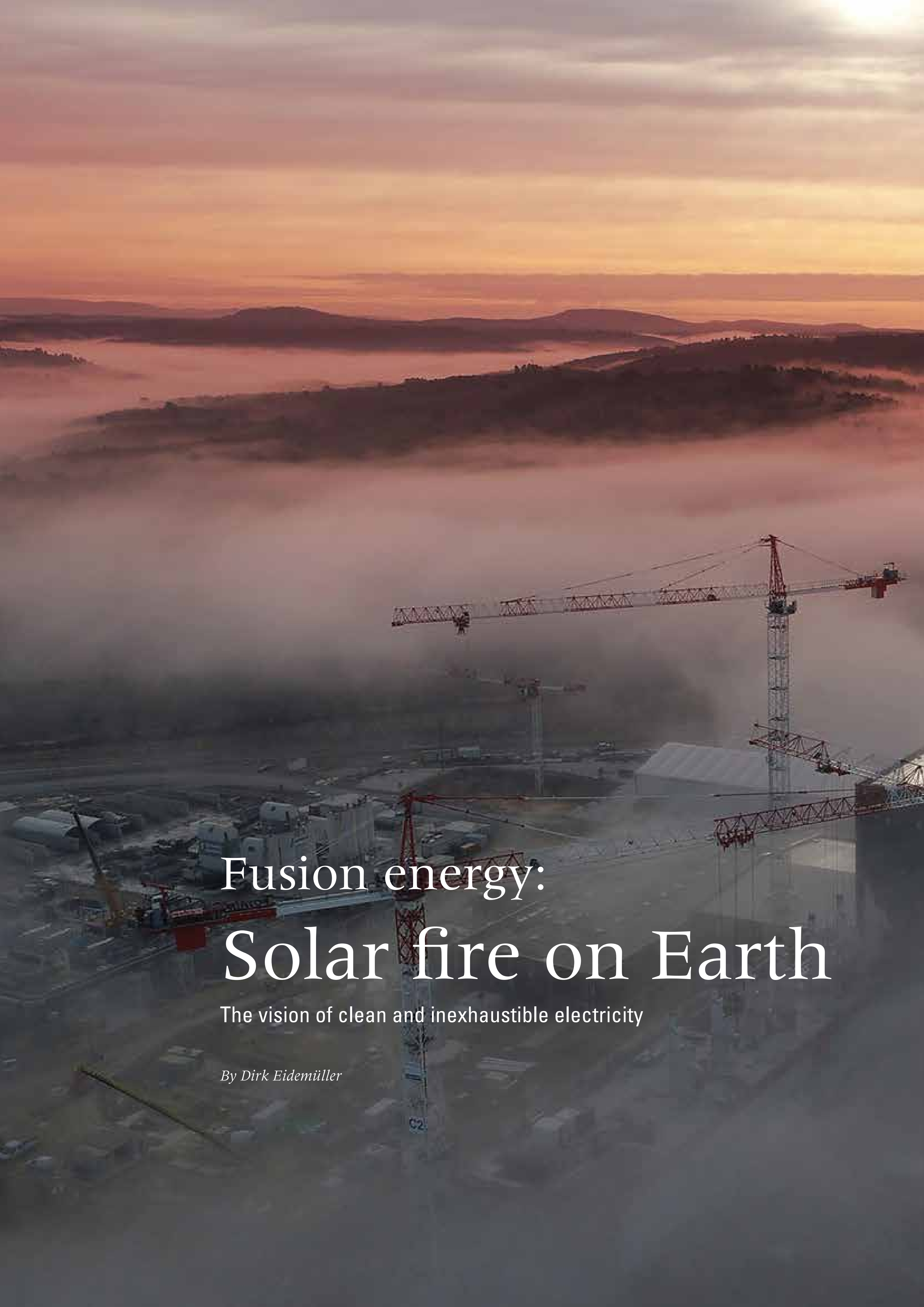

Fusion energy: Solar fire on Earth

The vision of clean and inexhaustible electricity

By Dirk Eidemüller

ITER, the experimental fusion reactor, is approaching the operational phase – important input is also coming from Frankfurt. Although the new technology will not contribute to reducing greenhouse gases in the short term, it could form an important pillar of future electricity supply.

It is an old dream of nuclear physics: Fusing light hydrogen atomic nuclei to tap the very energy source that lets stars like the Sun shine for billions of years. Through stable nuclear fusion, power plants would be conceivable that deliver a practically inexhaustible supply of electricity: As much energy could be extracted from 30 kilograms of hydrogen as from a supertanker with 260,000 metric tons of oil. At the same time, there would be significantly fewer problems with radiating nuclear waste than with nuclear power plants. Although fusion power plants indeed also produce radioactive materials, they are far less and not as long-lived either – this is, in fact, the real problem with highly radioactive waste from power plants.

