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[REGULAR POSTER TWIN] Overview of C-2W: High Temperature, Steady-State Beam-Driven Field-Reversed Configuration Plasmas

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TAE Technologies, Inc. (TAE) is a privately funded company pursuing an alternative approach to magnetically confined fusion, which relies on field-reversed configuration (FRC) plasmas composed of mostly energetic and well-confined particles by means of a state-of-the-art tunable energy neutral-beam (NB) injector system. TAE's current experimental device, C-2W (also called "Norman") shown in Fig. 1, is the world's largest compact toroid (CT) device [1] and has recently made significant progress in FRC performance, producing record breaking, high temperature advanced beam-driven FRC plasmas, dominated by injected fast particles and sustained in steady state for up to 30 ms, which is limited by NB pulse duration as can be seen in Fig. 2. C-2W has been producing significantly better FRC performance than the preceding C-2U experiment [2], in part due to Google's machine learning framework for experiment optimization, which has contributed to the discovery of a new operational regime where novel settings for the formation sections yield consistently reproducible, hot, stable plasmas.

In order to produce such high performance FRC plasmas, C-2W operates with the following key features [1]: reliable dynamic FRC formation scheme via colliding and merging two oppositely-directed CT plasmas (relative collision speed up to ~1000 km/s); tangential, co-current NB injection (NBI) into the FRC with high input power (total up to ~21 MW) and intra-discharge variable energy (15–40 keV) functionality; flexible edge-biasing electrode systems for stability control in both inner and outer divertors; neutral gas density control via ~2000 m^3/s pumping capability in the divertors; external magnetic field fast control capabilities, such as field ramp, and active feedback control of the FRC plasma using Trim and Saddle coils; and 50+ dedicated plasma diagnostics in the main confinement region and in divertors to characterize FRC and open-field-line plasma performance.

In the recent C-2W experiments, adequately controlled external magnetic-field profile throughout the machine and proper gas injection/fueling have led to more effective edge biasing from electrodes to globally stabilize plasma; thus, improving the efficiency of the NB-to-FRC coupling so that more plasma heating and current drive are obtained. Due to this synergistic effect of combining effective edge biasing and NBI on C-2W, beam-driven FRCs have achieved a high temperature regime as shown in Fig. 2; total temperature T_{tot} >2 keV (T_{tot} = $T_e + T_i$, based on a pressure balance), electron temperature T_e >250 eV. Other typical plasma parameters are: averaged electron density <n_e> ~1–$3\times10^{19}m^{-3}$, trapped magnetic flux (based on rigid-rotor model) ϕ_p ~5–10 mWb, and external axial magnetic field B_e ~1 kG. To date, the optimum C-2W discharges have reached T_{tot} up to ~3 keV and T_e ~300 eV at the peak inside the FRC.

Based on a careful global power balance analysis detailing input/loss channel characteristics and plasma timescales [2], there appears to be a strong positive correlation between T_e and energy confinement time. The previously reported C-2/2U scaling of the electron energy confinement time $\tau_{E,e}$ still persists at the higher T_e (i.e. collisionless plasma regime) in C-2W, as shown in Fig. 3. Given uncertainties in the measurements and assuming the power-law model, regression analysis shows that $\tau_{E,e}$ is approximately proportional to T_e^2 when fitting for the entire ensemble of the C-2W data set.

Dedicated equilibrium and transport simulations have been performed to better understand FRC global stability and confinement, NBI and edge biasing effects, and turbulence in the FRC core and open-field-line plasmas. Simulations predict that parallel electron heat loss is close to the minimal theoretical limit, which has been experimentally validated by end-loss energy analyzers in the outer divertor. Nonlinear kinetic simulations also qualitatively agree with experimental fluctuation measurements, where turbulent transport is greatly reduced by sheared flows due to edge biasing. Google also contributes to advanced data analysis where their Bayesian inversion algorithm reconstructs plasma density profiles and high-frequency fluctuations. Disruptions of fast-ion orbits can be studied from plasma displacement inferred from reconstructions, where detailed correlations with magnetic probes provide further insights into energy loss mechanisms. This paper will review the highlights of C-2W program, including recent experimental results of significantly advanced FRC performance as well as simulations. Future plans will be reported as well.

[1] H. Gota et al., Nucl. Fusion 59, 112009 (2019).
[2] H. Gota et al., Nucl. Fusion 57, 116021 (2017).

