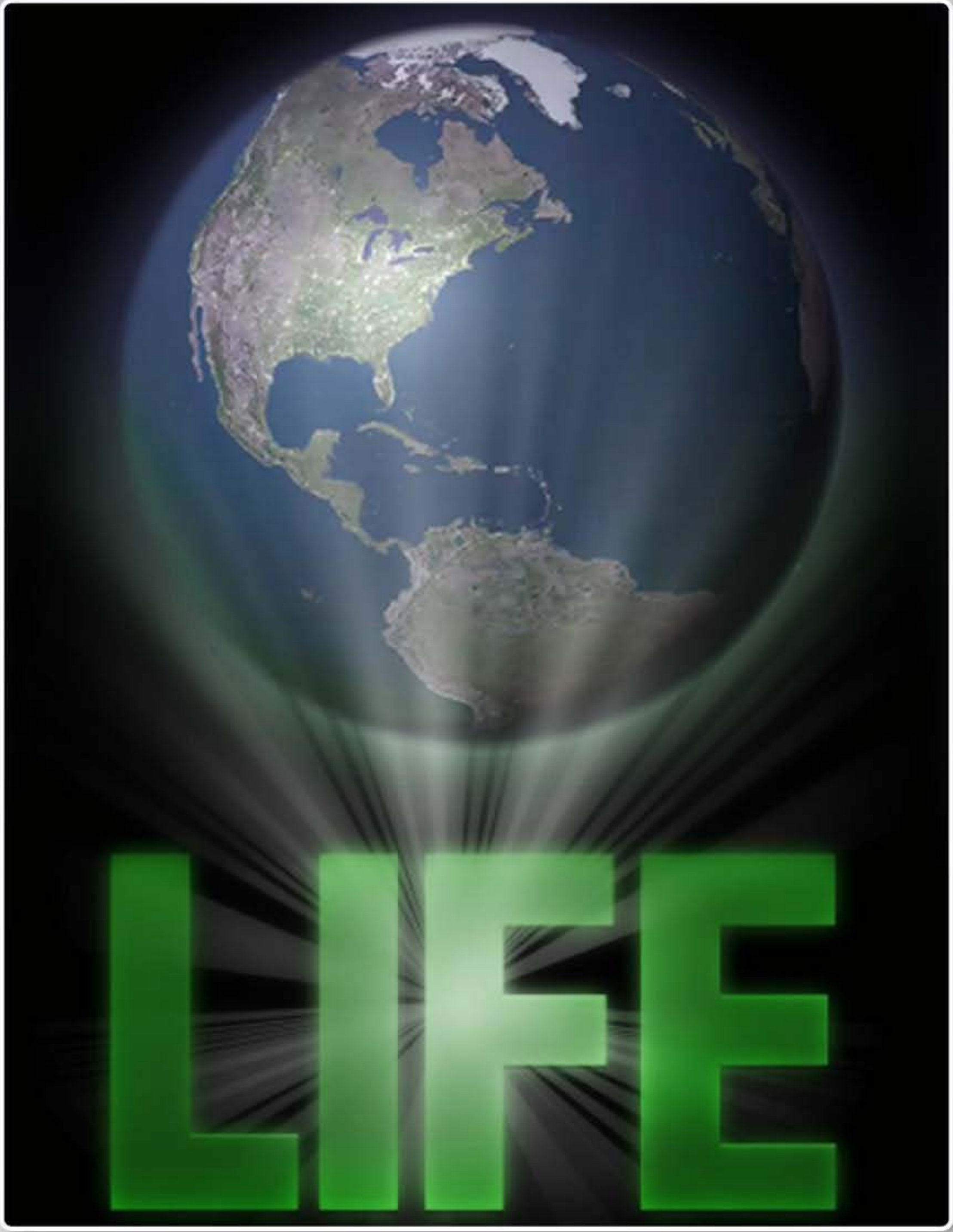

LIFE: Laser Inertial Fusion-based Energy

Presented by
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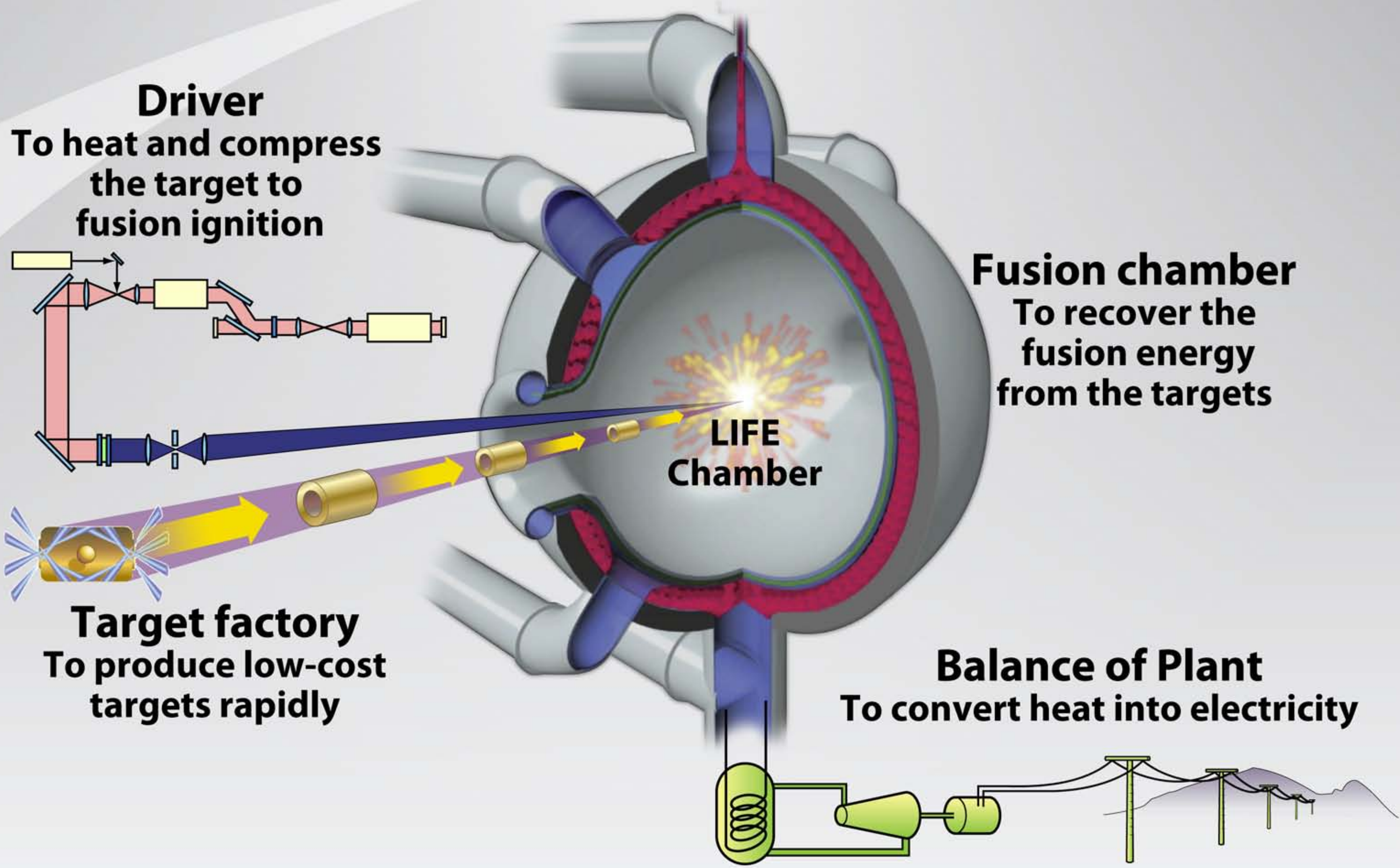
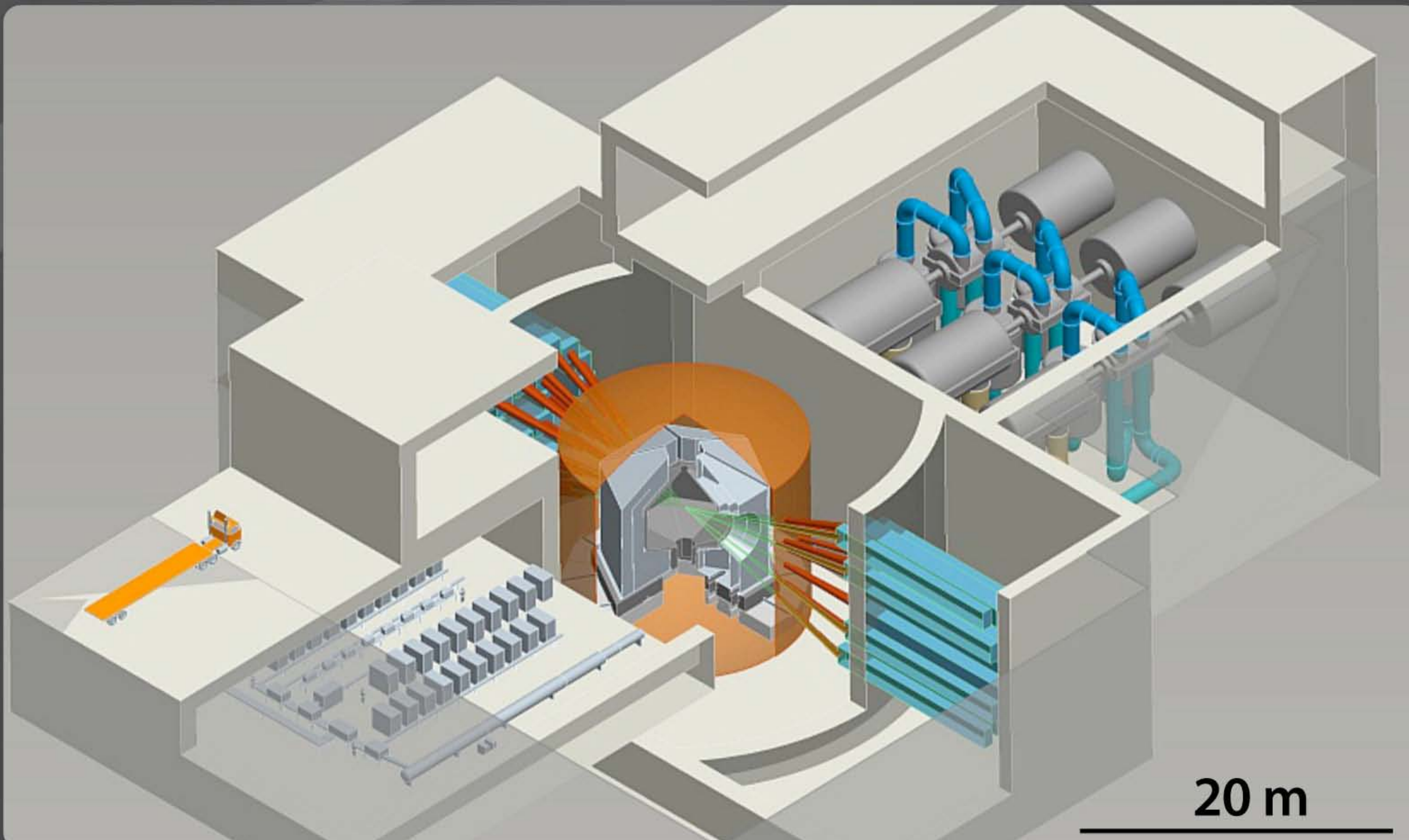
LIFE Chief Engineer

