2 Introduction to HiPER

2.1 Background

This is an exciting time for plasma physics and its application to fusion energy production. We are entering a period of huge investment in facilities that should demonstrate the scientific basis for this much heralded source of energy. Recently the international community took the decision to fund the ITER project to the tune of around 10 billion Euros. It is expected that in the early 2020s this device will use magnetic fields to confine a large, low-density plasma in quasi-steady state such that it releases more energy than it consumes. Alongside this, France and the USA are constructing multi-billion-Euro laser facilities to achieve net fusion energy production for the first time in the laboratory. Producing in excess of 10 times more energy than the lasers deliver, this will provide the scientific foundations for a pulsed fusion energy source.

This approach, known as Inertial Fusion Energy (IFE), has been studied for over 40 years as an attractive long-term energy solution, and as a means for creating the most extreme conditions achievable anywhere on Earth. The physics underlying inertial fusion is already proven. This is the approach adopted by Nature– inertial fusion powers the stars. Far more importantly, the process of net energy production from inertial fusion has already been demonstrated on Earth in an offshoot of the US defence mission in the 1980s. Demonstration of net energy production using a laser is now anticipated in 2010 on the National Ignition Facility: just 3 years away. This world-altering event will require a clear response to the public – it is essential therefore that our scientific community clearly understands the future path to an energy programme following this event. The field is still in the Research and Development phase, requiring international cooperation over the next decade centred on a next generation laser facility to allow academic and commercial exploitation into the energy and basic science sectors. Europe is ideally placed to lead the world in this journey, but requires a focused programme to ensure timely progress.

The High Power laser Energy Research facility, HiPER, meets this need by opening up a credible route to inertial fusion energy for commercial purposes whilst offering an internationally unique capability in the science of extreme conditions.

Such a move has been made feasible by recent evidence supporting a revolutionary approach to laser-driven fusion, in which an order-of-magnitude reduction in the scale of the drive laser seems achievable. Optimisation of this so-called “fast ignition” approach will be a principal goal of HiPER. This will pave the way for the development of an integrated reactor programme.

Whilst the energy mission addresses one of the highest societal priorities, the scientific requirement for HiPER is overwhelming. Analysis during the 2-year design study clearly indicated that “fast ignition” was the prime technical solution that could provide an optimum balance of scientific excellence and long-term energy options. HiPER meets the clear demand from the international science community to deliver a step-change in laser capabilities to open up entirely new research programmes in areas as diverse as laboratory astrophysics, extreme material science, turbulence, and fundamental atomic, nuclear and plasma physics.

Because the scale of HiPER is significantly greater than existing academic lasers, an intermediate scale facility (PETAL, in the Région Aquitaine, France) has already been commissioned. PETAL has been accepted as an integral part of the strategic path to HiPER. This is a major commitment, providing an essential stepping stone both in terms of the science and the technology for HiPER and the international user base.

No comparable laser system is underway anywhere in the world – HiPER will be a highly effective international attractor to Europe. There are significant industrial opportunities for Europe as part of the HiPER project – in the design and build phase, the operational phase, and from the ensuing technical spin-out opportunities. Furthermore, the long-term industrial impact associated with laser fusion is huge in scope.

A representative timeline for HiPER is shown in Figure 2.1. A 2-year design phase has just been completed. A 3-year preparatory construction phase is now planned to establish a consortium of nations, funding agencies, scientific institutions and industry to construct and operate the facility. The timing reflects the expected progress on existing facilities: achievement of fusion ignition on NIF (and subsequently Laser Mégajoule), and the establishment of the route to "fast ignition" using the FIREX-I (Japan), OMEGA-EP (USA) and PETAL (France) lasers.

