Sprachenpreis 2008

Green Solutions for the 21st Century – Sustainable Development

Nuclear Fusion – A Future Energy Source?

Patric Sherif
Medieninformatik Master
S748648
Patric.sherif@gmail.com
01634211050

24.09.2008

CONTENTS

INTRODUCTION

As we now approach the end of the first decade of this new Century, the terms *Global Warming* and *Energy Crisis* become more present in the news than ever before, transforming into subjects of public discussion.

The effects of humanity's reckless use of Earth's natural Resources - to ensure an ever-growing standard of living in the industrial countries - are now evident in the already changing climate[1], as well as in the greater occurrence of natural disasters all over the world[2].

This has now led to the realization, both in the public perception and after the UN's Global Warming Report[3] also on a governmental level that action has to be taken to reduce the output of Greenhouse Gases[4]. In the course of the last century, the industrial countries have blown incredible amounts of those gases into the atmosphere. Even if those countries' output may be declining and will decline further in the future, it will remain on a very high level. Additionally, developing countries are still increasing their output of greenhouse gases, due to the lack of affordable alternative methods of large-scale energy production, to push the development of their industries.

Another danger is the world's extreme reliance on oil as an energy source. Oil production has been ever increasing since its discovery and is estimated by some to reach its peak in as soon as some 5 years from today[5]. This would mean a constant decline in production afterwards, while the demand for oil will still be growing. The same is true for coal; although the coal reserves may be greater by comparison, its extraction and use as an energy source severely damage the environment[6], making it a less than attractive alternative to oil.

While it seems unlikely that complete substitutes for the use of fossil fuels will be found soon - especially in the case of oil which is the main resource for virtually all means of transportation worldwide - it seems now both possible and necessary to

[1] (UN News Centre)
[2] (BBC NEWS)
[3] (Intergovernmental Panel on Climate Change)
[4] (Energy Information Administration)
[5] (EurActiv Network), (ASPO International | The Association for the Study of Peak Oil and Gas)
[6] (National Parks Conservation Association), (The Union of Concerned Scientists)

find alternative *greener*, renewable energy sources. Possible candidates are solar energy, wind energy[7] and energy from nuclear fission the latter, however, bringing about its own problems of safety and the production of long-lasting radioactive waste[8].

Another very promising candidate is closely related to nuclear fission, while technically being the complete opposite: nuclear fusion. This new technology has been in development since the 1950's and its feasibility as a future energy source shall be the topic of the following report.

OF ATOMS AND NUCLEI

Now, what exactly are *nuclear fission*[9] and *nuclear fusion*[10]?

A *nucleus* (Latin: core) is the core of an atom. Atoms were long believed to be the smallest elements which matter could be split up to. An atom itself however, consists of multiple parts: the positively charged core, the *nucleus*, which makes up most of its mass, and one or more orbiting, negative particles: the *electrons*. The nucleus contains *protons*, which are positive and *neutrons*, which are neutral. Both of these particles are called *nucleons*[10].

The number of neutrons and protons in their nucleus and the number of electrons orbiting them define the various chemical elements like iron, hydrogen, etc. While it is not all too difficult to remove or add electrons from or to an atom – in fact the flow of electrons from atom to atom is, what commonly is referred to as electricity – it was not until the 1930's that splitting a nucleus seemed to become theoretically feasible.

This is exactly what the term nuclear fission describes: the splitting of a nucleus into two or more smaller, lighter nuclei with less protons and neutrons – releasing heat and radiation in the process[9].

Nuclear fusion describes the opposite process, fusing together two nuclei to create one heavier nucleus. This process also produces heat and radiation, and like nuclear

[7] (U.S. Department of Energy)
[8] (Facts on Nuclear Energy), (1 Million Europeans against NuclearPower)
[9] (Wikipedia)
[10] (Wikipedia), (EFDA-JET), (ITER)

fission, it is a form of elemental transmutation, since the number of protons and neutrons of the nucleus define the elements.

The released energy, in form of heat and various types of radiation, is dependent on the strength of the binding energy, which keeps the atoms together. Of all elements, iron and nickel have the strongest binding energy. This is important to know, since only such nuclei as have a lesser mass (a lower number of protons and electrons) than those elements, will release energy when fused together. In contrast to that, heavier nuclei will release energy when being split up[12].

While nuclear fission has long been subject to intense research with the goal of creating a weapon – thereby, almost as a side product, providing the required knowledge to construct the first nuclear plants - nuclear fusion research progressed at a slower pace.