Fusion Power Associates
December 3rd, 2009

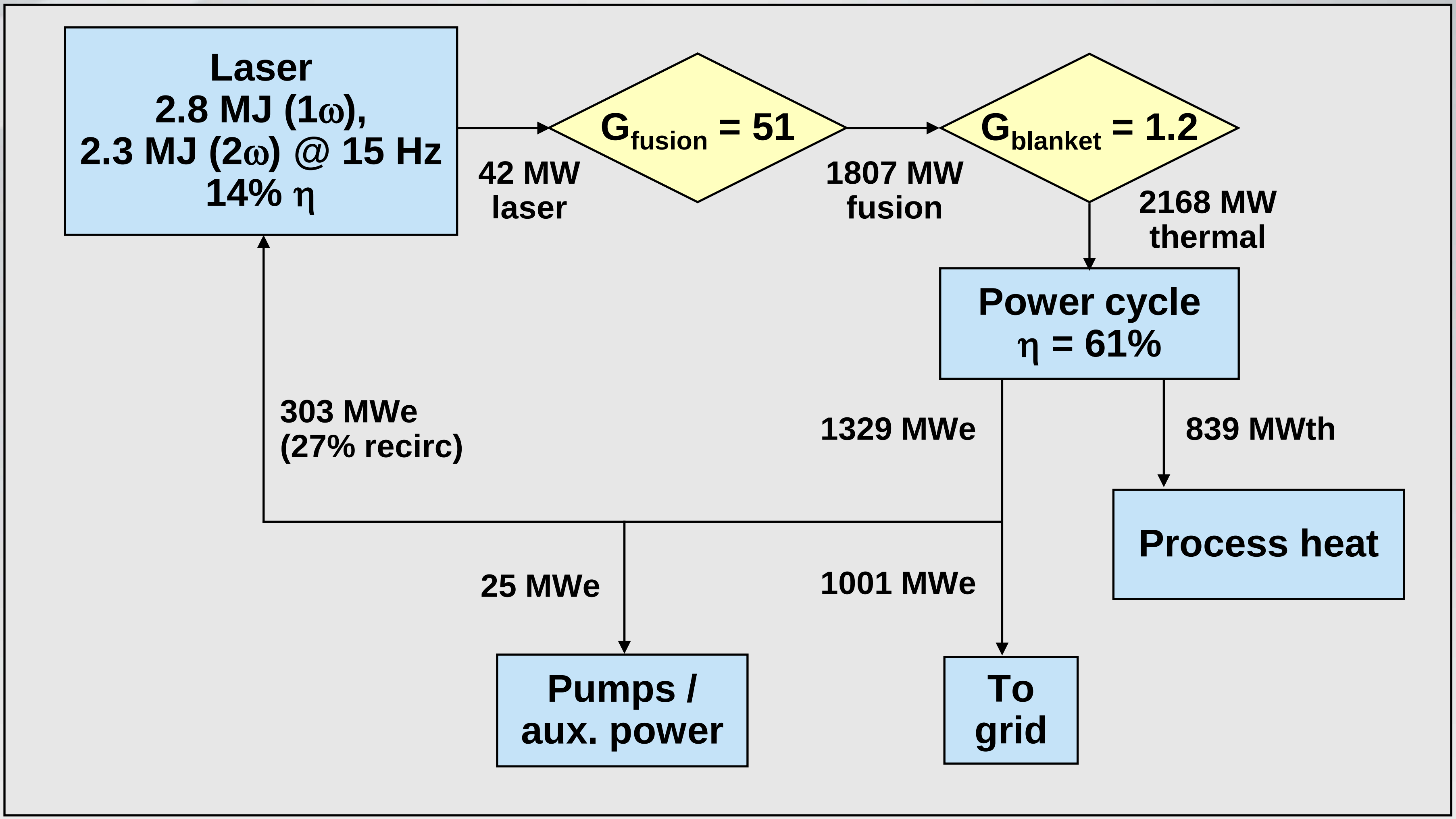
Laser inertial fusion energy is highly separable



Next-generation laser technology could result in a very compact LIFE engine



LIFE power flow for a hotspot pure fusion system



LIFE is a credible extension of NIF, ignition on NIF and ongoing developments in the nuclear industry

- NIF-like fusion performance
- NIF-based lasers
- Mass produced NIF-like targets
- Target injection and engagement
- Fusion environment
  - Protecting first wall
  - Laser beam propagation

Diodes are significantly more energy efficient than flashlamps

Flashlamps

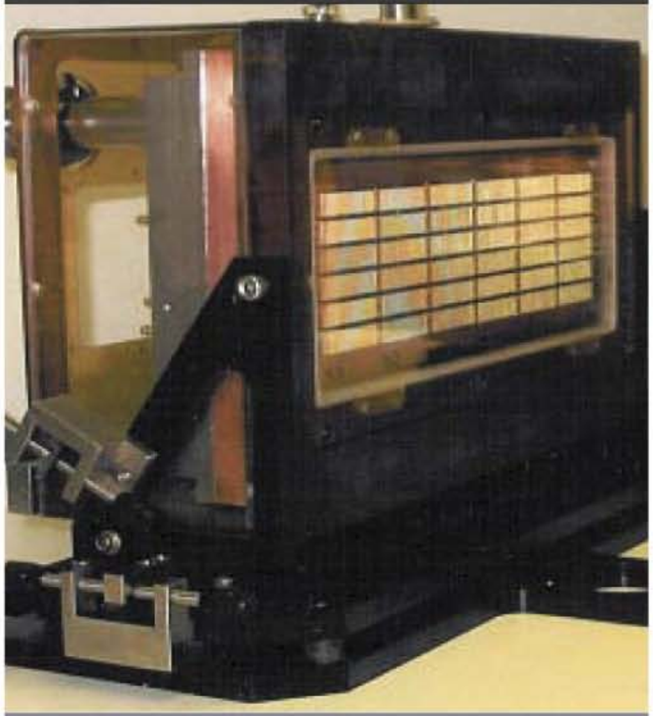
400 W average power electrical-optical efficiency

Diodes

30 kW average power electrical-optical efficiency

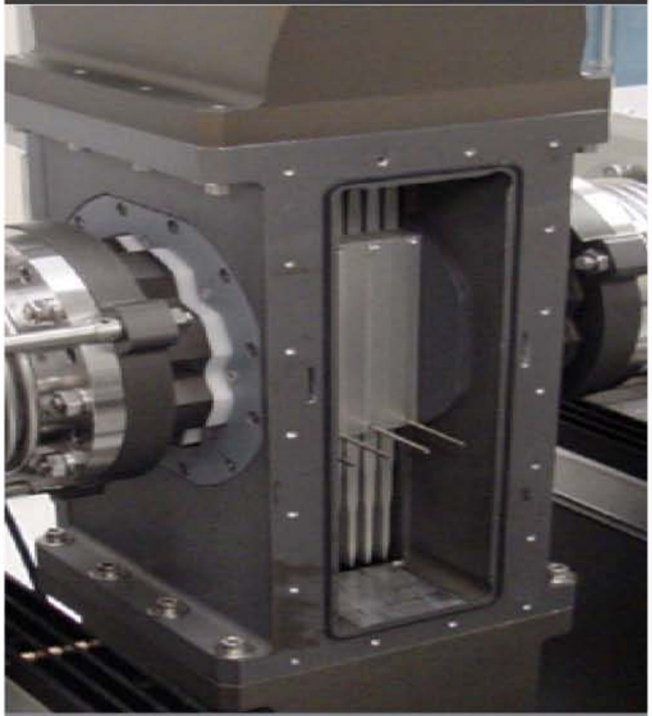
Laser diodes and helium gas cooling enable NIF-like architecture to meet LIFE requirements

