

Supporting Information for

## **Degradation study for membrane electrode assembly of anion exchange membrane fuel cell at a single-cell level**

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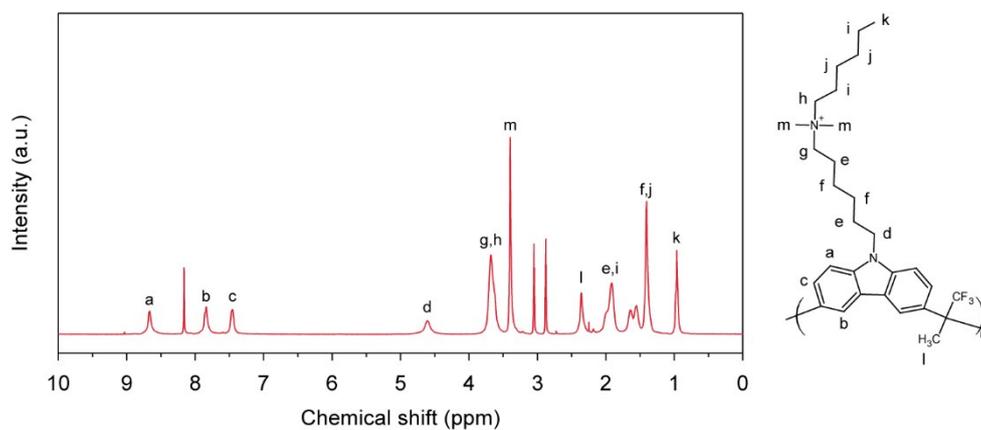
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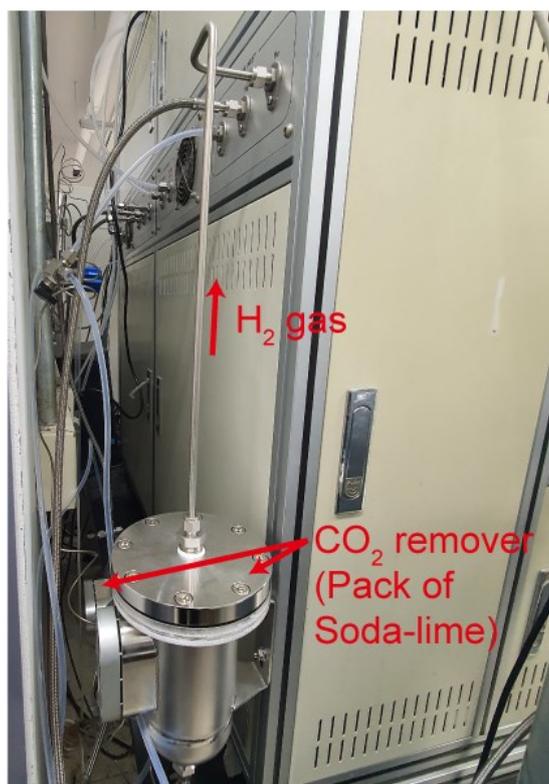
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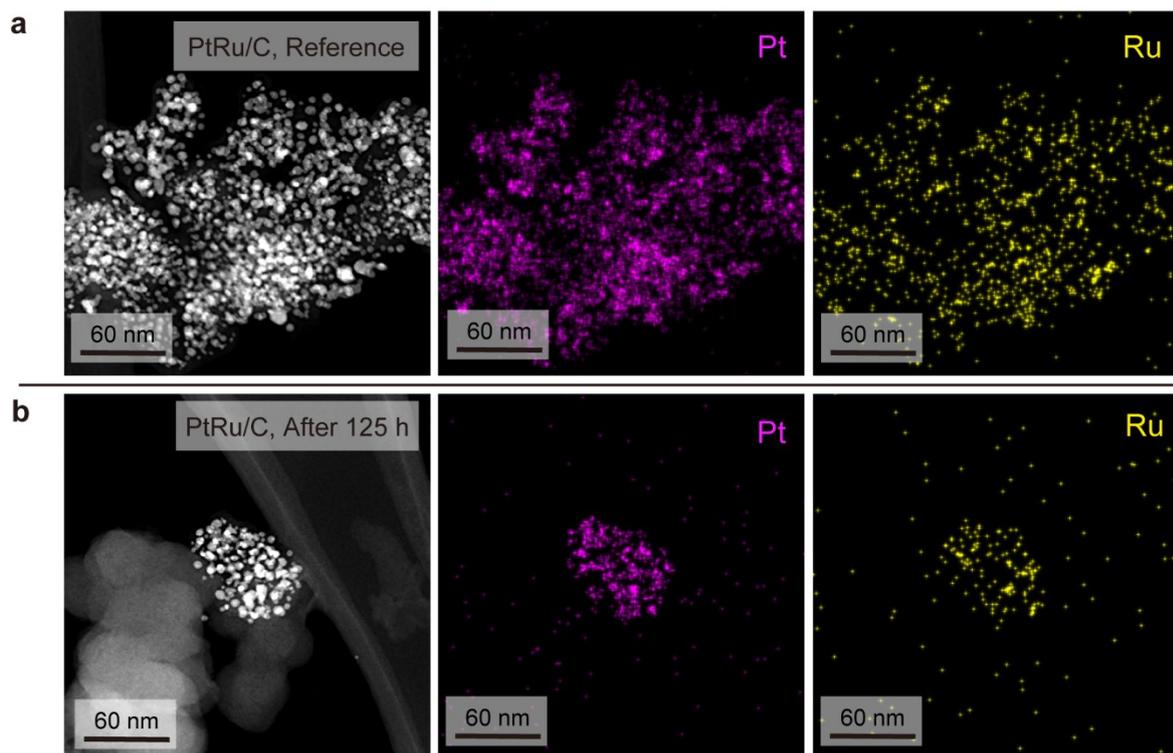
## Supporting Figures



