Fusion In Upheaval

On May first, congress released another climate change report. 841 pages of bad news [31]. Climate change is already happening. It will get worse. An ice sheet, the size of New Mexico and Arizona is sliding into the ocean [32]. Mankind can hear the slow ticking, of an environmental time bomb.

Climate change is manmade. It is caused by the burning of carbon fuels. We cannot seem to stop. To stop, we need a zero-emission energy alternative. One so cheap that pulls in the entire world. Energy that is so plentiful, it replaces all existing sources. Fusion could be that solution.

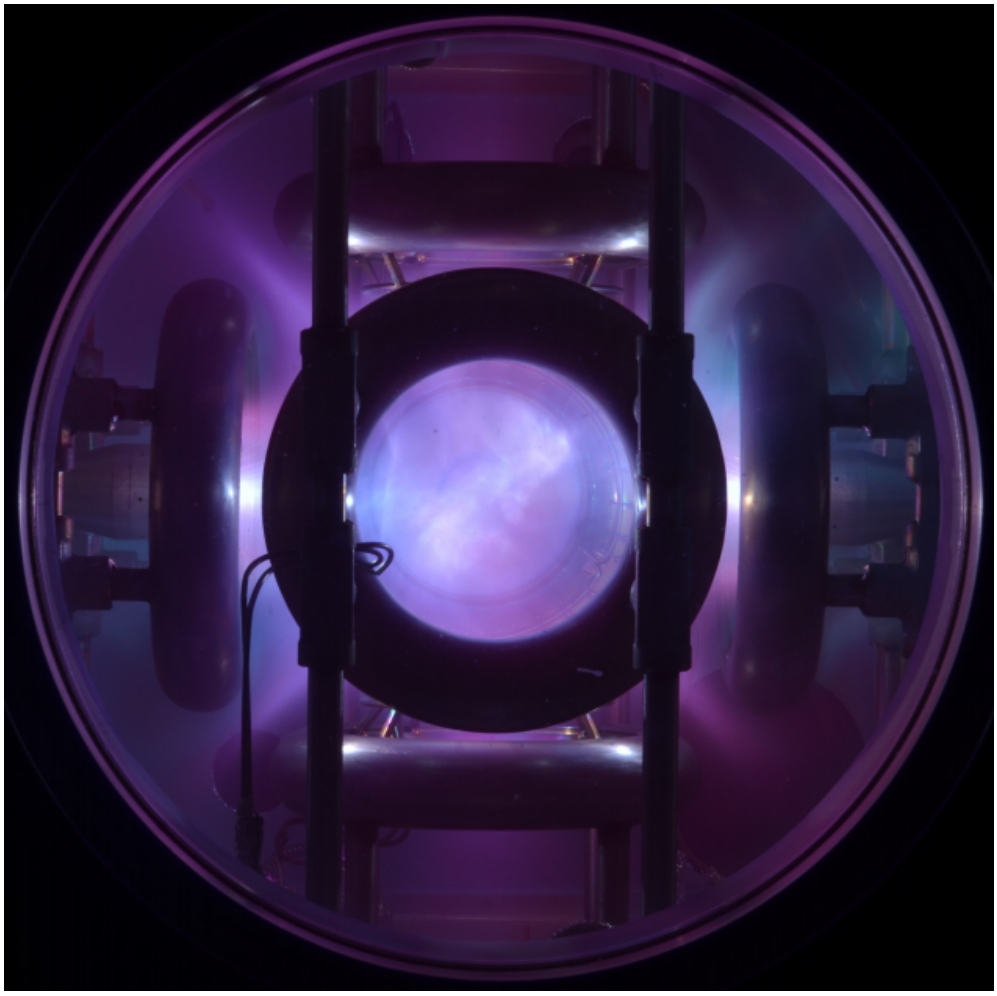
We need a determined effort to make it real. We are running out of time. We need to push every option. This is including (and especially) new options. Traditionally, funding has failed here. But that may finally be changing.

Fusion is in upheaval. The ignition effort has failed. Billionaires and crowds are funding ideas. Teenagers are becoming fusioneers. New paths are rising from obscurity. Few have noticed it yet - but a revolution is on its way.

