**Introduction**

You and I are solar powered, at least indirectly. It is the Sun's energy that grows plants that (one way or another) we eat and get our energy from. Until Einstein derived E = mc2 from his [special theory of relativity](http://www.emc2-explained.info/Special-Relativity/) it was a complete mystery as to what the fuel source of the Sun was. For example, it had been calculated that if the Sun was made of coal it would use up its total fuel supply in about 6000 years. With an ever-increasing understanding of the age of the Solar System, based mainly on geological research, it was clear that there must be a process going on within the Sun that we didn't understand. We now know that the Sun is about 4.6 *billion* years old and has about the same length of time before it will have used up all of its fuel.

**Fusion - An Atomic Process**

It's possible to turn mass into energy by taking less massive atoms, such as hydrogen, and squeezing them together to form another type of, and heavier, atom. This process is called *nuclear fusion*.

Fusion can occur with many different kinds of atom. In fact, over a third of all the different kinds of atoms, when fused, release energy. For now we will concentrate on the simplest form of nuclear fusion, that of hydrogen.

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| Hydrogen is the simplest of all atoms. The first isotope (having different numbers of neutrons than protons) of hydrogen contains nothing but a single proton, with a single electron in "orbit" around it. If the hydrogen atom is given energy (for example, by heating it or speeding it up) the electron is "shaken" away and we are left with just a proton. Strictly speaking we should now call the "atom" an "ion", but for our purposes we will continue to call it an atom in order to keep things simple (with apologies to chemists).  A proton (i.e. the nucleus of a hydrogen "atom") has a positive electrical charge, that is, it acts like the positive end of a magnet. If we bring two protons together they repel each other. The closer we try to push the protons together the more energy we need to overcome the repulsion. You may have experienced something similar yourself. If not, find two magnets and try to push either both the negative or both the positive ends together. You will find that when the magnets are far apart they are easy to move towards each other, but as they get closer more and more energy is required in order to push them together.  If we apply a *lot* of energy (on an atomic scale) we overcome the magnetic resistance and the two protons stick together; they have *fused*. In doing so they give up a little of their mass in the form of energy. In fact, the energy released is *greater* than the energy that was required to force the two protons together. We now have a source of energy: nuclear fusion.  Why is energy released during the fusion of hydrogen? We said that when two protons are forced together they fuse. However, that's not all that happens. What actually happens is that one of the protons changes into another particle; it "transmutes" from being a proton into being a neutron. Not only that, but in doing so it ejects two further particles: a positron (a positively charged electron) and a strange, almost mass-less, particle called a neutrino. We can show this in a schematic diagram:  We now have the nucleus of an atom that is the second isotope of hydrogen, called *deuterium* (d). It contains one proton and one neutron. The positron and neutrino go flying off with kinetic energy supplied by converting some of the mass of the transmuted proton into kinetic energy, in accordance with E = mc2.  http://www.emc2-explained.info/Emc2/Short-blue-line.png  **The Sun's Fusion**  When the Sun was formed about 4.6 billion years ago, it did so out of a huge cloud of gas. Most of that gas was hydrogen, but it also contained some helium (about 30%) and small amounts of many other elements such as carbon, oxygen, silicon, and so on. The gas cloud contracted under its own gravity and started to spin, in doing so ejecting most of the heavier elements, some of which became the planets, asteroids and comets, and some of which eventually ended up as you and me. What remained was a huge ball of mostly hydrogen and helium that we now call the Sun.  Deuterium. The gas in the Sun continued to contract under its own gravity until the pressure at the core grew to enormous proportions (about 100 billion times the pressure of air on the Earth). A law of nature states that if you squeeze anything it heats up. As the centre of the Sun became more and more compressed the temperature at the core reached about 15 *million* degrees Celsius (27 million degrees Fahrenheit). This meant that the protons (hydrogen "atoms") at the core possessed, in atomic terms, huge amounts of energy. So much energy in fact, that some of them could overcome any magnetic resistance and fuse into deuterium, releasing even more energy in the process. This is the first stage in the Sun's source of energy:  Helium-3 The second major stage is the formation of helium-3 (He-3), again by a process of fusion. There are four isotopes of helium, He-3, -4, -5, and -6. He-5 and -6 have short half-lives (in the case of He-5 only 6 x 10**-20** seconds!) and we will not be concerned with them here. Each helium atom, by definition, has two protons.  We now have an "atom" of deuterium (a proton and neutron) in a sea of highly energetic hydrogen "atoms" (protons). Sooner or later (but usually sooner!) the two types of atoms will collide and fuse. When they do so they combine to make the atomic nucleus of helium-3, and eject yet another high-energy photon:  Helium-4 Lastly, the third stage is the production of helium-4. In this process, two He-3 "atoms" come together and fuse, releasing two protons. The two protons fly off in separate directions and go back to being hydrogen "atoms", from which they can take part in the whole process again. The process looks like this:  Throughout each stage some mass was converted into energy and a total of 6 high-energy photons was produced. However, we *still* haven't seen any visible light. The visible light from the Sun is due to the ejected particles jostling with other atoms and so transferring some energy to them. This causes the latter atoms to emit photons with a wide range of frequencies, including those in the visible part of the spectrum. At last, we have visible sunlight! |  |

All three stages taken together is sometimes called the "proton-proton" chain.

The Total Energy  
The energies we have been talking about, while large on an atomic scale, are still *very* small in everyday terms. However, there is something we must take into account about the Sun, and that is it's *enormous*! It has the same volume as 1.3 *million* planet Earths. Some numbers about the rate at which nuclear fusion takes place in the Sun will be instructive:

* There are around 8.5 x 1037 fusion cycles per second at the Sun's core.

Written out it looks like:

* This leads to a total energy output from the Sun of around 3.8 x 1026 Joules per *second*.
* The Sun converts 4 *million* tons (4.4 million tons) of mass into energy every *second*.

In pounds, it’s:

* Each square centimeter of the Sun's surface is as bright as a 6000W light bulb.

The amount of mass converted into energy at the Sun's core is stunning. However, the Sun has a mass of around 2 x 1030 kg and has enough hydrogen to continue its proton-proton chain for around another 4 billion years. After that, as we shall see, the Sun will use another process to keep shining for a "little" longer.

Lastly, it's worth mentioning that the "sunlight" produced at the core doesn't just fly off into space. As has been seen, the proton-proton chain doesn't even produce light in the visible part of the spectrum. Instead, the high-energy protons and resultant kinetic energy produced induces other atoms in the Sun to vibrate and, in turn, release photons of many different frequencies, including those in the visible part of the spectrum. These photons are re-absorbed and re-emitted by adjacent atoms, each, on average, slightly closer to the surface of the Sun. Finally, after around 100 to 200 thousand years an atom at the surface of the Sun absorbs and then re-emits a photon, which flies off into space. Then, if heading in our direction, it takes around 8.5 minutes for the photon to reach the Earth. All of the daylight that we use to see by started on its journey a very long time ago.

Courtesy (modifications made for length): <http://www.emc2-explained.info/Emc2/Fusion.htm#.VdodAmeFOM8>