So What's Next ?

Inertial Confinement Fusion to Inertial Fusion Energy

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National Academies Report

NAS commissioned by US Administration to consider prospects for inertial fusion energy – 2 years to report

"…. *provide a compelling rationale for establishing inertial fusion energy R&D as part of the long-term U.S. energy R&D portfolio*."

"The appropriate time for the establishment of a national, coordinated, broad-based inertial fusion energy program within DOE is when ignition is achieved"

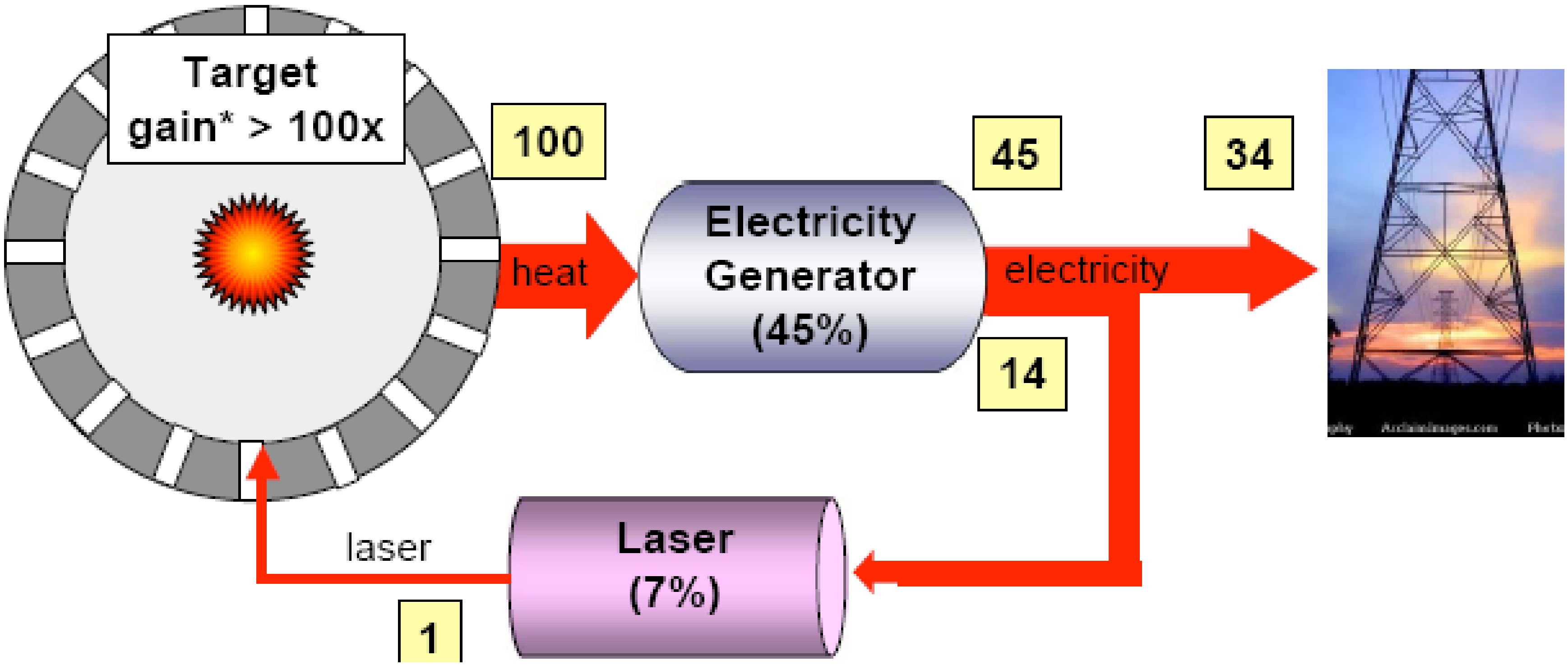
"…does not believe that the fact that NIF did not achieve ignition by the end of the National Ignition Campaign on September 30, 2012 lessens the long-term technical prospects for inertial fusion energy."

"It is important to note that none of the expert committees that reviewed NIF's target performance concluded that ignition would not be achievable at the facility…"

Or, put another way

Major investment in Science & Technology of IFE

Some Challenges for IFE



Lasers – High Energy, High Average Power & High Efficiency
Targets – Mass Production, Injection, Tracking & Engagement
Physics - High Gain Ignition Scheme(s)
Chamber – Concept, First Wall, Materials, Blanket, Survival
System - Integrated, Industrial, Accessible, Regulation
Economics – has to be competitive
Community - growth is essential

HiPER – A European ESFRI Project

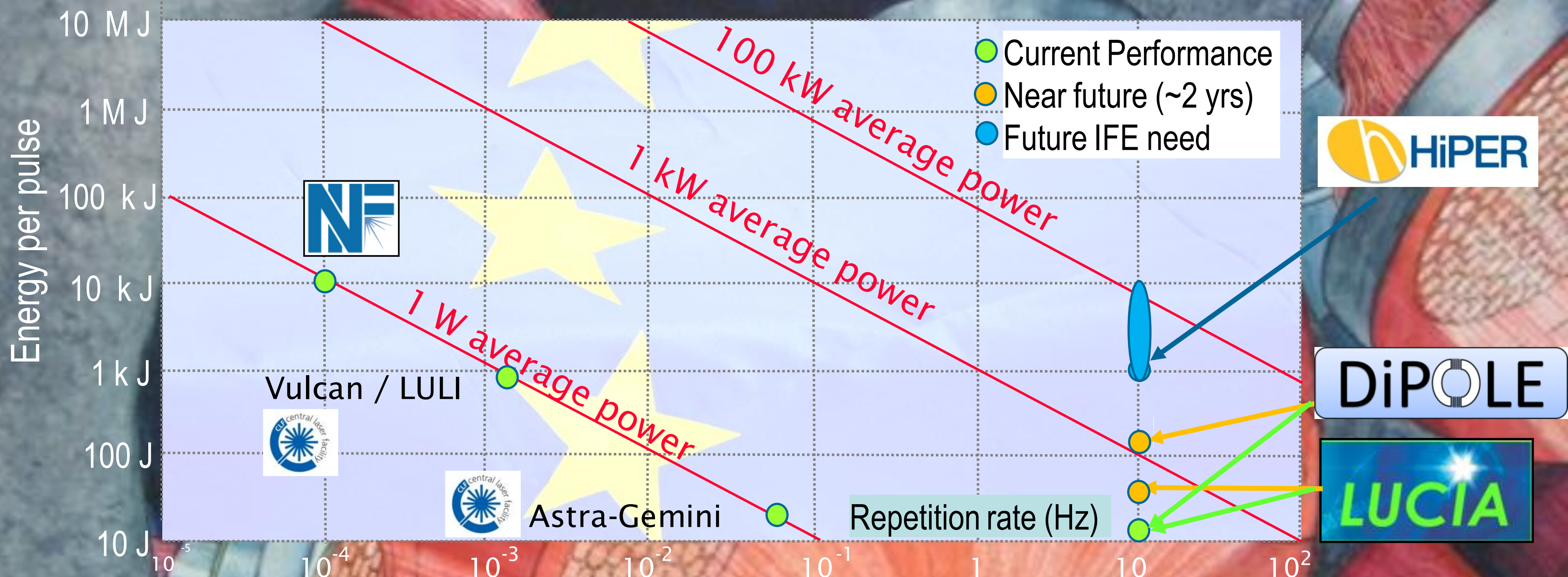
Funding Agency involvement by 10 partners

