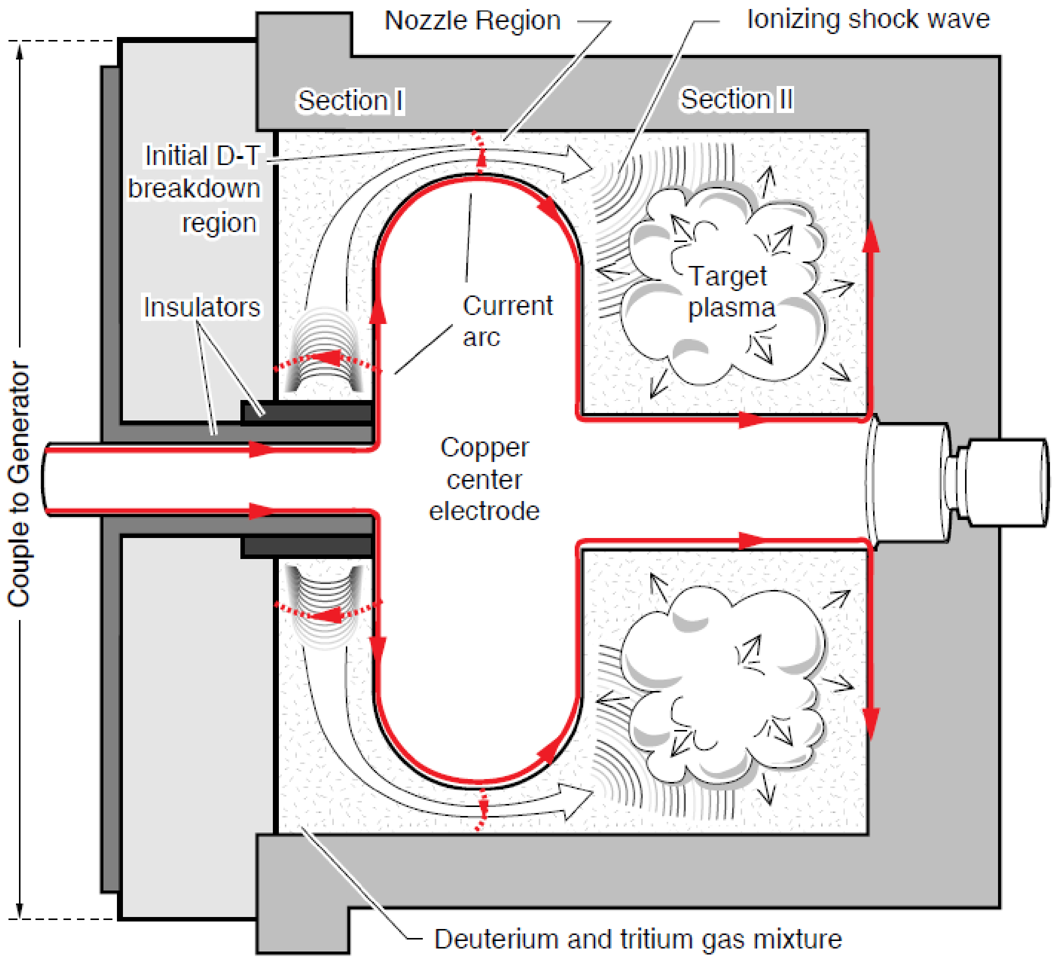


CTX, SSPX: Spheromak research projects at Los Alamos and Lawrence Livermore National Laboratories in the 1990s, no compression

Zap: sheared flow stabilized Z-pinch, University of Washington

MAGO - Russia

generalfusion



Explosive-driven current generator 100 MA

Plasma formation completed

- 300 eV
- 10 T
- 10 µs
- 1×10^{18} cm^{-3}

Explosive-driven mechanical compression not performed

MAGO was shut down in the late 1990s, but may have been restarted

ALPHA portfolio of intermediate density approaches

Los Alamos NATIONAL LABORATORY Plasma liner implosion by merging supersonic plasma jets	Helion Energy Staged magnetic compression of field-reversed configuration plasmas.	W UNIVERSITY of WASHINGTON Shear-flow stabilized Z-pinch pushed to higher density and fusion conditions
BERKELEY LAB Lawrence Berkeley National Laboratory Scalable ion beam driver based on microelectromechanical systems (MEMS) technology	NumerEx Piston-driven implosion of rotating liquid metal liner as fusion driver	SWARTHMORE "Plasma rope" plumes as a potential magneto-inertial fusion target.
Sandia National Laboratories Compression and heating of high energy density, magnetized plasmas at fusion relevant conditions	MIFTI Clean Energy Staged Z-pinch – a radially-imploding liner on a target plasma	CALIFORNIA INSTITUTE OF TECHNOLOGY 1891 Investigate collisions of plasma jets and targets to characterize fusion scaling laws

Some other fusion companies

Tokamak Energy (UK): High temperature superconductor spherical tokamak

First light (UK): shock wave collapse bubbles and accelerate material to ultrahigh velocity (1000 km/s). Stopping this high velocity material increase temperature to fusion temperature

Fusion Power Corporation (USA): Inertial fusion driven by particle beams

CT Fusion (USA): DC spheromak with helicity injection called Dynomak

MIFTI (USA): Two stages Z pinch

Why private fusion now

generalfusion

- Physicists believe ITER will work, we now know how to do fusion
- ITER cost and time line excessive for private
- New scheme less advanced, less likely to work, but if it works faster and cheaper
- Max ~10 years to prototype power plant for private
- Patient capital can wait that long
- Venture Capital max ~5 years. Must be bought out by the big guys (GE, Westinghouse, etc) after results impressive enough to get their attention
- ~500 M$ private investment so far, starting to be real money
- Many lower probability companies, good chance one will pan out, hopefully General Fusion