WHAT CONFINES A FUSION REACTION & WHY IS IT NECESSARY?

For practical purposes, matter exists in four states: solid, liquid, gas, and plasma. In terms of density (mass per unit volume), from the greatest to least density, generally they are solids, liquids, gases and plasmas, though plasmas can exist at all densities.

A plasma occurs when atoms become ionized (i.e. when atoms or molecules, individually or in a group, become highly electrically charged with extremely high kinetic energy). Stars are essentially superheated balls of plasma. It is estimated that more than 99% of the universe exists in a plasma state.

Fusion is the process that powers the sun and all stars. It occurs when two isotopes of hydrogen or other low atomic number isotopes combine, or “fuse”, to form a heavier atom. The fusion process with the lowest energy threshold is between deuterium and tritium (isotopes of hydrogen) which fuse to produce an atom of helium and a neutron with a concurrent significant release of energy. The state of matter that supports fusion is plasma. To make fusion happen, hydrogen atoms must be heated to very high temperatures (100 to 150 million degrees C) so that they have sufficient energy to enable fusion. Besides temperature, the ionized atoms must be held together long enough to fuse (i.e. confinement of the plasma). The sun and stars do this by gravity. The approaches being used today in fusion research laboratories are either the application of strong magnetic fields (for long confinement times of low density plasma) or inertial confinement (for ultra-short confinement times of ultra-dense plasma). The former uses large magnetic coils such as the Tokomak Reactor. The latter utilizes lasers for compression and intense heating of the hydrogen fuel.

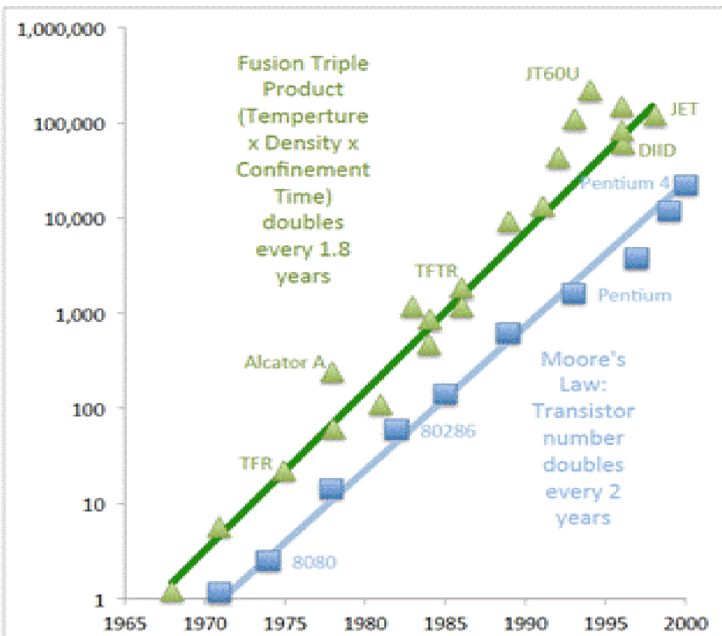
In both approaches, to achieve net energy out, the confinement period multiplied by the density must exceed a certain value determined by energy losses from the hot plasma. Note that the relatively small amount of confined high temperature plasma in a fusion reactor would be quenched immediately upon contact with an external surface (analogous to a teaspoon of boiling water being dumped into a litre of cold water – the resulting mixture of water essentially has the same temperature as the original temperature of the litre of cold water with no boiling). Confinement in practical application of a fusion reactor also refers to the need for the internal high temperature plasma state being kept away from any external wall.

Today, numerous laboratories have achieved plasma conditions required for fusion to occur but not yet in a sustained way. The following graph, “Moore’s Law for Magnetic Fusion”, shows how plasma conditions have progressed as defined by the “fusion triple product” (i.e. the triple product of temperature times density times confinement time, which also equals pressure times confinement time). Comparison is made to the speed of advancement following Moore’s Law which states that the advancement in computer technology over the past 50 years has followed a pattern of computer processing power doubling every two years. The fusion triple product has also doubled every two years in the same time-frame.

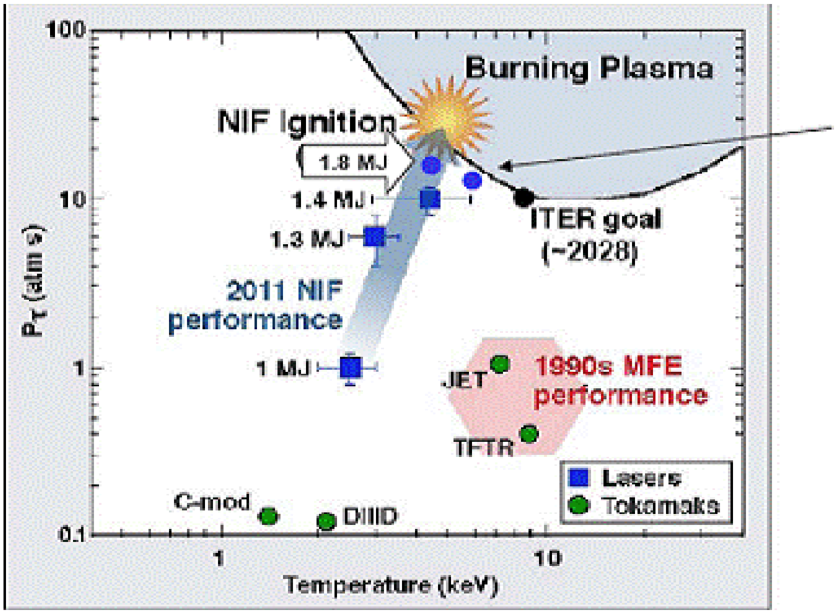
While complete fusion has not been achieved (i.e. full burn or fusion of available hydrogen atoms), ignition has been achieved where some of the available hydrogen has been ignited or fused. If fusion continues to develop at its current pace, full ignition is expected to occur in a time-frame that would support the planning and development of a continuous pilot electric power generating plant in the 2030-2040 time frame. The following graph, “Progress to Ignition for Inertial & Magnetic Fusion” shows the progression to reaching fusion “ignition” for both magnetic and inertial confinement.

There is an interesting relationship between computing power and fusion development. Today, one of the world's most advanced computing infrastructure is part of the Lawrence Livermore National Laboratory in Livermore, California, which is the world's most advanced operating laser fusion ignition facility. Computers provide the ability to manage complex environments far beyond human and pure mechanical capabilities. This is evident today, whether it is in controlling the fuel mixtures in automobiles or managing complex electrical energy systems that require response times much less than a second.

Moore's Law for Magnetic Fusion



Progress to Ignition for Inertial & Magnetic Fusion



Burning Plasma
NIF Ignition
1.8 MJ
1.4 MJ
1.3 MJ
2011 NIF performance
1 MJ
ITER goal (~2028)
JET
1990s MFE performance
TFTR
C-mod
DIIID
Lasers
Tokamaks
Pτ (atm s)
Temperature (keV)
100
10
1
0.1
1
10