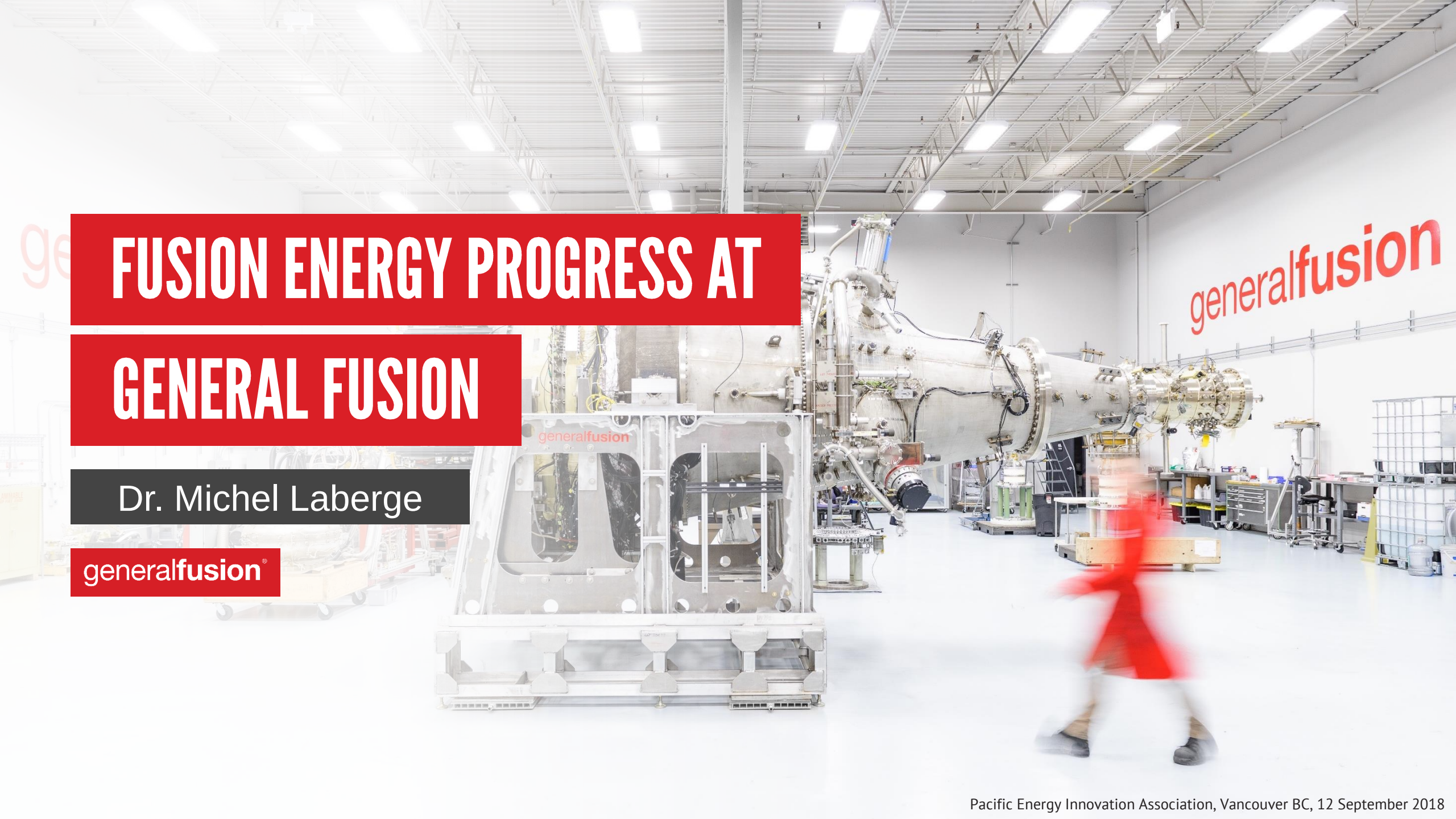
FUSION ENERGY PROGRESS AT GENERAL FUSION

Dr. Michel Laberge

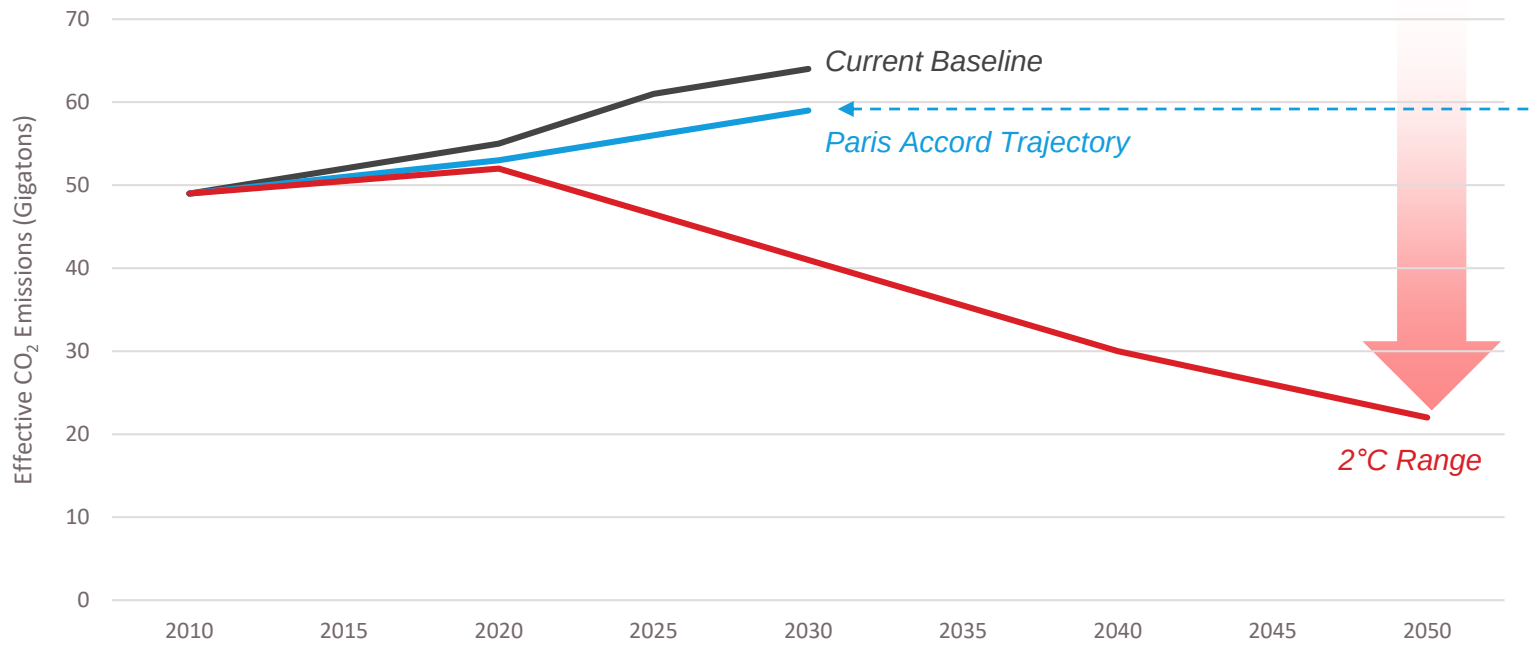
generalfusion®



Pacific Energy Innovation Association, Vancouver BC, 12 September 2018

Current Carbon Emission Reduction Plans are Insufficient

Paris Accord Emission Reduction Goals



Reductions set forth in Paris Agreement

Massive additional reductions are necessary to limit global temperature increase to below 2°C by 2100

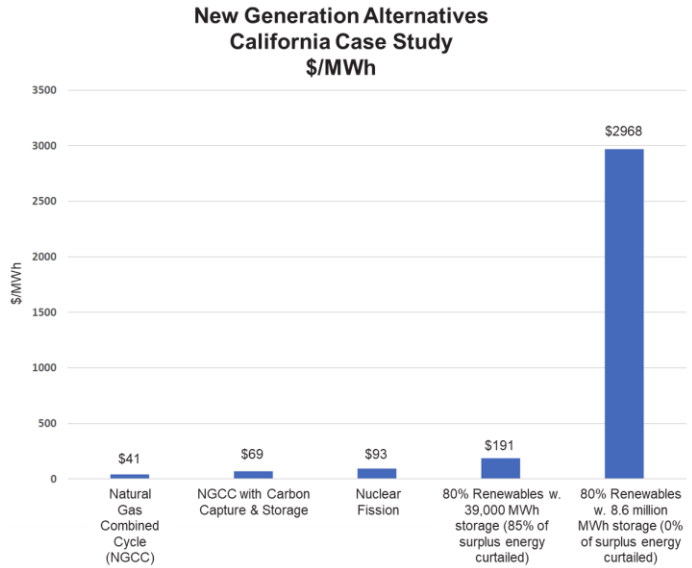
Although renewables are growing more rapidly than other energy production, they are inadequate to significantly curtail climate change

Energy is single largest source of carbon emissions … no practical complement to renewables exists

Source: Global Energy Consumption, Global Trends in Renewable Energy Investment 2017, United Nations Environment Program Emissions Gap Report (2016).

Fusion is a Long-Term Clean Energy Solution…

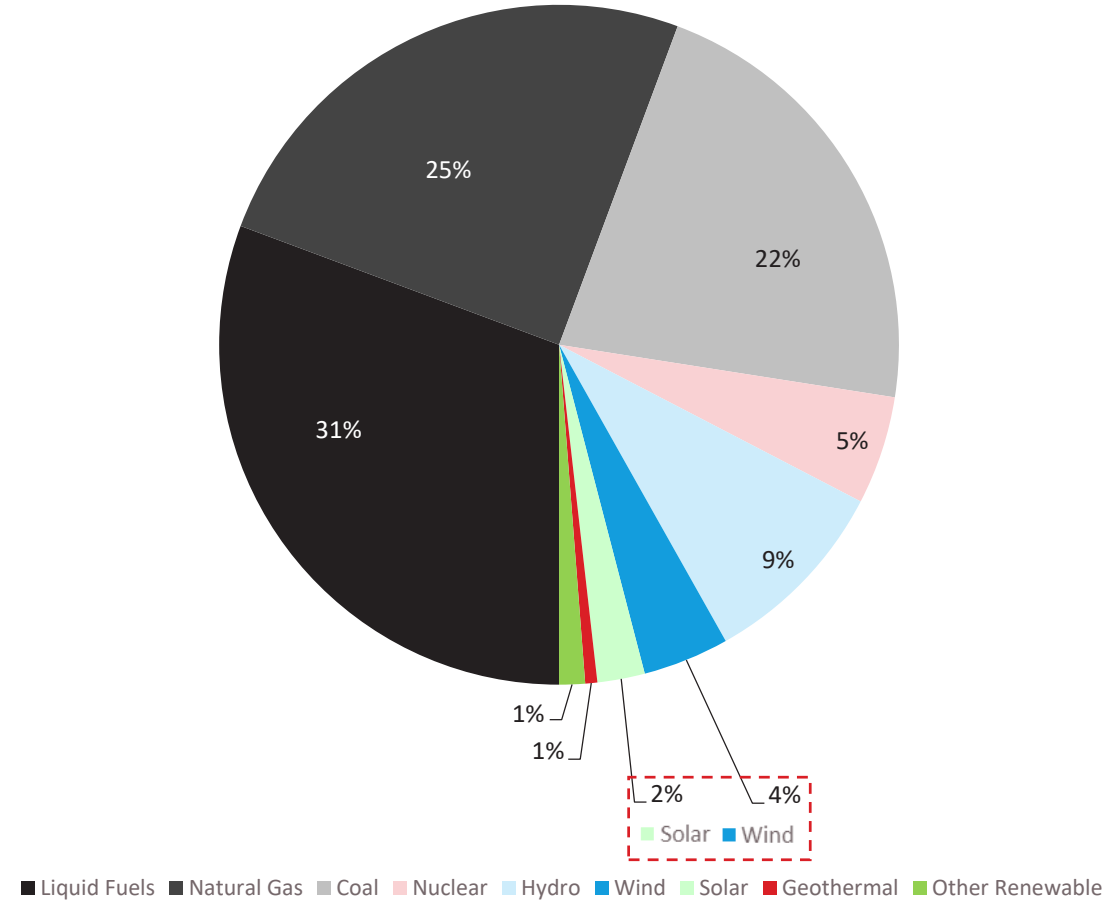
- Over 50% of renewable electricity is from hydro
- Solar & wind are forecast to make up **only ~6% of energy mix** by 2040
- Renewables limited by: high land utilization, costly transmission lines, location, intermittent power generation, and storage / battery capacity



