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Digitalization

BAVARIAN CHIPS ALLIANCE

Position Paper of the Sustainable Electronics Working Group

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Regional Development and Energy

Executive Summary

A key industry in securing Europe's technological sovereignty, the electronics and semiconductor sector, faces the challenge of integrating sustainability across the entire value chain and product development process.

This position paper outlines industry-driven solutions and highlights practical approaches throughout the product life cycle, from design to recycling, with a strong focus on using data to advance sustainability.

Key action areas

1. Promoting sustainable design

- design products for repair, reuse and recycling from the start
- enable reuse of fully assembled printed circuit boards
- integrate monitoring functions into ICs to ensure life cycle traceability

2. Improving sustainability in production

- build and expand regional manufacturing capacities within the EU
- promote energy-efficient processes in semiconductor and electronics production
- scale up successful sustainability initiatives from pilot plants

3. Promoting repairability

- implement modular product designs and clear component labelling
- provide standardized repair instructions

4. Facilitating returns

- establish legal and technical frameworks for B2B marketplaces handling production waste and end-of-life products
- create harmonized standards for material definition, quality and sustainability

5. Expanding recycling infrastructure

- develop and implement straightforward, practical systems for sorting production waste
- establish reliable certification procedures for recycled materials
- boost research and infrastructure for recycling technologies across Europe to maximise the economic and environmental benefits of secondary raw materials

6. Harnessing data

- use the digital product passport as a key tool for carbon, energy and material transparency
- define standardized data formats and calculation methods
- ensure practical implementation, especially for SMEs

Purpose of the position paper

This position paper presents the views jointly developed by companies and organisations within the working group on current trends in sustainable electronics.

It aims to inform about these developments and provide concrete proposals and measures that companies and organisations in the semiconductor and electronics sectors can use to tackle these issues.

The paper also offers researchers key insights into industry-relevant trends, serving as a basis for cooperation and knowledge transfer.

Additionally, it is designed to support European policymakers by providing information that can guide strategic decisions related to sustainable electronics.

Description of the process

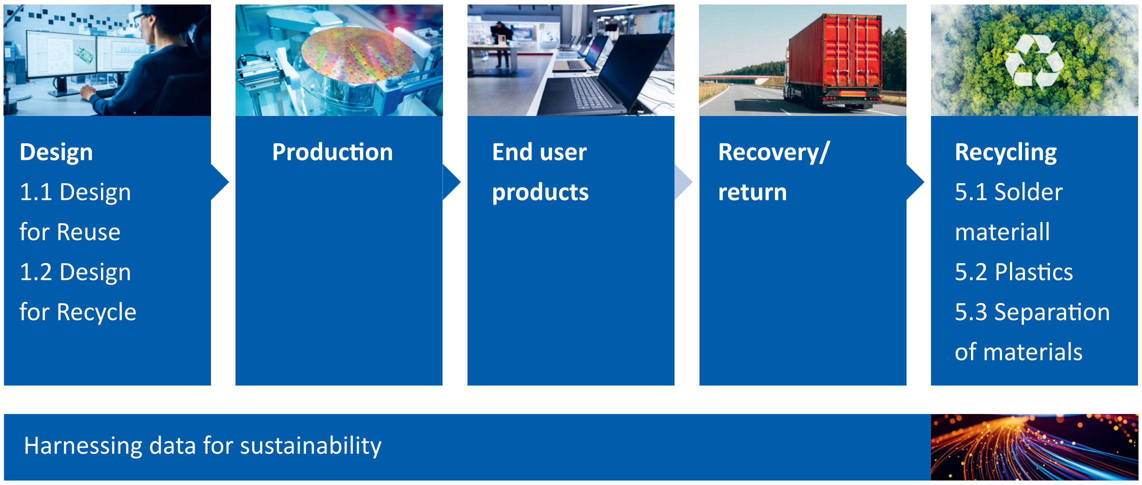
The participants of the Sustainable Electronics Working Group aimed to develop a position paper that explores current challenges and solutions for sustainable electronics in the semiconductor and electronics industry in Bavaria and beyond.

