An Ode To The Fusioneer

"Here's To The Crazy Ones. The misfits. The rebels. The trouble-makers. The round pegs in the square holes. The ones who see things differently. They're not fond of rules, and they have no respect for the status-quo." – Steve Jobs

Introduction:

It is hard to imagine a bigger problem than energy. We know that oil, coal and gas will eventually run dry. We know that using these fuels heats up the planet. We know that sustainable energy – which keeps earth habitable - must be found.

We know the market will always do what is cheap and simple. Therefore, we need an energy source which is cheap, sustainable, simple and green. There are many options. Each option has limitations. Sustainable is often not cheap. Cheap is often not green. Green is often not simple.

Fusion produces more energy than any other option. It does so with zero greenhouse gases and on ubiquitous fuel. Fusion is therefore: cheap, sustainable and green. If it works - it will trump every other solution developed today. Why then, should we waste our time with solutions which would be made irrelevant?

Executive Summary:

This post looks at the constraints, technology and organizations involved in fusion power. The failure to get ignition at NIF is connected to compression, laser-plasma interactions, fuel mix and errors in measurement and experiments. NIF will slowly decline making a shift in research, not seen in decades. Ion beams and excess electrons are discussed as a method for ion injection and well preservation in polywells. The Lawson criterion points to net power by raising fusion and efficiency and lowering conduction and radiation losses. An argument radiation losses in the polywell were overestimated is discussed. A 48% energy capture experiment using direct conversion is summarized.

Technology is covered, starting with the first fusion machine in 1958. Early magnetic ideas including mirrors, biconic cusps, picket fences and rings are reviewed and connected to the polywell. Biconic cusp work reveals three electrons types which may also exist in polywells. The history of electrostatic machines is covered including Elmore-Tuck-Watson, fusors and polywells. Issues common to these machines: cloud structure, angular momentum, uniform convergence and modes of operation emerge. Polywell mechanism is illustrated and fusion with ion beams is mentioned.

Three organizations to realize fusion are contrasted: public bureaucracies, individual innovators and amateur communities. Fusion is unfit for government bureaucracy because it needs cognitive work, has no deadline, disrupts markets, is considered impossible and has no war driving it. Bureaucratic strengths and weakness

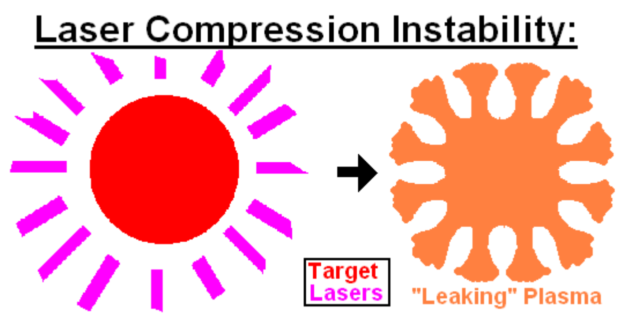
are discussed. Solo innovators add vision and speed but suffer risk, poverty and alienation by society. The homebrew computer club is examined as an amateur community; it is compared with today's fusion communities. Amateur communities makes markets and acceptance for a new technology. Finally, a desktop polywell is suggested.

"I have never thought of writing for reputation and honor. What I have in my heart must come out; that is the reason why I compose." – Beethoven.

<u>NIF is Failing:</u>

NIF is failing. That is the big fusion news. A NIF failure will change everything. The fusion experts did not expect this. The goal for decades has been ignition. Ignition is when the hot products from fusion start a fusion chain reaction. The key is to trap these products before they leave the compressed plasma, so they will leave energy behind. This has not occurred. Here are some possible reasons for this failure.

1. **Non-Uniform Compression.** Imagine trying to squeeze a water balloon by pushing on it with pencils. Water squirts out the sides. ICF suffers from an analogous problem when compressing fuel with laser beams [39]. This problem has been plaguing ICF for decades.



2. **Laser Plasma Interactions**. NIF attempts to beat the first problem by bathing the target in x-rays. The idea is that this indirect method will cause a more uniform compression. Unfortunately, it adds extra steps. These steps result in the inevitable non-uniformities [23].

3. **Inability to Link Errors to Causes**. NIF requires a level of precision that pushes the boundaries of manufacturing. Every implosion is slightly different; either the target or the laser changes or the alignment changes. Researchers cannot systematically connect a change to a new result [23].

4. **Hard to Measure**. An implosion on NIF takes about 20 nanoseconds and occurs in a space of ~1E-7 cubic meters [30, 31].   Building the sixty tools to measure the implosion is a feat of science - but we cannot help but wonder it would be just simpler to avoid such ridiculous constraints [23].

5. **Fuel Mix.** During compression extra material mixes into the hot fuel [23]. This cools off the target, reducing the odds of ignition. This mixing is due to three instabilities: the Rayleigh-Taylor, the Richtmyer-Meshkov and the Kelvin-Helmholtz instabilities [40].

Researchers use a number to measure ignition: the Integrated Threshold Factor Experimental [22]. If this is over one, ignition occurs. One tenth of this has been achieved [23, 42]. That is the big problem. It cost 3.54 billion dollars to build NIF and the machine was designed to exceed one [24, 37]. The National Ignition Facility has missed Congress's deadline by a wide margin [42]. Now, the facility is requesting another 450 million a year to solve the problems [43]. They are touting a new National Academies of Science report which sings the praises of the facility and is a rehash of old work[45]. This is an attempt to hide the glaring failure. Insiders are worried. A NIF failure represents a seismic shift – one the fusion research has not witness in decades. Things are going to change.

Polywell Problems:

This blog has promised to present the science as we find it; not as we would like it. We have found big problems with ion injection and the well. These must be addressed. In WB6, there is a positive voltage drop outside the rings. Any ion formed here, would fall in the wrong direction. Hence - to cross this gap, the deuterium must be uncharged. When the gas reaches the inside of the rings it touches the electron cloud. It exchanges energy with the electrons. This heats the ion up past 16 eV and the ion is made. The ions fall into the center, hit and fuse. It is important to realize that an ion is 3,626 times more massive than the electron. This setup gives us no control over ion formation. This randomizes several things, leading to ion problems discussed below [87].

1. **Ion Starting Location:** The ion will form in random locations. A millimeter to the left or right and an ion may experience a completely different acceleration. Ions can form too close or too far away from the center. We cannot control this in WB6.

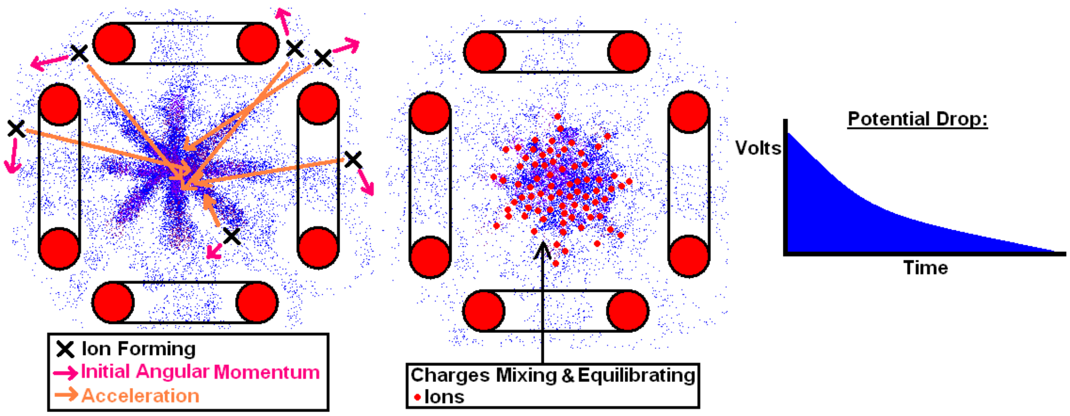
2. **Ion Starting Motion:** The ion starts with some random motion. This includes a twisting motion – known as angular momentum. It also includes a velocity vector. This changes the path the ion takes into the center.

