FUSION INDUSTRY ASSOCIATION

UK Atomic Energy Authority

The global fusion industry in 2021

Fusion Companies Survey by the Fusion Industry Association and the UK Atomic Energy Authority

FOREWORD

It is an exciting time for fusion energy now. The widespread realisation of the profound effects of climate change have brought focus on the need for low-carbon energy generation as never before, and this is bringing increased attention to fusion energy. Investment in private fusion developers has been growing for several years.

Some governments are seizing this momentum by increasing the number of ways that private fusion companies can work with public laboratories to leverage expertise, facilities, and public investment. Regulators are determining the appropriate frameworks to support fusion safety and development. Designs are being drawn up for fusion demonstrators and pilot power plants. And new private fusion companies are coming onto the scene every year, exploring new concepts and new technologies with the aim of getting to commercial fusion energy by the quickest path.

In light of all this progress, the Fusion Industry Association has come together with the UK Atomic Energy Authority to produce this Fusion Companies Survey. Our joint aim is to build a directory of fusion energy businesses and gather statistics to provide a useful reference point for this emerging, and growing, sector.

In this report, we strive to be impartial, presenting the information on the various companies as it has been conveyed to us. All company achievements and data are entirely self-reported. It is not an exhaustive survey. We approached the fusion businesses that we know about and where contact information was available. Their responses were entirely voluntary.

There will be companies that we have missed because we do not yet know about them, or because they declined to participate. This survey should be seen as a snapshot in time; a view of the industry when the survey was conducted in the second quarter of 2021. Repeating the activity year on year will enable us to see the picture evolving.

Many private fusion companies are members of the Fusion Industry Association, though this is not a requirement for the report and we have not treated members and non-members differently in the survey. Membership is marked on company pages by an FIA Member badge. Membership of the FIA requires companies to have a plan for fusion commercialisation, to demonstrate private investment to support their mission, and to pay dues. Companies playing a supportive role in the fusion industry may join as Affiliate Members, but these wider-industry companies are not the subject of this report.

In this survey, fusion companies declared almost $1.9bn of private funding to date, plus an additional $85 million in grants and other funding from governments. The top four companies in terms of investment raised account for 85% of the private funding.

The field has seen an increase in the number of private companies working towards fusion over the last 30 years, with accelerated growth more recently. 15 of the 23 respondents to our survey (65%) were founded in the last decade, and 12 of them (52%) in the last 5 years alone.

The most popular broad technical approach taken by private companies is magnetic confinement, followed by magneto-inertial confinement. Within this broader categorisation there is considerable diversity in the specific technical approaches and, of course, private companies will each have their own particular technical focus. The main target markets for fusion companies are electricity generation or space propulsion, though many companies see multiple target markets.

The evidence from our survey is patchy, but suggests that, as a group, fusion needs to try harder to have a diverse and representative workforce, both in terms of gender and ethnicity. However, this is not an issue unique to fusion[1].

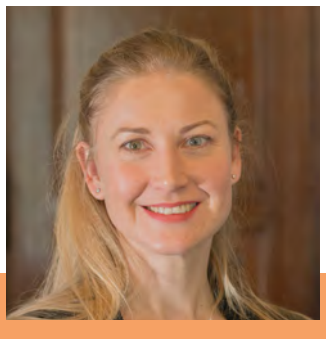
It's interesting to see that the majority of respondents believe that we will first see fusion power on the grid sometime in the 2030s, and fusion for space propulsion either in the 2030s or 2040s. Private companies are all pushing towards fusion on ambitious timescales, eager to have fusion contributing towards solving our most pressing global problems. These timescales demonstrate the drive and commitment that exists within this growing industry.

[1] Women made up 21% of the UK workforce in the engineering sector (any role) in 2016, according to a report by Engineering UK and data from the Office of National Statistics. The National Science Foundation states that in the US, women make up 26% of STEM occupations, with the representation being lower than this average in physical sciences and engineering.
https://www.engineeringuk.com/media/1691/gender-disparity-in-engineering.pdf
https://ncses.nsf.gov/pubs/nsf21321/data-tables#group6

The rising amounts of investment coming into the field and the positive activity being taken by governments in developing regulatory frameworks can only support these ambitions.

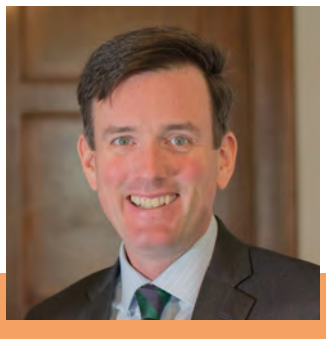
We would like to thank all the companies involved for coming forward to talk about their businesses and scientific progress to help us build this picture of the fusion industry. We hope it will become a useful resource for both the fusion community and those outside the fusion sector wishing to know more.

Report Sponsors: The Fusion Industry Association (FIA) and the UK Atomic Energy Authority (UKAEA)
The FIA is the unified voice of the new fusion industry and a central point for coordination across the fusion community to support accelerated growth. The UKAEA has been at the forefront of global fusion research for decades, and is an organisation focused on the delivery of sustainable fusion energy. Both FIA and UKAEA are committed to the prospect of fusion energy being a key part of future global low-carbon energy supply, and both strongly support this developing commercial sector.



Melanie Windridge
Communications Director

Fusion Industry Association
Lead Report Author



Andrew Holland
Chief Executive Officer

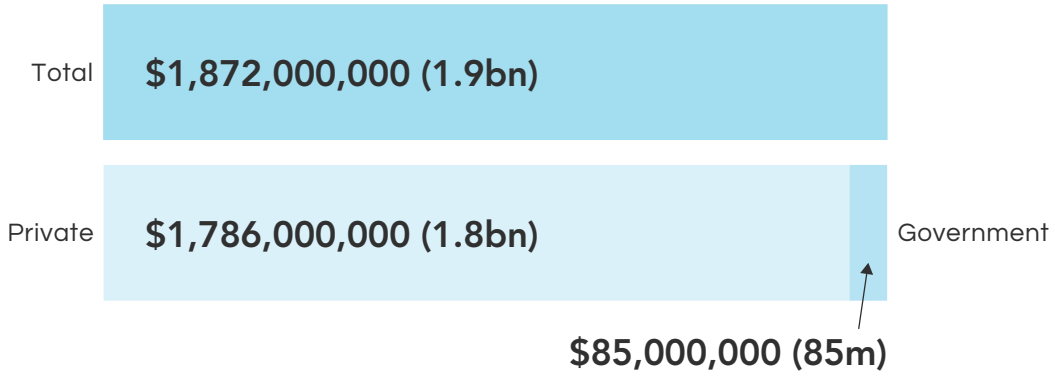
Fusion Industry Association

Tim Bestwick
Chief Technology Officer and Director of Strategy, Communications & Business Development

UK Atomic Energy Authority

HIGHLIGHTS TO DATE[+]

1. Funding for fusion companies



Of the 23 respondents, 18 declared funding.

[+]All charts are based on responses from the 23 private fusion companies who responded to our survey.

2. Companies by location

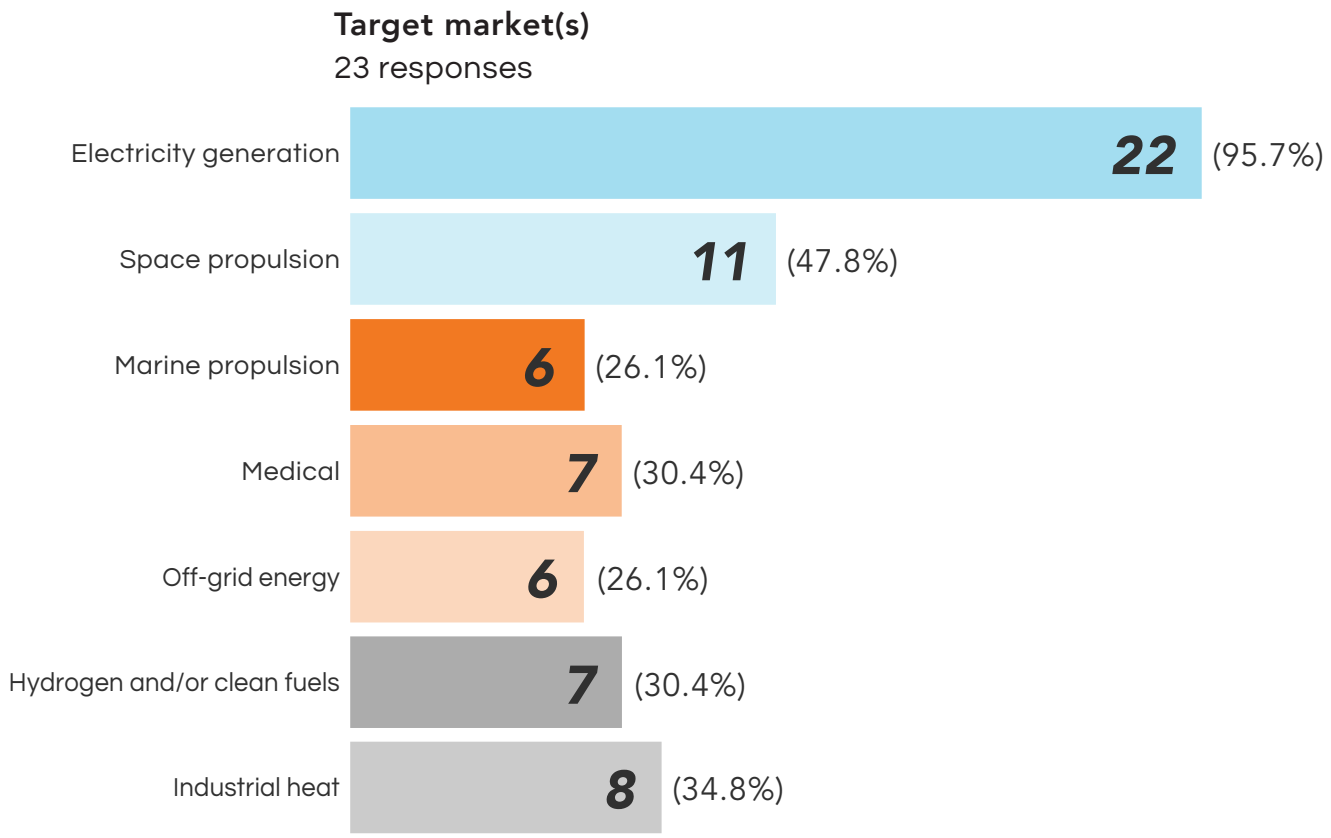
3. Selected* investors in fusion

Addition
Art Samberg
Bezos Expeditions
Breakthrough Energy Ventures
Capricorn Investment Group (Jeff Skoll)
Cenovus Energy
Charles Schwab
Chevron Technology Ventures
David Harding (CEO of Winton Group)
Dr Hans-Peter Wild (Owner of Capri Sun)
Dusting Moskovistz
Energy Impact Partners
Eni
Equinor
GA Capital
GIC
Google
Grantham Foundation for the Environment
IP Group
Khazanah Nasional
Khosla Ventures
Kuwait Investment Authority
Legal and General
Lowercarbon Capital
Lukasz Gadowski
Mithril Capital (Peter Thiel)
Oxford Sciences Innovation
Reid Hoffman
Sam Altman
Temasek
Venrock
Vulcan Capital
Wellcome Trust
Y Combinator

*All of these investors have been publicly identified in previous publications. The FIA and the UKAEA are not responsible for the responses listed in this report from survey participants and do not intend to disclose any proprietary information.

