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The Advanced Tokamak Path to a Compact Fusion Pilot Plant

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First of a kind physics-based simulations project a compact net electric fusion pilot plant with a nuclear testing mission is possible at modest scale based on the advanced tokamak concept, and identify key parameters for its optimization. The advanced tokamak approach is built on an alignment between strong shaping, broad profiles, high stability, good confinement and high self-driven 'bootstrap' currents. These new studies utilize a new integrated 1.5D core-edge approach for whole device modeling to predict plasma performance, by self-consistently applying the latest transport, pedestal, equilibrium, stability and current drive physics models to converge fully non-inductive stationary solutions without any significant free parameters. This contrasts with previous "systems code" approaches, where parameters are simply set to desired values.

This physics-based approach has led to new insights and understanding of reactor optimization. Results highlight the critical levering roles of density, plasma pressure and β (see figure), in increasing fusion performance and self-driven 'bootstrap currents', as well as broad profiles, to enable an efficient confinement, thereby reducing heating and current drive demands leading to high pressure solutions at compact scale with net electricity generation. Plasmas at 6-7T with ~4m major radius scale and 200MW net electricity are found with margins and trade-offs identified in achievable parameters. Auxiliary current drive is projected from neutral beam and ultra-high harmonic (helicon) fast wave, though other advanced current drive approaches presently being developed also have potential.

The resulting low recirculating power in a double null configuration leads to a divertor heat flux challenge that is comparable to ITER, though reactor solutions may need to increase dissipation further. Neutron wall loadings appear tolerable. Strong H-mode access (factor >2 margin over the L-H transition scaling) and ITER-like heat fluxes are maintained with ~20-60% core radiation. The approach would benefit from high temperature superconductors, the higher fields of which increase performance margins, while their potential for demountability may facilitate a nuclear testing mission. Solutions are possible with conventional superconductors. An advanced load sharing and reactive bucking approach in the machine centrepost region provides improved mechanical stress handling.

The prospect of an affordable test device which could close the loop on net-electric production and conduct essential nuclear materials and breeding research is thus compelling, motivating research to prove the techniques projected here. This talk will explain advanced tokamak fundamentals and the results of these latest exciting projections.

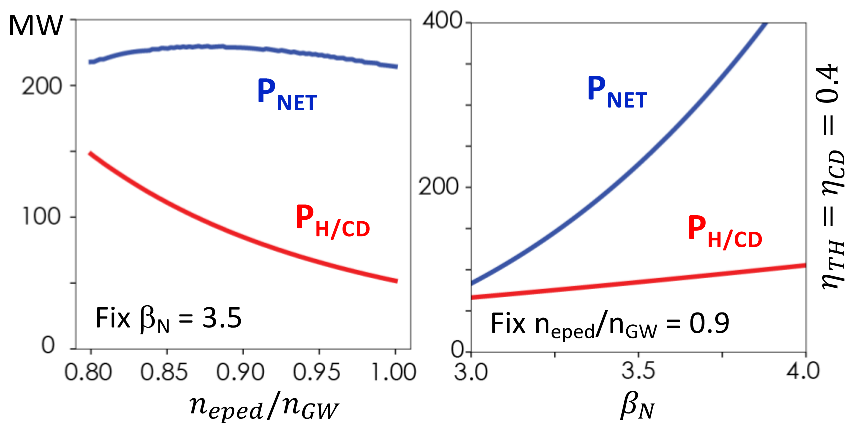

Figure: Projected dependencies of net electric performance and required heating and current drive power for a 4m, 7T, net electric fusion pilot plant based on the advanced tokamak approach.

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