High power diode arrays



100 kW peak power

High speed gas cooling

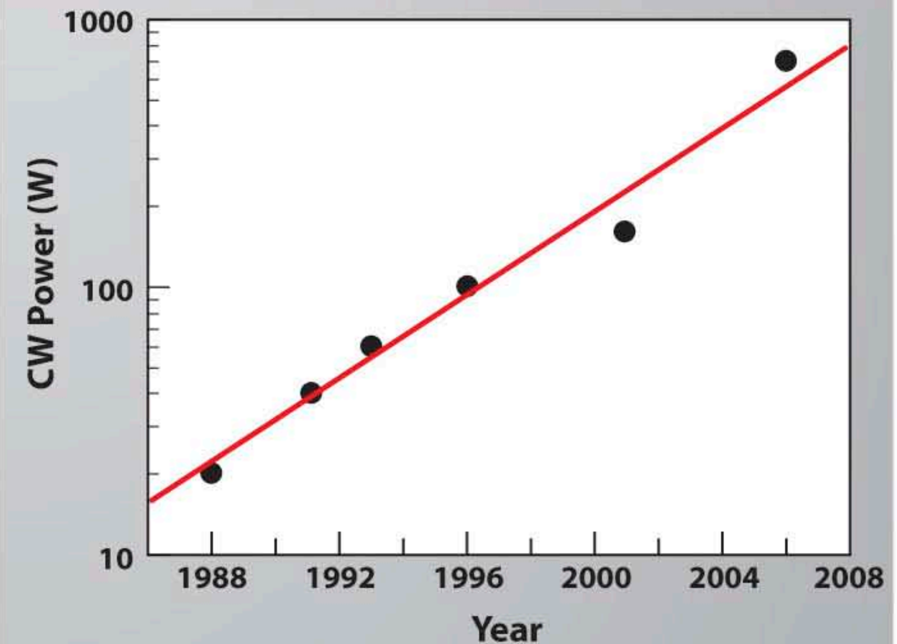


3 W/cm^2 cooling (average)

These technologies have been developed as part of the Mercury Project

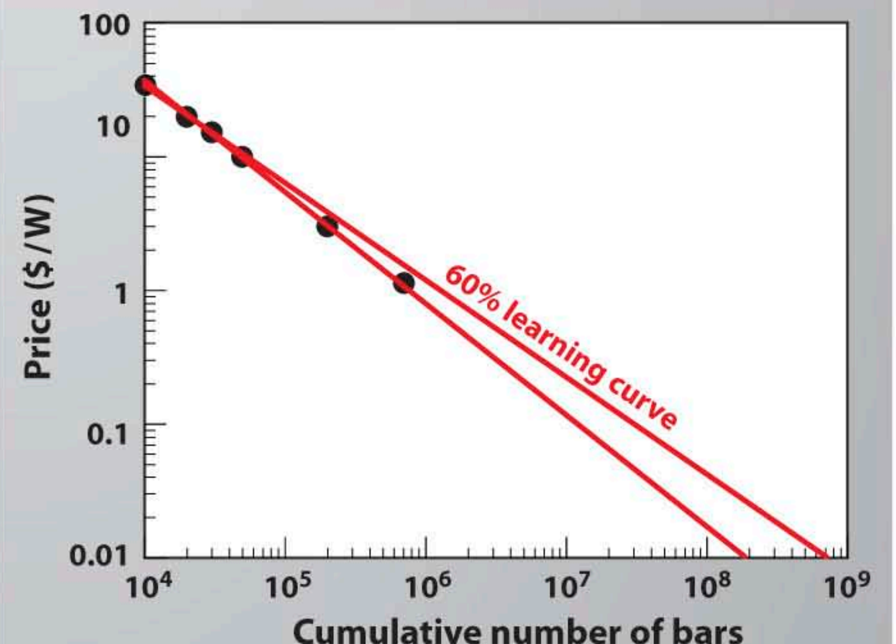
Diodes are experiencing aggressive learning

Continuous wave diode bar performance has increased by 35× since 1988



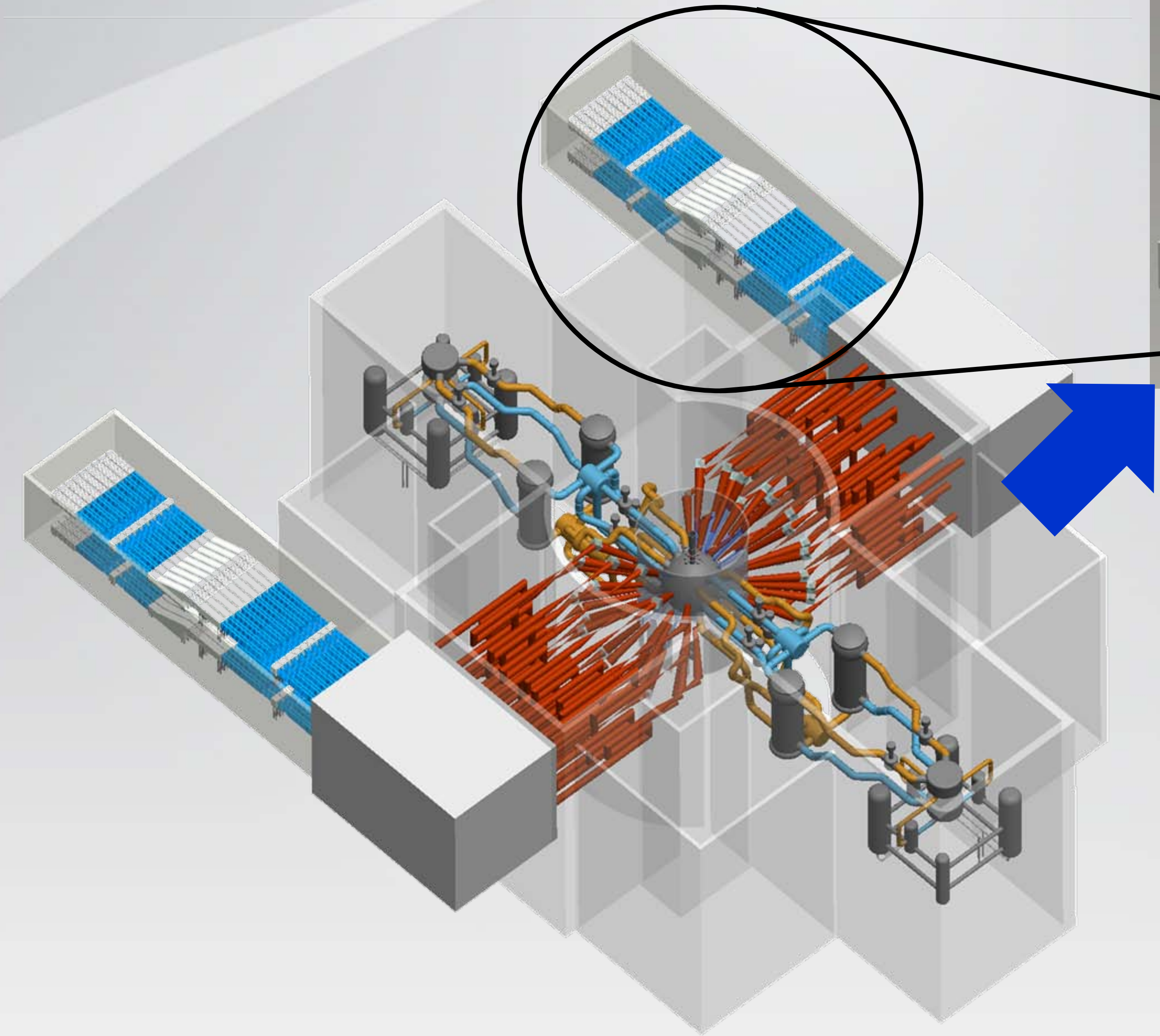
1 cm bar CW power vs year

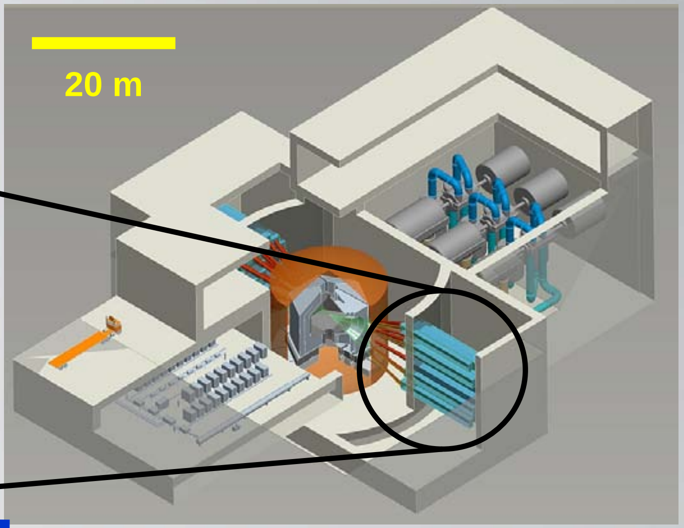
Diode bar prices are dropping with growing market



1 cm bar 60% learning curve

Advanced lasers and modular systems make the facility small and enable rapid construction and maintenance

