Laser Fusion in Canada

Robert Fedosejevs

Department of Electrical and Computer Engineering
University of Alberta
And
Alberta/Canada Fusion Technology Alliance

Presented at the Fusion Forum
Edmonton, November 4, 2017

Canadian Laser Fusion Research (1970's - present)

The major Laser Fusion related research groups in the past were

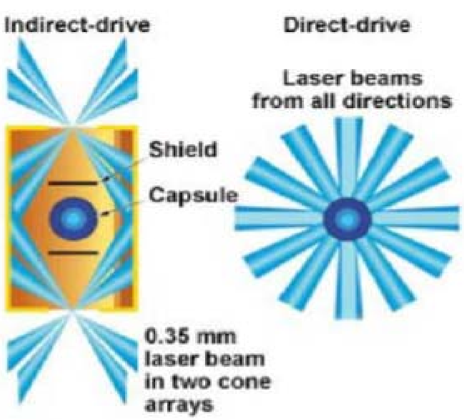
- **National Research Council of Canada** – nanosecond carbon dioxide and solid state laser plasma studies (1972 – 1990)
- University of British Columbia – carbon dioxide and solid state laser plasma studies (~1973 – 2000)
- **INRS Quebec** - carbon dioxide laser plasma studies (~1973 – 2000)
- **University of Alberta** – nanosecond to sub picosecond carbon dioxide, krypton fluoride and solid state laser plasma studies (~1973 - present)

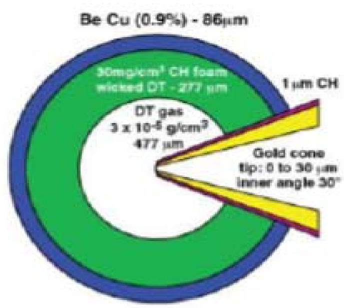
UofA Research Currently Focused on New Concepts for Laser Fusion

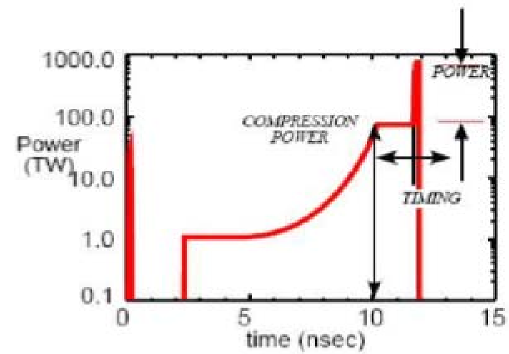
Traditional Concepts

New Concepts - Separate Ignition Pulse (Fast Ignition)