In 2024, the Working Group took the following steps to address sustainable electronics:

- identifying specific use cases
- defining the current challenges
- developing solution approaches
- creating positive future scenarios
- outlining concrete measures

This position paper was developed based on the content collaboratively produced by the participants.

Figure 1: Structure based on the lifecycle



Structure

The position paper covers a wide range of topics throughout the entire semiconductor value chain, from design and manufacturing to end users, production waste trading and end-of-life products, recycling and harnessing data to promote sustainability (see Figure 1).

The topics outlined also reflect the network of the Bavarian Chips Alliance which works with its partners to cover the entire semiconductor value chain including electronics and specialised applications, focusing on topics relevant to its partners.

Defining sustainability

In the electronics and semiconductor sectors, sustainability entails a holistic approach to designing products, processes and business models with the aim to minimize environmental impact, strengthen economic resilience and take on social responsibility throughout the product life cycle.

Sustainability begins with designing for circularity, systematically accounting for reuse, repairability and recyclability from the outset. In production, the focus is on resource efficiency, energy savings and using sustainable materials ideally through regional, low-emission value chains.

Usage and return must be designed to keep products in service longer, facilitating repair and ensuring effective reintegration into circular processes.

Content

1. Design

Addressing sustainability in electronics must start at the product design stage, with appropriate recycling strategies developed and defined for the end of the product's life cycle. This position paper focuses on design for reuse and design for recycle in an industrial context.

Design for repair will be discussed separately in Section 3 ("End user products") as repair strategies differ significantly between consumer electronics and industrial electronics. In high-end industrial electronics, repair is essential to maintain cost efficiency and availability, whereas consumer electronics still have significant untapped potential for repair.

Before examining the specific challenges and solutions for each design approach, it is important to highlight a set of overarching principles that underpin sustainable design.

These include sufficiency, consistency and energy efficiency alongside compliance with regulatory frameworks such as the Ecodesign Regulation.

1.1. Design for Reuse

Challenges

Design for reuse is a cornerstone of sustainable electronics. However, present recycling practices in this field focus almost exclusively on material recovery with the direct reuse of components being uncommon.

One of the greatest challenges is the lack of publicly accessible data and studies on the lifespan of semiconductor parts. There are currently no standardized criteria or classifications to assess the lifecycle stage of a component. Take the example of a microprocessor:

How long can it operate reliably within its specifications? So far, there are hardly any established concepts for its reuse, e.g. in consumer electronics. Key questions need to be answered to ensure safe and reliable reuse:

- How long has the microprocessor been in operation?
- Under what conditions was it used?
- Has it sustained damage from overload?
- For applications with particularly high quality requirements:
  Is desoldering and resoldering acceptable?

As a result, the actual condition of an integrated circuit (IC) remains uncertain in most cases.

Future scenario

In a positive future scenario, the reuse of durable components and ICs is ensured. Manufacturers support this process through dedicated features and labels that provide transparency on the condition and remaining lifetime of components.

This is supported by the following measures:

- avoiding encapsulation compounds in the design to facilitate later disassembly
- integrating monitoring functions into ICs:
  - built-in diagnostic features in circuit design
  - facilities for functional re-testing at EMS providers (Electronics Manufacturing Services)
  - providing manufacturer data on use cases and maximum operating life
- establishing concepts for reusing fully assembled circuit boards
- enhancing lifecycle transparency to improve traceability and reuse
- transferring established standards from other industries to ICs

Target groups

These measures are primarily aimed at companies in the semiconductor and electronics sectors as well as the relevant industry associations which play a key role in establishing standards and frameworks for sustainable reuse.

1.2. Design for Recycle

Challenges

Implementing "Design for recycle" currently faces several challenges. In particular, there is uncertainty about which materials, packaging technologies and especially polymers are best suited for subsequent material separation. The choice of components has a decisive impact on the requirements for recycling-oriented design. Insufficient standardization and inconsistent regulatory frameworks hinder effective recycling optimization.

Future scenario

In a positive future scenario, a limited but well-defined set of established recycling processes exists with clearly defined benefits and boundary conditions. Developers and manufacturers of electronic assemblies can rely on the long-term availability of these processes, enabling them to implement effective "Design for recycle". In the design phase, special attention is paid to selecting the right materials, using the product carbon footprint as a lever to improve sustainability.

