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EES Catalysis 2025 Outstanding Papers

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We are proud to announce the launch of the *EES Catalysis* Outstanding Papers. This is an opportunity to recognise the exceptional work published in the journal and celebrate the authors behind the work by selecting one Outstanding Article and one Outstanding Review each year.

These papers are chosen from a shortlist compiled by the Editorial Office using a range of metrics. The journal's Editorial and Advisory Boards review and vote on these papers based on the science presented and the potential impact. The Editor-in-Chief selects the final winning papers, taking the Board members' votes into account.

We are delighted to introduce the inaugural Outstanding Article and Outstanding Review. Please join us in congratulating the authors behind these exceptional contributions.

EES Catalysis 2025 Outstanding Article

A reversed gas diffusion electrode enables collection of high purity gas products from CO_2 electroreduction

Bo Wu, Lakshmi Devi Voleti, Aidan Q. Fenwick, Chao Wu, Jiguang Zhang, Ning Ling, Meng Wang, Yuewen Jia, Weng Weei Tjiu, Mingsheng Zhang, Zainul Aabdin, Shibo Xi, Channamallikarjun S. Mathpati, Sui Zhang, Harry A. Atwater, Iftekhar A. Karimi and Yanwei Lum

"This paper introduces a 'reversed' gas diffusion electrode design that enables the continuous collection of high-purity gas products from electrochemical CO_2 reduction.[1] *By using electrolyte pressure and optimized pore architecture, the authors achieve stable, oxygen-tolerant syngas production over 76 hours with a full-cell energy efficiency of 37%. This work is important because it offers a viable pathway toward economically scalable CO_2 electroreduction while eliminating the need for energy-intensive downstream separations."* – Shizhang Qiao, Editor-in-Chief, *EES Catalysis*

We spoke to the authors Bo Wu, Lakshmi Devi Voleti, Aidan Q. Fenwick, Chao Wu, Jiguang Zhang, Ning Ling, Meng Wang, Yuewen Jia, Weng Weei Tjiu, Mingsheng Zhang, Zainul Aabdin, Shibo Xi, Channamallikarjun S. Mathpati, Sui Zhang, Harry A. Atwater, Iftekhar A. Karimi and Yanwei Lum about their work.

Which part of this paper do you think will have the greatest impact?

Electroreduction of carbon dioxide (CO_2R) into chemicals can be realized with high selectivity but necessary separation steps result in high operational cost and process complexity. Our reversed gas diffusion electrode concept is capable of collecting CO_2R products with high purity and eliminating the cost associated with additional separation steps, which offers a solution to this problem, potentially simplifying the path toward large-scale application of CO_2R.

What was the most challenging part of completing this research?

The most challenging aspect was identifying the resistance for the gas product transportation. Addressing this required careful dry gas permeation experimental design and true gas flux calculation to ensure that the observed trends were really intrinsic to the system.

What are the next steps for this research?

Building on this work, future efforts will focus on scaling up the concept and integrating the system into a practical

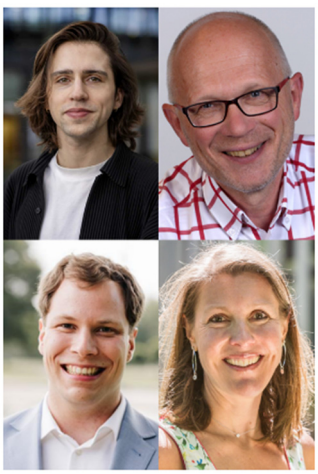
thermocatalytic platform for the conversion of high-purity syngas into value-added products. In parallel, we will explore the broader applicability of this strategy to other energy- and sustainability-relevant transformations.

EES Catalysis 2025 Outstanding Review

Plasma catalysis: what is needed to create synergy?

