Written Statement of

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INTRODUCTION

Chairman Weber, Ranking Member Grayson and Members of the Subcommittee, thank you for the opportunity to testify on the emergence of new innovative fusion energy concepts and the importance of governmental support for these concepts in parallel with longstanding fusion energy research activities.

My name is Nathan Gilliland, Chief Executive Officer of General Fusion, one of the leading private fusion energy companies. I have been asked to provide background on the value of General Fusion's partnerships and relationships with U.S. agencies, labs, universities and other institutions, as well as the emergence of innovative alternative fusion energy concepts.

Though it is mentioned frequently, the game-changing nature of fusion energy bears repeating: energy production that is safe, clean, and abundant that would change the landscape of energy forever and greatly enhance energy security. In a fusion reaction, one kilogram of hydrogen fuel has the equivalent energy of 10 million kilograms of coal—humanity would have abundant energy for millions of years. There is also no long-lived radioactive waste and no chance of meltdown in fusion reactors. Net energy gain from fusion energy has proven more difficult to achieve than expected, and more costly, however the benefits of reaching this milestone in a commercially viable reactor can hardly be overstated.

As the Committee knows well, the U.S. has been the leader in developing fusion energy for many decades, beyond the significant support for ITER, and similar concepts. The U.S. has also led the way in inertial confinement fusion, the culmination being the National Ignition Facility. ITER and NIF have justifiably been highlights of the U.S. fusion energy framework. The resources and time put into both pathways, though very different, have significantly expanded the knowledge-base for all fusion concepts, including a number of innovative alternatives. Though neither program has progressed on a perfectly straight line, the pathway that they have and are creating is unquestionably worth it.

INNOVATION IN FUSION ENERGY AND THE 'MIDDLE GROUND'

The depth and breadth of U.S. research in fusion energy has led to significant innovation, and the development of potentially viable alternative concepts. Nearly all of these concepts borrow ideas and research from ITER and other magnetic fusion programs, as well as NIF and related laser fusion programs. And just like ITER and NIF, each have their benefits and their drawbacks. All have challenges, whether they are scientific and engineering hurdles, speed or cost.

There is a wide arrangement of parameters used in these alternatives, from magnetic fields to compression to even the type of fuel used. The progress of these alternative concepts was featured last summer in both the journals *Science* and *Nature*.

As an example, Sandia's MagLIF experiment demonstrated impressive neutron production using their approach that combines a magnetized plasma with a Z-pinch compression, and published these results in 2014.[1] Though not yet fully proven, Z-pinch has the potential to be a cheaper reactor.

The University of Rochester has also tested a hybrid approach, and is collaborating with the MagLIF team. The University of Rochester used the OMEGA Laser Facility to perform experiments using magnetic field combined with laser compression and demonstrated improved neutron yield. Omega outlined their progress on laser-plasma interaction in December of 2014.[2]

The University of Washington's Helicity Injected Torus program has demonstrated a new mechanism for sustaining a stable plasma.[3] The team has proposed how the technology could be tested at larger scale, as well as an intriguing reactor concept, called a Dynomak, that could be more practical to implement than ITER-style plasmas