Executive Summary:

This covers developments in fusion: the navy work, LIFE ending, high school fusioneers and General Fusion. The navy work will be significant because of: firm theory, a credible team, fine equipment and a supporting community. Grad predicted that high pressure, cusped confinement would be MHD stable. The polywell seems to behave this way. When compared to other confinement schemes, this has advantages. In April, Livermore quietly ended the Laser Inertial Fusion Energy program. The historic goals of the 13 billion dollar ICF program are summarized. Carl Greningers' northwest nuclear consortium is reviewed. The program gives high school students access to a fusion machine. They have won 410,000 dollars in college scholarships and international science fairs. General Fusion Inc. is introduced. Their idea is to compress plasma inside spinning liquid metal,

using pistons. The merits of this, along with details of their prototype, are reviewed. The physics of one piston strike and a model of the pressure made are given. This was a boundary conditions for 2D and 3D CFD code. The post closes with a call for government leadership and funding of new fusion ideas.



Part 1: A Polywell Publication

Introduction:

In June, Energy Matter Conversion Company opened up a submitted paper to the public. If this data is true, the navy may have found the worlds' best plasma trap. Check it out yourself. The response has been electric. The link ricocheted around twitter, Linkedin and Google+. Several blogs are covering this, as did NBC News [56]. Long dormant users, have

suddenly rejoined Talk-Polywell. There is plenty to celebrate. This paper is spectacular. It will turn heads; and here is why:

1. **Firm Theory:** James Tuck and Harold Grad predicted this data. Dr. Tuck was a forefather of fusion research and a key part of the Manhattan project. Grad was a famous NYU professor. Grad's body of work gives the Navy a rock solid theoretical basis [51].

2. **Great Team:** A very large, credible, team contributed: nine authors and thirteen helpers [50]. Several groups are represented: two companies, a European university, Los Alamos and the US Navy.

3. **Fine Equipment**: The machine was finely made; and very powerful. Eight tools measured the plasma [50]. This gave totally new data. Data that has long been sought – but that was always too expensive to get. View a model of their machine here.

4. **Supporting Cast:** Amateur fusion is spreading. As people see live demonstrations of fusion the public opinion will shift. This research will get noticed.

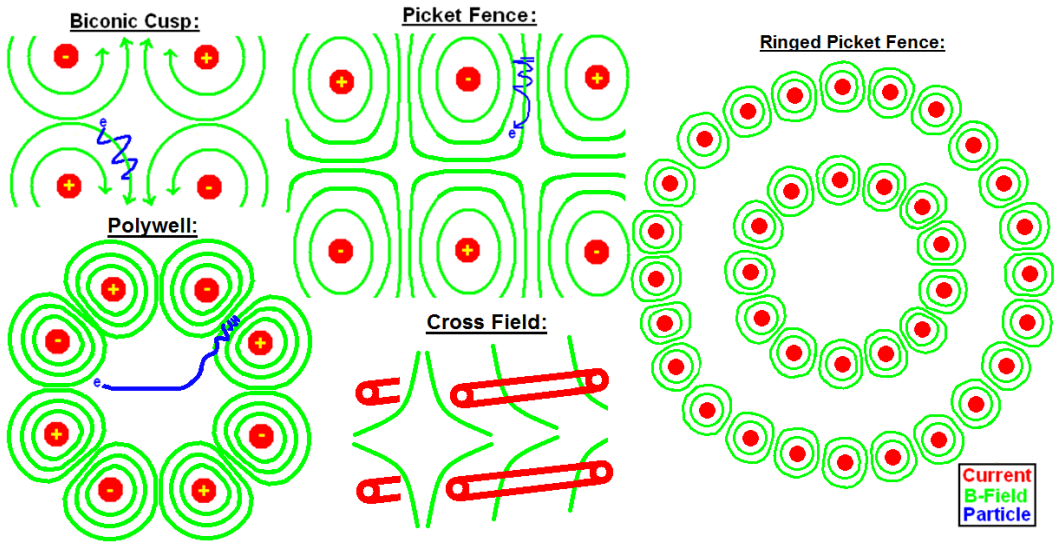
5. **Strong Messenger:** Dr. Park has a doctorate in plasma physics from Princeton and worked at Los Alamos for 12 years. His creditability can sell this [54]. He has started with a physic seminar at UC Irvine and a talk at Wisconsin-Madison [52, 53].

There will be scientific criticism. This is healthy. It will come from many quarters. If the data holds – it will put the polywell on a firm footing. Something that other ideas never had. That does not mean the polywell is: "the greatest idea ever" or "totally bogus." What it means is: we need to fully fund research; now. Right now. Currently, this work is looking for a new home. Will it be a company, or a university, or a national lab? Only time will tell.