Central Ignition | **Fast Ignition** | **Shock Ignition**

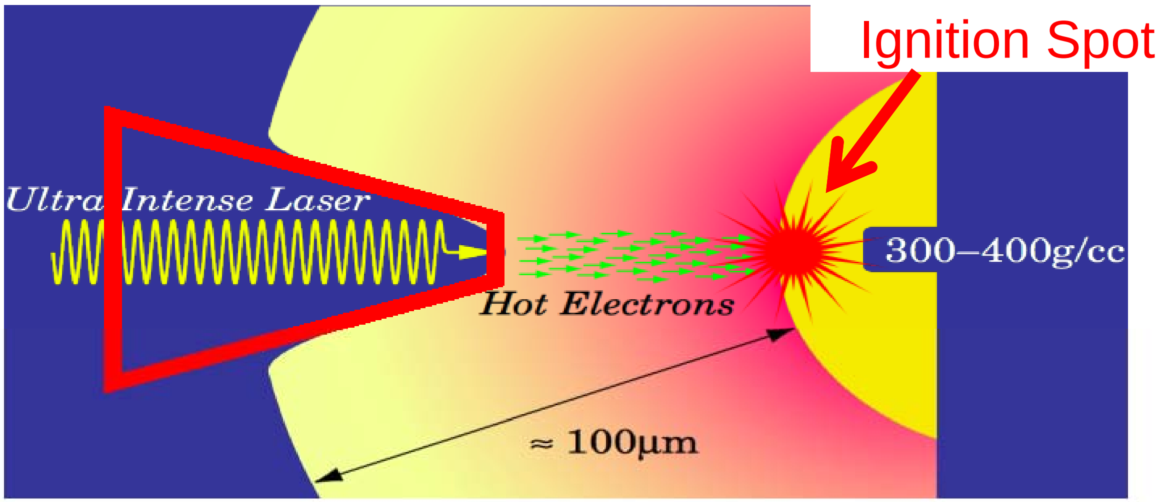






New concepts would require much lower laser driver energy

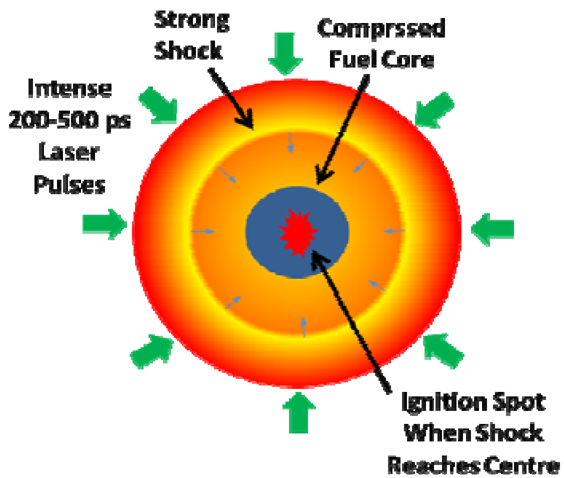
New Concept Fast Ignition

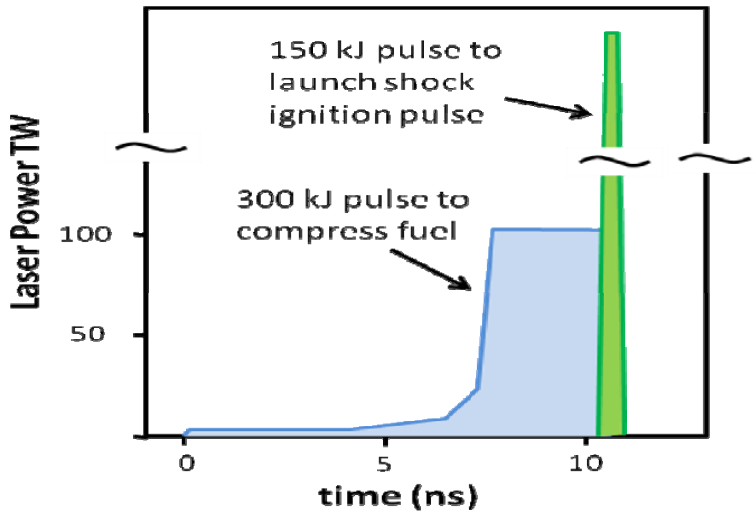


Laser cannot penetrate into the core

Therefore deliver energy in the form of MeV electrons or ions driven by ultra-intense short pulse laser

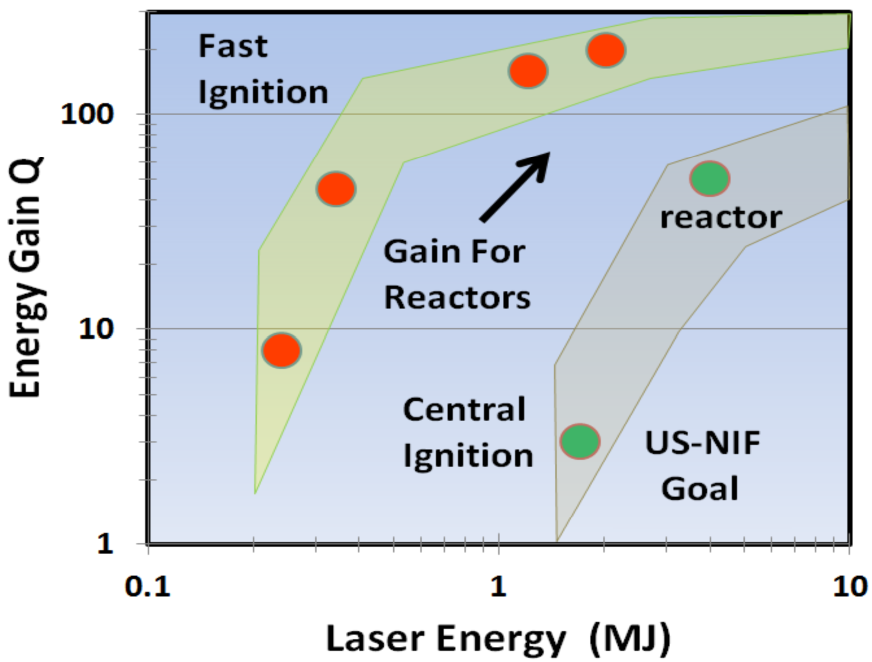
New Concept - Shock Ignition





- Strong shock at the end of the compression pulse causes ignition of compressed fuel core - recently proposed in detail in 2007

