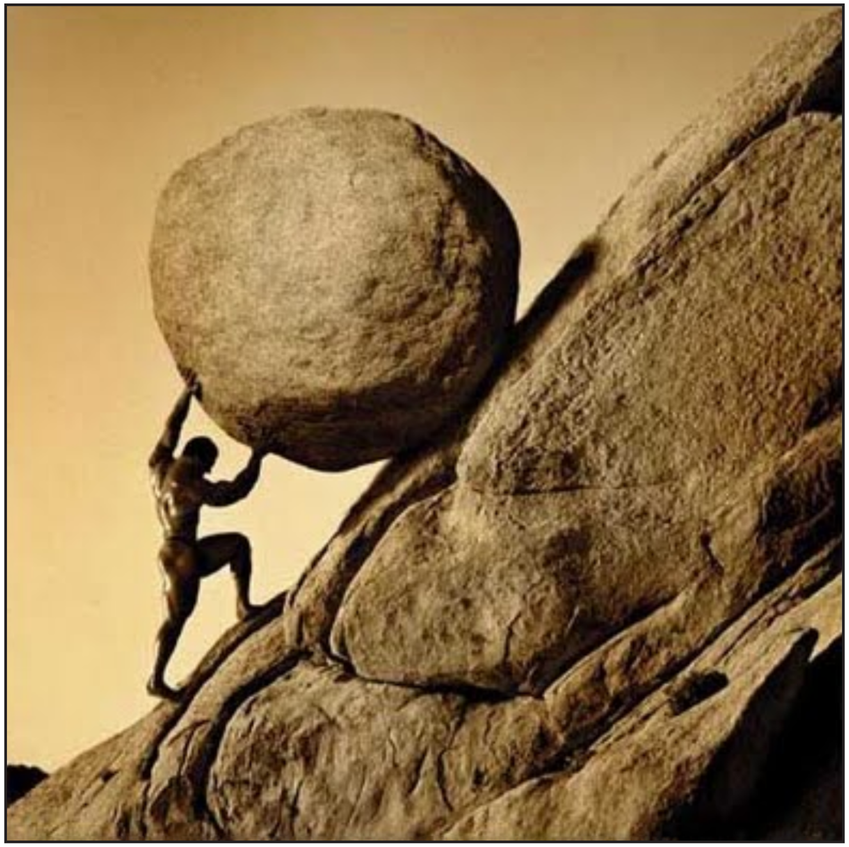
Perspectives on Inertial Fusion Energy



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Fusion Power Associates
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Washington, DC
16 December 2014

Summary

The development of commercial inertial fusion energy (IFE) will be a long process

UR LLE

- Ongoing increases in fossil fuel reserves may reduce the urgency
- Talking about power on the grid in a decade (or even seven more years) reduces credibility
- Demonstrating ignition is an essential first step
  - a robust and reliable ignition platform is required
- Direct drive has advantages for laser-driven IFE
  - more energy coupled to the simplest possible target
- The direct-drive ignition concept could be validated with polar drive on the National Ignition Facility (NIF)

The development of fusion energy is a grand challenge worthy of a great nation—but it will take decades!

