

The Correlation between Nuclear Fusion and climate change

Research question: To what extent is nuclear fusion the answer to the global warming and climate change

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Problems of Global Warming

Global warming and climate change are a worldwide phenomenon and probably the definitional “international issue” of our times. Scientists around the world have been noting a dramatic and exponentially increasing rise in the earth’s temperature since the 1800s as the industrial revolution has spread across the world (IPCC, 1).

The effect of this rising temperature on the climate and our ecosystem is catastrophic. Global temperatures are now far above long term mean values. Extreme weather patterns like wildfires and hurricanes as well as ice blizzards are becoming more common with each year. Polar ice caps and glaciers are melting fast and the rising sea levels and change of oceanic currents is not only driving extinction of marine species but will soon dramatically affect coastal and low-lying areas of human inhabitation (Lindsey, 1).

Low lying countries like the Maldives and Bangladesh expect to lose much of their densely populated coastlines in the next fifty years. Close to home Florida is expected to lose as much as 10% of its coastline with a 1 degree rise in temperature (Parkinson, 1). In addition to sea level rise the loss of crops and drinking water are going to cause enormous crises in heavily populated parts of Asia as the major glaciers melt. This can cause famines and water conflict between countries as they compete for scarce resources (National Geographic, 1).

Climate drivers can also trigger strong feedback loops that intensify or weaken the original forcing factors (Climate Council, 1). For example, warming from increased greenhouse gases also increases oceanic evaporation, which increases water vapor in the atmosphere and intensifies the warming from greenhouse gases. Similarly, loss of ice caps leads to less reflective energy and more sunlight being absorbed by the arctic continent driving temperatures further upward and

melting the poles faster. These feedback loops can cause runaway heating if they are not mitigated early.

The United Nations and the world leaders have taken serious note of this issue. Several climate conferences have been held and nations have committed to aggressively tackling these issues by reducing their contribution to global warming. The latest of these agreements are the Kyoto Climate Accord and the Paris agreement which commits to reduce global warming to 1.5c over the next 25 years ending with net zero emissions by 2100 (Maizland, 1). The effort to contain and cap temperature rise is driven by the net zero initiative.

Yet with all the attention it is still extremely difficult to achieve these goals and the fate of the world hangs on this outcome. Will our future generations live in a lush blue planet that is teeming with life or in a volatile world that is mostly desert as rainfall drops, with hurricanes and flooded coastlines destroying the ecosystem for humans and other species?

Causes of Global warming

In this section of the paper, I will study the underlying causes of global warming from a scientific perspective and relate it to the underlying energy use changes thus driving to possible solutions. Understanding the contribution from the various factors is a critical first step before someone can explore solution approaches and analyze their relative efficacy. If the warming is driven by several factors (like fossil fuels, deforestation, livestock rise) then understanding the impact of each factor is crucial to developing a multi-pronged approach to tackle warming. Each potential technology within those approaches can then be compared to others for effect and cost. This will allow for a systematically analyzed solutions and set the context for emerging or novel approaches like nuclear fusion to cover the gaps.

Many studies show that the rise in earth's temperature in modern times is highly correlated to the amount of greenhouse gases (especially CO₂) which in turn is highly proportional to energy the population consumes. The Global Temperature and Carbon Dioxide graph shows that since the advent of the industrial revolution in the 1800s there has been a continuous and clear rise in temperatures and rise of CO₂. Most of this is directly attributable to the use of wood, charcoal, coal burning which has been used in ever increasing quantities to fuel industry, homes, and transport. It began with coal powered steam engines and has since been added to by other fuels such as petroleum for automobiles and airplanes, and coal and gas powerplants that produce the electricity for our factories, offices, and home. In addition to fuel there are other secondary effects such as massive construction, deforestation, and huge amounts of livestock. Deforestation has removed trees which are extremely important in removing carbon dioxide from the air and livestock raised for food produce methane and other biogasses that can drive the greenhouse effect. However, energy production dominates at nearly 75% of the total emission (Global Warming, 1).

Thus, human population growth, increasing energy, and food demands are the major drivers of global warming and will need to be addressed to return the earth to temperature balance. It is important here to note that it is not the total energy that is the culprit but the pollutants and by-product gases (like Carbon dioxide) that are the issue. Hence a move towards cleaner fuels presents an attractive sustainable option to continue growth while minimizing the climate impact.

