Overview of NIF and the LIFE Power Plant

Symposium on Fusion Engineering

June 27, 2011

Mike Dunne et al, LLNL

with contributions from
LLE, GA, LANL, U Wisc, U Illinois, UCSD, PPPL, NPS, SRNL, Parsons Engineering

NIF is now operational

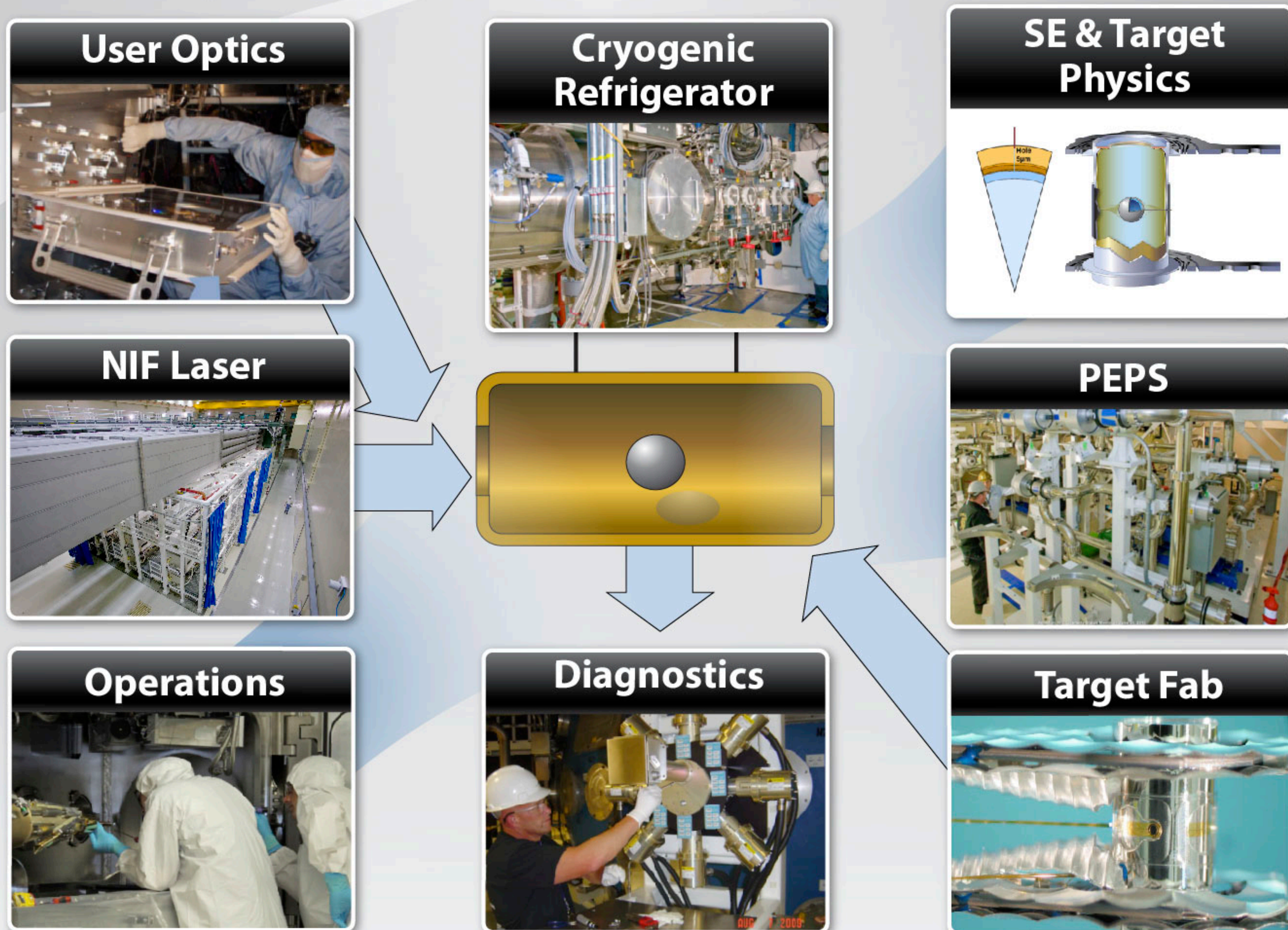
This is the largest scientific construction project successfully completed by DOE

Our NIF Team won PMI Project of the year!

"The National Ignition Facility is a stellar example of how properly applied project management excellence can bring together global teams to deliver a project of this scale and importance efficiently"

- Gregory Balestrero, president and chief executive officer of PMI

All the elements are in place for "integrated ignition experiments"



Shield Door Installation

Tritium Processing

CryoTARPOS

National Ignition Campaign

NNSA
National Nuclear Security Administration

GENERAL ATOMICS

UR LLE

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

MIT

AWE

cea

NSTec

BERKELEY LAB

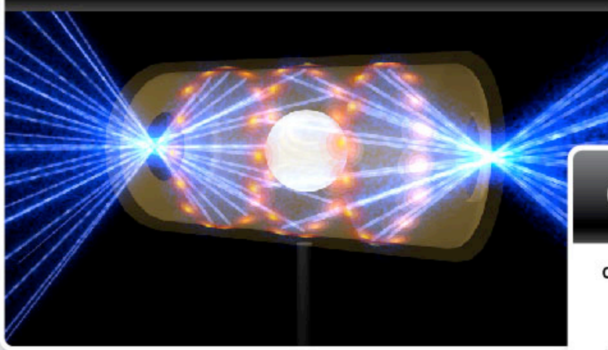
Duke UNIVERSITY

Four steps to ignition

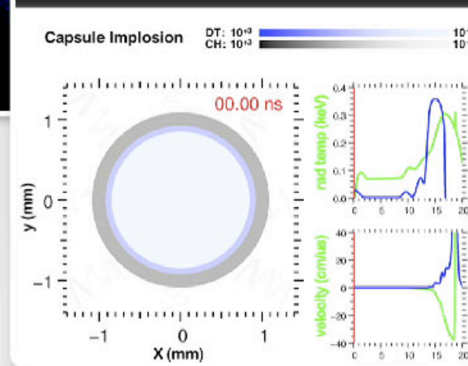
We are taking a systematic approach to learning and improving our engineering design to achieve ignition

Commission laser

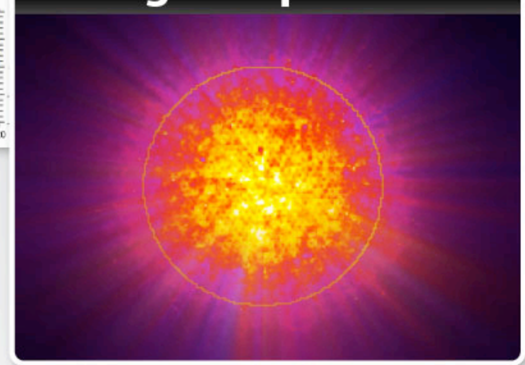
Commission hohlraum



Commission capsule



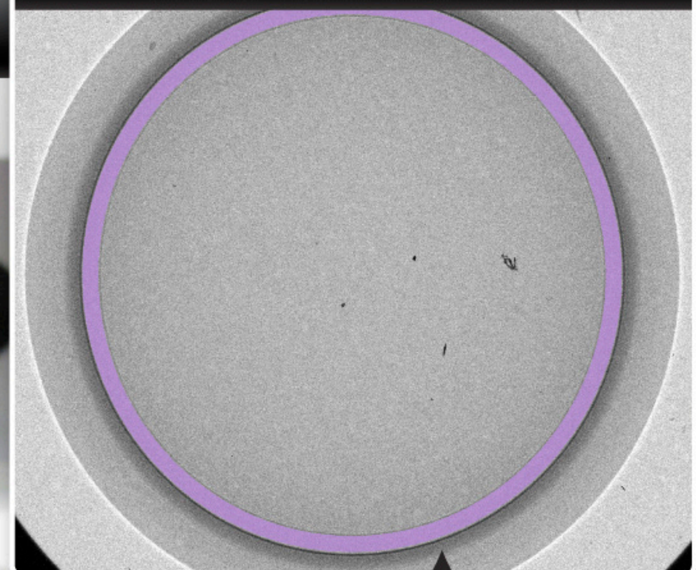
Commission layered target implosions



On September 29, 2010 NIC conducted the first cryo-layered target experiment on NIF

