Advancing nuclear fusion with nanotechnology

NAPLIFE

Nuclear fusion has long been discussed for its potential as an abundant source of energy. Yet owing to the immense technological challenges involved, the global rollout of the technology still seems a long way off. Dr Tamás Biró and colleagues at the Nano-Plasmonic Laser Inertial Fusion Experiment (NAPLIFE) project, Wigner Research Centre for Physics, Hungary, believe a solution could be found through a new approach to fusion, where nuclear fuel is ignited more efficiently by rapid laser pulses when inserting nanoparticles in the target. Through their research, Biró and his colleagues show how the technique could be made possible through the latest advances in fields including laser technology, fluid dynamics, and nanotechnology.

Today, the need to transition away from our reliance on fossil fuels is growing increasingly urgent. Although the expansion of renewable energy and nuclear fusion will likely be key to achieving this goal, this rollout isn’t happening fast enough to avoid catastrophic damages to societies and natural ecosystems in the near future.

For several decades, physicists have discussed how an alternative solution could lie with nuclear fusion. In theory, this technique could be used to harvest vast amounts of energy as small atomic nuclei – namely a mixture of hydrogen isotopes deuterium and tritium – are fused into larger helium nuclei, through the same mechanism which powers our Sun.

Yet despite such clear benefits, the vision of a global society powered by nuclear fusion still seems many years away. ‘Fusion power plants can produce large amounts of energy, but no such power plant has been built anywhere,’ explains Dr Tamás Biró at the Wigner Research Centre for Physics in Budapest, Hungary. ‘It must be heated to the Sun’s core temperature of one hundred million degrees Celsius, where it must hold the fusion fuel and the hot plasma together.’

To achieve such extreme conditions, physicists so far mainly have used powerful magnets to generate stable plasmas of hydrogen isotopes, deuterium and tritium, within a hollow, doughnut-shaped reactor, and containing them for long enough for fusion to initiate. If full fusion could be achieved, the energy produced in the process would be enough for the reaction to sustain itself – allowing energy to be harvested indefinitely. This principle is a central goal of ITER: an international fusion project currently under construction in the south of France, which is aiming to achieve full nuclear fusion in 2035. Clearly, this is a long way off – and before global, commercially-viable fusion can become a reality, we will need to wait even longer still. On top of this, an unavoidable consequence of fusion based on the d+t reaction is its production of high-energy neutrons, which can damage the expensive equipment required to contain the plasma. However, this approach isn’t the only proposed technique for initiating fusion.

ALTERNATIVES THROUGH COMPRESSION

In their research, Biró and his colleagues at the NAPLIFE project explore an alternative approach, where heated fusion fuel is packed into a gel just one hundred micrometers across, and subjected to sudden, extreme irradiation. Ideally, fusion could be achieved in this scenario, without generating any damaging, high-energy neutrons.

‘At the National Ignition Facility in the USA a capsule containing the fusion material is symmetrically compressed from several directions by high-energy laser or ion beams,’ Biró illustrates. ‘In principle, this can create the necessary conditions for fusion in a material that condenses due to huge pressure.’

To achieve these conditions, the researchers hope to use the short, intense laser pulses available at the Wigner Research Centre for Physics, which in principle would be vastly more efficient than heating plasma to extreme temperatures inside giant reactors. However, the technique doesn’t come without its own challenges: even during pulses lasting for just a few nano seconds, some parts of the fuel will be more compressed than others – leading to a flow named a ‘Rayleigh–Taylor instability’.

This effect can be found in many scenarios in nature where fluids with different densities interact with each other: from the motion of oil when water is poured on top of it, to the mushroom clouds which develop during volcanic eruptions. In this case, motions generated in a fuel which has been compacted to varying densities will prevent it from igniting, creating a need to eliminate any instability.
Behind the Research

Dr Tamás Biró

Dr Tamás Biró aims to enhance the energy effectiveness of nuclear fusion using nanotechnology.

Research Objectives

The NAPLIFE project team, plus external colleagues

Collaborators

The NAPLIFE project team, plus external colleagues

References


Personal Response

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Could compression-based nuclear fusion eventually compete with projects like ITER?

The NIF project is already on the right track. Our nanotechnology improvements to the target, used in combination with various fusion fuels, could in theory increase energy density by a factor of 1,000 or more. As a result, the initial amount of energy required to jump-start the reaction is far smaller. Competitiveness lies not only in achieving ignition (here, ITER has decades of advantage) but also in taming and varying the fusion processes to make the production free from other problems, such as instabilities or energetic neutrons eroding the containment device. Everyone works on such questions – we are trying out some new ideas by connecting nanotechnology with laser-induced nuclear fusion concepts.

In astronomical-sized stars, fusion is a natural process; it is a challenge to create fusion in a giant power plant. It remains to be seen whether table-top or car-engine-size fusion-energy generation belongs to the realms of science fiction or is attainable. I think that, through fusion-fusion, the latter will be made possible in the future.