Helical Fusion

Helical Fusion Reactor HESTIA, and its possible synergy with DIII-D capabilities

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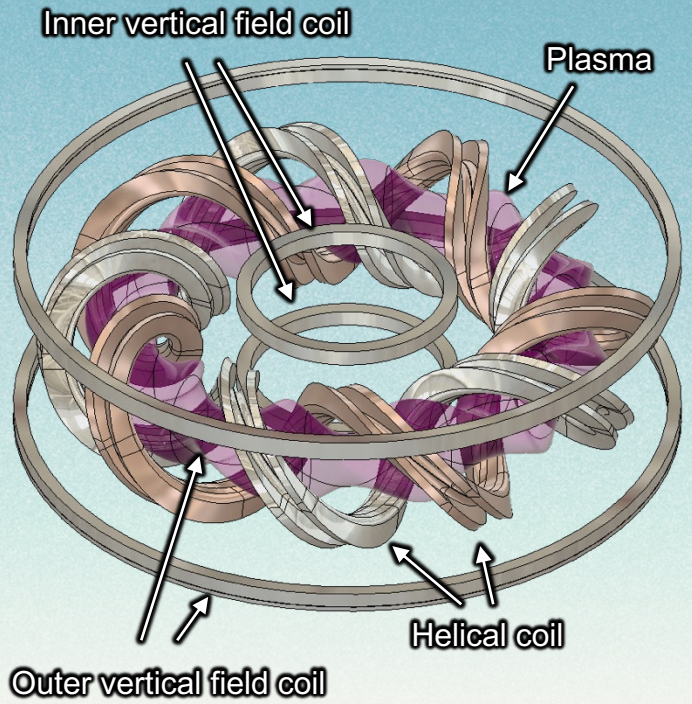
HESTIA is a Stellarator/Heliotron

HESTIA is a kind of stellarator called heliotron composed of two continuously wound helical coils and four planar vertical field coils, **based on Large Helical Device (LHD)** in Japan.

Helical plasma is quite stable and requires **no complicated plasma position control** as in tokamaks, even in plasma start-up and/or shut-down phases.

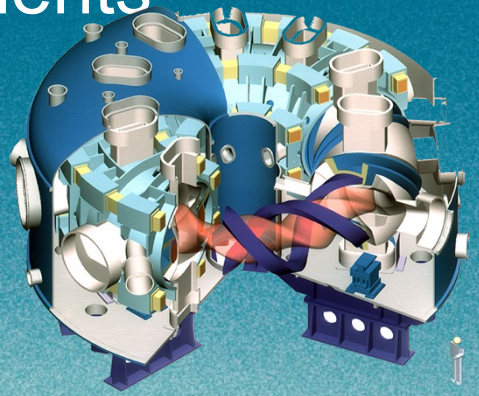
Helical plasma is **free from plasma current disruptions** jeopardizing the VV integrity.



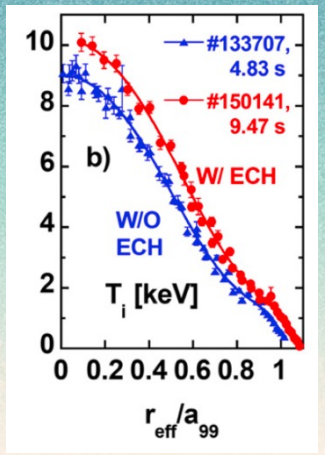
HTS magnet coils of HESTIA

The plasma is based on LHD's achievements

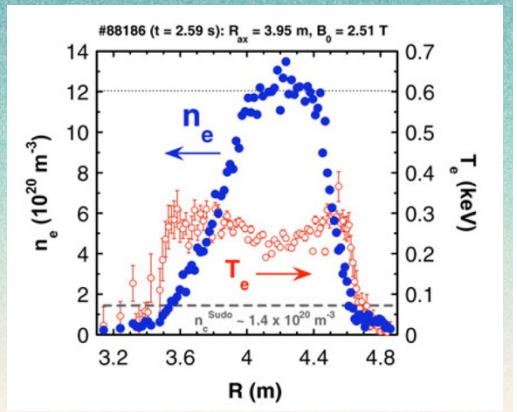
Central ion temperature, T_{i0}, higher than 10 keV
Central electron density, n_{e0}, higher than 1.2 x 10^{21} m^{-3}
Energy confinement time, τ_E, of 0.23 s
Fusion triple product, $n_{e0}T_{e0}\tau_E$, of 0.52 x 10^{20} m^{-3} keV s
Plasma duration time, $\tau_{duration}$, of 3,000 s
(although these were achieved individually)



