Nuclear Fusion and the ITER: The Solution to the Energy Crisis

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Abstract

Fossils fuels, the main producer of energy, are becoming less abundant while also destroying the environment. Further, our dependence on energy is growing as we progress into a more digitalized society. Nuclear fusion could solve our energy problem.

Nuclear fusion is a chemical reaction that produces massive amounts of energy, 4 million times more than the combustion of the same amount of coal. Nuclear fusion involves colliding two atoms, creating a singular, more massive atom. This larger atom has slightly less mass than the sum of the masses of the two smaller atoms. This discrepancy in the masses creates most of the energy, given by the famous equation $E = mc^2$. Currently, there are no fusion reactors that yield a net positive amount of energy. However, the closest reactor to coming into fruition is the International Thermonuclear Experimental Reactor, or ITER.

The ITER is an international joint research project based in Europe. Once completed, it will be the first fusion reactor to produce a net positive energy. The ITER utilizes Tokamak reactors, large chambers that produce energy through the fusion of tritium (H^3) and deuterium (H^2), which yields a more massive helium atom plus a neutron plus energy in the form of heat. The Tokamak reactors collect this energy by either slowing down the released neutrons or collecting the heat energy.

The ITER is very lucrative technology important to everyone. If nuclear fusion were to become a widespread process, it would reduce the prices for energy worldwide.

Fossil Fuels

The production of energy is crippling the environment and changing Earth's climate, which is leading to an advancement in alternative forms of renewable energy. We are reexamining the use of fossil fuels as the primary source of energy. The future abundance of fossil fuels is uncertain, and the harm of burning these substances is beginning to have an extreme impact on Earth. Oil, gas, and coal are some of the most common fossil fuels. When these substances burn, they release carbon into the air. The released carbon and oxygen in the air combine to form carbon dioxide. Carbon dioxide traps the heat in the atmosphere raising the temperature of Earth.

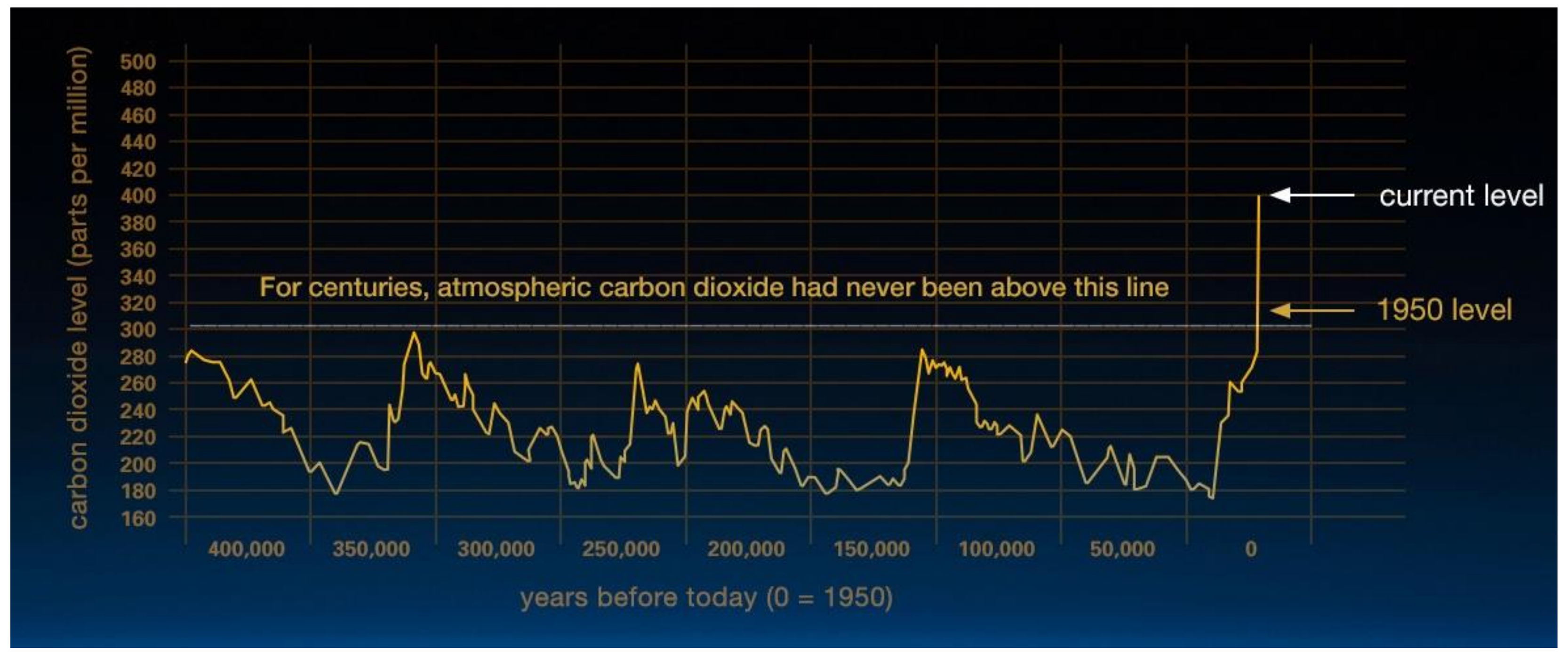
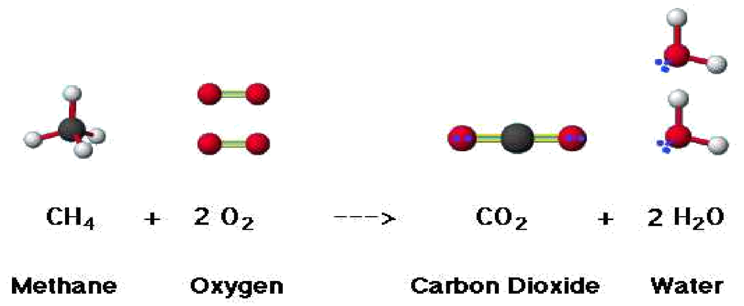


