Fusion Energy – Status and Prospects

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Context for Today's Discussions

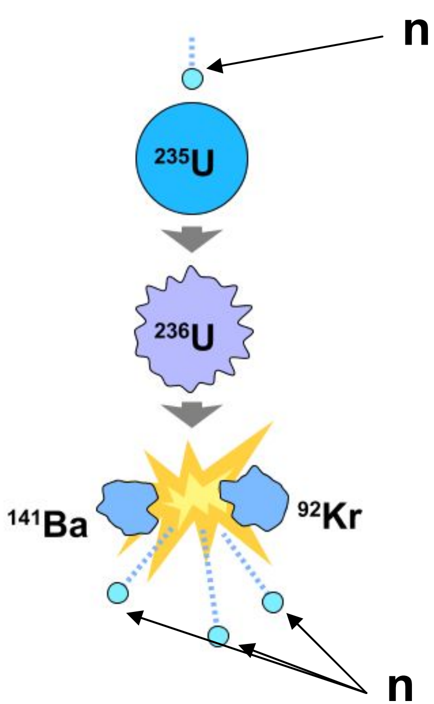
- Fusion energy will become important by mid-century (2050) or sooner (excepting Canada, much of the world is involved)

- Rationale for Alberta involvement in fusion energy development: (i) fusion as a GameChanger; (ii) implications and opportunities for Alberta

- Ways and Means for Alberta involvement (government, industry, R&D institutions) – clean energy, enabling technologies, capacity building, leverage global investment, world's first demo plant

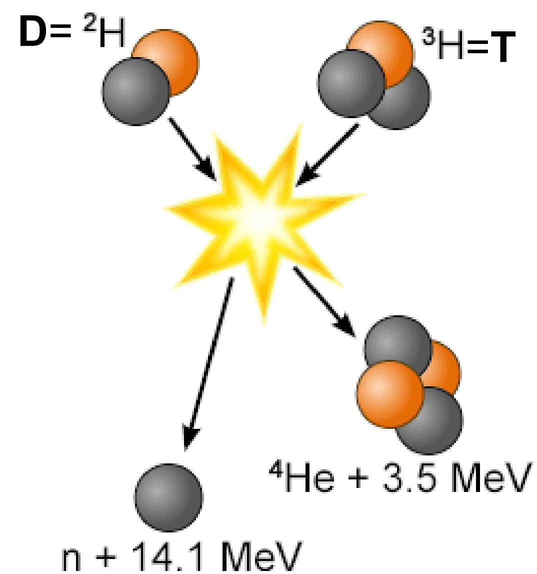
What is Fusion (vs Fission) Energy?

Fission of heavy elements



Energy +
radioactive daughter nuclei

Fusion of light elements



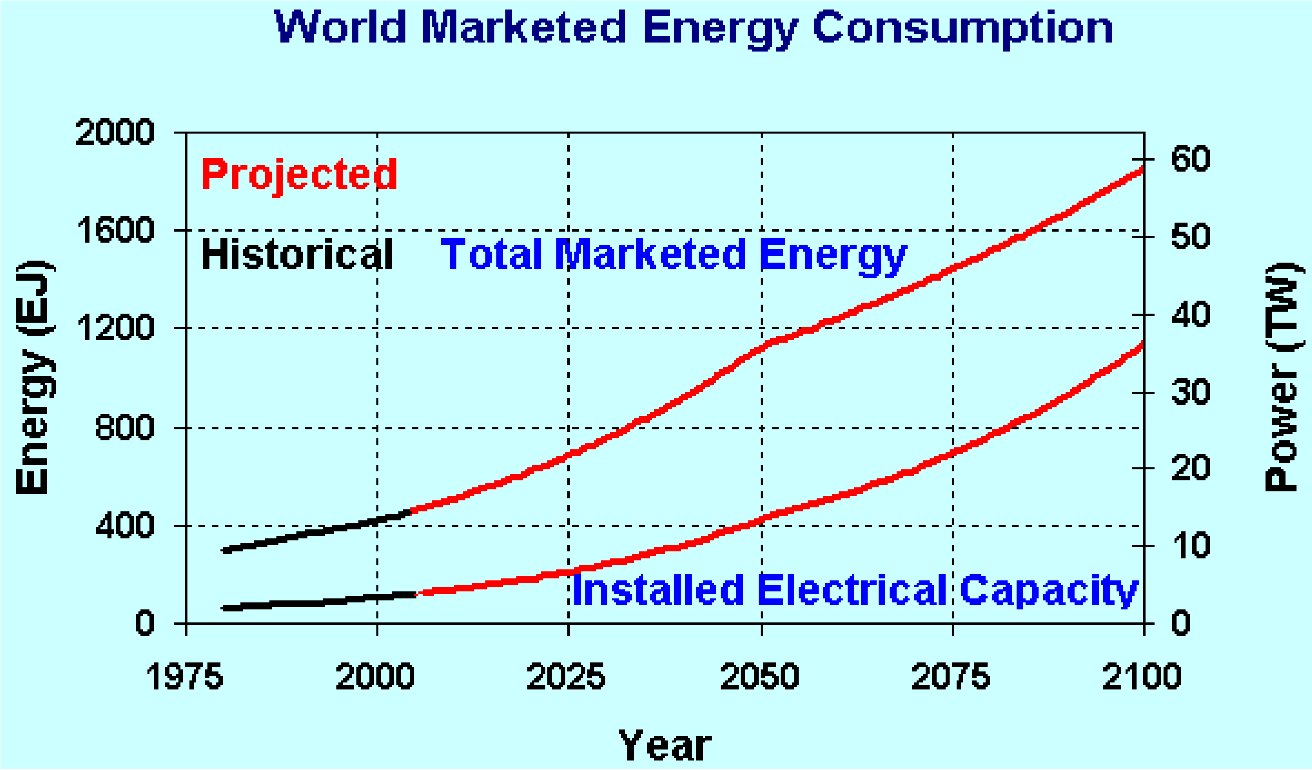
(Li + n → T + He)

Energy +
non-radioactive daughter nuclei

Why is Fusion Energy Important?

- **Increasingly, electricity is energy currency: (~40TW by 2100)**
- **Fusion is one of few sustainable, non-carbon solutions for fueling central power plants – major economic impact**
  - fission (sustainable only with fuel breeding, leaves waste)
  - fusion (sustainable, primary energy source, electricity/heat/H_2)
  - renewables (sustainable, secondary energy source)
- **Fusion applications**
  - base-load electric power generation
  - heat for thermal/chemical processing, etc.
  - production of hydrogen/synthetic fuels
  - desalination of sea-water
  - clean-up fission waste (transmutation of radioactive nuclides)

Why is Fusion Energy Needed?