3. **Ion Acceleration:** The electron cloud is shifting. If this storm of electrons moves around while the ions form randomly - then the ion acceleration will be non-uniform.

4. **Ion Convergence: A** random location, momentum and acceleration it makes it hard to get the ions to collide in the center.

5. **Maintaining Voltage:** The biggest problem may be that the charges mix over time. The mixing would destroy the voltage drop. This will also screw with any cloud structure.

Problems with Ion Injection, Acceleration, Focus and Mixing:



There may be ways around these problems. Ion beams seem very likely. In science, you want control over any experimental variable. Ions beams offer some control. However, a beam may add complications to the experiment and it is important to keep things simple. To our knowledge WB-6 had no beams, but beams were discussed in the past [94, 18]. Each of these problems would make the polywell hard to test. Tests would not be reproducible, which would be frustrating. These issues also point to operations saturated with electrons. Could you just dump enough electrons on the core to maintain the voltage?

"Never doubt that a small group of thoughtful committed citizens can change the world; indeed it's the only thing that ever has." – Margaret Mead

Part I: Net Power

Net Power:

Let's examine net power the same way the early researchers did. If you assume that a fusion reactor contains a hot plasma cloud it is subject to three energy losses [10]. The first is an inefficiency to capture the electrical power. Every power plant suffers from this; for example, a typical coal plant is 33% efficient [11]. The next loss is from conduction. That is the loss of mass. When electrons or ions touch a surface they will be conducted away. The last loss is radiation. This is the loss of energy. Lots of energy leaves a plasma cloud as light. The light comes in many wavelengths (IR, X-ray, visible, UV) and is made every time a particle accelerates or decelerates [12]. This can happen for a variety of reasons: particle-particle interactions, field deflections, normal acceleration, etcetera [16, 13, 14]. If you put these rates together you arrive at an expression for net power.

$$\textbf{Net Power} = (\textbf{Fusion} - \textbf{Conduction} - \textbf{Radiation}) * \textbf{Efficiency}$$

This is the Lawson criterion. He argued that if you plot these loss rates against the volumetric fusion equation you find minimum conditions for net power. It has been adopted [21] to apply to inertial confinement fusion and tokamaks. A popular way to express this is that net power arises after hot plasma has been confined for 10 atmosphere seconds [44]. Often, Lawson is used to excuse a fusion idea, carte blanch.

Raising Fusion:

Thus far, research has focused on increasing the fusion rate. This leads to giant, expensive machines. These are far away from net power. Fusion power is calculated from the volumetric rate equation, shown below.

$$\mathbf{Fusion_{Energy} = Density_{A} * Density_{B} * Velocity * Cross\ Section * Energy_{A\&B}}$$

In this equation: velocity is the speed when ions A and B slam together, the cross section measures the fusibility of these ions and energy is amount released per fusion reaction. The goal is to slam the ions together. When this happens, it will convert hydrogen into helium. When two atoms fuse into a larger atom, some of their mass is lost. This mass becomes energy through $e = mc^2$. This process makes more energy than anything else known to mankind.

Reducing Conduction:

Conduction is the loss of mass.   The electrons and ions escape when they touch surfaces. Energy leaves with this mass. Conduction losses kill Fusors. Fortunately, we can steer the ions and electrons. Like cars on a highway, they will follow electric and magnetic field lines. Hence any solution, cannot have fields that run into surfaces. The Polywell is a fusor variant which follows this rule. Tokamaks, the levitating dipole, spheromaks and stellarators all reduce conduction in the same way. But, sharply curving fields are not perfect. Plasma will drift outwards in a curved field. This flings it against the walls [68]. This could be reduced by lowering the overall temperature [49, page 43]. The polywell and biconic cusp may also lose mass by scattering it through the center [52].

Reducing Radiation:

Radiation is the loss of energy. Plenty of energy leaves the cloud as light. Radiation includes visible, x-ray, infrared and ultraviolet. When electrons are packed densely enough, they will reabsorb this energy [17]. This is why lead can absorb x-rays [53]. In plasmas, this critical density is difficult to reach. The x-rays may also be reflected off the chamber walls [54]. However, the plasma may not be dense enough to reabsorb the reflected light [17]. Arguments against the polywell have focused on radiation losses [13, 14, 15].

These losses may have been overestimated [87]. During polywell operation, the electrons fly into the rings at high speeds. When they move towards the center, they encounter a ball of electrons. This repels them. The electrons slow down. They lose kinetic and gain potential energy. This makes the electrons in the center, cold. Meanwhile the ions are attracted. They speed up. They get hot. This implies the electrons and ions are at two distinct temperatures [87].

This is an unsettled argument. It directly conflicts with Riders papers and thesis [13, 14, 88]. Rider argues that ions and electrons must be at the same temperature [88]. This was based off energy transfer between the two populations. This topic is not well understood. Rider had to write an whole paper to estimate the rate. The paper has not been used in 19 years since. It has not been checked experimentally. Since radiation scales as temperature to the fourth power - hot electrons radiate more. If the electrons are cold then these losses are much lower than expected. This is a major boon for the polywell. However, this is not enough to ensure that the Polywell works.

Raising Efficiency:

Efficiency may be the most unexplored concept in fusion. Efficiency means changing the input and output energies. Few groups explore lowering the input power. The NIF system is horribly inefficient. For every unit of laser energy, about 200 times that amount in electrical energy is used [69]. In response, the naval research labs have designed a 7% efficient laser. However, without ignition this will not matter [70]. By comparison, fusors and polywells do fusion with almost no input power.

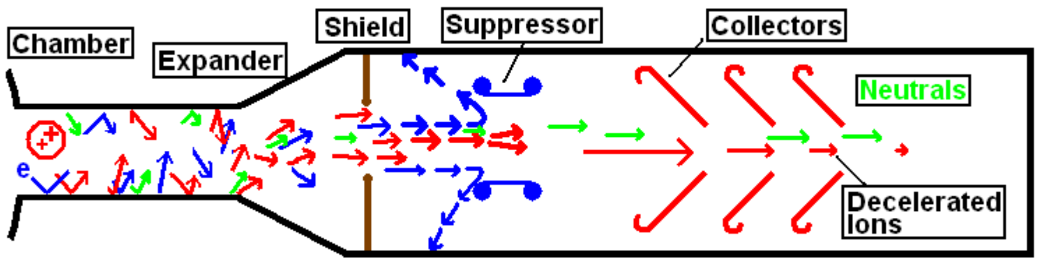
Increasing output power means finding better ways to capture the energy. Three methods have been purposed. The first is using the neutrons from fusion to recharge fission material [71]. This seems unlikely for cost effectiveness. It may be a good commercial application for fusors. The second is using heat to capture the energy. This method is valid for deuterium and deuterium tritium fuel and will have a typical power plant efficiency. The last method is using direct conversion to capture the energy.

