

# Energy & Environmental Science

rsc.li/ees

The Royal Society of Chemistry is the world's leading chemistry community. Through our high impact journals and publications we connect the world with the chemical sciences and invest the profits back into the chemistry community.

## IN THIS ISSUE

ISSN 1754-5706 CODEN EESNBY 16(4) 1321-1800 (2023)



### Cover

See Kui Jiao *et al.*,  
pp. 1466–1479.  
Image reproduced by  
permission of  
Linhao Fan from  
*Energy Environ. Sci.*,  
2023, 16, 1466.



### Inside cover

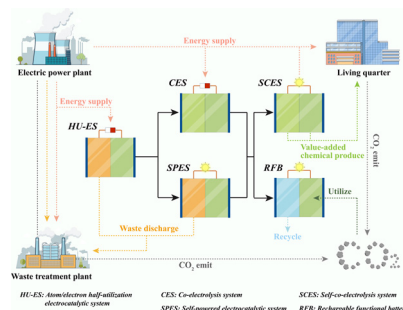
See Xianru He, Yu Qiao,  
Xin Wang *et al.*,  
pp. 1662–1675.  
Image reproduced by  
permission of  
Xin Wang from  
*Energy Environ. Sci.*,  
2023, 16, 1662.

## REVIEWS

1334

### Advanced electrocatalytic systems for enhanced atom/electron utilization

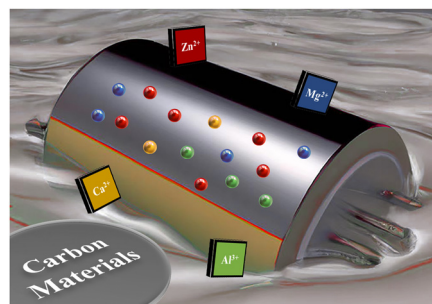
Heng Xu, Lisong Chen\* and Jianlin Shi\*



1364

### Recent advances in carbon-based nanomaterials for multivalent-ion hybrid capacitors: a review

Xuan Gao, Haoyu Wu, Chang Su, Chuanming Lu,  
Yuhang Dai, Siyu Zhao, Xueying Hu, Fangjia Zhao,  
Wei Zhang, Ivan P. Parkin, Claire J. Carmalt\* and  
Guanjie He\*



## Editorial Staff

### Executive Editor

Neil Scriven

### Deputy Editor

Sarah Holmes

### Development Editor

Lily Newton

### Editorial Production Manager

Claire Darby

### Publisher

Sam Keltie

### Publishing Editors

Emma Carlisle, Hannah Hamilton, Irene Sanchez Molina Santos, Michael Spence, Callum Woof, Lauren Yarrow-Wright

### Editorial Assistant

Kate Bando

### Publishing Assistant

Linda Warncke

For queries about submitted articles, please contact Claire Darby, Editorial Production Manager, in the first instance. E-mail: [ees@rsc.org](mailto:ees@rsc.org)

For pre-submission queries, please contact Neil Scriven, Executive Editor.

E-mail: [ees-rsc@rsc.org](mailto:ees-rsc@rsc.org)

Energy & Environmental Science (EES) (electronic: ISSN 1754-5706) is published 12 times a year by the Royal Society of Chemistry, Thomas Graham House, Science Park, Milton Road, Cambridge, CB4 0WF, UK.

All orders, with cheques made payable to the Royal Society of Chemistry, should be sent to the Royal Society of Chemistry Order Department, Royal Society of Chemistry, Thomas Graham House, Science Park, Milton Road, Cambridge, CB4 0WF, UK. Tel +44 (0)1223 432398; E-mail [orders@rsc.org](mailto:orders@rsc.org)

2023 Annual (electronic) subscription price: £1521; US\$2752. Customers in Canada will be subject to a surcharge to cover GST. Customers in the EU subscribing to the electronic version only will be charged VAT.

If you take an institutional subscription to any Royal Society of Chemistry journal you are entitled to free, site-wide web access to that journal. You can arrange access via Internet Protocol (IP) address at [www.rsc.org/ip](http://www.rsc.org/ip)

Customers should make payments by cheque in sterling payable on a UK clearing bank or in US dollars payable on a US clearing bank.

Whilst this material has been produced with all due care, the Royal Society of Chemistry cannot be held responsible or liable for its accuracy and completeness, nor for any consequences arising from any errors or the use of the information contained in this publication. The publication of advertisements does not constitute any endorsement by the Royal Society of Chemistry or Authors of any products advertised. The views and opinions advanced by contributors do not necessarily reflect those of the Royal Society of Chemistry which shall not be liable for any resulting loss or damage arising as a result of reliance upon this material. The Royal Society of Chemistry is a charity, registered in England and Wales, Number 207890, and a company incorporated in England by Royal Charter (Registered No. RC000524), registered office: Burlington House, Piccadilly, London W1J 0BA, UK, Telephone: +44 (0) 207 4378 6556.

