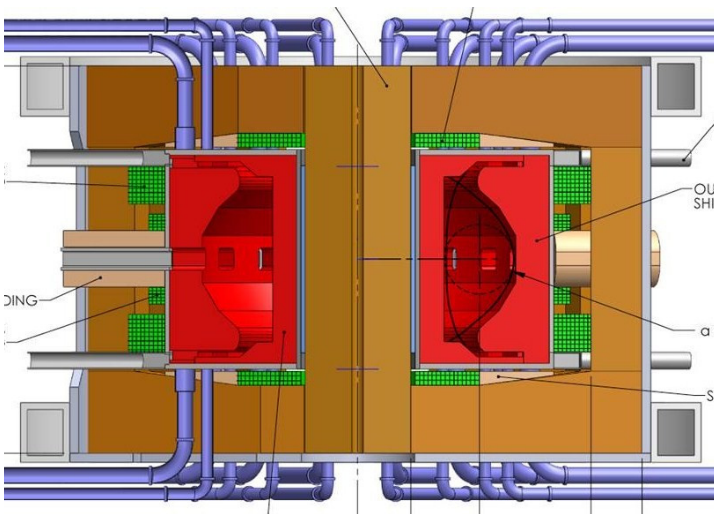
Fusion Nuclear Science Facility: Its Mission, Characteristics, etc.



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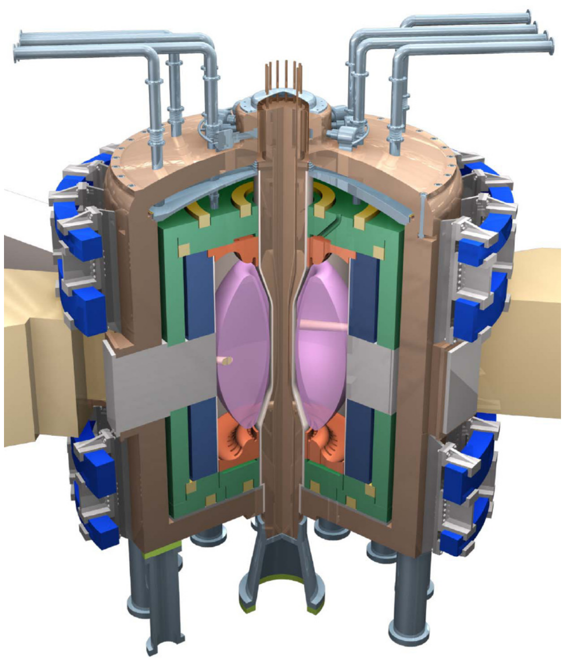
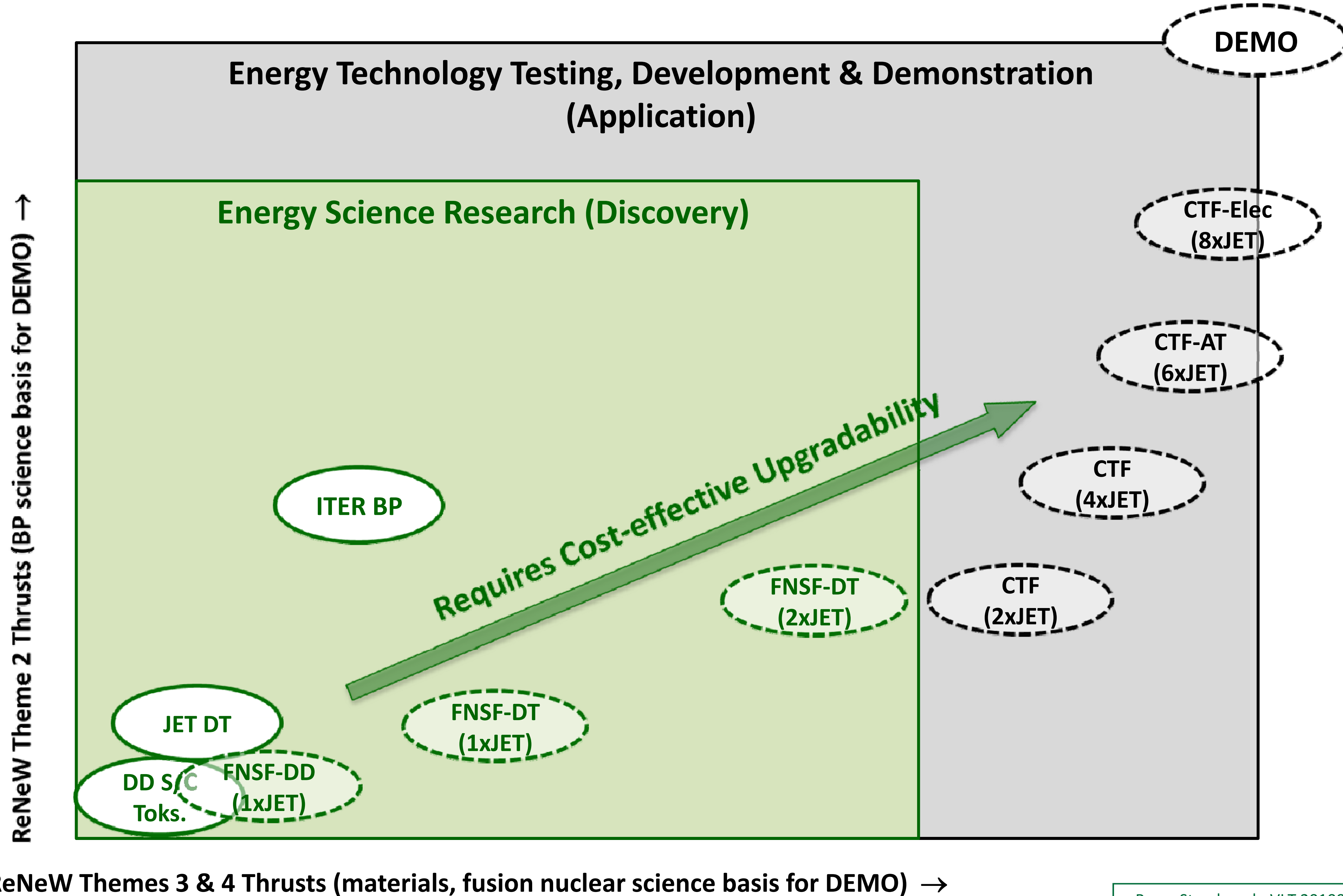