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 energy requirements approximately 5 times:

Smaller and less expensive initial IFE reactors possible

UofA Past Research on Laser Fusion (1970's - present)

High power carbon dioxide laser development

- 500 J 10's of nanosecond duration electron beam assisted discharge laser to study laser heated solenoids
- Some of the first observations of Laser-Plasma Instabilities

Short pulse UV laser development (Alberta government funded project)

- Few joule subnanosecond electron beam pumped laser development using nonlinear optical techniques
- Some of the first studies of high hydrodynamic drive efficiency and high x-ray generation efficiency using UV lasers
- Laser-plasma interaction studies using UV laser pulses
- Major laser fusion programs all switched to UV lasers

Early Observation of Raman Instability

VOLUME 49, NUMBER 6 PHYSICAL REVIEW LETTERS 9 AUGUST 1982

Stimulated Raman Backscatter from a Magnetically Confined Plasma Column

A. A. Offenberger, R. Fedosejevs, W. Tighe, and W. Rozmus[a]

Department of Electrical Engineering, University of Alberta, Edmonton, Alberta T6G 2G7, Canada

(Received 28 December 1981)

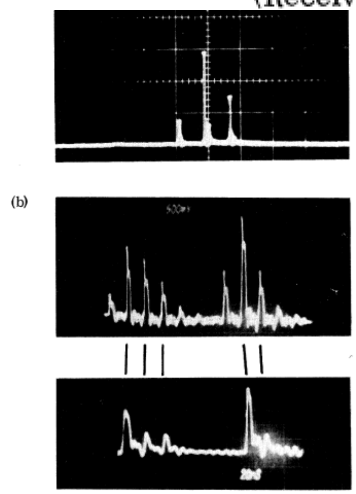


FIG. 1. Oscilloscope traces of corresponding input CO_2 (upper trace) and Raman backscatter (lower trace) pulses (a) at 200 ns/division and (b) for a different shot in the tail of the CO_2 laser pulse at 20 ns/small division.

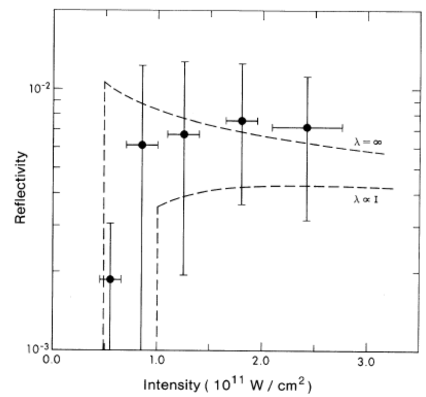
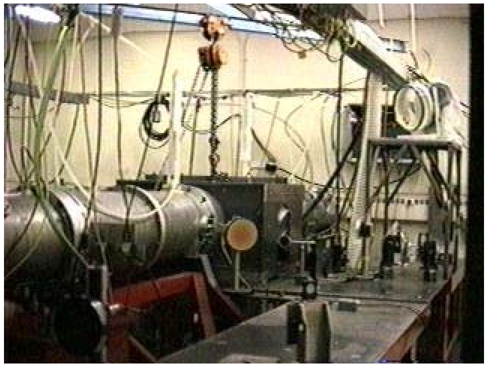
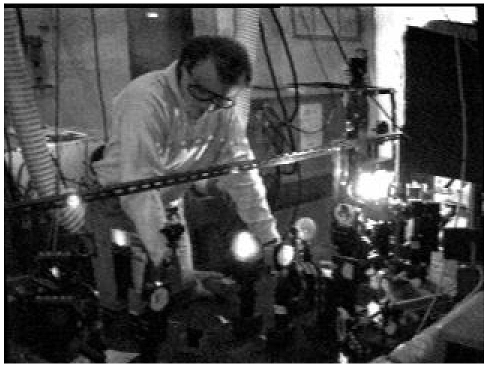
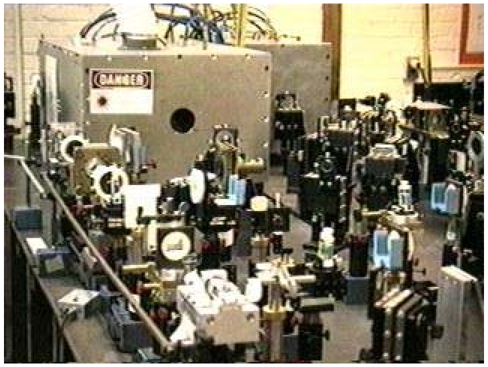