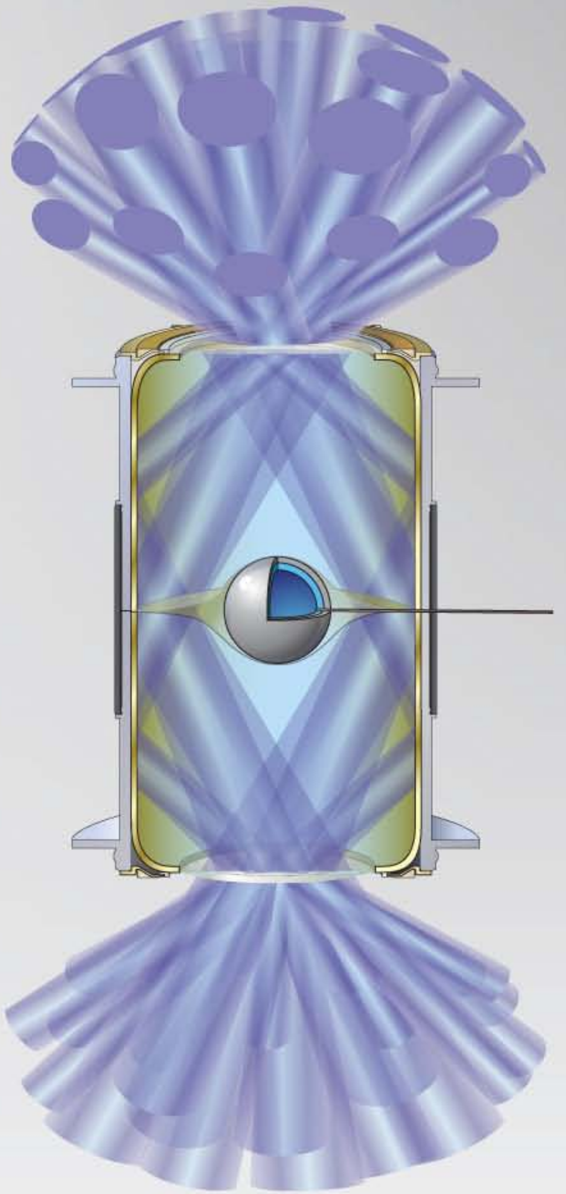




- **Modular (advanced architecture) lasers that could be factory built**
- **Separate first wall & blanket modules for rapid & independent replacement**

Targets can be produced very cost effectively

- Targets will be made with technologies from high-volume manufacturing industries
  - Low-cost materials: pennies per component
    - Silicon mandrel: Ball bearing technology
    - High-density carbon capsules: CH4 pyrolysis
    - High-Z: <$.01 per target
    - Low-Z foam: SiO_2, Carbon
  - Automated fabrication/ assembly processes:
    - Laser drilling/machining of capsules
    - Stamped cones and hohlraums
    - Robotic assembly and packaging

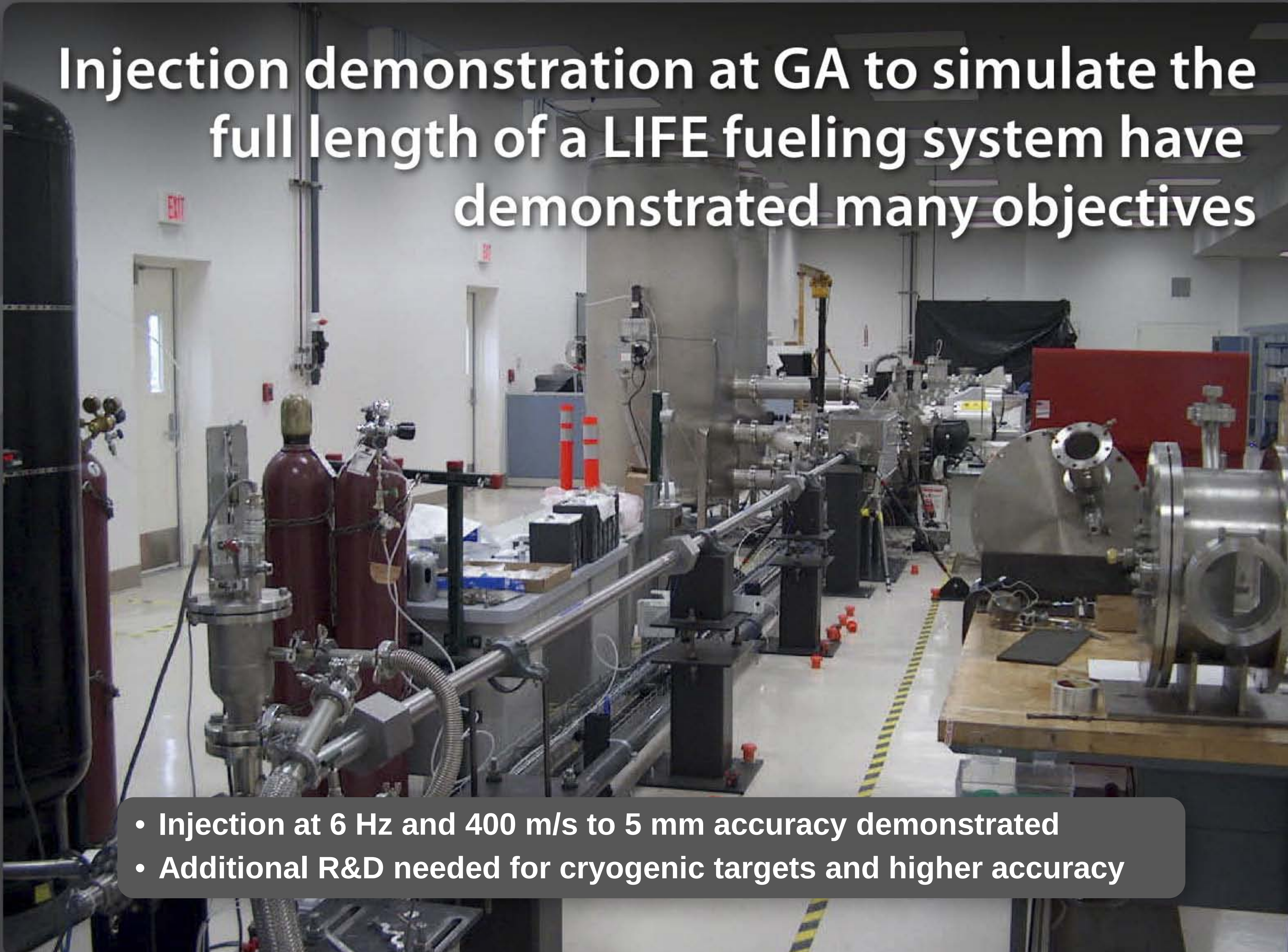


Examples of mass produced components that are comparable to LIFE requirements in volume, precision, and cost

	LIFE	Lego ®	Mil Spec Bullet	Aluminum Cans
Number/year	$3–6 \times 10^8$	1.8×10^9	9×10^9	1×10^{11}
Dimensional tolerance	± 50 μm	± 10 μm	± 40 μm	± 100 μm
Cost	$0.20–0.30	$0.06	$0.21	$0.012

Bullets are an interesting comparison; they are multi-component, multi-materials, that tolerate high acceleration and high velocity

Injection demonstration at GA to simulate the full length of a LIFE fueling system have demonstrated many objectives



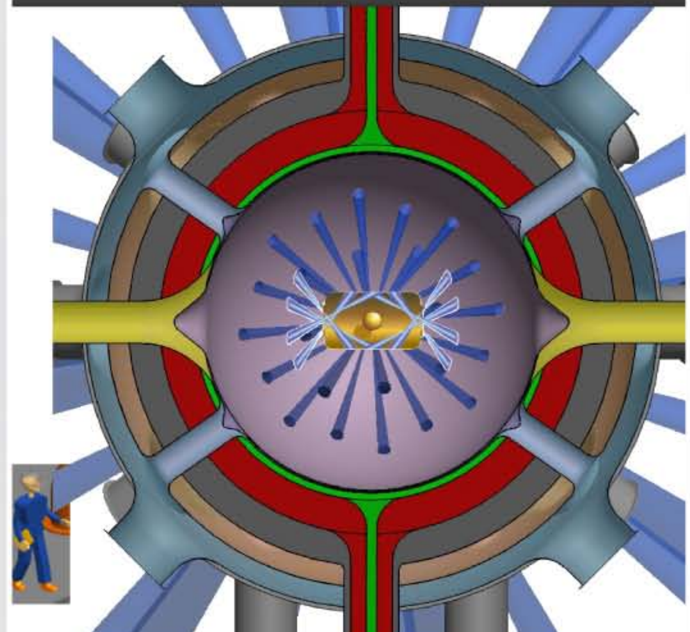
- **Injection at 6 Hz and 400 m/s to 5 mm accuracy demonstrated**
- **Additional R&D needed for cryogenic targets and higher accuracy**

LIFE targeting requirement is similar to that of other demanding systems

Airborne Laser

~1 μrad angular precision
(~10 cm, 100 km)

LIFE



2 μrad precision
(HS, 50 μm, f = 25 m)

Developing an integrated target injection, in-flight tracking and beam engagement system is a key technical challenge

