Product and material passports are only useful for the circular economy if they are linked to products and materials robustly and reliably!

Short Version (April, 20th, 2022)

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1 Introduction

The *European Green Deal*[3], the initiative for sustainable products[4] and the revision of the Eco-Design-Directive[5] foresee a Digital Product Passport (DPP) when placing various products on the market in almost all sectors. This includes, for example, information on the origin, composition, environmental data, repair and disassembly options as well as the handling at the end of a product's life. With the DPP, there will be a central place that contains all information about the product. This could be, for example, a central database that users can access. In this way, the DPP creates the basis for uniform and transparent product information and contributes to the promotion of an environmentally sound circular economy - from the sustainable extraction of raw materials and the support of conscious purchasing decisions by consumers to professional recycling. Closely related to this is the Digital Material Passport (DMP), which is often used in the context of buildings. In the building sector, deconstruction or demolition processes are currently rarely associated with the extraction of raw materials, but rather with the challenges of disposal. To change this, detailed information about the products, components and materials used in the building must be available, which is compiled in corresponding DMPs. In principle, however, the DMP is not limited to buildings.

Both, a Digital Product Passport (DPP) and a Digital Material Passport (DMP), essentially consist of the following components:

- the unique and at least over the period of use robust product/material identification,
- the corresponding necessary identification technologies,
- the data stored in a database (e.g. date of manufacture, batch number, digital twin),
- the protocol for transmitting the data.

What kind of information that should be taken into account depends on the product. The establishment of a DPP for complex products (e.g. electrical appliances, vehicles) is significantly more complex than for simpler products such as packaging.

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[3] Europäische Kommission. „Sustainable Product Initiative". 2020. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en. (letzter Zugriff: 24.01.2022)

[4] EU-Kommission. „Der Europäische Grüne Deal". COM(2019) 640 final, 2019.

[5] EU-Kommission, March 30th 2022, https://ec.europa.eu/environment/publications/communication-making-sustainable-products-norm_de

2 Regulatory Background

There are already initial regulatory approaches in the EU to increase the transparency of product information over the entire life cycle of a product. The reason for this is that when the life cycle is interrupted by the use of a (private) end consumer, valuable information is usually lost ("information gap"), including, for example, material information that was added on the label. By developing digital product and material passports, information needs can be digitalised, specified and expanded. However, the prerequisite is that a forgery-proof, robust physical link to the product or material exists.

Within the framework of the European Green Deal, one of the EU Commission's goals is to minimise the environmental impact of products. Specifically, the Sustainable Products Initiative (SPI) aims to make products fit for a climate-neutral, circular economy while improving their overall sustainability performance. In doing so, the Commission is considering the establishment of sustainability principles and other appropriate regulatory options, including reducing the carbon and environmental footprint and mobilising the potential of digitising product information by solutions such as digital passports, labelling and marking. In the revision of the Ecodesign Directive, the scope of application is now significantly expanded (ESPR - Ecodesign for Sustainable Products Regulation). In future, design requirements will be imposed on many more products: textiles, shoes, packaging, chemicals, batteries, buildings.

In addition to several other revision processes, the EU Commission is also preparing the amendment of the requirements for batteries and their disposal. The current Battery Directive (2006/66/EC) has been fundamentally revised and provides some new obligations for distributors and manufacturers of batteries. The first draft contains the requirement of a product passport. Thus, from January 2026, industrial and electric vehicle batteries placed on the market with a capacity of more than 2 kWh are to be assigned a specific electronic file ("battery passport"), which is to be linked to information on essential characteristics of the battery. This is a new approach in the regulatory area of extended producer responsibility.

