

# Green Chemistry

Cutting-edge research for a greener sustainable future

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ISSN 1463-9262 CODEN GRCHFJ 26(3) 1025–1664 (2024)



### Cover

See Julien Legros, Jean-Christophe M. Monbaliu *et al.*, pp. 1281–1288.

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### Inside cover

See Dianhua Liu *et al.*, pp. 1399–1413.

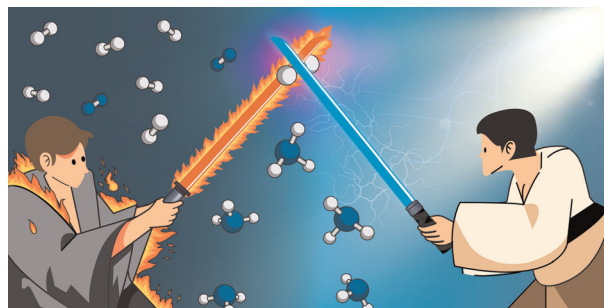
Image reproduced by permission of Dianhua Liu from *Green Chem.*, 2024, **26**, 1399.

## CRITICAL REVIEWS

1041

### Challenges and opportunities for the photo-(thermal) synthesis of ammonia

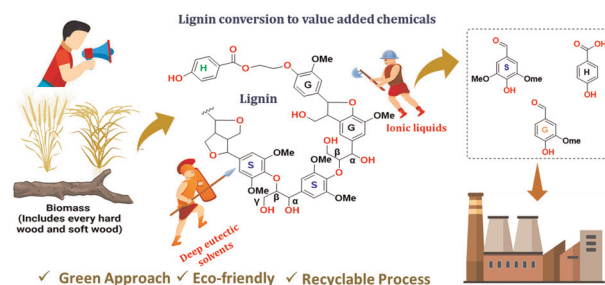
Diego Mateo,\* Angel Sousa, Maksim Zakharzhevskii and Jorge Gascon\*



1062

### Recent advances in catalytic conversion of lignin to value-added chemicals using ionic liquids and deep eutectic solvents: a critical review

Kuldeep Singh, Sanjay Mehra and Arvind Kumar\*



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Fundamental questions  
Elemental answers

## CRITICAL REVIEWS

1092

## Protic ionic liquids for sustainable uses

Josh Bailey, Emily L. Byrne, Peter Goodrich,  
Paul Kavanagh and Małgorzata Swadźba-Kwaśny\*

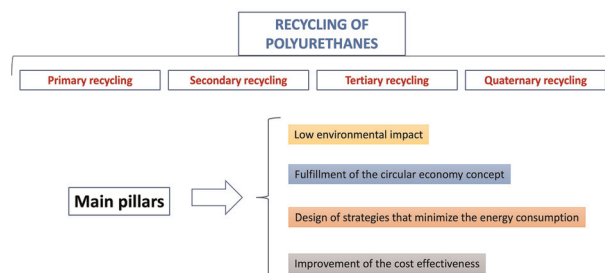


## TUTORIAL REVIEWS

1132

## Recycling of polyurethanes: where we are and where we are going

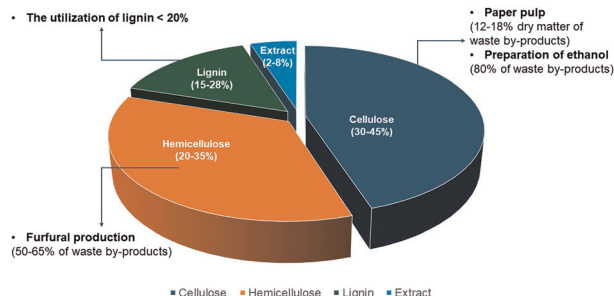
Gabriele Rossignolo, Giulio Malucelli\* and  
Alessandra Lorenzetti



1153

## Advancements and applications of microwave-assisted deep eutectic solvent (MW-DES) lignin extraction: a comprehensive review

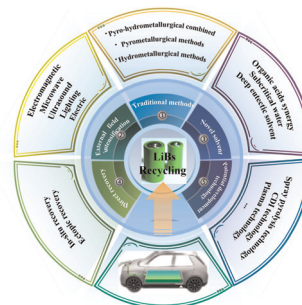
Rongge Zou, Xu Zhou, Moriko Qian, Chenxi Wang,  
Dorin Boldor, Hanwu Lei\* and Xiao Zhang\*



1170

## A systematic review of efficient recycling for the cathode materials of spent lithium-ion batteries: process intensification technologies beyond traditional methods

