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Electronics can be more sustainable

Integrated design assisted by materials and technology innovations can help a transition from traditional to sustainable electronics.

Electronic devices are increasingly prevalent in our modern life, leading to unprecedented challenges to handle the ever-growing amount of electronic waste (e-waste). More than 50 million tons of e-waste is generated globally every year, and it is projected to reach 74 million tons in 2030[1]. e-waste contains toxic metals or chemicals, which are not biodegradable and can accumulate in the environment over a long time, leading to harmful consequences. To address this challenge of e-waste, considerations are needed about how to reduce or recycle e-waste at the end of a product's life. But, more importantly, these considerations should be thought of at the design stage, such as strategies to evaluate environmental impact, choosing biodegradable or earth-abundant materials to replace rare metals or hazardous chemicals, or utilizing advanced manufacturing technologies to make smaller and shape-adjustable components suitable for reuse and recycling. There are many opportunities to facilitate a transition from traditional to sustainable electronics in the long value chain of an electronic product.

In this issue of *Nature Materials*, we bring together two Perspective articles and a Q&A in a Focus on the current challenges and opportunities for sustainable electronics. The pieces discuss early design strategies, innovations in materials choice, synthesis or manufacturing technologies, and recycling strategies to help integrate sustainability considerations into every part of the life cycle of electronic products.

Traditional electronics use metals or metal oxides that are hard to recycle, and require energy-consuming fabrication processes. Natural materials, such as cellulose or textiles, would be a better choice. Through innovative fabrication and advanced technologies, such as additive manufacturing or printing technologies, these natural materials can be made into flexible devices that consume less energy and avoid harmful chemical usage. In their Perspective article, Shery Huang and colleagues propose a 4R (which stands for repair, recycle, replacement and reduction) design strategy for sustainable electronic textiles (e-textiles). They suggest biomass-based and earth-abundant materials that are low cost, biocompatible and environmentally friendly as the raw materials to fabricate e-textiles. In particular, they highlight delocalized production, taking advantage of additive manufacturing or 3D printing technologies to make smaller, easily assembled components and customizable shapes. The resulting e-textiles can be disassembled into their components, which are convenient to be repaired, recycled or replaced for scaled-up production, thus facilitating a sustainable circle. With a view towards possible commercialization, the authors highlight efforts to standardize processes for cross-compatibility, automated assembly, and shared databases among designers, manufacturers and users.

A pile of e-waste waiting to be recycled.

Although a holistic design strategy for a sustainable electronics device in the early stages of development cannot be overemphasized, it is also crucial to make a balanced and integrated assessment to avoid trade-offs between multiple factors. In their Perspective article on organic electronic products, Iain McCulloch and colleagues discuss the carbon footprint of organic electronics, options for sustainable materials and manufacturing processes, and end-of-life treatments. They highlight a cradle-to-cradle approach to emphasize the importance of integrated design towards a closed-loop product lifecycle. A viable design strategy for organic electronics should not only consider materials scarcity and toxicity, but also the complex synthesis processes that may contain multiple purification steps along with their associated environmental impacts. Moreover, such a strategy should also consider device performance and possible recycling solutions at the end of life of the product. However, recycling can be challenging in terms of the fast evolution of the relevant technologies. For example, recycling fullerenes from an organic solar cell product that was fabricated ten years ago provides no value for the current generation of organic solar cells because they do not use fullerenes, but they may be attractive for ultraviolet photodetectors. Hence, readapting recycled materials for new technologies should be carefully considered.

It is clear that there are both challenges and opportunities, and it is also clear that scientific advances in materials, synthesis, fabrication and manufacturing technologies are key to bringing sustainable electronics forward. In a Q&A, Xiaodong Chen, an expert on flexible electronics, shares his views on sustainable electronics. He highlights sustainable strategies such as using engineered nanomaterials to enable improved flexibility and compatibility, transient electronics using biomaterials in implantable biomedical devices and the use of artificial intelligence in manufacturing. Moreover, he notes the importance of collaborations across organizations and even countries, such as the Singapore–CEA Alliance for Research in Circular Economy (SCARCE). There is no doubt that the future of sustainable electronics, or sustainable materials more generally, can only be assured by collaborative efforts. For young researchers, there are plenty of opportunities for a bright career ahead.

Traditional electronics is at a crossroad in the transition to a more sustainable form, not only as a result of the challenges arising from the growing amount of e-waste, but also the development of knowledge in materials and advanced manufacturing technologies. With more scientific innovations continuously integrated in this field, a more sustainable future for electronics is coming.

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