Report and Discussion
VLT Conference Call
April 21, 2010

A broadly defined “Fusion Materials and Fusion Nuclear Science R&D” strategy



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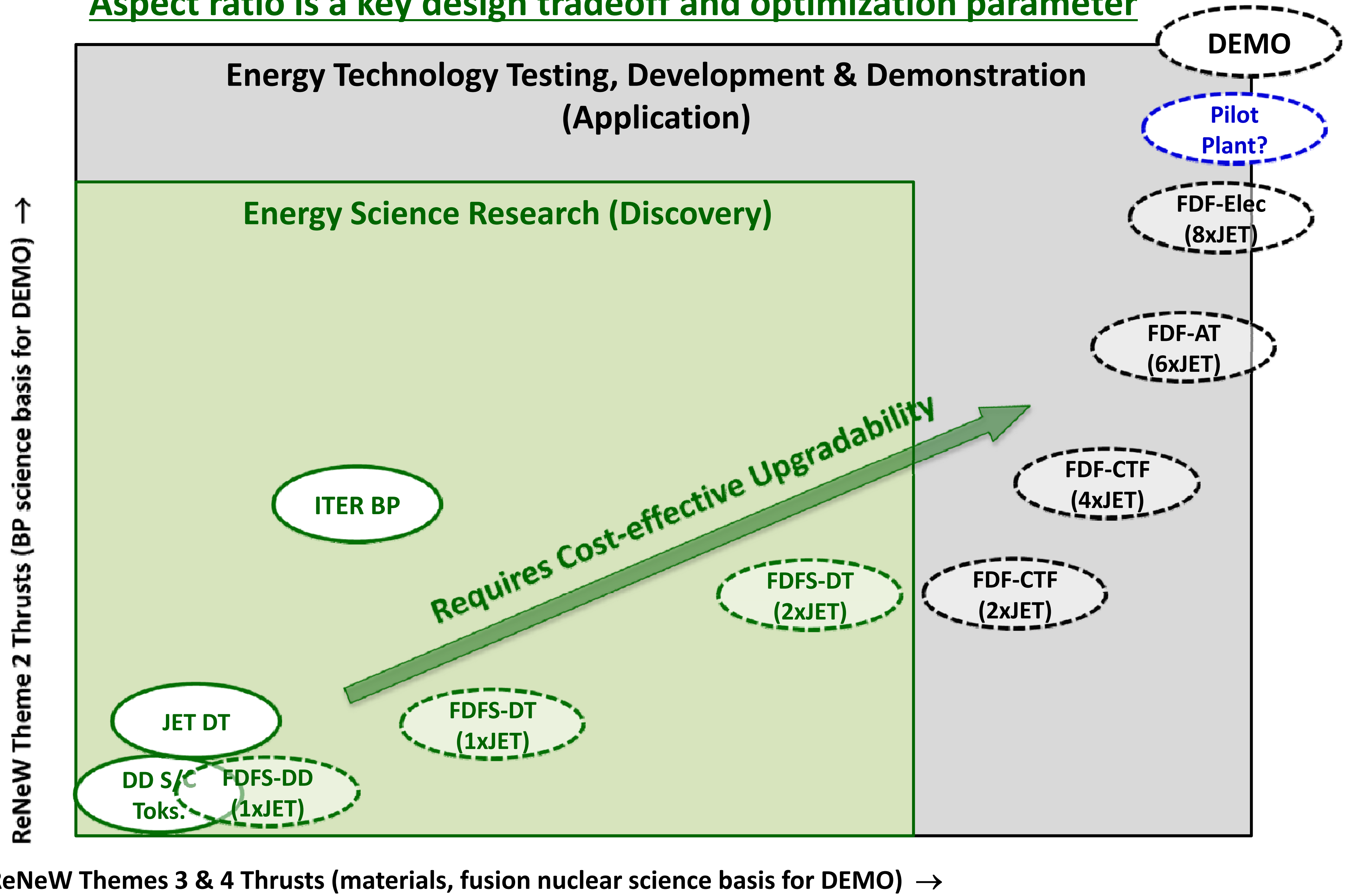
This strategy applies equally to FDF – *FDFS = FDF Science*

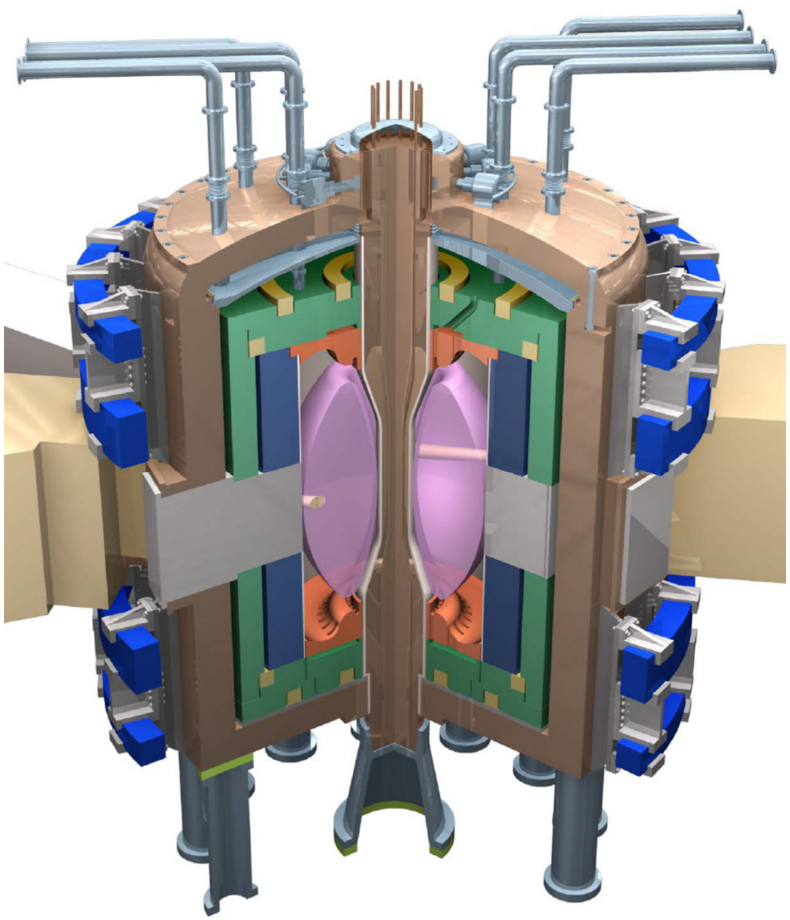
Aspect ratio is a key design tradeoff and optimization parameter



