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Abstract:

Each year, the output of carbon dioxide and carbon fuels continues to rise and it becomes increasingly necessary to find alternative sources of energy that do not lead to climate change and pollution. Some cleaner and more eco-friendly alternatives include wind, solar, hydropower, and nuclear energy.

Wind, solar, and hydropower energy are clean, but they struggle to find consistency. Variations in the weather (sunlight and wind) and the stream of water can lead to inconsistent sources of energy. Further, there has not been an easy way to store the energy collected efficiently, and thus, remains difficult for large scale operations.[26]

Nuclear energy, on the other hand, produces vast amounts of energy from only a small amount of mass, making it seem to be the ideal energy source. However, there are very large risks associated with it, particularly with the dangerous radiation that leaks out if the waste is not stored or managed effectively. One particularly dangerous case was the Chernobyl disaster in Russia, where the failure now makes the region unlivable for an estimated 3,000 years.

Natural forms of energy are inconsistent and difficult, while nuclear energy is dangerous. The last major form of clean energy remaining is fusion energy, which is the energy released when two atoms fuse together.. This energy is still in its developing stages, but its potential is enormous.

In fact, the sun, the "original" source for nearly all energy on Earth, uses fusion energy. It will be expensive, but if research and development is done correctly, it has the ability to power all of society consistently and with little danger. It will be like having our own miniature sun on Earth.[27]

Theory:

Theory: Fusion's Potential

Hydrogen's natural form is H2 and a helium atom's formula is He2. Since the atomic weight of hydrogen is 1.007825 u, meanwhile the atomic weight of helium is 4.002603254130 u. Since each helium molecule has two helium molecules, and a helium atom is a fusion of 4 hydrogen atoms, then a helium molecule should be 4x the weight of a hydrogen molecule. A hydrogen molecule has the weight 1.007825, and therefore, the helium molecule should weight 1.007825*4=4.031. Meanwhile, the actual weight of a helium molecule is 4.002603. There is a clear discrepancy in the weight: 4.031-4.003= 0.028 u.

In order to calculate the energy released from this mass discrepancy, we rely on Einstein's equation E=mc^2. This equation indicates that mass can be converted into energy. The constant c is the speed of light, 3.0*10^8.

Let's take our example above with hydrogen and helium. Let's say you have a mole of hydrogen atoms, so it would have a mass of roughly 1 gram. If all the hydrogen fuses into helium, you would have:

1 moles of hydrogen atoms(1 helium atom/4 hydrogen atoms)(0.028 g difference/1 helium atom)*(1 kg/1000 g)*=0.5*0.028/1000= 0.000007 kilograms

Then, using E=mc^2, you have:

E=0.000007 kilograms*(3*10^8)^2= 6.3 10^11 joules produced. To put this energy into perspective, the average American household will utilize 108 million joules per day. Just fusing this one mol of hydrogen atoms will thus yield 5,833.33 days of energy to American households, and therefore, this one mole of hydrogen can last an American family roughly 16 years. This energy is several times more efficient than any other alternative energy source.[27]

Theory: The Coulomb Barrier

However, fusing hydrogen is extremely difficult. The key difficulty is with the electrostatic repulsion between the two protons, which is demonstrated through the equation F=kQq/r^2, where k is a constant, Q is the charge of one particle, q is the charge of the other particle, and r is the distance between the two particles. As demonstrated by the equation, decreasing the distance for two protons is extremely difficult because the repulsive force will be extremely high.

Also, if one is only aware of the electrostatic forces, it might seem that fusion is impossible. However, there is another force present in particles like protons and neutrons, referred to as the nuclear strong force. This force binds the quarks located in protons and neutrons, and once two particles are close enough, the nuclear strong force comes in effect and overcomes the electrostatic force. The barrier that is preventing this is referred to as the Coulomb Barrier.[28]

Theory: The Sun's Cheat Code

First, the sun has extremely high pressure caused by the massive mass. This already brings the particles several times closer together than is typically possible on Earth making fusion a lot more likely.

Additionally, the sun actually uses another cheat code referred to as quantum tunneling. This concept is based on the Heisenberg Uncertainty Principle, which indicates the following:
$\Delta x*\Delta p>h/4pi$.[29]

This principle indicates that there is uncertainty regarding a wave traveling particle's position and momentum. It finds that the more certain we are about the particle's momentum, the less certain we are about its position. Thus, for any given momentum, and therefore, kinetic energy, there is a range of positions the particle can be in.

For a certain particle with energy below the coulomb barrier, due to this uncertainty principle, there is a small chance that the particle's position could actually be right next to another particle, and thus, lead to fusion.

This quantum tunneling is relatively unlikely, and thus, it is only practical for the sun because of the already high temperature and pressures, along with the extremely high amount of mass makes it so that tunneling becomes nearly inevitable and happens frequently.[30]

On Earth, we do not have nearly the same amount of mass, and thus, need to rely on a higher rate of fusion than the sun which simply makes fusion inevitable through its amount of mass.[30]

Theory On Earth: Fuel

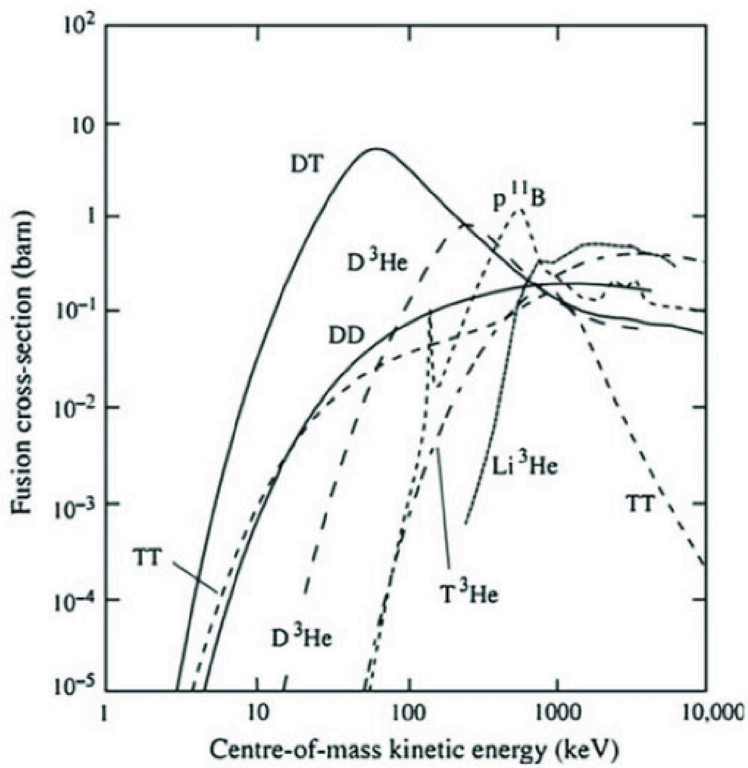
On Earth, we cannot simply rely on excessive mass and pressure to achieve fusion. We have to increase the probability of fusion to a much higher degree to actually receive energy from the reaction.

