Breakthrough in Nuclear Fusion Energy

Why in news?

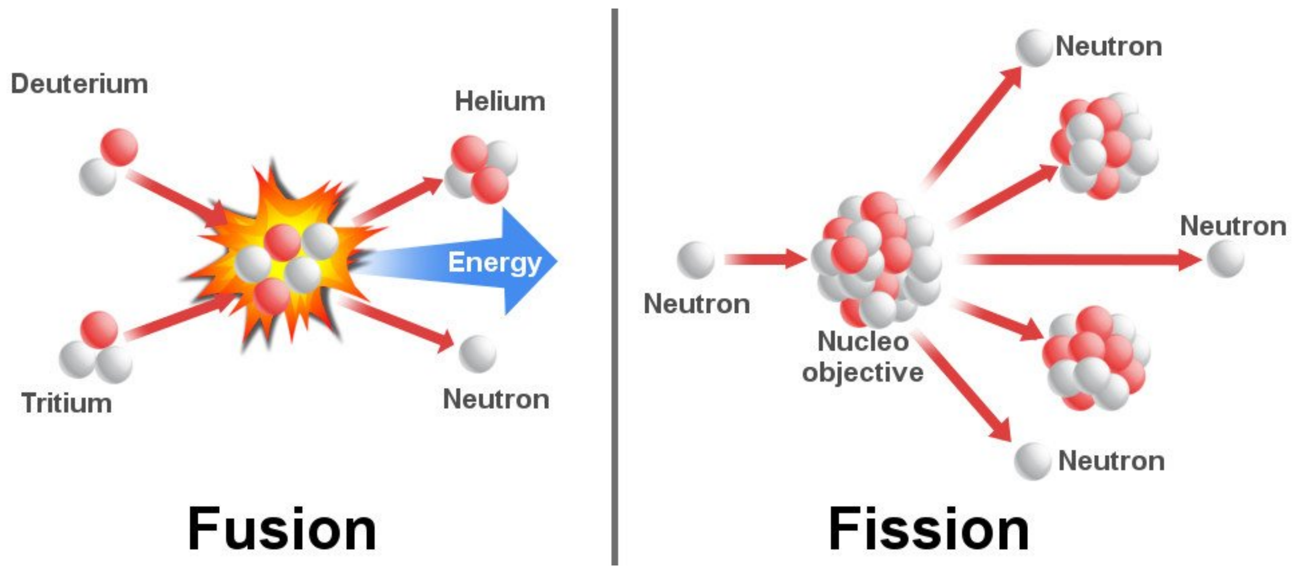
Researchers at the Lawrence Livermore National Laboratory in California for the first time produced more energy in a fusion reaction than was used to ignite it, something called net energy gain.

What is nuclear fusion?

- Nuclear fusion reactions power the sun and other stars.
- Nuclear fusion reaction happens when two light nuclei (hydrogen) merge to form a single heavier nucleus (helium), releasing enormous amounts of energy and heat.
- To combine two identical elements is actually very hard because they have the same positive charge and naturally repel each other.
- A lot of energy is needed to overcome this resistance.
- In the Sun, this happens due to extremely high temperatures of around 10 million degrees Celsius, and significant pressure of more than 100 billion times that of the Earth's atmosphere.

Differences between nuclear fission and fusion

- Fusion is the joining of atomic nuclei and fission is the splitting of atomic nuclei.
- Fusion produces far more energy than that created by fission.
- Fusion, unlike fission, does not create harmful radioactive by-products that need to be stored for thousands of years.



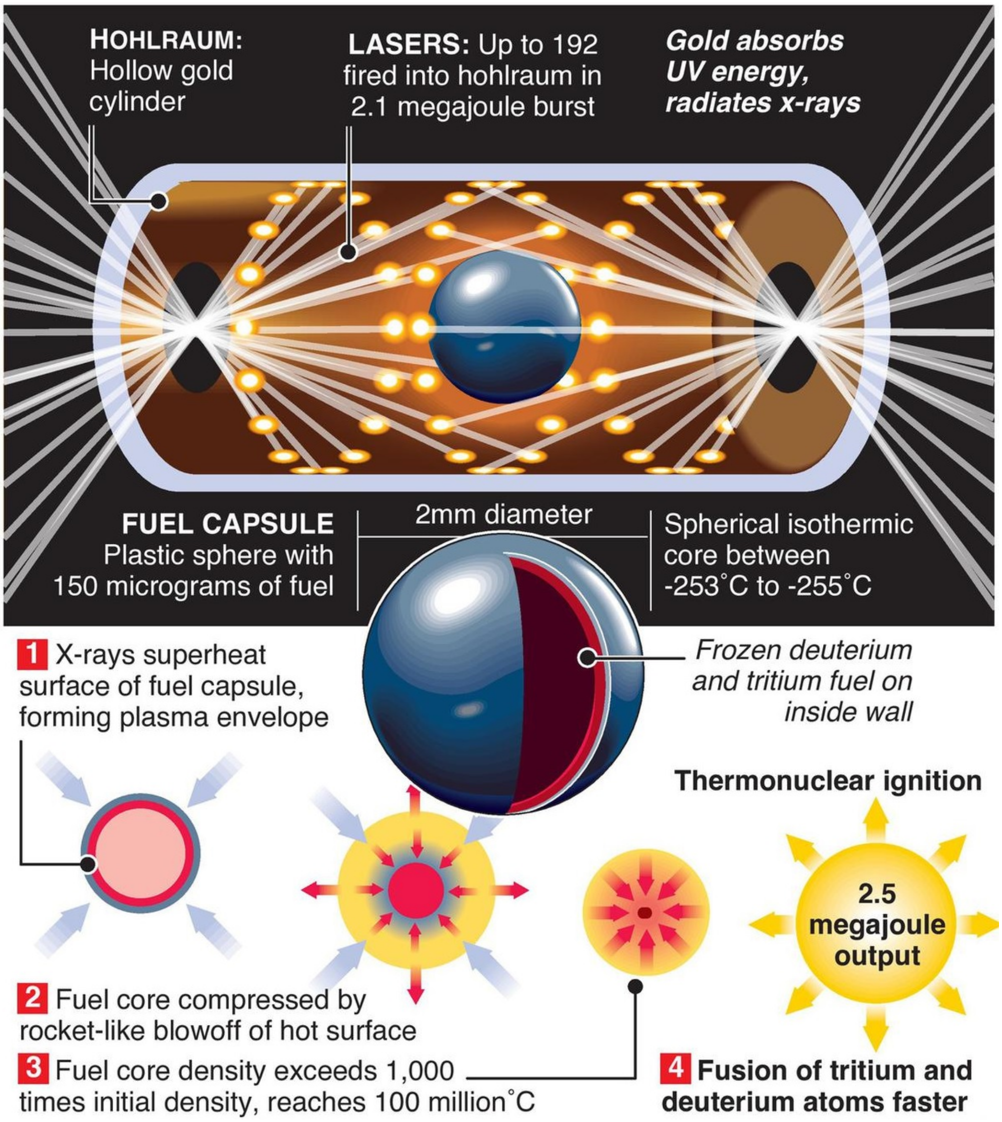
Why is fusion energy so significant?