### Advertisement sales:

Tel +44 (0) 1223 432246; Fax +44 (0) 1223 426017; E-mail [advertising@rsc.org](mailto:advertising@rsc.org)

For marketing opportunities relating to this journal, contact [marketing@rsc.org](mailto:marketing@rsc.org)

# Energy & Environmental Science

[rsc.li/ees](http://rsc.li/ees)

*Energy & Environmental Science* links all aspects of science relating to energy conversion and storage, alternative fuel technologies and environmental science.

## Editorial Board

### Chair

Jenny Nelson, Imperial College London, UK

### Editorial Board Members

Xinhe Bao, Dalian Institute of Chemical Physics (DICP), China  
Christoph Brabec, University of Erlangen-Nuremberg, Germany  
William Chueh, Stanford University, USA  
Linda Nazar, University of Waterloo, Canada  
Jan Rossmeisl, University of Copenhagen, Denmark  
Jennifer Wilcox, University of Pennsylvania, USA  
Karen Wilson, RMIT, Australia

## Advisory Board

Markus Antonietti, Max Planck Institute of Colloids and Interfaces, Germany  
Juan Bisquert, Jaume I University, Spain  
Bernie Bulkin, Sustainable Development Commission, UK  
Stephen Campbell, Automotive Fuel Cell Cooperation, Canada  
Emily Carter, Princeton University, USA  
Kylie Catchpole, Australian National University, Australia  
Jaephil Cho, Ulsan National Institute of Science and Technology (UNIST), Korea  
Wonyong Choi, Korea Institute of Energy Technology, Korea  
Ib Chorkendorff, Technical University of Denmark, Denmark  
Peter Dobson, University of Oxford, UK  
Kazunari Domen, Tokyo Institute of Technology, Japan  
Nieves Espinosa, University of Murcia, Spain  
Hongjin Fan, Nanyang Technological University, Singapore  
Elzbieta Frackowiak, Poznan University of Technology, Poland  
Hermenegildo Garcia, Universidad Politécnica de Valencia, Spain  
Laura Herz, University of Oxford, UK  
José Goldemberg, University of São Paulo, Brazil  
Harry Gray, California Institute of Technology (Caltech), USA  
Dirk Guld, Friedrich-Alexander University Erlangen-Nürnberg, Germany  
Anders Hagfeldt, Uppsala University, Sweden  
Steven Holdcroft, Simon Fraser University/NRC Institute for Fuel Cell Innovation, Canada  
George Huber, University of Wisconsin-Madison, USA  
Oliver Inderwildi, University of Oxford, UK  
Saiful Islam, University of Oxford, UK  
Mercouri G Kanatzidis, Northwestern University, USA  
Akihiko Kudo, Tokyo University of Science, Japan  
Pooi See Lee, Nanyang Technological University, Singapore  
Nathan Lewis, California Institute of Technology (Caltech), USA  
Chengdu Liang, Oak Ridge National Laboratory, USA  
Jeffrey R Long, University of California Berkeley, USA  
Yi-Chun Lu, Chinese University of Hong Kong, China  
Shelley Minteer, The University of Utah, USA  
Christopher R McNeill, Monash University, Australia  
Arthur Nozik, National Renewable Energy Laboratory, USA  
Satish Ogale, National Chemical Laboratory (CSIR-NCL), India  
Annunziata Petrozza, Istituto Italiano di Tecnologia, Italy  
Seeram Ramakrishna, National University of

Singapore, Singapore  
Zhiyong Jason Ren, Princeton University, USA  
Rodney Ruoff, Ulsan National Institute of Science & Technology (UNIST), South Korea  
Jennifer Rupp, Massachusetts Institute of Technology, USA  
Srinivasan Sampath, Indian Institute of Science, India  
Uwe Schröder, TU-Braunschweig, Germany  
David Sinton, University of Toronto, Canada  
Henry Snaith, University of Oxford, UK  
Robert Socolow, Princeton University, USA  
Jefferson W Tester, Cornell University, USA  
Dan Wang, Institute of Process Engineering, Chinese Academy of Sciences, China  
Peng Wang, Zhejiang University, China  
Michael R Wasielewski, Northwestern University, USA  
Li-Zhu Wu, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, China  
Bilge Yildiz, Massachusetts Institute of Technology, USA  
Kyung Byung Yoon, Sogang University, South Korea  
Yan Yu, University of Science and Technology of China, China  
Jincai Zhao, Institute of Chemistry, Chinese Academy of Sciences, China  
Tim S. Zhao, The Hong Kong University of Science & Technology, Hong Kong

## Information for Authors

Full details on how to submit material for publication in EES are given in the Instructions for Authors (available from <http://www.rsc.org/authors>). Submissions should be made via the journal's homepage: [rsc.li/ees](http://rsc.li/ees)

Authors may reproduce/republish portions of their published contribution without seeking permission from the Royal Society of Chemistry, provided that any such republication is accompanied by an acknowledgement in the form: (Original Citation)–Reproduced by permission of the Royal Society of Chemistry.

