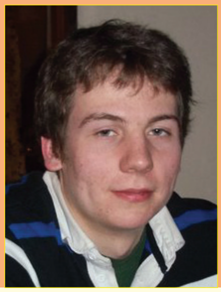
Can nuclear power save the climate?



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The Problem

During the 20th century, the average global temperature rose by 0.74°C (±0.18), and it is predicted to rise by a further 1.1°C (with some estimates predicting as much as 6.4°C) during the 21st century [Figure 1].[1]

Considering the incredibly delicate nature of the conditions required for life, especially the complex organisms and varied ecosystems existing on Earth, even slight temperature changes by a single degree can lead to dire consequences for many species. It is therefore of the utmost importance to discover why the Earth is warming up and whether anything can be done about it.

Why is it Happening?

It is known that greenhouse gases cause the heating of the Earth's atmosphere (ironically needed for organisms to survive) by trapping infrared radiation reflected by the Earth (originally from the Sun), and one of the main greenhouse gases is carbon dioxide, which makes up somewhere between 9 and 26% of the greenhouse gases.[2] The total carbon dioxide emissions in 2006 were 28,431,741 thousand metric tonnes,[3] and in an assessment report, the Intergovernmental Panel on Climate Change (IPCC) has announced that most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.[4] About three-quarters (90% in the USA) of the increase in CO_2 from human activity over the past 20 years has been caused by the burning of fossil fuels.[5]

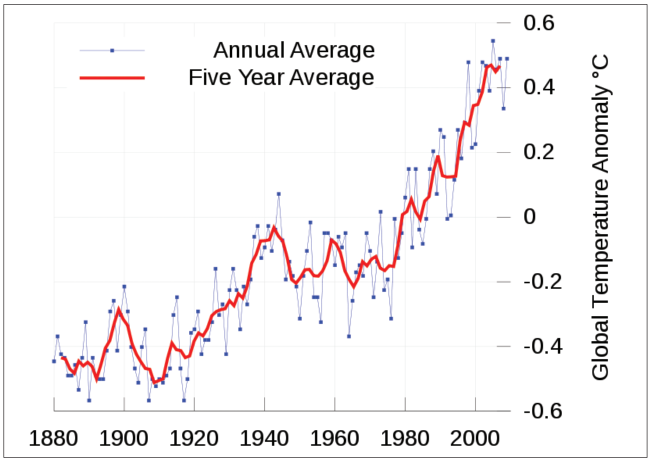

Figure 1: A graph showing how global temperatures changed in the 20th century (from http://en.wikipedia.org/wiki/File:Instrumental_Temperature_Record_(NASA).svg)

The Problem with Fossil Fuels

The world relies on the burning of fossil fuels for 80–90% of its energy consumption [474 EJ (x10^{18} J) in 2008].[6] This energy consumption is likely to increase in the immediate future as more countries "develop". In India, a developing country, the energy use per person is about 0.7 kW, whereas in the USA, a developed country, the energy use per person is about 11.4 kW,[6] which is over 16 times as much. Although fossil fuels are an effective way of producing energy, they are finite as they form over millions of years. The remaining energy reserves of fossil fuels and amount of time that they are likely to last is shown in Table 1.

Therefore, the main way that humans currently tap energy reserves (by burning fossil fuels) is not only contributing to climate change by releasing vast

Table 1: Fossil fuel energy reserves

Fuel	Energy reserves [ZJ ($\times 10^{21}$ J)]	Time that this resource is likely to last (years)
Coal	290.0	417
Oil	18.4	167
Gas	15.7	43

amounts of greenhouse gases, but will also run out in the near future. Because of this, it is extremely important to come up with an alternative and effective way of producing energy. The release of greenhouse gases from the combustion of fossil fuels is not the only cause of climate change, but it is a major one and is likely to increase rapidly in the future. Furthermore, the Earth has been shown to be able to "heal" itself, if damaging changes happen to it. For example, the ozone layer is now reforming back to its original size, having been broken down by various human chemicals such as CFCs, which are now strictly controlled. Theories like the "Gaia Hypothesis" help to explain this ability of the Earth as a whole to deal with changes up to a point. If the release of fossil fuels into the atmosphere is stopped very soon, before the damage becomes irreversible, then it would appear likely that the Earth will be able to recover from the damage that has been caused. Therefore, the main concern for the human race is surely to discover an alternative way of producing energy, not only to deal with the massive and increasing energy demand, but also to prevent the need to burn fossil fuels, which are causing climate change and will run out in the near future.