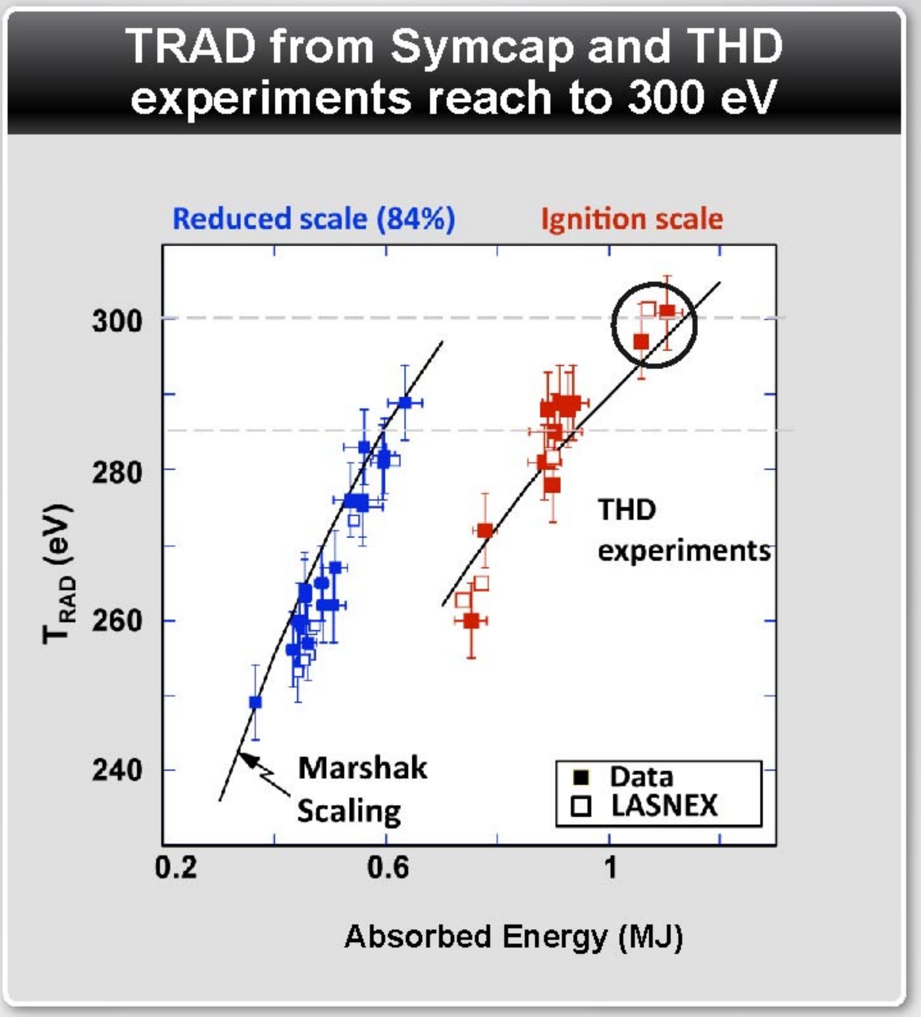
Target before the shot

View of target from laser entrance hole

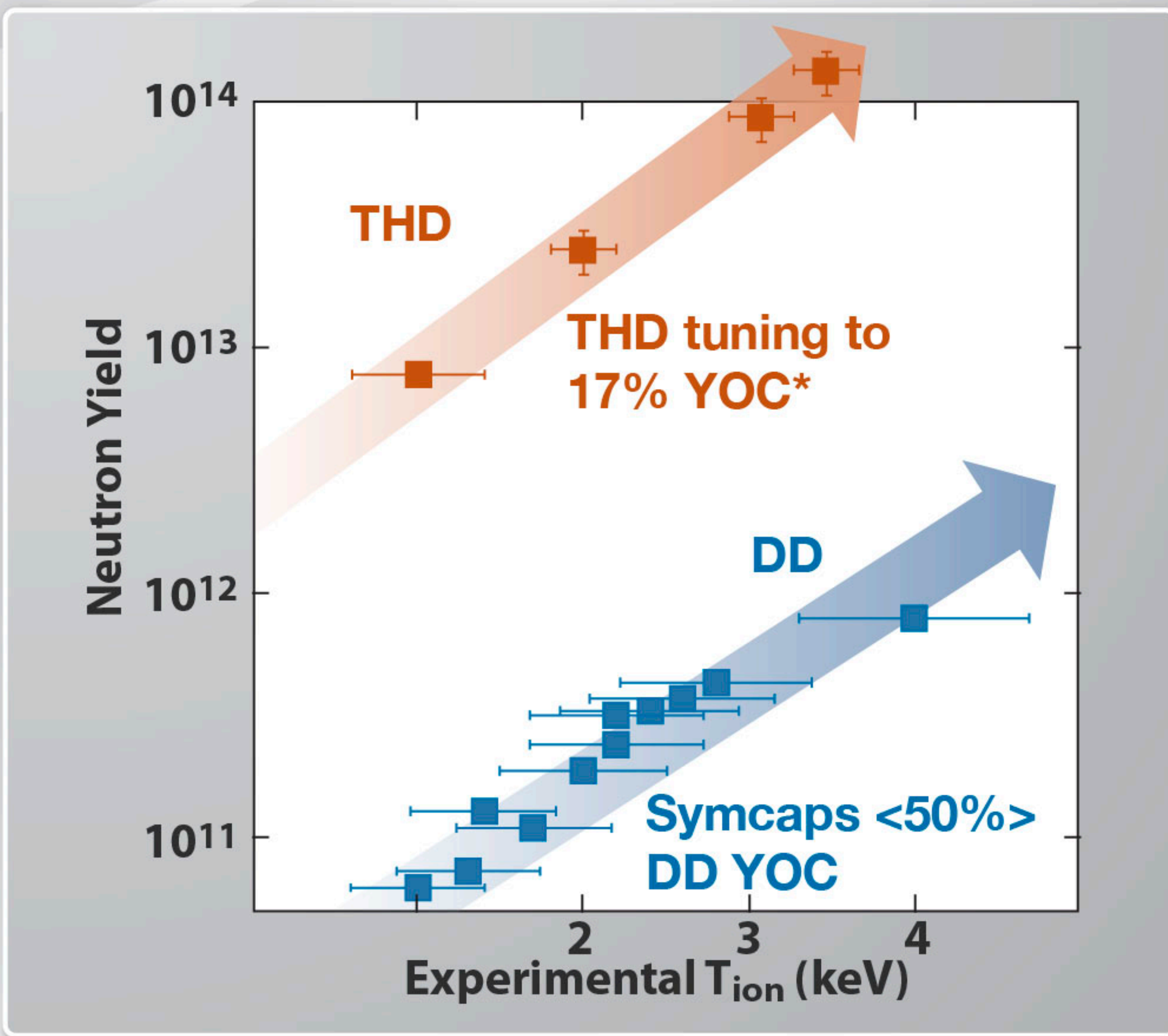


"Cryo THD ice layer" at ~19 deg K

Ignition scale target temperatures have been demonstrated



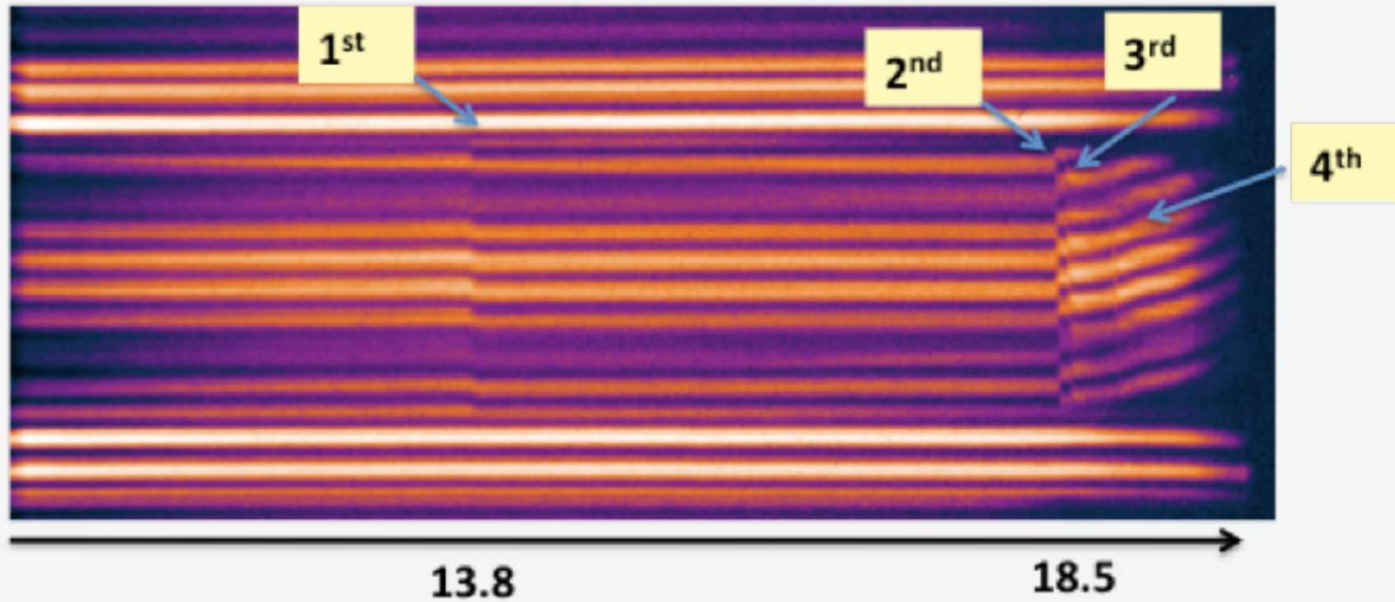
Implosion experiments are encouraging – achieved record neutron yield (~$2x10^{14}$n)



* Based on pre-shot calculation

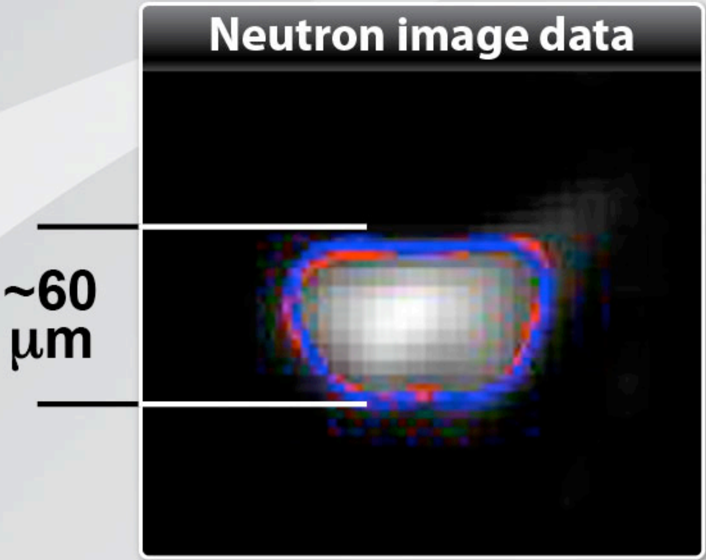
Precision shock timing experiments led to higher capsule compression in ignition experimental campaign

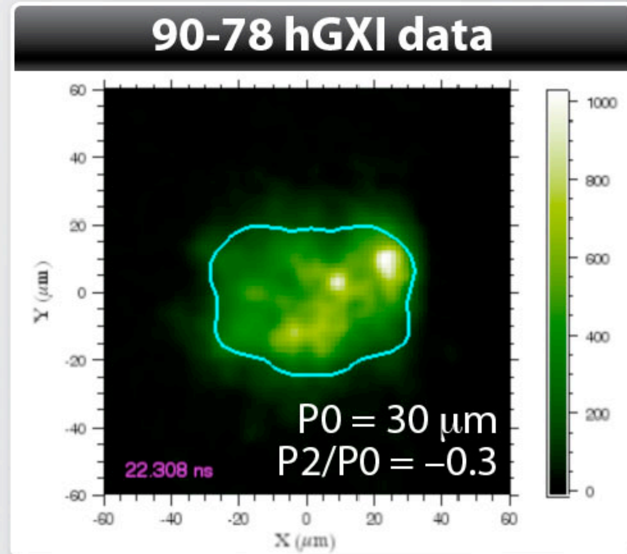
VISAR data for shock tuning

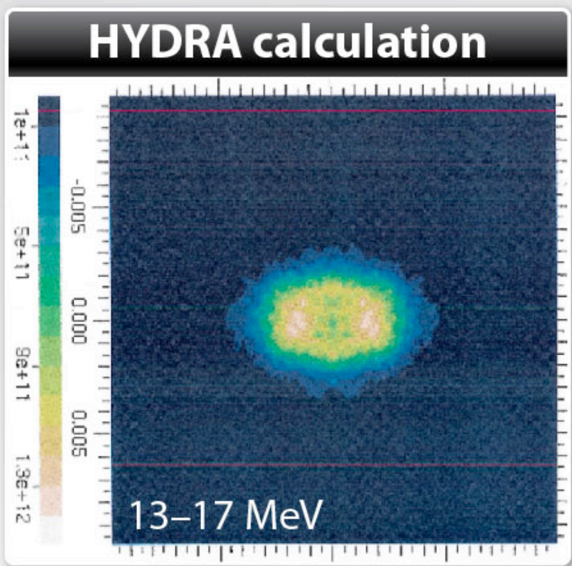


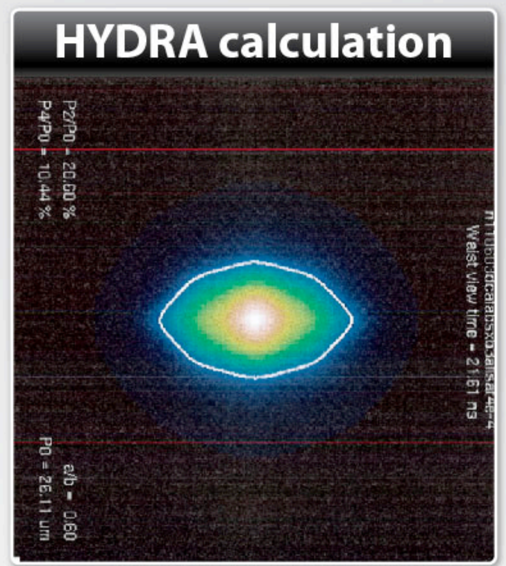
Compression for THD-5 shows 50% improvement over previous THD implosions

June 8, 2011: First 50/50 DT implosion—Neutron Imager data and x-ray emission show close similarity



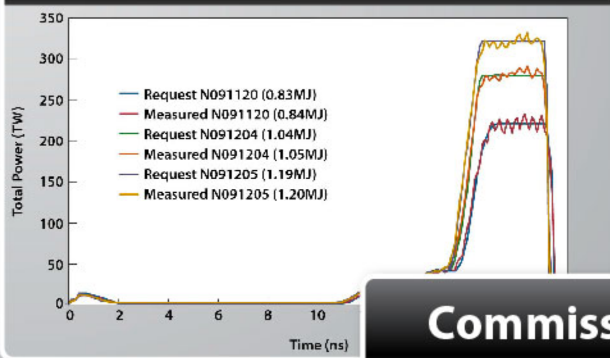




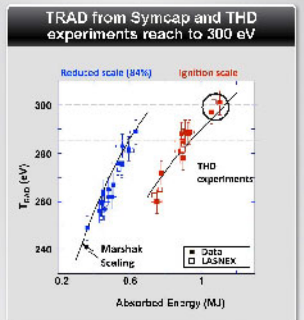


Ignition: Next steps: Work on velocity and shape!

