Supporting Information

A carbon-free, precious-metal-free, high-performance O_2 electrode for regenerative fuel cells and metal-air batteries

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Supporting Figures

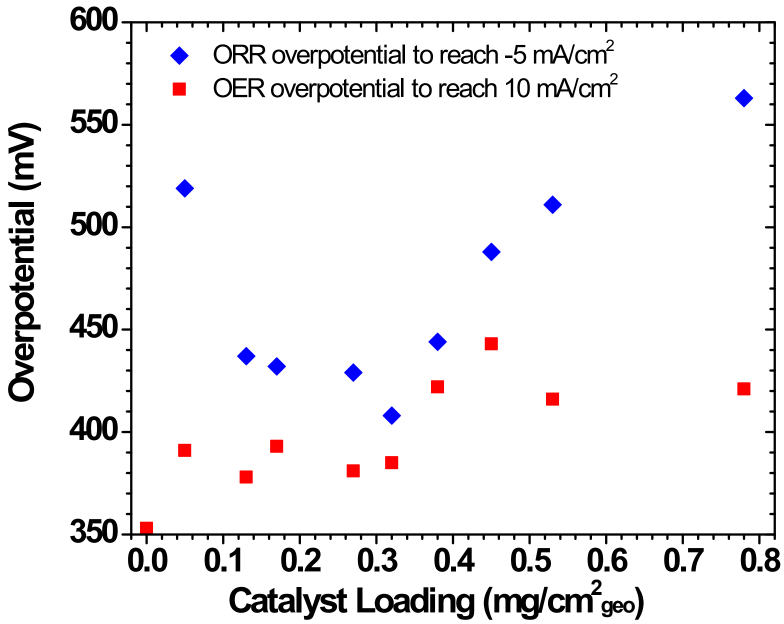

Figure S1. ORR and OER overpotentials required to reach -5 and 10 $mA.cm^{-2}$ respectively for MnO_x-SS electrodes as a function of MnO_x loading.

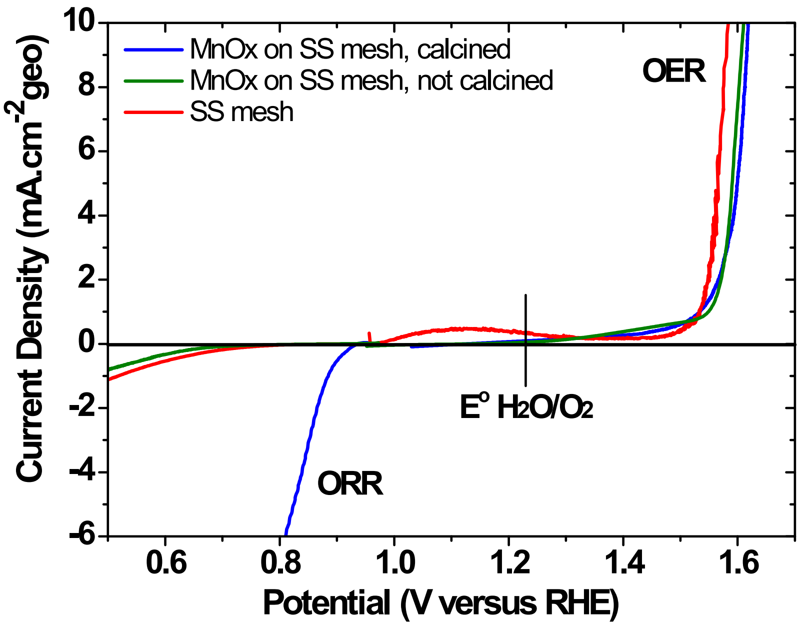

Figure S2. Rotating electrode voltammograms displaying the oxygen reduction and evolution activities of uncalcined and calcined MnO_x-SS electrodes, and an uncoated stainless steel mesh.

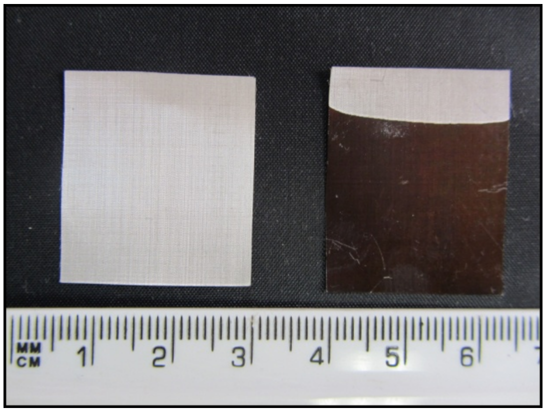

Figure S3. Photograph displaying (left) bare stainless steel mesh and (right) MnO_x electrodeposited on stainless steel mesh.

