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Spontaneous electrochemical uranium extraction from wastewater with net electrical energy production

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Highly Efficient Recovery of Uranium from Seawater Using an Electrochemical Approach

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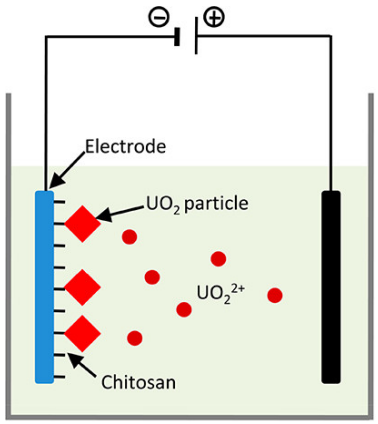

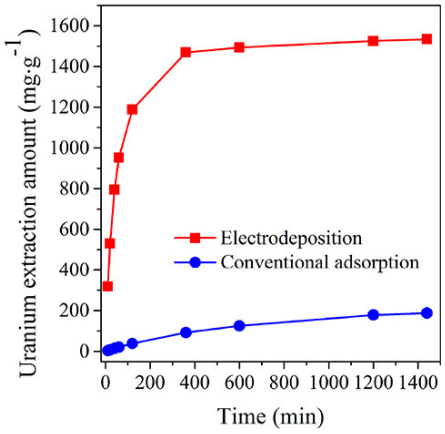

ENVIRONMENTAL Science & Technology

Article

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Reduced Uranium Phases Produced from Anaerobic Reaction with Nanoscale Zerovalent Iron

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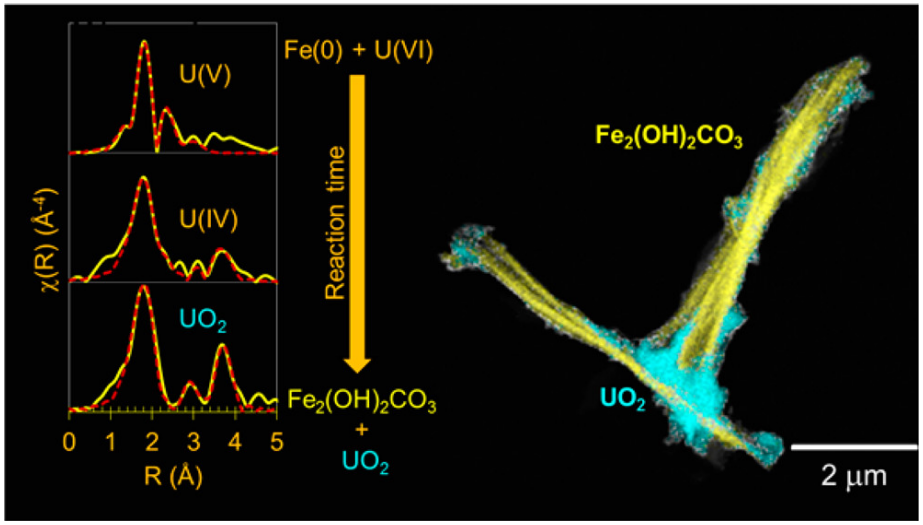

Environmental Science & Technology > Vol 32/Issue 21 > Article

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ARTICLE | September 3, 1998

Reductive Precipitation of Uranium(VI) by Zero-Valent Iron

B. Gu, L. Liang, M. J. Dickey, X. Yin, and S. Dai

Introduction

- Here they reported a spontaneous electrochemical (SPEC) method driven by zero-valent iron (ZVI) oxidation for uranium extraction with simultaneous energy recovery.
- In the SPEC system, the U(VI) adsorption occurs on the surface of a porous carbonaceous cathode, while the oxidation of Fe^0 to Fe^{2+} takes place in the anodic chamber, providing electrons that flow through an external circuit to the cathode to drive the reduction of U(VI) to U(IV).
- The SPEC method has achieved a uranium extraction capacity of 2,438 mg g^{-1} using simulated wastewater and 303 mg g^{-1} using real uranium mine wastewater without saturation, and the uranium extraction products are easily recoverable.
- The whole uranium extraction–recovery process requires no energy input, and net electrical energy production has been attained.

Why this paper?

- The system not only extracts uranium but also generates net electrical energy during the process. This dual function—resource recovery and energy production—adds significant value, making the method sustainable and energy-efficient.
- Interestingly, the reused electrode exhibited better uranium extraction performance than the fresh electrode.
- If the method is scalable, it could potentially be applied to various industrial sectors.

