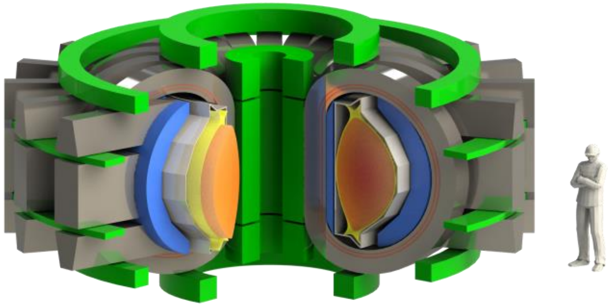

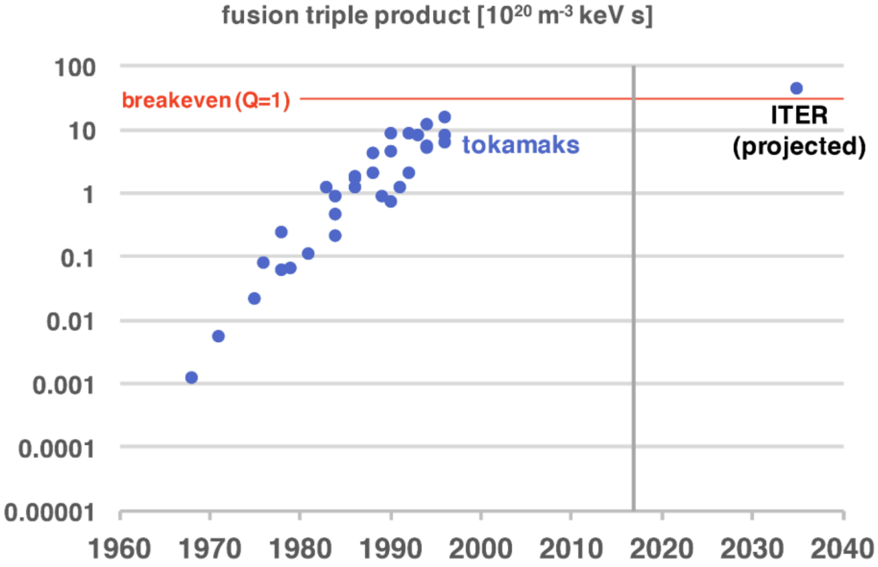

Ultra-high magnetic field fusion energy

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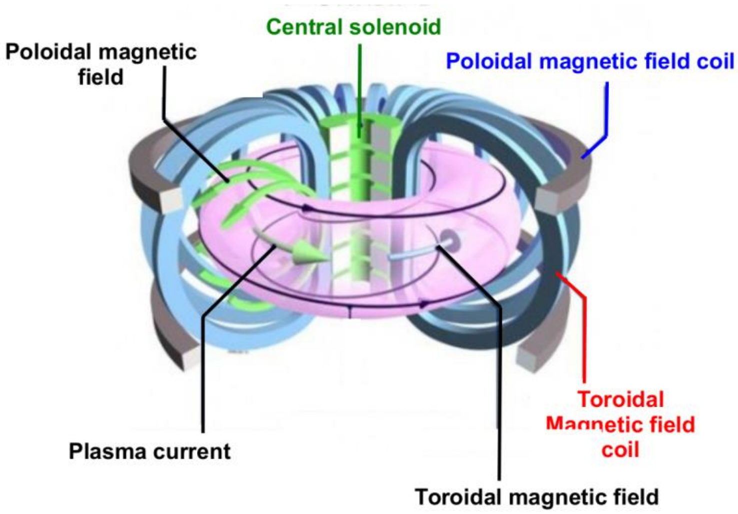
MIT Plasma Science and Fusion Center

MT 26
International Conference on Magnet Technology
Vancouver, Canada
Sept 22-27, 2019

Fusion magnet characteristics for ultra high-field

The high-field frontier in fusion is developing large-bore (> a few meters) high-field (>20 tesla) AC and DC magnets



Parameter	Value
Magnet requirement	TF: Steady-state high-field (Tesla) CS/PF: Total flux swing (Webers)
Magnet operation mode	Steady-state / DC (TF magnet) Pulsed / AC (CS and PF magnets)
Electrical current range	25 – 75 kA
Peak B-fields on coil	> 20 T
Operating temperatures	4 – 30 K
Stored Energy per magnet	5 – 50 GJ (The TF magnet)
Required fusion features	• >kW nuclear heat removal • Complex and extreme IxB forces • Thermal and mechanical cycling • Ability to handle quench events • Robustness to radiation damage
Desirable fusion features	Demountable joints
Superconductor choices	HTS is the only available choice (REBCO)