3 Technologies for the unique marking and identification of products and materials

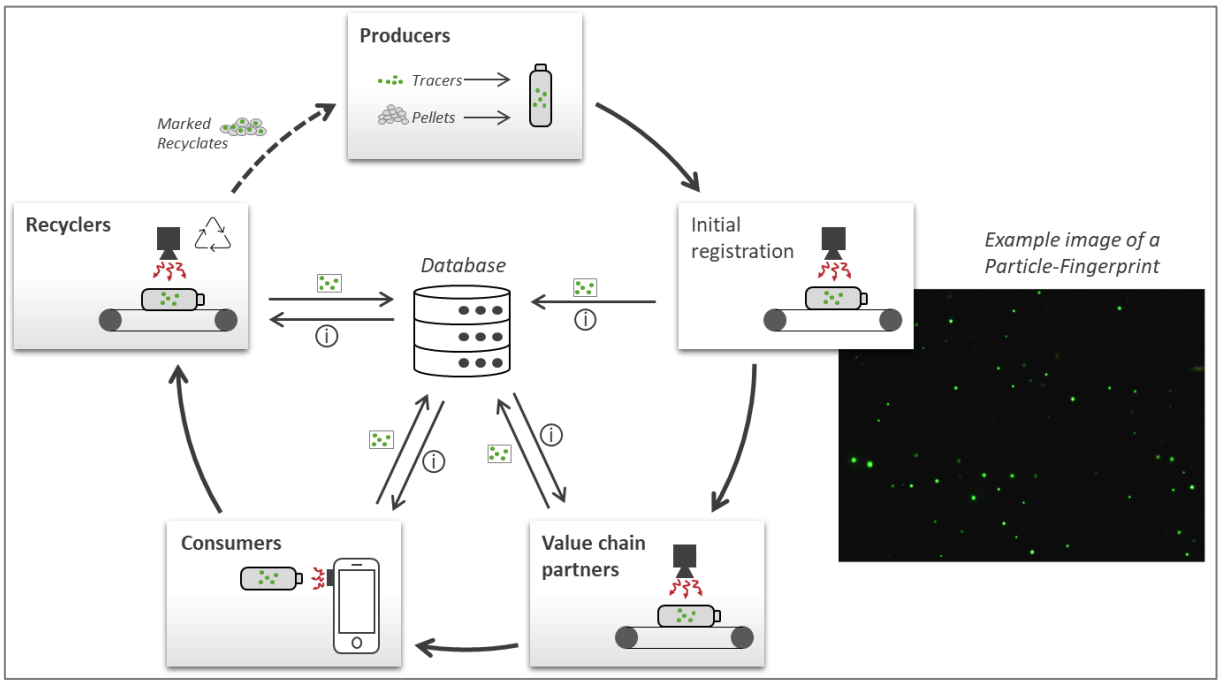
3.1 Particle-Fingerprints (PFP) on the implementation of Digital Product Passports (DPP)

The uniqueness and counterfeit protection of individual product identification is of central importance when mapping DPPs. Polysecure has developed a new innovative technology for this purpose. With the so-called Particle Fingerprint (PFP), the position of upconversion fluorescence particles is measured (see pict. 1, right), that have been added to the raw material (e.g. plastics, coatings of metals, etc.) in advance and arrange themselves completely randomly in its solidification process. Due to the upconversion effect, only the fluorescent particles emit visible light when excited with suitable radiation. All other material components remain dark. This results in a comparatively high contrast, which in turn enables a reliable, fast

measurement at very low particle concentrations. Due to the aspect of randomness, the resulting "fingerprint" is on the one hand unique and on the other hand cannot be deterministically copied and reproduced. The PFPs are therefore, in contrast to barcodes, RFID tags or digital watermarks, maximally forgery-proof.

The fluorescent particles themselves are highly annealed crystalline particles (> 1 µm) that are thermally and chemically very stable. They have good biocompatibility and are compliant with EU substance law requirements. Approval for contact with drinking water has already been granted. Approval for food contact is expected soon, as all toxicological tests have been completed with very good results.

The embedding of the particles in the materials enables an enormously robust marking, so that a unique identifier is generated for individual products. The PFP can be detected in the entire value chain of the product and provides corresponding access to the information stored in the database (see Pict. 1, left). Concrete examples of application are, for example, batteries, electronic goods, medical products or, in general, products that are at risk of counterfeiting, that require a secure return system or that need a product passport for regulatory reasons.



Pict. 1: Process flow of the particle fingerprint (left) and illustration of a Particle-Fingerprint (right). Source: Polysecure GmbH, Freiburg.

3.2 POLTAG®-Macromolecules on the implementation of Digital Material Passports (DMP)

In close cooperation with the Charles Sadron Institute (ICS), Polysecure has developed another innovative technology with which DMPs can actually be anchored in the material[6]. This provides, for the first time, a secure and accurate identification technology for materials that solves the following challenges, which play an increasingly important role in modern and circular industries:

- **Authentication of materials** or material components to ward off unjustified warranty claims triggered by other materials or counterfeits. Such plagiarism protection also serves to protect the quality and corporate image.
- **Tracing materials or material components** for origin, certification, composition, manufacturing and batch data to meet regulatory or organisational requirements.
- **Monitoring of recyclates and materials in the circular economy**, e.g. to be able to check the proportion of recyclates in products or the number of recycling cycles.

