Research Highlight | Open Access

Energy Materials

Han *et al. Energy Mater.* **2026**, *6*, 600164 **DOI:**10.20517/energymater.2026.300

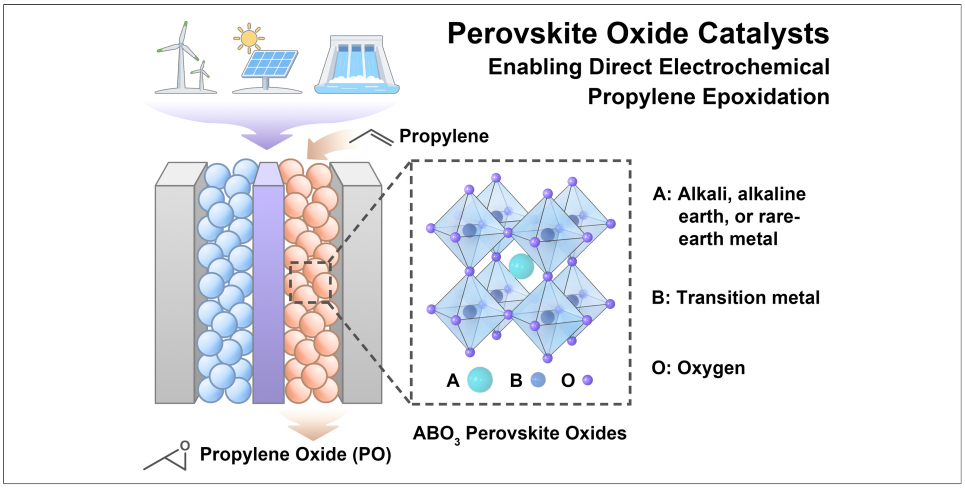
Earth-abundant perovskite oxide catalysts enabling direct electrochemical propylene epoxidation in aqueous electrolytes

Xiaowen Han, Sha Luo, Xiaomin Xu*

Citation: Han, X.; Luo, S.; Xu, X. Earth-abundant perovskite oxide catalysts enabling direct electrochemical propylene epoxidation in aqueous electrolytes. *Energy Mater.* **2026**, *6*, 600164. https://dx.doi.org/10.20517/energymater.2026.300

Received: 31 Aug 2026 **First Decision:** 9 Oct 2026 **Revised:** 20 Nov 2026 **Accepted:** 23 Nov 2026 **Published:** 27 Nov 2026

Academic Editor: Soo Young Kim **Copy Editor:** Fangling Lan **Production Editor:** Fangling Lan



Propylene oxide (PO) and its hydrolysis product, propylene glycol (PG), represent important industrial intermediates that can be used for the manufacture of polyurethanes and polyesters, among many other commodity chemicals. Conventionally, PO is industrially produced by two major approaches[1]: the chlorohydrin process [Figure 1A] and the hydrogen peroxide to propylene oxide (HPPO) process [Figure 1B]. These methods, however, are heavily dependent on strong oxidants such as chlorine and hydrogen peroxide, posing considerable environmental and safety risks, respectively. Recently, electrochemical propylene epoxidation (EPEP) has emerged as a potentially more sustainable alternative, particularly when powered by electricity generated from renewables (solar, wind, *etc.*). This reaction can occur under ambient conditions, either through an indirect pathway mediated by halides such as chlorides or bromides (which is a mimic of the chlorohydrin process) [Figure 1C][2], or via a direct pathway in which water serves as the oxygen source [Figure 1D][3]. Comparatively speaking, the direct pathway (full-cell reaction: $C_3H_6 + H_2O \rightarrow C_3H_6O + H_2$; standard cell voltage: 0.77 V) is more attractive compared to the indirect pathway as it avoids the formation of hazardous,

Curtin Centre for Advanced Energy Materials and Technologies (CAEMT), Western Australian School of Mines (WASM), Curtin University, Perth, WA 6102, Australia.

