Electronic Design

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5 Ways to Improve the Sustainability of Electronics

New initiatives focused on electronics circularity are putting the pressure on manufacturers to create more sustainable flexible products. This article outlines five plans of attack.

By 2030, global electronic waste will reach 74 million metric tons, with only 20% collected or recycled properly (Forti et al 2020). Today, the electronics industry faces major challenges with availability of critical materials and increasing pressure to cut its environmental footprint and move toward circularity.

In March 2022, the European Commission published its Sustainable Products Initiative, which aims to ensure that all products placed on the EU market become more sustainable.

The European Commission also adopted the new circular economy action plan (CEAP) in March 2020. It's one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The EU's transition to a circular economy aims to reduce pressure on natural resources and create sustainable growth and jobs.

Because these initiatives ultimately cover and include the electronics industry, manufacturers are met with increasing pressure to meet new sustainability requirements in the years to come.

That's easier said than done—the major looming question is how to actualize these goals. Electronic waste is piling up, and numerous factors exacerbate the problem. Electronic waste is notoriously difficult to recycle because many tiny working parts and multitudes of different materials make it a challenge to separate. Product turnover and demand for new gadgets accelerates every year, so people replace their old phones and gadgets at unprecedented rates.

In addition, mandatory device registration makes it difficult to pass used devices on to a second-hand life. As a result, many products wind up in landfills or office drawers well before their time. Due to rapid production rates and high demand, it's also increasingly difficult to access the necessary raw materials to build new products, and the list goes on.

The fact that these problems exist is widely discussed, but how can the industry realistically tackle a problem with so many nuanced angles? In January 2019, we established the ECOtronics project at VTT Technical Research Centre of Finland in collaboration with national universities and industry partners, and we set out to find concrete answers to the challenges at hand.

Over the course of the next two years, we conducted experiments and trials to determine how electronics can have a more sustainable future. The work continues in the KDT JU Sustronics project, an EU-wide three-year initiative with 46 partners that started in June 2023.

Known as the country that pioneered and popularized personal mobile phones in the 1990s, Finland is a considerable technology development hub that has made its mark on the world. Coupled with a strong nature connection, sustainability-minded thinking and innovation is widespread in Finland. It's with this backdrop that VTT has set out to tackle the e-waste issue.

We began with the goal of setting a new standard for sustainability in the electronics industry and answering one key question: How can we increase circularity and sustainability at every stage of the electronics life cycle?

The ECOtronics project ultimately found that the industry needs to improve upon five main areas to achieve more sustainability in flexible electronics. These include designing for circularity, using more sustainable raw materials, creating more efficient manufacturing techniques, and designing for sustainability for both the use and end-of-life phases. Our focus in the project was to study these aspects in connection with flexible electronic products.

1. Design with circularity in mind

On average, the global consumption of electrical and electronics products increases by 2.5 million metric tons of total weight each year (Forti et al., 2020). Electronic products need to be designed so that the aforementioned EU environmental targets are incorporated at every phase of their lifecycle. This means designing with sustainability in mind from the ground up, and for each component. Holistic and streamlined sustainability assessment should support the design phase to achieve those goals.

One major blockage to circular design is planned obsolescence, which has become a major obstacle in the circularity and lifespan of electronics (Elia et al., 2017; Guiltinan, 2009). Products are thrown away and replaced unnecessarily quickly because they're designed to stop working early. That said, rethinking business models is increasingly important in the transition to a circular economy. Currently, many business models are product-based, but to shift into a more sustainable electronics industry, we need to see the focus change from products to service-based models (Bocken et al., 2019).

One of the major challenges to recycling current electronics is that they're often composed of various components and materials in small quantities. Components consisting of monomaterials are ideal for any recycling and recovery process.

We found that new products could be designed in a modular way so that they can effectively be separated for reuse or for remanufacturing. This potentially lengthens the lifecycle of components and materials, but it can also help to alleviate raw material shortages by enabling access to secondary raw materials. However, process development for more efficient material recycling and recovery is needed as well.

One example is the modular and biodegradable ECG patch, which we pioneered at VTT. Today, disposable single-use ECG sensor patches consist of skin-adhesive electrodes and embedded electronics, and they're based in plastic materials. The new nanocellulose ECG patch that we developed is made of a recyclable and biodegradable nanocellulose plastic alternative while the electronics are detachable. Therefore, they can easily be peeled off for reuse.

The objectives of ecodesign and circular design need to include energy efficiency, material efficiency, longer product lifecycles, upgradability, and the ease of recycling the materials.