Alternative Sources of Energy

Apart from fossil fuels, there are many other energy reserves, most of which are sustainable. However, considering that the combustion of fossil fuels makes up such a large percentage of total energy production, the alternative forms of energy used at the moment are clearly not as effective as burning fossil fuels, so will not be able to easily replace them in producing energy for humans. For example, one of the largest renewable energy sources is hydropower, which produces only around 2% of the world's total energy requirements.[6] The building of large hydroelectric power stations and dams has many drawbacks: it is expensive, they can only be built in certain places, and there are many environmental issues associated with them, such as flooding (not always accidental) which can destroy ecosystems and even force tens of thousands of people to move. Other renewable resources have similar problems with expense and specific requirements for their situation, and also have the problem of producing energy unreliably: for example, wind turbines only rotate if there is enough wind from the right direction, and if there is too much wind, they must be stopped as it is too dangerous to allow them to run. Therefore, the most sustainable and reliable source of energy that is known of at the present is nuclear power.

Nuclear power

There are two ways of sourcing usable energy using nuclear power: nuclear fusion and nuclear fission.

Nuclear fission

Nuclear fission is already widely used in nuclear power stations, currently generating around 6% of all the world's energy needs.[7] This works by harnessing the energy released when a large unstable isotope of a particular radioactive element (such as uranium-235 or plutonium-239) is split apart by a slow-moving neutron into two smaller elements and three more slow moving neutrons (thus starting a chain reaction). However, nuclear fission has a few drawbacks. It produces a large amount of harmful radioactive waste, around 3 m^3 annually from a large nuclear reactor. By 2007, the USA had amassed over 50,000 metric tons of radioactive waste.[7] This waste is dangerously radioactive: it must be stored in safe conditions for as much as 10,000 years to prevent harm to the general public by radiation. Furthermore, the main fissile fuel for nuclear reactors is uranium, which is a finite resource. The known reserves are thought to last for about a century, but uranium deposits are spread quite thinly, which can make economic mining difficult. So, although nuclear fission does not produce greenhouse gases, which cause climate change, it produces hazardous nuclear waste which is difficult to deal with, uranium is a finite resource, and there are serious concerns about whether nuclear fusion has the capacity to replace fossil fuels as the primary method of generating energy for humans. Therefore, nuclear fusion is the only known effective potential substitute for fossil fuels that will not cause climate change [Figure 2].

Nuclear fusion

Nuclear fusion is the process which powers the stars. It is therefore a very potent source of energy, and if tapped properly could produce vast amounts of energy quickly, effectively and relatively safely. It relies on the idea that the fusing (joining together) of two nuclei of an element lighter than iron into a single heavier element releases energy. However, at long distances, the two nuclei repel each other as there are strong repulsive electrostatic forces between the positively charged protons of the two nuclei. The nuclei must be brought closer together to allow the nuclear force (which is stronger at shorter distances) to overcome the electrostatic force, and allow the nuclei to fuse. Therefore, the two nuclei need to have energy themselves in order to get close enough to fuse. This energy can be provided through accelerating the nuclei at high speeds toward one another. This is called beam–beam fusion when both nuclei are accelerating and beam–target fusion when one nucleus is accelerated toward another. The energy can also be provided by heating them to a high temperature (thermonuclear fusion). When the nuclei are heated to a very high temperature, they enter the plasma state.

There are three main types of fusion: D–D (where two deuterium nuclei, an isotope of hydrogen with two neutrons instead of one, fuse), D–T (where a deuterium nucleus and a tritium nucleus, another isotope of hydrogen with three neutrons, fuse) and D–He_3 (where deuterium fuses with an isotope of helium with only three neutrons). Nearly all the reactants of these fusions are isotopes of hydrogen [Figure 3]. This is because hydrogen is the element with the lowest atomic number, so has the fewest number of protons (only one) and results in a weak electrostatic force that needs to be overcome for fusion to occur. Figure 4 shows how the speed of these three reactions depends upon the temperature that the reactants are heated to (in thermonuclear fusion).

Figure 4 shows that the optimum temperature needed for the D–T reaction (the fastest of all three) is around 10 billion Kelvin [or 100 keV (kilo electron volts, a unit of energy] – a huge amount of energy. Therefore, attempts are being made to discover other ways of reaching the required temperature without merely heating. One example is a "tokamak", a machine which uses a toroidal (the shape created when a circle is rotated around a fixed point, i.e. roughly the shape of a ring donut) magnetic field to confine super heated plasma necessary for a state of stable equilibrium, needed for controlled thermonuclear fusion power.

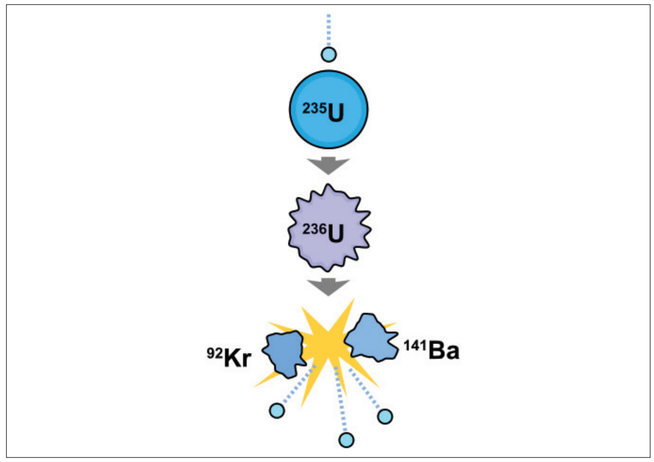

Figure 2: A diagram showing an example of nuclear fission (from http://en.wikipedia.org/wiki/File:Nuclear_fission.svg)

