

PRESS RELEASE

March 31, 2026 || Page 1 | 9

Fraunhofer ILT Develops Key Technologies for the Future Market of Fusion

By 2029, the German government will invest over €2 billion in fusion research, with the Fraunhofer Institute for Laser Technology ILT in Aachen already positioned as an early mover in this field. In collaborative research projects, it is researching and developing solutions for fusion power plants together with partners from industry and research. They are establishing robust supply chains and developing processes for automated mass production. Internationally, the institute cooperates closely with the Lawrence Livermore National Laboratory, among others. The laboratory's National Ignition Facility has repeatedly ignited fusion plasma using what is currently the world's largest laser, achieving steadily increasing energy surpluses in the process. Spillover effects are also emerging out of the development of this innovative power plant technology, effects that could open up new application markets for photonics.

Fusion research has been on the rise worldwide since December 2022, when researchers at the Lawrence Livermore National Laboratory (LLNL) achieved a historic breakthrough at the National Ignition Facility (NIF) in California. For the first time, an inertial confinement fusion (IFE) experiment triggered by a high-energy laser released more energy than the laser had concentrated onto a pinhead-sized pellet of fusion fuel. Since then, LLNL has repeated the experiment multiple times with increasing energy surpluses, which confirms that the underlying physics works.

Fusion as a climate-neutral, virtually unlimited energy source is more within reach than ever. Furthermore, IFE facilities are inherently safe because the plasma ignites only under enormous pressure and at temperatures around 150 million °C. Without the fuel supply and ignition pulses, the fusion reaction ceases immediately. For it is only under these extreme conditions that the mutually repelling nuclei of the hydrogen isotopes deuterium and tritium are able to overcome the Coulomb barrier and fuse. To maintain continuous power plant operation, 10 to 15 pellets per second must be compressed with high-energy laser pulses, converted into plasma, and ignited. Maintained in this way, fusion generates baseload-capable energy on a large scale: Just 1 kg of fusion fuel contains as much energy as 22,500 tons of lignite, which corresponds to the cargo load of a 6 km-long freight train. No substance with a similar energy density is known in the entire universe.

Press contact

Petra Nolis M.A. | Head of the Communications Group | Telephone +49 241 8906-662 | petra.nolis@ilt.fraunhofer.de
Fraunhofer Institute for Laser Technology ILT | Steinbachstraße 15 | 52074 Aachen, Germany | www.ilt.fraunhofer.de

German government invests over 2 billion euros in fusion research

March 31, 2026 || Page 2 | 9

As a climate-neutral, baseload-capable energy source, fusion could become an important complement to future energy systems in which cost-effective but intermittent wind and solar power cover the majority of demand. According to forecasts by the International Energy Agency (IEA), global electricity demand will increase 2.5-fold by mid-century to 70 petawatt-hours (PWh) per year. To meet just one-tenth of that demand, nearly 1,000 fusion power plants would be required, a need that signals an emerging market for photonics that will significantly exceed its current revenue volume. Governments and private investors have recognized this opportunity and are channeling substantial sums of funding and venture capital into this field of the future. Currently, they are focusing not only on developing the core technologies for such power plants, but also on establishing robust supply chains and developing processes for the mass-scale, highly automated manufacturing of power plant components. This is where the Fraunhofer Society's application-oriented research comes into play.

Enormous technological and operational challenges still lie ahead before commercial power plants become available. In addition, there is another promising approach: magnetic fusion (MFE). The German government is supporting both approaches through the "Fusion 2040" program. The Ministry of Research, Technology, and Space (BMFTR), which leads the initiative, recently increased its budget to over 2 billion euros through 2029 – good news for photonics. High-energy and high-power lasers, optics, sensors, and highly flexible laser-based manufacturing technology are considered key technologies not only for IFE power plants, but also for the development, construction, and operation of the complex tokamak and stellarator reactors for magnetic fusion.

U.S. test facility is just a blueprint – the road to a fusion power plant is long

Fraunhofer ILT is one of the pioneers in fusion research. It is developing the technological foundations for fusion power plants through national and international projects along with partners from industry and research (more than 20 Fraunhofer Institutes alone are active in this field). These collaborative research consortia serve as building blocks for the urgently needed supply chains. The projects focus on realistically modeling and simulating components, subsystems, and even entire power plants, as well as on developing rugged optics and driver lasers for the high-energy lasers intended to ignite fusion plasma at a 15-hertz rate in the IFE power plants of the future. To achieve such a frequency, only complex diode-pumped solid-state lasers (DPSSLs) are viable options.

