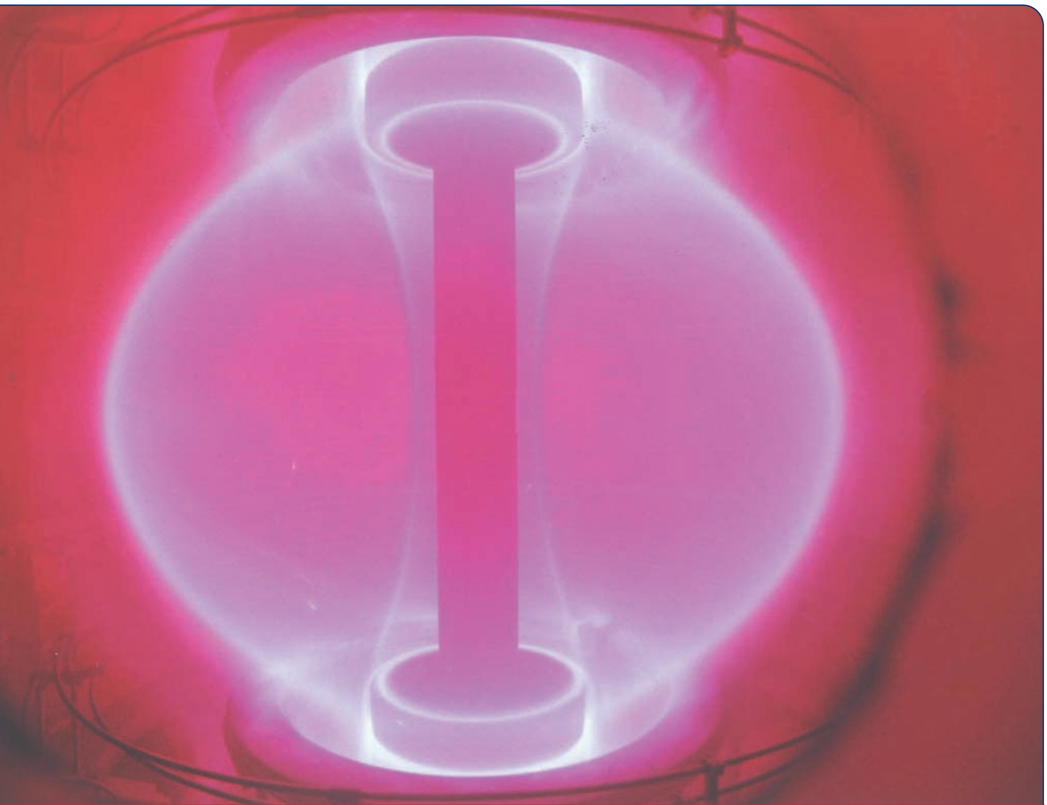
Fusion Energy

An Energy Source of the Future?



Plasma image from the START experiment at UKAEA Culham

With an increasing world population and a growing economy, the demand for energy is sure to grow. The latest predictions for world energy demand all show an upward trend and even with increased energy efficiency we will still need substantially more energy by 2050 than we use today. Where's it to come from? Dr Federico Casci of the European Fusion Development Agreement (EFDA) organisation believes part of the answer is fusion…

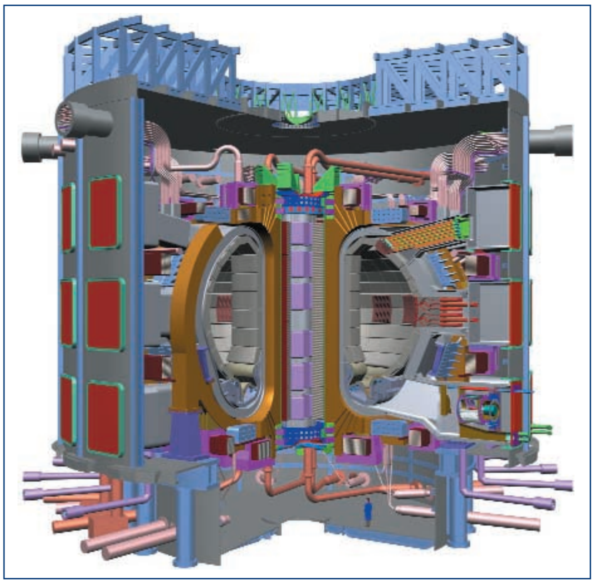
World Energy Outlook, published recently by the International Energy Agency (IEA), foresees a 57% increase in worldwide primary energy demand in the period between 1997 and 2020. This corresponds to a 60% increase of CO_2 emissions. New solutions will be required for providing a targeted answer to both the energy demand and the emission problems. By mid-century, fusion could be an energy option ready to move out of the laboratory and into production. It would be able to provide an ideal complement to renewables, covering base load electricity production.

