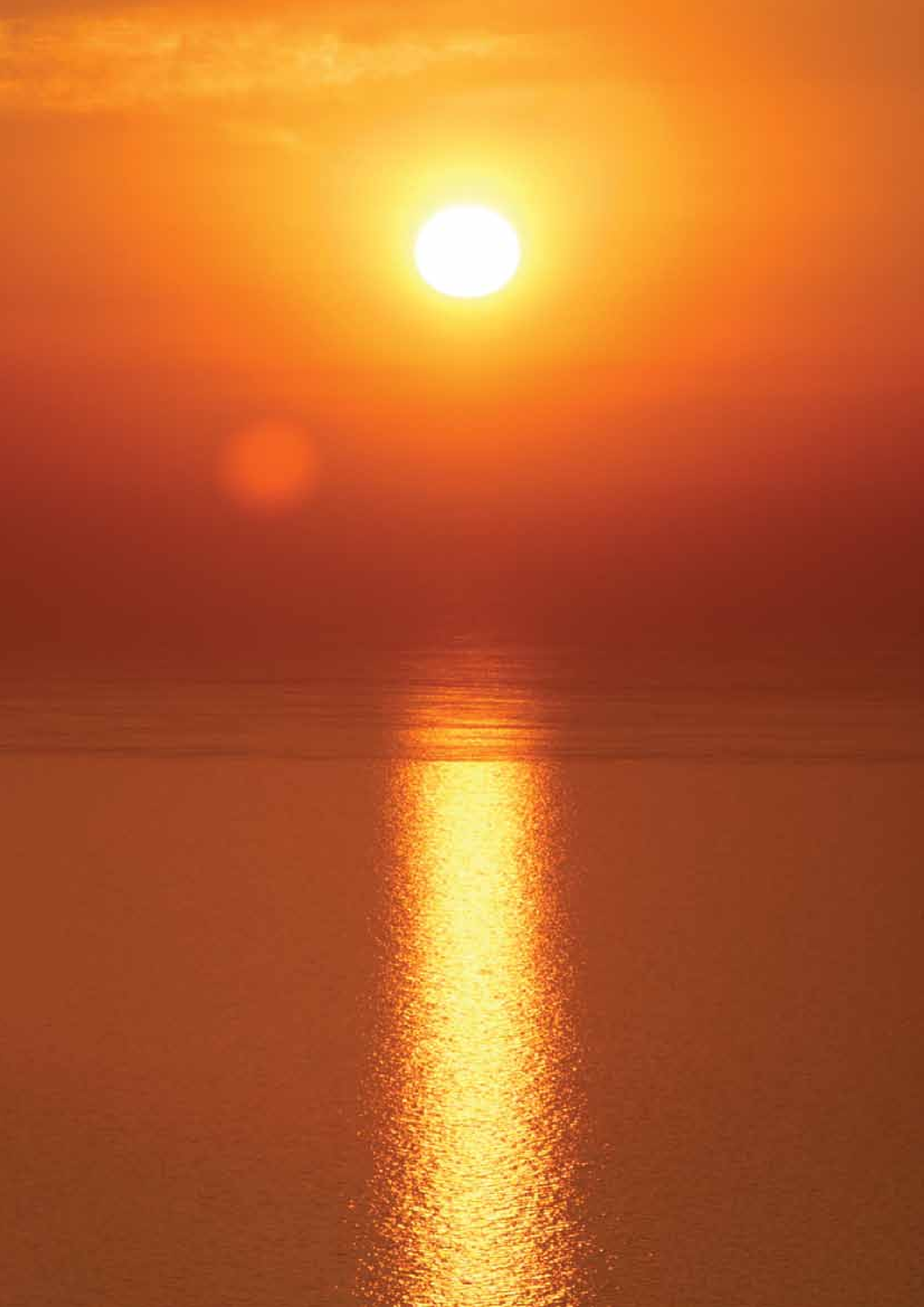
Fusion - A clean future
Research at Culham Centre for Fusion Energy

CCFE
CULHAM CENTRE FOR FUSION ENERGY

Increasing energy demands, concerns over climate change and limited supplies of fossil fuels mean that the world needs to find new, cleaner ways of powering itself. Nuclear fusion – the process that provides the sun's energy – can play a big part in our sustainable energy future.