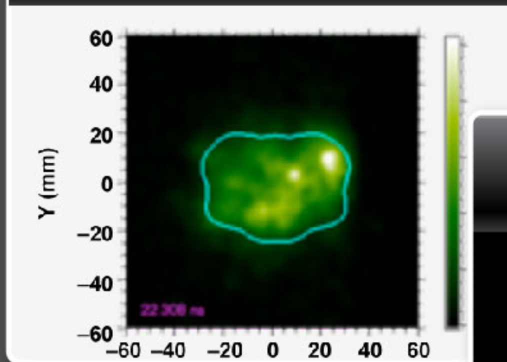
Commission NIF



Commission hohlraum

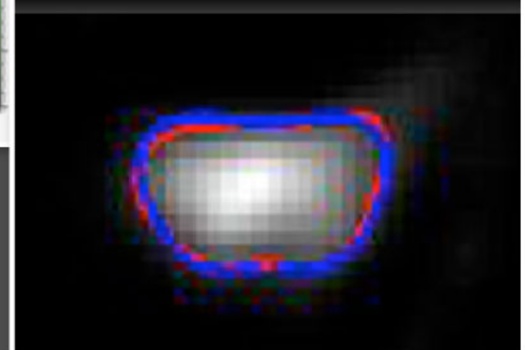


X-ray image

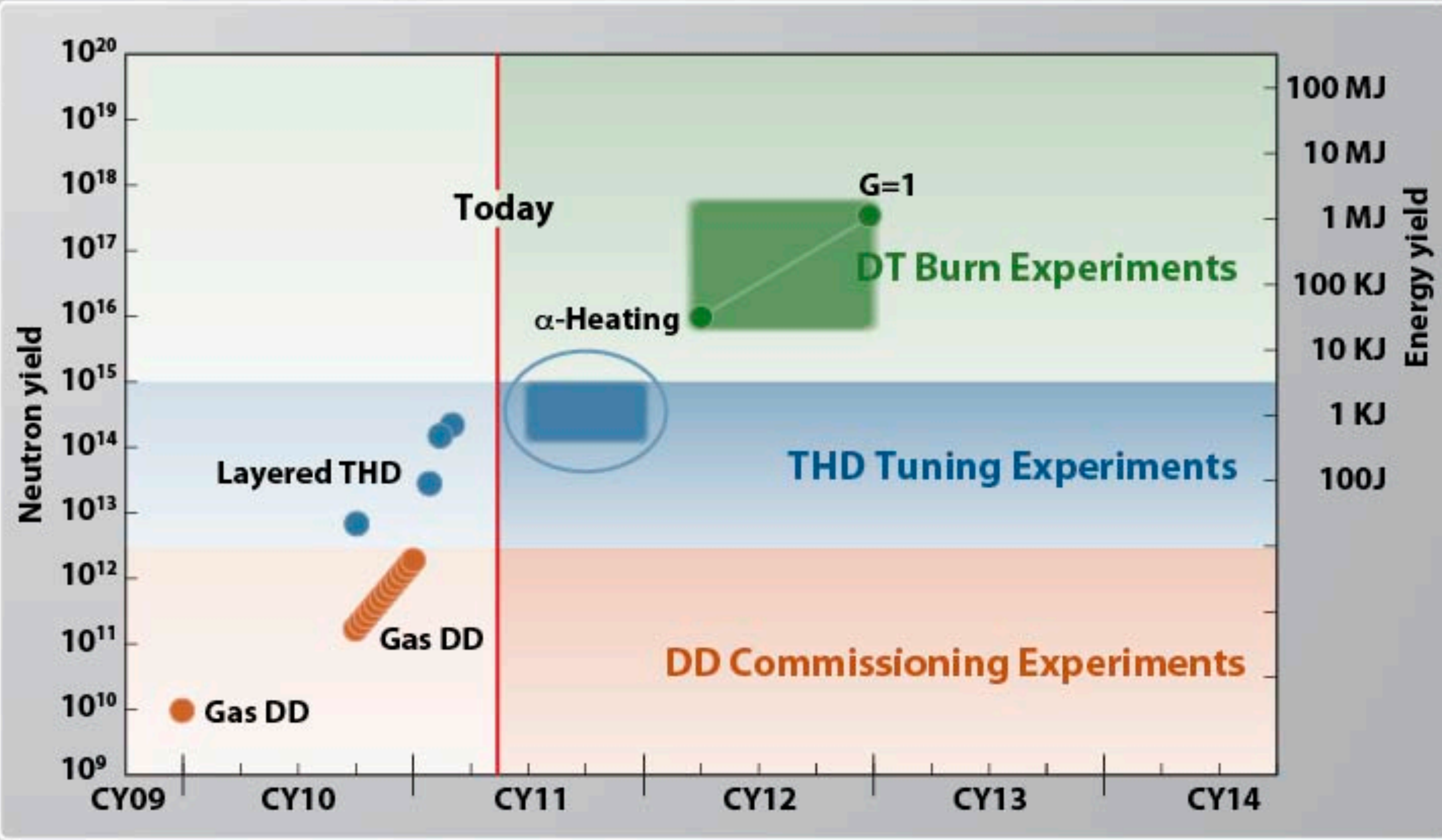


Underway

Neutron image



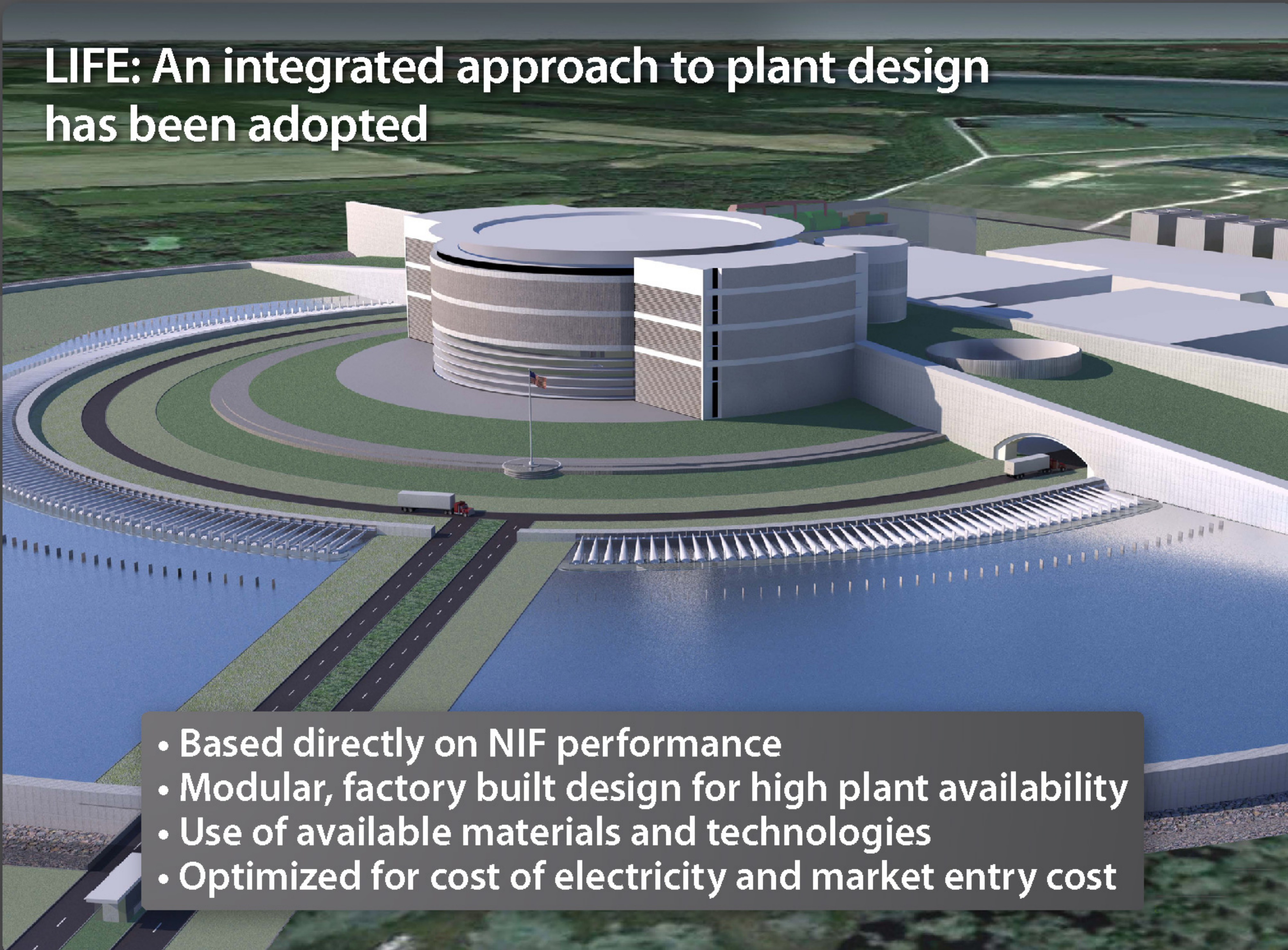
Ignition playbook — fall/winter heating goal



15EIM/mlm • NIF-0511-21970s1 L6

NIF can demonstrate full-scale performance for a power plant based on Laser Inertial Fusion Energy (LIFE)

