Advancing the S&T of the Argon Fluoride Laser for Inertial Fusion Energy

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Stephen Obenschain, U.S. Naval Research Laboratory
Matthew Wolford, U.S. Naval Research Laboratory

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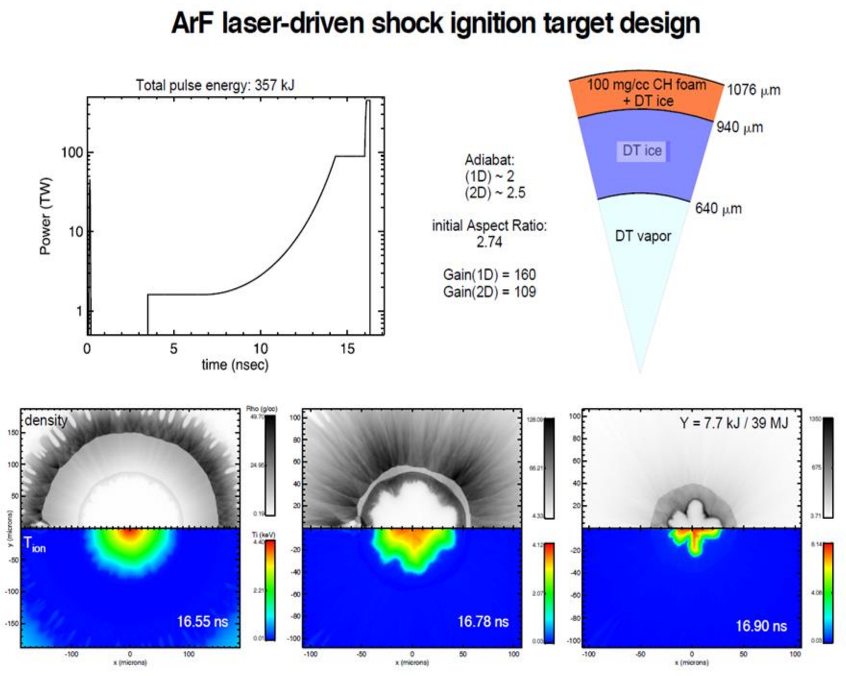
Team members and roles

- Dr. Stephen Obenschain – PI
- Dr. Matthew Wolford - Leader of Electra ArF research project
- Mr. Matthew Myers - Electra chief research engineer: pulse power, e-beam diode and e-beam deposition measurements.
- Mr. T. Jude Kessler - Electra physicist: laser diagnostics
- Mr. Laodice Granger - Electra chief technician
- Ms. Lori Pastor -   Administrative assistance
- Dr. Malcolm McGeoch – Plex Inc.: consultant on ArF S&T
- Dr. Andrew Schmitt – radiation hydrocode simulations of high-gain laser direct-drive targets
- Dr. Jason Bates – simulations on mitigation effects of broad bandwidth and short laser wavelength on laser plasma instabilities
- Dr. James Weaver – lead on advancing S&T for achieving broad bandwidth output from ArF lasers

Electra electron-beam-pumped amplifier

High-level motivation and goals for ArF direct drive as a path to practical and economical inertial fusion energy.

- This project will advance the science and technologies of the ArF laser for IFE – focusing on the science.
- E-beam pumped ArF is predicted to have intrinsic efficiency ≥16% enabling 10% wall plug efficiency for laser light onto target.
- ArF's short wavelength (193 nm) and capability to provide broad bandwidth (10 THz) highly uniform light on target could enable the robust high energy gains (>100) required for inertial fusion energy (IFE) at energies below 1 MJ.
- The ArF laser could thereby enable enable smaller, lower cost laser IFE power plant modules.



High resolution two-dimensional simulation of a direct-drive shock-ignited target using a 357 kJ ArF driver – gain of 106 with 39 MJ yield.*

*__Fig 3__ from Phil. Trans. A. Volume 378, Issue 218, (2020) DOI https://doi.org/10.1098/rsta.2020.0031.

