US Strategies for an Innovative Stellarator-Based FNSF

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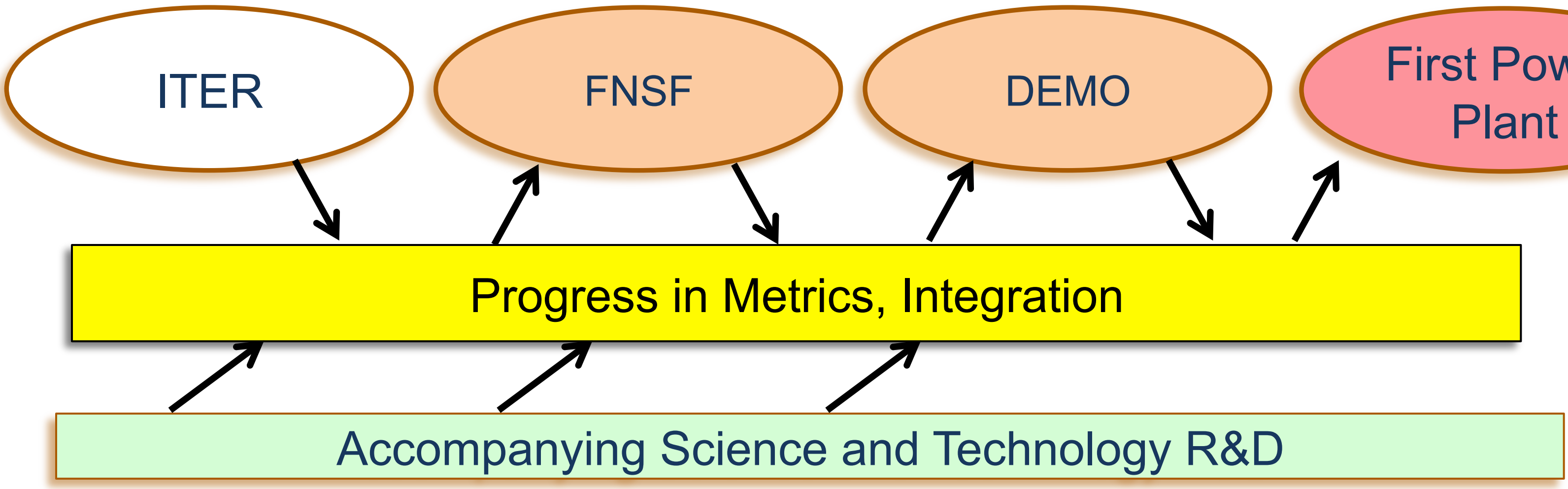
For the US Stellarator Steering Committee

FESAC Strategic Planning Panel
3 June 2014

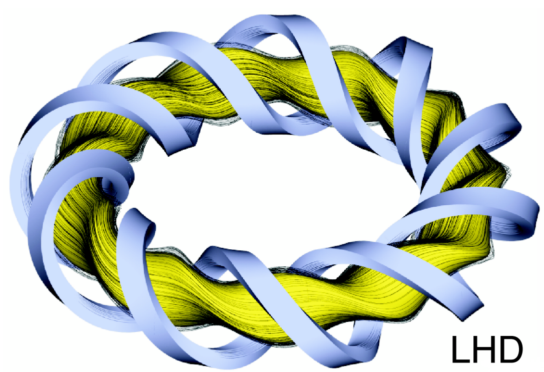
Context



FNSF: fully integrated fusion plasma and technological environment

- Long-pulse, high duty factor
- Integration testing and validation; tritium breeding

Stellarators: helical magnetic field torus, like tokamaks
full field from 3D coils, 3D plasma shaping



Stellarators Already Provide Advanced Characteristics

Steady-state: field from 3D coils, not plasma current

✓No disruptions.

✓No current drive ⇒ potential high fusion gain, higher reliability

✓Quiescent high-beta ≥ 5%,

✓Energy confinement similar to tokamaks.