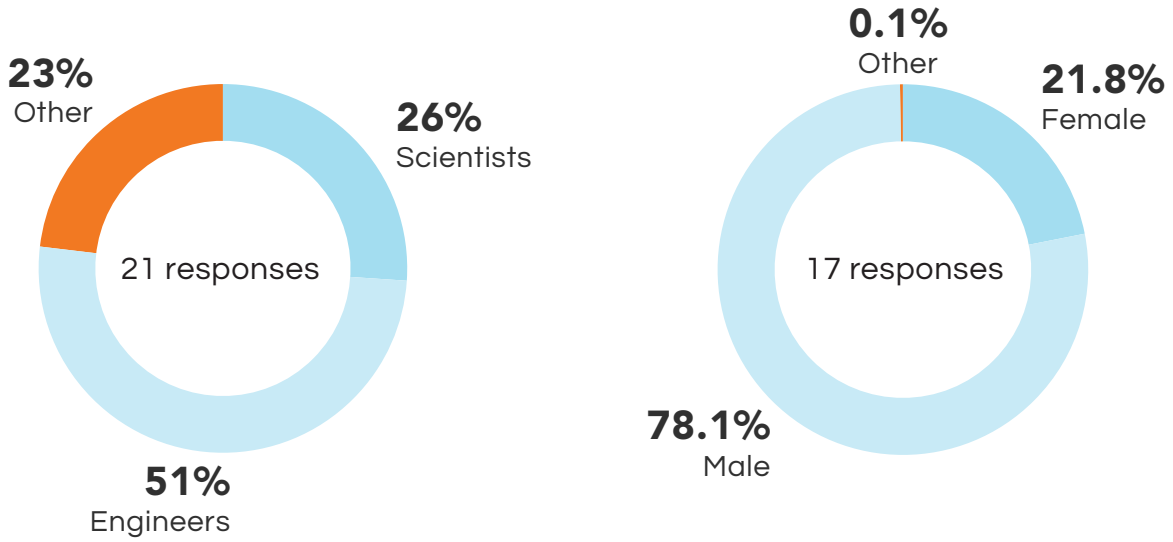
4. Target markets for global fusion companies

Respondents could tick multiple boxes

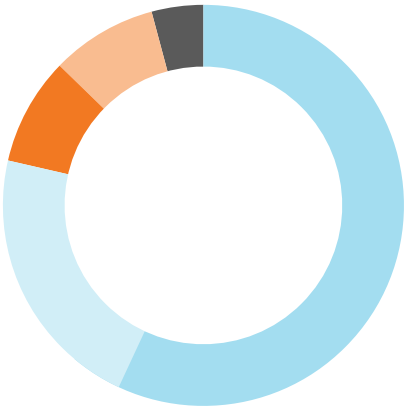


5. Average employees by role and gender

Numbers are approximate. Reporting was rounded to nearest 10% and aggregated.



6. Technical approach taken by global fusion companies



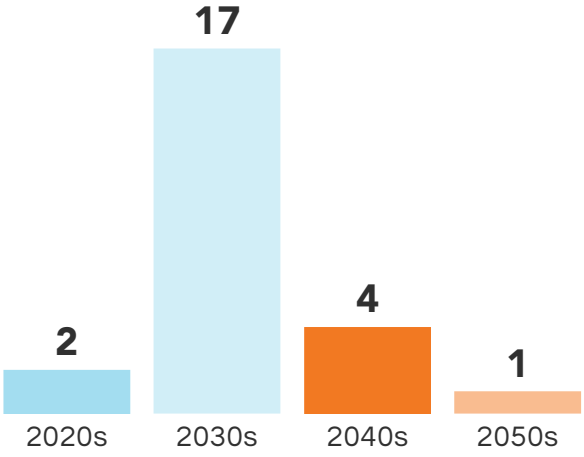
General approach

- 13 Magnetic confinement
- 5 Magneto-inertial
- 2 Hybrid electrostatic confinement
- 2 Inertial confinement
- 1 Non-thermal laser fusion
- 0 Cold fusion/LENR
- 0 Muon-catalysed fusion

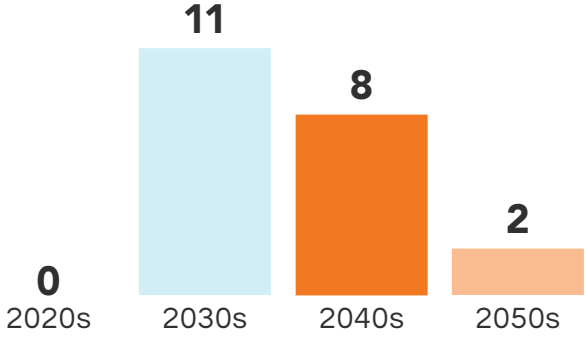
Specific approach

- 3 Field Reversed Configuration
- 3 Tokamak
- 2 Spherical tokamak
- 2 Stellarator
- 2 Z-pinch
- 1 Dense plasma focus
- 1 Direct laser-driven pB11
- 1 Inertial-electrostatic confinement
- 1 Laser-driven inertial confinement (quantum enhanced)
- 1 Magnetic-electrostatic confinement
- 1 Magnetized target fusion
- 1 Plasma jet driven magneto-inertial fusion
- 1 Plectoneme
- 1 Shock-driven inertial confinement
- 1 Spheromak
- 1 undeclared
- 0 Laser-driven inertial confinement

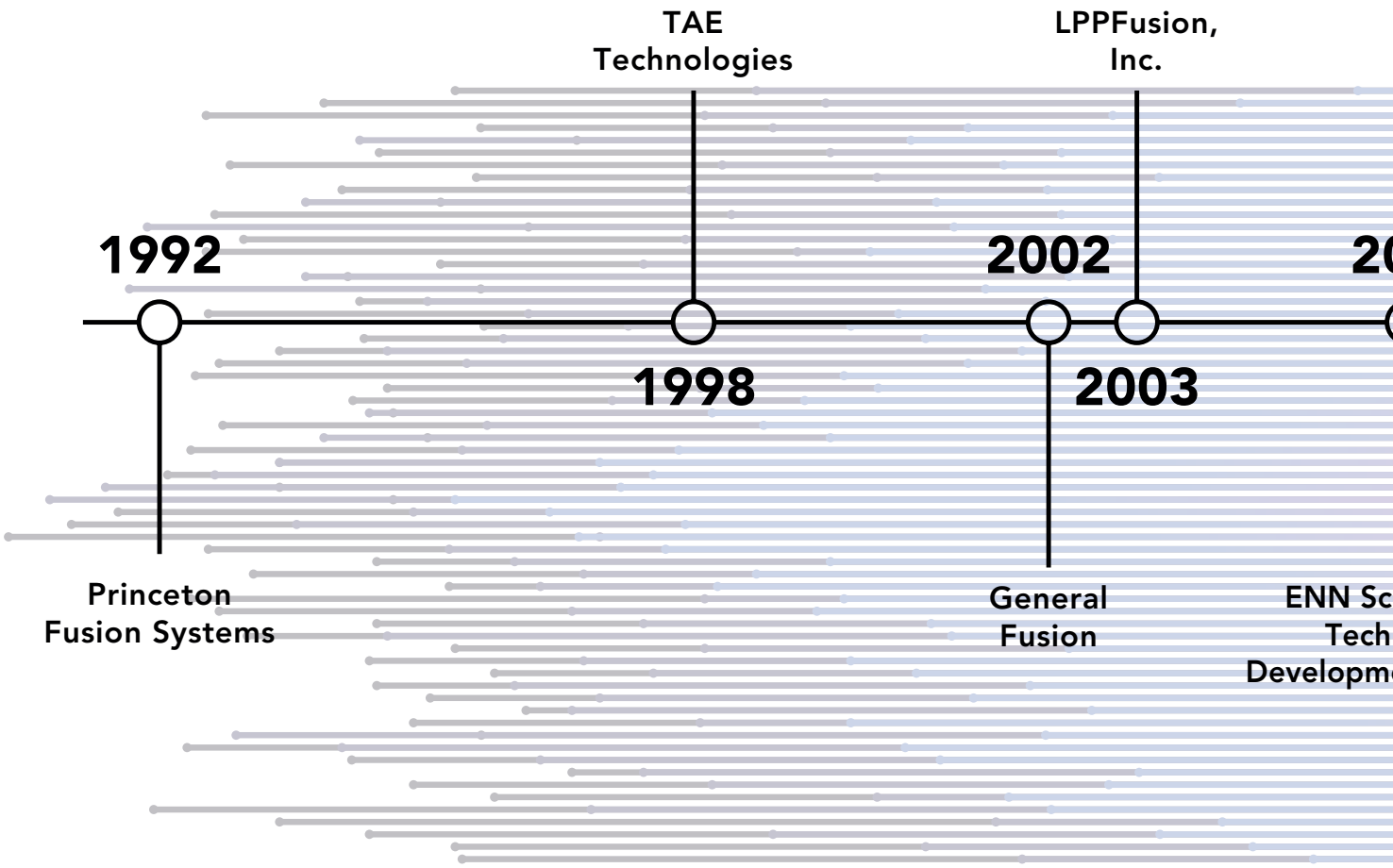
7. When will fusion first power the grid somewhere in the world?



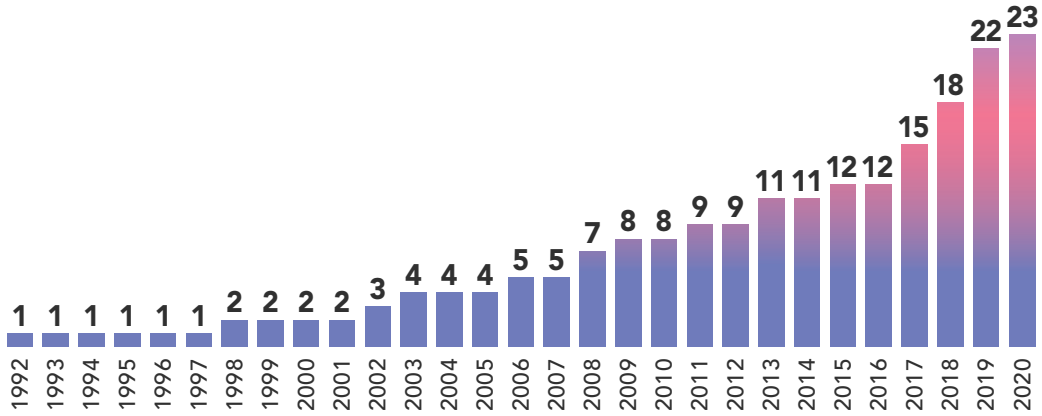
8. When will fusion first be used for space propulsion?

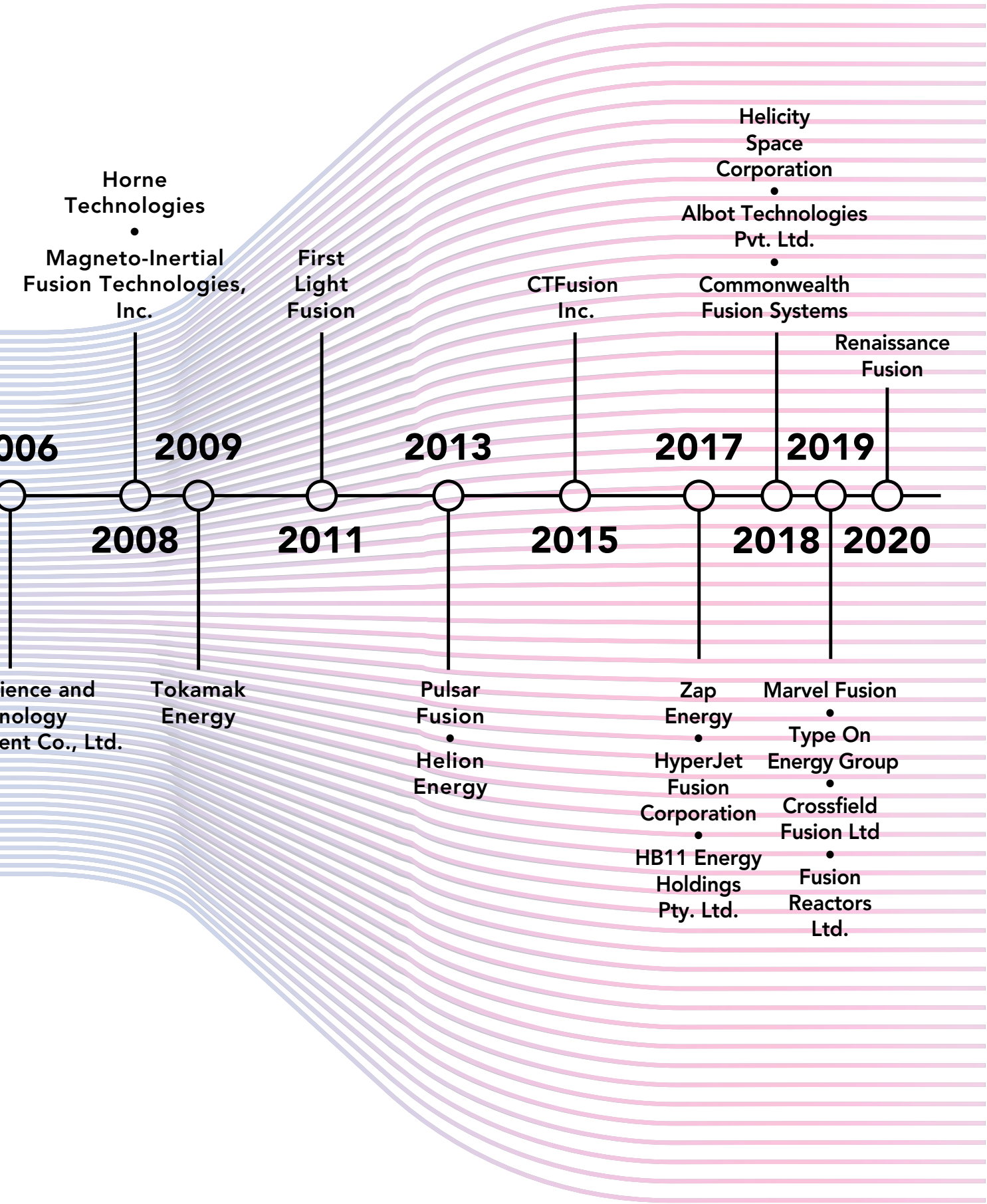


9. Fusion companies founded in the last 30 years



10. Number of private fusion companies in existence by year




Horne Technologies • Magneto-Inertial Fusion Technologies, Inc.
First Light Fusion
CTFusion Inc.
Helicity Space Corporation • Albot Technologies Pvt. Ltd. • Commonwealth Fusion Systems
Renaissance Fusion
006
2009
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ience and nology ent Co., Ltd.
Tokamak Energy
Pulsar Fusion • Helion Energy
Zap Energy • HyperJet Fusion Corporation • HB11 Energy Holdings Pty. Ltd.
Marvel Fusion • Type On Energy Group • Crossfield Fusion Ltd • Fusion Reactors Ltd.