Figure 1 [3]



Combustion Reaction

Introduction of the Nuclear Reaction

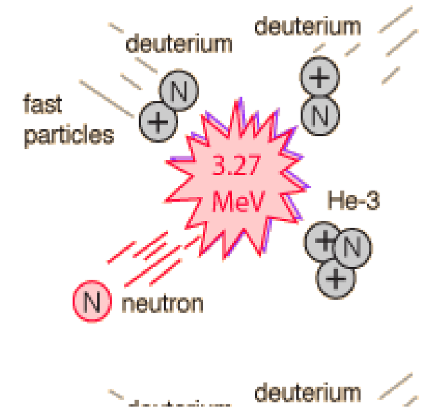
A nuclear reaction is defined as a process in which two nuclei or nuclear particles collide, producing different products than the initial particles. The interaction is so strong, the fundamental pieces of the atom change. Atoms are composed of protons and neutrons in a densely packed center called the nucleus, and a cloud of surrounding negatively charged particles called electrons. Nuclear fusion is a form of nuclear reaction in which two or more atoms collide together, forming a singular, more massive, atom. Fusion is a very scarcely seen reaction on earth due to its large activation energy, the amount of energy required to begin a reaction.

Fuel	Energy density
	($MJkg^{-1}$)
Nuclear fusion of hydrogen	300,000,000
Nuclear fission of uranium 235	77,000,000
Liquid hydrogen	143
Natural gas (compressed to 200×10^5 Pa)	54
Petrol	46
Diesel fuel	45
Aviation fuel	43
Residential heating oil	43
Vegetable oil	42
Crude oil	42
Liquified natural gas	37
Coal (anthracite)	33
Charcoal	29
Coal (bituminous)	24
Wood	6–18
Liquid hydrogen and liquid oxygen	13
Household waste	8-10
TNT	4.2