Like nuclear fission, which gave birth to the *nuclear bomb*[11], nuclear fusion's first successful application was also a weapon: the *hydrogen bomb*[11]. Inside the bomb the hydrogen atoms, which have the smallest and lightest nuclei of all elements, are fused together, releasing an incredible amount of energy. This, however, can only be achieved by using a small nuclear fission bomb to ignite the process of nuclear fusion, since nuclear fusion can only take place at extremely high pressure and extreme heat[11].

Nuclei are positively charged, thus they normally repel each other. To initiate a fusion it is necessary to bring them very close together. At some point the so-called *strong nuclear force*, which is also the binding force keeping nuclei together, will overcome the electrostatic repulsion and fuse the nuclei[12].

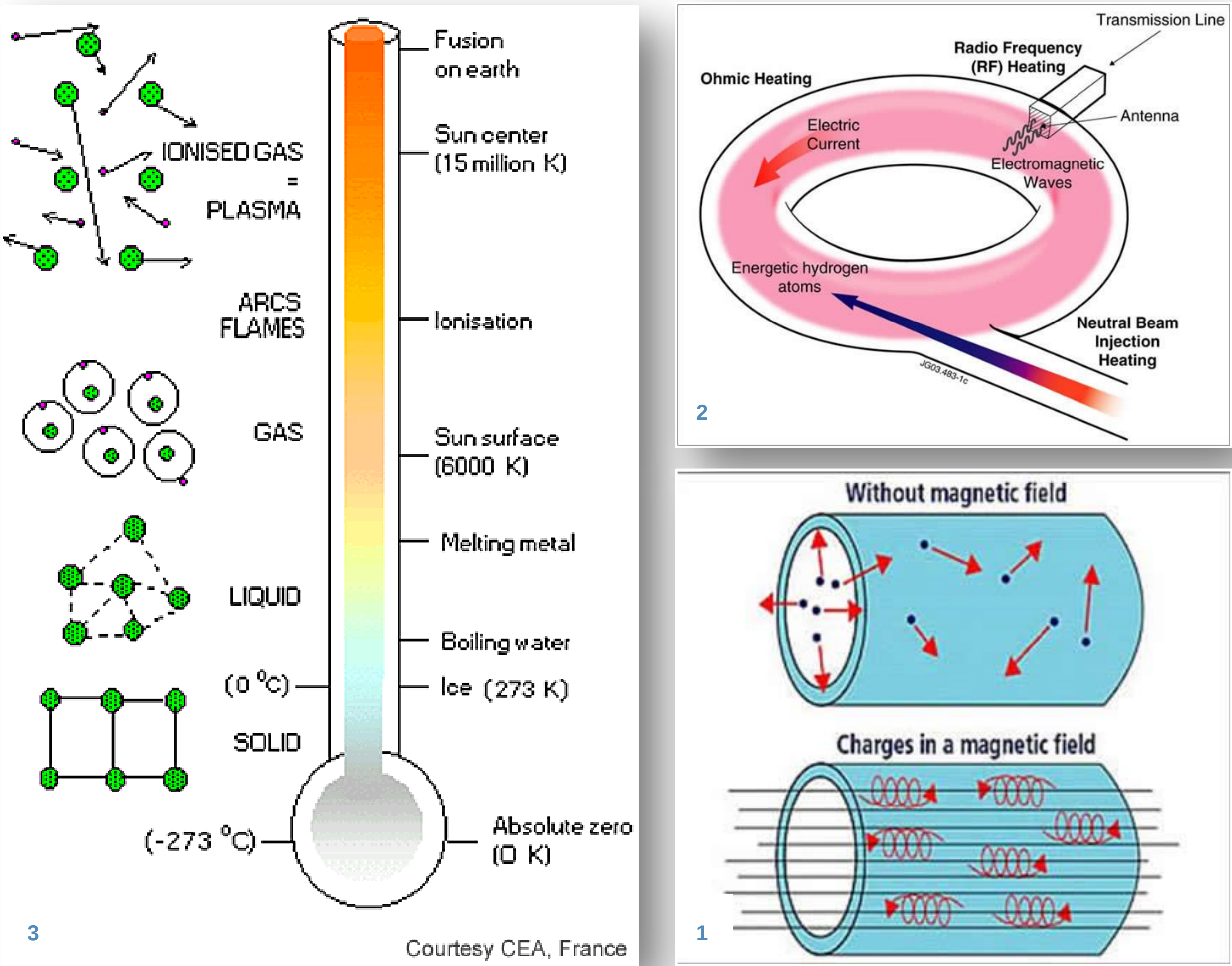
A hydrogen bomb releases all of its energy in a single uncontrolled burst, making it difficult to use as an immediate means of producing energy, especially since it requires a nuclear bomb for ignition. The viability of nuclear fusion as a sustainable source of energy, however, is proven to humanity every day when the sun rises above the horizon. Essentially the sun is, like all the stars, one giant fusion reactor.