This journal is © The Royal Society of Chemistry 2023.

Apart from fair dealing for the purposes of research or private study for non-commercial purposes, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988 and the Copyright and Related Rights Regulation 2003, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the Publishers or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency in the UK. US copyright law is applicable to users in the USA.

Registered charity number: 207890

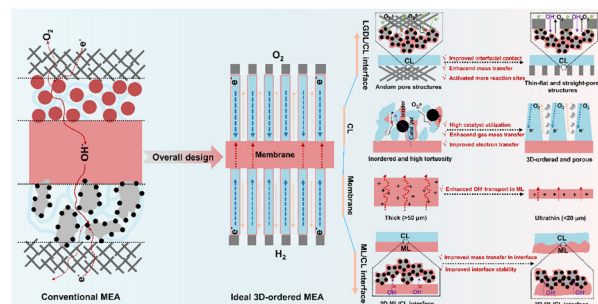


## REVIEWS

1384

## Key components and design strategy of the membrane electrode assembly for alkaline water electrolysis

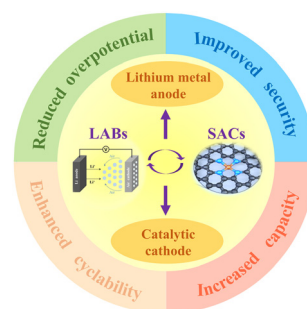
Lei Wan, Ziang Xu, Qin Xu, Maobing Pang, Dongcheng Lin, Jing Liu and Baoguo Wang\*



1431

## Recent progress on single-atom catalysts for lithium–air battery applications

Tiansheng Bai, Deping Li,\* Shenyi Xiao, Fengjun Ji, Shuai Zhang, Chu Wang, Jingyu Lu,\* Quan Gao and Lijie Ci\*

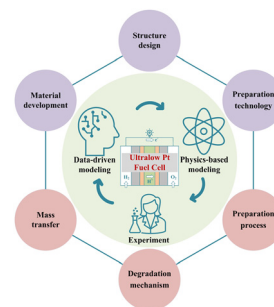


## PERSPECTIVES

1466

## Towards ultralow platinum loading proton exchange membrane fuel cells

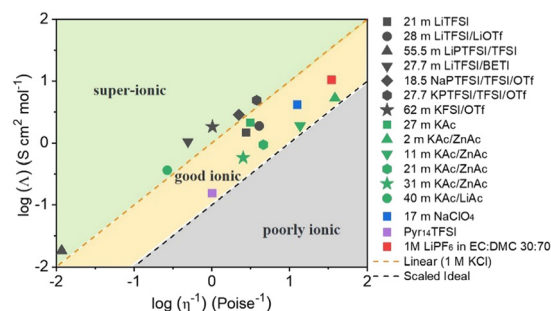
Linhao Fan, Hao Deng, Yingguang Zhang, Qing Du, Dennis Y. C. Leung, Yun Wang and Kui Jiao\*



1480

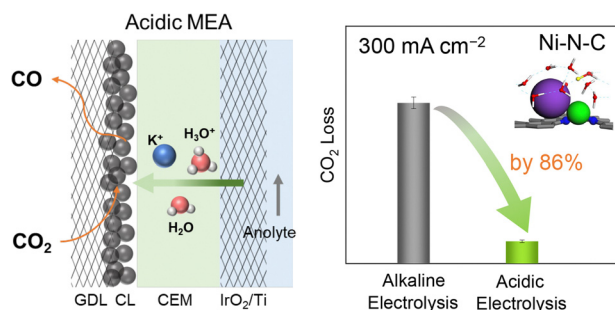
## A perspective on the role of anions in highly concentrated aqueous electrolytes

Jin Han, Alessandro Mariani,\* Stefano Passerini and Alberto Varzi\*



## COMMUNICATIONS

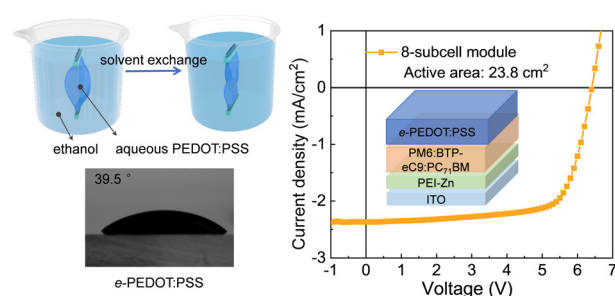
1502



### Tailoring acidic microenvironments for carbon-efficient CO<sub>2</sub> electrolysis over a Ni–N–C catalyst in a membrane electrode assembly electrolyzer

