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Abstract

Whatever became of nuclear fusion?

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There is a popular view that nuclear fusion has been just over the horizon for decades, and that it has failed to deliver. Although there are reasons for this perception, it is false. Nuclear fusion offers perhaps the best potential for a solution to the world's energy needs, and now is the time for renewed focus on the remaining scientific challenges that must be overcome before a viable fusion power station can be built.

The fusion community has long touted the promise of effectively unlimited clean energy. The perception that fusion has not delivered on this promise is partly due to the community itself overselling what can be achieved and when. One researcher famously claimed in the 1950s that fusion power would be on-stream in 50 years. Today, we know it is still 50 years from commercialisation. This has understandably led to scepticism. Nevertheless, we have learned a great deal over the last half century, scientific progress has been impressive, such that today's predictions can be made with far greater conviction.

Why fusion? There is a growing awareness that demand for energy is on the rise while supply is increasingly stretched by environmental constraints and cost. In the 40 years leading to 2000, the world's population doubled to 6 billion, and it is predicted to double again before 2100. No currently available source of energy can satisfy the accompanying need for clean energy. Oil and gas are running out, nuclear fission faces strong public resistance and very real problems related to waste unless new schemes are developed with an integrated fuel cycle. Renewables, important though they are, will only ever be able to satisfy a small fraction of the world's future energy needs. If the energy supply industry is to satisfy demand, while at the same time restricting atmospheric CO2 to the much-stated level of 550ppm, besides coal burning plant with total sequestration of the CO2 produced, fusion reactor (in concurrence or competition with possible new scheme of nuclear fission) must start to progressively replace conventional power stations from around 2050. For this to happen, the international ITER fusion project is a necessary next step.

Fusion is the power source of the stars, which burn lighter elements into heavier ones with the release of energy. In the Sun, the primary reaction combines hydrogen into helium. For controlled fusion on Earth, that process is too slow to be viable for energy production and we use the heavier isotopes of hydrogen: deuterium and tritium.

Fusion has many appealing features. For the most promising potential fusion device, the deuterium and lithium fuel is almost inexhaustible. The fusion process is environmentally friendly, with no greenhouse gas emission and no long-lived radioactive by-products. After 100 years, the residual radiotoxicity of a decommissioned fusion reaction would be lower than that from a decommissioned coal-fired power station. With no chance of runaway reactions and a very small fuel inventory, used in tens of seconds, the safety case for a fusion reactor does not lead to difficult or controversial issues.

In a coal-fired station, the combustion is chemical; in a fusion reactor, it is nuclear. In the two cases, some fraction of the power generated by the reaction is needed to maintain the physical conditions necessary for combustion. A fusion reactor requires a temperature of the order of 100 million degrees Kelvin, ten times that of the core of the Sun.

Two main approaches have been followed to generate such conditions: inertial confinement during pulses whereby pellets of fuel are compressed by intense laser or ion beams, and for steady state magnetic confinement in which the fuel takes the form of a hot plasma confined by powerful magnetic fields. Both have their merits, but magnetic confinement is currently further advanced. The Joint European Torus (JET), the world's largest fusion device, has already achieved energy break-even. JET has made great advances, but is unable, and indeed was never designed to produce a blueprint for an energy-producing reactor. This is why the next generation machine, ITER, which should see its first plasma around 2015, is necessary.

Today, JET has allowed us to produce the blueprint for ITER, which will pin down all the scientific parameters and test the technologies necessary for energy production. ITER's experimental programme will lead to a design for an energy-producing reactor within the coming decades. Many of the plasma parameters necessary for energy production can be achieved separately in existing devices such as JET, but it requires a larger machine to realise together all plasma parameters necessary to sustain a burning plasma. ITER, first proposed by the Soviet premier Mikhail Gorbachev in 1986, is of a sufficient scale to do this and has developed through inter-regional cooperation.

ITER will be the final step of scientific validation on the road to a technically viable reactor. If successful, it will be followed by an energy-producing demonstrator that will allow the technology for large-scale energy production to be put through its paces before a prototype of fusion reactor can show its economic competitiveness. The need for ITER, a machine integrating the science and technology of fusion energy production, is undisputed. There is a strong consensus that ITER will achieve its objectives, paving the way to energy production in the second half of the century. With all ITER design issues resolved by the end of 2003, and agreement imminent on building the machine (probably at Cadarache in France), it is safe to say that nuclear fusion is alive and well.