What should be the mission elements of FM&FNS R&D? Next: "FNSF" & "FDF" drafts

Example: Conservative parameters are available for R_0 = 1.3m, A = 1.7 plasmas to address the FMFNS mission

FNSF-CTF



Disruption-minimized: $\beta_N \leq 0.75\beta_{N\text{-no-wall}}$; HH $\leq$ 1.25; $q_{cyl} \geq$ 2xlimit; $J_{avgTF} \leq$ 4 kA/cm^2

Plasma Pressure	JET-DD	JET-DT	2xJET	4xJET
Tests enabled	PFC	FNS	FNS-CTF	CTF
W_L (MW/m^2)	0.005	0.25	1.0	2.0
Current, I_p (MA)	4.2	4.2	6.7	8.4
Field, B_T (T)	2.7	2.7	2.9	3.6
Safety factor, q_{cyl}	6.0	6.0	4.1	4.1
Toroidal beta, β_T (%)	4.4	4.4	10.1	10.8
$B_T^2\beta_T$ (T^2-%)	32	32	85	140
Normal beta, β_N	2.1	2.1	3.3	3.5
Avg density, n_e (10^{20}/m^3)	0.54	0.54	1.1	1.5
Avg ion T_i (keV)	7.7	7.6	10.2	11.8
Avg electron T_e (keV)	4.2	4.3	5.7	7.2
BS current fraction	0.45	0.47	0.50	0.53
NBI H&CD power (MW)	26	22	44	61
Fusion power (MW)	0.2	19	76	152
NBI energy (kV)	120	120	235	330

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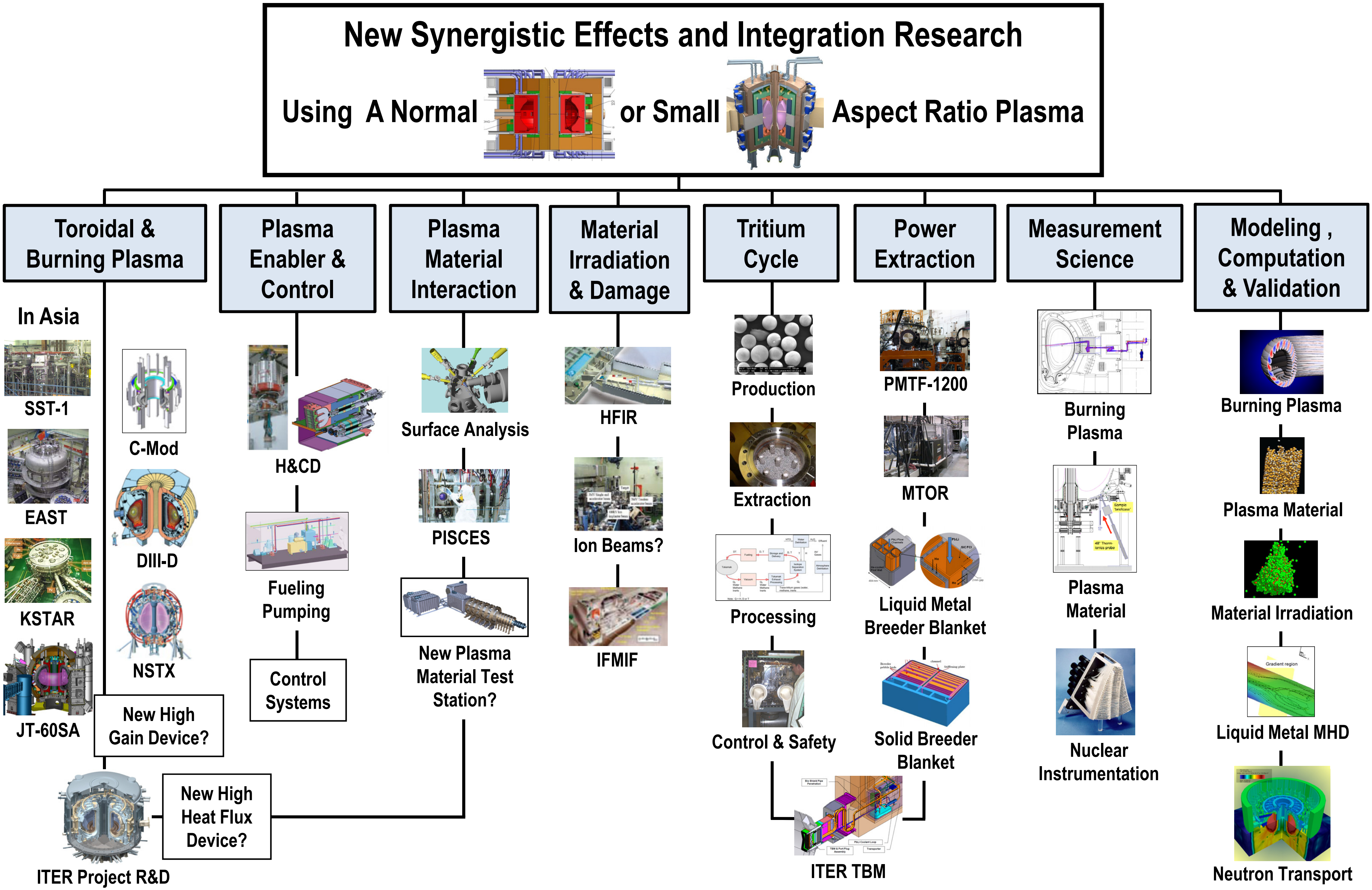
Fusion Material & Fusion Nuclear Science Program Mission – Draft

To answer the remaining challenges of fusion material & fusion nuclear science outside the ITER scope to complete the scientific basis for transition to a fusion energy development program.

