The Iter fusion project has been grabbing headlines. But the proponents of the rival laser-driven fusion reckon it could deliver power stations more cheaply and speedily. Ben Sampson reports

Fast track to fusion

Laser facility: Hiper will investigate astrophysics as well as nuclear fusion

Taking things apart is often a lot easier than putting them back together. For example, we cracked our first hydrogen atom more than 50 years ago, and have been harnessing energy from nuclear fission ever since. But joining atoms together has proved much more difficult.

Recreating on earth the process that occurs at the centre of the sun was never going to be easy. But if it can be achieved the prize is momentous – a virtually unlimited energy source, without fission's downside of long-lasting radioactive waste. This, say the scientists, is the real answer to our impending energy crisis.

The way towards fusion being presented to the public is the Iter research project, the international treaty for which was signed last month. Construction will soon begin in France on the project's advanced reactor, which at its heart will use massive superconducting magnets to control the fusion reaction. It is hoped that the experimental plant will pave the way for commercial fusion power stations.

But it's not the only way to fuse hydrogen atoms together. Interest in an alternative, less well-known method has been gathering pace in the past few years. The scientists in the know reckon that laser-driven fusion will achieve the holy grail of more energy out than in before Iter is even built, and could cost a lot less.

Efforts to ensure that laser fusion is not overlooked in the wake of Iter have centred on the quiet and leafy Rutherford Appleton Laboratory in Oxfordshire. Mike Dunne, director of the Central Laser Facility there, is one of laser fusion's main proponents and the leader of the Hiper – High Power Energy Research laser – project. Hiper is a group of 50 leading scientists from 10 European nations who have been designing and lobbying for a laser system capable of achieving fusion for the past two years.

"In terms of scientific proof of principle, without a shadow of a doubt, laser fusion will be there first by about five years," says Dunne. "There are programmes in California and Bordeaux that will have proven the physics in the laboratory by at the latest 2012. But the magnetic approach is still the most attractive route to a commercial power plant. They are much further down the line than the laser fusion people when it comes to an integrated reactor design."

The Hiper group wants to catch up on this lost ground by producing a detailed design for the laser within three years. It is seeking €47 million to fund this design, and estimates that a further €800 million will be required to build the plant by 2017. This is way below Iter's €10 billion price tag.

Hiper's design differs substantially from the laser facilities that could prove fusion at the end of the decade. Hiper will be the first laser system to use "fast ignition". This technique uses two laser systems – a long pulse to compress the hydrogen fuel and another short pulse which starts the fusion reaction. This significantly reduces the size of the facility, making it a more economical proposition and opening up the possibility of industrial exploitation. Ultimately, the expectation is that laser power plants using fast ignition could match or exceed Iter's output of between 10 and 30 times more energy out than in.

"Fast ignition offers real hope that laser fusion can be turned from a scientific curiosity into an engineering reality," says Dunne. "We know how to get to a commercial reactor programme. The next step is proving fast ignition in the laboratory."

CREATING A NUCLEAR COMBUSTION ENGINE

Magnetic fusion can be thought of as a continuously burning nuclear furnace, whereas laser fusion is more like an internal combustion engine, where the energy is delivered in bursts.

Mike Dunne, director of the Central Laser Facility at Rutherford Appleton, says: "What we are trying to make is basically a commercially viable nuclear combustion engine, except you are using a sphere instead of a piston." In a diesel engine a piston compresses the fuel, which then ignites and the exhaust gases escape. The cycle is then repeated. With nuclear fusion you inject fuel and compress it until it ignites and burns in the nuclear sense. Energy escapes and the process is repeated. This has been the conventional approach to laser fusion for the past 30 years.

Hiper will be more like a petrol engine than a diesel engine, says Dunne: "We will compress the fuel a little bit, then inject some energy at the highest point of density to start the nuclear combustion, in a similar way that a petrol engine uses a spark plug."

Recent research at the Rutherford Appleton Laboratory and at Osaka University in Japan has focused on how to inject the "spark plug" laser into the centre of the hollowed-out fuel pellets. It was thought initially that a system was needed where one laser drills through the pellet to blow material out of the way for the spark plug laser. But engineering the pellets with a gold cone inserted into them, to direct the laser, has recently been shown to be a more successful method.

LASERS SIMULATE CONDITIONS AT THE SUN

The sun achieves nuclear fusion with gravity, which pulls inwards to create an intense pressure that forces hydrogen atoms together. It is an almost unimaginably colossal engineering challenge to recreate such conditions on earth. From an engineering perspective, you clearly cannot use gravity, and there are two main ways available.

Magnetic fusion heats up the hydrogen atoms and holds them together in a doughnut-shaped bottle, called a tokamak, which contains hydrogen in the form of deuterium and tritium. After a while the atoms in the fuel become energetic enough to overcome their natural repulsion, and fusion occurs.

Laser fusion uses an opposite approach, creating a high-density mass for a short time rather than a low-density mass for a long time, as in magnetic fusion.