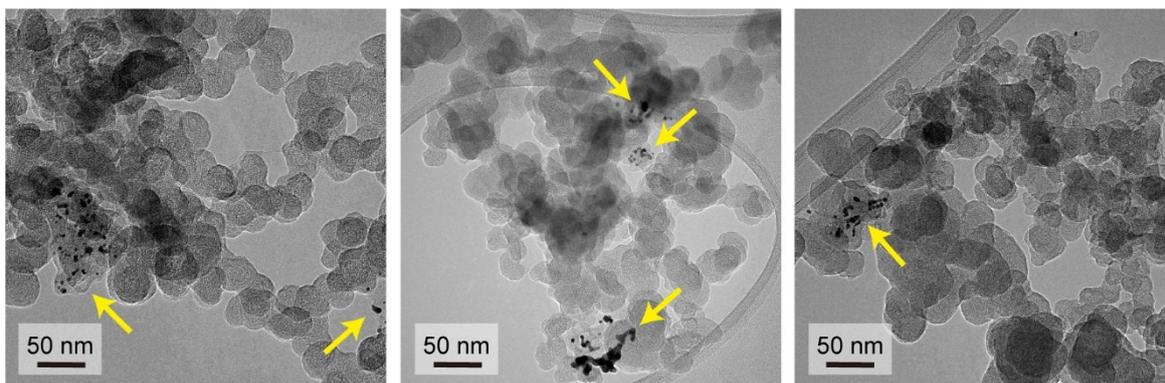
**Fig. S1**  $^1\text{H}$  NMR spectra of QPC-DMHA AEI.



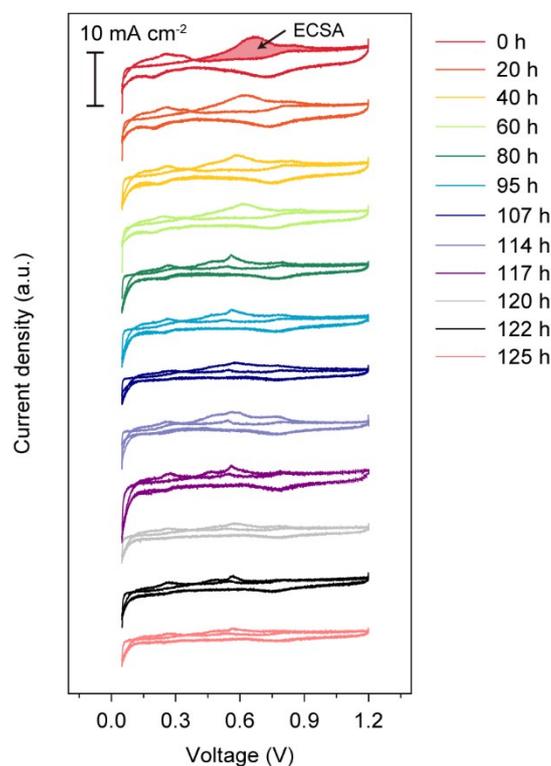
**Fig. S2** Test station with a CO<sub>2</sub> remover. A CO<sub>2</sub> removal unit was installed in the fuel cell station to eliminate CO<sub>2</sub> from the incoming H<sub>2</sub> and O<sub>2</sub> gases. The CO<sub>2</sub> remover is filled with soda-lime pellets (mixture of sodium hydroxide, potassium hydroxide, and calcium hydroxide) which can absorb CO<sub>2</sub>.