Mission Components

1) Synergistic Effects and Integration – To elucidate and resolve, using a fusion nuclear science facility, the synergistic effects in multiple material interactions, fuel management, and power extraction – simultaneously encountering four phases of matter across the nuclear, atomic, nano, meso, and macroscopic scales for continuous durations of up to ~week, in an integrated fusion nuclear environment of substantial fusion neutron flux and fluence (1 MW-yr/m^2), using stable operating plasmas with moderate fusion gains (0.8 – 3).
2) Toroidal & Burning Plasma – *To*
3) Plasma Enabler & Control – *To develop the science needed to efficiently heat, maintain, fuel, and control the fusion plasma in FNSF toward energy applications.*
4) Plasma Material Interaction – *To decipher the evolution of the plasma-material interface in an integrated nuclear environment including: surface morphology, hydrogen retention and recombination, surface chemistry and mixing, and near-surface particle migration.*
5) Material Irradiation & Damage – *To investigate and understand the synergistic materials effects from the integrated tests on a FNSF for comparison with the simulated tests for up to 10 dpa.*
6) Tritium Cycle – *To develop the science and technology needed to properly supply and handle tritium in FNSF to enable energy applications.*
7) Power Extraction – *To develop the science and technology needed to properly extract useful power from fusion neutrons and plasma heat in FNSF to enable energy applications.*
8) Measurement Science – *To*
9) Modeling, Computation & Validation – *To develop a "virtual" FNSF using high-performance computing, accounting for the key scientific properties of interest to the preceding areas of research, for use to analyze, integrate, and optimize the fusion nuclear science facility concept and the supporting research and development activities.*

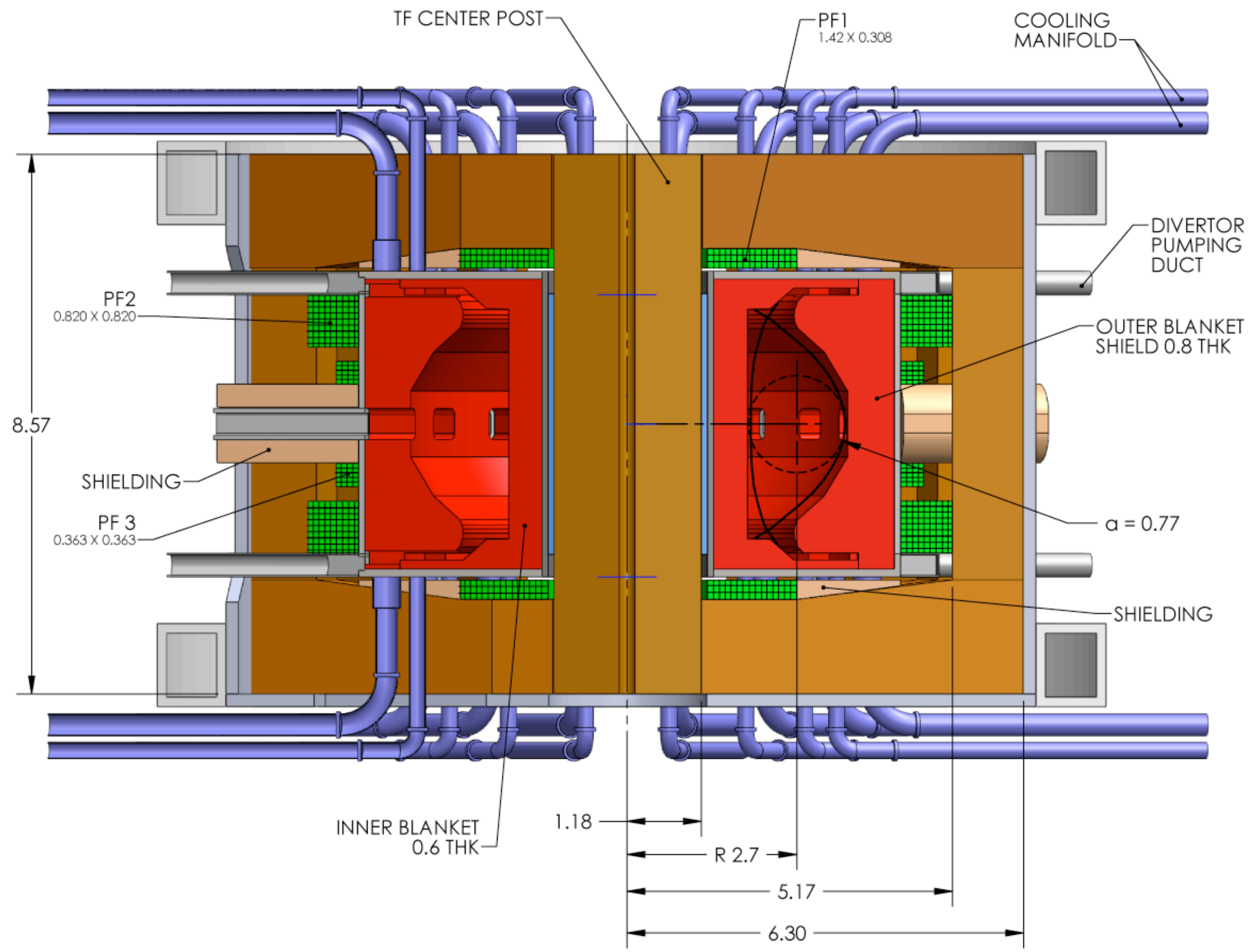
Available and Potentially Needed Capabilities of A Fusion Nuclear Science Program