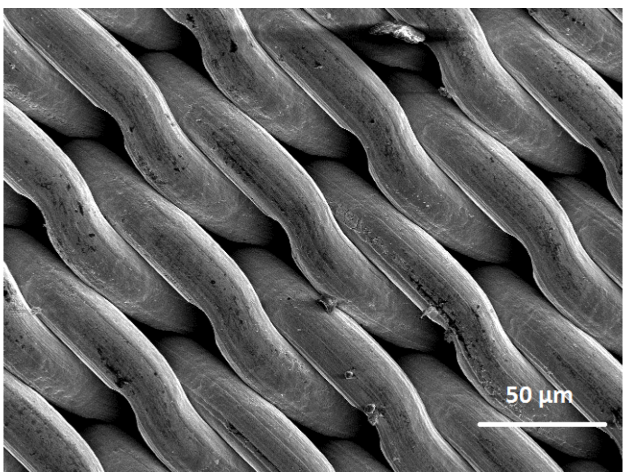

Figure S4. SEM image of bare stainless steel mesh.

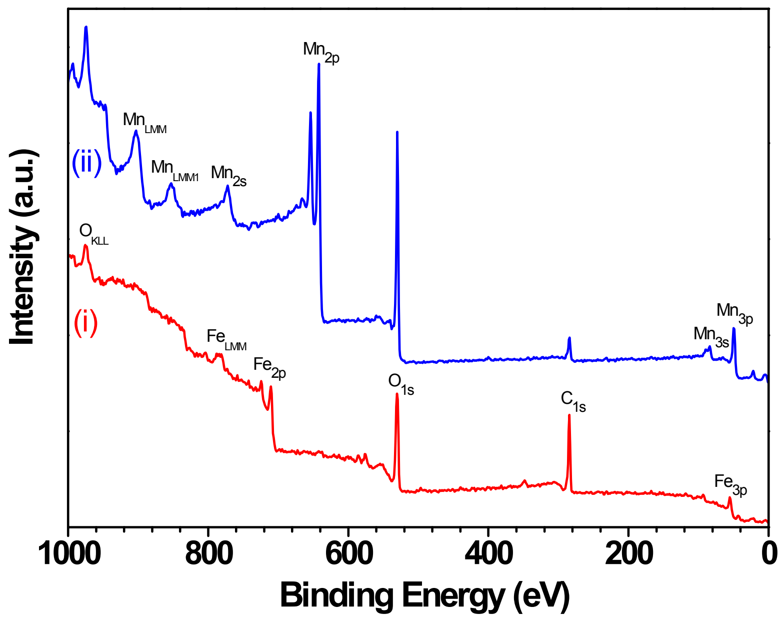

Figure S5. Survey XPS spectra of stainless steel mesh (i) before and (ii) after electrodeposition of MnO_x.

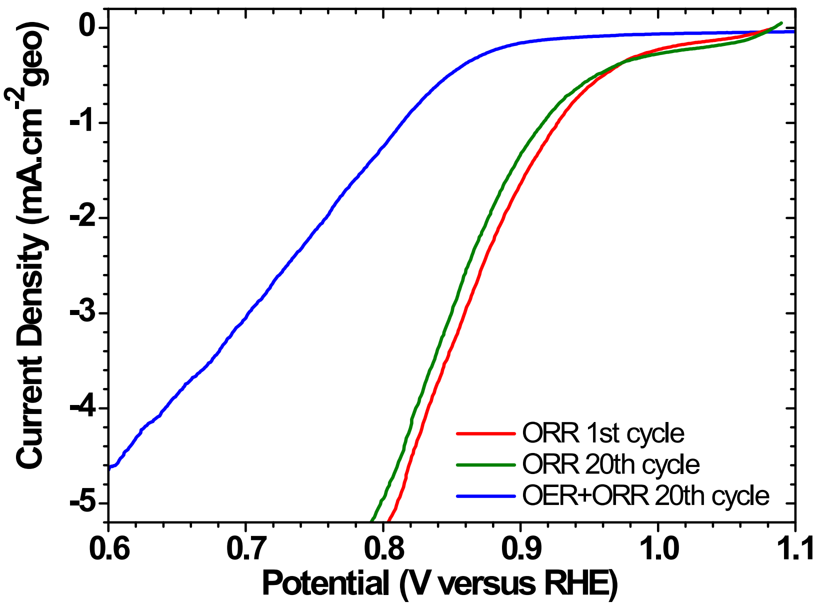

Figure S6. Rotating electrode voltammograms displaying the oxygen reduction activities of the Pt/C-SS electrode after cycling in either a purely ORR-relevant potential range (0.05 V to 1.1 V vs. RHE at 10 mV.s^{-1}) or a combined ORR and OER-relevant potential range (0.05 V to 1.7 V vs. RHE at 10 mV.s^{-1}).