– STFC	(UK)
– CEA, CNRS and CRA	(France)
– MSMT	(Czech Republic)
– GSRT	(Greece)
– MEC and CAM (through UPM)	(Spain)
– ENEA and CNR	(Italy)
– European Commission	

Institutional involvement by 17 other partners

– IST Lisbon	(Portugal)
– CNSIM	(Italy)
– TEI, TUC	(Greece)
– IOP-PALS	(Czech Republic)
– IPPLM	(Poland)
– FVB, FSU Jena, GSI, TUD	(Germany)
– Lebedev Physical Institute, Institute of Applied Physics-RAS	(Russia)
– Imperial College London, Universities of York, Oxford, Strathclyde, Queens Belfast	(UK)

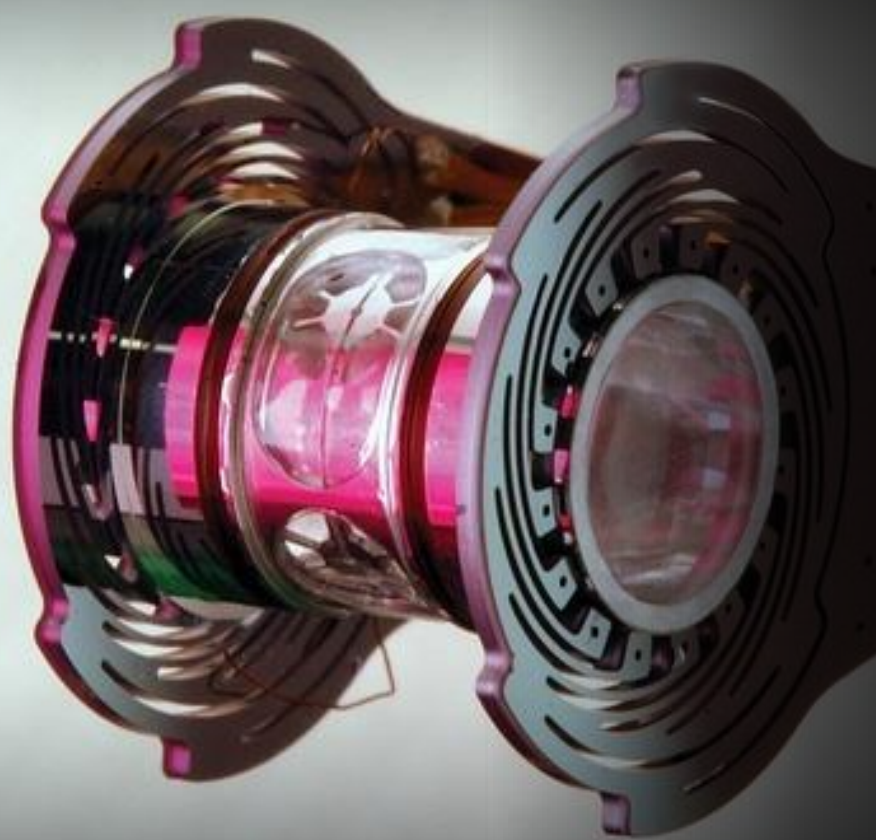
The Laser Challenge



HiPER Laser Strategy

- Focus on average power solutions
- Two 1 kW Diode Pumped Lasers are being constructed in Europe at the moment
- Considerable opportunity for industrial and economic application
- Will drive development independently of IFE

The Target Challenge



One of the most precision engineered objects ever made

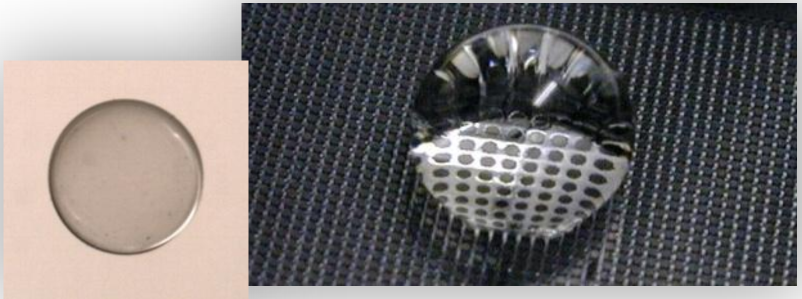
Several a week

$10,000’s each

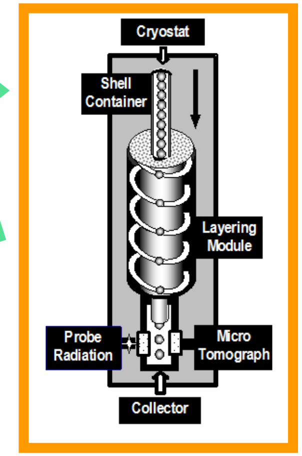
Challenge is to make 10 a second for < 1$ each