PROFILES OF TODAY'S PLAYERS IN FUSION

This section summarises the details of 23 fusion companies that responded to our survey, detailing their approach, progress, and funding.

Not all were able to provide the same level of detail about their business, either because they are newer and are not yet ready to share these details or there are issues around commercial sensitivity. Not all answers were applicable to all companies. We have only included fields where companies were able to provide an answer. The decision not to provide certain information may be because it is too early to say, because the company considers it commercially sensitive, because it was not applicable to their approach, or any other reason. As this survey evolves year on year, we expect to see ever more detail from companies, and more questions answered from the newer companies.

Note on temperatures achieved
Temperatures are quoted in keV (kilo-electron volts) and Kelvin, taking 1 eV as approximately 10,000 K.

The threshold temperature for fusion to occur is around 10 keV or 100,000,000 K.
100 million K ≈ 100 million °C ≈ 180 million °F

Note on $nT\tau$ and Q

In this survey we have asked companies questions about the highest plasma temperature and highest energy confinement time achieved in their experiments. We also asked about their fusion triple product. Several companies omitted these questions, but since some did answer, it's worth giving some explanation as to the meaning of these values. A more complete discussion of this issue can be found in the pre-print paper "Progress toward Fusion Energy Breakeven and Gain as Measured against the Lawson Criterion" by Wurzel and Hsu, 2021[2].

The Lawson criterion relates the fuel density n, the energy confinement time τ_E, and the fuel temperature T to the energy gain Q_{fuel} of a fusion plasma. In doing so, it gives a measure of progress towards achieving fusion energy gain.

Density is how close together the fuel particles are; temperature is how fast they are moving; energy confinement time is how long the input heat energy remains in the plasma before leaking out.

The combination of $n\tau_E$ and T is a scientific indicator of how far or near a fusion energy experiment is from energy breakeven and gain. All thermonuclear fusion approaches (i.e. ones that initiate fusion using heat) must achieve certain thresholds of $n^*\tau_E$ and T to achieve high enough values of Q_{fuel} for practical energy production.

However, although $n\tau_E$ and T are important, they are not the only metrics that matter.

Firstly, it is not straightforward to compare the achieved triple-product values between magnetic confinement fusion and inertial confinement fusion. The energy confinement time parameter τ_E has subtly different meanings across concepts.

Secondly, there are other Q (gain) parameters that are important. Q_{fuel} is the energy gain of the fusion plasma itself. Q_{sci} is the energy gain relative to the external energy, or heating power, delivered to the fuel (e.g. by lasers in inertial confinement, or heating beams in magnetic confinement). Q_{eng} is the electricity produced relative to recirculating power. These will vary significantly across concepts depending on efficiency of the driver and the recirculating power. This means that approaches that have a very efficient driver and very low recirculating power can achieve the same Q_{eng} for lower values of Q_{fuel} and Q_{sci}.

This is why comparing values of $n\tau_E$ and T cannot give a complete picture of progress towards a commercial fusion device. High values of this triple product, which are required for energy gain, are a necessary but not sufficient condition for commercially viable fusion energy.

[2] *https://arxiv.org/abs/2105.10954*

ALBOT TECHNOLOGIES

Albot Technologies is a startup founded by Akash Singh that comprises a group of innovators and physicists who are committed to develop clean energy for India and the world.

Location	Pune, India
Contact details	akash@albot.io
Year founded	2018
Founder Names	Akash Singh, Neelam Singh
Target market(s)	Electricity generation; Space propulsion; Medical
Total funding to date	Boot strapped
Employees (incl. full time consultants)	8
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Tokamak
Fuel Source (e.g. DT, pB11, DD)	DT

FUEL SOURCE KEY

DT	deuterium - tritium
DD	deuterium - deuterium
pB11	proton - boron
DHe3	deuterium - helium3

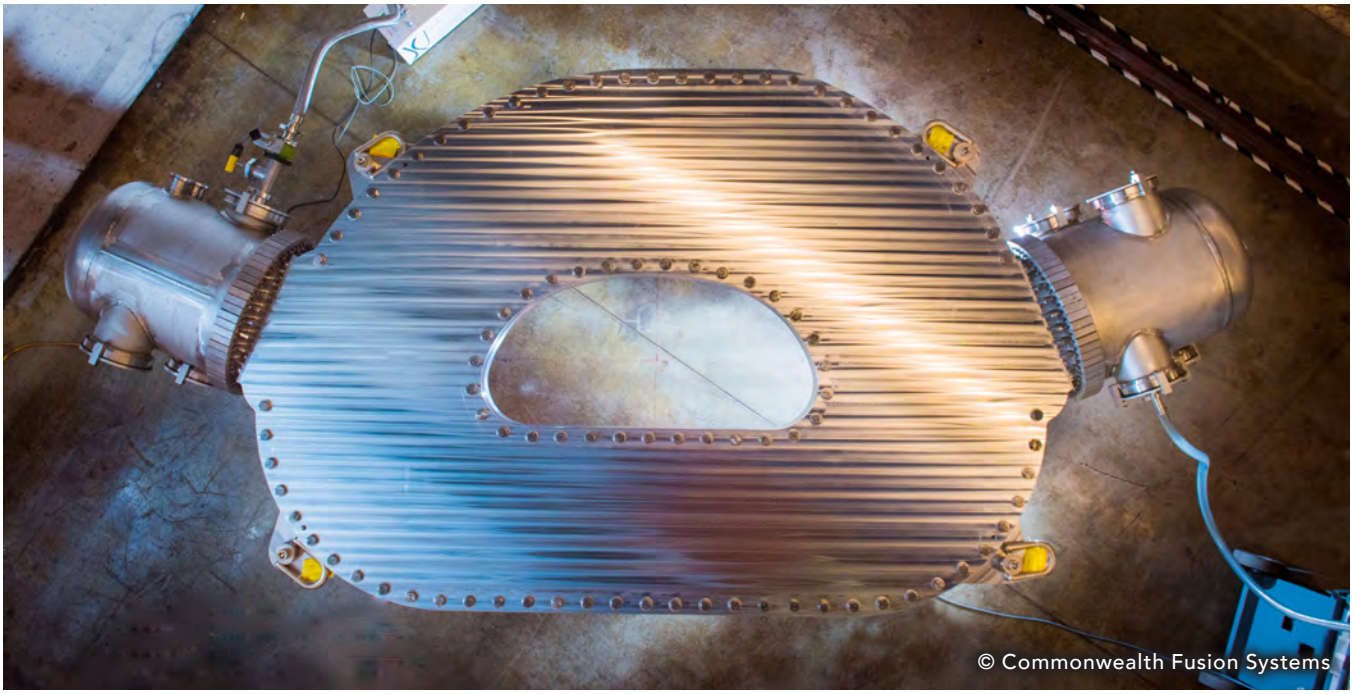
Commonwealth Fusion Systems

FIA MEMBER

COMMONWEALTH FUSION SYSTEMS

Commonwealth Fusion Systems (CFS) was spun out of MIT's Plasma Science and Fusion Center and is using high temperature superconductors to build smaller, lower-cost fusion power plants faster.

Location	Cambridge, MA, USA
Contact details	info@cfs.energy
Year founded	2018
Founder Names	Bob Mumgaard, Dan Brunner, Brandon Sorbom, Dennis Whyte, Martin Greenwald, and Zach Hartwig
Target market(s)	Electricity generation
Total funding to date	$250 million+ USD
Employees (incl. full time consultants)	165 employees
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Tokamak
Fuel Source (e.g. DT, pB11, DD)	DT
Milestones in past 12 months	**October 2020**: Designed, built, and demonstrated a new high-temperature superconductor (HTS) cable for magnets applicable to the high magnetic field approach to fusion. **March 2021**: Announced plans to build a 47-acre commercial fusion energy campus in Devens, Massachusetts which will house the compact fusion device SPARC. **September 2021**: With MIT's Plasma Science and Fusion Center, built and tested a near full-scale, large-bore high temperature superconducting (HTS) magnet, proving a magnet built at scale can reach a sustained magnetic field of more than 20 tesla. This HTS magnet technology will be used in SPARC and the ARC fusion power plant.
Pilot plant timescale	Construction of SPARC, the world's first net-energy fusion demonstration, is underway and operations are scheduled to start in 2025. ARC, a commercial plant, aims to put two hundred megawatts of fusion electricity on the grid in the early 2030s.
Anticipated MWe of the operating plant?	200+ MWe
Spin outs/patents	High-field HTS magnets



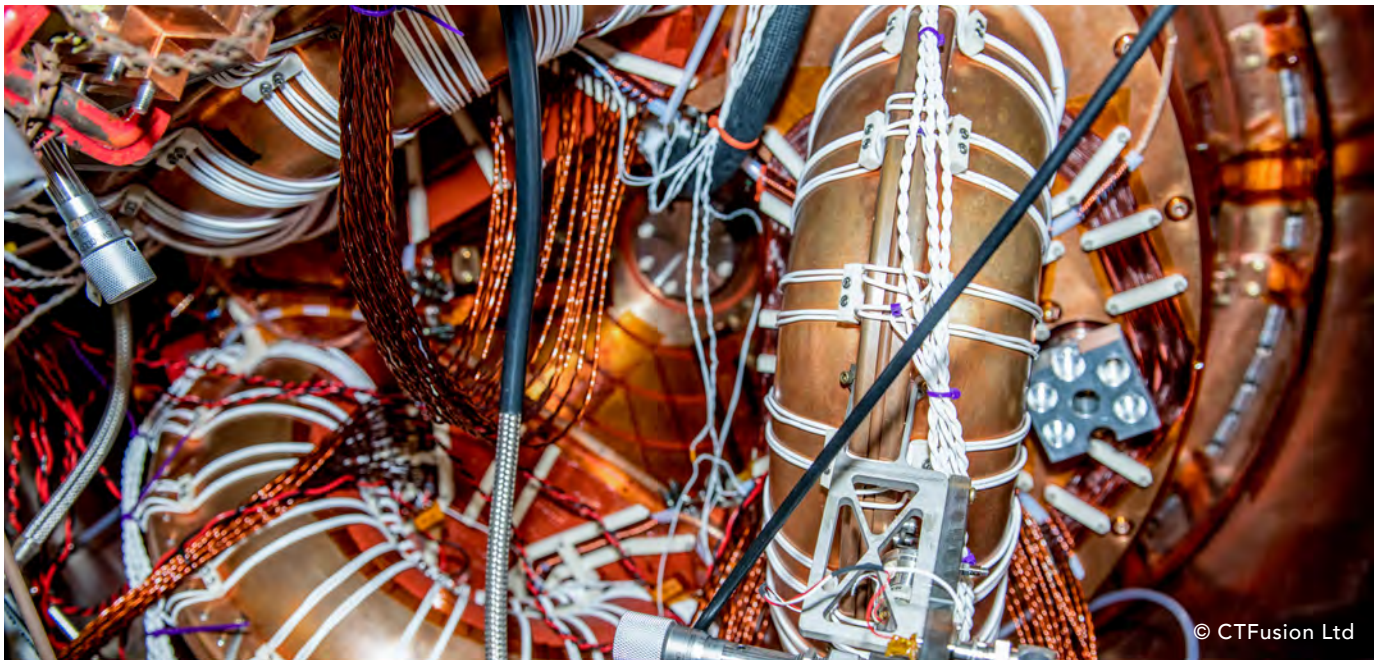
Key collaborators/partners	Massachusetts Institute of Technology; Argonne National Lab; Brookhaven National Lab; Columbia University; Idaho National Lab; Lawrence Berkeley National Lab; Lawrence Livermore National Lab; Los Alamos National Lab; Max Planck Institute for Plasma Physics; Oak Ridge National Lab; Princeton Plasma Physics Lab; Robinson Research Institute; Savannah River National Lab; Stony Brook University; University of California at San Diego; University of Maryland; University of Rochester; University of Texas at Austin; University of Wisconsin.
Recent Published Papers	[1] Journal of Plasma Physics, September 2020, seven papers validating CFS's approach to fusion: ***https://www.cambridge.org/core/journals/journal-of-plasma-physics/collections/status-of-the-sparc-physics-basis*** [2] VIPER: an industrially scalable high-current high-temperature superconductor cable, October 2020: ***https://iopscience.iop.org/article/10.1088/1361-6668/abb8c0/meta*** [3] Development and large volume production of extremely high current density YBa2Cu3O7 superconducting wires for fusion, Nature, January 2021: ***https://www.nature.com/articles/s41598-021-81559-z***

CROSSFIELD FUSION LTD

Crossfield Fusion Ltd is developing a novel compact fusion reactor targeting carbon free heat and power generation. It's vision is to manufacture compact fusion reactors the size of a small shipping containers that can be mass produced in factories. It expects its fusion reactor technology to scale up to about 1MWe of electrical output or 2-3MWt of heat, complementary in application to larger fusion reactors.