***Correspondence to:** Dr. Xiaomin Xu, Curtin Centre for Advanced Energy Materials and Technologies (CAEMT), Western Australian School of Mines (WASM), Curtin University, Perth, WA 6102, Australia. E-mail: xiaomin.xu@curtin.edu.au

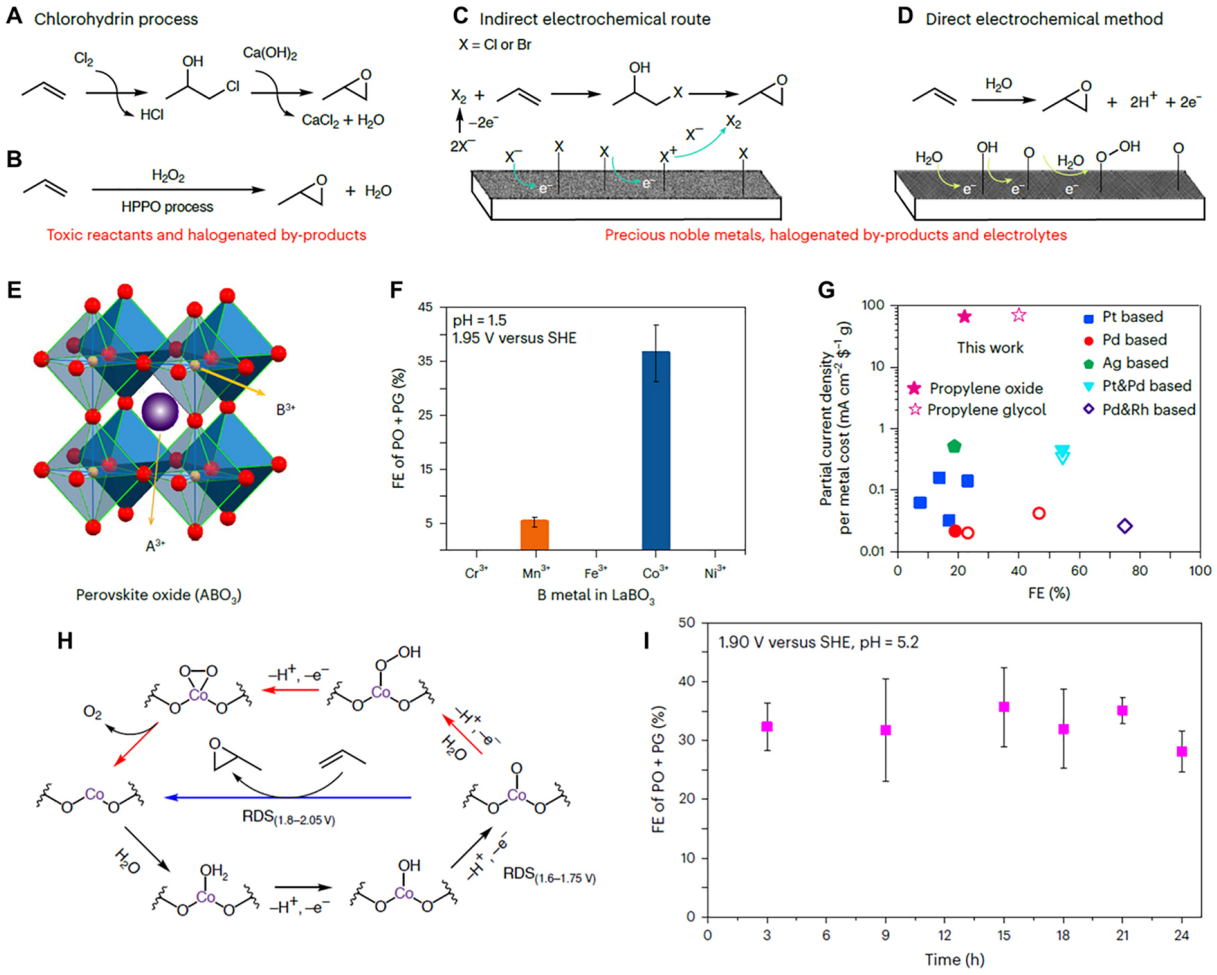


Figure 1. Perovskite oxides as a family of viable electrocatalysts for D-EPEP. (A-D) Comparison of several existing propylene epoxidation routes including chlorohydrin process (A), HPPO process (B), indirect electrochemical route (C), and direct electrochemical route (D-EPEP) (D). (E) Illustration of the perovskite oxide structure. (F) Propylene epoxidation selectivity over $LaBO_3$ series (B = Cr, Mn, Fe, Co, Ni) at 1.95 V *vs.* SHE (pH = 1.5). (G) Benchmarking with noble metal-based catalysts. (H) A proposed mechanism for the D-EPEP over $LaCoO_3$ perovskite. (I) Stability data showing changes of epoxidation FE at different time intervals for 24 h at 1.90 V *vs.* SHE (pH = 5.2). The figure is reproduced with permission from Ref.[7], Copyright © 2026 Springer Nature. SHE: Standard hydrogen electrode; FE: faradaic efficiency.

halogenated by-products, while generating green hydrogen as a more value-added by-product. However, the direct electrochemical propylene epoxidation (D-EPEP) (half-reaction: $C_3H_6 + H_2O \rightarrow C_3H_6O + 2H^+ + 2e^-$; standard equilibrium potential: 0.77 V *vs.* reversible hydrogen electrode (RHE)) competes with the oxygen evolution reaction (OER) (half-reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$; standard equilibrium potential: 1.23 V *vs.* RHE) in aqueous water, and the currently available heterogeneous catalysts that show moderate selectivity toward D-EPEP have been largely limited to those comprising noble metals like platinum (Pt)[3,4], palladium (Pd)[4], silver (Ag)[5], and rhodium (Rh)[6]. Their scarcity and high cost present a critical barrier to the wider-scale, industrial deployment of D-EPEP.