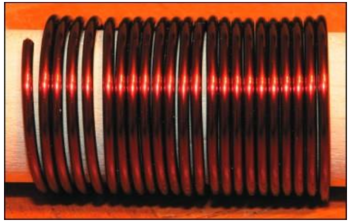
MIT PSFC

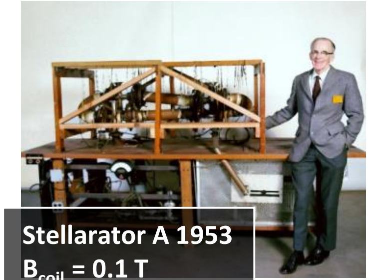
Increasingly higher field magnets have driven fusion energy forward

1950-1960s:

Copper wire

The pioneers





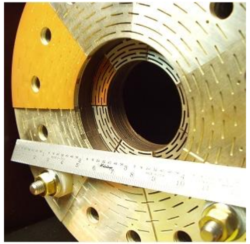
Stellarator A 1953

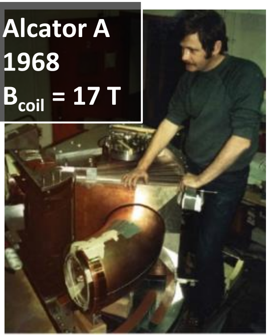
B_{coil} = 0.1 T

1960-1980s:

Cryogenic Bitter plates

The Alcators at MIT





Alcator A

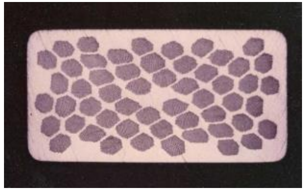
1968

B_{coil} = 17 T

1980-2000s:

NbTi superconductors

First SC fusion devices



Tore Supra 1988

B_{coil} = 9 T

1990s-2010s:

Nb_3Sn for higher field

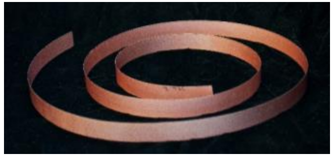
Reactor-class devices

ITER 2015

B_{coil} = 13 T

2010-2020s:

REBCO: very high magnetic fields



? ? ?

B_{coil} > 20 T

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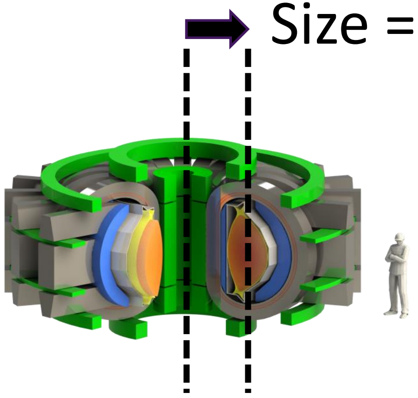
Magnetic field strength fundamentally sets size, cost, and time to build