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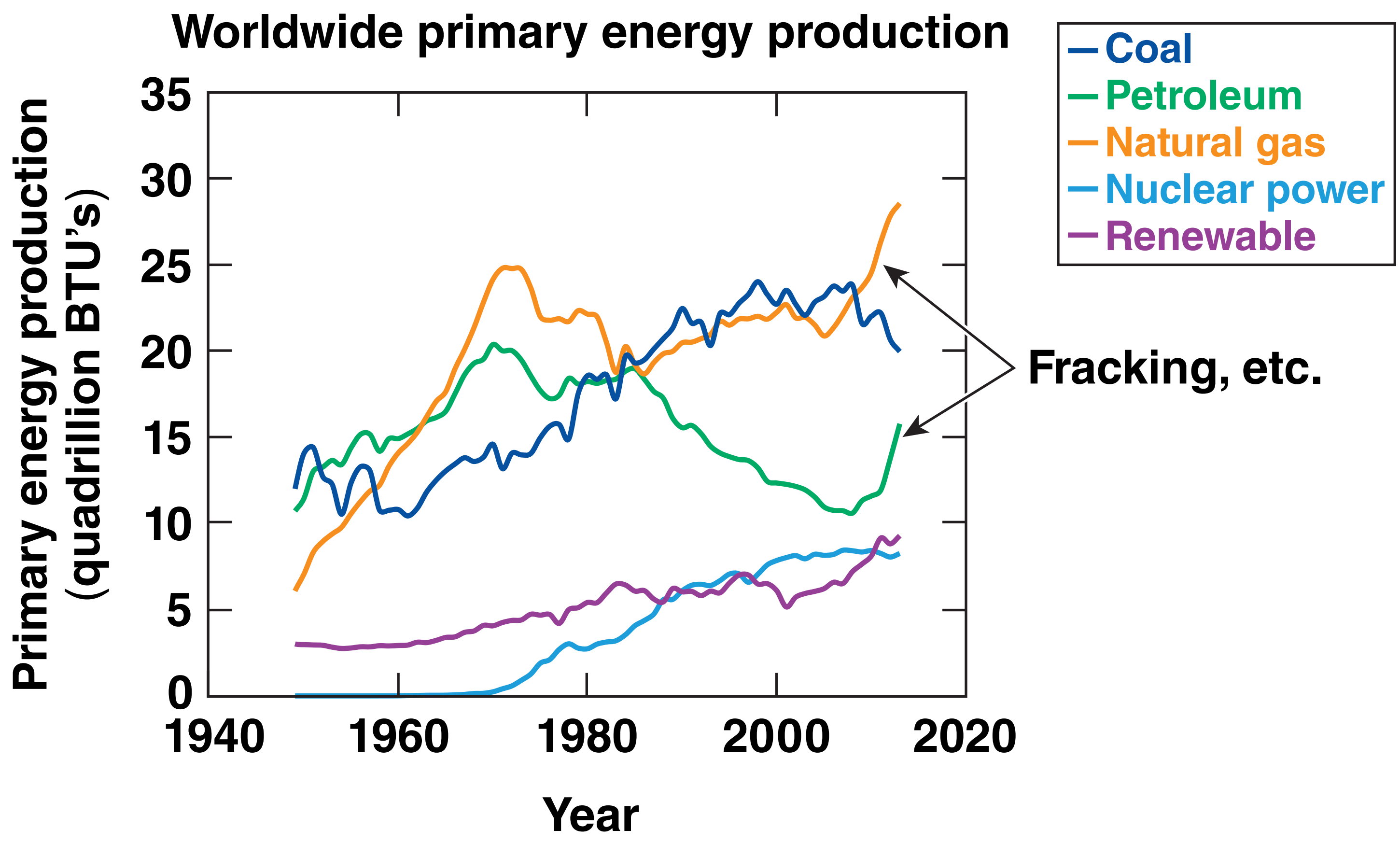
New techniques are increasing petroleum and natural gas production



U.S. Energy Information Administration (EIA), International Energy Statistics (U.S. Department of Energy, Washington, DC, 2014), http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=5&pid=5&aid=2.

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In the past decade, the estimated fossil fuel reserves have increased, even with significant consumption

	2005		2014	
Fossil fuel	Estimated reserves	Years remaining	Estimated reserves	Years remaining
Petroleum	1.2 trillion barrels	39	1.6 trillion barrels	50
Natural gas	6,000 trillion cubic ft	61	6,800 trillion cubic ft	57
Coal	1,081 billion short tons	164	980 billion short tons	116

U.S. Energy Information Administration (EIA), International Energy Statistics (U.S. Department of Energy, Washington, DC, 2014), http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=5&pid=5&aid=2.