Direct Conversion:

Direct conversion uses a charged particles' motion to make a voltage. This voltage drives electricity in a wire. This becomes the electrical power. People usually see this process in reverse. Ordinarily, a voltage puts a particle in motion. Direct conversion does the opposite. It has been described is a linear accelerator running backwards [90]. William Barr deserves a share of credit for demonstrating direct conversion. Over ten years he developed experimental and theoretical systems to prove this concept. Dr. Barr retired from Livermore and passed away in 2004 [72]. In 1982, he demonstrated an energy capture efficiency of 48% [76]. Wow! This efficient was realized on a real working fusion reactor, the TMX. The TMX was a giant mirror machine. There are many fine points to running these machines [78]. A full treatment cannot be done here. This method has been used to recover energy in many ways [92].

Material from a fusion reactor has positive ions, negative electrons and neutrals. The exhaust comes in as random gas. The converter has to beat this stuff into submission and extract energy from it. The basic design is shown here [74, 75, 76].

Basic Direct Converter (2 Stage):



First, it must get the particles to fly straight. It does this by using a magnetic expander [74]. This makes a beam out of the material. Next, the beam passes through a grounded plate. This insulates different fields within the converter. Next, the electrons are suppressed. This is done by applying a negative voltage across the beam. The electrons are repulsed. Lastly, the ions push against a positive field. This raises the voltage of the collectors. The efficiency depends on the number of collectors [91]. These collectors become the positive side of a circuit. This drives power. The machine has extracted energy from the ions.

Part II: Some Early Machines

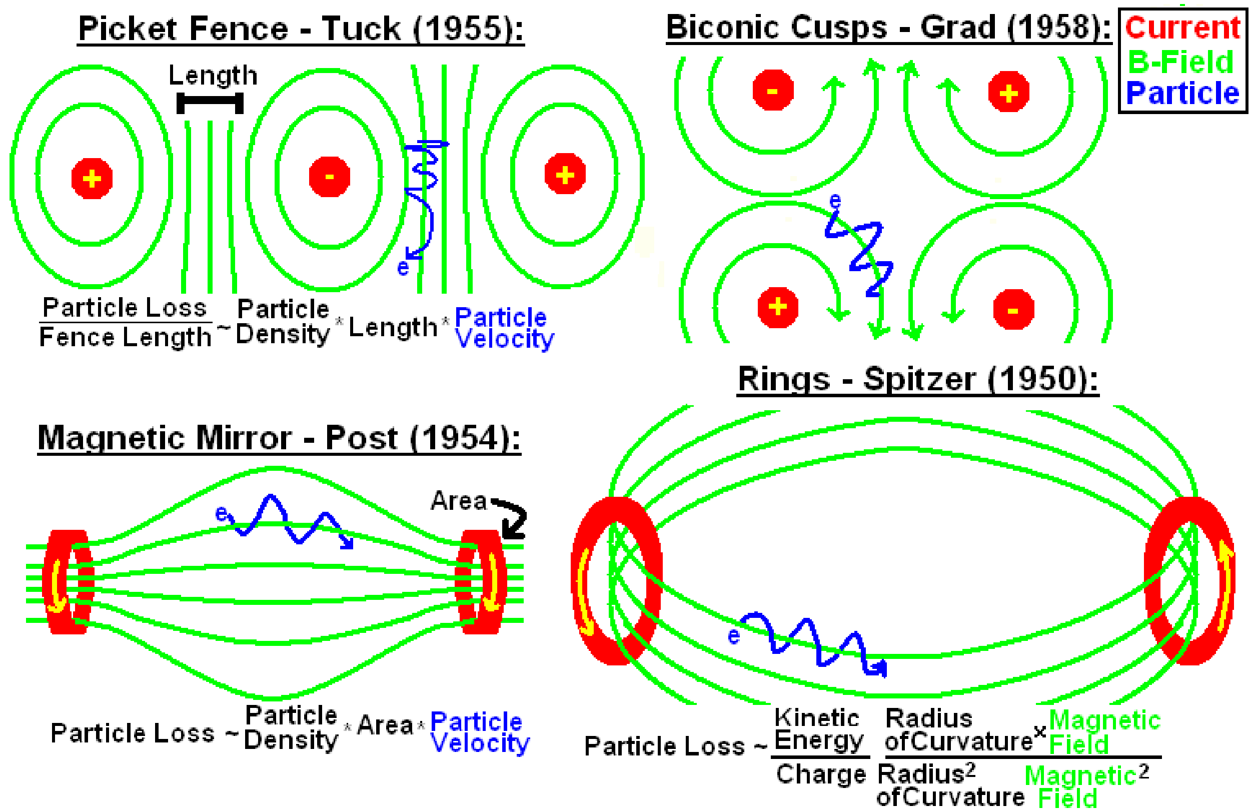
Scyalla I

If fusioneers were painters; their palettes would have four colors. These would be: magnetic fields, electric fields, electrons and ions. Their goal is to employ these to make the ions slam together. When they hit, they can fuse. The first controlled fusion reaction was recorded in over 55 years ago. The machine that did it was named Scylla I. It was a pinch machine. It had a cylinder full of deuterium. Electric current shot down the sides of the cylinder [47, 48]. The current made magnetic fields which compressed the plasma to 15 million degrees celsius [47]. At the time, only a few people at the Los Alamos National labs knew that this event had ever happened. Mankind had silently slipped into the fusion age.

Magnetic Ideas:

An ion collision means that two deuterium atoms hit with 10-20 KeV of energy. When NIF was purposed in 1995, the plan was to get the average plasma temperature over 20 KeV, under confinement [38]. In the early fusion days, there were many schemes for this. In magnetic confinement, the ideas included: magnetic mirrors, picket fences, rings and cusp systems [4]. Each had its own set of supporters and critics. Each method is shown here [4, 46, 49, 50].

Early Magnetic Confinement Ideas:

