LIFE

Overview of the LIFE Power Plant

Presentation to

National Research Council's review on "Prospects for Inertial Confinement Fusion Energy Systems"

January 29, 2011

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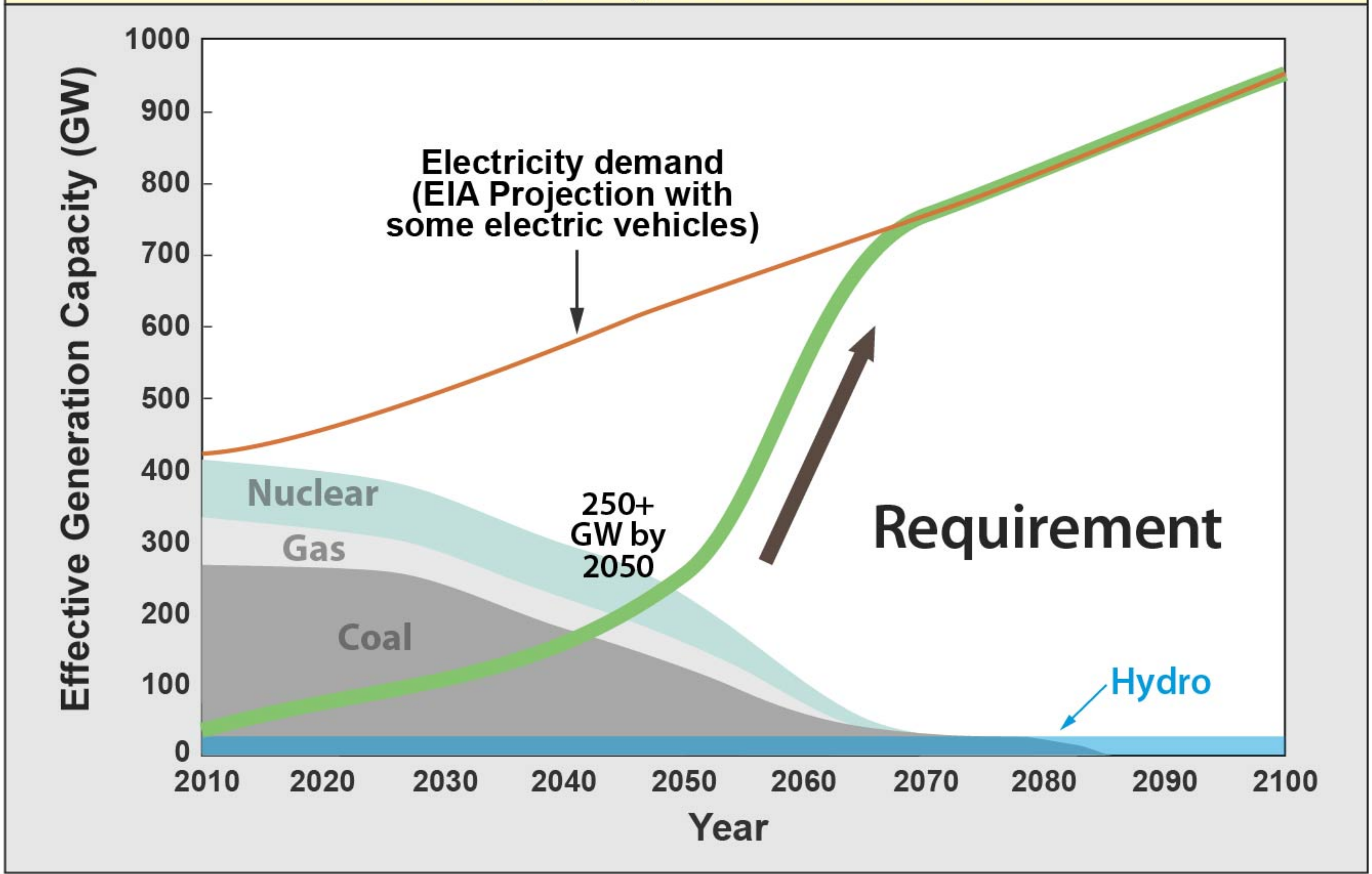
with contributions from

LLE, GA, LANL, U Wisc, U Illinois, UCSD, PPPL, NPS, SRNL

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

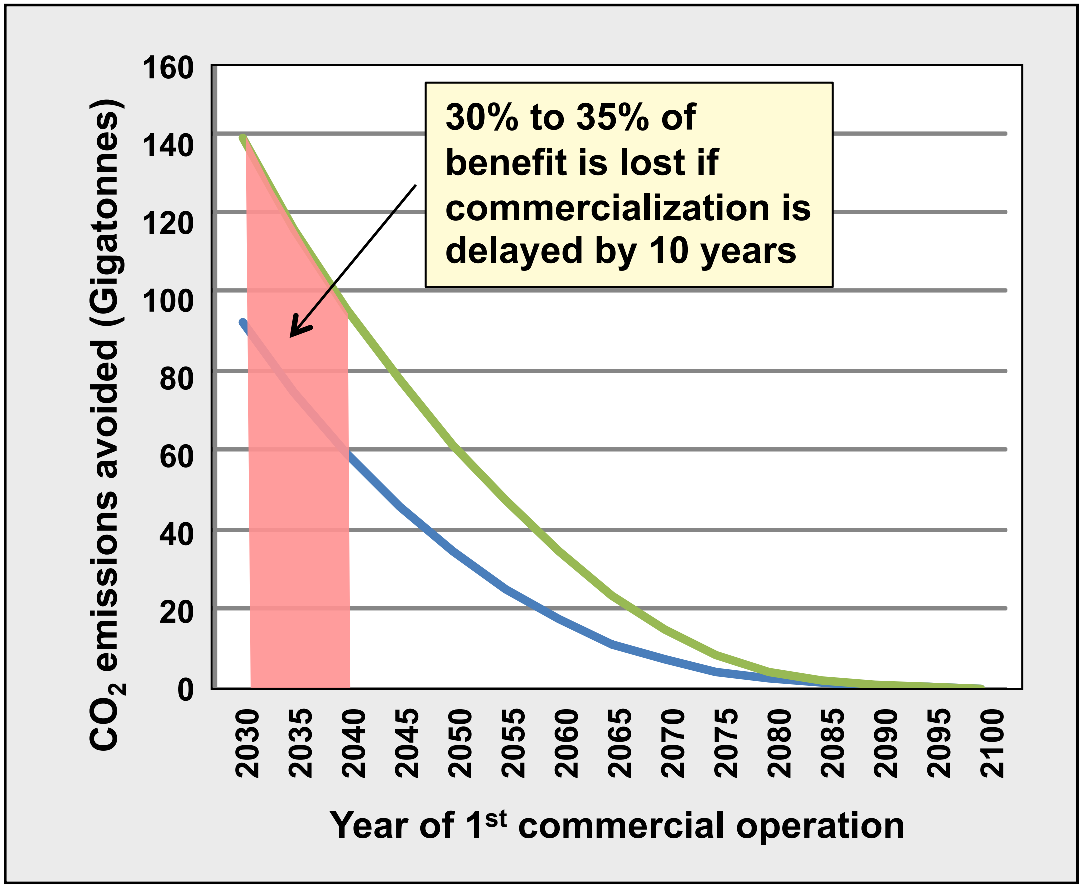
Power plant delivery timescales are set by the need to impact renewal of the US fleet

Based on U.S. Energy Information Agency's Annual Energy Outlook (2009), Retirement of Plants



Early market entry for fusion has a big impact – displacing coal, LWRs, or fast breeders [US alone]

