Path to a direct-drive ignition facility for fusion energy research that requires substantially less laser energy

High Average Power Laser Program Workshop
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Work conducted by NRL Laser Fusion Research Team
Special thanks to Denis Colombant for rapid advances

There appears to be a route to a much less expensive high-rep ignition facility

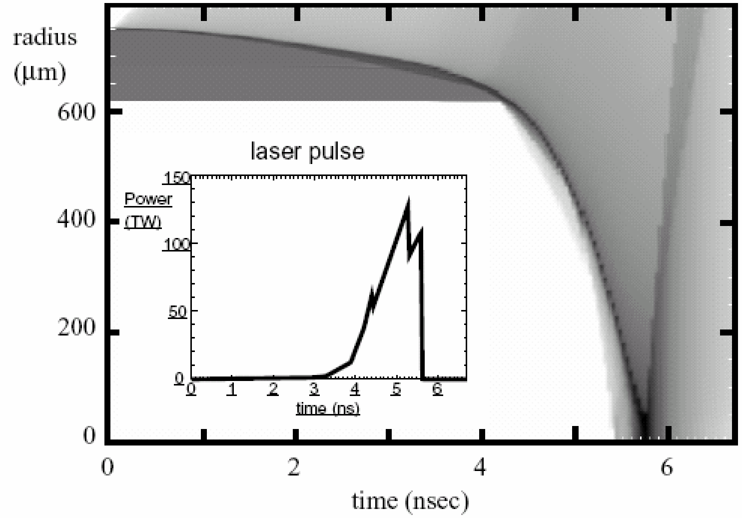
- Increasing the implosion velocity from the nominal 300 km/sec to 400-500 km/sec substantially reduces the energy needed for ignition.
- These higher velocities can be achieved by various combinations of increased drive intensity and increased pellet aspect ratio (radius to thickness)
- The best route for hydro-instability is increased drive intensity
- The upper bound on intensity is set by deleterious laser-plasma instabilities whose thresholds tend to scale as $I\lambda^2$
- The combination of a factor of 2 advantage in λ^2 and >THz bandwidth gives the KrF laser an advantage
- Our calculations indicate ignition with KrF at about 140 kJ and gains >20 at 250 kJ

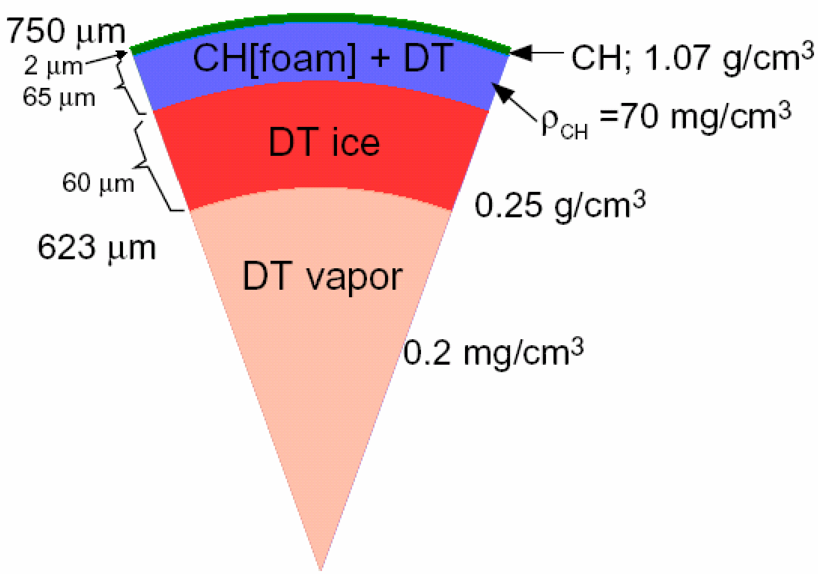
Low Energy KrF-driven target produces gain with high laser intensity and implosion velocity