In a recent study published in Nature Catalysis, Koner and colleagues interrogated for the first time the perovskite oxide family as earth-abundant catalysts for facilitating D-EPEP toward selective production of PO (and PG, formed through the hydrolysis of PO) [Figure 1E-I][7]. Perovskite oxides with a general formula of ABO_3, where A is an alkali, alkaline-earth, or rare-earth metal and B a transition metal, are known for their compositional and structural flexibility, allowing for structure-property relationship understanding in electrocatalysis[8]. Koner *et al.*'s initial screening across the ABO_3 series (A = La and B = Cr, Mn, Fe, Co, Ni)

identified $LaMnO_3$ and $LaCoO_3$ as active candidates for propylene epoxidation, with $LaCoO_3$ delivering a more desirable epoxidation selectivity (characterized by combined PO/PG Faradaic efficiency (FE)) [Figure 1F][7]. Remarkably, when accounting for both selectivity and cost-effectiveness, $LaCoO_3$ was found to rank among the most promising catalysts for PO + PG production via D-EPEP, outperforming a great majority of the noble metal-based counterparts [Figure 1G]. Control experiments using cobalt-based oxides (e.g., CoO, Co_3O_4) and oxyhydroxides (e.g., CoOOH) resulted in significantly lower epoxidation selectivity relative to $LaCoO_3$, indicating the importance of forming a perovskite framework[7]. More specifically, the perovskite structure is capable of accommodating transition metals at high-valent states [such as Co(III) or Co(IV)], which are known to favor oxygen-atom transfer from water to propylene. Through *ex situ* characterizations combining X-ray photoelectron spectroscopy, X-ray diffraction, and electron paramagnetic resonance, it was found that an amorphous $LaCoO_3$ layer featuring low-spin Co(IV) species, which was formed *in situ* during anodic polarization, likely served as the catalytically active surface. Further, in the presence of a good proton-accepting electrolyte, anodic polarization likely facilitated an *in situ* surface activation through a proton-coupled electron transfer process[9], leading to the shrinkage of $LaCoO_3$ crystalline domains (from approximately 100 to 10 nm), as revealed by high-resolution transmission electron microscopy.

