

High Energy Density Plasma Physics: An evolving role on the national scene

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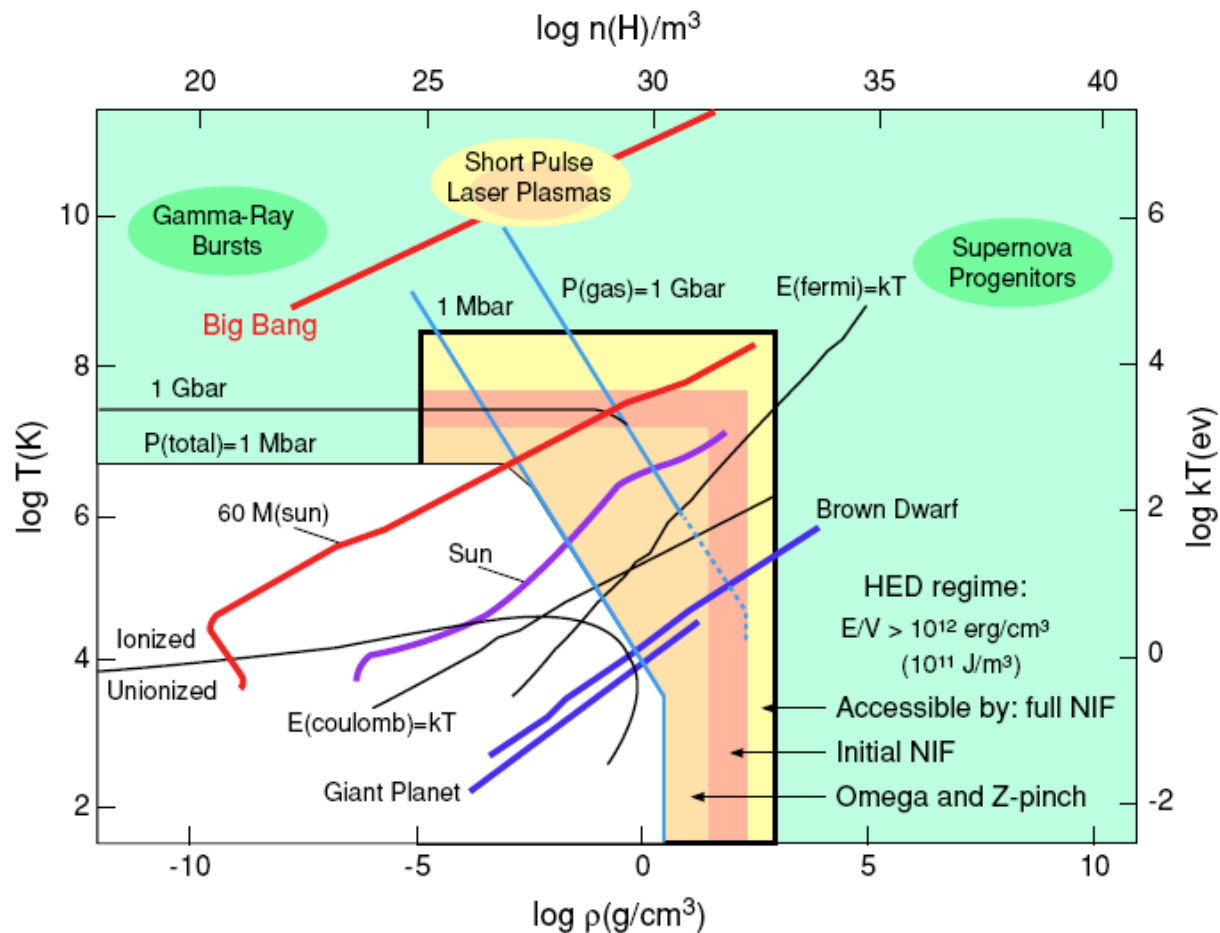
presented to
MIPSE Graduate Student Symposium
University of Michigan, Ann Arbor
September 21, 2011

Outline

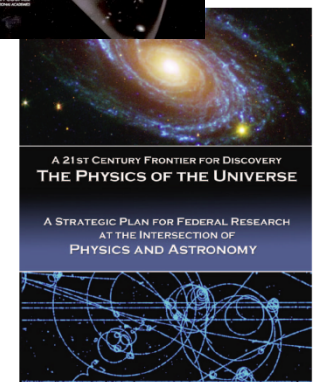
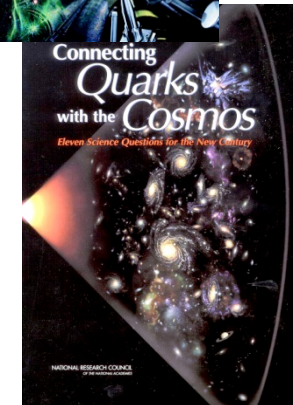
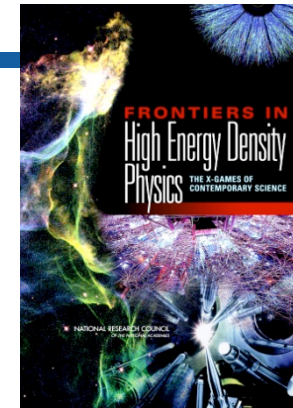
- The emergence of the field of HED science
- HED science and the DOE
- DOE's current HED science portfolio
- Ignition and NIF
- The energy landscape
- Path forward



What is high energy density matter?

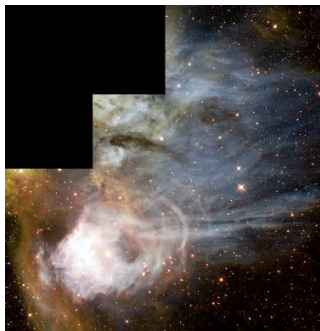


HEDP is important in astrophysics, inertial confinement fusion and weapon science



HED plasmas and materials are central to many interesting systems

High Mach Number
unstable flows



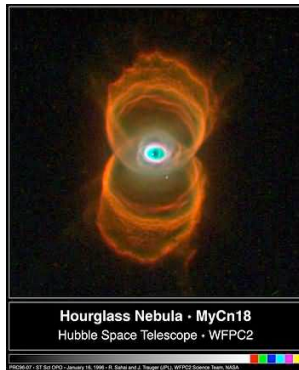
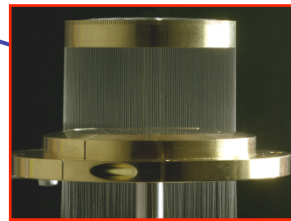
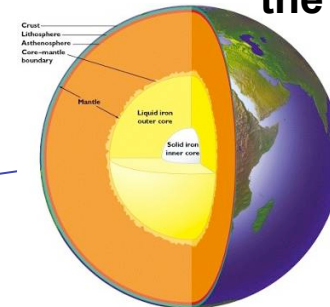
Jets



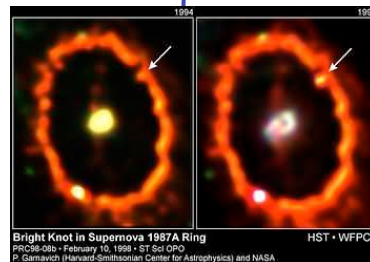
Rayleigh Taylor
Instabilities



Materials in
the Extreme



Warm Dense Matter



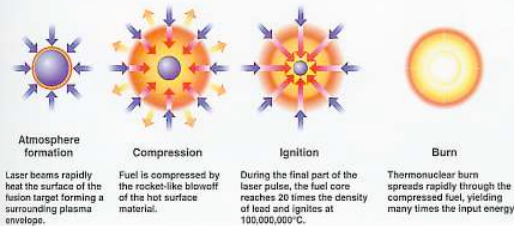
Shocks and radiation transport



MHD and thermo-
electric, effects

HEDP is important for understanding astrophysical objects, ICF and weapons

Inertial Confinement Fusion



$$\Gamma_{ii} \sim 1 - 100,$$

- Transport of low z particles (alphas)
- Screening-partially degenerate
- Non-LTE and LTE conditions
- Little or no data