Background

Fusion research started some decades ago, but only at the end of the 1960s did major scientific events, such as the use of the tokamak machines for the magnetic confinement approach, exponentially enhance the level of knowledge of the physics behind it and put fusion on the path towards being a future energy source. Fusion - the energy source of the sun and the stars - is one non-fossil option, which offers the prospect of meeting the requirements of operational safety, environmental compatibility and sustainability. It has the potential to play a key role in long term, base-load electricity production. Fusion fuels are cheap and evenly distributed on the Earth. There are no significant constraints on resource availability even for an extensive use of fusion energy over centuries. The safety and environmental aspects of fusion power have been assessed in extensive, in-depth studies, all of which have confirmed the attractive characteristics of fusion power.

There is no possibility of uncontrolled power runaway since inherent physical processes limit power excursions of the plasma. Moreover, the plasma vessel of a fusion reactor will only contain enough fuel for a relatively short burning time - in the order of minutes. Thus, even in the case of a total loss of active cooling, melting of the reactor structures is excluded due to the low density of decay heat of the materials present in the reactor. The safety and environmental friendliness of fusion are largely based on the passive and inherent features of the design, rather than on highly reliable safety systems. Even in the worst possible in-plant driven accident scenario, the risk to the general public would be below the level at which evacuation would be required. The fusion fuel cycle does not involve any input of radioactive material and there is no radioactive waste associated with spent fuel. Radioactivity is present in the intermediate fuel, tritium, but there is no radioactive fuel cycle outside the power station. With the exception of a charge of tritium for the initial fuelling, there are no major fuel shipments as part of the fuel cycle, and no inventory of fissile or fertile materials. The radiotoxicity of the activated materials generated by fusion reactors during their lifetime will only last for approximately one hundred years, which is comparable to the radiotoxicity of the ash from coal power stations. Unlike nuclear fission, therefore, fusion waste would not constitute a permanent burden for future generations.

The R&D strategy of the European Fusion Programme has been successfully based on work with a single, large, central facility, complemented by a number of specialised small and medium-sized devices run



Cutaway view of the ITER reactor

by more than 20 individual member states. The central facility, the Joint European Torus (JET), a tokamak experiment, was approved in the 1970s, began operations in 1983 and is currently planned to continue until 2006. The focusing of significant European fusion research funding on JET has made it the pre-eminent fusion facility in the world and allowed Europe to take major strides in fusion research. JET has produced significant fusion power in deuterium/tritium plasmas (up to 16 MW) for extended periods of time without suffering the instability events that limited earlier work. 'Break-even' conditions, where the fusion output power equals the external input power required to heat the plasma, have almost been reached. Moreover, JET has demonstrated that fusion devices can be operated safely with radioactive tritium fuel and that radioactive structures can be maintained and modified using remote handling techniques.

Next steps

Due to the success of JET and other experiments, the world fusion community is now ready to take the "Next Step" of constructing a larger device, which will produce burning plasmas under reactor conditions of high power gain and provide a reliable basis for proceeding to a demonstration reactor, capable of producing electricity. The design of a "Next Step" is being carried out within the framework of the ITER collaboration between the EU (with the participation of Canada), Japan, and Russia (the USA participated until July 1999). The current design is a cost-effective tokamak, which could allow the study of burning plasmas under physics conditions extrapolable to a reactor and integrating important reactor technologies. The ITER (International Thermonuclear Experimental Reactor) participants now have to approve the construction of the machine and select the site where this international project should come to life. A decision about how to proceed with ITER is expected by 2002. There are still numerous challenges ahead if fusion is to become an energy source of the future. For instance, after ITER, in which the conversion of fusion produced heat to electrical power will not be addressed, an additional step (DEMO) will be needed to demonstrate that an efficient production of electricity from fusion is both practicable and compatible with a low environmental impact. If politicians give their backing and take the necessary decisions at the appropriate time, it is expected that a "first-of-a-kind" power plant will start operation in about 50 years from now.