Cusp Confinement:

What makes this, the worlds' best plasma trap? It uses cusp confinement. This was always an idea on paper, but had never been a working system. Cusps are sharply curved fields. They bend into one another. This trapping method dates back to the early days of fusion research. A family of designs tried to realize it. Some examples are shown below [55].

Family of Cusped Confinement Designs:



In the 1950's, mathematicians predicted that these designs could be very stable [55, 58]. They started from first principals. Using the equations that give equilibrium in a conducting fluid - in the presence of a magnetic field – Harold Grad analyzed many configurations. The high pressure, cusped system came out as stable. These equations are shown below [59].

Equilibrium Conditions In A Conducting Fluid, In A B-Field:

$$\nabla \text{Fluid Pressure} = \text{Current Density Vector Field} \times \text{Magnetic Vector Field}$$

$$\nabla \times \text{Magnetic Vector Field} = \text{Viscosity} * \text{Current Density Vector Field}$$

$$\nabla \bullet \text{Magnetic Vector Field} = 0$$

Or,

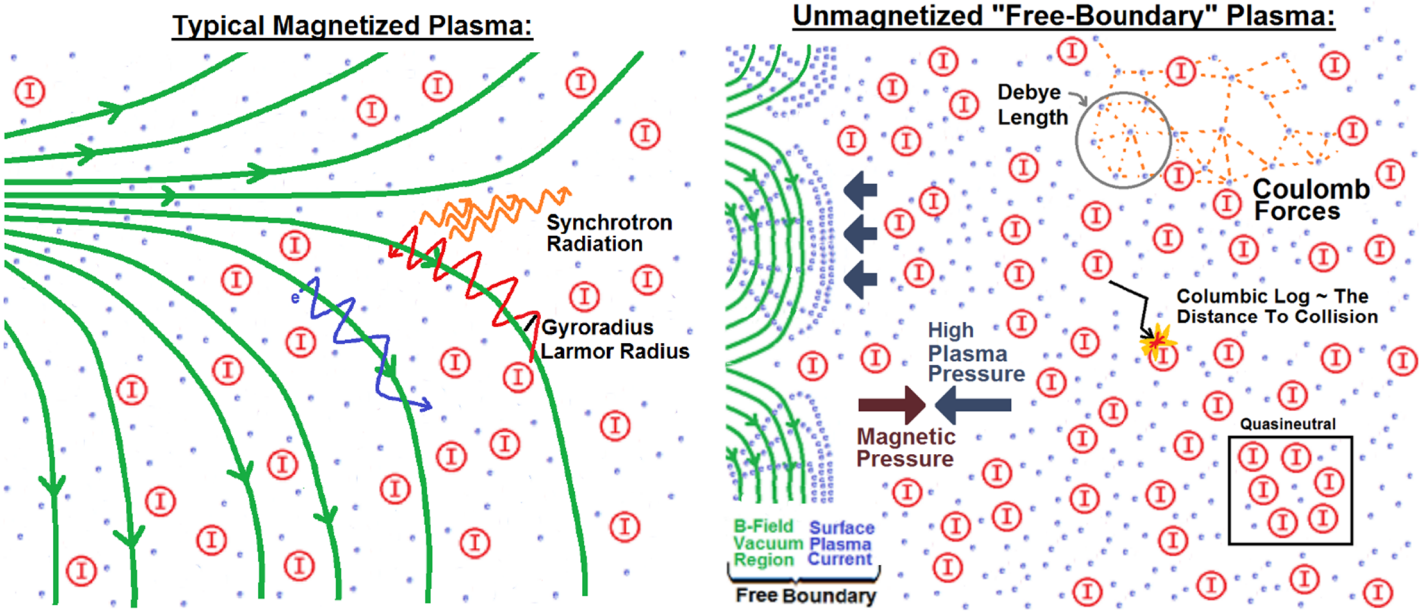
$$\nabla \left[\text{Fluid Pressure} + \frac{\text{Magnetic Strength}^2}{2 * \text{Viscosity}} \right] = \frac{\left[\text{Magnetic Vector Field} \bullet \nabla \right] \text{Magnetic Vector Field}}{\text{Viscosity}}$$

$$\nabla \bullet \text{Magnetic Vector Field} = 0$$

The reason for the stability was: that the magnetic field was balanced by a surface current [59]. A thin current ran down the edges of the plasma. The high pressure meant that ions and electrons push into the edge. This was called the “free-boundary” [55]. I am still trying to understand Grads’ work, as well as this system. If the field does not penetrate the cloud, then there are many implications.

