A Pilot Plant: The Fastest Path to Commercial Fusion Power

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FNSF+ Could be the Pilot Plant for Commercial Fusion

Pilot Plant

Shippingport, 60 MWe, 1957

Oyster Creek, 620 MWe, 1969

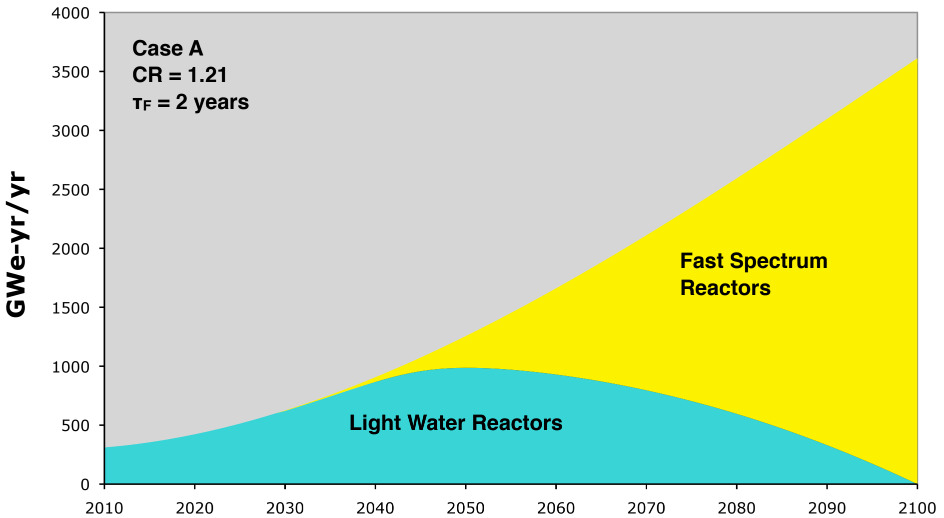
Commercial Plant

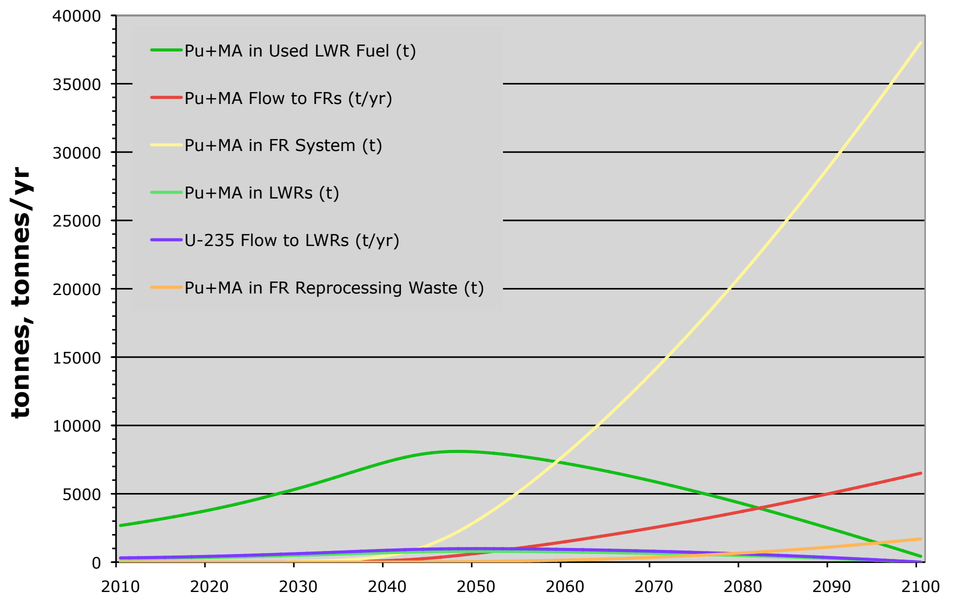
- **The smallest facility to *pilot* the route to commercial fusion – by doing fusion nuclear science, demonstrating practical operation, and making net electricity, based on**
  - ITER + magnetic fusion R&D,
  - or NIF + inertial fusion R&D.
- **The next step would be a commercial power plant.**
- **Results from NIF + ITER *well underway* could trigger a common preparatory R&D program – if (and only if) we have a compelling roadmap to commercial fusion power.**