Considering the compositional tunability of perovskite oxides, the authors attempted to enhance the epoxidation selectivity of the screened $LaCoO_3$ catalyst through either A-site or B-site doping[7]. Substituting the A-site La with strontium (Sr) at levels up to 20% had no obvious effect on the epoxidation selectivity, while substitution at levels greater than 20% had a detrimental effect. On the other hand, B-site doping turned out to be unsuccessful either. Partially replacing Co with Cr, Mn, Fe, or Ni did not give rise to better epoxidation selectivity, with $LaCoO_3$ having Co alone at the B site remaining the most active candidate for epoxidation. These doping strategies did not give rise to enhanced epoxidation selectivity, suggesting that the competing OER started to prevail over those dopant-modified perovskite surfaces. Beyond catalyst composition, the authors further attempted to optimize testing parameters such as electrode preparation, electrolyte composition (e.g., electrolyte anion, cyclic phosphate additives, and electrolyte pH), and applied anodic potential. Eventually, an optimized FE of 37(±5)% toward PO and PG production was achieved on $LaCoO_3$ loaded on a hydrophilic carbon paper support as the gas diffusion electrode and in a 1 M mixture electrolyte of H_3PO_4 and sodium hexametaphosphate (SHMP) (at a 3:1 molar ratio; pH 1.5) at an applied potential of 1.95 V versus the standard hydrogen electrode [Figure 1F]. Of note, the cyclic phosphate additives (i.e., SHMP) were intentionally adopted to regulate the solvation structure and orientation of water molecules near the active sites, thereby enhancing propylene epoxidation activity[10].

Koner *et al.* further conducted a thorough electrochemical kinetic study investigating how the partial current density for epoxidation changed with the electrolyte pH, propylene partial pressure, applied potential, and isotopic substitutions. Based on these kinetic data, a possible mechanism for D-EPEP was proposed[7]. As illustrated in Figure 1H, the propylene epoxidation over the $LaCoO_3$ perovskite initiates with a water activation step on cobalt sites (rate-determining at lower potentials) forming reactive oxygenated intermediates, which are subsequently consumed through a competition between a further two-electron electrochemical oxidation step to form O_2 and a thermochemical reaction step with propylene to form PO (rate-determining at higher potentials). Stability is also an important factor for real-world applications of electrocatalytic conversion, for example, the D-EPEP. Notably, preliminary electrochemical testing suggests that $LaCoO_3$ exhibited excellent stability toward continuous propylene epoxidation over a 24-h period [Figure 1I].

In summary, this landmark study by Koner and colleagues represents an important step towards safer and more sustainable propylene epoxidation by replacing noble-metal catalysts and hazardous halogenated electrolytes with an earth-abundant perovskite catalyst operating in aqueous media. While a plausible

reaction mechanism was proposed over the amorphized perovskite catalyst, the mechanistic understanding remains incomplete. Further insight will require combined *in situ*/operando characterizations and theoretical calculations to establish a robust structure–activity relationship, which can, in turn, be utilized to develop improved catalysts based on perovskite oxides. Moving forward, researchers can leverage the tunability of the wider perovskite oxide family, including not just ABO_3 single perovskites but also $A_2B_2O_6$ double perovskites and $A_{n+1}B_nO_{3n+1}$ Ruddlesden-Popper layered perovskites[8], to explore further possibilities for electrocatalytic propylene epoxidation and other possible organic conversions. To go one step further toward practical applications, future efforts should be devoted to enhancing the epoxidation selectivity, partial current density, and operating lifetime to industrially relevant levels, through combined materials and device engineering[11].

DECLARATIONS

Authors' contributions

Conceptualization and supervision: Xu, X.
Manuscript preparation and revision: Han, X.; Luo, S.; Xu, X.