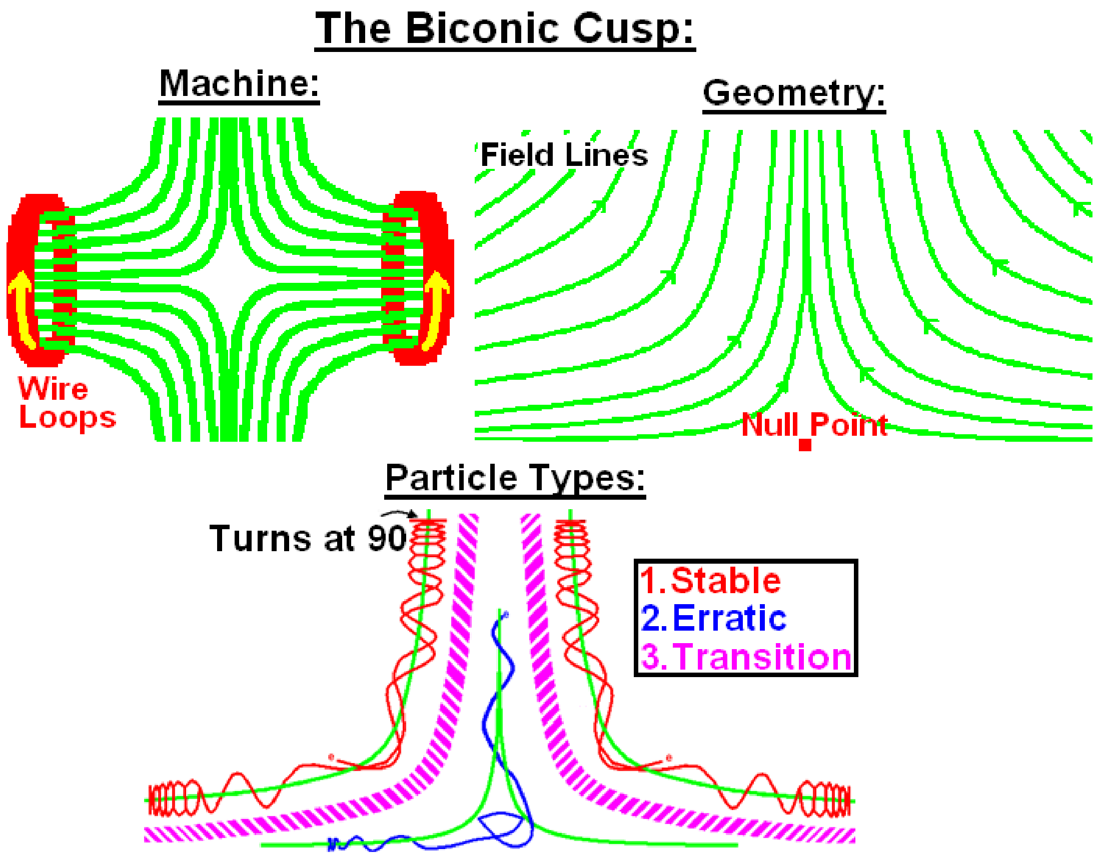


Magnetic Mirrors:

Magnetic mirrors were being studied by Dr. Posts' group at Livermore National Lab [5]. These machines were two plasma mirrors facing each other. The ions would bounce around the middle and hopefully hit one another. The field were similar to a bundle of wire that is tight at both ends and bulged in the middle. A particle corkscrews along these field lines, from one end to the other. If the magnetic moment of the particle remains constant, then the particle is reflected from the dense field. This forces it back into the center [49, Pages 30-34]. Eventually, the ion will be lost. A federally funded, decade long, program built many mirror machines. These included: Table Top, Toy Top, Baseball, TMX and TMX-U [65]. The program culminated in the MFTF, a 372 million dollar machine. They finished it, but never turned it on [66]. Reagan officials cut funding to balance the federal budget. The polywell uses the same effect to trap electrons. The polywell combines the fusor and a magnetic mirror.

Biconic Cusps:

The biconic cusp idea was explored Dr. Harold Grad at NYU in the fifties and sixties. Biconic cusps are funny arrangements. They are fields generated when two electromagnet rings are placed close to one another. The fields looks like two water hoses facing each other – field lines spray out in all directions from the center. Between these magnets there is a null point. It is in the middle of the field. Particles passing through this point are scattered. It is easy to see commonality with the polywell. This is shown below.



This geometry was first simulated in 1961 [8].   Simulations found that there were three types of particles: stable, erratic and a transition. The stable particles move very far away from the null point. This particle has a constant magnetic moment. When this particle reaches a dense field it is reflected. This is the same mechanism as in the mirror machines. The second particle type makes a full revolution very close to the middles. These are erratic. The third set is a transition, between these types. Fifty years later, Joe Khachan argued that these three types of electrons exist inside the polywell [7].

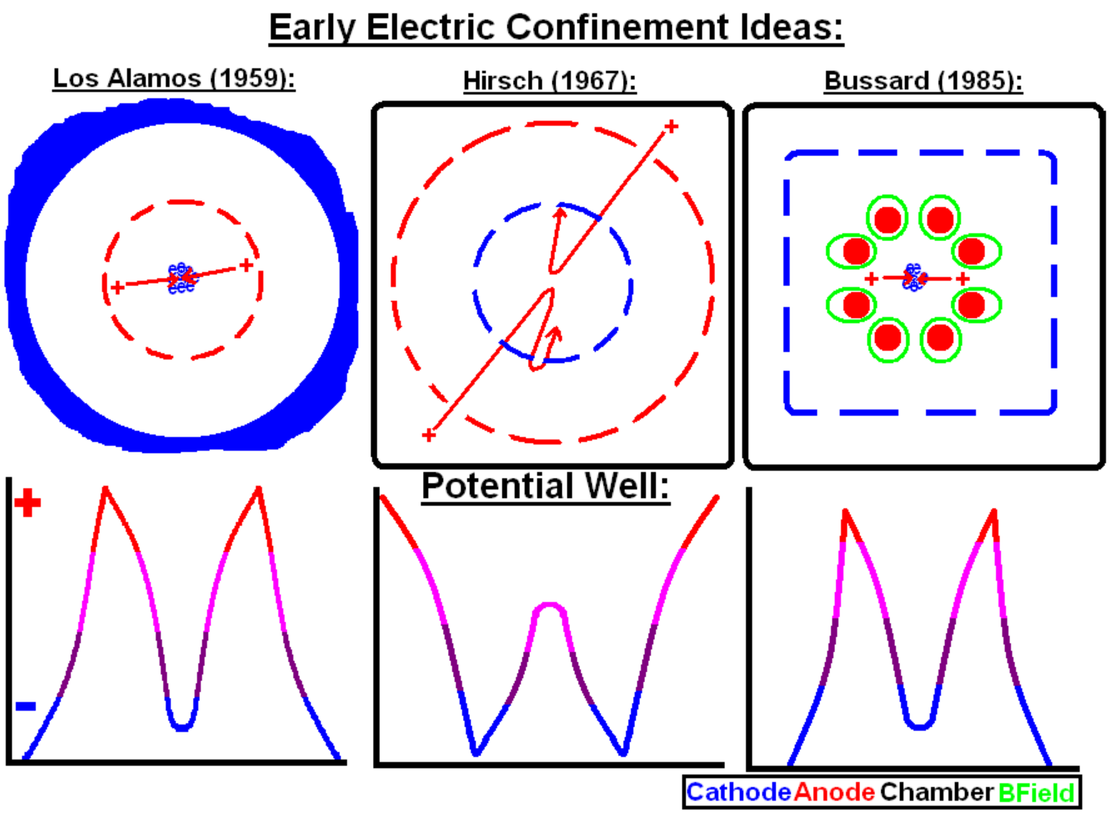
Rings And Fences:

The picket fence concept was being pushed by James Tuck, at Los Alamos [6]. This used opposing directed wires in a "fence" configuration. This design became part of the tokomak later. The ring concept was advocated by Lyman J. Spitzer at Princeton. Rings come in many variations. These include the spheromak, the levitating dipole, the stellarator and the tokamak. Each machine has its own history and constraints. The ring concept has been thoroughly studied and none are close to net power. As of March 2011 there were an estimated 177 tokamak experiments either planned, decommissioned or currently operating, worldwide [89]. It is time to move on.