Joran Van Turnhout, Kevin Rouwenhorst, Leon Lefferts and Annemie Bogaerts

"This perspective provides a timely and insightful look into the fundamental barriers preventing true synergy between plasma processes and catalysts.[2] *The paper highlights gaps in mechanistic understanding, mismatches between catalyst materials and plasma environments, energy losses from reverse reactions, and shortcomings in reactor design. The authors stress the need for rigorous measurement and reporting standards, and identify promising plasma–material combinations beyond traditional catalysts for a way forward in a rapidly developing field."* – Shizhang Qiao, Editor-in-Chief, *EES Catalysis*



The authors Joran Van Turnhout, Kevin Rouwenhorst, Leon Lefferts and Annemie Bogaerts were invited to answer a few questions about their perspective.

What do you see as the most significant insights or conclusions from your review?

As the field of plasma catalysis for sustainable chemistry applications grows in popularity, we see an increasing number of claims about plasma–catalytic synergy. Meanwhile, the field has not yet made the substantial improvements in energy efficiency needed to compete with other technologies such as thermal catalysis and electro-catalysis for synthesis of chemicals and fuels. We believe this is because of a lack of understanding of the underlying processes, and we feel most recent works focus on arbitrarily improving the performance of complex systems, which generally does not improve the fundamental understanding of plasma catalysis. In addition, results are not always reported transparently based on rigorous correct measurements. Thus, in this perspective, which resulted from many discussions within and between our research groups, we identify what we consider as the main hurdles for plasma catalysis to become more energy efficient, and possible ways to overcome these hurdles.

One of the most important insights, we believe, is that in many of the used plasma-catalytic systems, especially in systems without external heating, the plasma chemistry likely overshadows any possible catalytic effect. We believe this is in part because the interaction between active plasma species, such as vibrationally excited species and radicals, and the catalytic surface is minimal due to low prevalence of these species and/or the short lifetimes leading to short diffusion lengths in porous catalyst particles. This means that any pursuit to find a suitable catalyst material cannot be fruitful without tuning the plasma conditions. In addition, smaller void sizes between catalyst particles in packed beds could also increase plasma–catalyst interactions, and thus the contribution of the catalyst in the overall process.

What are the biggest challenges currently facing researchers in this area?

Plasma catalysis is inherently interdisciplinary, because plasma physics, plasma chemistry, surface chemistry, heterogeneous catalysis, materials engineering and catalytic reactor engineering are inevitably intertwined in a plasma-catalytic system. This makes the topic particularly challenging to study, especially since most groups either have a background in (thermal) catalysis, plasma physics or plasma chemistry. For example, plasma is often treated as a black box in catalysis research, and in-depth electrical characterization of the plasma is often lacking, while this can often explain the observed trends in performance. Vice versa, the chemical engineering aspect of heterogeneous catalysis is often not considered in plasma research. However, this challenge clearly also creates great opportunities for interdisciplinary collaborations.

Unfortunately, the field also faces its own replication crisis, largely due to a lack of standardization, but sometimes also due to incorrect analyses, e.g., overestimating oxygenate selectivities in liquid product without considering the mass balance over all reactants and products in both the gas phase and liquid phase. This is hampering rigorous comparison of data between setups and research groups. To ensure the integrity of the field, we believe that discrepancy in observations and interpretations should be discussed more critically and transparently.

What do you hope readers take away from your review?

At present, most research in the field, also from our own groups, has focused on finding the right catalyst for a packed-bed dielectric barrier discharge reactor by testing various thermal catalysts in the same plasma configuration. We hope that our perspective makes it clear that plasma cannot be treated as a black box if we want to significantly improve the energy efficiency. Monitoring the plasma and tuning the distribution of excited species are crucial, and in our opinion underexplored in the field. We believe we need to evolve away from packed-bed dielectric barrier configurations, and that thinking out-of-the-box is necessary to achieve significant progress. Furthermore, plasma excites not only reactants but also products; in order to achieve high conversion with sufficient energy efficiency, integration of plasma conversion and product separation is required. Finally, process design including, e.g., separation of products and heat integration is essential to achieving practical processes based on plasma-catalytic synthesis of chemicals and fuels.

In general, we hope that some of our proposed solutions will be starting points for other researchers in the field. We have already had many fruitful conversations with colleagues based on this perspective, and we hope to continue doing so.