Direct drive allows for higher coupling efficiency so that significantly more fuel can be compressed to ignition conditions than with indirect drive (ID)

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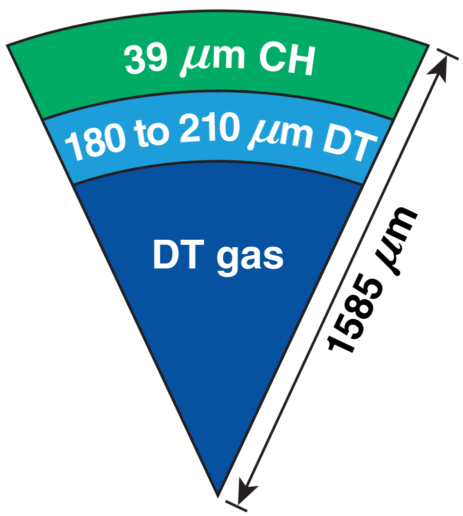
Basic point design of symmetric 1.8-MJ ignition design*



Apart from design details

- At least 7× more fuel to the same V_{imp}
- 4× lower stagnation pressure required (~100 Gbar for margin 1 symmetric 1.8 MJ)
- 1.5× lower convergence
- 3× higher fuel adiabat
- Margin comparable to ID ($P\tau/P\tau_{ign}$)
- Relatively simple plasma conditions compared to a hohlraum
- Simple, low-cost targets with little debris
- Open geometry for diagnostic access

*V. N. Goncharov *et al.*, Phys. Rev. Lett. 104, 165001 (2010).

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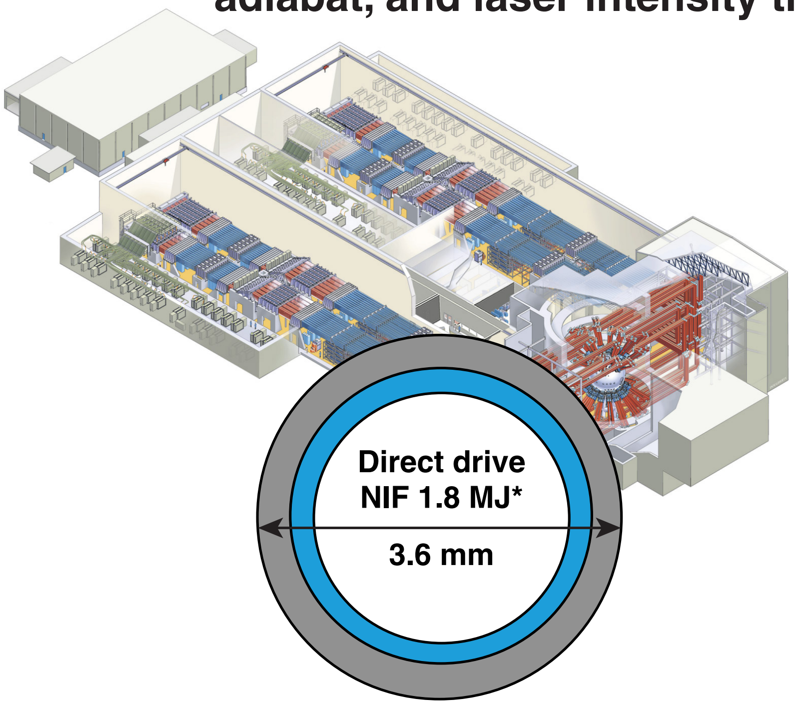
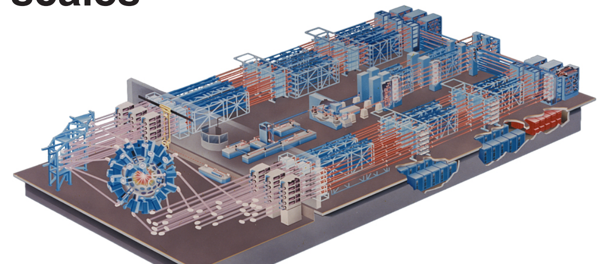
Symmetric direct-drive–ignition designs* can be scaled for hydrodynamic equivalence at the OMEGA scale

