Environmental, Safety, and Economic Studies of Inertial Fusion Power Plants

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University of Wisconsin-Madison

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Princeton Plasma Physics Laboratory
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Inertial fusion energy (IFE) power plants of the future will consist of four parts:

**Target factory**
To produce low-cost targets rapidly
- $1-2 \times 10^8$/yr
- Cost $< 30c$/target
- Survivable targets

**Driver**
To heat and compress the target to fusion ignition
- Many beams
- 5-10 Hz operation
- $\eta > 5\%$ (depends on target gain)
- > 500 TW total peak power
- Brightness sufficient to illuminate target at > 5 m standoff

**Fusion chamber**
To recover the fusion energy pulses from the targets
- High rep-rate operation (5-10 Hz)
- Protected first wall
- High availability (> 95%)

**Steam plant**
To convert fusion heat into electricity
- Conversion efficiency 40-50%

An IFE power-plant would ignite five to ten targets per second to produce as much electricity as today’s one gigawatt power plant.
Approximately 80% of the IFE Reactor Designs are 15 Years Old and Need to Incorporate Recent Target, Driver, and Chamber Improvements

- The level of research on IFE power plants has historically been much lower (by a factor of ≈ 10) than for MFE power plants

- In spite of the lower level of investment, there have been over 50 individual IFE power plants analyzed since 1972
Inertial Fusion Energy (IFE) Reactor Design Studies Project

Industrial/University Teams Sponsored by USDOE

Objective: Evaluation of IFE for Electric Power Production
Start: October 1990
Finish: March 1992

W.J. Schafer
Bechtel
General Atomics
Textron
University of Wisconsin

McDonnell Douglas
Ebasco
KMS
TRW
UCLA
CFFTP / SPAR

SOMBRERO
laser

OSIRIS
heavy ion beam

Prometheus-L
laser

Prometheus-H
heavy ion beam
IFE has potential advantages that could shorten the fusion energy development time and cost, with a more attractive final product.

- Modularity of drivers allows one module to validate a full driver and will facilitate future power plant upgrades to higher output in stages.

- Small confinement systems (targets) allow new targets to be innovated and tested relatively quickly.

- Separation of driver, fusion chamber, and target injection systems allows significant development in parallel and will aid accessibility for future plant maintenance.

- Beams can propagate in poor vacuum, which allows liquid chamber wall protection, reducing need for development of damage-resistant materials.

- IFE technology has significant spin-off and spin-back benefits:
  - Advanced radiography
  - Laser cutting
• To uncover problems that exist at the interface between technologies

• To test innovative solutions to those problems and determine the effect of those innovations on the rest of the power plant

• To determine whether the innovative solutions improve or degrade the environmental, safety, and economic features of the power plant

**Power Plant System Studies are NOT meant to:**

• *Determine accurate* (i.e., ± 10%) *absolute costs*

• *Be a "blueprint" for construction*
There are 4 Current ICF Drivers

**Laser**

- Metallic Grazing Incidence Mirror
- Coated Final Focusing Optics
- Neutron Traps

**Heavy Ion Beam**

- HYLIFE-II
- Chamber
- Target Systems

**Light Ion Beam**

- Z-Pinch – Energy application depends on finding a credible rep-rate concept

**Light ion development currently on hold due to inability to focus adequately**
## Laser Fusion Reactors Have Evolved Over the Past 20 Years