HiPER IFE Targetry Strategy

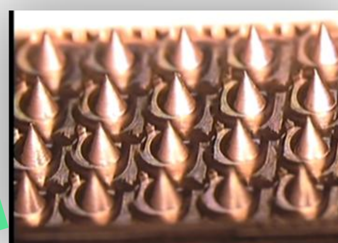
1. Shell mass production



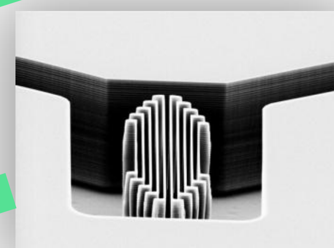
2. Fill and Layering



3. Microcomponent mass production



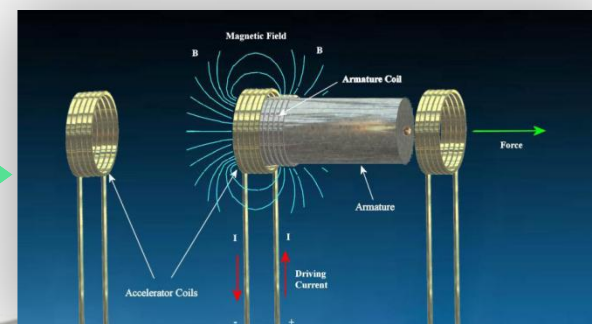
4. Microassembly



5. MEMS Fabrication

6. Characterisation

7. Handling



8. Injection, steering, engagement

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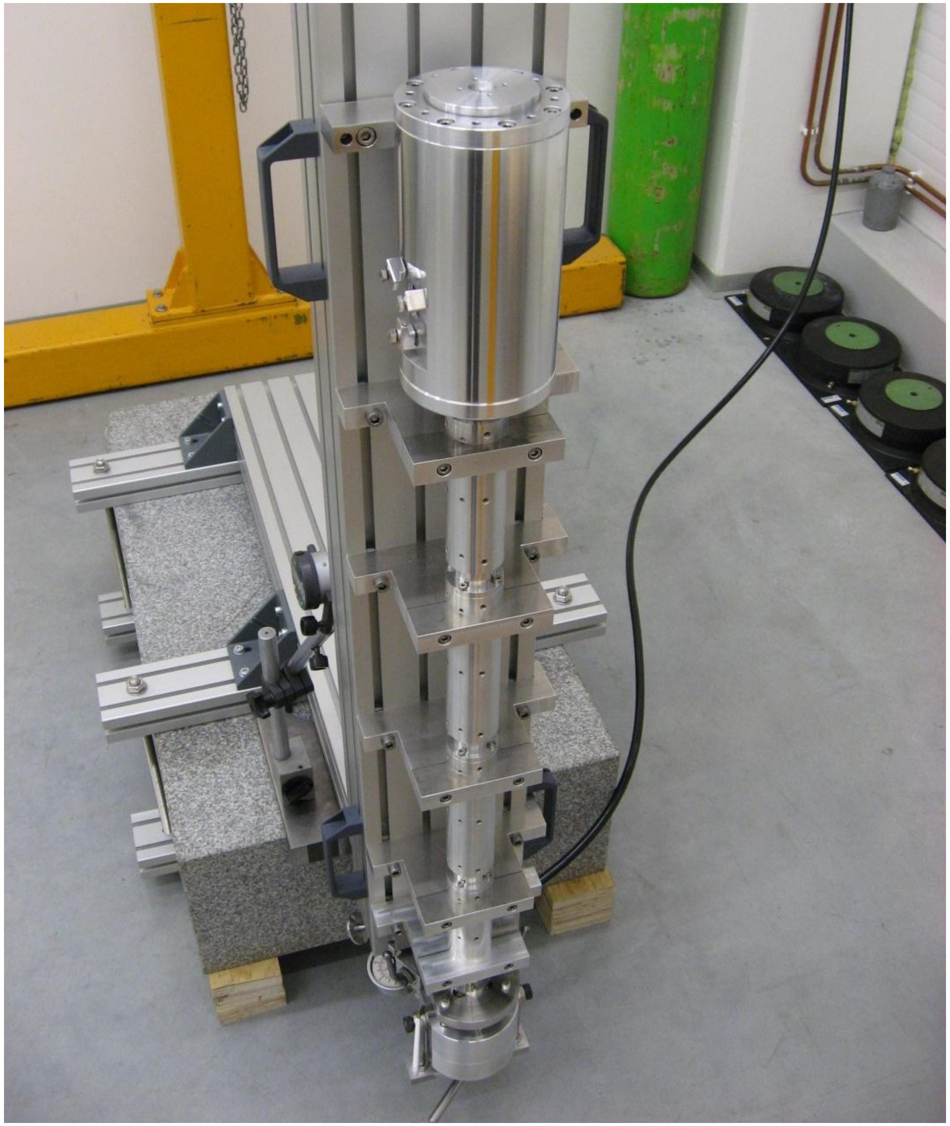
Experimental Injector Development



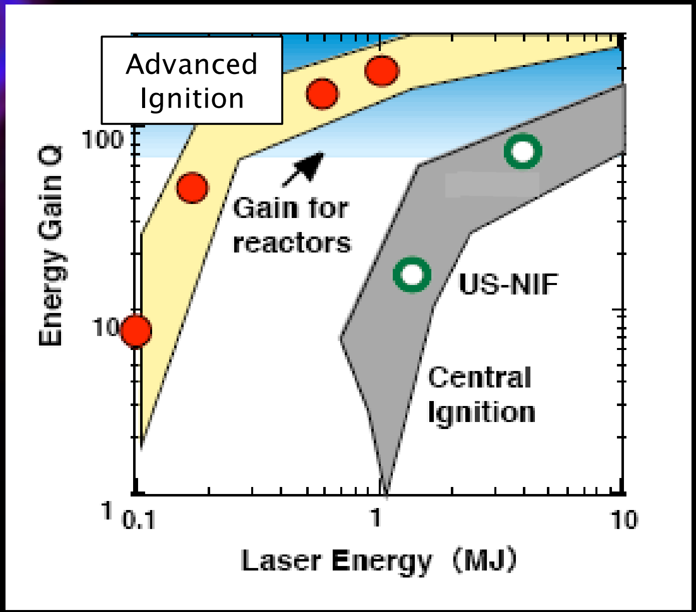
Injector demonstrator assembling - Czech Republic

1 meter long segment of the gas-acceleration section of the injector assembled (January 2011)

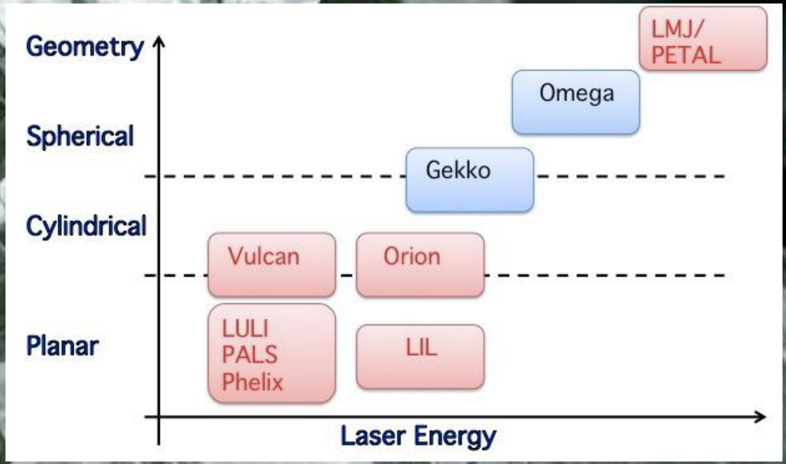
Diagnostic package to measure precision of the velocity (high-speed camera) and of lateral guiding (interferometer) being installed

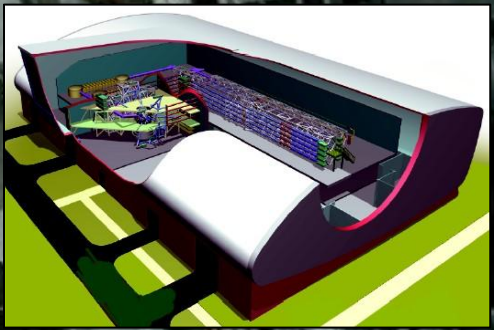
Physics Challenge

- NIF will provide the "Proof of Principle" that laser driven ICF works with initial Gain ~1
- IFE requires Gain >60
- Optimising the fusion scheme gain will be important
- Focus in Europe is on a number of high gain "advanced ignition" approaches being explored in
- Builds on experimental infrastructure (LMJ & others) & High Performance Computing / models



