Fusion: Breaking it Down

By: Mia Dungan

NIF Breakthrough

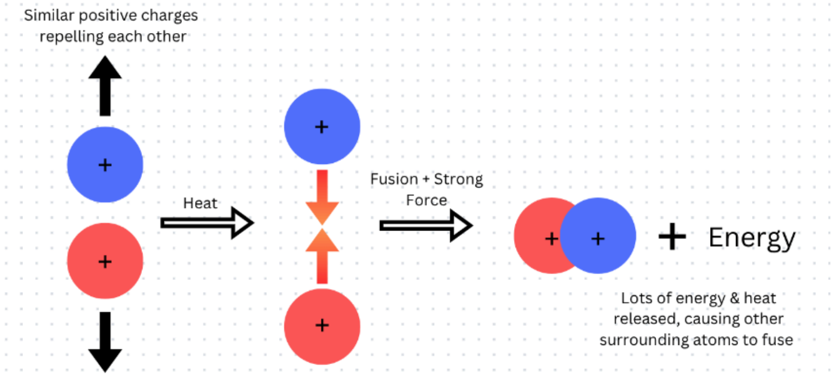
In 2022, Lawrence Livermore National Laboratory's National Ignition Facility (NIF) conducted an astonishing nuclear fusion experiment, where the potential of clean and limitless energy was truly revealed in the fusion sphere (David, 2022). NIF's major accomplishment lay in its ability to create a fusion reaction that produced more energy than initially contributed to trigger the reaction. While this breakthrough opens up gateways to revolutionary clean energy for humanity, it's primarily important to know what nuclear fusion truly is, to understand its limitless capabilities in the future.

What is Nuclear Fusion?

Nuclear fusion is an atomic reaction in which two atoms fuse together, to become a singular, dense atom. During this process, an enormous amount of energy is released from the fusion of the two atoms (DOE, n.d.). For an extreme reaction like this to occur, the atomic collision must take place in a state of gas-like matter, called a plasma, that, when energy is added, achieves extremely hot conditions. Atoms of similar charge repel each other, but the severity of the heat allows the atoms that are being forced to merge to overcome this mutual electrical repulsion. Subsequently, the strong force, which binds the components of the nuclei, overcomes the repulsion force and the atoms fuse together into one, releasing energy in the process (Webb, n.d.).

Ignition

Once the atoms have fused, the energy that is released from this reaction heats up surrounding particles, enabling a domino effect of fusion processes. This process is called ignition and is what leads to a higher energy production than initially used to heat up the particles (Tollefson, 2023).



Atomic nuclear fusion reaction diagram, representing heat and energy emission.

Fusion Potential

Scientists have been striving to achieve this exact fusion ignition for over 60 years (Greshko, 2022). An energy yield from this reaction hints at a plethora of future applications of nuclear fusion energy that may have the ability to power and enhance transportation systems like spacecraft. Not only does fusion have immense potential in transportation, but it will also be able to substantially minimize the severities of global warming. Depending on the speed of fusion technology advancements, nuclear fusion energy may be pivotal in achieving the world's 2050 net-zero carbon emissions goal.

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Fusion: Traveling on Infinite Energy

By: Mia Dungan

Traditional Spacecraft Propulsion Systems

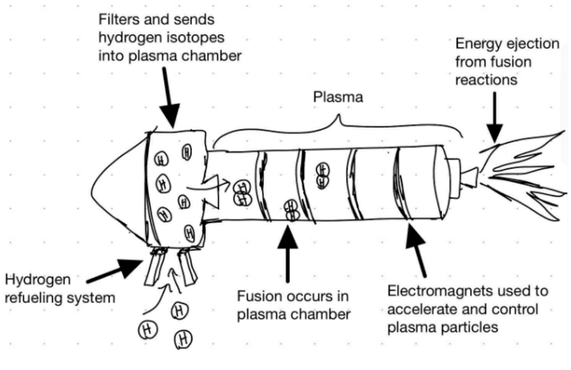
Current state-of-the-art spacecraft rely on chemical or electric propulsion. To deploy a chemical reaction strong enough to propel a rocket, a fuel source comes in contact with an oxidizer, generating an explosive combustion reaction (e.g. fire), converted to thrust out the back of the spacecraft. An example of a typical fuel-oxidizer pair is liquid hydrogen and liquid oxygen. However, some challenges to using chemical propulsion are that the fuel burns so quickly (approximately 7 minutes) that rockets must store enough fuel to propel them into space, adding immense mass that has to be accounted for during launch time and occupying a large portion of the spacecraft (NASA, n.d.). Additionally, the fuel is nonrenewable which leads engineers to add more fuel to the system than is necessary for redundancy purposes, which only serves to add more mass to the system.