First, we need to choose our fuel efficiently. Different materials will yield different amounts of energy and have different coulomb barriers to overcome.

For example, if we fuse a mole of carbon, the mass difference will be much greater than fusing two hydrogens, and thus, yield more energy according to E=mc^2. However, at the same time, the atomic numbers and therefore, coulomb barrier is much higher, making it several times more difficult to achieve fusion. [31]

This difference in the Coulomb Barrier is the primary reason hydrogen variants are preferred over other atoms. Even inside the archetype of hydrogens, there are varying amounts of neutrons inside them.

In order to determine which types of hydrogen atoms to use, scientists rely on cross-section graphs. Please refer to the graph below.[7]



The graph demonstrates the relationship between fusion cross-sections and the kinetic energy of the center of mass. The fusion cross-section is the area over which the particles will react together, and the center of mass kinetic energy is how much energy is required. Thus, the graph demonstrates how much kinetic energy is needed for particle-particle interaction, and therefore, needed for fusion.

Scientists will want the highest area from the graph to the x-axis, as a high area means there are more opportunities and scenarios in which the atoms fuse. As you can see, the graph with the highest area is the DT line, which is Deuterium and Tritium, variants of hydrogen with 2 and 3 neutrons, respectively. Thus, scientists will use these materials.

Theory On Earth: Temperature

The Coulomb Barrier can be calculated using the equation V=height of the Coulomb Barrier= e^2k([Za][Zb])/([Ra]+[Rb]). Here, e is the charge of the particle, k is the electromagnetic constant, Za and Zb are the atomic numbers, and Ra and RB are the atomic radii. Using this, we find that for a typical hydrogen atom:

Coulomb barrier= (1.602*10^-19)^2(8.99*10^9)(1*1)/(1.2*10^-15+1.2*10^-15)= 0.9613*10^-13 joules

Here, 1.602*10^-19 is the charge of hydrogen, the k constant is 8.99*10^9, the atomic numbers of both hydrogens are 1, and the standard distance used is 1.2*10^-15 since that is the distance in which the strong force first starts to act.

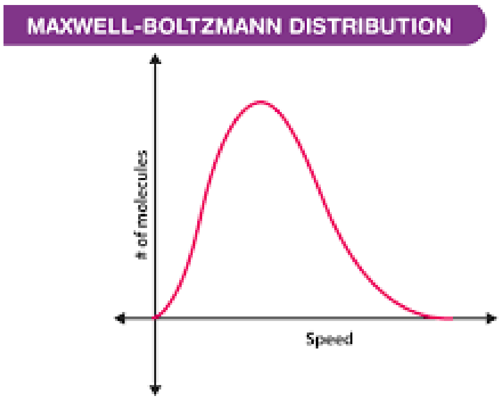
Next, let's derive the temperature we would need to typically overcome the coulomb barrier. The average kinetic energy of a particle inside a given temperature is given through the below equation:
Ke=3/2 *kT, where T is the boltzmann constant and values* 1.38*10^-23

Let's the two energies equal to each other:
0.9613*10^-13= 3/2 *1.38*10^-23*T
T=2/3/(1.3810*10^-23)*0.9613*10^-13= 0.464*10^10.

While it seems that the issue is solved, the temperature is rather concerning. This temperature is not only extremely rare in the known universe, but extraordinarily difficult to create on Earth. Thankfully, in this case, it appears that our temperature for fusion is actually wrong. Scientists tend to instead use the value of 100 million kelvin for fusion reactions. Let's look at the way to actually find the temperature.

First, for head-on collisions (the main one we are concerned about), both hydrogen atoms will have this energy, so we can sum their energies together. Thus, we can have the temperature to be half of this value.

Additionally, there is also the fact that the temperature value calculated is not the absolute temperature of all particles. Rather, it is represented by a pdf distribution, which is a graph that demonstrates the probability spread of several occurrences. Please reference the Maxwellian graph below[5]:



The average temperature is at the peak of the graph, but as you can see, the right of the graph has several molecules that are actually faster than the average. Thus, we can lower the temperature even lower due to these outliers on the right hand side.

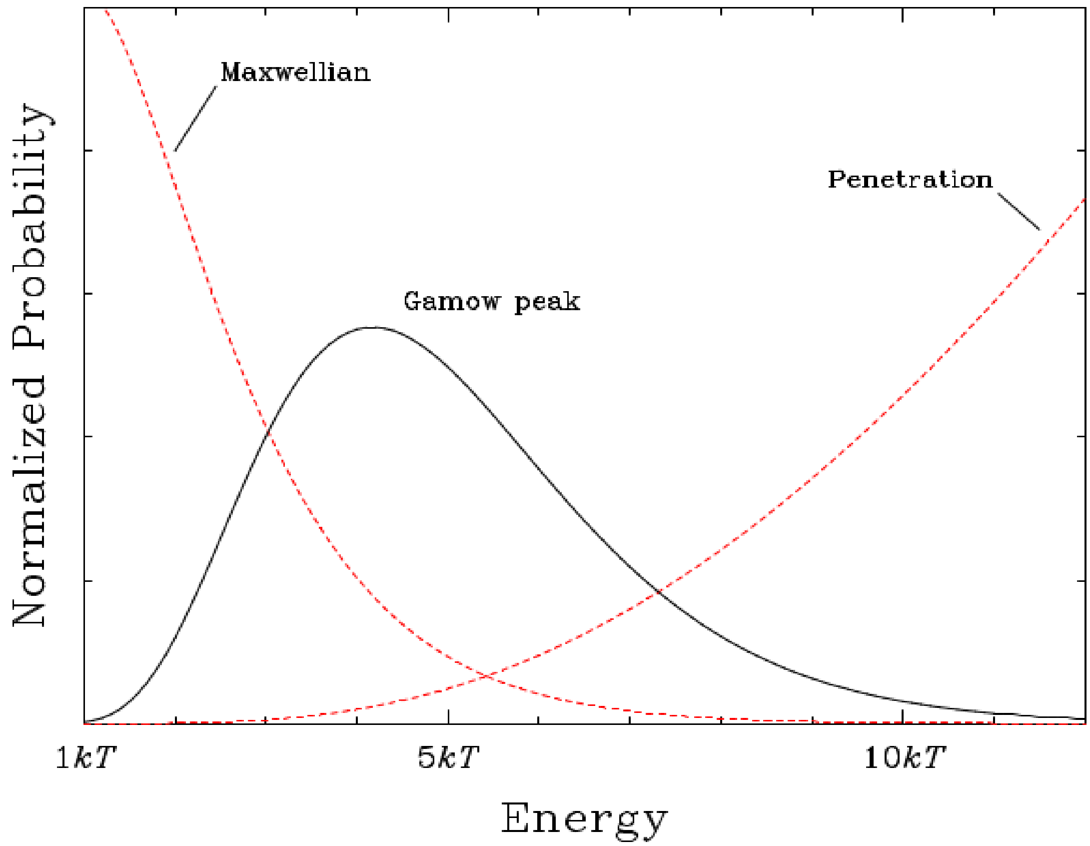
The last factor we need to also consider is quantum tunneling. Since particles travel in waves, there is a small, but still possible chance that the wave motions can perfectly pass such that it goes through the Coulomb Barrier.