Around the world, scientists and engineers are working together to make clean energy from fusion a reality. At the forefront of this research is **Culham Centre for Fusion Energy**, where the UK's national fusion programme co-exists with JET, the world's largest fusion device, which CCFE operates for scientists from around Europe under the European Fusion Development Agreement.



Why we need fusion energy

Energy consumption is expected to grow dramatically over the next fifty years as the world's population expands and developing countries become more industrialised. The population of the developing world is predicted to double to over eight billion by 2050. As a consequence, a large increase in energy demand can be expected, even if energy can be used more efficiently.

Furthermore, our current energy sources are under scrutiny: the world's attention is focussed on the dangers of climate change from the unrestrained use of fossil fuels, and reserves of these fuels are finite. Governments are divided on whether to continue to include nuclear fission power plants in energy portfolios. There is an urgent need to find alternative ways of producing energy.

Nuclear fusion can be an important long-term energy source, to complement other non-carbon options including renewables such as hydro, wind and solar. Fusion could start providing commercial electricity in about 30 years, and it has the potential to supply up to 20% of the world's electricity by the year 2100. Fusion energy will have a range of advantages:

The earth lit up at night (NASA/Goddard Space Flight Center Scientific Visualization Studio)

- No atmospheric pollution. The fusion reaction produces helium, which is an inert gas – no greenhouse gases or acid rain are produced;
- Abundant fuels. Deuterium and tritium, the fuels likely to be used for fusion energy, are both forms of hydrogen. Deuterium can be readily extracted from ordinary water, and tritium could be produced in a fusion power plant from a light metal, lithium, which is found in the earth's crust;
- An efficient way of making energy. Just one kilogram of fusion fuel produces the same amount of energy as 10,000,000 kilograms of fossil fuel;
- An inherently safe system. Even the most unlikely accident would not require evacuation of the surrounding population;
- No long-lived radioactive waste. All irradiated material from plant components will be safe to dispose of conventionally within 100 years. It will therefore not be a long-term environmental burden for future generations;
- Economically competitive. The cost of fusion-generated electricity is predicted to be comparable to fossil fuel or fission-generated electricity.

Fusion fact

The amount of lithium contained in a laptop battery, combined with less than half a bathtub of water, can provide enough fusion fuel to supply the average European person's total energy needs for 30 years.


A fusion plasma in the Joint European Torus vacuum chamber

How fusion works

In a fusion reaction, energy is produced when light atoms are fused together to form heavier atoms. This is the same process that provides the energy in the sun and other stars.