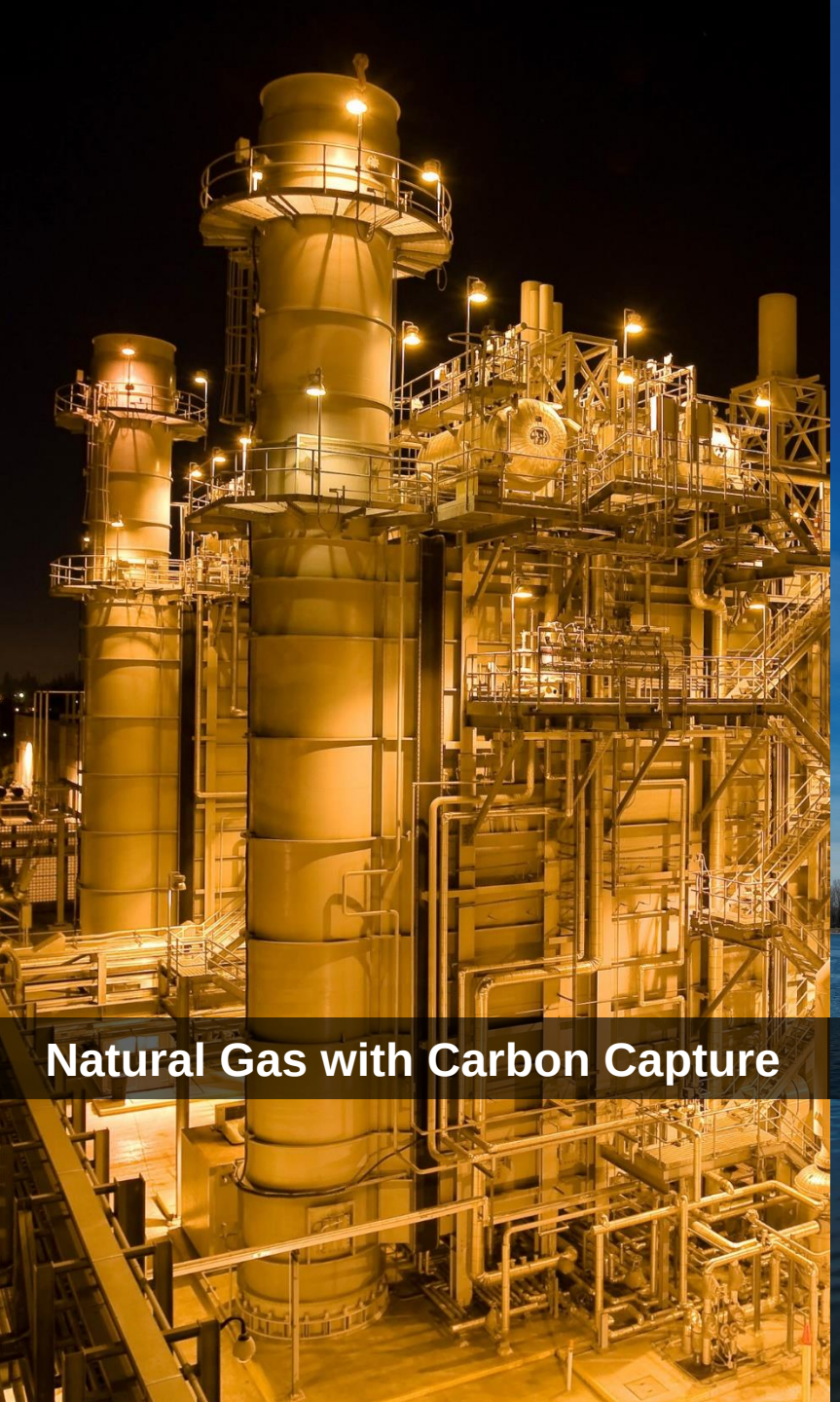
Source: Brick & Thernstrom, 2016. Renewables and decarbonization: Studies of California, Wisconsin and Germany

Solar and Wind are a Small Fraction of Energy Production

Energy Mix in 2040

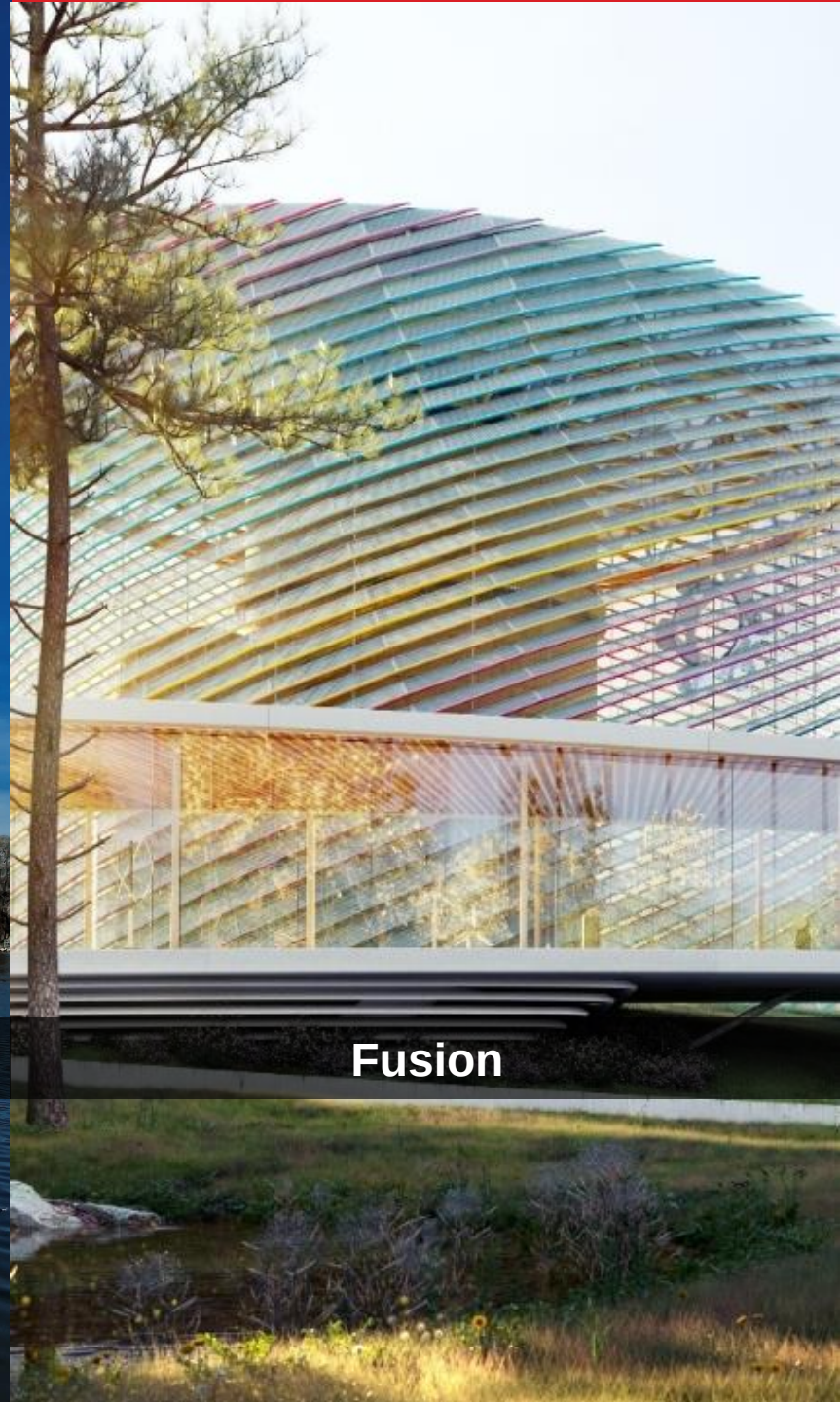


Source: Global Trends in Renewable Energy Investment 2017, BP Energy Outlook 2017, U.S. Energy Information Administration