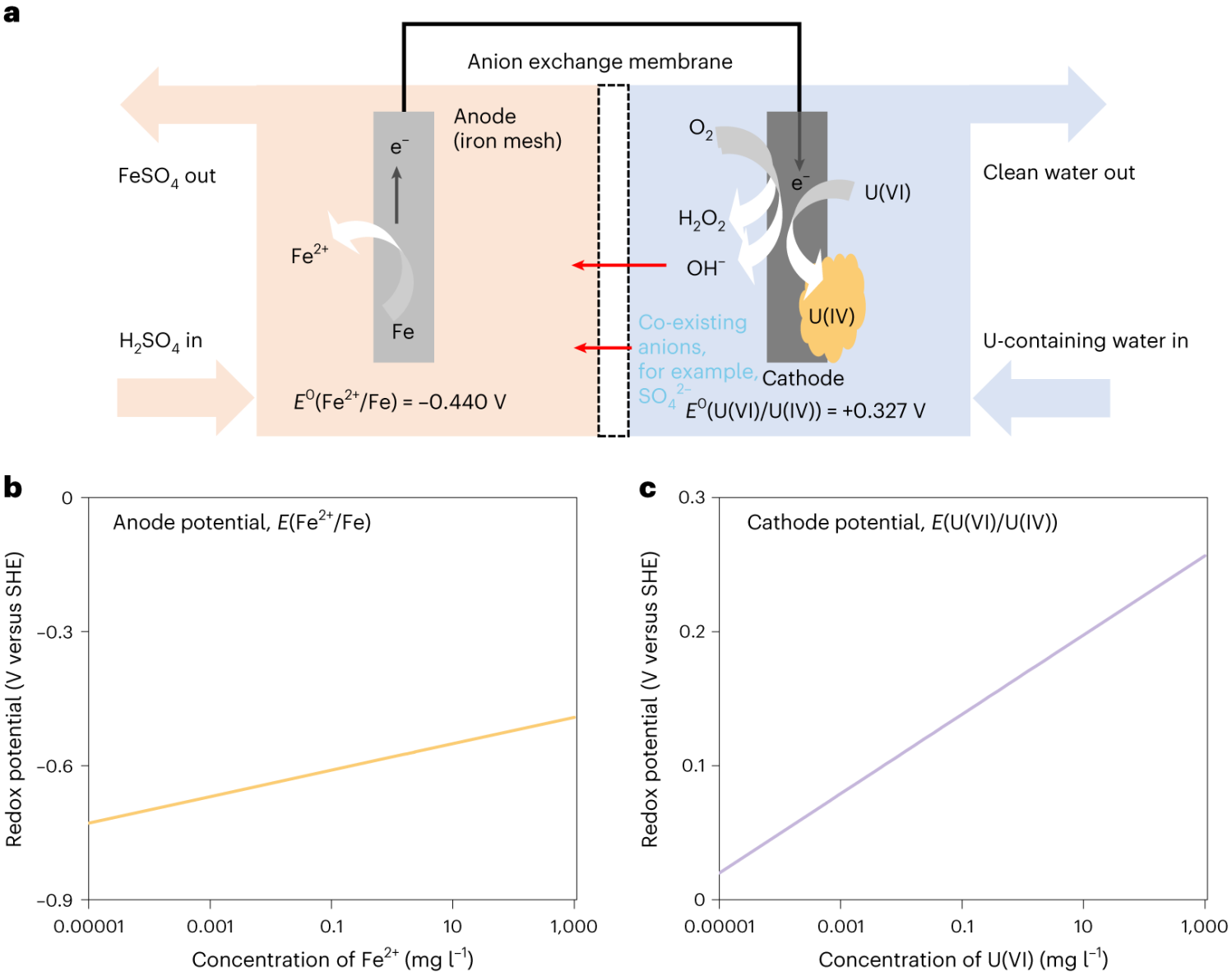

Fig. 1. Aschematic representation of the SPEC method and the calculated potentials. a, Aschematic representation of the SPEC uranium extraction method. **b,** The calculated anode potential as a function of Fe^{2+} concentration. **c,** The calculated cathode potential as a function of U(VI) concentration.