Immediate Approach: Cap and Reduce Energy Consumption

One of the most immediate ways that scientists suggest helping arrest global warming is by energy conservation. Energy conservation is the practice of reducing energy consumption to help the environment. It allows for scientists to halt the warming and have figure out more long-term solutions for global warming. This has led to many regulations and improvements like energy certified appliances, billions of old lightbulbs being converted to LEDs and even the arrival of electric cars that replace gasoline based pollution. These are a welcome direction, and the effects of these changes are already visible in our day-to-day life and are a key component of the clean environment strategy. However, several challenges remain from allowing this to succeed alone. One core challenge is population rise.

The Human population has risen from 1 billion in the 1880s to 7.7 billion by today (Roser, 1). By 2050 earth's population is expected to plateau near 9.7 billion people (United Nations, 1), this means there will be almost a 25% increase in energy demand from the population alone. Also, second lifestyles around the world are improving which means longer lifespans, greater demand for automobiles, electricity and appliances and energy. Green Tech Media estimated that if half the developing world reaches the standards enjoyed by the advanced nations today then the energy demand will grow by 124% in the coming century by 2100 (Deign, 1). This is being driven by large countries like India and China where massive populations are demanding more energy and the greatest increase in oil, coal and fuel is anticipated.

It is impossible to halt the developing nations and ask them not to industrialize or offer equal lifestyles to their populations while the west enjoys the same benefits. So new technologies and massive amounts of financial aid to move development to those more expensive emerging

technologies will be required. Here too we see that economical and clean energy source holds the key. This leads us to our second approach.

Long term Approach 2: invest in alternative energy choices

It has been established so far that global warming is directly correlated to human energy consumption and that fossil fuels specifically are the biggest contributors to pollutants and greenhouse gases like CO₂. It has also established that while some reduction in consumption can slow the rise of temperature, the increasing population and needs for energy as countries develop will continue to drive warming well into the next century. As a result of this the primary approach for reducing warming long term needs to be a decisive move away from fossil fuels and towards clean fuels that can support development while eliminating the pollutants that drive warming. Around the world scientists and engineers are working on these new renewable and clean energy sources like solar, wind energy, hydroelectric and nuclear. To evaluate our need for fusion there first needs to be an overview of these alternative energy sources to understand their effect and how far they can contribute to reducing global warming.

Solar power energy is when technologies are created to convert sunlight into energy. The technologies used are either photovoltaic panels or mirrors that can concentrate solar radiation. (Solar Energy Technologies Office). The photoelectric effect was created by Edmond Becquerel in 1839 and the first solar conversion panel was created in 1844 by Charles Fritts (True South Solar, 1). Today, worldwide, solar panels are a big business and are growing fast. Solar power produces completely clean energy by transforming sunlight into electricity directly. In Sunny or equatorial climates, energy by the sun on the surface of the earth is $1.74 * 10^{17}$ watts (Fleming, 1) and is expected that by 2100 solar energy will constitute of 50% of the worldwide energy

demand (Poon, 1). Solar power however also faces many challenges. Since the sun only shines half of the day at best in warm climate areas and significantly less in areas further from the equator, this uneven production of energy is poorly matched with demand. This will then create a necessity for huge investments in battery or storage technology which drives up costs, complexity, and pollution due to the toxic materials used in batteries.

Hydroelectric power is a type of renewable electrical energy that is produced by moving water (OpenEi, 1). Hydroelectric power can be created using dams, watermills, etc. Dams are used to hold back massive quantities of water that flows through rivers. This means that the dams potential energy due to gravity can be used to turn turbines which then generate electric energy. Hydroelectric dams use natural and mostly renewable energy and can produce very large amounts of energy to cities. However, like solar energy, hydroelectric energy has many challenges. For example, dams occupy massive amounts of space submerging hundreds of square kilometers of fragile mountains or river land. Also, dams can burst with floods or earthquakes and can become hazardous to cities and towns nearby. Dams are also extremely expensive, slow to build, and can take decades before energy can even be harnessed by them. Ultimately, they are also finite as there are only so many rivers and water bodies that can have dams created on them. Thus, dams and hydroelectric power represents a useful but limited option for creating energy.

Another solution is trying to use cleaner fuels to help the climate. Countries have started to move from coal, the cheapest, to natural gases that are abundant and less polluting. The volume of natural gas in the world today is rising but is also non-renewable and finite. A similar effort is to make biological fuels like alcohol that can be added to petroleum to reduce the amount of gasoline consumed. Electric cars, however, offer a safer and cleaner alternative to

biofuels if a clean source of electricity can be developed. Thus, this solution only offers short term reductions while the search for helping climate change continues.

