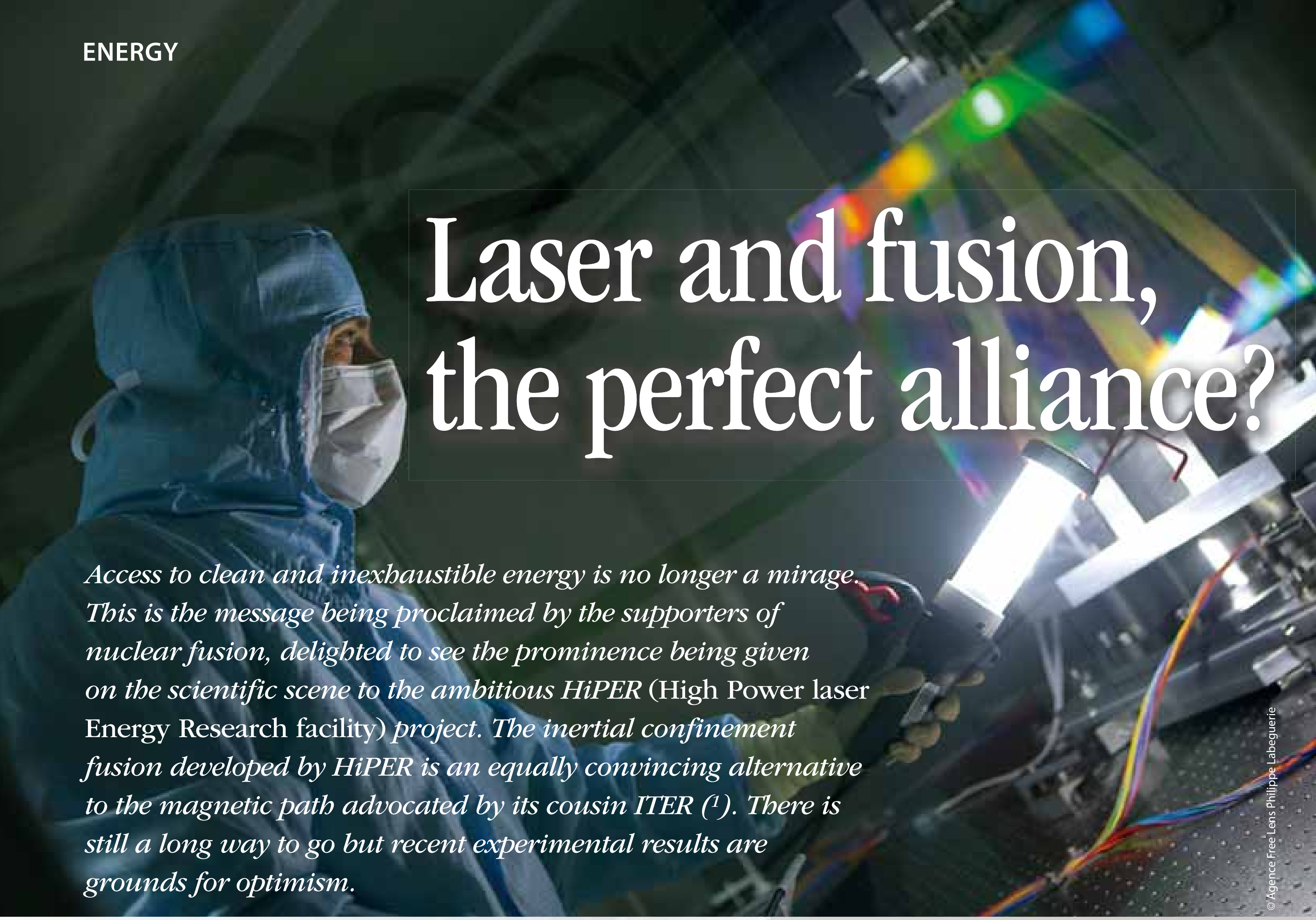

Laser and fusion, the perfect alliance?

Access to clean and inexhaustible energy is no longer a mirage. This is the message being proclaimed by the supporters of nuclear fusion, delighted to see the prominence being given on the scientific scene to the ambitious HiPER (High Power laser Energy Research facility) *project. The inertial confinement fusion developed by HiPER is an equally convincing alternative to the magnetic path advocated by its cousin ITER (1). There is still a long way to go but recent experimental results are grounds for optimism.*

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Inexhaustible resources, low waste, low environmental impact, foolproof security and compatibility with existing electricity networks. The benefits of fusion are such that humanity can no longer do without it. The process itself has been known since the '50s: a forced meeting of the nuclei of deuterium and tritium to produce helium, neutrons and an enormous quantity of energy. Simple enough on paper, but complicated to implement, given the conditions of extreme density and temperature at which this reaction is triggered.

Theoretical and experimental studies concur on two possible approaches. The first is to design a torus in which hot plasma is confined by a magnetic field – this is the *ITER* approach. The second, inertial confinement, also known as laser fusion, involves using powerful laser beams to implode pellets of pre-compressed fuel. It is this second approach that *HiPER*'s designers have opted for.

High value added

"We are pleased that since 2006, *HiPER* is among the scientific facilities supported by ESFRI – European strategy forum on research infrastructures," says Mike Dunne, general coordinator of the project. "Right now, *HiPER* is in its preparatory phase, funded to the tune of three million euros by the 'infrastructure' activity of the Seventh Framework Programme (FP7) and several times that amount by national agencies." The technology demonstration phase will begin in 2011, leading, at the end of the next decade, to the construction of the facility itself, at a cost of around 1 billion euros.

