

Inertial Fusion Energy Technology

Robert Fedosejevs

Department of Electrical and Computer Engineering

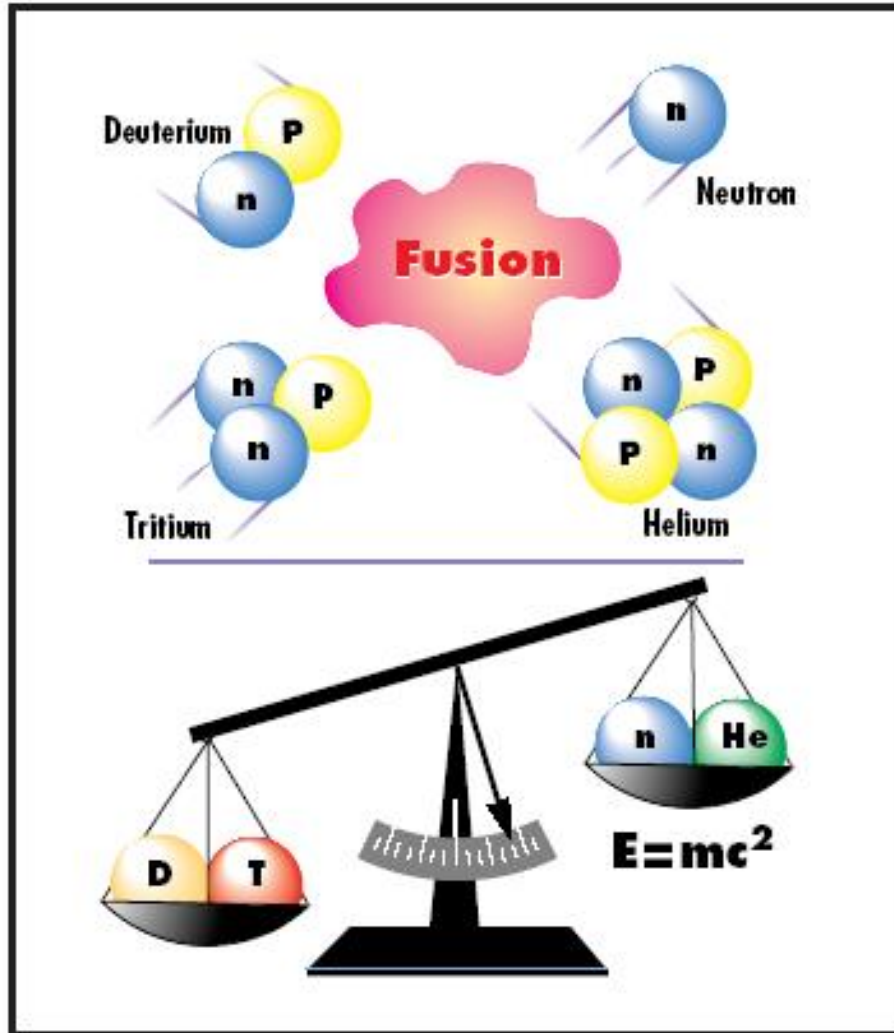
University of Alberta

And

Alberta/Canada Fusion Technology Alliance

Presented at the Canadian Nuclear Society Annual Conference
Niagara Falls, June 5-7, 2017

Deuterium Tritium Fusion



Fuel

Isotopes of hydrogen

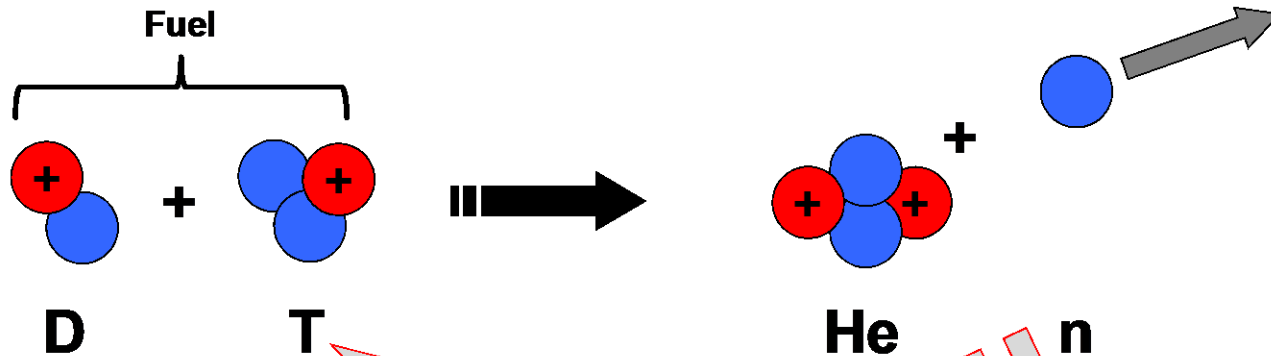
High Energy Density

At 100% burn efficiency
94 kg DT fuel generates
1 GW-yr_{th}

Clean

Ash is helium gas

Fuel Cycle

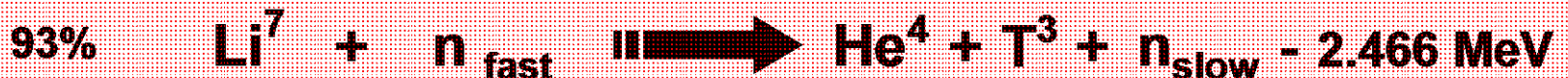
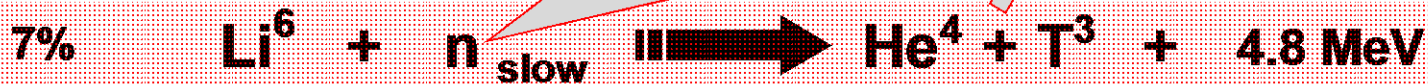


Deuterium plentiful in seawater
(1 part in 6000)

Breed tritium from lithium

TBR > 1.1

Li: abundant in earth's crust



Breed Tritium from the neutrons reacting with lithium
in a blanket surrounding the reactor core

Fusion - High Energy Density

Small footprint:

<1km square for 1GWe power plant or
1000 W/m²

Compare to other clean energy alternatives:

Solar PV ~ 10 W/m²

Wind ~ 2-3 W/m²

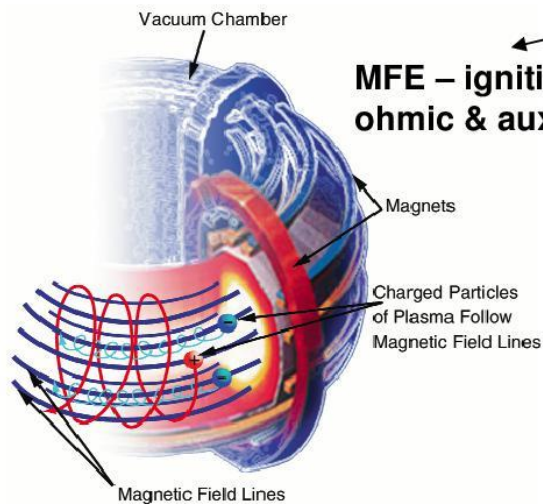
Biomass ~ 0.5 W/m²

Hydro ~ 0.25 W/m²

Ref: DJC McKay (2009)

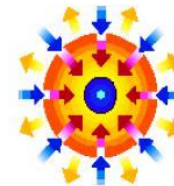
Requirements for Net Energy Yield

- **Need high temperature for ignition** ($T > 100,000,000$ degrees C)
- **Need confinement for net energy** ($n_i \tau_E > 2 \times 10^{20} \text{ m}^{-3} \text{ s}$)
- Burning occurs when heating is self-sustained (by helium from fusion)
- Two confinement approaches: (i) **magnetic (MFE)**; (ii) **inertial (IFE)**



