Engineering 21 (2023) 1–2

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Editorial

Advanced Batteries, Solar Cells, and Fuel Cells: Innovations in Materials and Technologies Will Power the Future

Hailing Tu [a,b], Suping Peng [c]

[a] General Research Institute for Nonferrous Metals, Beijing 100088, China
[b] Key Laboratory of Advanced Materials for Smart Sensing, GRINM Group Co., Ltd., Beijing 100088, China
[c] Research Center of Solid Oxide Fuel Cells, State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology-Beijing, Beijing 100083, China

Hailing Tu

Suping Peng

Thus far, the 21st century has witnessed steady growth in China's renewable energy capacity, especially in recent years, amid the country's efforts to achieve a peak in carbon dioxide emissions and carbon neutrality. As of the end of June 2022, for example, China's accumulative installed solar energy has risen to around 336 GW. However, reaching net-zero emissions globally is a critical and formidable goal [1], and energy structure transformation is still one of the unprecedented challenges humanity will face over the coming decades. Currently, the development of energy conversion and storage technologies is at the forefront of engineering applications geared toward a sustainable, low-carbon world. To achieve a clean, inexpensive, and abundant energy supply, we must constantly innovate and develop superior energy conversion and storage technologies capable of higher charge capacities, specific energies, and efficiencies. Advanced batteries, solar cells, and fuel cells (FCs) are the most exciting innovation areas in the energy sector, with diversified new structures, materials, and technologies. Despite the many scientific and technological breakthroughs on the horizon, numerous fundamental and engineering challenges remain to be resolved for the widespread use of these battery and cell technologies, including safety, cost, manufacturing, performance, and durability.

In this issue, we present nine contributions from world-leading professors, engineers, and entrepreneurs, in which they share their thoughts and visions on advanced batteries, solar cells, and FCs. When Thomas Edison invented the nickel–iron reversible galvanic battery around 120 years ago, he encouraged other researchers by saying, "There is a way to do it better. Find it." After 50 years of struggle, the Nobel Prize in Chemistry in 2019 was awarded for the development of lithium-ion batteries (LIBs), which lay the foundation for an information-based, fossil-fuel-free society and are likely to revolutionize our lives. Advanced batteries are also an integral component of sustainable energy, as they can efficiently store and release intermittent renewable energy on demand.

Nevertheless, this is far from the end of the story. The rapid development of LIB technology and the continuous expansion of the market have put great pressure on battery safety. In their article, Liquan Chen et al.—the pioneers of LIBs in China—comment on current strategies to improve LIB safety and the new opportunity for designing batteries that are intrinsically safe at the material, device, and system levels. In addition, it is the right time for LIB researchers to consider second-life LIBs and their echelon utilization [2].

Solid-state batteries (SSBs) using solid-state electrolytes (SSEs) have drawn considerable interest and are considered to be the next-generation secondary battery technology due to their intrinsic safety and high energy density. In this issue, Xueliang Sun et al. introduce the latest progress in SSEs, recap related interfacial issues, and suggest several perspectives for future study to further improve SSEs. Beyond traditional LIBs, an advanced battery system based on a multi-electron reaction mechanism may be the most effective solution to meet the growing demand for high specific energy secondary batteries. Feng Wu et al.—who are also advanced battery pioneers in China—report on the key technologies of, implementation strategies for, and future development of the new multi-electron battery system.

Recent studies on magnesium secondary batteries have revealed a promising strategy to increase the energy density in order to transition from monovalent to multivalent batteries, and several research groups have made significant progress in this area

https://doi.org/10.1016/j.eng.2022.12.003

[3,4]. This development trend and the huge opportunity for sodium-ion batteries (SIBs) are now hot topics. SIBs are naturally an alternative approach to lithium battery technology, particularly at a time when lithium resources are in short supply and lithium is becoming extremely expensive. Moreover, according to Chuying Ouyang—the chief technology officer (CTO) of Contemporary Amperex Technology Limited (CATL)—and coworkers, SIBs exhibit a much longer use span and higher energy density than LIBs and could provide more room for future concepts of vehicle intelligence. To date, large-scale energy storage has become the major bottleneck for the promotion and application of renewable energies. Vanadium flow batteries, which have been developed in China for a decade, are well suited for grid energy storage and have been garnering much attention. Xianfeng Li and coworkers, who have many years of experience in this field, share their views on the trends in flow batteries in terms of energy density, cost, safety, and environmental issues. Reducing the cost of flow batteries is the right development direction, and comprehensive technological breakthroughs for energy storage are widely needed. It is noteworthy that an iron flow battery has recently been proposed for low-cost energy storage devices [5,6].