Stellar Interiors



$$\Gamma_{ii} \sim 1 - \text{hundreds},$$

- Transport of low and mid z ions, alphas,
- Screening-degenerate, partially, degenerate
- LTE conditions
- Little or no data

Weapons Physics

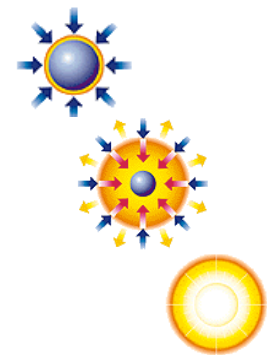
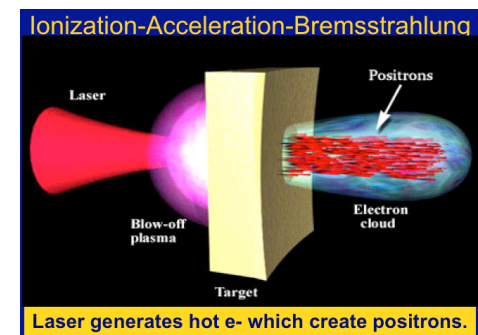


$$\Gamma_{ii} \sim 0.1 - 10,$$

- Transport of low z , mid z , high z particles
- Screening-partially degenerate
- Non-LTE and LTE conditions
- Little or no data

HED research supports DOE's basic science, nuclear security and energy missions

- Broad array of research topics
 - *plasma science, materials at extreme conditions, laboratory astrophysics, weapon science, inertial confinement fusion...*
- Variety of major experimental facilities
 - *lasers, light sources, accelerators, pulsed power facilities, ...*
 - *advanced diagnostic development*
- Development of simulation capabilities for HED science



A user's guide to HEDP and fusion at DOE...

Secretary of Energy
Dr. Steven Chu

Under Secretary of Energy

Under Secretary for Science
Dr. Steven E. Koonin

- ST&E advisor to Secretary
- Monitor R&D across DOE
- Strategic framework for ST&E in DOE

**Under Secretary for
Nuclear Security/NNSA
Administrator**
Thomas P. D'Agostino

**Asst. Secretary for
Nuclear Energy**
Dr. Peter Lyons

Office of Science

Fusion Energy Sciences
Dr. Edmund Synakowski

**Advanced Simulation and
Computing Research**
Dr. Daniel Hitchcock (Acting)

Basic Energy Sciences
Dr. Harriet Kung

Defense Programs

ICF and NIF
Dr. Jeffrey Quintenz

Defense Science
Dr. Christopher J. Deeney

**Advanced Simulation
and Computing**
Robert Meisner

The evolution of HED science as a discipline grew out of unique DOE capabilities

- Creating the most extreme states of matter takes significant experimental capability
 - A decade or so ago this was largely the purview of the national laboratories
 - Academic researchers could utilize lab facilities but local capabilities were very limited
- New technologies, particularly the development of lasers and compact pulsed power systems, have made this much more broadly accessible
- Now the focus is on developing and expanding the community of HEDS researchers

The DOE laboratories continue to push the leading edge of capability

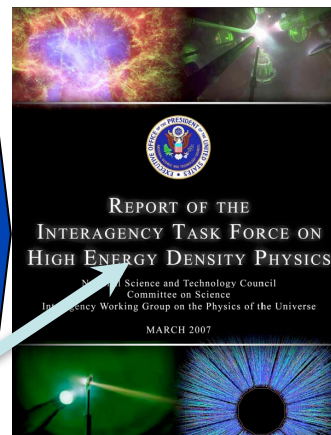
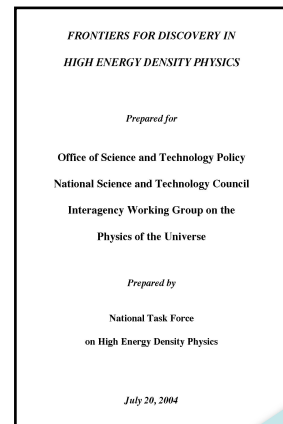
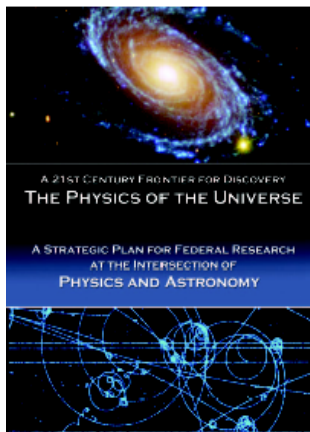
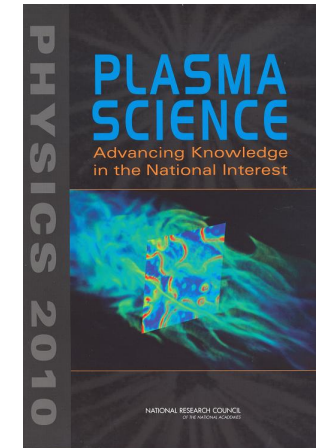
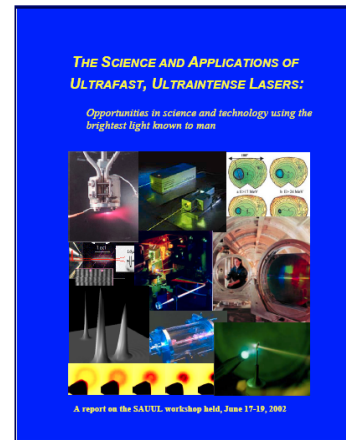
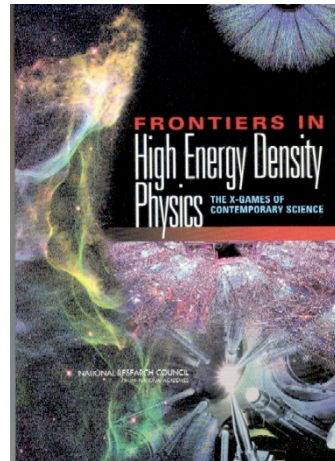
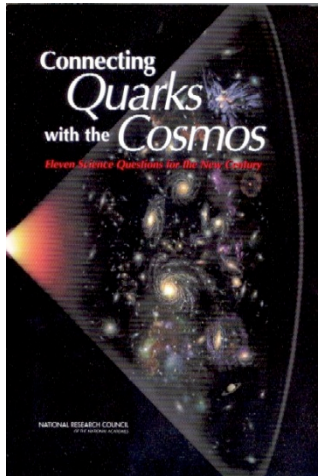
- Major user facilities provide the capability to access the most extreme states of matter
 - DOE investments emphasize the lab's particular capability to do 'science at scale'
 - User facility model enables access by a broad array of users
- Intermediate scale facilities enable direct hands-on experience for researchers and students
 - Mix of lab and university facilities
 - Facilitate high-risk research, diagnostic and technique development
- Small-scale HEDS experimental capabilities are widely available