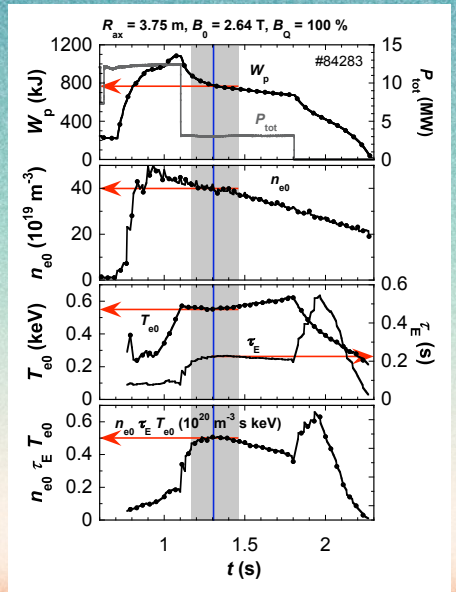
Large Helical Device (LHD)
https://www.nifs.ac.jp

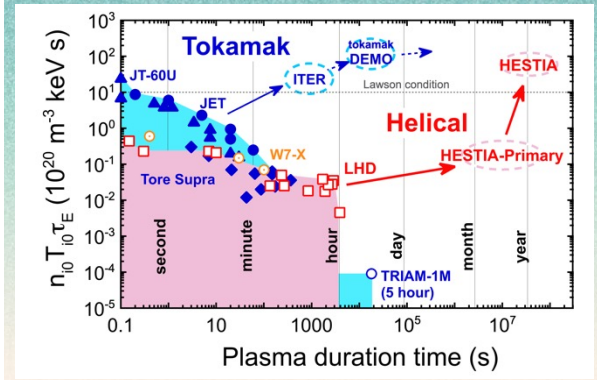


M. Osakabe et al., NF **62** (2022) 042019



J. Miyazawa et al., FST **58** (2010) 200





T. Seki et al., PFR **10** (2015) 3405046 (modified)

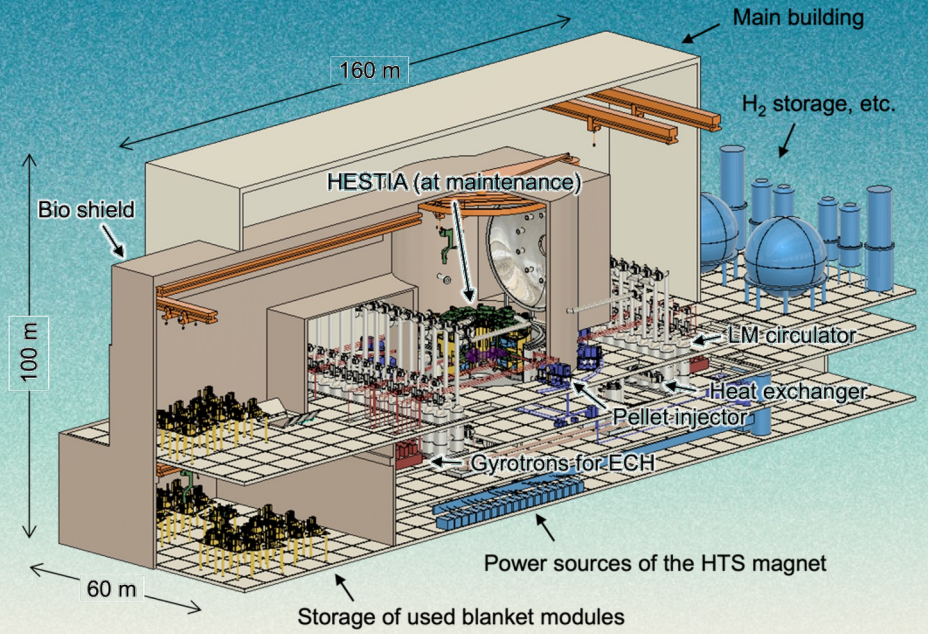
Fusion Pilot Plant: HESTIA

Helical Fusion is developing a 50 MWe-class FPP named HESTIA.

The FOAK power plant following HESTIA will be a 100 MWe-class steady-state helical fusion reactor.