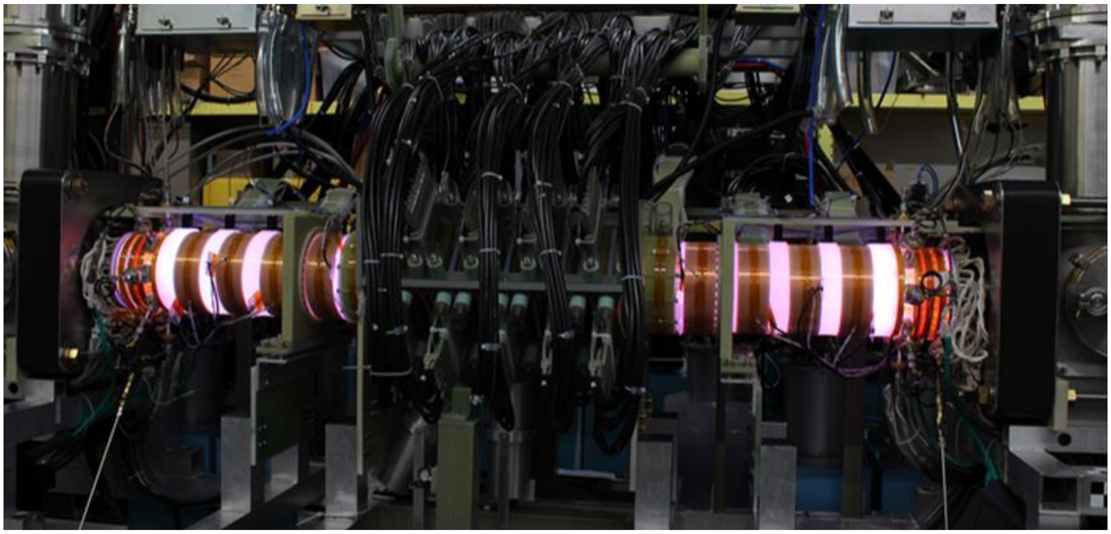
I will provide an on the three leading private companies in the fusion space as well.

Tri Alpha Energy, based in Orange County, uses a magnetic plasma configuration called an FRC and runs continuously to directly extract electricity. Unlike ITER or NIF, they do not plan to use just hydrogen as their core fuel, but rather hydrogen and an isotope of Boron. Though harder from a physics standpoint than using traditional fuels, this approach would avoid neutron damage to the reactor and produce electricity directly. They have extended the lifetime of this FRC plasma to a record five milliseconds, which is a solid step forward. These results were published in 2015. [4]

Helion, is another private company that has demonstrated progress. Located in Redmond, Washington, they also use an FRC plasma like Tri Alpha Energy. Instead of running continuously, Helion creates

[1] Gomez, M. R. et al., "Experimental Demonstration of Fusion-Relevant Conditions in Magnetized Liner Inertial Fusion", *Physical Review Letters* Vol 113 (2014)
[2] Chang, P. et al., "Fusion Yield Enhancement in Magnetized Laser-Driven Implosions.", *Physical Review Letters* Vol 107 (2011)
[3] Jarboe, T.R. et al., "A Proof of Principle of Imposed Dynamo Current Drive: Demonstration of Sufficient Confinement.", *Fusion Science and Technology* Vol 66, No. 3 (2014)
[4] Guo, H. Y. et al., "Achieving a long-lived high-beta plasma state by energetic beam injection", *Nature Communications* Vol 6 (2015)

fusion reactions in a rapid pulse. Helion uses a strong magnetic field to compress this plasma to high temperature. They published reaching a temperature of approximately 35 million degrees Celsius[5],