- **Hydrodynamic similarity is ensured by keeping the implosion velocity, adiabat, and laser intensity the same at the two scales****

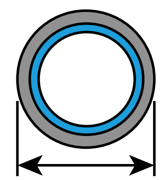




Scale 1:70 in energy

Hydrodynamic scaling

OMEGA 26 kJ



Capsule radius ~ $E_L^{1/3}$
Shell thickness Δ ~ $E_L^{1/3}$
Laser power ~ $E_L^{2/3}$
Pulse length ~ $E_L^{1/3}$
Mass fuel ~ E_L

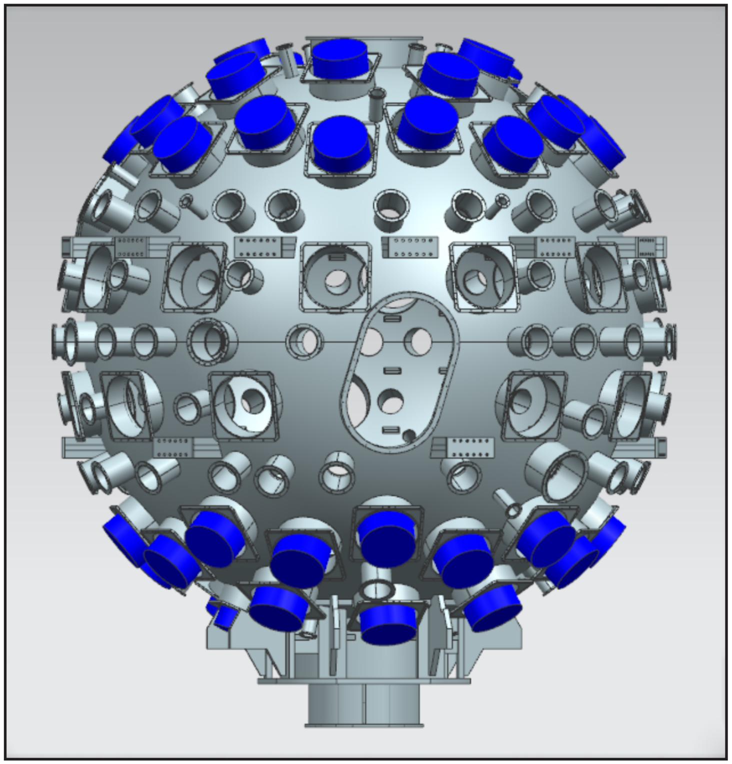
Performance metrics include $P\tau$ (atm-s), pressure (Gbar), yield, and compressed fuel ρR (g/cm^2)

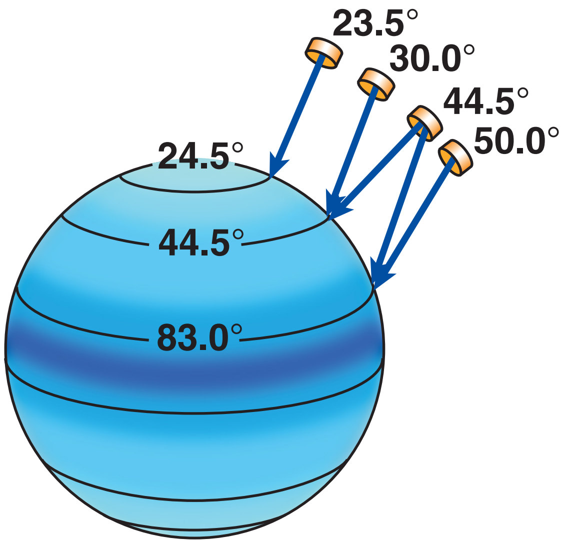
*V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010).
**R. Betti, "Theory of Ignition and Hydro-Equivalence for Inertial Confinement Fusion," presented at the 24th IAEA Fusion Energy Conference, San Diego, CA, 8–13 October 2012.

