George Buhl
ENL101-54
Research 1st draft
11/28/05

Nuclear Fusion

With fossil fuels in decline many alternative energy resources have been getting a lot of attention. While all of them are worthwhile to investigate and develop, one stands out as having the biggest potential for mass producing large quantities of energy at very low cost. This technology is nuclear fusion.

Almost all of the energy on earth comes from the sun in one form or another. The sun's energy comes from a massive nuclear reaction, but not the type of reaction that occurs in nuclear power plants around the world today. They operate by splitting large atoms in a process known as fission. The sun's nuclear reaction is a fusion reaction in which small atoms are combined releasing enormous amounts of energy.

Scientists first discovered that a fusion reaction could be produced here on earth when they detonated the first hydrogen bomb on November 1, 1952. Since then they have yearned to harness the power of fusion in a less destructive form.

There are many benefits of fusion power over existing forms of power generation. Coal and other forms of fossil fuels produce CO2 gas which is harmful to the environment. A fusion reaction would produce no air pollution. In fact, according to the October 2005 edition of Modern Power Systems, "the impact on health, climate and the environment – will be essentially zero" (Smith, Todd, and Ward 12). Unlike fossil fuel supplies which are beginning to run low, fuel to supply a fusion reaction is very plentiful and is basically unlimited.

Compared with fission, fusion reactions are extremely safe. The fuels used inside a fusion reactor have half-lives of only a few decades compared with the thousands of years for fission reactors. This would greatly reduce the amount of waste produced by a fusion reactor compared to a fission reactor. The reactors also do not contain large quantities of hazardous fuel that could be released into the surrounding environment in the event of a natural disaster or act of terrorism. The nature of a fusion reaction does not lend itself to a catastrophic failure like that which is possible with a fission reactor. This is because a fusion power plant would not contain enough energy to cause a major accident (Smith, Todd, and Ward 12). Additionally, the fuel inside the reactor must be kept extremely pure in order to sustain the reaction, meaning if part of the reactor was to melt due to a containment failure the contamination would immediately cause the reaction to shut down (Jozefowicz 6).

Additionally the small amount of waste that is produced by a fusion reactor would not be suitable in any way to make nuclear weaponry. This is a major drawback in current fission reactors since many countries can secretly develop nuclear weaponry by claiming that they are using the reactors to generate power and not weapons grade material. This is a major concern with the current nuclear technology.

There are however a few drawbacks to fusion. The biggest being, at the present time, fusion reactions are not breakeven which means that the energy required to sustain the reaction is greater than the energy that the reaction produces. (Clery) JET (short for Joint European Torus) which holds the record for fusion power production at 16MW is still not close to breakeven (Smith, Todd, and Ward 14). The reactors being used for experimenting and reactors that are currently being designed and built for future testing are also very expensive. ITER, (short for International Thermonuclear Experimental Reactor) currently under construction in France, is the reactor with the most potential for creating a reaction that exceeds the breakeven point and it has an estimated cost of $5 Billion to construct. (Hutchison). ITER is scheduled to be completed and operational by 2016 (Jozefowicz 7). Because fusion is still in a very early stage it is unknown whether or not the cost of producing energy this way will be commercially feasible.

The current reactors called tokamak reactors create fusion by injecting a small amount of deuterium and tritium gas into a doughnut shaped vacuum chamber and heating it to create plasma. This is a state of matter in which the electrons and the nuclei of an atom separate and remain in a cloud called plasma. The plasma is further heated to a temperature of over 100 million°C. No material on earth can withstand that temperature (ten times hotter than the core of the sun) so the reactors use extremely powerful magnetic fields to keep this plasma from touching the sides of chamber. At these high temperatures the nuclei from the deuterium atom and the nuclei from the tritium atom combine to create a helium atom and in the process release a neutron and a large quantity of energy (Smith, Todd, and Ward 11). Because the huge magnetic fields require a lot electricity to maintain, and a tremendous amount of electricity is required to heat the plasma to the temperatures required to produce fusion these reactors consume more power than they produce and are very costly to operate. However scientists are hopeful that the ITER reactor will surpass the breakeven point possibly bringing fusion power closer to reality.

ITER fusion research is an international effort between China, the European Union, Japan, Russia, Switzerland, and the United States. In order for their efforts to be successful, all countries need to be committed fully to not only the research but the financing of the research. Currently the United States is a minority partner in the ITER effort contributing only $150 million per year. However fusion researchers in the United States have led the way for ITER, with two very successful, well known tokamaks, one at MIT and the other at General Atomics in Sand Diego. But financially the United States only contributes about 10 percent to ITER (Hutchinson). With a technology with so much potential for future power production, the United States seems to be somewhat under involved.