Hefei Li, Haobo Li, Pengfei Wei, Yi Wang, Yipeng Zang, Dunfeng Gao,\* Guoxiong Wang\* and Xinhe Bao\*

1511

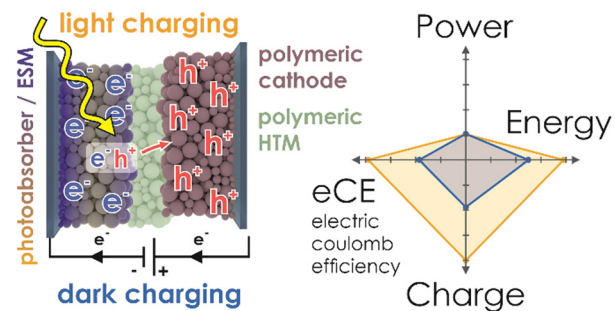


### Two-in-one alcohol-processed PEDOT electrodes produced by solvent exchange for organic solar cells

Xinyun Dong, Xianmin Zhou, Yang Liu, Sixing Xiong, Jingyu Cheng, Youyu Jiang\* and Yinhua Zhou\*

## PAPERS

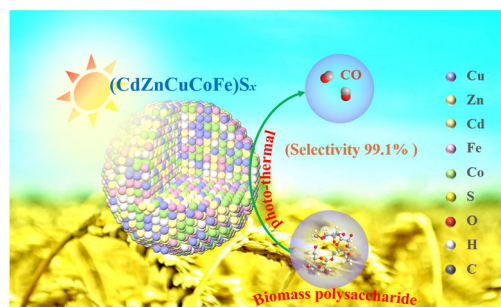
1520



### An integrated solar battery based on a charge storing 2D carbon nitride

A. Gouder, F. Podjaski,\* A. Jiménez-Solano, J. Kröger, Y. Wang and B. V. Lotsch\*

1531



### Peroxide-mediated selective conversion of biomass polysaccharides over high entropy sulfides via solar energy catalysis

Yixue Xu, Li Wang, Zhonglian Shi, Na Su, Chao Li, Yingping Huang,\* Niu Huang, Yu Deng, Hui Li, Tianyi Ma,\* Xin Ying Kong, Wenjing Lin, Ying Zhou and Liqun Ye\*



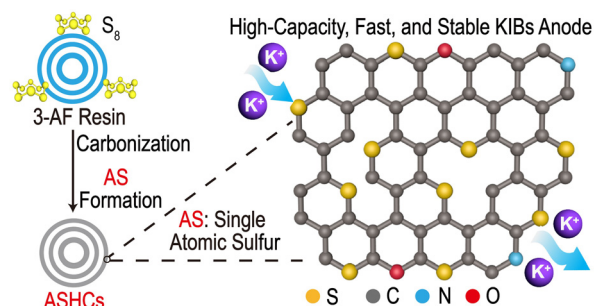


## PAPERS

1540

# Surface-dominated potassium storage enabled by single-atomic sulfur for high-performance K-ion battery anodes

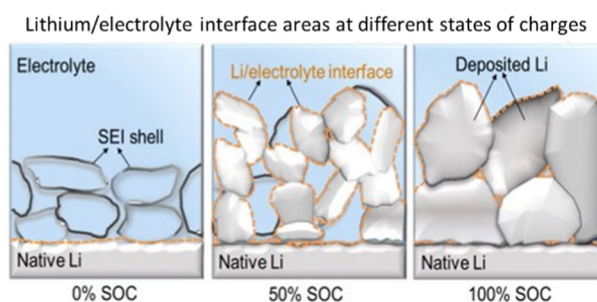
Guo-Zhan Yang, Yan-Fei Chen, Bao-Qi Feng, Chen-Xin Ye, Xue-Bin Ye, Hongchang Jin, En Zhou, Xian Zeng, Ze-Lin Zheng, Xue-Ling Chen, De-Shan Bin\* and An-Min Cao\*



1548

# Stability of solid electrolyte interphases and calendar life of lithium metal batteries

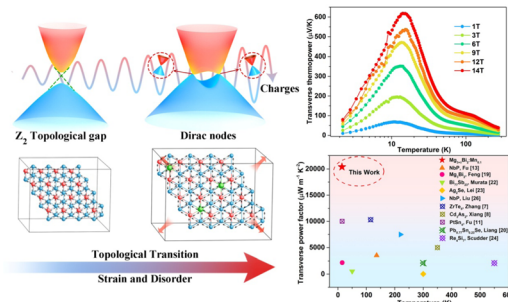
Xia Cao, Yaobin Xu, Lianfeng Zou, Jie Bao, Yunxiang Chen, Bethany E. Matthews, Jiangtao Hu, Xinzi He, Mark H. Engelhard, Chaojiang Niu, Bruce W. Arey, Chunsheng Wang, Jie Xiao, Jun Liu, Chongmin Wang,\* Wu Xu\* and Ji-Guang Zhang\*