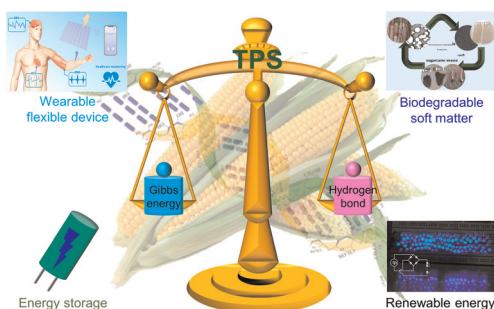
Lijuan Men, Shuyao Feng, Jiafeng Zhang,\* Xubiao Luo\*  
and Yefeng Zhou\*





## TUTORIAL REVIEWS

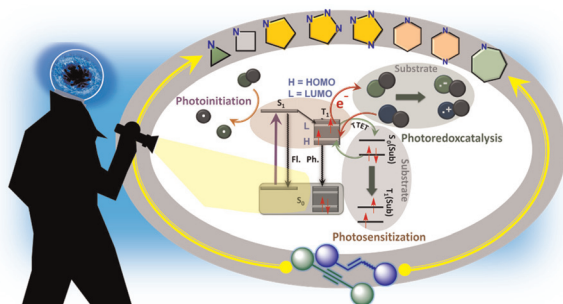
1194



### The green manufacturing of thermoplastic starch for low-carbon and sustainable energy applications: a review on its progress

Wanjie Si and Shuidong Zhang\*

1223

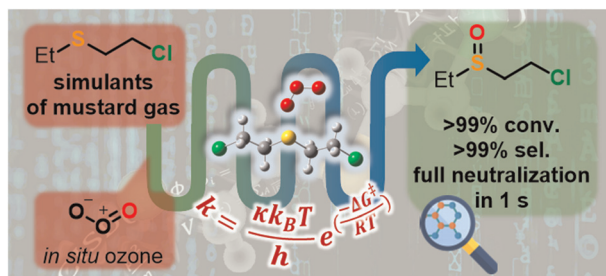


### Photocatalysis as a green alternative toolkit for the construction of nitrogen-enriched heterocycles via the direct and indirect activation of alkynes/alkenes

Anupam Das, Siddan Gouthaman and K. R. Justin Thomas\*

## COMMUNICATIONS

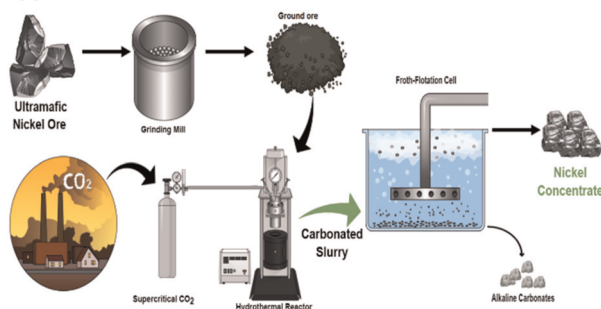
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### A miniaturized ozonolysis flow platform for expeditious sulfur mustard warfare simulant neutralization

Maxime Boddaert, Pauline Bianchi, Diana V. Silva-Brenes, Ancuta Musina, Marc Winter, Philippe M. C. Roth, Pierre-Yves Renard, Julien Legros\* and Jean-Christophe M. Monbaliu\*

1289



### CO<sub>2</sub> sequestration in ultramafic ores: impacts on the efficiency of nickel beneficiation

Shaihz Khan,\* Mohammad Shoaib, Lindsey K. Fiddes, Omar Wani and Erin R. Bobicki\*



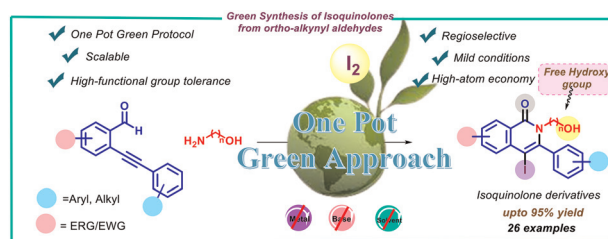


## COMMUNICATIONS

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# An environmentally benign and atom-economical protocol for the regioselective synthesis of isoquinolones from *o*-alkynylaldehydes

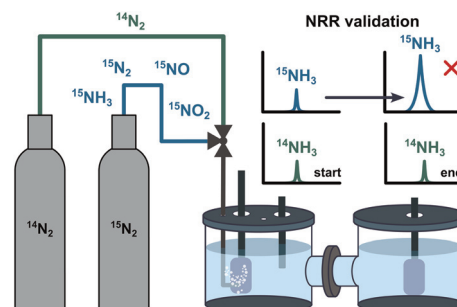
Muskan and Akhilesh K. Verma\*



1302

# Beyond acceptable limits: intrinsic contamination in commercial $^{15}\text{N}_2$ impedes reliable $\text{N}_2$ reduction experiments