- 90 to 140 Gtons CO_2 displaced
- 350 to 600 B$ Net Present Value
- Or, displace 3 to 4.5 Yucca Mtns
- Or, displace 3000 to 4000 tons Pu



The LIFE power plant design is optimized to address the end-user requirement (utilities, vendors, licensing)

Utilities (CEO/SVP level)
• Pinnacle West Capital Corp • PG&E Corporation • MidAmerican Energy Company • Wisconsin Energy • Nuclear Management Company • Constellation Energy • Dominion Generation • Exelon Generation Company • Southern California Edison

Vendor companies

Supply chain

Plant Primary Criteria (partial list)
Cost of electricity
Rate and cost of build
Licensing simplicity
Reliability, Availability, Maintainability, Inspectability (RAMI)
High capacity credit & capacity load factor
Predictable shutdown and quick restart
Protection of capital investment
Meet urban environmental and safety standards (minimize grid impact)
Public acceptability
Timely delivery

This can drive a very different design solution and delivery path to conventional approaches based on technical performance alone

Utility Executives have formed an advisory committee to guide the LIFE project

Charter

To complement LIFE's internal functions to advise the Director, NIF and Photon Science, using its own industry expertise, experience and insights. The committee will consider end user needs, safety, reliability, economics and established or needed regulations, codes and standards as they apply to LIFE development."

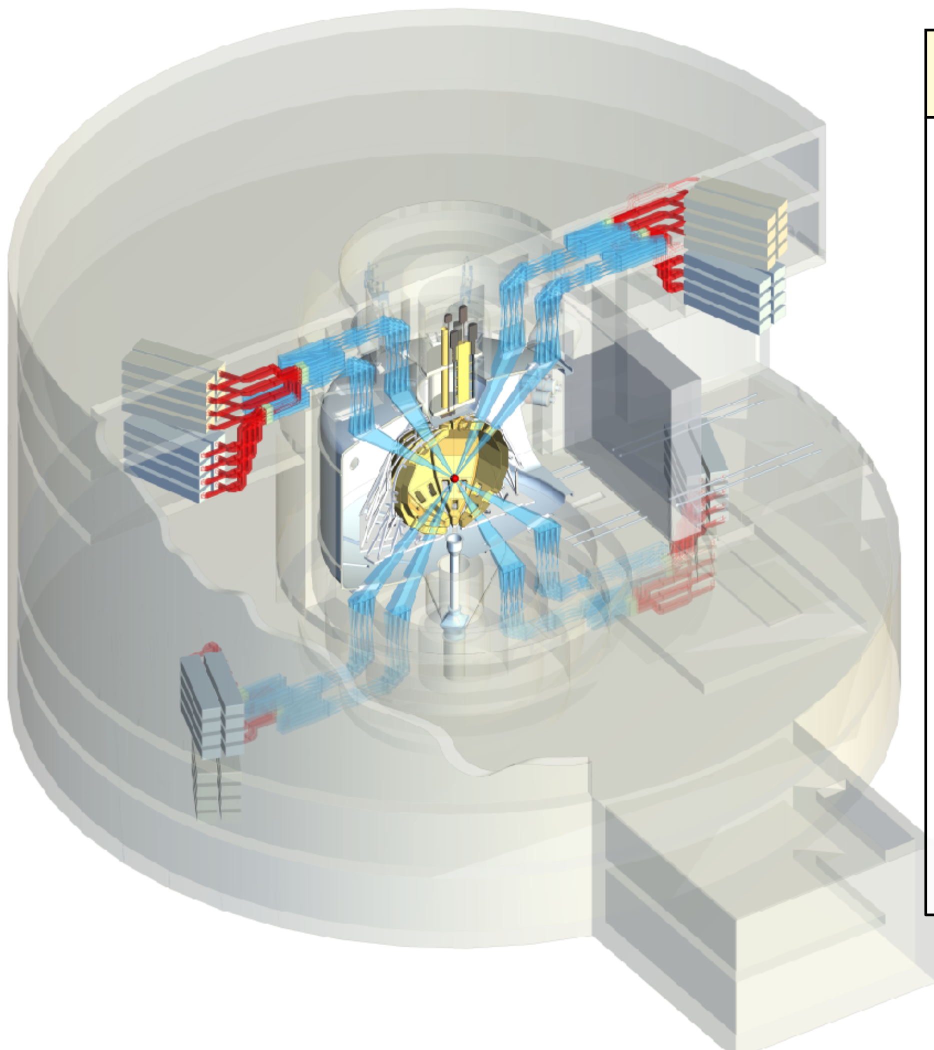
Membership

- **Michael Sellman (Chairman) – CEO, Nuclear Management Company (Ret.)**
- **Peter Darbee – Chairman, CEO and President, Pacific Gas & Electric Company**
- **Michael Wallace – President and CEO, Constellation Energy Group**
- **Donald Brandt – President and CEO, Pinnacle West Capital Corporation**
- **William Fehrman – President and CEO, MidAmerica Energy Company**
- **Richard Kuester – CEO, Wisconsin Energy Corporation**
- **David Christian – CEO, Dominion Generation; President Virginia Power**

Non-Voting Member

- **Brian Debs – CEO, Baran Bryant Group; previous SVP Ontario Power Generation Corp**

An integrated approach to plant design was adopted, trading performance between the various sub-systems



Example Technical Variables
• Target robustness and gain • Laser size, layout and efficiency • Blanket gain • Tritium breeding ratio & inventory • Thermo-electric performance • Ancillary equipment (power load) • Waste streams • Structural material response • Material availability for rollout • Operating performance margin • Sub-system self consistency

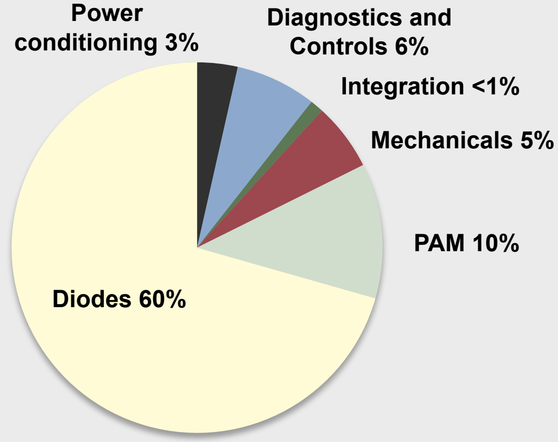
Accessible materials and technology selected wherever possible

A detailed cost and economics model was iterated with the technology performance assessment

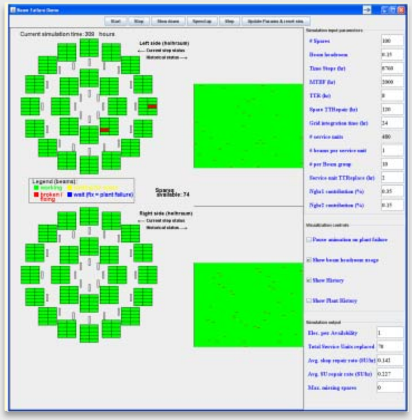
Economic factors

- Capital cost
- Availability
- Reliability
- Maintainability
- Fuel/consumable costs
- Licensing
- Supply chain
- Environmental cost
- Time to market