1560

# Giant transverse thermoelectric effect induced by topological transition in polycrystalline Dirac semimetal $\text{Mg}_3\text{Bi}_2$

Tao Feng, Panshuo Wang, Zhijia Han, Liang Zhou, Zhiran Wang, Wenqing Zhang,\* Qihang Liu\* and Weishu Liu\*

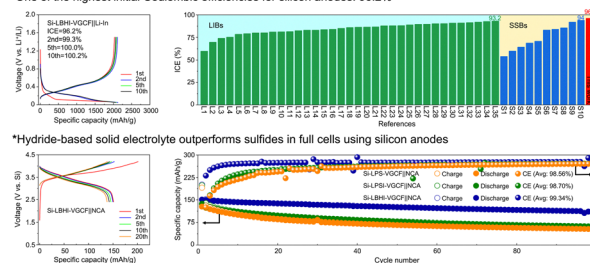


1569

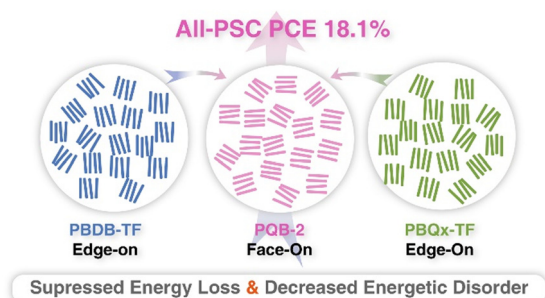
# Solid-state silicon anode with extremely high initial coulombic efficiency

Yonglin Huang, Bowen Shao, Yan Wang\* and Fudong Han\*

\*One of the highest initial Coulombic efficiencies for silicon anodes: 96.2%



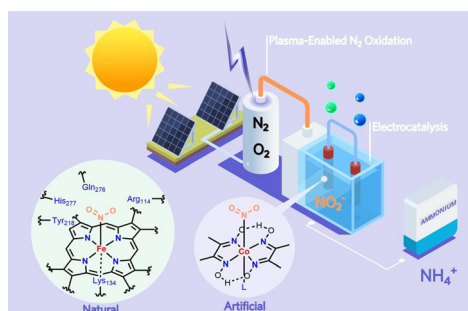
1581



### Suppressing the energetic disorder of all-polymer solar cells enables over 18% efficiency

Tao Zhang, Ye Xu, Huifeng Yao,\* Jianqi Zhang, Pengqing Bi, Zhihao Chen, Jingwen Wang, Yong Cui, Lijiao Ma, Kaihu Xian, Zi Li, Xiaotao Hao, Zhixiang Wei and Jianhui Hou\*

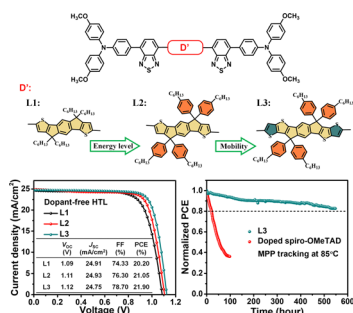
1590



### Cobaloximes: selective nitrite reduction catalysts for tandem ammonia synthesis

Shu-Lin Meng, Chen Zhang, Chen Ye, Jia-Hao Li, Shuai Zhou, Lei Zhu, Xu-Bing Li, Chen-Ho Tung and Li-Zhu Wu\*

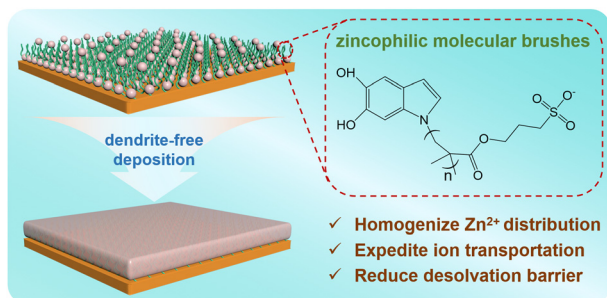
1597



### A conformally bonded molecular interface retarded iodine migration for durable perovskite solar cells

Ligang Yuan, Weiya Zhu, Yiheng Zhang, Yuan Li,\* Christopher C. S. Chan, Minchao Qin, Jianhang Qiu, Kaicheng Zhang, Jiaxing Huang, Jiarong Wang, Huiming Luo, Zheng Zhang, Ruipeng Chen, Weixuan Liang, Qi Wei, Kam Sing Wong, Xinhui Lu, Ning Li,\* Christoph J. Brabec, Liming Ding and Keyou Yan\*

1610



### Molecular brush: an ion-redistributor to homogenize fast $\text{Zn}^{2+}$ flux and deposition for calendar-life Zn batteries