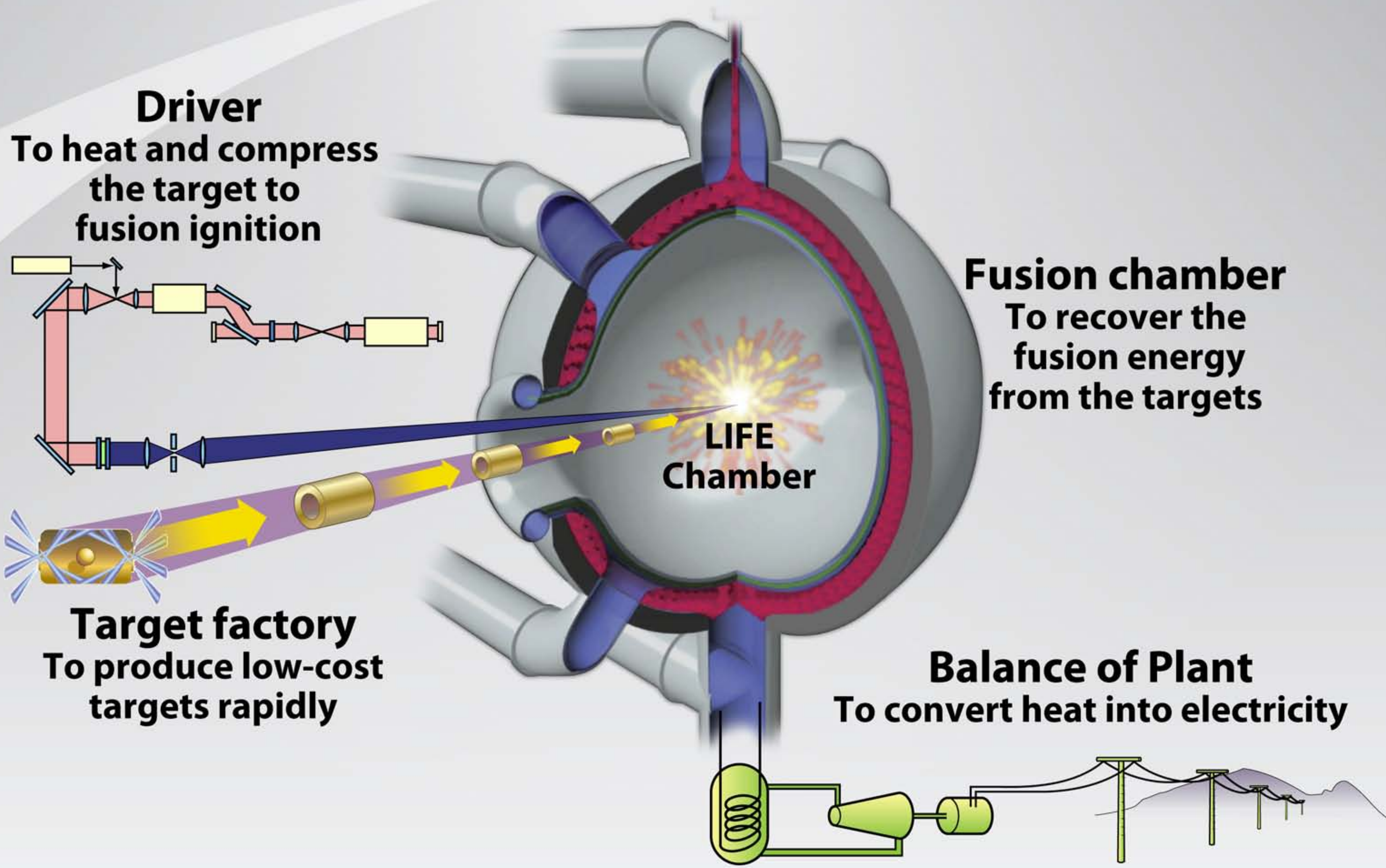
Target fratricide and heating during injection are manageable

- DT ice preheat of 100 mK is deemed acceptable (and conservative):
  - Target injector parameters satisfy fratricide constraints:
    - Injector nozzle ~15 m from chamber center
    - Two mean free paths of neutron shielding (~15 cm) on shutter
    - 250 m/s injection velocity

- Hohlraum acts as thermal insulator to protect capsule during injection:
  - Radiation heating to capsule:
    - Polyimide transmits in the IR
    - Radiation shield (Al/polyimide/Al) gives 99% reflectivity
  - Convective heating of polyimide window dominates:
    - Heat transfer coefficient ~8 W/m^2-K at window edge
    - Window heats to ~80% of decomposition temperature

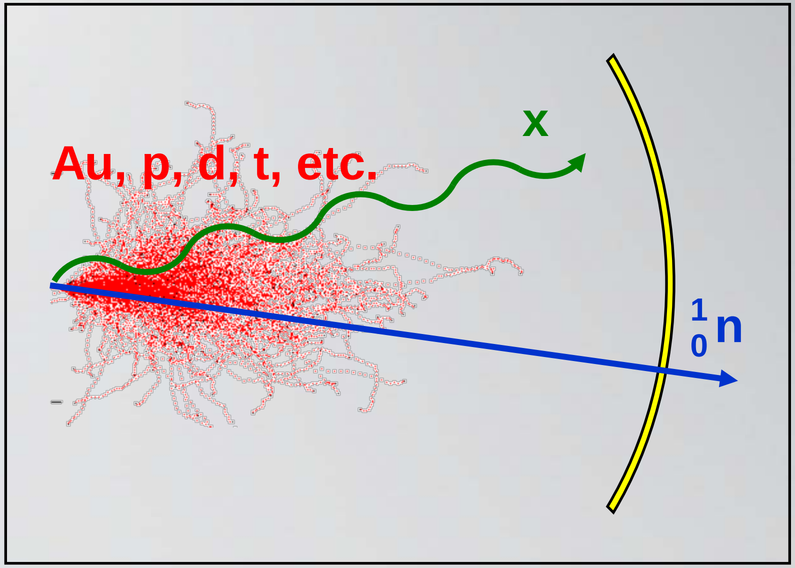
- Several options for reducing target injection risk:
  - Higher velocities / shorter distances → reduced heating time
  - Tailored target output → reduced chamber gas density
  - Injection with cool gas plume → reduced ΔT and h

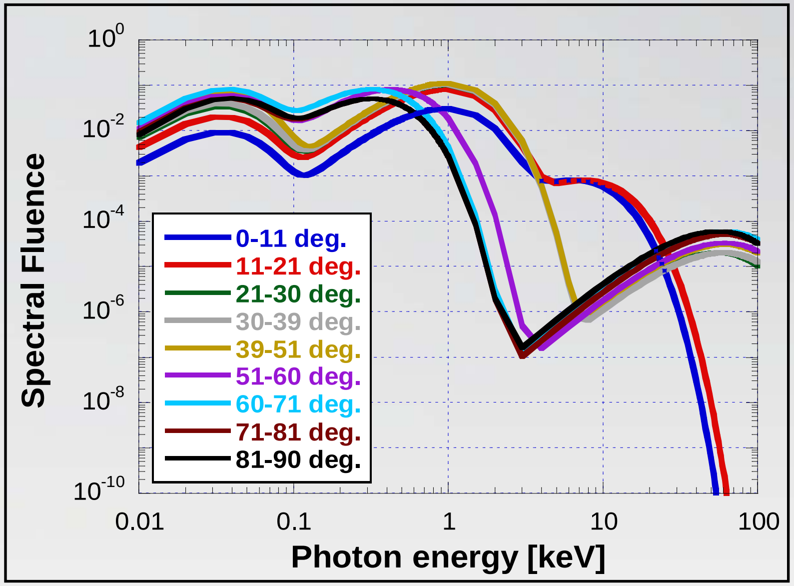
Laser inertial fusion energy is highly separable



X-rays and ion fluxes are simply mitigated

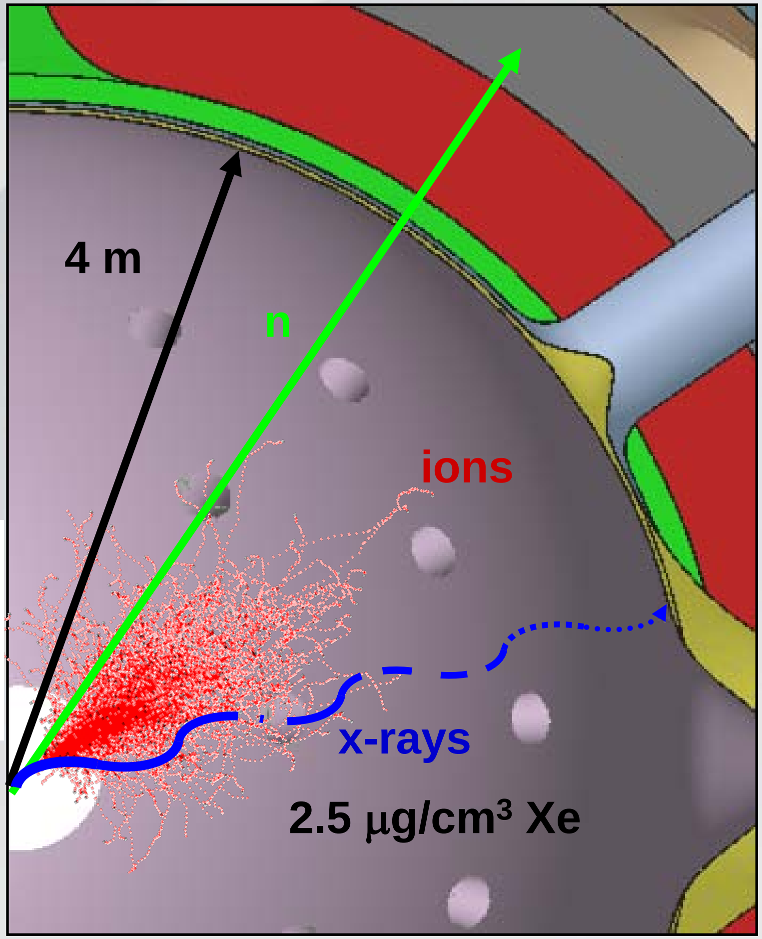
Parameter	Value
Target yield	120 MJ
Repetition rate	15 Hz
Fusion power	1800 MW
Chamber radius	4 m
X-rays	14 MJ (12%)
Ions	12 MJ (10%)

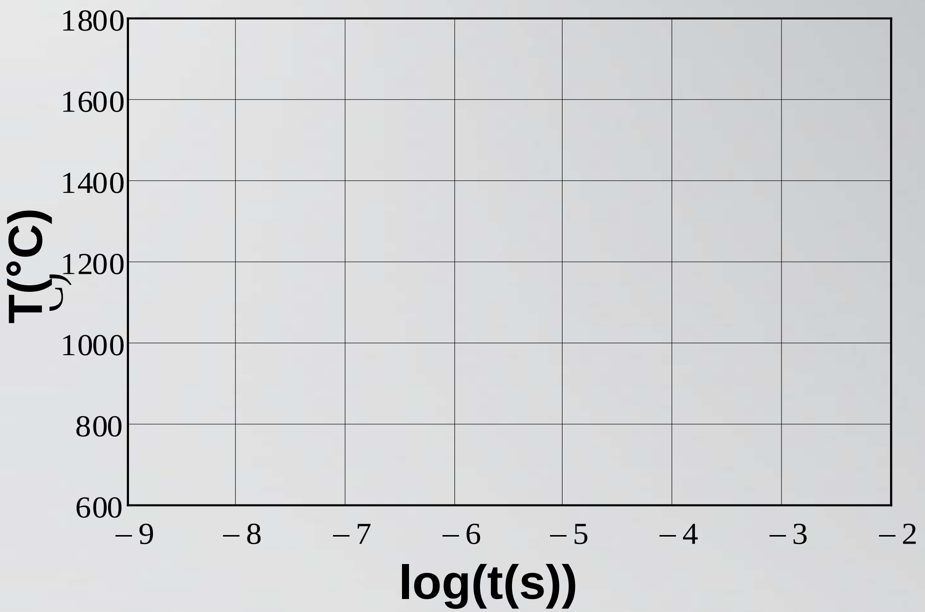




Chamber fill gas can attenuate x-rays and ions to protect the first wall

Thermally robust targets allow for a protective chamber gas to absorb all ions and 90% of x-rays