Another approach is electric propulsion. There are many techniques under the umbrella of electric propulsion. One example that is widely utilized in the aerospace industry is the ion engine. The ion engine performs a reaction in a plasma where ions, which are positively charged atoms, are formed and ejected out of the spacecraft with the assistance of high-voltage electrical power (NASA, n.d.). While the electrical route is a cleaner alternative for the environment, it usually achieves lower thrust power than chemical propulsion.

Although these systems have remained sufficient over countless years, there is room to improve. This is where fusion propulsion inserts itself into the picture of revolutionizing spacecraft systems.

Nuclear Fusion Propulsion

In attempts to advance effective propulsion systems, aerospace scientists have been studying the possibilities of integrating nuclear fusion reactions into spacecraft engines. Given its complex mechanisms that must be mastered to achieve full functionality, Pulsar Fusion, a company based in England that is currently developing a nuclear fusion-based aerospace engine, predicts to test launch its first fusion rocket by 2027 (Houser, 2023). As discussed in the previous article, fusion reactions require a series of demanding conditions in order to sustain a reaction. Recall that two hydrogen atoms are



Hypothetical nuclear fusion engine component for spacecraft forced to overcome their electric repulsion with each other as they fuse and expel vast amounts of energy.

In an aerospace setting, scientists at Pulsar Fusion are trying to figure out how to control smoldering hot plasma in a confined space like a spacecraft, as well as how to sustain the fusion reaction through ignition, which involves the energy released by one fusion reaction to cascade into more reactions. Many theoretical mechanisms have been designed to accommodate this type of propulsion, such as NASA's Fusion Driven Rocket, and Pulsar Fusion's Direct Fusion Drive. Hypothetically, a nuclear fusion reactor in a spacecraft would include a chamber where plasma would be created through magnetic reconnection (David, 2022). Magnetic reconnection is the process in which magnetic field lines break and sporadically join back later, producing lots of energy and accelerating particles in a plasma, where atoms can then fuse together (David, 2022). This energy production would then be translated into thrust as the spacecraft would eject the gas/energy production from the fusion reaction. In addition, the spacecraft could contain a refueling system, allowing for fusion to be a renewable propulsion source since hydrogen is present everywhere in outer space and the spacecraft could collect fuel anywhere it traveled (Bonsor, 2023).

Fusion Propulsion Advantages

There are many advantages to adopting a fusion propulsion system. Specifically in regards to efficiency, nuclear fusion propulsion could fine-tune velocity by optimizing travel times to Mars by 50% (Bonsor, 2023). For perspective, a fusion plasma exhaust velocity could reach approximately 1000x greater than that of the Hall Effect Thruster, an electric propulsion system (David, 2022). Minimizing travel time also means healthier travel for astronauts; reducing weightlessness problems. After astronauts travel in zero-gravity conditions for long durations, coming back to Earth where gravity's force is 9.8 m/s^2 creates long recovery times for gaining their muscle and weight back. A successful evolution of nuclear fusion propulsion systems can subsequently result in far more space exploration and discovery for humans. A fusion-powered spacecraft crew could exit our solar system into interstellar space, something that has only ever been done by unmanned satellites because of time constraints.