Specifications of HESTIA

- Helical coil major radius, R_c: 7.8 m
- Magnetic field, B_c (at R_c): 8.0 T
- ECH power, P_{ECH}: 20 MW
- Fusion power, P_{fusion}: 260 MW
- Net electricity: 70 MWe
- Continuous operation time: 1 year
- Availability: > 80 %

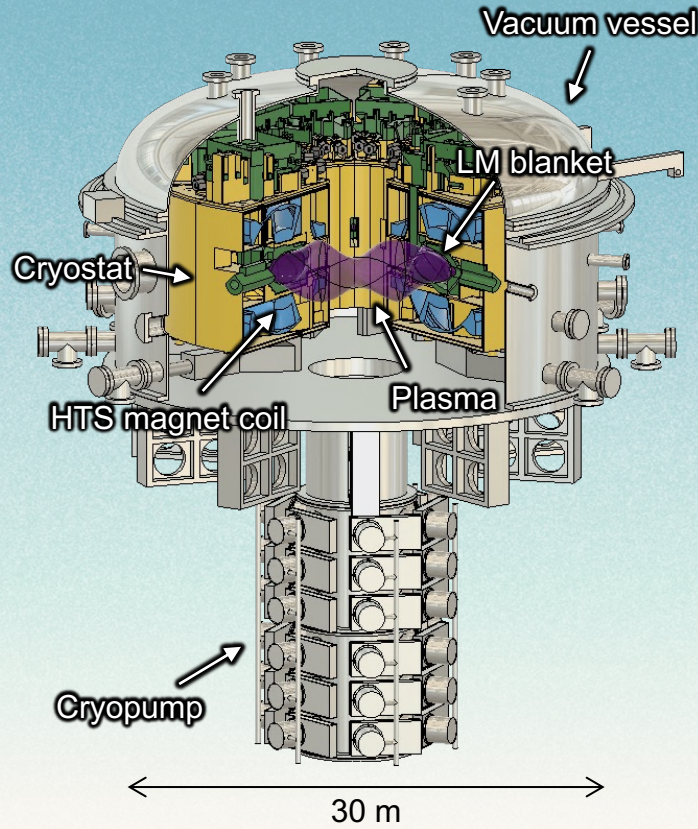


Overall view of HESTIA

J. Miyazawa et al., PoP **30** (2023) 050601.

HESTIA is Composed of New Technologies

- Helical coil major radius, R_{ax} : 7.8 m (LHD x 2)
- Magnetic field strength at R_{ax} : 6.6 T (LHD x 2.5)
- DT fusion reactor
- HTS magnets cooled by 20 K helium gas
- Liquid metal blanket (without divertor)
- ECH (without NBI and ICH)
- Pellet injection with direct internal fuel gas recycling
- Zero initial tritium loading (DD startup)
- Supercritical CO_2 turbine generator



Main body of HESTIA

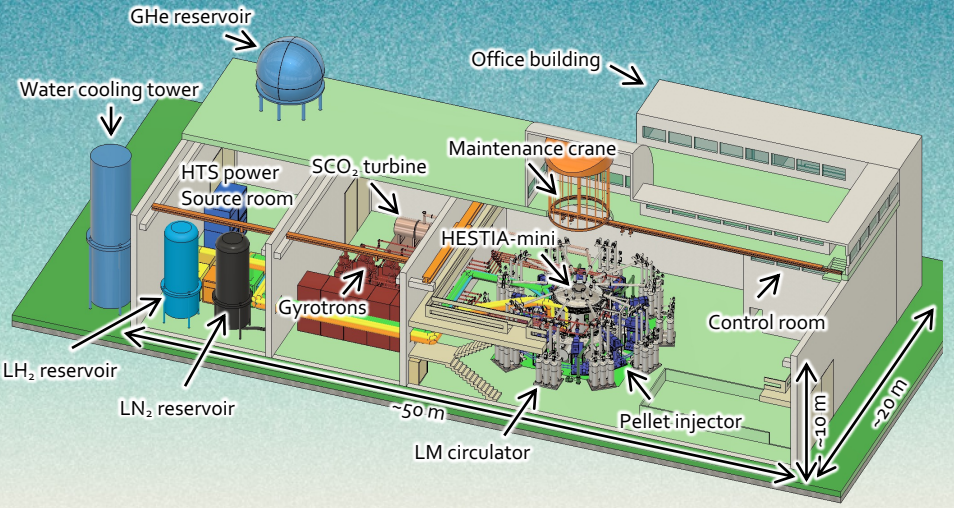
Prototype: HESTIA-mini

Before proceeding to HESTIA, demonstration is necessary of technology integration of plasma, HTS magnet, pellet injection with DIR, gyrotrons and LM blanket.

