The Fork in the Road to Electric Power From Fusion

HyperJet Fusion Corporation

Peter Lobner, 1 February 2021

Introduction

HyperV Technologies Corp. is a privately held fusion energy research and development company founded by F. Douglas Witherspoon in 2004 in Chantilly, VA. In May 2017, HyperV merged with the newly formed HyperJet Fusion Corporation founded by Witherspoon and Francis Thio, with seed funding from the venture fund Strong Atomics. All facilities, equipment and intellectual property from HyperV were transferred to HyperJet Fusion Corporation. Staff are being transferred to HyperJet Fusion Corporation as the contracts still held by HyperV are completed.

HyperJet (and previously HyperV) is a member of a team developing Plasma Jet Driven Magneto-Inertial Fusion (PJMIF). Other team members include Los Alamos National Laboratory (LANL), and the University of New Mexico. During work on the PLX-α experiment under the Department of Energy's (DOE) Advanced Research Projects Agency – Energy (ARPA-E) ALPHA program, the team announced that HyperJet will lead the effort beyond the ALPHA program.

The HyperJet website is here: http://hyperjetfusion.com

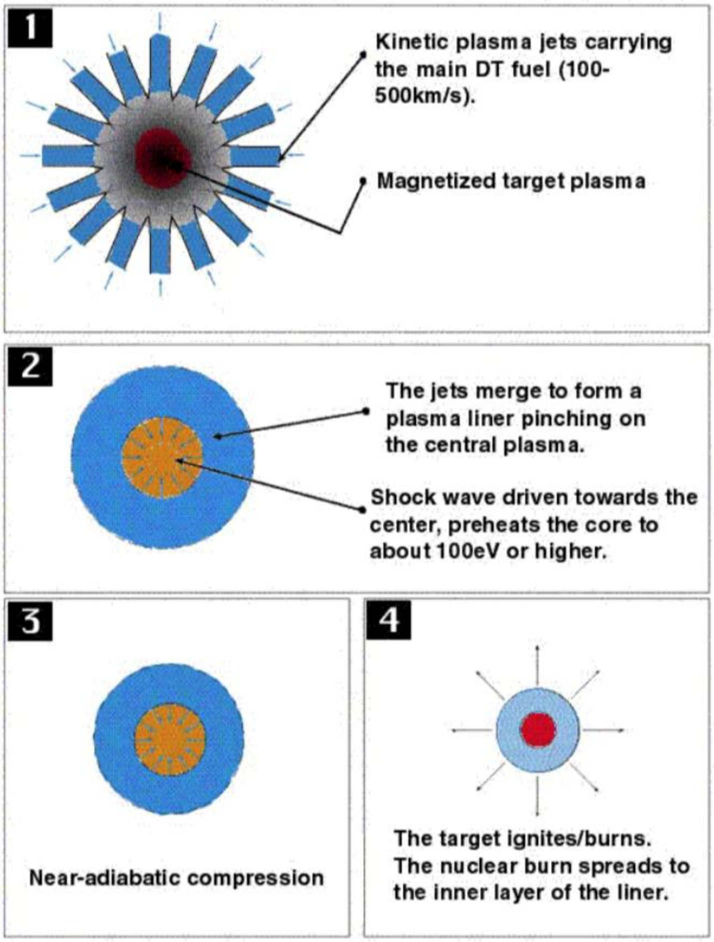
The HyperV website is here: http://hyperv.com

Plasma Jet Driven Magneto-Inertial Fusion (PJMIF) basics

PJMIF is a form of magneto-inertial fusion (MIF). The following description is based on the 1998 paper by Thio, et al. that introduced the concept.

The target is a magnetized deuterium-tritium (D-T) plasma at the center of a large sphere. The target is formed from two merging compact plasma toroids. The presence of the magnetic field in the target has profound effects on the course of the implosion and the consequent fusion yield.