LIFE: An integrated approach to plant design has been adopted



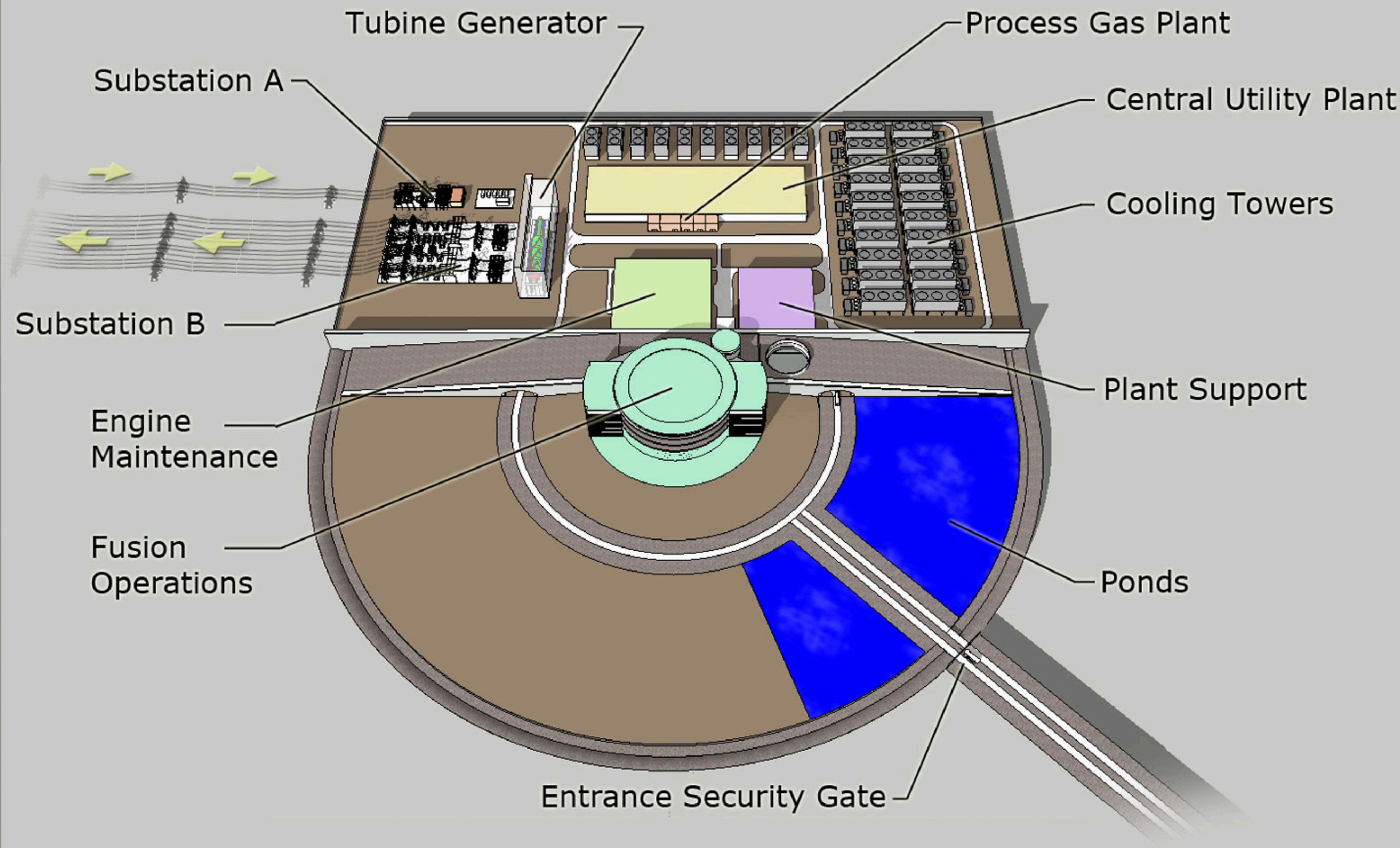
- Based directly on NIF performance
- Modular, factory built design for high plant availability
- Use of available materials and technologies
- Optimized for cost of electricity and market entry cost

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
Mid-American Energy Company
Wisconsin Energy
Nuclear Management Company
Constellation Energy
Dominion Generation
Exelon Generation Company
Southern California Edison

Plant Primary Criteria (partial list)
Cost of electricity
Rate and cost of build
Licensing simplicity
Reliability, Availability, Maintainability, Inspectability (RAMI)
Higher capacity credit and 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

Single LIFE plant

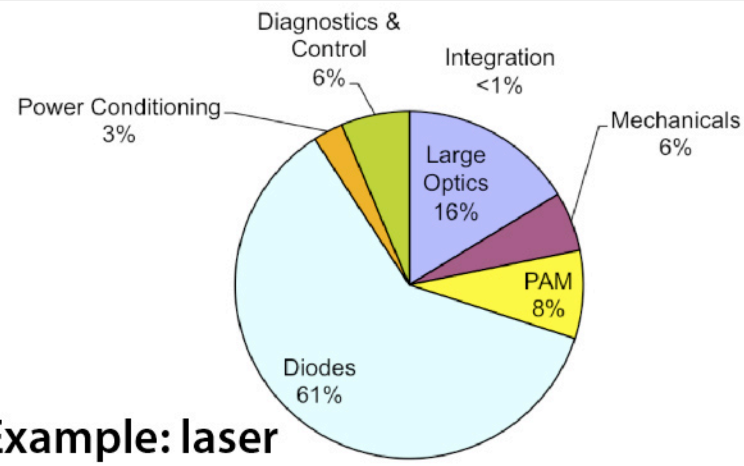


A detailed cost and economics model was iterated with the technology performance assessment

Economic factors

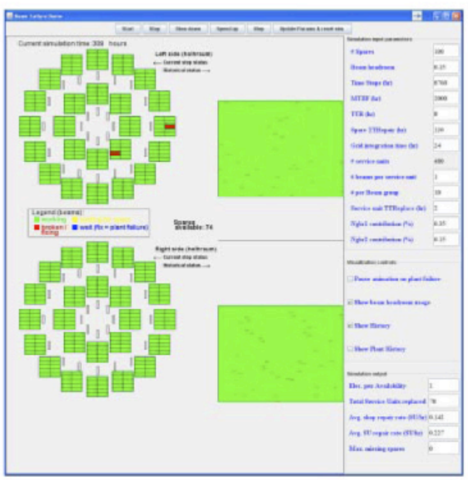
Capital cost
Availability
Reliability
Maintainability
Fuel/consumable costs
Licensing
Supply chain
Environmental cost
Time to market

Capital cost areas

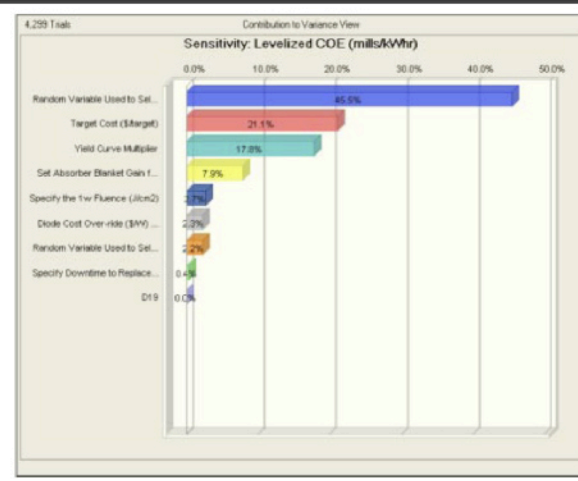


Example: laser

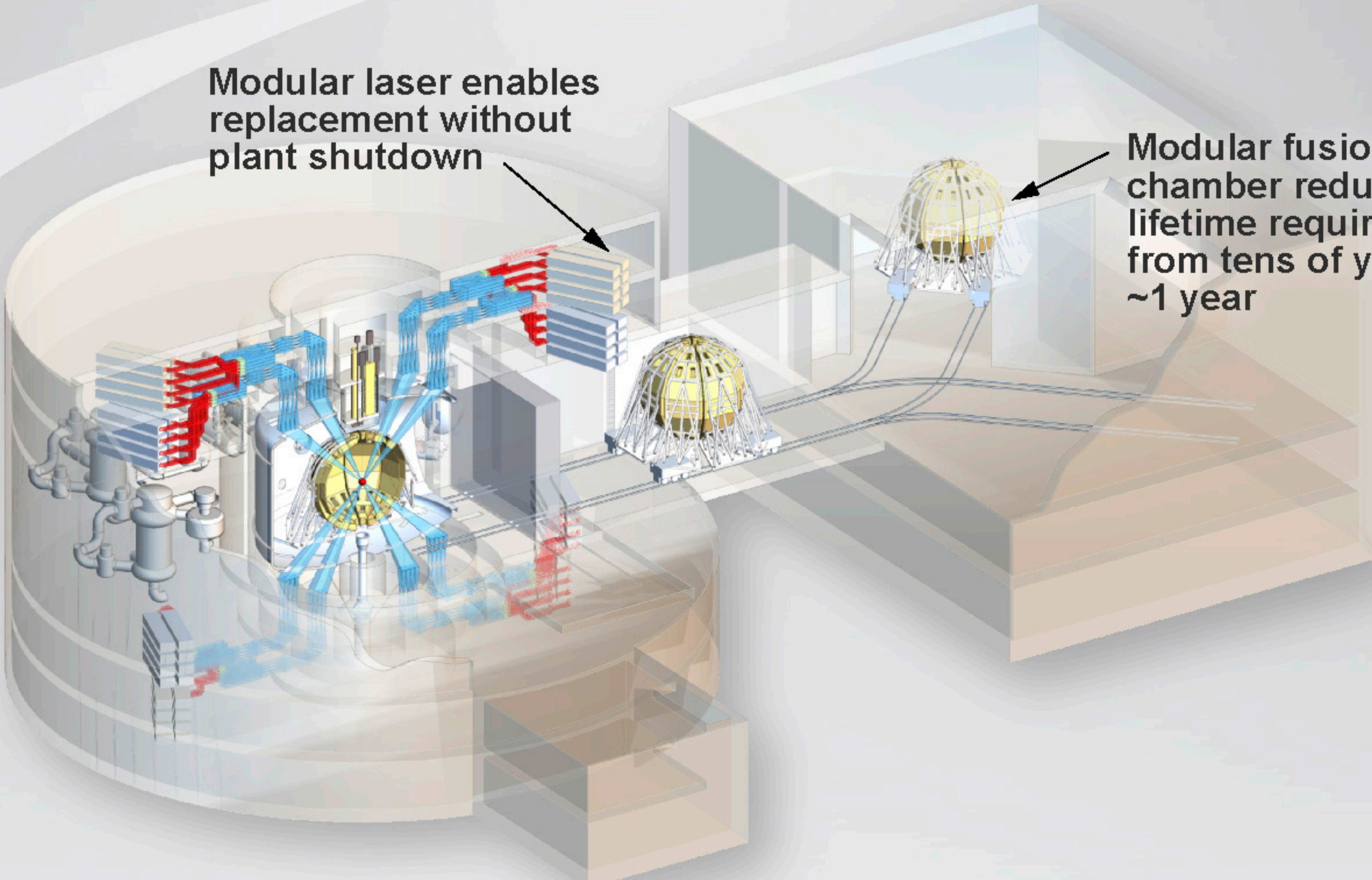
Monte Carlo availability



Technology investment impact



LIFE's modular architecture is what enables commercialization in a relevant timeframe