Further developments needed

In parallel to the realisation of ITER, the Fusion Programme will need to come up with further technology developments and concept improvements in order to build a commercial electricity-producing reactor. Technological progress is required in several areas, especially in the development of plasma-facing materials sustaining high heat loads and of low activation structural materials, the latter to reduce the quantity of radioactive waste from a fusion reactor. In addition to public and political awareness, the European Fusion Programme has an increasing engagement with industry in order to enhance their technology and engineering expertise. If next-generation fusion devices are to become a reality the participation of industry will be vital. The eventual realisation of fusion as an energy source will require a widespread social acceptability. Studies on such issues are carried out within the European Fusion Programme through the Socio-Economic Research on Fusion (SERF). The purpose of these activities is to bring together scientists and engineers from the fusion community, with researchers from the economic, social and environmental sciences. Aspects being addressed include the external costs of fusion energy and issues of governance and accountability in complex systems. Concerning the cost of a commercial reactor, and the cost of the electricity produced, it is very difficult to make reliable projections referring to 40-50 years from now. The current tools used to predict future energy scenarios do not go beyond 2050. Therefore the analysis of the fusion impact on the overall energy scenario requires the capability of these prediction tools to be extended to cover the second half of this century. Work in this area has already been carried out and will continue.

Commerically viable?

To be a viable commercial option, fusion must be competitive with other mid-21st century electricity-generation technologies. As in nuclear fission, the investment cost dominates in assessing the cost of electricity (equivalent to more than 70%). The fuel would represent a negligible percentage. Many studies have been conducted within the framework of the fusion programme to evaluate electricity costs for fusion and

The JET tokamak

compare them with those of other advanced or renewable energy sources. The consensus is that the costs foreseen for fusion would be competitive with most renewables and with fossil fuels, when the externalities (environmental costs) are taken into consideration. In contrast to renewables, however, fusion has the advantage of being able to provide base load electricity, without additional cost for storage. Among the studies carried out on long-term energy scenarios, one of particular interest was performed by the Netherlands Energy Research Foundation. Its aim was to find the cheapest discounted way to generate Western Europe's electricity up to 2100, taking into account a range of constraints on cumulative carbon dioxide emission budgets, on limits applied to the power share of nuclear fission (to reflect social acceptance difficulties) and on the speed with which fusion power could be deployed. This study shows that fusion would capture roughly twenty to twenty five percent of the electricity market by the end of the century under these constraints. Satisfying the energy demand without fusion would be more expensive.

Fusion is currently not considered an immediately helpful CO_2-mitigation technology, because it is not expected to be economically available before the second half of the 21st century. Intermediate solutions, like the substitution of coal by natural gas could, however, help to reduce the greenhouse gas emissions in the short and medium term and fusion could then be available when a replacement of these technologies is necessary because of the exhaustion of resources. With these long-term prospects in mind, it is clear that public funding is still needed for further fusion energy development. Since the relevant industries are oriented towards short-term profit, their early participation in fusion funding cannot be expected, although their involvement will be necessary at some stage.

A future for fusion?

The uncertainties in predicting future energy demands are well known but the upward trend is definitely a reality that needs to be faced. The options for meeting that demand in a sustainable way have either yet to prove their feasibility, or have intrinsic limitations to the amount they can furnish at acceptable prices. Some options also face problems of social acceptance, as does the adoption of strong measures to contain energy consumption. The decrease of greenhouse gas emissions is the most urgent problem each government has to deal with in order to avoid predicted catastrophic effects such as an increase in global temperatures and rising sea levels rise. The answer to CO_2, and other harmful gas, reductions is a sustainable development path, which in turn calls for diversity. We need a full range of safe and environmentally-friendly energy options applicable to the near-term, medium-term and long-term. With its inherent environmental and safety advantages fusion should be seen as an important element in any global strategy designed to allow continued economic growth. Particularly as an option for baseload electricity generation fusion has many advantages and it does not risk major environmental degradation. Fusion technology, brought to fruition, will be an asset of the utmost value to give to our descendants.

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