---

11 (NuclearFiles.org)
12 (Wikipedia), (ITER) , (EFDA-JET)

To create serviceable nuclear fusion on earth, similar conditions to those existent in the centre of the sun - a combination of extreme heat and extremely high pressure - have to be reproduced and sustained[13].

Providing the technological means to create, control and further understand the necessary conditions for sustained nuclear fusion, has been a focus of research since the middle of the last century.



2 States of Matter in relation to temperature 3 Heating a Tokamak 1 Effects of the magnetic field inside a Tokamak (All pictures taken from www.iter.org)

[13] (Wikipedia), (EFDA-JET), (ITER)

FUSION POWER

Multiple promising approaches to the creation of a fusion reactor are currently being researched. Though the production of a commercially usable fusion plant is probably still many years into the future, fusion science has made increasingly faster progress in the course of the last decades. The most prominent and best developed approaches are now receiving a great amount of both national and international funding.

One of these is the *Magnetic Confinement Fusion*[14], which has been greatly advanced by the *Joint European Torus (JET)*[14] project, funded by the European Union and located in the United Kingdom. This approach uses a very strong magnetic field to contain the fusion fuel, which consists of Deuterium and Tritium, both isotopes of Hydrogen. *Isotopes* are variations of the same element, the only difference being a higher number of neutrons in the nucleus. This fuel combination is used in almost all approaches to nuclear fusion, since the required conditions are less demanding in heat and pressure than for other types of fuel[14].

The JET reactor is a so-called *Tokamak* [14][15](*fig.*3, 1), its design originally being Russian. It has in the form of a torus, not unlike a giant donut. The magnetic field, which is created by devices placed in the centre of the torus, as well as along its sides, has the main purpose of containing the fuel when it is being heated. At the extremely high temperatures necessary to initiate fusion, the fuel turns into *plasma* [13](*fig.*2) - hot gas consisting of charged particles - which would normally expand quickly, thus lowering the pressure. Preventing this purely by containing it within the walls of the torus, would cool down the plasma, as well as corrode the torus's walls. Heating the plasma is achieved by multiple means: injection of electrical current, high-energy beams of deuterium and tritium atoms and the application of electromagnetic waves, as well as the self-heating effect once the fusion reaction is triggered.

The JET reactor has achieved a peak efficiency of 70%, meaning that the produced energy amounts to afore mentioned percentage of the energy input needed to initiate and sustain the fusion.

[14] (Wikipedia), (EFDA-JET), (ITER)
[15] (Wikipedia)

JET's successor is the *ITER*[16] project - an acronym for *International Thermonuclear Experimental Reactor*, it also means *way, journey* or *direction* in Latin. ITER is internationally funded and still being constructed in Cadarache, France. Its main objective is to produce more energy than is requires to sustain the reaction, thus providing the basis for more efficient, energy producing reactors in the future. Ultimately, the goal is to reach the point of *ignition*[17], at which the fusion reaction is self-sustaining, that is to say the energy and heat from occurring fusion reactions is enough to initiate further reactions. This would mean a very high, sustained energy output, requiring only a constant addition of fuel.

ITER is scheduled to launch in 2016.

The other major approach is the *Inertial Confinement Fusion*[18]. This approach uses high-energy beams of laser, electrons or ions to explode the outer layer of the deuterium-tritium fuel, present in the form of a small sphere. The resulting explosive forces compress the centre of the sphere, while also sending powerful shockwaves inwards. Thus the immense pressure will cause fusion reactions at the centre, which will in turn create immense heat spreading outward igniting the remainder of the fuel.

This approach requires extremely sophisticated and powerful beam systems, as well as the technical means to produce the nearly perfect fuel spheres, necessary to evenly ignite the reaction.

Most of the concerning research has taken place in the USA, partially funded by a weapons research program. The *National Ignition Facility*[19], which is due to finish construction in 2009, is the most advanced and best-funded Inertial Confinement Fusion facility. It will use an extremely powerful new laser system. This Research may however also lead to a hydrogen bomb, capable of detonating without the need for a Nuclear Bomb to ignite it, which might explain the project's heavy funding.

A fusion reactor based on this approach, would use a series of small fusion fuel spheres being shot and ignited by the laser one after the other, instead of a continued, possibly self-sustaining fusion reaction[20].