MFE – ignition requires ohmic & auxiliary heating

IFE – ignition requires driver beams to heat & compress target



Fuel Burn

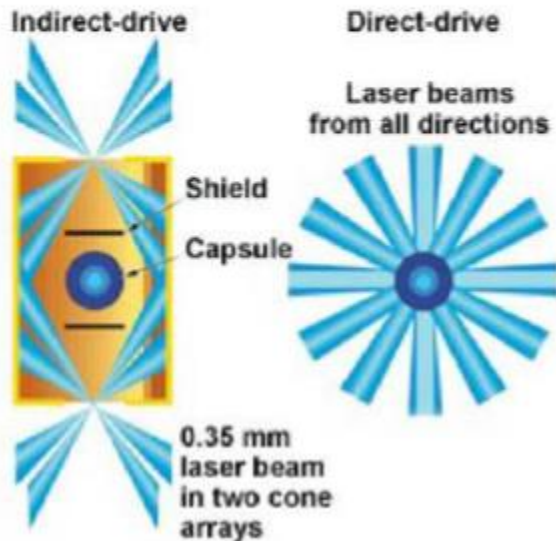
Inertial Fusion Energy

Laser Fusion

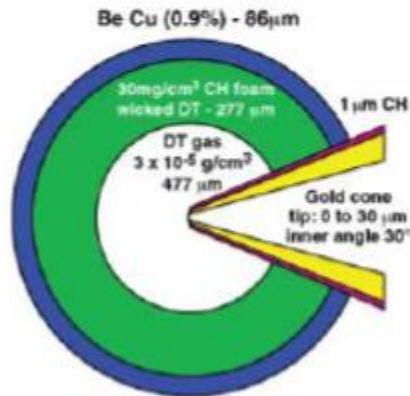
Traditional
Concepts

New Concepts - Separate
Ignition Pulse (Fast Ignition)

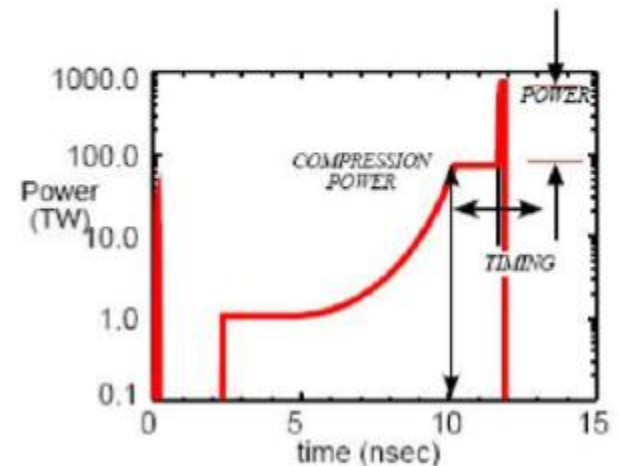
Central Ignition



Fast Ignition



Shock Ignition

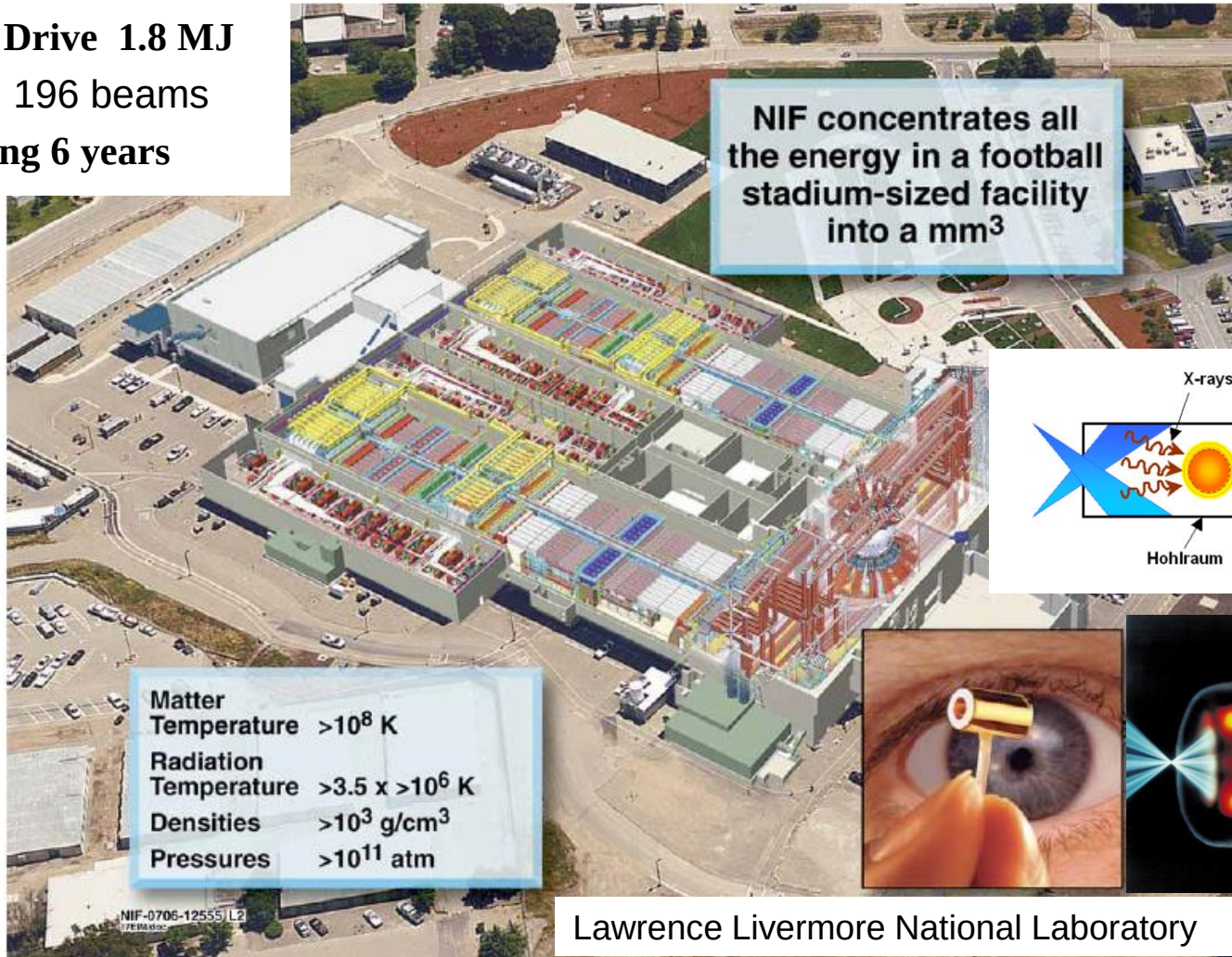


Laser Fusion has advantage of separation of
reactor chamber and expensive laser driver