We extend our sincerest congratulations to the authors of our 2025 Outstanding Papers whose work will continue to advance and shape catalysis research. We look forward to celebrating more exceptional work in the years to come.

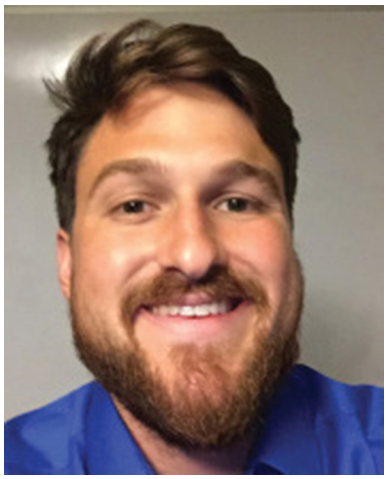
Author Biographies

***EES Catalysis* 2025 Outstanding Article**

A reversed gas diffusion electrode enables collection of high purity gas products from CO_2 electroreduction

Bo Wu received his BS in 2018 from Jiangnan University, China and MS in 2021 from Tianjin University, China. He is currently a PhD student at the Department of Chemical and Biomolecular Engineering, NUS, under the supervision of Prof. Yanwei Lum. His research focuses on electrochemically driven small-molecule transfer.

Lakshmi Devi Voleti received her BEng in 2019 from Chaitanya Bharathi Institute of Technology (CBIT), India, and her Masters in 2021 from Birla Institute of Technology & Science (BITS). She received her MEng in 2025 from the National University of Singapore (NUS). Her research addresses process modelling, techno-economic viability, and environmental performance of electrochemical CO_2 reduction systems, with applications in carbon nanotube production and electrolyzer electrode design.



Aidan Q. Fenwick is currently a PhD student at the California Institute of Technology under the supervision of Prof. Harry Atwater. His research focuses on catalyst design for CO_2 conversion into chemicals and fuels.

Chao Wu received his BS in 2017 and MS in 2020 from Sichuan University, China. He then obtained his PhD degree in Materials Physics and Chemistry from Sichuan University under the supervision of Prof. Jiagang Wu. From 2023 to 2024, he was a Visiting PhD Scholar at the Singapore Synchrotron Light Source under the A*STAR Scholarship, supervised by Dr Shibo Xi. He is currently a lecturer at Chengdu Technological University. His research focuses on synchrotron-based X-ray absorption fine structure (XAFS) spectroscopy, with applications in areas such as electrocatalytic water splitting for hydrogen production, CO_2 reduction, and lithium battery research.

Jiguang Zhang received his BS in 2018 from Harbin Institute of Technology, China and MS in 2021 from Xiamen University, China. He is currently a PhD student at the Department of Chemical and Biomolecular Engineering, NUS under the supervision of Prof. Yanwei Lum. His research interests include understanding the mechanisms of electrochemical nitrate reduction to ammonia, and CO_2 reduction to chemicals/fuels.

Ning Ling received her PhD degree in 2022 from Sungkyunkwan University,

South Korea. She then joined the NUS as a Postdoctoral Fellow. Her research focuses on the development of two-dimensional (2D) material electronic devices and their applications in electrocatalysis, including hydrogen evolution reaction (HER) and electrochemical CO_2 reduction.

Meng Wang received his BS in 2019 from Taiyuan University of Technology, China, and MS in 2022 from Chongqing University, China. He is currently a PhD student at the Department of Chemical and Biomolecular Engineering, NUS, under the supervision of Prof. Yanwei Lum. His research focuses on catalyst design for direct conversion of dilute CO_2 in flue gas to chemicals and fuels.

Yuewen Jia received her BSc degree in Environmental Science from Beijing Normal University in 2019, followed by an MSc degree in Environmental Engineering from the Korea Advanced Institute of Science and Technology (KAIST) in 2021. She obtained her PhD degree in Chemical Engineering from the NUS in 2025, under the supervision of Prof. Sui Zhang. She is currently a Postdoctoral Research Fellow at the NUS. Her research interests focus on membrane separation technologies, particularly for gas separation and organic solvent nanofiltration.