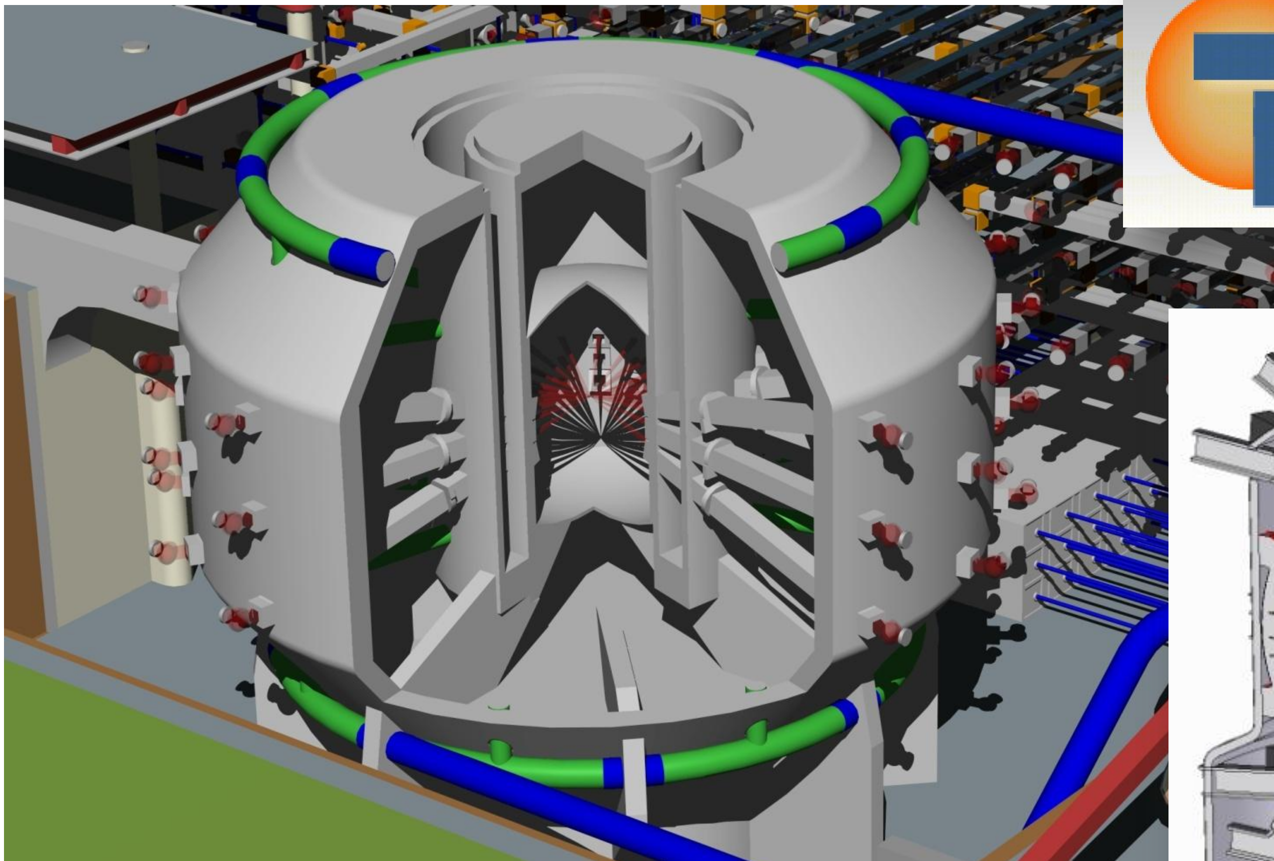
HiPER Physics Strategy



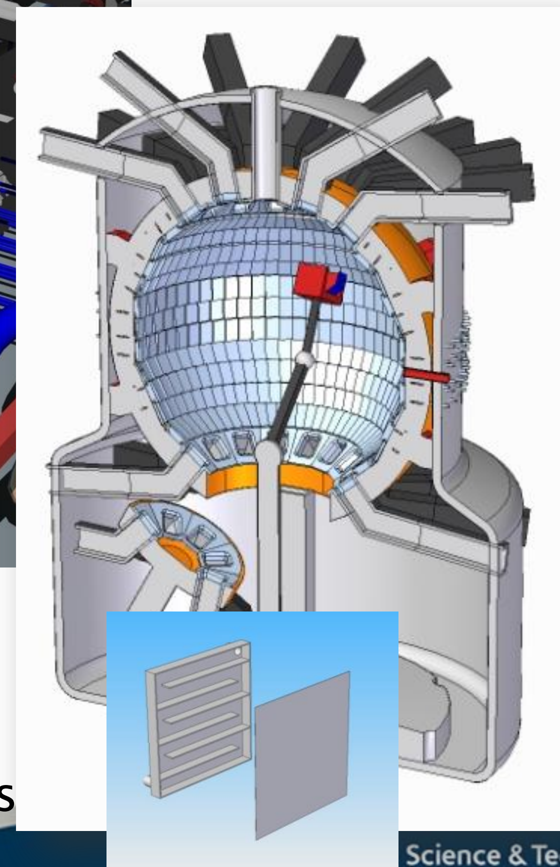


The Laser MegaJoule comes online in a phased manner from 2016
Upto 30% of the time is open access
Testing of gain scaling physics and ideas will be possible in Europe

Two Stage Fusion Engine Strategy



TechnoFusión
Centro Nacional de
Tecnologías para la Fusión



- Technology integration then blanket
- Capitalise on a key IFE feature – separability of blanket and containment
- Blanket “Swap Out” approach by design mitigates need for new materials