Why is Fusion Energy Desirable?

- **Virtually inexhaustible fuel supply** (D in water and Li on land and sea to breed T)
- **No GHG or air pollution** (He^4 is the only "ash")
- **No long-lived radioactive products as for fission**
- **No risk of nuclear accident** (no public evacuation in vicinity of plant)
- **Fusion consumes less fuel mass per unit energy than any other source** (less resource investment, easy fuel deliverability)
- **Less environmental impact** (finding, producing, consuming)

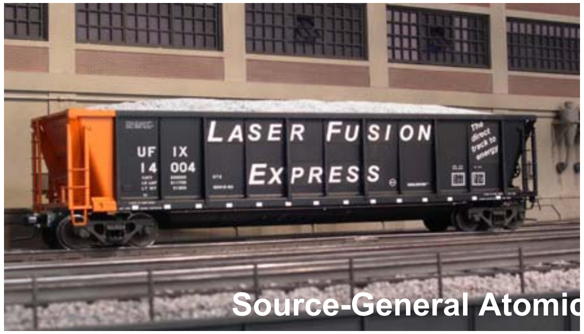
- **In summary- fusion can provide universal, abundant, clean energy**

Fuel/Waste Processing Comparison

Daily fuel consumption & waste production for 1GWe plant

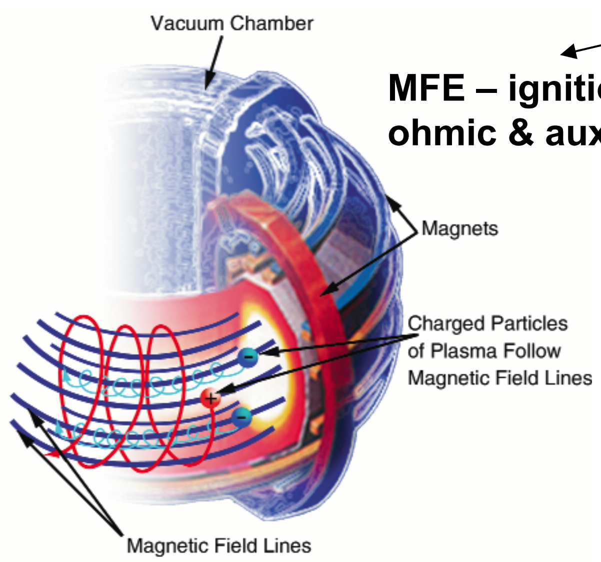
	Coal plant	Fission plant (U)	Fusion plant (D,T)
Fuel	~ 10,000T	~77kg	~ 0.27kg D ~ 0.82kg Li^6 (0.41kg T)
Waste	~ 30,000T CO_2 ~ 600T SO_2 ~ 40T NO_x ~ 600T fly ash	~77kg	~ 1.09kg He ("ash") **(advantage fusion)**

Hopper filled with coal – 10-20 min fuel
Filled with fusion targets – 7 years fuel



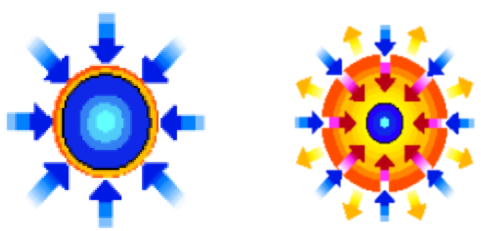
Why is Fusion Difficult?

- **Need high temperature for ignition:** $T_{ign} \geq$ **100 million deg C**
- **Need confinement for net energy out:** $n\tau >$ **2x10**^{20} **m**$^{-3}$ **sec**
- Burning occurs when heating is self-sustained (by helium from fusion)
- Two confinement approaches: (i) **magnetic (MFE)**; (ii) **inertial (IFE)**



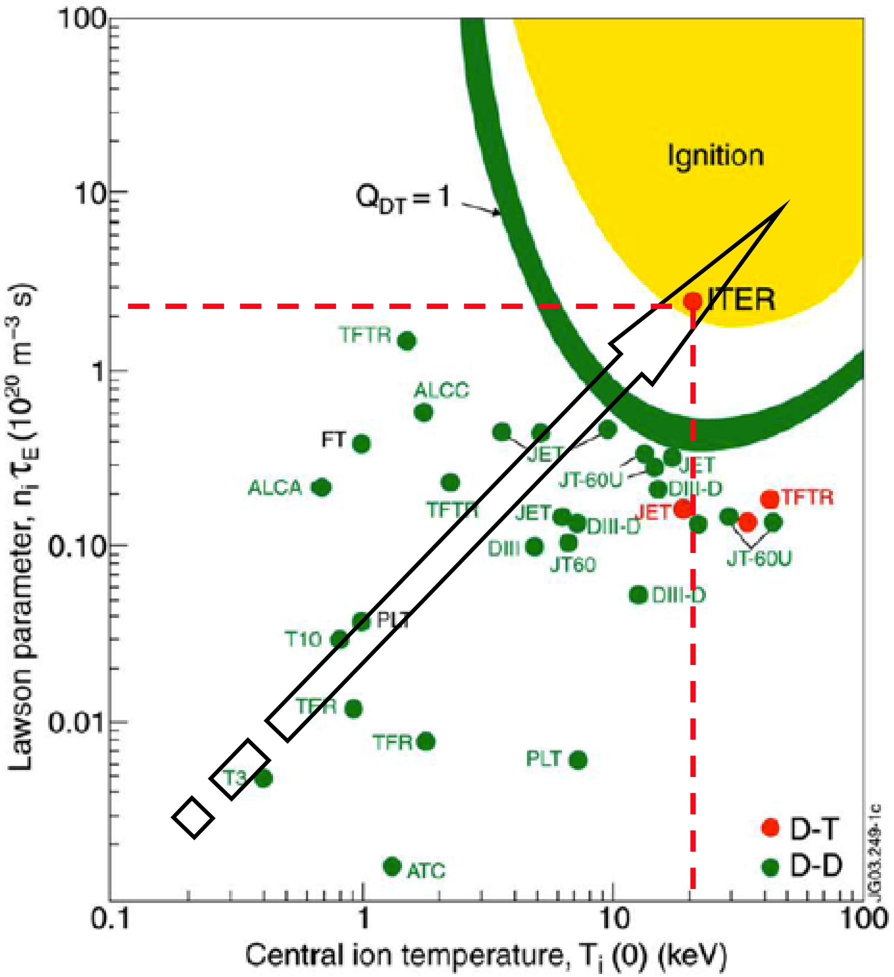
MFE – ignition requires ohmic & auxiliary heating