Historically, most HEDS research has been sponsored by NNSA

- NNSA's HEDP and ICF programs are designed to support the stockpile stewardship mission
 - Suite of major user facilities - NIF, Omega, Z, ...
 - Experimental and simulation programs
 - Stewardship Science Academic Alliance Program
 - Stewardship Science Graduate Fellowship Program
 - Joint Program in HEDLP
- FES pursues basic plasma science and fusion energy research
 - Magnetic fusion energy program (ITER, DIII-D ...)
 - Basic Plasma Science
 - Theory and simulation programs (FSP, SciDAC, ...)
 - Joint Program in HEDLP
 - Materials in Extreme Conditions end station at LCLS

FES is moving to take a strong stewardship role in High Energy Density Laboratory Plasmas (HEDLP)

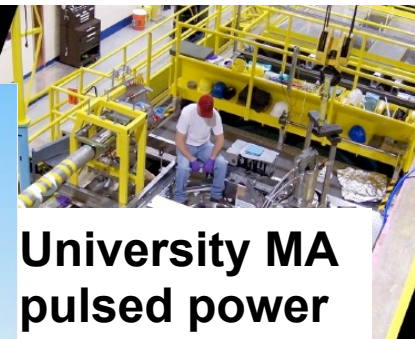
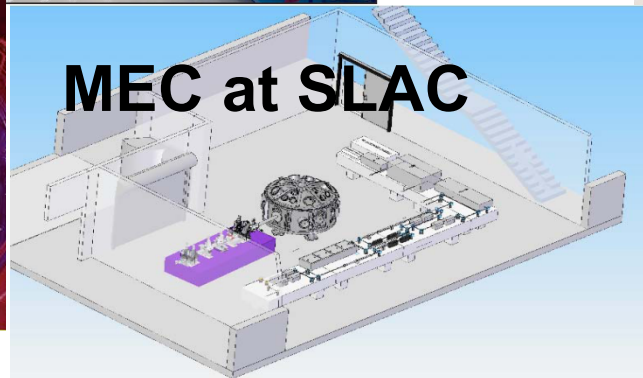
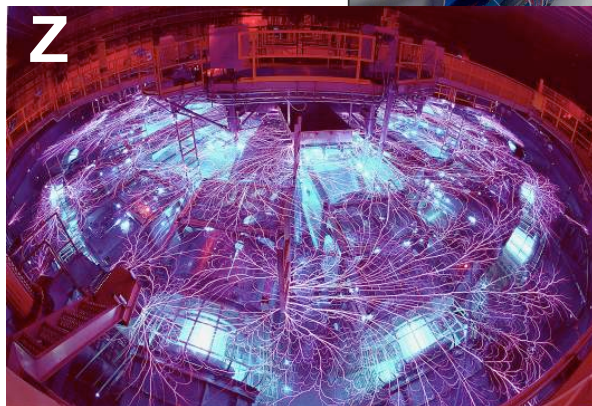
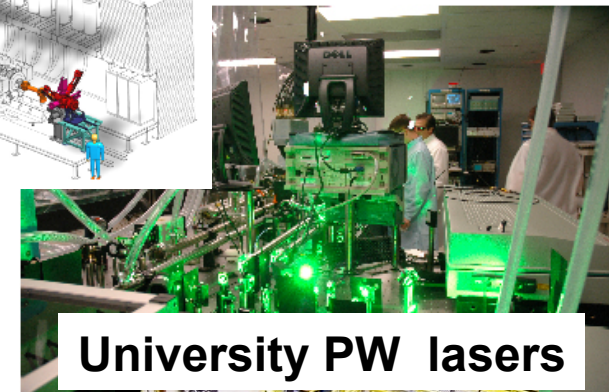
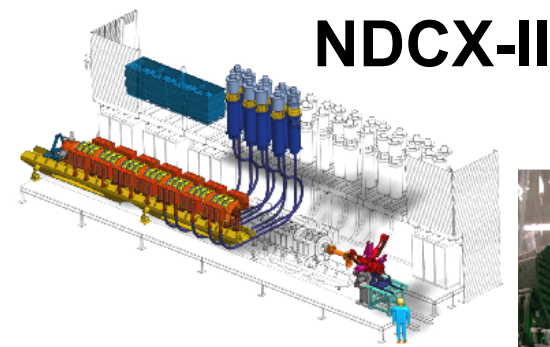
Motivated and encouraged by National Academy/workshop reports:



The recent FES/NNSA ReNEW Workshop defined the major questions for HEDLP

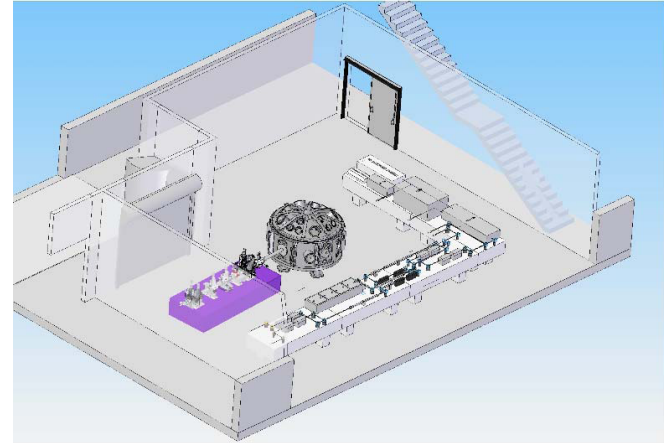
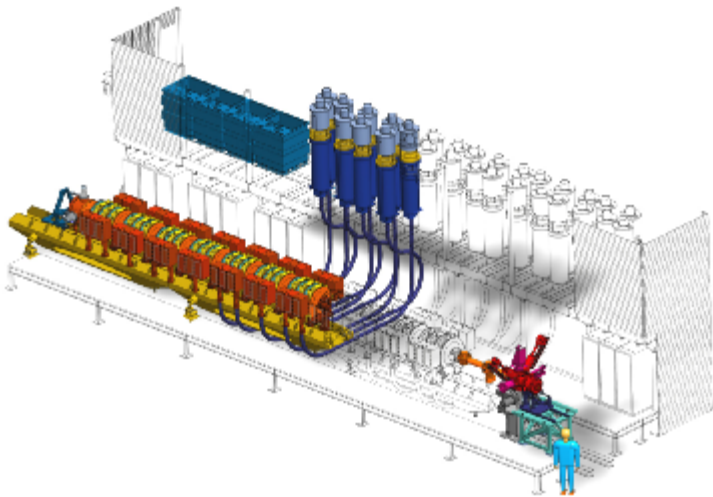
- How does the exotic behavior of dense collections of electrons, ions and photons arise?
- What can creating cosmic conditions in the laboratory reveal?
- Can transient intense flows of energy and particles, unconstrained by conventional material limits, be manipulated and exploited?
- Can the interactions of matter under extreme conditions be controlled to enable practical inertial fusion energy?
- How does self-organization arise within high-energy density matter?