There are other methods being researched that possibly could produce fusion. Some that may not require huge complex and expensive machinery. These methods are widely criticized by the scientific community but have been recently gaining interest by once skeptical scientists. One such is called sonofusion or sonoluminescence. This occurs when a jar of deuterium filled fluid is subjected to sound waves which causes a tiny bubble to be formed in the center of the jar. That bubble is then stretched by the force of the sound waves until it reaches a point and collapses in on itself. When it collapses in on itself it releases a lot of energy in the form of heat and a flash of light can be observed. Scientists at Perdue University claim that the gas within the bubble is actually hot enough to produce a small fusion reaction. However there has been much skepticism over these claims and similar clams by researchers at Oak Ridge in 2002 because scientists have been unable to consistently measure neutrons, the tell tale sign of a fusion reaction, emitted from this phenomenon (Chang).

Another form of fusion being researched is referred to as cold fusion. This form of fusion was reported to have been discovered by University of Utah scientists in 1989.

Their claim was disregarded by the scientific community because their experiments were never reproduced sufficiently to prove the existence of a fusion reaction. Their method is the simplest of all. It consisted of a jar of heavy water, that is water molecules containing deuterium atoms and two palladium electrodes. An electrical current was passed through the water and supposedly the deuterium atoms were drawn to the electrodes where they fused together creating heat. Since these claims were never verified and current theory has no explanation for a fusion reaction occurring in this way the idea of cold fusion was dismissed by the scientific community. However, recently this type of experiment has been gaining more attention, although still with much skepticism. In 2004 the Energy Department decided to review the possibility of cold fusion giving hope to a handful of scientists who have continued the research of cold fusion despite being shunned by the rest of the scientific community (Chang). However, the findings of the review by the Energy department were considered inconclusive, but noted that there were interesting questions raised by the study that warranted further research (Chang).

In 2005 a team from University of California in Los Angeles reported to have produced a fusion reaction inside a foot long cylinder five inches in diameter. This experiment uses a special crystal of lithium tantalite which is classified as a pyroelectric material which means it is capable of generating strong electrical fields when heated or cooled. The crystal is inside a tube surrounded by deuterium gas. Warming the crystal creates a 1000 volt charge stripping the electrons from the deuterium atoms and accelerating them into a target also containing deuterium. The resulting collision causes the deuterium atoms to fuse, creating a stream of neutrons. However, only about one in million collisions create fusion. This is not feasible as a commercial power source but scientists have a lot to learn, if in fact fusion is actually occurring (Chang). This device could someday be used for irradiating tumors, creating baggage scanners and powering small space crafts by utilizing the neutrons generated by the tiny reaction inside (Horgan).

Reactors such as JET have lead the way, by allowing scientist to study fusion reactions with the eventual purpose of using them to produce electricity commercially. ITER is a new reactor being built in France that will take almost everything learned from older smaller tokamak reactors and incorporate it into one reactor. It will be the biggest reactor of it’s kind, with a reaction chamber about twice the size of JET and will utilize brand new technology in order for it to reach the breakeven point. It is being designed as a proof of concept specifically designed to test the feasibility of using fusion as a practical form of power generation. It will be designed to test many different aspects required to make power generation a reality.

Up until now most tokamak reactors have used massive copper coils to produce an electromagnetic field. This works well, but since the amount of energy required to produce such a strong magnetic field is so high, the coils heat up very quickly and cannot be used for more than a few seconds at a time which means that the reaction cannot be sustained for longer periods of time. The ITER reactor will utilize superconducting magnets which have been used in other tokamak reactors but not on a scale of this size. ITER will test manufacturing techniques and operability of these magnets. In order for the magnets to super conduct they have to be chilled to temperatures only a few degrees above absolute zero which means that very specialized cryosystems need to be tested in order to provide the critical liquid helium to cool the magnets. If successful, these superconducting magnets along with many other new technologies will allow ITER to operate for extended periods of time, which will be a first for any fusion reaction (Korane 104).

In order to sustain the fusion reaction, there needs to be a lot of monitoring and adjustments made throughout the operation cycle. Until recent years the capability to actively control and adjust the magnets containing the plasma was very difficult if not impossible. But due to extremely powerful computers and complex software, scientists are now able to monitor fluctuations in the strength of the magnetic fields in real-time and adjust for them almost instantly. This is extremely complicated and is accomplished by using very complex analog and digital circuitry called hybrid neural networks, that work similarly to a human brain. They use powerful computers to look up proximate solutions to non linier equations and solve them in a matter of milliseconds (Smith, Todd, and Ward).

In order for scientists to understand fusion they have to spend a lot of time studying it. Since most of what occurs during a fusion reaction is at an atomic level scientist utilize special equipment to measure neutron emissions and other measurable aspects of the reaction such as heat and energy released. The easiest way for them to study these is to watch a reaction occur and collect the data from it. Because it is against international law to test nuclear weaponry scientists are developing creative new ways to initiate fusion reactions without the use of a nuclear bomb. Tokamak reactors currently are the most reliable way but a group of scientist working at Lawrence Livermore National Laboratories are working on a project with the specific goal to create a fusion reaction in order to study it so they can further understand what is occurring during it.