Deuterium and Tritium Reaction

The most common type of nuclear reaction is the deuterium tritium reaction. The reaction says that colliding deuterium and tritium produces helium and the addition a neutron particle. The sum of masses of products and reactants are not always equal in nuclear reactions. Nuclear reactions do not follow the law of conservation of mass. Rather, they follow a better-defined law which combines conservation of mass and conservation of energy. This new law is called the law of mass-energy. According to this law, mass and energy are convertible into each other via the equation $E = mc^2$[1], which is derived from Einstein's theory of relativity. Our previous D-T reaction does as well; the difference in masses is simply converted into energy. The statistical value of energy will amount to around 17.6 MeV for each reaction [2]. Approximately 1/5 of this energy is released in the form of heat, and the remaining 4/5 is carried as kinetic energy on the moving free neutron .

$$^2_1H + ^2_1H \rightarrow ^3_2He + ^1_0n + 3.27MeV$$



Deuterium-deuterium Fusion

Benefits

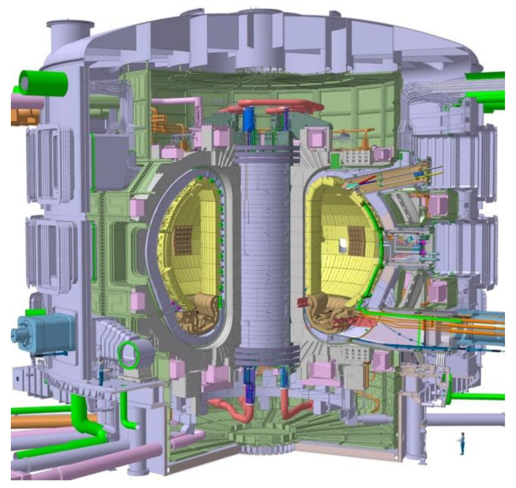
- Environmental sustainability
- Immense energy supply
- Renewable reactants
- Greater understanding of nuclear reactions
- Large possible future market

Shortcomings

- Large monetary costs for reactants and construction
- Long time investment to build

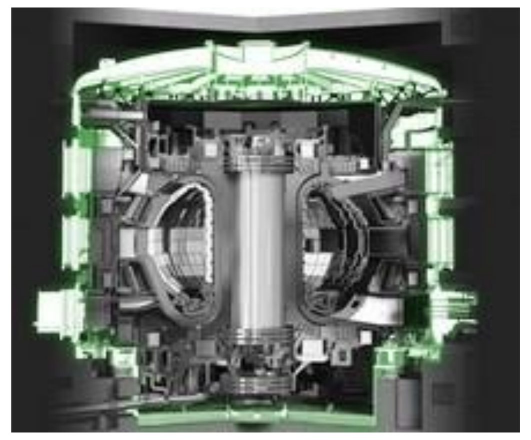
Tokamak Reactor

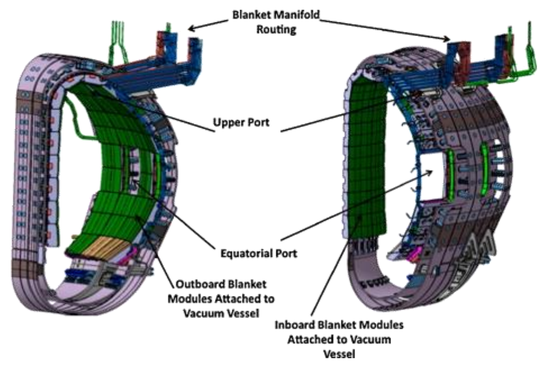
Most fusion reactors, including the ITER, employ the use of tokamaks. Tokamaks are doughnut shaped vacuum chambers that contain plasma created by the reaction. Plasmas are similar to gases but are a fourth state of matter. They have no definite volume and will expand outwards for as much space as possible. Once the plasma undergoes fusion, neutrons will be released as a product of the reaction. Neutrons have no charge, so they are not affected by a magnetic field. The neutrons will connect with the outside of the chamber, where the walls known as "blankets" slow them down and collect their thermal and kinetic energy.



