The Role of Packaging for Sustainable and Green Electronics

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***Abstract*— The electronics industry needs to take a closer look at its contribution to global environmental impacts, in particular to climate changing emissions and achieving carbon neutrality. Packaging technologies and packaging experts have a crucial role to play, even though the highest environmental impacts do not originate from the packaging sector.**

***Index Terms*— sustainable, green electronics, energy, hybrid electronics, stretchable electronics, 3D printing, additive manufacturing**

I. Introduction

Action against climate change is more pressing than ever – and is recognized not only by more political players, but also by industry. The electronics industry has long had the luxury of presenting itself as a clean industry, and as an active part of solving sustainability questions rather than adding to the problems.

With the climate crisis becoming clearer and more pronounced, the electronics sector needs to take a closer look at their responsibilities to really meet environmental goals within the next ten years. Electronic packaging may not be the biggest contributor to the environmental footprint of electronics, but the packaging technologies play a crucial role, in that they link the power and advancement of components – particularly the semiconductor components – with the product level. At this juncture the material composition of the product is determined, and therefore a relevant portion of the resource footprint of the product is fixed.

Sustainable or green electronics needs the right packaging technology choices, and these decision points need to incorporate environmental aspects urgently and on the industrial scale.

So, is the burden for saving the planet solely resting on electronic packaging? Certainly not. I am simply asking you to view the problem through the lens of packaging, but will at the same time admit and explain, that other factors play a much bigger role than the choice of packaging technologies.

II. Three Big Levers and a Specialized One

The biggest and most direct effect for improving the footprint of electronic systems comes from switching to green or renewable energy. This will in the long run reduce carbon emissions by a factor of four or five over many industries including the electronics industry. Energy systems engineers are the ones to shape the transition, and packaging engineers need not and in my view should not spend too much of their time analyzing this transition in their daily work. Keeping up to date on when and how much this slow change has to guide their decisions is of course a new requirement for all of us.

A similar factor of improvement is still predicted for semiconductor improvements when looking ten years ahead. Through higher energy efficiency and through higher integration density more functionality can be achieved with fewer resources. The progress rate for CMOS circuits, but also for power semiconductors, might be slowing down compared to a decade ago – but advanced packaging thrives in new options to alleviate that gap. So the total rate of progress (IC improvement plus advanced packaging) is not secure, but so far still quite dependable.

The third major lever hinges on the question in which applications we employ new and future electronics. If all new uses of electronics would lead to higher environmental savings than the environmental burden associated with the electronics, then employing more electronics would be always be environmentally positive. Following this argument, more electronics everywhere could eventually “save” the climate – but obviously this does not work on a systems level and nor has is worked out over the last 20 years. Otherwise we would have seen marked absolute reductions of the electronics footprint and of all applications using electronics.

Once more, packaging and our packaging expertise contributes to two opposing ends: we develop smaller, more versatile or robust packaging options, which allow the implementation of the new environmentally “net positive” applications – some of which would otherwise not be possible. At the same time, we enable massive growth and deployment of applications that are net negative for the environment and may even remain negative in balance, when driven by green

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energy. In both directions, it is the choice of application or business model that determines the scale and direction of environmental impact, yet packaging may be a crucial enabler in either case.

So while these three levers determine to a large degree, how much electronics can and will contribute to combatting climate change, two of the three are linked to the specialized leverage of the packaging community already.

This leads to the core observation – at once trivial, but certainly worth stressing – that packaging experts should concentrate on reducing environmental impacts in their field of expertise, and let other experts worry about and work on reductions in their fields. Try a thought experiment for your area of work, and it will quite inevitably lead to the situation that you would contribute a specific reduction of for example 50% of environmental impact, yet your impact changes only a small part of the total. Others would have valid claim to reduce the total footprint by 50% via greening the energy mix.

Should we and all companies then only go for renewable energy and leave the technology changes for later? That would be a disastrous decision, although you might imagine some managers thinking this way. Even though resources for transformation are always limited (be it investments, manpower or specialized knowledge), we need the comparatively smaller contributions from technology improvements in three ways.

First, we need to maintain the rate of functionality increase in electronics mentioned before without increasing the environmental footprint - else the footprint of all data infrastructure could still rise exponentially, despite a slow greening of electric energy.

Second, we do help to reduce the burden on the energy transition: any reduction on the power consumption side helps to reach goals earlier on the power generation side.

And third, we need to develop more extreme green solutions towards market readiness now for the time when we have nearly renewable energy supply.