IFE – ignition requires driver beams to heat & compress target



Fuel Burn

Magnetic Fusion – Progress



International Tokamaks

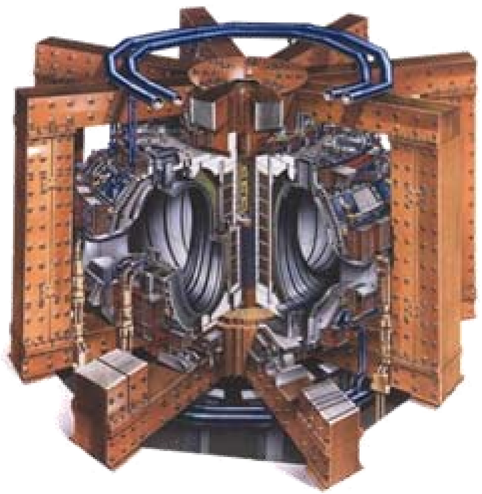
Iter "The way" in Latin

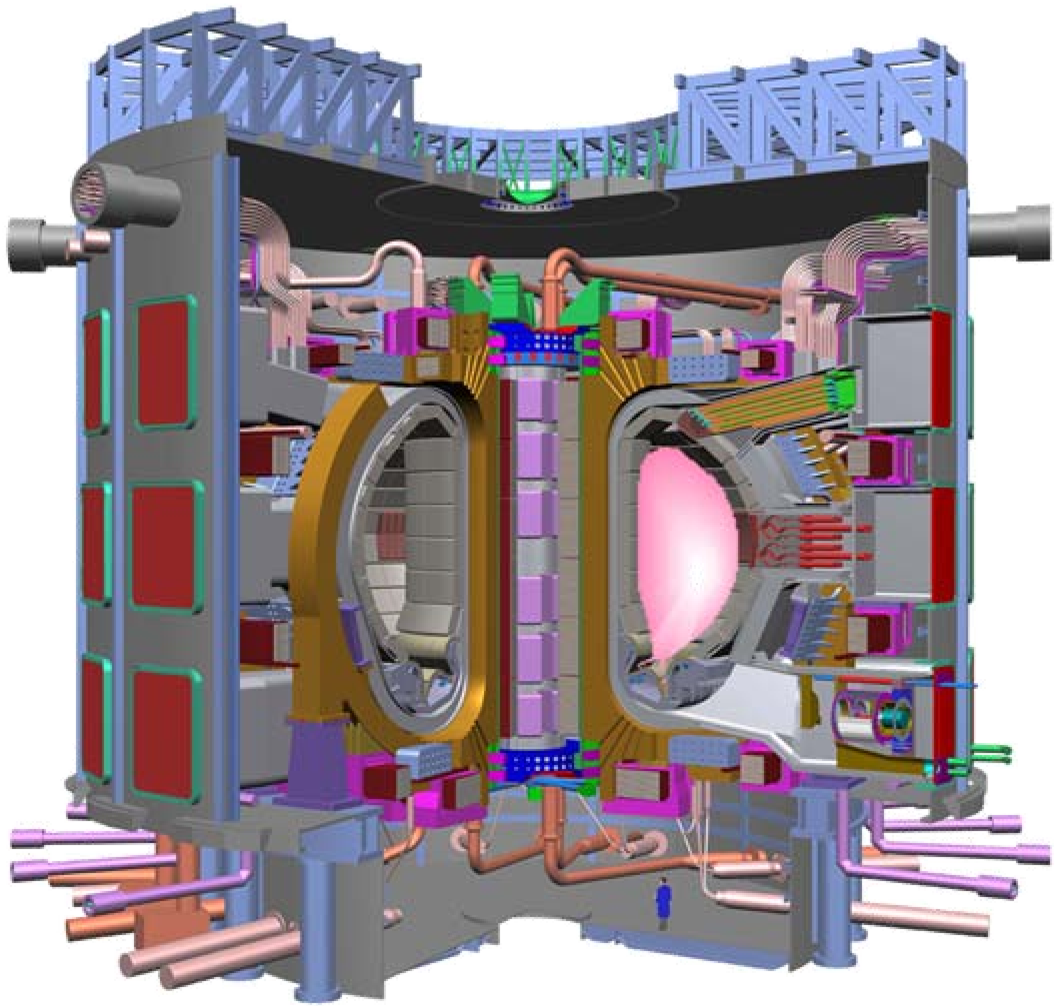
ITER explores the region of high gain (Q>5) and ignition

MFE - Tokamaks (JET & ITER)

ITER – 1,000 m^3
P = 500 MW; Q=10
τ=400 sec

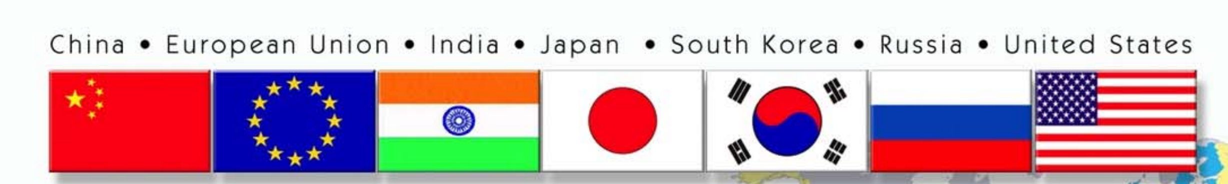
JET – 100 m^3
P = 16 MW; Q=0.65



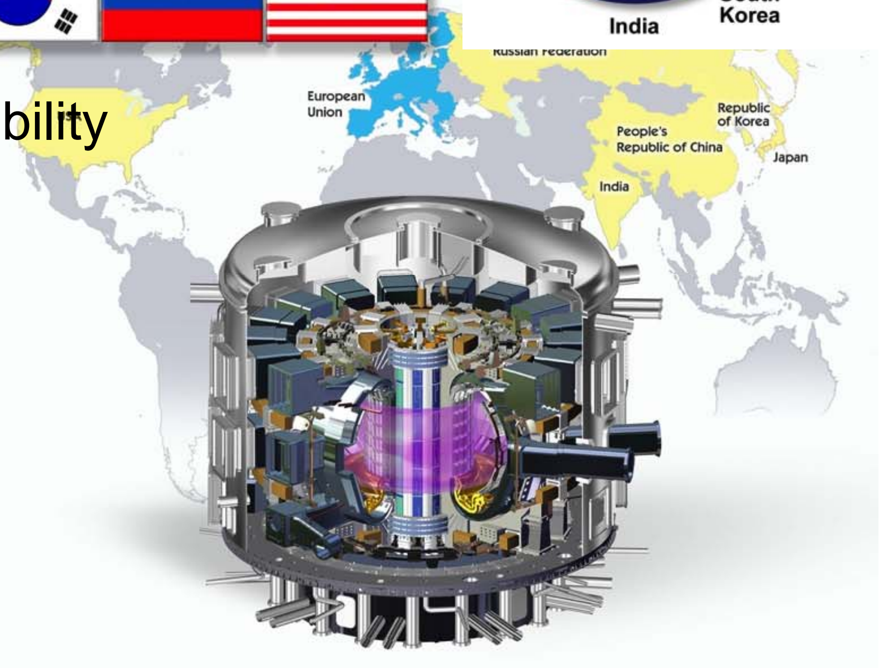


ITER – Global Initiative

Partnership: Seven signatories jointly responsible for construction and operation