Cryostat and Vacuum Chamber

The cryostat is a large ellipsoid which houses nearly all other systems of the ITER. The vacuum chamber is located within the cryostat and holds the plasma as the first line of safety containment barrier. Its torus shape allows the plasma to spiral inside without touching the walls. Its maximum volume will be 10 times that of any reactor currently in existence.





Cooling Systems

Water is delivered through pipes at 70 degrees Celsius to the outside of vacuum chamber. Through convection, the heat is transferred to the water to reach a state of equilibrium before it is discharged to a nearby river.

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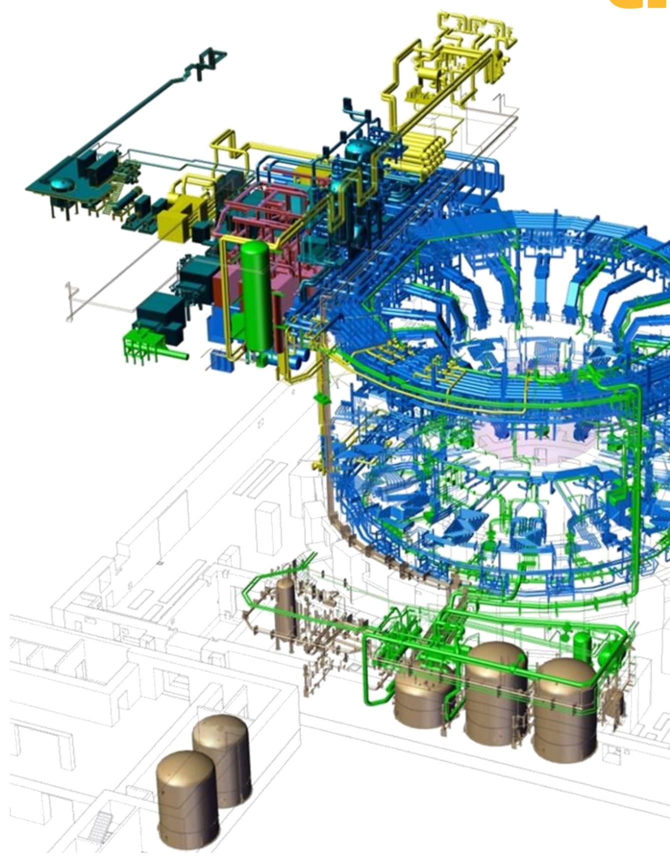
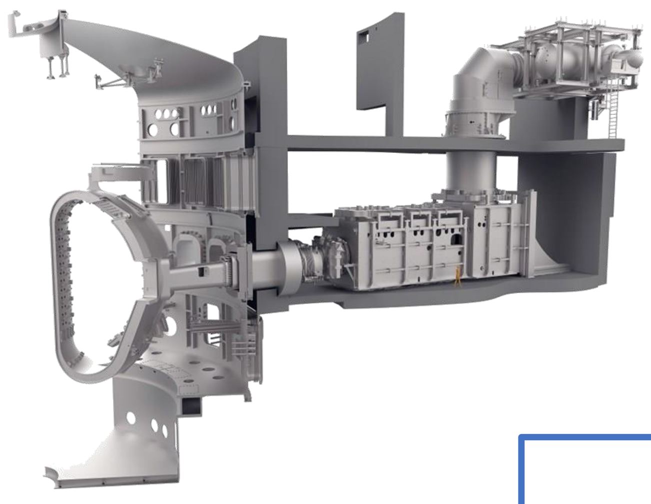
china eu india japan korea russia usa