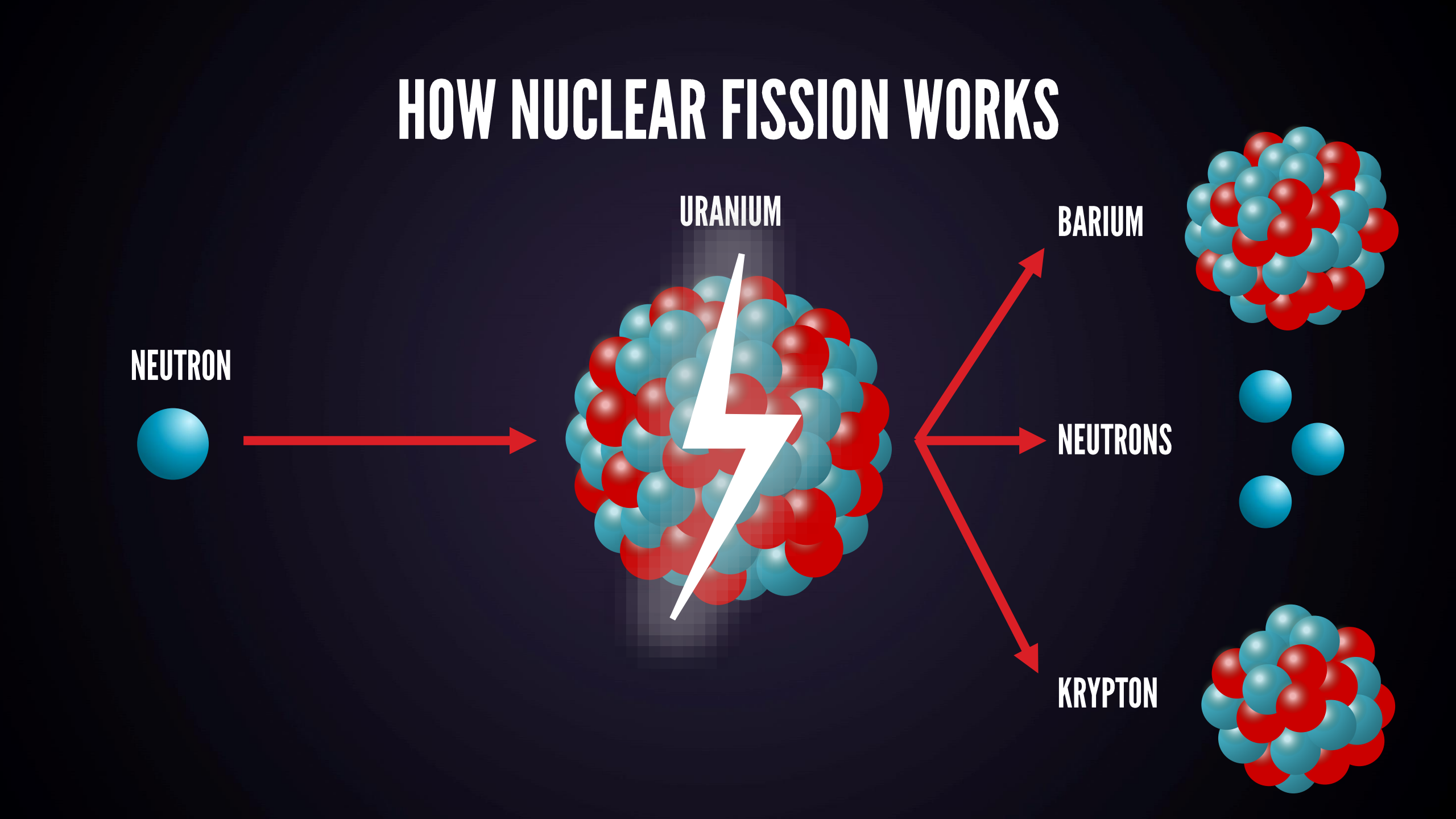
Natural Gas with Carbon Capture

Nuclear Fission

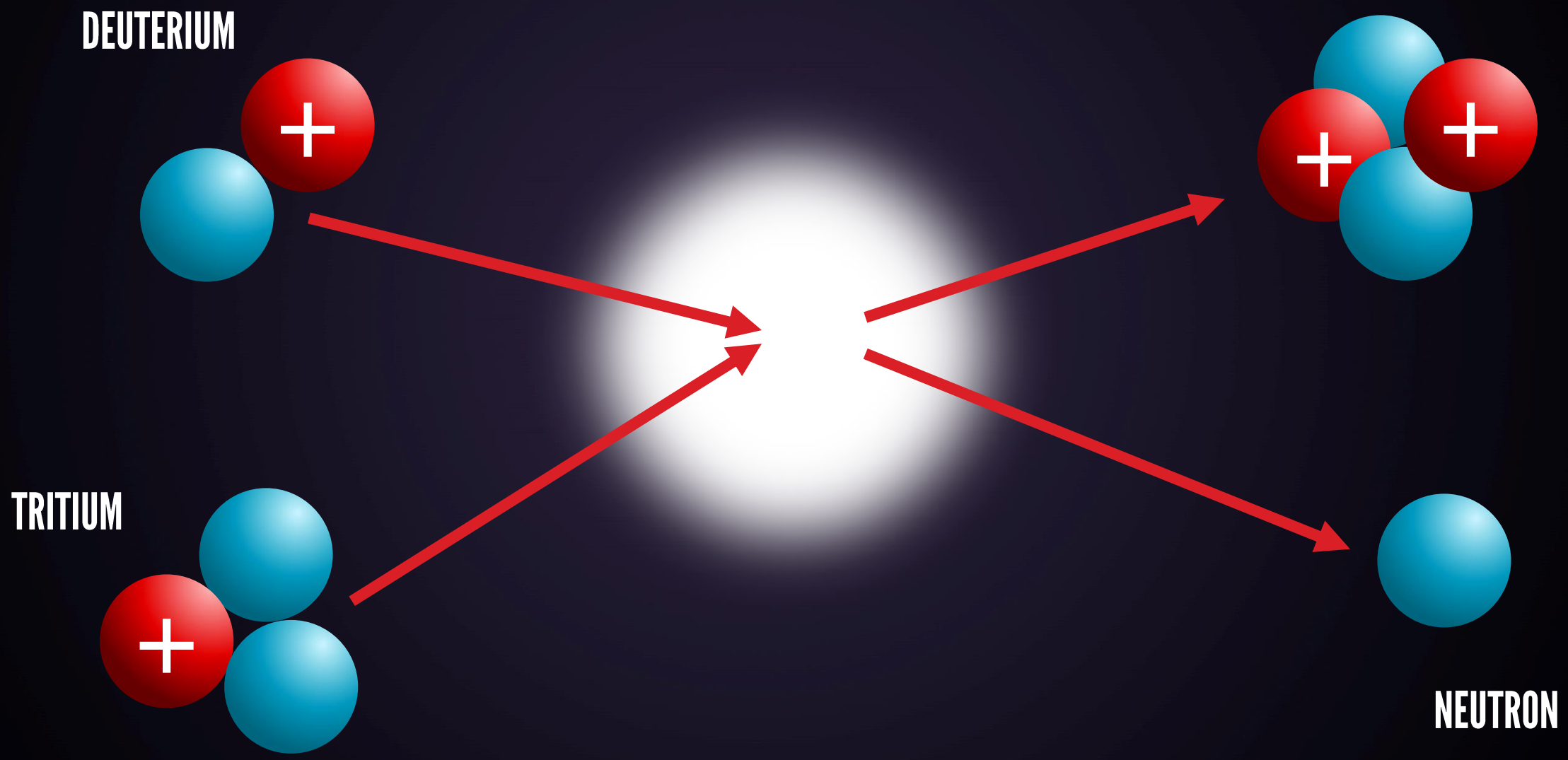


Fusion

HOW NUCLEAR FISSION WORKS



HOW FUSION WORKS



Fusion: Zero emission, on-demand electricity that is plentiful and safe

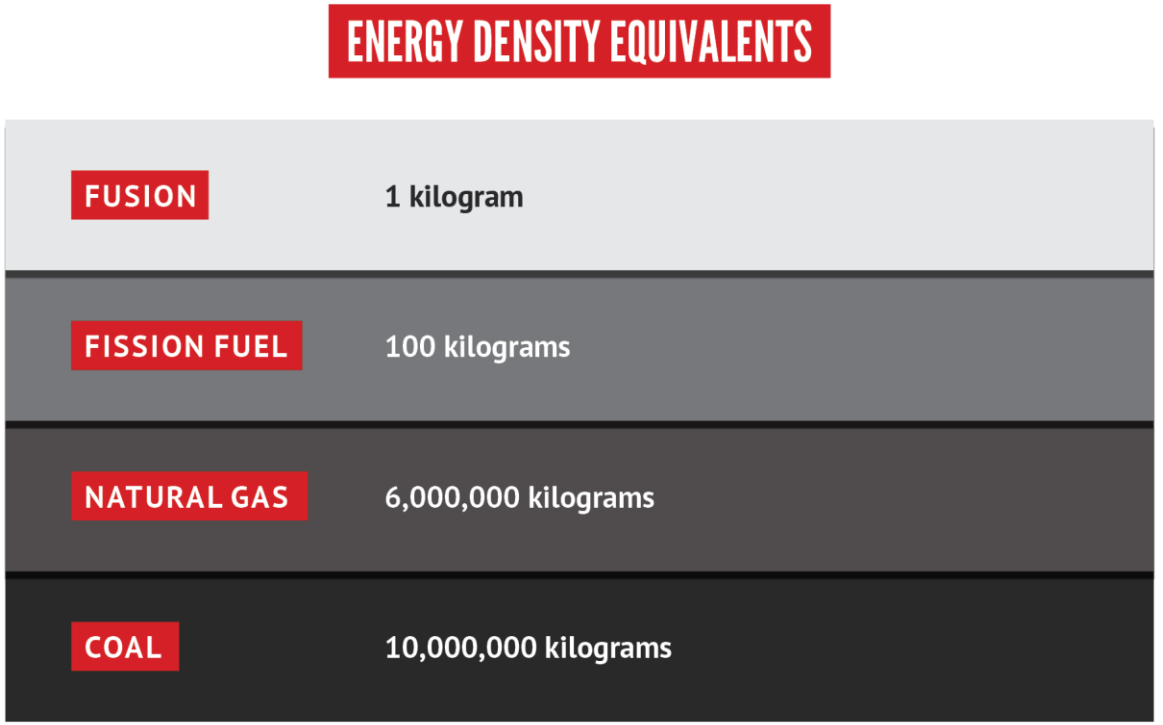
Clean: No GHG emissions

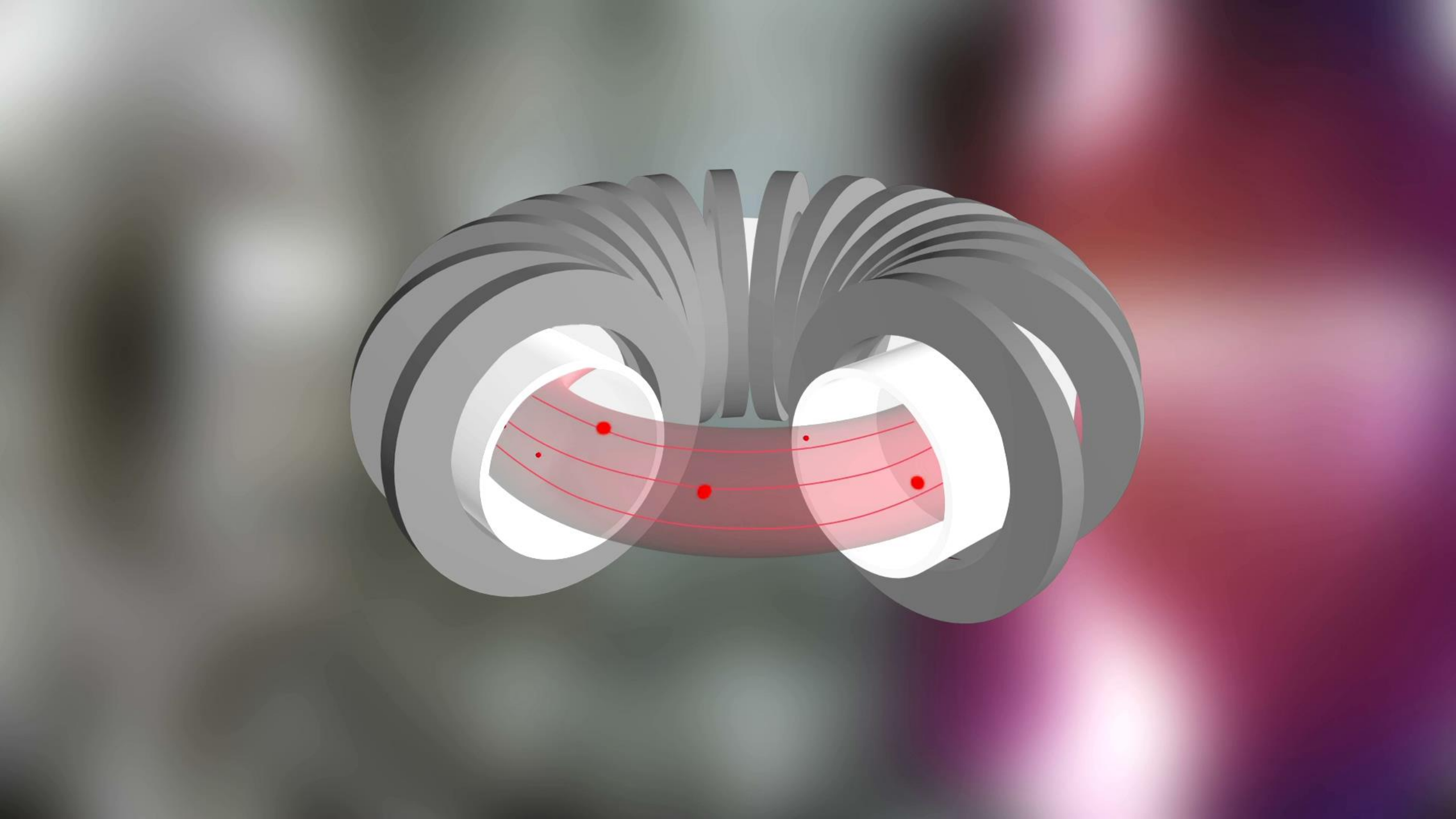
Safe: Meltdown impossible and no long lived waste

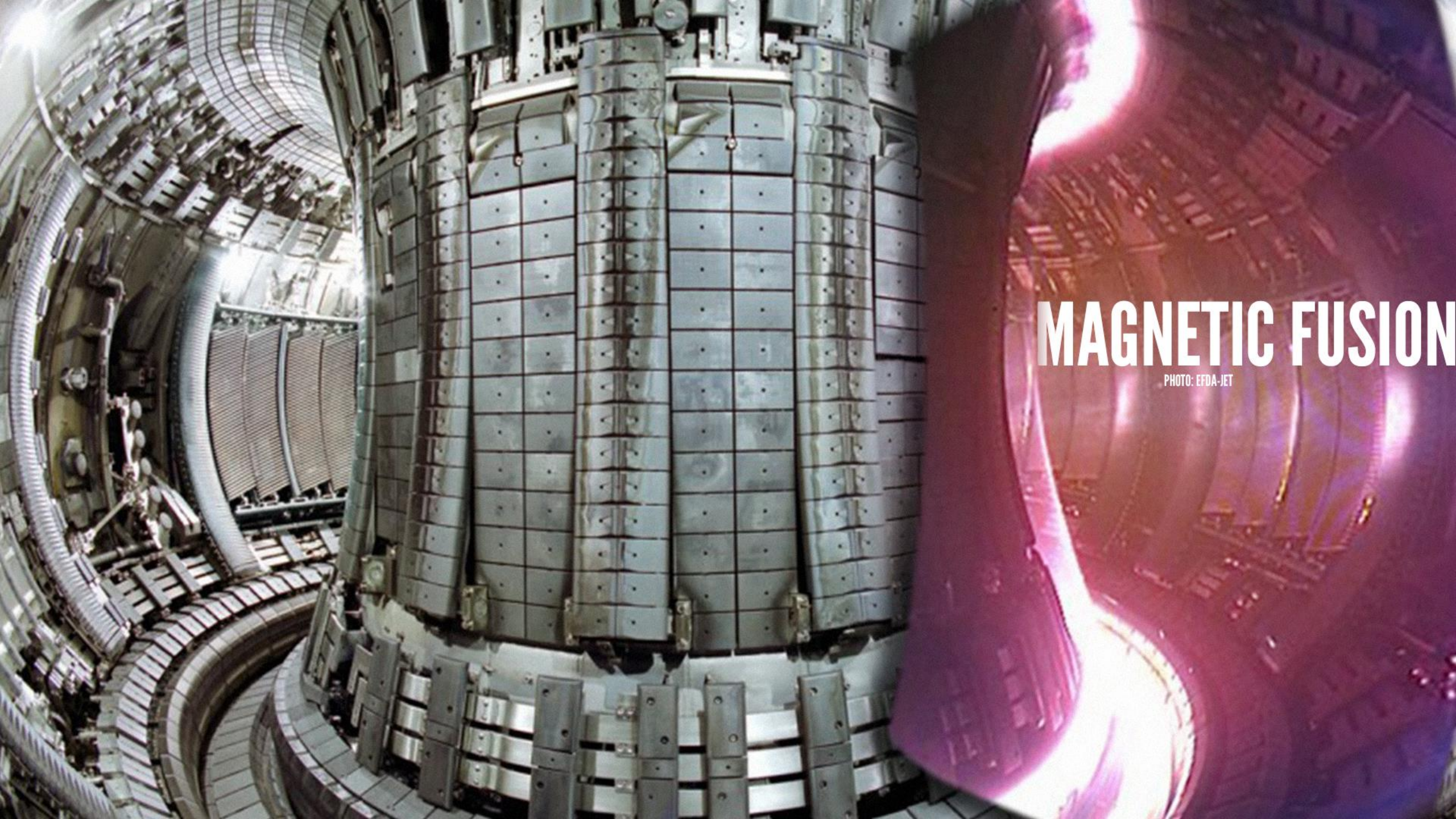
Abundant: Fuel derived from sea water, millions of years worth available