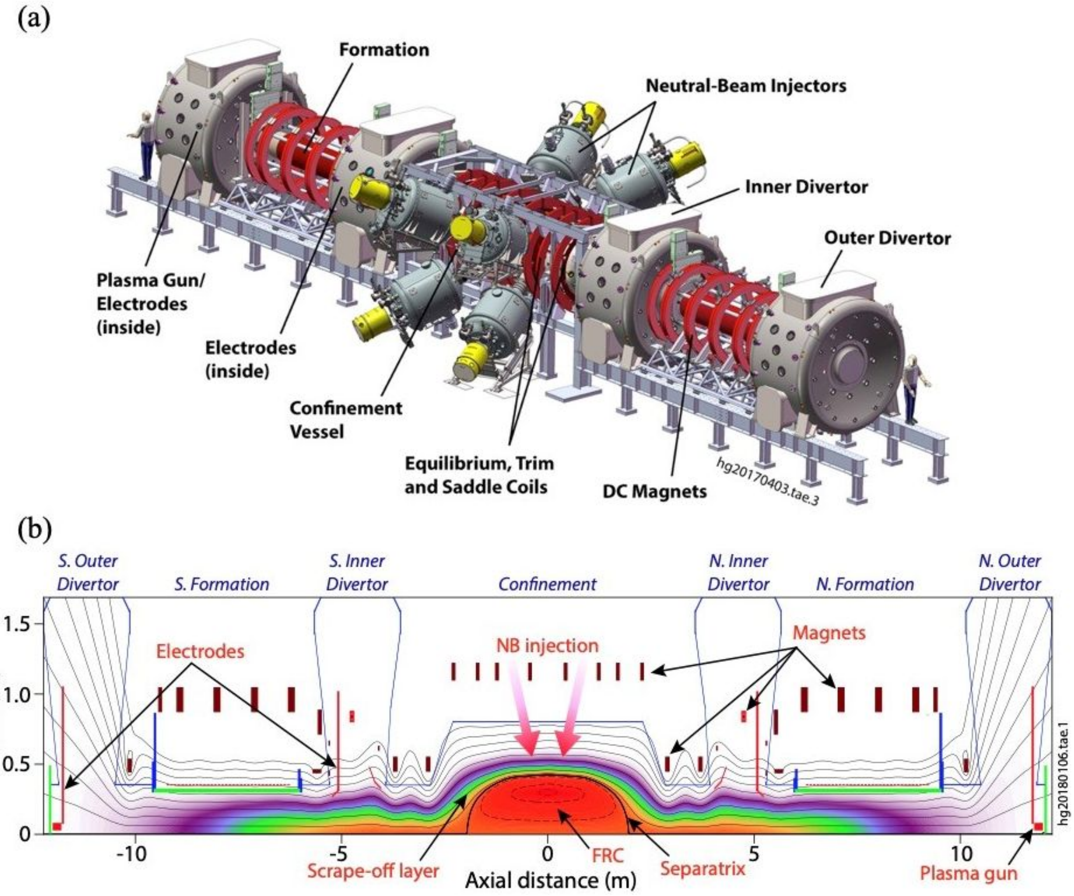

Figure 1: FIG. 1. (a) C-2W experimental device; (b) A sketch of FRC magnetic topology and density contours, calculated by 2D multifluid force-balanced LReqMI equilibrium code.

