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26 February 2022

Nuclear Green Energy

In our present day, many objects we use are made or function with plasma that is not fully ionized for fusion, but rather ionized partially with electron temperatures under 4eV [6]. Examples include lamps with low-temperature plasmas, fluorescent lighting which uses argon, or neon plasma with mercury for light generation. Other objects such as TVs, windows (for different light wave transmissions), and even jet engines also operate with the fundamentals of plasma physics. Not only can plasma be used in engineering but also in the studies of medicine where plasmas are used for the sterilization of tools as well as ion implantation [6]. As well see soon, plasma is one of the building blocks for nuclear fusion power, a more sustainable and efficient method of harvesting and generating electricity. Green energy can come in many different methods including solar, wind, and hydroelectric power. Nuclear can sometimes be left out of the plate when it comes to the discussion of renewable energy methods. Nuclear energy plays a large factor in being one of the lowest carbon electricity power sources and can reduce air. Nuclear power is generated through nuclear fission where certain atoms split during the process. The splitting of these atoms is similar to the steam generator where the heat is used to spin turbines that can generate electricity without other chemicals being created such as traditional fossil fuels. There are drawbacks to this process as nothing is ever truly free or green. Other parts of the nuclear cycle from mining and extracting the materials can be costly and done with unclean methods. The costs of this technology are relatively new and will need time and funding to complete. In this paper, we will dive into the fundamentals of nuclear energy, its processes, and what it would take to be widely adopted in the U.S.

To begin, we must glance over the core concepts of plasma and its backbone composition. Matter by definition is anything that has mass and volume. This means everyday objects we come into contact with, consist of matter. Mass that is seen with the visible eye is self-explanatory, but once matter is introduced into the micro and even nanoscale, it can get very overcomplicated [1]. This brings us into the world of atoms and molecules. Atoms themselves are forms of matter which can be gasses, liquids, or solids. Atoms are made of protons, neutrons, and electrons. The number of protons and electrons will have a net positive or negative charge which will eventually bond to other atoms to create molecules and other bonds helpful to us. When these atoms or molecules have a charge imbalance, they are ions [2]. With our understanding of these basic concepts, we can further elaborate on the challenges nuclear energy has for us.

In simple terms, plasma is matter that is heated to very high temperatures. Electrons are heated so much they are ejected from their respective atoms and form ionized gasses [11]. Plasma can be thought of as the fourth state of matter because of its continuation from the three more common forms of matter being heated. Solid can be heated to a liquid, liquid can be heated to gasses, and heating gas at high temperatures will form plasma (ions). Plasma has a profound interest for engineers and researchers when it is at the temperatures needed for fusion energy which can prove to be immensely beneficial to human energy needs. At a higher level, our sun is what fuels all of our world's energy needs such as fossil fuel from trees that grew centuries ago. Evaporation caused by sunlight also gives us rain and snow for our hydropower electricity generation. The sun's interior temperature is 1keV and takes millions of year until they are released as helium for energy [6]. Nuclear energy is energy that is released from the splitting of atoms. The element that is mainly used for this reaction is the uranium atom. Nuclear fusion is the same process that powers the sun and stars as hydrogen atoms are able to fuse and form helium where matter is converted into heat energy [3]. This heat can then be harvested for practical purposes such as electricity generation. We will get into electricity generation later. Hydrogen that is heated to very high temperatures changes from gas to plasma where the negatively-charged electrons would then separate from positively-charged atomic nuclei also known as ions [3].

Under normal circumstances, "fusion is not possible because the strongly repulsive electrostatic forces between the positively charged nuclei prevent them from getting close enough together to collide and for fusion to occur" [3]. This is due to the positively-charged electric fields pointing outwards which cause the like forces to repel each other electrostatically. If the nuclei cannot get close enough to each other, there is no collision and hence, no fusion. A core challenge is to get the emitted heat from the plasmas to be higher than that of the energy that is being injected into the plasma. This is because fusion energy must be heated to very high temperatures (5e+7 **Kelvin**) while simultaneously being contained under pressure allowing the nuclei to fuse together [5].