On-Demand: Able to provide baseload power around the clock

Cost-competitive: Effectively zero fuel cost, high density energy

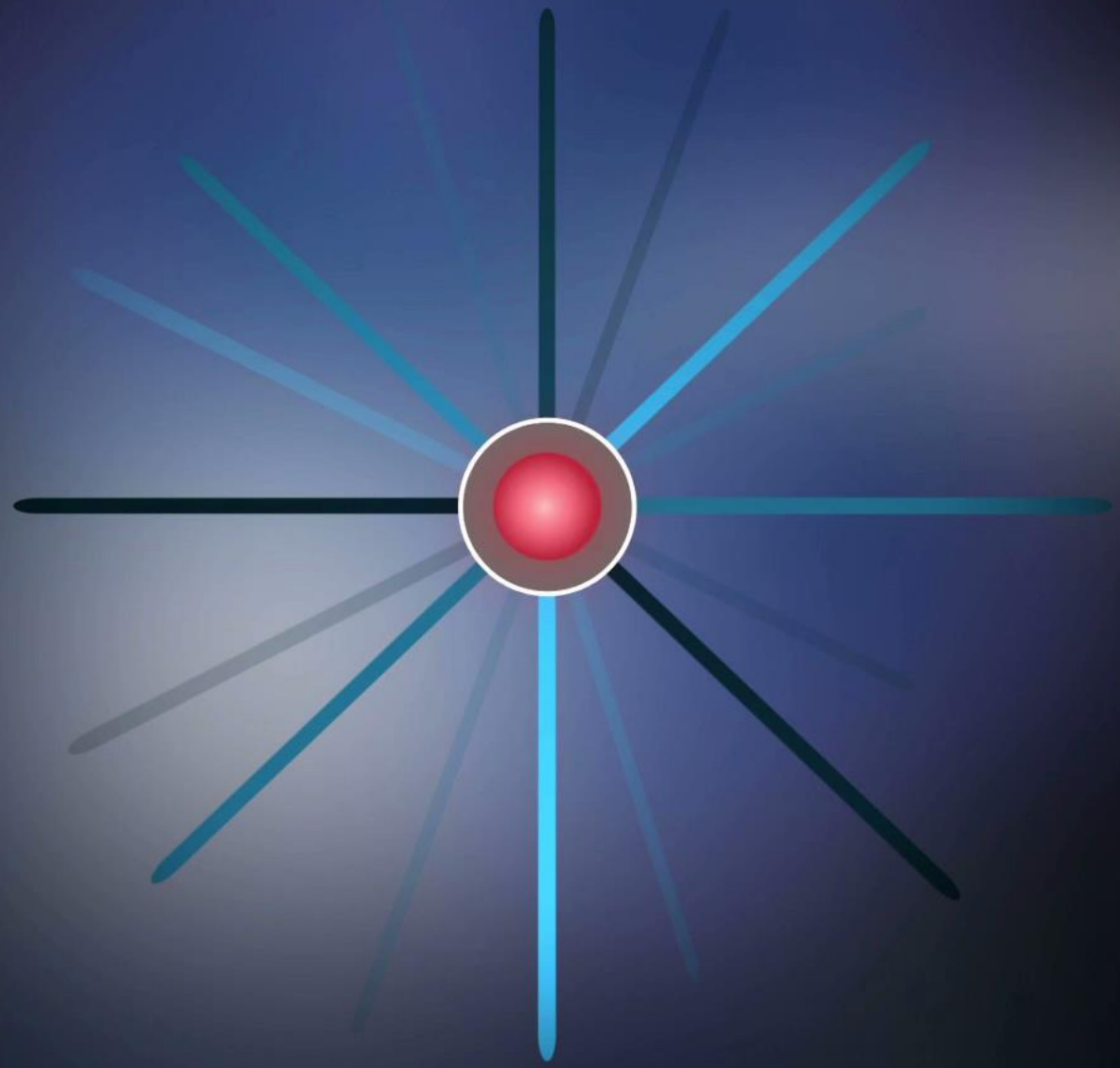






MAGNETIC FUSION

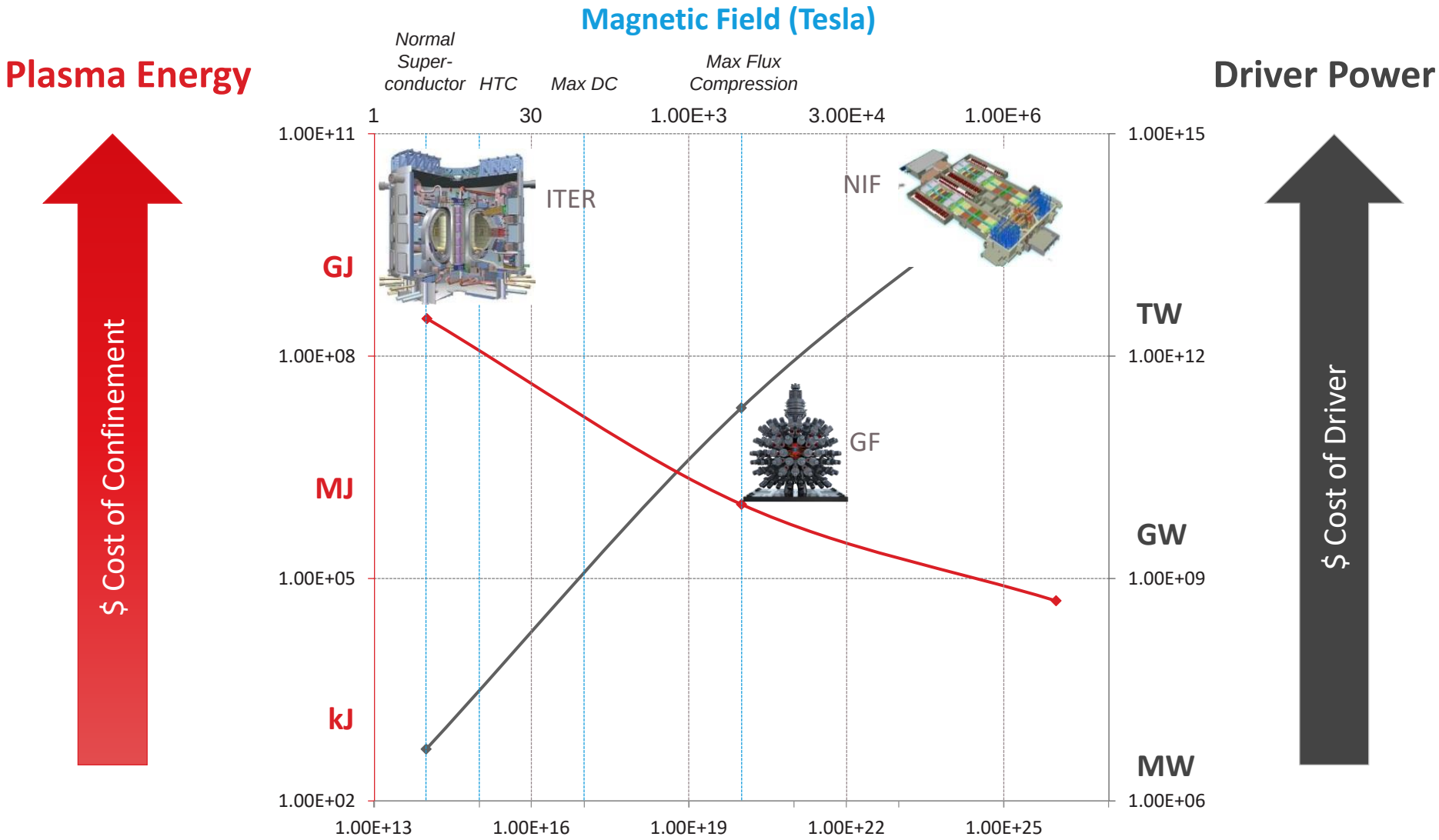
PHOTO: EFDA-JET

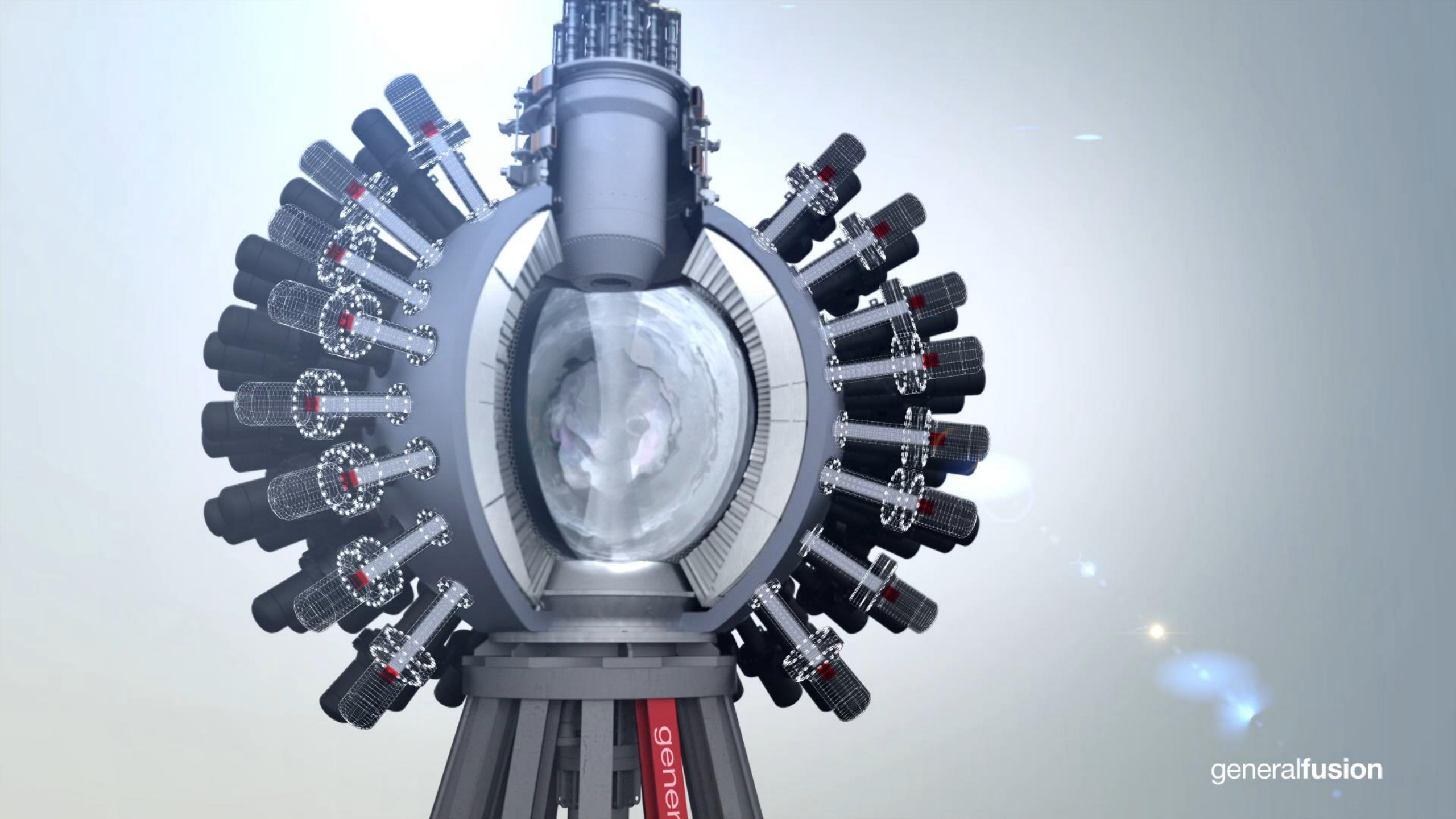


LASER FUSION

PHOTOS: LAWRENCE LIVERMORE NATIONAL LABORATORY / XREZ

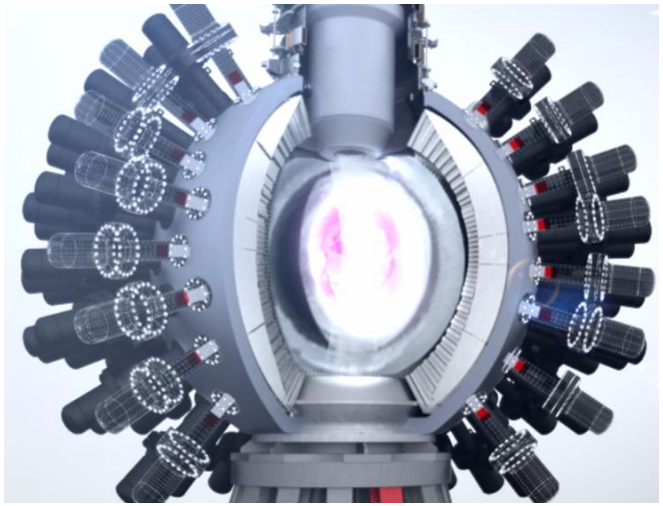
Fusion Technology Comparison




generalfusion

Resolving the Traditional Barriers to Fusion

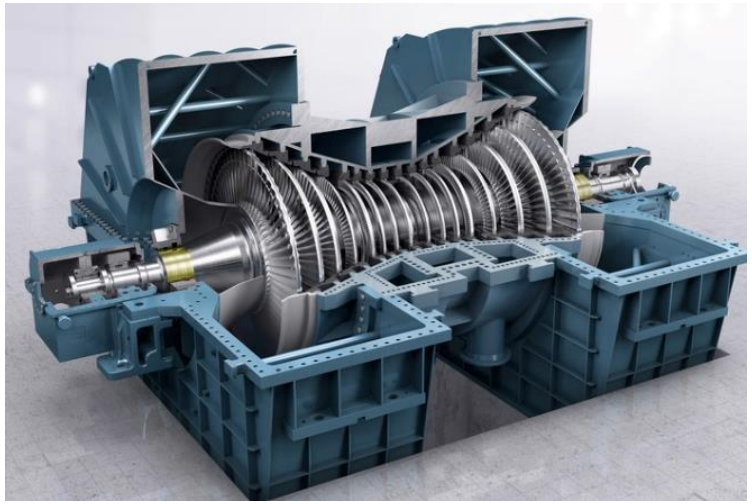
Fusion Conditions



General Fusion's pulsed fusion process eliminates the need for complex and costly:

- Long heat confinement
- Complex plasma heating systems
- Consumable fuel targets

Energy Conversion



General Fusion's energy conversion system uses proven energy technology:

- Proven liquid metal heat exchanger
- Conventional steam turbine/generator
- Inexpensive compressed gas driver

System Durability

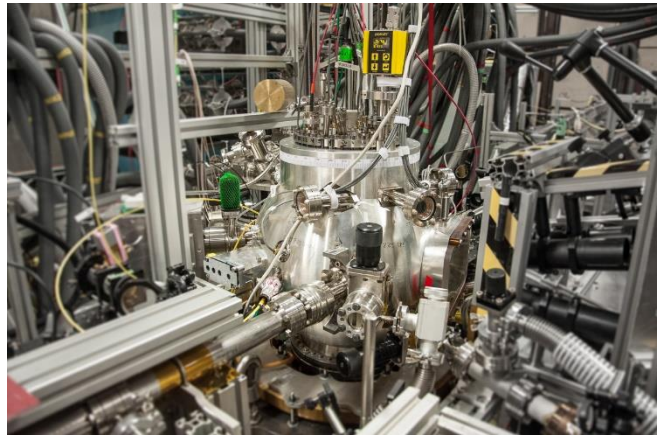
General Fusion's liquid-metal plasma compression and fusion cavity avoids:

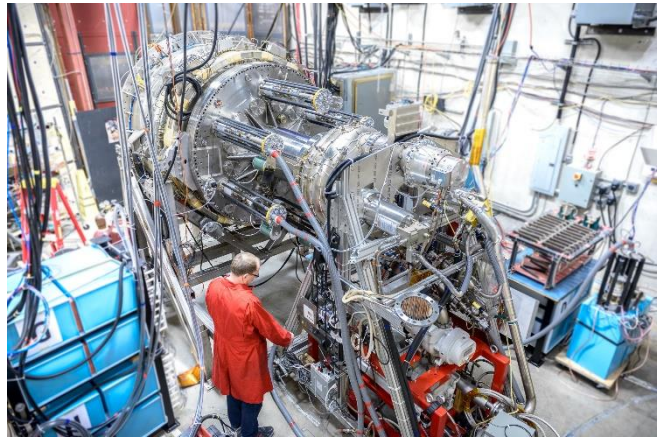
- Solid materials neutron degradation
- Problem of insufficient tritium creation