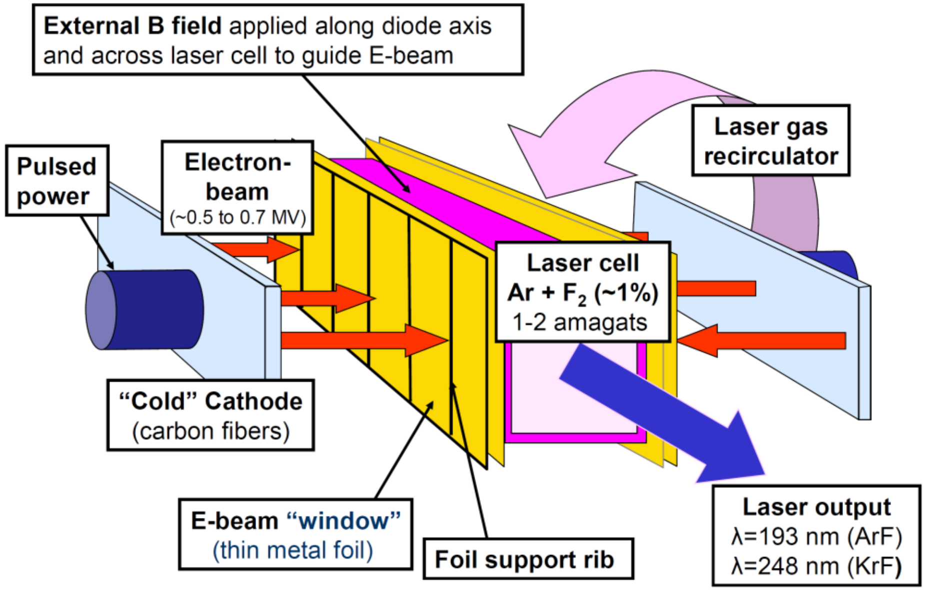
arpa·e
CHANGING WHAT'S POSSIBLE

Major tasks (and technical risks), milestones, and desired project outcomes -- advance S&T of high-energy high efficiency ArF lasers for IFE

- **Modify Electra to obtain 40% increase in E-beam deposition into laser gas with ArF gas mixtures (M2.1)** – *Electra was designed for KrF mixtures which have larger e-beam stopping coefficients*.
- **15-cm x 30-cm oscillator optics installed on Electra (M2.2)** – *optimize aperture and e-beam pump for ArF oscillator operation*
- **Obtain >300 J from Electra in oscillator mode (M2.3)**
- **Diagnostics and laser hardware in place for intrinsic efficiency measurements (M3.2.1)**

DEMO ≥16% ArF intrinsic power efficiency (M3.2.2)

- *Intrinsic efficiency is the ratio of the laser power (energy) out divided by the E-beam pump power (energy) deposited in the ArF gas.*
- *Determine gas mixtures, pressures and pump rates that enable high intrinsic efficiency*
- *Compare results with ArF simulations*



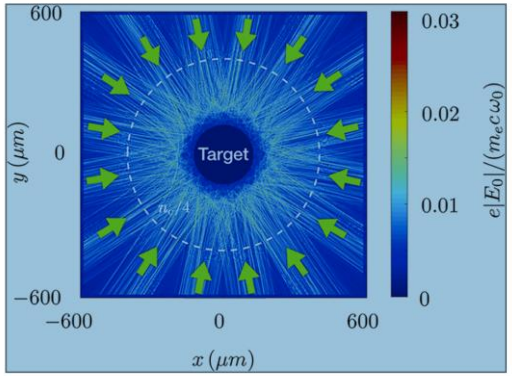
Major tasks (and technical risks), milestones, and desired project outcomes

advance high-gain ArF target designs and S&T of achieving broad bandwidth

- Using 1-D and 2-D hydrocode simulations **develop high-gain target designs with reduced laser energy (<1MJ).**
- **Evaluate risks from laser plasma instabilities (LPI)** and develop mitigation strategy through use of shorter wavelength and broad laser bandwidth.
- **Iterate hydro-code and LPI simulations** to identify design regimes where the implosions are high-gain yet resistant to both hydro and laser plasma instabilities.
- **Determine bandwidth capability of electron beam pumped ArF lasers using the Electra facility**.

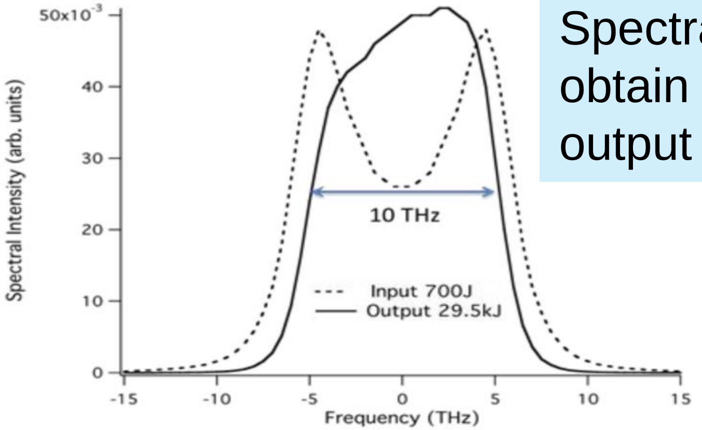
  - measurements gain vs input wavelength

  - develop path to both broad bandwidth (>8 THz) while retaining high intrinsic efficiency.