The Fusion Development Facility Mission: Develop Fusion's Energy Applications

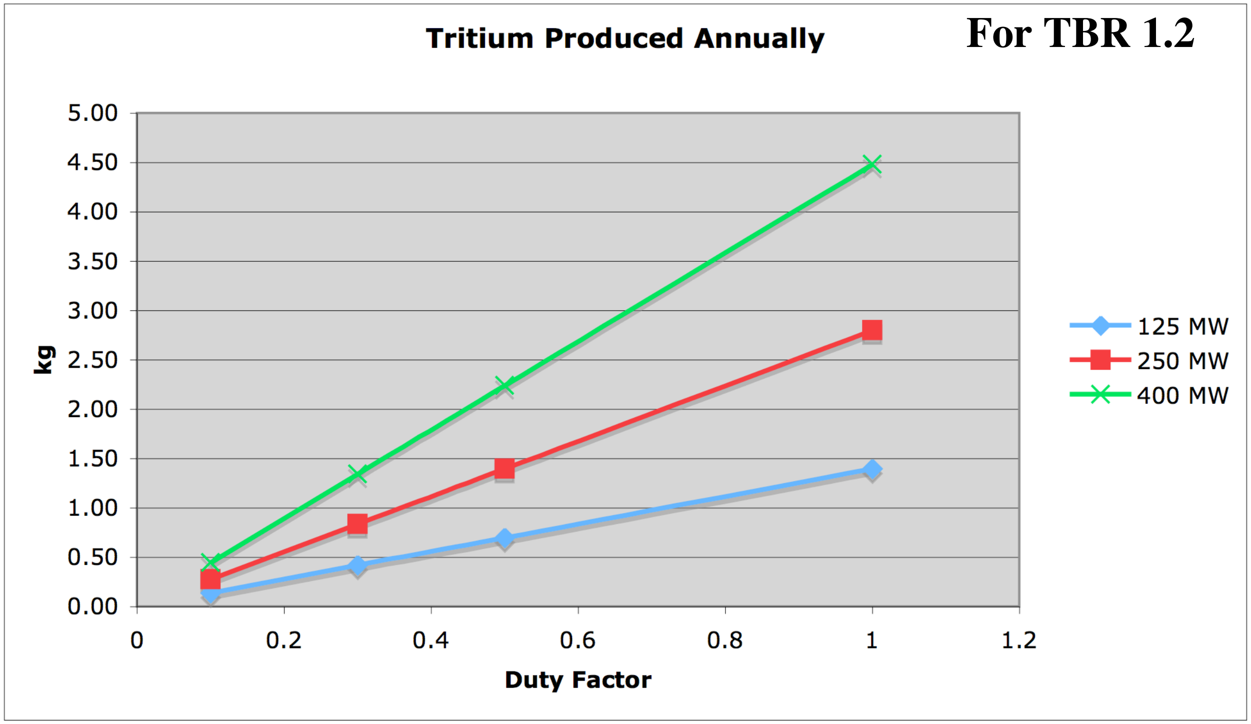
- **FDF will:**
  - **Close the fusion fuel cycle**
  - **Show electricity production from fusion.**
  - **Develop high temperature blankets for high efficiency electricity production.**
  - **Show hydrogen production from fusion.**
  - **Provide a materials irradiation facility to develop fusion materials.**
- **By using conservative Advanced Tokamak physics to run steady-state and produce 100-250 MW fusion power**
  - Modest energy gain (Q<7)
  - Continuous operation for 30% of a year in 2 weeks periods
  - Test materials with high neutron fluence (3-6 MW-yr/m^2)
  - Further develop all elements of Advanced Tokamak physics, qualifying them for an advanced performance DEMO
- **With ITER and IFMIF, provide the basis for a fusion DEMO Power Plant**

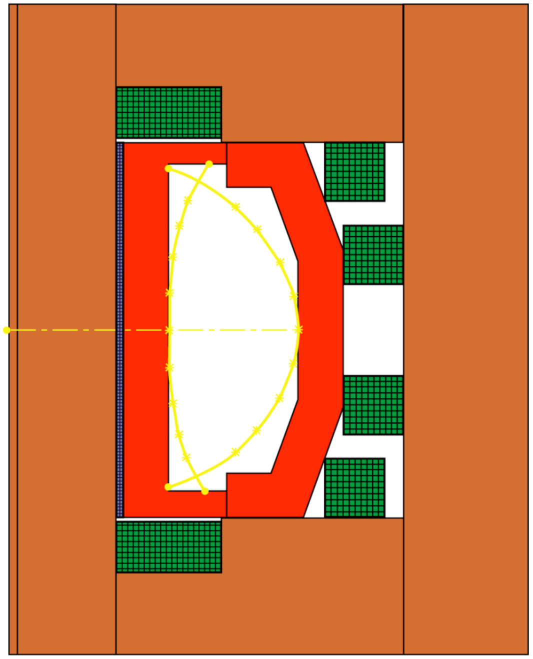
Rebaselined FDF Incorporating Increased Blanket/ Shield, Realistic Divertor Geometry, Plasma Wall Gaps



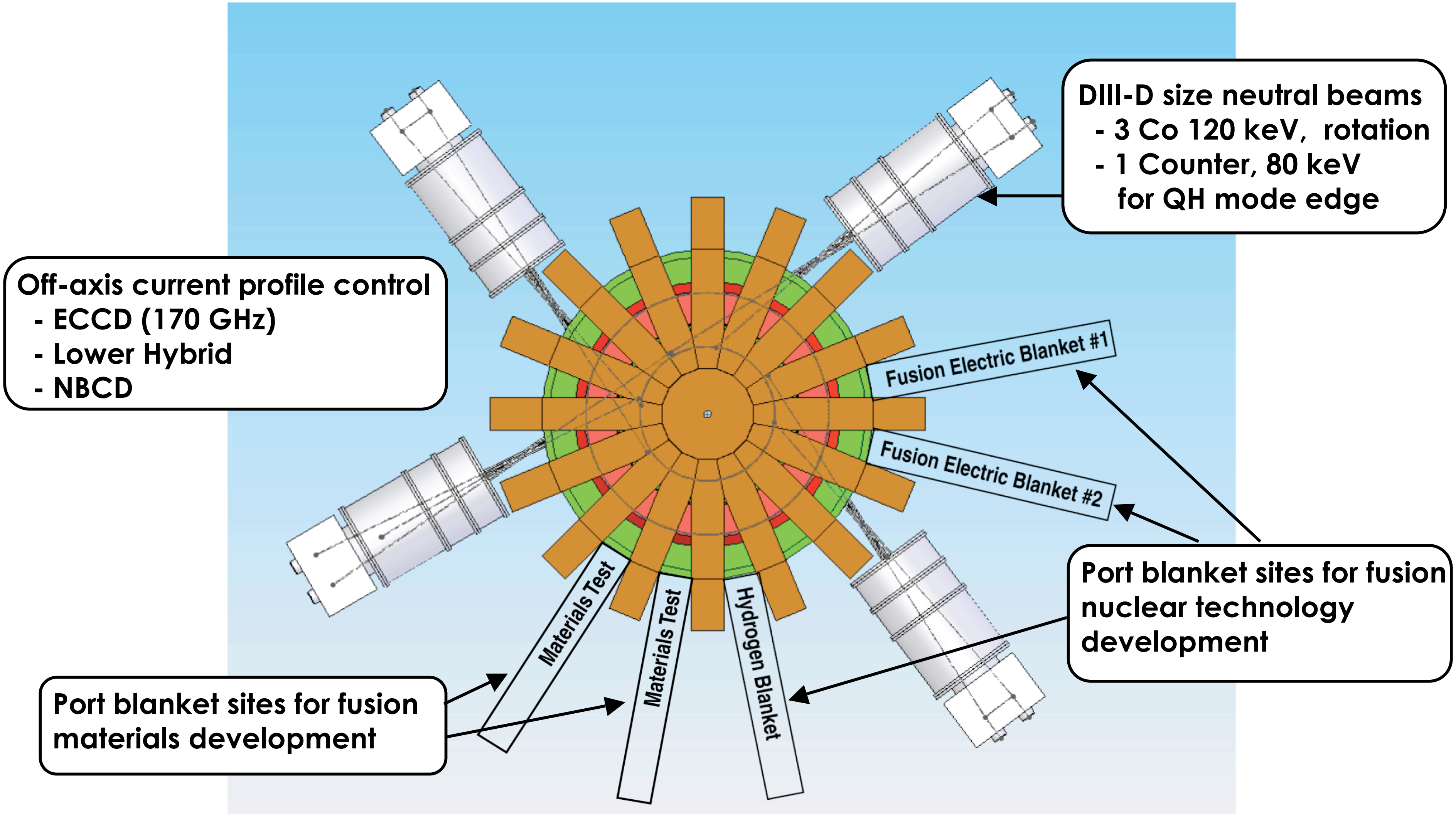
To Show Fusion Can Close its Fuel Cycle, FDF Will Demonstrate Efficient Net Tritium Production