A uniquely practical solution to the challenges of fusion

Component Level Development

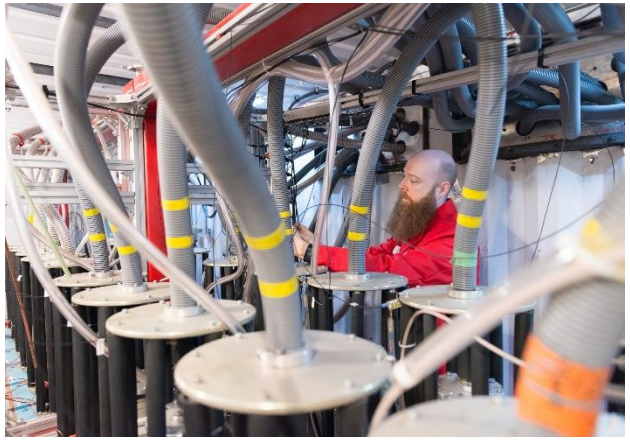
Plasma Formation





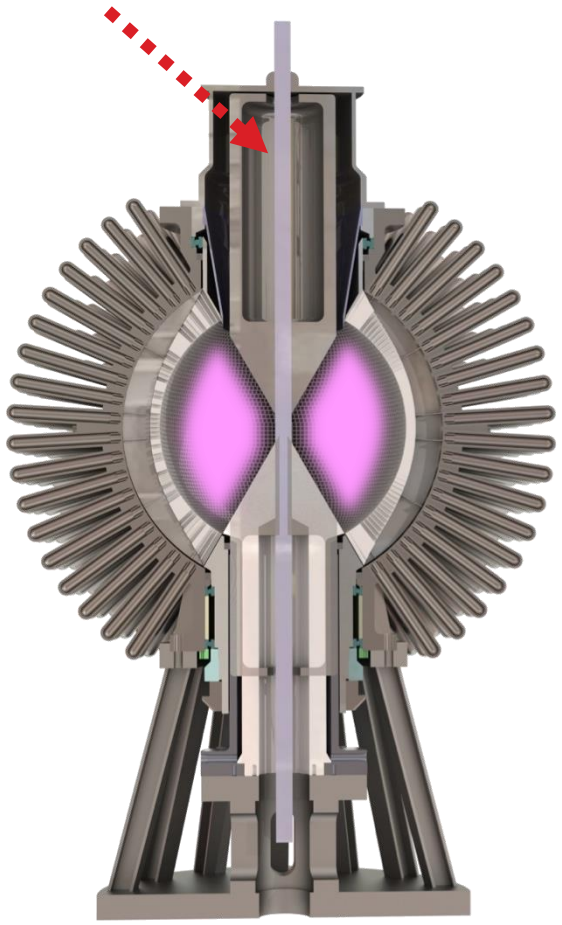
Liquid Metal Systems

Plasma Compression



Plasma formation

Plasma Injector



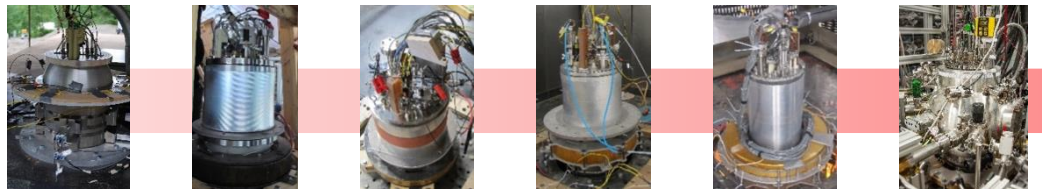
World's biggest and most powerful plasma injectors

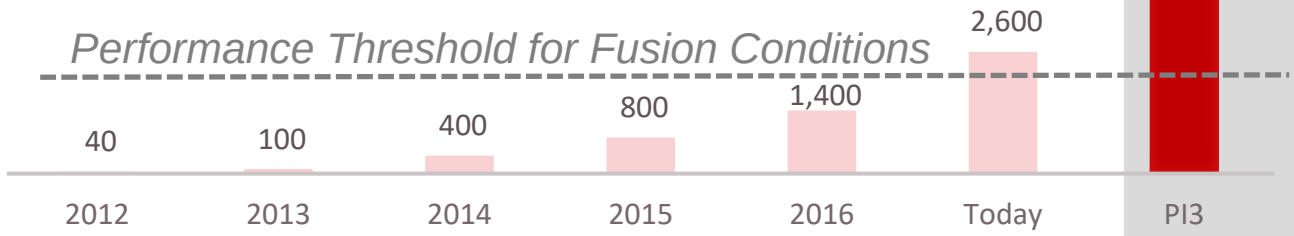
500 eV pre-compression plasma with life-time >2,600 microseconds

Developed and operated 18 generations of injectors since 2010

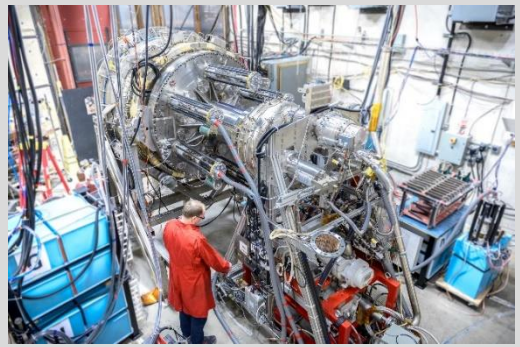
Library of over 150,000 plasma experiments

Plasma Performance - Lifetime in Microseconds



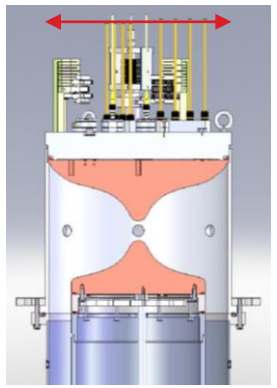


PI3 Prototype-Scale Plasma Injector

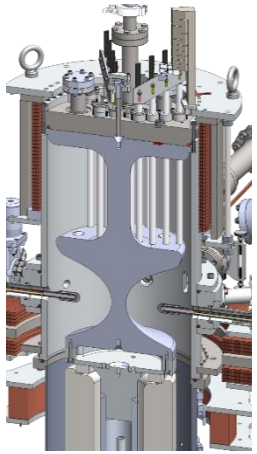


Small plasma injectors

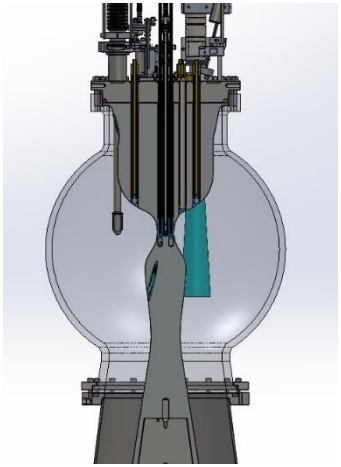
- Built on a reduced scale to reduce iteration time and expense
- Allow a variety of geometries and magnetic field configuration to be explored
- 15 small injectors built so far
- SPECTOR has achieved 500 eV, lifespan >3,300 μs



