Fusion is the fundamental energy source of the universe. It is the process that powers the sun and the stars. In a fusion reaction, energy is released when the nuclei of two light atoms (such as hydrogen) fuse together to form a heavier one. Tapping into this energy source offers the prospect of a long-term, safe, environmentally friendly option to meet the energy needs of a growing world population. 

Fusion is a particularly attractive energy solution as it uses a fuel that is abundant or can be manufactured easily. The fuels used in fusion are isotopes of the light element hydrogen. By fusing these isotopes at very high temperatures it is possible to generate large amounts of energy. The hydrogen isotopes used are deuterium, which can be readily extracted from water (there is around 30g of deuterium in every cubic metre of water), and tritium, which can be generated from lithium, an abundant light metal.

In most hydrogen atoms the centre (or nucleus) contains only one proton. In deuterium the nucleus contains an additional neutron particle, while for tritium there are two neutrons with the proton. The fusion of one deuterium nucleus with a tritium nucleus makes a new nucleus of the element helium (also known as an alpha particle), a neutron and energy – lots of it! One gram of fusion fuel could generate 100 000 kilowatt hours of electricity – to supply the equivalent power you would need to burn eight tonnes of coal! The extra neutron can be used to generate more tritium fuel from lithium.

Fusion occurs naturally in the sun at temperatures of 10 -15 million ?C, producing the energy that sustains life on earth. However, in the sun the fusion fuel is heated and compressed by massive gravitational forces. On earth we cannot use gravity, so the challenge for fusion researchers is to compensate by heating a lower-density plasma to a higher temperature (about 100 million ?C, or 10 times hotter than the core of the sun) with excellent thermal insulation to initiate self-sustaining fusion reactions. Fusion reactions occur at high temperatures when the nuclei collide with sufficient energy to overcome the natural repulsive forces of their electrical charges. 100 million ?C is well above the temperature at which a gas is completely ionised and becomes a plasma, the fourth state of matter. In an ionised plasma the positively-charged nuclei and negatively-charged electrons of atoms are separated and move about freely like molecules in a gas. More than 99% of our universe exists as plasma.

To reach such temperatures, powerful heating is necessary and heat loss must be kept to a minimum by holding the hot plasma thermally insulated from the reactor walls – a process known as confinement. This is an extremely difficult task, both in terms of understanding the complex physical processes happening and the need for sophisticated technologies. Fusion research has developed two different technologies: magnetic confinement and inertial confinement.

Magnetic confinement uses strong magnetic fields to provide the thermal insulation of the plasma and allows the possibility of steady state operation, whilst inertial confinement uses high-power lasers or ion beams to heat and compress minuscule pellets of fuel to very high density and ignition for a very brief time.