These colossal investments are explained at once by the complexity of the technological innovations themselves and by the applications that are potentially available once the processes are mastered. "Fifty years of experiments have shown that self-sustaining fusion requires a temperature close to 50 million degrees and a density of at least 1 kg/cm^3, 50 times that of gold", Mike Dunne continues. "Moreover, it is a high repetition technology, since we need to align the laser pulses of around one nanosecond each with pellets of one millimetre in diameter, five times a second." To achieve the goal of controlled fusion, scientists are therefore exploring areas of physics that are still poorly understood and which, it is hoped, will open the door to future applications.

"And the list will be long!" Mike Dunne adds. "Mastering high repetition and high energy laser technology together opens the way to activities as diverse as radioisotope production, oncology and even next-generation light sources. On a more fundamental level, we can expect major breakthroughs in extreme materials science and in nuclear and plasma physics."

Hand in hand

There is still a long way to go to meet this technology challenge. Each difficulty of the *HiPER* process has been the object of preliminary studies. These include the *PETAL – Petawatt Aquitaine Laser* – project – funded at European (ERDF), national (France) and regional (Aquitaine) levels – the primary role of which is to develop a suitable laser-target architecture for triggering the fusion reactions. The main technological choices, using innovative technology to overcome the obstacles which became evident at the experimental stage, have just been successfully

◀ **Surface state observations of diffraction gratings** in the *PETAL* mechanical enclosure where they are vacuum-packed.

validated, and the construction of the instrument is underway.

"The project coordinators decided, in 2006, to link up *PETAL* with *HiPER* on the ESFRI roadmap", explains Christine Labaune, research director at France's National Center for Scientific Research (CNRS) and a member of both programmes' scientific committee. "On the scientific and technological level, *PETAL* acts as the first phase of *HiPER*. Since it was launched, an international scientific committee has coordinated the preparation of experiments to validate the areas of physics that ensure the success of *HiPER*. *PETAL* will also offer an educational platform for scientists to gain know-how in manipulating large dimension lasers. It is also an opportunity for everyone to collaborate on a programme that will put Europe on a competitive footing with our Asian and American cousins." It must be recognised, however, that while *PETAL* is scheduled for 2011, the *Omega EP* facility in the U.S. and *FIREX* in Japan are already up and running.

High-flying technology

Just a few years ago, scientists thought they could achieve fusion using nanosecond beams to compress the deuterium-tritium target to produce a hot spot. But too much instability invalidated this scheme. The *PETAL* and *HiPER* teams therefore decided to pursue another path, as Christine Labaune explains. "We believe it is essential to disjoin the compression and the heating phases. This is what we call rapid ignition. The principle is to use short pulse petawatt beams (2) as lighters, after compressing the target with other nanosecond beams. The system ought to be more reliable, with an energy gain higher than 1, and possibly rising as high as 10 or 100."

"*PETAL's* objective", Christine Labaune continues, "is to demonstrate our ability to conceptualise the technologies for generating the short, high-energy beams needed for ignition. Specifically, a high-energy laser system breaks down into three parts. An oscillator-amplifier generates a small, low-dimater pulse. This then passes through a series of glass plates doped with neodymium and pumped by flashlamp, resulting in the emission of photons. These are retrieved by the initial pulse, which is then gradually amplified. Simultaneously, the diameter of the pulse is broadened, in order to maintain a reasonable energy density so as to conserve the optical instrumentation. The pulse lasts a fraction of a pico-second (3) on entry, is then stretched over the entire pathway, then compressed again by a series of gratings, just before the exit. In this way, an initial pulse of a few milli-joules ultimately reaches about 3 500 joules, while remaining short. This will make *PETAL* the laser facility with the highest power-energy ratio in the world."

Raising investor awareness

In view of the sums invested, *PETAL* and *HiPER* will be an occasion to deploy a large basic research programme to understand matter in its extreme states. Even so, the primary objective remains the controlled production of fusion energy. Once we know that the lithium (a source of tritium) contained in an ordinary notebook battery coupled with the deuterium present in half a bathtub of water is sufficient to cover the electricity needs of the United Kingdom for 30 years, the reluctance of the private sector to invest heavily in these projects can be surprising.

"It is indeed regrettable", confirms Christine Labaune. "The only long-term energy that will remain inexhaustible is nuclear. Given the many problems of nuclear fission in terms of waste, safety, and limited supplies, the only solution for humanity remains fusion. We maintain that lasers are excellent candidates for reproducing the fusion process on Earth. For this we need applied research. It is therefore desirable for private institutions to take an interest in the problem. We need to find out who are the industrialists who will be building and earning profits from tomorrow's power stations. They ought to be investing today in the research that will allow Europe to retain its energy independence. If our scientific community lacks sufficient resources to remain at the forefront, we become completely dependent on countries that have mastered this technology." ●

Marie-Françoise Lefèvre

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A pre-amplifier module (PAM) integrating the two stages of wide spectral bandwidth parametric amplification. In the first phase of the *PETAL* project, the PAM serves as the demonstration pulse compression source.

i **HiPER**
26 partners, 9 countries
(CZ, DE, ES, FR, GR, IT, PL, PT, UK),
6 non-Union countries
(CA, CN, JP, KR, RU, US)
www.hiper.org

PETAL
http://petal.aquitaine.fr

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(1) *ITER – International Thermonuclear Experimental Reactor*, see "*ITER* emerges from the earth", *research*eu* number 61, July 2009.
(2) Peta = 10^{15}
(3) Pico = 10^{-12}