TC10256f

LLE is developing polar direct drive (PDD):* a platform for direct-drive inertial confinement fusion (ICF) on the NIF using the x-ray-drive beam geometry

X-ray drive
(beams around the poles)





- Increasingly oblique irradiation near the equator
  - reduced absorption
  - reduced hydroefficiency
  - lateral heat flow
  - cross-beam energy transfer (CBET)

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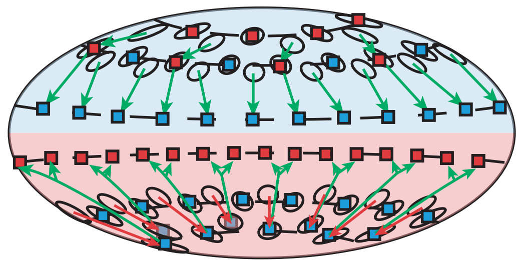
*S. Skupsky *et al*., Phys. Plasmas 11, 2763 (2004).

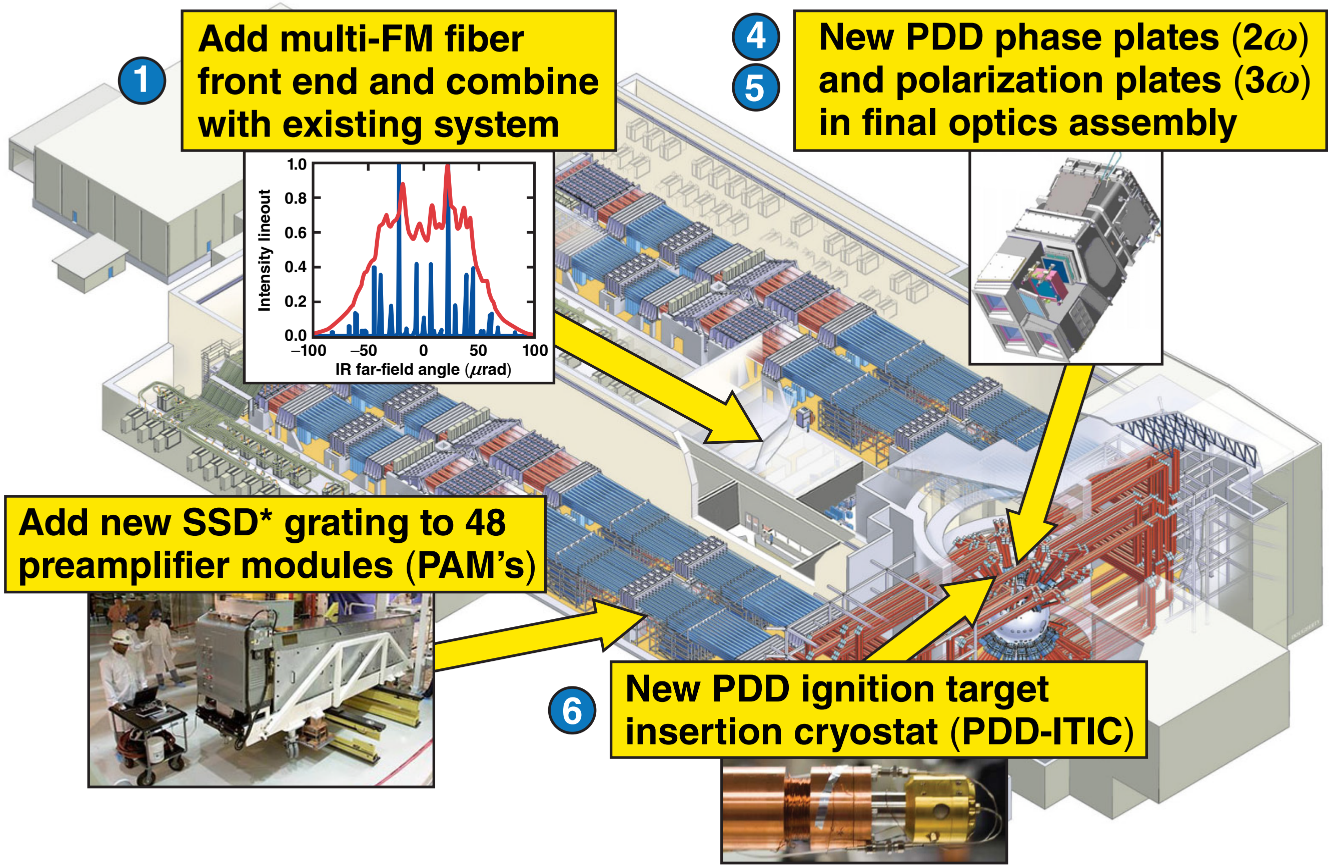
PDD ignition requires additional capabilities on the NIF

