Comments on Progress Toward and Opportunities for Attractive Magnetic Fusion Power Plants

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Fusion should demonstrate that it can be a safe, clean, & economically attractive option

- Energy research in US is conducted in an environment when energy is abundant. Energy research has been justified and pursued because:
  * limited fossil fuels and/or geographic position of resources (not very credible),
  * environmental damage caused by CO_2 , acid rain, etc. (which is getting more attention these days).
- Fusion will compete with technologies which solve the above problems and not with present energy sources (cheap fuel with no penalty for CO_2 production).

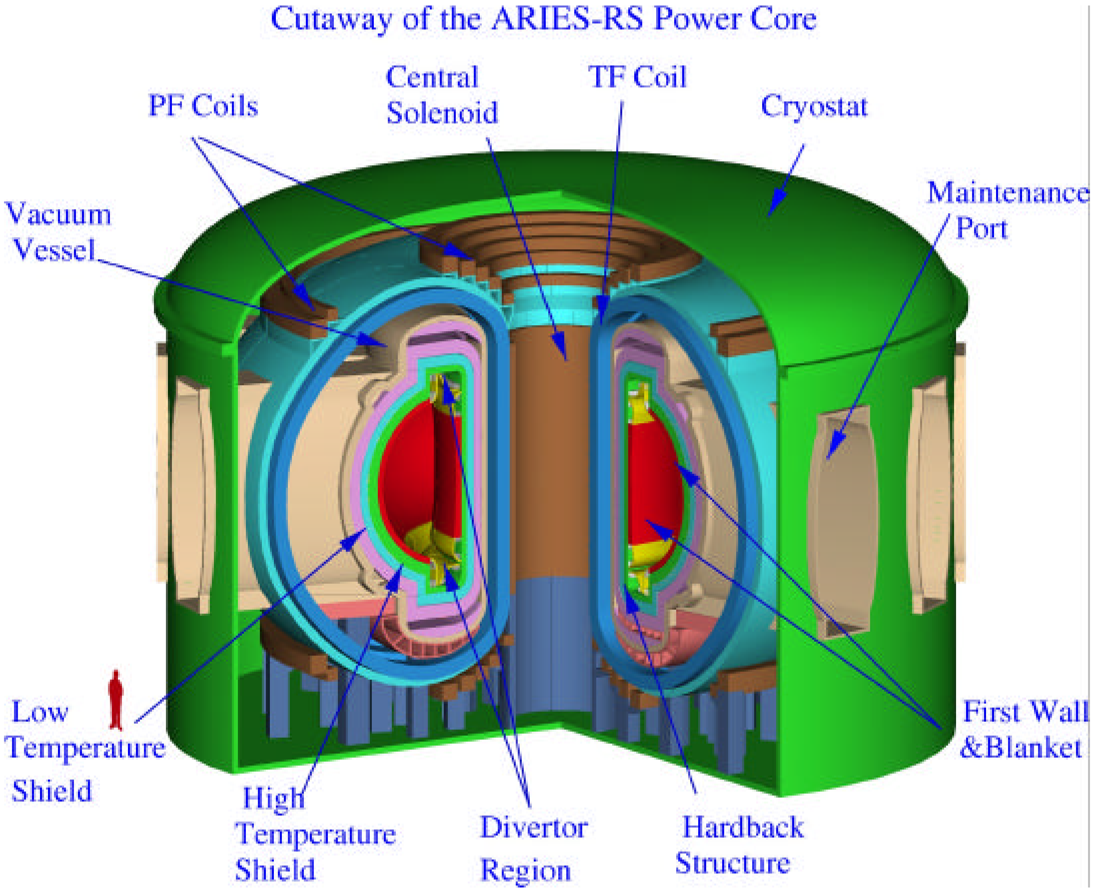
Fusion is a long-term option which is not demonstrated and has expensive development steps

- Fusion electricity competes favorably assuming fusion potential environmental potential is realized and physics and technology issues are resolved.
  - Funding is limited because total government expenditure in energy is small, not that fusion receives a small fraction of total energy expenditure.
  - Practical Fusion is too far away and as such does not appear on energy forecasting and planning
  - It is expected that the final product would be more expensive than intermediate devices. As such, expensive development devices undermine any argument that final product will be attractive.

ARIES-RS is a conceptual 1000MWe power plant based on a Reversed-Shear tokamak plasma

ARIES-RS represents an attractive vision for fusion with a reasonable extrapolation in physics and technology:

- Minimum cost of electricity
- Low level waste
- Public and worker safety
- High availability



Our Vision of Tokamaks Has Improved Drastically in the Last Decade

	80s physics	90s physics	
	Pulsar	**ARIES-I**	**ARIES-RS**
Major radius (m)	9	7	5.5
β	2.3%	1.9%	5%
β_N	3	3.2	4.8
Plasma current (MA)	10	10 (68% BS)	11 (88% BS)
COE (c/kWh)	13	9.5	7.5

Fusion research cannot afford to rule out any options.