Fast Reactors Burning Pu + MA are Targeting 2040 - 2050 Commercialization

A Fast Reactor Scenario

- Nuclear = 30% of world electric power in 2100
- Burn 80% of all IAEA discovered + undiscovered uranium
- Load all Pu + MA from LWRs
- Peak of 8x Yucca Mt. storage of Pu + MA, worldwide
- 38,000t of Pu + MA in use in 2100
- Fuels reactors with 6500t/yr Pu + MA ~1 million bombs/yr in 2100
- IAEA MUFs 1% ~ 10,000 bombs/yr
- *Fusion would have much lower proliferation risks*





A Pilot Plant 2/3 of the Size of a Power Plant would Make Net Electricity

- Reduce linear dimensions to 2/3 power plant
- For fixed β, B, and T, P_{fus} down to $(2/3)^3 = 30\%$
- Current drive power is down by 4/9 for fixed T (tokamak)
- But Greenwald limit is up by 3/2: can run at higher n, lower T

  Allows lower T, higher P_{fus}, but current drive power is higher
- For conservatism, assume P_{recirc} is unchanged from power plant
- For P_{fus} = 30%, Q_{eng} > 1 if Q_{eng} of the power plant > 3.33
- Pilot plant can do CTF/FDF mission: neutron flux > 2/3 power plant.

  Surface area is 4/9. Can adjust ^{6}Li enrichment.

Obviously there are other factors (*e.g.,* neutron m.f.p.).

On the other hand P_{recirc} = constant is conservative.

Initial looks at Tokamak, ST, Stellarator support 2/3 reduction

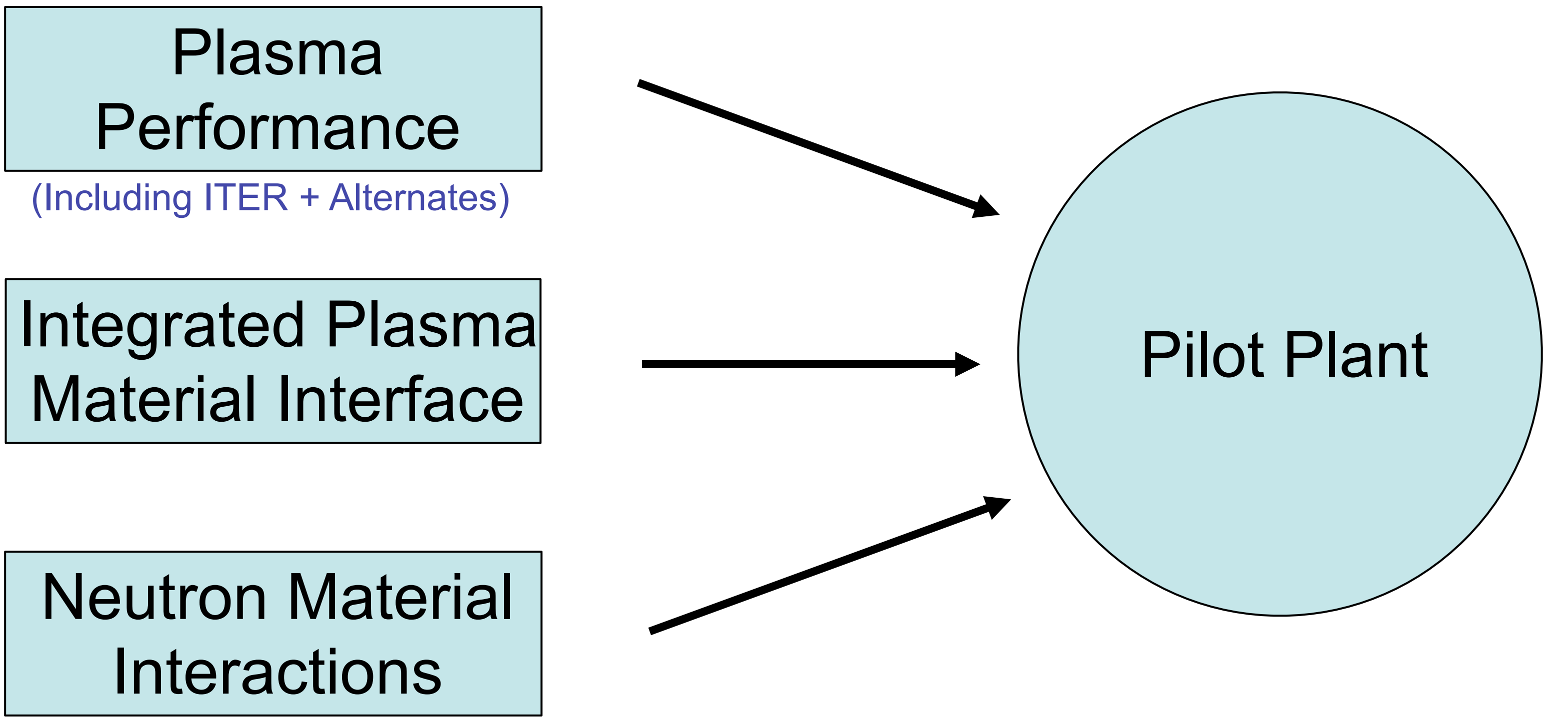
Spreadsheet Pilot Plants are Encouraging