Availability of data and materials

Not applicable.

AI and AI-assisted tools statement

Not applicable.

Financial support and sponsorship

This work was supported by the Australian Research Council Discovery Early Career Researcher Award (No. DE240101013).

Conflicts of interest

Xu, X. is a Guest Editor of the Special Issue "Earth-Abundant Materials for Electrocatalytic Small Molecule Conversion" of the journal *Energy Materials*. Xu, X. was not involved in any steps of editorial processing, including reviewers' selection, manuscript handling, and decision-making, while the other authors have declared that they have no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Copyright

© The Author(s) 2026.

REFERENCES

1. Wang, Z.; Han, J.; Usama; et al. Recent advances in design of heterogeneous electrocatalyst for direct olefin epoxidation with water as the oxygen source. *Adv. Synth. Catal.* **2026**, *368*, e70582. DOI
2. Leow, W. R.; Lum, Y.; Ozden, A.; et al. Chloride-mediated selective electrosynthesis of ethylene and propylene oxides at high current density. *Science* **2020**, *368*, 1228-33. DOI
3. Iguchi, S.; Kataoka, M.; Hoshino, R.; Yamanaka, I. Direct epoxidation of propylene with water at a PtO_x anode using a solid-polymer-electrolyte electrolysis cell. *Catal. Sci. Technol.* **2022**, *12*, 469-73. DOI
4. Chung, M.; Maalouf, J. H.; Adams, J. S.; Jiang, C.; Román-Leshkov, Y.; Manthiram, K. Direct propylene epoxidation via water activation over Pd-Pt electrocatalysts. *Science* **2024**, *383*, 49-55. DOI PubMed

5. Pi, D.; Yang, X.; Chen, M.; et al. In-situ spectroscopic insights into the dual-site synergistic electrocatalytic mechanism of propylene epoxidation over single-Ag-atom catalyst. *Nat. Commun.* **2025**, *17*, 691. DOI PubMed PMC
6. Huang, J. E.; Chen, Y.; Ou, P.; et al. Selective electrified propylene-to-propylene glycol oxidation on activated Rh-doped Pd. *J. Am. Chem. Soc.* **2024**, *146*, 8641-9. DOI
7. Koner, K.; Adams, J. S.; Miu, E. V.; et al. Direct electrochemical propylene epoxidation over amorphized perovskite oxide in non-halogenated aqueous electrolyte. *Nat. Catal.* **2026**, *9*, 542-51. DOI
8. Xu, X.; Pan, Y.; Zhong, Y.; Ran, R.; Shao, Z. Ruddlesden-Popper perovskites in electrocatalysis. *Mater. Horiz.* **2020**, *7*, 2519-65. DOI
9. Kanan, M. W.; Nocera, D. G. In situ formation of an oxygen-evolving catalyst in neutral water containing phosphate and Co^{2+}. *Science* **2008**, *321*, 1072-5. DOI PubMed
10. Maki, H.; Ibaragi, K.; Fujimoto, Y.; Nariai, H.; Mizuhata, M. Transitions from simple electrolyte to polyelectrolyte in a series of polyphosphates. *Colloids. Surf. A.* **2015**, *484*, 153-63. DOI
11. Li, Y.; Li, H.; Zhang, Y.; et al. Direct electrocatalytic epoxidation of olefins: advances in membrane electrode assemblies and beyond. *Nanoscale. Horiz.* **2026**, *11*, 972-82. DOI

Disclaimer/Publisher's Note: All statements, opinions, and data contained in this publication are solely those of the individual author(s) and contributor(s) and do not necessarily reflect those of OAE and/or the editor(s). OAE and/or the editor(s) disclaim any responsibility for harm to persons or property resulting from the use of any ideas, methods, instructions, or products mentioned in the content.



© The Author(s) 2026. Open Access This article is licensed under a Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, sharing, adaptation, distribution and reproduction in any medium or format, for any purpose, even commercially, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.