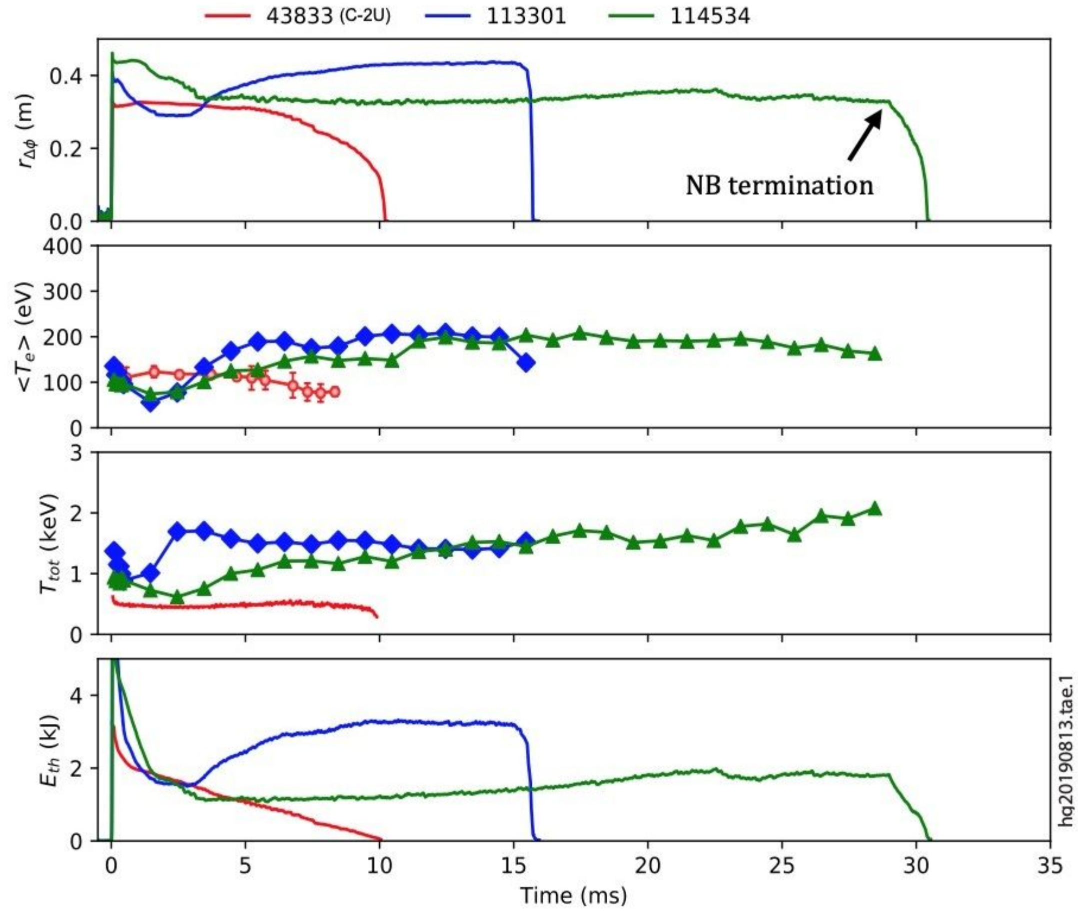

Figure 2: FIG. 2. Time evolutions of excluded-flux radius, electron temperature, total temperature, and thermal energy of FRCs for shots 113301 and 114534 in C-2W, compared with shot 43833 in C-2U [2].

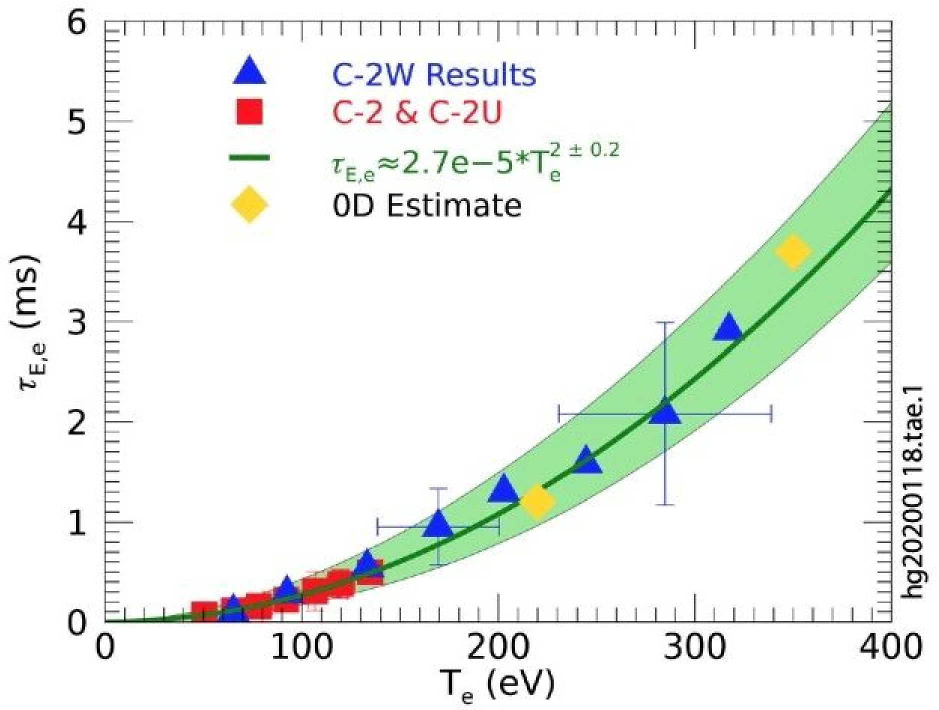

Figure 3: FIG. 3. Confinement scaling: global energy confinement time as a function of electron temperature in C-2/2U [2] and C-2W.

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