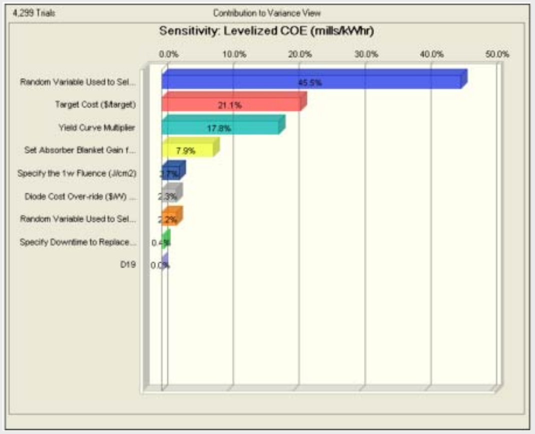
Capital cost areas



Monte Carlo availability



Technology investment impact

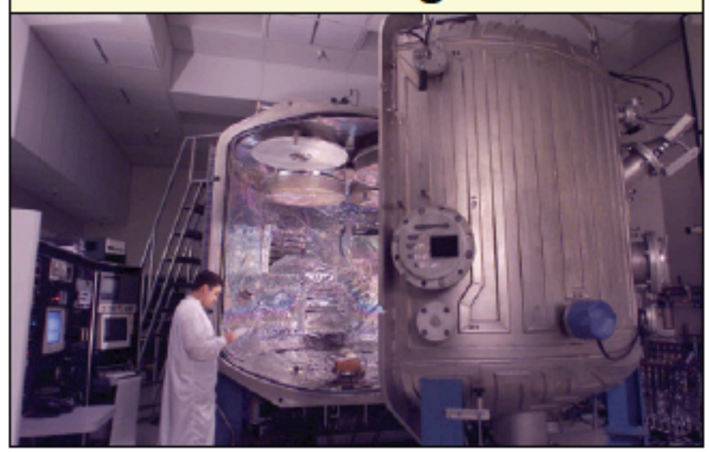


Industrial partners were consulted to determine component availability, performance and cost

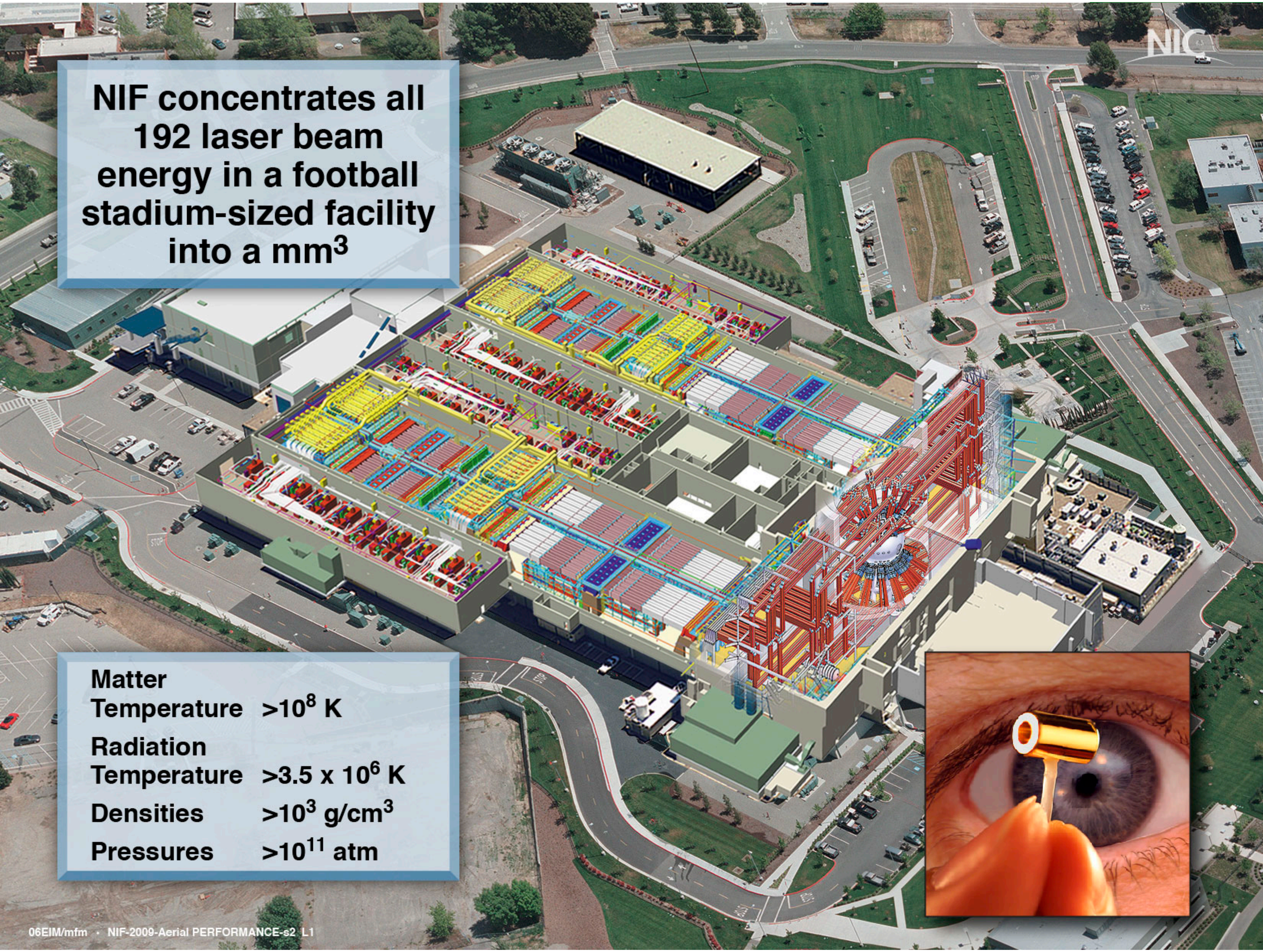
- **30+ major vendors engaged from the semiconductor, optics, laser, construction, controls, nuclear, project delivery and regulatory industries**
  - white papers produced detailing technology readiness and cost
  - market assessments and industrial advice have driven the LIFE design
- **Example output:**
  - **Semiconductor industry**: quantified laser diode performance, cost and capacity (joint paper from 14 companies)
  - **Optics industry**: glass production readiness (Schott APG-1)
  - **Manufacturing industry**: e.g. production of low activation HT-9 tubes
  - **Construction / Engineering** : facility design, commissioning and operations
  - Many of the key LIFE manufacturing processes are already in place