<table>
<thead>
<tr>
<th></th>
<th>SOLASE</th>
<th>HYLIFE</th>
<th>Cascade</th>
<th>SOMBRERO</th>
<th>KOYO</th>
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<tbody>
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<td><strong>Year Published</strong></td>
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<td>1978</td>
<td>1983</td>
<td>1992</td>
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<tr>
<td><strong>Laser</strong></td>
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<td>SWL</td>
<td>SWL</td>
<td>KrF</td>
<td>DPSSL</td>
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<td><strong>Laser Energy, MJ</strong></td>
<td>1</td>
<td>4.5</td>
<td>1.5</td>
<td>4</td>
<td>4</td>
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<tr>
<td><strong>Th. Eff., %</strong></td>
<td>43</td>
<td>39</td>
<td>55</td>
<td>47</td>
<td>43</td>
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<tr>
<td><strong>Breeding Matl.</strong></td>
<td>Li₂O</td>
<td>Li</td>
<td>LiAlO₂</td>
<td>Li₂O</td>
<td>PbLi</td>
</tr>
<tr>
<td><strong>Structural Matl.</strong></td>
<td>C</td>
<td>Steel</td>
<td>SiC</td>
<td>C</td>
<td>SiC</td>
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<tr>
<td><strong>Target Gain</strong></td>
<td>150</td>
<td>400</td>
<td>200</td>
<td>118</td>
<td>150</td>
</tr>
<tr>
<td><strong>Rep Rate, Hz</strong></td>
<td>20</td>
<td>1.5</td>
<td>5</td>
<td>6.7</td>
<td>3</td>
</tr>
<tr>
<td><strong>n, MW/m²</strong></td>
<td>5</td>
<td>0.3</td>
<td>0.2</td>
<td>3.5</td>
<td>0.07</td>
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<tr>
<td><strong>Net Power, MWe</strong></td>
<td>965</td>
<td>1010</td>
<td>800</td>
<td>1000</td>
<td>2840 (4 units)</td>
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<tr>
<td><strong>Driver Eff., %</strong></td>
<td>6.7</td>
<td>5</td>
<td>10</td>
<td>7.5</td>
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<td><strong>Illumination</strong></td>
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<td>2-sided</td>
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<td>symmetric</td>
<td>symmetric</td>
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<tr>
<td><strong>n, MW/m²</strong></td>
<td>5</td>
<td>0.3</td>
<td>0.2</td>
<td>3.5</td>
<td>0.07</td>
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</table>
Heavy Ion Beam Fusion Reactor Designs Have Evolved Over the Past 15 Years

<table>
<thead>
<tr>
<th></th>
<th>HIBALL-II</th>
<th>HYLIFE-II</th>
<th>Prometheus-H</th>
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<tr>
<td>Year Published</td>
<td>1984</td>
<td>1991</td>
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<tr>
<td>Accelerator Type</td>
<td>RF Linac</td>
<td>Recirculating Induction Linac</td>
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<tr>
<td>Beam Energy, MJ</td>
<td>5</td>
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<td>7</td>
<td>5</td>
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<tr>
<td>Ion Energy, GeV</td>
<td>10</td>
<td>10</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Net Power, MWe</td>
<td>946 x 4</td>
<td>1083</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Driver Eff., %</td>
<td>27</td>
<td>20</td>
<td>20</td>
<td>28 Illumination</td>
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<tr>
<td></td>
<td>cyl. sym.</td>
<td>2-sided</td>
<td>2-sided</td>
<td>2-sided</td>
</tr>
<tr>
<td>Target Gain</td>
<td>83</td>
<td>70</td>
<td>103</td>
<td>87</td>
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<tr>
<td>Rep Rate, Hz</td>
<td>5/cavity</td>
<td>8.2</td>
<td>3.5</td>
<td>4.6</td>
</tr>
<tr>
<td>n, MW/m² (on struc. matl.)</td>
<td>0.3</td>
<td>0.3</td>
<td>7.1</td>
<td>0.1</td>
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<tr>
<td>Gross Th. Eff., %</td>
<td>42</td>
<td>46</td>
<td>43</td>
<td>45</td>
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<tr>
<td>Breeding Matl.</td>
<td>Pb₈₃Li₁₇</td>
<td>Flibe</td>
<td>Li₂O</td>
<td>Flibe</td>
</tr>
<tr>
<td>Structural Matl.</td>
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<td>Steel</td>
<td>SiC</td>
<td>C</td>
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</table>
A Variety of Ion Beam Transport Schemes Have Been Investigated Which Could Apply to Light or Heavy Ion IFE Power Plants