“Free-boundary” Plasmas:

It must be stressed that this design is very new. More work is needed. First to verify it, then to understand it and finally to use it. If true, it provides a sharp contrast with typical systems. This is best explained with illustration.



These are very different pictures. The first is a magnetized plasma. Normally, the field enters the plasma. The particles follow the field; corkscrewing around. As they move, they radiate energy [63, 64]. This path may take them out of the trap. If the fields curved, it can also fling particles outward [62]. The second is the “free-boundary” concept. Ideally, sharply curved fields and high pressure plasmas would be required. The field does not enter the bulk. Because of this, the particles corkscrewed less. This lead to a drop in synchrotron radiation losses [51]. That is a big help for any power plant scheme. More critically - this system may be

magnetohydrodynamically stable [55, 58]. In fifties, few people grasped the consequences of this. In the 50+ years since we have learned just how unstable plasma is. There are tons of instabilities. Avoiding even a handful would be great.

A New, Old Path:

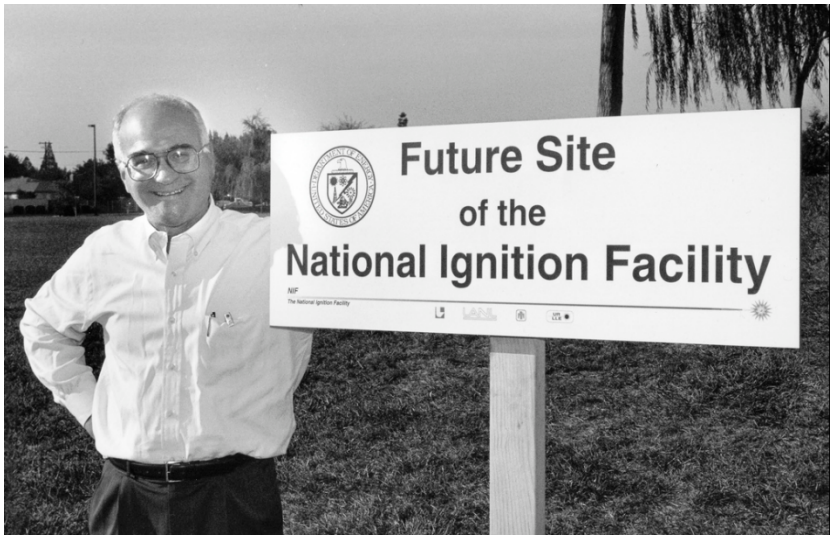
Work has been done on cusped system. Efforts were made to model [58, 59] explain [57] and even build [60, 61] these machines. But, making a high pressure plasma is hard to do - and the low pressure systems leaked [50]. They leaked a lot. Many people tried to plug leaks. Sharp fields were even used in the mirror program. This also failed. People moved on. The fields were looped; making tokomaks. The "free boundary" became more of an idea. Taught in lecture – or used in astrophysics. Not something we could do; and certainly not involved in manmade fusion. The navy work could change all that.

Part 2: Livermore Ends LIFE

Livermore: What are you doing?

NIF has put on a dazzling show lately. In February they heralded a gain in energy: more energy out, than in [15]. The press proclaimed this as a 'breakthrough'. It was all over the news [16 - 23]. Head researcher Omar Hurricane was hailed. CBS compared it to the Wright Brothers' first flights [24]. Things were looking up.

Then Livermore did something even more profound: it ended laser fusion energy [25]. In April, the lab quietly shelved the LIFE program. This was a path to fusion energy using lasers. The media failed to notice this change. It is a quiet admission, of a colossal misstep. A decade's long, multi-billion dollar mistake: the National Ignition Facility has failed to get Ignition. Worst still - a paper from LANL has suggested it's farther off than predicted [29]. How was 13 billion spent [28] and ignition never achieved? Why is no one *furious*?