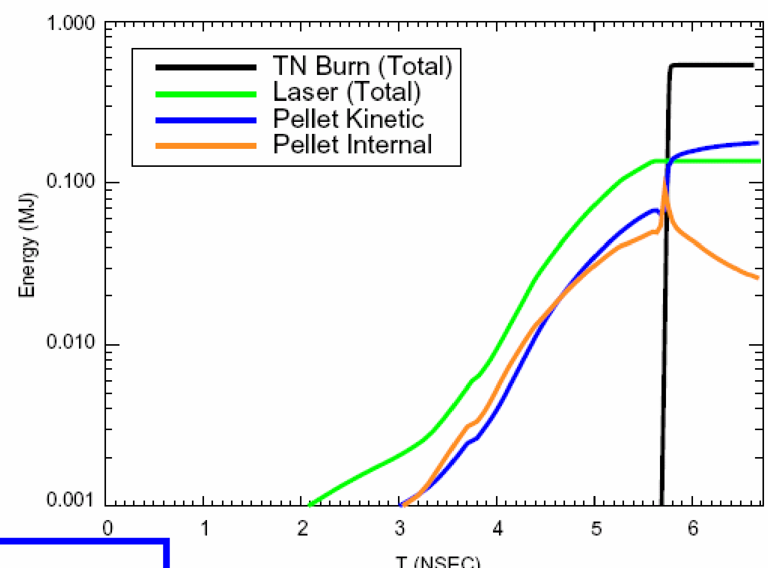
140 KJ KrF Laser Target (1D)

Laser Energy	140 kJ
(absorbed)	(120 kJ)
Yield	540 kJ
$V_{implosion}$	5.7×10^{7} cm/sec
hydro efficiency	12.2 %
coupling efficiency	10.6 %
Max. Intensity	3×10^{15} W/cm^2