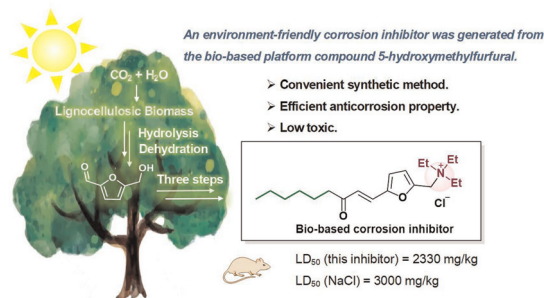
Michiel De Ras, Lander Hollevoet, Johan. A. Martens, Tianxi Liu, Bart M. Nicolai, Maarten L. A. T. M. Hertog, Johan Hofkens and Maarten B. J. Roefsaers\*



1306

# Upgrading of the biomass-derived platform compound 5-hydroxymethylfurfural to high-value chemicals: an environment-friendly corrosion inhibitor

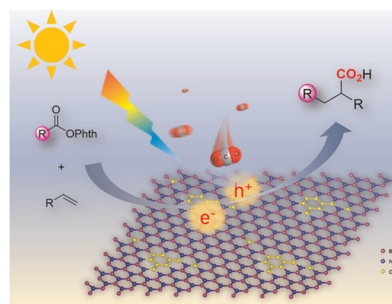
Wenying Ai,\* Kexin Liu, Zhenfeng Cao, Jiawei Zou, Ping Li, Siwen Cui, Haiyan Yang, Yu Yang, Jian Cao\* and Mingli Jiao\*



1317

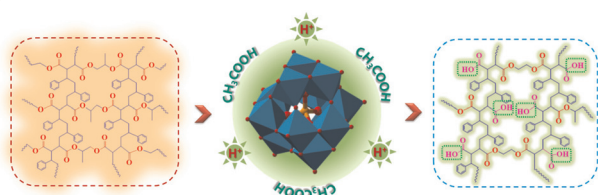
# Metal-free semiconductors for visible-light-induced carbocarboxylation of styrenes with aliphatic redox-active esters and $\text{CO}_2$

Hao Hou, Meizhen Luo, Senmao Zhai, Tao Yuan, Meifang Zheng\* and Sibao Wang\*



## COMMUNICATIONS

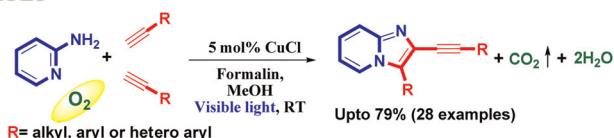
1322



### Catalytic degradation of a thermosetting unsaturated polyester via a green coupled acid catalytic system

Li-Juan Liu, Xiong-Lei Wang,\* Yong-Zheng Liu, Jia-Yu Yang, Zhan-Yong Gu and Tao Chang\*

1329

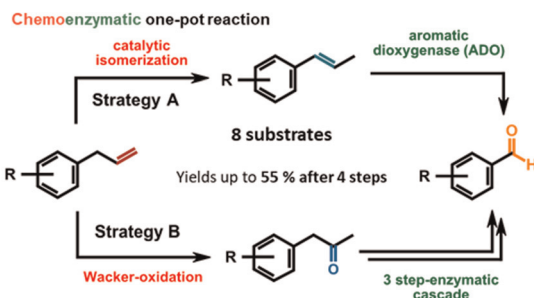


1. Simple, inexpensive CuCl as catalyst and O<sub>2</sub> as oxidant
2. Mild reaction conditions (Green process)
3. Involves the formation of two C-N and one C-C bond at RT
4. Easy scale up to a gram scale
5. Low *E*-factor and high reaction mass efficiency (RME)

### Visible light-mediated copper catalyzed regioselective diamination of terminal alkynes at room temperature: a facile synthesis of substituted imidazo[1,2-α]pyridines

Vaibhav Pramod Charpe, Mahima Gupta and Kuo Chu Hwang\*

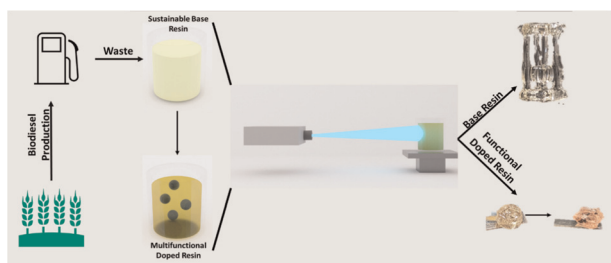
1338



### Nature stays natural: two novel chemo-enzymatic one-pot cascades for the synthesis of fragrance and flavor aldehydes

Stefan Giparakis, Margit Winkler and Florian Rudroff\*

1345



### Glycerol-based sustainably sourced resin for volumetric printing

Eduards Krumins, Joachim C. Lentz, Ben Sutcliffe, Ali Sohaib, Philippa L. Jacob, Benedetta Brugnoli, Valentina Cuzzucoli Crucitti, Robert Cavanagh, Robert Owen, Cara Moloney, Laura Ruiz-Cantu, Iolanda Francolini, Steven M. Howdle, Maxim Shusteff, Felicity R. A. J. Rose, Ricky D. Wildman, Yinfeng He\* and Vincenzo Taresco\*