Lawrence Livermore National Laboratory National Ignition Facility - USA

Goal to reach ignition and produce modest target gains

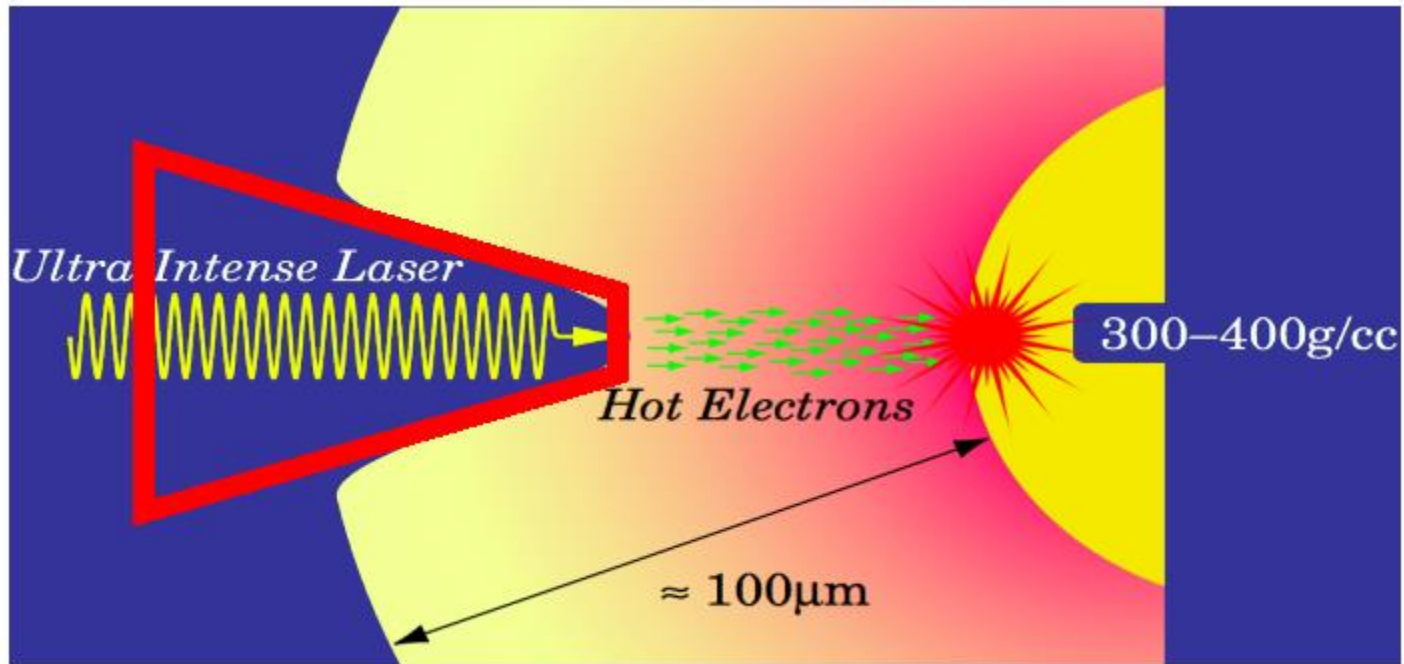
- Indirect Drive 1.8 MJ
- 0.35 μm 196 beams
- Operating 6 years



Laser Bay

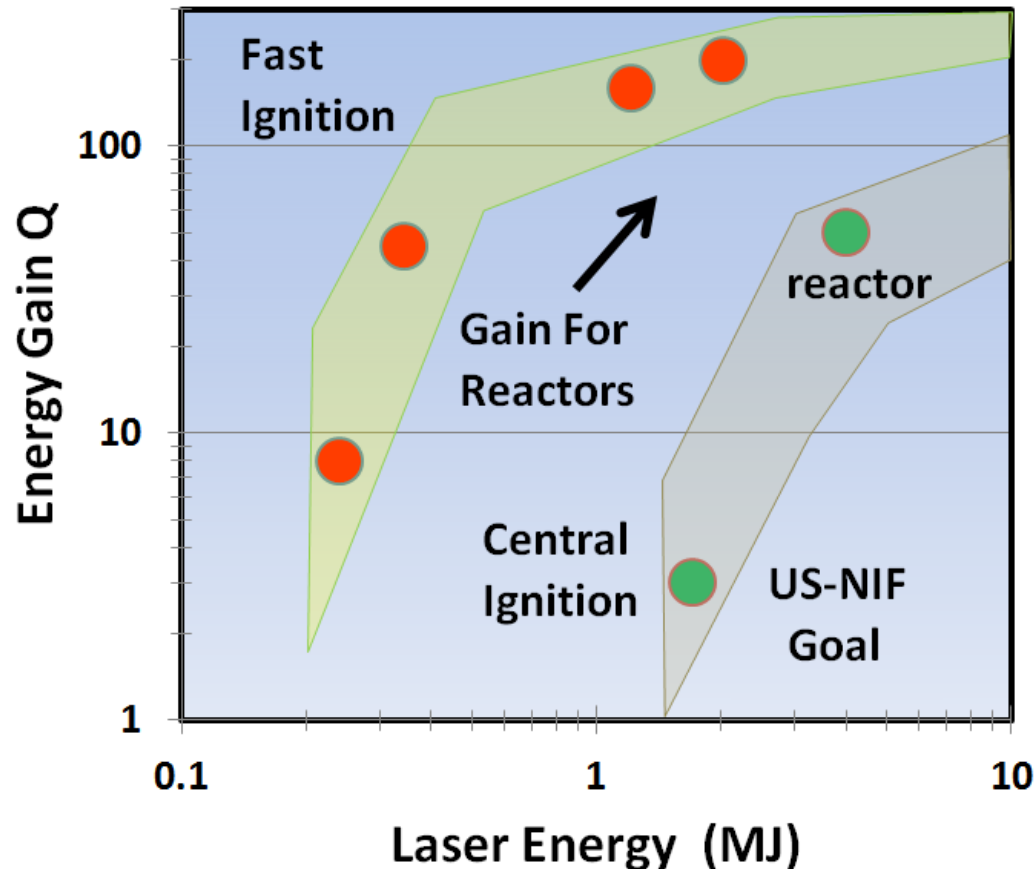


Fast Ignition



Laser cannot penetrate into the core
Therefore deliver in the form of MeV electrons
or ions driven by Ultra-intense (PW) short pulse
laser

Energy Gain Scaling for Fast Ignition

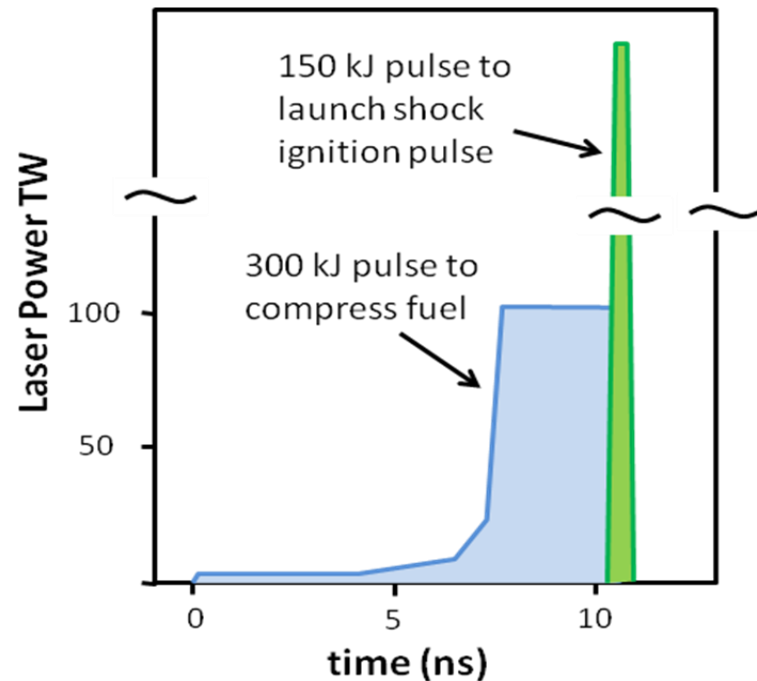
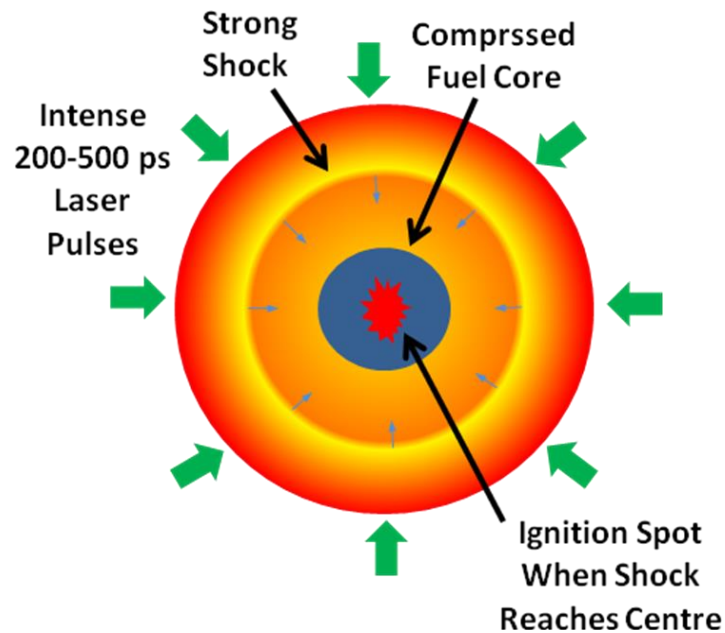