density flow diagram: radius vs. time

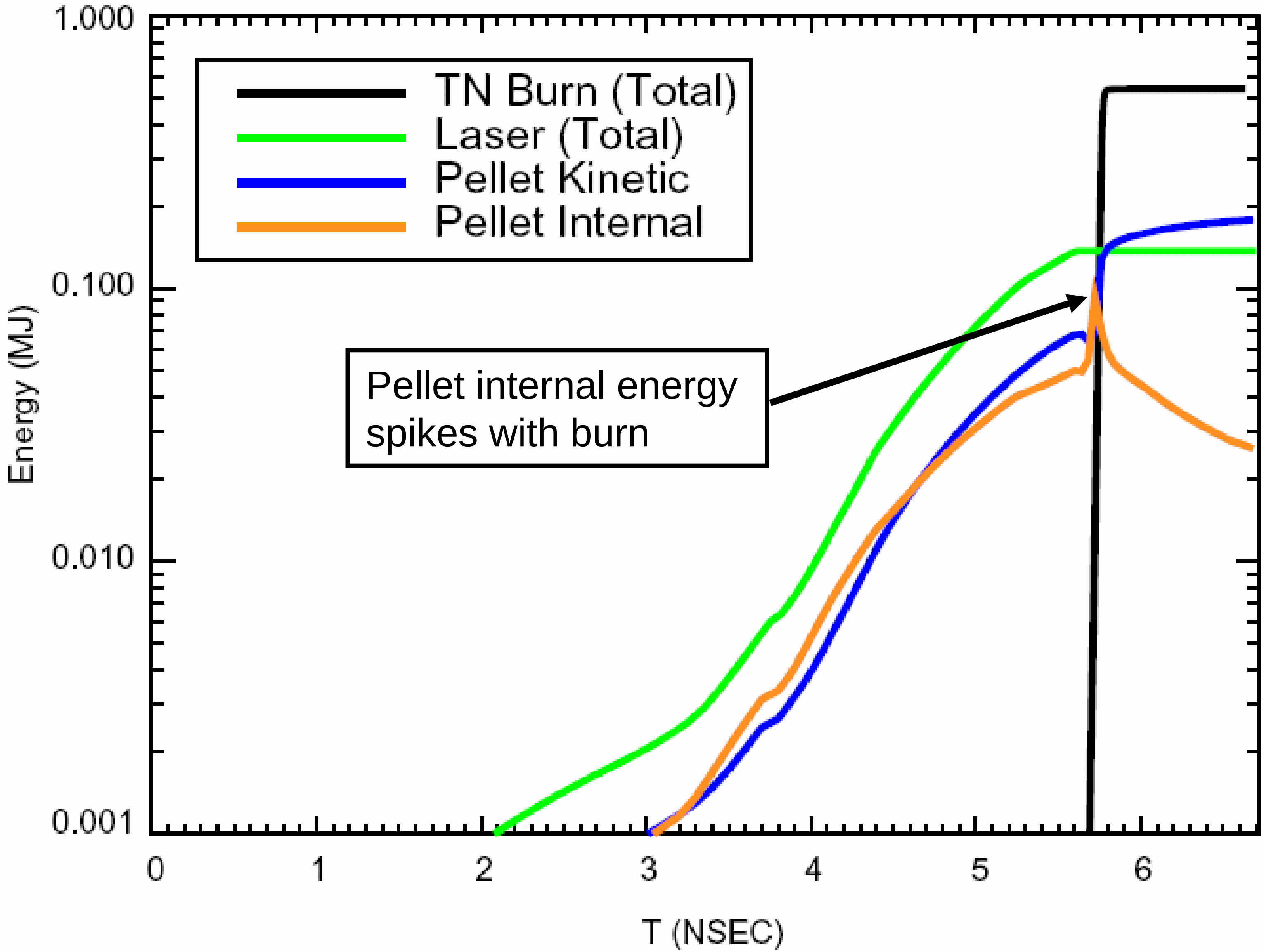






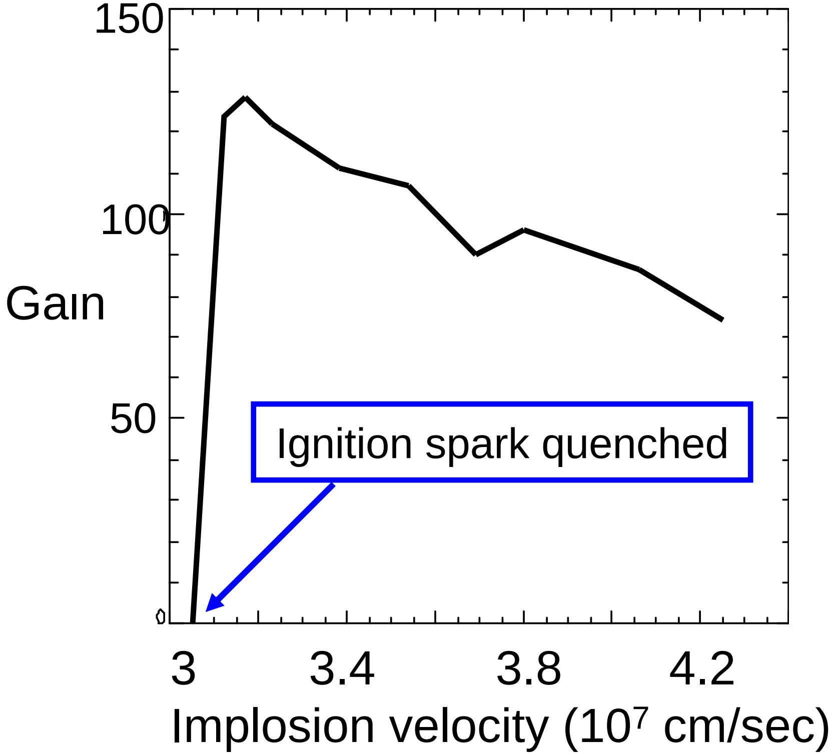
Ignition @ 140 kJ – 1/13th of NIF design energy