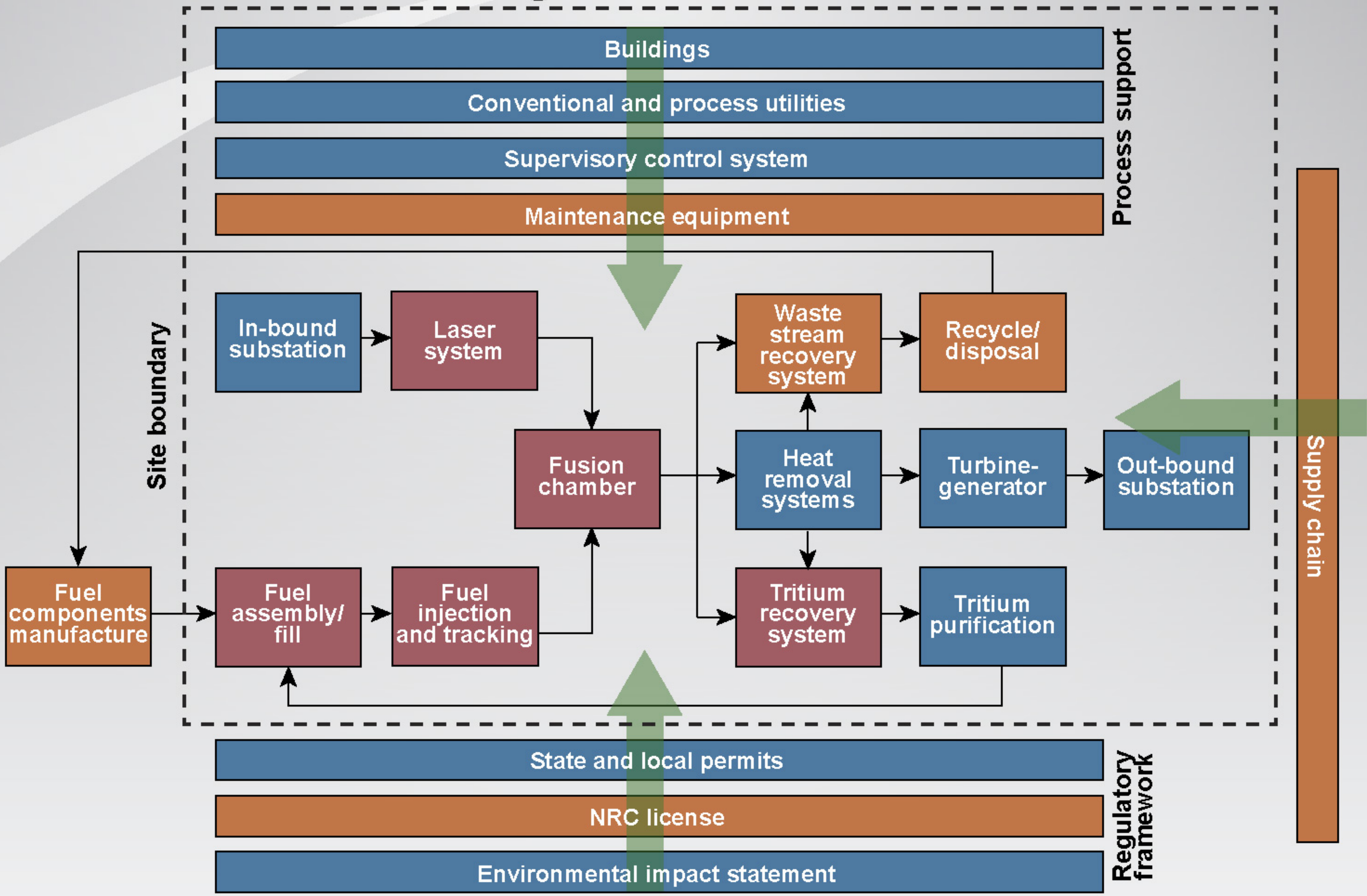


Pilot plant fusion chamber can use conventional FM steel rather than wait for new radiation resistant alloys to be developed

High availability using hot-swappable components was demonstrated on AVLIS

AVLIS maintained long-term (10 year) 24/7 operation at 99% availability with 1500 hr MTBF line replaceable units (LRUs)

Delivery plan scope is tailored to readiness of constituent technologies



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

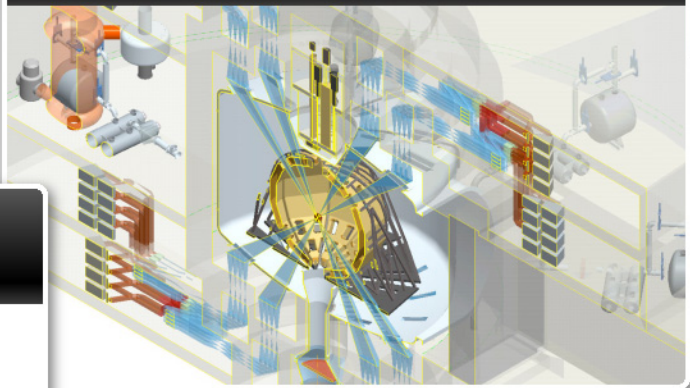
Polishing & Figuring

Coating

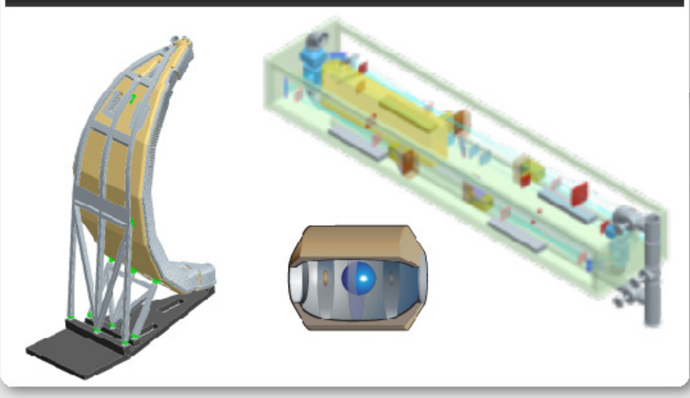
LIFE delivery plan details staged progression to retire risk in each of the key sub-systems

400 – 1500 MWe plant rollout

Pilot Plant, 400 MWe electricity output



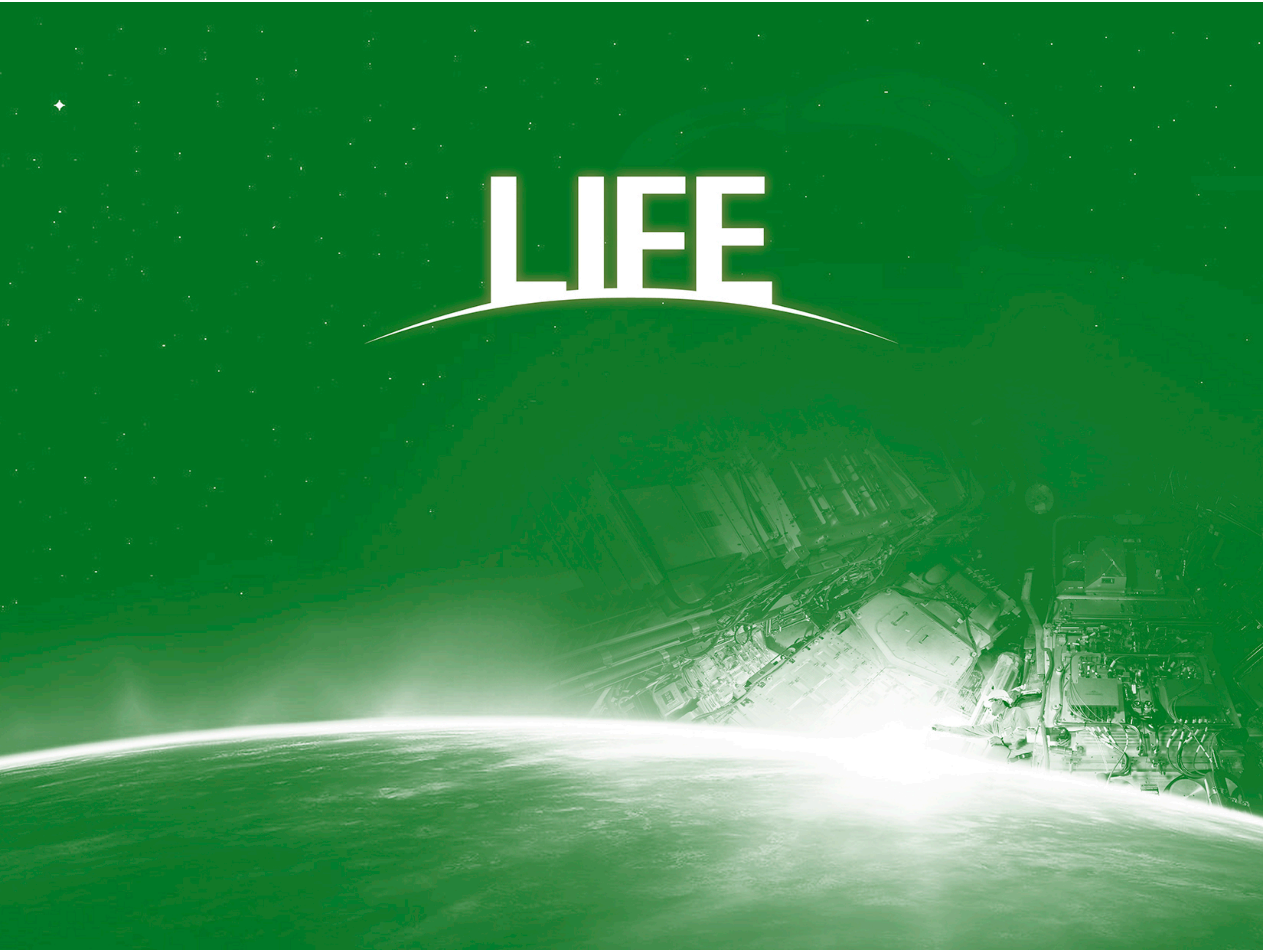
Component and Subsystem Level Demonstrations



Delivery plan based on 370-element Work Breakdown Structure, with 970 work statements and 185 milestones

Conclusions

- LIFE has been designed to address primary criteria set by the power industry
  - Guided by a committee of Utility CEOs, along with advice from vendors, environmental groups, licensing and manufacturing experts
  - Capital cost and Cost of Electricity look very competitive
- LIFE can deliver an operational, scalable plant by the 2020s
  - pragmatic use of modular, available technologies and materials
- The LIFE solution leverages
  - design, construction, operational and performance experience from NIF and a wide range of high average power laser systems
  - direct evidence of fusion performance – at full scale – on the NIF
  - market development of key technologies
  - international expertise and investment in LIFE-compatible technology

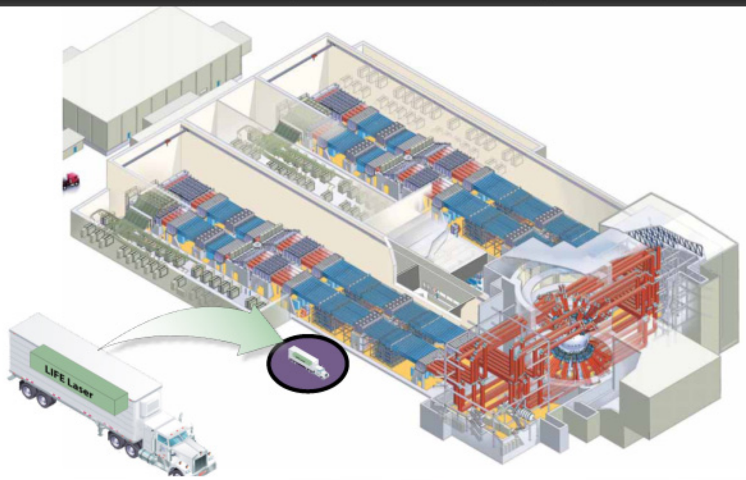

LIFE

LIFE box in laser bay

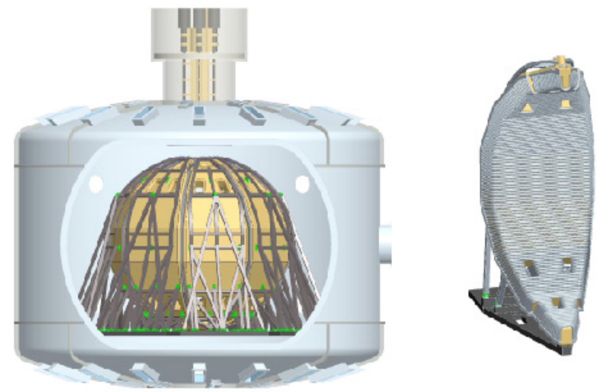
High repetition, 25 kW laser in operation