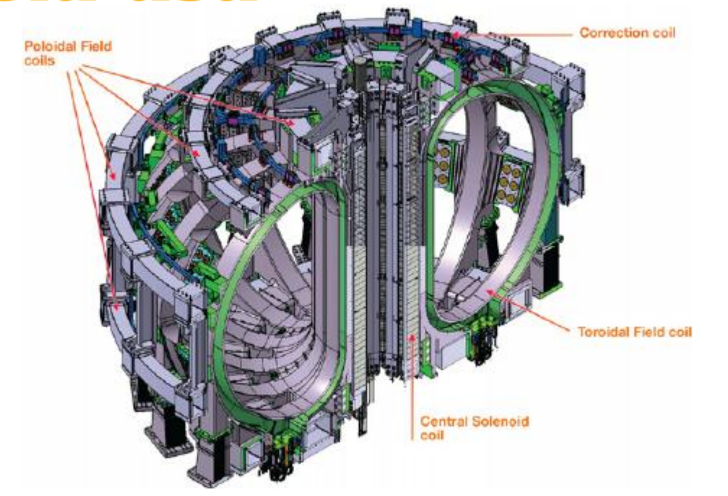
Figure 2 [4]

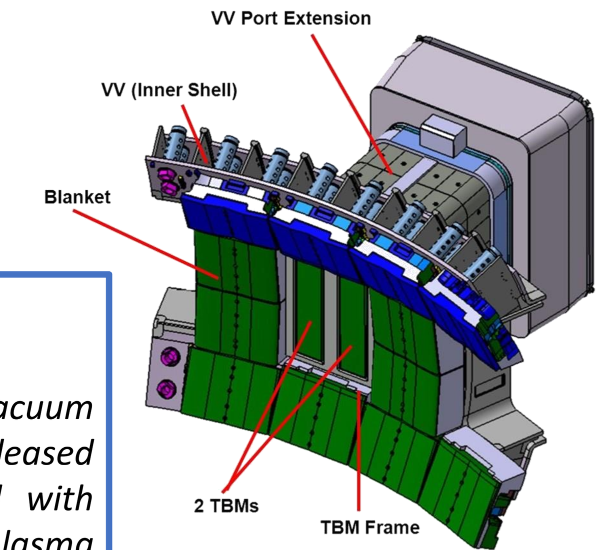
Plasma Confinement Magnets

Strong magnetic fields are the primary way to manipulate plasma, preventing structural damage from heat. Manipulation by magnets is made possible by plasma's inherent charge. Vertical (toroidal) magnets create a field circling with the reactor. A second set of magnets (poloidal) create a field looping perpendicular to the toroidal magnets. The third set of magnets (central solenoid) are stacked in the middle to allow greater precision in confinement of the plasma. The combination of all three fields confine the plasma to a desired area.









Blanket System

The blanket system is set of layers lining the vacuum chamber walls used to collect energy from neutrons released during a D-T reaction. The inner layer is constructed with beryllium, for its high heat resistance and low plasma contamination. The second lining is composes of high strength copper and stainless steel for absorption of kinetic and thermal energy.

Heating Systems

Plasmas reach a functional temperature upwards of 150 million degrees Celsius through the employment of one internal and two external heating methods. The Internal heating process is known as ohmic process. Plasma, like electricity, carries current. As magnets increase the strength of current in plasma, the power given off and in turn, the heat, also increases through Joules first law. The first external process is neutral beam injection. Neutral deuterium atoms are stripped of electrons. An external machine induces electric field which interacts with the positively charged deuterium. The process increases kinetic energy, and the high kinetic energy particles are injected into the plasma to collide in turn increasing temperature. The second external method is ion cyclotron heating. Uses radio waves at varying frequencies to heat the plasma. Plasma ions rotate around magnetic field lines and at the right frequencies resonate, causing temperature increase.

References: [1] "Conservation Laws in Nuclear Reactions." Nuclear Power. Accessed 3.1.2018. https://www.nuclear-power.net/laws-of-conservation/conservation-laws-in-nuclear-reactions/
[2] R. Nave. "Nuclear Fusion." Hyperphysics. Accessed 3.1.2018. http://hyperphysics.phy-astr.gsu.edu/hbase/NucEne/fusion.html
[3] "Graphic: The Relentless Rise of Carbon Dioxide." *NASA*, NASA, 8 Nov. 2016, climate.nasa.gov/climate_resources/24/.
[4] "The Way to New Energy." *ITER*, 4 Apr. 2018, www.iter.org/.