Electric Ideas:

There is another way to fuse the ion. It can fall towards a negative point. As it falls the electric field does work on the particle. This increases its kinetic energy to fusion conditions. If it hits another ion it will fuse. This was first observed by Philo Farnsworth in 1935 [38]. The key is to make and hold a negative point charge. The point must be very negative, on the order of ten thousand volts. An ions formed outside this point will fly in from opposite directions, hit and fuse. This idea works. It is the simplest way to fuse the atom. It is the basis for the fusor.

This point can be made in various ways. Three variations are shown below. You can think of these as the evolution of the idea. Each design builds off of the previous one.



Los Alamos - 1959:

This concept was explored by three researchers at Los Alamos in 1959 [84]. They never built a machine. They only modeled it. This design is crude. It tried to collect electron to a point, with their collective motion. A positive cage was placed inside a negative chamber. Cages create charge oscillations. Electrons would oscillate around the cage, like flies around a light [84]. The goal was to get enough movement into the center that a point would form. The electrons would attract ions and make them slam together. The ions would fuse. The team used the Poisson equation to explore this idea. They estimated they could make a one centimeter ball of electrons inside a one meter machine [84]. They also estimated the power input and output. This is shown below.

$$\textbf{Power}_{\textbf{In}} = \frac{\textbf{Grid Current * Grid Voltage}}{\textbf{Number Of Electron Transits}}$$

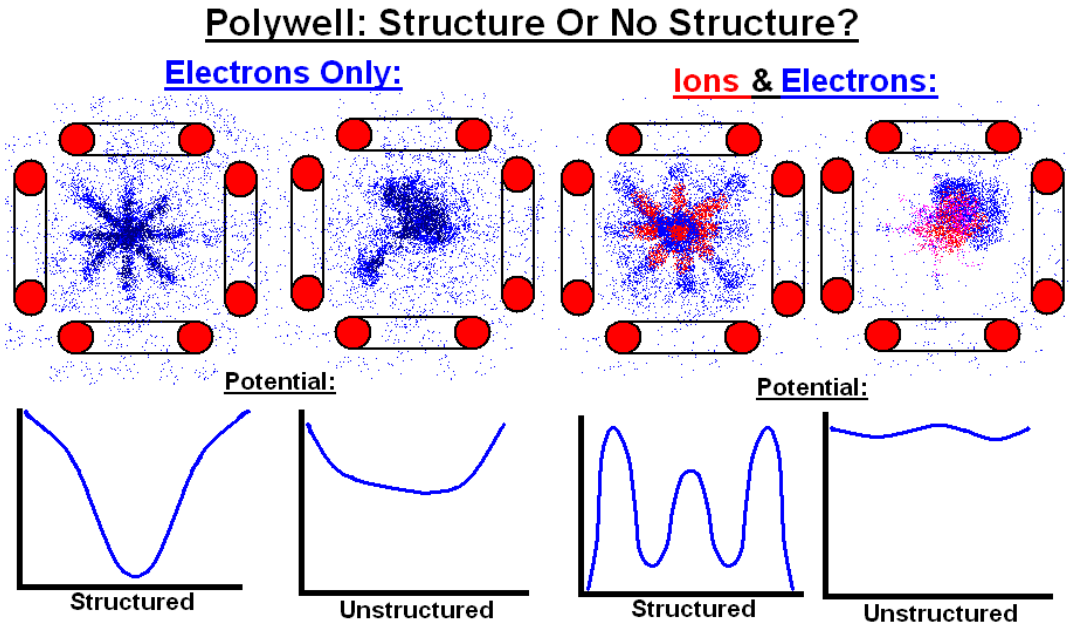
$$\textbf{Power}_{\textbf{Out}} = \textbf{Center Volume} * \left[\frac{\textbf{Ion density}^2}{\textbf{4}}\right] * \textbf{Cross Section} * \textbf{Velocity} * \textbf{EnergyPerRxn}$$

The team identified a common problem for all these machines. The electrons and ions can lose focus in the center. This could be due to non-uniformities in the cage, motion of the particle tangent to the cage, collisions which do not generate fusion, scattering through the central null point or electric forces between the particles themselves [85, 84, 38, 7, 86]. Ideally, ions should be a small, tight, dense mass in the center. The maximum ion density was estimated. The clouds' stability was also analyzed using Earnshaw's theorem. This mathematically relates the interactions within a cluster of charged objects, to the cloud stability. Stability reduces to a (+) or (-) number. They found the system had a negative or unstable result [84]. This was an early argument against these machines.

Hirsch -1967:

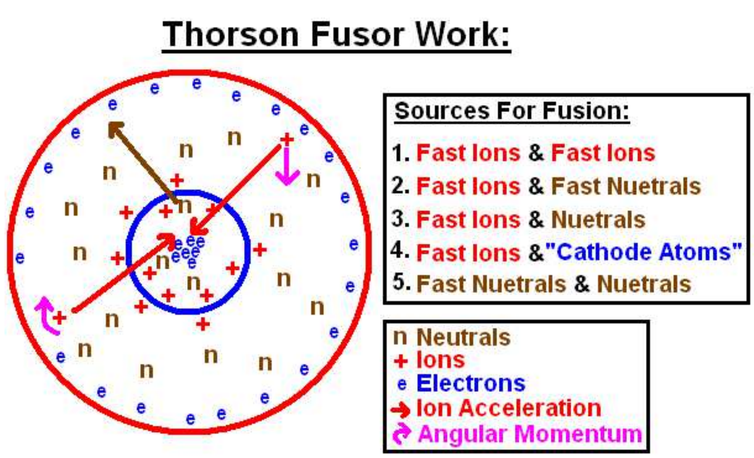
Robert Hirsch published 8 years later. His machine had a negative inner cage. This was a major improvement. The negative point could be fixed in space and time, because it was a metal cage. Ions would fly towards the cage. They could miss and hit in the center. This is the modern fusor (or IXL). Hirsch used six ions beams to inject the particles. He observed that fusion had an inverse relationship to vacuum pressure and beam energy. It also rose as more ions were injected [85, 38]. Like the Los Alamos design, the inner cage made oscillations. The ions would oscillate around the cage. This oscillation resulted in a positive point forming. This was dubbed the virtual anode.

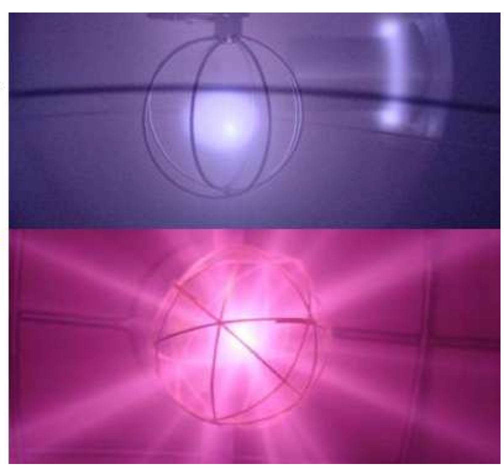
This is part of universal question, common to all these machines: does the cloud have structure? This structure has been named many things: a multiple-well, a virtual anode, a space charge limited region, a focused cloud and an edge annealing effect. They all fit under the umbrella of structure. Is it there? Hirsch and Bussard argued yes [38, 18] Thomas Dolan offered a maybe [93], Rider, Thorson, Hockney and Nevins argued a theoretical no [13, 14, 85]. This is important. Cloud structure affects the ion and electron temperature, electron containment, the fusion rate and the radiation losses. The cloud is also dynamic. It moves constantly. We need data. We need measurements of the actual plasma inside a polywell. Different polywell options are shown below.