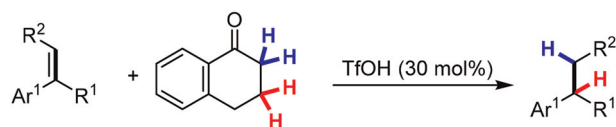


## COMMUNICATIONS

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**TfOH-catalyzed transfer hydrogenation reaction using 1-tetralone as a novel dihydrogen source**

Yishu Bao, Siyuan Ma, Jin Zhu, Zonghao Dai, Qikun Zhou, Xiuqin Yang, Qingfa Zhou\* and Fulai Yang\*

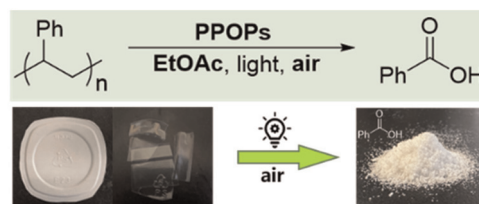


- ✓ **TfOH as catalyst**
- ✓ **1-Tetralone as a novel dihydrogen source**
- ✓ **1-Tetralone is cheap and commercial**
- ✓ **Hydrogen from different sites step by step**

1363

**Metal-free upcycling of plastic waste: photo-induced oxidative degradation of polystyrene in air**

Shuoyu Xu, Shuxin Liu, Wangze Song and Nan Zheng\*

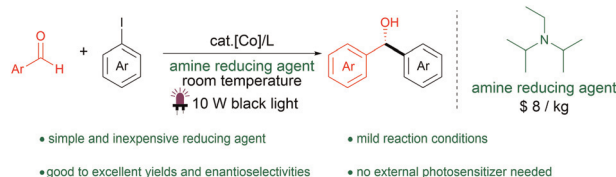


- **Low cost**
- **Mild reaction conditions**
- **High selectivity and yield**
- **Open air**
- **Green solvent**
- **Plastics to fine chemicals**

1370

**Light-driven asymmetric coupling of aromatic aldehydes and aryl iodides using a simple amine reductant**

Tongyu Han, Quansheng Mou, Yuyu Lv and Mingxin Liu\*



- simple and inexpensive reducing agent
- good to excellent yields and enantioselectivities
- mild reaction conditions
- no external photosensitizer needed

1375

**Visible-light-induced tandem ring opening/1,6-conjugate addition of cyclobutanols with *p*-quinone methides under metal- and additive-free conditions**

Tongyao Zhou, Jie Zeng, Yang Liu, Hang Chen, Haifeng Wang, Qiongjiao Yan, Wei Wang\* and Fener Chen\*



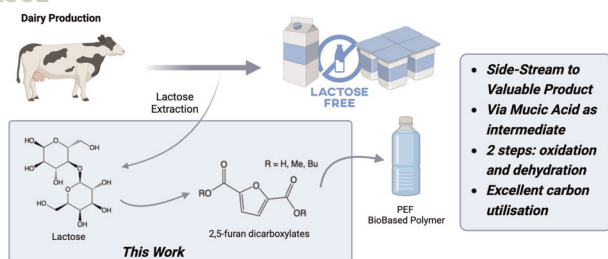
- ◆ **>35 examples, up to 96% yield**
- ◆ **metal- and additive-free**
- ◆ **simple operations and mild conditions**
- ◆ **environmentally benign**
- ◆ **Gram-scale synthesis**
- ◆ **broad substrate scope**





## COMMUNICATIONS

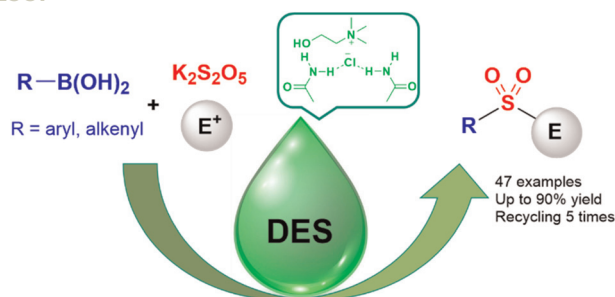
1381



### Lactose utilisation to furan carboxylates: a unique source for platform molecules

Joseph Install, Anže Zupanc, Mikko Nikunen, Janne Jänis and Timo Repo\*

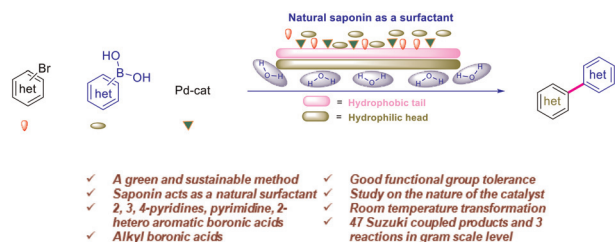
1387



### Deep eutectic solvents as sustainable media for multicomponent sulfonylation: an efficient strategy to synthesize (hetero)aryl sulfones