HESTIA-mini will be constructed as a prototype for this purpose.

Specifications of HESTIA-mini

- Helical coil major radius, R_c: 1.092 m
- Magnetic field, B_c (at R_c): 2.0 T
- ECH power, P_{ECH}: 2 - 10 MW
- Continuous operation time: > 1 day
- Non-nuclear in the 1st phase exp.
- **DT operation will be conducted in the 2nd phase, after relocation to a fusion reactor construction site.**



Overall view of HESTIA

Phased Development Plan

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	2020	2025	2030	2035	2040	2045	2050
Individual Technologies	Small-scale Demonstration	Large-scale Demonstration					
Prototype (HESTIA-mini)		Construction	Non-nuclear Operation	DT Operation			
FPP (HESTIA)			Construction	DT Operation			
FOAK Power Plant			2034	Construction	DT Operation		

R&D on individual technologies

- Configuration optimization
- HTS magnet
- Liquid Metal Blanket
- ECH (Electron Cyclotron Heating)
- **Pipe-gun pellet injector**
- **DIR (Direct Internal Recycling)**
- SCO_2 gas turbine generator
- H_2 liquefaction and storage system

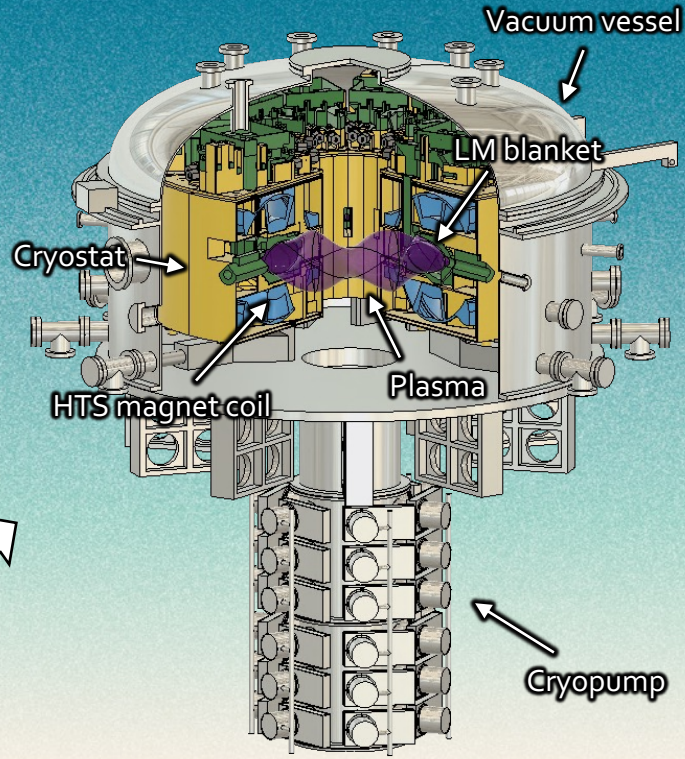
HESTIA-mini

as Prototype

4 m

HESTIA

as FPP (Fusion Pilot Plant)



