Charting a sustainable course for batteries

A panel of leading global experts working at the forefront of battery research and applications shares insights into how further development of this critical energy technology can effectively integrate sustainability principles.

Back in May 2021, *Nature Sustainability* announced[1] an international Expert Panel on the sustainability of batteries. This is the first Expert Panel with a focus on technology that we have convened, and we are now pleased to present the main outcome to our readers. Despite the disruption caused by the COVID-19 pandemic, the 23 experts who first met in April 2021 have now finalized their work and present a report[2] that we hope will stimulate further thinking and new research collaborations, both among and beyond the panellists who authored the report.

Batteries are a promising tool to transition society from its current reliance on fossil fuels towards a more sustainable power supply. Rechargeable lithium-ion batteries have played a fundamental role in revolutionizing portable electronics, and are expected to be critical in the decarbonization of transport, that is, by enabling battery-powered electric vehicles. Given current projections, the exponential market growth for batteries due to electric vehicle uptake will lead to a substantial sustainability problem. Looking at the batteries' life cycle, challenges will emerge because the raw materials that are required for the current battery chemistry are scarce and rarely sourced sustainably, but also because current battery manufacturing and end-of-life disposal practices are far from sustainable. Against this backdrop, our panellists, led by four co-chairs from the fields of battery science and systems analysis as well as from industry, exchanged fresh ideas and competitive knowledge with the aim of defining a path towards greening batteries. The dialogue was intense but fruitful, thanks to the diversity of the backgrounds and experiences of the panellists: over the course of the initial workshop last year, the panellists reviewed research progress so far, identified the outstanding sustainability challenges for batteries, and formulated a way forward in terms of technology innovation and industrial implementation.

One essential message stemming from the report is that the challenges of increasing the sustainability of lithium-ion batteries span their entire life cycle: from availability and processing of raw materials, to battery design and manufacturing, to device application and to end-of-life management. This means that progress cannot be achieved by simply addressing the sustainability challenges of lithium-ion batteries in the specific phases of their life cycle separately; instead, a holistic and systems approach must be embraced to develop feasible and truly sustainable solutions. This message is at the centre of a Comment by the panellists published in this issue of *Nature Sustainability*. The Comment is also part of a collection titled 'A sustainable future for batteries', which includes a Review Article and three research articles with accompanying News & Views articles — the collection highlights the latest research progress on emerging battery chemistry and cathode materials with alternative metals as well as the role of sensing techniques to monitor battery health for extended lifespan.

Going back to the Expert Panel, their view is that batteries are sustainable only if each single component in the whole process chain is designed and manufactured in line with the principles of sustainability and if the resources and materials used and the device configuration are chosen by taking into account the end-of-life phase of the process chain. Accordingly, environmental, economic and social sustainability considerations should be integrated into the life cycle of batteries, with increasing efforts directed towards strengthening innovation capabilities and filling the technological gaps related to earth-abundant materials, green processing, eco-friendly battery chemistry, key performance metrics, safety, recycling and repurposing.

The panel experts have further established a blueprint for the future development of batteries under the sustainable product policy. All of their considerations and recommendations are laid out in the independent report[2]. Batteries that are designed to move away from needing rare elements, such as lithium and cobalt, towards those that use more abundant elements form an important research direction. Also, chemists are researching ways to extract lithium from seawater to address the long-term lithium supply crisis, particularly for regions without access to lithium reserves. Sodium-ion batteries are heralded as one of the potential alternatives to lithium-ion batteries and the first-generation sodium-ion batteries have recently hit the market thanks to pioneering manufacturing techniques. Zinc batteries are another main contender for large-scale energy-storage applications, with benefits in terms of cost, safety, capacity and chemical stability as well as environmental compliance, thus they have the potential to satisfy key sustainability and performance requirements. The recycling of batteries at the end of their life is probably the weakest node in a sustainability loop. The dominant recycling methods, pyrometallurgy, hydrometallurgy or combined pyro- and hydrometallurgy, are energy intensive or require toxic chemicals. This calls for revolutionary recycling technologies that require minimal water and electricity input and prevent the release of polluting gases and waste residues.

Although there is still a long way to go before the green ambitions for batteries are fulfilled, we hope that thinking about their design, production, service and management under the umbrella of sustainability — with a holistic view throughout the entire battery value chain — will inspire our readers to engage in further debates and collaborations to accelerate the research and development of batteries that are sustainable, high performing, economical and safe. ❐

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References

1. *Nat. Sustain.* **4**, 373 (2021).
2. Huang, Y. H. et al. *Advancing Sustainability of Batteries: Report of the International Expert Panel on Sustainable Batteries* (Tongji University, Springer Nature, 2022); https://go.nature.com/36wEsHe