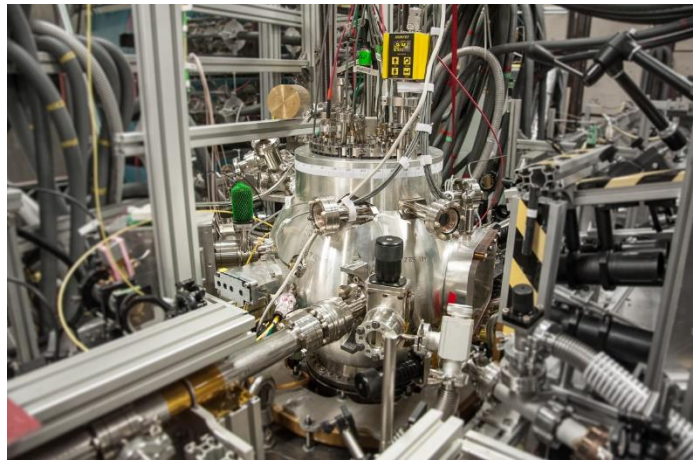
***MrT* : Magnetic Ring Test**



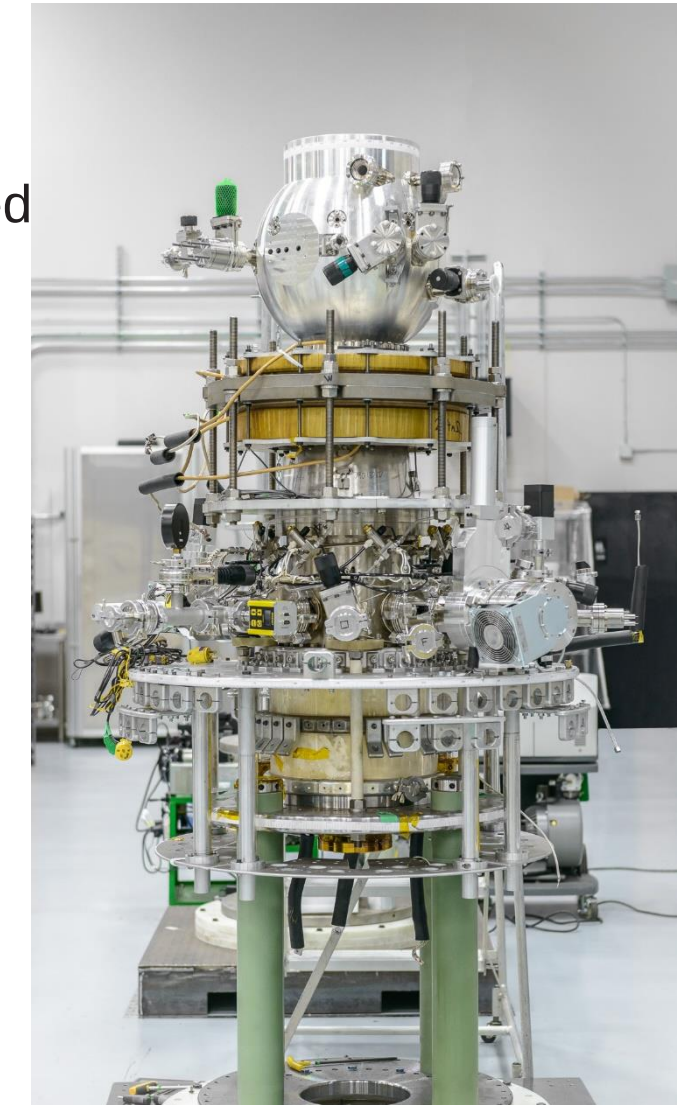
PROSPECTOR



SPECTOR **Sp**herical **C**ompact **Tor**oid

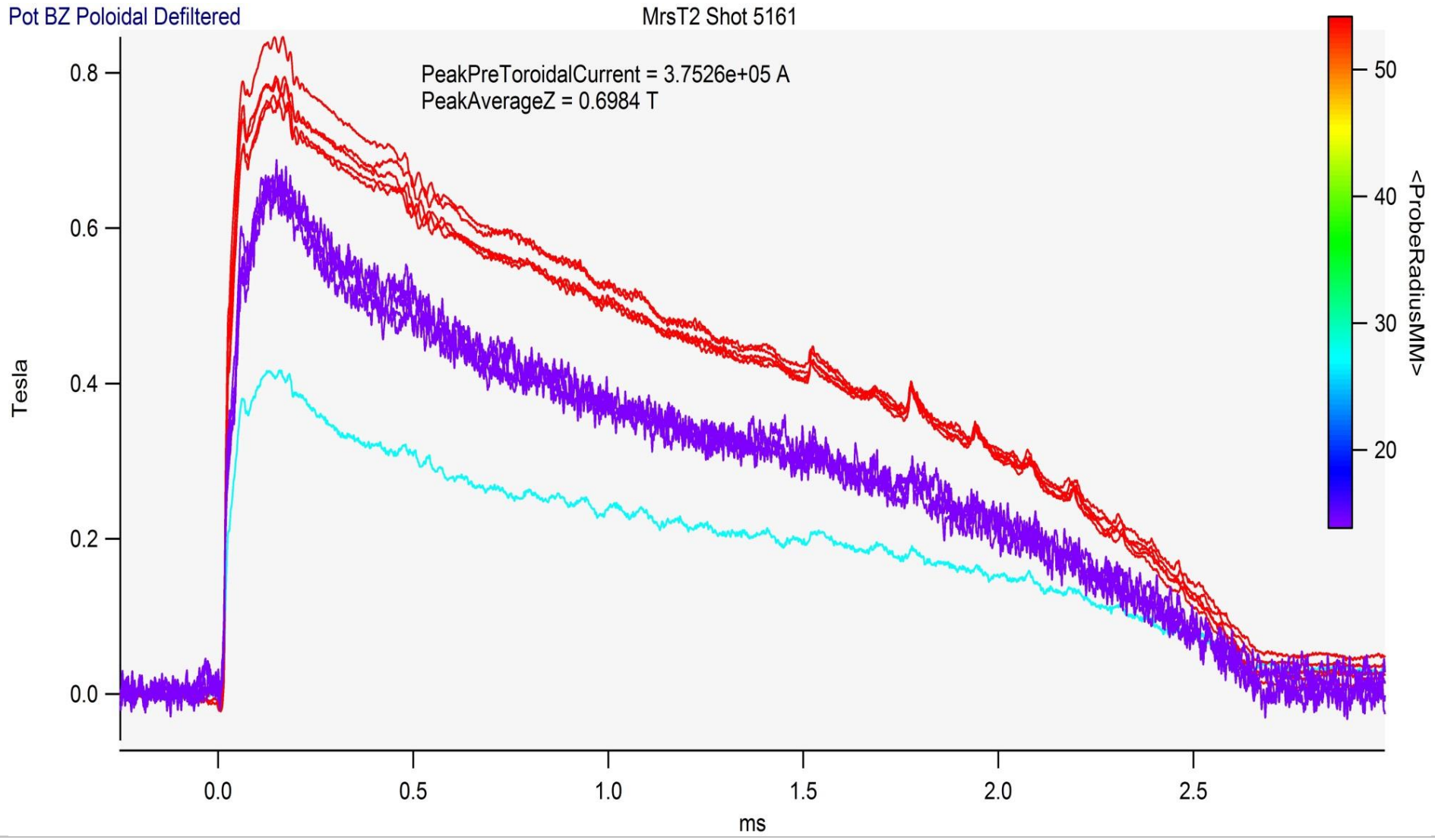


SPECTOR in lab with diagnostics



SPECTOR injector

Spherical tokamak: 500 eV measured by Thomson Scattering

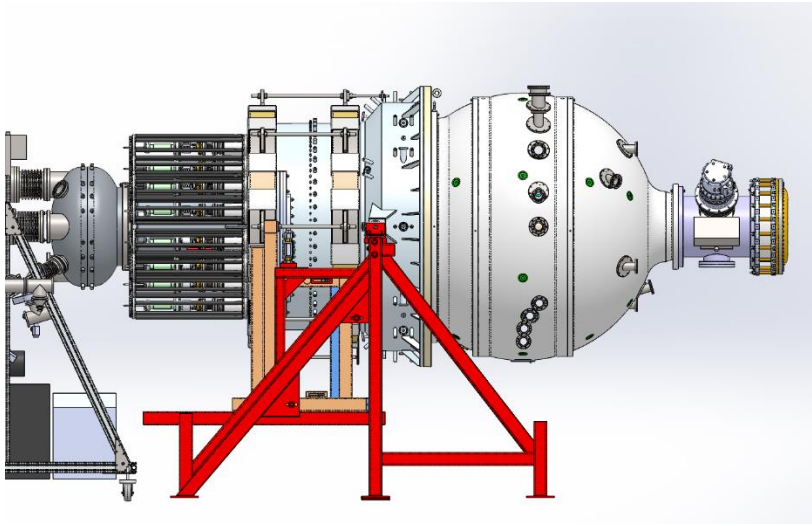


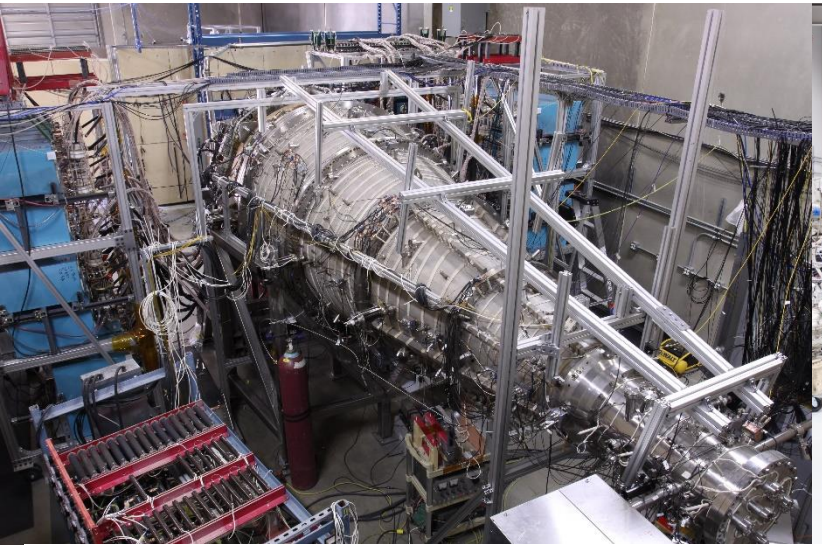
2017

- 2600 µs lifetimes
- 500 eV

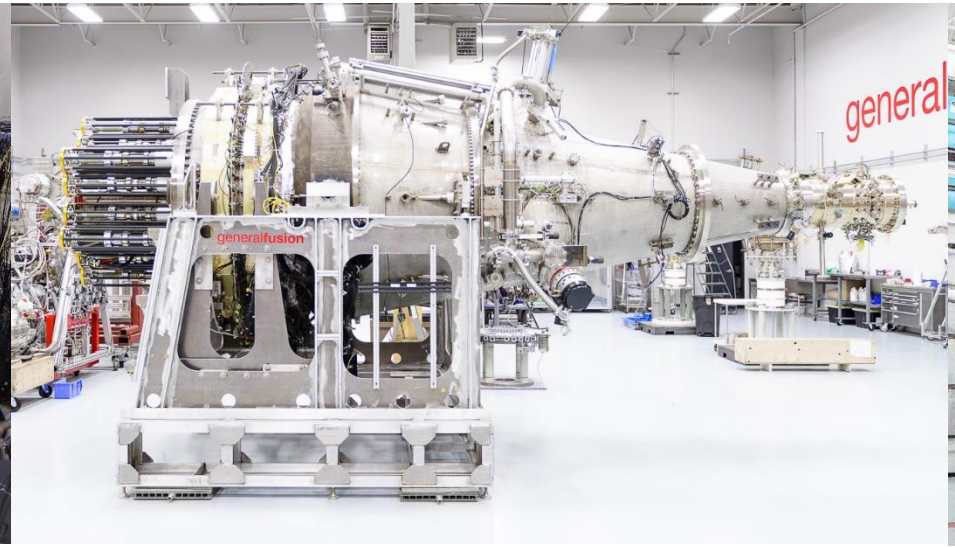
Large plasma injectors

- Injectors built to a similar scale as expected for power plant
- Pi1 and Pi2 demonstrated magnetic compression heating of a spheromak to over 400 eV and 3.2T magnetic fields
- Pi3 first plasma at end of 2017

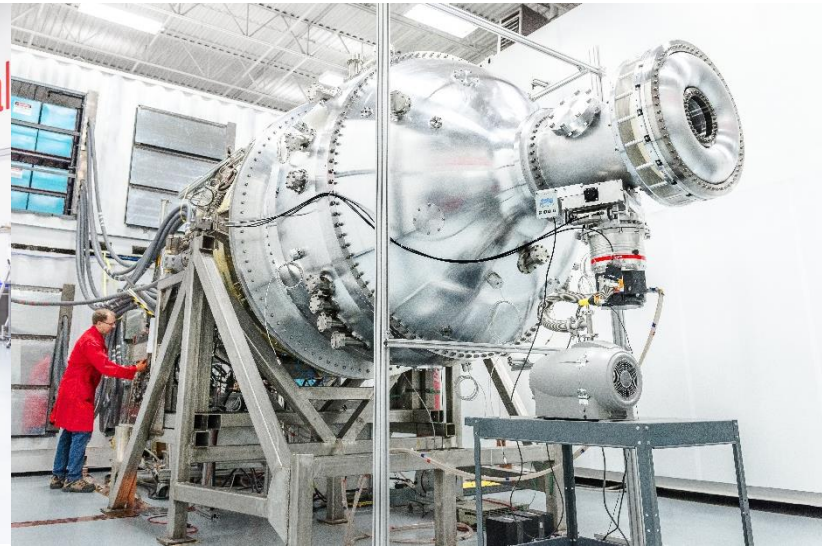




Pi1



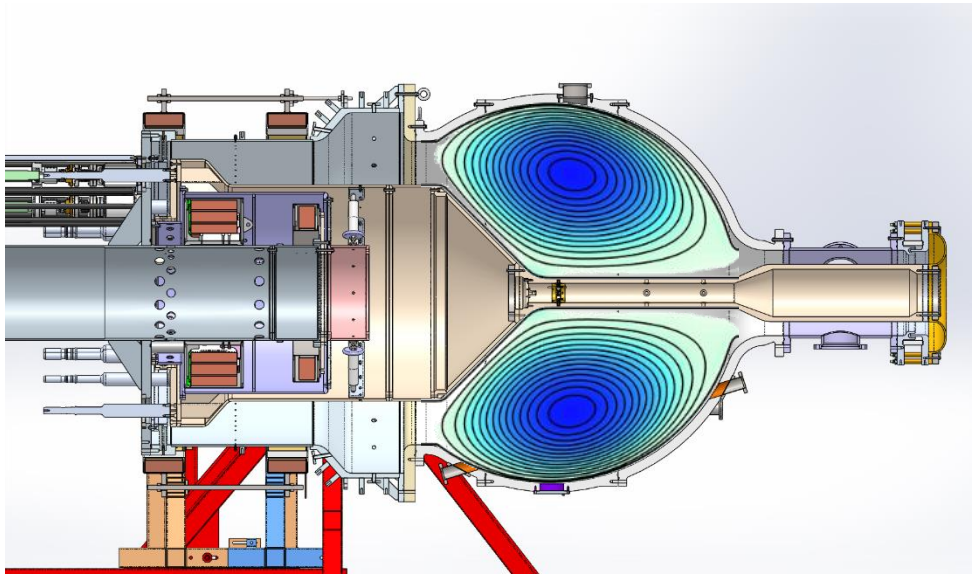
Pi2

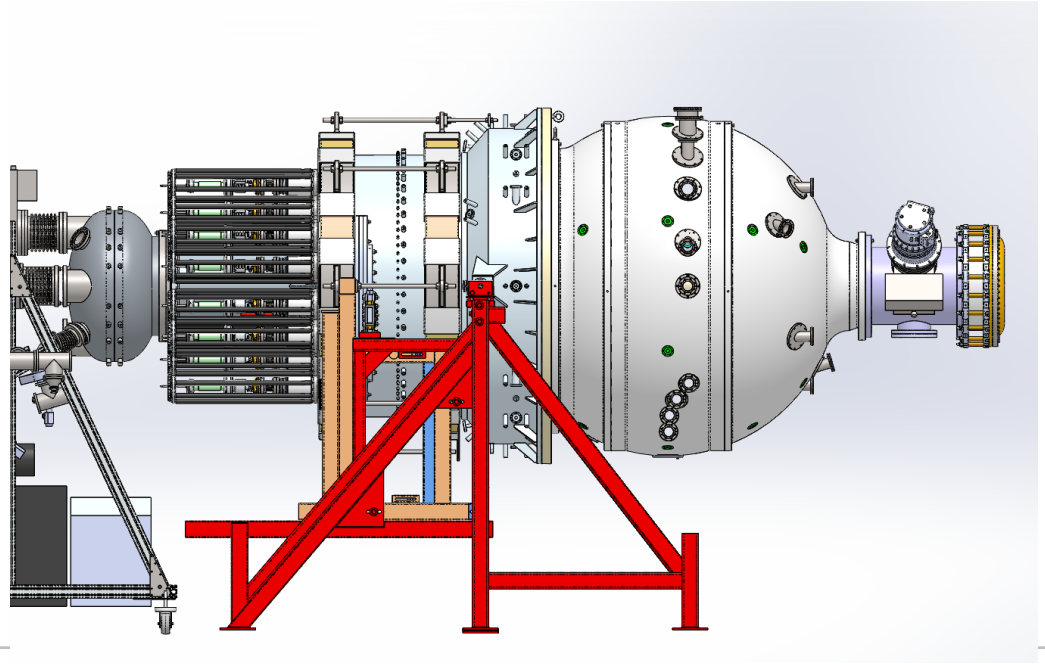


Pi3

Pi3 large injector

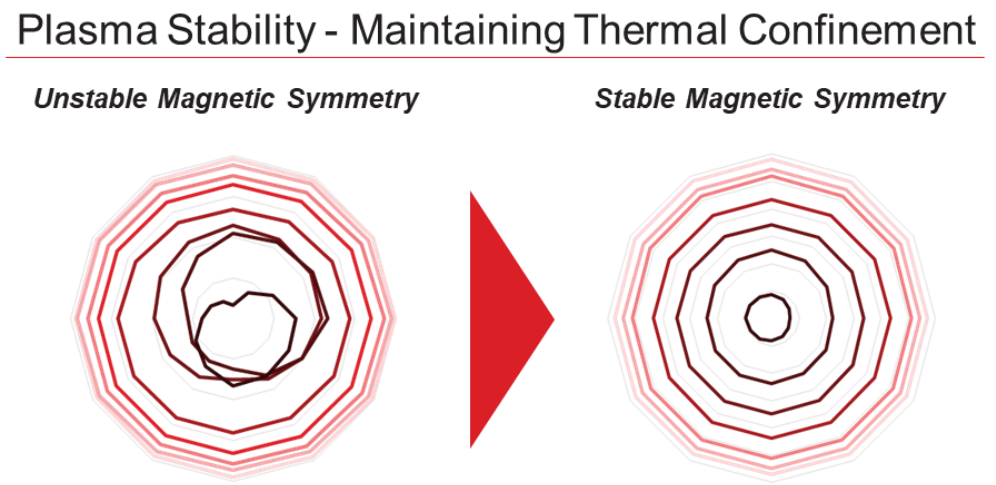
- Spherical tokamak plasma target
  - Major radius: 0.6-0.7 m
  - Temperature $T_{electron}$ ~ T_{ion}: 100-500 eV
  - Plasma lifespan expected (size): 50 ms
  - 10 MJ capacitor bank