3.9 x gain as well as heating by burn indicates ignition @ 140 kJ KrF

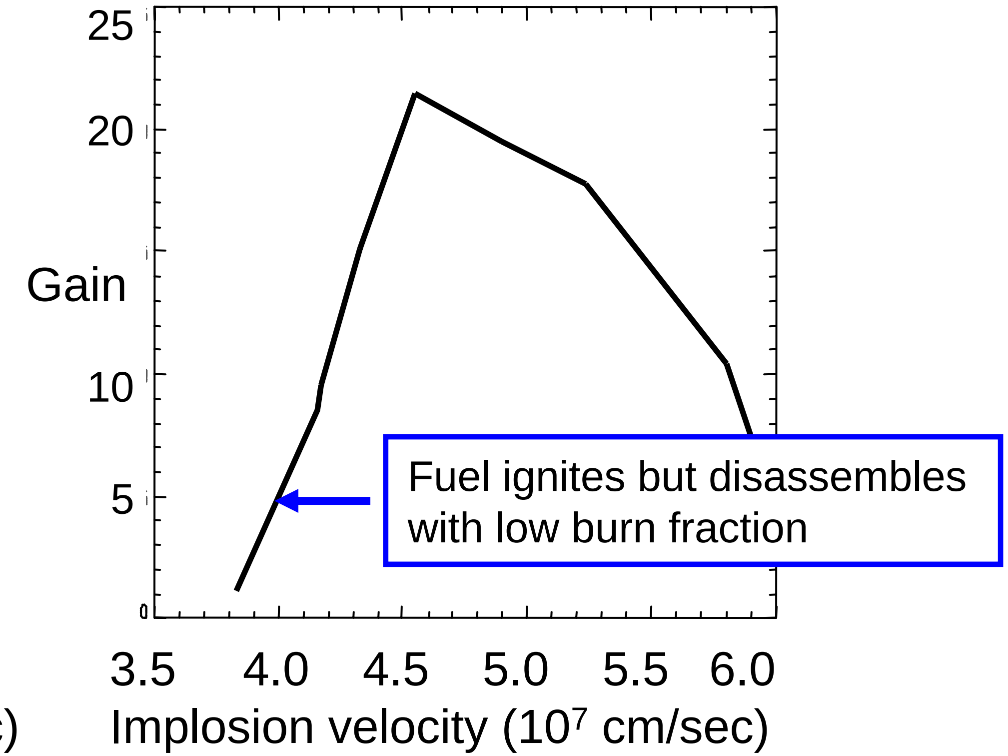


High and low implosion velocity pellets behave differently

1.2 MJ KrF 1.5×10^{15} W/cm^2



0.25 MJ KrF 3.5×10^{15} W/cm^2



Parametric studies utilized conventional pulse shapes and those with “spike” pre-pulses that can increase hydro-stability

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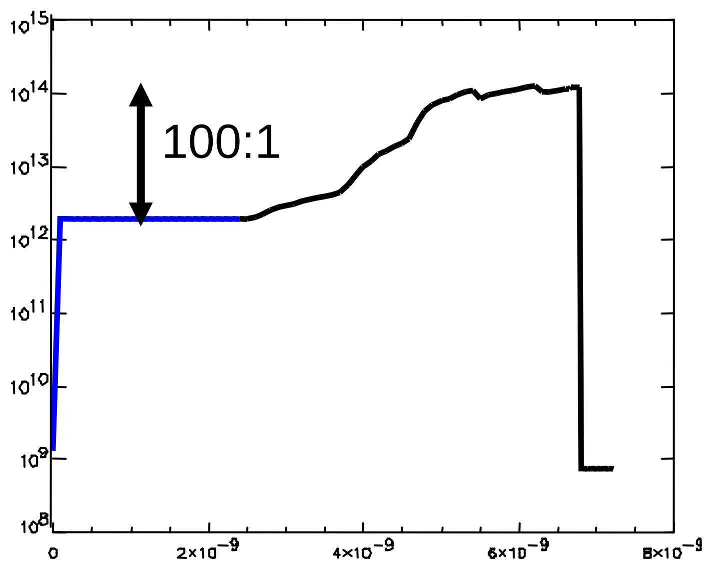
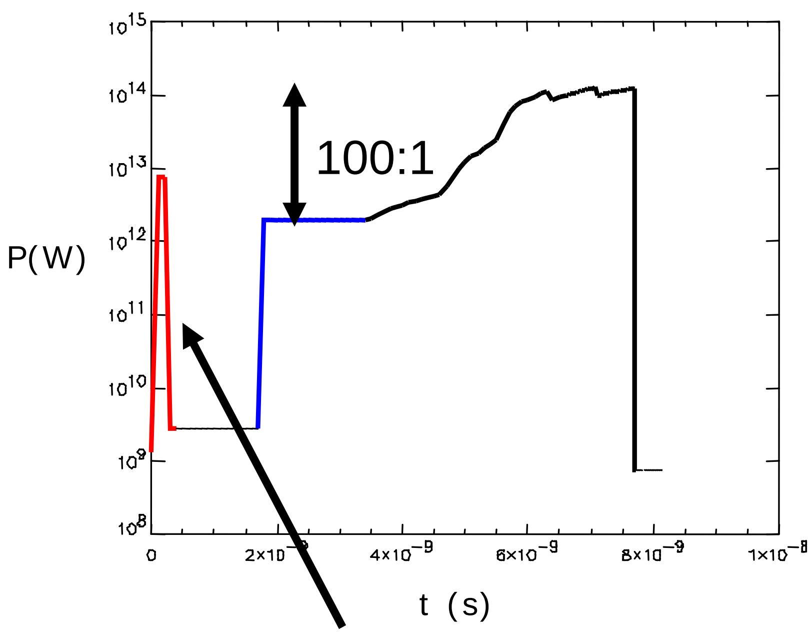
0.25 MJ Laser Pulse (no spike)