This is a time of unprecedented experimental capability for HED science



ARRA is enabling significant investment in HEDLP for FES

- **NDCX-II: heavy ion accelerator for warm dense matter and heavy ion fusion science research. \$11M**
 - Lever NNSA accelerator components to upgrade from 300 keV system to 2 – 3 MeV



- **LCLS: the Matter under Extreme Conditions (MEC) End Station: \$20M.**
 - First-of-kind creation and fs measurements of warm and hot dense matter.
 - Bringing LCLS into the FES portfolio is a boon

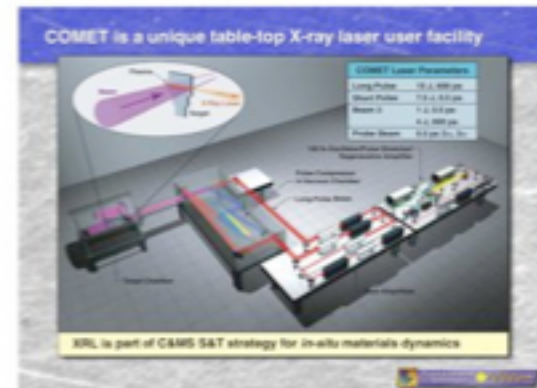
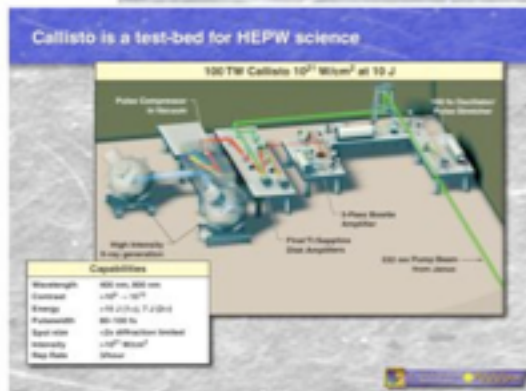
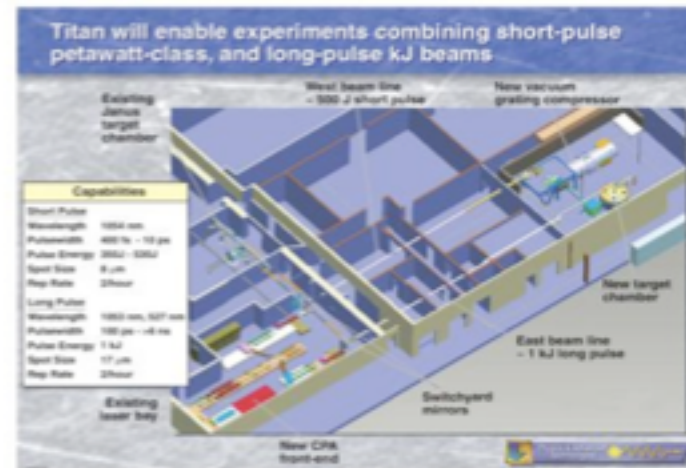
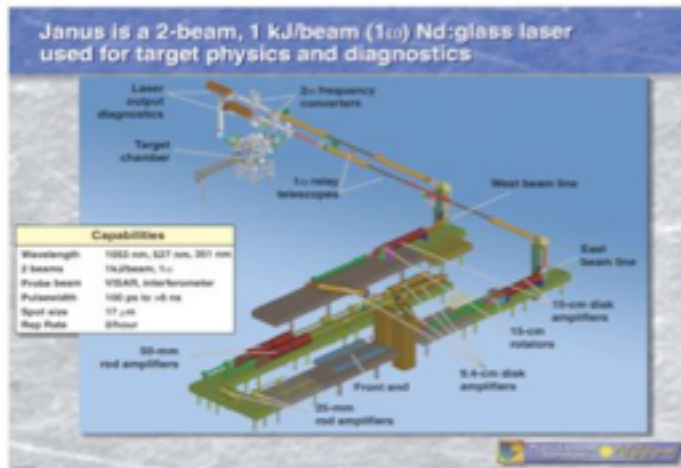
The Trident 200 TW laser facility is an intermediate scale laser facility at LANL



- 2 long-pulse laser beams with:
 - 250 J each at 527-nm, 100 ps - 5 ns
 - 1 kJ each at 1054-nm, 100 ps - 10 μ s
- 1 short-pulse laser beam:
 - 200 TW, 100 J, 500 fs
- laser intensity $> 10^{20}$ W/cm² for relativistic laser-matter interactions (comparable to or exceeding PW performance)
- lowest pre-pulse for high-density laser-matter interactions
- $< 10^{-7}$ (conventional)
- $< 10^{-10}$ (new)



Jupiter is a multi-platform laser user facility for HEDP at LLNL



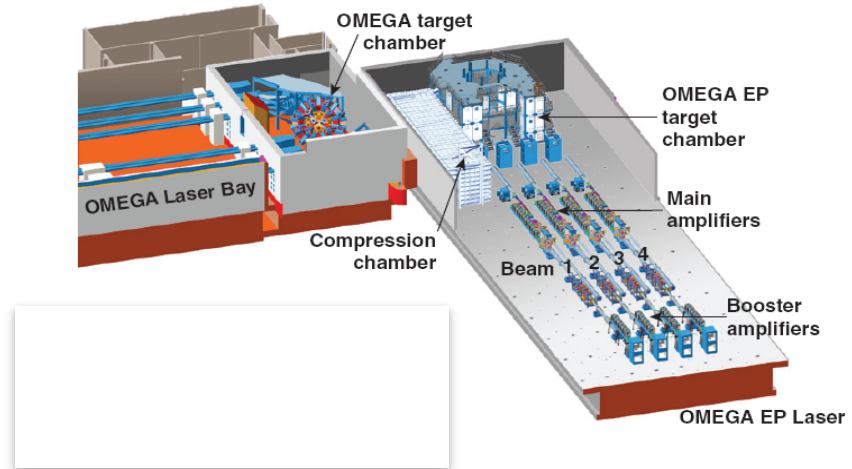
UR-LLE operates the Omega Laser as a National Users' Facility for NNSA

OMEGA Laser System

- Operating at LLE since 1995
- Up to 1500 shots/year
- Fully instrumented
- 60 beams
- >30-kJ UV on target
- 1% to 2% irradiation nonuniformity
- Flexible pulse shaping
- Short shot cycle (1 h)

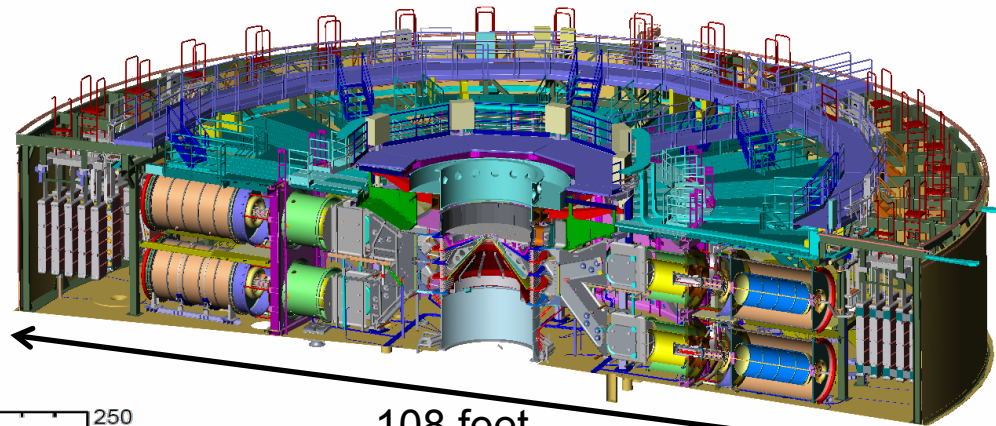
OMEGA EP Laser System

- Construction complete 25 April 2008
- Adds four NIF-like beamlines; 6.5-kJ UV (10 ns)
- Two beams can be high-energy petawatt
 - 2.6-kJ IR in 10 ps
 - Can propagate to the OMEGA or OMEGA EP target chamber.



