Spin-Polarized Fuel for Enhanced Tritium Self-Sufficiency and Electric Power Output

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Spin-polarized deuterium-tritium (D-T) fuel can markedly improve both net electric power and tritium burn efficiency (TBE) in fusion power plants (FPPs). By polarizing the nuclear spins of the fusion fuel, the fusion cross section is predicted to increase by 50%, and the emission spectra of fusion products can be altered [1]. Complementary studies indicate that spin-polarized fuel (SPF) may boost fusion thermal power by up to 90% [2,3]. SPF offers other benefits including an enhanced tritium breeding ratio, extended magnet lifetimes [4], and a reduction in the tritium startup inventory requirement by 90% [5,6]. Overall, SPF has the potential to multiply the net electric output relative to unpolarized fuel, a benefit that becomes especially significant for FPPs operating near engineering breakeven—where even a modest 25% increase in fusion power in an ITER-like device translates into disproportionately large gains in net electricity.

Moreover, our results demonstrate that reducing the tritium fraction in the D-T mixture—when combined with spin polarization—can improve TBE by an order of magnitude without compromising fusion power [7,8]. For example, in an ARC-like tokamak producing 482 MW with a 51:49 D-T mix, the minimum startup tritium inventory falls from 0.69 kg to 0.03 kg when the fuel is fully spin polarized and the mix is optimized to 61:39. These findings highlight the role of high plasma performance in enhancing TBE. With further improvements in helium divertor pumping efficiency [7], operating at tritium fractions as low as 10–40% can still yield robust power output while drastically reducing both the startup and circulating tritium inventory.

Our work thus strongly motivates the development of spin-polarized fuels and low-tritium-fraction strategies to drive burning plasmas toward greater tritium self-sufficiency and more economical fusion power. We conclude by discussing the primary challenges that remain before SPF can be deployed in practical fusion systems [2,9,10].

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