Must control electron transport to the core using strong magnetic fields or use alternative MeV protons to couple energy to the core

These are areas of current research

**Reduce Laser Requirements almost an order of magnitude:
Smaller and less expensive initial IFE reactors possible**

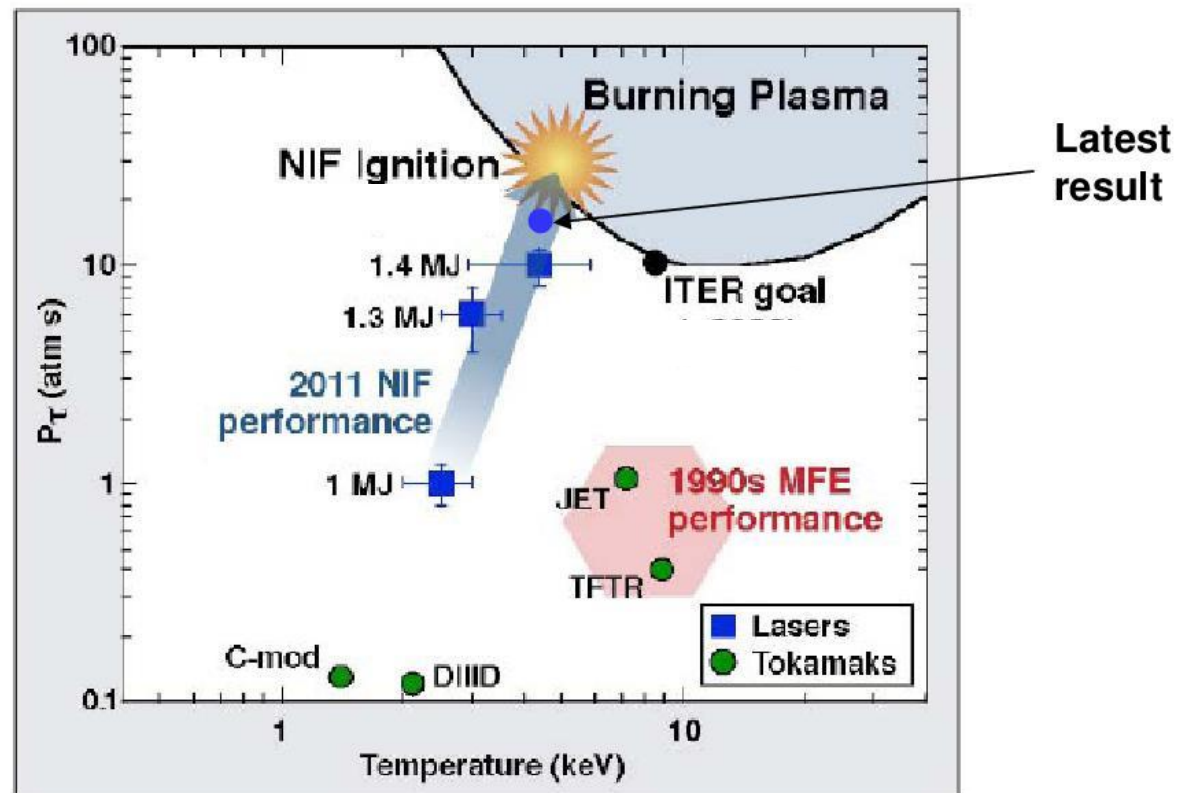
New Concept - Shock Ignition



- Strong shock at the end of the compression pulse causes ignition of compressed fuel core
- Recently proposed in detail in 2007 by Betti et al. (PRL 98, 155001 (2007))
- Similar Concept by Shcherbakov, Sov. J. Plasma Phys. 9(2) 240 (1983)

Inertial Fusion - Progress

NIF is designed to provide full-scale evidence of fusion performance in the near future



Uniquely, NIF provides the full-scale platform to allow direct progression to a power plant

Fuel gain exceeding unity in an inertially confined fusion implosion

Nature vol. 506, p. 343 (2014)

O. A. Hurricane¹, D. A. Callahan¹, D. T. Casey¹, P. M. Celliers¹, C. Cerjan¹, E. L. Dewald¹, T. R. Dittrich¹, T. Döppner¹, D. E. Hinkel¹, L. F. Berzak Hopkins¹, J. L. Kline², S. Le Pape², T. Ma¹, A. G. MacPhee¹, J. L. Milovich¹, A. Pak¹, H.-S. Park¹, P. K. Patel¹, B. A. Remington¹, J. D. Salmonson¹, P. T. Springer¹ & R. Tommasini¹

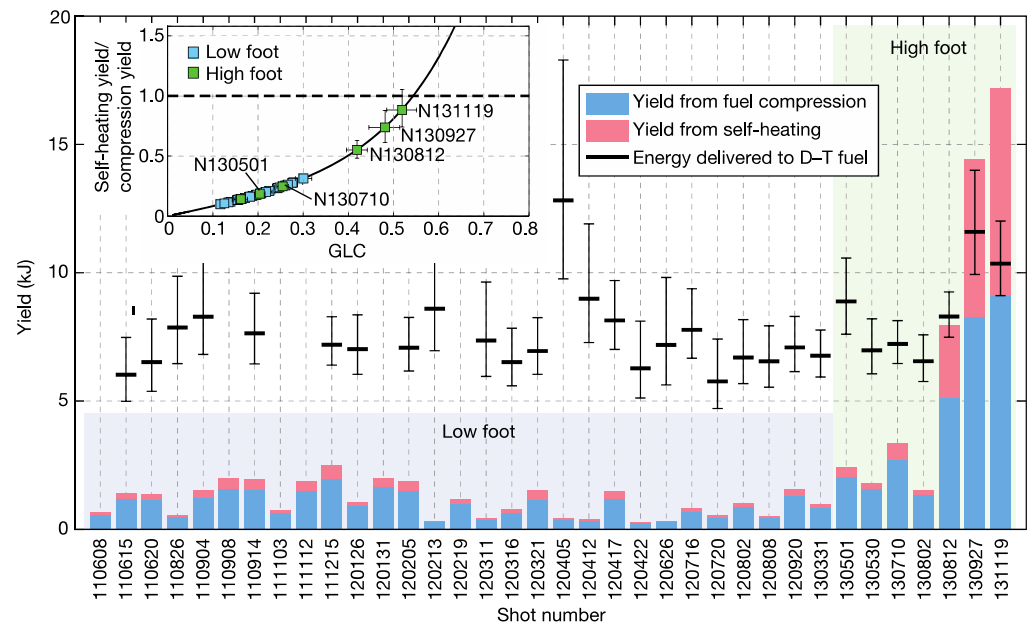
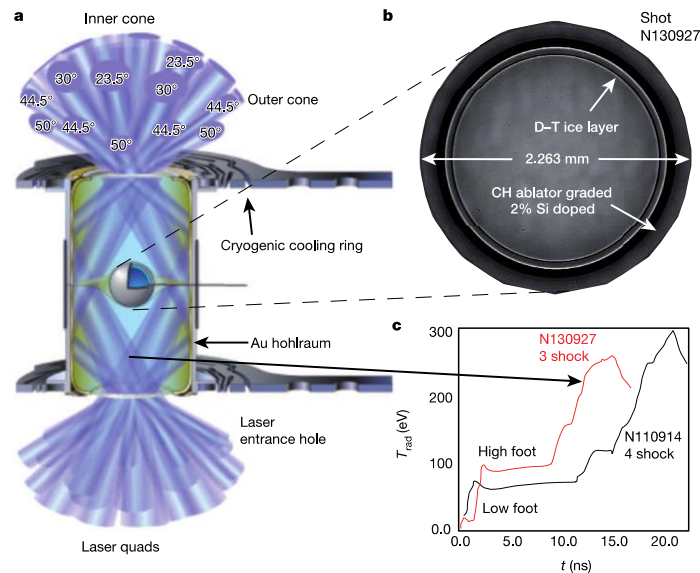
responsible for part of the observed degraded yield performance¹ and the ablator–fuel mix inferred from X-ray emissions in combination with primary neutron yield^{8,9}.