Polishing & Figuring

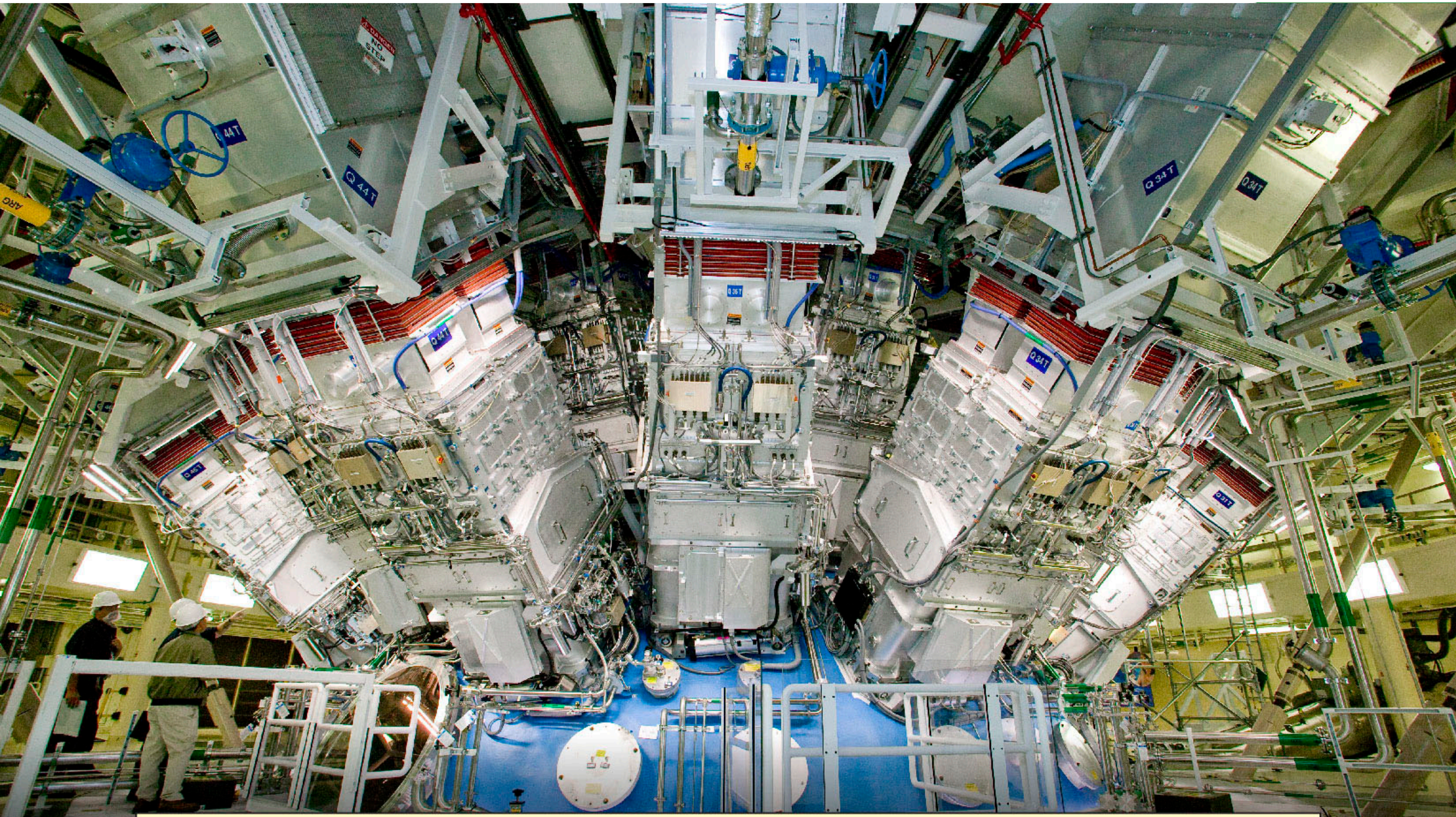
Coating



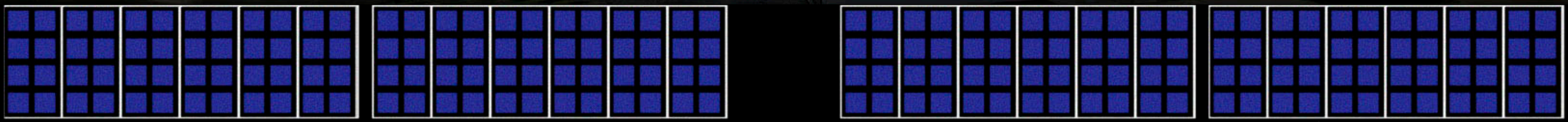
LIFE fusion performance will be set by measurements on the National Ignition Facility


NIC
NIF concentrates all 192 laser beam energy in a football stadium-sized facility into a mm3
Matter Temperature >10⁸ K
Radiation Temperature >3.5 x 10⁶ K
Densities >10³ g/cm³
Pressures >10¹¹ atm
06EIM/mfm • NIF-2009-Aerial PERFORMANCE-s2 L1