I = 5×10^{14} W/cm ^{2} onto spherical target

2-D LPSE simulation indicates ArF 193 nm light @ 5 THz bandwidth enables 91% absorption (vs 65% with a 351 nm laser @ 1 THz) *



Spectral shaped input to obtain 10 THz FWHM ArF output (kinetic simulation)**

* **Fig 8** Jason Bates et al,. High Energy Density Physics 36 (2020) 100772

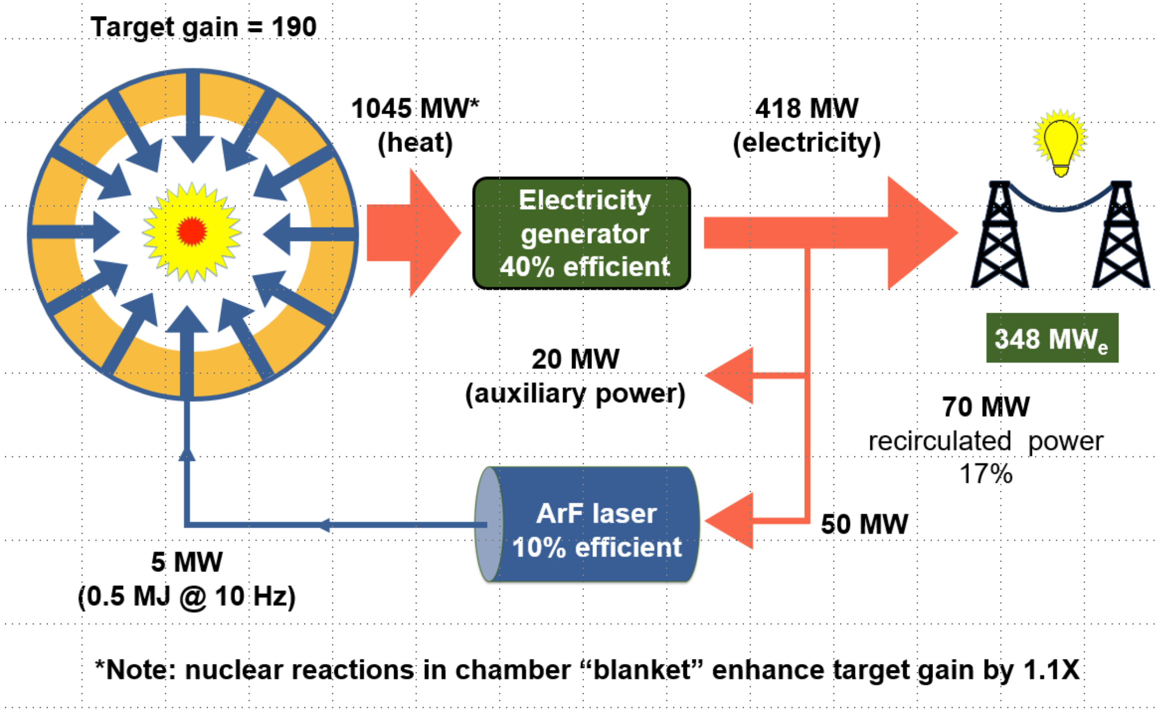
** **Fig 6** S.P. Obenschain et al., Phil. Trans. A. Volume 378, Issue 218, (2020) DC https://doi.org/10.1098/rsta.2020.0031.

Key techno-economic metrics of the project (and, if applicable, its commercial fusion-energy application)

The BETHE NRL ArF program will advance two critical elements of a laser IFE power plant:

- Determine operating regimes where ArF will have high electrical efficiency.
- Develop robust high-gain target designs that require less than 1MJ energy*

* NRL and LLE will compare/discuss hydrocode and LPI simulations



IFE power plant using ArF direct drive implosions
High target gain @ (0.5 MJ) in combination with relatively high (10%) laser efficiency allows most of the generated electricity to be sent to the power grid.

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