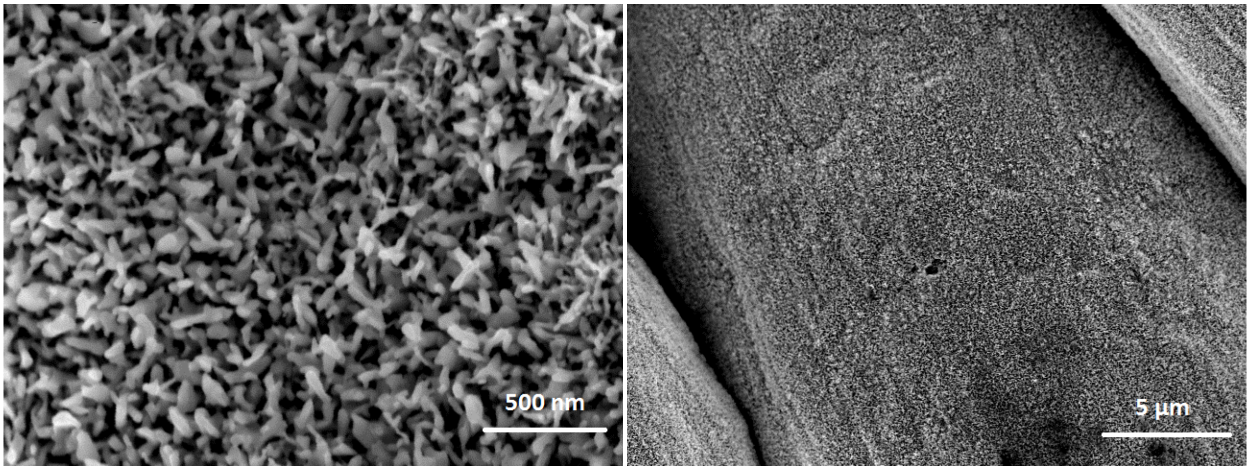

Figure S7. SEM images of MnO_x electrodeposited on stainless steel mesh after electrochemical stability testing at different magnifications.

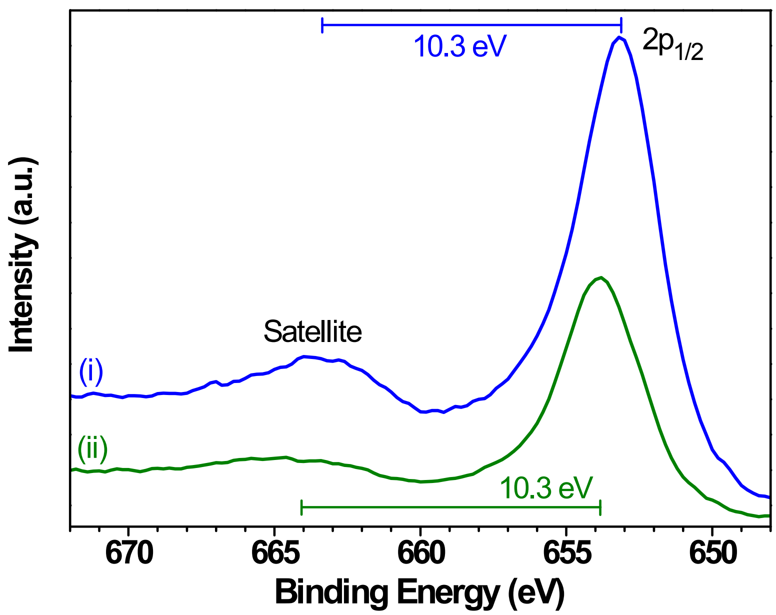

Figure S8. High resolution XPS spectra (Mn-$2p_{1/2}$ region) of MnO_x-SS electrode (i) before and (ii) after electrochemical testing. The difference in binding energy between the Mn-$2p_{1/2}$ peak and its satellite peak for both samples are shown.