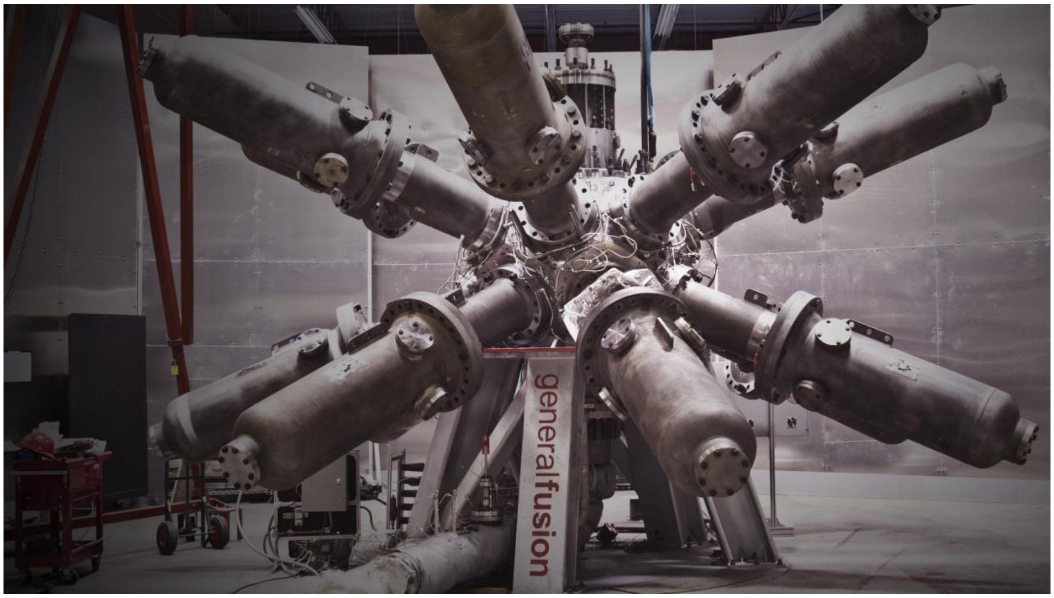
Source: Helion Energy © 2015 Helion Energy

General Fusion, my company, also fits 'between' ITER and NIF, as we use magnetic field to contain heat, but use compression of this plasma to reach fusion conditions.

General Fusion fits into a category of fusion energy called Magnetized Target Fusion (MTF). We also use a specialized plasma, form it to specific temperature and density requirements, and then compress it in a pulsed reaction. We use an array of large, high-precision steam pistons to compress this plasma to fusion conditions. Using pistons to put energy into plasma has one key benefit: cost. Using steam to drive energy into plasma is less expensive than lasers, particle beams, or superconducting magnets. Additionally, we use a liquid metal blanket to surround the fusion reaction, protecting the reactor from neutrons produced and making it much simpler to extract energy.

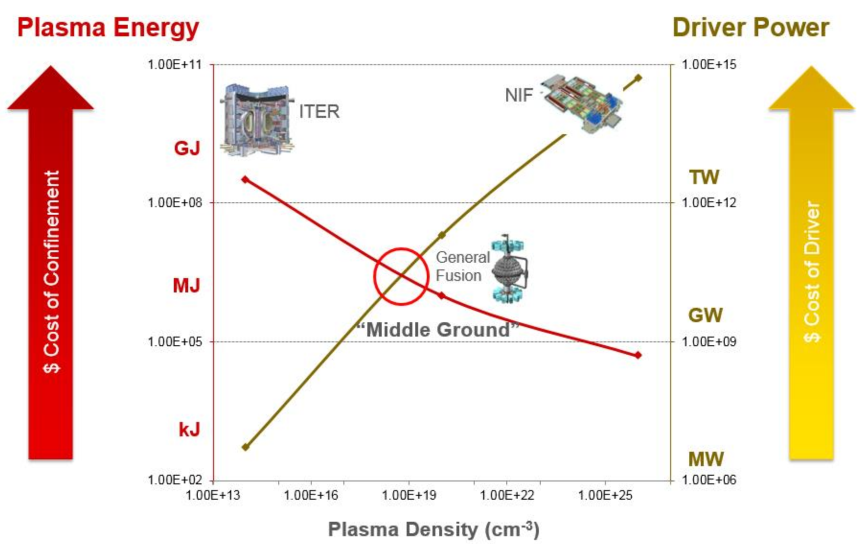
In 2014, building on past research at SSPX (Lawrence Livermore National Laboratory) and CTX (Los Alamos), General Fusion produced the best thermal confinement ever in spheromak plasmas.[6]

[5] Slough, J. et al., "Creation of a high-temperature plasma through merging and compression of supersonic field reversed configuration plasmoids.", *Nuclear Fusion* Vol 51, No. 5 (2011)
[6] Froese, A. et al., "Spheromak Compression Experiments at General Fusion", *Pacific Basin Nuclear Conference Proceedings*, (2014)



Source: General Fusion Inc.