They are mostly interested in using this knowledge in order to be able to maintain the United States' nuclear weapons without testing them. But their knowledge of fusion may also lead to a better source of commercial energy. After all the first fission reactions were started with the purpose of creating a nuclear bomb.

The team at the Lawrence Livermore's National Ignition Facility are using a new approach to the fusion problem. But the basics remain the same, heat and pressure. They are attempting to focus 192 high powered laser beams at a BB sized pellet of frozen hydrogen. The laser used in this experiment has 60 times the power of any other laser on earth. They hope that when they fire the laser at the target the intense heat and pressure will cause a fusion reaction to take place (Seife and Malakoff 1127).

Although this sounds like a simple thing it is actually a very complicated task. Because they need to compress the pellet of hydrogen they have to fire the laser beams at all angles of the pellet evenly so the pellet will not break apart instead of compressing. Scientist liken this to squeezing a water balloon. Squeezing it unevenly will cause it to bulge instead of compress (Seife and Malakoff 1129).

Another problem to overcome is that such high powered lasers are very hard to create and keep running. Because lasers use light and that light gets very hot, they can only shine through perfectly clear optics. If there is any sort of defect in the glass or even a spec of dust on the glass the glass will basically explode from the intense energy of the laser beam. And even if perfect optics are used the laser tends to etch the glass over time which requires it to be replaced regularly (Seife and Malakoff 1129).

Critics of the Livermore laser say that they are doubtful that the experiment will even be successful. Other problems plague the project too. Currently the project is way behind schedule and over budget. The project was supposed to be finished in 2002 at a cost of 2 billion dollars (Seife and Malakoff 1126). It is still not completed and has a projected cost of more than double it's original estimate which makes it the single most expensive project in the Department of Energy's history. That's an awful lot of money to spend on an experiment that many say may not even work.

These drawbacks make this type of technology extremely impractical for power generation. However the lessons learned and the data collected from these experiments, if successful, may lead scientists to better methods of creating fusion and at the least, allow scientists the opportunity to understand fusion reactions better.

Using nuclear fusion as a viable form of power is still a long way off. But with an international effort such as ITER, it is very likely that fusion will someday be a common source of power. It's many advantages seem to outweigh the great cost of developing such a powerful source of energy. Much research is still needed in order to refine fusion into a practical source of energy. The international community needs to be committed to fully developing fusion with the goal of power production. With earth's natural resources beginning to decline and as the need for cheap clean electricity rises, fusion seems like a technology with the potential to solve these problems.

Works Cited

Chang, Kenneth. "Evidence on Cold Fusion Remains Inconclusive." New York Times 2 Dec. 2004, Late East Coast ed., sec. A. ProQuest. Wilkens Library. 15 Nov. 2005 <http://proquest.com/umi/>.

Chang, Kenneth. "Itty-Bitty and Shrinking, Fusion Device Has Big Ideas." New York Times 28 Apr. 2005, Late East Coast ed., sec. A. ProQuest. Wilkens Library. 15 Nov. 2005 <http://proquest.com/umi/>.

Chang, Kenneth. "Tiny Bubbles Implode With the Heat of a Star." New York Times 15 Mar. 2005, Late East Coast ed., sec. F. ProQuest. Wilkens Library. 15 Nov. 2005 <http://proquest.com/umi/>.

Clery, Dan. "A Miniature Star on Earth." Popular Science Feb. 2005. 15 Nov. 2005 <http://www.popsci.com/popsci/science/86630b4511b84010vgnvcm1000004eecbccdrcrd.html>.

David, Charles, and David Malakoff. "Will Livermore Laser Ever Burn Brightly?" Science 289 (2000): 1126-1129. Academic Search Premier. EBSCO. Wilkens Library. 15 Nov. 2005 < http://www.epnet.com/>.

Horgan, John. "DESKTOP FUSION." Newsweek 146 (2005): 59. Academic Search Premier. EBSCO. Wilkens Library. 15 Nov. 2005 < http://www.epnet.com/>.

Hutchinson, Ian H. "Fusion Research: What about the U.S.?" Technology Review 108.9 (2005): 43. Academic Search Premier. EBSCO. Wilkens Library. 15 Nov. 2005 < http://www.epnet.com/>.

Jozefowicz, Chris. "A Star Is Born?" Currnet Science 91.3 (2005): 6-7. Academic Search Premier. EBSCO. Wilkens Library. 15 Nov. 2005 < http://www.epnet.com/>.

Korane, Kenneth J. "SMASHING! The future of fusion heats up." Machine Design 77.18 (2005): 100-107. Academic Search Premier. EBSCO. Wilkens Library. 15 Nov. 2005 < http://www.epnet.com/>.

Smith, Chris L., Tom Todd, and David Ward. "JET, ITER and Beyond." Modern Power Systems 25.9 (2005): 11-15. Business Source Premier. EBSCO. Wilkens Library. 15 Nov. 2005 < http://www.epnet.com/>.