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LIBRA</th>
<th>LIBRA-LiTE</th>
<th>LIBRA-SP</th>
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<tbody>
<tr>
<td>Year Published</td>
<td>1989</td>
<td>1991</td>
<td>1995</td>
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<tr>
<td>Focus Mechanism</td>
<td>Channel Transport</td>
<td>Ballistic</td>
<td>Self-Pinched</td>
</tr>
<tr>
<td>Net Electric Power, MWe</td>
<td>331</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Li Ion Beam Energy to Target, MJ</td>
<td>4</td>
<td>6</td>
<td>7.2</td>
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<tr>
<td>Target Yield, MJ/Rep Rate, Hz</td>
<td>320/3</td>
<td>600/4</td>
<td>589/3.9</td>
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<tr>
<td>Coolant/Breeder</td>
<td>PbLi</td>
<td>Li</td>
<td>PbLi</td>
</tr>
<tr>
<td>First Wall Protection</td>
<td>SiC-INPORT</td>
<td>Steel-INPORT</td>
<td>Fan Spray Rigid Steel Tube</td>
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<tr>
<td>Secondary Heat Transfer Fluid</td>
<td>He</td>
<td>Organic</td>
<td>He</td>
</tr>
</tbody>
</table>

Use 25–35 MeV Li ions from Helia type driver
The Environmental, Safety, and Economic Features of IFE Power Plants are Greatly Influenced by 3 Factors

- Target Designs
- Driver Technology
- Reactor Chamber Design
Baseline Target Gain Curves Were Used for the Last Laser Fusion Power Plant Designs
Proposed high gain direct-drive laser fusion target design.

Overcoat: CH + 5% W
Ablator: CH Foam + DT
Fuel: DT

$E_{\text{laser}} = 1.2 \text{ MJ}$
Yield = 160 MJ
Gain = 135
$R_0 = 1900 \mu\text{m}$
$R_{\text{hot spot}} \sim 60 \mu\text{m}$

Factor of $\sim 30$

convergence ratio
The National Ignition Facility and supporting OFES programs gives the U.S. a unique opportunity for world leadership in inertial fusion energy

- Demonstrate ignition and gain for both direct and indirect-drive
- Provide key data on target chamber and target fabrication technologies
- Confirm predictive target modeling capabilities
Recent Heavy Ion Beam Fusion Reactor Studies Have Used Conservative Gain Curves

![Graph showing target gain vs. input energy for different beam energies and target thicknesses.](image-url)
High gain (G > 50) target designs have been developed thru DOE-DP and DOE-OFES sponsorship: **indirect drive with heavy ions**

**Conventional**

Ion beam characteristics:
- 4 GeV Pb+ ions
- 5.9 MJ input energy
- 2.7 mm effective radius spot
- T\(_r\) = 240 eV

**Close Coupled**

Ion beam characteristics:
- 3.5 GeV Pb+ ions
- 3.3 MJ input energy
- 1.7 mm effective radius spot
- T\(_r\) = 240 eV

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Callahan 3/99
Recent Light Ion Beam Fusion Reactor Studies Have Used Conservative Gain Curves
LIBRA Light Ion Targets are Spherically Symmetric and Use Internal Pulse Shaping

\[ \text{Ion beam} = 8 \text{ MJ} \]
\[ \text{E}_{\text{yield}} = 552 \text{ MJ} \]
\[ \text{Gain} = 70 \]
Pulsed-power high yield capsules are designed to the baseline NIF ignition capsule implosion criteria.

- **Z-pinch driven hohlraum**: 400 - 1200 MJ
- **Static-walled hohlraum**: > 200 MJ
- **Dynamic hohlraum**: 600 MJ

- Drive Temp. = 300 eV
- $E_{\text{xray}} = 16 \text{ MJ}$
- $Y = 560 \text{ MJ}$
- Gain = 35

Los Alamos
# Key Considerations for IFE Power Plant Designs

<table>
<thead>
<tr>
<th>Target</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lasers</td>
<td>• Best data base (30 kJ, 100 TW)</td>
</tr>
<tr>
<td></td>
<td>• Direct or Indirect Drive</td>
</tr>
<tr>
<td>Heavy Ions</td>
<td>• Recent Target Designs Show High Gain</td>
</tr>
<tr>
<td></td>
<td>• Indirect Drive</td>
</tr>
<tr>
<td>Light Ions</td>
<td>• Internal Pulse Shaping Targets Reduce Need for Beam Pulse Shaping</td>
</tr>
<tr>
<td></td>
<td>• Indirect Drive</td>
</tr>
<tr>
<td>Z Pinch</td>
<td>• Recent X-ray Production Experiments Encouraging (2 MJ, 300 TW)</td>
</tr>
<tr>
<td></td>
<td>• Indirect Drive</td>
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</table>
## Characteristics of Drivers for Recent IFE Power Plant Designs