Thorson - 1996

Tim Thorson got his PhD from Wisconsin in fusors. He had a deep understanding of these machines. The machine he used fused at sixty thousand volts and did 10^7 fusions per second [85]. By comparison, Bussard improved on this a one hundred fold. Bussard did this with only one sixth the voltage [18]. Tim's work dealt with key issues. The first was the ions' angular momentum. This is the motion the ion has before it is accelerated. This will hurt fusion [85]. Several models agree that if the ions had no initial velocity a virtual anode would likely form [85, Page 42]. The ion initial motion effects cloud structure. Rider raised the angular momentum issue against the polywell. In Tim's work, fusion happened any time a fast object hit something. This could be fast neutral or a fast ion. They could hit each other, themselves, a slow neutral, a slow ion or even atoms trapped near the cathode. How each reaction went effects the total fusion rate. This work is illustrated below.

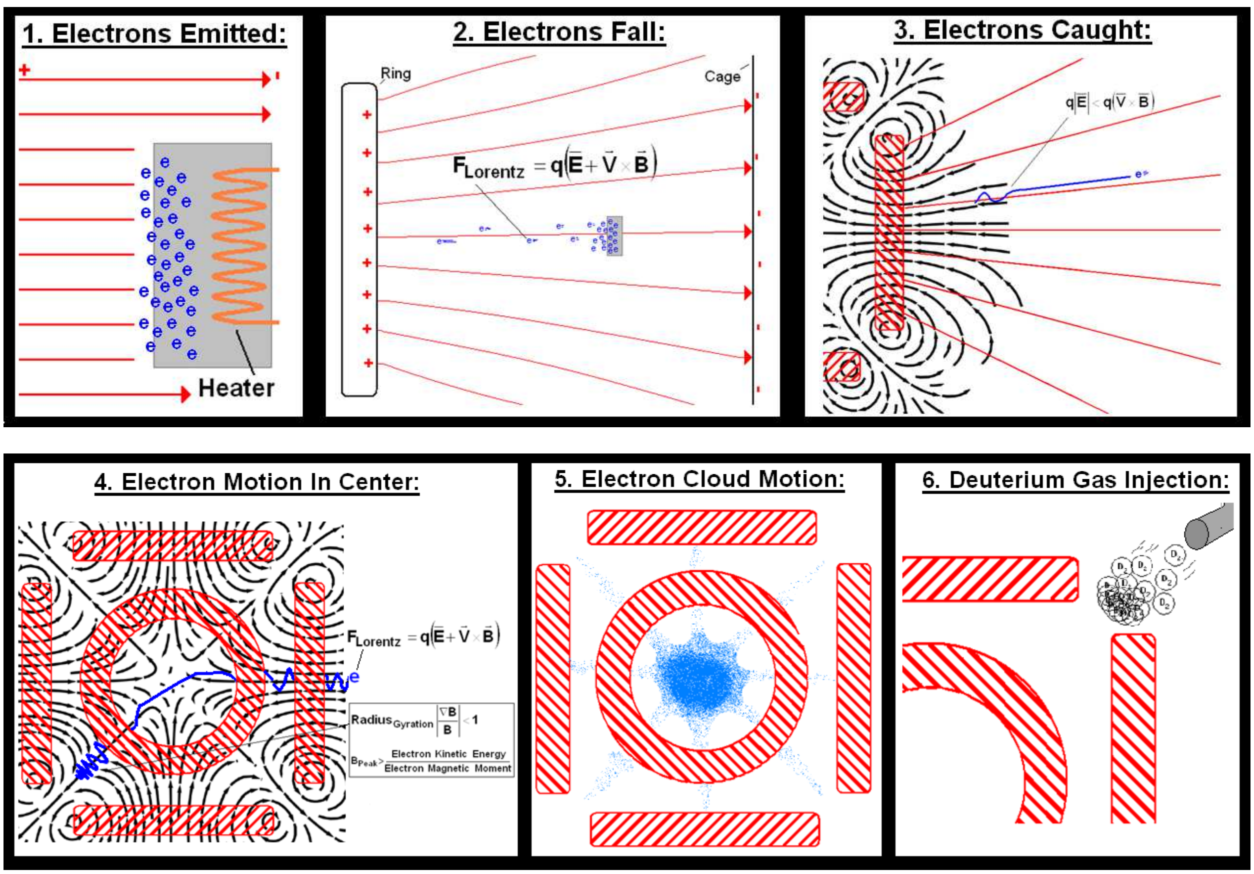


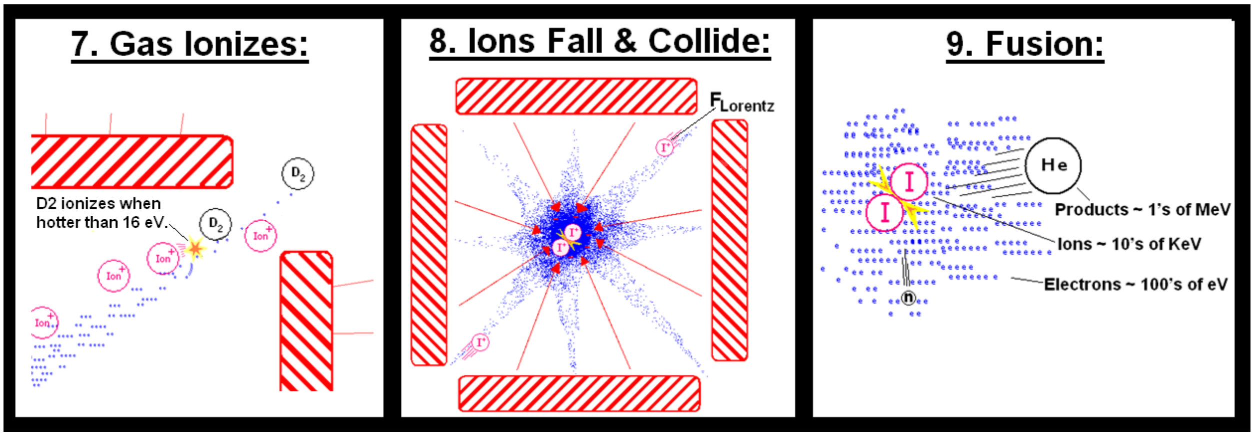


Tim reported three modes of operation. Examples of the first two are shown above. This was consistent with George Miley's findings. First, at a high tank pressure (> 2 Pascals) the machine worked in the halo mode. Halo mode is a board symmetric glow, with one or two electron beams exiting the structure. There is little fusion. The gas is so diffuse that the ions cannot find one another. At medium pressures (0.01 to 2 Pascals) the machine operates in star mode. Star mode looks like bright beams of light emanating from device center. At low pressures (< 0.1 Pascals) the machine enters the converged core mode. In this mode, an external source of ions is needed to maintain the plasma.

Bussard – 1985:

In 1985 Robert Bussard filed a patent for the polywell [94]. He had, had the idea since the early eighties. The concept was to trap the electrons using a magnetic mirror. This was a combination of a fusor and a magnetic mirror. The idea faced challenges. These included: maintaining the (-) voltage as (+) ions were added, how to hold the electrons and how to control ion formation, acceleration and collision. The nine steps for fusion in a polywell are illustrated below.