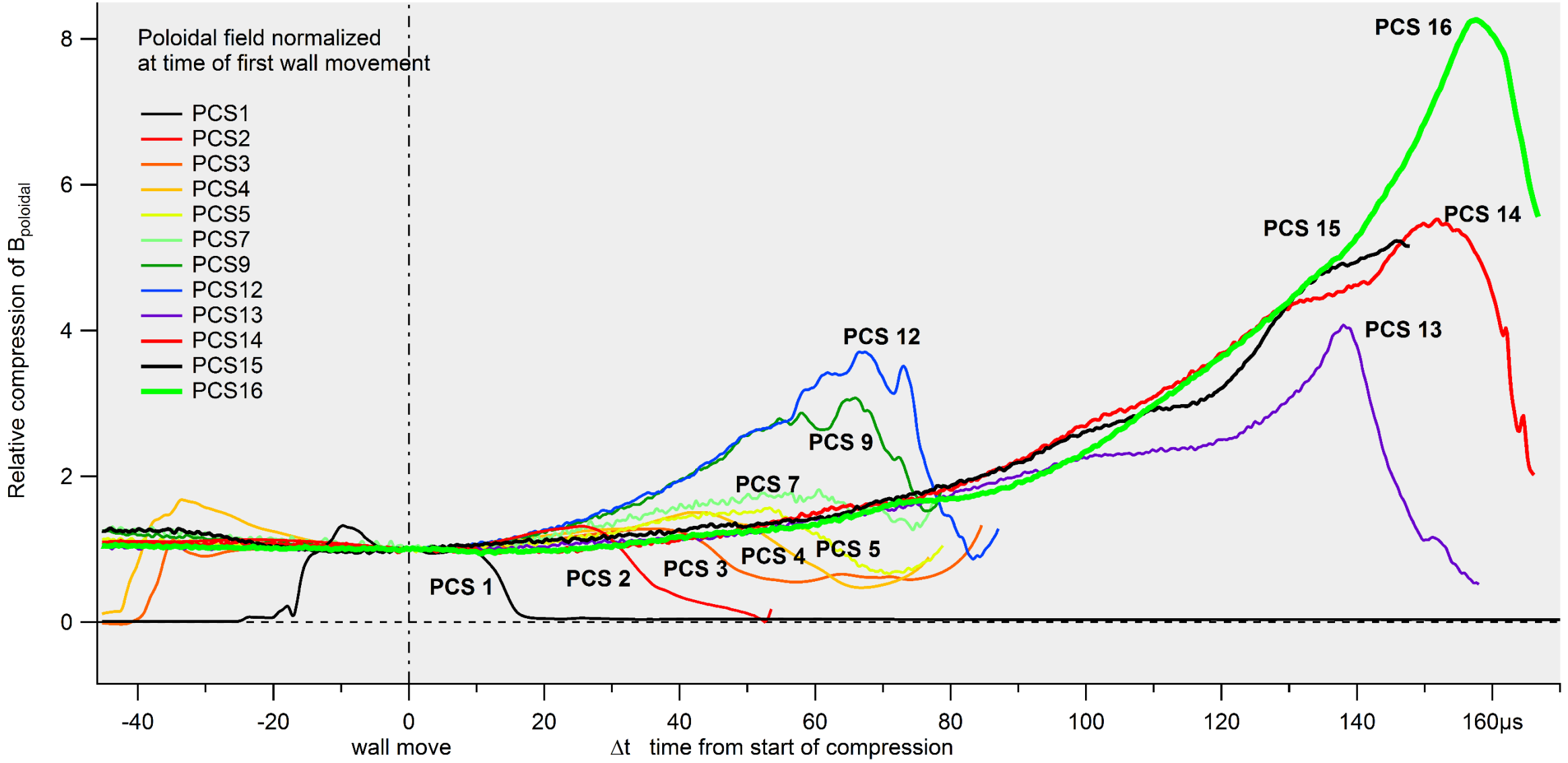


Plasma compression

- Mechanical compression of magnetized plasma
- Major advances in plasma systems, materials, coatings, and diagnostics
- Recent experiments show good magnetic stability

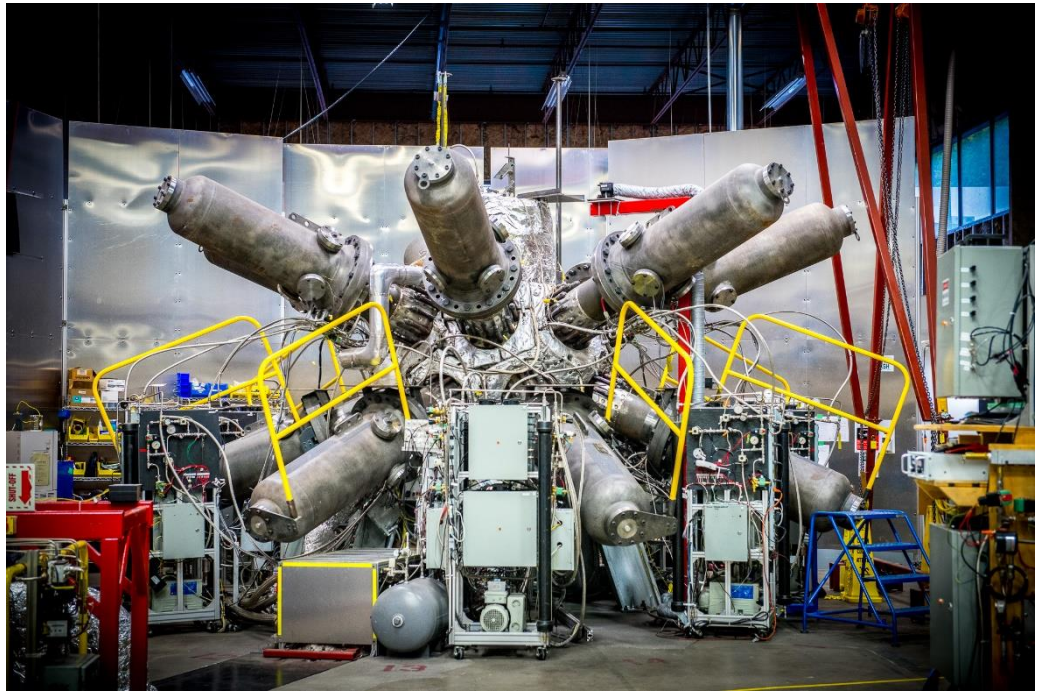


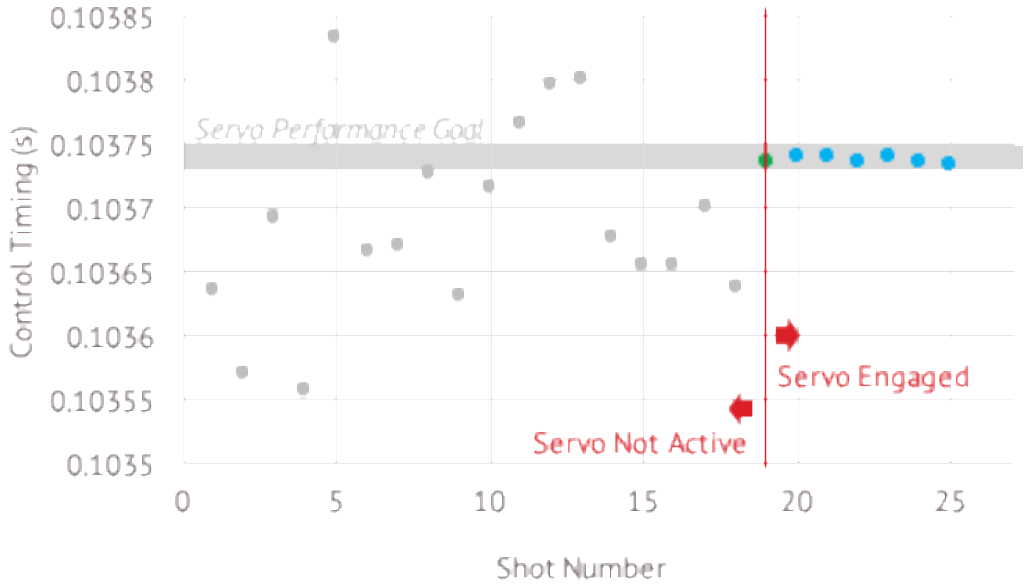
All PCS Shots: Poloidal Field Compression



Compression technology

- Compression of 400°C liquid lead liner with pistons
- Demonstrated synchronization accuracy of +/-2 µs with frictionless servo
- Cavity formation and stabilization





Compression Driver Control System Performance

Big Data

General Fusion has conducted >150,000 plasma shots to date

Each shot generates ~500 Mb of data

Partnering with Microsoft to create new analysis tools and share data with the scientific community