The laser at the experimental facility in California has 192 optical paths, in which glass plates pumped by flash lamps amplify the laser pulses. In this process, their photons

FRAUNHOFER INSTITUTE FOR LASERTECHNOLOGY ILT

interact with electrons in crystal glass plates. The energy level of an initial nanojoule pulse increases to the extent that it is akin to amplifying a normal handclap acoustically to the level of a severe earthquake. This pumping takes place in the infrared wavelength range. Distributed across 192 beam paths, the pulse is then converted into green and blue wavelengths, and becomes ultra-short-pulse X-ray radiation when all 192 beams strike the target synchronously with more than 2 megajoules of combined pulse energy. For a few nanoseconds, the trigger pulse reaches the same power as the entire U.S. power grid. Accordingly, huge capacitors are needed to temporarily store the necessary electrical energy. And after the shot, the system must cool down for hours. For the high-energy lasers of future power plants, this is unthinkable. They must deliver up to 15 shots per second with high efficiency. This efficiency – of converting electrical energy into optical energy – must increase by a factor of 10 to 15 compared to the NIF system. In contrast, the California test facility was never designed for energy production, but rather for plasma research.

March 31, 2026 || Page 3 | 9

Funded projects are developing the photonic foundation for fusion power plants

DPSSLs are key components for IFE power plants. Instead of being pumped by flash lamps, they are pumped by efficient high-power laser diodes. In the BMFTR-funded DioHELIOS project, Fraunhofer ILT is participating in a broad consortium dedicated to the development of the high-power laser diodes required in large quantities for fusion power plants. In addition to modeling the diodes, the project will integrate them into actively cooled modules—including collimating lenses—as well as designing highly automated production lines. The goals are ambitious: The pulse energy achievable with the diode-pumped modules has to increase by a factor of 50, accompanied by improved efficiency and more homogeneous, stable spectral characteristics.

On top of that, the consortium plans to reduce the cost of diode laser modules to less than one cent per watt of power through fully automated mass production. That would be less than one-fortieth of their current cost. However, this must not come at the expense of quality: The heavily stressed hardware is expected to last 30 years in power plant operation. The scale of the challenge is also evident in the fact that today's global annual production of high-power diodes does not even cover the demand of a single IFE power plant. Together with its partners in the DioHELIOS consortium, Fraunhofer ILT is already seeking concrete solutions to this problem.

DioHELIOS is one of the initiatives in the "Fusion 2040" program. In the closely related PriFUSIO project, a consortium led by Fraunhofer ILT is working on the key optical components of high-energy lasers for fusion power plants. "We are focusing on systematically developing and validating them," explains Dr. Sarah Klein, coordinator of fusion research at Fraunhofer ILT. The project is dedicated to new processes for the

FRAUNHOFER INSTITUTE FOR LASERTECHNOLOGY ILT

fabrication, coating, and quality testing of lenses and optical gratings, as well as the simulation and material development of the amplifier plates, which, in combination with high-power laser diodes, are intended to amplify the ignition pulses into the megajoule range. "All optical components must withstand 24/7 power plant operation. To achieve this, it is necessary, among other things, to significantly increase their damage thresholds," she says. In addition, new approaches are needed to manufacture the optical components cost-effectively—some of which are very large—that are initially required in only small quantities. Fraunhofer ILT is also pursuing a promising approach for this: laser-based process chains for shaping, polishing, and post-processing. Compared to mechanical methods, this tool introduces fewer microcracks and defects into the optical components from the outset, which increases their robustness and service life.

March 31, 2026 || Page 4 | 9

Fusion requires laser-based manufacturing processes

In the "IFE-Targetry-HUB" and "Durable" projects, teams from Fraunhofer ILT are also at the forefront of developing key technologies for fusion power plants. "Durable" focuses on simulation and process development for the additive manufacturing of wall components facing the plasma radiation. During 24/7 power plant operation, neutrons released by the fusion reaction continuously bombard the walls. Their kinetic energy is transferred within the walls to a coolant, which vaporizes and drives a turbine. Special wall elements are also required in which the neutrons are used to breed the hydrogen isotope tritium from lithium. "Laser-based additive manufacturing processes are ideal for shaping the high-temperature-resistant, extremely robust tungsten alloys used in the walls," explains Klein. Fraunhofer ILT invented and patented metal 3D printing, and has been systematically refining it ever since. AI is playing an increasingly important role in this, as it does in Extreme High-Speed Laser Cladding (EHLA), which was also conceived and patented at the institute. "Both additive processes have great potential for the manufacture of power plant components," she says.