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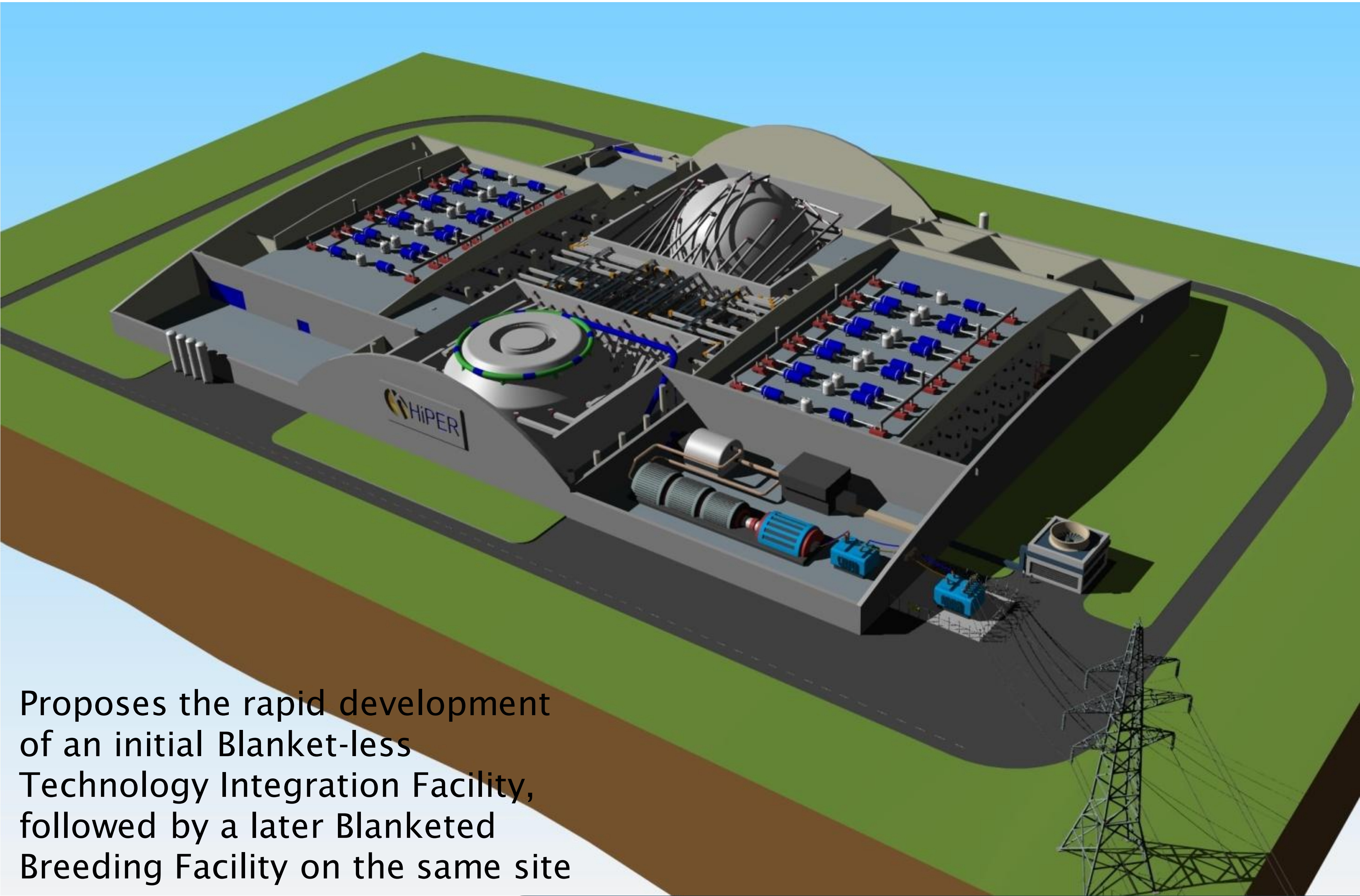
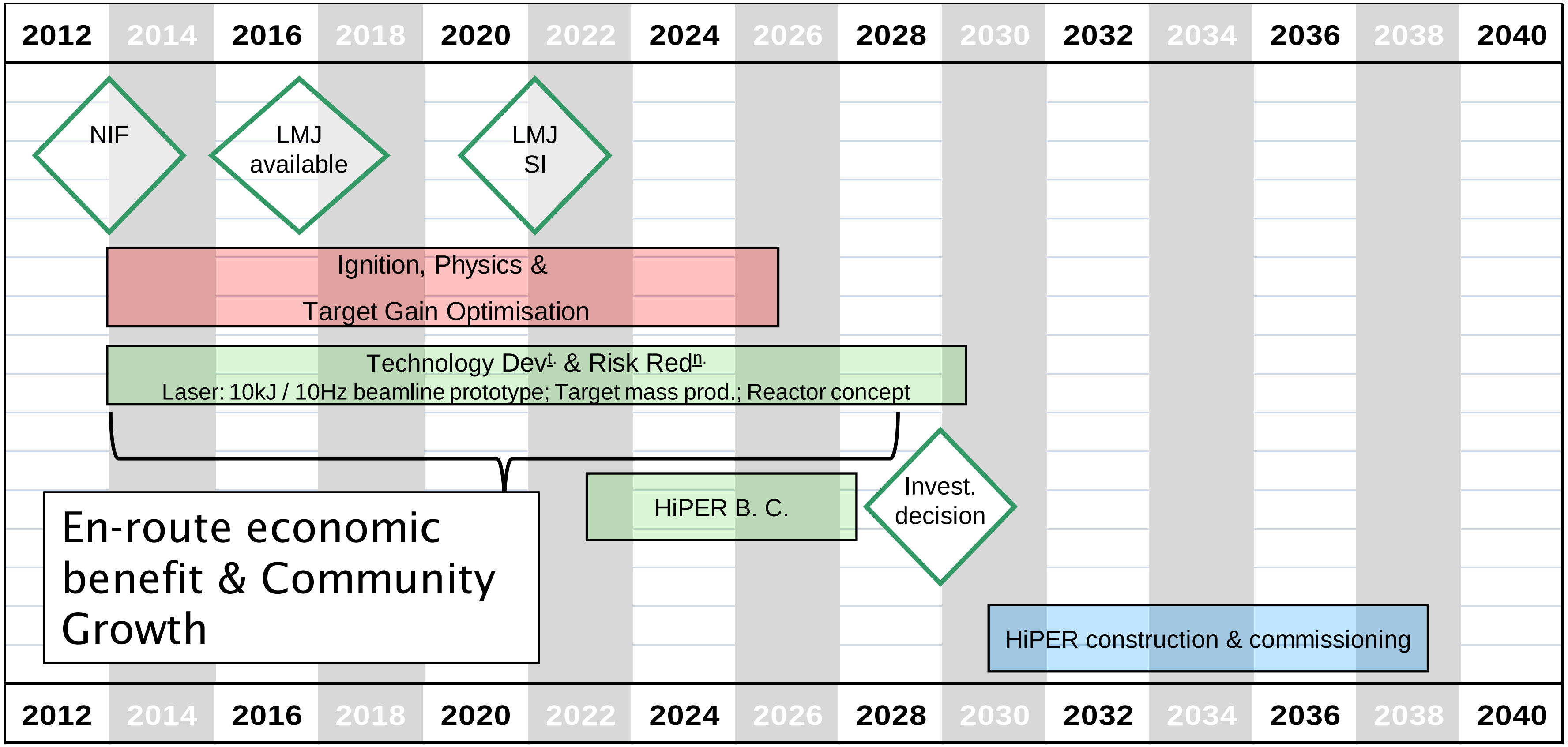
HiPER – A Single Site Strategy