This is supported by the following measures:

- fostering consortia across the value chain to strengthen understanding and collaboration, involving:
    - IC design
    - integrated device manufacturers (IDMs)
    - assembly manufacturers and EMS providers
    - recycling companies
    - equipment manufacturers for recycling processes
- involving recyclers early in the design planning phase

Target groups

These measures are directed at industry associations and all relevant companies across the value chain whose effective collaboration is essential for advancing recycling-oriented design.

2. Production

Enhancing the sustainability of semiconductor and electronic product manufacturing is a key lever for driving progress in sustainable electronics. This can also provide valuable insights for industrial equipment production which is not covered in detail here.

Challenges

The production of semiconductors and electronic components currently faces significant challenges in terms of sustainability. Many chip manufacturing processes are highly resource-intensive, for example due to large water consumption. Although several manufacturers have implemented improvements through site-specific project, industry-wide scaling has yet to take place.

Global supply chains further complicate the picture. Long-distance transport of raw materials and components generates a substantial carbon footprint. The share of renewable energy in production also varies greatly by region. Sites dependent on fossil fuels bear significantly higher environmental impacts from semiconductor manufacturing.

In addition, the rebound effect plays an important role: efficiency gains that lower production costs or energy demand can paradoxically drive higher consumption and output, thereby offsetting potential sustainability benefits.

Future scenario

In a positive future scenario, the semiconductor and electronics industry has significantly reduced both its carbon footprint and resource consumption through innovative technologies and new production methods. Sustainability initiatives are no longer isolated efforts but scaled broadly across the industry, helping to green the entire value chain.

This is supported by the following measures:

- cross-industry collaboration: setting up working groups to scale sustainability solutions in production
- research and optimization in the field sustainable production:
    - developing and deploying more sustainable chemicals and materials
    - reducing material usage
    - optimizing exhaust gas purification
    - substituting climate-impacting and toxic gases
    - reuse of materials used in production (slurry, ultra-pure water, ...)
    - using resource-efficient coating, particularly in photolithography processes
- localisation of production: establishing and expanding production capacities within the European Union to reduce transport distances and related emissions
- promoting sustainable innovations in production
- renewable energy use: transition to green energy sources for production processes e.g. climate-neutral cleanrooms
- incorporating additive processes as substitutes for subtractive process chains to minimise material waste

Target groups

These measures are aimed at various stakeholders along the value chain as well as research and politics, including:

- industry/original equipment manufacturer (OEMs)
- recycling companies
- chemical manufacturers
- tool and equipment manufacturers (energy management, tool production and design)
- research institutes and universities
- EU bodies/EU policy

3. End user products

Device repairability is a central aspect of sustainable electronics in end-user products, which will be discussed in the following section.

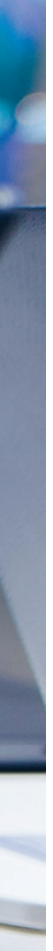
Unlike Section 1, which addressed the industrial context, the emphasis here is on "Design for repair" in consumer electronics.

Challenges

Currently, significant barriers hinder long-term use and repair of devices. In many cases, product design complicates or even entirely prevents repair. Even when repair is technically feasible, end users often lack the required tools or materials, as manufacturers rarely provide repair kits.

Moreover, awareness of repair options is limited among the general public. Many users do not know how to fix defects themselves and instead depend on specialized service providers whose availability is often limited depending on the device type. Financial aspects are another significant obstacle: In many cases, repairs are more expensive than buying a new device, prompting consumers to opt for replacement rather than repair. However, repair decisions should prioritize the reduction of electronic waste rather than focusing on the product's value or the replacement cost.

Additionally, companies often lack the economic incentives necessary to produce repair-friendly designs. So far, market forces have mainly supported new device sales rather than the adoption of repair-friendly practices. As a result, faulty electronic devices are disposed of on a large scale despite being repairable in principle.