2. **Sustainable choices of raw materials**

With global consumption of material resources expected to roughly double between 2017 and 2060 according to the OECD, the electronics industry needs to start using more and more raw materials that are based on renewable natural resources, such as replacement of fossil-based composite and plastic substrates with cellulose or bio-polymer based materials.

Assembling electronics inherently consumes energy, and if the raw materials are ultimately wasted, then the consumption goes up. One solution focuses on circular targets. This means using secondary raw materials instead of primary raw materials. Secondary materials have been used before and are recovered from waste and recycling.

An ultimate goal for the industry is that almost all electronic materials come from secondary sources. Keeping electronics modular also means that the parts with limited lifespans are easy to replace or dispose of.

As an example, in the ECOtronics project, VTT and collaborators investigated the replacement of commonly used plastics with bioplastics and successfully realized a smart label based on bioplastics and printed organic photovoltaic cells for energy harvesting and printed supercapacitors for energy storage. Use of new energy harvesting solutions improves energy efficiency of electronic products, and ultimately makes them energy autonomous.

In addition to substrate materials, metals are used in electrical leads, soldering materials, and components. For example, silver is a great material for electrical leads and is commonly used for printed electronics, but it has a high environmental impact. Silver is also becoming a scarce material and is scattered throughout the earth, so it requires many resources to be located and mined.

In some cases, silver can be replaced with more abundant and less valuable alternatives, such as copper or carbon-based materials. Silver dominates the environmental impact of any printed device, and the global warming potential decreases significantly, up to approximately 80%, by replacing it with copper—and even more so with carbon, as reported by LUT University and VTT (Nassajfar, 2023). However, their conductive properties aren't as good as silver and must be compensated through design.

Other examples of potential bio replacement materials could include cellulose and even silk. Cellulose can be used to make paper, which is superior to other deformable passive materials due to its low price, flexibility, and roll-to-roll (R2R) fabrication capability at a fast process speed of about 25 $m{\cdot}s^{-1}$ (Fuentes, 2021).

In addition, silk-derived carbon materials have good conductivity and can be easily formed into different structures and shapes. This natural material has a long history that's been applied in the dielectric layer and as an electronic device substrate (Barras, 2017).

3. Energy-efficient and material-efficient manufacturing techniques

One of our most significant findings showed that environmental impact could be reduced by 86% when additive printing methods are used to create flexible electronic components, as reported in detail by the Finnish LUT University.

Many traditional technologies used in the manufacture of electronics are based on subtractive processes. However, printing and other additive and roll-to-roll compatible technologies significantly reduce material waste and energy use during the manufacturing process.

Changing the substrate utilized in printed electronics has a drastic effect on a product's sustainability. Traditionally, metal electronics parts are etched out of copper sheets in a process called PCB etching. The process removes unwanted copper from a printed circuit board; therefore, only the required circuit remains while the rest of the sheet isn't used. The team found that flexible metal electronics parts can instead be printed onto bio-based substrates, like paper or bio-plastic film.

The process requires less energy and avoids the use of harmful chemicals while drastically reducing material waste and increasing the use of renewable materials. We found that this change in the manufacturing process is the single largest factor in potentially reducing the climate impact of flexible electronics.

4. Sustainability for the use phase

We also found new solutions to make electronic products more sustainable during the use phase. For example, the energy consumption of products can be decreased by creating more low-cost and low-weight devices, as well as new technology enabled by thin and flexible bio-based materials combined with additive manufacturing.

Extending product life expectancy and increasing durability also contributes to sustainability. Furthermore, energy-harvesting capabilities, such as using organic photovoltaics (OPV), offer new opportunities for energy autonomous devices.

Efficiency benefits can be achieved by applying new manufacturing technologies, such as additive manufacturing and roll-to-roll printing, to produce affordable and intelligent devices. In one example, the weight of a car was reduced when using flat printed cables, thus contributing to lower emissions during the car's lifetime (Hakola, 2022).

Another example is a smart label that's printed on bio-based plastic substrate and powered by a rechargeable supercapacitor with photovoltaics capable of harvesting even indoor light. This label can be added as a part of the product packaging and be used to monitor, for example, the transport conditions of food and medicines or other temperature-sensitive products. The environmental impact of this smart label is overcompensated with the sustainability improvements in logistics that it enables.

As a third scenario, the global amount of food waste is estimated at 1.6 billion metric tons per year, of which the edible parts amount to 1.3 billion metric tons (FAO, 2022). RFID or other intelligent tags could potentially be used to monitor and prevent this loss and the associated environmental footprint associated.