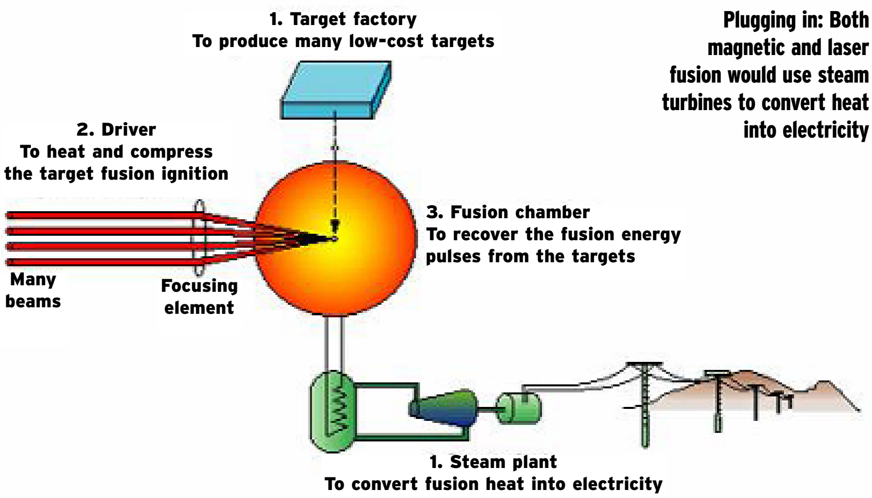
Imagine holding a sponge and squeezing it with your hand, compressing it to a smaller volume and increasing the foam's density. Imagine doing the same thing to a bar of lead, but squeezing it to a density 40 times greater than it was initially. This is the level of compression required to enable thermonuclear ignition, and it only needs to be held for a few trillionths of a second to achieve fusion.

To take it one step further and create your own (theoretical) laser-driven fusion reactor, swap your bar of lead for a perfectly formed, cryogenically frozen, hollowed-out sphere of deuterium and tritium fuel about 1mm in size – in effect a tiny pellet. Instead of your hand, use a series of laser beams to focus intense levels of energy down on to the pellet in a series of precise symmetrical points.

This heats the sphere's surface to such a high temperature that it turns into an ionised gas, a plasma. One of plasma's characteristics is that it expands and, when it does this in the sphere, it pushes an equal force into the rest of the pellet, causing the compression. The process continues until a maximum point of density, resulting in the same amount of mass but a smaller volume.

With a large enough laser and a high enough temperature, thermonuclear ignition occurs. Because it is energetically favourable to have a dense material, with a high enough density and enough reactions occurring, a chain reaction similar to the one at the core of the sun is triggered, and the process becomes self-sustaining.

Until recently, fusion in such a way had only been achieved in the US, using nuclear warheads to fuel the process. But lasers can deliver large amounts of energy in a very short accurate pulse and can compress matter to very high densities, suiting them to this application. Advances in laser technology mean that systems of the required magnitude can now be created. It is anticipated that advances in solid-state laser diode technology will allow such conditions to be achieved at high efficiency and repetition rate for a future reactor.



Plugging in: Both magnetic and laser fusion would use steam turbines to convert heat into electricity

But fast ignition is an unproven process, and it will require some incredibly clever engineering to build Hiper. First, the lasers used for the implosion need to be "two orders of magnitude greater than anything that currently exists" and "in the region of 20% efficient when you currently have 1% efficiency," says Dunne. For a commercial power plant to be feasible it would need to fire five times a second. For comparison, the laser machines operating at the end of this decade will fire once every few hours.

Then there is the fuel, which needs to be made and stored cryogenically because it is composed of hydrogen isotopes. Fuel pellets are currently hand made into a perfect 1mm sphere, with a surface roughness measured on the nanoscale. Considering that five pellets will be used a second in any power plant, it will require an entire industry, using technologies not even demonstrated yet.

"But the biggest engineering challenge is figuring out how to integrate the reactor," Dunne says. "You need a system injecting pellets into the centre of a vacuum chamber in a way which enables the laser to hit each pellet with the right level of uniformity. The system has to remain cryogenic, but it also has to be able to sustain a thermonuclear explosion. You then have to clear out the whole system in time for the next shot."

There are laser engineering challenges in the stability and uniformity of the illumination, and micro engineering challenges associated with target injection and fabrication. Then there are the challenges associated with the choice of materials with which to build the reactor chamber.

The project will borrow from other areas to surmount these obstacles. The technology for the "spark plug" laser will come from work with large optical telescopes, and use segmented mirrors to split the beam and focus it into a single point. Dunne also believes that the MEMS semiconductor industry will yield secrets that will aid the invention of a bulk manufacturing process for the target pellets.

Glitter ball: Gold is used in the target pellet's core because of its malleable and smooth properties

"Nuclear fusion always seems to be 30 years away whenever you ask," Dunne says. "Now it's just round the corner, you still have to be realistic and ask how can we turn this into an engineering commercial reality? And there you are talking about a long-term programme still."

Dunne thinks fusion, whether magnetic or laser, is not an immediate solution to our energy problems. Alternatives should be examined over the next few decades, including renewables, fission, or possibly fusion/fission hybrids. "You could be waiting until mid-century for a series of fusion power plants," he says. "But for a 10, 20, 30% contribution to the energy mix, you are talking end of century. But what are the alternatives? Fusion is one of the only long-term fuel sources one can envision.

"If I was a politician, I would want to know all the options. I would still put money into Iter, but it is by no means certain they will achieve their end goal. We want money for the design work that puts this option on the table. It's then up to the politicians to judge whether or not it's worth proceeding."