The inertial compression is provided by a large number of plasma guns (electromagnetic accelerators) installed on the inner surface of the sphere. The guns are designed to fire very high velocity (on the order of 125 km/s) plasma jets radially toward the center of the sphere. The first set of guns launch plasma jets carrying the main D-T fuel (“cold fuel”), followed immediately by high atomic weight, high inertia plasma jets (a high-Z gas, argon) fired by the second set of guns. As the first plasma jets merge, they form a symmetrical imploding spherical plasma liner that initiates a shock wave that is driven toward the central target plasma, which gets pinched and preheated by the shockwave (becoming the “hot fuel”). The second layer of the plasma liner is formed when the high-Z jets merge, and with their high inertia, they adiabatically compress the target and the inner liner. Fusion is initiated in the hot fuel of the target and spreads to the first layer of the imploding liner containing the cold fuel. This process is shown in the following graphic.



The PJMIF process. Source: Thio (1998)

In their 1998 paper, Thio, et al. provide the following details on how this PJMIF process proceeds after fusion is initiated in the target:

> “The radial convergence of the plasma liner is halted abruptly by the nuclear burning central plasma sending a stagnating shock expanding outwards through the plasma liner, compressing the plasma liner to form a highly dense cold fuel layer on the inside. The cold fuel layer is ignited by the nuclear burning central plasma serving therefore as a ‘hot spot’. The pressure and the inertia of the shocked and compressed liner provide the inertia confinement for itself and the nuclear burning hot spot. When the expanding shock wave reaches the outer boundary of the plasma liner, the liner expands and a rarefaction wave emanates radially inwards from the surface of this outer boundary. This results in the expansion and the disassembly of the plasma liner, terminating the confinement of the nuclear burning fireball.”

Because the plasma guns are located a significant distance away from the fusion burn region, they constitute a “standoff driver” and should be protected from damage during repeated cycles. PJMIF is the only embodiment of MIF that has the unique combination of standoff implosion and high implosion velocity.

The PLX-α experiment

In May 2015, the PLX-α team (LANL, HyperV, UNM and others) was awarded $5.88 million under the ARPA-E ALPHA program for a three-year project to develop new coaxial plasma guns, construct and operate a new 60 gun spherically imploding Plasma Liner Experiment machine (PLX-α) at LANL, and conduct extensive diagnostic measurements and computational modeling of the imploding plasma liner physics.

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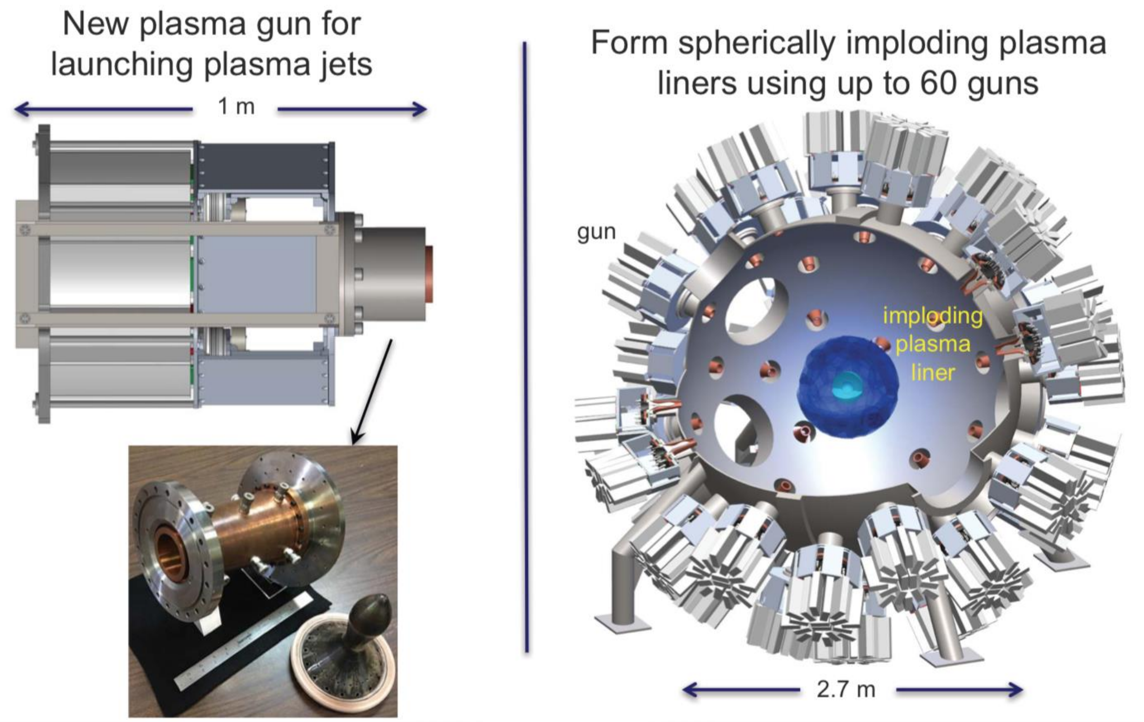