At that point – let's assume 2040 rather than 2030 – the material consumption and slowing down the use of virgin materials will have at least the same relevance as the reduction of power consumption. The strong focus on CO_2 emissions from the power generation would by then be a passing phenomenon – on the positive assumption that at least the industrialized countries all transition their energy power generation, even if at differing speeds. Keep in mind, though, that even 100% renewable energy does have environmental impacts, so energy use reductions will always remain a focus.

III. Three Green Electronics Transformation Interventions

It helps to generalize a bit who in packaging can do what at this point. One differentiation we use is by the market readiness of the technology or of the application, in which the technology is employed. These intervention points work in conjunction, there is no choice for following either one or the other.

The intervention points coincide with three time frames for changing the impact of products, in this case specifically changing electronic products through packaging choices. This time lag between development and a hopefully positive impact in the real world is the core of the argument, why waiting until the energy transition "solves our problem" is not an option.

In technology development, we tend to talk about impacting the next product generation, but changes really only take effect in later generations. Basically, new options for future design choices are opened up, or existing options are optimized in such a way that for functionality, reliability and qualification reasons, they practically count as new. These interventions can be subsumed as "future generation options". The timeframe effecting change in reality even for just two product generations ahead is 4 years at minimum, and easily 10 years for safety critical applications. These are the years until the first commercial products enter the market, hence only the start of improving the average of the installed base.

In product development (and service and business model development) we then choose the technology options to achieve our functionality, pricing etc. Often times implicit decision points are based around the technology readiness level (if a TRL below 8 can even be considered) and the security of supply (for less established technologies). Even though the processes are very varied in reality, let's call these "product design choices". Unless we are dealing with very rapid development processes or redesigns, it will still take a minimum of 2 years until market entry, then depending on market uptake many years, before the technology improvements can have wide scale impact.

The third and often overlooked type of intervention changes the environmental profile of a product after it has been produced and put on the market. From ecodesign experience we should strive to include all environmental factors into the design decisions, or in short "80% of environmental impact of a product is determined at the design stage". But a number of factors, and indeed factors requiring technology development, cannot be included at the time of design. Let's call these "after sales technologies".

The first two intervention types should be familiar to all readers, but the third warrants a few more examples. The typical – non-technology associated – examples are the influence of the user, or the influence of yet unknown power grid or location aspects. Creative misuse and modding of products by the users for example can lead to environmental impacts way higher than the design brief the manufacturer took into consideration (although users can also be creative in lowering impacts). Additional technology – not initially planned and provided by the manufacturer – comes into play with reliability issues, extension of the product lifetime and end-of-life treatment. In the optimal case, the manufacturer has reviewed the relevant scenarios during design, but nevertheless technologies may be developed afterwards as well. Consider repair, reuse or refurbishment processes, which can be advanced technology developments.

IV. Your Role

For understanding your potential contribution to reducing environmental impact in a limited timeframe, think about which types of interventions are within scope for you. I am not advocating to stop all "future generation options" research and concentrate only on the shorter term "after sales technologies", but separating the roles and more openly discussing the realistic delays until developments impact real life emissions should be part of the decision making.

Possibly some companies or research institutions could put more focus and resources on the shorter term improvements, even if they are less rewarding in terms of scientific merit, IP generation or inventiveness. Repair – of high-tech electronics – is urgently needed to transition to a Circular Economy, but still has the stigma of dirty, low-tech and low return activities. That is gradually changing, so team up with others exploring circularity as a business proposition, both in industry terms and in research.

If you are in a position to influence "future generation options", define more explicitly how your development can contribute to environmental benefit. Radically new materials including nano-carbon, bio-based materials, bio-degradable materials, conductive polymers; thinned, flexible extremely light-weight electronics; 3D printable electronics: all these approaches are promising, but usually have built-in environmental (or technical performance) issues that need to be openly addresses in early development already.

Each case may be a high percentage improvement to a relatively small part of the total, but packaging does have strong leverage in the long run, as explained above. Be bold and disruptive in your technology approach, but don't overstate the environmental benefits of your solution as a game changer within the next ten years. New technologies are shaping the sustainability corridor farther out, but should not be expected to solve the problems until 2030.

And if I managed to spark your interest for these environmental topics, please let me know, so we can expand the discussion and exchange within IEEE EPS. We need to elevate the topic in the technical committee level, in the EPS roadmapping and at EPS related conferences. Let's contribute our part to greening electronics through the packaging focus of EPS. It's an excellent place to start.

Contact nils.nissen@izm.fraunhofer.de to join the exchange.

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