All these factors reduce the actual temperature needed to achieve sufficient fusion.

In order to find the actual temperature, you need to consider the Maxwell-Boltzmann Distribution and the Gamow factor, which is an equation that represents the chance of quantum tunneling.
Using the Maxwell-Boltzmann Distribution function, we can derive an expression that determines the probability of fusing based on the particle's size, atomic number, and velocity.[32]

The term is proportional to the following term: e^-([pi]Z1Z2e^2/ε0hv), where Z1 and Z2 are the atomic numbers, e is the elementary charge, epsilon naught is the permittivity of free space constant, h is the planck's constant, and v is the velocity.
Further, the Gamow factor distribution across various various velocities and temperatures is equal to: e^-(mv^2/[2kT]), where m is mass, v is velocity, k is the boltzmann constant, and T is temperature.[34]

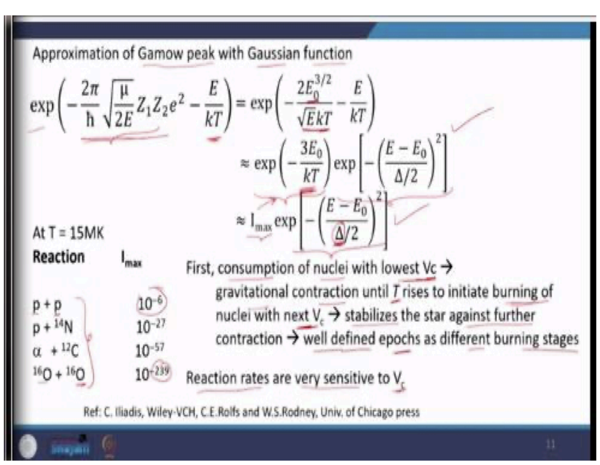
Since both are probability density functions, we can multiply them together to find the total probability density function for fusion with particles of certain energies. Here is the graph[6]:



The peak of the gamow graph is referred to as the gamow peak, and is the energy that has the highest probability of fusion. Thus, scientists take this energy peak, and convert it to temperature.

Using this, it has been determined that the ideal temperature for fusion of deuterium and tritium is about 150 million kelvin. [9]

<u>Sidenote</u>:



We did try to do the mathematical derivation ourselves. However, the math and science was too rigorous and we could not successfully derive this portion of the theory. We were looking at works of math as complicated as this:

We thought this might be slightly above the current understanding of the standard AP Physics C student.

Theory On Earth: Lawson's Criterion

So far, we have determined the ideal temperature and the best fuel for our fusion reaction. Now, it is important to determine the other conditions necessary for net energy gain.

The most notable factor is referred to as Lawson's Criterion. This law indicates that the product of the density of the ions of the fuel (n) and the time that fusion reaction takes place (τ) should at least be a certain value.

For the specific fuel of deuterium and tritium, the Lawson's Criterion can be represented by the following equation[33]:
$n*\tau <= 10^{14}$ s/cm^3

This equation has fascinating implications, as it allows several potential methods to achieve effective fusion.
You can either:

1) Hold fusion reactions for a long time, but with less confined pressure
    a) This is the basis for magnetic confinement fusion reactors

OR

2) Hold fusion for a very short time but with very extreme pressure
    a) This is the basis for inertial confinement fusion reactors[33]

Now that we have concluded the basic theory for fusion reactors and now know the best temperature, fuel, and options for Lawson's Criterion, we can start to observe the engineering methods that are being explored to make use of fusion science.

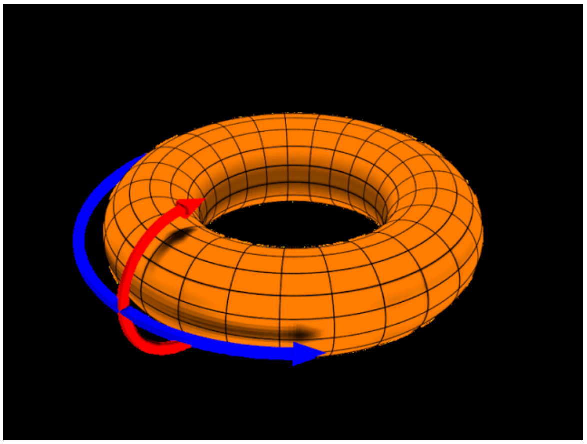
Methods

The two main methods used in modern day labs are magnetic confinement and laser inertial confinement. As we will soon explain, the names are representative of the method used to generate fusion energy. There are various other methods used, however the two we will outline are the most prevalent and used by government funded research facilities.

