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PRESS RELEASE

From lab to power plant: LLNL and Fraunhofer ILT lay the foundation for the next generation of fusion lasers

Two world-leading research institutions are joining forces and their laser design and simulation expertise – to successfully transition laser-ignited inertial fusion from the experimental stage to industrial application. In the project ICONIC-FL (International Cooperation on Next-gen Inertial Confinement Fusion Lasers), the US Lawrence Livermore National Laboratory (LLNL) and the Fraunhofer Institute for Laser Technology ILT Aachen, Germany, are diligently collating their sophisticated laser simulation models. The shared aim is the development of high-energy lasers that can ignite a fusion reaction and will run at maximum efficiency in 24/7 power plant operation. This requires precise and highly accurate predictions of laser performance, which is why powerful computer simulations play a central role in the development of laser architecture.

Fusion research has been facing its next major hurdle – technological scaling – ever since LLNL made its historic breakthrough in December 2022, when it extracted more energy from fusion than was introduced by lasers (ignition) for the first time.

From experiment to power plant: the next major hurdle

At the National Ignition Facility (NIF), the engineers focused on addressing plasma physics issues, such as the conditions required to heat the fusion fuel deuterium-tritium to over 100 million degrees, compress it extremely, and trigger a self-sustaining fusion reaction. When this occurs, more energy is released than introduced into the fuel capsule – the target – from outside by lasers. Since its breakthrough at the end of 2022, LLNL has demonstrated that the physical principle works, several times and with increasing energy yield. A single ignition, however, will not be sufficient for a future power plant. Rather, the plant will require approximately 15 shots per second (!). This requires the use of efficient diode-pumped solid-state lasers (DPSSL) that can fire dozens of times per second.

Two laser heavyweights, LLNL and Fraunhofer ILT, are now pooling their complementary expertise to develop these lasers: While LLNL brings along decades of experience in high-energy laser technology to the table, the Aachen-based institute is a global leader in the development and industrial scaling of DPSSLs.

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Virtual stress test for tomorrow's hardware

The laser design must be validated in simulations before expensive prototypes can be built. In the ICONIC-FL (International Cooperation on Next-gen Inertial Confinement Fusion Lasers) project, the partners are pursuing the common goal of simulating the amplification stages of high-energy lasers in as much detail as possible—thus laying the foundation for a later design. They are focusing on the heart of the system: the laser amplifiers. These amplify an initially small laser pulse to the laser energies required for fusion. In these laser pulses, the photons transfer an energy of many millions of joules. Laser media used for this purpose consist of stacks of laser glass or crystal plates with an area of up to 40 cm x 40 cm and a thickness of a few millimeters; they are cooled with transparent cooling media during operation. The amplifier plates are exposed to enormous thermal and optical stress.

"24/7 operation leads to heating, refraction effects, and aberrations that could distort the laser beam. Even the smallest, unpredictable effects are significant here and lead either to efficiency losses or direct damage to the optics. We want to understand exactly what is happening in each individual plate so that we can then simulate complex plate stacks with precision," explains Johannes Weitenberg, project manager at Fraunhofer ILT.

Independent cross-validation: security through two models

In the ICONIC-FL research project, the partners will diligently collate their respective simulation solutions, which they have developed over many years, to achieve increasingly detailed and realistic simulations. They will systematically compare and cross-validate simulations without exchanging the actual code. "It's not about merging the simulation models, but about learning from each other and double-checking our results," Weitenberg clarifies. Nevertheless, this methodical approach is extremely valuable from a scientific, technical, and economic perspective: The partners can guarantee that their simulated predictions are extremely robust and reliable by independently applying their respective codes – developed to maturity in different fields of application – to the same design. This approach can significantly accelerate the development of lasers for real power plants and avoid costly missteps in a process worth billions.

The cooperation combines the cutting-edge expertise of both institutes, which they have systematically built and deepened since the 1990s, in order to massively reduce development time. By validating the designs in the simulation, the partners avoid not only technical but also enormous financial risks: With up to 400 beam paths in future power plant designs, even the smallest overlooked detail in the transition to series production can result in significant costs.

Strategic partnership for clean energy

"The transition from basic research to power plant development requires the rapid, robust development of rugged new laser systems rapidly. Fraunhofer ILT's expertise in the industrial scaling of diode-pumped lasers is crucial for accelerating our IFE program. In this transatlantic collaboration, we will efficiently consolidate the technological basis for the fusion power plant," explains Tammy Ma, head of fusion research at LLNL. Prof. Constantin Häfner, Executive Vice President for Research and Transfer at the Fraunhofer-Gesellschaft, emphasizes: "We are in the decisive decade for fusion energy. For inertial fusion to reach its full potential, we need to develop new laser architectures with uncompromising perfection. Combining the expertise of LLNL with the industrial scaling expertise of Fraunhofer and its institute ILT is a powerful response to this challenge. Here we are laying the foundation for future power plants."

Fusion power plants could generate competitive, climate-neutral electricity 24/7, making them an important complement to volatile renewable energies. With ICONIC-FL, Germany and the USA are jointly laying the mathematical foundation for this future technology.

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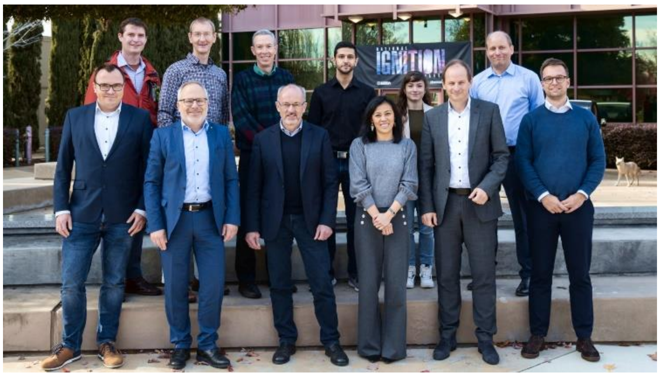

Image 1:
Fusion researchers at Fraunhofer ILT and Lawrence Livermore National Laboratory.
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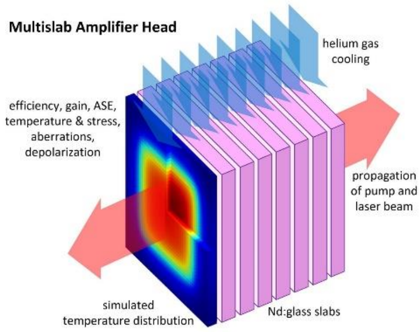

Image 2:
Multislab amplifier.
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Image 3:
A production line was set up on site during the construction of the National Ignition Facility (NIF) specifically for the manufacture of the laser glass plates.
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