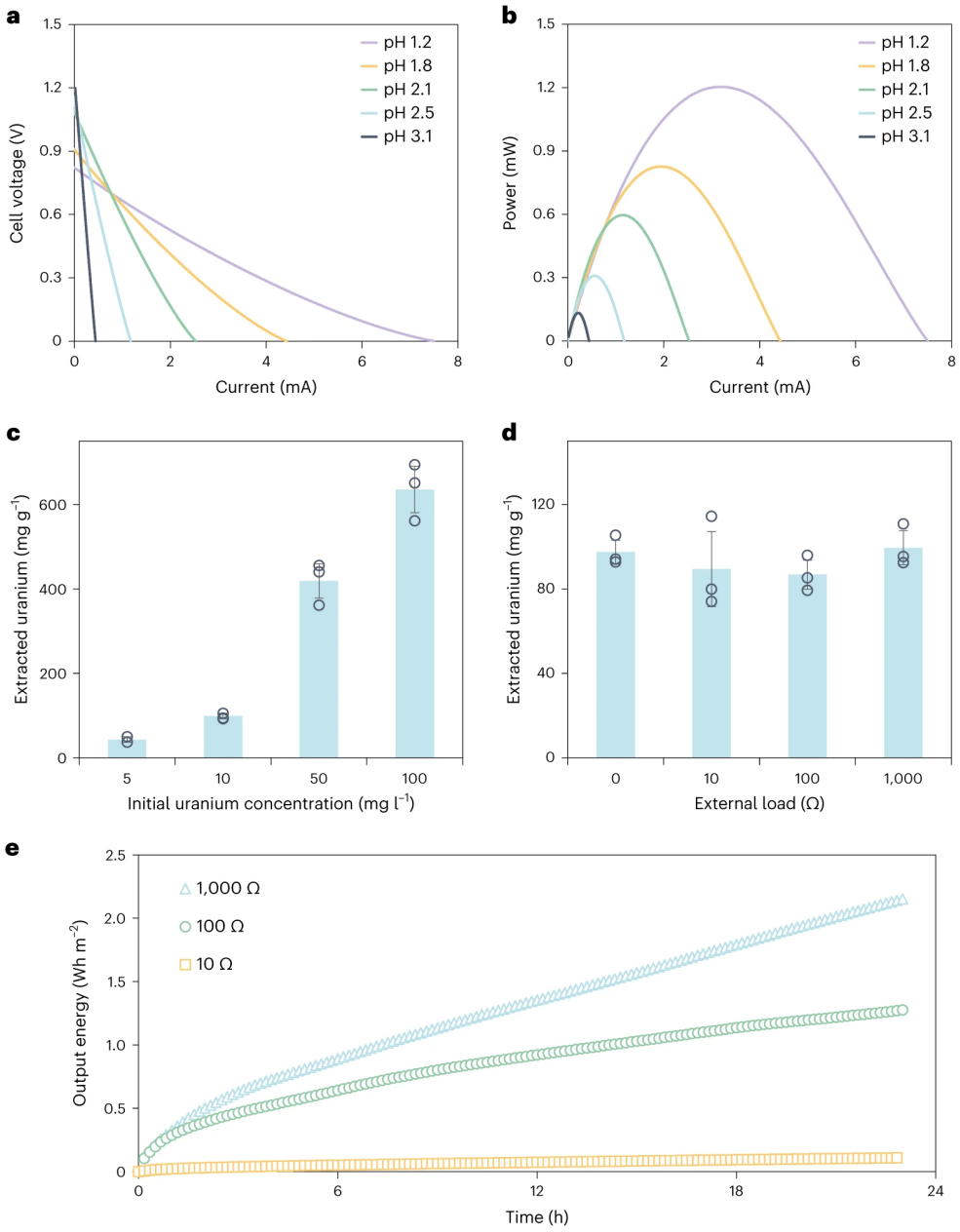

Fig. 2. Uranium extraction from water by the SPEC method with simultaneous energy recovery. a, Polarization curves of the SPEC system containing H_2SO_4 solution at varied pH as the anodic solution and simulated uranium-containing wastewater (10 mg l^{-1}) as the cathodic solution. **b,** The power of the SPEC system calculated according to the polarization curves. **c,** The total uranium extraction efficiency of the SPEC method after 23 h of operation using simulated uranium-containing wastewater with varied initial uranium concentration ($[U]_0$). The data are presented as mean ± s.d. (n = 3), while the overlaid dot plots are the corresponding data points. **d,** The total uranium extraction efficiency of the SPEC method after 23 h of operation using simulated uranium-containing wastewater ($[U]_0$ = 10 mg l^{-1}) with varied external load. The data are presented as mean ± s.d. (n = 3), while the overlaid dot plots are the corresponding data points. **e,** The accumulated output energy density as a function of the operating time during SPEC uranium extraction using simulated uranium-containing wastewater ($[U]_0$ = 10 mg l^{-1}) with varied external load. The effective area of the CCF electrode was 2.5 cm^2.

