A detailed demonstration of ideal Brayton cycles with solid oxide fuel cells

The schematic diagram for the ideal Brayton cycles with solid oxide fuel cells is shown in Figure S1. Air from the compressor enters into the SOFC power system. Fresh fuel is injected into SOFC power system and the combustor. Meanwhile, SOFC exhausts contains lots of unreacted fuel. If the temperature compressed is too low, SOFC will do not work because SOFC works well when the temperature is in the range 600℃ to 1000℃. The air provided for SOFC is preheated by the compressor to some degree. Therefore, the pressure ratio plays an important role in the highly efficient operation of the SOFC jet hybrid engine.
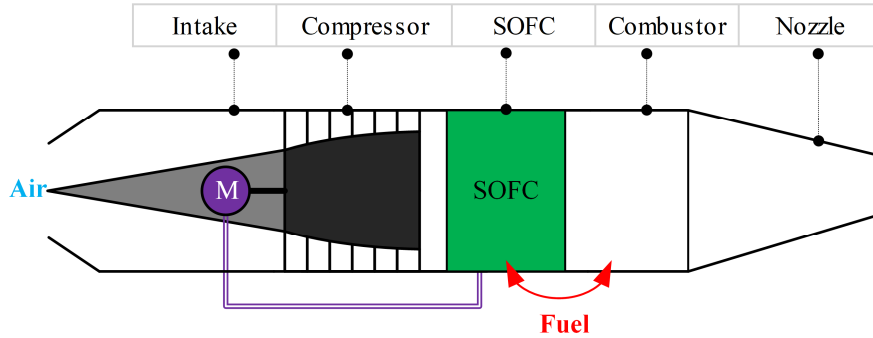

Figure S1 The schematic diagram of an ideal Brayton cycle with SOFCs

Figure S2 shows the detailed schematic diagrams of ideal Brayton cycles with solid oxide fuel cells, which operates with propane on account of its high energy density and flexible reforming. Atmospheric air compressed is split into two parts. Some air is utilized by the reformer and the rest of air enters into SOFC cathode channel. The anode and cathode exhausts are both recirculated by the ejectors.

On the anode loop, the high-pressure fuel enters the primary fluid inlet of the anode ejector 1. The partial air is entrained and mixed with the fuel in the anode ejector 1. The mixed gases enter the primary fluid inlet of the anode ejector 2. The partial anode exhausts are entrained and mixed with the gases from the anode ejector 1 exit. The recirculated anode exhausts are used to heat the mixed gases as well as to supply steam for auto-thermal reforming in the reformer. The mixed gases containing fuel, air and steam enter into the reformer for reforming. Then, the reformed gases enter the SOFC anode channel for participating in the electrochemical reaction.

On the cathode loop, the pressurized air is fed into the primary fluid inlet of the cathode ejector to entrain and mix with a part of cathode exhausts. At the same time, the air is further heated by the recirculated cathode exhausts. Then the mixed and pressurized air enters the fuel cell cathode channel to provide O_2 in the purpose of participating in the electrochemical reaction.

The SOFC exhausts enter the combustor to burn completely. The fresh fuel also enters into the combustor to react with SOFC exhausts. SOFC produces electric power to drive the compressor by the motor. At last, exhausts expand in the nozzle and produce propulsion power.
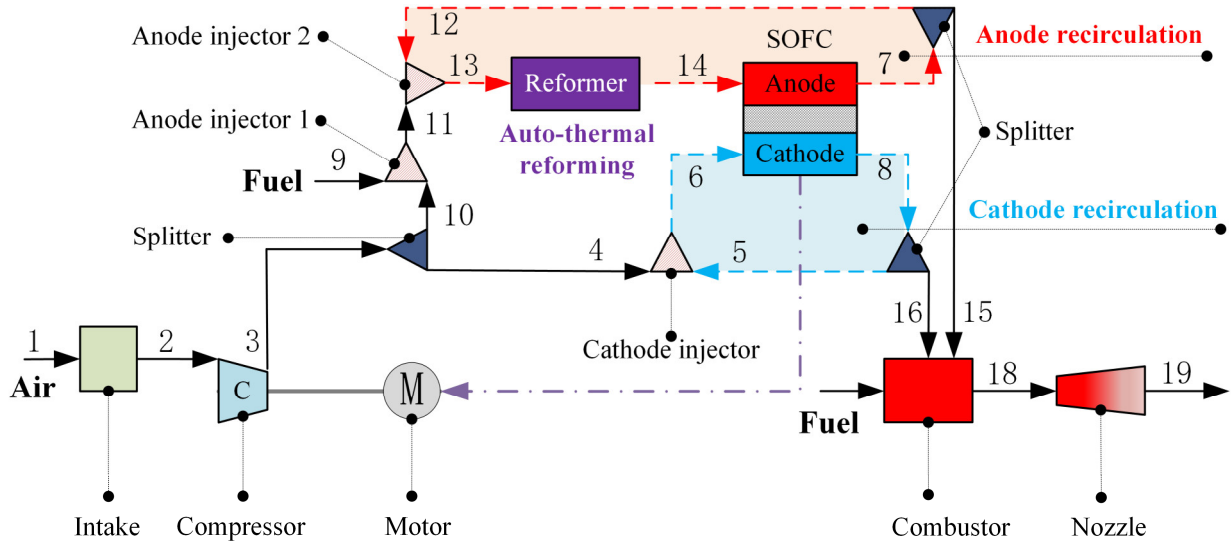
Figure S2 Detailed Scheme diagrams of the ideal Brayton cycles with solid oxide fuel cells