Future scenario

In a positive future scenario, end users experience no disadvantages in terms of functionality or usability due to sustainable product design. Companies consistently implement ESGRC principles (Environmental, Social, Governance, Risk & Compliance), leading to improved device repairability. The total lifecycle costs, including economic, ecological and social factors, are reflected in the consumer price, enabling fair comparability and fair competition. This has created a repair culture along with the awareness that electronic products are valuable resources often produced with considerable labour and energy input.

This is supported by the following measures:

- modular design: devices are designed to allow easy removal and replacement of individual modules
- repair instructions: manufacturers provide standardized repair instructions with their products
- component labelling: standardized markings (e.g. barcodes, QR codes or chemical markers) facilitate identification and replacement of parts
- technology-assisted repair: innovative solutions such as augmented reality glasses could support and simplify repairs
- factoring in lifecycle costs in the consumer price makes repairs economically more attractive
- repair incentives or higher disposal fees: financial incentives encourage consumers to repair rather than replace provided that regulatory bodies secure the necessary funding
- transparency for end users: repairability seals similar to mandatory energy efficiency labels on household appliances inform consumers about repair options
- regulations ensure that all market participants are equally obliged to meet repairability standards for electronic components
- ESGRC requirements are linked to binding certifications for stakeholders
- manufacturers provide hardware and software documentation for a reasonable period after production ends, especially in the event of insolvency

Target groups

These measures are primarily aimed at EU policymakers who must establish the relevant regulatory frameworks. At the same time, industry associations such as VDA and VDI are called upon to develop common standards for enhanced repairability.

4. Recovery/return

Another application of sustainable electronics is the recovery and trading of production waste and end-of-life (EoL) products through specialized B2B marketplaces, enabling their reintegration into the circular economy. These platforms enable companies to economically recover waste materials for reuse in other production processes, thereby conserving resources. They act as key intermediaries that connect suppliers and buyers.

Challenges

Although several smaller platforms already exist, some central challenges remain unsolved: There is a lack of uniform standards across platforms, making it difficult to locate specific raw materials even within individual marketplaces. Furthermore, quality assessment of production waste or EOL products is frequently complicated by a lack of clearly defined criteria.

Additionally, there are logistical challenges to overcome: Companies face considerable difficulties due to long transport routes and the need for extensive storage capacity. Particularly in international trade, language barriers and different material definitions and terminology often make it harder to use these platforms. Additionally, matchmaking algorithms need to be improved to ensure efficient and demand-driven connections between suppliers and purchasers. Finally, successfully implementing such marketplaces requires changing established supply chains which currently limits the scaling of these solutions.

Future scenario

In einem positiven Zukunftsszenario werden Produktionsabfälle und EoL-Produkte durch B2B-Marktplätze wieder in den Umlauf gebracht. Bei Unternehmen sind diese Plattformen als transparente und verlässliche Einkaufskanäle anerkannt, in denen Qualität und Herkunft der angebotenen Materialien klar ersichtlich sind. Durch die Integration von Systemen, wie dem digitalen Produktpass, wird die Rückverfolgbarkeit von Produktionsabfällen und EoL-Produkten erleichtert, was Vertrauen in den Sekundärrohstoffmarkt schafft. Darüber hinaus bieten die Marktplätze eine hohe Verfügbarkeit an Materialien, sodass Unternehmen jederzeit auf die benötigten Rohstoffe zugreifen können.

This is supported by the following measures:

- development of a standardized sustainability evaluation index for marketplaces, incorporating logistics and transport routes
- possibility to order material samples prior to purchase to verify quality and suitability
- provision of detailed technical specifications for offered materials to facilitate comparability
- establishing standards for purity and quality of recycled materials to ensure their usability
- use of automation and artificial intelligence (AI) to increase efficiency and reduce costs
- developing industry-specific marketplaces tailored to the unique needs of individual sectors

Target groups

These measures are primarily aimed at industry associations tasked with establishing common standards as well as policymakers at the European level who must create the appropriate regulatory frameworks.

5. Recycling

Recycling in the semiconductor and electronics industry involves a wide range of materials, including:

- metals
- alloys
- polymers
- composite materials (displays, printed circuit boards (PCB)...)
- glass
- ...