Equally important are laser-assisted processes for manufacturing fuel targets. If fusion power plants operate at 15 Hz and ignite up to 1.3 million times a day, target costs must be reduced by many orders of magnitude, down to the cent range. Researchers at Fraunhofer ILT are also tackling this challenge as part of the "IFE-Targetry-HUB" project. Fusion research brings together a great many threads that the institute has picked up and spun further over the past decades. Now this groundwork is paying off. "Our projects operate at the typical Fraunhofer focal point: it's about rethinking technologies and transferring them from research to concrete industrial application," says the fusion research coordinator.

Understanding high-energy lasers from the ground up

March 31, 2026 || Page 5 | 9

The high-energy lasers in future IFE power plants are expected to have many hundreds of parallel beam paths. In each, thousands of high-power laser diode bars will pump amplifier plates made of special glass or crystal to amplify the pulses to the energy level required for ignition. Such complex lasers cannot be built through a trial-and-error approach. Rather, computational methods are needed to first test and optimize them virtually before building prototypes. By using virtual prototypes of the components, subsystems, and ultimately the complete high-energy laser, researchers can explore their functions and simulate them realistically in a virtualized environment. In recent years, Fraunhofer ILT has developed sophisticated laser simulation models for designing, developing, and industrially scaling DPSSLs. It is now putting these models to the test by comparing them with comparable solutions from LLNL in the "ICONIC-FL" project.

The U.S. institute specializes in the simulation and construction of high-energy lasers, while Fraunhofer ILT focuses on DPSSLs with high average powers. Both partners thus contribute complementary expertise. "This project is not about merging our simulation models or exchanging code," emphasizes Johannes Weitenberg, project manager at Fraunhofer ILT. Rather, the two institutes aim to learn from each other and independently double-check their simulation results to develop the next generation of DPSSLs for fusion power plants by subjecting the laser design to independent cross-validation. To this end, they will each use their own solutions to simulate the gain stages of the high-energy lasers. In doing so, they intend to get to the bottom of complex physical effects: "In 24/7 operation, heating, refractive effects, and aberrations can distort the laser beam. Here, even the smallest effects matter and can cause efficiency losses or even directly damage the optics," says Weitenberg. The goal is to understand exactly what is happening in the individual amplifier plate so that complex plate stacks can be simulated later.

Ultimately, current fusion research aims to drive technological breakthroughs through multidisciplinary approaches. The example of the NIF demonstrates what is possible: By using scientific and engineering expertise, as well as simulation- and AI-based process optimization, researchers there have succeeded in increasing the energy surplus of the fusion from 1.5 times to 4 times the energy input by the laser. The goal now is to increase this by a factor of 50 to 100 using high-energy lasers specifically optimized for IFE power plants.

High-energy lasers are not only of interest for fusion

For the large-scale fusion power plant project to succeed, industry and research must cooperate closely. Government funding programs can lay the technological

FRAUNHOFER INSTITUTE FOR LASERTECHNOLOGY ILT

groundwork, but in the long term, companies must invest and build supply chains. For innovations, this means they should be geared not only toward the long-term goal of a fusion power plant, but also toward other application markets. For example, new applications must be developed to build the necessary manufacturing capacity for high-power laser diodes and reduce their costs to the required level through economies of scale. “In this regard, our institute supports industry with concentrated expertise we have acquired over more than 40 years,” explains Klein.

March 31, 2026 || Page 6 | 9

The first spillover effects are already becoming apparent. For instance, the PriFUSIO project has yielded a new generation of synthetic quartz glass plates that, in addition to fusion, are also of interest for other high-power laser applications in the near-infrared range, including laser cutting and welding. Manufacturer Heraeus Covantics has optimized both the performance and cost of the manufacturing process, which can also produce a far great range of plate sizes. The new material is characterized by very low absorption and high power density.