Haibo Zhu,\* Yangbo Zhong, Liyuan Yan, Honglei Zhang, Yajing Shen, Zhanggao Le, Qiangwen Fan\* and Zongbo Xie\*

1393

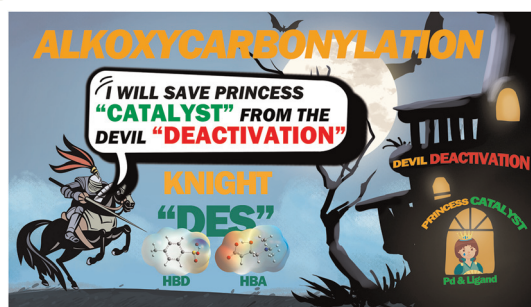


### Saponin: a green and efficient natural surfactant for Suzuki–Miyaura cross-couplings of heteroaryl substrates in aqueous media at ambient conditions

Vinothkumar Vinayagam,\* Subir Kumar Sadhukhan, Sreenivasa Reddy Kasu, Ravi Kumar Maroju, Tanguturi Venkatanarayana Hajay Kumar, Satish Kumar Karre and Dhurwasulu Baledi

## PAPERS

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### Rationally designed acidic deep eutectic solvent induced catalysis and spontaneous catalyst recycling of Pd-catalyzed ethylene alkoxy carbonylation

Jianhua Song, Xiaoping Wang, Lin Xu, Chonghao Chen and Dianhua Liu\*

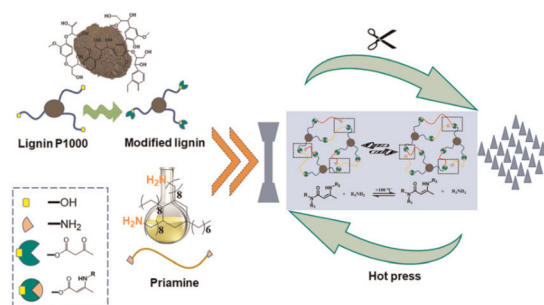


## PAPERS

1414

### Preparation of lignin-based vinyllogous urethane vitrimer materials and their potential use as on-demand removable adhesives

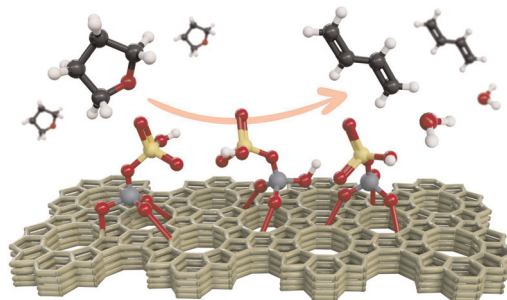
Jian Liu, Andrij Pich and Katrien V. Bernaerts\*



1430

### Sulfurous zeosils for dehydra-decyclization of tetrahydrofuran to renewable butadiene

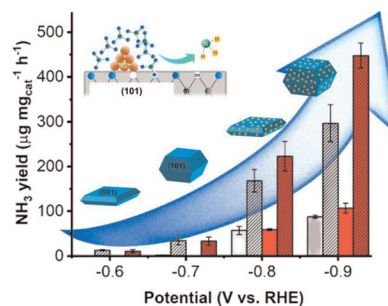
Raisa Carmen Andeme Ela, Jorge Barroso, Gaurav Kumar, Kaivalya Gawande, Sophie A. Brauer, Manish Shetty, Xinyu Li, Wei Fan, Bess Vlasisjevich\* and Paul J. Dauenhauer\*



1443

### Tailoring metal–support interaction over faceted TiO<sub>2</sub> and copper nanoparticles for electrocatalytic nitrate reduction to ammonia

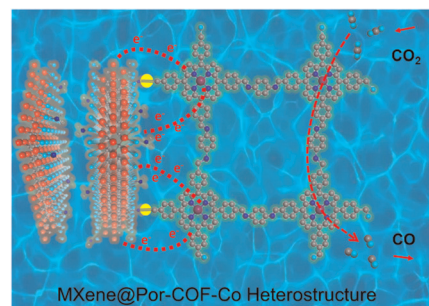
Wahyu Prasetyo Utomo, Hao Wu,\* Rui Liu and Yun Hau Ng\*



1454

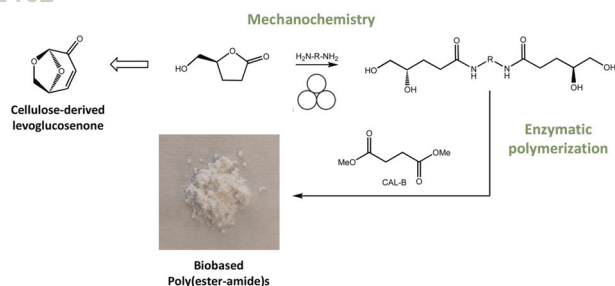
### Heterostructure construction of covalent organic frameworks/Ti<sub>3</sub>C<sub>2</sub>-MXene for high-efficiency electrocatalytic CO<sub>2</sub> reduction