5. End-of-life management for the circular economy

In the EU, e-waste continues to be one of the fastest-growing waste streams (Circular Economy Action plan, 2022). End-of-life management for electronics still holds challenges in separating electronic material fractions, such as metals, for recycling and reuse without losing material value in landfilling and incineration.

Every year, 1.5 billion new mobile phones enter circulation. Old handsets end up in desk drawers or in landfills, which means that their materials and components are lost. But these materials need to be returned to the industry for reuse. End-of-life solutions and strategies are something that we haven't completely cracked yet. Questions like, "What are the most compatible waste streams?" and "How do we arrange efficient material recovery?" are issues that we're still tackling.

Single-use diagnostic tests and other single-use products, such as smart labels, are new emerging electronic devices that need to be designed for sustainable end-of-life management. Since the number of intelligent electronic features integrated into packages is expected to grow, the packaging waste of electronics recycling is a mounting concern. Thus, electronic material recovery should be considered.

The concerns also relate to safety if the recycled content is circulated back into, say, food packaging or toys. Therefore, it would be important to separate the electronic materials before package recycling processes.

Designing with biodegradability in mind is also important in some cases. Effective collection of electronic devices is a challenge, and some products will inevitably end up in waste streams or the environment.

In addition, designing biodegradable components wherever possible contributes to less e-waste—this might apply to packaging, plastic waste, or substrate material. However, remember that these materials are then lost from circulation and will thus not contribute to material shortage issues.

VTT's new nanocellulose electrocardiogram (ECG or EKG) patch is a good example. Because the device is modular, electronic components can be easily removed from the disposable patch and used again. The patch itself is biodegradable, consisting of nanocellulose and printed with carbon conductors and sensing electrodes. Traditional ECG patches are made of plastic-based materials with electronic components that can't be removed.

Pushing Progress in the Right Direction

The electronics industry has several possibilities to decrease its environmental impact. It all starts at the design phase with the selection of layouts, materials, and manufacturing processes. New materials and processes are currently being scaled up for the electronics industry to start using them.

However, all three aspects of sustainability—environmental, social, and economic—are important to consider when finding an optimal balance between cost, performance, and environmental impact for future electronic products.

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References

Barras, R.; Cunha, I.; Gaspar, D.; Fortunato, E.; Martins, R.; Pereira, L., "Printable cellulose-based electroconductive composites for sensing elements in paper electronics," *Flexible and Printed Electronics*, 2017, 2, pp. 1-12.

N.M.P. Bocken, I. de Pauw, C. Bakker, B. van der Grinten, "Product design and business model strategies for a circular economy," *J. Ind. Prod. Eng.*, 33 (2016), pp. 308-320.

Curto Fuentes, M., "Strategic Research and Innovation Agenda 2021, Electronic components and systems," Publisher: EPoSS, Germany, 2021.

V. Elia, M.G. Gnoni, F. Tornese, "Measuring circular economy strategies through index methods: a critical analysis," *J. Clean. Prod.*, 142 (2017), pp. 2741-2751.

Forti, V., Baldé, C.P., Kuehr, R., Bel, G. "The Global E-waste Monitor 2020."

J. Guiltinan, "Creative destruction and destructive creations: environmental ethics and planned obsolescence," *J. Bus. Ethics*, 89 (2009), pp. 19-28.

Hakola, L.; Immonen, K.; Välimäki, M.; Väisänen, K-L.; Sokka, L.; Eiroma, K.; Suhonen, M.; Leppäniemi, J.; Mäntysalo, M.; Keskinen, J.; Jauho, A.; Li, M.; Leminen, V.; Tanninen, P.; Deviatkin, I.; Horttanainen, M.; Lyytikäinen, J.; Roine, S., "Final report on ECOtronics research project carried out in Finland 2019-2022," 2022, 90 pg., available online: www.ecotronics.fi (accessed on 14 12 2022).

Mohammad Naji Nassajfar,, Marja Välimäki, Liisa Hakola2, Kim Eiroma, Kirsi Immonen, Mariam Abdulkareem1 and Mika Horttanainen,"The effect of conductive ink alternation on the sustainability and functioning of printed electronics."

Mohammad Naji Nassajfar,*ORCID, Ivan Deviatkin, Ville Leminen, and Mika Horttanainen, "Alternative Materials for Printed Circuit Board Production: An Environmental Perspective."

Food and Agriculture Organization of the United Nations (FAO), "Food wastage footprint. Impacts on natural resources," Summary Report. ISBN 978-92-5-107752-8, 2013.

Circular Economy Action Plan, available online (accessed 14 12 2022).