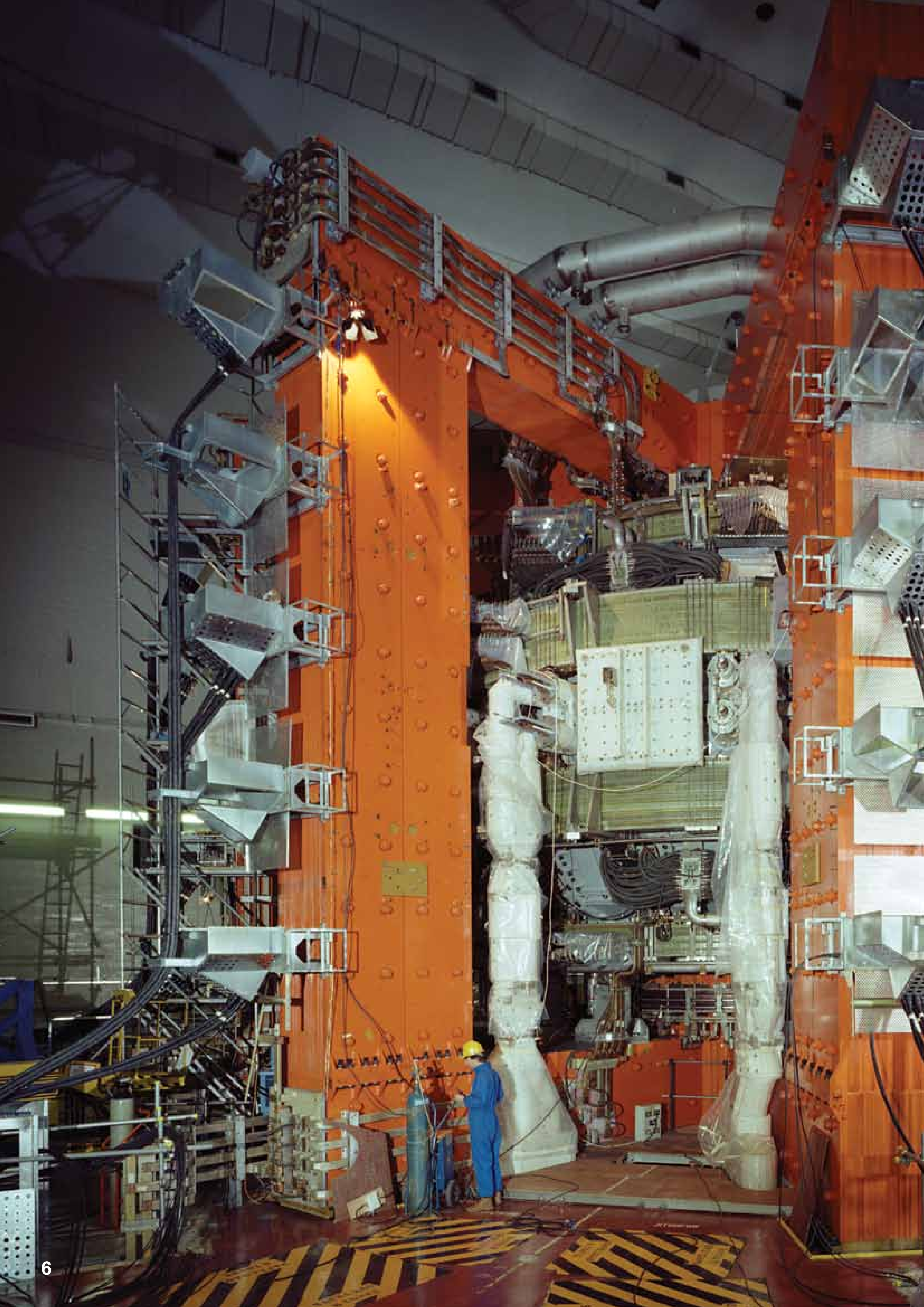
To utilise fusion reactions as an energy source on earth, a gaseous fuel is heated to temperatures in excess of 100 million degrees – ten times hotter than the centre of the sun. At these temperatures, the gas becomes a plasma. (Plasma is common on earth – for example in neon signs, flames and lightning – and in the form of stars and interstellar material it makes up 99% of the universe.)

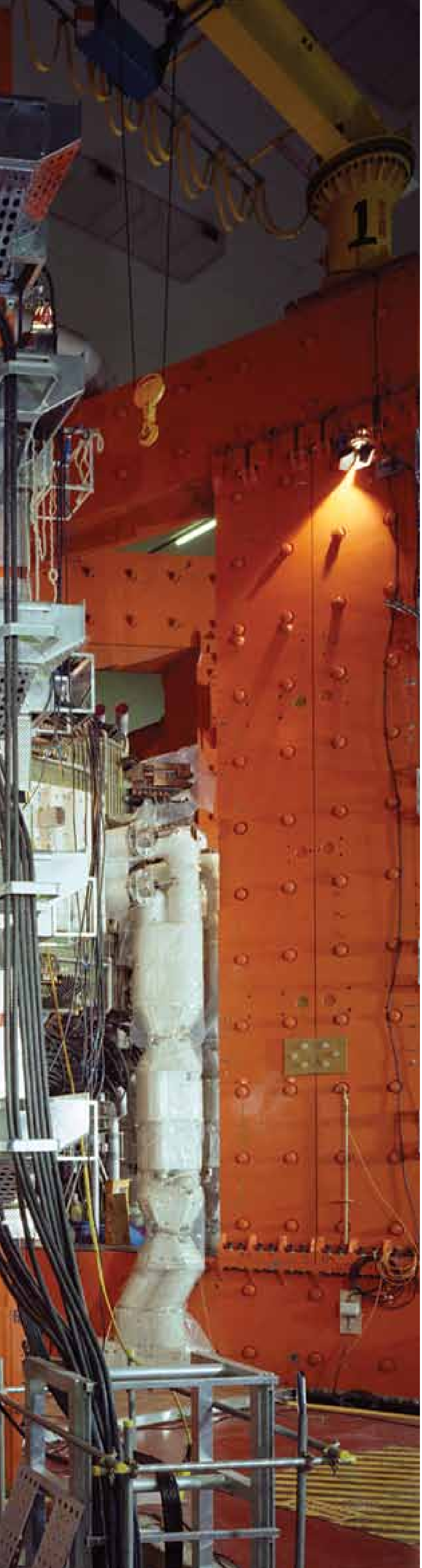
At these temperatures, the particles, deuterium and tritium – both heavy forms of hydrogen – fuse together to form helium and high-speed neutrons, carrying significant amounts of energy. A commercial power station will use the kinetic energy carried by the neutrons, as they are slowed down by a blanket of denser material (lithium), to generate electricity.