Mission: Demonstrate the feasibility of fusion energy

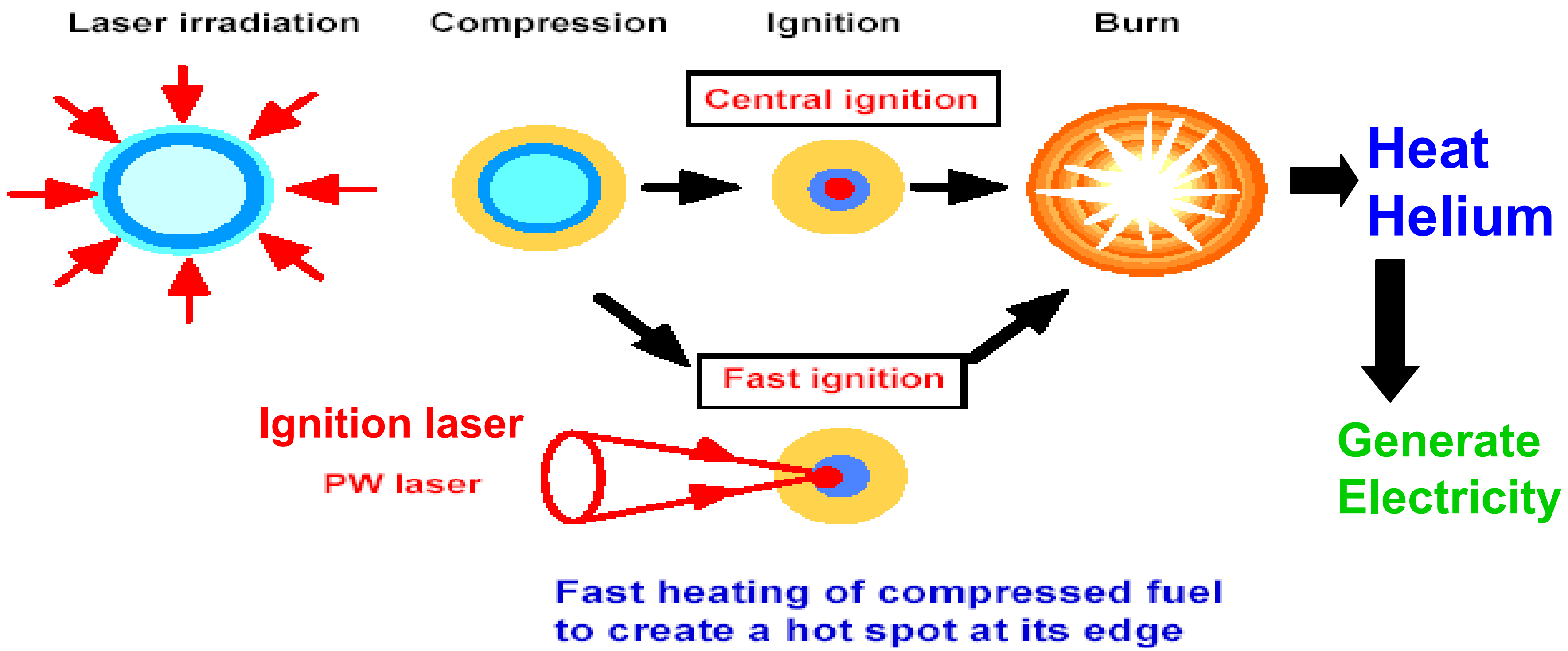


Tokamaks - ITER Timeline

- **Commission in 2022** – ITER plasma experiments until late 2027
- **D,T burning** (fusion) experiments in late 2027, early 2028
- Operate ITER as a fusion experiment for ~10-12 years
- Design and build **DEMO in 2040-2050** period – power to the grid
- Design and build auxiliary devices for material science studies
- **China has 2030’s objective** for fusion power plant – push timeline