- FDF will produce 0.4–1.3 kg of Tritium per year at its nominal duty factor of 0.3
- This amount should be sufficient for FDF and can build the T supply needed for DEMO

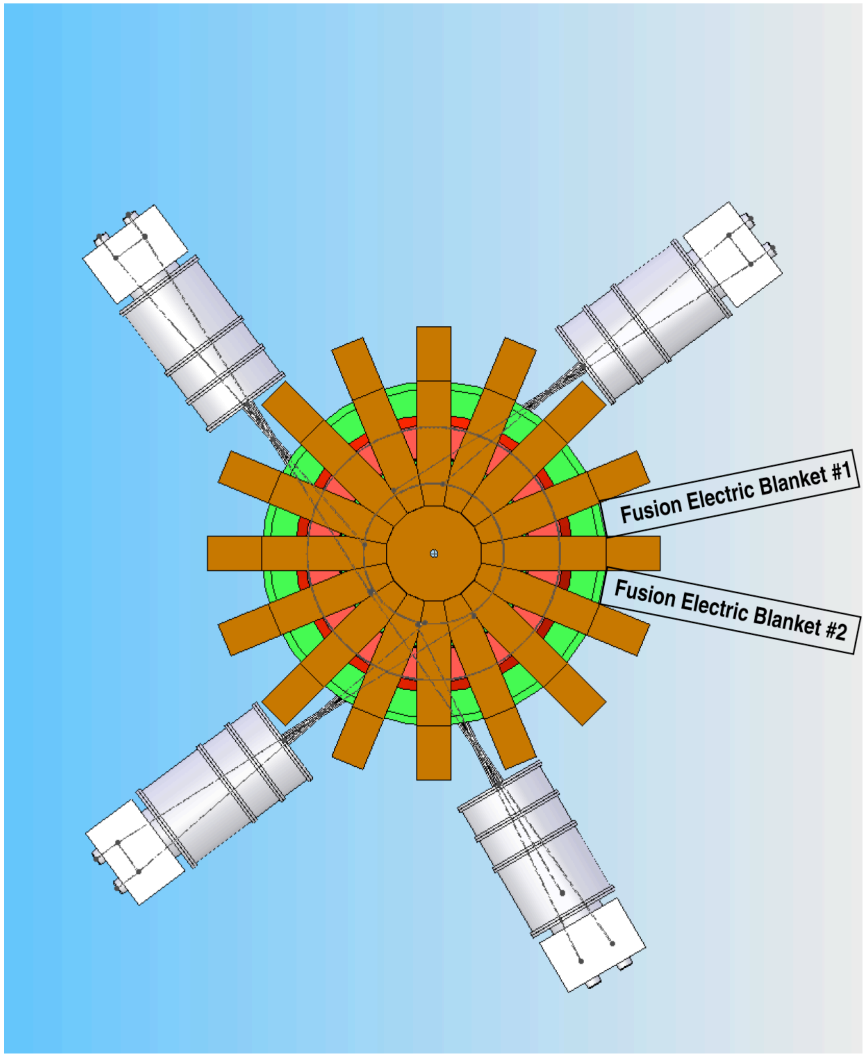




Port Sites Enable Nuclear and Materials Science.



Teams of Universities, Labs, and Industry Will Work with the Site to Field Test Blanket Modules on FDF



- **Fusion electric blankets require**
  - High temperature (500-700 ^{0}C) heat extraction
  - Complex neutronics issues
  - Tritium breeding ratio > 1.0
  - Chemistry effects (hot, corrosive, neutrons)
  - Environmentally attractive materials
  - High reliability, (disruptions, off-normal events)

- **Fusion blanket development requires testing**
  - Solid breeders (3), Liquid breeders (2)
  - Various Coolants (2)
  - Advanced, Low Activation, Structural materials (2)

- **Desirable capabilities of a development facility**
  - 1–2 MW/m^2 14 MeV neutron flux
  - 10 m^2 test area, relevant gradients(heat, neutrons)
  - Continuous on time of 1-2 weeks
  - Integrated testing with fluence 6 MW-yr/m^2