I call MTF and some of these other approaches a 'middle ground,' in fusion research. What do I mean by that? While ITER uses a very low density plasma with magnetic field that runs continuously, NIF and other inertial confinement fusion concepts use no magnetic field but instead use a very rapid pulse reaction using lasers. MTF and other alternative concepts are pursuing a middle ground-- higher density than ITER, but less than NIF: compression like NIF, but at much, much lower speeds. The idea is that lower extremes in magnetic field or compression speed will lead to simpler, less expensive fusion reactors: less expense to confine plasma, and less expense to put energy into this plasma to create fusion conditions:



Source: General Fusion Inc.

Though the nuances of each fusion energy alternative are real, they have several key items in common:

1. Lower cost of confining plasma, and lower cost to put energy into plasma
2. Potentially lower cost commercial power plants
3. Simpler, and in some cases smaller, fusion reactors
4. Progress toward achieving break-even energy

Increased commercial viability, lower cost power, and faster progress are common threads in comparison to ITER and NIF. But of course there are no silver bullets. These alternative approaches tend to be less researched and studied, and are simply newer. Fewer resources, private or public, have been allocated to their study. The core physics of many of these alternatives is less explored – potentially faster, smaller and cheaper, but at an earlier stage in their development.

I would argue the viability and efficacy of these alternative approaches can be demonstrated for less money. Some will show rapid progress, others will not. Dollar for dollar progress or failure can be determined much more quickly.

As the Committee is likely aware, ARPA-E launched its first-ever fusion energy program announcement in 2014, targeting this 'middle ground.' ARPA-E is clearly cognizant of both the value of fusion as an energy source, but also the viability of these alternative approaches as potentially faster, less expensive pathways. As a proponent of this 'middle ground' set of approaches, we were impressed with the program they formulated. We would love to see additional DOE support of this regime in the future.

As an analog, I am aware this Committee has evaluated a number of types of energy storage options: lithium-ion batteries, lead-acid batteries, molten salts, flywheels and many others-options that are highly diverse in their cost and application. It is much too early to declare one dramatically superior. Each has its benefits and its drawbacks and they represent a basket of alternatives for a variety of situations and applications.

Further, like so many other new energy sources, whether fossil fuels, solar or wind, this is not a 'winner-take-all' industry we are developing. Small fusion reactors have certain applications, while large reactors can power cities. Some fusion reactors will be used to make industrial heat, while others electricity. There isn't one solar company or one oil & gas company, and there will be multiple fusion energy companies.

VALUE OF GENERAL FUSION'S PARTNERSHIPS WITH U.S. AGENCIES, LABS, UNIVERSITIES AND OTHER INSTITUTIONS.

The Committee also asked me to comment on my company--General Fusion—and its experience with U.S. labs, universities and agencies.

Founded in 2002, General Fusion is a private, venture-capital backed company with sixty employees based in Canada. The majority of our capital has been sourced privately, and totals nearly $100 million raised from a global investor base. We have also received support from various Canadian government programs.

Though the majority of fusion research has been publicly funded, there is a place for private companies, who can build on previous research and innovate faster. SpaceX and Celera Genomics are good analogs. The NIH led research and created the framework for the Human Genome Project. Private company Celera rapidly innovated, and ultimately led the way to what is today rapid and inexpensive gene sequencing. Large government-backed programs built the framework, and created the opportunity, but private industry was able to drive down cost, and move more quickly.

None of this is to say that the time has arrived to turn all fusion research over to private companies – it is too early for that step.

U.S. labs and universities engage in the world's leading research and much of the most advanced experimentation, and as a private company we are keen to draw on this expertise wherever we can.