✓Very high density limit ⇒ potential higher fusion reactivity
colder edge, for easier divertor
reduced fast-ion instability drive

✓No need for feedback stabilization ⇒ simplify plasma control,
reduce diagnostics needed in fusion environment

Closes some technical gaps, reduces some R&D needs.

Simplifies FNSF and DEMO designs.

Need to demonstrate these capabilities can be simultanious

Stellarator Research is Active World-wide

Large international programs:

- LHD, R=3.7m superconducting, partially optimized (Japan, 1998)
- W-7X, R=5.5m superconducting, quasi-omnigenous (Germany, 2015)

US:

- Historically, strong theory program.
  - Methods to optimize confinement in 3D
  - quasi-symmetry (QS): tokamak-like transport
- Pioneering novel Concept Exploration experiments, e.g.
  - HSX, quasi-helically symmetric
  - CTH, disruption onset thresholds
- NCSX project: partially built mid-scale experiment
  - study sustainable high performance, quasi-axisymmetric
  - synergy: tokamak-like transport and stellarator stability.
  - cancelled in 2008, due to cost-overruns. Major components done.

QS Stellarator FNSF has Moderate Size

	R (m)	<a> (m)	B (T)	β (%)	Pfus (MW)	Neut. Wall load. (MW/ m^2)
• W7-X-like H.Wobig et al, NF 43 (2003) 889	18	2.1	4.5	3.6	1500	0.9
• ARIES-CS-like J.Menard et al, NF 51 (2011) 103014	4.75	1.05	5.6	6	529	2
• LHD-like A. Sugara et al, FED 87 (2012) 594	14.4	2.5	4.7	5	3000	1.5

All target FNSF neutron flux. All are ignited or very close to ignition.

Similar to power plant designs -> prototype reactor integration issues directly

All are high gain. Would produce net power: can be pilot plants.

Lack of Current Drive Has Practical Benefits

- Minimizes wall penetrations & blocking of breeding blankets

- Relieves engineering constraints. Provides design margin on performance. Makes design easier.

- Simplifies sub-systems and control

- Strongly reduces recirculating power. Allows net power production at lower fusion power.

For stellarator DT experiments:

Component Test Facility = High Q_{DT} = Pilot-plant

Stellarator R&D Gaps to FNSF

- Integrated high performance of QS-optimized stellarators
  - Simultaneous high beta, high confinement, without disruptions. Benign ELMs.
  - Requires experimental validation

- Simplified coil design, via new coil strategies or simpler shape
- Predictive capability for plasma behavior and operation
  - Operating limits
  - Validation of theoretical models; including relationship to tokamak physics understanding.

- Effective divertor design, compatible with high performance
- Impurity and fusion ash accumulation control

US Stellarator Initiative is Needed (1)

1. Strong international collaboration with W7X, LHD (G.Wurden)
   - W-7X will be the first large, fully-optimized 3D experiment
   - Long-pulse, high-power, high-beta capabilities. Divertor program.
   - But, not quasi-symmetric – hard to connect with ITER.
   - Project to very large FNSF or DEMO.

2. US mid-scale QS experiment (J. Harris)
   - Integrated high performance for QS; divertor; impurity accumulation; predictive understanding
   - QUASAR using NCSX components (~4 years)