Hemispheric wavelength detuning



$\Delta\lambda \geq -6$ Å (UV)
$\Delta\lambda \geq +6$ Å (UV)

Current capability:
$\Delta\lambda \sim \pm 2$ Å (UV)

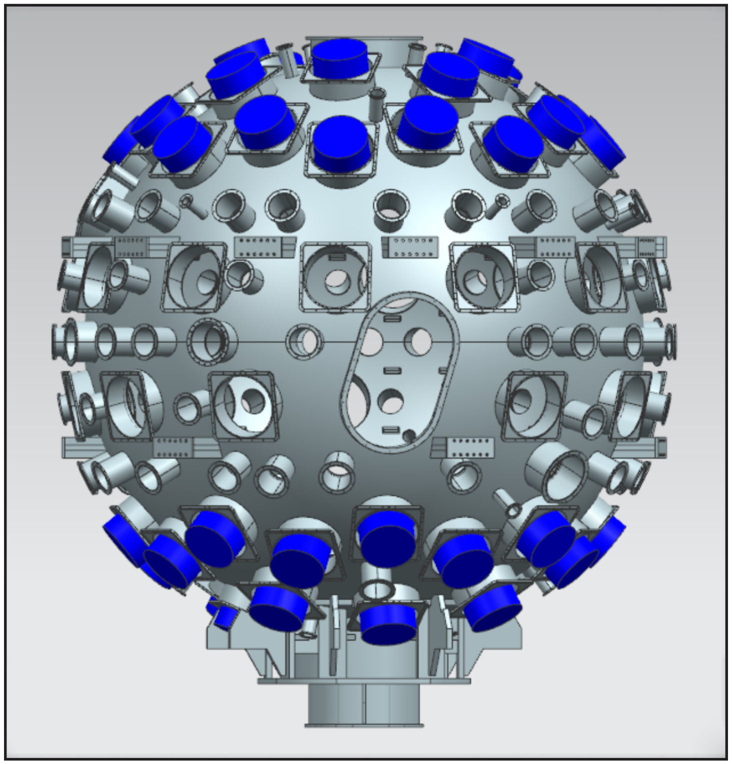


The NIF PDD Laser Path-Forward working group is actively engaged in adding beam smoothing, phase plates, polarization smoothing, and hemispheric $\Delta\lambda$.