General configuration of the PLX-α machine and plasma guns.
Source: LANL / Hyperjet (2017)

In their 2019 retrospective of the ALPHA program, the authors (C. L. Nehi, et al.) reported that the PLX-α team designed, built, and tested seven state-of-the-art coaxial plasma guns, and used them to merge up to seven hypersonic plasma jets to form a section of a spherically imploding plasma liner. The team assessed two key scientific issues of plasma-liner formation via merging plasma jets and produced positive results:

- **Shock heating**, which could reduce the sonic Mach number of the merged jets and thereby reduce predicted energy gain. Tests showed the merged shock wave remained above Mach 10.
- **Degree of uniformity of the liner,** which is formed when the many discrete plasma jets merge. Upgrades to the plasma jets reduced non-uniformity to about 2%, resulting in the formation of a section of the plasma liner in good agreement with simulations.

PLX-α machine. Source: LANL

Beyond PLX-α, HyperJet's longer-range plans include:

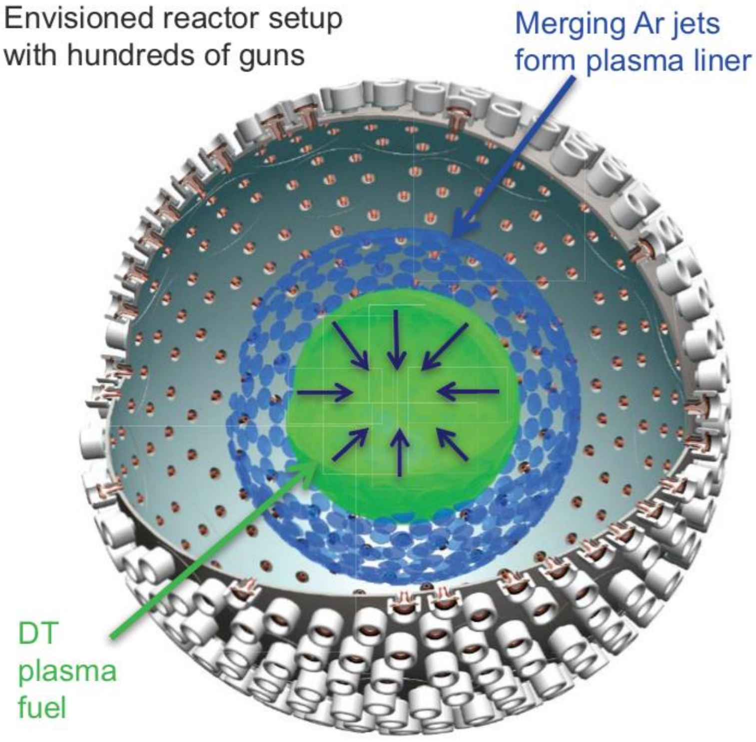
- Demonstrate fusion breakeven for less than $300 million in a single-shot mode
- Demonstrate fusion gain required for a commercial power reactor for $450 million in a single shot mode

Beyond that is the challenge of developing a PJMIF fusion reactor that operates in continuous pulse mode for long periods of time.