<table>
<thead>
<tr>
<th>Laser</th>
<th>HIB</th>
<th>LIB</th>
<th>Z-Pinch (estimated)</th>
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<tbody>
<tr>
<td>Energy - MJ/pulse @ ~300-500 TW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5</td>
<td>2-5</td>
<td>5-10</td>
<td>5-20</td>
</tr>
<tr>
<td>Driver Efficiency-%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;5</td>
<td>25-40</td>
<td>20-25</td>
<td>15-20</td>
</tr>
<tr>
<td>Efficiency to Capsule-%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;5</td>
<td>2-3</td>
<td>2-3</td>
<td>1-2</td>
</tr>
<tr>
<td>Total # Pulses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;10(^{10})</td>
<td>&gt;10(^{10})</td>
<td>&gt;10(^{10})</td>
<td>&gt;10(^{9})</td>
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<tr>
<td>Current Status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Glass ~ 40 kJ, 40 TW x-rays</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• KrF ~ 5 kJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• DPSSL ~ 0.1 kJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• NIF-1.8 MJ, 500 TW</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• SLAC~10(^{11}) pulses, 180 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• (I_{\text{inj}})~1 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Hermes ~ 300 kJ, 13 TW, 10(^{-4}) Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• RHEPP-II~3 kJ, 120 Hz</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>• Z ~ 1.8 MJ, 280 TW x-rays, 2x10(^{-5}) Hz</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
## Key Considerations for IFE Power Plant Designs

<table>
<thead>
<tr>
<th>Driver</th>
<th>Details</th>
</tr>
</thead>
</table>
| **Lasers** | • NIF Will Give Reactor Level Energies (1.8 MJ, 500 TW)  
• SWL KrF/DPSSL Lasers Needed for Rep Rate |
| **Heavy Ions** | • RF or Induction Linacs Favored  
• Must Scale up to Higher Energy (both MJ and GeV) |
| **Light Ions** | • "Inexpensive' Hermes Technology Demonstrated at Reactor Level Energies  
• Have Not Demonstrated Sufficient Beam Focusing and Purity |
| **Z Pinch** | • "Inexpensive" Pulsed Power Demonstrated  
• Rep Rated Coupling to Target Design Not Shown |
Three Light Ion Beam Propagation Schemes Have Been Utilized

LIBRA (1989)
Channel beam propagation
Driver technology, HELIA
Li + ions, 25-35 MeV
Energy on target, 4 MJ
Target gain, 80
Rep-rate, 3

LIBRA-Lite (1991)
Ballistic beam propagation
Driver technology, HELIA
Li + ions, 25-35 MeV
Energy on target, 6 MJ
Target gain, 100
Rep-rate, 3.9

LIBRA-SP (1995)
Self-pinched beam propagation
Driver technology, HELIA
Li + ions, 30 MeV
Energy on target, 7.2 MJ
Target gain, 82
Rep-rate, 3.9
### Key Considerations for IFE Power Plant Designs

<table>
<thead>
<tr>
<th>Chamber</th>
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</thead>
<tbody>
<tr>
<td><strong>Lasers</strong></td>
<td>• Symmetric Illumination Favors Dry/Wetted Wall Approach With Gas Protection</td>
</tr>
<tr>
<td><strong>Heavy Ions</strong></td>
<td>• 2 Sided Indirect Drive Allows for Thick Free or Inhibited Flow Liquid Metallic/Molten Salt Protective Walls</td>
</tr>
<tr>
<td><strong>Light Ions</strong></td>
<td>• Could Use Dry/Wetted/Liquid Walls With Gas Protection</td>
</tr>
<tr>
<td><strong>Z Pinch</strong></td>
<td>• Chamber Design Uncertain Until Rep Rated System Identified</td>
</tr>
<tr>
<td></td>
<td>• Shrapnel from Target Will be a Problem</td>
</tr>
</tbody>
</table>
Fireballs and Blasts in Gas Protected IFE Target Chambers

**Issue:** Target explosions generate fireballs in target chamber fill gases, which transmit a shock and a radiant heat pulse to target chamber structures. The strength of each can be adjusted with gas density and species.

**Status:** Radiation-hydro codes (BUCKY, RAGE, Lasnex) can model fireballs. **UW Shock Tube** simulates blast flow around target chamber structures (100 k$/yr); is a testbed for structural response of target chamber. **NRL laser** generated blasts in the 80’s validated BUCKY ion deposition in gases.