Magnetic Confinement:

Magnetic confinement starts with the shape of a Tokamak. The basic idea is that it utilizes magnetic fields in order to contain the fuel used for fusion reactions: Plasma. This plasma is created by superheating a gas (usually hydrogen for fusion reactions) to temperatures exceeding that of the sun. The high temperature and containment of the plasma allows particles to "fuse" together and generate energy.[24]

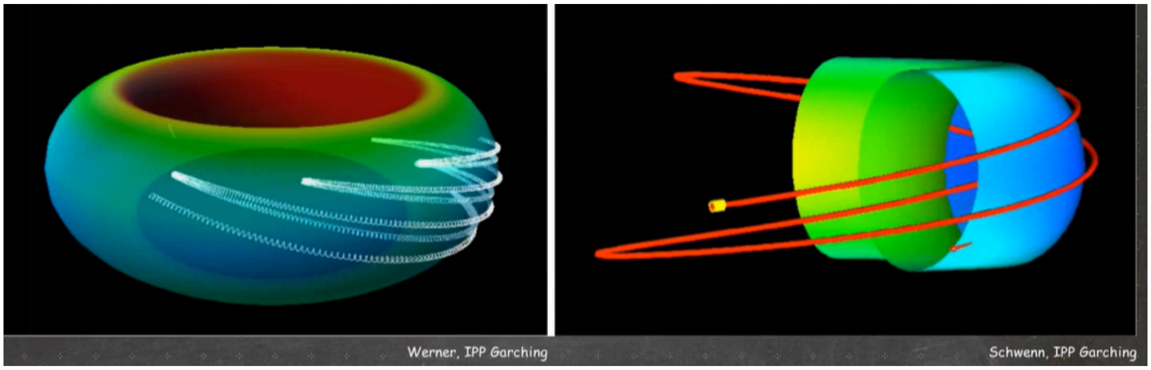
Explaining Gyrocenter Motion:



With the shape of the tokamak having a greater field inside than outside, an issue comes to light. The magnetic confinement issue arises in the toroidal geometry because from Ampere's law it follows that the field will be stronger near the inner part of the torus. This causes charged particles to drift either up or down as they spiral around the field lines since due to the varying field strength the local radius of curvature alternates between larger and smaller.[23]

To solve this issue, we use multiple magnetic fields in various directions. The toroidal direction alone will cause drift, and won't contain plasma. A second magnetic field in the Poloidal direction is introduced to counteract this first field.

The combination of the toroidal and poloidal fields creates a helical (twisted) magnetic field, like the stripes on a candy cane. The toroidal is represented by the blue arrow and the poloidal is represented by the red arrow.[23]

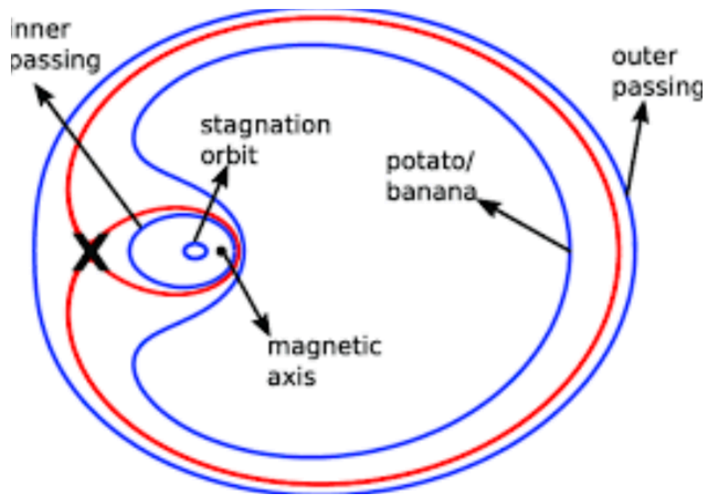


Describing Particle Motion:

As a result of the interaction between the multiple fields, the path we observe a “banana orbit” for the particle within the tokamak. This is one of 2 sets of motion. A 2d image of this is shown in the image further down. A 3d image shown with side by side pictures also shows this path. [22]

The motion has turning points and changing lengths with each path, working its way along the side of the tokamak. The second set of motion is simply particles moving in the toroidal direction.

The orbits are a result of the induced toroidal and poloidal magnetic fields, and they are evidence of a resistance to the tendency for particles to move radially and disrupt the process of fusion.[22]

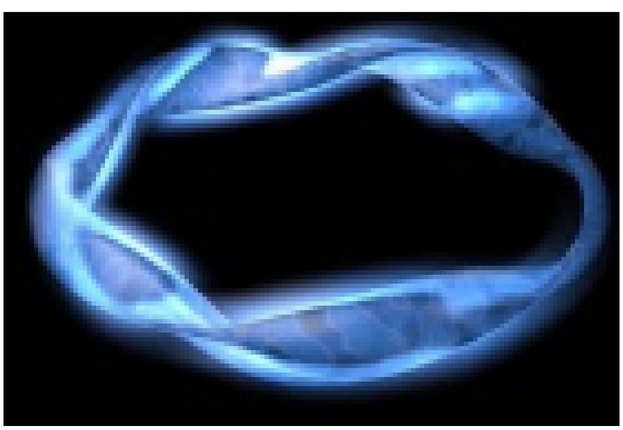


Within the banana orbits specifically we have various different phases. Those being pinch and stagnation orbits. Pinch orbits are transitional between banana orbits. The letter D corresponds to the cross section. We will come back to this “D” and describe how modern advancements actually use predictive AI models to prevent distortions in the D cross-sections.

When the 2 sets of motion are combined, and considering that multiple particles undergo such motion, we can visualize the motion of the plasma as something shown with the image below.