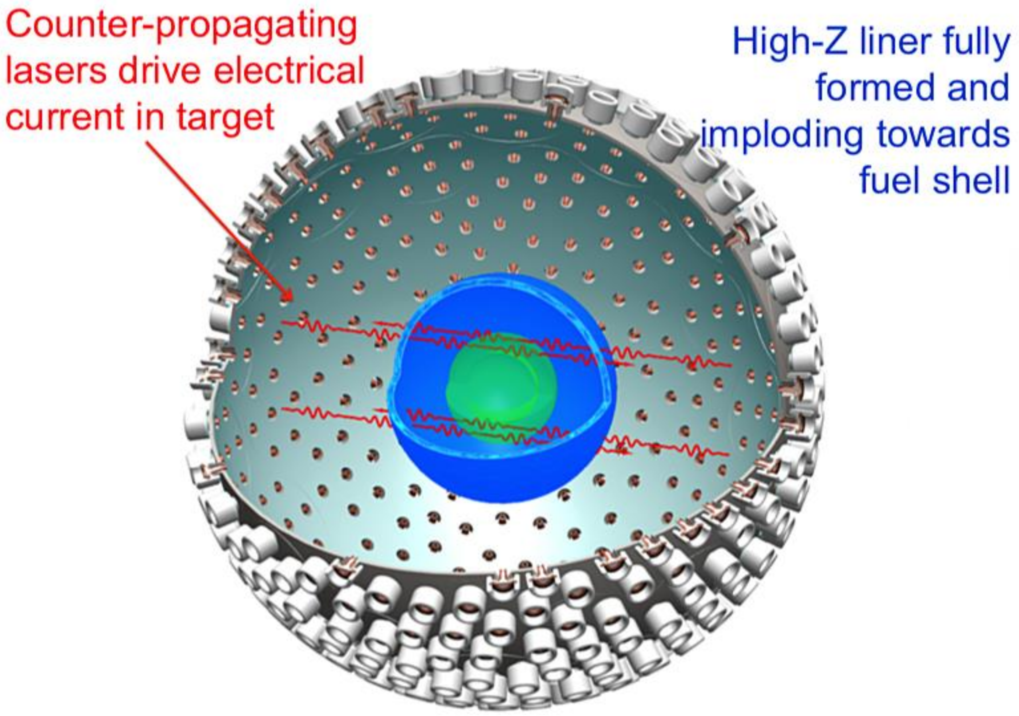
Commercial power reactor concept

A commercial PJMIF fusion power reactor will operate on similar principles to those described previously, but in a larger spherical vessel (25 foot / 7.6 m) with many more plasma guns (about 600) and a longer compression distance. A key difference is in the lack of an initial magnetized target plasma. During the ALPHA project, the PLX-α team presented a concept in which the D-T cold fuel liner and the high-Z argon liner were formed as described previously. After the high-Z liner has fully formed around the D-T liner, laser beat wave pairs are fired into the imploding D-T liner to induce a magnetic field, enabling this now-spherical inner liner to function as the target. At peak compression, the assembled plasma sphere has a diameter of about 0.8 inch (2 cm) and fusion is initiated.

Residual gases will be pumped out of the fusion reaction chamber and the machine will be ready for the next shot. PJMIF has the potential for a relatively high repetition rate of 1 to 2 cycles per second, which would approximate a continuous fusion power source.



General arrangement. Source: LANL / Hyperjet (2017)



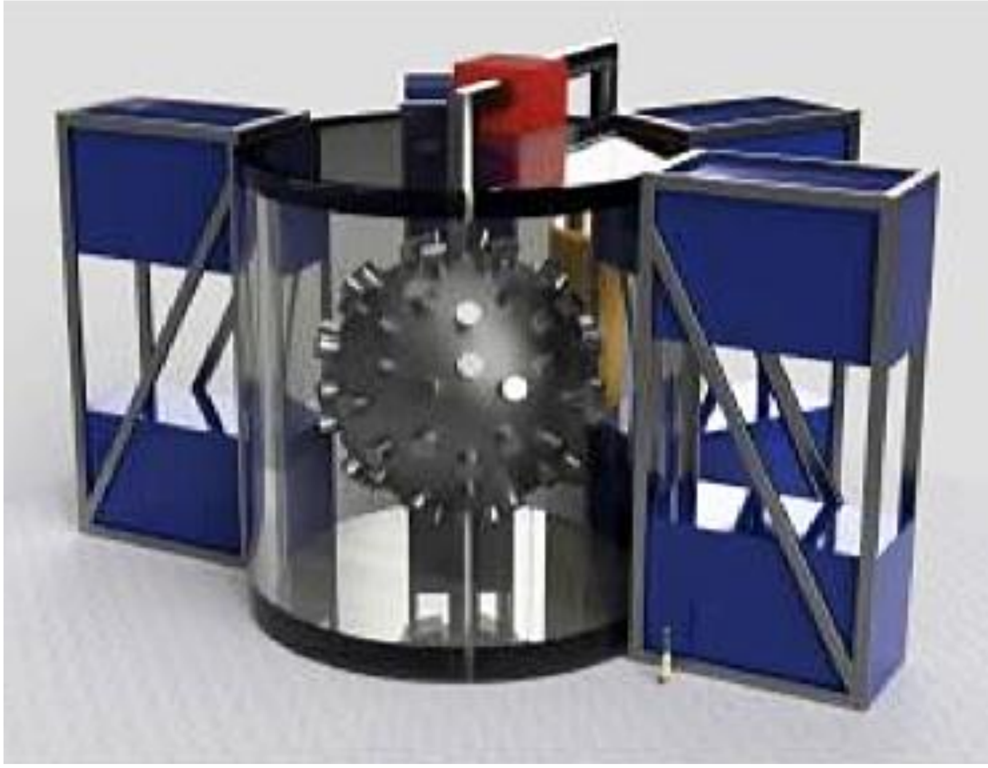
Magnetizing the target. Source: LANL / Hyperjet (2017)