Alignment of technology development allows us to addresses the long-standing challenges for IFE

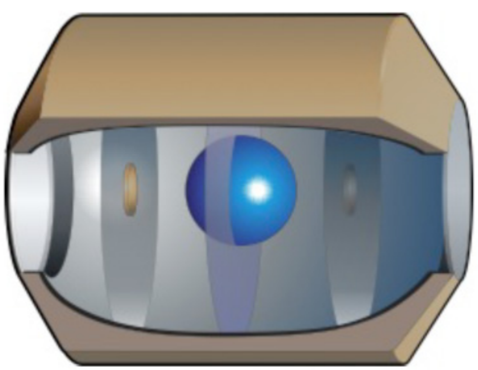
Compact, affordable, efficient diode-pumped laser system



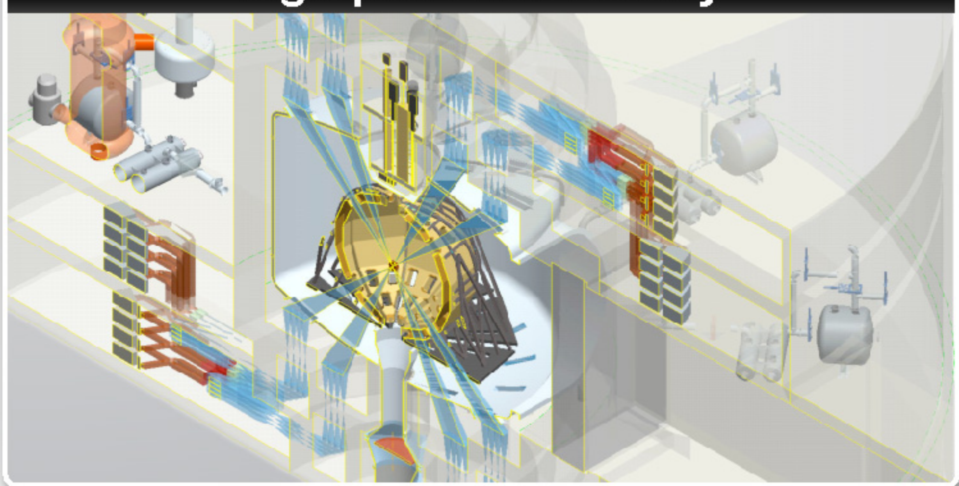
Conventional materials with very low tritium inventory



NIF-based fusion performance, amenable to mass manufacture



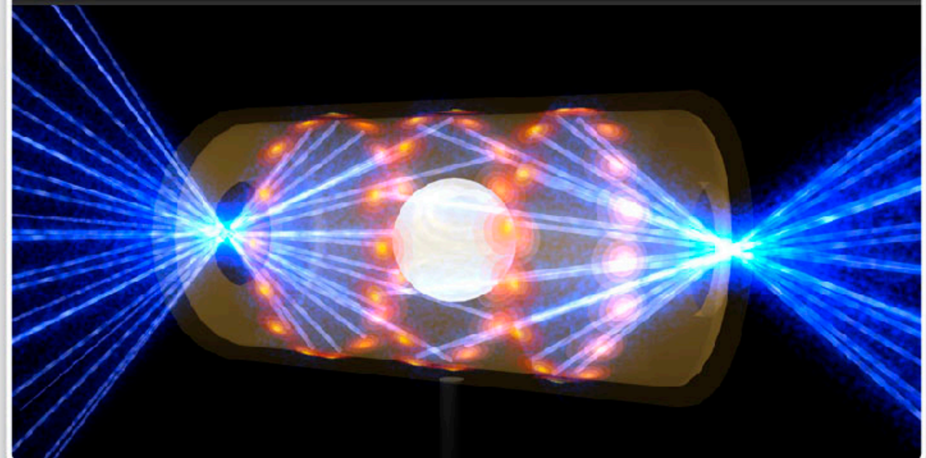
Modular, accessible architecture for high plant availability



