



# Feature issue introduction: laser driven inertial confinement fusion and bridging the gaps to inertial fusion energy systems

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**Abstract:** Major fusion research milestones have been achieved using laser driven inertial confinement fusion (ICF) in recent years, and these successes have ignited tremendous enthusiasm for inertial fusion energy (IFE). However, the complexity and difficulty of obtaining fusion ignition with a laser driver in a research setting are often underappreciated, as are the gaps to high driver efficiency, high repetition rates, and laser and target durability requirements needs for IFE. On the academic side, several new research laser systems have been constructed over the past few years, enabling researchers to probe the limits of ICF physics and engineering. This feature issue highlights the challenges and capabilities of laser research and development targeted towards advancing IFE.

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## 1. Forward

Shortly after the invention of the laser [1] it was proposed that with a laser, plasmas could be generated and heated [2,3]. While some fusion may be generated by illuminating a plasma of fusion fuel with a laser, the conditions for generating the thermodynamic feedback-loop and copious thermonuclear energy production known as “ignition” [4] requires more than just heating (temperature), additionally needing density and time. It was soon realized that lasers could be used to implode a capsule of fusion fuel [5], compressing the fuel to ultra-high density and exceeding the critical thermal temperature [6] where fusion heating exceeds radiative cooling.

If the density ( $\rho$ ) of the compressed fusion fuel is high enough, as measured by the integral of density and radius ( $R$ ),  $\int \rho(R)dR$ , the fusing plasma will be confined by its own inertia, for a time, perhaps long enough for ignition to occur before fully blowing apart – this is the physics of inertial confinement fusion (ICF).

Since the 1970's, researchers from across the World have pursued ignition using ICF approaches but it was not until recently that ignition [7–9] was actually achieved, using the technique of x-ray (“indirect”) drive [10], after an initial stumble in 2012 and then a decade-long series of problem solving steps [11]. A little over a year after obtaining ignition, fusion energy production exceeded the amount laser energy delivered to the fusion target (“target energy gain” a.k.a. scientific breakeven) [12–15], utilizing crucial enhancements to the laser energy delivery capability [16] of the National Ignition Facility [17] laser and improvements in fusion target quality [18].

While an “existence proof” of a burning plasma and ignition has now been demonstrated in a laboratory setting, fusion for energy production (regardless of scheme) is still in the regime of science fiction. However, many technologies that were at one time science fiction are in practical use today and it is with this in mind, that this special issue was motivated.

Key laser and optics technology research priorities that will be to enable IFE are reducing the cost of diode pumps in diode-pumped solid-state lasers (DPSSL), increase the damage threshold of optics and crystals in high-fluence lasers at multi-Hertz repetition-rate, improve the reliability of the pulse-power supplying energy to the lasers, increase laser bandwidth, and develop conceptual design studies of complete IFE systems.

## 2. Optics damage and beam control

In the area of controlling optics damage, Batysta and colleagues [19] demonstrate a novel method using a quartz rotator to simplify the mitigation of depolarization resulting from thermal stress in high-average-power laser amplifiers and include a discussion of the scalability of the idea to IFE.

While Shevtsov and colleagues [20] describe a method for fabricating large-aperture waveplates with low transmission losses in the near-ultraviolet region with a laser-induced-damage threshold approaching that of native fused silica substrate. A strategy that appears to nearly double the transverse stimulated Raman scattering threshold of ICF laser drivers is developed by Fan and colleagues [21]. While testing of inductively-coupled plasma reactive-ion etching in grating fabrication show an increase in etch-related defects, as reported upon by Dent and colleagues [22], indicating that new cleaning methods must be employed. Finally, authors Zong, *et al.* [23] describe experimental results of a spatial beam shaping method that enables high-precision near-field control and reduced risks of optics damage.

## 3. Conceptual design

In the area of conceptual design studies for IFE systems, Banerjee and colleagues [24] report on a modular kilojoule-class element laser architecture for scaling to multi-megajoule IFE facilities. The numerical modeling presented, suggests significantly improved longitudinal energy extraction from the pump. Promising laser architectures for ICF applications are reported on by Lebegue and colleagues [25], who focus upon spatial coherent beam combining strategies.

While Sunahara *et al.* [26] describe IFE reactor concept using high-finesse optical enhancement cavities pumped by fiber lasers. Authors McGeoch and Obenschain [27] consider argon-fluoride (ArF) amplifier chains for their direct-drive IFE scheme, arguing that high-energy deep UV (193 nm) ArF lasers can indeed be built, and are desirable for achieving the high fusion gain needed for IFE systems. Finally, recognizing that diode pumps are, by far, the largest single expense in DPSSL IFE systems, Crump and colleagues [28] discuss the technology requirements and potential paths to lower cost.

## 4. Target related physics

In the area of exploring ICF and IFE target physics, experiments and simulations of  $3\omega$  and  $7\omega$   $4\omega$  laser shine-through on plastic ablaters, the element of an ICF target that is responsible for converting laser direct-drive energy into the pressure that accelerates the fusion fuel inwards upon itself, are performed by Pineau and colleagues [29]. A key finding is that the potential problem of laser shine-through in a directly-driven ICF target is essentially eliminated with  $4\omega$  light, albeit the authors also suggest that engineering the band-gap of the ablator material may also be a solution for  $3\omega$  light. Lastly, the capability of generating high-quality betatron x-rays for probing high-energy-density targets for tomography or temporally along a single line-of-sight is the focus of Nutting and colleagues [30] at the ZEUS laser facility.

**Acknowledgment.** The guest co-editors would like to thank the Optica publishing group staff for their help in administrating this feature issue. This work performed under the auspices of U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or

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**Disclosures.** O.A.H. has been Chief Scientist for the LLNL indirect-drive ICF Program since 2014 and has contributed to advisory reports on IFE for both the U.S. and German governments. O.A.H. has also done ICF target design work, under contract, for IFE companies Focused Energy and Inertia. JMGMN has been the NIF Laser Systems Chief engineer since 2020, modeling and commissioning the NIF, ARC, and HAPLS laser architectures. Before joining LLNL, he was involved with the French Atomic Energy Commission, as lead for the modeling and commissioning of LMJ's laser prototype. D.H.F. is the Director for both the IFE-Science & Technology Accelerated Research (IFE-STAR) and IFE-Consortium On LPI Research (IFE-COLOr) programs. C.L.H. was lead author on a recent IFE report for the German government. S.O. is the founder and CEO of LaserFusionX.

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