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Fusion: Keeping it Clean

By: Mia Dungan

Why Nuclear Fusion is Environmentally Sustainable and Clean

Climate change is one of the most pressing issues of today. Nuclear fusion energy in spacecraft would work to substantially decrease the environmental effects that are often overlooked in the aerospace industry. In 2022 alone, aviation CO_2 emissions reached approximately 800 metric tons of CO_2 as global travel came back in high demand after the COVID-19 pandemic (IEA, 2023). To put this into perspective, 800 metric tons of CO_2 is equivalent to the CO_2 emissions from 896,123 pounds of coal burned (EPA, n.d.). Implementing clean fusion energy engines could provide a solution to these staggering emissions across all aviation transportation modes. Nuclear fusion engines in air (and space) travel would entail zero detrimental atmospheric emissions, meaning that fusion would not affect greenhouse gas accumulation (IAEA, 2016).

Theoretically, nuclear fusion energy would be 100 percent renewable as its primary fuel sources are hydrogen isotopes. Luckily, hydrogen is one of the most abundant elements in the universe, implying that a scarcity of the reaction's fuel would be improbable. Not only would this shift in energy sources within the aviation industry create substantial change, but there is also potential for nuclear fusion to become a part of bigger-picture energy applications and sources, like power plants.

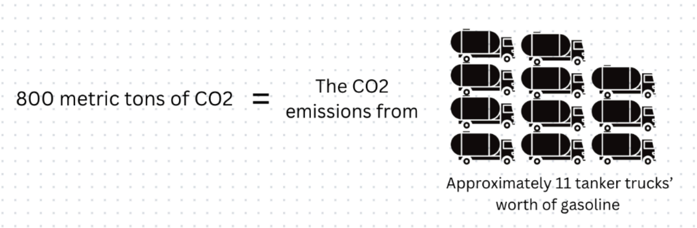
Nuclear Fusion Reactors and CO_2 Emissions

It is presumed that if large energy companies successfully transitioned to fusion energy reactors as their main-scale energy production by 2050, global warming rates would decrease exponentially. In comparison with power plants that burn fossil fuels such as coal, fusion energy serves as an advanced and clean alternative. In 2022, a staggering 15.22 billion metric tons of CO_2 was produced globally solely from coal combustion (Tiseo, 2023). If coal power plants were replaced with fusion energy reactors, 40 percent of total greenhouse gas emissions could be depleted (CSRIO, n.d.). Besides CO_2 emissions, there are other environmentally concerning factors that can be remedied through nuclear fusion power plants, such as the radiation concerns from today's fission reactors.

Radiation from Nuclear Reactors

Throughout history, there have been several horrific radiation leaks from fission power plants, which left millions of citizens in danger of fatal radioactive exposure. For instance, Japan's 2011 Fukushima Daiichi reactor meltdown accident from a tsunami caused national panic as radioactive seafood contamination surged throughout the country (World Nuclear Association, n.d.). However, with the possibility of nuclear fusion power plants, we can diminish any large radioactive threats from periodic power plant leaks. This is because fusion reactions don't produce any long-lasting, and therefore harmful, radioactive nuclear waste. As discussed in the first article, nuclear fusion can occur through the collision of hydrogen isotopes-deuterium and tritium. While tritium is known to be radioactive, its half-life is short, meaning that it does not emit radiation for long durations (around 12.5 years) (Safety Commission, 2021). Tritium is such a weak source of radiation that it is unable to penetrate the human skin. This characteristic of tritium ultimately reduces the risk found in fusion reactors if a meltdown were to ever occur, especially when compared to the abundance of radiation resulting from fission reactions.

What Nuclear Fusion Means for the Future



Comparison of 2022 CO_2 emissions from the aviation industry versus tanker truck gasoline emissions. Source: EPA.gov

Prospectively, nuclear fusion energy evidently holds the potential to transcend future transportation energy systems, such as spacecraft. This atomic reaction foreshadows a crucial step up in space exploration and discovery for humanity. If nuclear fusion power plants are successful in the near future, Earth's global warming threats will ultimately be relieved and global zero net carbon emission goals will be quickly met.

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