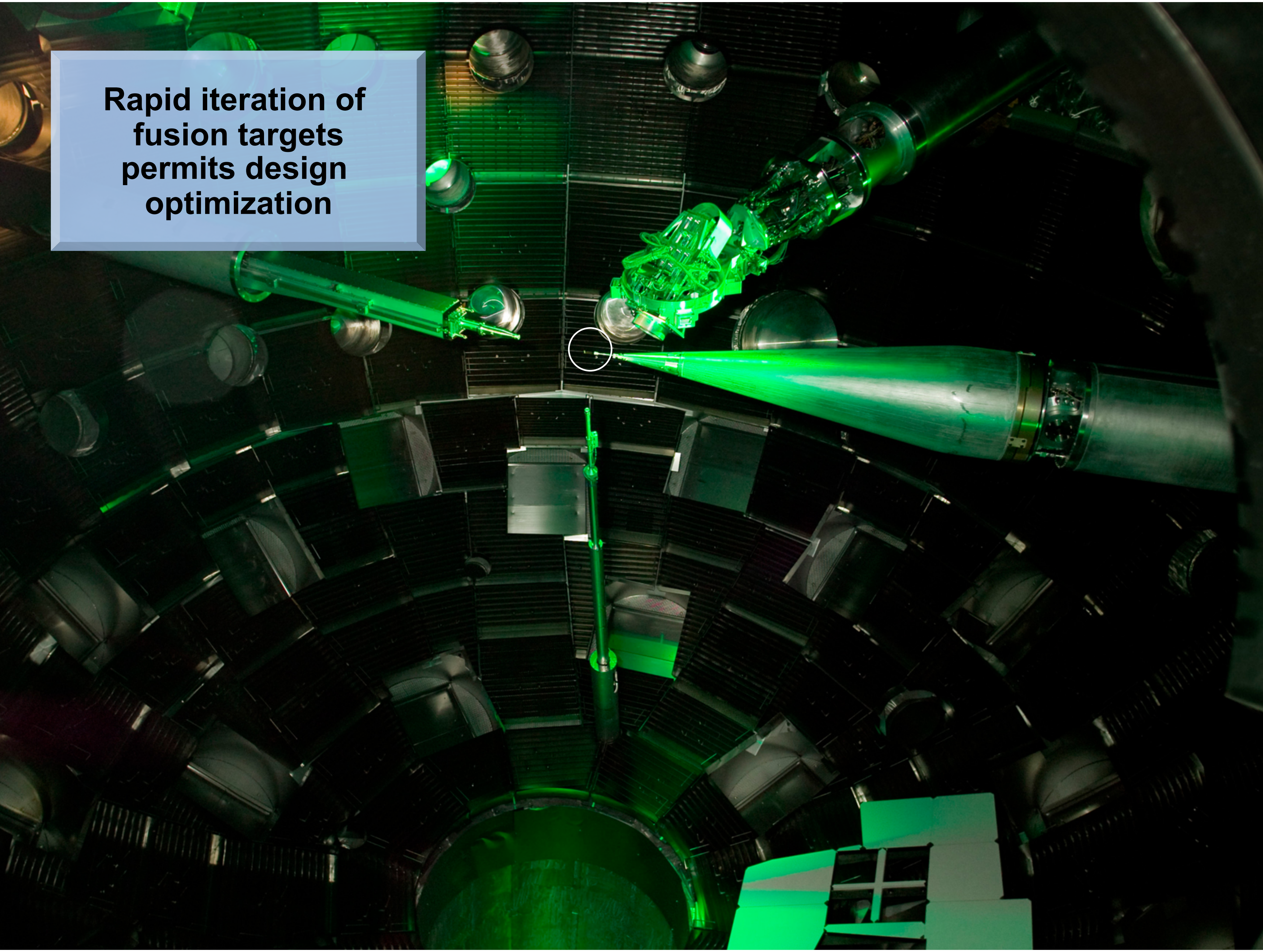
Laser Bay



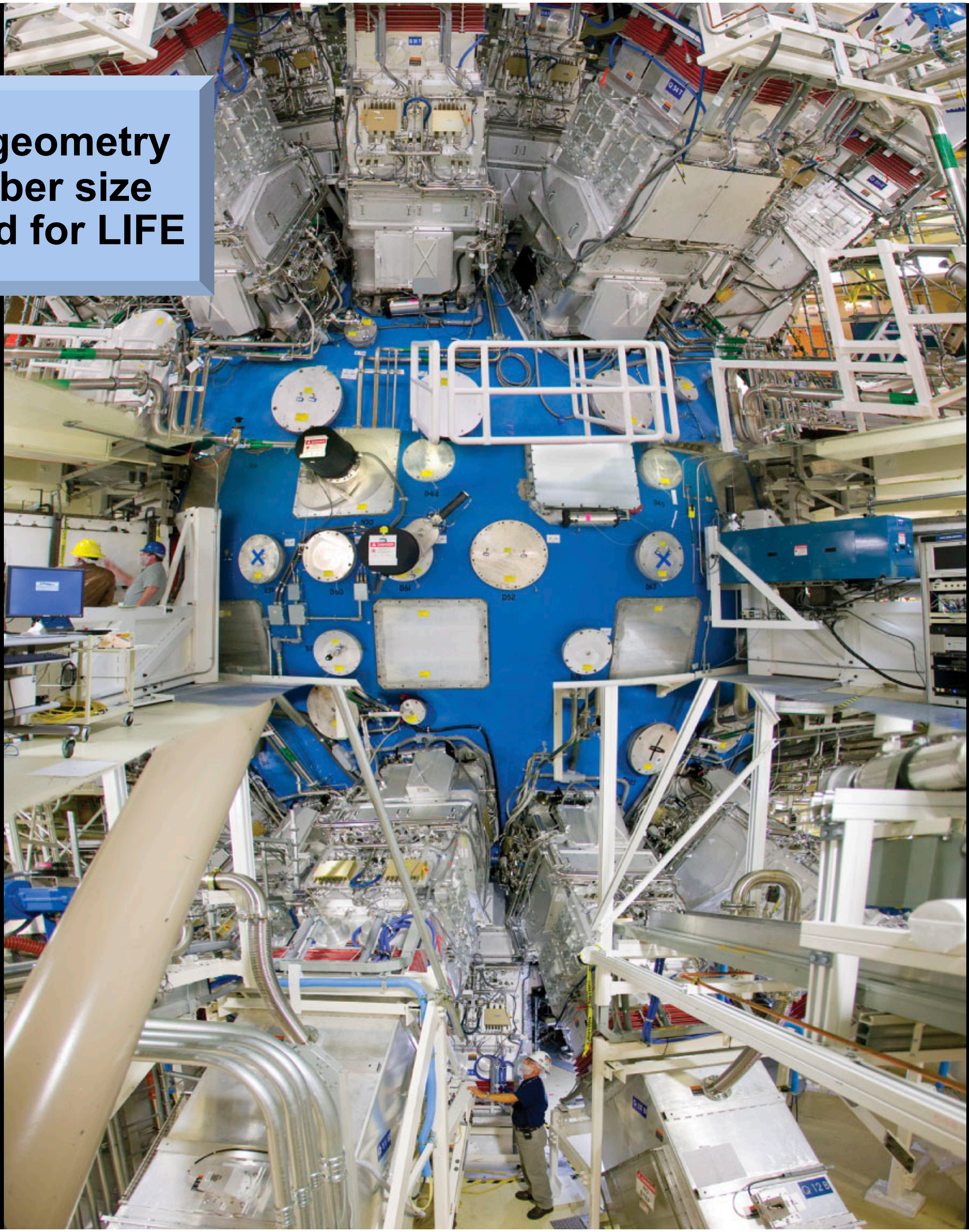
NIF is the World's first Mega-Joule Facility — 1.3 MJ 3ω