- **Less radioactive** - The waste produced by nuclear fusion is less radioactive and decays much more quickly.

- **No need for fossil fuels** - Nuclear fusion doesn't need fossil fuels like oil or gas.
- **No GHGs** - It also doesn't generate greenhouse gases (GHGs).
- **Targeting net zero** - Widescale use of nuclear fusion could help countries meet their targets to produce net zero emissions by 2050.
- **Availability** - Since most fusion experiments use hydrogen, which can be extracted cheaply from seawater and lithium, nuclear fusion offers the possibility of “basically unlimited” fuel.
- **Self-limiting process** - Fusion is a self-limiting process in which the machine switches itself off if the reaction cannot be controlled.
- Because of its significance, it has been described as the "**holy grail**" of energy production.

How are scientists trying to produce fusion energy?

- **Magnetic confinement -** Magnetic confinement uses a reactor called tokamak, in which a hydrogen plasma is heated to high temperature and the nuclei are guided by strong magnetic fields.
- **International Thermonuclear Experimental Reactor (ITER)** is a famous example of an experiment trying to achieve fusion using magnetic confinement.
- **Inertial confinement** - In the Livermore lab, a 192-beam laser fire pulses at a small capsule filled with deuterium-tritium atoms inside a cylinder called a hohlraum.
- The latter heats up and releases X-rays, which heat the nuclei to millions of degrees centigrade and compress them to billions of Earth-atmospheres.
- It is called inertial confinement because the nuclei’s inertia creates a short window between implosion and explosion in which the strong nuclear force dominates, fusing the nuclei.
- It is relatively easier to attain break-even energy levels through inertial fusion compared to magnetic fusion.



What has the experiment achieved?

- **Gain** - The ratio of the output energy to the input delivered to the container is the gain.
- A gain of 1 is called ‘**scientific breakeven’** – an important milestone in the development of fusion energy.
- **Lawson criterion** - In August 2022, the facility reported it had produced a burning plasma that met the Lawson criterion.
- According to Lawson criterion, the heat generated was sufficient to potentially trigger other fusion reactions as well as offset heat loss during the reaction.
- Now, the facility has reportedly achieved a burning plasma that meets the Lawson criterion as well as a gain greater than 1.

What issues lie ahead?

- **Effectiveness** - Some of the input energy is devoted to compressing the capsule instead of raising the temperature.
- This fraction will increase as the amount of fuel increases, creating another barrier to high gain.
- **Gain** - Future research will need to focus on reaching the next major milestone – a

target gain of G > 100, which is required to run a power plant efficiently.

- **Rate of firing** - The rate at which any reactor fires its lasers at the hydrogen capsules needs to be orders of magnitude faster.
- **Conversion to usable form** - Even if the inertial fusion process is more efficient, the produced energy still needs to be converted into usable electricity.
- **Cost** - The cost to run and maintain an inertial fusion reactor needs to decrease dramatically.
- **Commercial viability** - It is still not obvious whether inertial fusion can be commercially competitive.
- Fusion is still far from reality.

Quick facts

International Thermonuclear Experimental Reactor (ITER)

- ITER is the world's largest experimental fusion reactor facility in **France**.
- It is a large-scale scientific experiment intended to prove the viability of fusion as an energy source.
- It includes the contributions of 35 countries, including **India,** China, South Korea, Japan, Russia and the United States.
- ITER will not produce electricity, but it will resolve critical scientific and technical issues in order to take fusion to the point where industrial applications can be designed.

References

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2. The Indian Express| Why fusion could be a clean-energy
3. BBC| Nuclear fusion breakthrough
4. IEEE Spectrum| Fusion breakthrough won't lead to practical fusion energy
5. ITER| International Thermonuclear Experimental Reactor (ITER)