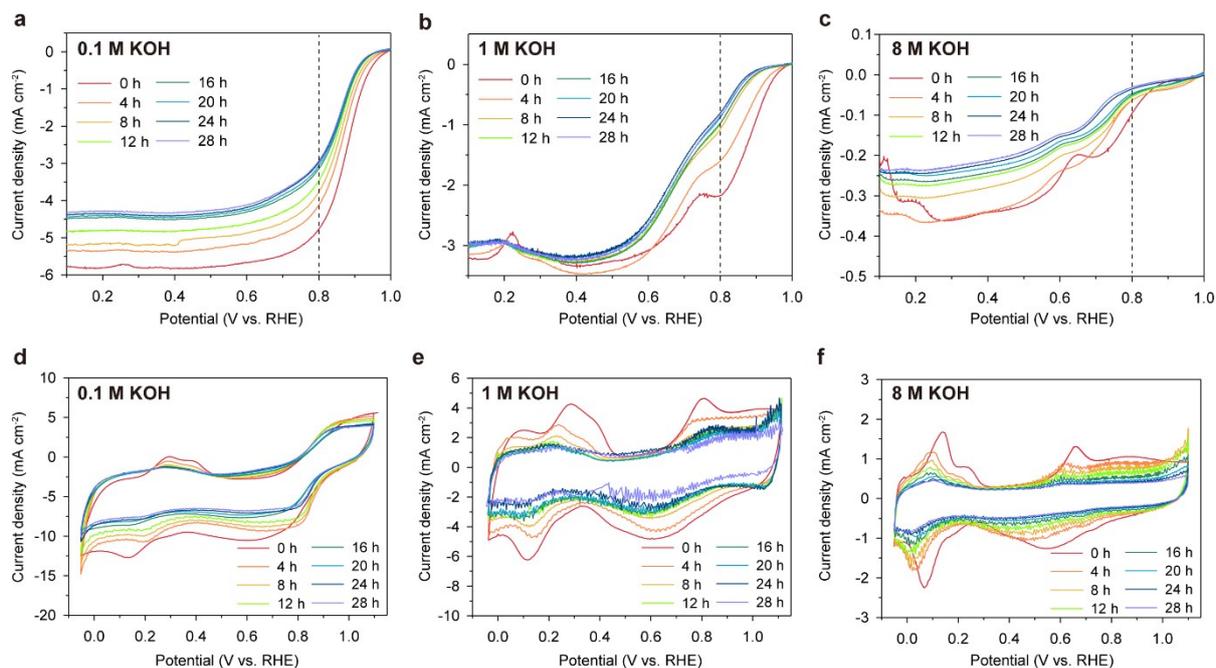
**Fig. S3** STEM-EDS images for the PtRu/C catalyst taken from the anode CL. The STEM-EDS images for PtRu/C catalyst (a) before and (b) after the CC durability test. The high-angle annular dark-field (HAADF) images are displayed on the left. PtRu nanoparticles appear to be the bright spots in HAADF images. The EDS mapping images for Pt (pink) and Ru (yellow) elements are shown in the middle and right, respectively.