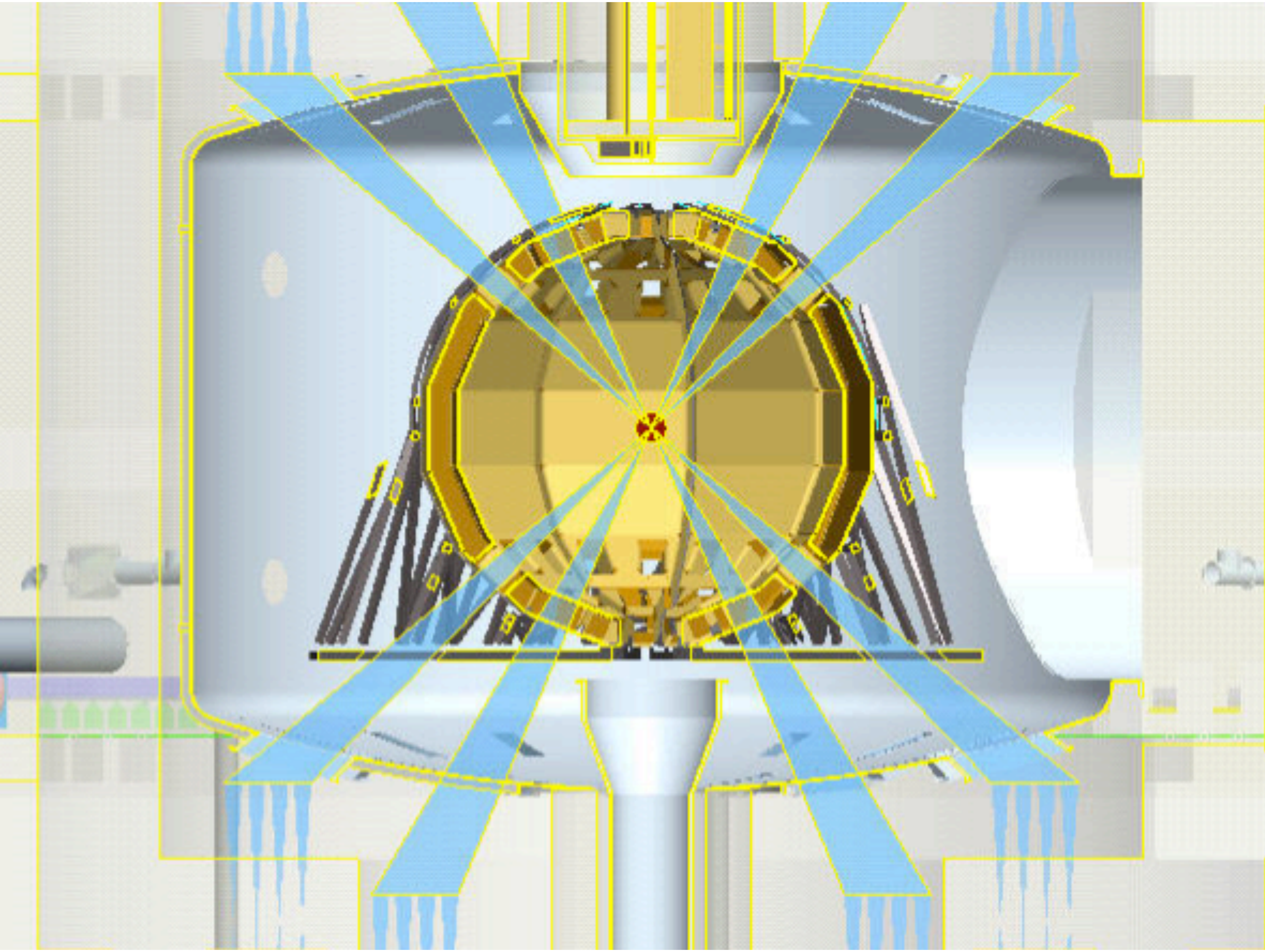


Cluster 4 | Cluster 3 | Cluster 2 | Cluster 1

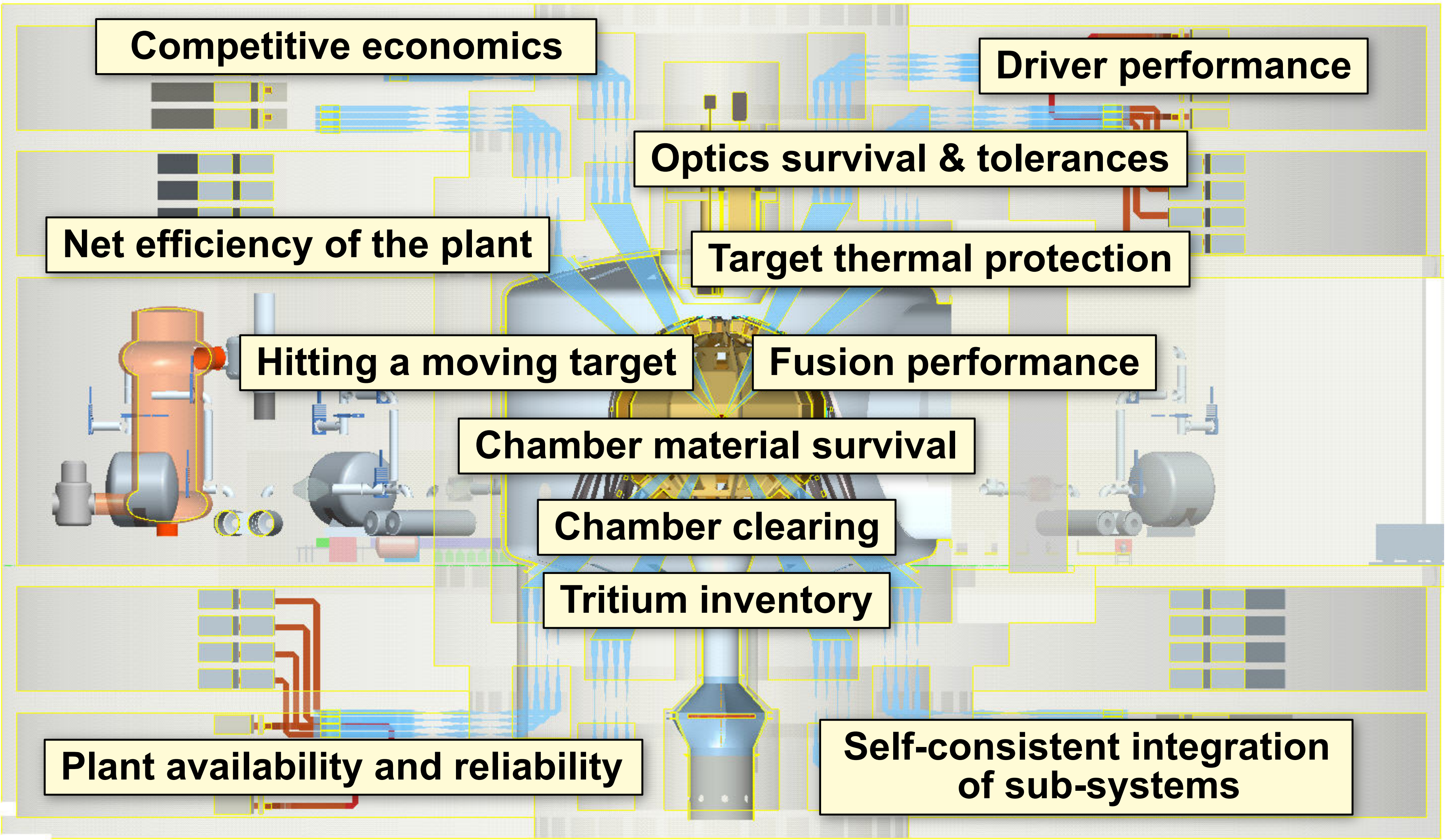

Rapid iteration of fusion targets permits design optimization

NIF beam geometry and chamber size will be used for LIFE



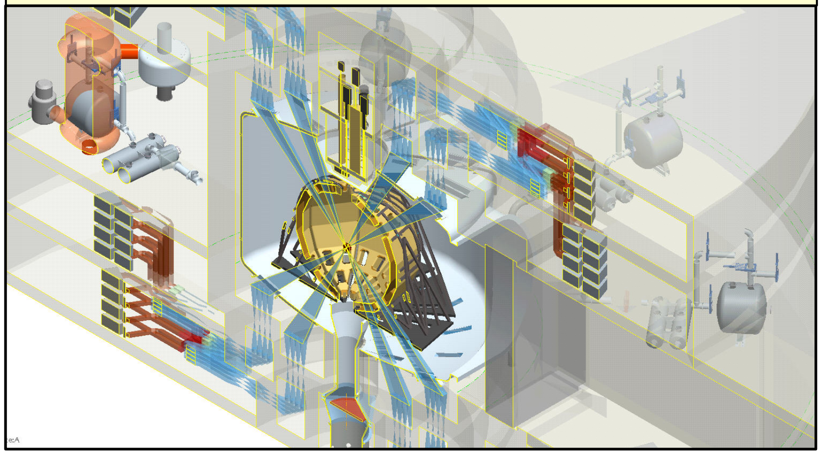


The LIFE design addresses the long-standing science and technology challenges for IFE

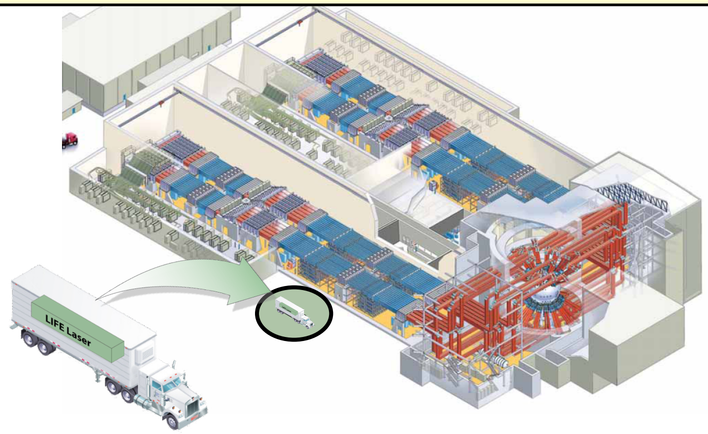


The LIFE design addresses the long-standing science and technology challenges for IFE

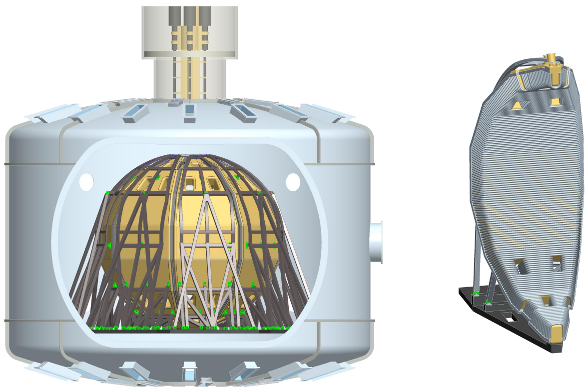
Modular, accessible architecture for high plant availability



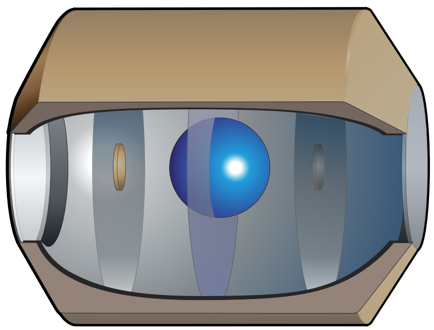
Compact, affordable, efficient diode-pumped laser system