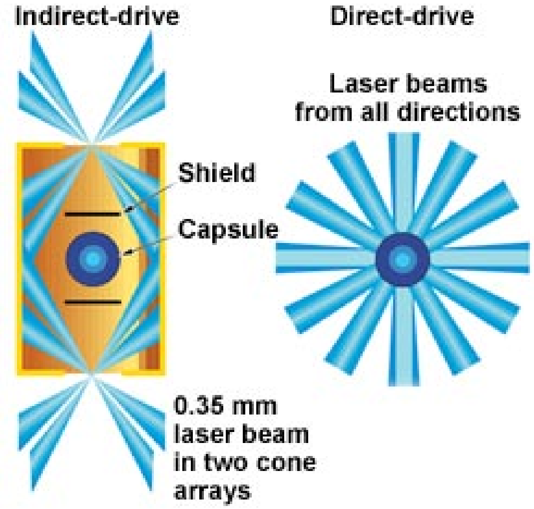
How Inertial Fusion Works

Direct drive pathways – central and fast/shock ignition



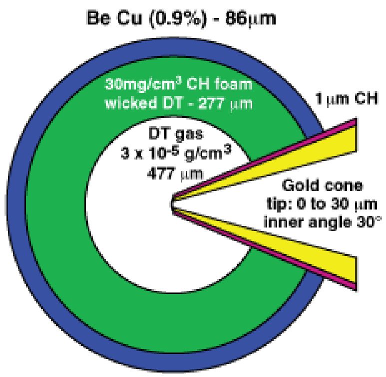
IFE – Some Approaches

Central Ignition



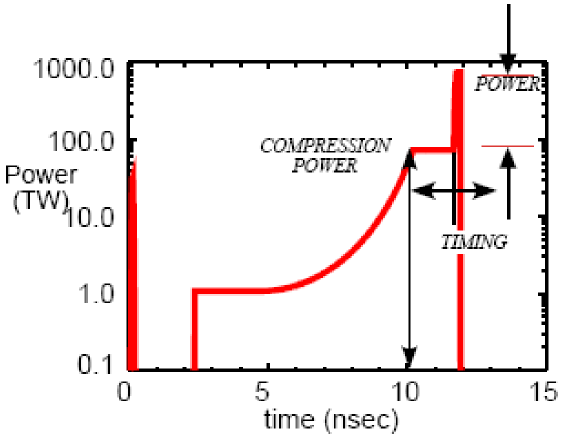
Uses shaped laser pulse

Fast Ignition



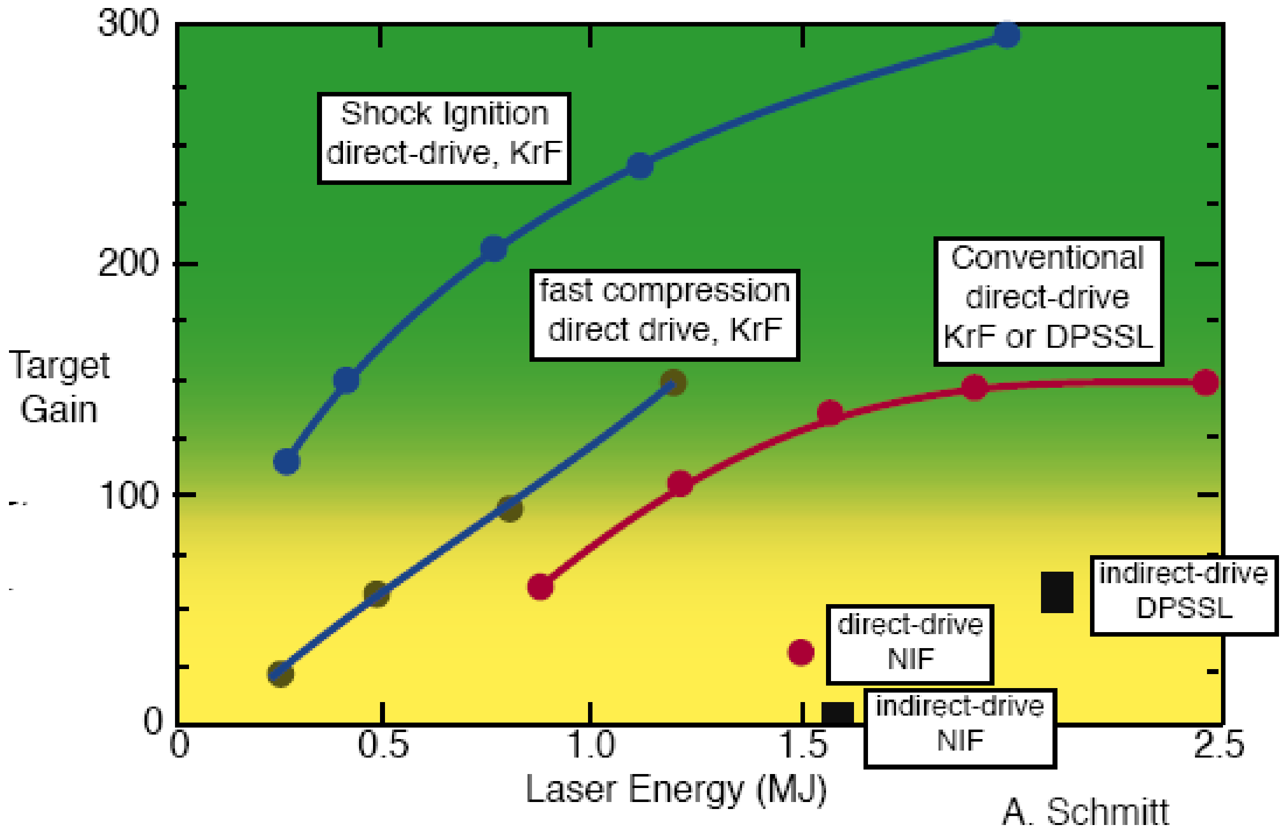
Uses PW, ps pulse

Shock Ignition



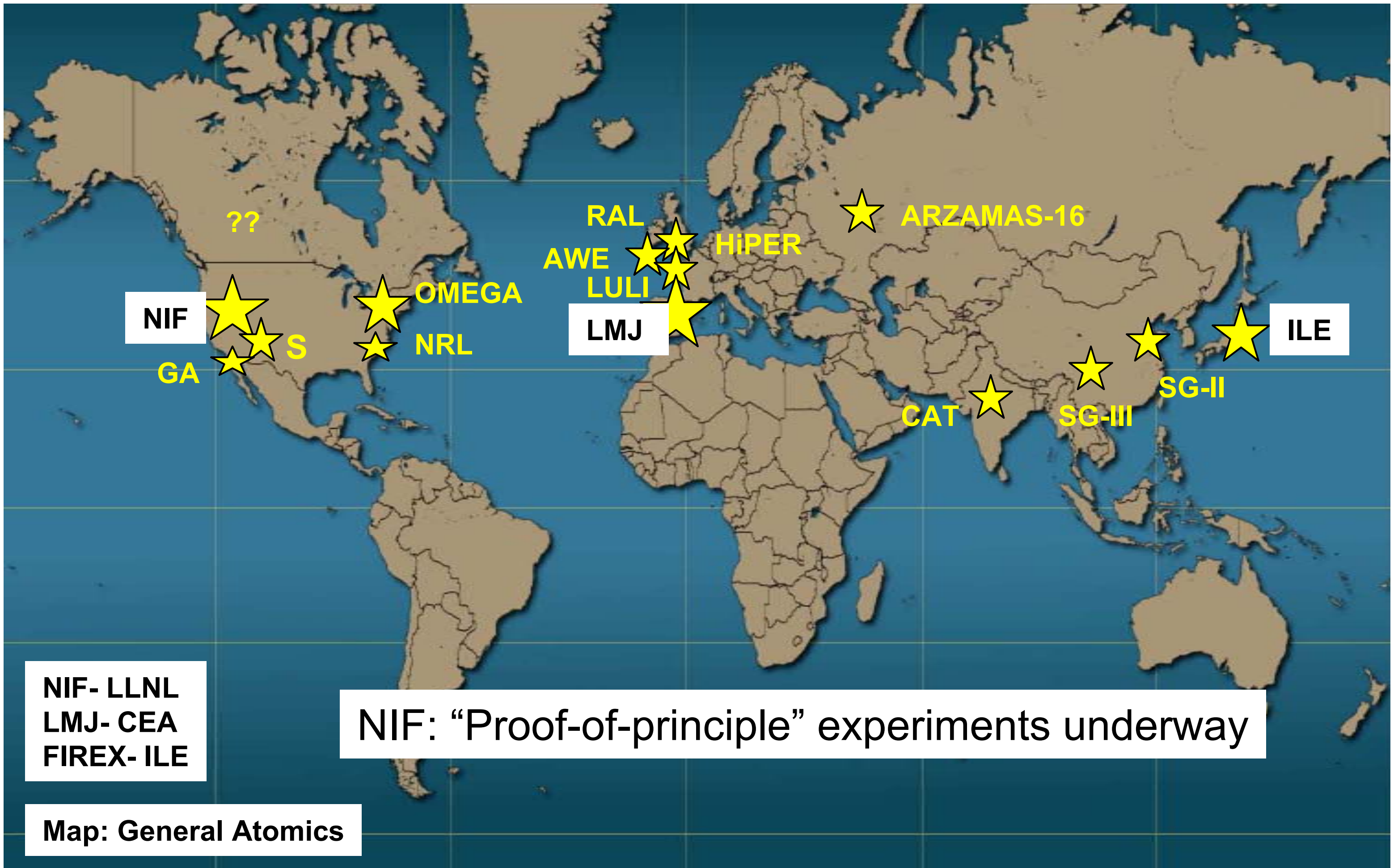
Uses high power peak at end of shaped pulse