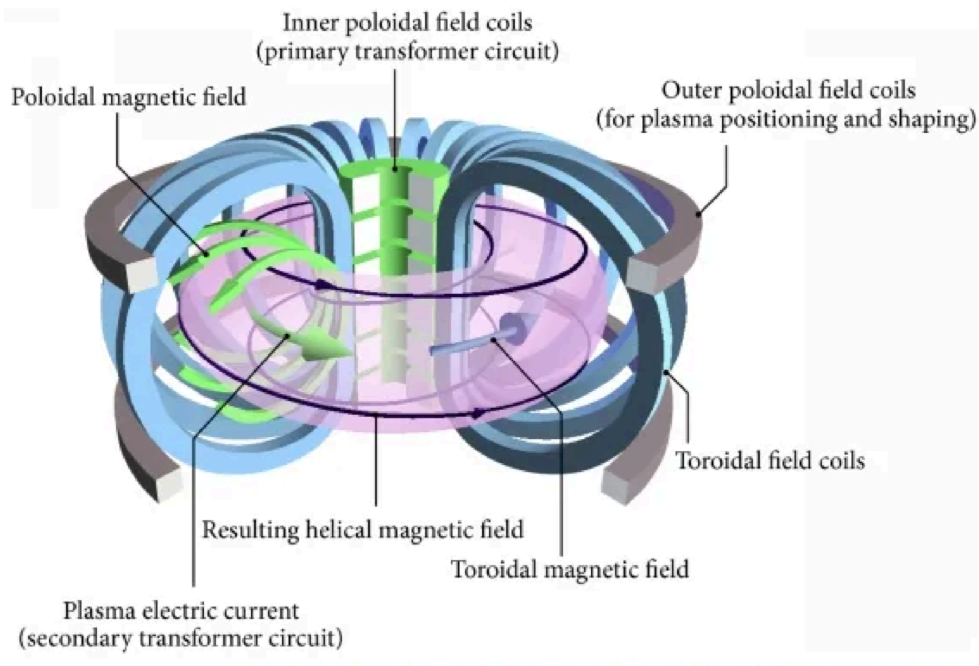
Along with the toroidal and poloidal directions, while considering the tendency described earlier with ampere’s law, the forces in the radial direction must also be overcome. [23]

The radial velocity is not simply a product of the toroidal and poloidal velocities. Instead, it is a distinct component that arises due to various drift mechanisms, collisions, and electric field effects.[23] In ideal magnetohydrodynamics (MHD), particles are tightly bound to magnetic surfaces, so their average radial velocity is zero.[23] However, in reality, small but crucial radial motions occur due to:



- Collisional transport (classical and neoclassical)
- Drifts (e.g., curvature and grad-B drifts)
- Turbulence and microinstabilities
- These processes allow particles to slowly "leak" across magnetic surfaces, leading to radial transport of particles, momentum, and energy

Being able to consider these various forces and induce fields to keep the particles in perfect motion and not touch the outer wall (ending the reaction), scientists face severe challenges, especially in needing to maintain such a complex reaction for so long.[21]



Methods of Heating (Magnetic Confinement):

In general there are 3 main ways of heating in magnetic confinement reactions.

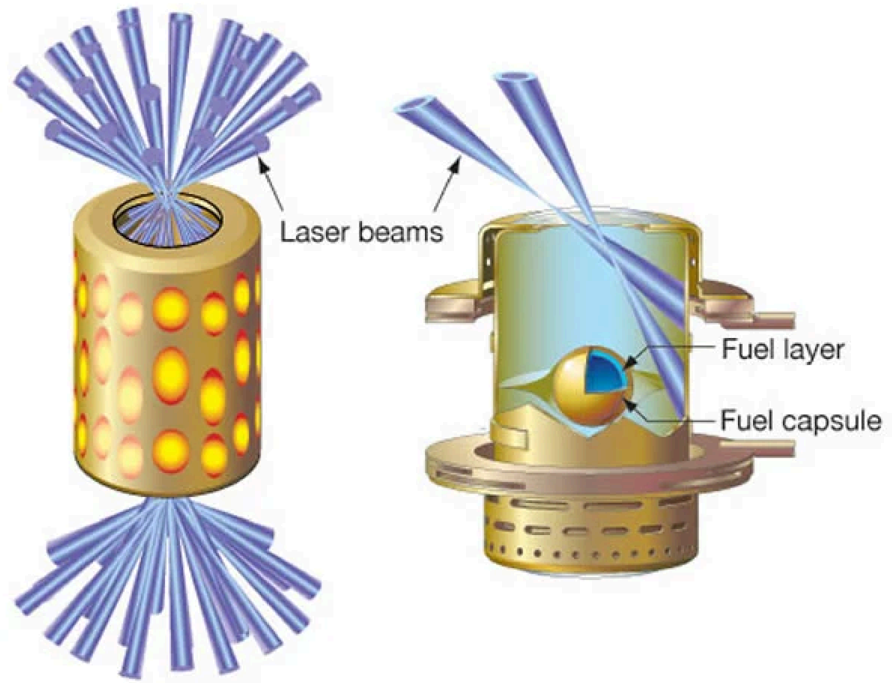
1. Ohmic Heating (Initial Stage)[20]
    a. Uses the plasma's own electrical resistance to generate heat through induced currents.
    b. Limited to ~15 million °C as plasma becomes less resistive at higher temperatures.
2. Neutral Beam Injection[20]
    a. Shoots high-energy neutral particles (1 MeV deuterium) into plasma
    b. Particles ionize and transfer energy through collisions, adding 16.5 MW per beam in ITER
    c. Effective for bulk plasma heating and current drive.
3. Radio Frequency Heating[20]
    a. Ion Cyclotron Resonance Heating: Uses 40-120 MHz waves to resonate with ion gyration
    b. Electron Cyclotron Heating: Applies 100-200 GHz microwaves to energize electrons
    c. Can target specific plasma regions for precision control