According to research conducted at the Massachusetts Institute of Technology, the amount of power that is produced is the square of pressure imposed [3]. As noted earlier, hydrogen atoms can take millions of years for energy to be released, thus temperature is increased. The heating of plasma can be done by increasing the inertia of collision with heavier isotopes deuterium (D) with one proton and one neutron, and tritium (T) with one proton and two neutrons [6]. These reactions change when the nuclei is heated to high temperatures. At such high temperatures, the nuclei will outweigh electrostatic forces where they would eventually be able to fuse with each other [3]. These two heavy isotopes cause D-T fusions which can release up to 17.6 MeV compared to 200 MeV for U-235 fission and 4 MeV for D-D fusion [3]. This means almost four times the amount of energy is released from D-T fusion reactions compared to the uranium fission process. There are two main methods of obtaining the energy from the D-T fusion collisions, magnetic confinement and inertial confinement [6].

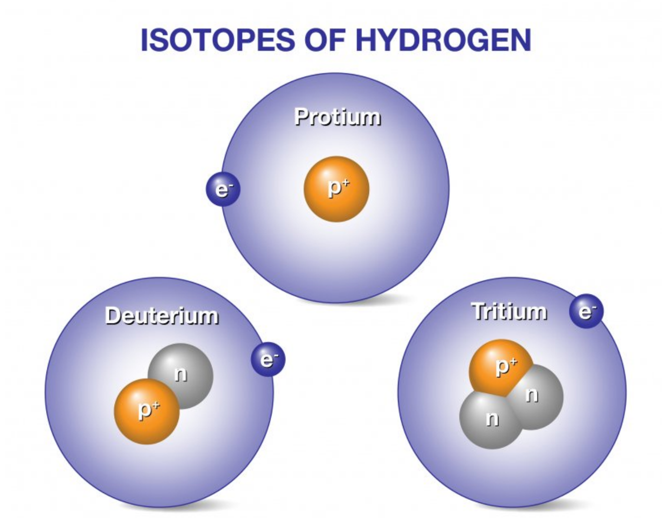

Figure 1: Isotopes of hydrogen (Protium, Deuterium, and Tritium)

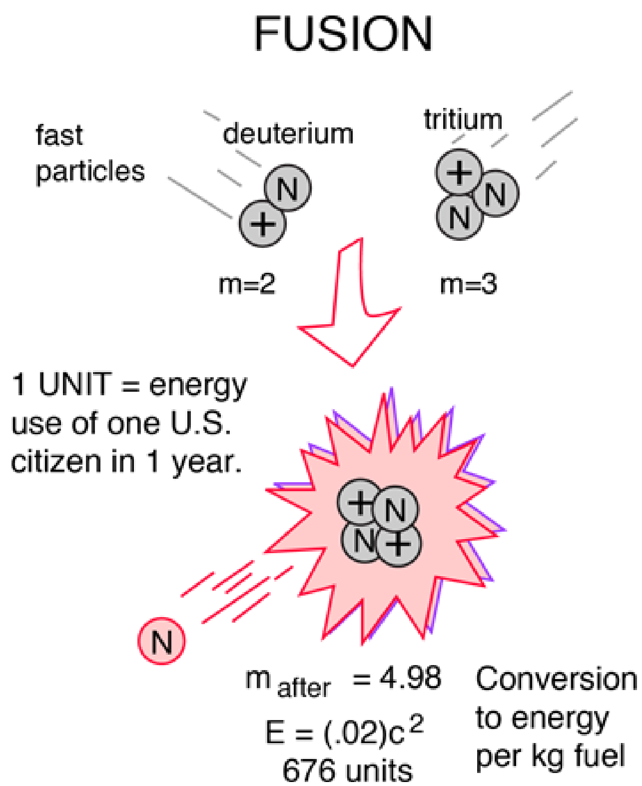

Figure 2: Fusion of Deuterium and Tritium which can yield 17.6 MeV of energy. Penetration of the coulomb barrier with the aid of tunneling is needed, which must be done at very high temperatures. [7]