Prior to achieving these end goals the company will exploit the technology commercially as high output compact neutron sources for radiotherapy, medical isotope production and material testing applications.

Location	Oxfordshire, UK
Contact details	enquiries@crossfieldfusion.com
Year founded	2019
Founder Names	James Mckenzie, Chris Macdonald-Bradley
Target market(s)	Electricity generation; Medical
Total funding to date	$695,000 USD (£500,000)
Employees (incl. full time consultants)	5
Technical approach (general)	Hybrid electrostatic confinement
Technical approach (specific)	Inertial-electrostatic confinement
Fuel Source (e.g. DT, pB11, DD)	DD
Anticipated MWe of the operating plant?	1 MWe



CTFUSION, INC.

CTFusion is developing its unique approach to magnetic fusion energy called the Dynomak. Using spheromak magnetic confinement, it's technology provides efficient sustainment of stable spheromak configurations for eventual use in DT fusion power plants. CTFusion is in a concept exploration phase funded by ARPA-E.

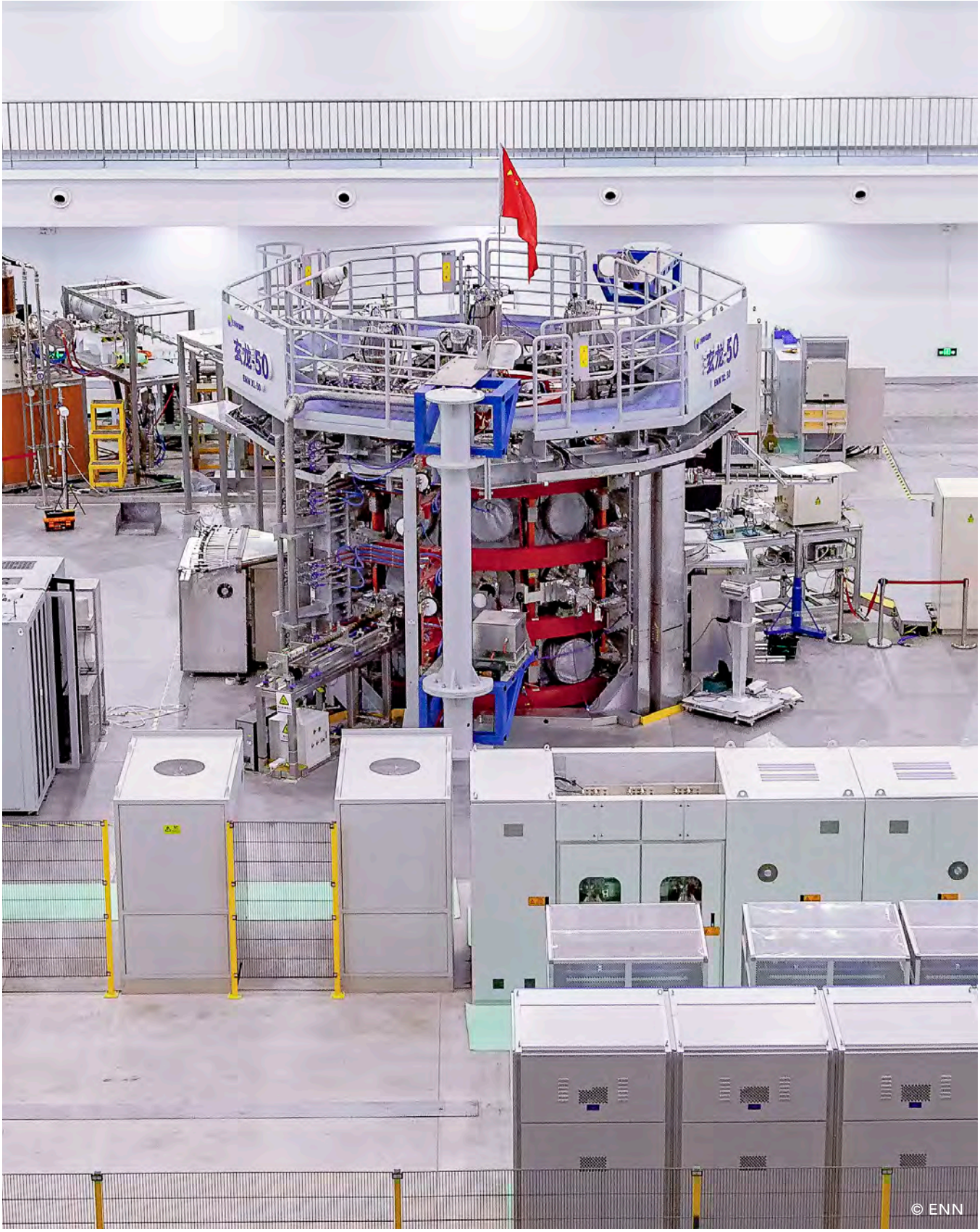
Location	Seattle, Washington, USA
Contact details	admin@ctfusion.net
Year founded	2015
Target market(s)	Electricity generation; Space propulsion; Hydrogen and/or clean fuels; Industrial heat
Total funding to date	$5 million USD
Employees (incl. full time consultants)	5
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Spheromak
Fuel Source (e.g. DT, pB11, DD)	DT
Milestones in past 12 months	Hit technical milestones of the ARPA-E project including: plasma currents exceeding 100 kA; injected powers exceeding 20 MW; and injector voltages exceeding 600 V. The assembly of its next prototype, HIT-SIU, is nearing completion and will begin operations in the second half of 2021.
Spin outs/patents	Plasma confinement system and methods for use ***https://patents.google.com/patent/US20150055739A1/en***
Key collaborators/partners	University of Washington - Seattle, ARPA-E
Recent published papers	[1] Driven resonant current amplification in self-organized plasma configurations with uniform λ and plasma pressure confinement Phys. Plasmas, 2021, ***https://doi.org/10.1063/5.0025959*** [2] High-speed feedback control of an oscillating magnetic helicity injector using a graphics processing unit, Rev. Sci. Instrum. 2021, ***https://doi.org/10.1063/5.0044805***

ENN FUSION TECHNOLOGY R&D CENTER, PART OF THE ENN SCIENCE AND TECHNOLOGY DEVELOPMENT CO., LTD.

In 2018, the ENN Fusion Technology R&D Center was established with an aim to deliver clean commercial fusion electricity and heat to customers and radically improve its energy supply network. It is part of the ENN Science and Technology Development Co., Ltd, which is dedicated to addressing humanity's energy challenges in a sustainable, reliable and economic manner.

Location	Langfang, China
Contact details	qixudong@enn.cn; +86-316-2597072
Year founded	ENN Science and Technology Development Co., Ltd founded in 2006 ENN Fusion Technology R&D Center founded in 2018
Founder Names	Yusuo WANG
Target market(s)	Electricity generation; Industrial heat
Total funding to date	$150 million USD
Employees (incl. full time consultants)	90
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Spherical tokamak
Fuel Source (e.g. DT, pB11, DD)	pB11
Milestones in past 12 months	Non-inductive ECRH*-driven plasma current of 172 kA by supplying a total of 150 kW ECRH power from the gyrotron source
Pilot plant timescale	15 years
Key collaborators/partners	Peking University, University of Tokyo, Southwestern Institute of Physics
Recent published papers	[1] Four-Fluid Axisymmetric Plasma Equilibrium Model Including Relativistic Electrons and Computational Method and Results, Phys. Plasmas 28, 032503, 2021: ***https://doi.org/10.1063/5.0027718*** [2] Toroidal plasma conditions where the p-11B fusion Lawson criterion could be eased', Research Square. [3] Two parameter modified rigid rotor radial equilibrium model for field reversed configurations [J]. Nuclear Fusion, 2021 [4] A new tool GSEQFRC for two dimensional field reversed configuration equilibrium. Nuclear Fusion, 2021 DOI: 10.1088/17414326/ac0232

*ECRH – electron cyclotron resonance heating



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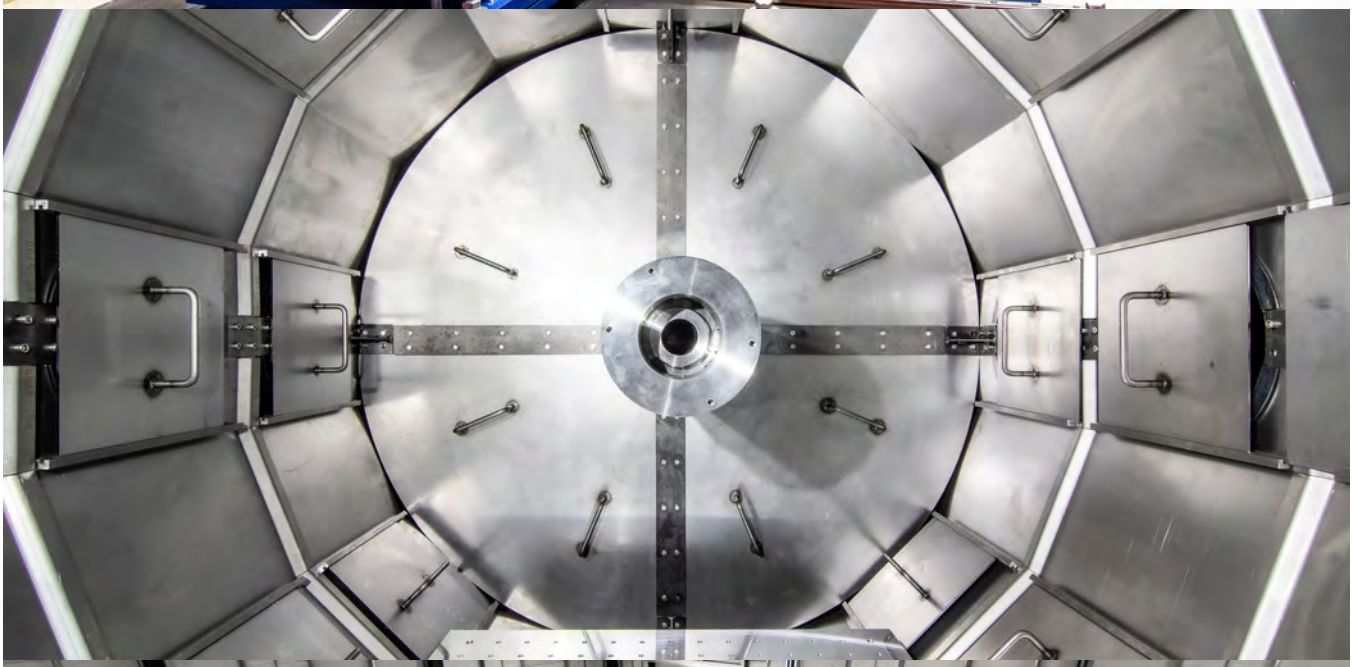
first light