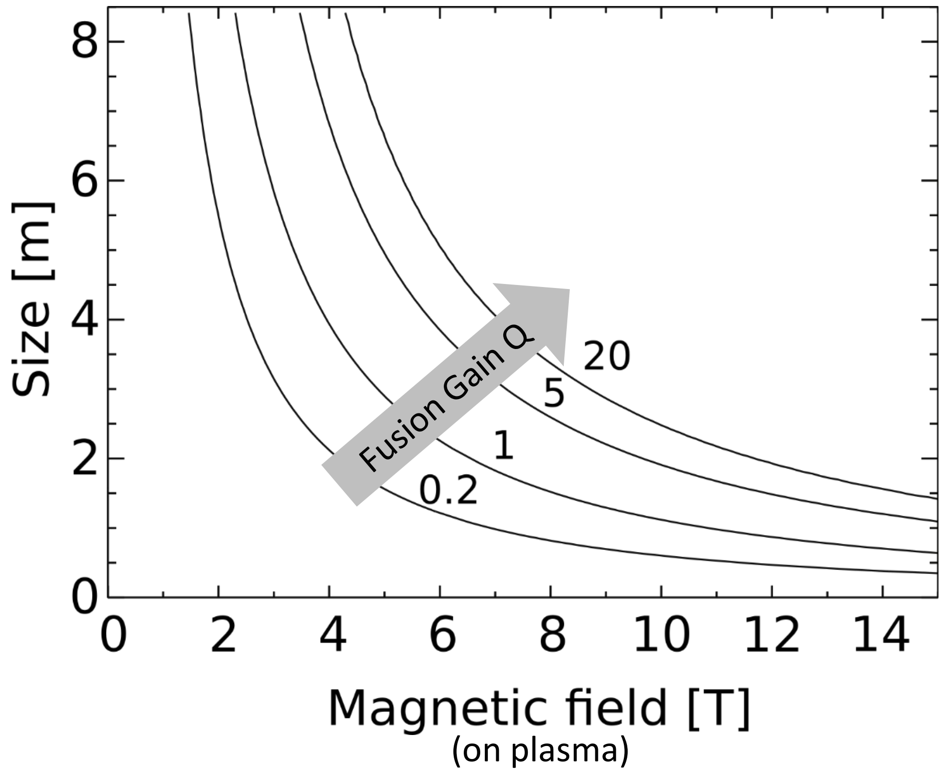


Global scale

National lab scale

University/company scale

Demonstrated unequivocally
With 50+ years and 170+ tokamaks!