Potential Economic Implications



Laser driver is a major capital cost item

Inertial Fusion - Global Initiative



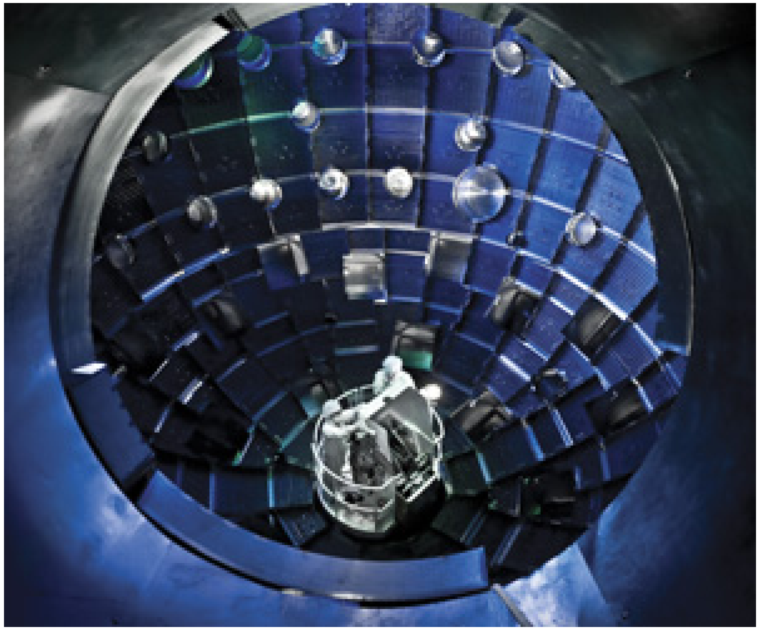
National Ignition Facility (NIF)

National Ignition Facility (NIF)