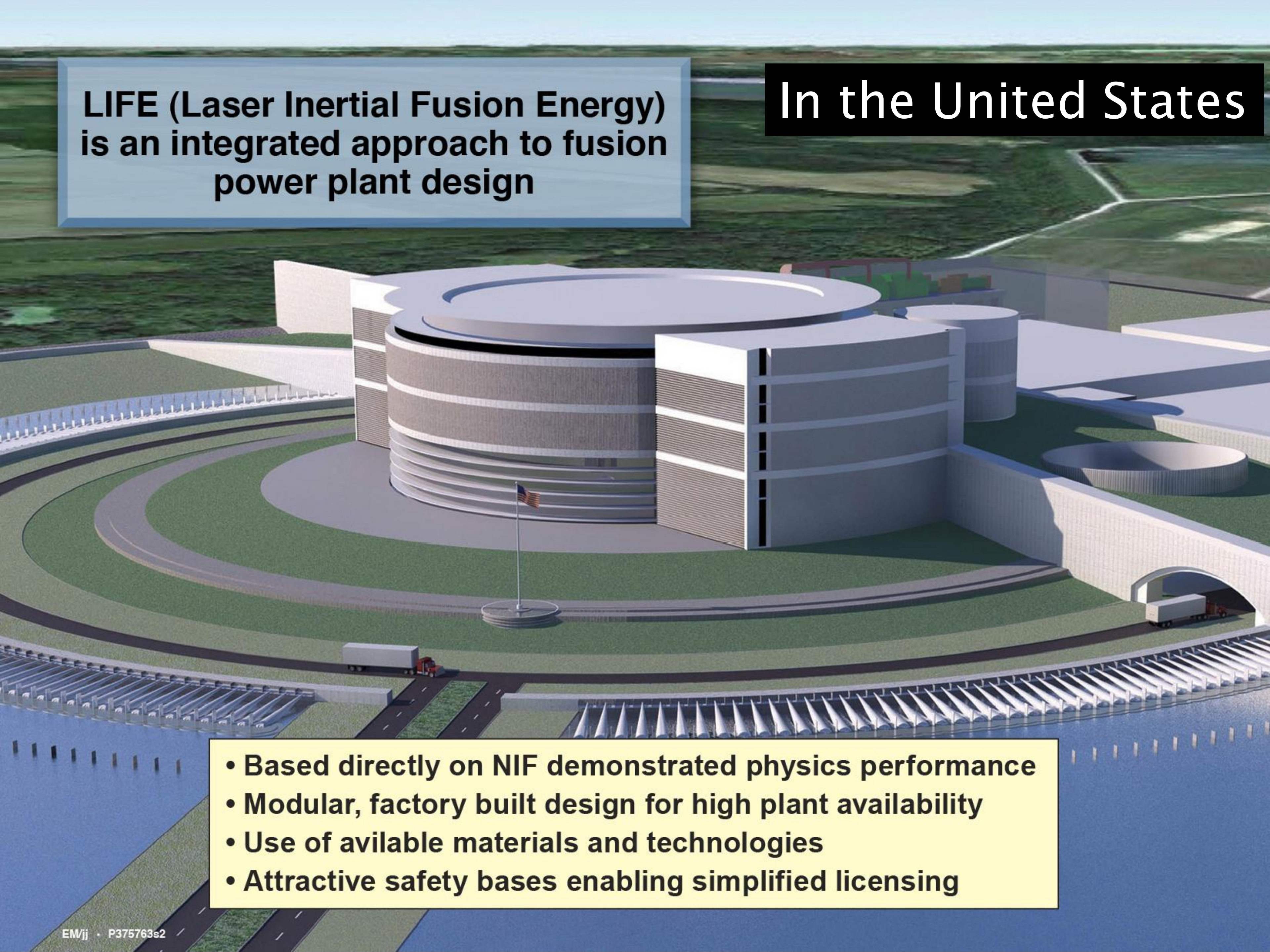


Proposes the rapid development of an initial Blanket-less Technology Integration Facility, followed by a later Blanketed Breeding Facility on the same site

HiPER Roadmap



- The modular and separable basis of IFE offers the important prospect of derivative economic value along the journey
- New Laser & MEMS technology - New applications


In the United States
LIFE (Laser Inertial Fusion Energy) is an integrated approach to fusion power plant design
• Based directly on NIF demonstrated physics performance
• Modular, factory built design for high plant availability
• Use of avilable materials and technologies
• Attractive safety bases enabling simplified licensing
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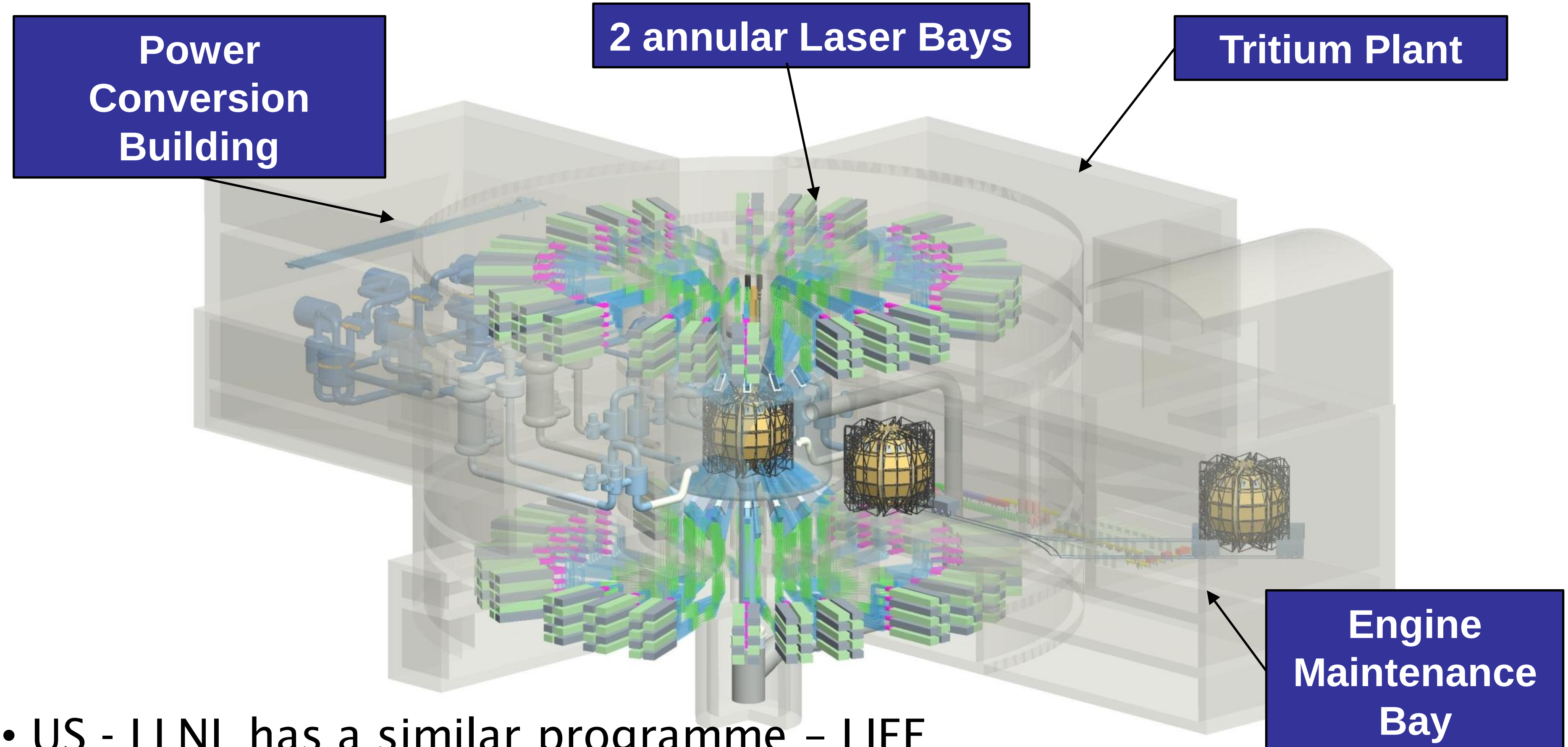
In the US - LIFE



- US - LLNL has a similar programme – LIFE
- Shares many similar characteristics in concept
- Technology options exist with LIFE and HiPER
- Opportunity for science and technology cooperation is clear

HiPER

www.hiper.org

Community Development

Community & Skills Growth

- HiPER has encouraged & supported the development of advanced skills within Europe
- e.g. Erasmus HED Summer Schools – last 4 years – 150 students – next 3 yrs funded
- Plasmas, Fusion, Science, Technology, Applications…

ERASMUS MUNDUS
Education and Culture DG

European MSc in Laser Fusion

Education and Culture DG

Lifelong Learning Programme

EACEA Education, Audiovisual & Culture Executive Agency

Curriculum Development Project "PLASMA PHYSICS & APPLICATIONS" - PLAPA

The PLAPA Squad

http://plapa.chania.teicrete.gr

PLAPA Plasma Physics & Application

Objective

The **main objective** of this project is the development of a curriculum of courses that will lead to a joined 2 years duration European MSc degree in the field of laser driven fusion. The project is strongly related to the **H**igh **P**ower laser **E**nergy **R**esearch (HIPER) project.