ICF: Moving Goal Posts

Laser fusion went public in 1972, with John Nuckolls famous paper [48]. This document was not much. Four short pages. It predicted that lasers - at one thousand joules - could lead to fusion energy. This was ignition, a fusion chain reaction. One thousand joules was a threshold (the first of many). When that failed, the labs predicted ignition at 5 kJ, then 10kJ, then 100kJ, then 200kJ, and finally 1.8 megajoules [33]. That too, has now failed [49].

Why was this allowed? The reasons are not wholly scientific. Since commercial fusion does not exist, there is a natural tug-of-war over what a plant would look like. Politicians fund one idea and kill others. Sadly, fusion gets political. Cold-war politics drove early fusion research. The US had to get it before the USSR. Later, the reasoning got more muddled. Was it good money following bad? Fighting between the national labs? A lack of public inquiry? Chris Paine, of the Resource Defense Council, has even suggested the process was underhanded. His article, When Peer Review Fails: The Roots of the NIF Debacle called the NIF approval process: “secretive and biased."

Historians can debate the reasons for decades to come – but climate change is here, now. It is not waiting on any of this. All efforts must be refocus on clean fusion power. Failed ideas, persisting for bad reasons, must die. New paths must be explored. We cannot waste any time.

Part 3: The Northwest Nuclear Consortium

Introduction:

Carl Greninger is one very passionate guy. His first passion is education; and he is not happy with the trends. He points to a high school dropout rate - in his state - of 24% [7]. Deeper still: Carl is upset that schools are not getting kids excited about science. The kids "…were not impressed, I suddenly saw that while we may be teaching the curriculum - if we're not inspiring, if we're not creating passion, then it is a waste of time…" [8]. Fed-up with this, Carl decided to act. He started the northwest nuclear consortium in 2010 [9]. This group is: "the only nuclear engineering curriculum for public high school students in the U.S. with a working fusion reactor" [10]. Each week, a group of students and instructors meet to do nuclear fusion at Mr. Greningers' home [12].

Standoffish parents - have rapidly become noisy supporters of NWNC. Their kids have collectively won $410,000 in college scholarships [9]. Wow. They also are crushing in science fairs. They won 2nd place in physics, at the Intel International Science and Engineering Fair beating out *millions* of other entries [11]. They have also won state and local competitions [12, 43]. There are currently four projects/teams listed [13]:

1. **Safety Team.** Neighbors fearful of safety flaws called the Office of Radiation Protection [14]. They sent Mike Brennan, a Washington state radiation health physicist. Mike declared: "I think that it is not only safe, but he is teaching safety [creating] a culture of safety…" A team monitors doses, metals, shielding and personal protection.

2. **Ion accelerator Team.** A team is making a tool that speeds ions down a negative 240K volt drop. The potential is made using an AC to DC voltage multiplier. The resulting ion beam will add to the groups' capabilities.

3. **CR-39 Team.** With fusion, come neutrons. Their release in fusors is not well understood. A team covered a wall with detectors, charting out the neutrons [43]. Results showed most fusion occurring when ions hit the cage, not one another.

4. **GEEKS**. A team is developing software to control the reactor remotely, using Microsoft Server 2012.

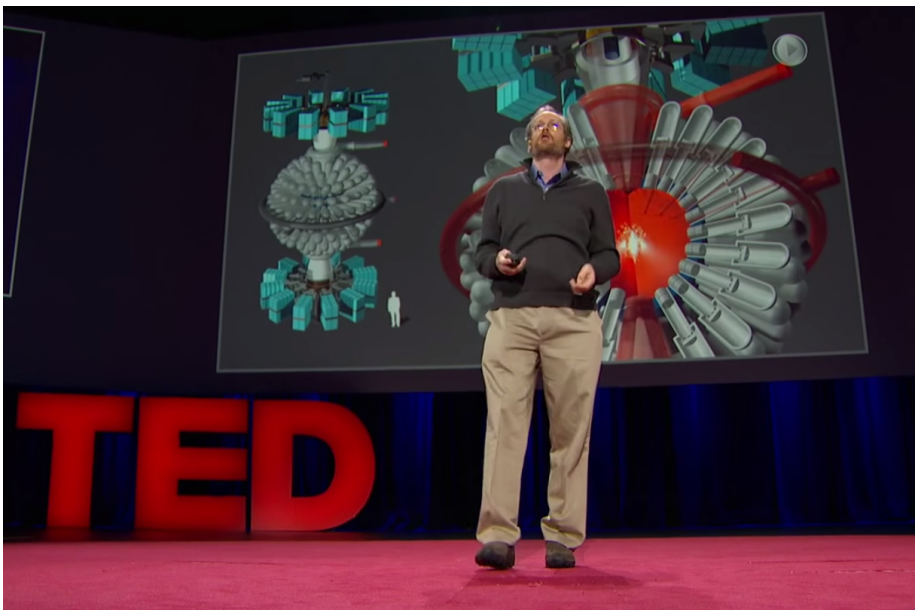
This group has started to turn heads. On May Sixth, representatives from Microsoft, Areva, Boeing and the American Nuclear Society attended an NWNC open house. They are waking up to what these 8th graders already know: there is something very exciting going on here.