P(W)
log
scale



4 ns

0.25 MJ Laser Pulse (with spike)



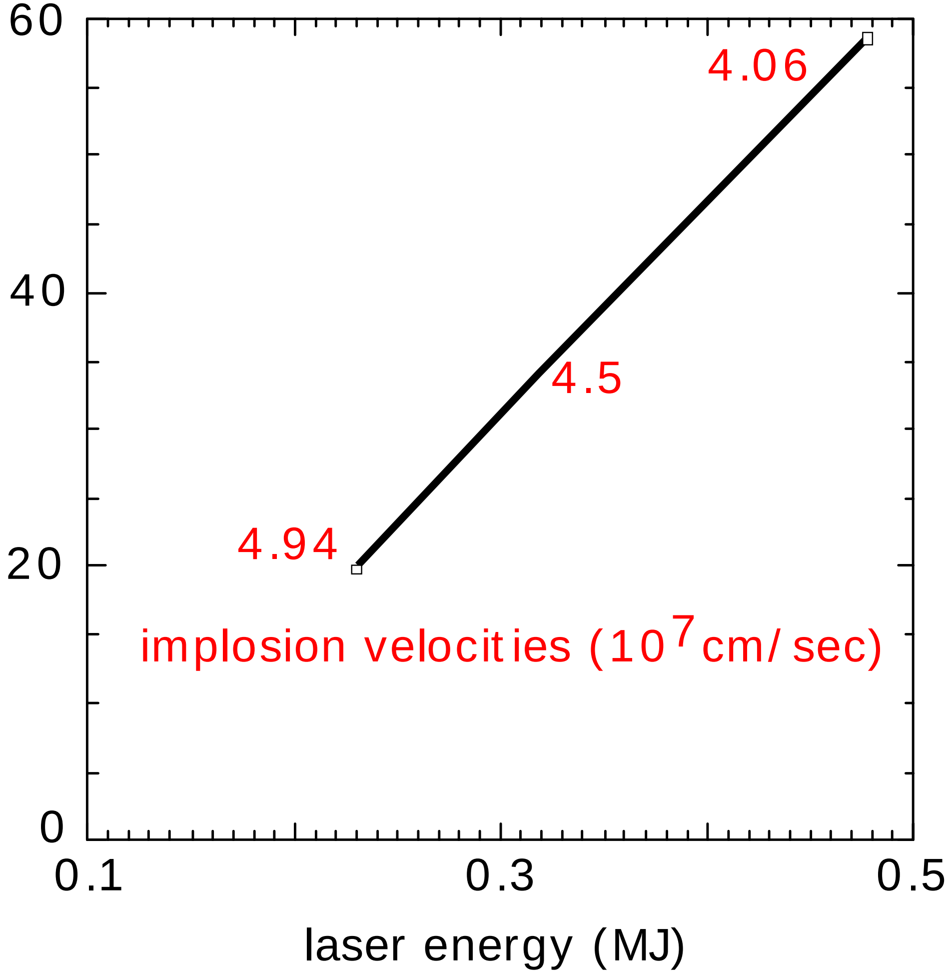
3.5% amplitude 200 ps spike separated 1.4 ns from main pulse

Gain increases and optimum implosion velocity decreases with laser energy

NRL Laser Fusion

(λ = 248 nm, I = 2.2-2.5x10^{15} W/cm^2)