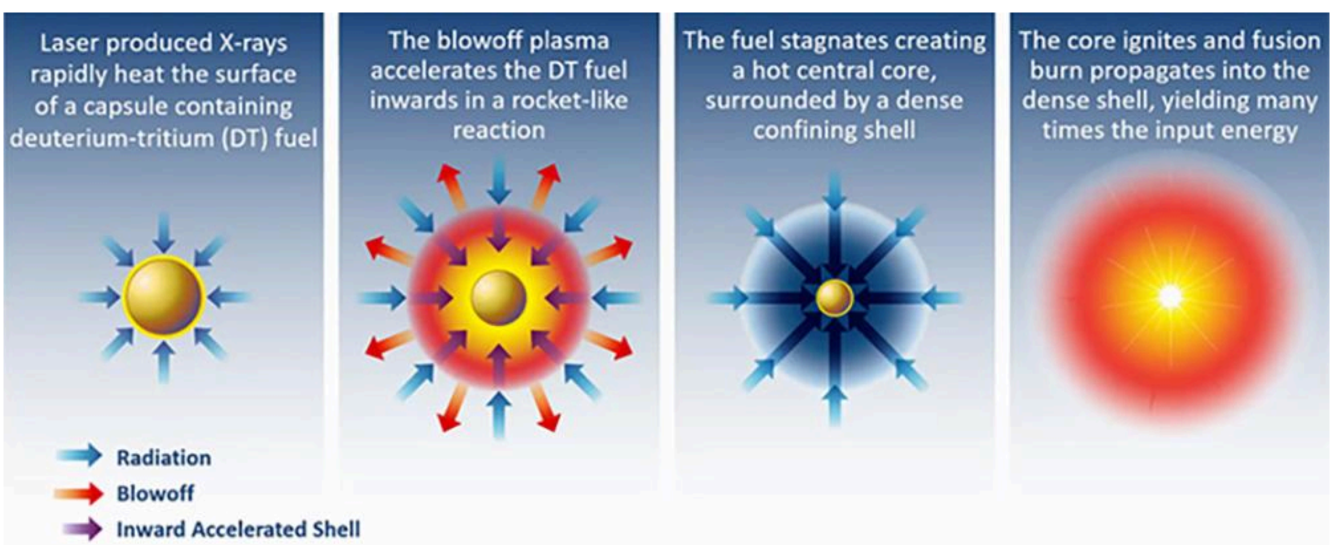
These methods work in tokamaks like ITER, where ohmic heating initiates the plasma before neutral beams and RF systems take over to reach fusion conditions. As we see, the different methods work together throughout different phases of the overall reaction. This contrasts fundamentally with inertial confinement's approach of using laser-induced shockwaves to compress fuel pellets.[20]

Laser Inertial Confinement:

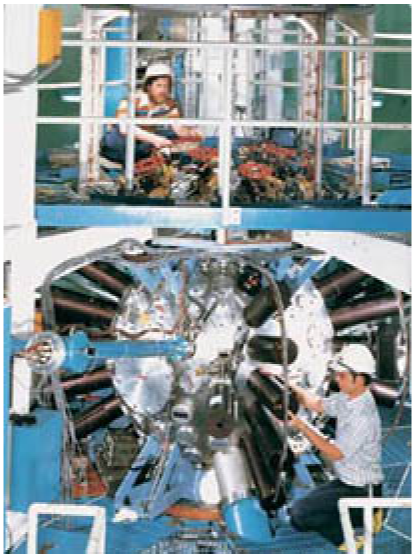
The broadest way to categorize the 2 methods is that magnetic confinement can last for 22 minutes. In general, the longer a magnetic confinement reaction can be sustained, the better. In contrast, an Inertial confinement reaction only lasts for nanoseconds. The goal is to fuse nuclei so fast that they don't have time to move apart.[19]

Laser inertial confinement, just like magnetic confinement, utilizes plasma. However in order to create this plasma, high powered lasers are used. Laser beams are focused on the outer surface of a small, hollow sphere (the "pellet") containing fusion fuel. This is the method of heating which is utilized by this style of reaction, in contrast to the previously described magnetic confinement. The "inertia" of the imploding pellet resists the outward pressure of the burning plasma, briefly confining it for the nanoseconds it takes for fusion reactions to occur.[17]





The high temperature and containment of the plasma allows particles to "fuse" together and generate energy. As described in the image below, we can see the broad phases of a fusion reaction.

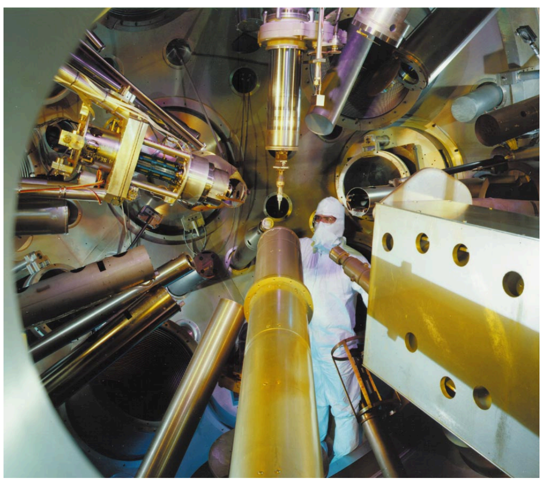


In ICF (Inertial Confinement Fusion), a tiny fuel pellet is compressed to extremely high densities and temperatures using a rapid, intense energy pulse (such as from lasers). The fusion reactions occur only for a few nanoseconds—typically around 10 nanoseconds—because the fuel rapidly disassembles due to the immense pressures and temperatures generated during the implosion. The inertia of the shell temporarily confines the hot plasma, but once the shell's momentum is overcome by the expanding fusion core, the system blows apart, ending the reaction.[19]

In regards to the way the reaction ends, the brief confinement is not an engineered "shutdown," but a natural consequence of the method: the reaction can only proceed while the compressed fuel remains together, which is for nanoseconds before it explodes outward. Only a small amount of fuel is used each time to avoid an uncontrolled explosion, and each fusion event is a short-lived micro-explosion.[18]

The name of "inertial confinement" comes from the fact that the explosion at the end of the reaction is so fast, it is contained by the natural inertia of the shell containing it.

As one could ascertain, a reaction releasing all energy is simply a Hydrogen Bomb.[19]

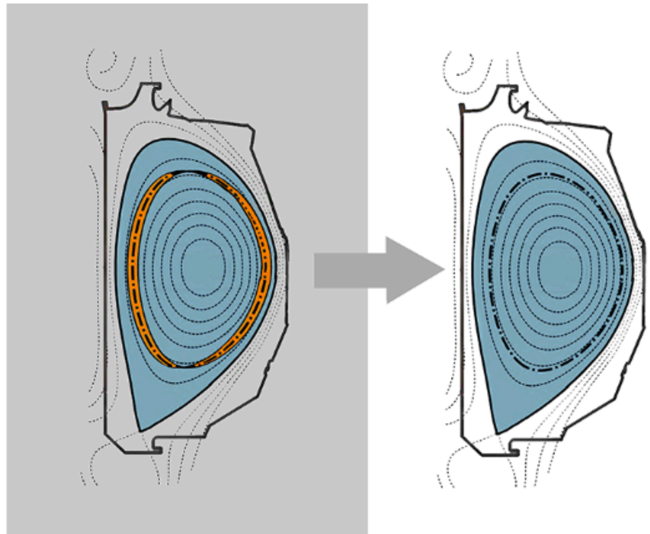


Currently, two experimental laser fusion devices have been developed at Lawrence Livermore Laboratory, called Shiva and Nova. They deliver high power bursts of laser light from multiple lasers on a small deuterium-tritium target. These lasers are neodymium glass lasers which are capable of extremely high power pulses (Nova below image, Shiva above image). [4,7]

The main goal of these various reactions is to somehow produce a net positive output, when considering the hundreds of thousands of joules of energy expended by the lasers. [19]

Modern Advancements:

Today various methods are employed to ensure fusion reactions don't disrupt. Whether that be AI, the materials used, or type of laser, the ways to tweak such a reaction are nearly endless.