The plasma must be kept away from material surfaces to avoid it being cooled and contaminated; strong magnetic fields are used for this purpose. The most promising magnetic confinement systems are toroidal (doughnut-shaped) devices called tokamaks. The Joint European Torus (JET), situated at Culham, is the largest tokamak in the world.

Fusion fact

The sun is a giant fusion reactor. It fuses 600 billion kg of hydrogen every second to release energy, powering all life on earth.





JET – the world's largest tokamak

JET, the Joint European Torus, located at Culham and operated by CCFE on behalf of its European partners, is the world's largest and most powerful fusion research facility. It is the only machine currently capable of operating with the deuterium and tritium fuel mixture that will be used in a commercial fusion power station. JET is the lead project of the European fusion programme being carried out in all member states (plus Switzerland). The programme is co-ordinated by the European Fusion Development Agreement (EFDA) and funded by member states and the Euratom fusion budget.

JET was designed to study fusion in conditions approaching those needed for a fusion power plant. Current research is focussed on using JET to prepare for its planned successor, the international project ITER – which is now being constructed in France – the next important step towards achieving commercial power.

Construction of JET began in 1978 and operations started in 1983. In 1991, JET became the first experiment to produce controlled fusion power from deuterium and tritium. In 1997, further JET experiments also used the mixed deuterium-tritium fuel planned for future fusion power plants.

The use of the JET experimental facilities under EFDA is an outstanding example of successful European collaboration. JET is a 'user facility' similar to those in other fields of physics research, such as CERN – used jointly by decentralised scientific teams. Task Forces of scientists from associated laboratories across Europe come to carry out experiments on JET within the integrated European programme, co-ordinated by the EFDA Close Support Unit.

Fusion fact

JET holds the world record for fusion power, at 16MW – achieved in 1997.

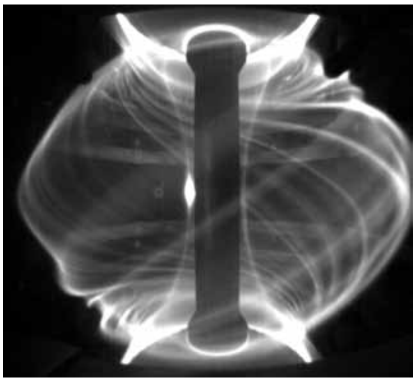
MAST – pioneering spherical tokamak research

Most fusion research has concentrated on the so-called 'conventional' tokamak with a D-shaped plasma, including JET. From 1991, however, a new design – the 'spherical tokamak' – has been pioneered by Culham and is now being explored by laboratories all over the world.

Spherical tokamaks are more compact devices. The plasma is held in a much tighter configuration – more like a cored apple than the 'car tyre' shape of conventional tokamaks. One of the chief advantages is that the magnetic field needed to hold the plasma and keep it stable (essential for an efficient fusion power plant) is much less in a spherical tokamak. This means a substantial gain in efficiency and better plasma performance for the engineering cost. Whilst the first fusion power stations will probably be based on the more mature conventional tokamak design, spherical devices could well provide an alternative for the second generation of plants.

Fusion fact

MAST's range of diagnostics includes unique plasma viewing capabilities. It is the only tokamak in the world able to capture images of the whole plasma – made possible by high-speed cameras operating at up to 250,000 frames per second.