To be specific, we have benefited in the following ways from U.S research efforts:

1. Our core concept is based on the ideas first developed in the LINUS program at the Naval Research Lab in the late 1970s and early 1980s.[7] Novel research and experimentation done by this group centered on using compressed gas pistons to compress plasmas. The concept was elegant for a variety of reasons, notably the ease of extracting heat. We continue to have an ongoing dialogue with Dr. Peter Turchi, one of the pioneers of Magnetized Target Fusion and this approach.
2. We have previously had a Cooperative R&D agreement with Los Alamos, and continue informal dialogue with current researchers.
3. We have Advisory Council members and consulting arrangements with individuals presently or previously affiliated with Lawrence Livermore National Laboratory, Los Alamos and Princeton.
4. We and others use a simulation code, NIMROD, extensively – this is a multi-lab project originally sponsored by the DOE's Office of Fusion Energy Sciences to create tools for fusion research.

However, if I could suggest one step as an industry we need to make, it is a change to our ethos. Often because of funding concerns, our industry is often dismissive of any other fusion concept. At times, ITER proponents don't support laser fusion. NIF proponents are quick to point out the flaws in tokamaks. The same is true in the basket of alternative pathways that I have discussed so far. We are at times quick to point out others' weaknesses – but we all have them. The world needs fusion energy, wherever we can get it. And the faster the better. I would like to see more initiative on the part of

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[7] Turchi, P. J., et al., "Linus fusion reactor design based on axisymmetric implosion of tangentially-injected liquid metal. Memorandum report.", *Naval Research Laboratory* (1981)

private companies as well as U.S. Labs to share best practices, share data, share simulation codes. There is no value in the silos that have been built.

ROLE OF U.S. LABS, UNIVERSITIES AND AGENCIES IN ALTERNATIVE FUSION CONCEPTS: WHAT IS NEXT?

Outside of funding for these alternative approaches, there are a number of more practical items, areas in which private companies would certainly invest:

Simulation codes. All fusion programs, big, small, longstanding or alternative use simulation codes. Two thoughts here. First, there are several codes that are validly restricted for national security reasons. I don't suggest opening these codes up completely, however, for private industry there ought to be a pathway to apply, be screened, and use these codes. An example is ALEGRA code, developed over many years by Sandia National Laboratory and designated "unclassified Export-Controlled Information". Let's find a pathway that protects the justifiable national security concerns, but allows for greater access. Companies like General Fusion are not only interested in using these codes, but are also prepared to commit resources to help develop and advance their capabilities for all users.

Additionally, all large fusion efforts generate huge volumes of data. Data from sensors, diagnostics, simulation and other sources. Private industry's capabilities in fast computing, analysis using "big data" tools and machine learning, have accelerated rapidly over the last five years. Use of these new tools would be beneficial to all of us. I believe a public-private partnership is in order here.

Entrepreneurial leave program. Some U.S. labs offer leave programs in which physicists can go into private industry for one to two years and return. This is a tremendous idea that should be offered more broadly, and incentives created to participate. This temporary transfer of experts could go both ways – from labs to industry, and from industry to labs. Knowledge and experience rest with people, and the movement of people will lead to greater information sharing and rapid advancement. General Fusion, and other private companies are prepared to commit resources to facilitate this program.

Information sharing is not as valued as it should be. This is true for U.S. laboratories in some cases, but it is true of the private fusion companies as well. We would like to see greater emphasis and initiative toward sharing experimental data--past and future—as there is no question it would benefit us all.

CONCLUSION

U.S. support for ITER and NIF have created a wealth of research data and experimental results which have significantly benefitted the entire fusion community. We encourage continued support for both approaches. Although less researched and potentially higher risk than ITER and NIF, fusion alternatives may offer less expensive, faster, and more commercial pathways to net gain. Given the demonstrated progress of these alternatives and their potential viability, we believe more financial support, along with initiatives to support greater information sharing and greater exchange of human capital, is warranted. Rapid information sharing and open innovation will all lead us more rapidly to the ultimate goal: commercial fusion energy. The faster the better.