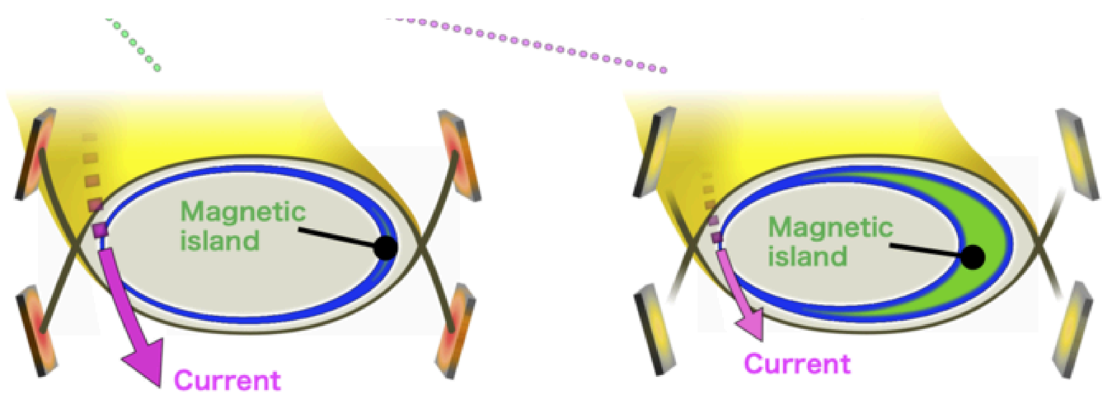


First, we'd like to delve into how AI is used in fusion reactions. As we talked in the earlier sections regarding magnetic confinement, one of the paths described was a D cross section. As shown on the right, we have one such cross section. As outlined by the orange color, those represent tearing instabilities in the D orbit.[22]

Plasmas can cease their reaction by what is known as a disruption. Typically however, disruptions are relatively easy to avoid, with scientists simply having to make sure that the stability boundaries within the tokamak are calculated, and the reaction kept from leaving the boundaries (via the magnetic fields).[10]

Tearing Instabilities:

Tearing instabilities, or tearing modes, are a class of magnetohydrodynamic (MHD) instabilities that occur in magnetized plasmas, such as those found in tokamaks. As described by Richard Fitzpatrick, tearing modes are characterized by the tearing and reconnection of magnetic field lines at specific resonant surfaces within the plasma. This process leads to the formation of radially localized structures known as magnetic island chains.[8]



From the various other instabilities that can occur during fusion, tearing instabilities take up the overwhelming majority, given that there are no stability boundary disruptions. Tearing modes are special in the way that they can become unstable even while the plasma is looking to be stable. The instability typically develops in a thin layer around the resonant surface as shown by the bright green in the image to the right. These are magnetic islands. [6]

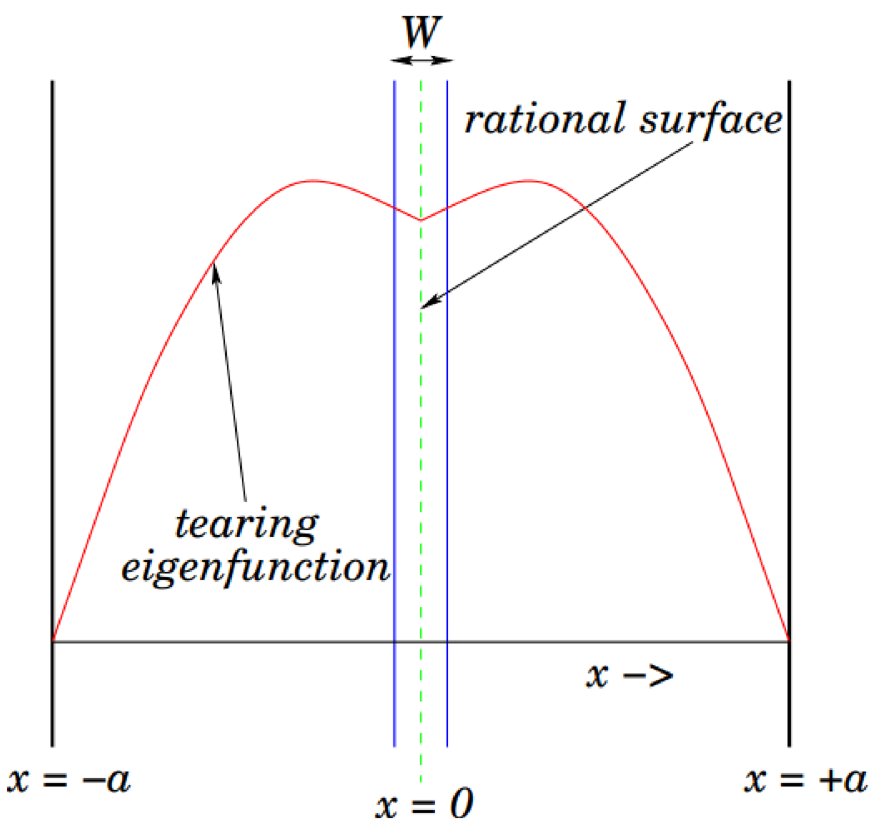
As the island forms and closes, this represents the process of tearing and reconnecting. The field of understanding what drives these tears is known as MHD (magnetohydrodynamic) theory. As shown below, taking a derivation from Ohm's law. [15]

- Tearing stability index:

$$\Delta' = \left[\frac{d \ln \psi^{(1)}}{dx} \right]_{0-}^{0+} .$$

- According to conventional MHD theory,[a] tearing mode is unstable if $\Delta' > 0$.