There is also a need for high-energy lasers beyond fusion: As drivers for secondary sources, they are expected to pave the way for new methods of generating extreme ultraviolet (EUV), X-ray, or neutron radiation. Among the promising applications is combined X-ray and neutron imaging, which Fraunhofer ILT is currently helping to develop as part of the PLANET collaborative project. It is intended to enable optical and material analyses of the contents of sealed drums and containers through their walls. Laser beam sources are crucial to miniaturizing the particle accelerators required for this and integrating them into compact, and possibly even mobile, devices in the future.

“Much of what we’re working on in fusion research is relevant to many markets. We’re not only working on power plant technology!” emphasizes Klein. Fusion represents a major opportunity for the laser and optics industry in Germany and Europe. Should the commercial success of laser fusion take longer than hoped for, the industry could tap into new markets with the technological leaps achieved in fusion research. If it becomes a success, a single power plant would require the current global annual production of high-power laser diodes as well as tens of thousands of large optical components. Even by conservative estimates, the current revenue volume of the global laser market would multiply overnight.

Fusion at AKL’26

In light of such prospects, the AKL – International Laser Technology Congress (April 22–24, 2026, in Aachen) will explore the economic and technological potential of the future fusion market in various sessions. In the Gerd Herziger Session on April 23, 2026, Prof. Constantin Häfner will provide current insights into the state of fusion

FRAUNHOFER INSTITUTE FOR LASERTECHNOLOGY ILT

research and the status of the required supply chains in his presentation “Laser Power Unleashed: Drivers for Fusion Energy and Industrial Ecosystems.” The Executive Director for Research and Transfer at the Fraunhofer Society is a renowned fusion expert and responsible for high-energy laser development at LLNL. He then provided significant impetus for fusion research in Germany during his time as director of Fraunhofer ILT and as an advisor to the German federal government. He will also participate in the panel discussion during the session.

March 31, 2026 || Page 7 | 9

Following this, Session 4, Laser Sources II, will provide in-depth technical insights into the development of high-energy lasers for fusion and secondary sources. In Session 7 - Laser Sources III on April 24, which focuses on ultrashort-pulse lasers, the “Diode Lasers” slot led by Dr. Sarah Klein will address semiconductor lasers for future fusion power plants.



Image 1:
“Fusion research is now at the typical Fraunhofer working point. The goal is to rethink technologies and translate them from research into industrial applications,” explains Dr. Sarah Klein, coordinator of fusion research at the Fraunhofer-Gesellschaft.

© Fraunhofer ILT, Aachen, Germany / Ralf Baumgarten.

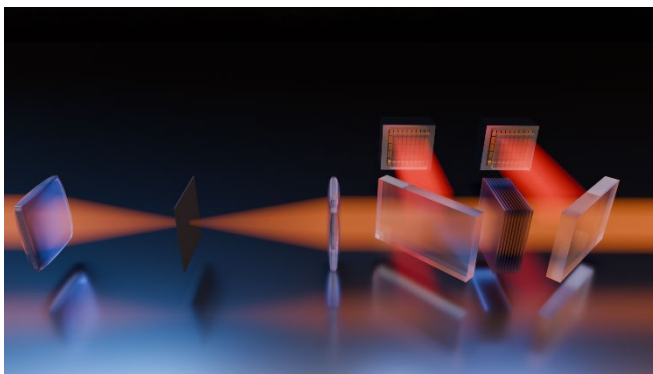


Image 2:
Visualization of a beam path. Laser pulses travel through optical components and amplifier plates. The high-power diode laser modules supply energy to amplify the pulses to the level required to ignite the fusion process.

© Fraunhofer ILT, Aachen, Germany.