FIA MEMBER

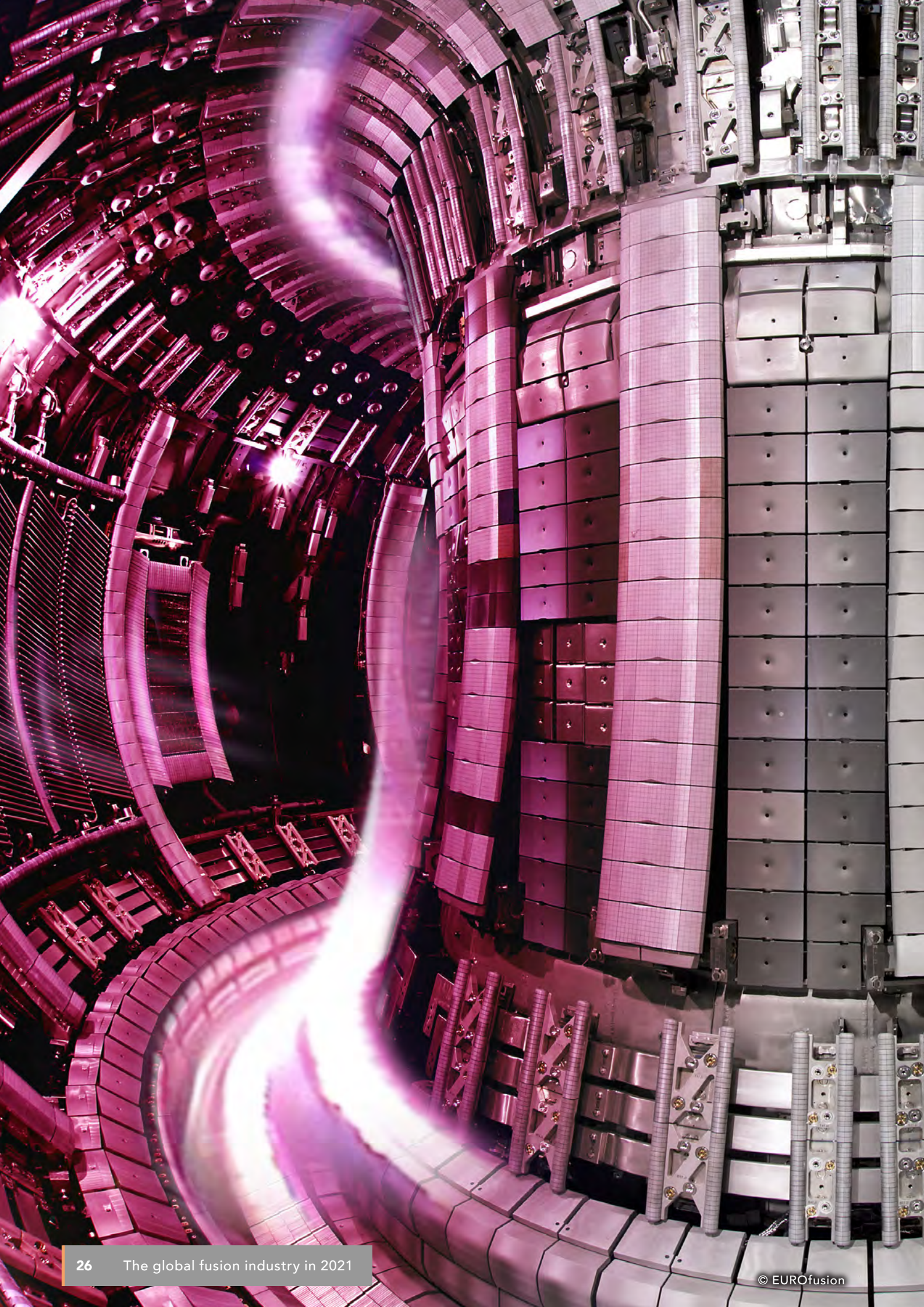
FIRST LIGHT FUSION

First Light Fusion was spun out from the University of Oxford in 2011 and is researching energy generation by inertial confinement fusion driven by shockwaves.

Location	Oxford, UK
Contact details	enquiries@firstlightfusion.com, +44 1865 807 670
Year founded	2011
Founder Names	Nicholas Hawker, Yiannis Ventikos
Target market(s)	Electricity generation
Total funding to date	$63 million USD (£45 million)
Employees (incl. full time consultants)	58
Technical approach (general)	Inertial confinement
Technical approach (specific)	Shock-driven inertial confinement
Fuel Source (e.g. DT, pB11, DD)	DT
Milestones in past 12 months	Running tritium experiments. Commissioning of new experimental device. Beating previous record of collapse velocity multiplication (now 11x).
Pilot plant timescale	2030s (Fully operational first of a kind power plant)
Anticipated MWe of the operating plant?	150-1,500 MWe
Key collaborators/partners	UKAEA, Jacobs, Mott MacDonald, Imperial College, University of Oxford, Loughborough University, University of York
Recent published papers	[1] A simplified economic model for inertial fusion: ***https://royalsocietypublishing.org/doi/10.1098/rsta.2020.0053***



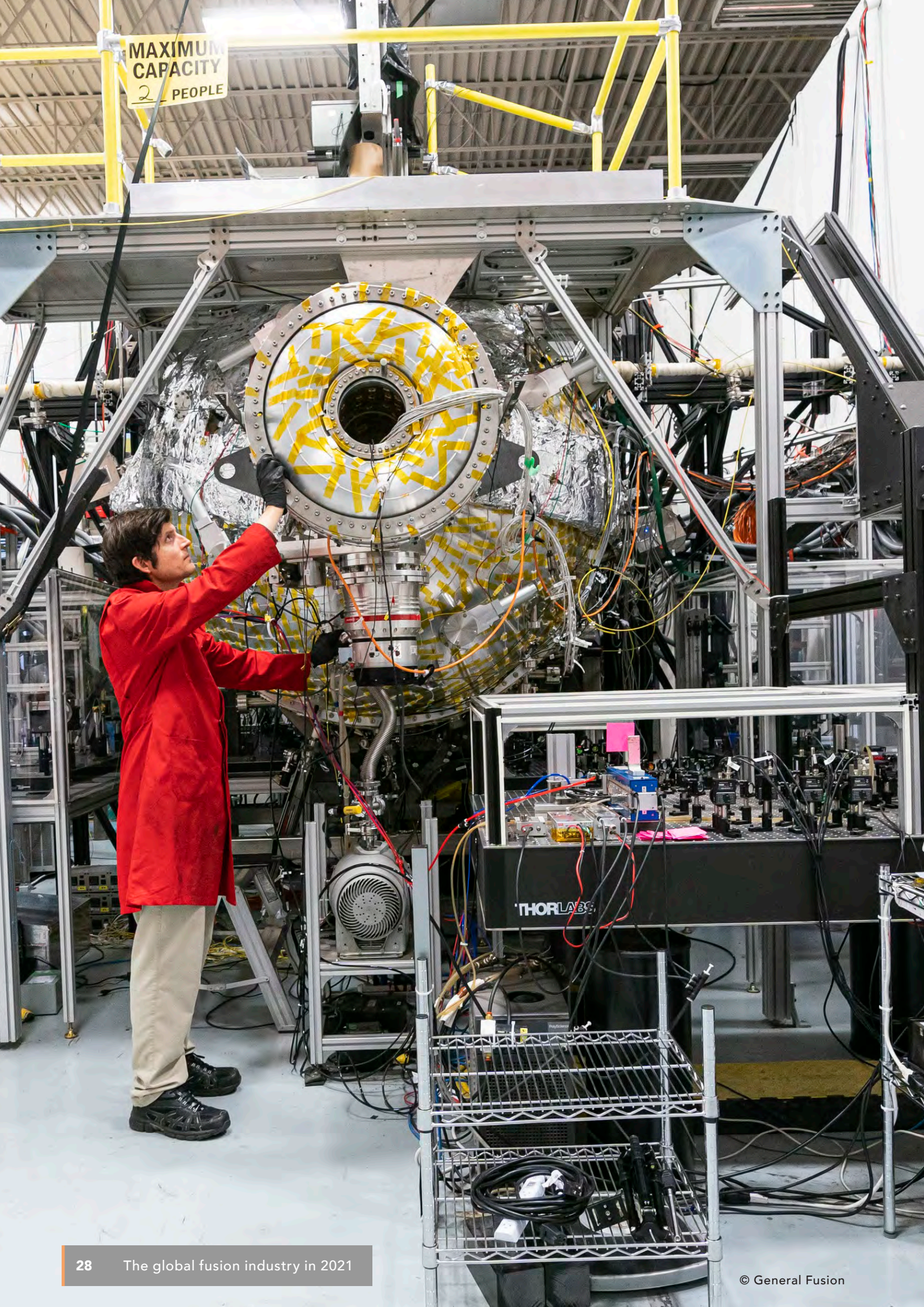
© First Light Fusion



FUSION REACTORS LTD

Fusion Reactors is commercialising fusion energy for electricity generation.

Location	UK
Contact details	contact@fusion-reactors.com
Year founded	2019
Founder Names	Christos Stavrou
Target market(s)	Electricity generation
Technical approach (general)	Magnetic confinement
Fuel Source (e.g. DT, pB11, DD)	DT



generalfusion

FIA MEMBER

GENERAL FUSION

General Fusion is pursuing a magnetized target fusion approach. The company was established in 2002 in Vancouver, Canada, and now has additional locations in Washington D.C. and London, U.K.

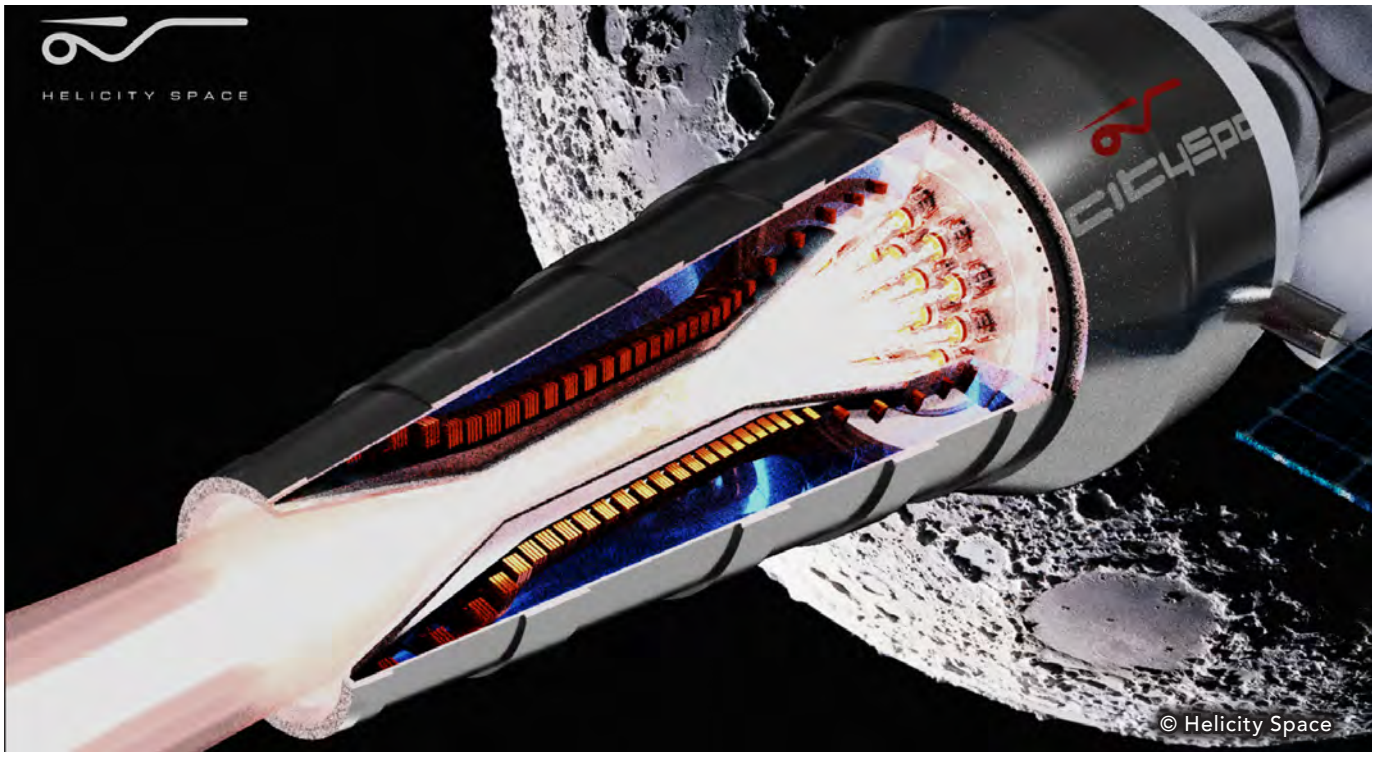
Location	Vancouver, Canada (with locations in Washington D.C. USA, and London, UK)
Contact details	info@generalfusion.com, +1 (604) 439-3003
Year founded	2002
Founder Names	Michel Laberge
Target market(s)	Electricity generation
Total funding to date	$200+ million USD
Employees (incl. full time consultants)	150
Technical approach (general)	Magneto-inertial
Technical approach (specific)	Magnetized target fusion
Fuel Source (e.g. DT, pB11, DD)	DT
Milestones in past 12 months	Completed the commissioning of its Fusion Demonstration Plant scale plasma injector in 2020. Entered the conceptual design phase of the Fusion Demonstration Plant and anticipates going into detailed design in second half of 2021.
Pilot plant timescale	Construction anticipated to begin in 2022, with operations beginning approximately three years later.
Anticipated MWe of the operating plant?	200 MWe per plant
Spin outs/patents	More than 150 patents
Key collaborators/partners	Strategic Innovation Fund, Sustainable Development Technology Canada, Princeton Plasma Physics Laboratory, Princeton University, McGill University, University of Illinois, DOE INFUSE Program -- collaboration with Princeton Plasma Physics, Laboratory, DOE INFUSE Program -- collaboration with Oak Ridge National Laboratory, Hatch, Microsoft, Queen Mary University of London, Sustainable Development Technology Canada, University of Saskatchewan, GE Additive

FIA MEMBER

HB11 ENERGY HOLDINGS PTY. LTD.