Graphically speaking, we can also see how the fusion reaction moves in and out of tearing and reconnecting. The blue line at x=0 represents where the tearing is most likely to occur. The red curve represents the amplitude of instability. The rational surface (width W) is where instability will develop if the plasma is unstable. Think of this as somewhat as a danger zone. In reality, there are various rational surfaces scattered throughout the plasma at various locations. To fully be stable and avoid tearing instabilities, *the plasma must be stable to tearing at all rational surfaces.* [15]

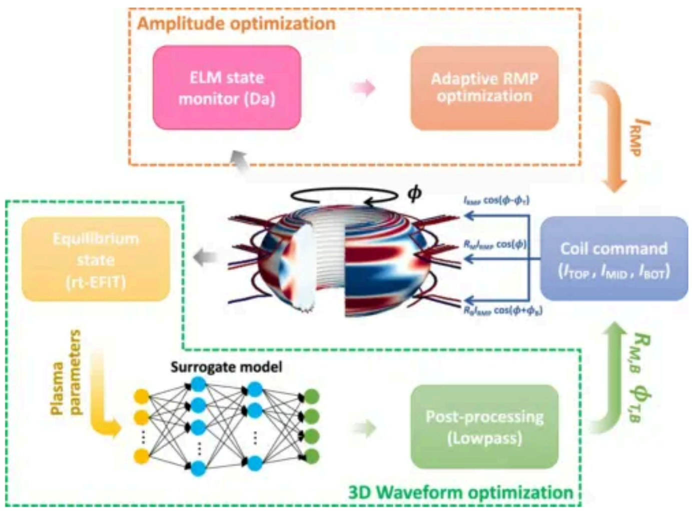


There are various ways to approach this. In q-profile tailoring, physicists monitor and control the safety factor q profile to avoid values that are especially prone to instability. They can also keep the current and pressure gradients gentle near rational surfaces, the drive for tearing is reduced. These methods are both examples of avoiding tearing instabilities at those unstable rational surfaces. If the plasma is unstable here, magnetic islands can form.[13]

The growth of tearing modes also depends on the gradients of current and pressure across the plasma. Through profile control, the pressure profiles can be manipulated to minimize the growth of tearing on these surfaces. The rate at which the direction of the magnetic field changes across the plasma is also manipulated to reduce instability.

There are various other ways to manipulate the plasma to avoid these instabilities, however the one we want to dive into a bit more is active monitoring. Magnetic sensors detect early signs of tearing modes. Following this, control systems apply small, targeted magnetic fields (using external coils) to suppress or "heal" the developing islands. Another way to detect early signs of tearing modes which has been recently used is predictive AI models. [14]

Princeton research has found that, using an AI controller trained off of various experiments in the past, the model was able to forecast the start of the tearing instability up to 300 milliseconds before the tear actually occurs. This gives the researchers enough time to account for the instability, and have measures in place to adjust the plasma such as the control systems described above. [11]



This new research is so incredibly important, because unlike traditional active monitoring which makes changes *after* seeing the start of instabilities, the use of predictive artificial intelligence is able to have measures in place before the tear even occurs. [12]

As shown in the image above, 3d waveform optimization is used in the AI model. This is a generative AI used quite commonly, albeit in different applications. A great, but unexpected example of basic 3d waveform optimization without the use of AI is generation software in the game minecraft. In the fusion reaction, instead of blocks however, the plasma itself is analyzed with the waveform optimization allowing the AI to visualize the plasma and then make predictive analysis.[16]

While we have just talked about preventing tearing instability, there are scenarios where inducing these instabilities may actually have some benefit.

<u>Utilizing Tearing:</u>

While the formation of magnetic islands are a means to disrupt fusion, under controlled conditions, they can also help dissipate excess heat at the plasma edge.

In the experiment outlined in the article, coils, much like the ones described earlier, were used to induce magnetic islands at the edge of the D shaped cross section of plasma.

As explained by Kobayashi, "The magnetic island is essential to reducing the plasma heat load, so the competitive oscillation between the magnetic island and the plasma current is also reflected in the plasma heat load on the divertor." The goal is to maintain desired plasma states (like detachment) and avoid dangerous conditions (like excessive heat load or uncontrolled tearing). By making the magnetic islands fully controlled, the measures are not reactionary to create unwanted disruptions, but rather already in place and preventative in nature.[10]

Advancements: Materials

Historically, the standard for fusion reactors was the use of Tungsten or Beryllium for the inner layer of walls. These surfaces were very strong and useful for lasting against the extreme temperatures and radiation from fusion reactions, but they struggled over time. It was common for these materials, and any other solid material to gradually erode and melt, decreasing the efficiency of the fusion reaction.[1]

The major alternative found is to instead coat the walls with a liquid. Liquids are easily removed, replaced, and suffer less damage since they can constantly flow and evaporate. Additionally, as the reactor loses its purity, having an easily replaceable layer of liquid makes it easy to remove such impurities.

Liquid lithium keeps the walls of the fusion reactor above much freer from erosion than other alternatives.[1]

The most prominent recommended and experimented coating is with liquid lithium. Due to its valence state (1 electron), it is easily ready to remove this electron, and thus, makes it highly reactive. This high reactivity makes it a very good candidate for coatings.

Furthermore, Lithium is found in experiments to absorb roughly 40% of hydrogen atoms that are shot out from the plasma. This high absorption ensures that these “cold” hydrogens do not return to the plasma, thus, making the plasma colder.

In summary, liquid lithium is a modern advancement that can completely change magnetic confinement reactors through its ability to increase reactor longevity, improve plasma temperature, and be easy to replace and coat with.

Looking to the Future

Looking ahead, there are still many struggles that guard us from being able to make full use of fusion technology.

Currently, we are still trying to increase the rate and efficiency of fusion reactors and are able to get just above net energy gain.

Additionally, tritium, one of the main fuel components for fusion, is not in excess. Due to its low half-life, it needs to be consistently produced artificially, increasing the costs of fusion reactors. If you also count the cost of building and running fusion reactors, the price only increases.

These above issues make it difficult for fusion reactors to be fully used since they are still far from economic profit, thus, making it not feasible for the market and society as a whole. And to make matters worse, the US government is reducing funding for fusion reactor research, making it even more difficult for engineering.[25]

All these remain as large obstacles for fusion reactors. It is expensive and difficult, but over time, given the right research, something better can happen. We have already found the fuel, temperature, pressure, confinement time necessary for fusion. All that is left is the little engineering details that will perfect the practice. If we can figure out how to make this fusion cheaper, and more efficient, we won’t ever have to worry about a lack of energy or sacrificing our comfort energy for the environment.

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