The general configuration of the machine is compatible with the use of a thick liquid inner wall (i.e., a flowing layer of liquid metal or molten salt) that can serve as the primary heat transfer medium for extracting heat from the fusion reaction chamber while also reducing the neutron damage to the vessel structure and serving as the tritium breeding medium to sustain the D-T fuel cycle for the reactor.

The PLX-α team identified the following key challenges for developing the commercial reactor:

- Achieving sufficient liner uniformity and pressure
- Forming compatible magnetized plasma target
- Engineering development of reactor-grade plasma guns

As part of a 2017 cost study for ARPA-E, Bechtel and Woodruff Scientific developed a conceptual design for a 150 MWe PJMIF power plant. The plant, shown below, included a single reactor module (grey), a power conversion system (yellow, in the background) and pumping and tritium systems (red). The power supplies (blue) are outside of the biological shield building (clear).



Concept design for a PJMIF power plant.
Source: Bechtel and Woodruff Scientific (2017)

A summary of that cost study is available here: https://nucleus.iaea.org/sites/fusionportal/Shared%20Documents/Enterprises/2018/Presentations/14.06/Woodruff.pdf

Funding

Funding for the PLX-α experiment and related follow-on machines implementing PJMIF has been going to multiple recipients, including LANL, HyperV and HyperJet Fusion Corporation. Awards to LANL likely included subcontracted work to other team members (HyperV and HyperJet).

- August 2015: $6.63 million under the DOE ARPA-E ALPHA program for LANL to fund the PLX-α team, which includes HyperV.
- May 2017: $2 million seed funding for HyperJet from Strong Atomics
- July 2018: $150,000 grant for HyperJet from DOE FES

- April 2020: $4.62 million under the DOE ARPA-E BETHE program for LANL to fund the PLX-α team, which includes HyperJet.

HyperJet reports that it is currently seeking $20 million in new investments to fund the following:

- Develop compatible plasma target
- Demonstrate liner-to-target compression for proof-of-concept
- Perform large-scale PJMIF computations
- Develop reactor-grade plasma guns

For more information

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- "Plasma Jet Driven Magneto-Inertial Fusion (PJMIF) - The Plasma Liner Experiment-Alpha (PLX-α)," HyperV Technologies Corp.: http://hyperv.com/current-projects/plasma-jet-magneto-inertial-fusion-pjmif-research-development/
- Poster, "Plasma-Jet-Driven Magneto-Inertial Fusion (PJMIF): A Faster, Cheaper Path to Economical Fusion Power," Los Alamos National Laboratory & HyperV Technologies Corp. for ARPA-E Energy Summit 2016: http://hyperv.com/wordpress/wp-content/uploads/2016/04/PJMIF-Fusion.pdf
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- S. Hsu & F. D. Witherspoon, "Spherically Imploding Plasma Liners: A Potentially Transformative Fusion Driver," presentation to ARPA-E ALPHA annual meeting, 29 August

2017: https://arpa-e.energy.gov/sites/default/files/02_HSU%20and%20WITHERSPOON.pdf

- C. L. Nehi, et al., “Retrospective of the ARPA-E ALPHA Fusion Program,” Journal of Fusion Energy, 38_506 – 521, 2019: https://www.osti.gov/biblio/1572943
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