Liyuan Zhou, Qingyong Tian,\* Xiaoqing Shang, Yanming Zhao, Weijing Yao, Hongpo Liu and Qun Xu\*



## PAPERS

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### Sustainable mechanosynthesis of diamide tetraols monomers and their enzymatic polymerization

Chloé Herrlé, Sami Fadlallah,\* Sylvestre Toumieux, Anne Wadouachi\* and Florent Allais\*

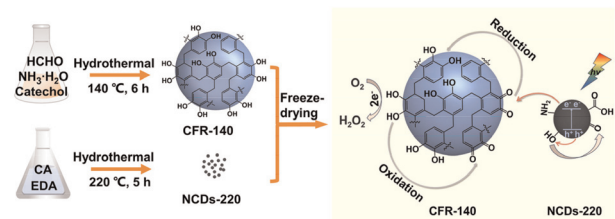
1471



### Cobalt nanoparticle-catalysed *N*-alkylation of amides with alcohols

Rui Ma, Jie Gao, Lan Zhang, Ning Wang, Yue Hu, Stephan Bartling, Henrik Lund, Sebastian Wohlrab,\* Rajenahally V. Jagadeesh\* and Matthias Beller\*

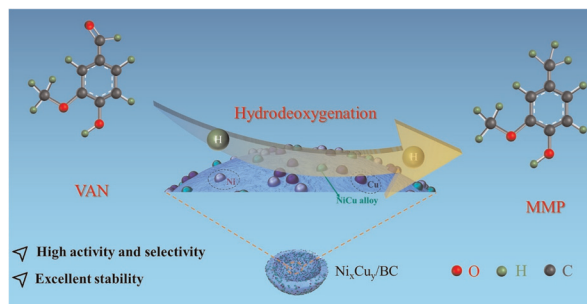
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### Sustainable photocatalytic synthesis of hydrogen peroxide from catechol-formaldehyde resin microspheres modulated by nitrogen-doped carbon dots

Yuxin Xiang, Zhinan Xia, Wanchao Hu, Cuiyan Tong\* and Changli Lü\*

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### Environmentally-friendly preparation of natural hollow carbon spheres derived from a biomass puffball for *in situ* upgrading of lignin-derived vanillin

Changzhou Chen,\* Xialin Ji, Yongzhi Xiong and Jianchun Jiang\*



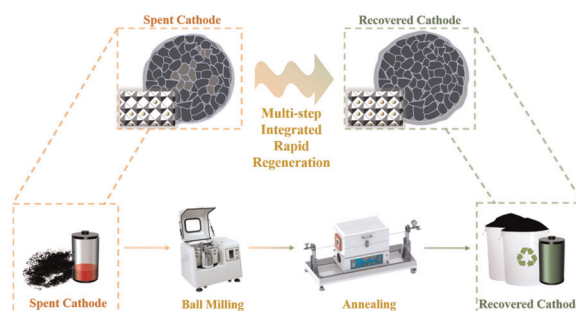


## PAPERS

1501

### Driving the rapid regeneration of $\text{LiFePO}_4$ from spent lithium-ion batteries through one-pot mechanochemical activation

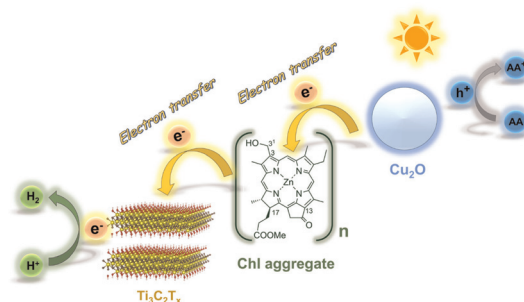
Chenyan Wang, Xuejing Qiu, Gaoyang Shen, Xizhuo Chen, Jiamei Wang, Lingling Xie, Qing Han, Limin Zhu,\* Jingjing Li\* and Xiaoyu Cao\*



1511

### Efficient photocatalytic hydrogen production by organic–inorganic heterojunction structure in $\text{Chl@Cu}_2\text{O}/\text{Ti}_3\text{C}_2\text{T}_x$

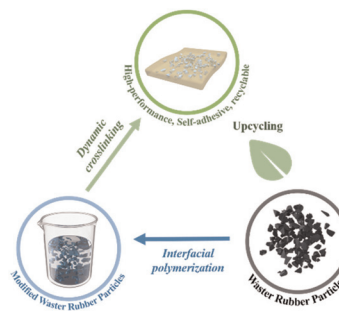
Yuanlin Li, Yanxiang Liu, Tianfang Zheng, Aijun Li, Georgiy G. Levchenko, Wei Han,\* Aleksey V. Pashchenko, Shin-ichi Sasaki, Hitoshi Tamiaki and Xiao-Feng Wang\*