30 m

Fueling system of HESTIA

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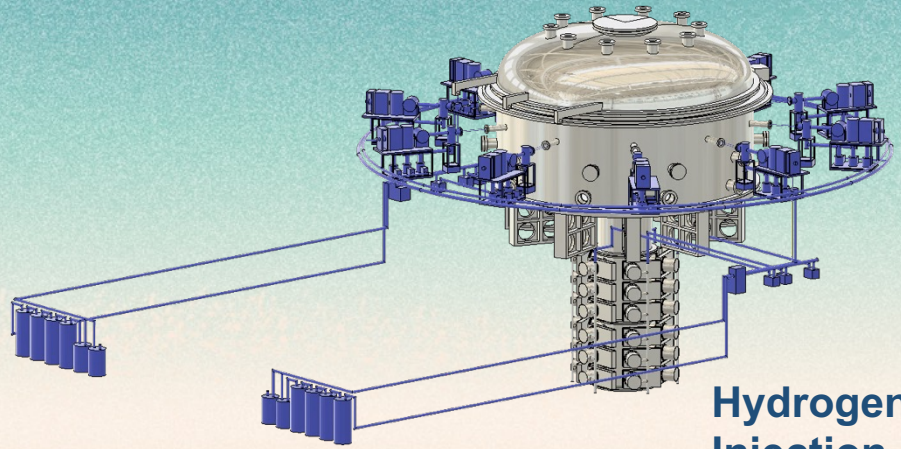
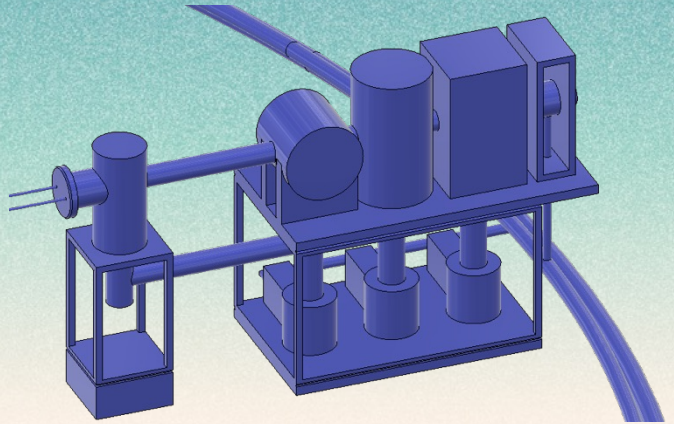
- 30-burrel Hydrogen-ice Pellet Injector (HPI)
- 10 HPIs will be installed on 10 outer ports of HESTIA to enable 3 Hz or more injection frequency with 300 barrels
- Accompanied with a direct internal fuel recycling (DIR), where the exhausted DT gas is directly supplied to the HPIs after purification and compression, to reduce the tritium site inventory



Hydrogen-ice Pellet Injection (HPI) system



Closeup view

Technology gap of HPI

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- We need a 30-barrel pipe-gun Hydrogen-ice Pellet Injector (HPI).
  - A few Hz of injection frequency
  - Planning to deploy 10 HPIs for continuous fueling
- We have a R&D collaboration with NIFS, where a 20-barrel pipe-gun HPI was developed previously.
- **However, where will the 30-barrel HPI be demonstrated ?**

Possible synergy with DIII-D capabilities

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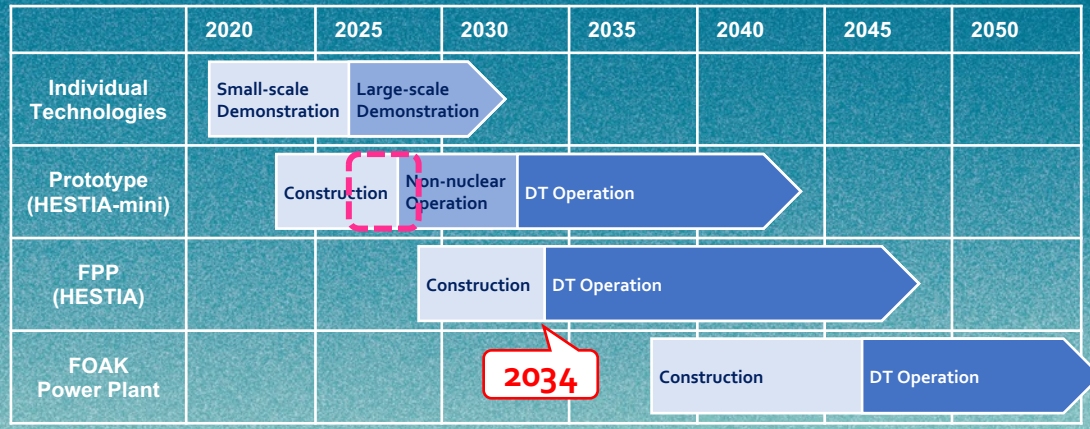
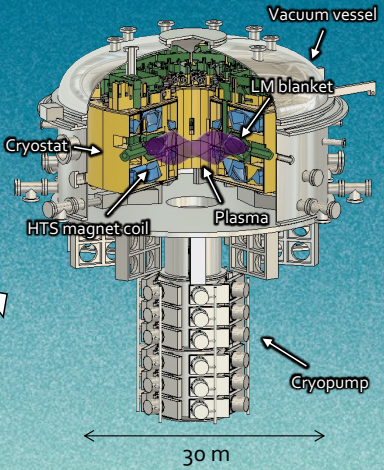


HESTIA
as FPP (Fusion Pilot Plant)

HESTIA-mini
as Prototype

4 m



- In our schedule, the construction of HESTIA-mini will begin in 2024, and the systems integration will finish in 2028.
- The R&D and prototype fabrication of the HPI will be completed in 2026.
- **We are looking for torus plasma devices to test our new HPI before the systems integration.**

Humanity evolves with nuclear fusion