**Needs:** Shock Tube experiments to optimize flow around structures (100 k$). High energy density fireball experiments on Z would simulate radiation driven fireballs (100 k$). Species and gas density effects on radiation flow and shock strength would be tested. Need a sample large enough to be optically thick.
Environmental Aspects of IFE Power Plants

• IFE and MFE have many attractive environmental features in common.

  1) Reduced land disruption to collect fuels and construction materials
  2) Less greenhouse gas emissions than fossil fuels
  3) Lower levels of long-lived radioisotopes than fission reactors

• There are 2 areas where IFE has unique features that could make it even more attractive environmentally.

  1) The ability to isolate the driver (e.g., laser, accelerator, pulsed power source, etc.) from the radiation source in the reaction chamber

  2) A more amenable geometry to use thick liquid walls in order to reduce the level of radiation damage, radioactivity, and volume of waste
There Are Two Ways to Use Liquids to Protect IFE Chamber Walls

### Free Flowing Liquids
- No exposed structural material
- Smaller chamber radius
- Reduced droplets (higher rep rate)
- Rapid flow, small $\Delta T$
- Isochoric heating-disassembly
- Low rep rate

### Inhibited Flow in Porous Tubes-INPORT
- Slower flow, larger $\Delta T$(small HX)
- Reduced droplets (higher rep rate)
- Finite life of porous tubes
- Requires larger chamber radius

Reduction in neutron effects by 10 to 100 times
The Use of Internal Liquid Walls Can Prolong the Life of a Steel First Wall

Reference: HIBALL, HT-9 Steel, 2 MW/m², 200 dpa life

Source: M. Sawan-Univ. Wisconsin
Recent Studies Have Concluded That the Safety of IFE Power Plants Can Be Superior to Today’s Nuclear Facilities

- Favorable Attributes Are Due to the:
  1) Ability to isolate the drivers from the chamber
  2) Low overall power density → low after-heat density
  3) General use of ceramic, non-volatile materials (with the exception of T₂)
  4) General use of low activation structural materials (C, SiC,…)
  5) Use of liquid metals (Li, Pb-Li, Flibe,….) in the chamber to lower the activity in the blanket

- Unique Areas That Require Continued Attention:
  1) T₂ inventory in target factory (could be on the order of 200-300 g)
  2) T₂ inventory in IFE blankets (currently ranges from 10 to 200 g)
  3) Activated target materials (could be as much as 50 tonnes/y)
  4) Pulsed neutron effect on increase in short lived activity
The Driver and Conventional Power Conversion Equipment Dominate the Capital Cost of IFE Power Plants

Example

<table>
<thead>
<tr>
<th></th>
<th>% of Total Capital Cost in Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Driver</td>
</tr>
<tr>
<td>SOMBRERO</td>
<td>31</td>
</tr>
<tr>
<td>OSIRIS</td>
<td>37</td>
</tr>
</tbody>
</table>

Conclusion: Highest leverage is gained through the driver. The cost of the chamber is only of secondary importance with respect to the capital cost.
IFE WILL REQUIRE TARGET DEVELOPMENT

- CURRENT ICF TARGETS COST ~$500-$2500 EACH DUE TO:
  - Few-of-a-kind designs — constantly changing
  - Small scale production — batches of ~5-25 targets
  - Extensive characterization — each individual target has a "pedigree"

- IFE TARGETS MUST COST £≤ 25¢ EACH

- WHAT DEVELOPMENT IS NEEDED?
  - IFE target designs — including fabrication considerations and tolerances
  - IFE-specific target fabrication development — capsules, hohlraums, assembly, fill and layering, characterization
High-temperature gas-cooled reactor (HTGR) fuel has similarity to IFE capsules
- Multiple layers of high and low density coatings
- Stringent quality requirements

Over $10^{11}$ fuel particles have been produced in a small commercial production facility for Fort St. Vrain reactor

Quality control was carried out by statistical means
- Production yield was ~90%

Cost reduction was ~$10^4$ due to scale-up
- Bench scale 20¢ per particle
- FSV was less than 0.2¢ per particle
- Projected commercial 0.002¢ per particle