Protective background gas re-radiates ion and x-ray energy over a timescale thermal conduction can effectively remove it

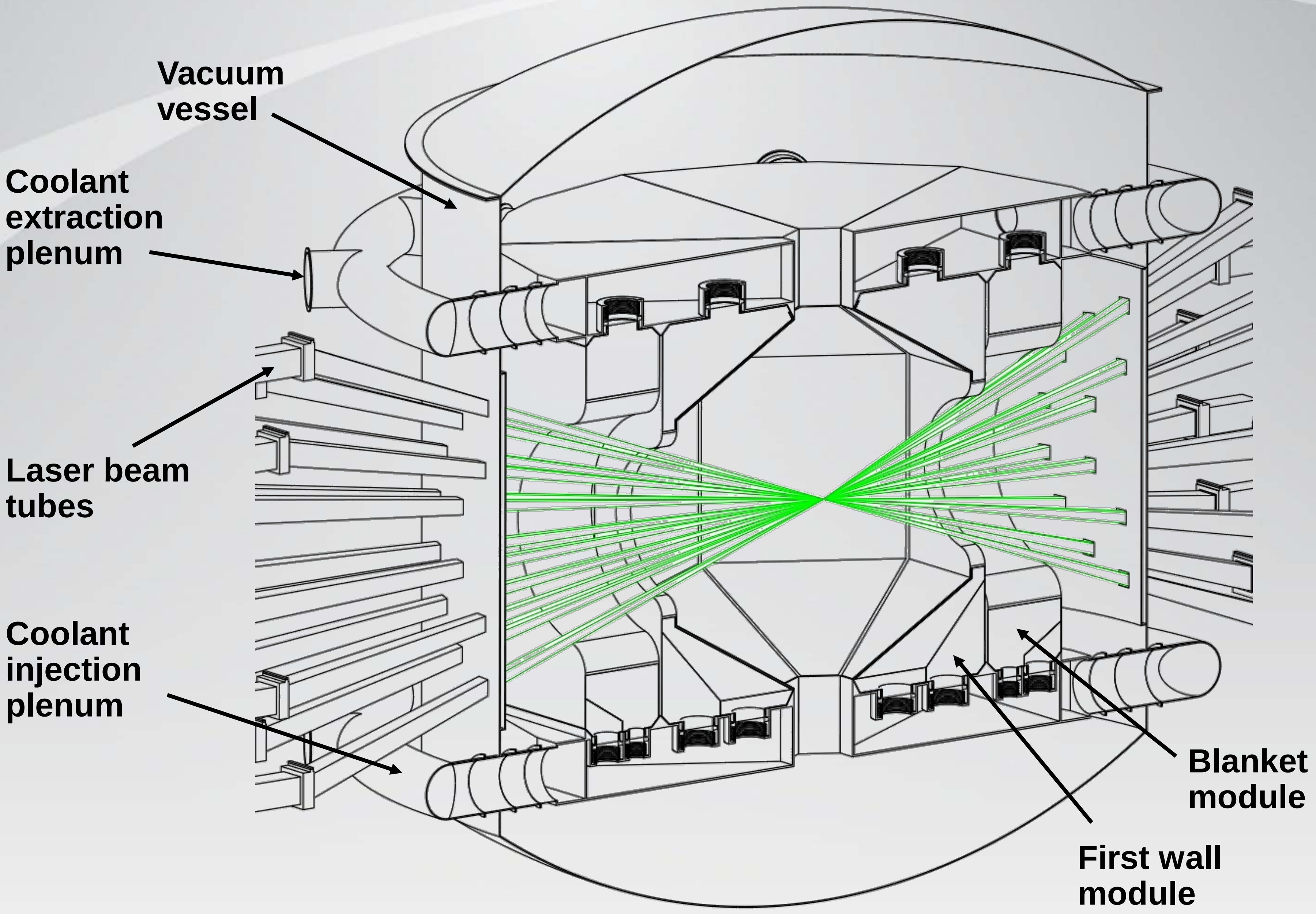
Chamber conditions must support laser beam propagation for the next shot

- **Base case design is robust with respect to chamber design:**
  - **120 MJ fusion yield @ 15 Hz**
  - **4 m radius**
  - **2.5 μg/cc xenon**

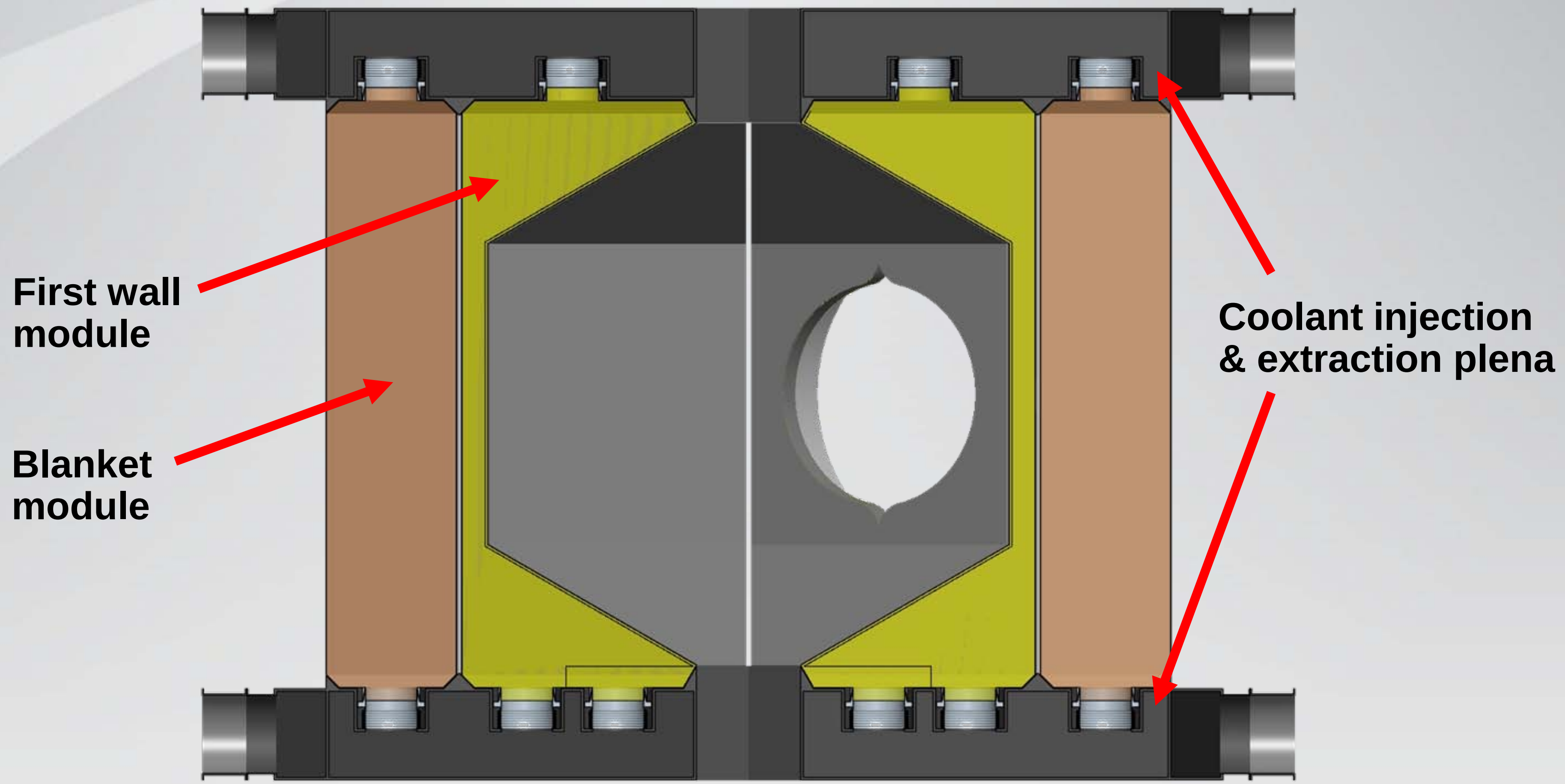
- **Chamber design trades-off:**
  - **First wall protection → stop ions & attenuate x-rays in Xe/Kr**
  - **Target heating during injection → dominated by IR from 1st wall**
  - **Laser beam propagation → ~1% inverse Bremsstrahlung loss**