Model verification and validation (V&V) assessments

Verification assessment

The purpose of verification is to quantify the error of a numerical simulation by demonstration of convergence for the particular model under consideration. [33] The key component in the hybrid engine is an SOFC. The rest of component models have been widely cited and are without verification assessments. Based on modeling and governing equation discussed, the calculation results obtained from thermodynamic analysis of SOFC have been validated with calculation results of Aguiar [34] et al. and the results have been found to be in good agreement with works as shown in Figure S. The standard deviation is less than 1%. The code-to-code comparisons as a means of calculation verification is completed, which provide circumstantial evidence.
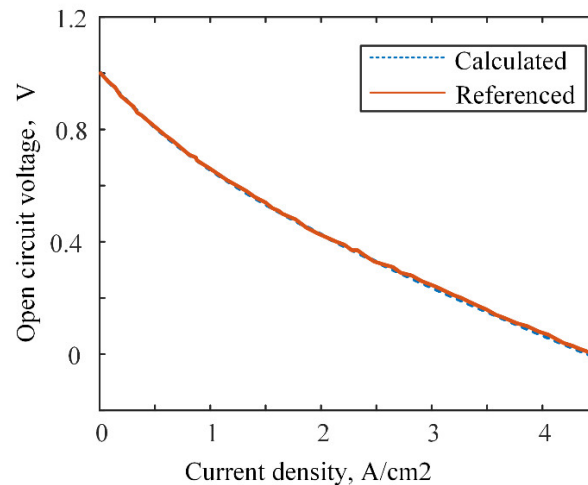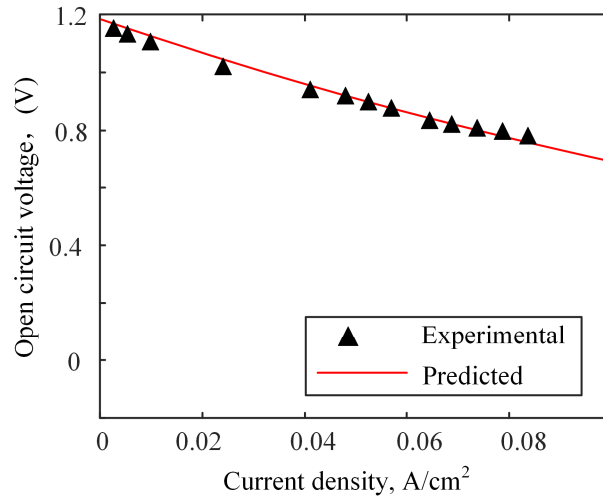

Figure S3 Verification of the SOFC model

Figure S4 Validation assessment of the SOFC model

Validation assessment

    The validation assessment is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. [35] The goal of validation is to quantify confidence in the predictive capability of the model by comparison with experimental data. [33] The SOFC simulation results is compared with the experiment work of Suwanwarangkul [36] et al. The results have been found to be in good agreement with experiment works as shown in Figure . The standard deviation is less than 3%. In general, the models built in this paper may exactly describe the thermodynamic processes in the real word.