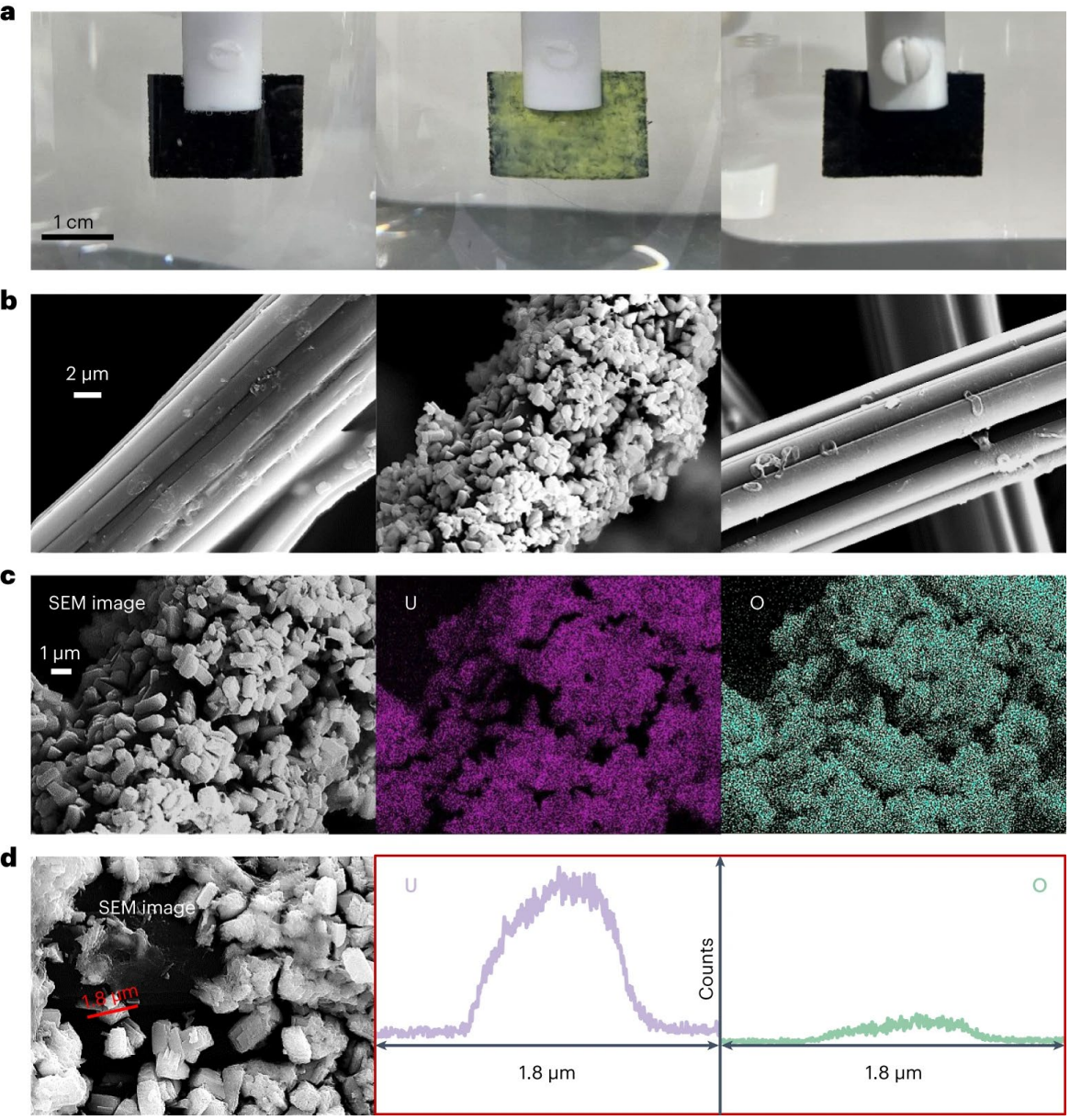

Fig. 3. Morphological characterizations of the extracted uranium. a, Photographs of the fresh CCF electrode (left), the CCF electrode after 23 h of uranium extraction via the SPEC method (centre) and the CCF electrode after 23 h of uranium extraction via the adsorption method (right). **b,** SEM images of the fresh CCF electrode (left) and the CCF electrode after 23 h of uranium extraction using the SPEC method (centre) and the adsorption method (right). **c,** EDS mapping showing the elemental composition of U (centre) and O (right) and distribution of the surface deposition layer (left) of the CCF electrode after SPEC uranium extraction. **d,** EDS line scans of U (centre) and O (right) along the red line across a microparticle (left) in the surface deposition layer shown in c. Conditions: simulated wastewater with $[U]_0 = 100$ mg l^{-1}, unadjusted pH, without external load and effective area of CCF electrode of 2.5 cm^2.