FIG. 2. Raman reflectivity as a function of incident intensity. The circles represent the average measured reflectivities from numerous laser shots with error bars showing the standard deviation for each averaged set of data. The lines represent theoretical curves for a saturated finite inhomogeneous absolute instability: upper curve for $\lambda = \infty$ and lower curve for $\lambda = (9.83 \times 10^{-12}\ \mathrm{cm^2/W})I$.

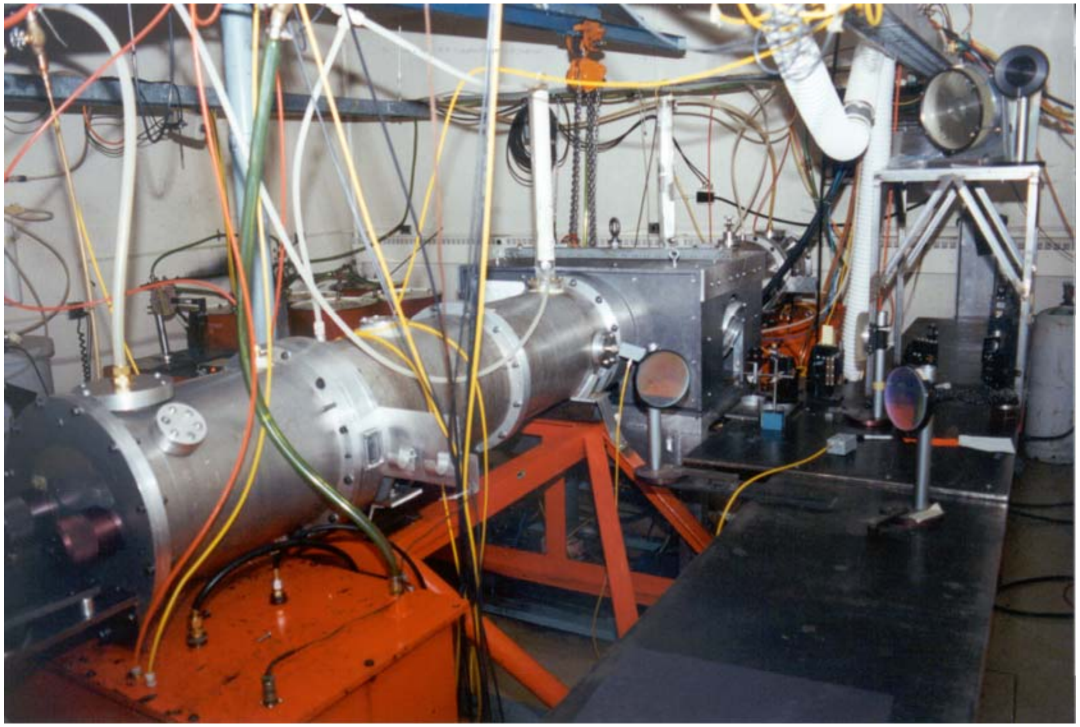
University of Alberta Excimer Lasers







University of Alberta
Electron Beam Pumped Laser



UofA Past Research on Laser Fusion (1970-present)

Picosecond and Femtosecond pulse UV Laser Development

- Development of picosecond and sub picosecond UV laser systems
- Demonstration of high efficiency x-ray generation for x-ray lithography
  – First 100nm linewidths written using x-ray lithography in Canada (1995)