A high-speed camera image of a MAST plasma

The first spherical tokamak, START (Small Tight Aspect Ratio Tokamak), was designed and built at Culham as a low cost experiment to test theoretical predictions. It operated from 1991 to 1998 and produced such impressive results that approval was given for a larger successor experiment, MAST (Mega-Amp Spherical Tokamak).

MAST started operations in 2000. Its objective is to test plasma physics in this tight configuration with strong additional heating. An impressive range of diagnostic equipment has brought new insights into how plasmas behave, which also benefit conventional tokamak research – MAST data is making important contributions to international databases predicting the performance of ITER.

An ongoing programme of improvements will extend the machine's capability even further. In particular, a £30 million upgrade of MAST is planned. The upgrade will explore the route to spherical tokamak fusion power plants, address key physics issues for ITER, and keep the UK at the forefront of fusion research.

Working with industry

Fusion research offers many 'spin-off' benefits for UK industry. Culham's Fusion and Industry team is helping firms to capitalise on these benefits.

Opportunities to work in the fusion sector are set to expand as the ITER project develops. CCFE is advising companies on these prospects and enabling them to register as suppliers at www.fusion-industry.org.uk.

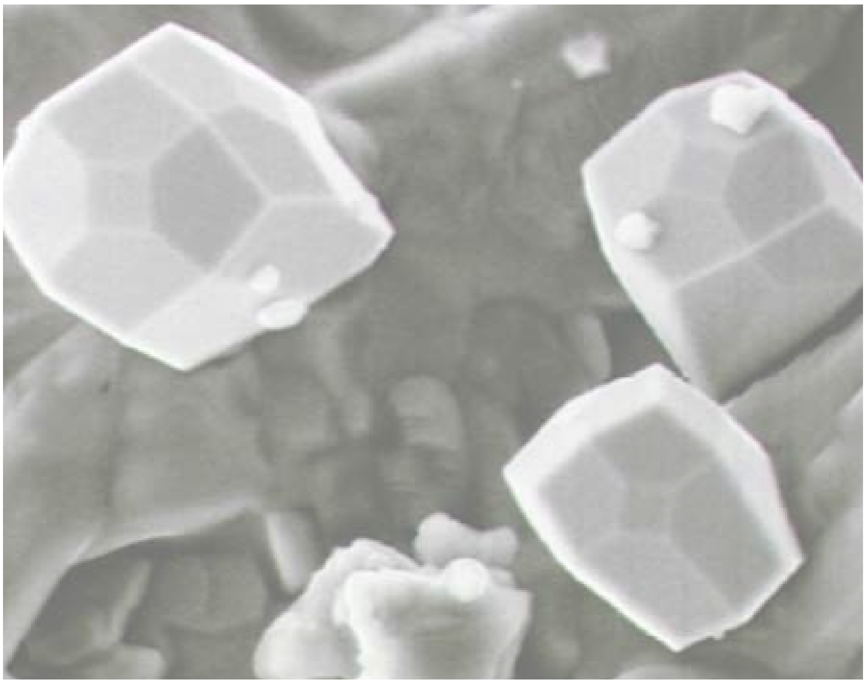
Fusion fact

CCFE is encouraging British hi-tech firms to bid for a share of the estimated €2 billion worth of contracts available in Europe during the construction of ITER.

Technology transfer from fusion to companies occurs in areas as diverse as space research, advanced braking systems and semi-conductor manufacture. The Culham Innovation Centre was set up in 2001 and is managed by Oxford Innovation Ltd, part of the Oxford Trust. It attracts start-up knowledge-based and service companies, which can use a CCFE technical support package to tap into the skills and technologies from fusion research at Culham. The package has been developed by CCFE to assist companies during the early stages of their business. Depending on their needs, a typical package could include technical advice and access to mechanical, electrical and electronic engineering skills, as well as computer modelling, precision diagnostics, cryogenic systems and microwave systems.

Spin-off technologies from fusion research are benefiting a range of hi-tech companies at the Culham Innovation Centre

Materials research at Culham



Choosing the right materials will be crucial to the development of fusion power plants. The options include special steels and more advanced materials, such as silicon carbide composites and lithium-based tritium generating materials. All of these materials have to be developed for use in the challenging environment within a power plant, which will impose a unique combination of temperature, neutron bombardment and stress conditions.