laser beams, through laser wavelength changes that affect the cross-beam transfer (the transfer of power from one beam to another via induced Brillouin scattering), to optimize the illumination pattern in

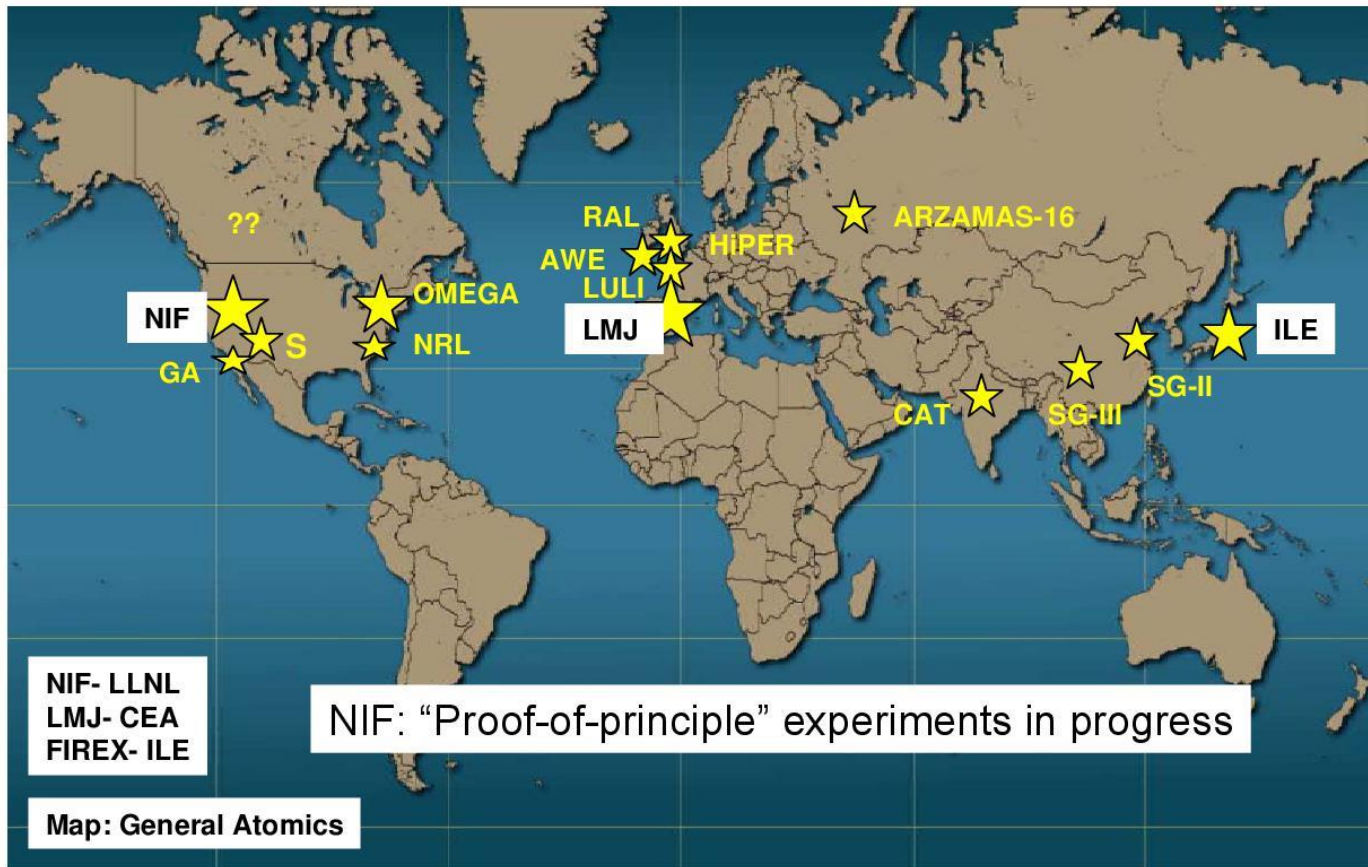
¹Lawrence Livermore National Laboratory, PO Box 808, Livermore, California 94551, USA. ²Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA.

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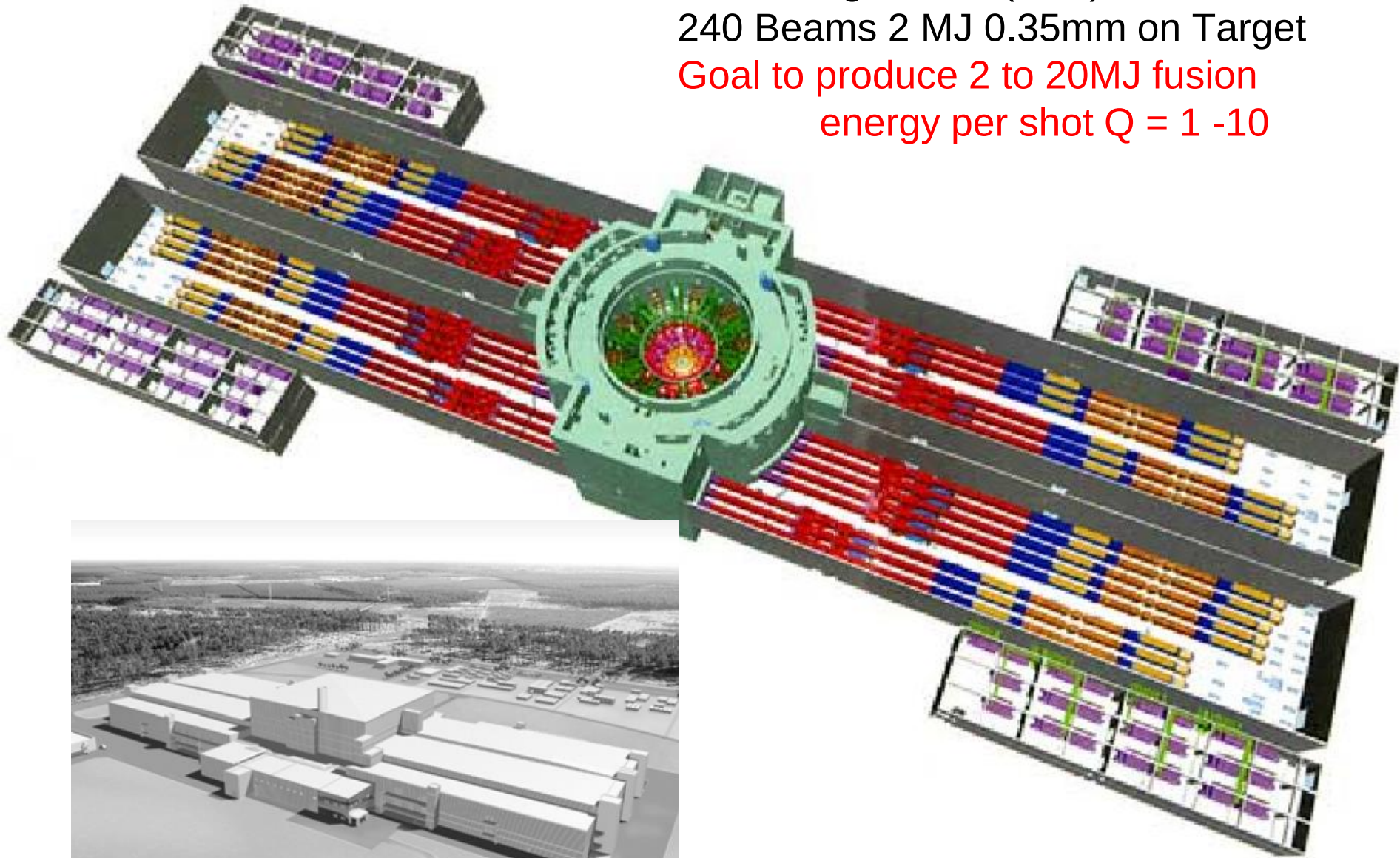