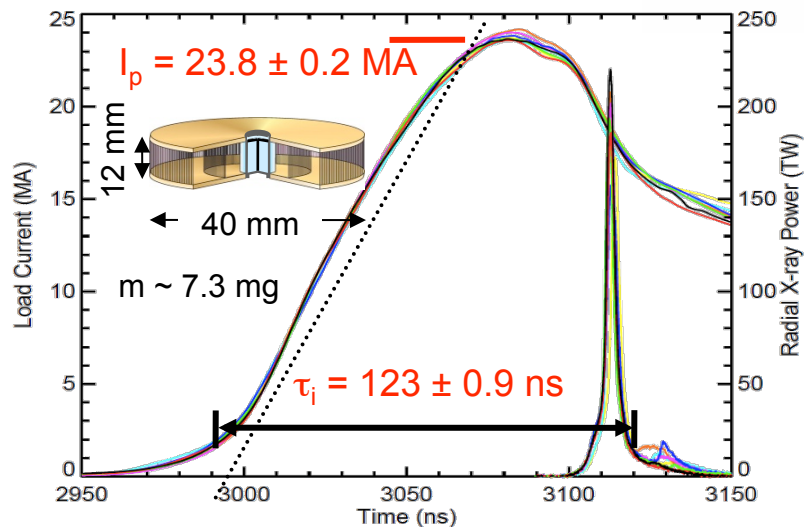
- Access to the Omega Laser Facility is managed through the National Laser Users' Facility (NLUF)
 - Peer-reviewed access beginning in 1979 with >150 approved proposals
 - Next NLUF solicitation in beginning of 2010 for FY11-12 shot time
- The OMEGA Users' Group currently has >150 members
- See www.lle.rochester.edu, or contact John Soures, jsou@lle.rochester.edu

The refurbished Z provides new capabilities for high energy density science



108 feet

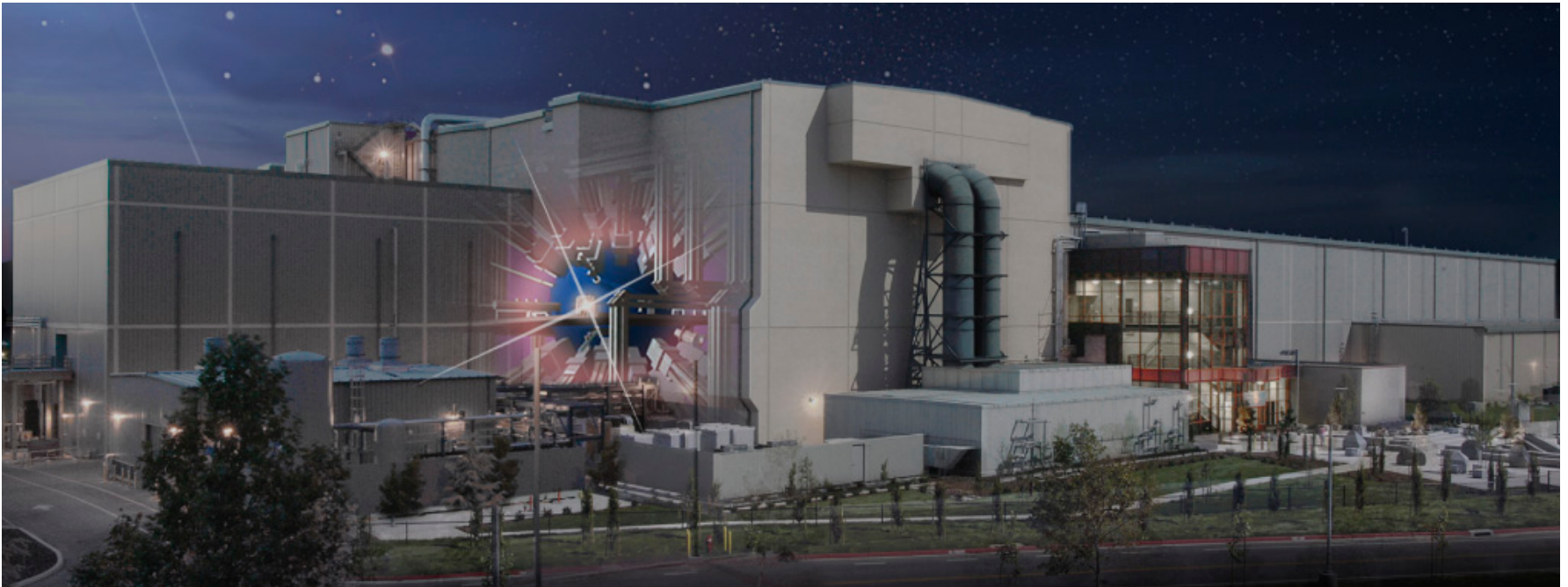
Enough energy is generated to make the machine jump about 1 cm.



Overlay of current and x-ray power for 8 experiments

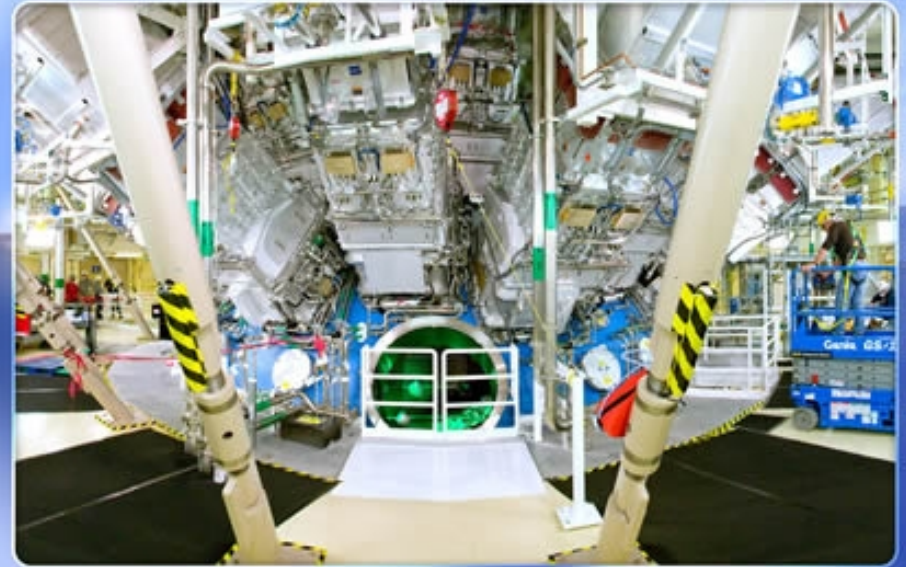


The National Ignition Facility (NIF) provides unprecedented capabilities for HEDP research



NIF was designed to achieve thermonuclear ignition in the laboratory but will enable a wide variety of HEDP applications

NIF can deliver up to 1.8 MJ of energy at 3ω with versatile pulse shaping and timing



		2009
Total LRUs Installed		6206
LRU Installation		COMPLETE
Laser Bay 1		COMPLETE
Laser Bay 2		COMPLETE
CORE		COMPLETE
Switchyard 1		COMPLETE
Switchyard 2		COMPLETE
Target Bay		COMPLETE
Beams Activated		192 COMPLETE
		4.24 MJ 1ω
		0.80 MJ 3ω