HB11 is pursuing pB11 (proton-boron) fusion directly driven by lasers.

Location	Sydney, Australia
Contact details	contact@hb11.energy
Year founded	2017
Founder Names	Heinrich Hora, Warren McKenzie, Jan Kirchhoff, Lukasz Gadowski
Target market(s)	Electricity generation; Space propulsion; Marine propulsion; Medical; Off-grid energy; Hydrogen and/or clean fuels
Total funding to date	$4 million USD
Employees (incl. full time consultants)	5
Technical approach (general)	Non-thermal laser fusion
Technical approach (specific)	Direct Laser Driven pB11
Fuel Source (e.g. DT, pB11, DD)	pB11
Milestones in past 12 months	First lab demonstration of reactions
Pilot plant timescale	2027
Anticipated MWe of the operating plant?	300-500 MWe per Block



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HELICITY SPACE

FIA MEMBER

HELICITY SPACE CORPORATION

Helicity Space Corporation is dedicated to developing compact fusion propulsion technology for the interplanetary propulsion and power of a spacefaring civilization. The vision is to enable space colonization and a clean Earth with fusion power and propulsion technology.

Location	California, USA
Contact details	marta.calvo@helicityspace.com
Year founded	2018
Founder Names	Setthivoine You, Stephane Lintner, Marta Calvo
Target market(s)	Space propulsion
Total funding to date	$750,000 USD
Employees (incl. full time consultants)	2 growing to 5
Technical approach (general)	Magneto-inertial
Technical approach (specific)	Plectoneme
Fuel Source (e.g. DT, pB11, DD)	DD, DHe3
Milestones in past 12 months	TRL 1: Basic Principles Observed and Reported TRL 2: Potential Application Validated
Pilot plant timescale	2040s
Anticipated MWe of the operating plant?	100 MWe
Spin outs/patents	Electric Power Station
Key collaborators/partners	Caltech, University of Maryland, Baltimore County, Aerospace Corp, Limitless Space Institute, University of Wisconsin, University of Tokyo, Centre National de la Recherche Scientifique
Recent published papers	[1] Helicity Drive: A Novel Scalable Fusion Concept for Deep Space Propulsion, AIAA Propulsion & Energy, 2020: ***https://doi.org/10.2514/6.2020-3835*** [2] Observations of a plectonemic configuration in a stable magnetized plasma jet, Physics of Plasmas, 2021: ***https://doi.org/10.1063/5.0044034***

HELION

FIA MEMBER

HELION ENERGY

Helion Energy, Inc. is developing a pulsed non-ignition fusion technology to produce fusion power using deuterium and helium-3.

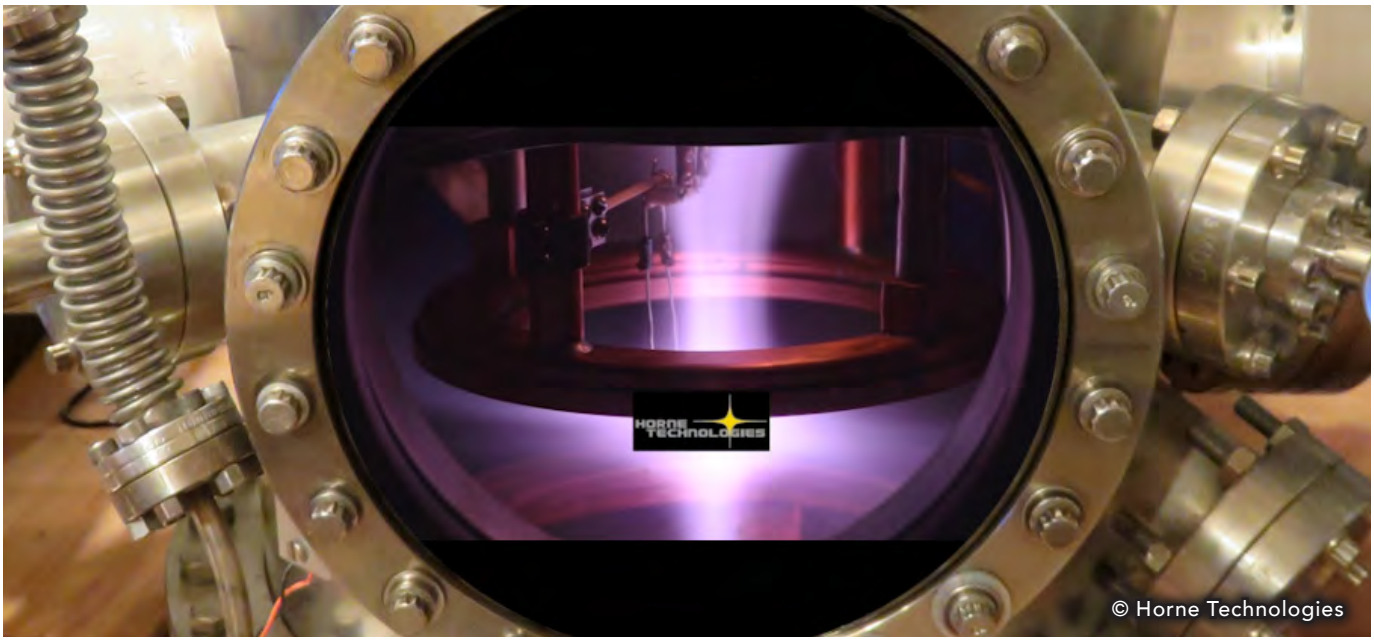
Location	Everett, Washington, USA
Contact details	inquiries@helionenergy.com
Year founded	2013
Founder Names	David Kirtley, Chris Pihl, John Slough, George Votroubek
Target market(s)	Electricity generation
Total funding to date	$78 million USD
Employees (incl. full time consultants)	60
Technical approach (general)	Magneto-Inertial Confinement
Technical approach (specific)	Field Reversed Configuration, Pulsed non-ignition
Fuel Source (e.g. DT, pB11, DD)	DHe3
Highest temperature, and year achieved – self reported	9 keV, 2020
Milestones in past 12 months	Plasma temperatures exceeding 9 keV. Executed a 16-month testing campaign that included completion of more than 10,000 high-power fusion pulses
Anticipated MWe of the operating plant?	50 MWe
Spin outs/patents	Sample patents: Advanced fuel cycle and fusion reactors utilizing the same; Advanced DHe3 fuel cycle for a pulsed fusion reactor; Apparatus, systems, and methods for fusion based power generation and engine thrust generation.

FIA MEMBER

HORNE TECHNOLOGIES

Horne Technologies is a commercial fusion company targeting affordable advancement of fusion technology for near-term energy and neutron production. Horne Technologies' hybrid approach enables rapid low-cost iteration with fusion-capable, continuously-operating devices.

Location	Longmont, Colorado, USA
Contact details	tannerhorne@hornetechnologies.com; +1 406-209-2210
Year founded	2008
Founder Names	Tanner Horne
Target market(s)	Electricity generation
Total funding to date	$140,000 USD
Employees (incl. full time consultants)	2
Technical approach (general)	Hybrid magnetic and electrostatic confinement
Technical approach (specific)	Spindle cusp, superconducting shielded-grid IEC
Fuel Source (e.g. DT, pB11, DD)	DD, pB11
Highest temperature, and year achieved – self reported	50 keV (580,000,000 K), 2020
Milestones in past 12 months	Construction of Gen-II device. All systems operational for fusion temperatures. Development of full power device utilizing 5T magnets and 100 keV temperature.
Pilot plant timescale	3-5 years
Anticipated MWe of the operating plant?	Less than 1 MWe
Spin outs/patents	Patent pending



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HYPERJET FUSION CORPORATION

HYPERJET FUSION CORPORATION

HyperJet Fusion Corporation designs and builds plasma guns. This technology is used by HyperJet's research partner Los Alamos National Laboratory in the development of Plasma Jet Driven Magneto Fusion (PJMIF). Los Alamos operates the Plasma Liner Experiment (PLX), which studies the feasibility of harnessing imploding plasma liners to drive pulsed fusion energy reactions.

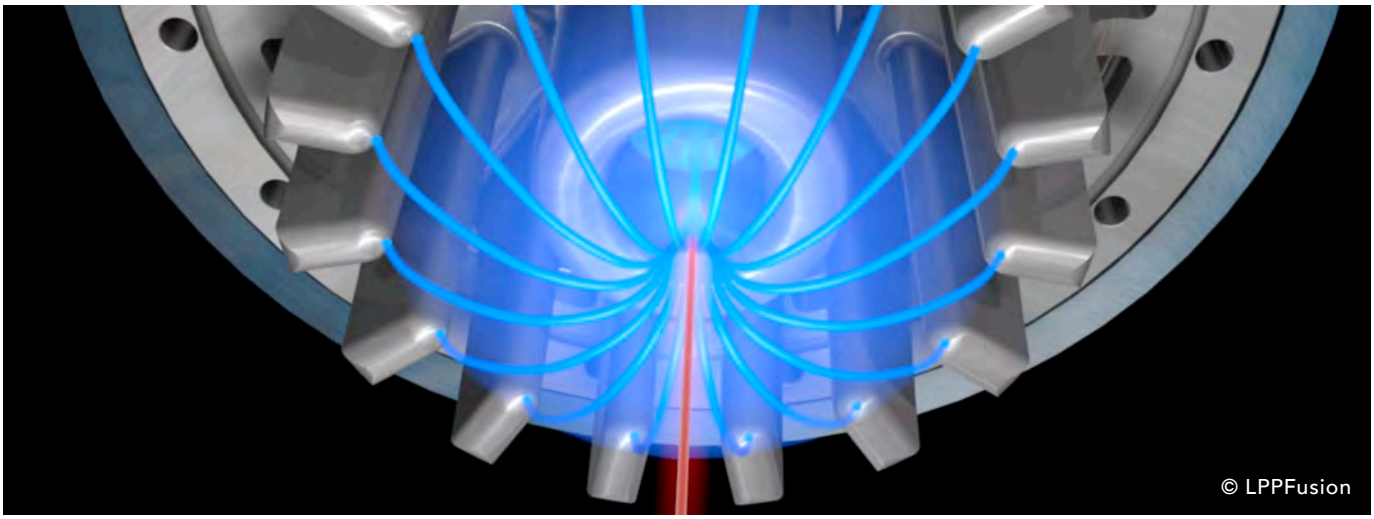
Location	Chantilly, Virginia USA
Contact details	cfaranetta@hyperjetfusion.com; +1 (703) 378-4882
Year founded	2017
Founder Names	Doug Witherspoon Ph.D.
Target market(s)	Electricity generation; Space propulsion; Industrial heat
Total funding to date	$14 million USD
Employees (incl. full time consultants)	7
Technical approach (general)	Magneto-inertial fusion
Technical approach (specific)	Plasma Jet Driven Magneto Inertial Fusion (PJMIF)
Fuel Source (e.g. DT, pB11, DD)	DT
Milestones in past 12 months	Developed magnetized target plasma gun.
Spin outs/patents	Precision metal powders, spacecraft electric propulsion
Key collaborators/partners	Los Alamos National Laboratory

FIA MEMBER

LPPFUSION, INC.

LPPFusion's mission is to provide clean and unlimited energy for everyone through the development of Focus Fusion technology, based on the Dense Plasma Focus device and hydrogen-boron fuel.