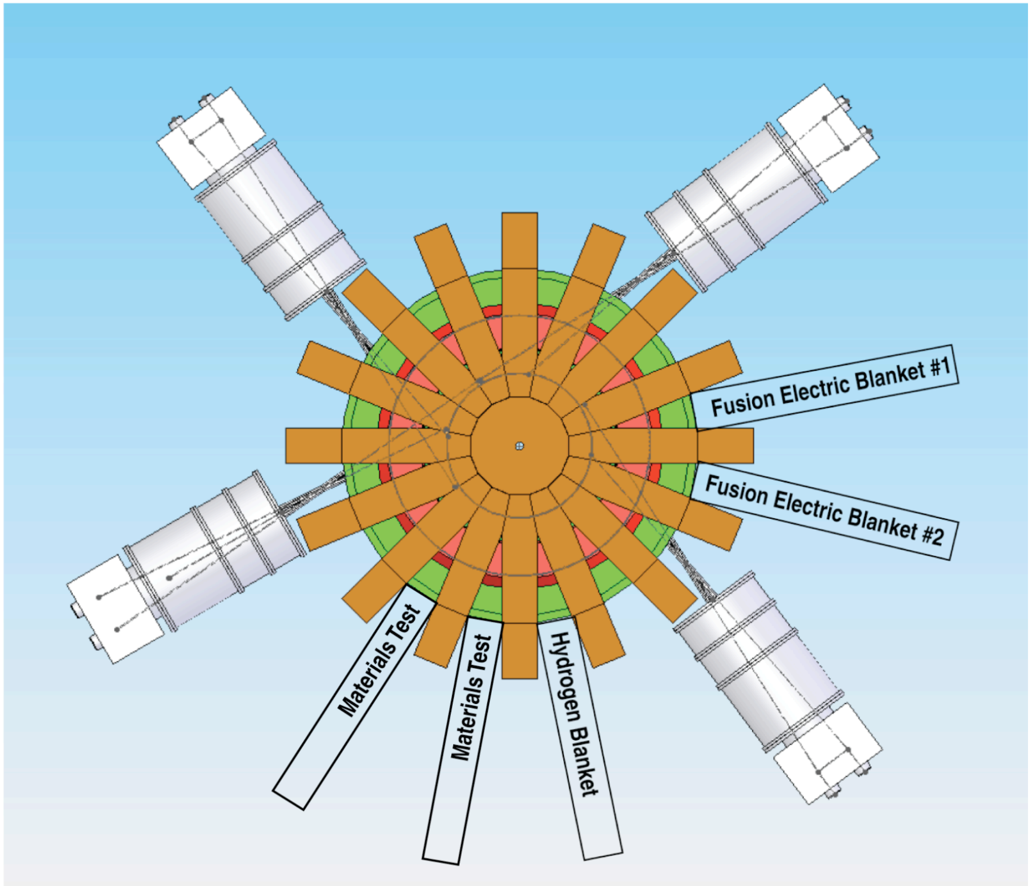
- **FDF can deliver all the above testing requirements**
  - Test two blankets every two years
  - In ten years, test 10 blanket approaches

Produce 300 kW electricity from one port blanket

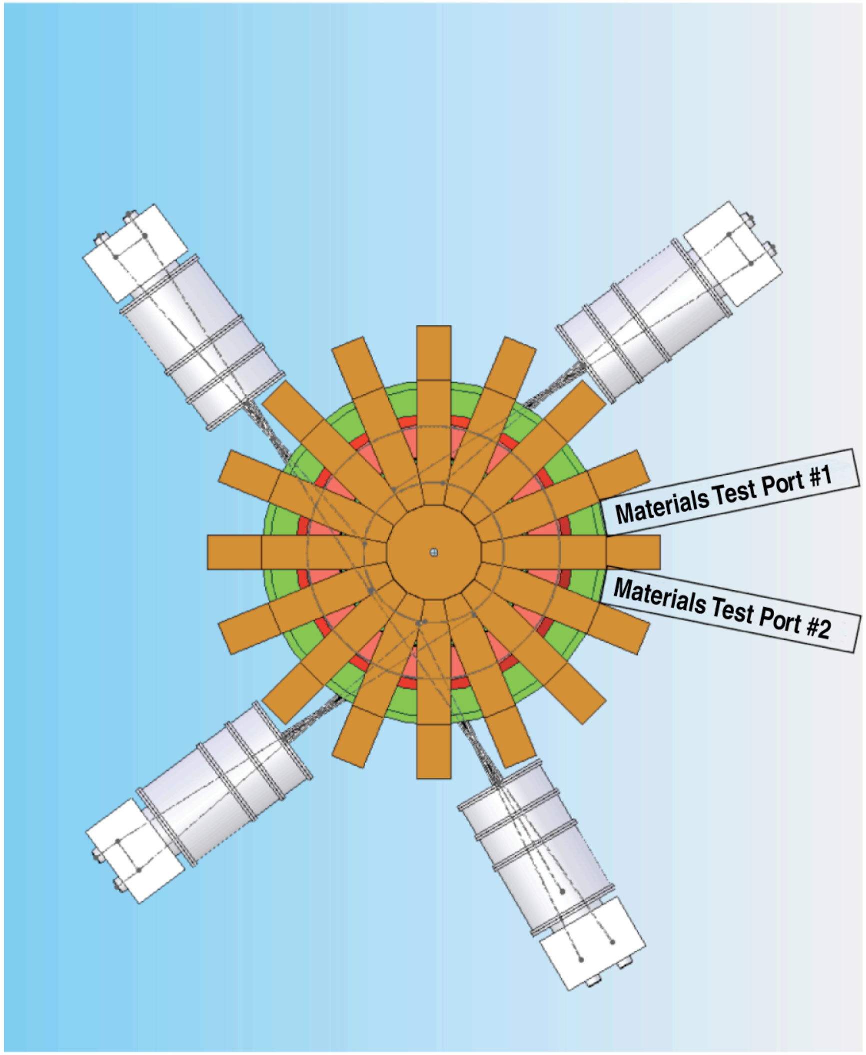
FDF will Motivate the Needed, Large, Supporting Fusion Nuclear Science Program

On Test Specimens and Components,

- Materials compositions
- Activation and transmutation
- Materials properties (irradiated)
- Thermo-hydraulics
- Thermal expansion and stress
- Mechanical and EM stresses
- Tritium breeding and retention
- Solubility, diffusivity, permeation
- Liquid metals crossing magnetic fields
- Coolant properties
- Chemistry
- and more…..