1523

### High performance, self-adhesive and recyclable dynamic crosslinked waste rubber particle blends toward upcycling of waste rubber

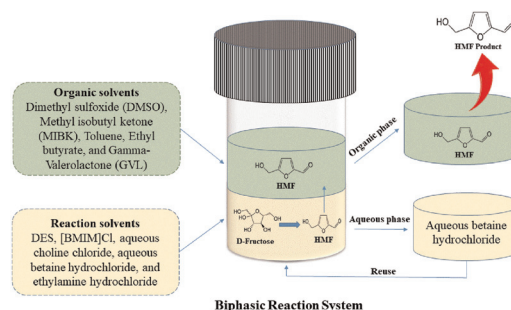
Lingmin Kong, Rui Wu, Junqi Zhang, Shaoqi Huang, Zhengtian Xie\* and Jinrong Wu\*



1533

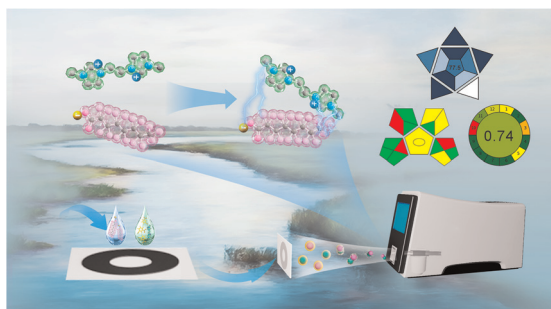
### Production of 5-hydroxymethylfurfural from fructose via inherent catalytic properties of a biphasic system without external catalyst addition

Quang Tam Huynh, Alexander F. Padilla, Jr., Mark Daniel G. de Luna, Po-Jung Huang, Pei-Shih Chen, Nor Aishah Saidina Amin, Ku-Fan Chen and Ken-Lin Chang\*



## PAPERS

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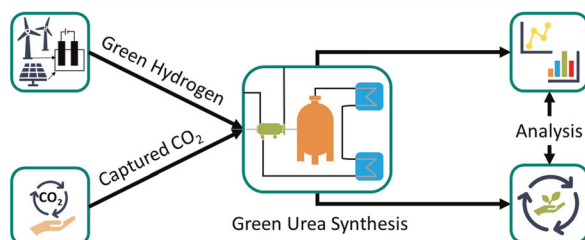


### Enhancing sensitivity in miniature mass spectrometry analysis via dicationic ionic liquid-based matrix-assisted ionization and charge inversion reactions

Xiangyu Guo, Yuncheng Ge, Hua Bai and Qiang Ma\*

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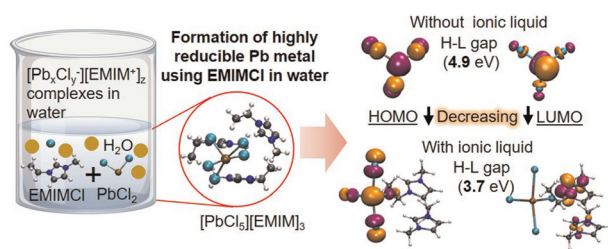
### PROCESS DESIGN, SIMULATION, AND SUSTAINABILITY ANALYSIS OF GREEN UREA SYNTHESIS



### Towards a low-carbon future: exploring green urea synthesis for sustainable agriculture

Ansub Khan, Abiha Abbas and Rofice Dickson\*

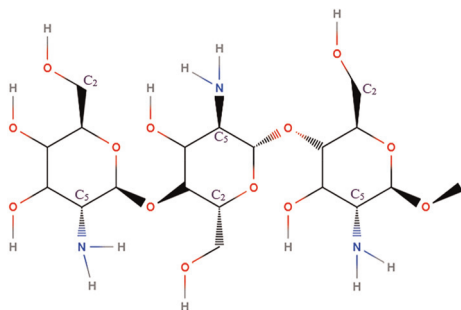
1566



### Complexation of heavy metal cations with imidazolium ionic liquids lowers their reduction energy: implications for electrochemical separations

Shuai Tan, Difan Zhang, Ying Chen, Benjamin A. Helfrecht, Eric T. Baxter, Wenjin Cao, Xue-Bin Wang, Manh-Thuong Nguyen,\* Grant E. Johnson\* and Venkateshkumar Prabhakaran\*

1577



### Screening of ionic liquids for the dissolution of chitosan using COSMO-RS

Shue Yee Mok, Magaret Sivapragasam,\* Maisara Shahrom Raja Shahrom, Mohammad Azmi Bustam @ Khalil and Zurina Zainal Abidin