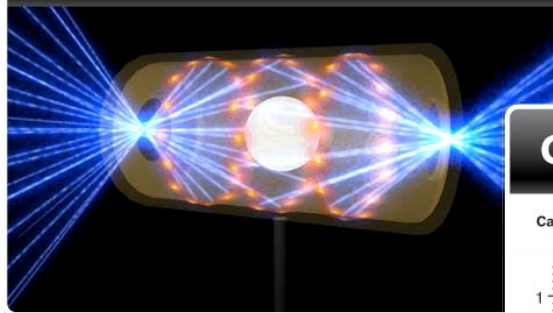
STATUS
100% COMPLETE

A four step approach to ignition is underway

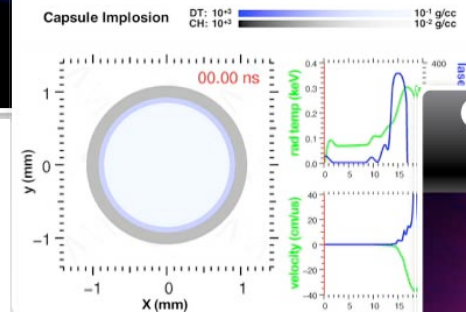
Commission laser



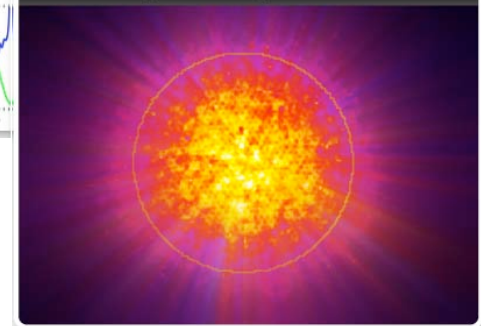
Commission hohlraum



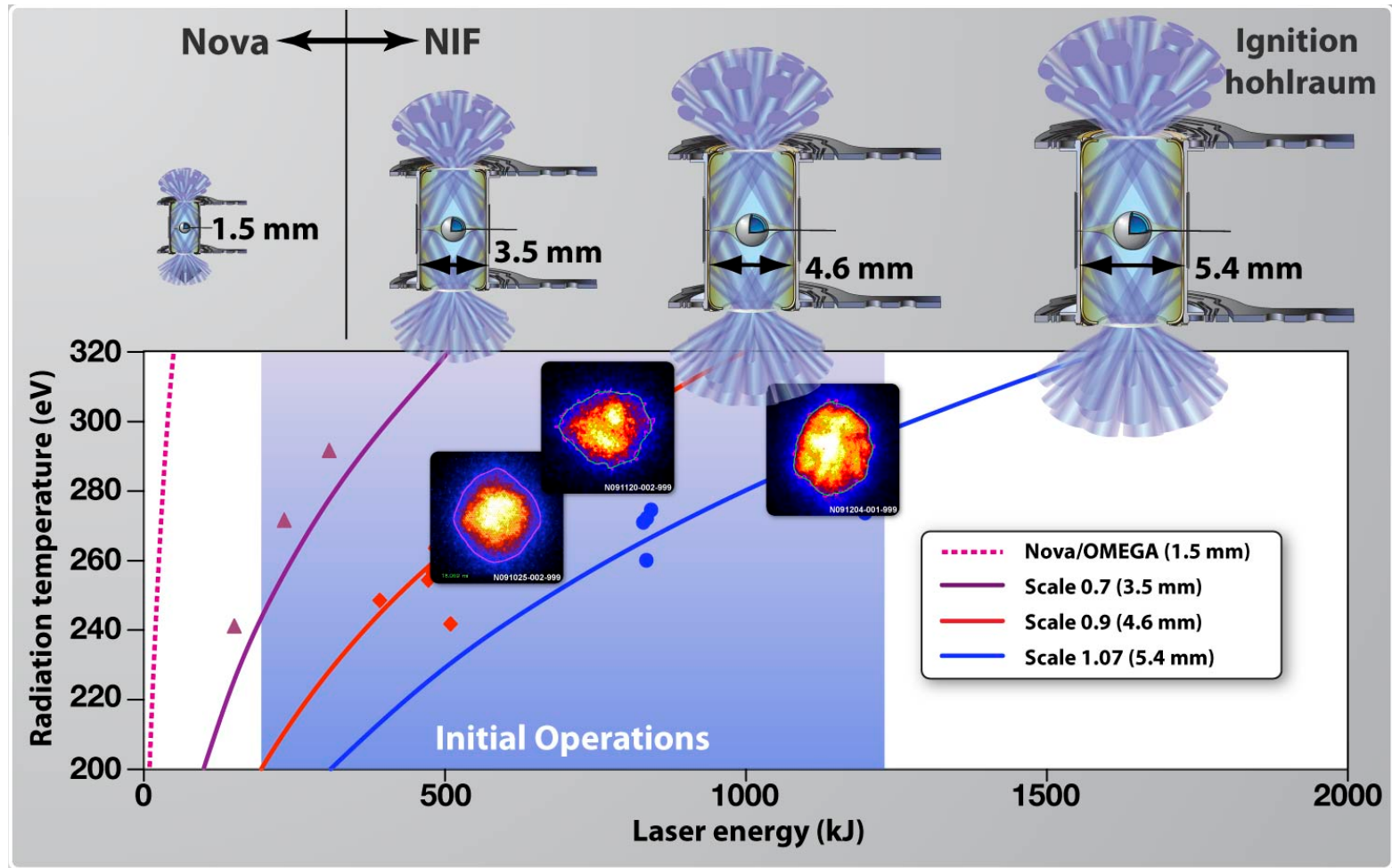
Commission capsule



Commission layered target implosions



Hohlraums that scale to ignition conditions have been demonstrated at NIF



DOE SC and NNSA teamed up to explore opportunities for science on NIF

- Basic Research Directions for User Science at the National Ignition Facility
 - NNSA/Office of Science Workshop held in May 2011 in Washington, DC
 - Co-chaired by John Sarrao (LANL), Michael Wiescher (Notre Dame), and Kim Budil (LLNL)
- 5 panels
 - Laboratory Astrophysics – Paul Drake
 - Nuclear Physics – Michael Wiescher, Rich Petrasso, Bill Goldstein
 - Materials at Extremes and Planetary Physics – Rus Hemley, Raymond Jeanloz
 - Beams and Plasma Physics – Warren Mori, Margaret Murnane
 - Crosscutting – Roger Falcone
- Goals
 - Educate the community about NIF's capabilities
 - Establish Priority Research Directions in each area
 - Gather input from the user community regarding facility capabilities