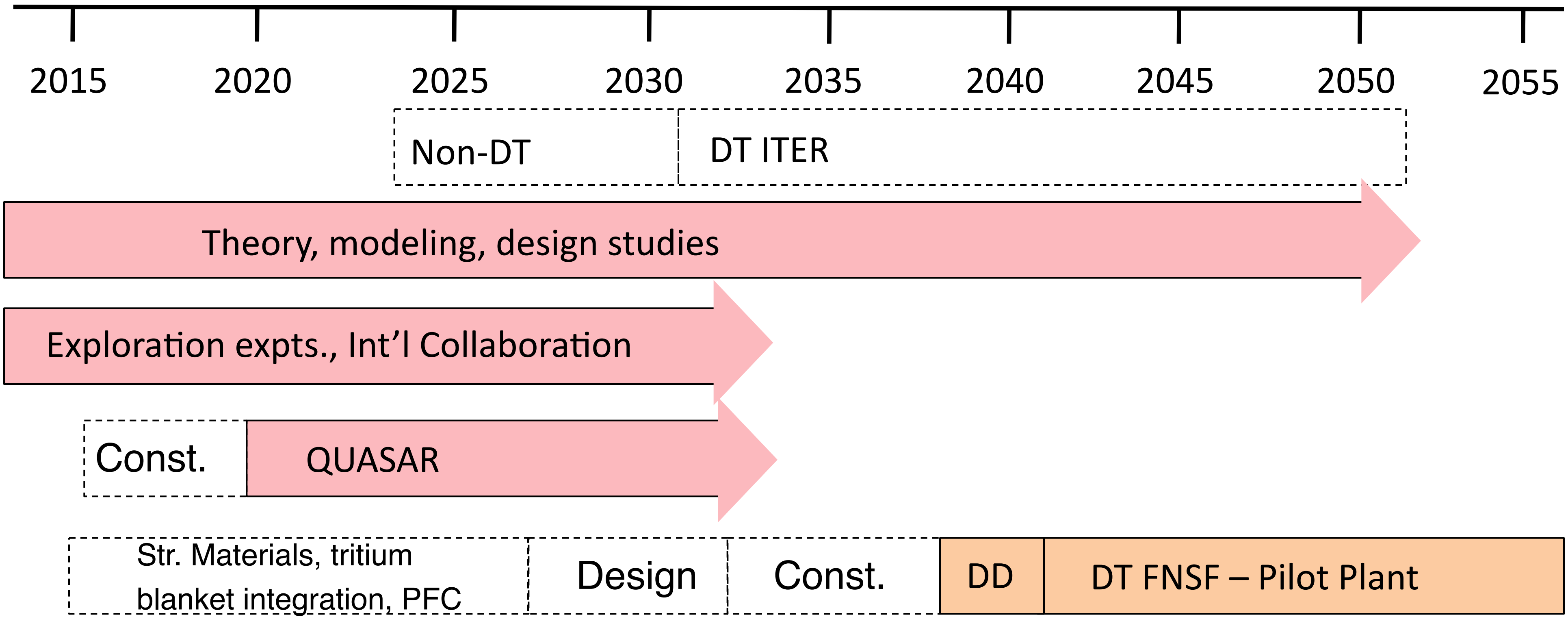
     Theory-based design for this mission
   - Managed as National & International collaboration.

US Stellarator Initiative is Needed (2)

3. Targetted exploration experiments (O. Schmitz)
   - Divertor design development
   - Simpler coils
   - Tests of turbulence optimization

4. Strengthened theory & computation program (M. Landreman)
   - Predictive understanding and modeling
   - Configuration optimization & improvement
   - Simpler coil design
   - Design of next-step experiments

Stellarator Initiative Fits in ITER Timescale



- Major reviews of Initiative in

  ~2015 (start)

  ~2024 (progress)

  ~2029 (readiness for next steps, decision on approaches)

Summary

- Stellarators can be a game-changer. Provide many of the needed characteristics for a FNSF and an advanced DEMO.
  - No disruptions. No current drive. High beta.
  - Stellarator FNSF is high gain, can be a pilot-plant.
- US opportunity to lead QS-optimization strategy
  - close connection to tokamak understanding; ITER results
  - can result in similar system scale as tokamaks.
- Need US Initiative to close remaining gaps
  - Strong collaboration with large international facilities
  - Mid-scale QS experiment: integrated performance
  - Concept exploration experiments on specific topics
  - Strong theory and modeling program.