Inertia must overcome the electric repulsion of ions with like charges (nuclei with repelling electrostatic forces). Inertial confinement can be used by compressing small amounts of fusion fuel to reach high densities with lasers and beams [3]. Lasers or ion beams can be focused onto the surface of the target, in case it is the D-T fuel. As stated by the World Nuclear Association, " This heats the outer layer of the material, which explodes outwards generating an inward-moving compression front or implosion that compresses and heats the inner layers of material. The core of the fuel may be compressed to one thousand times its liquid density, resulting in conditions where fusion can occur. The energy released then would heat the surrounding fuel, which may also undergo fusion leading to a chain reaction (known as ignition) as the reaction spreads outwards through the fuel" [3]. Recent studies from the Institute of Laser Engineering at Osaka University found that ignition can be done at lower temperatures by introducing additional laser pulses that can be guided by a cone onto the compressed fuel. The University of Osaka found that they could enhance ignition by using an extended double cone for fast electron guiding to imploded core [8].

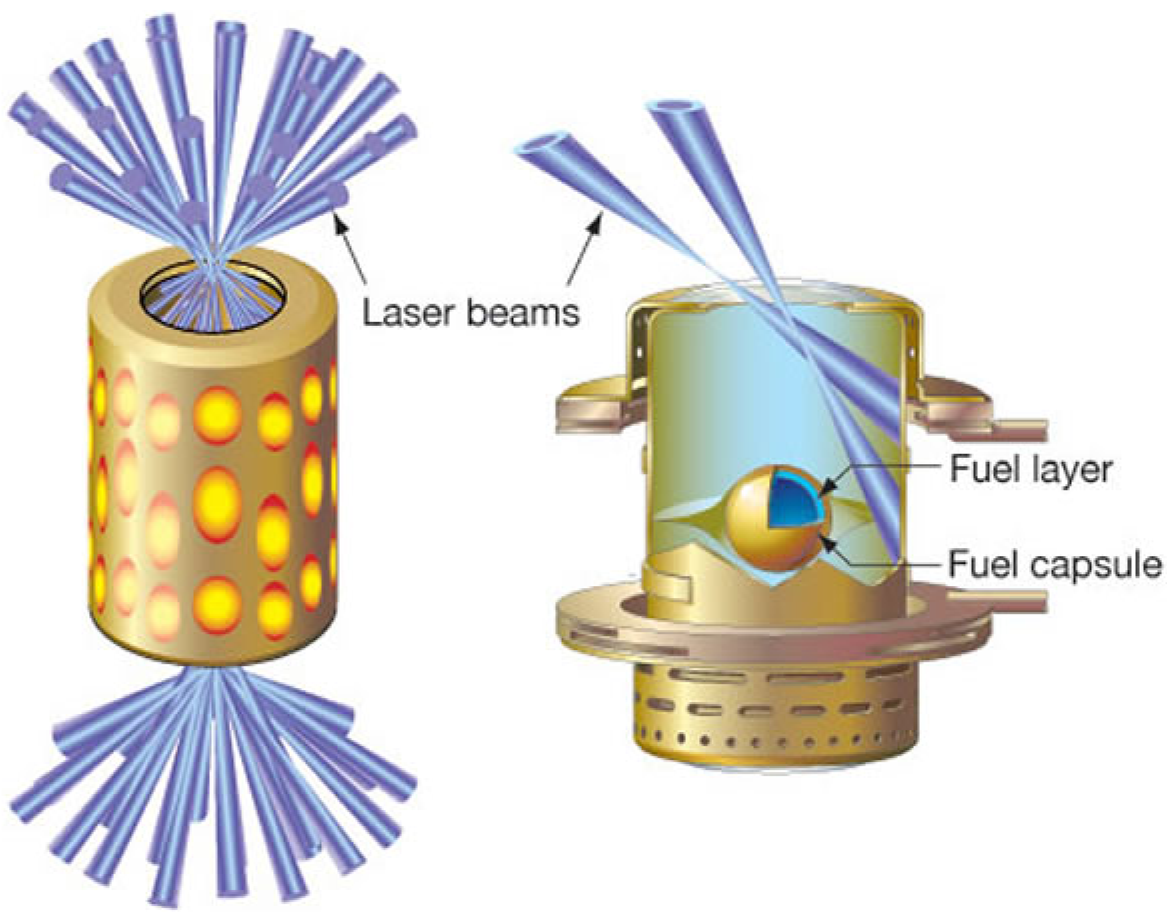