Outcome

The main target group of the PLAPA project are graduate students from Physics, Electronic Engineering, Materials Science Departments. The proposed curriculum intends to train the participants in a modern technology that promises unlimited amount of green energy for all nations.

Scientific Topic

Why consider Laser Fusion?

- ✓ The output of a fusion reaction releases a huge amount of green energy
- ✓ Provision of plentiful fuel that can meet mankind's long term needs
- ✓ Energy Security
- ✓ Safe Operation - Free of Fukushima type dangers
- ✓ It is a technology that is not a distant dream but a near term realistic goal

Curriculum Structure

1st Semester	2nd Semester
Introduction to Plasma Physics	Laser Physics Technology
Electrodynamics	Atomic Processes in Plasma
Principles of Scientific Computing	Plasma Diagnostics
Research Methodologies	Plasma Kinetics
Quantum Mechanics	Short Pedagogical Project

3rd Semester

IFP Direction	LP Direction
Principles of Laser Fusion	Principles of Laser Fusion
Laser Matter Interaction	Laser Matter Interaction
Plasma Diagnostics & Beam Transport	Radiation & Laser Safety
Target Reactor Technology	NonLinear Optics
Modeling & Numerical Methods	High Power Lasers & Diagnostics

PS Direction: Dense Plasmas; Laser Matter Interaction; NonLinear Dynamics & Instabilities in Plasmas; Modeling & Numerical Methods; Plasma Diagnostics & Beam Transport

4th Semester

MSc Thesis in one of the Partner Universities

Methods & Strategies

- ✓ 2 years duration MSc degree in laser fusion
- ✓ Use of European Credit Transfer System (120 ECTS)
- ✓ The ECTS credits are equally distributed among 4 semesters
- ✓ Use of Diploma Supplement
- ✓ Three different scientific directions: Laser Physics / Inertial Fusion Tech / Plasma Science
- ✓ The last semester is devoted to a practical project
- ✓ Development of an online educational platform
- ✓ Train future engineers in a very modern and a promising technology
- ✓ Signature of Bilateral Agreements between PLAPA partners
- ✓ Contribution to increase the student and teacher mobility across Europe
- ✓ Test the curriculum structure through teaching exchange program
- ✓ Application for an Erasmus Mundus Project

Pilot Test Events

Partners

Imperial College London; Queen's University Belfast; Università degli Studi di Milano Bicocca; instn; Université Bordeaux 1 Sciences Technologies

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Broadening Physics Network for IFE

COST
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

"Developing the Physics and the Scientific community for Inertial Confinement Fusion at the time of NIF ignition" – Cost Action MP1208

16 Countries
27 partners

UNIVERSITÉ DE BORDEAUX

Euratom EFDA KIT

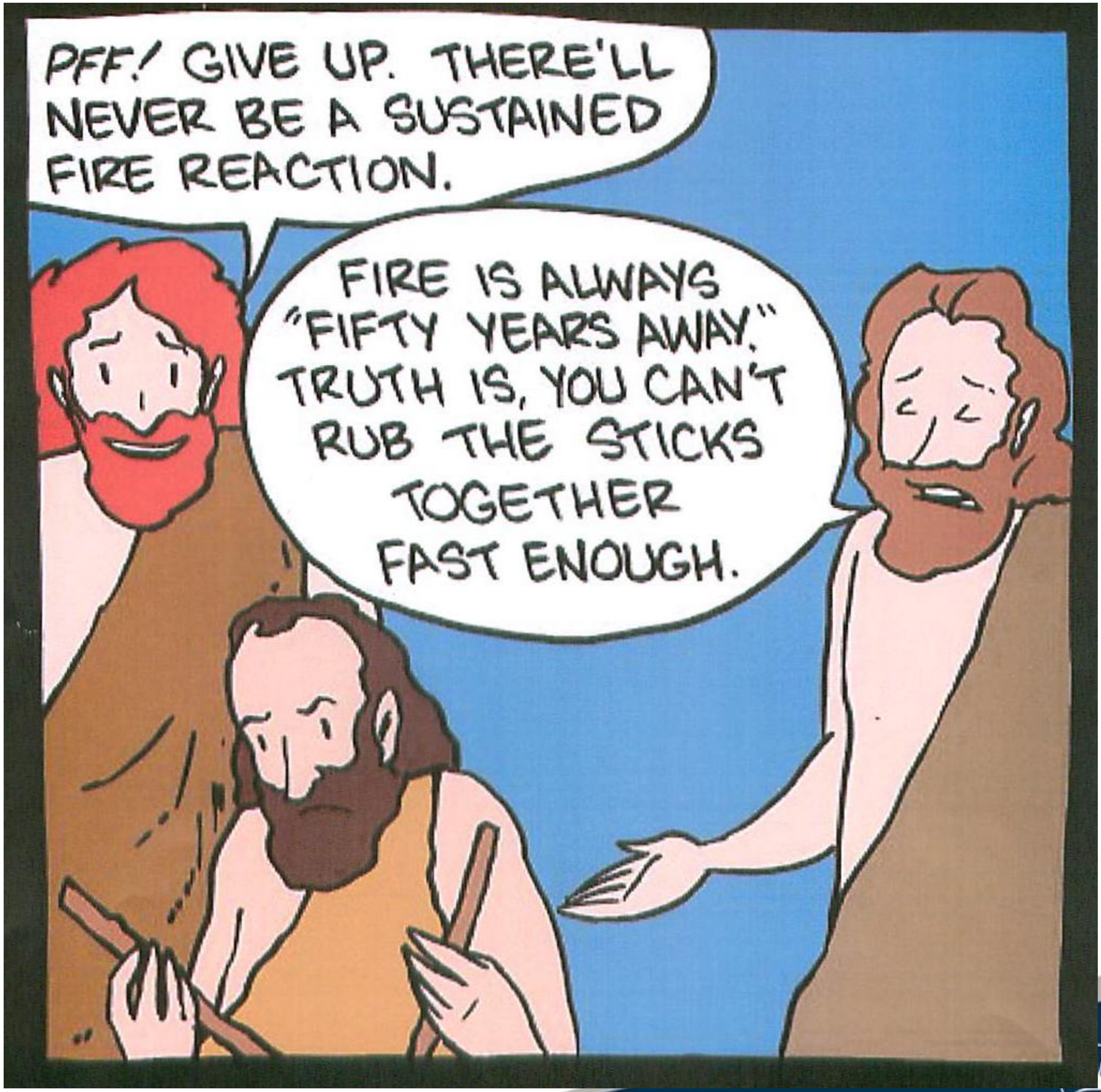
EFDA

Keep In Touch with IFE

Roadmap

- New insights into basic ignition physics
- Demonstration of alternative ignition concepts on LMJ & NIF
- Key Technologies for IFE
- Transnational European co-ordination activities

Communities ......