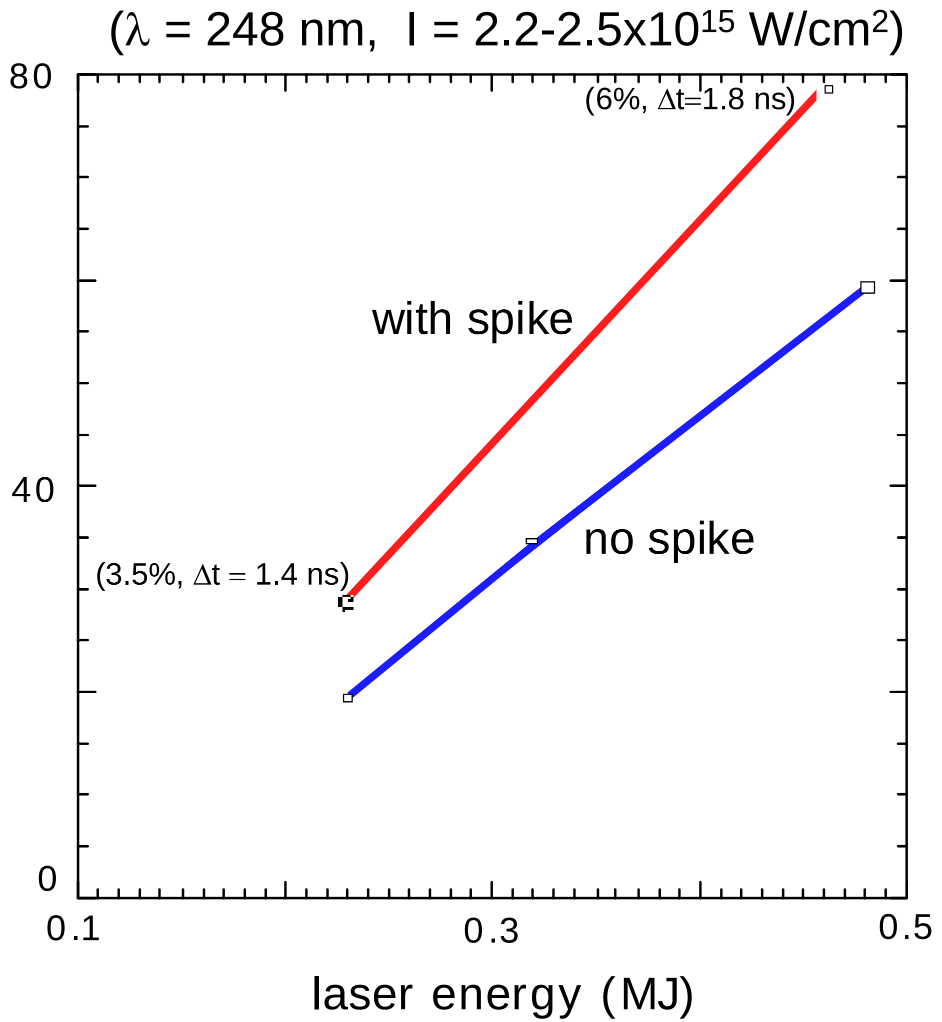
Conventional 100:1 pulse shape



Gain increased with addition of optimized spike!

Lots of room to trade off gain for stability if needed

NRL Laser Fusion



New (2005) vision and plan for laser fusion energy

Smaller lower-cost Fusion Test Facility (FTF) based on new pellet designs

Phase I:
1999-2006

Basic laser fusion technology

- Krypton fluoride laser
- Diode-pumped solid-state laser
- Target fabrication and injection
- Chamber materials and optics

Target design & physics

- 2D/3D simulations
- 1-30 kJ laser-target exp.