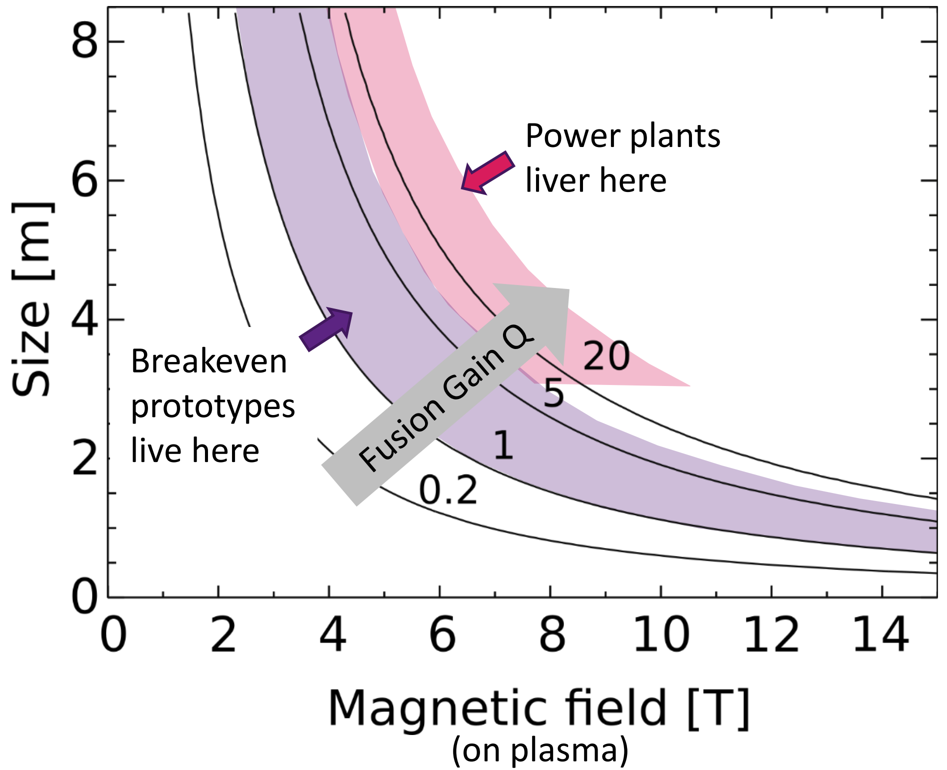


Magnetic field strength fundamentally sets size, cost, and time to build

Global scale

National lab scale

University/company scale



Magnetic field strength fundamentally sets size, cost, and time to build

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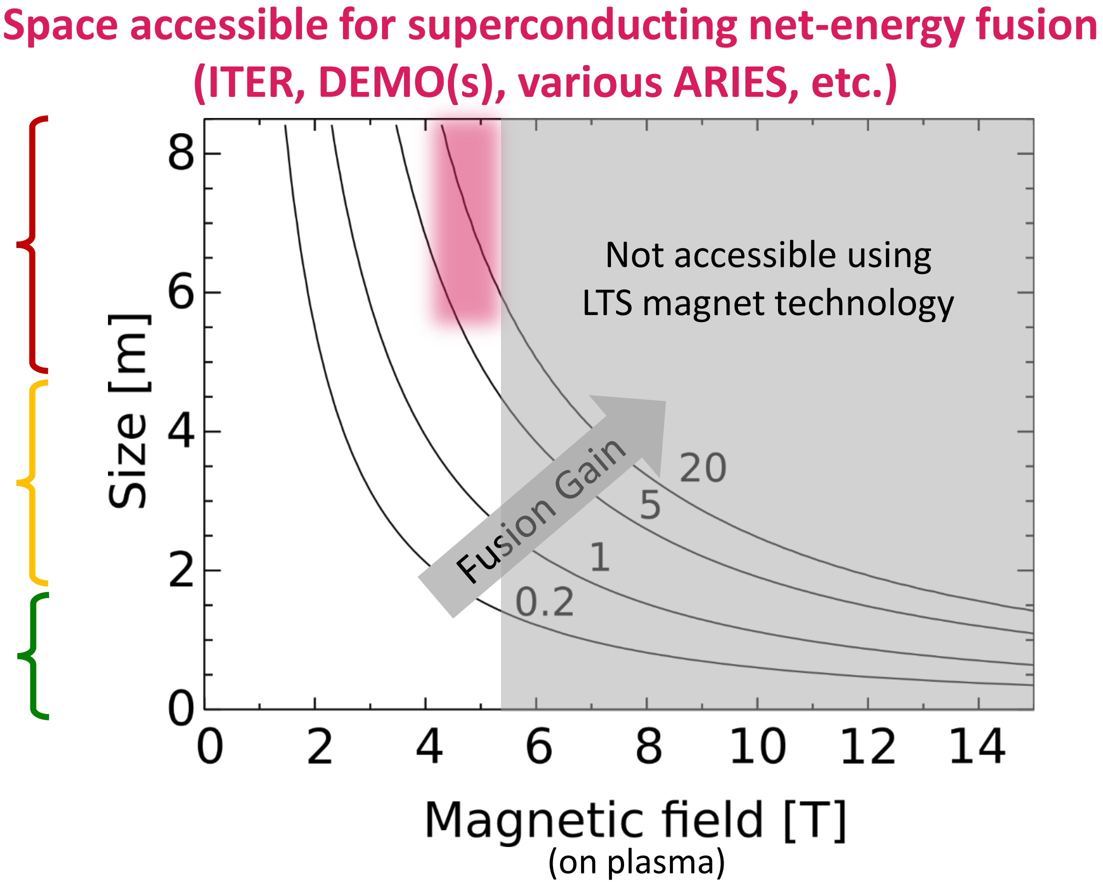


MIT
PSFC

HTS enables power plants, Q>1 experiments to live at modest scale

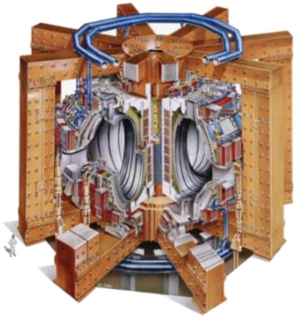
Examples from the MIT/CFS approach (only one of multiple approaches now under development)

ARC (fusion pilot plant concept) developed by graduate design design courses at MIT