In collaboration with university specialists and European colleagues, CCFE has started work on several important aspects of materials research. These include computer simulations of atomic behaviour and experimental work on candidate materials in JET and MAST, which will lead to a better understanding of materials properties and lifetimes.

Fusion fact

Fusion scientists analyse materials from sub-atomic scale right up to the size that will be used for ITER. This involves spanning a factor ten billion in scale – similar to comparing the size of Culham with that of the entire solar system.

The next steps…

The 'road-map' towards fusion energy production foresees two successive generations of international devices:

- ITER – the next-generation research device now under construction in Cadarache, France;
- DEMO – a prototype power plant which will generate electricity from fusion.

This would lead to the first electricity production in about 30 years.

Parallel development of appropriate fusion materials and the demonstration of the environmental and safety case for fusion power will be completed in time for DEMO's construction. The development of IFMIF (International Fusion Materials Irradiation Facility) is planned to take place alongside ITER. Completion of IFMIF's design is being taken forward as a joint European/Japanese project.

Fusion fact

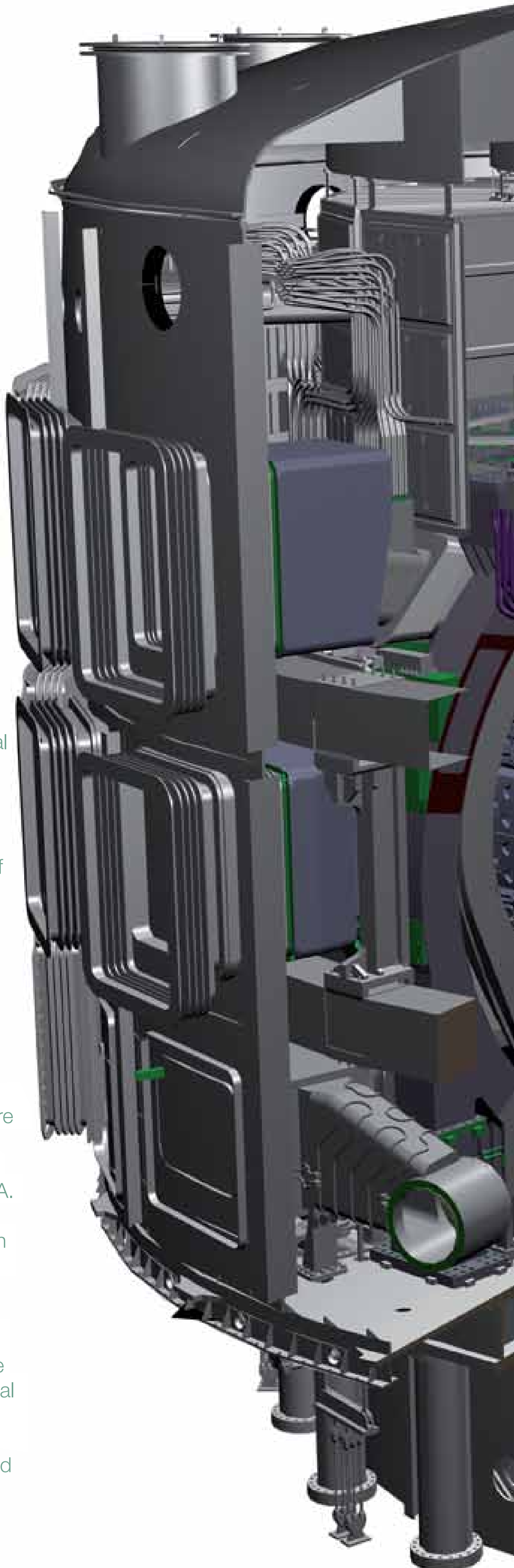
ITER will be the first fusion experiment to produce net power gain – releasing ten times the amount of energy put in.