Weng Weei Tjiu is a senior specialist at the Institute of Materials Research & Engineering.

Mingsheng Zhang is a senior specialist at the Institute of Materials Research & Engineering.

Zainul Aabdin received his MSc in Physics from the University of Allahabad and an MTech in Materials Science from the Indian Institute of Technology Kanpur, before completing his PhD in Applied Physics at the University of Tübingen, Germany. He subsequently joined the National University of Singapore as a Postdoctoral Research Fellow and later became a Research Scientist and Group Leader at A*STAR's Institute of Materials Research and Engineering in Singapore. His research interests span advanced transmission electron microscopy, nanoscale fabrication, *in situ* liquid and gas-phase studies, and AI-assisted microscopy analytics.

Shibo Xi received his PhD in Optics from the Beijing Synchrotron Radiation Facility (BSRF) at the Institute of High Energy Physics, Chinese Academy of Sciences. In 2012, he joined Singapore's Agency for Science, Technology and Research (A*STAR) and is a Senior Scientist II in

A*STAR's Institute of Sustainability for Chemicals, Energy and Environment (ISCE2). His research focuses on intensive use of synchrotron radiation for materials characterization, especially X-ray absorption fine structure (XAFS) spectroscopy.

Channamallikarjun S. Mathpati received his BEng in 2004 and his PhD degree in 2010. He is now an associate professor in Institute of Chemical Technology, Mumbai. His research interests include computational & experimental fluid dynamics, design of multiphase reactors, process modeling and simulation, and high temperature corrosion.

Sui Zhang received her BS in 2008 from Fudan University. She later obtained her PhD degree at National University of Singapore in 2012. She is now an associate Professor in Chemical and Biomolecular Engineering, NUS, as of 2024. Her research interests include nanoporous graphene and microporous polymer membranes and transport across emerging membranes.

Harry A. Atwater received his BS in 1982 from Massachusetts Institute of Technology. He later obtained his MS in 1983 and his PhD degree in 1987 at Caltech. He is now director of Liquid Sunlight Alliance, as of 2021. His research interests include quantum and nanophotonics, metamaterials and metasurfaces, artificial photosynthesis, two-dimensional materials, nano- and micro-structured photovoltaics, space solar power and plasmonics.

Iftekhar A. Karimi received his BS in 1980 from IIT Bombay. He later obtained his MS in 1982 and his PhD degree in 1984 at Purdue. He is now a professor in Department of Chemical and Biomolecular Engineering, NUS. His research interests include modeling and optimization, energy systems and energy efficiency, planning and scheduling, oil and gas supply chains and systems biology.

Yanwei Lum received his BEng (2012) degree in Materials Science and Engineering from Imperial College London (UK). He later obtained his PhD degree at University of California, Berkeley, in 2018. He then joined the University of Toronto for a stint as a Postdoctoral Fellow. He began his current position as a Presidential Young Assistant Professor at the National University of Singapore at the end of 2021. His research interests include electrochemical CO_2 conversion, electroorganic chemistry and ammonia production/utilization.

EES Catalysis 2025 Outstanding Article

Plasma catalysis: what is needed to create synergy?

Joran Van Turnhout (1998, MSc in chemistry at University of Antwerp) completed a research stay in the Laboratoire Catalyse et Spectrochimie in Caen, France as a part of his Master's program, where he studied plasma catalysis through the

lens of *in situ* infrared spectroscopy. He is currently pursuing a joint PhD on the topic of plasma-catalytic CO_2 hydrogenation at the University of Antwerp and the Eindhoven University of Technology under the supervision of Prof. Annemie Bogaerts and Prof. Emiel Hensen. Having a special interest in *in situ* catalyst characterization in a plasma environment, he aims to combine insights from thermal catalysis and plasma chemistry to help improve the understanding of plasma catalysis, particularly for applications related to CO_2 utilization. After the completion of his PhD, he plans to continue this pursuit with a continued emphasis on interdisciplinary collaboration.