LIFE builds on demonstrable science and technology

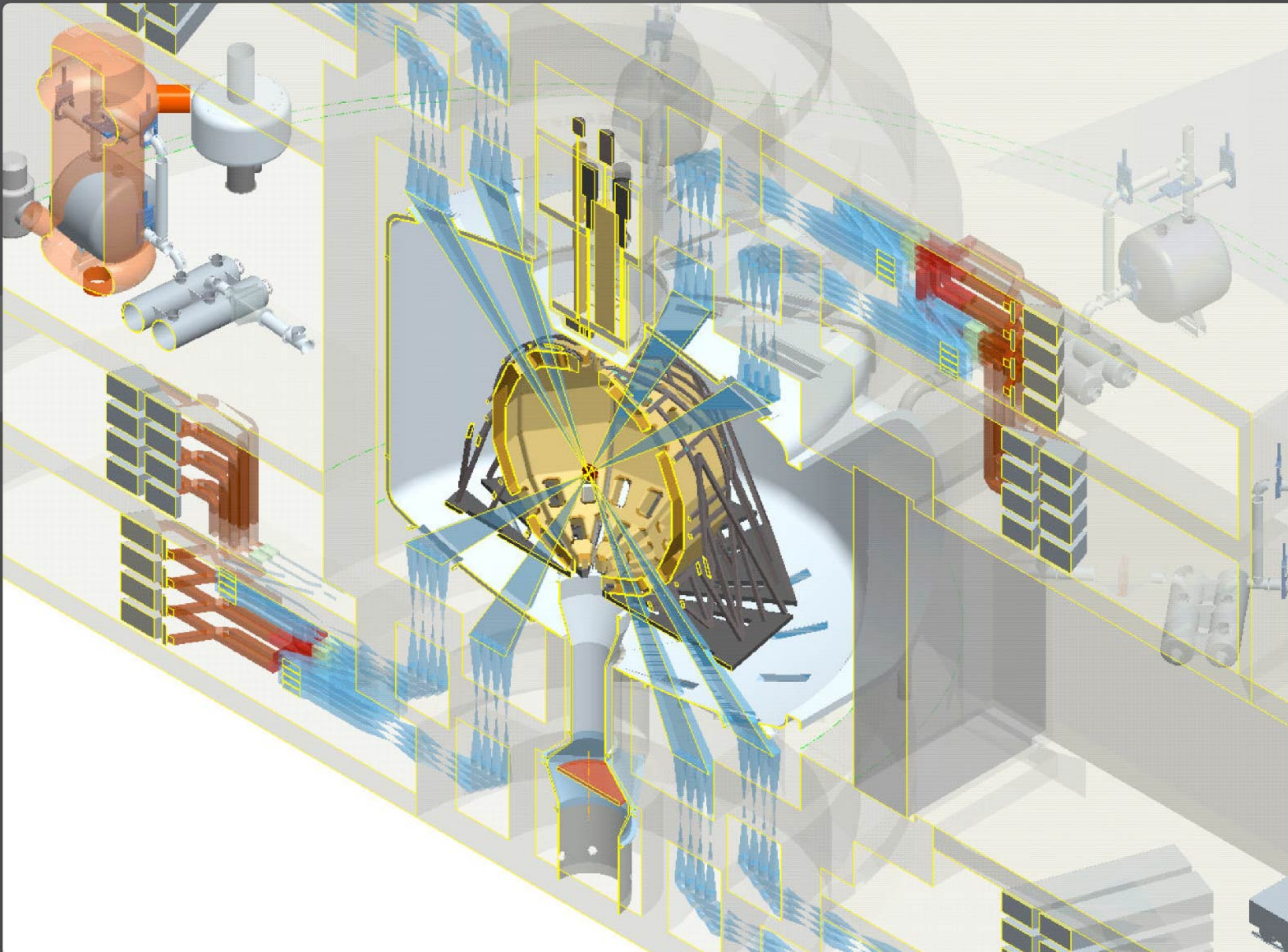
NIF completion 2009

NIF ignition 2012



First Of A Kind plant 2020's

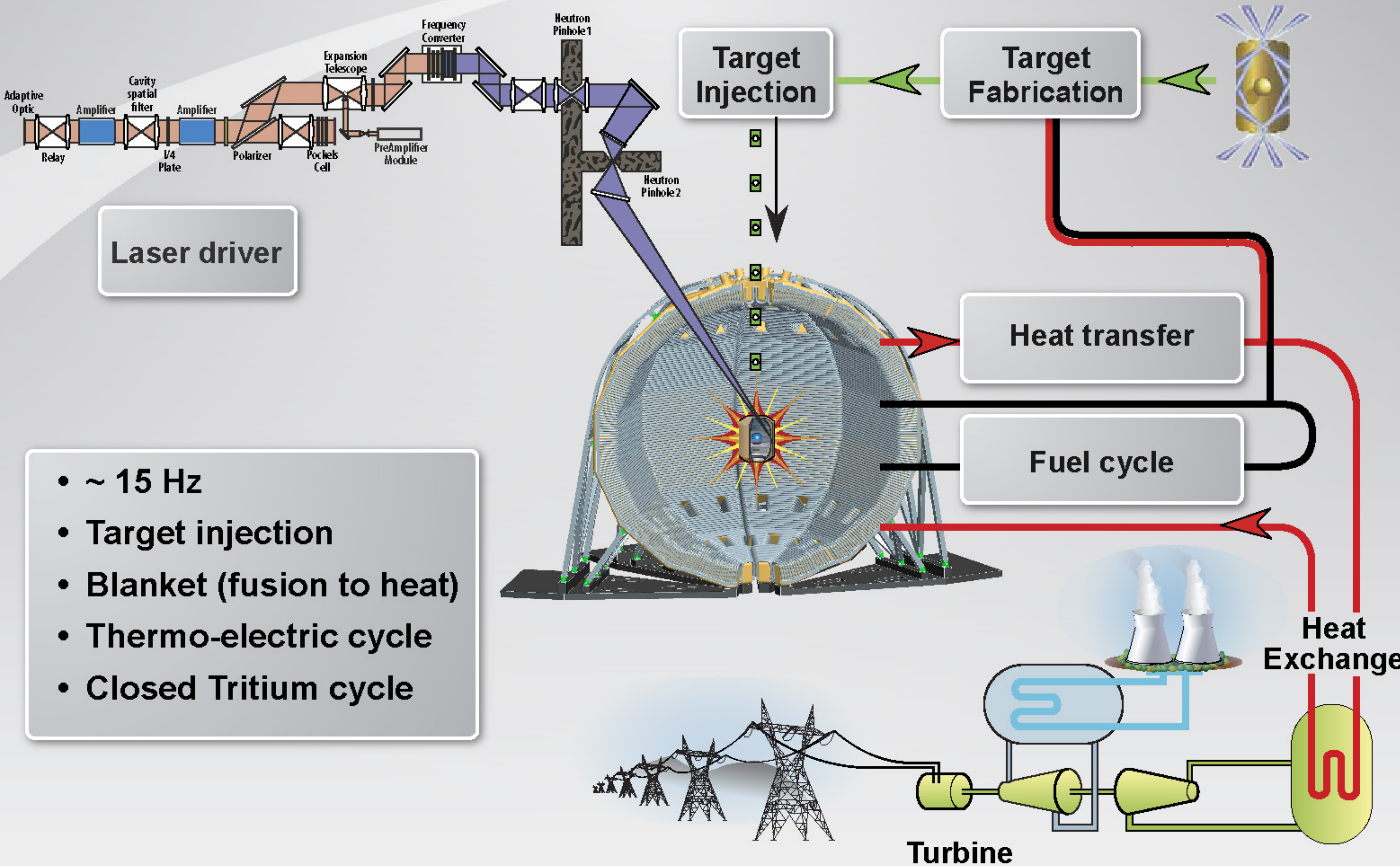
Market penetration 2030's



Foundational principles of LIFE: IFE soon enough to make a difference

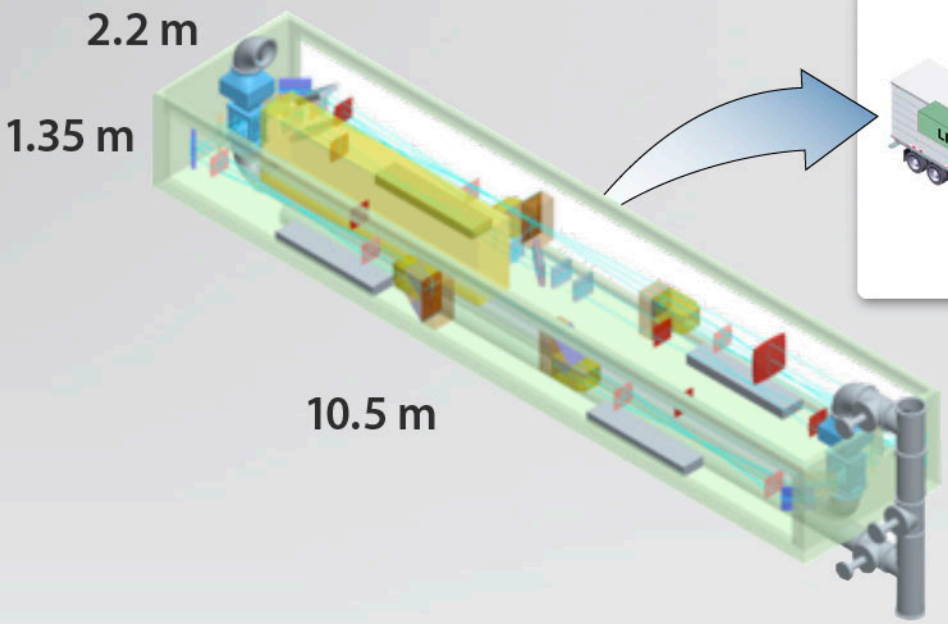
- Responsive to needs of the international energy/climate situation
- Based on the needs and considerations of the important stakeholders (utilities, environmental community, government, industry, etc.)
- Target physics can be fully demonstrated on the NIF
- System design enables very high availability with technologies that can, in principle, be procured today
- Cost targets are base on industrial scaling and commitments of major vendors and standard cost studies
- Separability of systems enables wide range of participants expert in all aspects of LIFE subsystem

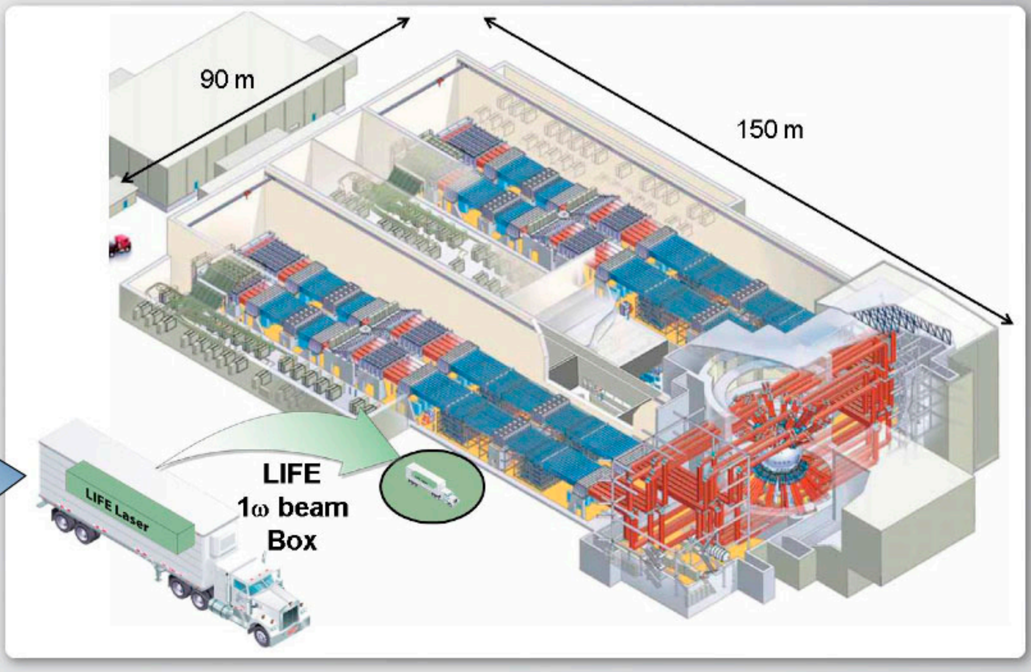
LIFE combines the "single shot" capability of NIF with the requirements for ~1000 MW electrical output



- ~ 15 Hz
- Target injection
- Blanket (fusion to heat)
- Thermo-electric cycle
- Closed Tritium cycle

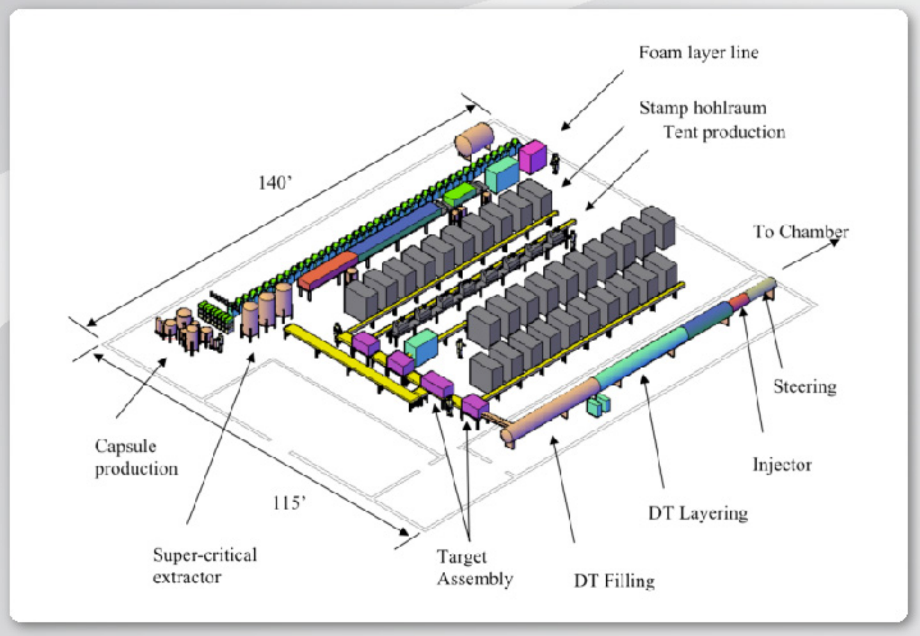
Each beamline folds into a transportable box, enabling an efficient & cost-effective supply chain



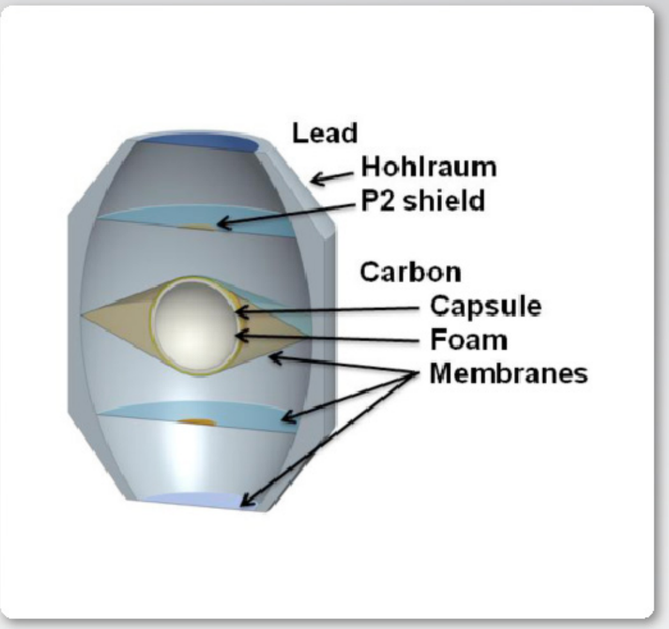


- **Offsite beamline factory**
- **Truck-shippable 1w beamline**
- **Low-overhead installation**
  - **Kinematic placement**
  - **Few interfaces**

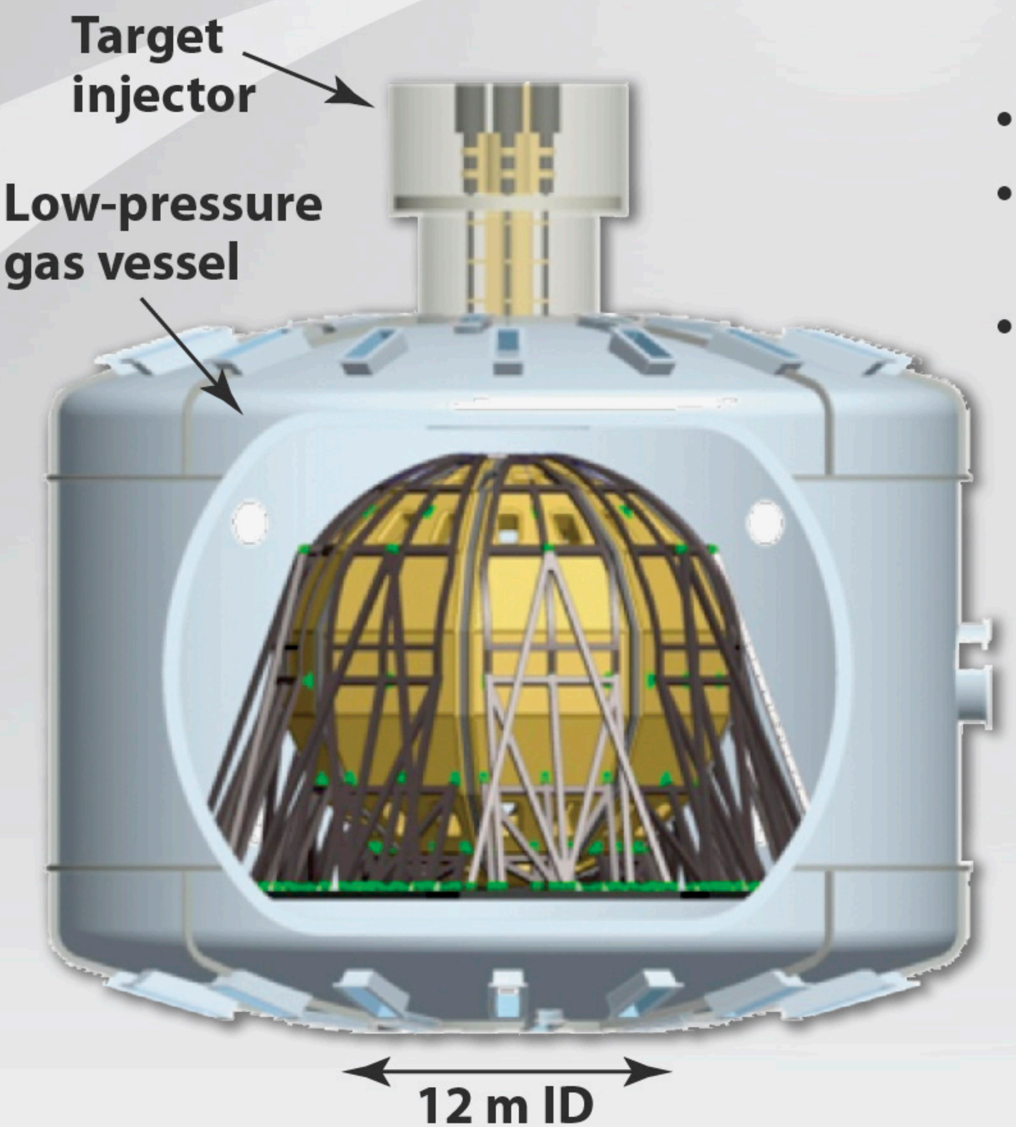
The fuel targets require mass manufacture (~1 million / day) at low unit cost (<$1 each)