---

[16] (ITER)
[17] (Wikipedia), (ITER)
[18] (Wikipedia), (Lawrence Livermore National Laboratory)
[19] (Lawrence Livermore National Laboratory)
[20] (Wikipedia)

Up to date this approach, while also making fast progress, appears to be farther removed from the goal of a commercially usable fusion reactor than the magnetic one. Energy output has been reported to be also as high as 70% percent of the input. However, additional difficulties with the reactor design will probably require more research: a serviceable reactor would probably need multiple fuel spheres to be ignited per minute - until now the lasers can fire only about once per day.

An entirely different approach to nuclear fusion provides the so-called *Cold Fusion*[21], a term created when two scientists claimed to have achieved a tabletop nuclear reaction in 1989. Following this claim, they were subsequently accused of fraud and came under attack for being perceived as unprofessional, since many other scientists failed to replicate their results.

A review panel, organized in the same year by the US Department of Energy, drove the final nails into Cold Fusion's coffin, by denying its viability[21]. Since then it has gained a reputation of being a pathological science and is met with great scepticism. In recent years however, there has been a growing number of scientists able to replicate the experiment, voicing their support for further research. This science is now often and more accurately called *Low Energy Nuclear Reactions (LENR)*[21], since newer research says that nuclear fission is taking place as well.

LENR research almost appears to be shrouded in mystery and has yet to receive any significant amounts of attention or funding, although it could very well be the ultimate energy source of the future. It is using chemical means to overcome the atom's resistance to fusion and fission, supposedly making both reactions possible at room temperatures in rather small jars.

In the face of current resistance, it seems very unlikely that greater funding or major advances in understanding the process will be gained in the near future.

[21] (NEW ENERGY FOUNDATION), (Wikipedia)

PROS AND CONS

Although there is no practical application of fusion power yet to be examined, based on the experimental reactors like JET and on current research, some statements about the advantages and disadvantages to the use of fusion power as an energy source can be made.

PROS[22]

No long-term radioactive waste – the end-product of deuterium-tritium fusion is harmless helium gas.

No radioactive fuels required – tritium is radioactive but can be produced inside the reactor from lithium, so no need to transport and contain radioactive fuels.

No Greenhouse Gas output – the only product is helium, which is very *green* indeed.

Abundance of fuel – deuterium is virtually inexhaustible (extracted from seawater), lithium is also available in great quantities, but hopes are for a deuterium-deuterium fusion.

Extremely high energy output – suitable to deliver enough power for whole cities.

High safety – no chance for a chain reaction to occur, since the reaction could not sustain itself in case of a malfunction.

Controllable, predictable energy output – unlike wind and solar energy, fusion power is not dependant on environmental conditions.

No radioactive products usable for weapons – as mentioned before the only product is helium, while fission reactors may produce weapons-grade uranium.

[22] (Princeton Plasma Physics Laboratory), (EFDA-JET)

CONS

Radiation – reactor parts become radioactive after some time and must be safely stored (50-100 years), but can then be reused. In the case of a malfunction, small radiation leaks (tritium) are also possible.

High requirements – a very high level of technology and infrastructure and thus initial funding is necessary, even higher than the required level for nuclear fission.

Not ready for use – yet unknown problems may be revealed and have to be overcome, before the first fully functional reactors can go online.

Weapon technology – nuclear fusion research results could be used in the construction of various types of hydrogen bombs, if knowledge of nuclear weapons was previously available.

CONCLUSION

While there is yet much to be researched, before humankind will truly be able to understand and harness the forces that power the sun, eventual success seems certain. Most of those involved in fusion research projects seem to agree that commercial fusion reactors shall be up and running by the middle of the century.

Technological know-how necessary for other alternative energy sources, such as solar and wind energy, is also steadily growing and those alternatives will doubtlessly see increased use in the next years. They are, however, limited by their dependence on environmental conditions and the comparatively low energy outputs, motivating many countries to expand their nuclear fission power programs instead. This is where fusion power, once ready for deployment on a large scale, might take over.

The extended use of fusion power could then supply the bulk of the energy needed for industries and cities in the industrialized countries. In combination with wind and solar energy, used according to the regional prerequisites, this would provide a *green* energy solution, having hardly any adverse effects on the environment.

It will however remain to be seen how freely the required knowledge will be distributed. Even would it be made widely available, smaller and less developed countries will hardly be able to use this technology any time soon. For such countries the use of locally available renewable energy resources, like hydroelectric, geothermal, wind and solar energy will probably be better suited and more cost-effective for the time being[23].