Solar power plays a key role in achieving the carbon neutrality goal, and the new global installed solar photovoltaic (PV) capacity has grown at a compound annual growth rate of approximately 40%, far outpacing other clean energy sources such as natural gas and wind. The strong growth momentum of the PV industry comes from its rapidly decreasing levelized cost of electricity (LCOE) due to technological improvements and large-scale applications. The lowest price of electricity produced from large-scale PV plants around the world has been reduced to 1.04×10^{-2} USD·(kW·h)$^{-1}$, and the Chinese government announced in 2021 that PV power generation would be the biggest power source in 20–30 years, making up approximately 40% of the total power generation. In his article, Zhenguo Li, a successful entrepreneur and the chief executive officer (CEO) of Longji Shares, outlines the technological improvements that boost the expansion of the PV industry, anticipates the evolution of high-efficiency PV cells in the future, and emphasizes feasible routes for the intensive participation of PVs in the energy-structure transformation.

In many aspects, perovskite solar cells (PSCs) are revolutionary energy devices to most PV engineers, and PSCs have drawn increasing attention from the PV industry community due to their potential advantages of low cost, high efficiency, and a wide range of applications. Wei Huang—the world's leading scientist in this field—and coworkers discuss promising development opportunities and application scenarios of perovskite-based tandem cells, which could be a desirable candidate and potential competitor in the future PV market. It is encouraging to see that a great deal of progress has been made each year in all kinds of solar cells.

FCs are efficient and clean devices that electrochemically convert the chemical energy of fuels such as hydrogen, natural gas, methanol, ethanol, and hydrocarbons into electricity, with high efficiency and relatively low greenhouse gas emissions. They can provide power for applications across multiple sectors, including transportation, industrial/commercial buildings, and urban systems. In current FC technology, cost, catalyzer, performance, and durability issues remain major challenges. Here, Suping Peng describes the present status of domestic and global proton-exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC) development and report on existing problems in this field in China. They also summarize the key tasks in PEMFC and SOFC supply-chain management and provide an outlook on safeguard measures and policy recommendations, which will be beneficial for fostering the large-scale commercial development of FCs. Importantly, Suping Peng's team has explored integrated gasification fuel cells (IGFCs), which can further increase the efficiency of coal gasification power generation and simultaneously achieve near-zero emissions of CO_2 and pollutants. Improving the quality of FCs is a common goal of FC engineers across the world; a research team from the Massachusetts Institute of Technology (MIT) Material Research Center has significantly increased the lifetime of SOFCs by coating the fuel/electrolysis cell cathode with lithium oxide, which changes the relative acidity of the surface [7].

Finally, Kevin Kendall et al. overview opportunities and challenging issues in the use of hydrogen FCs to replace internal combustion engines for heavy-duty vehicles, and predict a global surge in hydrogen FC battery electric vehicles by 2030. In fact, a fleet of hydrogen-powered heavy-duty trucks has been introduced in the Tangshan Haigang Economic Development Zone in northern China to optimize the industrial structure. It is also worth noting that microbial FCs have attracted many scientists' attention in recent years, since they can convert wet organic waste directly into electricity through the metabolism of the constituent microorganisms [8].

The goal of reaching net-zero carbon emissions worldwide introduces higher requirements for energy conversion and storage technology. We trust that these commentary articles related to emerging and disruptive technologies in this area can offer profound insights to readers in the fields of advanced batteries, solar cells, and FCs, and can encourage more scientists and researchers to contribute to shaping the future of new energy sources and creating a greener and more sustainable world.

References

[1] International Energy Agency (IEA). World energy outlook 2021—part of world energy outlook. Report. Paris: IEA; 2021.

[2] Fan E, Li L, Wang Z, Lin J, Huang Y, Yao Y, et al. Sustainable recycling technology for Li-ion batteries and beyond: challenges and future prospects. Chem Rev 2020;120(14):7020–63.

[3] Dong H, Tutusaus O, Liang YL, Zhang Y, Lebens-Higgins Z, Yang WL, et al. High-power Mg batteries enabled by heterogeneous enolization redox chemistry and weakly coordinating electrolytes. Nat Energy 2020;5(12):1043–50.

[4] Li D, Yuan Y, Liu J, Fichtner M, Pan F. A review on current anode materials for rechargeable Mg batteries. J Magn Alloy 2020;8(4):963–79.

[5] Yang M, Xu Z, Xiang W, Xu H, Ding M, Li L, et al. High performance and long cycle life neutral zinc–iron flow batteries enabled by zinc-bromide complexation. Energy Storage Mater 2022;44:433–40.

[6] Gong K, Ma X, Conforti KM, Kuttler KJ, Grunewald JB, Yeager KL, et al. A zinc–iron redox-flow battery under $100 per kW·h of system capital cost. Energy Environ Sci 2015;8(10):2941–5.

[7] Seo HG, Staerz A, Kim DS, Klotz D, Nicollet C, Xu M, et al. Reactivation of chromia poisoned oxygen exchange kinetics in mixed conducting solid oxide fuel cell electrodes by serial infiltration of lithia. Energy Environ Sci 2022;15(10):4038–47.

[8] Cao B, Zhao Z, Peng L, Shiu HY, Ding M, Song F, et al. Silver nanoparticles boost charge-extraction efficiency in *Shewanella* microbial fuel cells. Science 2021;373(6561):1336–40.