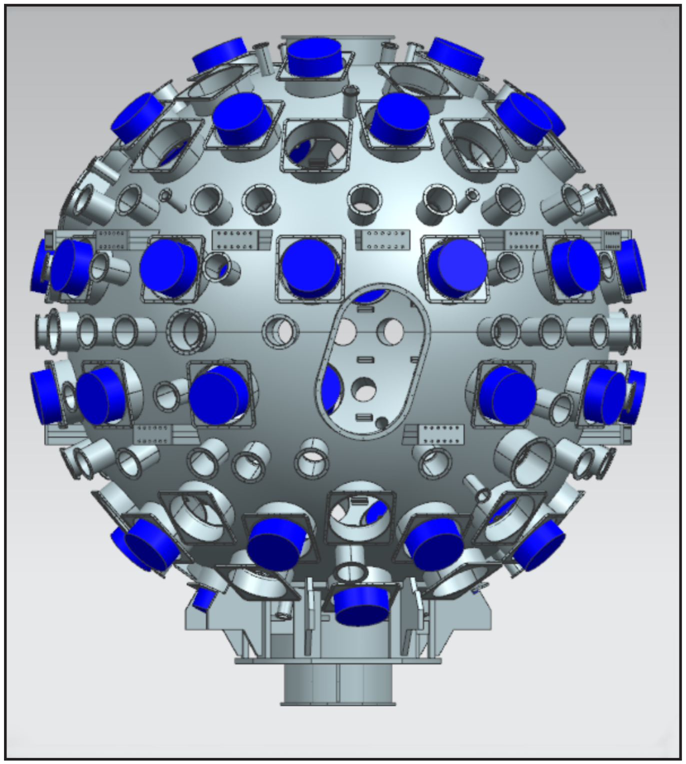
*SSD: smoothing by spectral dispersion

In the future, the NIF could be configured for symmetric direct drive

Current NIF: cylindrical symmetry



Future NIF (?): spherical symmetry*



*D. Eimerl, ed., Lawrence Livermore National Laboratory, Livermore, CA, Report UCRL-ID-120758, NTIS Order No. DE95017854 (1995).

ARPA-E's ALPHA solicitation provides transformative opportunities for fusion

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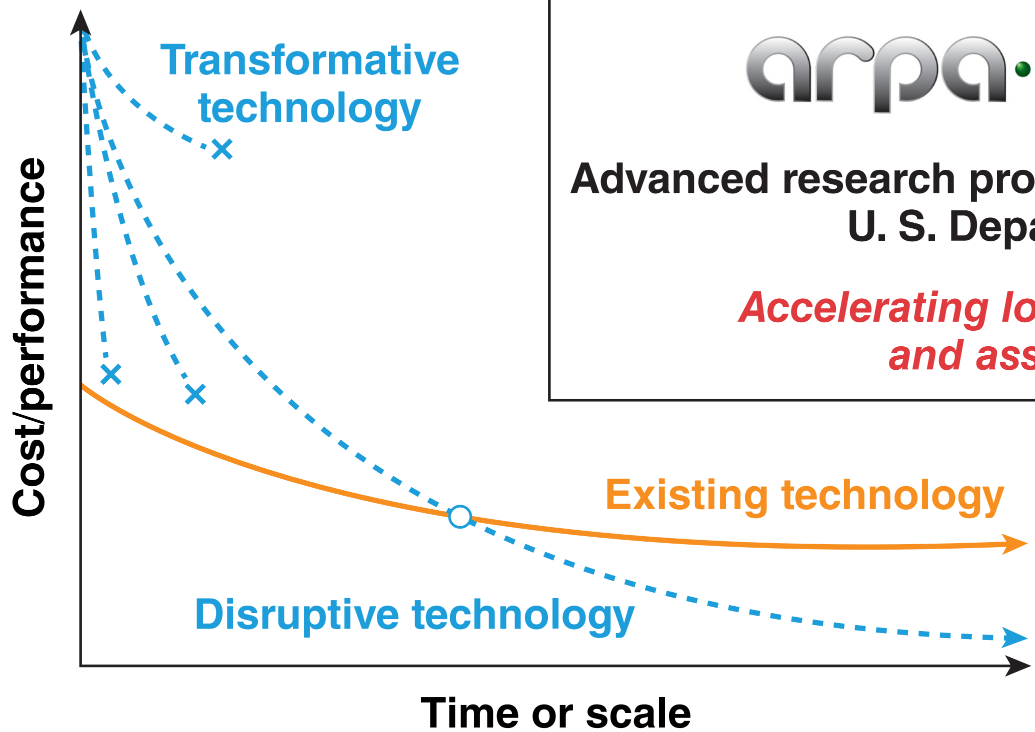

Financial assistance
funding opportunity announcement

arpa·e

Advanced research projects agency—energy (ARPA-E)
U. S. Department of Energy

Accelerating low-cost plasma heating and assembly (ALPHA)