In this position paper, we will focus on a limited selection of materials and specific recycling applications. Before exploring these applications, this section will take a look at the general prerequisites for recycling:

- the specification of materials
- logistics for material types
- process changes (not just replacing primary with secondary materials but exploring changed processes that utilize the advantages of secondary materials)

It should also be noted that some substances were still permitted in the old material but are no longer allowed in new material. This calls for solutions to remove such problematic substances (e.g. lead, certain flame retardants, stabilizers, etc.) with minimal effort.

5.1. Solder material

The use of solder material containing recycled components is one application case of recycling in sustainable electronics.

Challenges

Metals recovered from used solder can be reclaimed and used to produce new solder materials which can in turn be applied with high reliability. However, there is still a lack of awareness along the entire process chain about this possibility as well as limited acceptance of the use of recycled solder.

Future scenario

In a positive future scenario, the processes for material collection and sorting have significantly improved and are supported by the digital product passport. A closed-loop system for metals has been established, substantially reducing the use of primary raw materials.

This is supported by the following measures:

- development of systems and processes for easy and practical sorting of solder waste for all users (end users, manufacturers, recyclers, etc.) to maximize output
- after establishing the systems/processes: training programs to ensure proper sorting of solder waste to enable or facilitate recycling
- awareness campaigns by industry associations: promoting sustainability and recycling awareness within the electronics industry
- education and training: expansion of qualification programs for professionals to root knowledge about recycled solder materials in the industry
- tapping into scientific expertise: pooling knowledge from research and practice potentially supported by political funding to develop innovative recycling processes

Target groups

These measures are primarily aimed at relevant industry associations such as ZVEI and FED.

5.2. Plastics

The use of recycled plastics in the semiconductor and electronics industries is another application of recycling. This includes both plastics used during various stages of chip manufacturing and plastics used in printed circuit boards.

Challenges

Although many plastics can be recycled in principle, significant challenges remain. Polymer recycling is complex because monomer units cannot be reclaimed as easily as metal atoms from metals. Research into "sustainable polymers" is already underway, however, the transition from research to practical application is often still missing. Examples include natural fibers and polylactides for circuit boards, Leaftronics, Myceliotronics and others. Another

key challenge is that plastics containing recycled material often do not fully meet all regulatory requirements or specific customer demands. In addition, the cost of producing recycled plastics must be weighed against those of conventional plastics as well as the costs associated with necessary recertification of plastics in take-back schemes.

Future scenario

The envisioned positive future scenario includes improved recycling processes, standardized methods for material characterization and an increased use of polymer-based recycled materials in the semiconductor and electronics industries. Closed-loop plastic material cycles have also been established. Within three years, a limited number of well-functioning recycling processes have become standard practice and their benefits and boundary conditions are well understood. Moreover, a limited number of materials suitable for recycling are available in sufficient quantity and quality which meet the requirements of electronic components.

This is supported by the following measures:

- promoting knowledge exchange on feasible methods and processes in plastics recycling such as mechanical and chemical recycling or mass balancing
- stricter verification requirements for recycled plastics to ensure transparency and build trust in material quality
- adjustment of certification and customer requirements where recycled plastics demonstrably offer the same quality as virgin materials
- collaborating closely with customers from the semiconductor and electronics industry as well as other industries on recycled plastics
- strengthening regional value chains to reduce the carbon footprint and facilitate collaboration throughout the process chain, from manufacturer to recycler
- expanding and establishing take-back schemes for plastics from electronic products
- enhancing cooperation between semiconductor and electronics companies and recycling enterprises
- building efficient reverse-logistics networks to facilitate the collection and reuse of plastics

Target groups

These measures are directed in particular at customers in automation technology, development departments of module manufacturers and distributors involved in product life cycle (PLC) management. Moreover, the appropriate framework conditions can only be created at the European level, for example by the EU Commission.

5.3. Material and module separation of PCBAs

The separation of materials and modules at the end of the life cycle of assembled printed circuit boards (PCBAs) is an important application for sustainable electronics.