Beam Fusion:

The ion can also reach fusion conditions in a beam. The idea of having two charge beams facing one another was excused early on because of instabilities. Some schemes for fusion power include using ion beams to circumvent this [67]. It has also been proposed to combines ion beams and Polywells. The company Tri Alpha Energy is attempting a variation of this basic idea [61]. The Berkeley National lab has purposed Fusion by having the ion beams slam into a target [62, 64]. One problem with ion beams is that they experience instabilities [63].

Part III: Organizations:

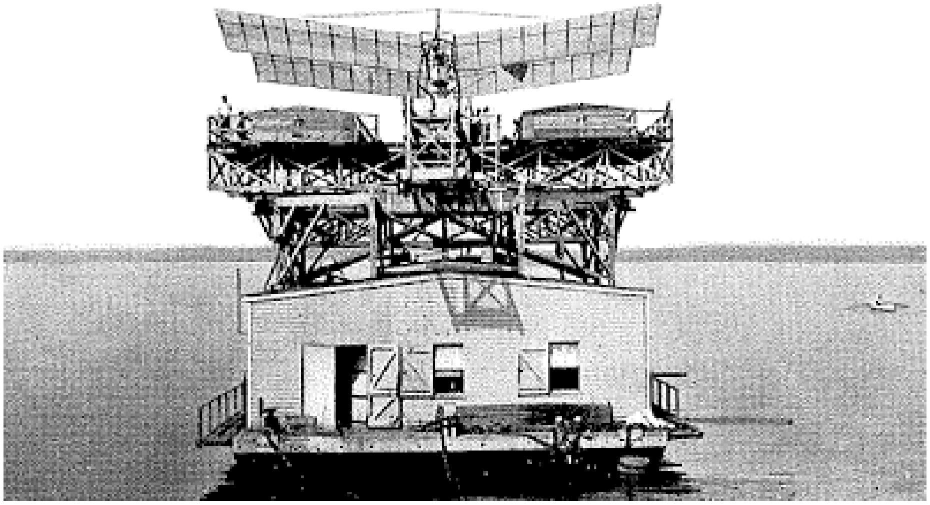
Fusion power requires a machine which reaches net power. It also needs a supporting organization. What is the best organization to realize fusion? This section compares three types of organizations. These include: large public bureaucracies, individual inventors and amateur communities. Fusion is new. History provides us with examples of how to realize new technologies.

Structure I: Public Run Bureaucracies:

This public bureaucracy excels when brute force is required. Good examples are construction projects like: the Hoover Dam, the Suez Canal or the Highway System. It is good for scaling up ideas when there are clear deadlines. Bureaucracies are also good for large numbers of routine tasks. Motivation studies show that routine work is improved by pay [33]. Unfortunately in any task needing basic cognitive skill - performance will deteriorate when pay increased [33]. This does not describe the Fusion Problem. The problem requires complex research and is not wholly solved by routine tasks. A government program might be a bad fit.

People may disagree with this. They will cite programs which solved hard technical problems. These include the Human Genome Project, the Manhattan Project or the Apollo program. At present, fusion has three key differences. First, Fusion disrupts lucrative industries. The Apollo, bomb and genome projects did not kill business at any major company. Second, fusion power is considered impossible by the public. The public understood rockets and DNA - and this helped sell the Apollo and Genome projects[36, 37]. Today you are considered crazy to do fusion. Third, fusion does not have a hot or cold war to drive it.

There is one example where the government tried to tackle fusion-like problem: flight. Flying was a highly technical problem. It lacked a clear solution and was widely considered to be impossible. In 1898, Sam Langley was given 1.31 million dollars (2013 currency) to build a flyer [27]. He attempted a brute force solution. A large staff was hired and a powerful engine was purchased. Allot of money was wasted on issues unconnected with flying. Efforts focused on getting enough power to fling the machine into the air. The Aerodrome was expensive, complex and high powered. It failed miserably.



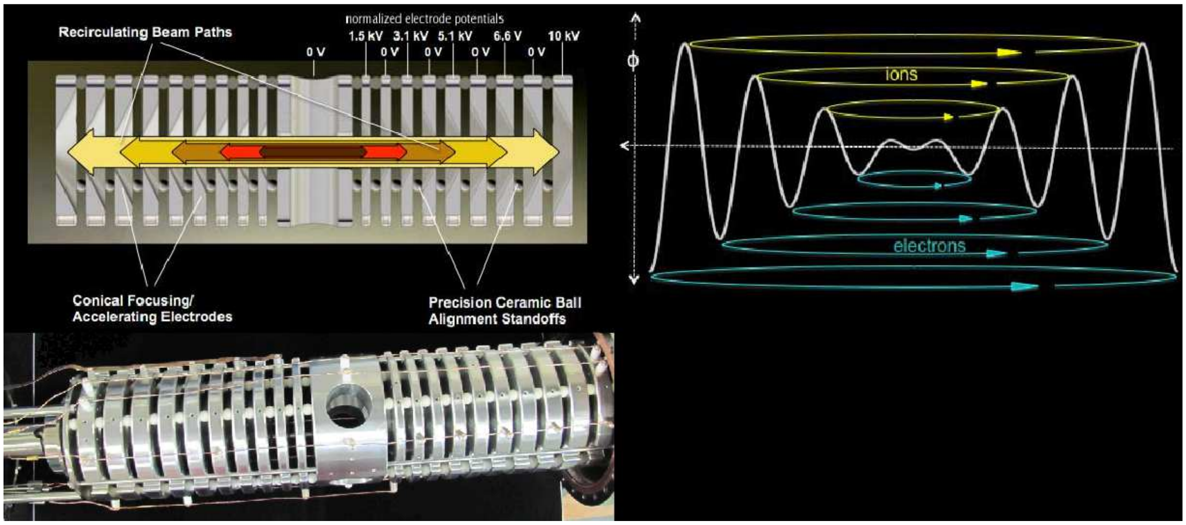
Common Bureaucratic Flaws:

Mr. Cyril Parkinson is widely considered the leading expert on bureaucracies. His book "Parkinson's Law" looks into public organizations [28]. He argues that they all share four common flaws. The first flaw is that a bureaucracy's' size will peak, when its purpose is most obscure. The classic example of this is the British Colonial Office. Over nineteen years the number of employees there more than quadrupled - while the size of the colonies fell by a third [28, 34]. His reasoning for this is bosses tend to hire more redundant underlings to improve their own stature. The second flaw is that public bureaucracies finish their largest works when the organization is outdated. Parkinson had three examples of this: the palace of Versailles, the palace of nations and the Vatican. In each case, the buildings were completed after the organization has passed its apex of influence [28, 29]. The reason is an organization only finds energy to build magnificent buildings after the important work is done. The current US congress may be a prime example of this. The third flaw is that the organization governing bodies expand until they become useless. This may include executive committees, board of directors or review panels. The British cabinet exemplifies this. The cabinet kept expanding until it had to be replaced by a new body. This occurred four times in British history [28]. The last flaw is that public work will expand to fill the allotted time. Many people can relate to this rule. we understand crunching for a deadline, and putting off projects when there is no deadline. Realizing fusion has a deadline.

