Nuclear Fusion

In brief

Nuclear fusion is an attractive long-term energy solution, although it is unlikely that the technology will be ready for commercial power generation in the near future.

Fusion is the process that produces the light and heat of the sun. Hydrogen nuclei collide in the sun’s core and release huge amounts of energy as they fuse into helium atoms. On Earth, fusion reactors heat gas to extreme temperatures to produce a plasma similar to the conditions found within a star. The many benefits of fusion include an essentially unlimited supply of fuel, passive intrinsic safety and no production of CO₂ or atmospheric pollutants. It is one of the very few candidates for the large-scale, carbon-free production of base-load power. Compared to nuclear fission, it produces relatively short-lived radioactive products, with half-lives limited to less than 50 years and most less than 10 years.

Fact file

- Under the Seventh Framework Programme (FP7) and FP7+2 (2012–13) the Euratom budget for fusion research was EUR 4.14 billion, most of it for ITER, DEMO and IFMIF.
- The Broader Approach agreement represents around EUR 340 million of EU investment.
- In 2011 the EU agreed to allocate to ITER additional funding of EUR 1.3 billion for the period 2012–2013.
- In 2013 the European Council set the maximum level of Euratom commitments to ITER at EUR 2.707 billion for the period 2014–2020.

The technology

The most efficient fusion reaction to use on Earth is different to that in the sun: the reaction between two hydrogen (H) isotopes: deuterium (D) and tritium (T), produces the highest energy gain at the ’lowest’ temperatures. Fusion power plant conceptual studies, including full lifetime and decommissioning costs, suggest that fusion could indeed be
The Joint European Torus (JET) project, which will operate until at least 2017-18, has successfully demonstrated nuclear fusion technology, producing 16 MW of fusion power. This represents an energy output of 70% of the energy put in, the best results so far for a fusion reactor.

The ITER Agreement (originally an acronym for the International Thermonuclear Experimental Reactor), signed in 2006 between the EU (via the Euratom Treaty) and six other countries – China, India, Japan, Russia, South Korea and the USA – was a major step forward. The Agreement was the impulse to start construction of the ITER fusion reactor in Cadarache (France) and oversees its continued construction to demonstrate the technical and scientific feasibility of ‘burning’ plasma on the scale of a power plant.

ITER is a first-of-a-kind global collaboration between its seven members. During the construction phase, Europe will bear approximately 45.5% of the construction costs, with the remaining six partners contributing approximately 9.1% each. Almost 90% of each member’s share is in the form of in-kind contributions, i.e. the members will deliver components and buildings directly to the ITER organisation, rather providing cash.

Another important step is the Broader Approach agreement, signed between the EU and Japan in 2007, which also includes final design work and prototyping for the International Fusion Materials Irradiation Facility (IFMIF), a device that will subject small samples of materials to the neutron fluxes that will be experienced in fusion power plants.

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The helium nucleus carries an electric charge, which responds to the magnetic fields of the tokamak and remains confined within the plasma. The neutron has no electrical charge, however, and so will carry some 80% of the energy away from the plasma.

These neutrons will be absorbed by the surrounding walls of the tokamak, transferring their energy as heat. In ITER, the neutrons are absorbed in the surrounding lithium blanket, producing heat which will be dispersed through cooling towers. The next fusion plant prototype DEMO and future industrial fusion installations will use this heat to produce steam and, by way of turbines and alternators in the conventional way, generate electricity.

Major challenges remain, however, in making ‘magnetic confinement’ fusion work reliably on the scale of a power plant: for example, how to sustain a large volume of hot plasma for long periods at pressures that will allow for a large net energy gain from the fusion reaction. Such a plant will need materials and components capable of resisting the extreme conditions required for continuous high power output.

The global energy demand will at least double and possibly quadruple by 2100, energy experts project. As we face the dangers of increased greenhouse gases in the atmosphere and peak oil production, fusion becomes a very attractive option for supplying this future demand.

<table>
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<tr>
<th>Site levelling</th>
<th>Start of Tokamak complex excavation</th>
<th>Tokamak complex construction</th>
<th>Start Tokamak assembly</th>
<th>Complete Tokamak assembly, start Torus pump down</th>
<th>First Plasma</th>
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The phases of ITER

Ongoing research

The integrated European/Euratom fusion development programme is addressing a number of challenges beyond ITER and IFMIF. The next aim is to produce electricity in a demonstrator fusion power plant (DEMO for short). This first demonstration of electricity production is expected in the next 30 years, with fusion then becoming available for deployment on a large scale. Nevertheless, there are still many issues and challenges to be resolved, such as those around reliability.

One recent proposal is for a ‘new paradigm’ in which electricity production would be demonstrated sooner, within the next 25 years, by a relatively modest ‘Early DEMO’ or ‘EDEMO’ plant. It would not be required to produce electricity at a stipulated cost and would use known materials that are expected to survive under fusion power plant conditions. This approach may gain the interest of industry earlier by demonstrating fusion feasibility.

Alternative magnetic configurations to the tokamak are also being explored, such as the stellarator, presently under construction in Greifswald, Germany. This is inherently more complex to build than a tokamak but has advantages in terms of reliability of steady-state operation.

