DPP16-2016-000689

Abstract for an Invited Paper
for the DPP16 Meeting of
the American Physical Society

Impact of physics and technology innovations on compact tokamak fusion pilot plants[1]

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For magnetic fusion to be economically attractive and have near-term impact on the world energy scene it is important to focus on key physics and technology innovations that could enable net electricity production at reduced size and cost. The tokamak is presently closest to achieving the fusion conditions necessary for net electricity at acceptable device size, although sustaining high-performance scenarios free of disruptions remains a significant challenge for the tokamak approach. Previous pilot plant studies have shown that electricity gain is proportional to the product of the fusion gain, blanket thermal conversion efficiency, and auxiliary heating wall-plug efficiency. In this work, the impact of several innovations is assessed with respect to maximizing fusion gain. At fixed bootstrap current fraction, fusion gain varies approximately as the square of the confinement multiplier, normalized beta, and major radius, and varies as the toroidal field and elongation both to the third power. For example, REBCO high-temperature superconductors (HTS) offer the potential to operate at much higher toroidal field than present fusion magnets, but HTS cables are also beginning to access winding pack current densities up to an order of magnitude higher than present technology, and smaller HTS TF magnet sizes make low-aspect-ratio HTS tokamaks potentially attractive by leveraging naturally higher normalized beta and elongation. Further, advances in kinetic stabilization and feedback control of resistive wall modes could also enable significant increases in normalized beta and fusion gain. Significant reductions in pilot plant size will also likely require increased plasma energy confinement, and control of turbulence and/or low edge recycling (for example using lithium walls) would have major impact on fusion gain. Reduced device size could also exacerbate divertor heat loads, and the impact of novel divertor solutions on pilot plant configurations is addressed. For missions including tritium breeding, high-thermal-efficiency liquid metal breeding blankets are attractive, and novel immersion blankets offer the potential for simplified fabrication and maintenance and reduced cost. Lastly, the optimal aspect ratio for a tokamak pilot plant is likely a function of the device mission and associated cost, with low aspect ratio favored for minimizing TF magnet mass and higher aspect ratio favored for minimizing blanket mass. The interplay between a range of physics and technology innovations for enabling compact pilot plants will be described.

[1]This work was supported by U.S. DOE Contract Number DE-AC02-09CH11466