- **Tokamak**
  - R/a = 4.0m/1.0m, B_0 = 6T, I_p = 8MA
  - H_H = 1.5, P_{fus} = 520MW, Q_p = 10, Q_{eng} ~ 1
- **ST**
  - R/a = 2m/1.2m, B_0 = 2.4T, I_p = 17 MA
  - H_H = 1.4, P_{fus} = 700MW, Q_p = 25, Q_{eng} ~ 1
- **Stellarator**
  - R/<a> = 4.5m/1.0m, B_0 = 5.7T
  - H_{ISS04} = 2, P_{fus} = 470MW, Q_p = 40, Q_{eng} ~ 4

These spreadsheet analyses are only very first looks.

Engineering scaled simply from ARIES studies.

Three Key Science Needs for a Technically Sound MFE Pilot Plant Design



Themes from FESAC Priorities, Gaps and Opportunities Report

Science Needs for a Technically Sound MFE Pilot Plant Design (1)

Plasma Performance

- **Scaling of confinement, operating limits and sustainment *in non-inductive tokamak plasmas***
- **Confinement scaling to relevant ρ^* and υ_*, low rotation**
- **Alpha heating physics**
- **Scaling information at low A**
  - Low A: cheapest, attractive maintenance approach
- **Scaling information for stellarators**
  - Stellarators: most credible for disruption avoidance, sustainment with low recirculating power
- **Are there faster/better/cheaper alternatives?**
  - ICCs

Science Needs for a Technically Sound MFE Pilot Plant Design (2)

Integrated Plasma-Materials Interface

- **High heat and particle flux and fluence**
  - What divertor designs work at needed power & duty factor?
  - What materials work at needed power & duty factor?
- **Tritium retention**
  - How to remove tritium in continuous operation?
  - All plasma-facing components (PFCs) must operate very hot.
- **Dust production**
  - How to remove dust in continuous operation?
- **Practical experience with high-pressure He-cooled PFCs**
- **Practical experience with liquid metal PFCs**
- ***Effects of ELMs and high-energy disruptions***
  - *Major issue for blanket / first wall survival in tokamaks & STs.*

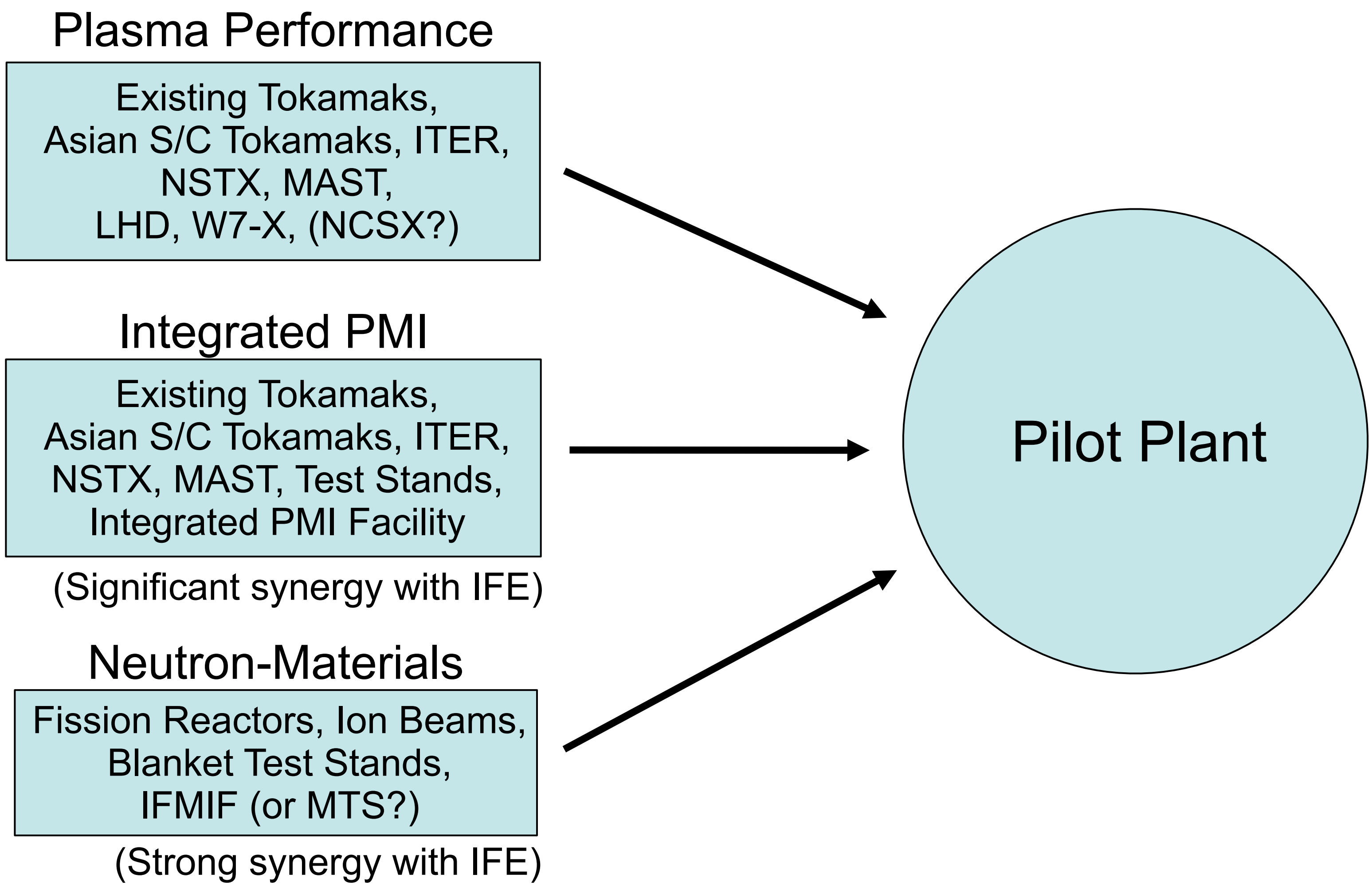
Significant synergy with many IFE concepts.