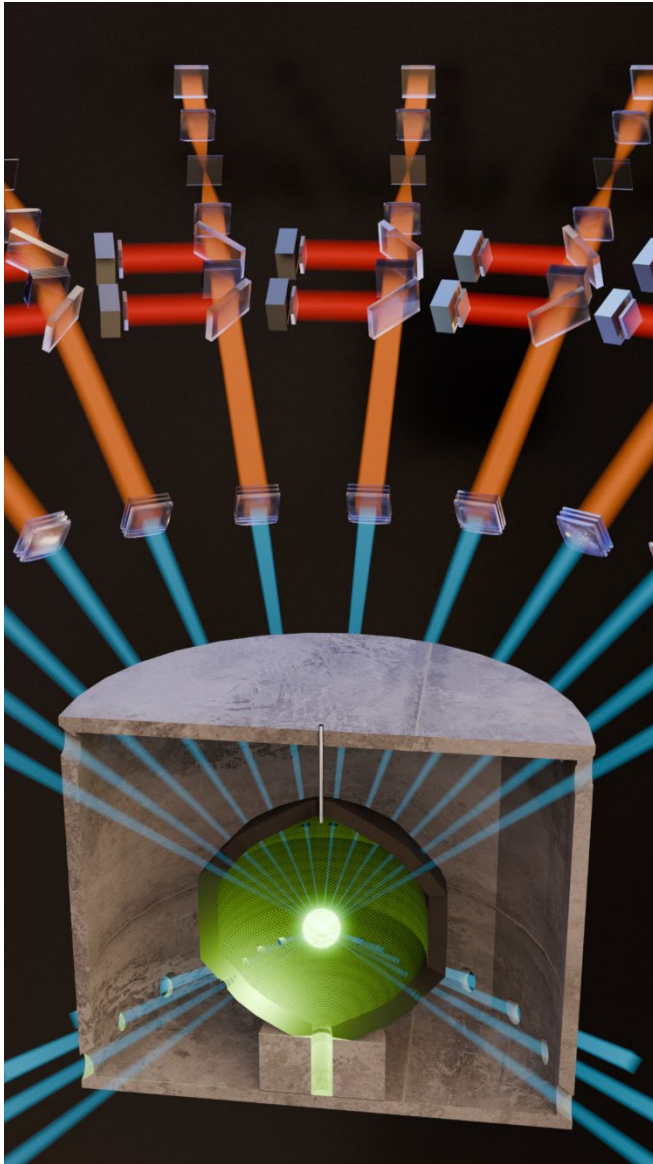


Image 3:
Cross-section of the target chamber in an artist's concept of an inertial fusion energy power plant. In it, a fusion plasma from the hydrogen isotopes deuterium and tritium would be ignited more than ten times a second to generate abundant, clean Energy.

© Fraunhofer ILT,
Aachen, Germany.

FRAUNHOFER INSTITUTE FOR LASERTECHNOLOGY ILT

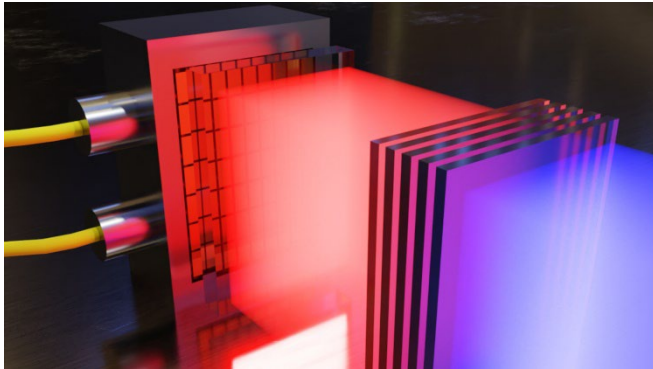


Image 4:
Artist's rendering of a diode laser module with beam shaping for pumping plate stack amplifiers in highenergy lasers. Such diode laser pump modules are considered a key component for fusion power plants of the future.
© Fraunhofer ILT, Aachen, Germany.

March 31, 2026 || Page 9 | 9

Professional contact

Dr. rer. nat. Sarah Klein

Fusion Research Coordinator at the Fraunhofer Society
Laser and Optical Systems Department
Phone +49 241 8906-8363
sarah.klein@ilt.fraunhofer.de

Dr. Johannes Weitenberg

Laser and Optical Systems Department
Phone +49 241 80-40427
johannes.weitenberg@ilt.fraunhofer.de

Fraunhofer Institute for Laser Technology ILT
Steinbachstraße 15
52074 Aachen, Germany
www.ilt.fraunhofer.de

The **Fraunhofer-Gesellschaft**, headquartered in Germany, is one of the world's leading organizations for applied research. It plays a major role in innovation by prioritizing research on cutting-edge technologies and the transfer of results to industry to strengthen Germany's industrial base and for the benefit of society as a whole.

Since its founding as a nonprofit organization in 1949, Fraunhofer has held a unique position in the German research and innovation ecosystem. With nearly 32,000 employees across 75 institutes and legally independent research units in Germany, Fraunhofer operates with an annual budget of €3.6 billion, €3.1 billion of which is generated by contract research — Fraunhofer's core business model.