IFE - Global Initiative



Laser Mega Joule - France

Laser Mega Joule (LMJ) France
240 Beams 2 MJ 0.35mm on Target
Goal to produce 2 to 20MJ fusion
energy per shot $Q = 1 - 10$



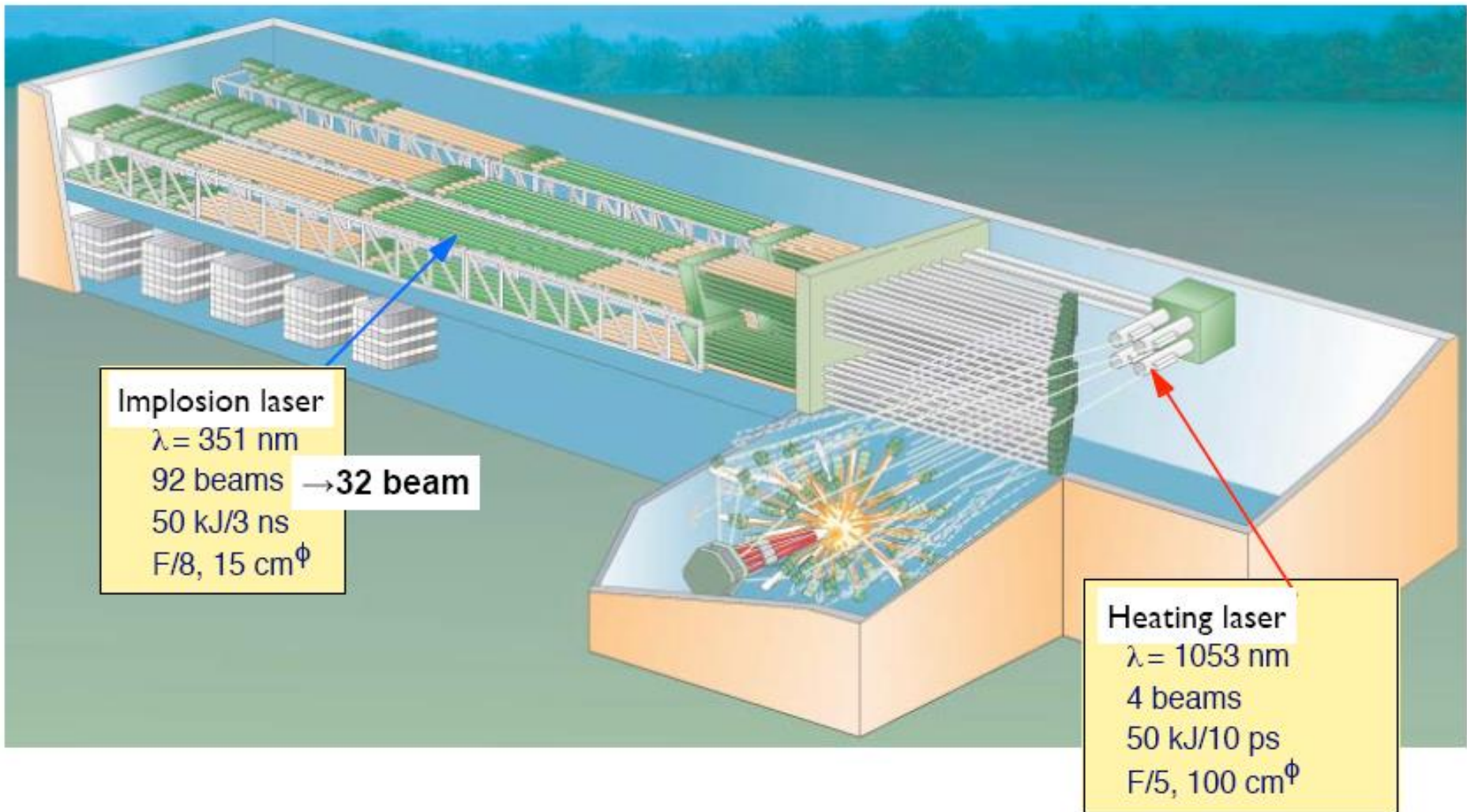
University of Rochester 40kJ Omega Laser System Direct Drive Fusion



OMEGA Laser facility

Scaling to NIF facility energy expected to yield 120kJ fusion yield
-> Need to control cross beam energy transfer to reach ignition conditions