Science Needs for a Technically Sound MFE Pilot Plant Design (3)

- **Design of Pilot Plant would be informed by a powerful point neutron source such as IFMIF (or MTS?).**
  - Vacuum vessel design depends on properties of hot main blankets: electrical conduction paths, structural integrity, size, services (coolant, T purge fluid).
  - Hot main blanket design depends on material properties w/14 MeV neutrons.
  - Same logic holds for many other components, *e.g.,* divertors, antennas.
  - Point neutron source needed to develop materials for test blankets.
  - *This was the ReNeW conclusion even about a CTF – need IFMIF first*
- **Tritium breeding uncertainties can be mitigated by Li isotopic mix.**
  - Tritium cycle can be confirmed in Pilot Plant.

A point neutron source has high synergy with many IFE concepts.

Facilities to Contribute to a Technically Sound MFE Pilot Plant Design



Roles of Existing & New Facilities

- **Plasma Performance**
  - Existing tokamaks, Asian S/C tokamaks for AT pilot plant option
  - NSTX, MAST for low aspect ratio pilot plant option
  - LHD, W7-X (NCSX?) for stellarator pilot plant option
  - ITER for ρ^* scaling, α–particle heating
  - ICC program for the wild-card option
- **Integrated Plasma-Material Interface**
  - Existing tokamaks, Asian S/C tokamaks, NSTX-U, MAST, test stands, for initial tests of new PFC materials and geometries
  - Long-pulse, hot walls, high-heat-flux DD confinement facility for integrated power and particle handling solutions
  - ITER for effects of high-energy ELMs and disruptions
- **Neutron Material Interactions**
  - Fission reactors, ion beams to sieve candidate materials.
  - Blanket test stands to develop required technologies.
  - IFMIF (or MTS?) with correct He/dpa to investigate materials physics at high fluence

A Pilot Plant is an Exciting Goal

- **We can explain it to our sponsors and the public**
  - We have a plan to make put electricity on the grid
  - The step after this would be commercial power plants
  - R&D can be triggered by NIF success, ITER well underway
- **It would culminate the key FESAC Themes**
  - Creating Predictable High-Performance Steady-State Plasmas
  - Taming the Plasma-Material Interface
  - Harnessing Fusion Power
- **Fusion Community Pilot Plant Study?**
  - What would a tokamak, ST or stellarator Pilot Plant look like?
    - Lifetime fluence, maintenance approach, cost
    - It should be designed to drive fusion R&D in the right directions
  - What supporting program is needed for a technically sound design?
  - Is there a game-changer from the ICC program?
  - A similar IFE Pilot Plant study should be carried out in parallel.