Location	Middlesex, New Jersey, USA
Contact details	fusionfan@lppfusion.com; +1 732-356-5900
Year founded	2003
Founder Names	Eric J. Lerner
Target market(s)	Electricity generation; Space propulsion; Marine propulsion; Medical; Off-grid energy; Hydrogen and/or clean fuels; Industrial heat
Total funding to date	$8 million USD
Employees (incl. full time consultants)	4
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Dense Plasma Focus
Fuel Source (e.g. DT, pB11, DD)	DD
Highest temperature, and year achieved – self reported	250 keV (2,500,000,000 K) (2016)
Longest energy confinement time achieved (and year achieved) – self reported	60 ns, 2016
Fusion triple product value achieved (and year achieved) – self reported	~10^{19} keV.s.m^{-3}, 2016
Milestones in past 12 months	Completed upgrade with new switches, new anode
Pilot plant timescale	2025
Anticipated MWe of the operating plant?	5 MWe
Spin outs/patents	***https://lppfusion.com/patents/***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MAGNETO-INERTIAL FUSION TECHNOLOGIES, INC.

Magneto-Inertial Fusion Technologies, Inc. (MIFTI) has invented a thermonuclear fusion process designed provide power for electricity and radiopharmaceutical products used in nuclear medicine. It's Staged Z-pinch (SZP) technology, fuelled by a simple isotope of hydrogen from seawater, is a modular, scalable system.

Location	Tustin, California, USA
Contact details	hafiz@miftec.com; +1 951 756-3826
Year founded	2008
Founder Names	Gerald Simmons; Dr. Hafiz Rahman; Mohammad Arshad
Target market(s)	Electricity generation; Space propulsion; Marine propulsion; Medical
Total funding to date	$9 million USD
Employees (incl. full time consultants)	9
Technical approach (general)	Magneto-inertial fusion
Technical approach (specific)	Z-pinch
Fuel Source (e.g. DT, pB11, DD)	DT
Highest temperature, and year achieved – self reported	8 keV (~80,000,000 K)
Longest energy confinement time achieved (and year achieved) – self reported	20 ns
Fusion triple product value achieved (and year achieved) – self reported	~10^{19} keV.s.m^{-3}
Milestones in past 12 months	10^{10} + in neutron yield
Pilot plant timescale	5-7 years
Anticipated MWe of the operating plant?	50+ MWe
Key collaborators/partners	Lawrence Livermore National Laboratory; University of Rochester; University of California, San Diego
Recent published papers	[1] The staged Z-pinch as a potential fusion energy source (AIP Physics of Plasmas, April 2020 ***https://doi.org/10.1063/1.5131770***

MARVEL FUSION

Marvel Fusion was founded in 2019 with the goal to build and operate commercial fusion power plants based on laser-driven direct drive inertial fusion energy (IFE). The company has identified and developed a novel concept for fusion that exploits substantial quantum enhancements of tunneling probabilities. This concept is not based on a thermal ignition but on the increase of fusion rates through quantum effects and is therefore called 'quantum-enhanced.' It overcomes many of the limitations that the industry has been facing for decades. It promises a much more efficient route to IFE and enables the use of advanced fuels -- like pB11 -- which are otherwise simply out of reach for commercial applications. The concept is enabled by ultra-short pulse, high intensity lasers and proprietary nanostructured targets that allow exploring this new physics regime.

Location	Munich, Germany
Contact details	info@marvelfusion.com
Year founded	2019
Founder Names	Moritz von der Linden, Georg Korn, Pasha Shabalin, Karl-Georg Schlesinger
Target market(s)	Electricity generation; hydrogen and/ or clean fuels
Employees (incl. full time consultants)	30
Technical approach (general)	Laser-driven inertial fusion
Technical approach (specific)	Quantum-enhanced direct drive pB11 fusion
Fuel Source (e.g. DT, pB11, DD)	Nanostructured pB11
Pilot plant timescale	2030
Anticipated MWe of the operating plant?	500-2,000 MWe
Key collaborators/partners	Marvel Fusion works with scientists at Stanford University, Massachusetts Institute of Technology, ELI Beamlines Laser Center, Princeton University, University of Rochester, Ludwig Maximilians University of Munich, University of New Hampshire; University of Göttingen

PRINCETON FUSION SYSTEMS

Princeton Fusion Systems is developing compact fusion reactors and power electronics for the fusion industry.

Location	Plainsboro, New Jersey, USA
Contact details	map@psatellite.com
Year founded	1992
Founder Names	Michael Paluszek
Target market(s)	Electricity generation; Space propulsion; Marine propulsion; Off-grid energy
Total funding to date	$4 million USD
Employees (incl. full time consultants)	5
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Field Reversed Configuration
Fuel Source (e.g. DT, pB11, DD)	DHe3
Highest temperature, and year achieved – self reported	Electron temperature 80 eV (800,000 K)
Longest energy confinement time achieved (and year achieved) – self reported	200 ms
Milestones in past 12 months	Reached 200 kW Rotating Magnetic Field Drive power, TALIF diagnostic
Pilot plant timescale	2027 This will produce kW of fusion but will validate the design.
Anticipated MWe of the operating plant?	1 MWe
Spin outs/patents	Patents #10,811,143 #10,752,385#10,229,756 #9,922,769
Key collaborators/partners	PPPL
Recent published papers	[1] Fast Human Missions To Mars Using Direct Fusion Drive with a Nuclear Thermal Stage, Lunar Cargo Tug Using Direct Fusion Drive ***https://doi.org/10.2514/6.2020-4080***


AIR
PRODUCTS

PULSAR FUSION

Investing in a diversified portfolio of Nuclear Fusion hardware assets in Aerospace and Energy.

Location	Bletchley, UK
Contact details	contact@pulsarfusion.com
Year founded	2013
Founder Names	Richard Dinan
Target market(s)	Electricity generation; Space propulsion
Employees (incl. full time consultants)	28
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Tokamak
Fuel Source (e.g. DT, pB11, DD)	Xenon/Krypton Plasmas 2020, DT in 2021

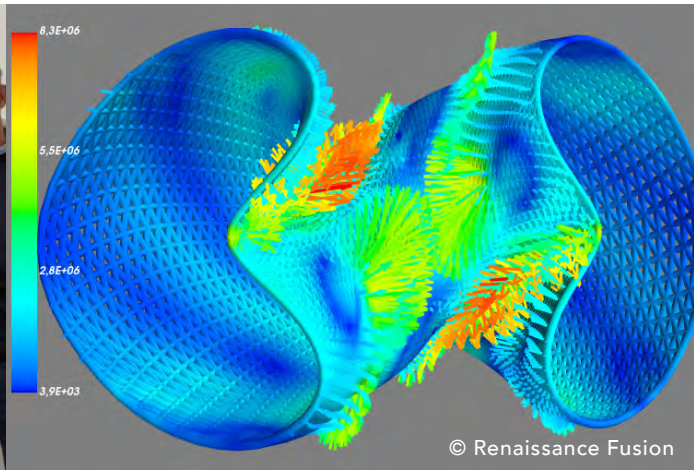
RENAISSANCE FUSION

FIA MEMBER

RENAISSANCE FUSION

Renaissance Fusion is making the stellarator concept reactor-ready by quadrupling the magnetic field and simplifying the design using proprietary High-Temperature Superconductors (HTS) manufacturing. It uses flowing liquid metal walls to protect the stellarator and the delicate HTS from neutrons, and to keep the level of radioactivity as low as in a radiology department in a hospital. In the shorter term, the company plans to commercialize its technologies in energy storage and medical imaging.

Location	Grenoble, France, with an office in Houston, Texas, USA
Contact details	francesco.volpe@renfusion.eu; +33 749209291
Year founded	2020
Founder Names	Francesco Volpe, Martin Kupp, Damien Paccard
Target market(s)	Electricity generation; Marine propulsion; Medical; Hydrogen and/or clean fuels; Industrial heat
Employees (incl. full time consultants)	10
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Stellarator
Fuel Source (e.g. DT, pB11, DD)	DT
Milestones in past 12 months	Hired management team, attracted six technical talents, initiated nine collaborations (7 in EU, 2 in US), numerically minimized forces on stellarator coils
Pilot plant timescale	2031
Anticipated MWe of the operating plant?	1,000 MWe
Key collaborators/partners	National Institute for Research in Digital Science and Technology (INRIA, France), Ampeers LLC (USA), BPI France, Creative Destruction Lab (Canada)
Recent published papers	[1] Minimization of magnetic forces on Stellarator coils: ***https://arxiv.org/abs/2103.13195***



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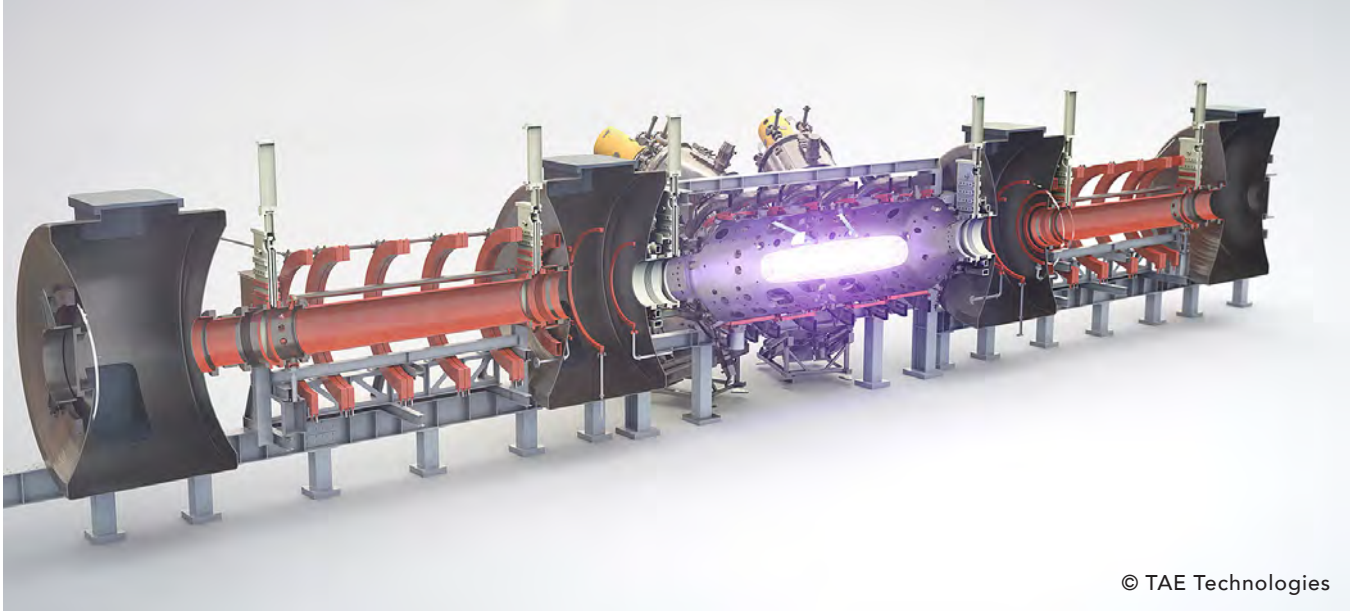
tae TECHNOLOGIES

TAE TECHNOLOGIES

TAE Technologies is commercializing safe, cost-effective fusion power. The company's approach to fusion has also led to commercial innovations in power management, electric mobility, life sciences, and more.