Collaborative high power laser experiments at the LLNL Petawatt laser facility

- First characterization of electron generation for Fast Ignition at 527 nm wavelength indicating good scaling but requirement for electron collimation

UofA Past Research on Laser Fusion (1970-present)

Collaborative high power laser experiments at the LLNL Petawatt laser facility (cont'd)

- Shock ignition studies of deleterious high energy particle generation indicating need for some high energy particle shielding in target designs
- Proton generation studies relevant to proton driven Fast Ignition

80 Terawatt laser experiments at the Advanced Laser Light Source (ALLS) located at INRS Montreal

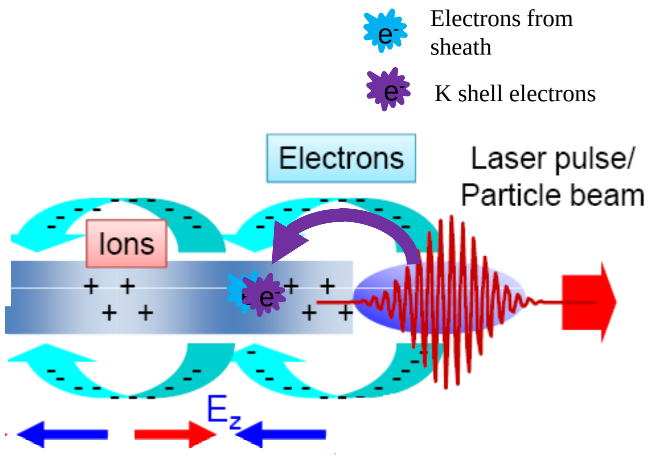
- First demonstration in Canada of laser acceleration of electrons up to GeV energies

Wakefield Acceleration of Electrons

Self-injection: injected electrons directly from electron sheath;
Typical gas: He and H_2
Approximate Injection Threshold: $a_0 \geq 2\text{-}3$ [1].

Ionization-induced injection: electrons from the K shell of tracer atoms formed at the peak of the laser field and inside the bubble whereas L shell forms in the sheath.

Typical gas: He mixed with N_2 or CO_2
Approximate Injection Threshold: $a_0 \geq 1.6$ [2].



1. F. S Tsung, et al., PRL, **93**,185002(2004).
2. A. Pak, et al., PRL, **104**, 025003(2010)

UofA Past Research on Laser Fusion (1970-present)

Collaborative experiments at ALLS (Montreal), the Stanford Linear Accelerator Laboratory (Stanford) and Centre for Pulsed Lasers (Spain)

- Studies of material properties at extreme densities and pressures as in compressed fusion fuel pellets and stellar and planetary interiors

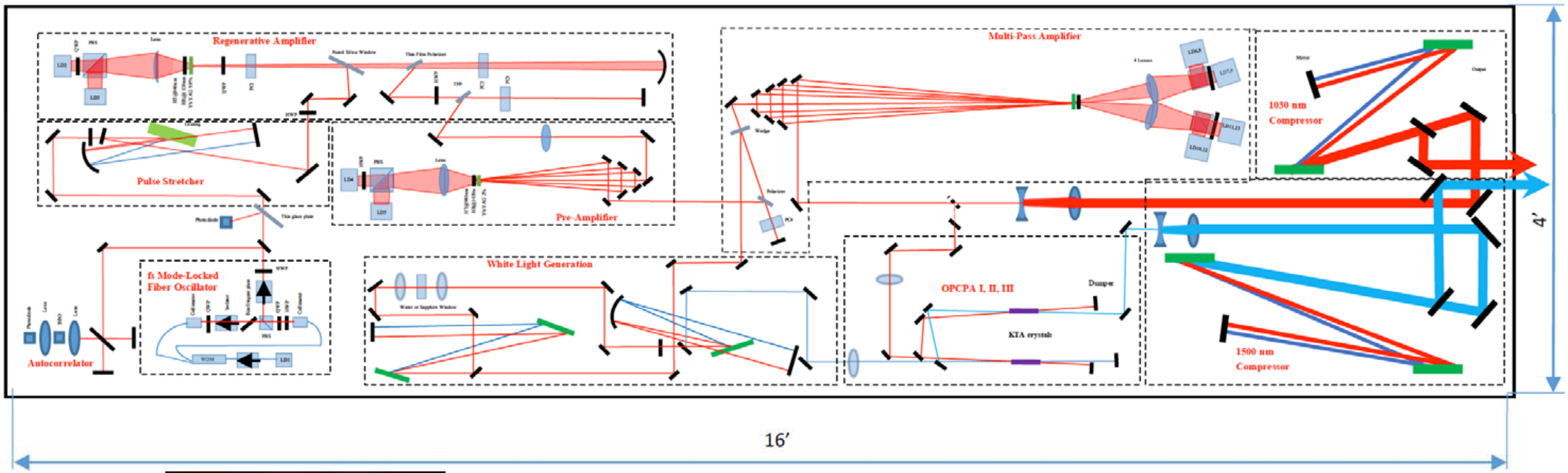
Collaborative studies with the Universidad Politécnica de Madrid