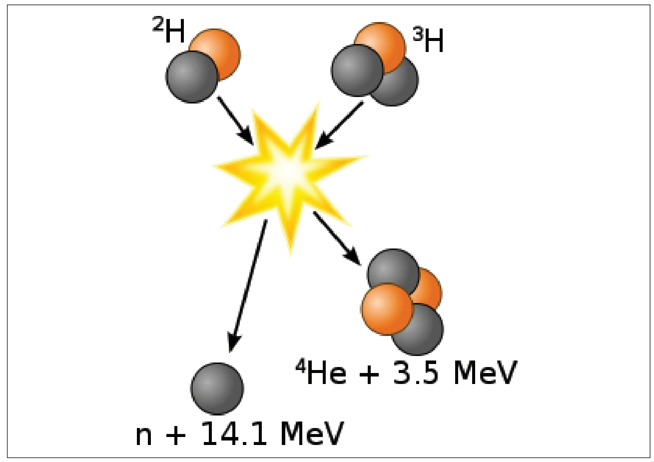

Figure 3: A diagram showing an example of nuclear fusion (from http://en.wikipedia.org/wiki/File:Deuterium-tritium_fusion.svg)

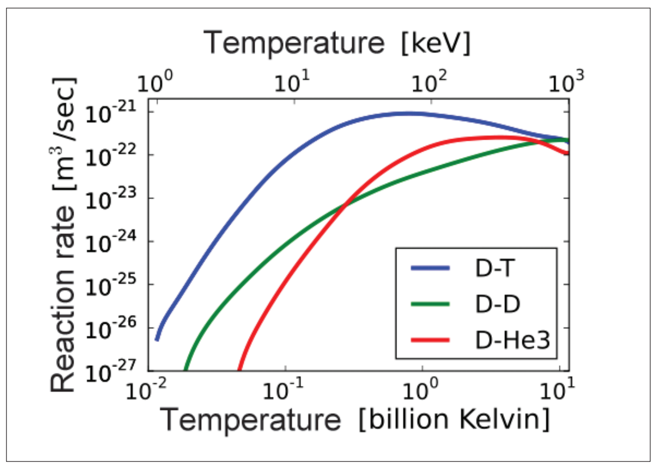

Figure 4: Fusion reaction rates (from http://en.wikipedia.org/wiki/File:Fusion_rxnrate.svg)

Application of nuclear fusion

Unfortunately, nuclear fusion has yet to be developed far enough to be used effectively in civilian power stations. However, it has been utilized by the military in the form of a "hydrogen bomb", first tested in 1952. The first fission–fusion–fission based nuclear weapons (where a fission reaction causes the main fusion reaction which then causes a final fission reaction) released around 500 times more energy than the first pure fission weapons. This shows that nuclear fusion has the potential to produce much more energy than nuclear fission. Although advances in the field of nuclear fusion have been slow over the last 50 years, the first nuclear fusion power station is estimated to be built by 2018.

The advantages of nuclear fusion

There is an abundant supply of all the resources needed for the various types of nuclear fusion. Deuterium can be easily extracted from ordinary water (the surface waters of the Earth contain more than 10 million million tons of deuterium).[8] Tritium can be extracted from lithium (which can be taken from sea waters, with enough reserves to last for 60 million years).[9] Secondly, there is much less of a chance of devastating nuclear accidents occurring, as there are only small amounts of deuterium and tritium in the fusion reaction zone. If any malfunction occurred, then the plasma within the containment vessel would merely hit the walls and cool. Thirdly, as there is no burning of any substance, no harmful gases are released which could accumulate in the atmosphere and cause climate change. Lastly, there are no highly radioactive products produced, which must be awkwardly stored, as there are from nuclear fission reactions.

Conclusion

Therefore, as climate change is mostly being caused by the proliferation of greenhouse gases in the atmosphere, these greenhouse gases (most importantly, carbon dioxide) must not be produced in the large quantities that they are today. The burning of fossil fuels to produce energy must be stopped, and another energy source be used to replace it. This will stop any further damage to the Earth through climate change, allowing it time to "recover". From the available data, it would appear that nuclear fusion is the way forward. Although it has still not been effectively implicated as a viable energy resource, this is likely to happen during the next 10 years. Nuclear fusion has clear advantages over other energy resources and has the potential to produce an enormous amount of energy. All life on Earth gets its energy from the Sun, and the Sun produces its energy through nuclear fusion. We should too.

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About the Author

Christopher Loyn is in the Upper 6th at The King's School Canterbury. He is studying Chemistry, Biology, Physics and English Literature, and has aspirations to read Medicine at University. His main hobby is music: he plays trombone and cello, and sings tenor in various choirs.