This is an important step toward greater collaboration between NNSA and SC

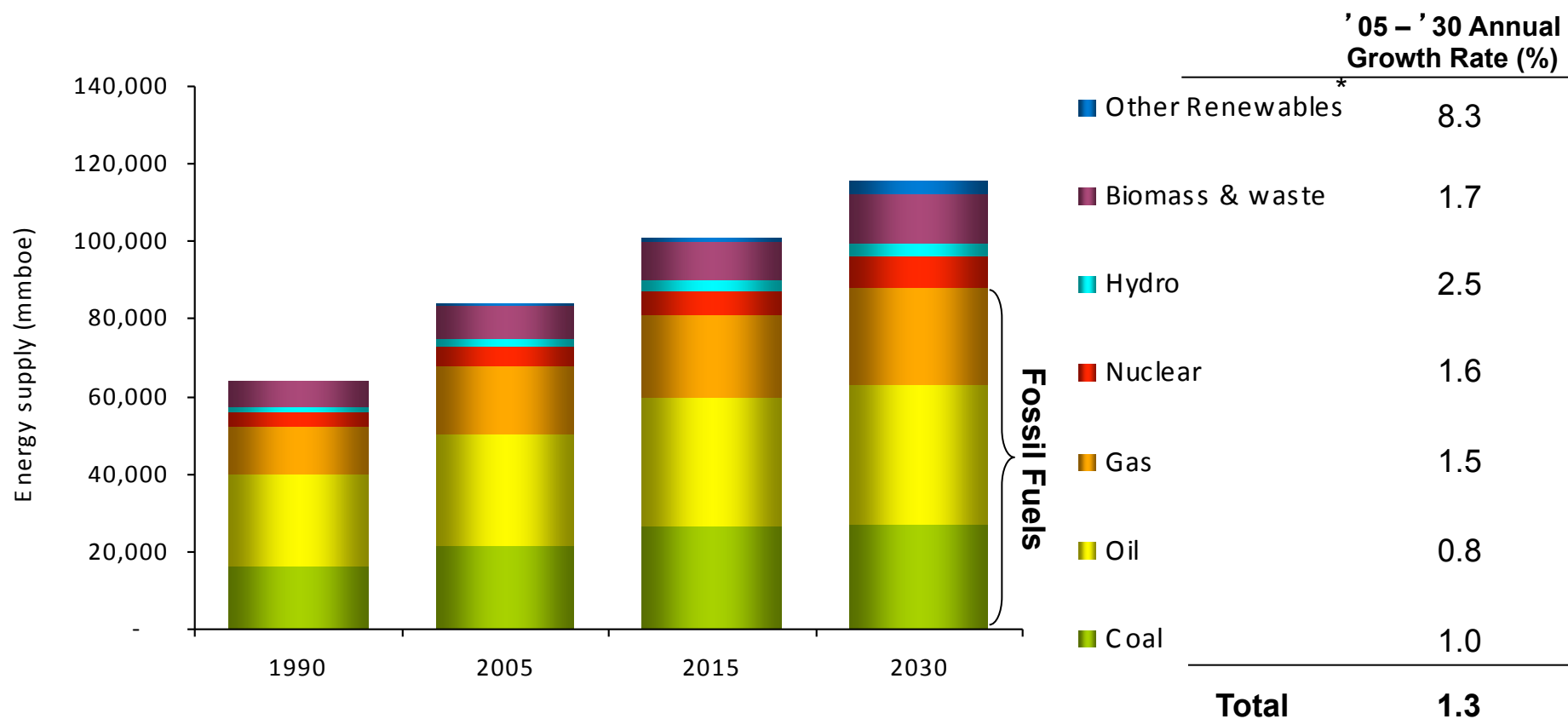
So what's next?

America's energy challenges

- **Energy security**
 - Reliable and economic energy supply
 - Mostly about liquid hydrocarbons for transport
 - **Goal: 3.5 M bbl/day reduction in crude use**
- **Greenhouse gas emissions**
 - Mostly about CO₂ from stationary sources (power and heat)
 - **Goal: ~20% reduction by 2020, 80% by 2050**
- **Significant changes in energy supply, transmission, storage, and use**

Identify, develop, and deploy
cost-effective, material, and timely solutions
and
Create jobs in the process