Costs of Diodes

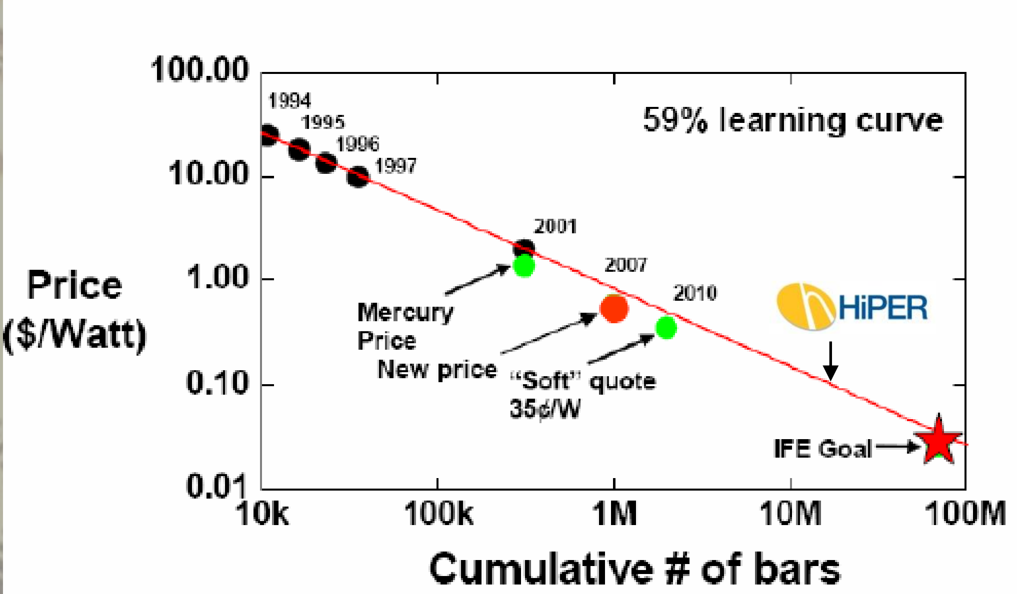
European (*International)* diode industry is well developed with respect to technologically advanced products

Technologically close to the long term requirements of IFE

BUT the cost of diodes to today is high - it's a manufacturing issue

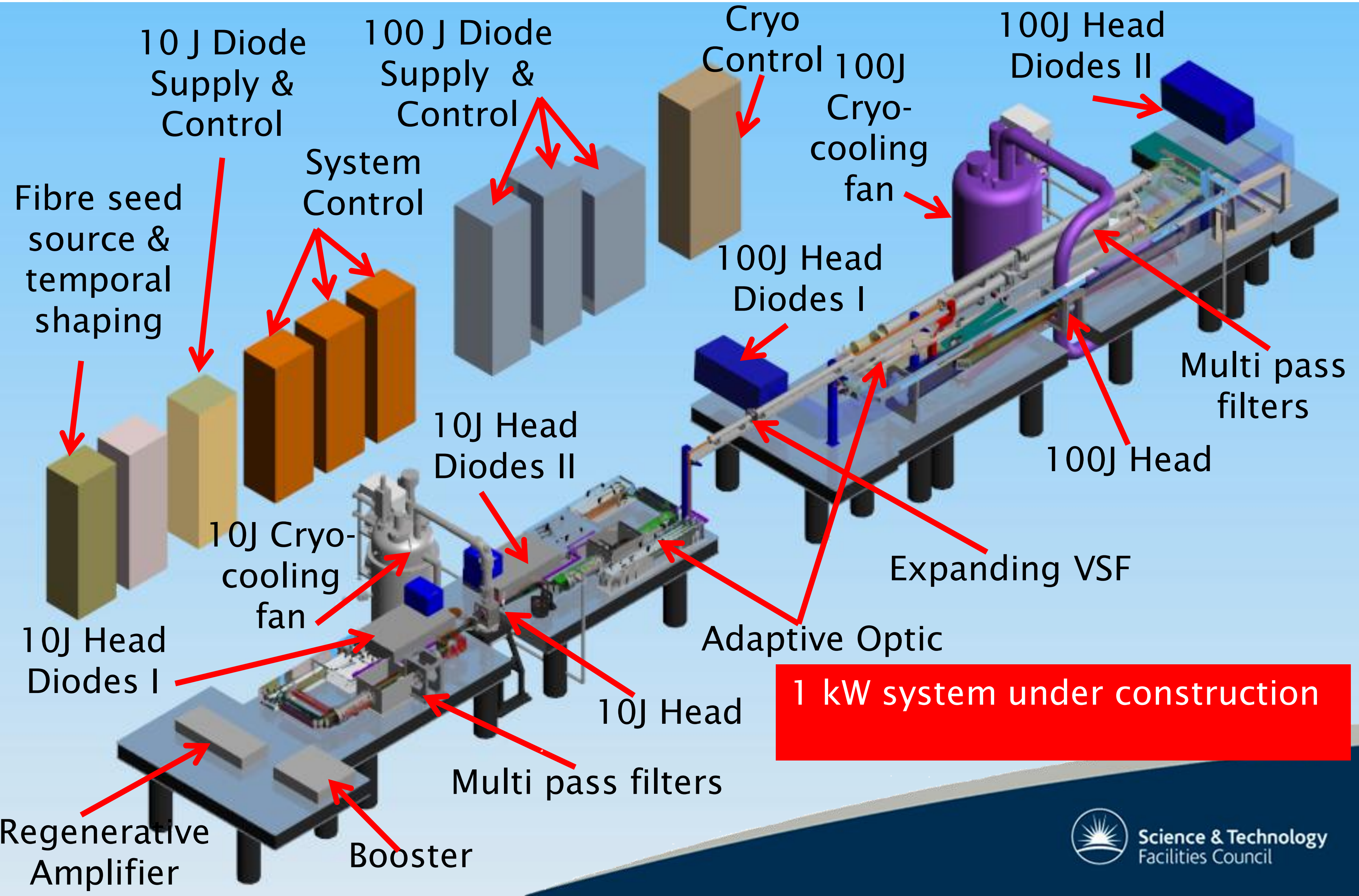
Vertical integration needed
End to End automation

Demand and investment driven



- IFE is extremely well placed to drive major industrial development in this area
- 2 independent industry studies for HiPER confirm cost viability
- Other industrial spin off benefits from this technology

DiPOLE 100J / 10 Hz (1 kW)



1 kW system under construction

Rutherford Appleton Laboratory