Huanyan Liu, Qian Ye, Da Lei, Zhidong Hou, Wei Hua, Yu Huan, Na Li, Chunguang Wei, Feiyu Kang and Jian-Gan Wang\*



## PAPERS

1620

### A 5 V-class cobalt-free battery cathode with high loading enabled by dry coating

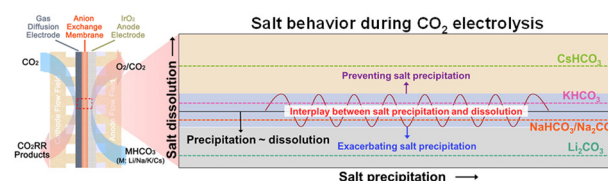
Weiliang Yao, Mehdi Chouchane, Weikang Li, Shuang Bai, Zhao Liu, Letian Li, Alexander X. Chen, Baharak Sayahpour, Ryosuke Shimizu, Ganesh Raghavendran, Marshall A. Schroeder, Yu-Ting Chen, Darren H. S. Tan, Bhagath Sreenarayanan, Crystal K. Waters, Allison Sichler, Benjamin Gould, Dennis J. Kountz, Darren J. Lipomi, Minghao Zhang\* and Ying Shirley Meng\*



1631

### How alkali cations affect salt precipitation and CO<sub>2</sub> electrolysis performance in membrane electrode assembly electrolyzers

Sahil Garg, Qiucheng Xu, Asger B. Moss, Marta Mirolo, Wanyu Deng, Ib Chorkendorff, Jakub Drnec and Brian Seger\*

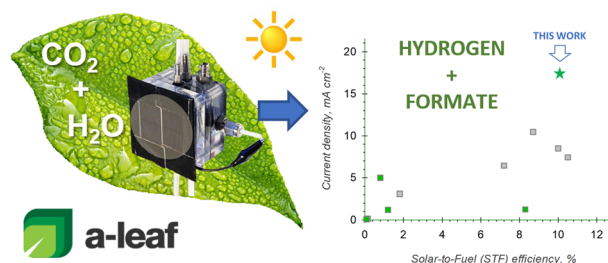


1644

### An artificial leaf device built with earth-abundant materials for combined H<sub>2</sub> production and storage as formate with efficiency > 10%

Claudio Ampelli,\* Daniele Giusi, Matteo Miceli, Tsvetelina Merdzhanova, Vladimir Smirnov, Ugochi Chime, Oleksandr Astakhov, Antonio José Martín, Florentine Louise Petronella Veenstra, Felipe Andrés Garcés Pineda, Jesús González-Cobos, Miguel García-Tecedor, Sixto Giménez, Wolfram Jaegermann, Gabriele Centi, Javier Pérez-Ramírez, José Ramón Galán-Mascarós and Siglinda Perathoner

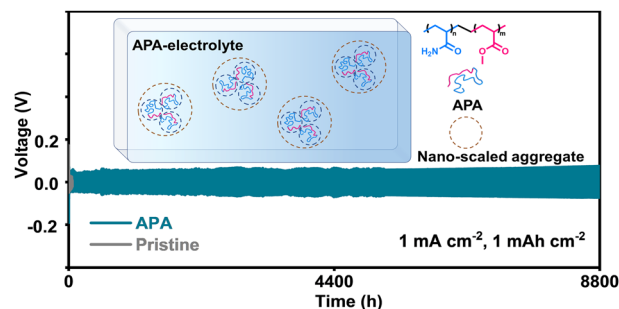
#### an ARTIFICIAL LEAF made of earth-abundant materials



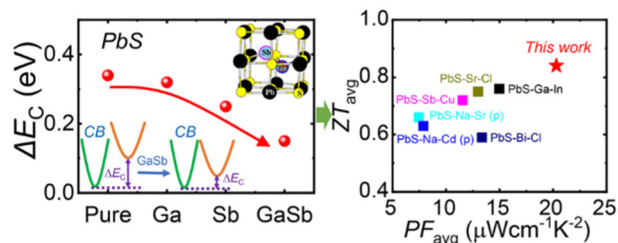
1662

### Nano-scaled hydrophobic confinement of aqueous electrolyte by a nonionic amphiphilic polymer for long-lasting and wide-temperature Zn-based energy storage

Ben Niu, Zhengang Li, Die Luo, Xinyu Ma, Qingshan Yang, Yu-E Liu, Xiaoyu Yu, Xianru He,\* Yu Qiao\* and Xin Wang\*



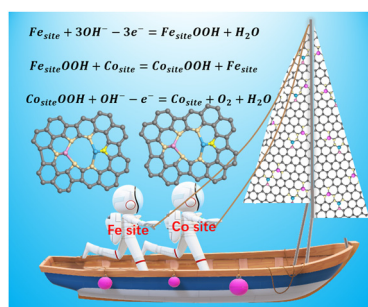
1676



### GaSb doping facilitates conduction band convergence and improves thermoelectric performance in n-type PbS

Zixuan Chen, Hong-Hua Cui, Shiqiang Hao, Yukun Liu, Hui Liu, Jing Zhou, Yan Yu, Qingyu Yan, Christopher Wolverton, Vinayak P. Dravid, Zhong-Zhen Luo,\* Zhigang Zou and Mercouri G. Kanatzidis\*