Part 4: General Fusion

Introduction:

On March seventeenth, General Fusion spoke at TED largest conference [46]. You can watch the talk here. Its founder, Michel Laberge has been in fusion for twelve years. He has earned this recognition. The company started as his kooky idea. He has some cash, a PhD and a mid-life crisis. Over time, it has moved down a typical startup path (by contrast, EMC2 and LPP have not). Board seats were first given to investors; and then later, to energy industry veterans [35]. This was needed to secure 55 million funding, get mainstream press and to hire the sixty employees [1]. But, the cash comes with strings. If successful - the VC firms will reap the

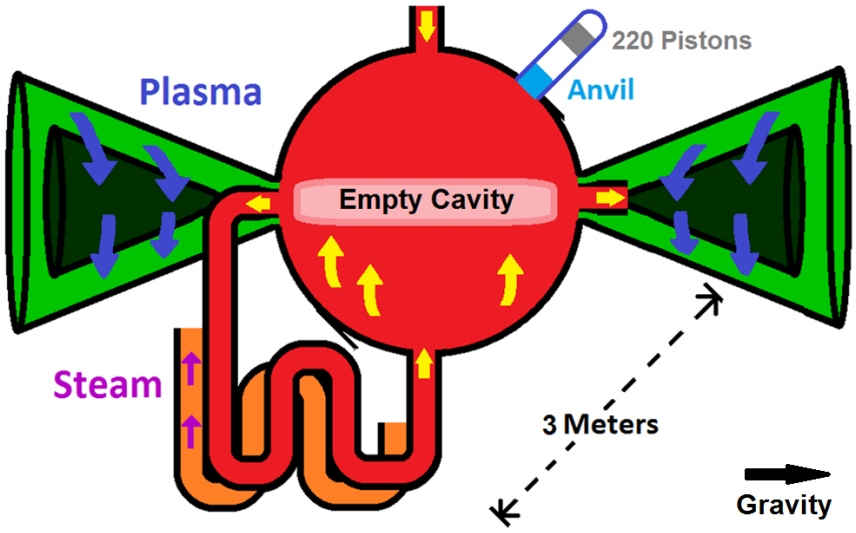
winnings. The company has also been publishing: four papers last year [3-6]. Blogger Henning Dekant recently got a look at their labs [2]. He described it as: "…an engineering approach to fusion and [we] are in a hurry…" Good. We need to hurry.



Overview:

Michels' first paper explains the idea simply [34]. It uses a lead-lithium liquid wall. This moves around a spherical chamber. Pumps spin the metal along the equator and draw it off at the poles. This forms a cavity in the center. Deuterium and tritium is shot into this cavity [36]. This is done with a toroid. It is then compressed by a pressure wave. The cavity reaches fusion condition. If fusion happens, the liquid metal absorbs any products. That liquid then exchanges heat with fluid stream. This turns turbines, making electrical power.