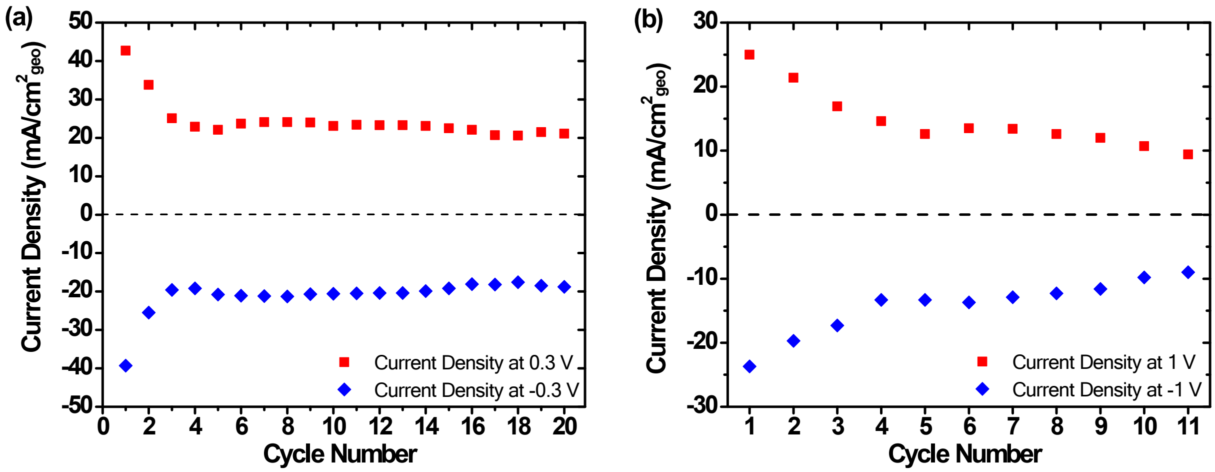

Figure S9. Symmetric cells used to determine the source of the instability seen for the cell with the MnO_x-SS O_2 electrode shown in Figure 5. (a) Symmetric H_2 cell with Pt/C catalyst. The cell was cycled between -0.3 V to 0.3 V at 50 mV and 15 s intervals, and a total of 20 cycles were performed. (b) Symmetric O_2 cell with MnO_x-SS electrodes. The cell was cycled between -1 V to 1 V at 250 mV and 15 s intervals for 11 cycles.

Table S1. List of prior work on bifunctional O_2 electrodes applied to energy storage devices based on O_2-H_2O chemistries. †

Catalysts	Gas diffusion electrode	Electrolyte	Presence of precious metals at O_2 electrode	Presence of carbon at O_2 electrode	Application	Reference
Electrodeposited MnO_x	Stainless steel	Commercial anion exchange membrane	No	No	AEM-URFC	This work
MnO_x/C and Ni/C	Carbon paper	Commercial anion exchange membrane	No	Yes	AEM-URFC	1
$Cu_{0.6}Mn_{0.3}Co_{2.1}O_4$	Carbon paper	Lab-made anion exchange membrane	No	Yes	AEM-URFC	2
$LaSr_3Fe_3O_{10}$	Au-coated mesh	Commercial anion exchange membrane	Yes	No	AEM-URFC	3
Pt/IrO_2	Carbon paper	Commercial Nafion 212 proton exchange membrane	Yes	Yes	PEM-URFC*	4
CoO/CNT and Ni-Fe layered double hydroxide	Carbon paper and Ni foam	6 M KOH	No	Yes	Zn-air battery	5
MnO_2 nanotubes with Co_3O_4 nanoparticles	Carbon paper	6 M KOH	No	Yes	Zn-air battery	6
MnO_2 nanotube and CNT composite	Carbon paper	6 M KOH	No	Yes	Zn-air battery	7
MnO_x nanowires on carbon	Ni foam	6 M KOH	No	Yes	Zn-air battery	8
Co_3O_4 nanowires	Stainless steel	6 M KOH	No	No	Zn-air battery	9
$MnCo_2O_4$/C on graphene	Carbon paper	1 M $LiClO_4$ in propylene carbonate	No	Yes	Li-O_2 battery	10
MnO_2 decorated with Au and Pd and mixed with carbon	Ni mesh	1 M $LiNO_3$ and 0.5 M LiOH	Yes	Yes	Li-O_2 battery	11
Co_3O_4	Ni foam	1 M $LiClO_4$ in propylene carbonate (PC)	No	No	Li-O_2 battery	12
Co_3O_4	Ni foam	1 M LiTFSI in TEGDME (organic)	No	No	Li-O_2 battery	13
MnO_2/C	Ni mesh	Glass microfiber filter separator soaked in 1 M LiTFSI in TEGDME	No	Yes	Li-O_2 battery	14
$Mn_{1.8}Fe_{0.2}O_3$ / C	Ti mesh	1 M LiTFSI / PC	No	Yes	Li-O_2 battery	15
MnOOH nanowires on carbon	Ni foam	PC or dimethoxyethane	No	Yes	Li-O_2 battery	16

† There are many other examples of bifunctional O_2 electrodes for PEM-URFCs but all of them require precious metal catalysts due to the acidic environment of the device.

Additional References

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