Way back in the 1950s, fusion power was already proclaimed as the panacea for the era after nuclear energy. At that time, it was said that fusion power would be ready to go in 50 years at the latest. This prediction has, however, hardly changed at all over the last 70 years because, even in optimistic estimates, it will still take several decades until the first fusion power plants go into operation. This is the reason why some of those people who scoff at fusion power have compared it to a certain Berlin airport, whose opening was also repeatedly postponed. However, building an airport is distinctly less complex than building a fusion power plant.

ITER is big enough for solar fire

»After some initial difficulties, work on ITER, the world's largest fusion reactor, is meanwhile progressing well,« says Holger Podlech, professor for accelerator physics at Goethe University. In a fusion reactor, an extremely hot and very thin plasma is enclosed in a doughnut-shaped ring with the help of special magnetic fields. It must not touch the wall, otherwise it would cool down immediately, making any form of fusion impossible. By means of microwaves, the plasma is heated to a very high temperature – several million degrees – until finally the atomic nuclei can overcome their reciprocal electrostatic repulsion, and the fusion reaction starts. This then releases enormous amounts of energy.

»This means that quite a lot of energy has to be put into the plasma first, before it produces energy itself,« explains Podlech. Thus, to obtain a positive energy balance overall, fusion power plants must be relatively big. In smaller plants, too much plasma is lost, making them uneconomical. ITER is large enough to enable ignition of the solar fire. It is not, however, suitable as a power plant that operates economically. It should serve as an experimental fusion reactor that allows researchers over the coming years to study the behaviour of the hot plasma. ITER should go into operation around the middle of the decade, initially, however, without properly igniting the plasma.

After about ten years of extensive material tests and experiments with the plasma, around 2035 the solar fire in the plasma chamber should then shine for the first time, that is, a stable fusion reaction will be ignited. This is exactly what earlier experiments had also promised, but they failed time and again due to unforeseen difficulties, such as peculiar turbulences in the hot plasma. Through sophisticated computer simulations and thanks to ITER's larger size, it should be possible to get these problems under control. »I'm absolutely certain that ITER will be a success,« says Podlech. The fundamental principles are meanwhile well enough understood,

The ITER experimental reactor has been under construction in France since 2007. It will be used to test whether electricity can be produced from energy generated by nuclear fusion.

The ITER construction site in February 2020. According to the current planning status, the first plasma will be ignited in 2025. Power generation tests will start ten years later.

IN A NUTSHELL

- Fusion energy generated when hydrogen nuclei fuse could become a just about inexhaustible source of energy.
- Better simulations of the solar fire in the fusion reactor and the development of new materials will help to solve scientific and technical problems.
- Fusion power plants will go into operation too late to help achieve the climate goal of 1.5 °C. However, they could one day cover the base load in conurbations.

and the problems of the preceding projects have been analysed in detail. In the past, fusion research was approached a little too optimistically. In the meantime, many of the properties of fusion plasmas that could only be roughly gauged at the time (and were gauged too positively) can be simulated in detail

Only a small amount of hot and hazardous material

The material properties of the chamber enclosing the solar fire play a particularly important role in the operation of future fusion power plants. It has to stand up to quite a bit, although the hot plasma is very thin, and the chamber houses just a few grams of it. This is a major safety advantage compared to nuclear power plants, which hold many tons of uranium and fission products. If something goes wrong in a fusion power plant, not a lot can happen. The amount of hot and hazardous material is simply too small. However, ignited plasma produces tremendous heat, and then there is the problem of extensive neutron radiation. This penetrates deep into the wall structure, blasts against the atomic nuclei of the materials and violently shakes their inner structure. It also allows gases to form which can also damage the wall structures from the inside.

»Indeed, the forces to which the materials in the torus are subjected are enormous and one of the biggest engineering challenges in the construction of fusion power plants,« explains Podlech. Researchers are currently working on composites made from special types of high-strength steel, which are expected to guarantee a certain durability. If the expensive structures had to be replaced too often, this would make operating a fusion power plant unprofitable.

At the present time, however, there is no possibility to conduct trials with such materials on a test stand under conditions as harsh as those the solar fire will create in the plasma chamber – not even in the most powerful research reactors. Simulations are not suitable either because they can never reproduce all the dimensions of such an extreme load. That is why the working group led by accelerator expert Podlech was involved in developing what is known as the International Fusion Materials Irradiation Facility (IFMIF). In this large-scale facility, powerful particle accelerators will produce a high-energy neutron beam that displays similar properties to the ignited plasma in a fusion power plant. This will make it possible to test materials that are to be used at ITER around the year 2035, when it can hopefully be said: The solar fire is burning steadily.

No panacea against climate change

But how does the future of fusion power look? Major developments in renewable energies have been seen worldwide over the last years in view of climate change – unfortunately with considerable delay – but nonetheless they are finally taking root. However, at least so far, renewable energies are scarcely suitable for covering the base load because electricity grids are insufficiently interconnected and storage possibilities are to date far too small (however, please see too the article »Electricity Storage«, page 89). Some countries are placing their bets on nuclear

About Holger Podlech

Prof. Dr. Holger Podlech, born in 1968, is head of the LINAC WG at the Institute of Applied Physics, which is working on the development of particle accelerators and their subcomponents. One of his projects deals with transmutation, which should help to shorten the half-lives of radioactive waste from nuclear power plants. Physicist Podlech has been professor at Goethe University since 2012, prior to which he worked as a lecturer and researcher there as well as at Michigan State University and the Max Planck Institute for Nuclear Physics in Heidelberg.