- Advanced tokamaks offer an attraction vision of future and the fusion community should strive to ensure that this vision is realized, but
  * There is no guaranty that advanced tokamaks work as advertised and
  * We should continue to strive to look for ways to make our product better by examining other concept, either in their own rights or because they expand our scientific and technological base, or because they may help in the fusion development steps.

Alternative Confinement Systems

- No current-drive (low recirculating power):
  - Stellarators (SPPS): recent advances bring the size in-line with advanced tokamaks. Needs coils and components with complicated geometry.
- No superconducting TF coils
  - Spherical tokamaks (ARIES-ST): Potential for high performance and small size devices for fusion research but requires high beta and perfect bootstrap alignment. Center-post is a challenge.
  - RFP (TITAN): Simple magnets and potential for high performance. Steady-state operation requires resolution of the conflict between current-drive and confinement.

Advanced Technologies Examples: High-Temperature Superconductors

- Physics Implications:
  - Operation at higher fields (limited by magnet structures and wall loading)
  - Smaller size, plasma current and current drive requirements.

- Engineering Implications:
  - Operation at higher temperatures simplifies cryogenics (specially is operation at liquid nitrogen temperature is possible)
  - Decreased sensitivity to nuclear heating of cryogenic environment.

Advanced Manufacturing Techniques can reduce the cost of fusion dramatically

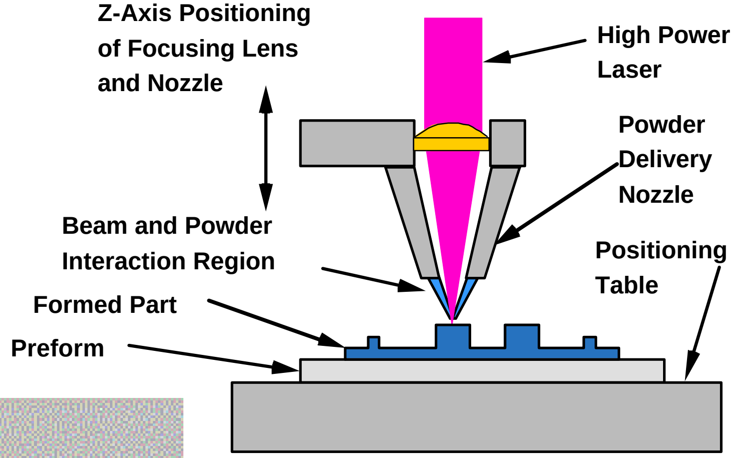
- Components manufacturing cost can be as high as ten times as raw material cost.

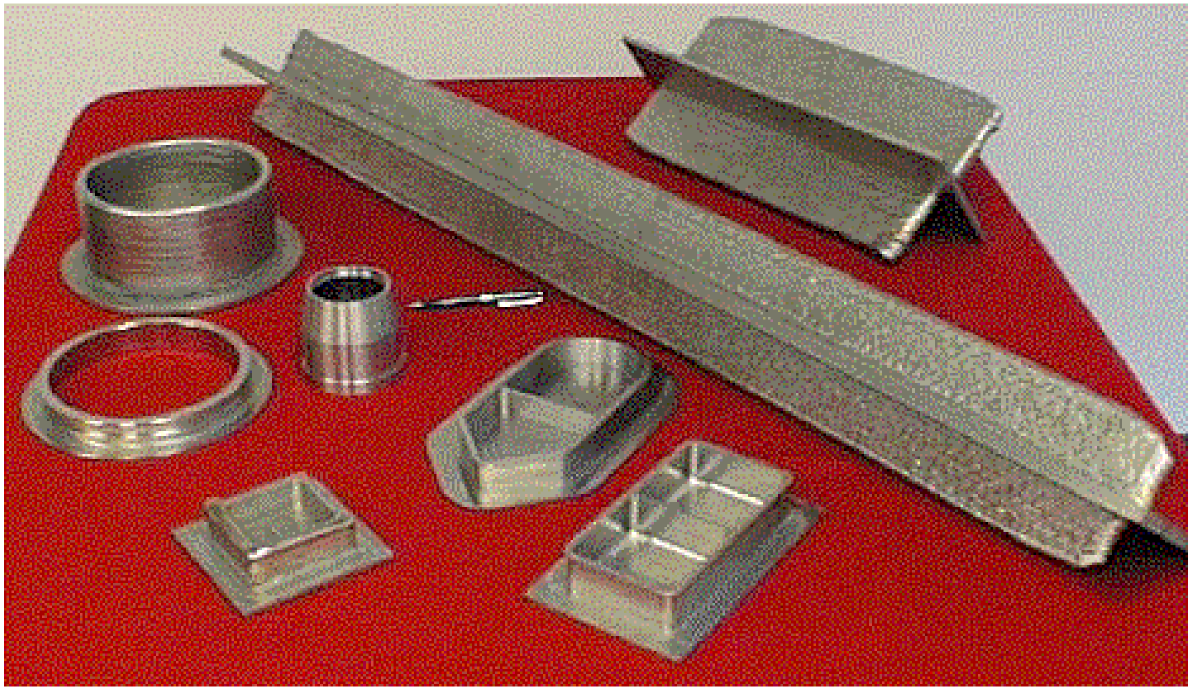
- New “Rapid Prototyping” techniques aim at producing near finished products directly from raw material (powder or bars) resulting in low-cost, accurate, and reliable components.