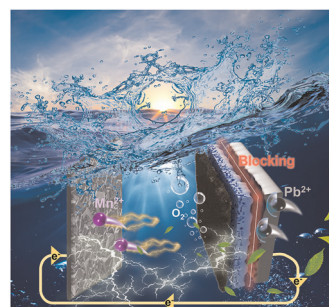


## PAPERS

1587

### Asymmetric structural tuning of industrial MnO<sub>2</sub> arrays on a hierarchical lead-based anode for manganese metallurgy

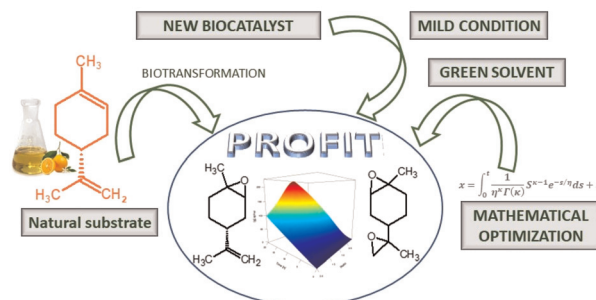
Binyuan Tang, Fan Yang,\* Chaoyi Chen, Changping Shi, Bo Wang, Junqi Li and Dongdong Zhang\*



1598

### Modelling of green biocatalytic (R)-(+)-limonene oxidation using the mycelium of psychrophilic *Cladosporium cladosporioides* 01

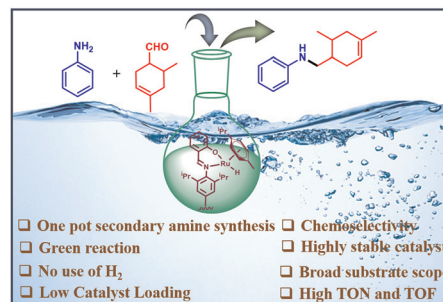
Mateusz Kutyla, Edward Kozłowski, Marek Stankevič, Agnieszka Świca and Mariusz Trytek\*



1610

### A highly active and chemoselective homobimetallic ruthenium catalyst for one-pot reductive amination in water

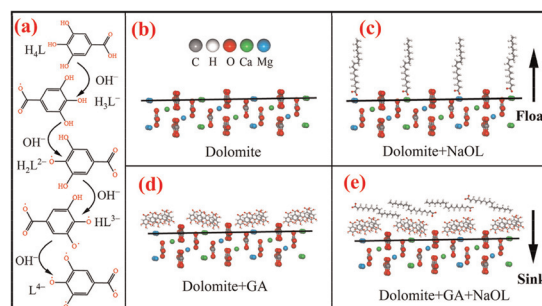
Gopal Deshmukh, Thakur Rochak Kumar Rana, Nikita Yadav, Gopalan Rajaraman\* and Ramaswamy Murugavel\*



1627

### Effective flotation separation of apatite from dolomite using a new eco-friendly depressant gallic acid

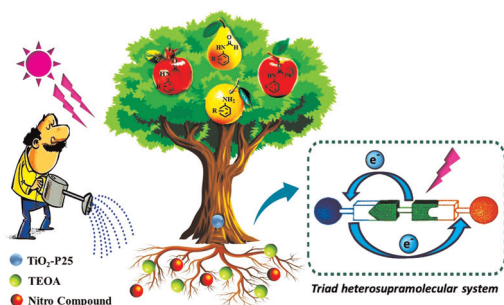
Shengzong Lan, Peilun Shen, Qifang Zheng, Lidong Qiao, Liuyang Dong\* and Dianwen Liu\*





## PAPERS

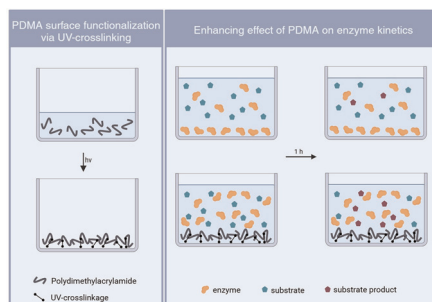
1637



### Highly chemoselective and fast practical visible photoreduction of nitroaromatic compounds to aromatic amines and amides using a self-assembled triad $\text{TiO}_2\text{-TEOA-NC}$ (LMCT/EDA) complex system

Mahshid Bagheri Natanzi, Foad Kazemi,\* Zahra Zand and Babak Kaboudin

1653



### Toward more sustainable enzyme reactions: enhancing kinetics by polydimethylacrylamide implementation

Simone Rentschler, Max Borgolte, René Csuk, Stefan Laufer and Hans-Peter Deigner\*

## CORRECTION

1660

### Correction: Alkyl radicals from diacyl peroxides: metal-/base-/additive-free photocatalytic alkylation of N-heteroaromatics

Fukun Cheng, Lulu Fan,\* Qiyan Lv, Xiaolan Chen\* and Bing Yu\*