- Use known high-throughput, low-cost manufacture techniques such as injection molding, plating
- Use large batch size for chemical processes
- Completely automated production line
- Statistical process control
- Approach based on consultation with relevant industrial suppliers



The LIFE "chamber" is an unsealed, segmented array sitting within a low pressure gas environment



- 6 m radius chamber lined with 10 cm diameter, 1 mm thick tubes
- Chamber is NOT the vacuum barrier
- Tubes provide excellent strength and superior cooling
- Tubes can be manufactured today via extrusion and flow forming

Extruded and flow formed ODS tubing (6")

Lithium coolant chosen to limit tritium to ~0.6 kg. Leverages large experience base in liquid metals.

LLNL has multi-decade experience in liquid metal technology from Atomic Vapor Laser Isotope Separation Program

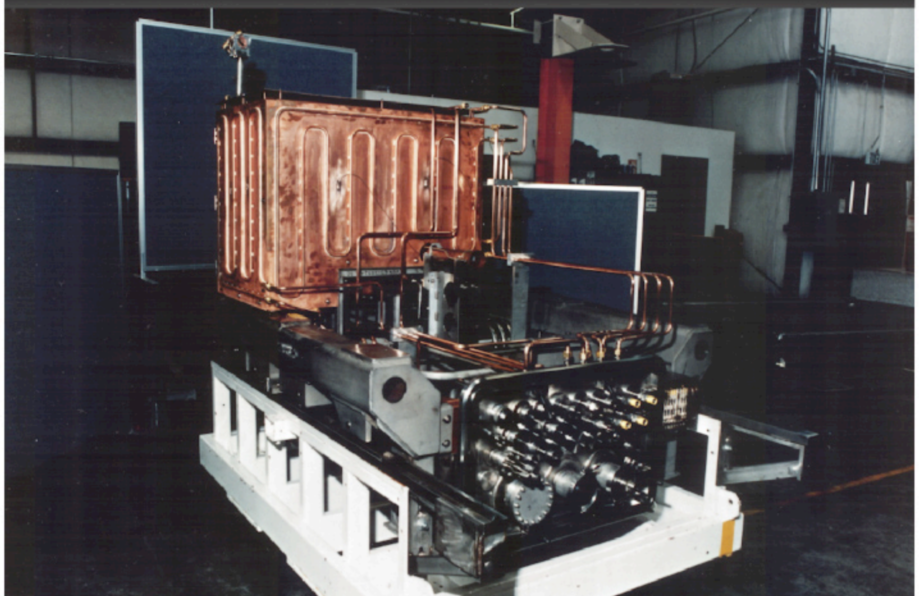


Photo: Plant scale uranium metal evaporator. Systems of this type were operated at metric ton levels of throughput. Program spanned roughly two decades.

EBR-II sodium-cooled reactor operated for 30 years at Idaho National Laboratory

- Generaged over two billion kW-hr of electricity
- Sodium-to-steam generator performance was exceptional
- EBR-II objective was achieved: sodium and water never came in contact during

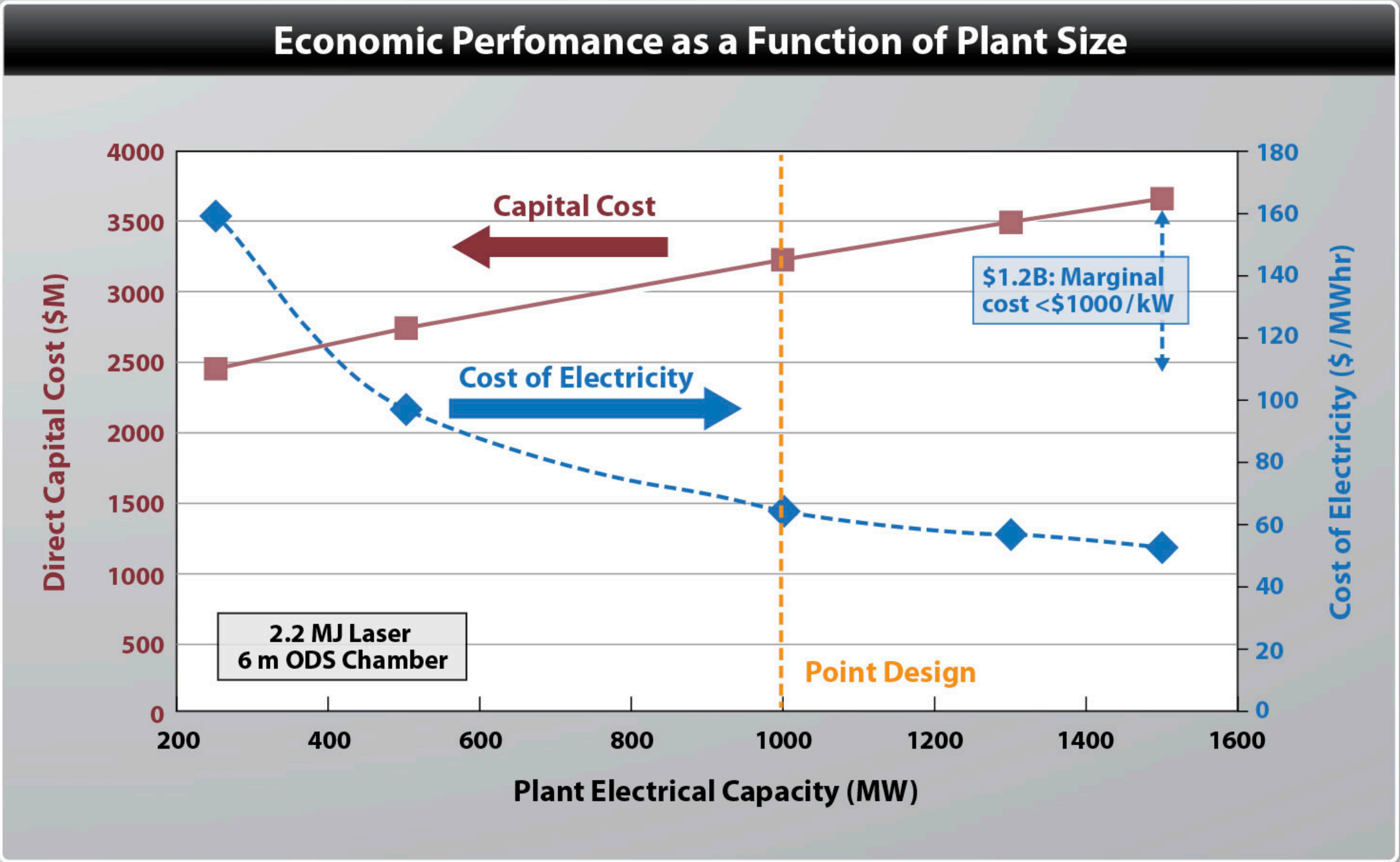
Delivery plan developed to ensure timely retirement of technical issues, and support staged funding

Issues		Consequence	Current Status	Modeling/Concept Level Development	Testing/Laboratory Environment	Testing/Initial Pilot Operations
Fusion Fuel Design and Performance						
	Gain >60	M				
	On-the-fly ignition	H				
	> ~99% probability of ignition	M				
	Fuel materials compatibilities	H				
Fusion Fuel Manufacturing						
	DT layer in production environment	H				
	Fuel survival: injection, flight	H				
	Mass manuf: 400M/yr, <$1	H				
	Tritium Inventory-Fuel Filling	M				
Tritium Fuel Cycle						
	Tritium Breeding Ratio	H				
	Recovery from Li	H				
	Recovery from Xe	H				
Fuel Pellet Injection and Tracking						
	Accurate and repeatable in fusion env	H				
	Injector reliability in fusion env	M				
	Fuel survival in injector (fusion env)	H				
	Injector availability	M				
	Pellet tracking in fusion env	H				
Laser Fusion Driver						
	Rep-rate operation	H				
	Final optic survival	H				
	Electrical efficiency	L				
	Pellet engagement	H				
	Focal spot consistent with LEH	H				
	Laser system availability	M				
Fusion Engine						
	First wall radiation damage survival (FMS) 10 dpa	H				
	Chamber clearing	H				
	Debris management-from chamber outlet	H				
	Heat Transport - from chamber outlet	M				
	Thermal and mechanical insults	H				
	Corrosion	M				
	Chamber Design consistent with Fabrication	M				
	Availability	M				
	Concept of chamber replacement	M				
	Production capability for Chamber Materials (FMS)	M				
Power Conversion Systems						
	Tritium release through Rankine cycle	M				
Licensing and Regulatory						
	Licensing strategy	H				
	Auth for initial ops	H				
	NRC license for ComOps	H				
	Regulator approval of waste streams	H				

- TRL-based assessment of progress
- Risk-managed delivery plan
- Integrated development, construction and licensing

Delivery plan
- Based on plant WBS
- 470 functional requirements
- 970 work statements
- 185 milestones
- > 30 vendors consulted

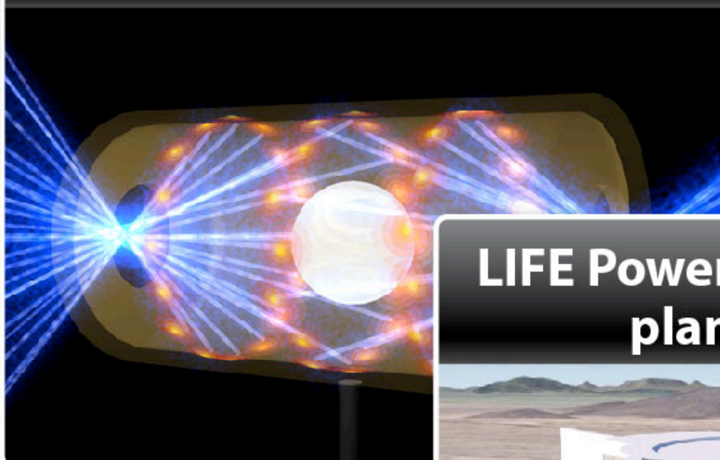
Result is a standardized design that can be up-powered to different plant sizes



Development and deployment paths are based on rational risk retirement management practices

NIF completion – 2009

NIF ignition – 2012



LIFE Power Demonstration plant – 2020's

Market Penetration – 2030's