Indicates that low cost IFE targets are not out of reach, but greater precision will be required
HTGR FUEL FABRICATION USED TECHNOLOGIES
THAT CAN BE ADAPTED TO IFE TARGET PRODUCTION

- HTGR and ICF sphere forming technologies have similarities
- HTGR coating technologies may be adaptable to IFE needs
- Filling and DT layering is unique to ICF
- High-volume handling, sorting, and quality control technologies may be adapted from industrial practices (semiconductors)
COST REDUCTION OF HTGR FUEL PARTICLES WAS SIGNIFICANT

Initial cost: ~20 cents/particle

Current cost: ~$2,000/target

Projected IFE-Target Cost

Cost (Cents/Particle)

Scale-up and Learning (Time)

Bench Scale 60's
Pilot Scale 70's
FSV 80's
Projected HTGR 00's
10's
20's
30's
40's

Cost (Dollars/Target)
• Past IFE Power Plant Studies Have Shown That The Predicted Cost of Electricity Can Be Reduced
• New IFE Designs Need to Incorporate the Progress of the Past Decade

Source: R. W. Moir & G. L. Kulcinski
IFE can be an attractive future energy source if it meets a number of criteria

- **Target gain and driver efficiency** high enough for <30% of power recirculated to driver ($\eta_G > 7$) [CoE increases 20% at $\eta_G = 5$].

- **Low cost driver**: <$1 \text{ B}$ total capital cost [CoE increases 20% at $2 \text{ B}$].

- **Low cost targets**: <30 cents/target [CoE increases 20% at $1.1/\text{target}$].

- **Lifetimes for driver, chamber, final optics** allowing >80% plant availability.

- **Radioactivity** low enough to avoid need for public evacuation plans (<1 REM site boundary dose in worst-case accidents), to avoid active safety systems, and to avoid high-level waste disposal (achieve Class C or better).

- **Affordable development**-driver test prototype <$150 \text{ M}$ hardware and ability to test fusion chambers at reduced scale (<1 m radius).
# Phase-I R&D addresses critical issues for chamber and target technologies

<table>
<thead>
<tr>
<th>Issue</th>
<th>Phase I Goals</th>
<th>Power Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>High rep-rate chamber</td>
<td>Demonstrate drop clearing with 1/4 scale single water jet, use models to determine clearing rate. Test of liquid vaporization and condensation (100 kJ of x-ray on Z allows 0.1 scale).</td>
<td>5-10 Hz</td>
</tr>
<tr>
<td>First wall protection</td>
<td>Conduct scaled tests of oscillating liquid jets. Validate fireball models and establish credibility of gas protection.</td>
<td>Ablation of first wall materials prevented</td>
</tr>
<tr>
<td>Chamber neutron damage life</td>
<td>Use existing data and modeling to select best candidate materials.</td>
<td>Life &gt; few years</td>
</tr>
<tr>
<td>Optics survival</td>
<td>Estimate fused silica life using irradiated samples and modeling. Determine viability of grazing incidence metal and liquid metal mirrors.</td>
<td>Life &gt; 1 year</td>
</tr>
<tr>
<td>Target production</td>
<td>Fabricate a few prototype target components. Explore/test individual production steps. Identify scalable, low cost production methods.</td>
<td>$1 - 2 \times 10^8$ per year &lt; 30 cents/target</td>
</tr>
<tr>
<td>Target injection</td>
<td>Test room-temp surrogate targets at few Hz.</td>
<td>5-10 Hz with cryo targets</td>
</tr>
<tr>
<td>Radioactive waste</td>
<td>Determine acceptable materials. Develop recycling scenarios.</td>
<td>Meet Class-C classification</td>
</tr>
<tr>
<td>Safety</td>
<td>Gather data on release fractions of critical isotopes and conduct safety analyses. Designs for cl rem dose at site boundary.</td>
<td>No evacuation plan</td>
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</tbody>
</table>
IFE Power Plants Can Present Favorable Environmental, Safety, and Economic Features to Future Generations

• Engineers and scientists have used a great deal of innovation (in the limited number of IFE conceptual designs done to date) to solve the technical problems confronting them.

• It is too soon to decide on the final IFE driver/target/chamber configuration for power plants.

• There is a need to conduct small scale tests of the more promising IFE technologies such as liquid metal walls, final focusing mirrors & magnets, and chamber clearing concepts.