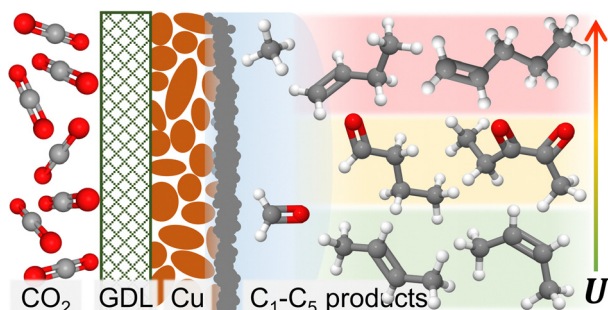
1685



### Adjacent Fe Site boosts electrocatalytic oxygen evolution at Co site in single-atom-catalyst through a dual-metal-site design

Changli Chen, Mingzi Sun, Fang Zhang, Haijing Li, Mengru Sun, Pin Fang, Tinglu Song, Wenxing Chen, Juncai Dong, Brian Rosen, Pengwan Chen, Bolong Huang\* and Yujing Li\*

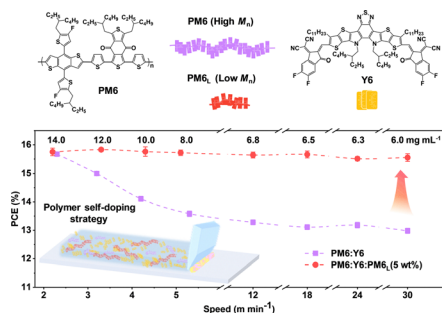
1697



### On the role of C<sub>4</sub> and C<sub>5</sub> products in electrochemical CO<sub>2</sub> reduction via copper-based catalysts

Simon D. Rihm, Mikhail K. Kovalev, Alexei A. Lapkin, Joel W. Ager and Markus Kraft\*

1711



### High-speed printing of a bulk-heterojunction architecture in organic solar cells films

Xinbi Zhao, Rui Sun,\* Xiaohei Wu, Meimei Zhang, Yuan Gao, Ji Wan and Jie Min\*



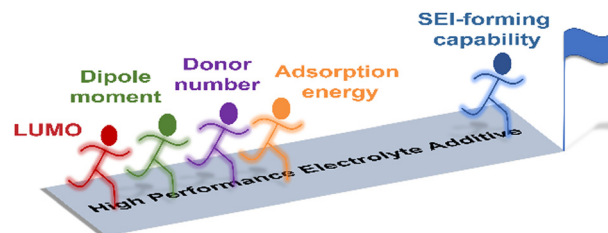


## PAPERS

1721

### Selection criteria for electrical double layer structure regulators enabling stable Zn metal anodes

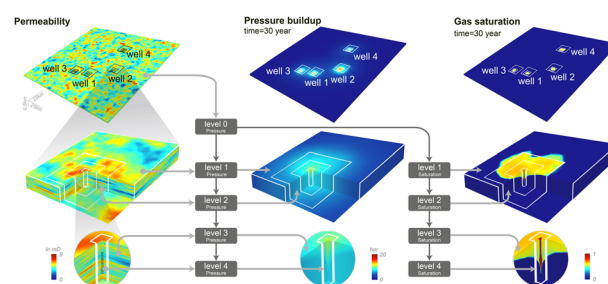
Cong Huang, Xin Zhao, Yisu Hao, Yujie Yang, Yang Qian, Ge Chang, Yan Zhang, Qunli Tang,\* Aiping Hu and Xiaohua Chen\*



1732

### Real-time high-resolution CO<sub>2</sub> geological storage prediction using nested Fourier neural operators

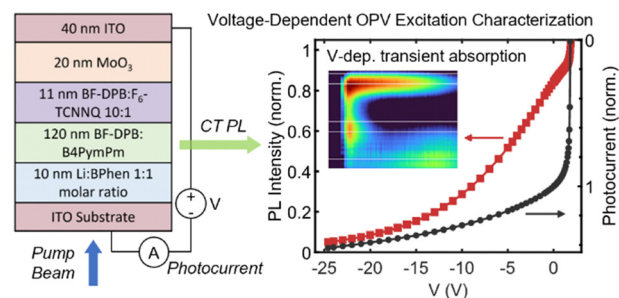
Gege Wen,\* Zongyi Li, Qirui Long, Kamyar Azizzadenesheli, Anima Anandkumar and Sally M. Benson