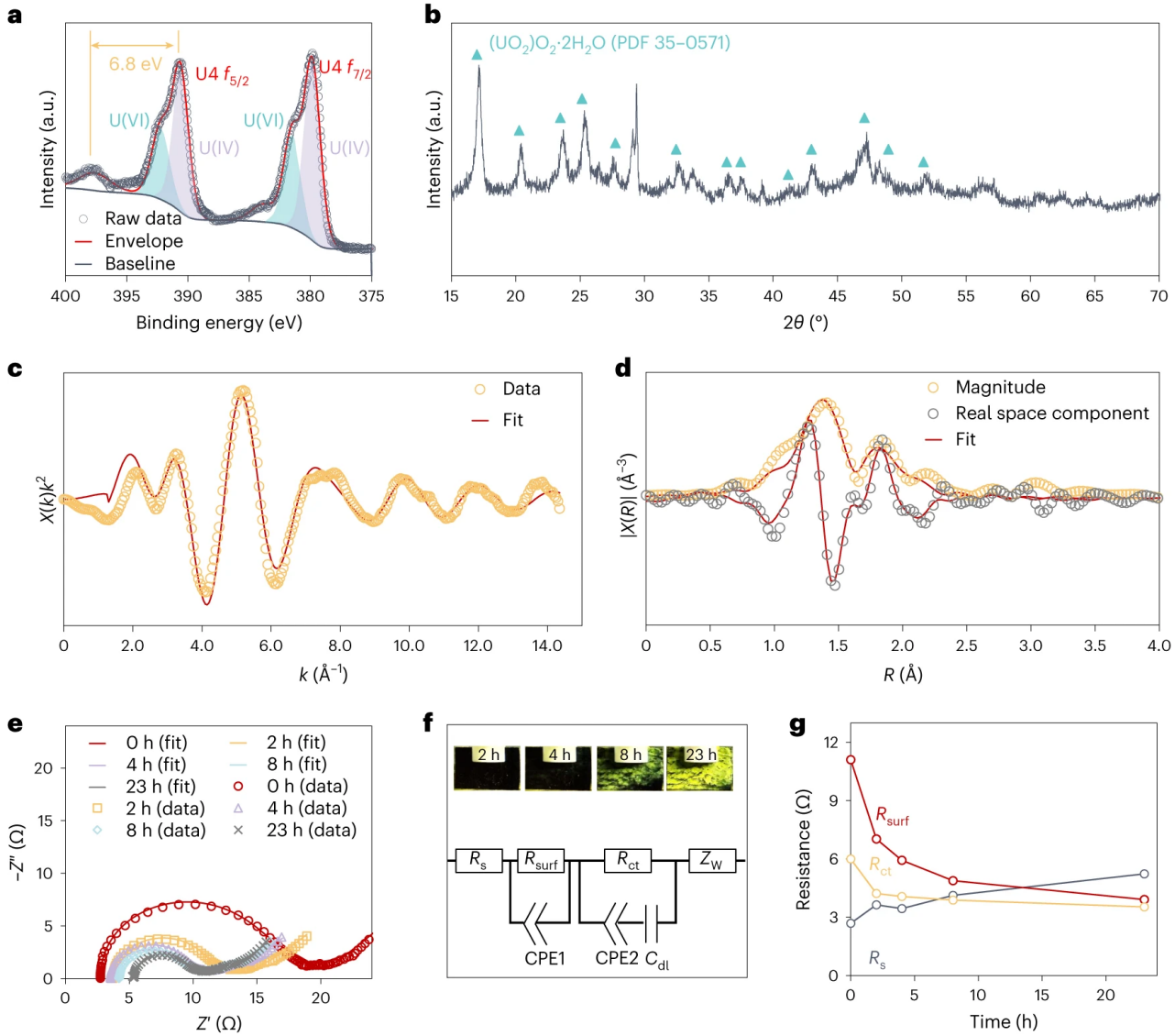

Fig. 4. Chemical properties of the extracted uranium. a, XPS U 4*f* spectrum. **b**, X-ray diffraction pattern. **c**, EXFAS *k*-space analysis. **d**, EXFAS *R*-space analysis of SPEC-extracted uranium species. **e**, Nyquist plots of the CCF electrode obtained by in situ EIS tests. **f**, The equivalent circuit used for electrochemical impedance spectroscopy (EIS) spectra fitting. *C*dl, capacitance of the double layer; CPE, constant phase element. Inset: photographs of the CCF electrode during SPEC uranium extraction. **g**, The evolution of different resistance components derived from the Nyquist plots shown in e. Conditions: simulated wastewater with [U]0 = 100 mg l^{-1}, unadjusted pH, without external load and an effective area of the CCF electrode of 2.5 cm^2.