Finally, nuclear fission is a type of energy that is being used in the world today. Nuclear energy is the final frontier in the quest of generating massive amounts of energy. Radioactivity was discovered in 1896 by Henri Becquerel (APS News, 1). After physicists started studying atoms it soon showed that heavy atoms breaking apart (fission) or light atoms combining (fusion) both could release huge amounts of energy. During World War two, the quest for nuclear explosives led to important breakthroughs in understanding how to split heavy atoms like uranium or plutonium that produce tremendous bursts of energy. Engineers developed technologies to control the speed of fission and soon commercial power reactors were created in order to produce steady fission at low levels generating massive amounts of heat that is used to boil water into steam and generate electricity. Nuclear power produces no greenhouse gases and can provide large volume of power however there have been many challenges found here too.

While the cost of setting up nuclear power is large it is less than hydroelectricity. However, the by products are radioactive and toxic to all life for thousands of years. Also, if the nuclear plant has any malfunction the fission can grow uncontrollably thus leading to massive explosions. Disasters at Chernobyl Russia and the Fukushima Daiichi nuclear disaster in Japan showed the huge dangers that nuclear fission power presents to humans. Lastly nuclear technology is not freely shared by countries nor are the heavy atoms like uranium or plutonium easy to procure as they are very rare in nature and mined only in a few countries.

Given the danger and complex technology challenges of nuclear fission it has been falling worldwide even though from a global warming perspective it is very effective counter.

Long term Approach: Nuclear fusion the infinite clean renewable energy

Soon after mastering fission (breaking apart of heavy atoms) scientists were also able to use the heat of nuclear fission to induce fusion i.e., combining light hydrogen atoms to join into heavier helium atoms under temperatures of millions of centigrade. This was achieved in 1952 when the first nuclear fusion bomb, the project called ivy mike, was exploded by using the heat from a fission bomb to set off secondary fusion in Deuterium (heavy Hydrogen) which turned into Helium (Atomic Archive, 13). These explosions were the largest amounts of energy ever generated by humans. This combination of atoms into heavier elements produces energy like what the stars including our Sun are creating every second. These stars are fantastic natural examples of boundless amounts of clean energy being generated for hundreds of millions of years by simple hydrogen atoms undergoing fusion. Our universe is full of fusion energy.

Not only does fusion produce enormous amounts of energy from abundant simple atoms like hydrogen but it also has the beauty of not requiring or producing hazardous radioactive products that are toxic or have any chance of runaway explosions. In fact, the problem of fusion is opposite - it is extremely difficult to start fusion and very easy to stop it. Stars use gravitational pressures millions of times that of earth and temperatures in hundreds of millions of degrees to start fusion. These conditions are very hard to mimic on earth (Lancot, 1). This in-fact this is the heart of the problem in realizing the huge promise of fusion.

While it has proven very difficult in practice for the last 30 years, it is expected that international teams of scientists and engineers will produce commercial clean fusion energy by 2050 thus making it the long-term solution to our sustainable energy needs, while other approaches keep the warming minimal in the interim (Chandler, 1).

Challenges of nuclear fusion:

Super heating matters up to tens of millions of degrees while containing it under pressure is easy inside stars - but very hard to do on earth. Such enormous heat and pressure require fantastic amounts of initial energy to start and the materials to hold the burning matter (plasma) itself would normally collapse under these situations.

In addition to the technical challenges this process of superheating and magnetic containment itself consumes a great deal of energy initially and the resulting fusion must be kept going for some time sustainably to extract more energy than was put in. This means energy output from the reaction must be greater than the input energy (factor $Q > 1$) for fusion to be successful as a commercial source of energy.

Fusion Reactor Design

The basic design to achieve a sustained nuclear fusion safely is a tokamak reactor. TOKAMAK is a short form for the Russian acronym toroidal chamber with magnetic coils and was invented by the soviet physicists Sakharov, tamm and lavrentiev in the late 1960s. (ITER, 1).

Magnetic Containment

In a tokamak a ring of extremely strong electromagnetic coils applies a great magnetic field compressing plasma gas inside the reactor and heating it electrically till it is super-heated to millions of celsius and starts to fuse. The magnetic field also holds the plasma in place by squeezing it so that it does not touch any other materials. The heat from the plasma in the reactor

tank is transferred by radiation out to a liquid like water in a tank which boils into steam thus driving a turbine that generates electricity.

ITER Prototype

The largest reactor of this type is the International Thermonuclear Experimental reactor being constructed in France that is funded by seven countries. It is a 10 year and 20-billion-dollar project that is expected to operate from 2025-30 by giving us the first working nuclear fusion power plant (ITER, 1).