Advanced solid state lasers will reduce the footprint > 10 times

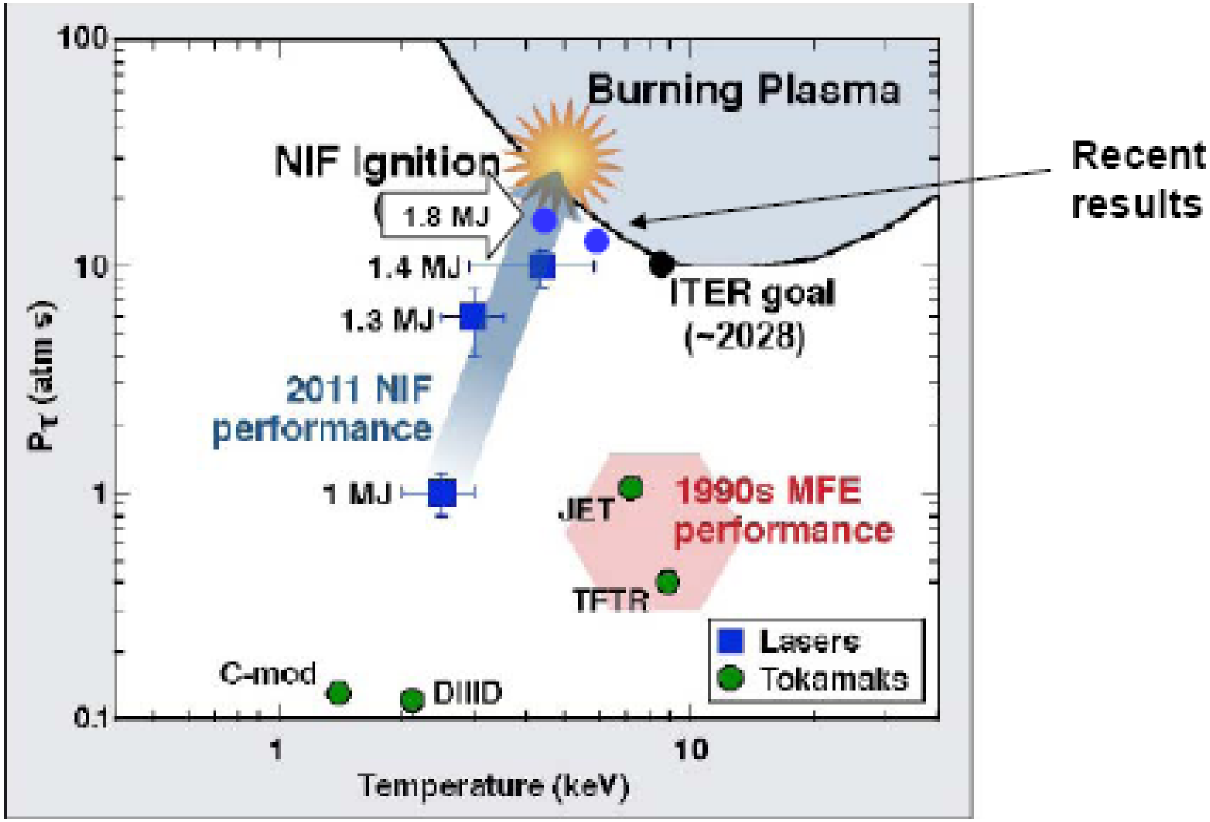
NIF Laser Bay/Target Chamber

View of 1 of 2 laser bays
192 laser beams; 1.8MJ; 500TW



Target chamber – 10m diameter

Inertial Fusion - Progress



Status of USA Program in IFE

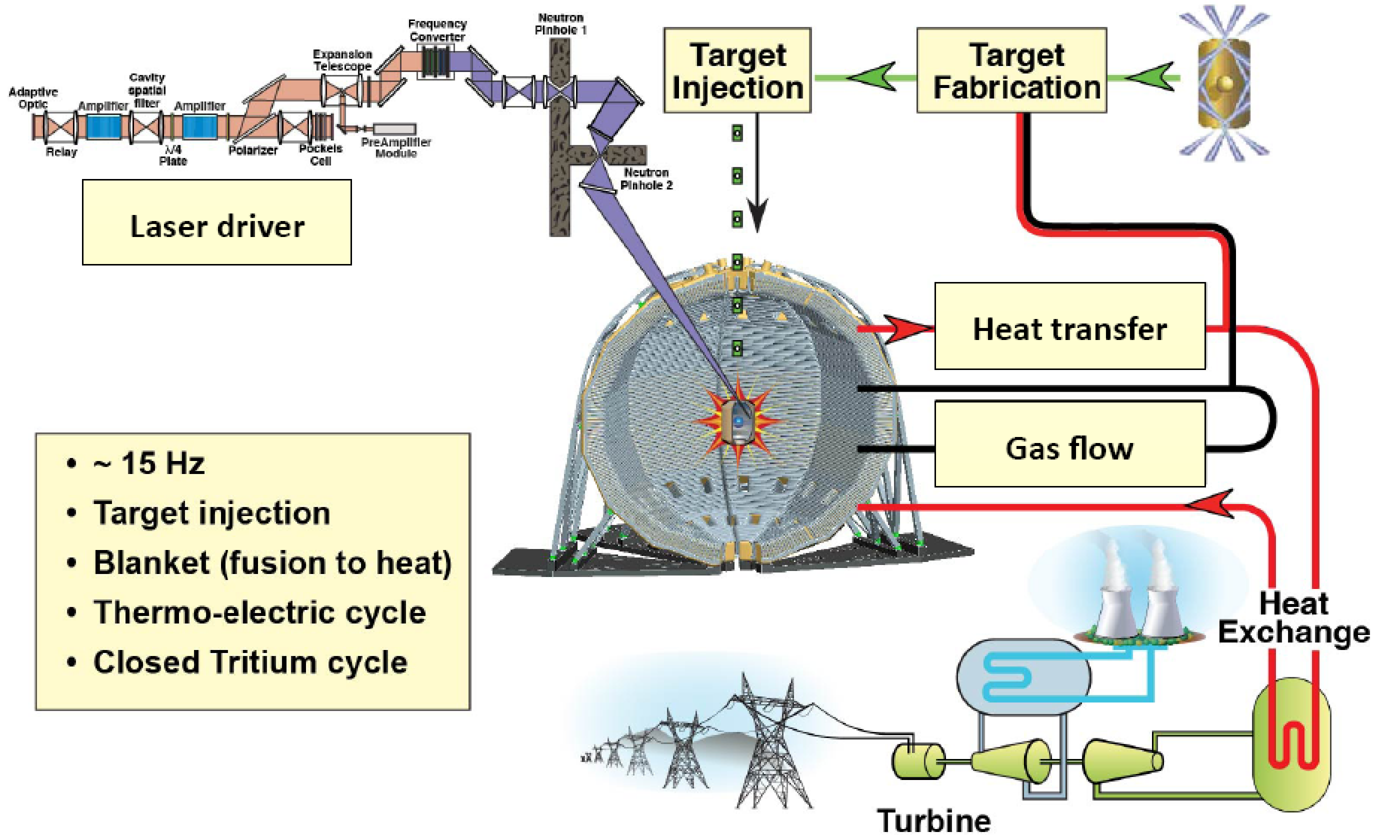
- **NIF in operation**
  - campaign of "single-shot" experiments underway (watch for "front-page" news)

- **Fusion power (LIFE) planning with utility/industry input**
  - major utilities engaged to determine end-product
  - 30+ major vendors engaged to provide delivery/cost for high plant availability (modular, factory built design)

- **LLNL projects LIFE power demonstration in 10 years, commercialization in 20** – develop "rep-rate" system (next step)