Replaceable, unsealed chamber using conventional materials

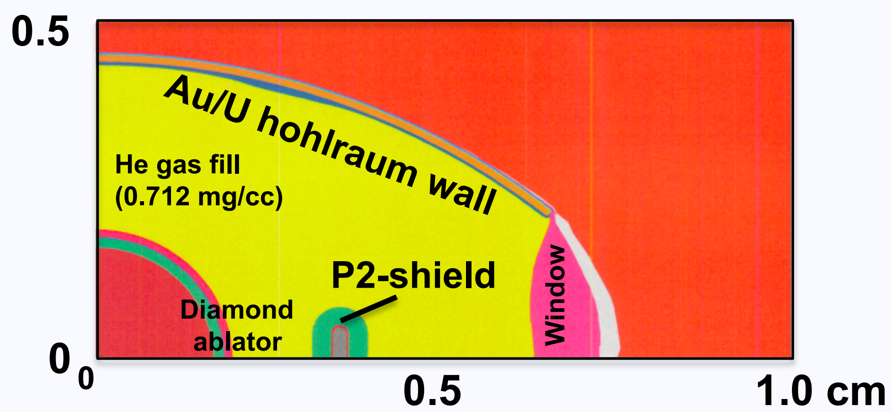


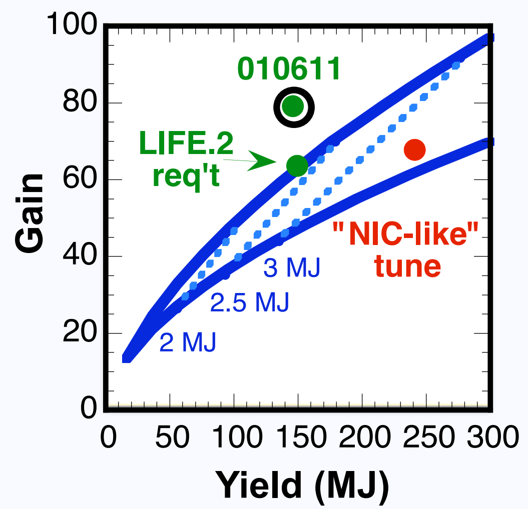
NIF-based fusion performance, with low tritium inventory in the plant



LIFE target design is based on NIC methodology, testable on NIF, based on conservative calculations

Requirement: Gain 60 for laser energy of 2 ± 0.2 MJ





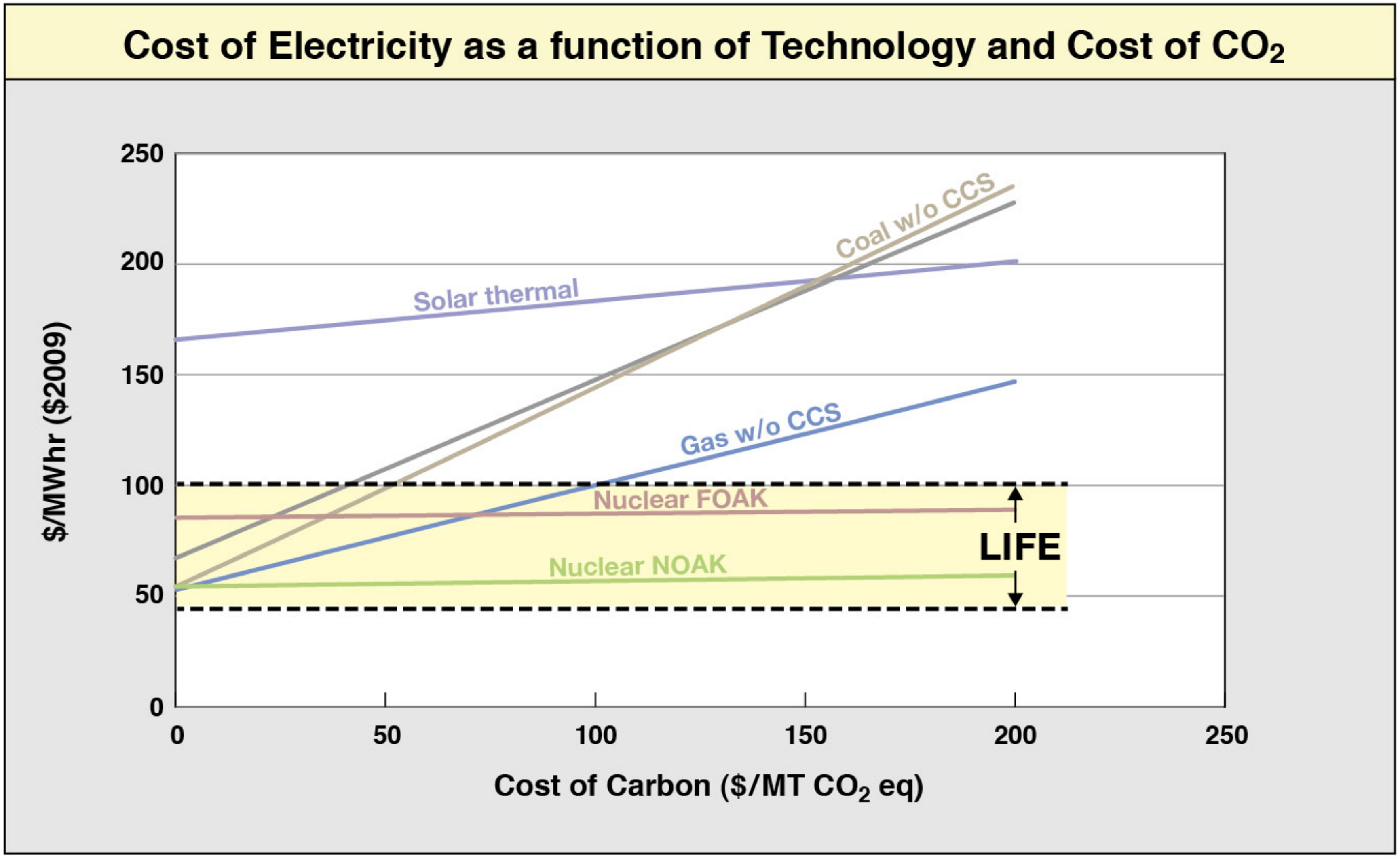
- Calculate gain 80-90 at 1.8 MJ laser energy, with ~30% fuel burn-up
- This will be reduced due to non-idealities (hohlraum material, capsule manufacture, instabilities)
- P2-shields also protect DT ice layer from IR heating, and protect the chamber from direct line-of-sight damage from alphas
- The target is completely unclassified, and leverages over 1000 FTE-years of development effort and ongoing demonstrations by multiple programs

LIFE has been designed to put electricity on the grid, based on a single-facility commissioning pathway

- **The commissioning plan for an "at-scale" high average power fusion facility can be undertaken directly on a First-Of-A-Kind power plant**
- **Ability to operate at low damage rates provides an intermediate power route to performance demonstration and market entry**
- **The RD&D plan is very closely integrated into the plant design activity**
- **Design features:**
  - — Direct implementation of an at-scale ignition solution
  - — Market-based technology (e.g. semiconductor vendors now offer a low cost diode solution)
  - — Gas protected "boiler" design mitigates debris and x-ray threats, allowing use of conventional materials and standard manufacturing techniques
  - — Modular "Line Replaceable Unit" architecture for all life-limited components delivers high plant availability and maintainability
  - — Low Tritium inventory and high margin for blanket performance
  - — System-wide optimization removes the need for "advanced" plasma concepts