Proposed FIREX-II Ignition and Burn



Commercialization and spinoff opportunities of Laser Fusion

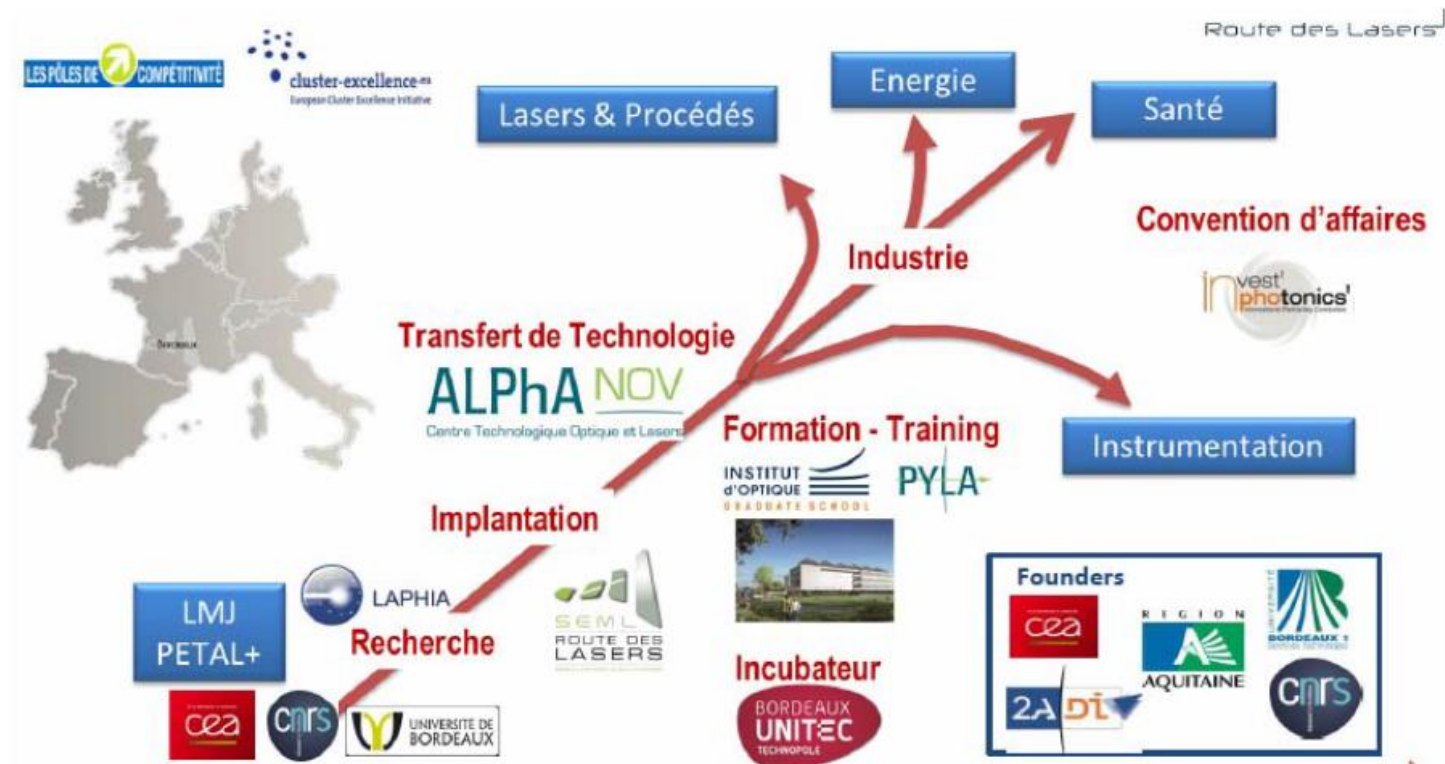


Fig. 14 Commercialization model of Routes des Lasers around the LMJ project

LLNL LIFE Power Plant Design

Addresses Engineering Requirements for a Real Reactor)