Figure 3: The energy of the NIF's 192 beams is directed inside a gold cylinder called a hohlraum, which is about the size of a dime. A tiny capsule inside the hohlraum contains atoms

of deuterium (hydrogen with one neutron) and tritium (hydrogen with two neutrons) that fuel the ignition process. [9]

Electric currents have different interactions with Magnetic Fields. A charged particle moving in a magnetic field with $B_z = B \cos \theta > 0$ and a component $B \sin \theta$ that flares radially out of the xy-plane in figure 4.

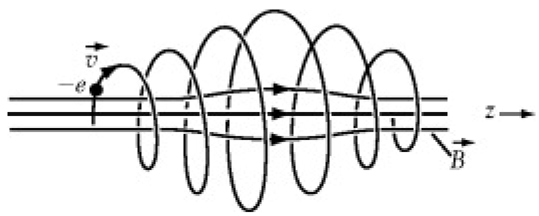

Figure 4: Electron with velocity has nonuniform magnetic field causing a spiral motion. [10]

The magnetic mirror (also magnetic bottle confinement) happens to both electrons and protons in the upper atmosphere of the earth, where they spiral back and forth from the south pole to the north and back again [10]. This means large volumes of D-T plasma are confined by magnetic fields at low amounts of atmospheric pressures and can be heated to fusion temperatures [3]. The trapping of these plasmas means the ions and electrons are in thermal equilibrium with Maxwell's distributions, energy gained or lost in collisions are returned to thermal distribution [6].

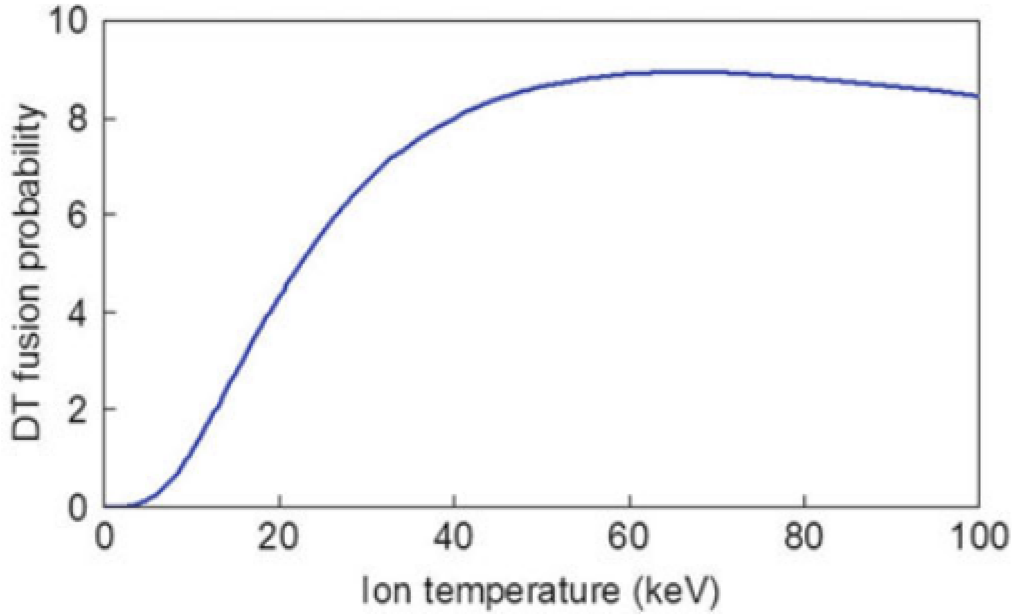

Figure 5: Reactivity of various fusion collisions [6]