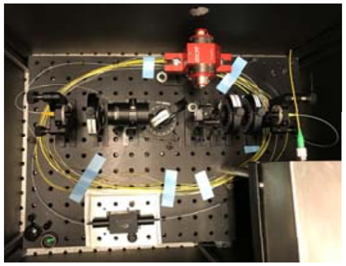
- Theoretical study of the gain enhancement using spin polarized tritium and deuterium fuel

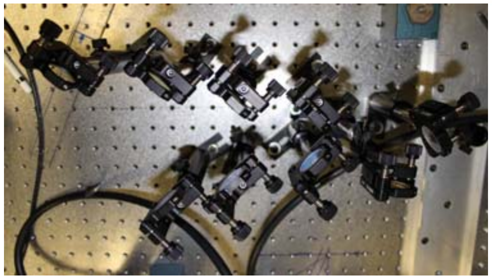
Terawatt diode-pumped Laser development

- Design and development of high efficiency Terawatt class diode pumped picosecond ceramic crystal based laser system – prototype technology for laser fusion driver systems

Terawatt Diode-Pumped Laser development







UofA Current 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
  - Manisha Gupta – Optical and X-ray Diagnostics
  - Jason Myatt – Leading expert on theory and simulations of laser fusion processes
  - Allan Offenberger – Emeritus Professor
  - ***Approval to expand with 3 additional 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, etc.)

Many External Linkages

- Laser Plasma Science
  - Canada - U of T, U Laval, U of O, INRS
  - USA – LLLNL (Livermore), LLE (Rochester), NRL (Washington), SLAC, UCSD
  - Other International – RAL (UK), LMJ, LULI, U.Bordeaux (France), ILE (Japan) CLPU(Spain), DESY (Germany)
- Materials and Targetry
  - Canada – NINT, U Laval, other Canadian Fusion labs
  - USA – LLLNL, LLE (Rochester), ORNL
  - Other International – RAL (UK), LMJ (France), ILE (Japan), CLPU(Spain)
- Industrial
  - Canada – INO, Micralyne, Applied Nanotools, Norcada, Precisely Microtechnology, other robotics and optical companies
  - International – General Atomics, Route des Lasers (Bordeaux)
  - Potential spinoff technologies – laser manufacturing, radioisotope production, medical applications, precision optics, target manufacturing, advanced coating materials, etc.

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

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Alberta/Canada Fusion Energy Program

Alberta Capacity Building Proposal

- **Led by Alberta/Canada Fusion Technology Alliance**
- **$25M five year program ($23M provincial, $2M 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

- **$50M Federal funding for five year program to develop world class infra-structure to support an inertial fusion energy program**
- **Laser Driver Development ($18M)**
  - High Efficiency, High repetition rate diode pumped laser driver development at the 100J, 10 Hz
- **Laser Plasma Interaction and Materials Testing Facility ($27M)**
  - Laser-Plasma Interaction Facility for Advanced Ignition Studies, Diagnostic Development, and Fusion Reactor Materials Testing
  - 1kJ 1-10ns laser together with 500TW 20fs laser plus target facilities
  - Nanoscale materials testing facility: high energy plasma, x-rays, MeV electrons, protons, and neutrons
- **Advanced Shock Ignition Studies ($5M)**
  - 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
- HiPER in the winds in Europe
- China and Russia also building Laser Fusion capabilities

Questions