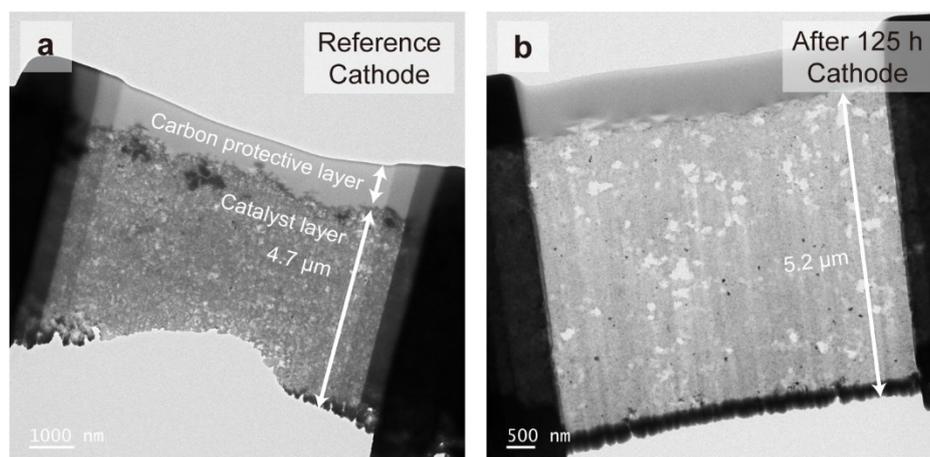
**Fig. S4** TEM images for the Pt/C catalyst taken from the cathode CL after the CC durability test (Skip the electrochemical analysis step). The Pt/C catalyst was obtained by scraping the cathode CL. Since the CL was coated on the gas diffusion layer, the carbon particles in the microporous layer were inevitably included in the TEM sample. The yellow arrows indicate the aggregated chain-like Pt catalysts. All the other Pt-free carbons correspond to the residue of the microporous layer.



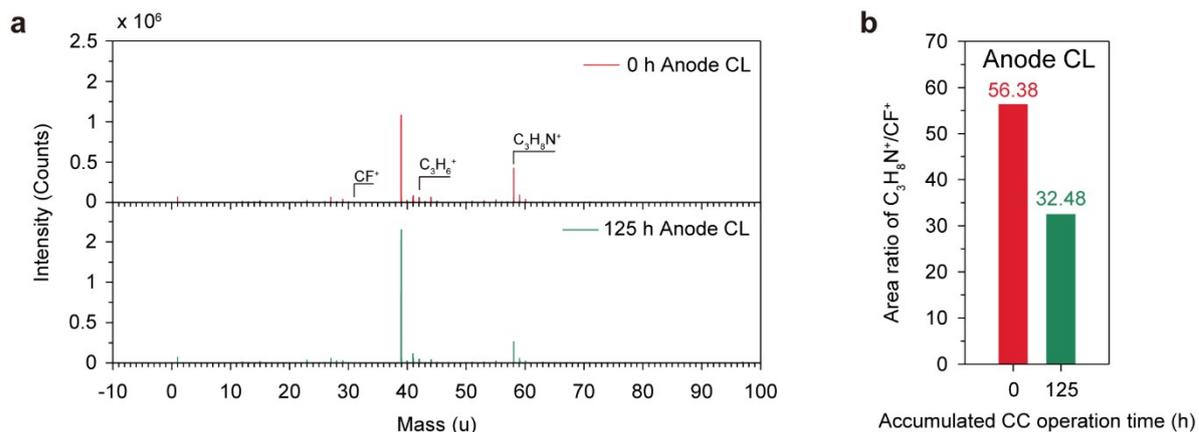
**Fig. S5** Changes of the CO stripping curves with the accumulated test time. The ECSA values were calculated from the highlighted area. As the CC durability test proceeded, the CO stripping peak and double-layer capacitance were gradually decreased.