Challenges

The material separation of PCBA components currently presents a major challenge. Bonded assemblies make it difficult to mechanically separate components from the printed circuit board while detaching bond wires, chips and solder material can also be challenging. Additionally, encapsulation materials such as silicones complicate the recycling process. The separation effort is particularly high for small assemblies and the associated costs must be factored in. Moreover, the question arises where the recycling process should take place. After all, a product is not necessarily located in the country where it was manufactured at the end of its life cycle, nor is it always returned to an official take-back point that has access to the product datasheet.

Future scenario

In a positive future scenario, material and module separation at the end of life of printed circuit board assemblies is standardized and applied across all economically viable use cases.

This is supported by the following measures:

- developing and establishing industry standards for material classification of recycled materials
- defining material-separating, energy-saving recycling technologies that can be safely applied at the end of the product life cycle
- applying cryogenic recycling processes to electronic products
- reducing material diversity within assemblies in order to simplify separation processes
- using recycling processes with a high tolerance toward encapsulation materials
- recycling in the EU: increased use of and research into recycling processes for raw materials within Europe to reduce dependencies, promote a circular economy and create economic incentives for using recyclates

Target groups

The measures are aimed particularly at relevant industry associations, especially ZVEI and FED.

6. Harnessing data for sustainability

The digital product passport (DPP) is an effective instrument for making electronics more sustainable by providing a unified data basis for driving key sustainability issues – from more efficient resource use to circular economy and calculation of the carbon footprint. This section explores how to harness data for sustainable electronics by highlighting the opportunities of the DPP and data spaces without placing an additional regulatory burden on companies.

Challenges

The current situation is marked by many (smaller) companies having little or no access to the necessary data infrastructure. However, over the next years much of this data will be required under EU regulations, making it essential for companies to deal with this issue now.

They have to answer key questions, such as what data to share with third parties. To facilitate such data exchanges, industry-specific data spaces are currently being established in Germany. In the semiconductor industry, the Semiconductor-X funding project, supported by the Federal Ministry for Economic Affairs and Climate Action under the EU's Manufacturing-X program, is working to address this challenge. To ensure acceptance, transparent communication of the functionality and added value of these data spaces will be crucial to build the necessary trust.

Another difficulty lies in the heterogeneity of available databases, as well as in the fact that consumption data is not always easy for companies to quantify. Moreover, there are no legal standards for determining comparable consumption levels across similar machine types.

Comparability of material declarations is also difficult at present since these do not follow any legislated standard. Nevertheless, complete material declarations are a prerequisite, e.g. for recycling and calculating the carbon footprint.

The Digital Product Passport provides the opportunity to consolidate all relevant product information, but it is crucial to define exactly which data are needed and the effort for data collection remains manageable. Close cooperation with industry is essential to identify approaches that do not overburden companies, especially SMEs.

Future scenario

In a positive future scenario, the proposed solutions have led to a harmonized digital product passport legally defined by standards covering the following key areas:

- material compliance
- environment, health and safety (EHS)
- energy consumption tables
- recycling instructions
- repair instructions
- footprints (carbon, water, ...)
- safety data sheet (SDS)

In this positive future scenario, the digital product passport is trusted for its data security thanks to measures such as encryption and anonymization. Industrial energy consumption data is fully transparent, providing a reliable basis for calculating carbon footprints. Data comparability is ensured through standardized formulas and norms with documented calculation methods.

This is supported by the following measures:

- collecting and understanding user requirements
- creating comparison references: developing standardized reference scenarios for comparing machines and other products
- comparability through standardized material declarations
- all values should be calculated according to uniform formulas and standards, taking into account the specific requirements of complex production processes in the semiconductor and electronics industries
- documenting the calculation methods used
- outlining and communicating the benefits of the DPP for companies
- adapting successful concepts: transferring proven solutions – for example from the battery passport – to electronics and semiconductor products
- collaborating with semiconductor and electronics industry associations to define the content of the digital product passport, including the integration of additional product footprints and more precise definition of footprints (e.g. the carbon footprint for Cradle-to-Cradle (C2C) or Cradle-to-Grave (C2G) assessments
- promoting knowledge exchange with associations from other sectors regarding the DPP

Target groups

The measures are primarily aimed at industry associations and EU policymakers.

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