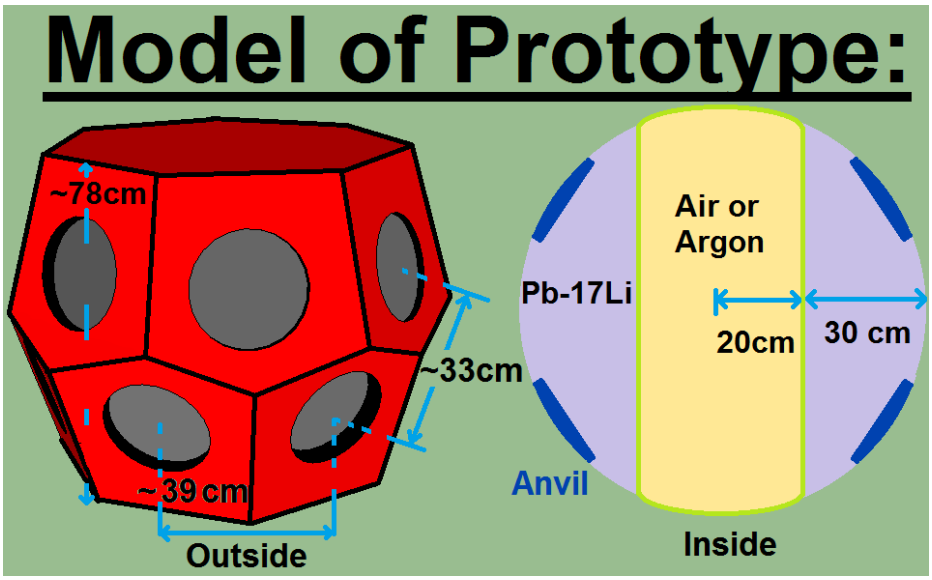
Reactor Concept:



On paper, I like this idea. Riders' thesis tells us that hot, uniform plasma with a bell curve of energy – is a bad direction to go in. This design goes in the opposing direction. It heats the plasma. It spins the plasma. It squeezes the plasma. It combines several old fusion ideas: a liquid wall, a closed magnetic field and compression [40]. Ken Fowler, fusion great, loved this idea [36]. On paper, it looks fine.

Modeling:

A model of their prototype was made. This is a machine being used now [46, 45]. The model is rough. Ballpark values were used. Since this is in the design phase, that is fine. Numbers will continue to vary – between tests, targets and what is affordable. The core is a one meter sphere. Fourteen pistons surround this chamber. They are steam driven. They hit steel anvils outside; not the lead itself. This is illustrated below. The chamber (a sixteen sided polyhedron) was estimated from pictures.

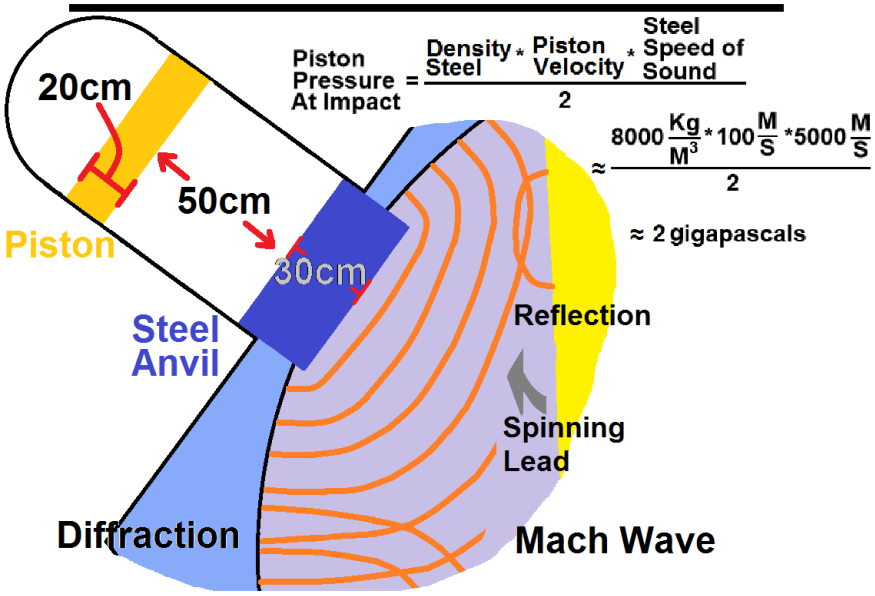


The chamber is filled with a mixture of lead, with a 7/10th percentage of lithium. This is at ~400 Celsius and at a density of ~10,000 kilogram per cubic meter [38, 39, 6]. It is spun at a few meters per second [47], around a forty centimeter cavity [37]. The cavity may be evacuated, filled with air or argon [4]. Control over spinning really gives them an edge over ICF. It controls their target, simplifying it. This may help with the Rayleigh–Taylor instability.

The Wave:

The compression can be modeled in three parts. First, we examine the pressure made by a single piston. The piston is fired. It speeds up towards a steel anvil. It hits. The wave is made. The anvil wiggles – moving the wave directly into the liquid lead [40]. An illustration of this impact is shown below [37, 40, 6].

