Despite various advantages of high-temperature solid oxide electrolysis cells (SOECs) over their low-temperature competitors, the insufficient long-term durability has prevented the commercialization of SOECs. Here, we address this challenge by employing two nanoengineered electrodes. The O2 electrode consists of a La0.6Sr0.4CoO3−δ (LSC) and Gd,Pr-co-doped CeO2 (CGPO) nanocomposite coating deposited on a Gd-doped CeO2 (CGO) scaffold, and the H2 electrode comprises a Ni/yttria stabilized zirconia (YSZ) electrode modified with a nano-granular CGO coating. The resulting cell with an active area of 4 × 4 cm2 exhibits a current density exceeding 1.2 A cm−2 at 1.3 V and 750 °C for steam electrolysis while also offering excellent long-term durability at 1 A cm−2 with a high steam-to-hydrogen conversion of ∼56%. We further unravel the degradation mechanism of the most commonly used Ni/YSZ electrode under these conditions and describe the mitigation of the discussed mechanism on our nanoengineered electrode. Our findings demonstrate the potential of designing robust SOECs by nanoengineering electrodes through infiltration and have significant implications for the practical integration of SOEC technology in the future sustainable energy system.