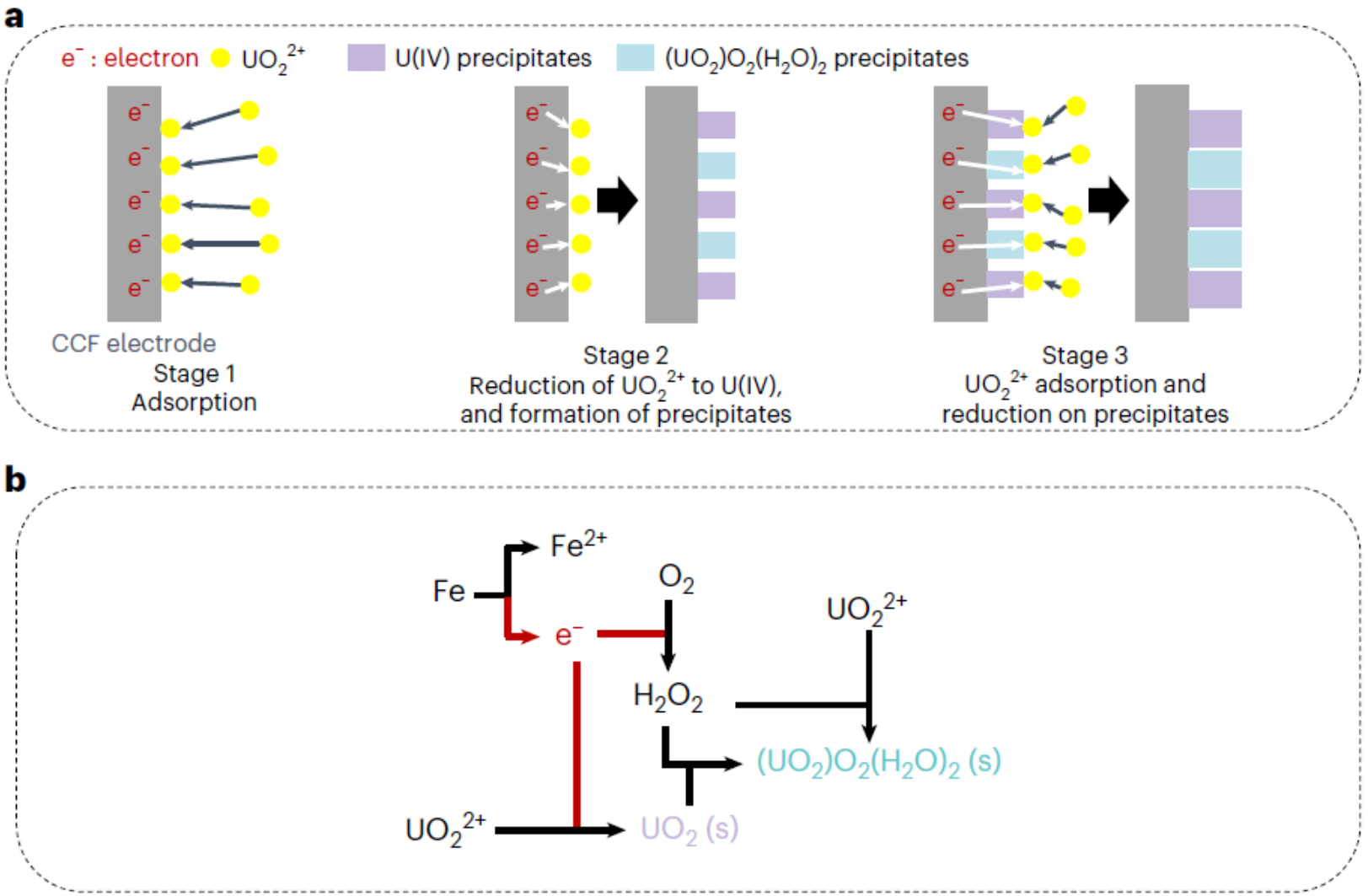

Fig. 5. Possible reactive pathways of the SPEC method. a,b, The proposed working mechanisms (**a**) and a schematic representation of the major reaction pathways (**b**) of the SPEC method.