Kevin Rouwenhorst (1995, MSc and PhD at University of Twente) was awarded the 1st prize in the gas industry category by the KHMW for his MSc thesis. He continued research at the University of Twente with a PhD project on 'Plasma-catalytic ammonia synthesis' under the supervision of Prof. Dr. Ir. L. Lefferts in the Catalytic Processes & Materials group at the University of Twente. The results of this research are presented in that PhD thesis. During his PhD research, he presented his work at various ammonia energy conferences and plasma chemistry conferences. He has published various articles, various book chapters, and an encyclopedia article, and filed for a patent. He graduated *cum laude* (top 5%) from his PhD at the University of Twente. Furthermore, he is the lead author of the report Innovation Outlook: Renewable Ammonia of the International Renewable Energy Agency (IRENA) and the Ammonia Energy Association (AEA), and he is the sole author of the book Low-emission Ammonia Production and Utilization (2026, Royal Society of Chemistry). Currently, he works at the Ammonia Energy Association as Technology Manager, and he holds a position as Industrial Fellow at the University of Twente.

Leon Lefferts (1960, MSc and PhD at University of Twente) received the Catalysis Prize of the Royal Dutch Chemical Society (1987). After joining DSM Research serving as research scientist, project leader and senior scientist, he was appointed full professor at the University of Twente in 1999. He has been visiting professor at the Tokyo Institute of Technology and Aalto University and was appointed honorary professor at Changzhou University in 2008 and 2025. He has supervised more than 40 PhD students and authored over 270 peer-reviewed publications with an *h*-index of 70. His research interests include activation of stable molecules including plasma catalysis, heterogeneous catalysis in liquid phase, membrane reactors and redox materials. He is currently co-chairing the Department of Chemical Engineering at the University of Twente.

Annemie Bogaerts (1971, MSc and PhD in chemistry at University of Antwerp) has been a full professor at the University of Antwerp since 2012. She is the head of the Plasma Lab for Applications in Sustainability and Medicine – ANTwerp (PLASMANT), which she started "from scratch", and which currently counts about 50 members. Her research focuses on plasma chemistry, plasma reactor design and plasma-surface interactions, by experiments and modeling, for various applications, but mostly for sustainable chemistry (electrification of chemical reactions, plasma catalysis) and medicine (cancer treatment).

She has had more than 700 peer-reviewed publications since 1995, and about 40 000 citations, with an *h*-index of 97 (Web of Science) (more than 55 000 citations and an *h*-index of 116 in Google Scholar). She has given almost 300 invited lectures (since 1995). She has been the supervisor of more than 70 finished PhD theses (since 2005), and is now supervising 30 PhD students (incl. several joint PhD students), and 15 postdocs.

She is on the editorial board of 15 different journals, and was/is guest editor of 24 special issues in several journals. She has also organized several conferences, and received more than 30 prestigious awards.

She was member of the Board of Directors of the International Plasma Chemistry Society (IPCS; ca 600 members; 2014–2023), Vice-president of the IPCS (2020–2022) and President of the IPCS (2022–2023). She is also member of

the Academia Europaea (since 2011), and of the Royal Flemish Academy of Belgium for Sciences and the Arts (since 2012).

References

1 B. Wu, L. D. Voleti, A. Q. Fenwick, C. Wu, J. Zhang, N. Ling, M. Wang, Y. Jia, W. W. Tjiu, M. Zhang, Z. Aabdin, S. Xi, C. S. Mathpati, S. Zhang, H. A. Atwater, I. A. Karimi and Y. Lum, A reversed gas diffusion electrode enables collection of high purity gas products from CO_2 electroreduction, *EES Catal.*, 2025, **3**, 318–326.

2 J. V. Turnhout, K. Rouwenhorst, L. Lefferts and A. Bogaerts, Plasma catalysis: what is needed to create synergy?, *EES Catal.*, 2025, **3**, 669–693.