LIFE economics are competitive

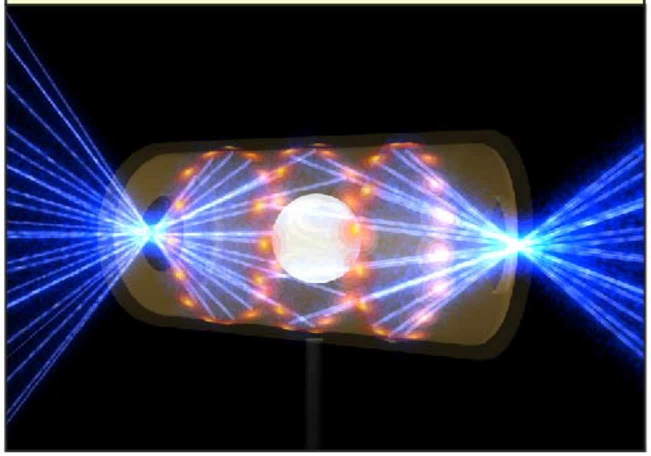
Nicholson et al, Energy (2010)



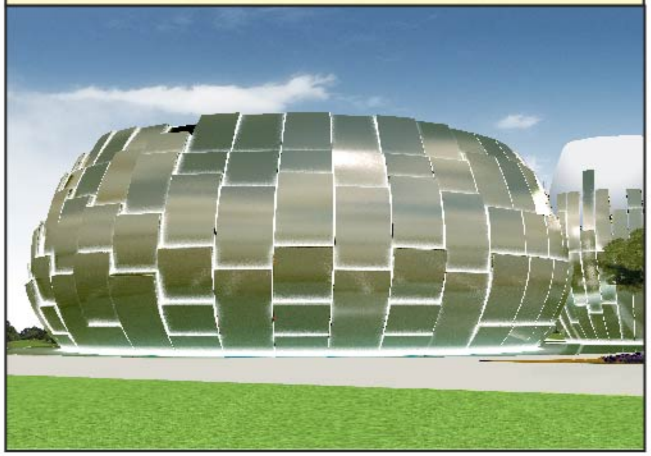
LIFE delivery timescale

NIF completion 2009

NIF ignition 2011/2012



LIFE demonstration 2020's



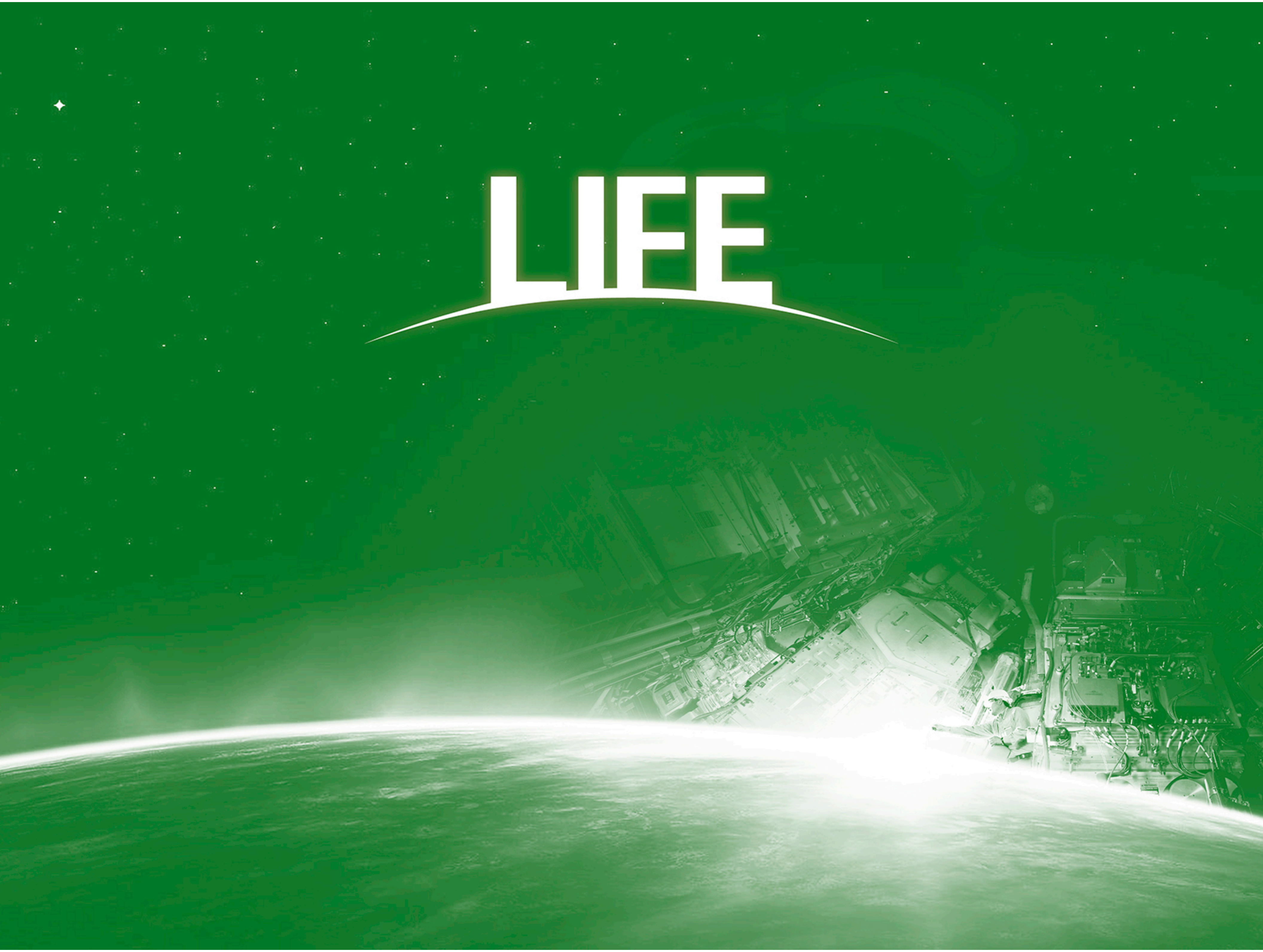
LIFE commercial 2030's

Conclusions

- **IFE delivery must address the primary criteria set by the power industry**
  — LIFE is being guided by a group of Utility CEOs and the vendor industry
- **Uncertainties in plasma physics mandate the use of demonstrated capsule performance, and adoption of the tested driver geometry and characteristics**
- **Strong coupling between sub-systems mandates an integrated facility approach, and at-scale demonstration of power plant performance**
  — LIFE allows substantial cost, time and risk reductions to be achieved by commissioning within a facility upwardly-compatible with power plant operations
- **The LIFE solution leverages**
  — design, construction, operational and performance experience from NIF and a wide range of high average power laser systems
  — vendor guidance and market availability for key technologies
  — a single-step to commercial plant operation
  — international expertise and investment in LIFE-compatible technology (e.g. European down-selection to DPSSL architecture)

The ICF community has a common viewpoint [Mary Hockaday et al]

- Demonstration of laboratory ignition will establish that the physics underpinning IFE exploitation is fundamentally sound.
- IFE is a field in which the US is a clear world leader – academically, technologically and industrially.
- We have an opportunity to capitalize on this leadership position over the next few years and leverage prior substantial defense program investment.
- Recent action by the DOE to propose a new IFE development program and secure a stable home for IFE is timely and very welcome.
- Moving forward, the IFE program needs to focus on the requirements of an operating power plant, with design choices managed at a systems-level.
- The inherent modularity and separability of IFE provides significant benefits when considering power plant development, operations and evolution.
- Taking advantage of significant prior research, future development activities in this program need to include IFE scale science and technology development and demonstration.
- IFE is a national scale program requiring a coordinated effort by academic, Laboratory, and industrial partners.
- A phased program with competition and unambiguous selection criteria is needed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