Phase II
2007-2013

Develop full-size components

- Power-plant laser beamline
- Target fab/injection
- Power plant & FTF design

Ignition physics validation

- Calibrated 3D simulations
- LPI experiments

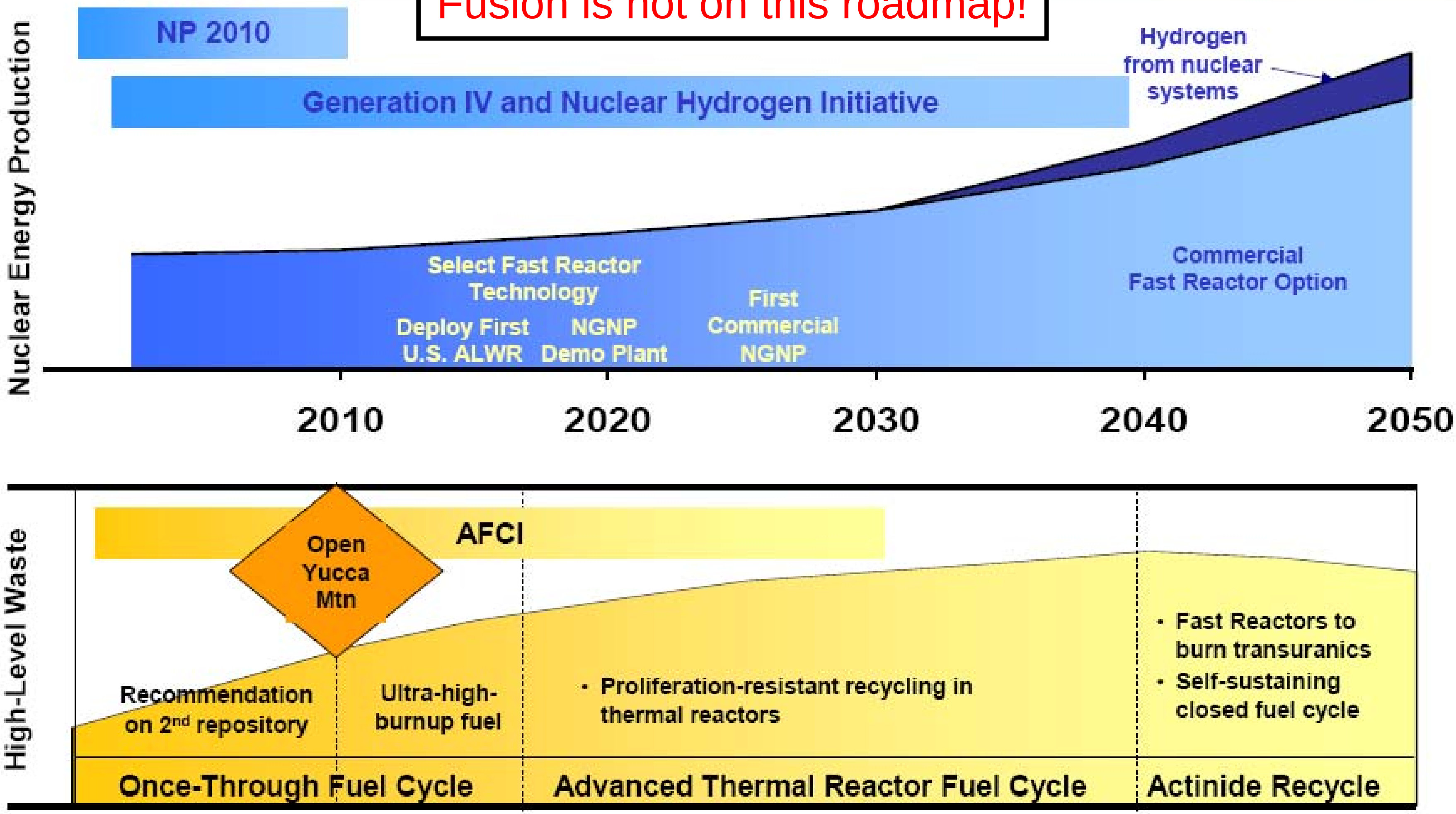
Phase III
FTF operating
~2018

Fusion Test Facility (FTF)