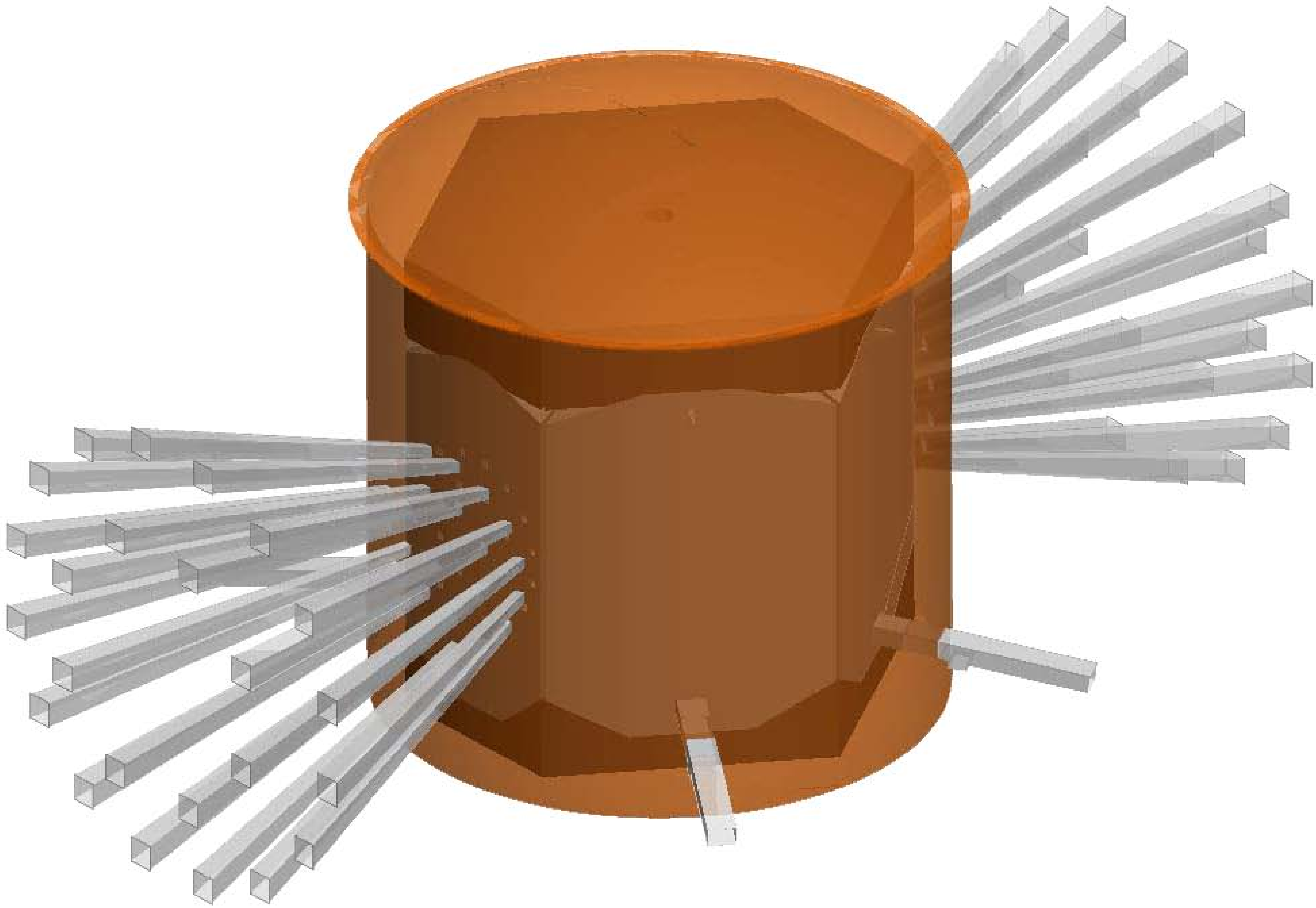
- **System optimization is likely to result in smaller chambers:**
  - **Beam propagation with increased gas densities**
  - **Gas cocktails for better x-ray attenuation**
  - **Tailored target output for fewer x-rays**

Chamber designed for rapid replacement

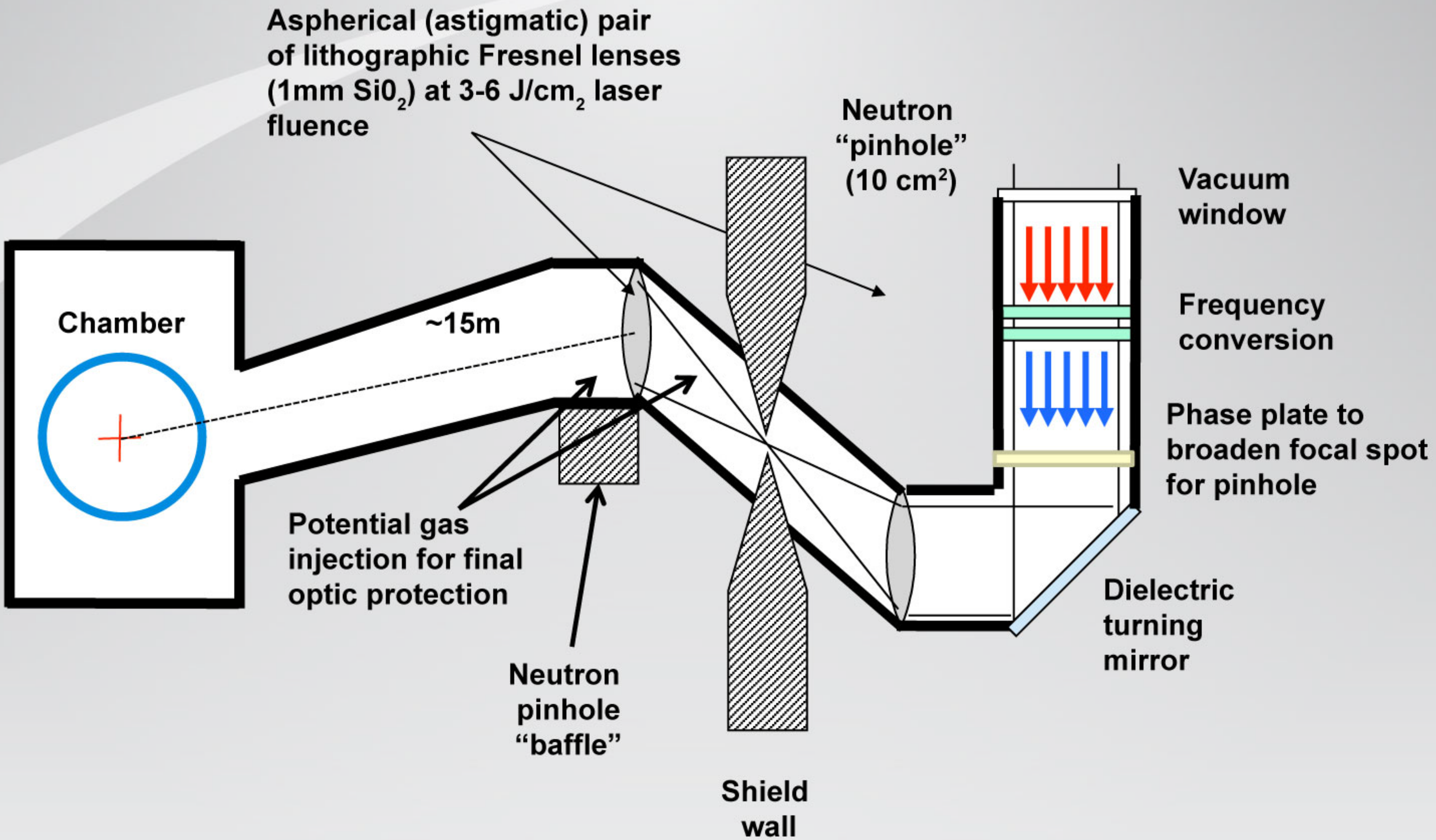


Modular chambers have independent first walls that can be replaced without moving the blanket



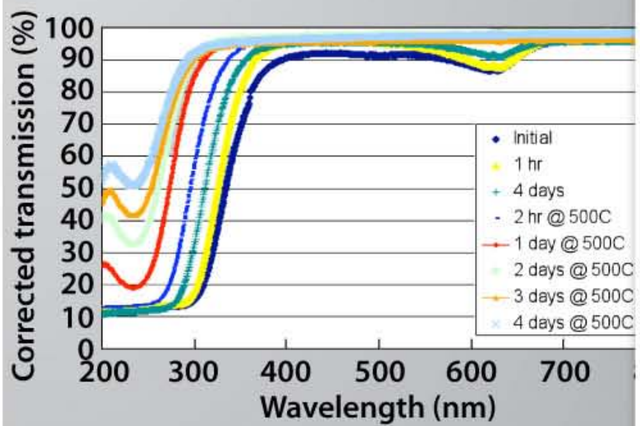


LIFE final optic system

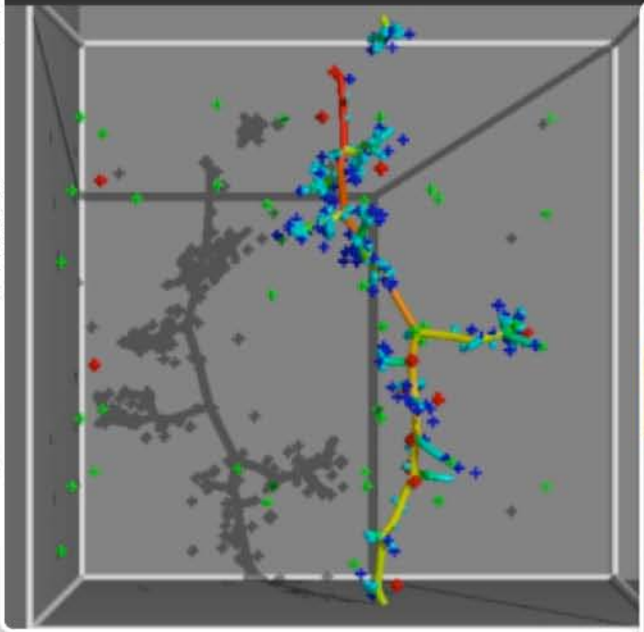


A fused silica Fresnel is an attractive option for the final optic

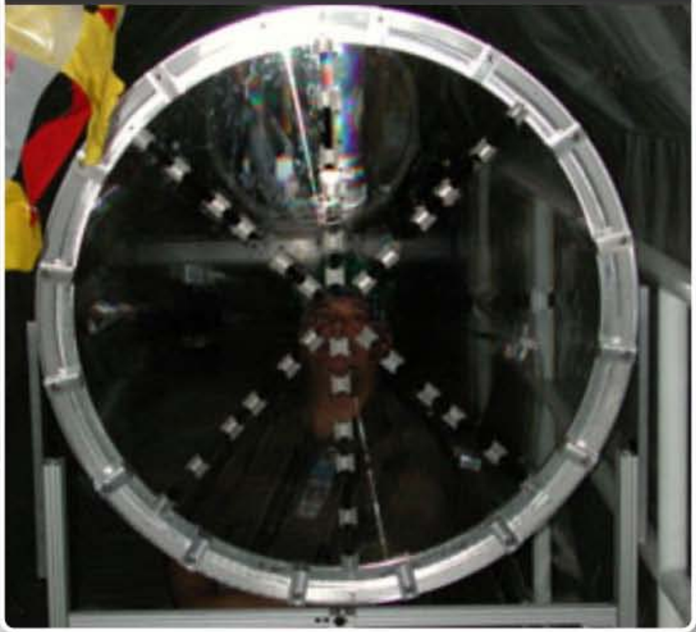
Neutron-irradiated SiO_2 can be annealed to remove color centers