Location	Foothill Ranch, CA
Contact details	press@tae.com; +1 949-830-2117
Year founded	1998
Founder Names	Numerous co-founders
Target market(s)	Electricity generation; power distribution; grid infrastructure; e-mobility; TAE Life Sciences spinoff in radiation oncology
Total funding to date	$880+ million USD
Employees (incl. full time consultants)	250
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Advanced Beam-Driven Field Reversed Configuration
Fuel Source (e.g. DT, pB11, DD)	pB11. Can accommodate all available fuel cycles
Highest temperature, and year achieved – self reported	50+ million degrees Celsius, 2021
Milestones in past 12 months	50+ M degrees Celsius on "Norman" platform, 2021
Pilot plant timescale	Net energy demonstration, "Copernicus," 2024-2025; first prototype power plant, "DaVinci," late 2020s
Anticipated MWe of the operating plant?	400-500 MWe
Spin outs/patents	Over 900
Key collaborators/partners	See Collaborators page on TAE.com
Recent published papers	See Research Library on TAE.com



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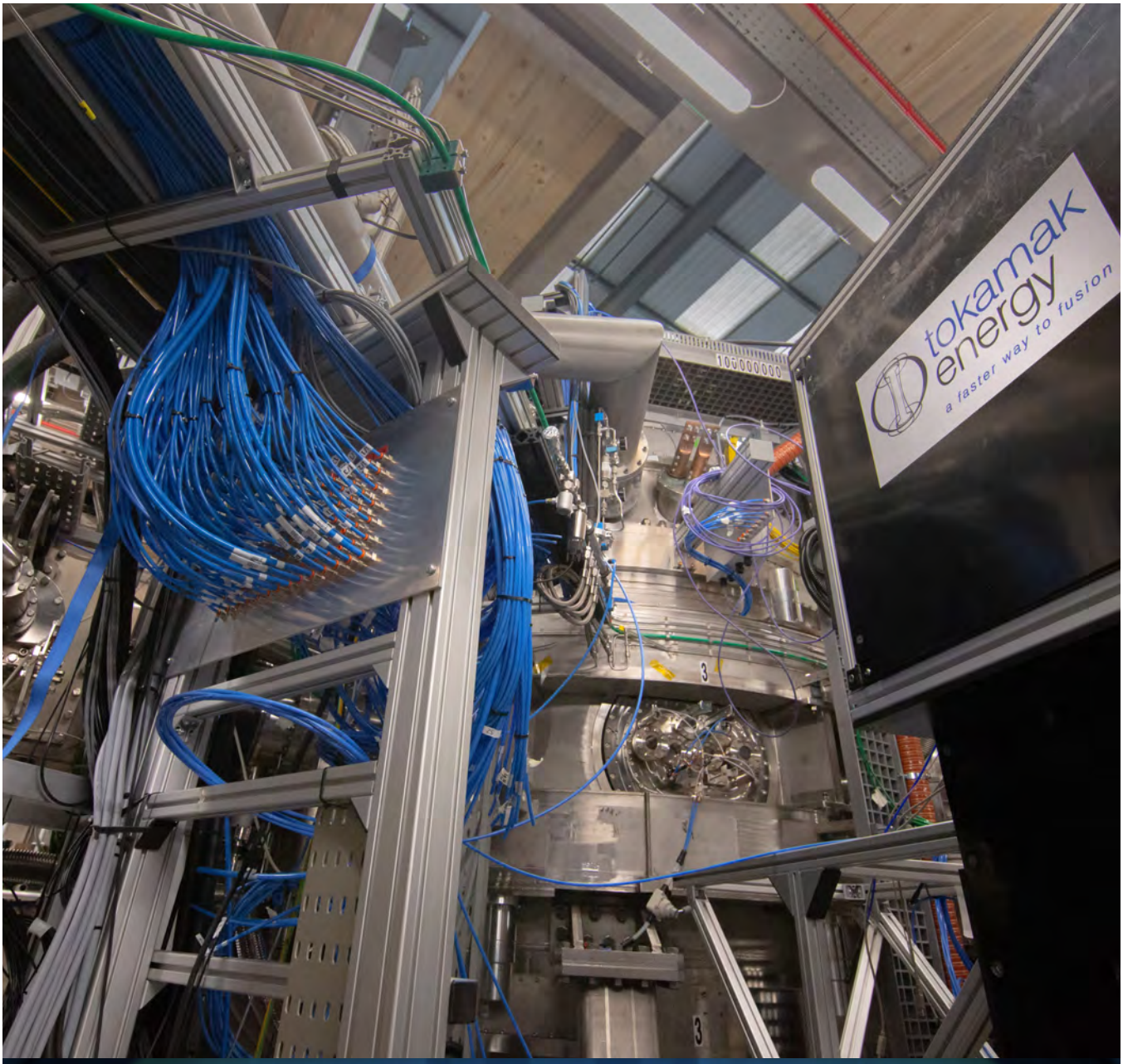
tokamak energy

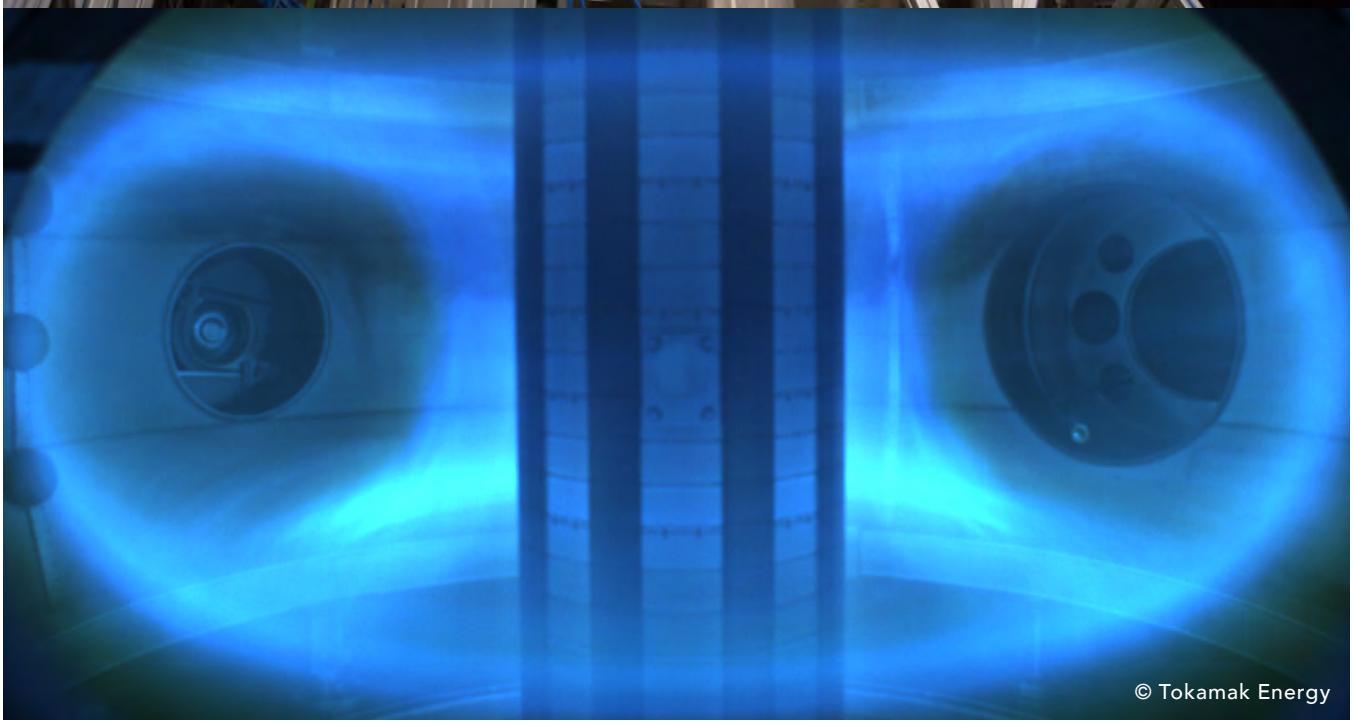
FIA MEMBER

TOKAMAK ENERGY

Tokamak Energy is accelerating the development of fusion energy based on spherical tokamaks with high temperature superconducting (HTS) magnets, as well as commercialising the tech applications of HTS magnets today - for high field science, space, electric aircraft and particle accelerators.

Location	Oxford, UK
Contact details	info@tokamakenergy.co.uk
Year founded	2009
Founder Names	Mikhail Gryaznevich, Alan Sykes and David Kingham
Target market(s)	Electricity generation; Hydrogen and/or clean fuels; Industrial heat; Space propulsion; Marine propulsion; Medical; Off-grid energy.
Total funding to date	$200 million USD
Employees (incl. full time consultants)	180
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Spherical tokamak
Fuel Source (e.g. DT, pB11, DD)	Hydrogen so far. DD soon. DT in the power module.
Highest temperature, and year achieved – self reported	1.5 keV (~15,000,000 K) in 2018
Milestones in past 12 months	Record toroidal field (2T) in a spherical tokamak; demonstration of robust quench protection in HTS magnets
Pilot plant timescale	Early 2030s
Anticipated MWe of the operating plant?	150 MWe per module
Spin outs/patents	Technology licensed to Paul Scherrer Institute to develop HTS magnets for particle accelerators
Key collaborators/partners	Princeton Plasma Physics Laboratory, Oak Ridge, Los Alamos - through INFUSE; Oxford, Cambridge and Tokyo Universities
Recent published papers	[1] Fusion performance of spherical and conventional tokamaks: implications for compact pilot plants and reactors, Plasma Physics and Controlled Fusion, January 2021: ***https://iopscience.iop.org/article/10.1088/1361-6587/abcdfc***





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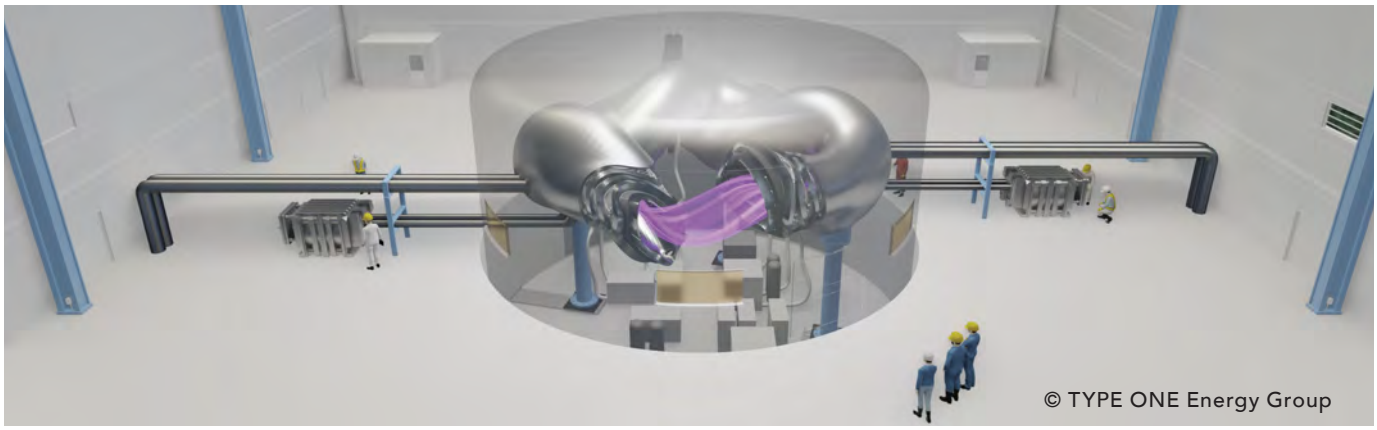
FIA MEMBER

TYPE ONE ENERGY

TYPE ONE ENERGY GROUP

Commercializing the stellarator fusion power system as an economical power plant through advances in high temperature superconducting (HTS) magnets and additive manufacturing.

Location	Madison, Wisconsin, USA
Contact details	+1 608 336 0792
Year founded	2019
Founder Names	Randall Volberg, David Anderson, Chris Hegna, John Canik, Brian Matthews, Paul Harris
Target market(s)	Electricity generation; Off-grid energy; Hydrogen and/or clean fuels; Industrial heat
Employees (incl. full time consultants)	20
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Stellarator
Fuel Source (e.g. DT, pB11, DD)	Catalyzed DD
Highest temperature, and year achieved – self reported	11.6 keV (116,000,000 K) – electron; 4.1 keV (41,000,000 K) – ion
Longest energy confinement time achieved (and year achieved) – self reported	250 ms
Milestones in past 12 months	Developed new high-temp superconducting cables for stellarator magnet and metal 3D-printed assemblies. Now building world's first HTS stellarator magnet.
Pilot plant timescale	Commercial demonstrator targeted for 2033, pilot plant target in 2037
Anticipated MWe of the operating plant?	500 MWe (Cat DD)
Key collaborators/partners	Massachusetts Institute of Technology, Commonwealth Fusion Systems, Oakridge National Laboratory, MELTIO Systems, ARPA-E, DOE INFUSE, and others.



FIA MEMBER

ZAP ENERGY

ZAP ENERGY

Zap Energy is building a seriously cheap, compact, scalable fusion reactor with the potential for a fast path to commercially viable fusion, without magnets.

Location	Seattle, Washington, USA
Contact details	reachout@zapenergyinc.com
Year founded	2017
Founder Names	Benj Conway, Brian Nelson, Uri Shumlak
Target market(s)	Electricity generation; Space propulsion; Off-grid energy; Industrial heat
Total funding to date	$43 million USD
Employees (incl. full time consultants)	25
Technical approach (general)	Magnetic confinement
Technical approach (specific)	Z-pinch
Fuel Source (e.g. DT, pB11, DD)	DT

We are also aware of 12 additional private companies who, for a variety of reasons, chose not to provide information or were uncontactable. We hope to include them in future years.

FUSION
INDUSTRY
ASSOCIATION

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United States

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