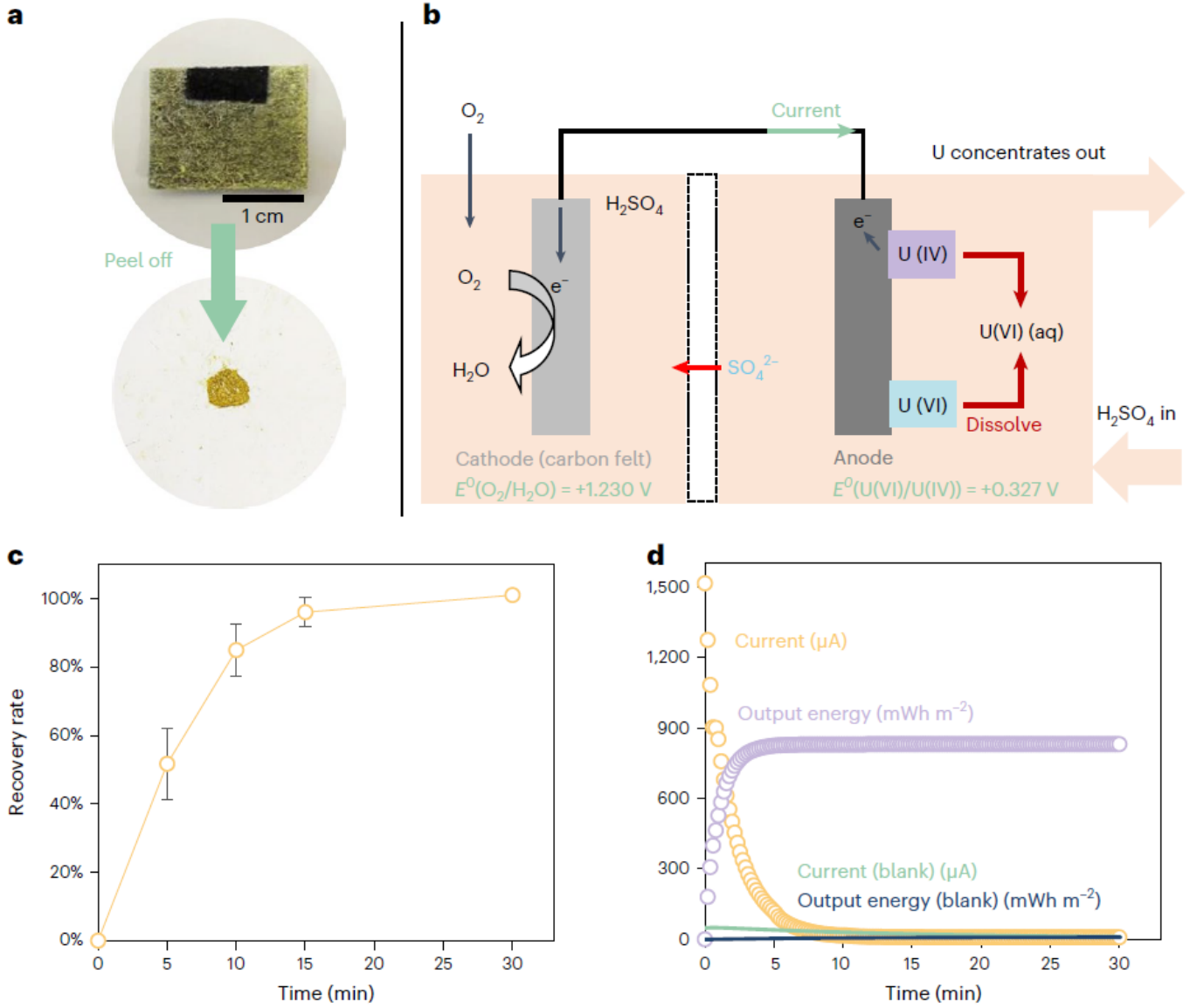

Fig. 6. Recovery of extracted uranium. a, Extracted uranium deposited on the surface of the electrode can be easily peeled off. **b,** A schematic representation of the U(IV)–DO cell concept for recovery of extracted uranium with simultaneous energy recovery. **c,** Uranium recovery using the U(IV)–DO cell. The data are presented as mean ± s.d. (n = 3). **d,** The output current and the accumulated output energy density as functions of time during uranium recovery using the U(IV)–DO cell.