Fusion power may provide a complete replacement for energy won from oil, coal and nuclear fission power plants, but it cannot provide a substitute for the use of petrol engines. Yet, if more sophisticated energy storage devices became available, fusion power could cheaply deliver the energy, necessary to employ electrical types of propulsion. The day that humankind tames the power of the sun may very well be the dawn of a new age. In the face of the incredible amounts of money, flowing into the international joint venture that is ITER, it seems likely that the first fully functional fusion reactors will be ready rather sooner than later. There can be but little doubt that fusion power will be *the* energy source of the future.

BIBLIOGRAPHY

1 Million Europeans against NuclearPower. 1 million europeans sign against nuclear power. [Online] http://www.million-against-nuclear.net/background/6reasons.htm.

ASPO International | The Association for the Study of Peak Oil and Gas. About Peak Oil | ASPO International | The Association for the Study of Peak Oil and Gas. [Online] http://www.peakoil.net/about-peak-oil.

BBC NEWS. BBC NEWS | In Depth | Natural disasters 'on the rise'. [Online] http://news.bbc.co.uk/2/hi/3666474.stm.

Clean Energy Ideas. Natural & Renewable Energy Sources - Clean Energy Ideas. [Online] http://www.clean-energy-ideas.com/index.html.

EFDA-JET. EFDA-JET - The world's largest nuclear fusion research experiment. [Online] http://www.jet.efda.org/index.html.

[23] (Clean Energy Ideas)

Energy Information Administration. EIA - Greenhouse Gases, Climate Change, and Energy. [Online] http://www.eia.doe.gov/bookshelf/brochures/greenhouse/Chapter1.htm.

EurActiv Network. EurActiv.com - Peak Oil | EU - European Information on Energy Supply. [Online] http://www.euractiv.com/en/energy/peak-oil/article-163927.

EURATOM/UKAEA Fusion Association . Fusion Power - Fusion research at UKAEA Culham. [Online] http://www.fusion.org.uk/.

European Commission. Research - Energy - - The advantages of fusion. [Online] http://ec.europa.eu/research/energy/fu/fu_int/article_1212_en.htm.

Facts on Nuclear Energy. Nuclear Power is a Dead End. [Online] http://www.facts-on-nuclear-energy.info/1_dead_end.php?size=b&l=en&f=.

Intergovernmental Panel on Climate Change. IPCC - Intergovernmental Panel on Climate Change. [Online] http://www.ipcc.ch/ipccreports/assessments-reports.htm.

International Atomic Energy Agency . WORLD SURVEY OF ACTIVITIES IN CONTROLLED FUSION RESEARCH. [Online] http://nds121.iaea.org/physics/index.php.

ITER. ITER. [Online] http://www.iter.org/.

Lawrence Livermore National Laboratory . National Ignition Facility & Photon Science - The Power of Light. [Online] https://lasers.llnl.gov/.

National Parks Conservation Association. NPCA | Dark Horizons: 10 National Parks Most Threatened by New Coal-Fired Power Plants. [Online] http://www.npca.org/darkhorizons/.

NEW ENERGY FOUNDATION, INC. Infinite Energy Magazine. [Online] http://www.infinite-energy.com/.

NuclearFiles.org. Key Issues: Nuclear Weapons: The Basics: Weapons Basics. [Online] http://www.nuclearfiles.org/menu/key-issues/nuclear-weapons/basics/weapons-basics.htm.

Princeton Plasma Physics Laboratory. Princeton Plasma Physics Laboratory. [Online] http://www.pppl.gov/index.cfm.

The Union of Concerned Scientists. coal power: air pollution | Union of Concerned Scientists. [Online] http://www.ucsusa.org/clean_energy/coalvswind/c02c.html.

U.S. Department of Energy. U.S. DOE Energy Efficiency and Renewable Energy (EERE) Home Page. [Online] http://www1.eere.energy.gov/maps_data/pdfs/eere_databook_091208.pdf.

UN News Centre. Evidence is now ‘unequivocal’ that humans are causing global warming – UN report. [Online] http://www.un.org/apps/news/story.asp?NewsID=21429&Cr=climate&Cr1=change.

Wikipedia. Cold fusion - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Cold_fusion.

—. Fusion power - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Fusion_power.

—. Inertial confinement fusion - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Inertial_fusion_energy.

—. Magnetic confinement fusion - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Magnetic_confinement_fusion.

—. Nuclear fission - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Nuclear_fission.

—. Nuclear fusion - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Nuclear_fusion.

—. Peak oil - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Peak_oil.

—. Tokamak - Wikipedia, the free encyclopedia. [Online] http://en.wikipedia.org/wiki/Tokamak.

World Nuclear Association. World Nuclear Association. [Online] http://www.world-nuclear.org/.