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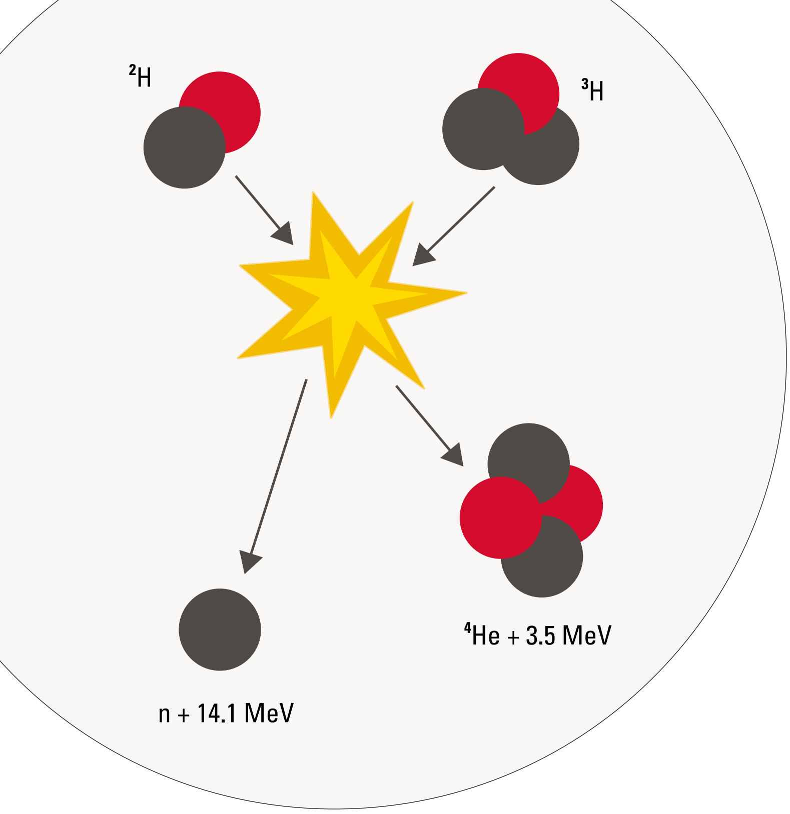

When the atomic nuclei of the two heavy hydrogen isotopes deuterium (2H) and tritium (3H) fuse, helium (4He) and a neutron (n) are produced. Researchers are exploring whether the energy released in this reaction can be used to generate electricity.

energy, at least as a bridge technology, while other countries, such as Germany, are focusing on coal, which is particularly harmful to the environment. According to calculations by climate researchers, humanity would have to consistently lower global greenhouse gas emissions down to zero already by the middle of this century in order to avoid dangerous global warming with highly negative consequences.

»Fusion power will not be a panacea for the 2050s, that's already obvious,« says Podlech. Even if everything at ITER goes as hoped, and the experiments deliver all the desired results by about 2040, the construction of countless large-scale fusion power plants could not be expected immediately afterwards. »After an experimental reactor like ITER, a larger prototype power plant would first be built, which although already suitable for electricity production also serves to gather experience in the operation of such plants,« says Podlech.

Future electricity supplier for conurbations

The planning and construction of such a prototype fusion power plant would certainly take well over a decade. Once it has supplied energy for a few years as planned, a more standardised construction line of commercial fusion power plants could then be developed on the basis of this experience. Building such large plants is also likely to take 10 to 20 years. This means that fusion power – even if everything were to run like clockwork – could not contribute to solving climate problems by 2050. It could, however, nonetheless serve as an interesting energy source later this century. Compared to renewable energies, it has the advantage of being able to generate a tremendous amount of energy in a small space. A fusion power plant could deliver about twice as much electricity as a large nuclear power plant. This makes the technology interesting for conurbations as well as for regions where not enough electricity for industry and the local population can be generated from either solar or wind power.

Of course, it is difficult to predict how prices in the energy market will develop up until the second half of this century. It might be that by then fusion power is hopelessly outpaced for reasons of economics, and regenerative energy sources, such as hydrogen or biofuels, or innovative storage technologies will be able to cover the entire energy demand at unbeatably low prices – but perhaps not. »I think we should explore fusion energy in depth,« says Podlech. »It's always good to have an ace up our sleeve in case we run into difficulties with other types of energy.« This could also be the case if conflicts over land use erupt or there are interventions in the landscape. Even if fusion research costs a few billion: Compared to international expenditure for energy supply, this is an almost infinitesimal sum. ●

The author

Dirk Eidemüller, born in 1975, studied physics (major) and philosophy (minor) in Darmstadt, Heidelberg, Rome and Berlin, earning a Diplom in astroparticle physics and his doctoral degree in philosophy of science. He lives in Berlin and works as a freelance author and science journalist.

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