1742

### Voltage-dependent excitation dynamics in UV-absorbing organic photovoltaics with efficient charge transfer exciton emission

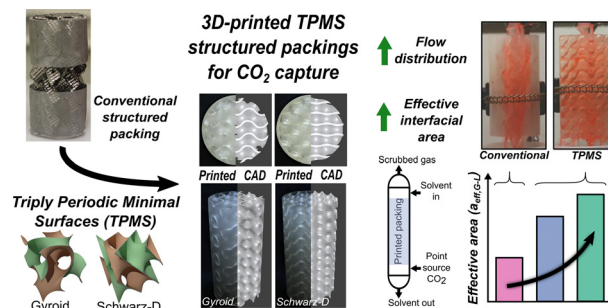
Quinn C. Burlingame,\* Xiao Liu, Melissa L. Ball, Barry P. Rand and Yueh-Lin Loo\*



1752

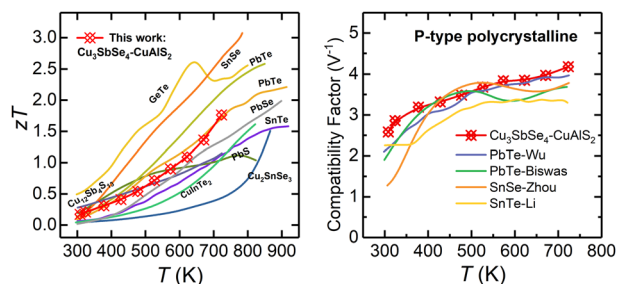
### 3D printed triply periodic minimal surfaces as advanced structured packings for solvent-based CO<sub>2</sub> capture

Nathan C. Ellebracht, Pratanu Roy, Thomas Moore, Aldair E. Gongora, Diego I. Oyarzun, Joshua K. Stolaroff and Du T. Nguyen\*



## PAPERS

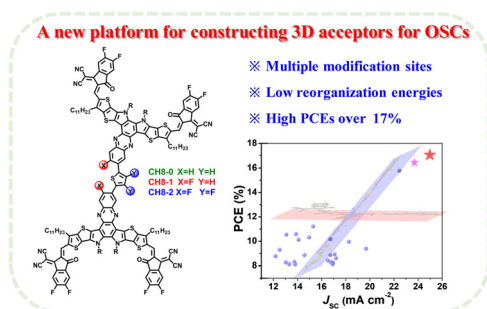
1763



### High thermoelectric performance and compatibility in $\text{Cu}_3\text{SbSe}_4\text{-CuAlS}_2$ composites

Yuling Huang, Xingchen Shen, Guiwen Wang, Bin Zhang, Sikang Zheng, Chun-Chuen Yang, Xuan Hu, Shaokuan Gong, Guang Han, Guoyu Wang, Xu Lu\* and Xiaoyuan Zhou\*

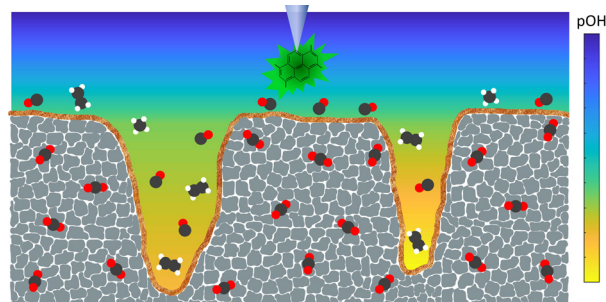
1773



### 3D acceptors with multiple A–D–A architectures for highly efficient organic solar cells

Hongbin Chen, Zhe Zhang, Peiran Wang, Yunxin Zhang, Kangqiao Ma, Yi Lin, Tainan Duan, Tengfei He, Zaifei Ma, Guankui Long, Chenxi Li, Bin Kan,\* Zhaoyang Yao,\* Xiangjian Wan and Yongsheng Chen\*

1783



### Direct observation of the local microenvironment in inhomogeneous $\text{CO}_2$ reduction gas diffusion electrodes via versatile pOH imaging

Annette Böhme, Justin C. Bui, Aidan Q. Fenwick, Rohit Bhide, Cassidy N. Feltenberger, Alexandra J. Welch, Alex J. King, Alexis T. Bell, Adam Z. Weber, Shane Ardo and Harry A. Atwater\*

## CORRECTIONS

1796

### Correction: Global potential of algae-based photobiological hydrogen production

Qingyang Chen, Lijie Wang, Yimin Chen\* and Chenba Zhu



## CORRECTIONS

1797

**Correction: Elucidating the chirality transfer mechanisms during enantioselective synthesis for the spin-controlled oxygen evolution reaction**

Hayoung Im, Sunihl Ma, Hyungsoo Lee, Jaemin Park, Young Sun Park, Juwon Yun, Jeongyoub Lee, Subin Moon and Jooho Moon\*