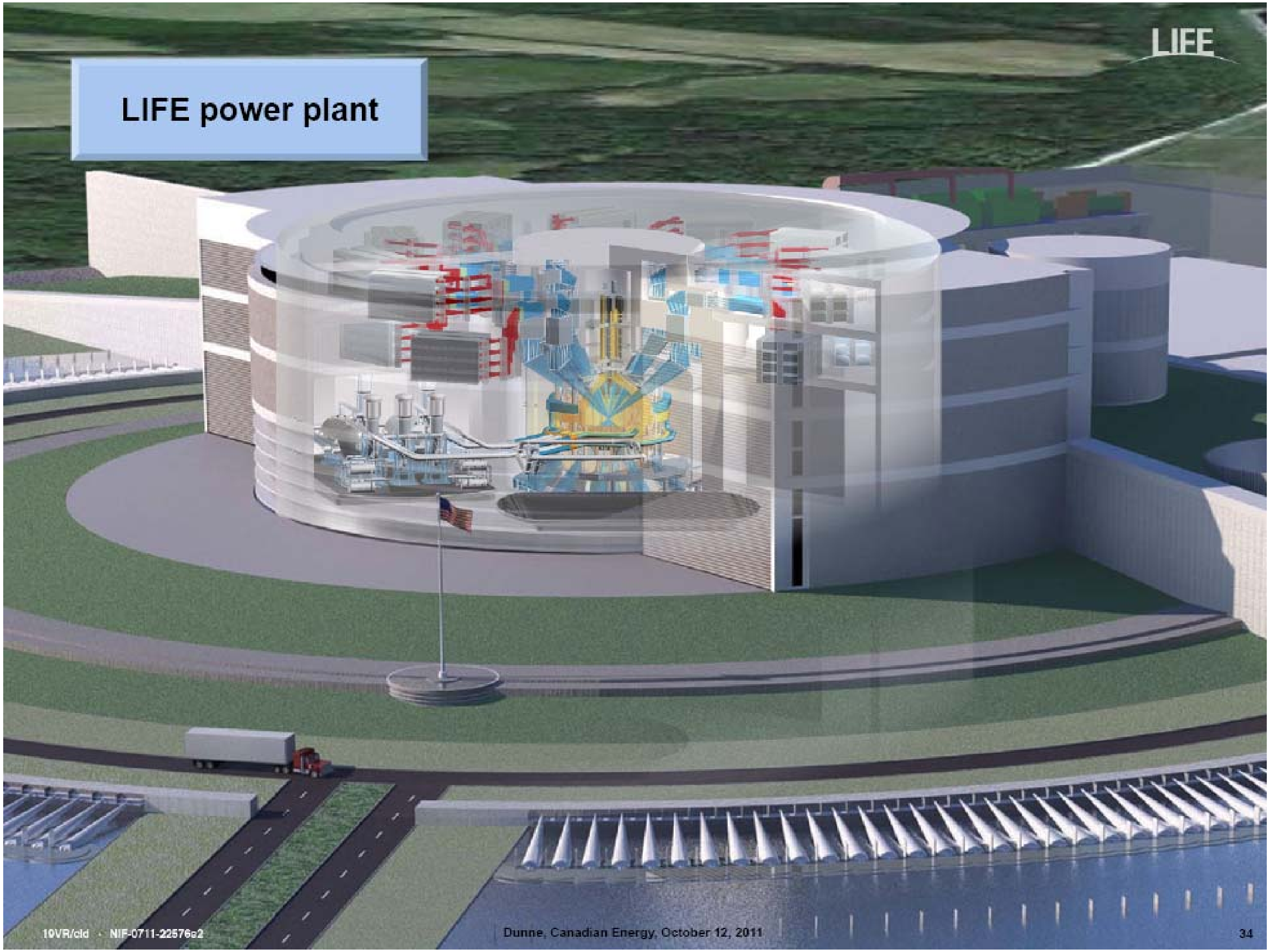
Laser Inertial Fusion Engine

LIFE combines the "single shot" capability of NIF with the 15 Hz requirements for ~1000 MW electrical output



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

LIFE power plant



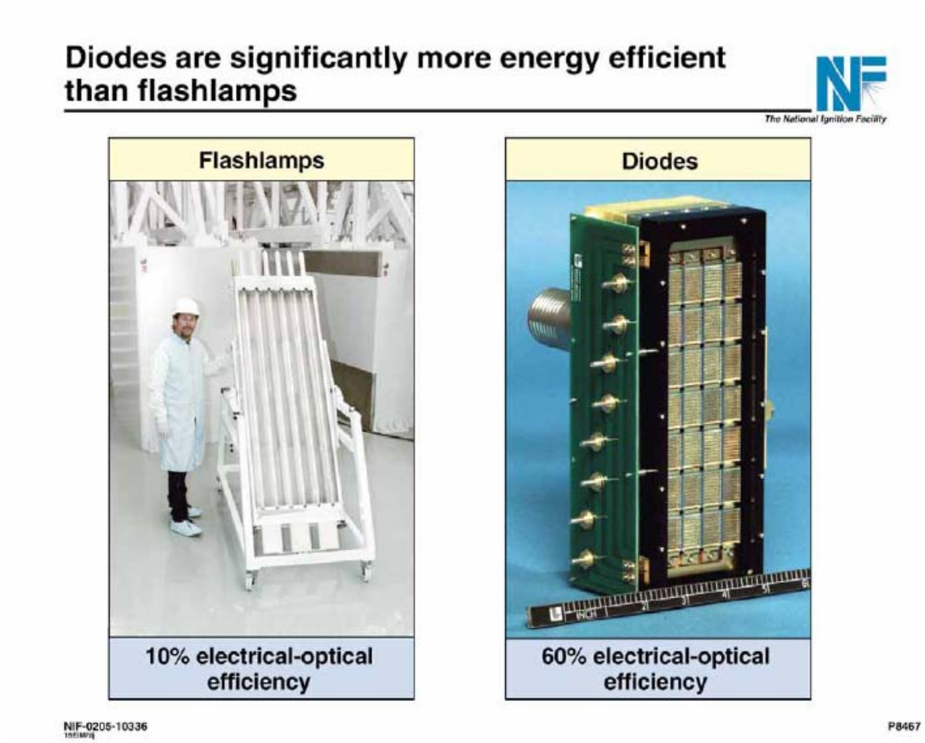
IFE Technology Opportunities

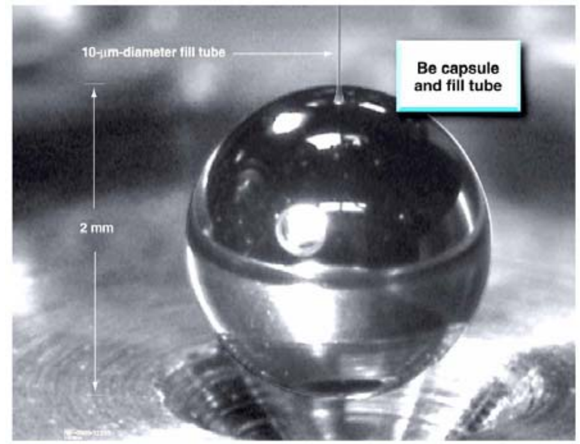
Inertial fusion R&D is a major driver of innovation

– Alberta could benefit economically from overarching technology driver

- **High power lasers** (diverse applications)
- **Precision optics** and opto-electronics
- **Photonics** (superseding electronics)
- **Sensors, instrumentation**
- **Robotics** (remote handling, line replacement modules)
- **Nanotechnology** (lasers, optics, targets, chamber materials)
- **Computer modeling** (control, data, analysis, etc)
- **Particle beam production & acceleration** (medical applications)
- **High energy density physics** (laboratory astrophysics)
- **Systems engineering** (design, construction, IP)
- **Additive manufacturing**

Inertial Fusion – Technology Impacts





Lasers, targets, optics, sensors, controls, materials, systems

Economic impacts of LIFE

OXFORD ECONOMICS

The Economic Impacts of LIFE

September 2012

OXFORD ECONOM

Similar industrial scale to

Aircraft manufacturing (230,000 jobs)

Machine shops (246,000 jobs)

Semiconductor manufacturing (182,000 jobs)

Possible Alberta Strategy

- **Build world's first IFE demo plant in Alberta jointly with USA**
- **Would stimulate diversification and innovation** – commercial and R&D (industry cluster) – as for Routes des Lasers in France
- **Build on strong links** with Europe, Japan & the USA to collaborate in developing **advanced approaches for IFE**
- **Would catapult Alberta into leading centre for fusion energy and advanced technologies**

Summary & Opportunity

- Fusion is coming & will be transformative – a global win! (energy/environment/economy)
- Demonstration fusion power plant:
  IFE (20 yrs; demonstration of "ignition" could make it 10 yrs)
  MFE (30 yrs; China/Korea/Japan could push agenda to 20 yrs)
- Canada is the only OECD country without a fusion energy program – Alberta can change this & provide Canadian leadership
- Europe, Japan & the USA have opened their doors for us to collaborate in developing IFE – linkage and leverage
- Alberta has an image opportunity – to position us as an energy leader (bridging to a low carbon future - fusion & renewables)