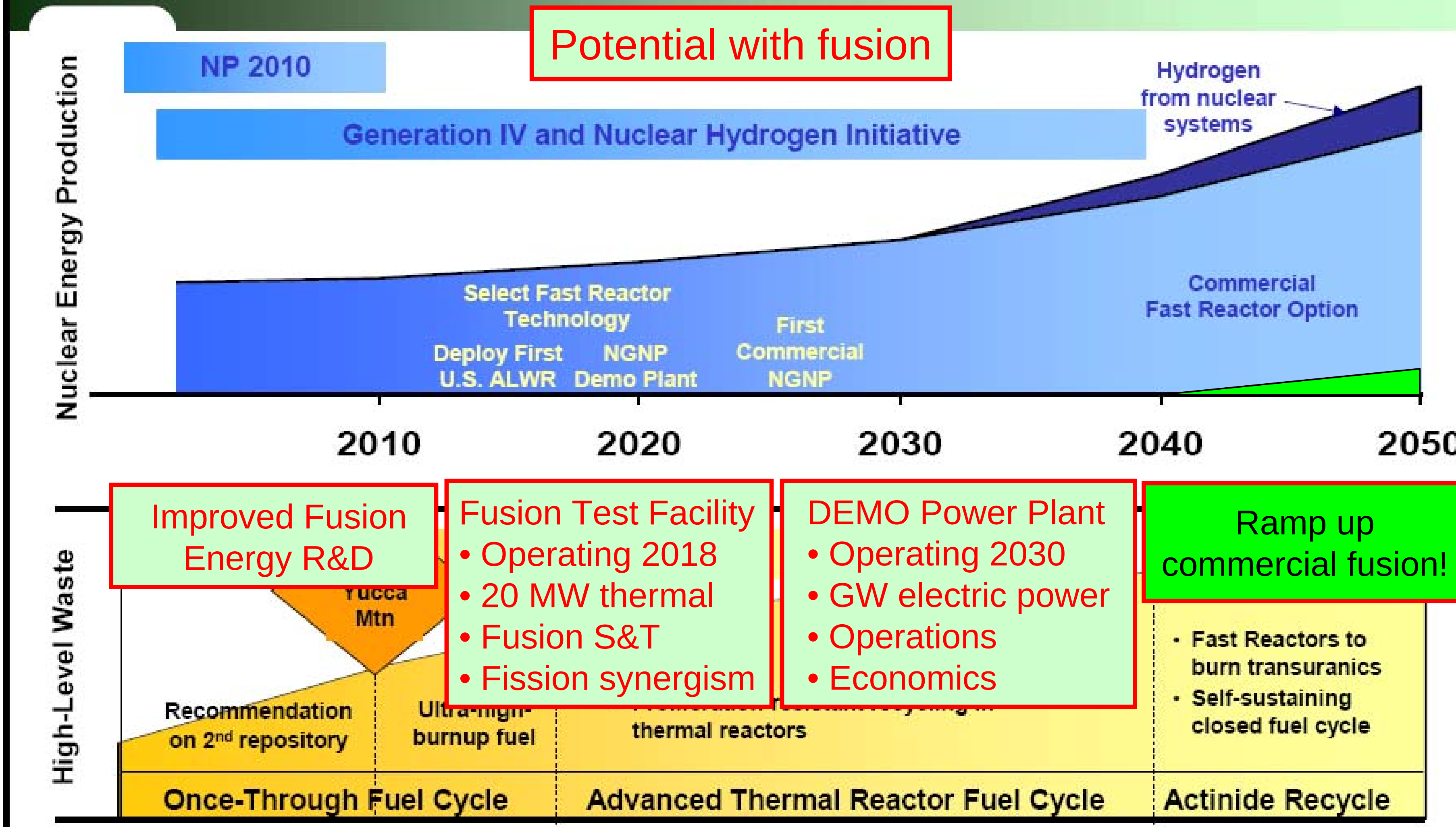
- 0.25 MJ laser-driven implosions @ 5 Hz
- Pellet gains of ~20
- 20-30 MW of fusion thermal power
- Develop chamber materials & components.
- ***Upgrade path to 0.5 MJ and ~150 MW fusion power***

A Long-Term U.S. Strategy for Nuclear Energy

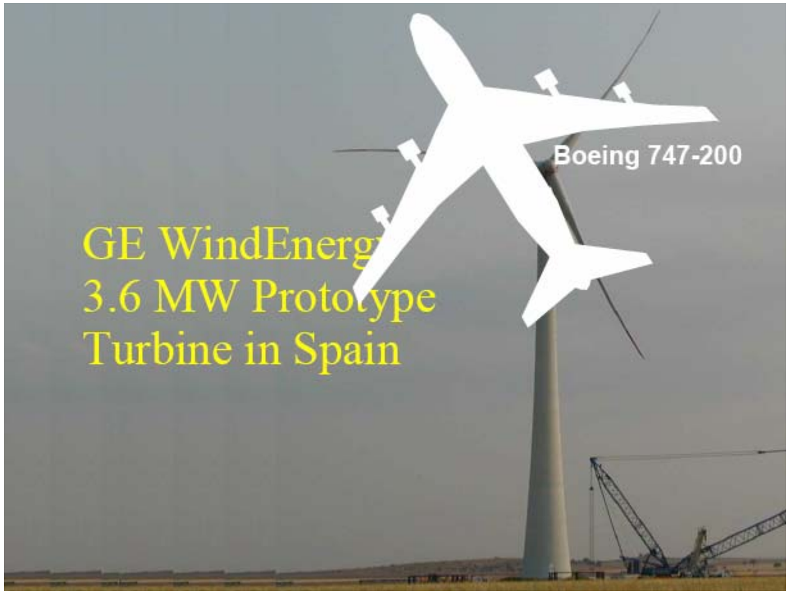
Fusion is not on this roadmap!



A Long-Term U.S. Strategy for Nuclear Energy



There will be formidable competition to fusion power.



- The NRL laser fusion program is fully committed to exploring and developing the path to a lower laser energy high-rep ignition facility.

- Design studies also indicate that we may be able to significantly reduce the minimum laser energy needed for the fusion power plants. (<1 MJ?)

- We invite and expect contributions by the other HAPL participants