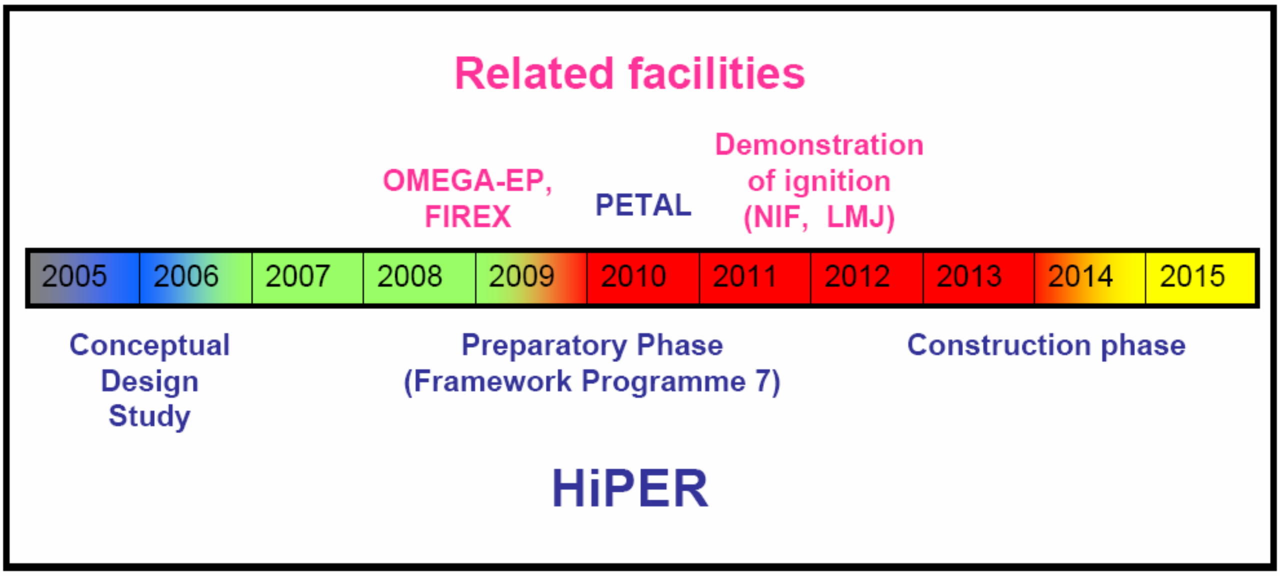

Fig 2.1 – HiPER milestones against the backdrop of international developments

In summary, HiPER represents a unique opportunity for Europe to take a leading role in the field of extreme science and ensure it targets the key challenge facing mankind – long term clean energy.

2.2 The Science mission of HiPER

Key to the needs of the large international user community is the provision of a flexible, responsive facility able to address a broad array of science programmes. The laser community has long experience of adapting its facilities for new users and new research areas. Lessons from facility operators and scientific users were pulled together in the conceptual design of HiPER to obtain a balance between the fusion energy mission and the wider science remit. The science programmes were selected for their compelling nature in terms of delivering an extreme science capability to Europe. The HiPER facility specification was then developed to provide an internationally leading capability in these areas.

The scope included:

- *Opacity and photoionization physics* - to address many outstanding fundamental atomic physics questions, along with their application to (for example) solar modelling.
- *Warm Dense Matter studies* – addressing the principal outstanding regime of material science in which there is no accepted theory (for which HiPER will offer exceptional probing and diagnostic capability).
- *Laboratory Astrophysics* – consistent with the fusion and high energy-density potential of HiPER, there is a wealth of astrophysical phenomena whose models could be tested in the laboratory, including supernovae evolution, proto-stellar jets, planetary nebulae, interacting binary systems, cosmic ray seeding and acceleration, and gamma-ray bursters.
- *Extreme Matter studies* – What are the fundamental properties of matter in extreme states? This includes studies in Gigagauss magnetic fields (otherwise only found in highly compact stellar objects, and in which the magnetic field dominates the electric field in determining sub-atomic motion), in Gigabar pressure regimes, in radiatively dominated systems, in burning plasmas, etc.
- *Turbulence* – how do compressible, nonlinear flows transition to turbulence and subsequently evolve? This is one of the few remaining fundamental uncertainties in classical physics.
- *Laser-plasma interaction physics* – including the question of how waves and matter interact under highly nonlinear conditions
- *Nuclear physics* under transient, excited state conditions – to study the effect of dense plasmas on nuclear cross sections, the behaviour of isomeric states via pump-probe studies of dressed states, and the creation of high density electron-position pair plasmas and the evolution of the ensuing pair-fireball.
- *Production and interaction of relativistic particle beams* – for example, whether macroscopic amounts of relativistic matter can be created (then studied and utilised)
- *Fundamental physics at the strong field limit*

It is clear that HiPER will open up entirely new areas of research, providing access to physics regimes which cannot be explored on any other science facility. Full details of the science case are provided in the following chapters