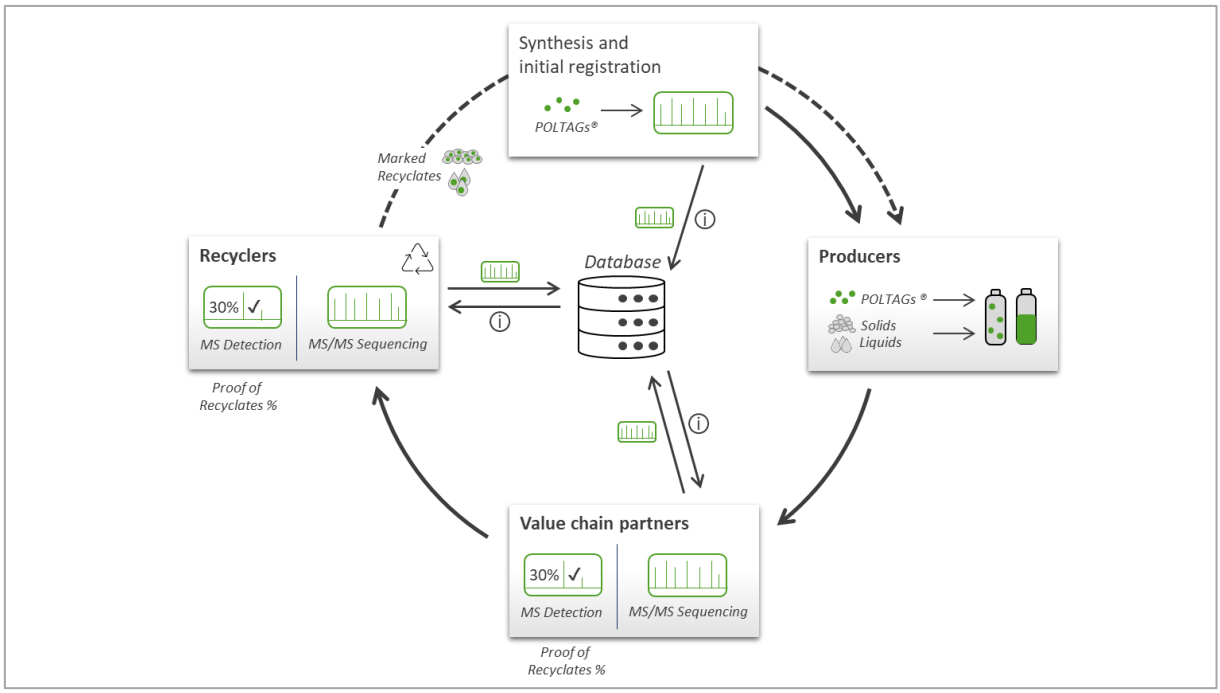
POLTAG®s are organic macromolecules whose monomer arrangement can be specifically synthesised. Due to the practically unlimited combinatorial possibilities, millions of individual molecules and thus distinguishable codes can be generated, that allow the identification of a correspondingly large number of materials in the sense of a "material DNA". The data behind the identification codes can include any information, such as manufacturer, batch number or production date, so that materials can be traced back to their origin[7,8].

The technical properties of the POLTAG® molecules can be adjusted and adapted to ensure maximum stability and compatibility with the target product and its specific application. The POLTAG®s are designed and synthesised individually for each customer by Polysecure, which also ensures a particularly high level of protection against counterfeiting and manipulation. POLTAG®s are thermally (up to 380 °C), chemically (e.g. resistant to UV radiation, acidic and basic solutions, organic solvents, etc.) and mechanically stable. Due to these robust properties, as well as the anchoring of the POLTAG®s directly in the material, they can be preserved and detected for many years. Thus, the assignment of the DMP to the material is possible over the entire life cycle (see Pict. 2). Furthermore, the POLTAG®s can be homogeneously processed in solids (e.g. thermoplastics and duroplastics) and liquids (e.g. organic solutions, fuels and water-based liquids), so that a very wide range of target materials can be marked.

[6] Lutz, J., et al. „Sequence-controlled polymers". 2013. Science 341.6146.

[7] Karamessini, D., et al. „Identification-tagging of methacrylate-based intraocular implants using sequence defined polyurethane barcodes". 2017. Advanced Functional Materials 27.3.

[8] Gunay, U., et al. „Chemoselective synthesis of uniform sequence-coded polyurethanes and their use as molecular tags". 2016. Chem 1.1



Pict. 2: Process flow of POLTAG®s in solids and liquids. Source: Polysecure GmbH, Freiburg.

The POLTAG® macromolecules are read out by sensitive and precise tandem mass spectroscopy (MS/MS). Even in the field, a few milligrams of labelled material at very low POLTAG® concentrations (polymers, solids: ~ 1 ppm, liquids: < 100 ppb) are sufficient for a precise detection.[9] Furthermore, the quantitative nature of mass spectroscopy enables that the detection of POLTAG®s can also be used to monitor and measure the concentration of marked materials in the end product (e.g. recyclate content).

4 Summary and Outlook

Currently, half of total greenhouse gas emissions and over 90% of biodiversity loss and water scarcity are due to resource extraction and processing. At the same time, global consumption of materials such as biomass, fossil fuels, metals and minerals is expected to double over the next four decades and annual waste generation is expected to increase by 70% by 2050. In this context, it is of central relevance to massively reduce the excessive consumption of goods and the resulting waste and to establish a true circular economy with sustainable, durable, repairable and recyclable products.

The implementation of Digital Product Passports (DPPs) and Digital Material Passports (DMPs) are a necessary instrument, which the European Commission has called for, but which should now also be implemented in concrete terms, e.g. within the framework of Extended Producer Responsibility (EPR). DPPs and DMPs should contain relevant information, e.g. on the origin,

[9] Al Ouahabi, A., et al. „Mass spectrometry sequencing of long digital polymers facilitated by programmed inter-byte fragmentation". 2017. Nature Communications 8.1.

production or environmentally sound handling of products or materials, so that they can be reused by actors along the entire life cycle and recycled in a high-quality manner.

A central component for the implementation of DPPs or DMPs is the clear labelling and identification of products and materials. The technologies that can be used to achieve this were examined in the article.