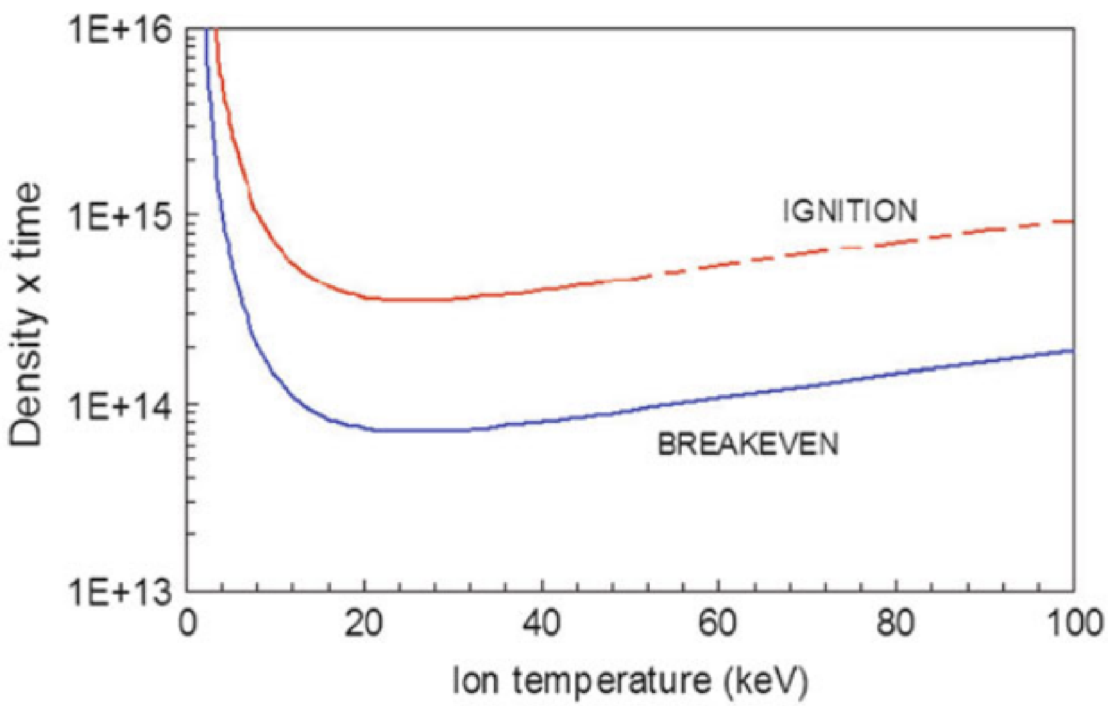

Figure 6: The fusion probability for various reactions shows us that the D-T reaction is the best [6]

Magnetic fields can be ideal for confining plasma since charges of the ions and electrons mean they follow magnetic field lines imposed. In nuclear fusion reactors, the toroidal magnetic configuration is the best as it is able to move particles away from reactor walls which would interfere with reactions and cause a loss in heat [3]. When combined with a poloidal field (perpendicular field component) magnetic field force lines will follow a spiral shape path creating helical configurations that will confine plasma [3].