Inertial confinement is also being investigated as an alternative to magnetic confinement fusion. Extremely high-power, short-pulse lasers are used to compress a small pellet of fuel to reach fusion conditions of density and temperature. Major facilities have been constructed in France and the US.
The industry

The main difference with all other low-carbon energy technologies is that fusion energy will not make any significant, commercial contribution to the electricity grid until around 2050. Nevertheless, fusion development is a huge opportunity for improving the competitiveness of European industry. Industrial take-up is already manifesting itself through the construction of ITER and increasing contributions towards related European R&D programmes.

In addition to the construction and operation of ITER, industry will need to be part of the DEMO design team from an early stage. Industry rarely commits itself to projects with a 30–40 year time horizon, but a decision to launch EDemo, with the accompanying component testing facilities, may indeed provide the impetus needed to trigger greater industrial involvement. Industry may then gradually shift its role from providing high-tech components to becoming a driver of fusion development.

Barriers

With the green light for ITER, there are currently no political barriers to nuclear fusion development. However, political obstacles may resurface in the future. Public perception, in particular concerning safety and waste, will be important once a commercially viable plant is planned for construction. The potential for difficulties will very much depend on the reputation of conventional nuclear energy production.

In our opinion, the use of fusion energy is a ‘must’ if we want to be serious about embarking on sustainable development for future generations.

ITER Organization

The availability of suitably trained scientists and engineers may pose problems over the long term. Excellent initiatives such as the European Fusion Training Scheme need to be made sustainable.

Financial barriers certainly exist, since funding is derived from national and international sources with limited industrial contributions. Increased funding would speed up the programme and allow major changes such as the introduction of the new paradigm.

As for many first-of-a-kind plants, the costs are very high: some hundreds of millions of euros are required to accelerate the research and complete the DEMO design, the capital costs of EDemo and its Component Test Facility are estimated as a few billion euro, and the cost of the planned DEMO at EUR 10 billion.

Scientific and technical barriers, including plasma physics and materials engineering, already figure in the Fusion Technology Roadmap. The lack of appropriate harmonised European Codes and Standards may also delay the necessary developments.

Needs

An EU policy for Nuclear Energy, as a framework onto which the necessary development programmes could be attached, would have a positive impact.

The fusion development community is well organised but currently is dominated by research institutes and universities. This needs to be strengthened with industrial partners.

EU Member States should be encouraged to make a greater contribution, including those who absent themselves from traditional nuclear technologies.

Targeted PR and dissemination of information supporting nuclear fusion should regularly address the general public. Education and training should be reinforced, and there should be recruitment campaigns to bring researchers into the field.

The present EU R&D programme should also be reinforced in order to ensure success and minimise risk in the construction phase of ITER and the design phase of DEMO.

Fact file

Deployment costs

- Studies currently suggest that fusion will be competitive with other environmentally-friendly energy sources. Prototype power plants could run at EUR 4–8 000 per kWe or 5–9 cents per kWh.
- Each stage of the Fusion Development Plan will bring elements with it which can be used to refine the cost evaluation.

Anticipated greenhouse gas savings

- The introduction of nuclear fusion technology would bring huge environmental benefits as it produces no CO2 or other atmospheric pollutants.

Security of Supply

- Nuclear fusion, along with renewable energy sources, is unrivalled for security of supply because the fuels (deuterium and lithium) are inexpensive and very widely available. Fusion also reduces depletion of non-renewable resources as well as CO2 emissions.

The 2011 earthquake and tsunami that damaged the Fukushima nuclear power plant in Japan also damaged some installations producing components for ITER. This introduced an estimated one-year delay. Following the disaster, the EU ordered stress tests (comprehensive risk assessments) of all 143 nuclear power plants in Europe.
Europe should also set up a DEMO design group, with substantial industrial involvement (technical and managerial), as soon as resources (manpower and money) allow this to be done without a negative impact on ITER. This group would design a buildable DEMO, consider whether EDEMO should be built without waiting for (full) results from ITER and IFMIF, and give clear direction to future R&D. It would also evaluate the potential of a Component Testing Facility and, if justified, proceed to a detailed design. All these proposals obviously need both resources and political will.

Installed capacity

It is difficult to forecast the pace of installation and implementation for a technology needing another 30–40 years to reach maturity. An EDEMO fusion power plant could be producing electricity by 2030, but fusion will still not be a significant player in the nuclear energy market at that time, as by then, it is expected that Generation III and IV nuclear fission plants will be providing much of the base-load electricity.

It is too early to speculate about the situation in 2050, but the current European Fusion Development Plan foresees fusion starting to be rolled out on a large-scale around the middle of the century. The proposed ‘new paradigm’ could accelerate this schedule. There do not appear to be any resource issues that would prevent fusion being deployed at least as rapidly as fission was deployed after the mid-20th century, given the will and the funding to do so.

“Fusion is arguably one of the major research challenges of the 21st Century. It is an option to provide environmentally benign energy for the future without depleting natural resources for next generations.”

International Energy Agency

For further information:

SETIS section on nuclear fusion
http://setis.ec.europa.eu/technologies/nuclear-fusion-power

ITER
https://www.iter.org/mach

European Fusion Development Agreement (EFDA)
http://www.efda.org

Fusion for energy (F4E)
http://fusionforenergy.europa.eu