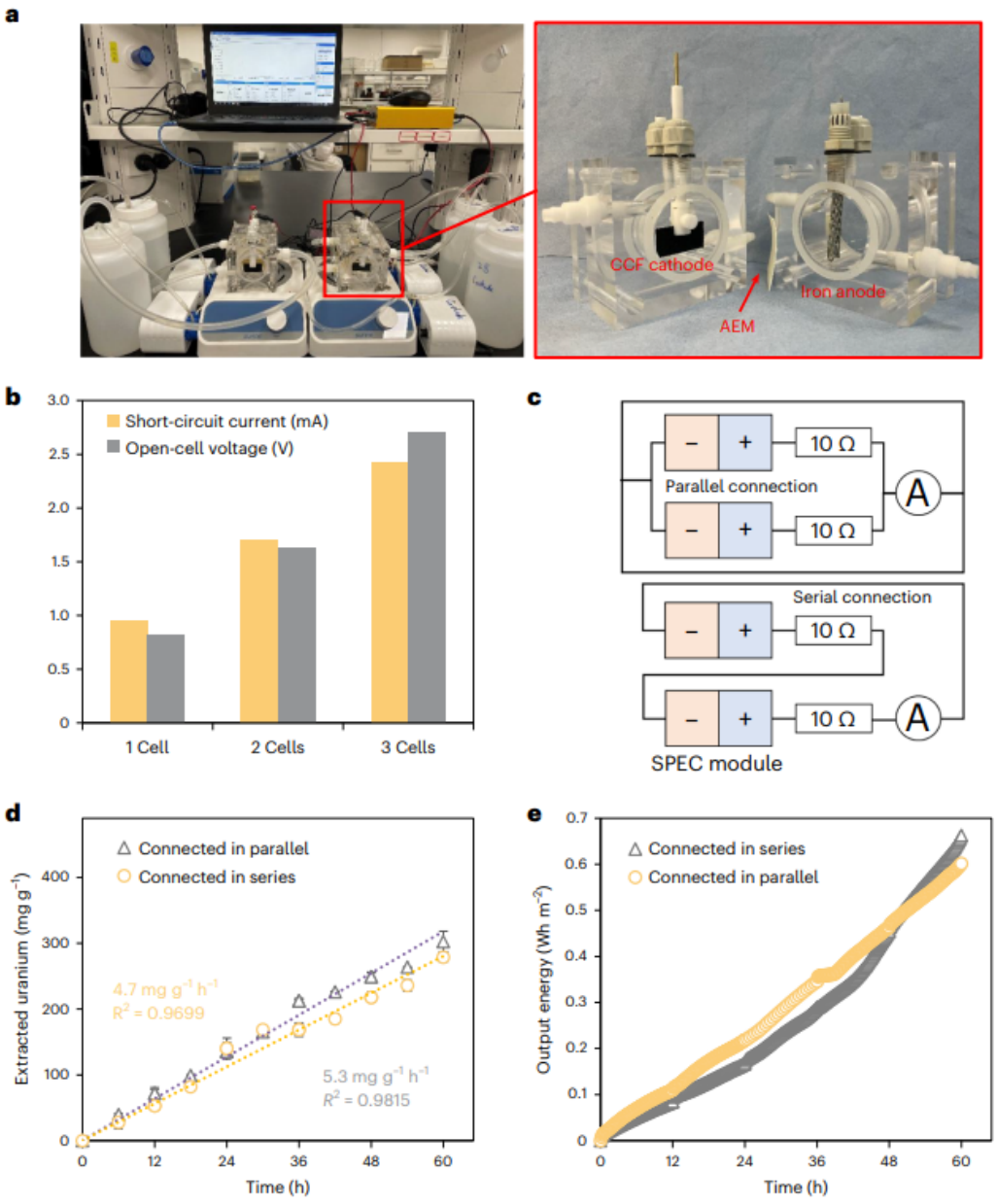

Fig. 7. SPEC uranium extraction from real uranium mine wastewater. a, Photographs of the SPEC system (left) and cell (right) used for uranium extraction from real wastewater. AEM, anion exchange membrane. **b,** System OCV (connected in series) and SCC (connected in parallel) versus module number. **c,** The equivalent circuits of the two-module SPEC system connected in different modes. **d,** The long-term uranium extraction performance (data presented as mean ± s.d. (n = 3)). **e,** The electrical energy production performance of the SPEC system.

Conclusion

- They introduced a SPEC method powered by iron oxidation that can achieve efficient uranium extraction from real mine wastewater, with high stability.
- The formation of a uranium precipitates layer that provides reactive sites and conducts electron flows is the key to obtaining stable and efficient uranium extraction in electrochemical uranium extraction processes.
- Unlike conventional adsorption methods, the extraction products are ready to recover by peeling.
- In bench-scale SPEC uranium extraction experiments with real mine wastewater without process optimization, the operating cost for uranium extraction is calculated to be USD 3.94–6.94 per kg of U.

Thank you