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

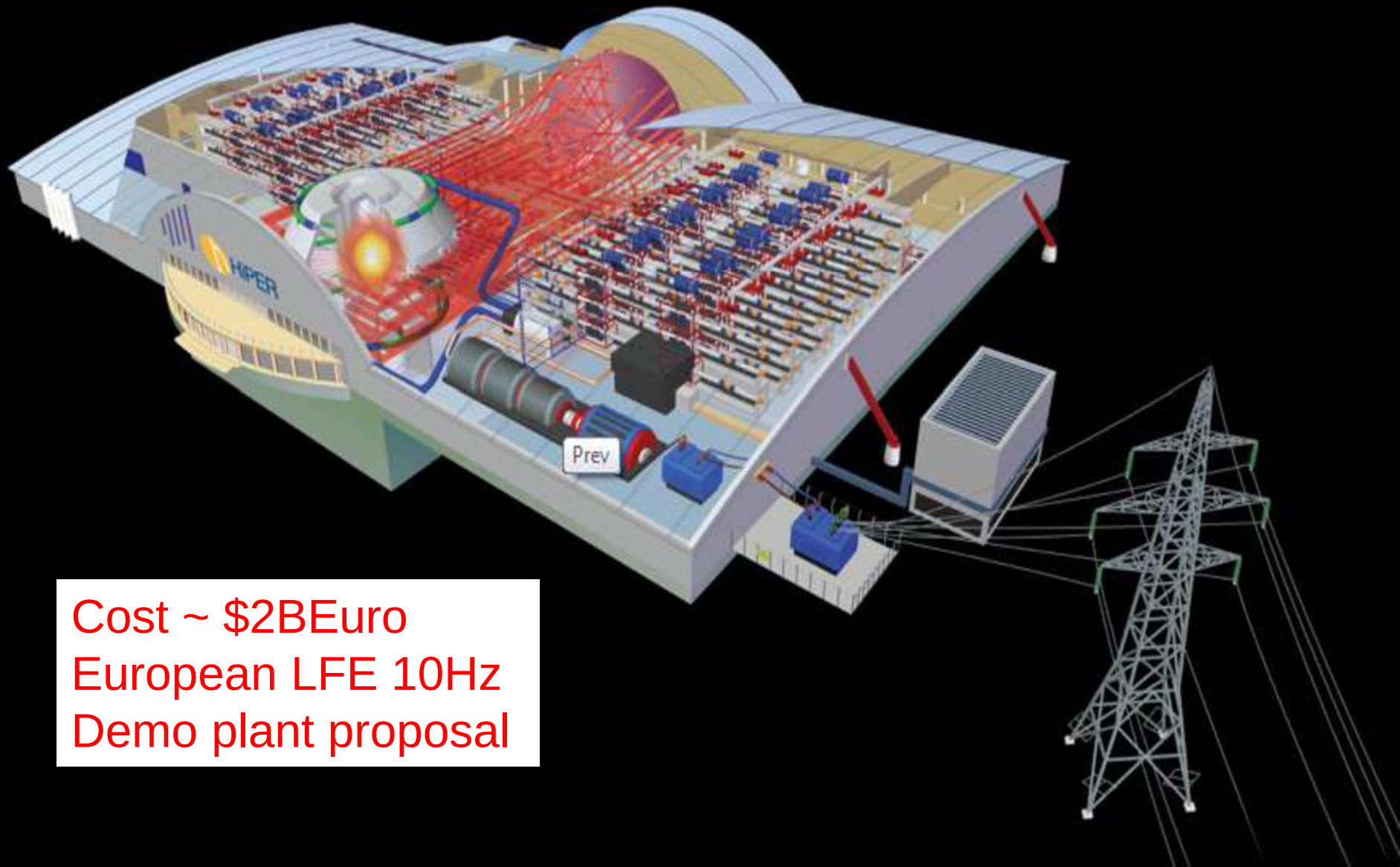


Use of commercially available materials and technologies

Focus on pure fusion, utility-scale, power-producing facility

LLNL : Initial engineering and planning already carried out

HiPER

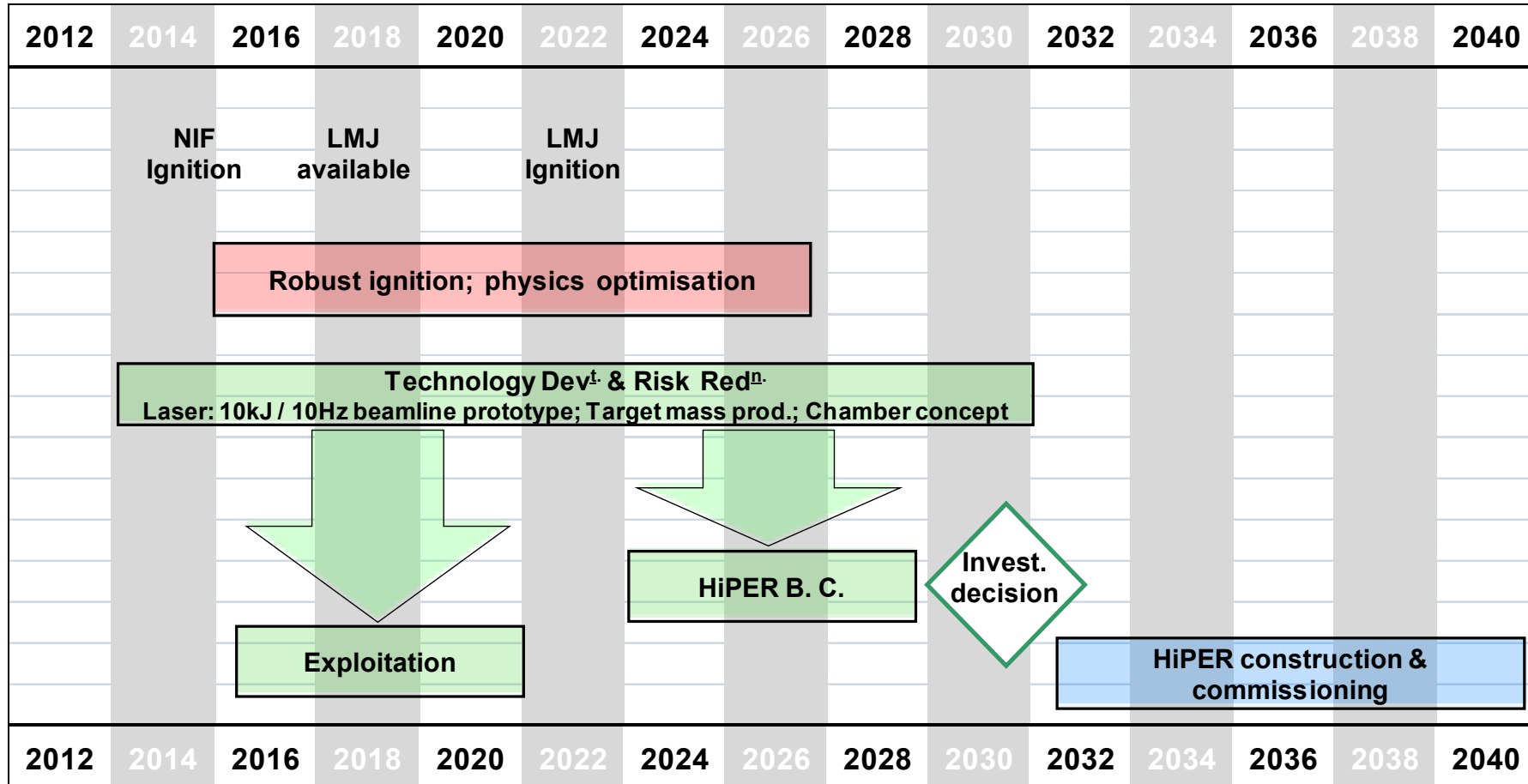


Cost ~ \$2BEuro
European LFE 10Hz
Demo plant proposal

European Inertial Fusion Energy Roadmap

A 2013-2020 roadmap towards Inertial Fusion Energy based on a 2007-2012 watching brief

The Consultative Committee for the EURATOM specific research and training programme in the field of Nuclear Energy (CCE-FU) endorsed in 2007 continuation of the keep-in-touch (KiT) activity over civilian research activities in inertial confinement fusion for energy (IFE), as part of the Annual Work Programmes of the involved Associations. To monitor this KiT activity, the CCE-FU set up the *Inertial Fusion Energy Working Group* (IFEWG) from whom annual Watching Briefs, as well as in-depth proposals, are requested.



Alberta Fusion Presence

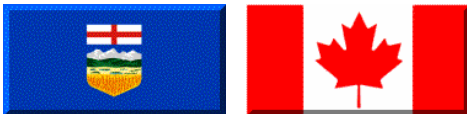
- **Alberta/Canada Fusion Technology Alliance**
 - Formed in May 2016
 - Group members instrumental in assessing the status of fusion for the Alberta Government with several reports in the past decade
 - Have prepared a \$27M proposal for building expertise and capacity in Inertial fusion energy to be presented to the Alberta Government
- **University of Alberta**
 - one of the strongest Research and Engineering Universities in Canada
 - strong existing background capabilities in many relevant areas
 - recent approval to hire 4 new faculty positions in the laser/plasma/fusion area in support of a fusion energy thrust
 - current and past MOU's with relevant international partners
- **Province of Alberta**
 - sees itself as an energy leader province
 - very strong engineering and large project management infrastructure

Alberta Council of Technologies Study Presented to Alberta Energy – March 31, 2014

STATUS OF FUSION ENERGY
Impact & Opportunity for Alberta

Volume I

Summary



Prepared by

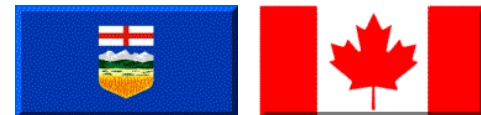


Alberta/Canada Fusion Energy Program

STATUS OF FUSION ENERGY
Impact & Opportunity for Alberta

Volume II

Appendices



Prepared by



Alberta/Canada Fusion Energy Program

Alberta Capacity Building Proposal

- **Led by Alberta/Canada Fusion Technology Alliance**
- **\$27M five year program (\$24M provincial, \$3M UofA)**
- **Develop expertise in relevant areas for inertial fusion energy (lasers, advanced ignition, diagnostics, targets)**
- **HQP development – 4 Faculty, 15 PDF/RAs, 15 Grad Students**
- **Diagnostic and technology development to support participation in collaborative experiments around the world**
- **Annual workshop and public forums**
- **Position Canada for participation in eventual IFE demo power reactor**
- **Significant technology spinoff potential expected**

Fusion 2030 Program Proposal

- **\$46M five year program to develop world class infrastructure to support an inertial fusion energy program**
- **Laser Driver Development (\$14.9M)**
 - High Efficiency, High repetition rate diode pumped laser driver development at the 100J, 1 Hz and 1kJ one shot per minute level
- **Laser Plasma Interaction and Materials Testing Facility (\$26.3M)**
 - Laser-Plasma Interaction Facility for Advanced Ignition Studies, Diagnostic Development, and Fusion Reactor Materials Testing
 - 1kJ 1-10ns laser and 500TW 20fs laser plus target facilities
 - Nanoscale materials testing facility: high energy plasma, x-rays, MeV electrons, protons, and neutrons
- **Advanced Shock Ignition Studies (\$4.9M)**
 - Collaborate with international efforts to demonstrate shock ignition under reactor scale conditions

The Way Forward - Laser Fusion

- Fusion is Coming! (whether we are part of it or not)
- NIF has a reasonable probability of reaching ignition by 2020 via indirect drive
- Direct Drive scaling is neck and neck with NIF and also has high chance of showing conditions equivalent to scaled ignition by 2020
- Major DOE review of laser fusion program in 2020 to decide on next steps – possible next generation demo system
- HiPER in the winds in Europe
- China and Russia also building Laser Fusion capabilities

Questions and Discussion

UofA Fusion Related Expertise

- **ECE Department (Engineering Physics Program)**
 - Robert Fedosejevs – Lasers, Advanced Ignition, X-ray and particle diagnostics
 - Ying Tsui – High Energy Density Physics, Advanced Ignition
 - Allan Offenberger – Emeritus Professor
 - ***Approval to expand with 4 new faculty positions in the Laser/ Plasma/ Fusion area***
- **Physics Department**
 - Strong Computational Plasma Physics Group – Wojciech Rozmus, Rick Sydora, Richard Marchand and Robert Rankin
- **Materials Science**
 - Strong materials science research community
 - World class nanofab capabilities, National Institute of Nanotechnology, Surface Science Centre and local MEMS companies (Micralyne, Applied Nanotools, Norcada, Precisely Microtechnology,...)

NIF - LIFE



OXFORD ECONOMICS

The Economic Impacts of LIFE

USA Direct Fusion Related Impact

- 152,200 – 417,400 jobs
- \$17.7 - \$47.7 billion GDP

Much larger indirect spinoff
and world impact expected

November 2012

<http://www.oxfordeconomics.com/my-oxford/projects/129038>

Next Steps – Fusion 2030

PROPOSED CANADIAN FUSION PROGRAM