It is planned to use 300 Megawatts of total power and send in about 50 Megawatt to heat the hydrogen plasma, developing 500 megawatts of output power for a Q (factor of energy production) of 10 times the input energy (New Energy Times, 1). These superconducting magnets require very complex technology and sustaining the fusion for a long time is a very hard problem that scientists are working on.

Once ITER is successful scientists expect to rapidly commercialize the technology with early commercial fusion reactors entering service by 2040-45 and rising to produce 10% - 25% of the world's electric load by 2070 and replacing fission by 2100 (ITER, 1).

2021 Technology Breakthroughs

Before I finally evaluate the contribution and impact of this most likely path for fusion technology on global warming, I also need to consider some exciting news that has just broken in 2021 that may dramatically accelerate the arrival of fusion.

Scientists at the National Ignition Facility have just announced having made major breakthroughs in achieving fusion using other forms of heating than tokamaks, such as very high-power lasers that are far more promising. Some of these may be able to deliver energy quickly within a few years and with far simpler designs requiring none of the complex magnetic and heating elements of a TOKAMAK (STARR, 1). In addition, MIT has just announced a new type of superconducting magnet that can be used to make magnets much stronger at small sizes. This leads to reactors less than room size which is about 40 times smaller than ITER and can be built at very low cost (Chandler, 1).

TOKAMAK Alternative - Inertial containment

In 2021 a major advance was made by the NIFT (source) that used 192 extremely high-powered lasers to blast small pellets of matter held in a special shape called hohlraum. The lasers generate X-rays in the target atoms that superheat and compress it simultaneously. The experiment successfully created 1.3 megajoules of energy exceeding the amount of energy input to the lasers (Kirmayer, 1).

This approach is very promising as it is faster, simpler and produces fusion with far less complexity than superheated magnetic containment. This also represents a dramatic improvement of the Q factor up to 75% which bests the world record so far of 25% i.e. sending only a quarter of the input energy as available output power. Fusion is thus on the cusp of realization a decade early.

Fusion Impact on energy and Global Warming

Given the observations about the state of the climate warming and our energy production alternatives we can now evaluate how likely is fusion to help avert this crisis. Fusion is likely to generate 4 trillion kilowatt hours by 2100 (Energy Strategy Reviews, 27). In 2020 the total electricity generation by all of the United States is also about 4 trillion kilowatt hours which creates 1.55 billion Tons of emissions per year (EIA, 1). China is the largest user of coal which is more polluting and would create 10.2 billion tons for the same amount of energy produced (Steinwehr, 1).

Projecting from this energy share it is easy to see that even if fusion achieves only a conservative 15% share of worldwide energy by 2100 it will still be a massive contributor to global warming reduction. Earth's temperature is expected to rise by 2 degrees Celsius for 270 Giga tons of Carbon Emission. Assuming a linear growth of fusion from 2050 to 2100 over the course of 50 years it will save us 1 billion tons of emissions each year on average. This in turn roughly implies a reduction of 50 gigatons or nearly a quarter of the emissions savings budgeted by the Climate accords to keep earth under 2 C rise. Fusion is thus essential to hit the net zero targets.

However given the delay and risk in the introduction of fusion to the mid-century it is also imperative that we invest in both reduction of coal and fossil fuels right now by replacing them with solar or wind and also increase our investment in research to expedite the arrival of clean sustainable energy.

Nuclear fusion: the road ahead

In summary, after the analysis of fusion so far it shows that fusion presents one of the best roads ahead for humanity to produce nearly infinite amounts of energy for development the same way that stars burn bright in space. It is a clean, inexhaustible source that promises to be very cheap and safe once the technologies are perfected later this century. Thus, it represents an excellent long-term option for the sustainable energy demands that will be needed to power the lives of billions of humans in the developing world without any impact to our ecosystem. Finally, fusion offers a promise to change the world in a deeply equitable way, where all countries will have access to energy as Hydrogen is abundant instead of fighting wars over scarce resources like oil and gas or coal mines or dams on rivers.

However, major technological challenges remain even though fusion experiments in labs and the stars above show the absolute validity of the underlying physical laws. Many companies and governments are racing to build alternative solutions and by 2050 scientists expect that nuclear fusion will become a significant and perhaps dominant player in the energy space as society run out of coal and fuel and switch to these alternatives around the world.

It is imperative that society reduces its carbon footprint immediately to avoid the rise in temperature that will take place in the next three decades if society will continue to rely on fossil fuels. To get to the world of limitless clean energy by fusion society first needs to have a bridge plan with alternative and renewable energy sources like solar or wind that can bring down the fossil fuel emissions and buy humanity the time needed to migrate to Fusion power by 2100.

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