ITER

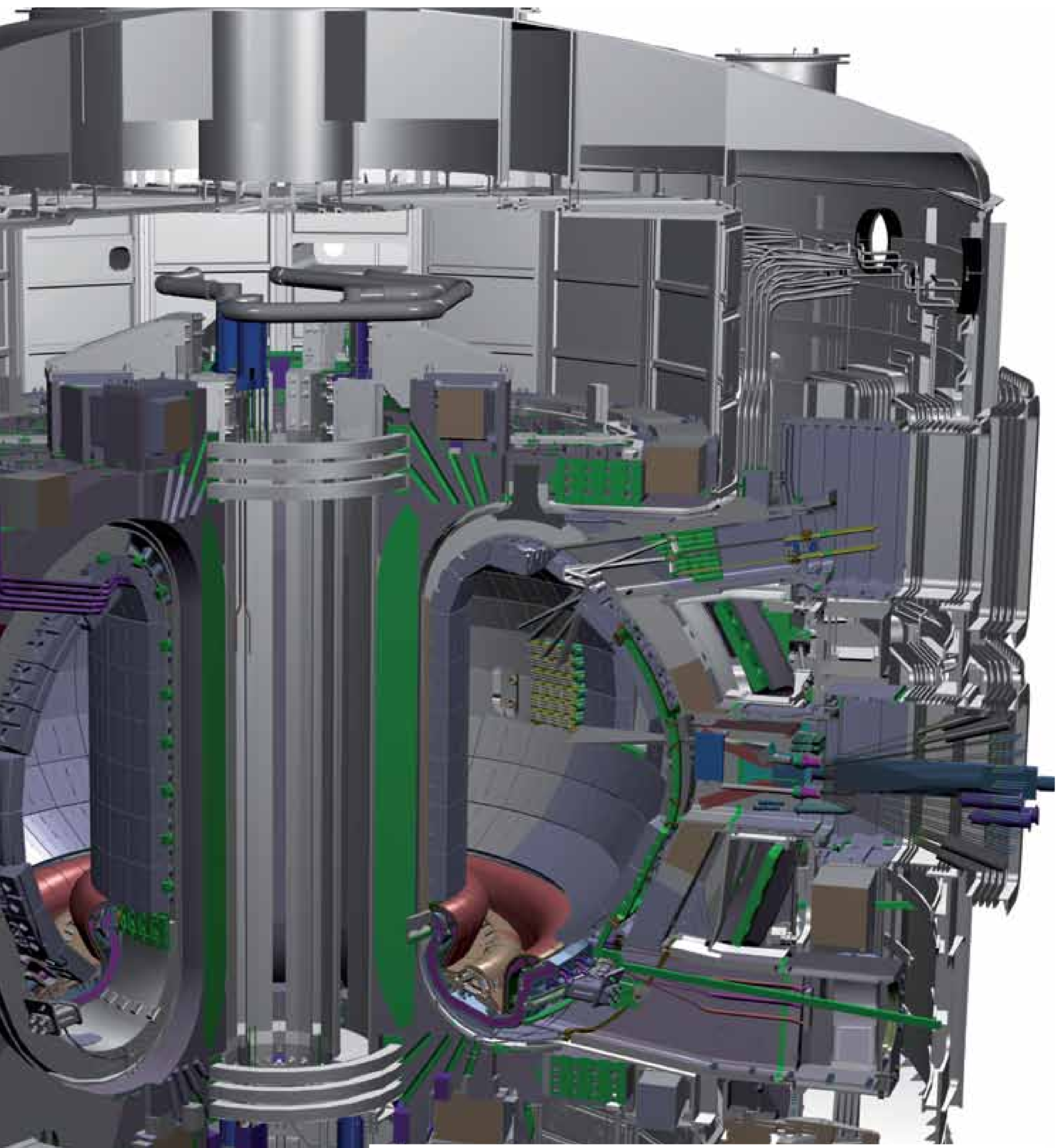
ITER is the next major international fusion project. As the forerunner to a demonstration power plant, it will be a crucial step towards commercial fusion energy. It is expected to prove the feasibility of electricity from fusion by releasing some 500MW of fusion power. ITER will be a scaled-up version of JET, with linear dimensions twice the size, but also using more advanced technologies – for example, superconducting magnetic coils.

Participants in ITER represent more than half the world's population: China, the European Union, India, Japan, Korea, Russia and the USA. ITER will be the world's largest international co-operative research and development project after the international space station.

ITER will be located at an existing energy research site at Cadarache in southern France. An international team is now constructing the machine at a cost in the region of €14 billion. Completion is expected in 2020. This will be followed by a lengthy period of operation that will test essential physics and technologies for the fusion power plants of the future.



A cutaway model of the ITER tokamak



The ITER construction site at Cadarache, France

World-leading science today…for the energy solutions of tomorrow

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