Laser or Plasma Arc Forming

- A laser or plasma-arc deposits a layer of metal (from powder) on a blank to begin the material buildup
- The laser head is directed to lay down the material in accordance with a CAD part specification

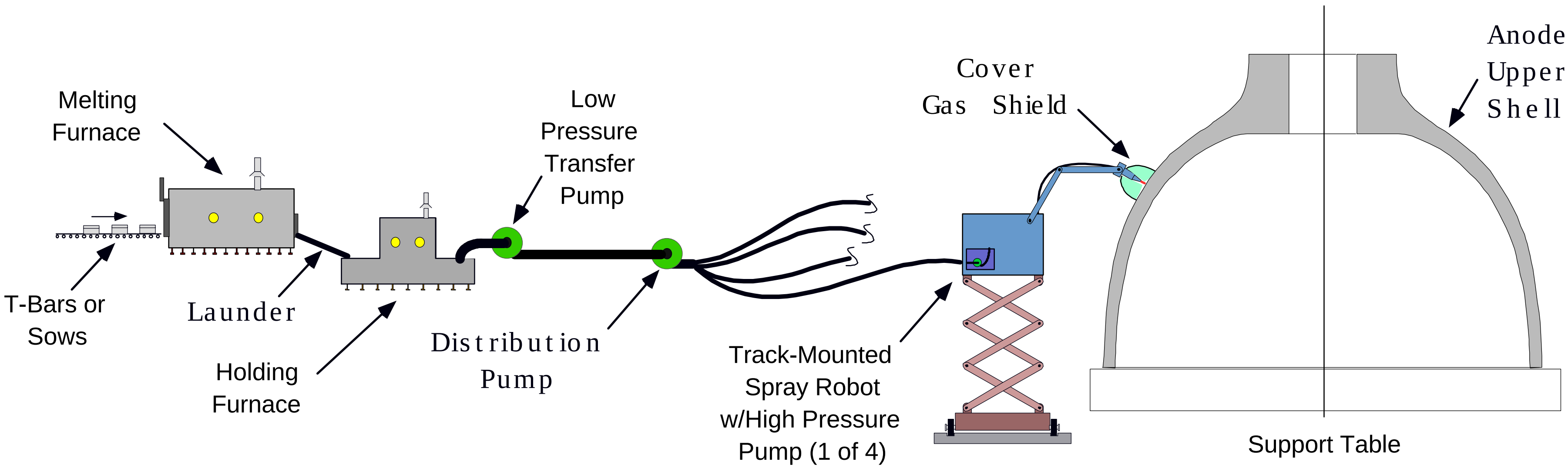
Schematic of Laser Forming Process

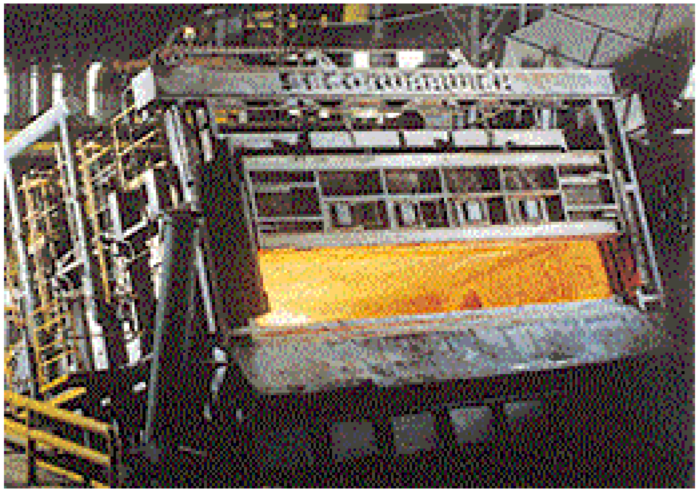




AeroMet has produced a variety of titanium parts as seen in attached photo. Some are in as-built condition and others machined to final shape. Also see Penn State for additional information.

Schematic of Spray Casting Process





Molten Metal Furnace, Courtesy of SECO/WARWICK, Inc

Summary

- Fusion will compete against fusion energy sources not today's.
- Progress in the last decade is impressive and indicates that fusion can achieve its potential as a safe, clean, and economically attractive power source.
- Fusion research should address three issues simultaneously :
  - Development steps with acceptable cost
  - Feasible end product
  - Attractive end product.
- Fusion research cannot afford to rule out any options. Alternative concepts, advanced technologies and advanced manufacturing techniques will help fusion deliver its potential.