- 200 MWe power plant at JET-scale

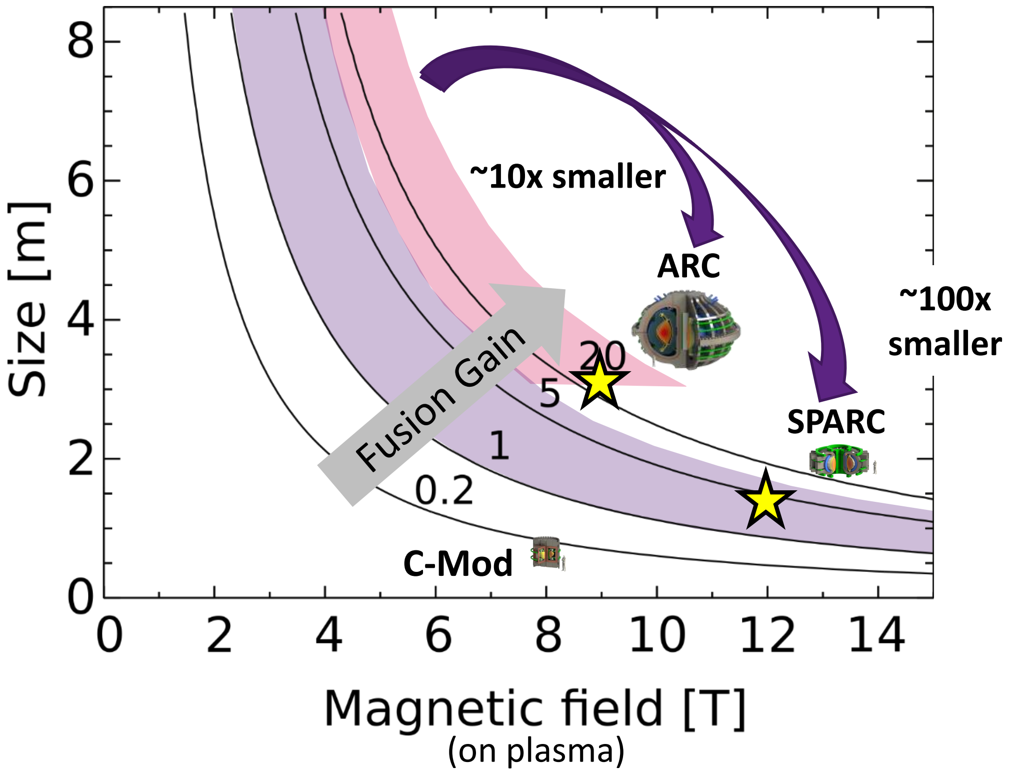
SPARC (net-energy experiment) under design by MIT PSFC and Commonwealth Fusion Systems

- Q>2, >50MW at ~2x Alcator C-Mod scale



JET (CCFE)

Alcator C-Mod (MIT)



A Fusion energy industry is taking advantage of HTS as enabling technology

Members of the Fusion Energy Industry Association

What's the potential market impact on HTS and magnets?

Very simplistic estimate for market potential of HTS:

- Displacing 1 TWe of fossil fuel energy with 200 MWe fusion plant requires ~5000 power plants
- For each fusion power plant assume:
  - Size: ARC-scale (R ~ 3m)
  - TF Magnet: ~9 T on axis (~120 MA-turns)
  - Cost: ~$10/kA-m for REBCO
  - Performance: Ic(20K,20T) ~ 500 A/12mm
- The market potential for HTS is on the order of:
  - O($30M) of REBCO per power plant
  - O($150B) of REBCO for 5,000 power plants

High-field fusion will transform the HTS industry and open new applications

Opportunity: Fusion presents the "problem" to HTS industries "solution" for large-scale growth

- HTS manufacturers have been producing an amazing product at high performance
- Applications have mostly been niche, small markets, and/or once-a-twenty years -> high cost!
- Sustained, ramping growth of fusion to 5,000 powerplants in next 50 years provides foundation

Example: The MIT-CFS SPARC project in the first 15 months

- 25+ km evaluation orders received, rigorously tested in <9 mo.
- Qualified some manufacturers to meet $Je(20K,20T,\theta_{worst})$ spec
- Supplier development contracts for 500+ km closed mid-2019
- Initial shipments already received, being processed
- Now in discussion for >20x order size for SPARC magnets
- Continued engagement with HTS industry to
  - Supply chain dev't with hastelloy, laser vendors
  - Ic(B,T,A) characterization for development
  - Engaging HTS investors, parent companies

High-field fusion energy offers HTS suppliers proof of market for large-volume purchases.

Commonwealth Fusion Systems, Tokamak Energy, CT Fusion, and others will transform HTS industry

A fusion-energy industry requires massive amounts of HTS.

High volumes and low-cost enable REBCO for many applications

Conclusion: HTS and high-field magnets are transformational for fusion energy

- In the tokamak, achieving large-bore (>3 m), high-field (>20 T) HTS magnets is **transformational** (not an incremental improvement) for fusion energy

- Dramatic scalings with field ($\sim B^4$) enable high-field fusion devices to be smaller, faster, lower-cost, and relevant to tackling 21st century energy issues

- Sustainable and vast markets targeted by a growing fusion energy industry are transforming the HTS industry, increasing volumes and performance while lowering unit cost. This opens new magnet industries and applications.