Aurora project – plasma data in the cloud

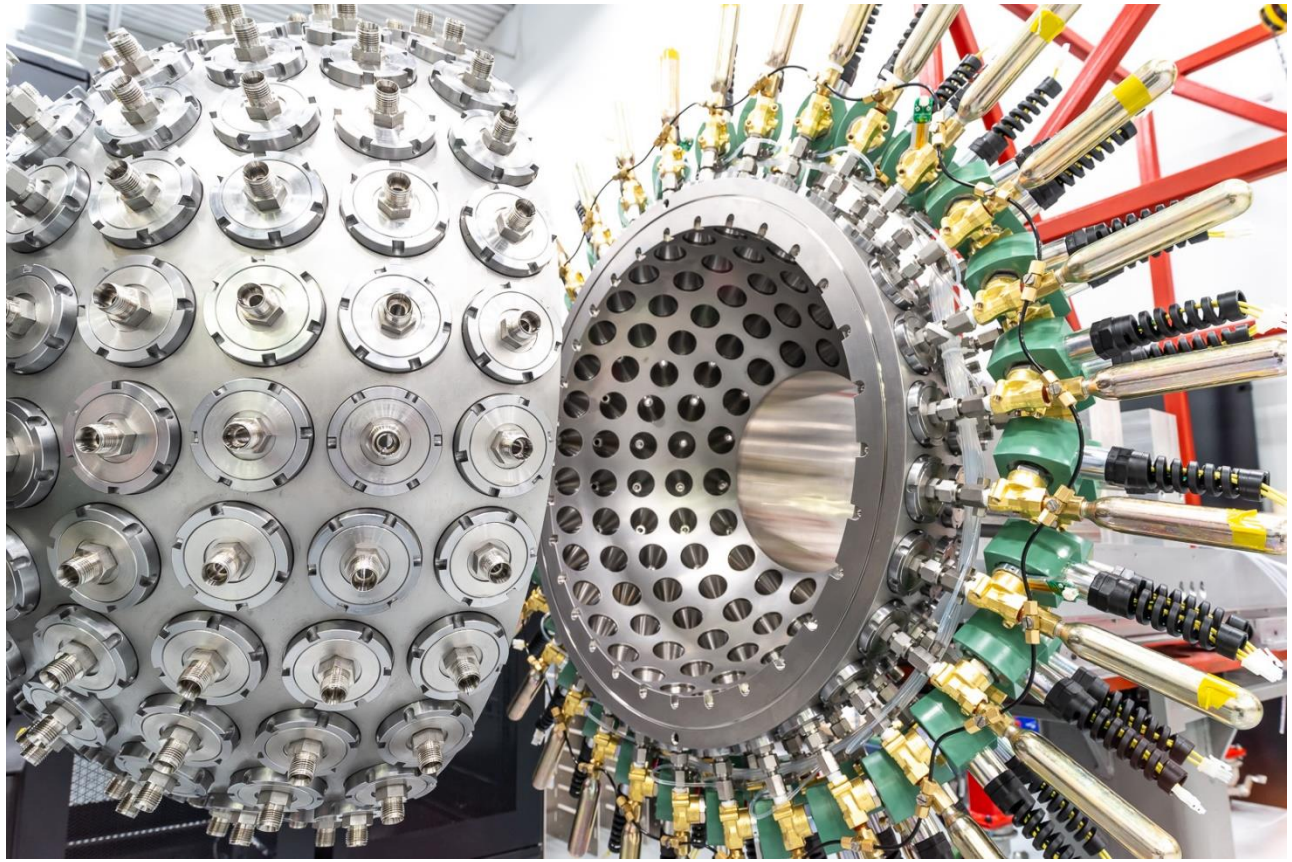
Big data + machine learning

Additive Manufacturing

Additive Manufacturing = industrial scale 3D printing

Ability to create shapes not possible before

Important applications in stabilizing liquid metal wall

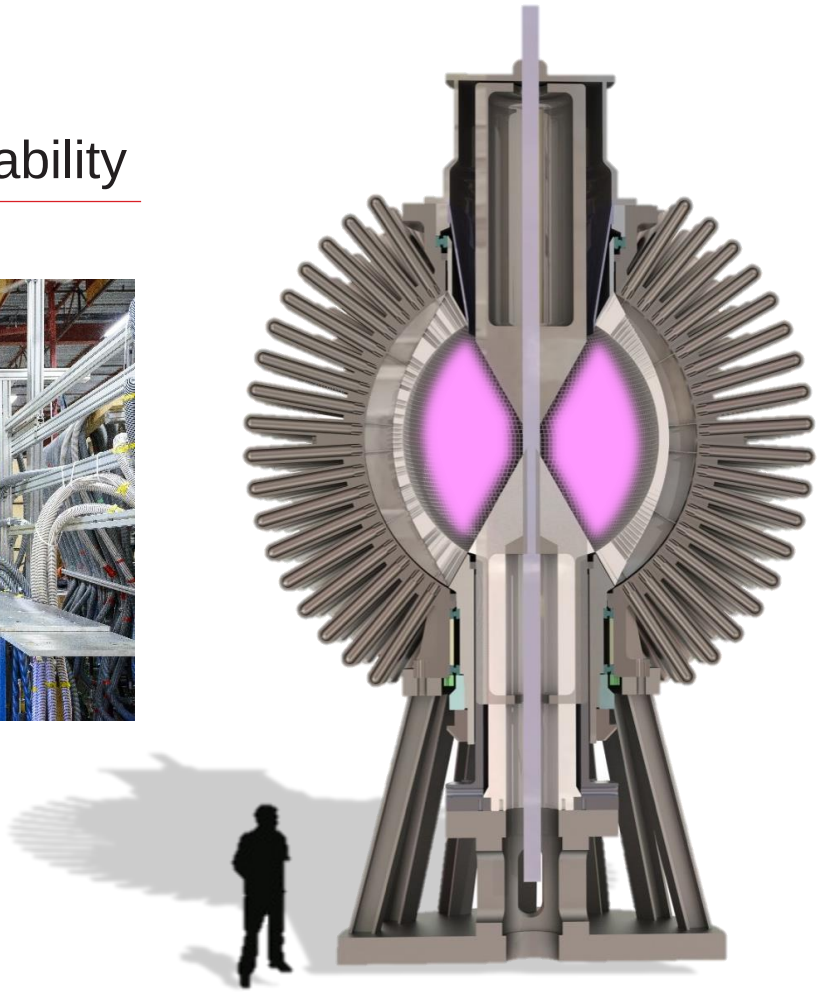


Core Technologies are in Place

Plasma Injector System

Compression System

Fusion Process Stability



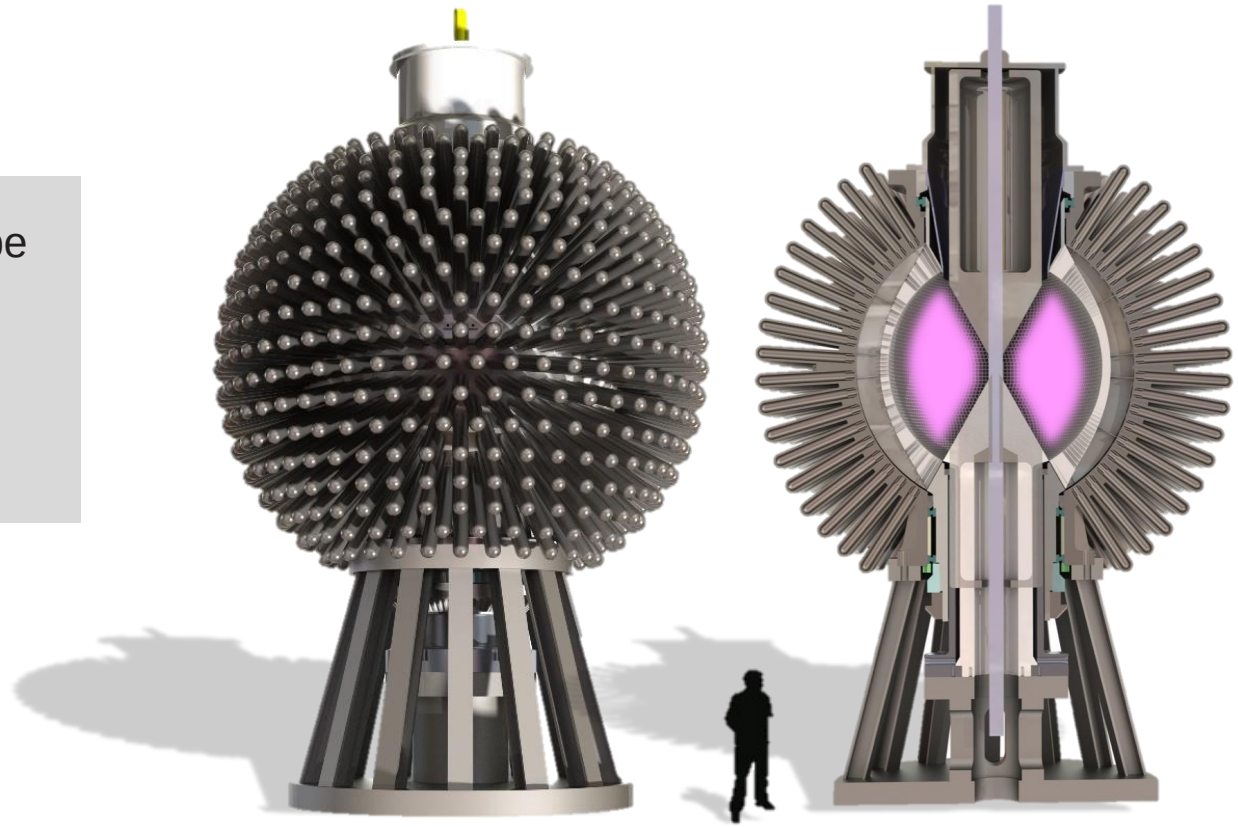
Backed by years of R&D progress, core technologies are in place, constructed, and tested at large scale

General Fusion Demonstration Program

- Embarking on a project to build and operate a fusion demonstration machine that will compress plasma to fusion temperature with pistons and liquid metal
- Builds on key milestones that have confirmed the Company's approach to fusion, achieved industry-recognized fusion system performance, established industrial partnerships for enabling technologies, and captured government support

Demonstration Program Goals

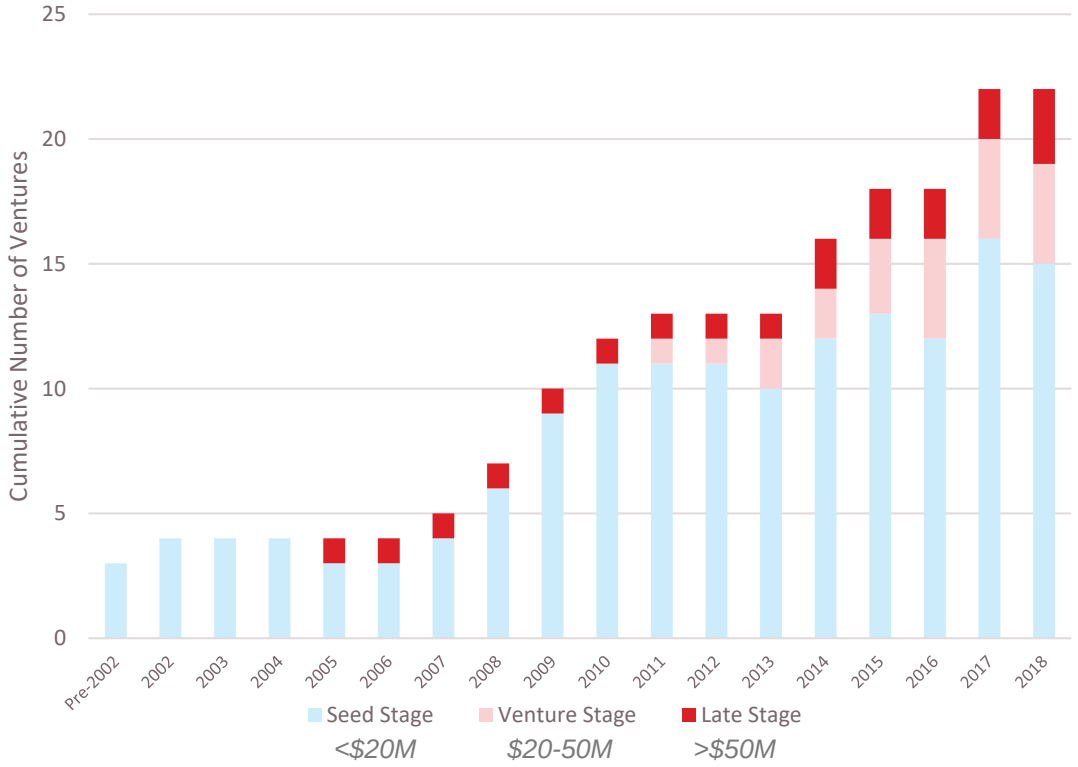
1. Demonstrate, at power plant-scale, that fusion conditions can be practically achieved using General Fusion's technology
2. Refine commercial power plant economics (ONC and LCOE), based on actual performance



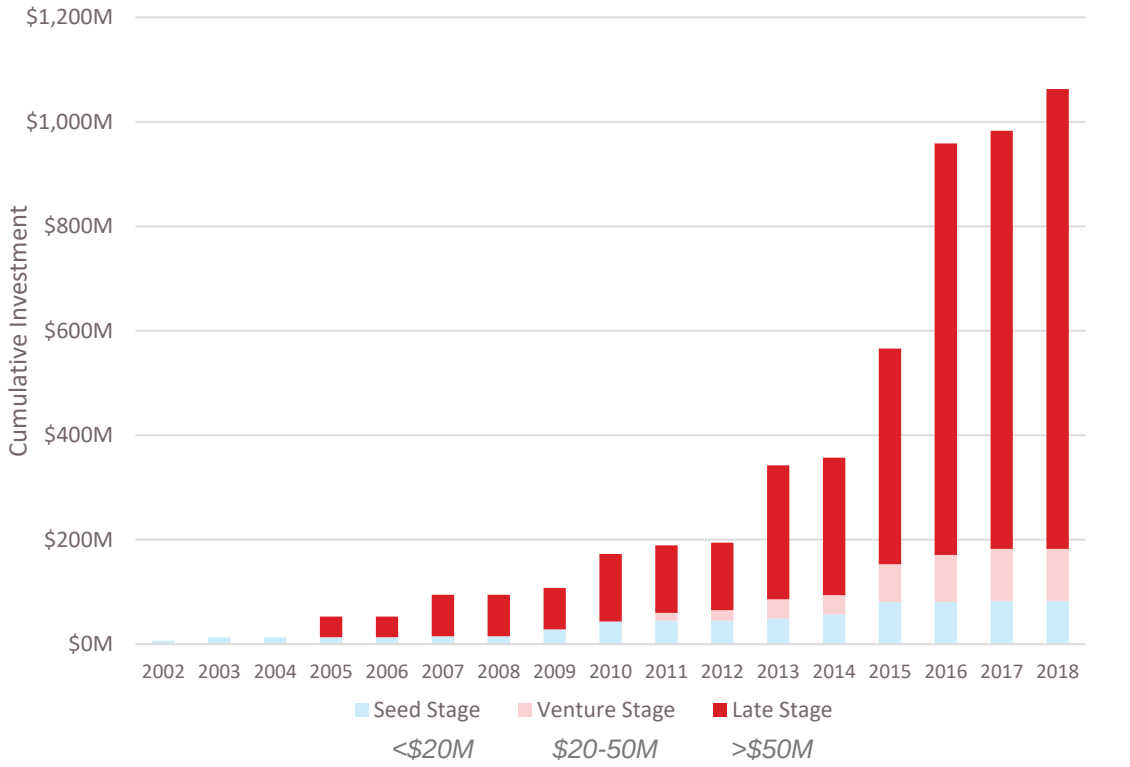
- Demonstration plant integrates all of General Fusion's core technologies
- Deuterium-only hydrogen fueled operation enables achievement of engineering and science objectives in a low risk and cost efficient manner
- Strategic partners mitigate engineering, manufacturing, construction risks

New Innovative Ventures

Private Fusion Ventures



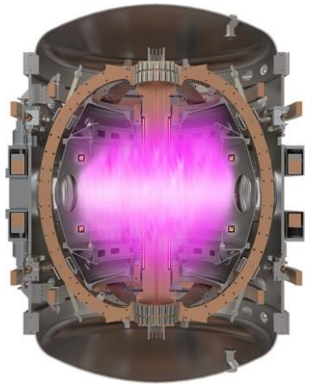
Investment in Private Fusion Ventures



Source: PitchBook, Crunchbase.

Private Fusion Technology Ventures

tokamak energy
a faster way to fusion



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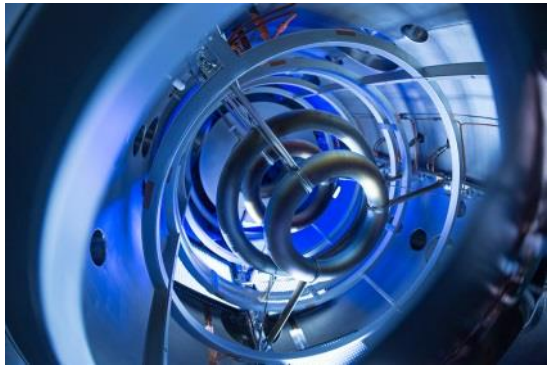
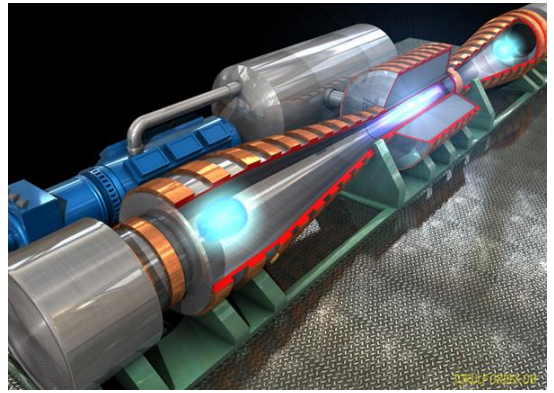
TRI ALPHA ENERGY
THE POWER OF INGENUITY

LOCKHEED MARTIN



first light

Helion Energy

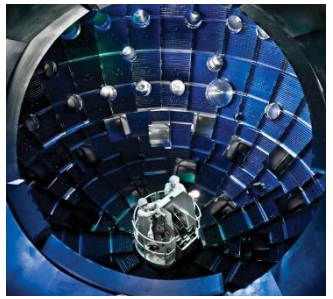


Note: List is not exhaustive; largest entities only.

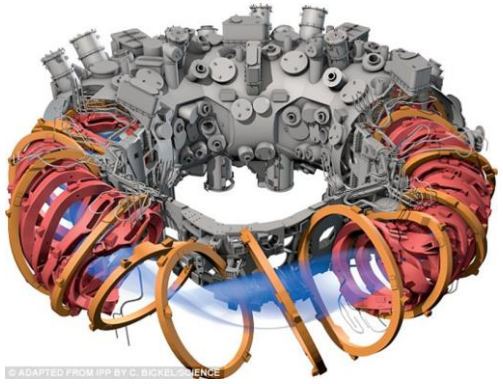
Publicly Funded Fusion Research

iter
china eu india japan korea russia usa

Lawrence Livermore National Laboratory
NIF



MAX-PLANCK-GESELLSCHAFT
Wendelstein 7-X



Experimental Advanced Superconducting Tokamak (EAST)

arpa·e

Note: List is not exhaustive; largest entities only.

Summary

- The increase in demand for energy worldwide cannot be met by existing renewable technologies.
- Fusion energy can transform the way the world is powered with sustainable carbon free energy.
- Newly matured enabling technologies are now opening innovative new pathways to commercial fusion energy.
- General Fusion is a big player in a growing ecosystem of private fusion companies emerging worldwide.
- Combining new technologies, proven industrial processes, and advances in fundamental fusion science, General Fusion's solution is getting closer to commercial reality.
- General Fusion's unique architecture removes the traditional barriers to practical fusion.

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