One Pressure Wave:

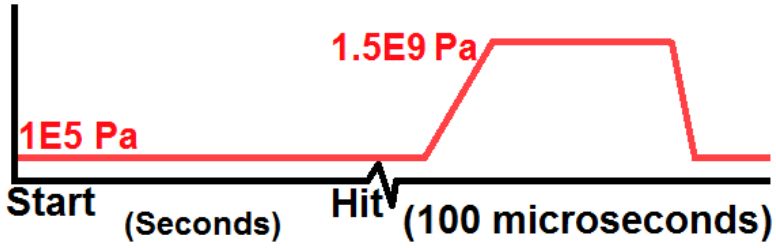


Next, the wave jumps from anvil to the lead. In the process, it loses nine percent of its energy [40]. What happens next, is not fully understood. In the lead, waves move inward. The liquids' spinning motion may effect this. Waves diffract with other waves - like ripples on water. Mach waves can also form [37]. The lead is already pressurized, but the wave increases pressure as it moves inward [6]. They focus into the center, and crush the cavity. Before the crush, spinning plasma is injected. The cavity squeezes down to one tenth its size [40]. Ideally, this initiates fusion.

Compression Analysis:

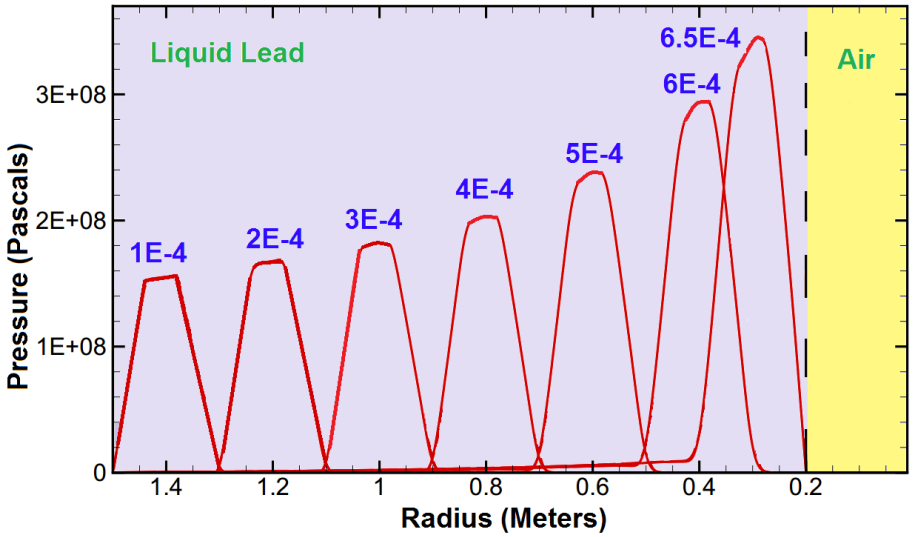
The compression is both complex and critical to the scheme working. General Fusion first used a masters' student to model it [37]. Later, a physicist was hired to do the same job [4, 5, 6]. To simplify the "anvil-wall-lead" system, a cheap finite element software was used [44]. This simplified to the wave shown below. This the model for one piston.

Simplified Pressure Wave (1 Piston):



This was the boundary condition for a second code. The team modeled liquid in the spherical chamber. An open-source CFD code was used [42]. First, they modelled the two dimensional case. A disc represented the liquid lead. A pressure wave enters the disc from the edge. The wave is the boundary condition shown above. It converges towards the center. As it converges – it rises and sharpens. The wave compresses the vortex in the center. These results were used in a three dimensional model. The results are shown below [6].

Moving Pressure Wave (3D Simulation):



The pressure wave increased as it converged. This is "geometric focusing", the energy occupying less space as it travels inward. Code predicts that in half a millisecond, the wave doubles in strength. Ideally, this compresses the center, making a high pressure plasma, leading to fusion.

In Summary:

Fusion is in upheaval. New paths have emerged that could take us to net power. This is occurring while the need for green energy is growing and amateur fusion is going public. Ideas once limited to ivory towers are going mainstream. Many factors are coming together - fusion is going in new directions. What is missing is our leadership. Where are they? Why is fusion today, a grassroots effort? Why did Eric Lerner need to appeal to the public for funding? Why isn't the government increasing funding for new ideas? Are we willing to bet ***everything*** that ITER will be commercial? We cannot afford to take that risk. We cannot wait any longer. We must move forward.

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