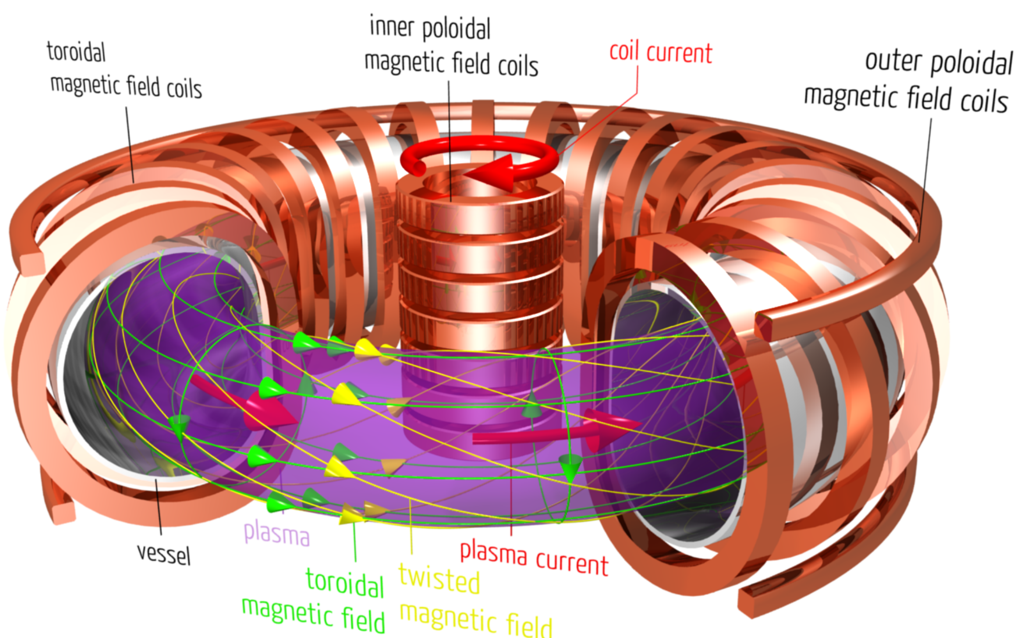

Figure 7: A stellarator with helical windings. Heating turns the gas into plasma and gets squeezed by superconducting magnets, thereby allowing fusion to occur. The most efficient shape for the magnetically confined plasma is a donut shape (toroid) with outer poloidal magnetic field coils as illustrated above. [Google Images, 2015]

The use of fusion power plants can play a major role in advancing more sustainable technologies in energy generation, especially with the world's ever-increasing demand for electricity as underdeveloped countries begin to have more access to power. Fusion power can be beneficial as they do not contribute to greenhouse gas effects directly. The heat that is released through fission is used similar to a steam engine which turns turbines to generate electricity without the byproducts; the process only generates heat. After the initial funding needed to build nuclear power plants, fusion power has the advantage of being one of the more cost-effective options when it comes to power generation. The cost will be much lower when compared to fossil fuels such as gas, coal, and oil which all have a limited supply. Fusion energy is cheaper because its operations and maintenance are usually cheaper when compared to something such as coal. Nuclear plants are 93% efficient and thus a better option for power, meaning nuclear fission has a very high energy density [12]. Lastly, fusion power is much more reliable as it does not rely on external factors such as weather. Similar renewable energy generation such as windmills and solar panels require windy and sunny days respectively.

Figure 8:Nuclear power plants with the nuclear reactor being contained inside a sphere-shaped building [Kernkraftwerk Grafenrheinfeld].

Assessing fusion power though seems like a technology that needs more development before it is ready for mass production. One of the first few reasons it is not going to be available for quite some time is because of the mass funding that is needed for such a large-scale integration. Just between the years 2002 and 2008, the estimated cost of constructing a nuclear power plant grew from 2-4 billion to nearly 9 billion dollars with these plans usually costing more than what was originally budgeted for [13]. While fusion power does not attribute to greenhouse gas emissions, there would be short to mid-term radioactive effects that could pose a problem to human health. This waste must be treated and stored until it is deemed safe for the environment. There is never a free lunch, an issue that also has to be looked at is the supply of uranium and thorium that can be used for nuclear energy as well as what else would be done if those elements are to run out [4].

While fusion power has a lot to offer once the technology is fully developed and tets, there are still many issues currently that must be addressed first before it can be implemented. The byproducts of these reactions might not affect greenhouse gasses as much, but do present a danger to human and wildlife health. Accidental events could also multiply these risks and effects in much higher magnitudes. A more sustainable future is inevitable and more must be done to speed up this process. People must learn about the pros and cons of fusion power to form their own thoughts about this technology if it is to become a widely used future energy source. Nuclear power proves to be a viable option for a cleaner method of generating electricity and a long-term strategy should be formed and pursued for a more sustainable future; for the benefit of all.

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