- Transformational and disruptive technologies in terms of cost per unit performance versus time or scale; ARPA-E seeks to support research that establishes new learning curves that lead to disruptive technologies

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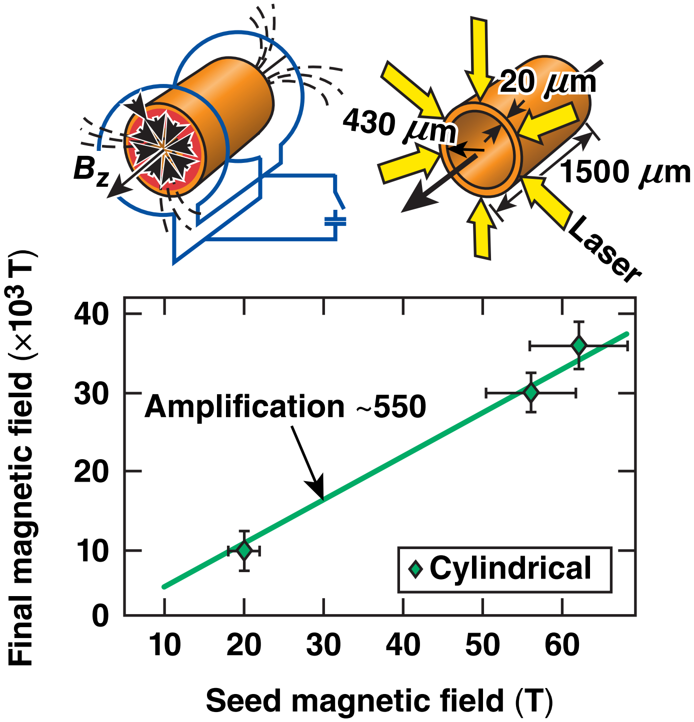
Magnetized inertial fusion concepts seem well-matched to the ALPHA solicitation

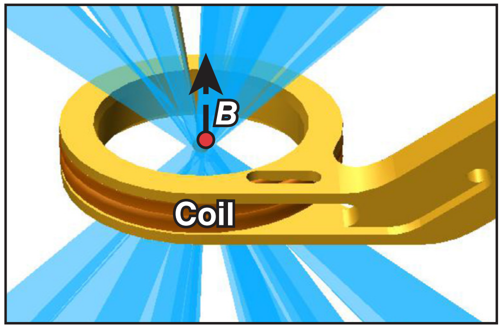
From Funding Opportunity No. DE-FOA-0001184

- This program seeks to develop and demonstrate low-cost tools to aid in the development of fusion power, with a focus on approaches to produce thermonuclear plasmas in the final density range of 10^{18} to 10^{23} ions/cm^3...

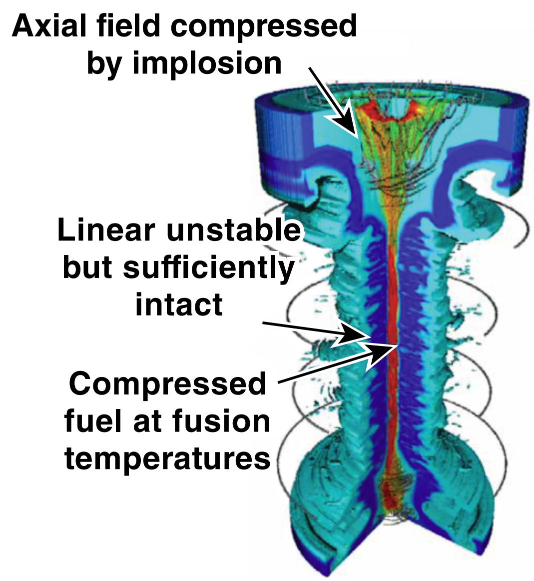


Cylindrical Implosions on OMEGA

40 OMEGA beams in PDD configuration



Spherical Implosions on OMEGA



MagLIF developed at Sandia National Laboratories

Summary/Conclusions

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