Molecular dynamics simulations confirm SiO_2 self-annealing



Thin Fresnel technology has been demonstrated at large aperture



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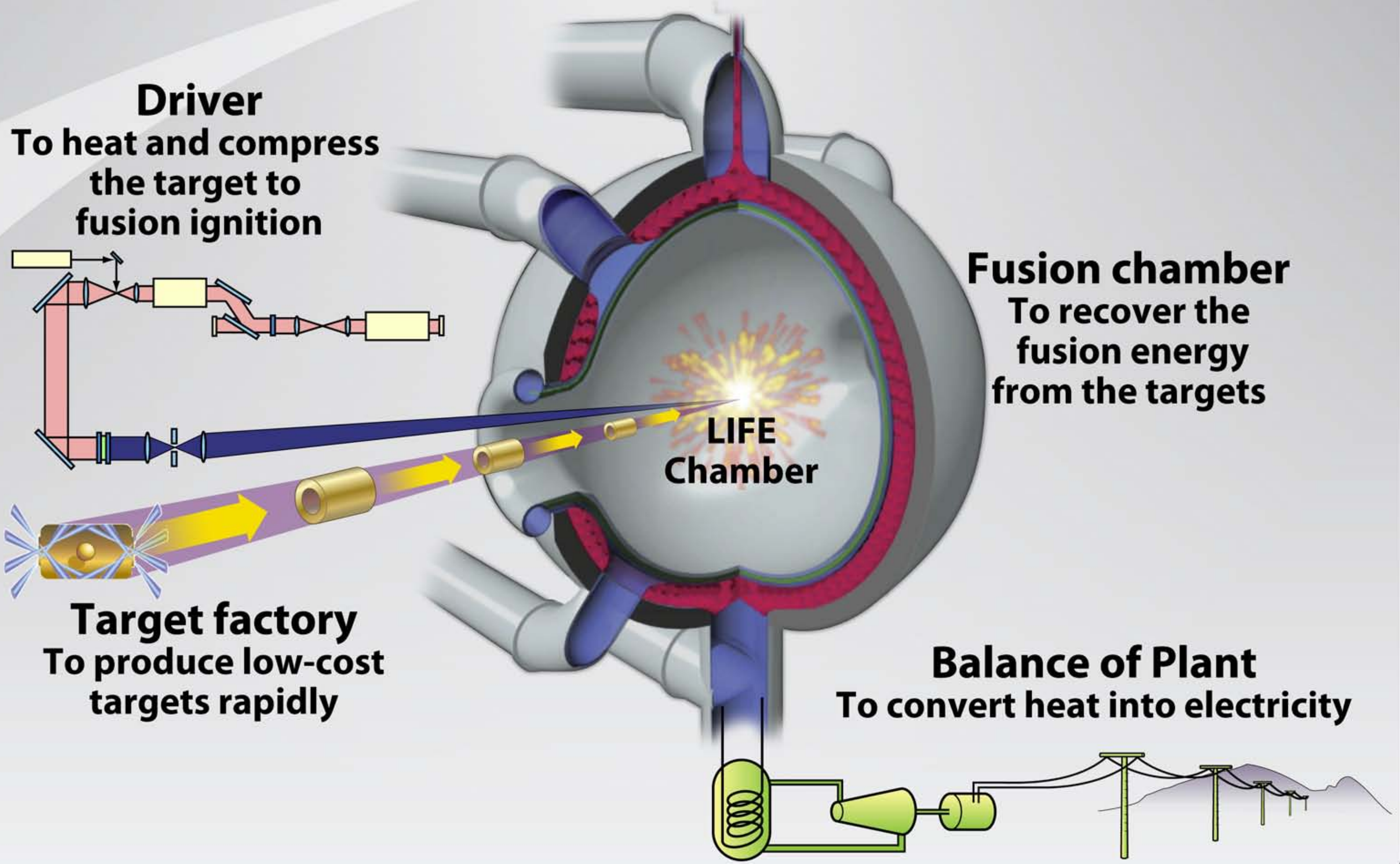
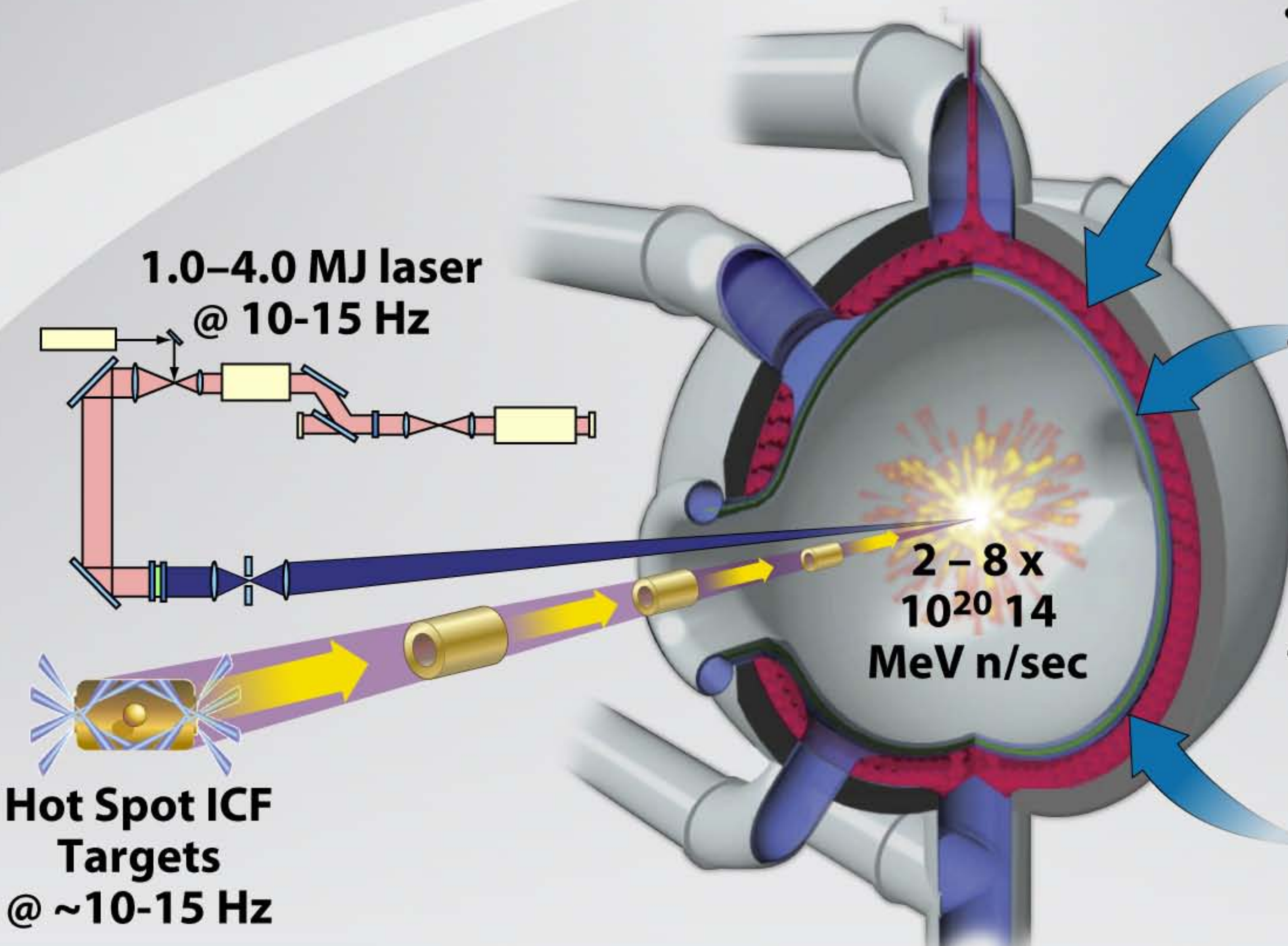


Different LIFE blankets provide unique energy systems



ICF Gain 15-70 provides 150-1750 MW fusion

LIFE blankets options

- Li-based salt to make electricity and produce T for other LIFE-based missions (pure fusion-base case)
- Coolant with U, DU or TH pebbles for Once-Through Closed Energy Production (> 99% burn-up)
- Coolant with fertile or fissile pebbles for Once-Through Closed Waste Burning (> 99% burn-up)
  — SNF
  — WG – Pu, HEU

Summary

- LIFE systems will be highly modular and more compact than NIF
- The high degree of separability inherent to IFE translates into a significant development path advantage
- LIFE could be fielded as a pure fusion plant or as a hybrid to complete waste-related missions
- A pilot plant could be operational a decade after NIF ignition and that a commercial power plant could be running a decade after that

LIFE

Laser Inertial Fusion Energy