Teams of Universities, Labs, and Industries Will Conduct a National Program of Materials Irradiation



- **Provides up to 60 dpa of DT fusion neutron irradiation in controlled environment materials test ports for:**
  - First wall chamber materials
  - Structural materials
  - Breeders
  - Neutron multipliers
  - Tritium permeation barriers
  - Composites
  - Electrical and thermal insulators

- **Materials compatibility tests in an integrated tokamak environment**
  - Flow channel inserts for DCLL blanket option
  - Chamber components and diagnostics development

The U.S. Fusion Nuclear Science Community Suggested an Aggressive Phased Research Plan

	Years 1–4: ← START UP → H	D	DT	Years 5–9: FIRST MAIN BLANKET		Years 10–11	Years 12–16: SECOND MAIN BLANKET		Years 17–18	Years 19–23: THIRD MAIN BLANKET	
Fusion Power (MW)	0	0	125	125	250		250	250		250	400
P_N/A_{WALL} (MW/m^2)			1	1	2		2	2		2	3.2
Pulse Length (Min)	1		10	SS	SS		SS	SS		SS	SS
Duty Factor	0.01		0.04	0.1	0.2		0.2	0.3		0.3	0.3
T Burned/Year (kG)			0.28	0.7	2.8		2.8	4.2		4.2	5
Net Produced/Year (kG)				–0.14	0.56		0.56	0.84		0.84	1
Main Blanket	He Cooled Solid Breeder Ferritic Steel						Dual Coolant Pb-Li Ferritic Steel			Best of TBMs RAFS?	
TBR				0.8	1.2		1.2	1.2		1.2	1.2
Test Blankets				1,2			3,4	5,6		7,8	9,10
Accumulated Fluence (MW-yr/m^2)			0.06		1.2			3.7			7.6

Fusion Nuclear Science Program - Goals

Goals and Objectives

Produce significant fusion power.

Make high performance, steady-state, burning plasmas.

Develop low activation, high strength, high temperature, radiation resistant materials for fusion.

Demonstrate the production of high grade process heat from fusion.

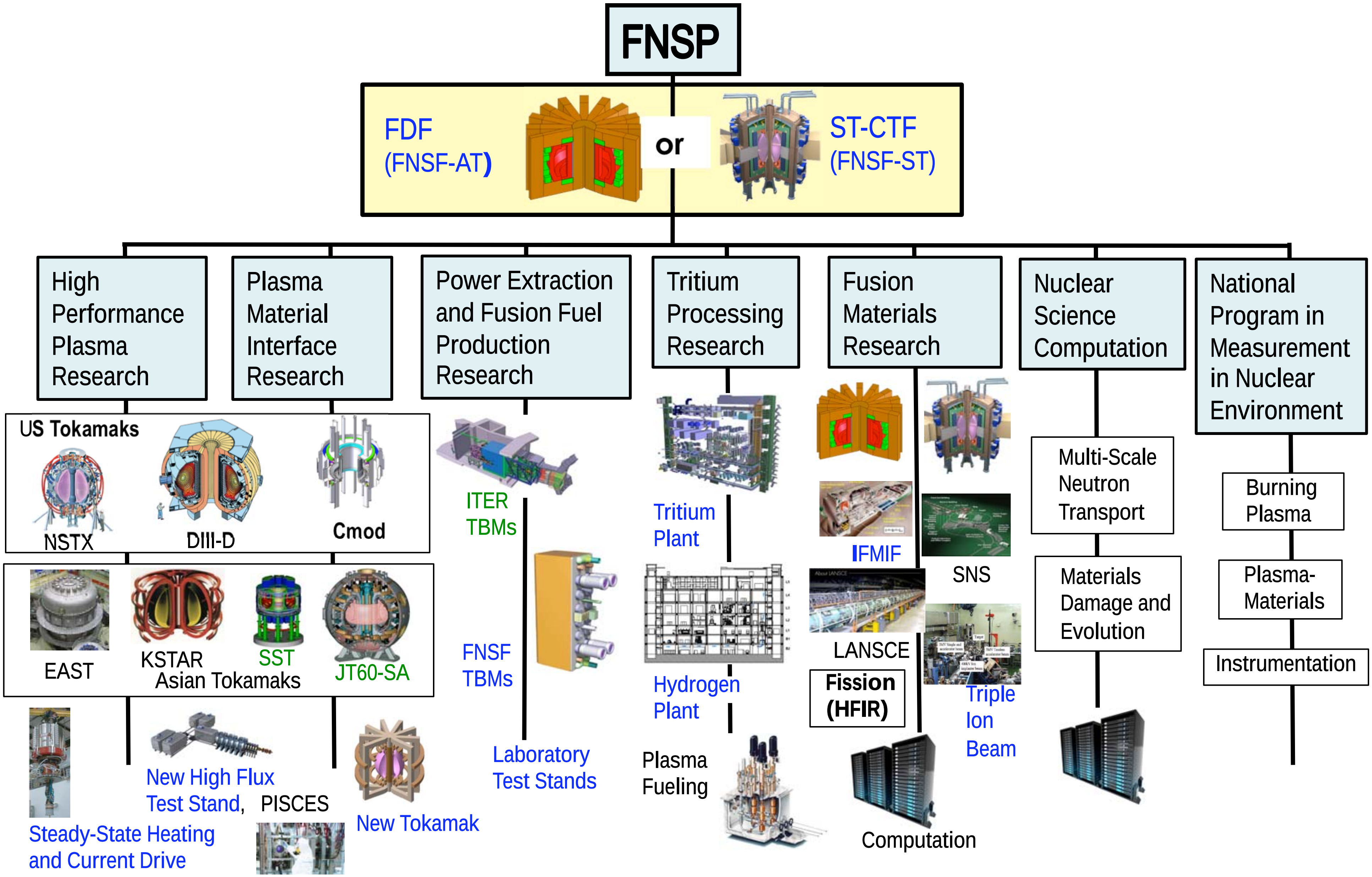
Demonstrate fusion fuel self-sufficiency.

Show fusion can produce electricity.

Show fusion can produce hydrogen.

Obtain first reliability, availability, and maintainability experience.

Fusion Nuclear Science Program (FNSP):
The Scientific Basis for Fusion Energy Applications



Issues worthy of further discussion

- Discuss and identify key characteristic for FM&FNS "Facility" and "Program"
- Vet mission components for VLT topical areas
- Outreach to vet mission components for burning plasma science topical areas
- Vet the mission component for "synergistic effects and integration"
- Move on to "programmatic needs" working with VLT and BP stakeholders
- Report results to community for feedback (a national workshop?)
- Other issues?