

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- | | | |
|-------------------------------------|-------------------------------------|--|
| ☐ | ☒ | The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☐ | ☒ | A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☒ | ☐ | The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ | A description of all covariates tested |
| ☒ | ☐ | A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ | A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☒ | ☐ | For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☒ | ☐ | For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ | For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☒ | ☐ | Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection Vienna Ab-initio Simulation Package (VASP) for DFT and all other data are obtained by direct experimentation. The 3ds Max Interactive 2.0 and Microsoft Office 2024 are used for schematic diagram.

Data analysis Origin 2022 XPS PEAK 41 Athena Artemis

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

Source data are provided with this paper.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender

Reporting on race, ethnicity, or other socially relevant groupings

Population characteristics

Recruitment

Ethics oversight

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This work develops a domino catalytic system based on dual sites that effectively addresses the long-standing challenge of the activity-stability trade-off in advanced oxidation processes. The synergistic interaction between Mg and Co sites enables Mg to selectively photoreduce O ₂ into H ₂ O ₂ under light irradiation, while in-situ generated H ₂ O ₂ and its derived surface hydroxyl groups progressively tailor the electronic structure of the adjacent Co site, forming a dynamic and self-evolving catalytic approach. This strategy offers a sustainable and efficient solution for water purification.
Research sample	Not applicable.
Sampling strategy	Not applicable.
Data collection	Characterization studies used the following techniques. The high-resolution spherical aberration-corrected HAADF-STEM images were recorded by JEOL JEM-ARM200F TEM/STEM with a spherical aberration corrector working at 300 kV. XRD pattern was recorded using a Rigaku D/Max-2550 diffractometer via Cu K α radiation at 50 kV and 200 mA in the 2 θ range between 10-70° at a scanning rate of 5°/min. The FT-IR spectra were obtained by a VERTEX 70 spectrophotometer (Bruker, Germany). The XAFS spectroscopy measurements were performed at the Co and Mg K-edges. Co and Mg K-edges analyses were performed with Si (111) crystal monochromators at the BL11B beamlines at the Shanghai Synchrotron Radiation Facility (SSRF), China. The XPS measurements were performed by a Thermo VG Scientific ESCALAB 250 spectrometer using monochromatized Al K α excitation. The EPR measurements were performed on a Bruker 300 system. The ESR spectra of reactive oxygen species trapped in water and methanol by DMPO or TEMP were analyzed by a Brooke A300 system. The in-situ Raman spectra were recorded with a Renishaw confocal micro-Raman spectroscopy system with a 532 nm excitation laser. The in-situ EPR spectra were detected a Bruker 300 system. The degradation products were identified by LC-MS. The mass spectrometer analysis was performed in a positive ion mode over the range of m/z 50-750 with an electrospray ionization source under the following conditions: capillary voltage 3500 V, cone voltage 30 V, source temperature 110 °C, desolvation temperature 380 °C, cone gas flow 80 L/h and desolvation gas flow 600 L/h. The acute toxicity of LC ₅₀ , LD ₅₀ , developmental toxicity and mutagenicity for CBZ and its products were assessed by quantitative structure activity relationship predication using Toxicity Estimation Software Tool in the consensus method. LCA was a method for assessing the environmental impacts and potential impacts of all inputs and outputs throughout the life cycle of a product or service system (cited from ISO 14040, 14044).
Timing and spatial scale	From March 2023 to August 2026, relevant experiments were conducted at Jilin University.
Data exclusions	Not applicable.
Reproducibility	Each set of experiments was repeated three times, with the error bars representing the standard deviation of the three replicate trials.
Randomization	Not applicable.

Blinding

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☐	☒ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Dual use research of concern

Policy information about [dual use research of concern](#)

Hazards

Could the accidental, deliberate or reckless misuse of agents or technologies generated in the work, or the application of information presented in the manuscript, pose a threat to:

No	Yes
☒	☐ Public health
☒	☐ National security
☒	☐ Crops and/or livestock
☒	☐ Ecosystems
☒	☐ Any other significant area

Experiments of concern

Does the work involve any of these experiments of concern:

No	Yes
☒	☐ Demonstrate how to render a vaccine ineffective
☒	☐ Confer resistance to therapeutically useful antibiotics or antiviral agents
☒	☐ Enhance the virulence of a pathogen or render a nonpathogen virulent
☒	☐ Increase transmissibility of a pathogen
☒	☐ Alter the host range of a pathogen
☒	☐ Enable evasion of diagnostic/detection modalities
☒	☐ Enable the weaponization of a biological agent or toxin
☒	☐ Any other potentially harmful combination of experiments and agents

Plants

Seed stocks	Bean sprouts
Novel plant genotypes	Not applicable
Authentication	Not applicable