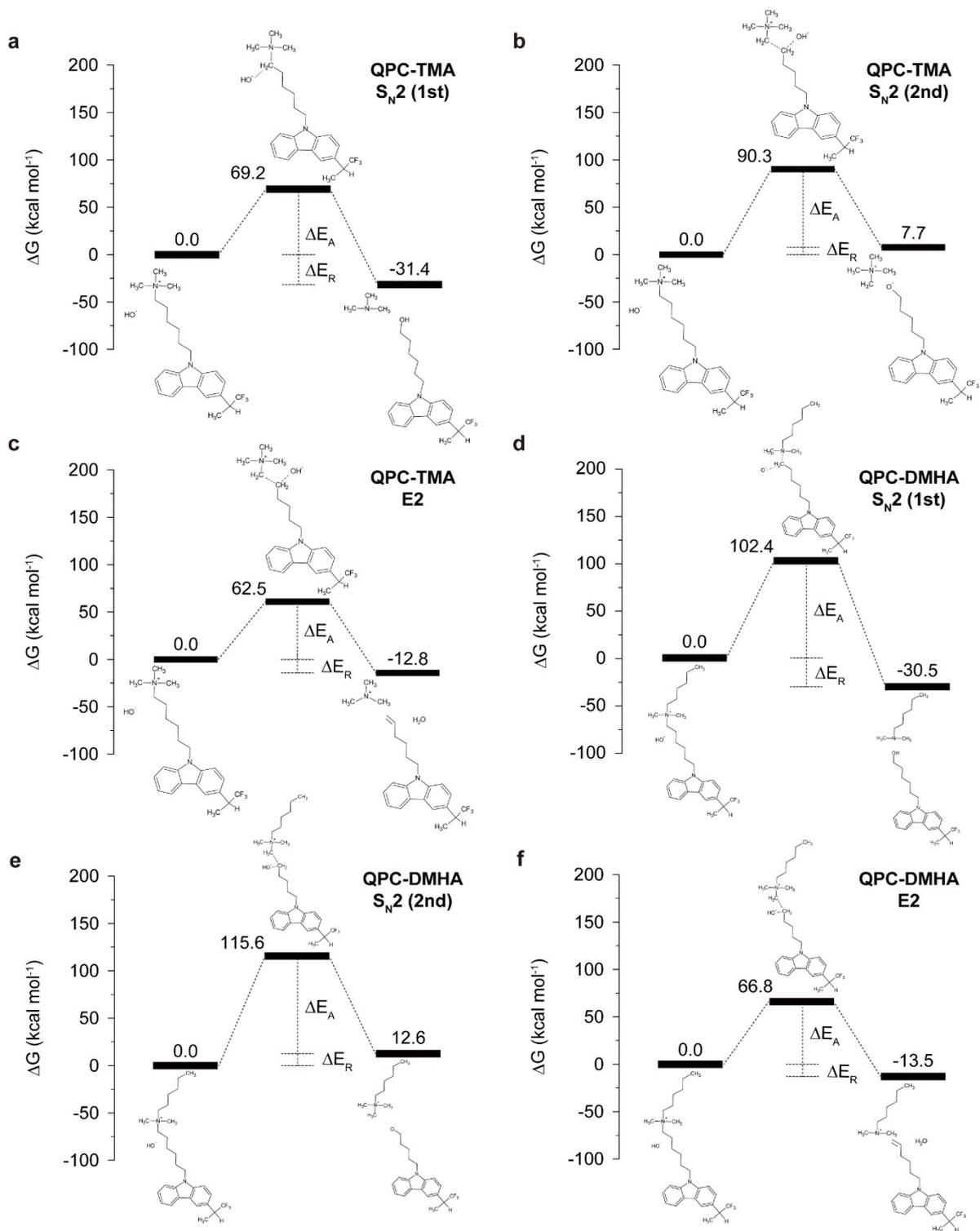
**Fig. S6** Degradation of Pt/C under various alkaline conditions. ORR polarization curves for Pt/C catalyst in the half-cell during CC mode operation with O<sub>2</sub>-saturated (a) 0.1, (b) 1, and (c) 8 M KOH aqueous solution. CV curves measured at 500 mV s<sup>-1</sup> for Pt/C catalyst in the half-cell during the CC mode operation with O<sub>2</sub>-saturated (d) 0.1, (e) 1, and (f) 8 M KOH aqueous solution.



**Fig. S7** Low magnified TEM images of a sliced cross-section of the cathode CLs. TEM images of the cathode CL (a) before and (b) after the CC durability test. The cross-sections of the CLs were sliced to a thickness of 100 nm by FIB. On the top of the samples, carbon was coated to prevent damage by the ion beam.



**Fig. S8** Ionomer degradation at the anode CL. (a) Positive ToF-SIMS spectra of the anode CL. (b) The intensity ratio of the C<sub>3</sub>H<sub>8</sub>N<sup>+</sup> signal and CF<sup>+</sup> signal in the positive ToF-SIMS spectra of the anode CL before and after the CC durability test (125 h).



**Fig. S9** Free-energy profiles of  $S_N2$  and E2 reaction for QPC-TMA and QPC-DMHA. Free-energy profiles of  $S_N2$  and E2 reaction for (a), (b), (c) QPC-TMA and (d), (e), (f) QPC-DMHA. (a), (b), (d), (e) are the free-energy profiles for the  $S_N2$  reaction and (c), (f) are the E2 reactions.