The Twinkle in Mother Earth's Eye: Promising fusion power

What if you could have a miniature star powering your house, your computer, and your car? How cool would that be! Stars produce a lot of energy, and they get that energy through a process called fusion.   Thanks to recent research at the National Ignition Facility (NIF), we're now one step closer to using fusion as an energy source.

Fusion is when two small atoms collide and stick together into a single, larger atom. Sounds simple, but atoms really don't like being forced together. Every atoms has a nucleus is that is positively charged. When these two positively charged nuclei are forced together, they repel each other thanks to the electromagnetic force, a lot like how two magnets repel one another when they're facing the right way. But in stars, there is so much gravity pushing these atoms together that it overcomes that repulsion, and we get a new element!

If we combine several hydrogen atoms together, we get helium.But the mass of the new helium is less than the sum of the masses of the initial hydrogen atoms. So where did the missing mass go? According to Einstein's famous equation E=mc^2, the mass (m) becomes energy (E)! That means if we can harness the extra energy, or missing mass, produced from this collision. This would provide another source of renewable energy to replace the fossil fuels that provide most of the electrical power in the modern world.

But, harnessing energy like a star on Earth is really difficult. According to NASA, the sun fuses about 600 million tons of hydrogen every second. Fusion is why the sun is a huge fireball producing so much energy. How could we possibly do that on Earth? Physicists have spent decades trying to answer that question, designing and building powerful fusion reactors to try and re-create the extreme pressure and temperature you find inside a star. .

There are two main types of fusion that we have on Earth: Magnetic Confinement Fusion and Inertial Confinement Fusion. This article goes into more detail, but Magnetic Confinement means that a magnetic field is used to hold the fusion fuel—a plasma of hot hydrogen isotopes—in place, because no container could withstand the heat. Ordinary hydrogen atoms are made of a single proton and a single electron, but the kind used in fusion have neutrons in their nuclei—adding one neutron makes deuterium, and two neutrons makes tritium. When heat is applied to a combination of tritium and deuterium, the fusion fuel as a gas gets so hot that the electrons are torn away from their atoms, leaving a pool of random electrons and hydrogen isotopes: a plasma. This plasma is where the helium is produced, along with some highly energetic neutrons that will heat the walls of the chamber, eventually boiling water to produce electricity with a steam turbine.

Inertial confinement fusion, the method NIF uses,works a little differently. Instead of a fuel in the form of gas, there is a solid fuel pellet made of super cold deuterium and tritium, surrounded by a high-density capsule to hold it in one place. 192 lasers are aimed at the capsule from all sides, and fired all at once to transfer a huge amount of energy to it! The capsule absorbs this energy and expands, but the walls of the fusion reactor are strong, so they push back on the capsule and direct the energy inwards—causing the capsule and fuel pellet to implode. The pressure created by the implosion makes the gas become a plasma, which then produces the same helium, some neutrons, and energy. At a certain point, the system becomes self heating, meaning the heat and energy produced from the initial reaction continue the cycle to perpetuate more reactions.

NIF's fusion experiments have been very successful. Their recently published article, "Fusion Energy Output Greater Than the Kinetic Energy of an Imploding Shell at the National Ignition Facility" has shown that the energy they are getting from their inertial confinement fusion is greater than the energy they are putting into the fuel pellet. Breaking even has always been a problem with regards to fusion experiments, because fusion requires so much energy to get started. The scientists at NIF are now getting about twice the amount of kinetic energy out (~54 kJ) as they put into the fuel pellet (~21 kJ). They have also worked on ways to encourage the system to self-heat. Self-heating has been difficult to achieve in an experimental setting, because energy can escape too quickly, but NIF says that once they increase how long the experiment is running—what's called the confinement time—then self-heating can occur. That would make it easier to get more energy out from this process. The pressure inside of the reaction, or the hot spot, is now greater than the pressure at the center of the sun, meaning a star can actually be made in their facility.

If you are an avid Physics Central reader, you may remember the article about fusion published in 2014 called "In Depth: Fusion Strides at NIF". In that article, fusion is explained in greater detail, and we talked about how the "High-foot" method, which alters the laser's power throughout the reaction, allowed NIF to "break even" on energy in their experiments. Using High foot, NIF was able to refine the method that brought them to an equilibrium back in 2014 and get more energy out of the fusion reactor than in previous experiments. It’s really exciting to find that this type of fusion is on its way to unity. Unity is when the amount of energy that is put into the system equals the amount that comes out.

That hasn’t been achieved in fusion yet, but NIF is on its way to bridging the gap in energy that fusion is notorious for.

Now let’s bring it all back to Earth. Fusion requires a lot of energy to get started. NIF did get some positive net energy from their experiments, but unfortunately, this can be misleading. In 2014, NIF broke even, meaning that the amount of energy in their activated pellet was the same as the amount of energy that the process produced—but there was still a lot more energy going into the system. Every step in the process, turning fuel into electricity, electrical energy into laser light, then laser light into the heat and kinetic energy of the capsule, involves losses—so the total energy going into the system was still much greater than the energy produced by fusion. Now, the NIF has been able to recover some energy. From their results, they got two times the amount of energy they got back in 2014, but that’s still not enough to break even at a larger scale: fusion is still not producing more energy than is required to get it started.

Looking beyond the lack of energy produced, the byproducts of fusion are neutrons and helium. Helium isn’t so bad, but neutrons are problematic. When neutrons react with the container of the fusion reactors, the walls become radioactive, making the whole experiment much more dangerous. However, these byproducts are arguably better—or at least easier to contain—than the byproducts of fossil fuel.

Investigating the pros and cons of each potential alternative energy source is necessary to determine how to provide safe energy. Although there’s plenty left to learn about fusion, pursuing research into safer forms of power generation still promises an even brighter future for our planet.