Structure II: Individual Innovators:

An innovator excels when vision and speed is required. Individuals can move through new ideas rapidly. This puts them way ahead of the mainstream. This has good and bad effects. Typically, the market has not caught up to the technology. Hence, there is no one there to buy or invest in an invention yet. Hence, the innovator often suffers. Ironically, this may improve development. Any tech entrepreneur will attest to getting their best work done under financial duress.

Fusion has one modern day example of this: Dr. Alex Klein. Doctor Klein started innovating while he was a graduate student at Columbia University in the late nineties [87]. In 1999, he started working on the Polywell. He came to the conclusion that ion injection was the major issue facing these machines. In response he envisioned MIX, a system designed to fuse atoms. Dr. Klein moved on to work at Oxford, MIT and the Joint European Torus. It took him roughly a decade to get the organizational and monetary support (3 million) to build MIX, and he discovered a hither-to-unknown instability which killed the idea [67]. In response he designed MARBLE, shown below. I cannot speak to this technology. The downside for an innovator approach is that the technology cannot yet be supported or adopted into society. If it is disruptive it may even be suppressed. This happened to Edwin Armstrong. In 1922, he invented FM radio. This directly challenged RCA's dominance in radio. The company fought back and delayed the widespread adoption of FM on till the late 1950's. Ed killed himself.



Structure III: Amateur Community:

This community based method works best when a market needs to grow. The best example of a technology started by amateurs is the homebrew computer club. The club started in Gordon French's' garage on March 15th 1975 [79]. Most of the thirty two members did not have a machine, just an interest [80]. Like fusion today, mini computers were also considered impossible. When Bob Marsh saw the ad for this in January 1975 his comment was: "it is clear this thing is a fake!" [82, 83]. There was no market. Techies were just interested. The first machines were made solely for hobbyists. This was the Altair 8800.


HOW TO "READ" FM TUNER SPECIFICATIONS

Popular Electronics

WORLD'S LARGEST-SELLING ELECTRONICS MAGAZINE JANUARY 1975/75¢

PROJECT BREAKTHROUGH!

World's First Minicomputer Kit to Rival Commercial Models...

"ALTAIR 8800" SAVE OVER $1000

ALTAIR 8800

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TEST REPORTS:

Technics 200 Speaker System

Pioneer RT-1011 Open-Reel Recorder

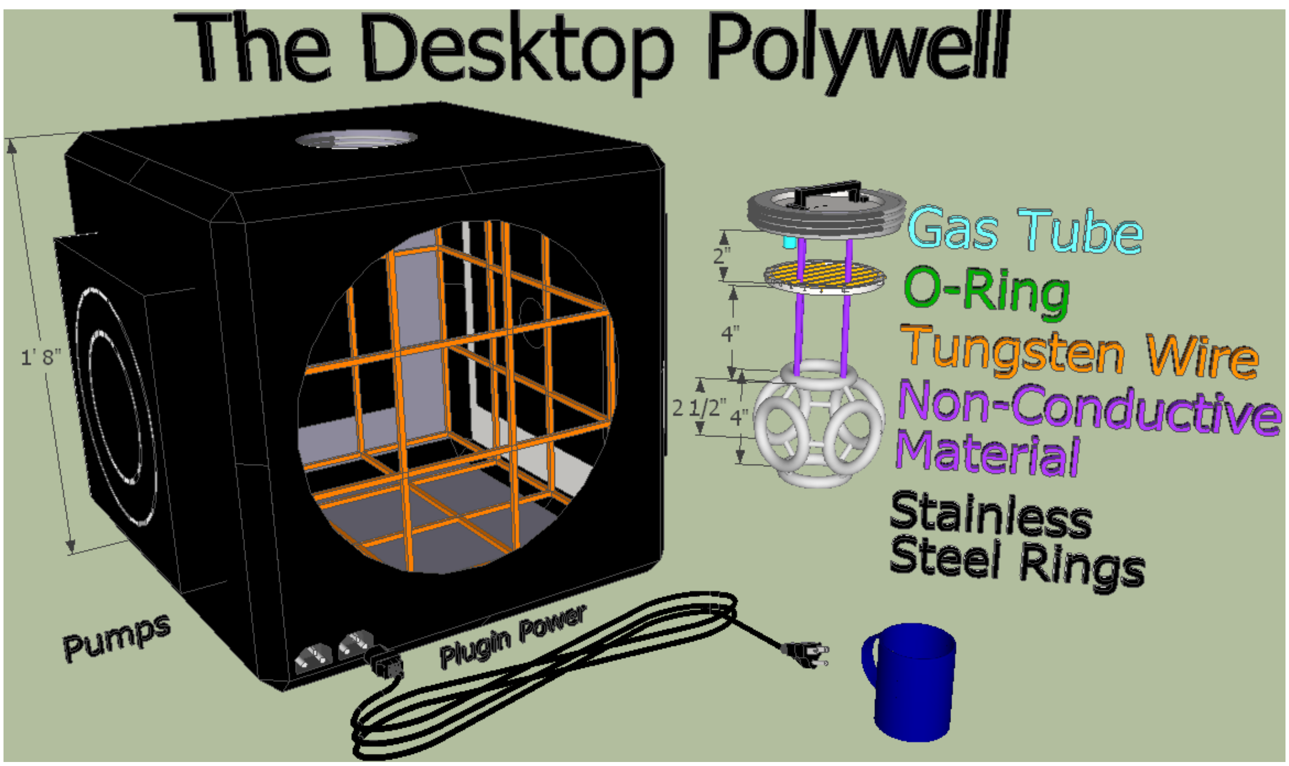
Like fusors today, early machines were clunky and unyielding. They were discussed by tech oriented individuals and in a technical manner. Early Homebrew newsletters read much like the posts on Talk-Polywell or the Fusor forums.

The purpose of the club was to combine galvanized people. Fred Moore summed it up in an early newsletter: "…the club is to facilitate our access to each other…we each know something or have something, even if it is only time and energy. The assumption is we are all learners and doers….." Working together pushed each member. Apple co-founder Steve Wozniak described it as: "It was the types of people, their personalities, how they were excited, that inspired me." Jeff Raskin got involved because "this is going to be fun" [82]. Members were engineers, machinists, musicians, high school students and lawyers.

Amateur communities may be the most promising path to fusion. We see a similar group forming around fusion today. There are three promising communities: the fusor, polywell and focus fusion communities. The fusor crowd consists of amateurs building fusors in their homes. Many connect through the Fusor Forum. The Polywell group consists of supporters of Polywell fusion, a fusor variant. Many connect through the Talk-Polywell Forum. The focus fusion bunch consists of supporters of the Focus Fusion machine. I cannot speak to the soundness of this technology; but it is clear Eric Lerner and his bunch believes in this idea. Their group connects through the Focus Fusion Society Forum.

The Altair 8800 of Fusion:

Today, could money be made selling fusor or polywell to the hobbyist market? This may be a place to start. The first product would be the Altair 8800, for fusion. The product ought to be simple, small and run off wall current. Below is a suggested design. A simple product like this will expand the hobbyist community.



Conclusion:

To get power, the direct approach has not yet been tried. Build a polywell with a direct converter. Put in electricity meter on both ends. Measure the power in and power out. Do not use expansive models or theory, just run this machine constantly. Try and find break even. If the direct converter can realize 48% energy capture, this may compensate for radiation and conduction losses. This is the approach the Wright Brothers would have taken.

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