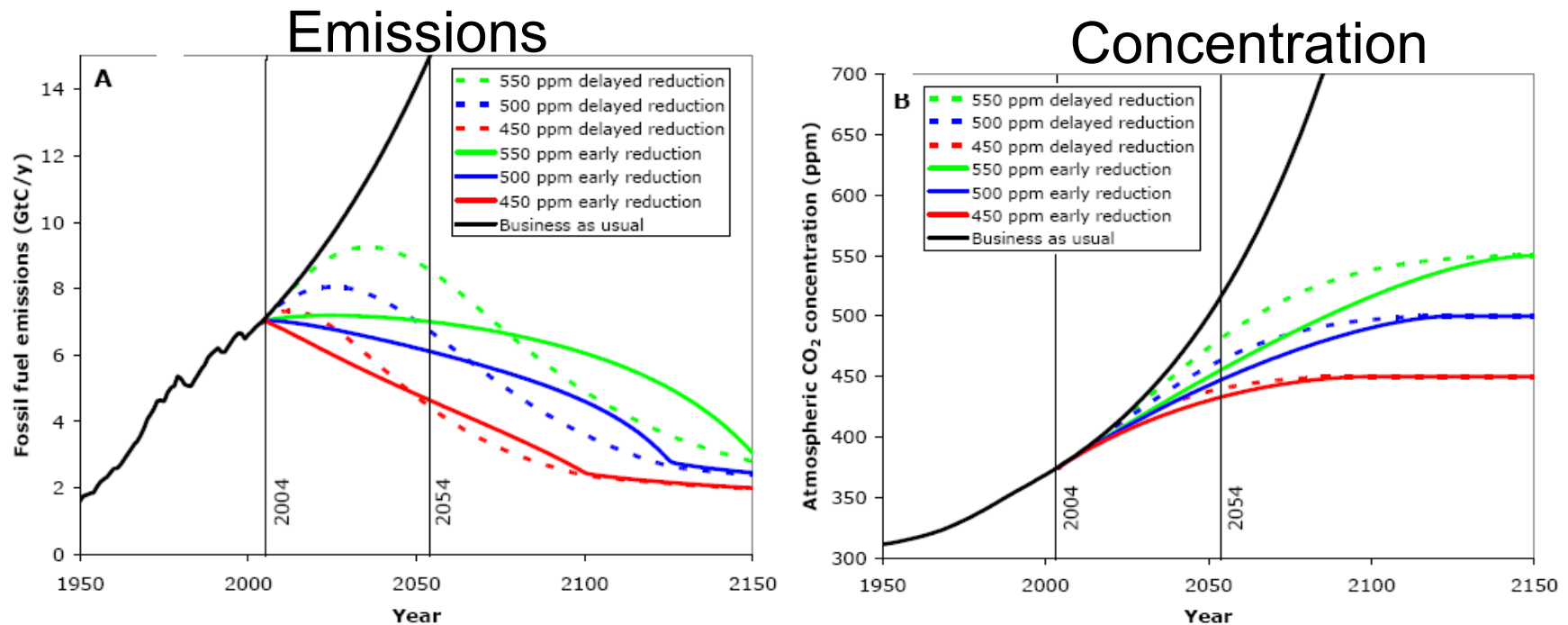
Fossil fuels are 80% of global energy



Source: EIA

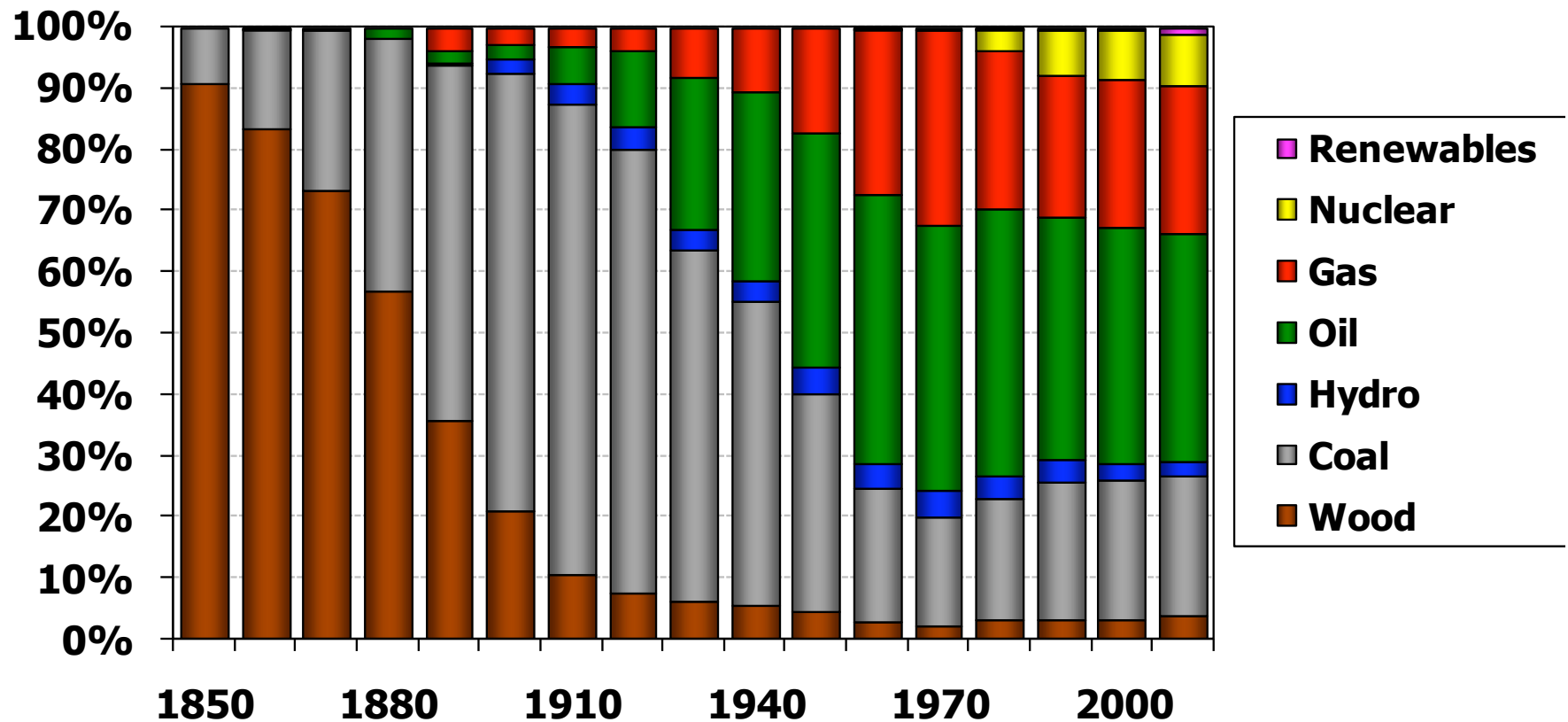
*'Other renewables' include geothermal, solar, wind, tide and wave energy for electricity generation

Most energy must be low-emission by 2100 – fusion could be part of solution



Energy technologies change slowly

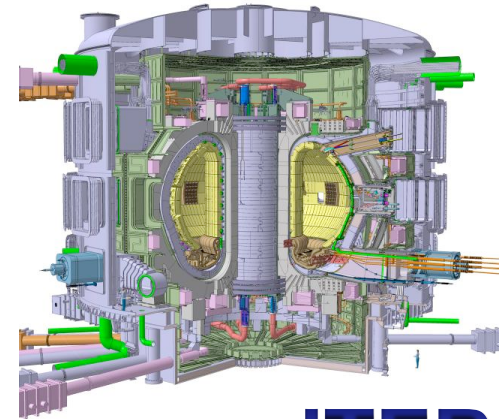
US energy supply since 1850



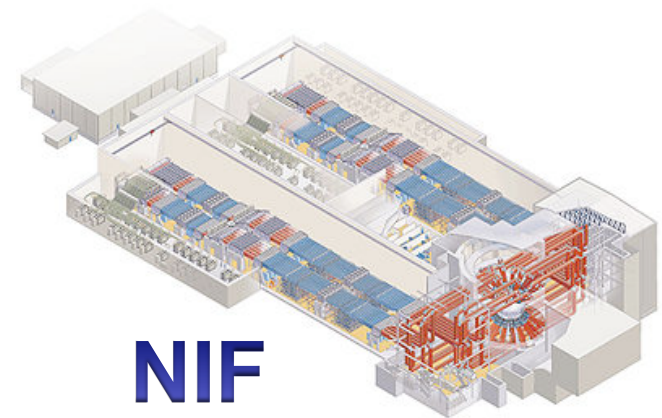
Source: EIA

This is a unique time for fusion energy research

- Fusion energy research underway
 - Goals of sustained burning plasma (continuous v. pulsed), energy technology development and demo
- ITER: Magnetic fusion
 - National Academy Study (2004) recommendation for a burning plasma experiment
- NIF: Inertial fusion
 - Laboratory ignition demonstration
 - National security motivation



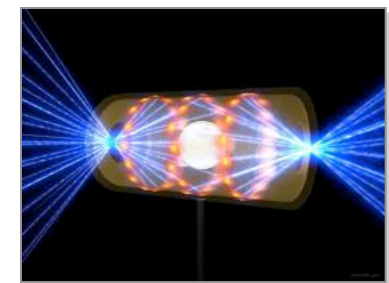
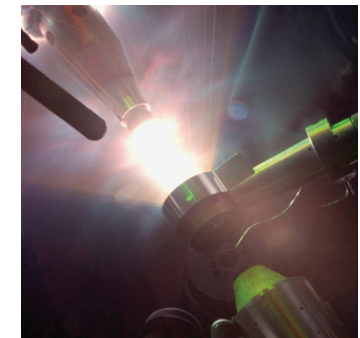
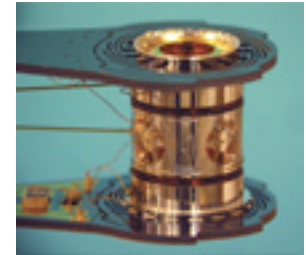
ITER



NIF

NIF – on the path to ignition

- DOE is preparing for NIF success
 - IFE and MFE have substantially different technical risk portfolios.
 - Technological diversity is a good strategy in such a high-stakes endeavor.
 - NNSA has made a significant investment in NIF and ICF
 - OFES can leverage this to help establish IFE path forward



DOE Under Secretary for Science has asked the National Academies to look at IFE path forward from ignition

NAS review of IFE prospects is now well underway

- Prospects for Inertial Confinement Fusion Energy Systems
 - Co-chaired by Ron Davidson (Princeton) and Gerry Kulcinski (University of Wisconsin-Madison)
 - Four meetings completed, 5th scheduled for 10/31/11
 - Two groups – main committee and target physics panel
 - Target Physics Panel chaired by John Ahearne (Sigma Xi)
 - Site visits to main participant locations (LLNL, SNL, Rochester)
- Committee charge
 - Assess the prospects for generating power using inertial confinement fusion; Identify scientific and engineering challenges, cost targets, and R&D objectives associated with developing an IFE demonstration plant; and advise the U.S. Department of Energy on its development of an R&D roadmap aimed at creating a conceptual design for an inertial fusion energy demonstration plant.
- Panel role:
 - assess the current performance of fusion targets associated with various Inertial Confinement Fusion (ICF) concepts in order to understand: spectrum output, illumination geometry, high-gain geometry, and robustness of the target design

This study should provide a framework for making informed decisions on how to structure an IFE program

U/S Koonin: “Fusion needs an ‘All hands on deck’ approach”

- Resources are limited so cooperation and collaboration are key
- Harness all the intellectual resources of the DOE – SC and NNSA labs, academic partners
- Science and technology challenges must both be pursued
- MFE and IFE need to seek common areas of interest
- Validated simulation capability can help drive the field forward
- SC, NNSA, and NE are launching a broad coordinated initiative in materials for fission and fusion applications

Success in fusion has game-changing potential

Questions/Comments?