PIONEER PROJECT

HolyGrail: tagging packaging for accurate sorting and high-quality recycling

Pioneer project HolyGrail aims to speed up the transition to a circular economy for plastics by focusing on an important pillar to increase recycling rates, namely improved sorting of post-consumer packaging with the help of chemical tracers and digital watermarks. Next to designing plastics packaging for circularity and ensuring they are collected after use, high quality sorting is a crucial component to increase current poor recycling rates. Improved sorting can improve both the quality and quantity of recycled on the market, which would mean more plastics go back to the marketplace and bring value instead of becoming waste.

The concept of a circular economy is gaining traction all over the world. We need to move away from the linear plastics economy, where we take, make, and waste plastic - towards a circular system, where we keep useful plastics in the economy and out of the environment.

To keep plastics in circulation, we will need actions on several fronts. In addition to the elimination of problematic and unnecessary plastics, and switching from single-use to reuse models, recycling the plastics that we do need is crucial. However, today only a very small fraction of plastic packaging is actually recycled.

One of the biggest hurdles to high volumes and quality of recycled plastics is the complexity of the packaging design. Countless packaging formats with many material combinations are in use while the sorting technology on the end-of-use side is capable

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of recognising only a few properties (such as 3D vs. 2D shapes or different infrared absorption for different polymers and/or VIS for colour recognition). There are several examples where the design of packaging disrupts the recycling, either by making an item 'invisible' (e.g. black PET trays cannot be seen by detectors) or leading to false positives/negatives (such as the negative sorting of a full-sleeve PET bottle because the sleeve is typically made of a different material which means the PET is not detected).

One approach to improve automated detection and sorting that has received a lot of interest is to 'tag' an item with a unique 'code'. There are several ways of doing this. The methods that have received the most interest involve chemical tracers and digital watermarks. Tagging is accomplished by applying chemical(s) to the label, sleeve or plastic object (chemical tracers) or by applying a 'digital watermark', which can be printed on the label (shrink sleeve, in-mould label, paper or other material) or physically incorporated as a subtle pattern embossed in the plastic itself. Pioneer Project HolyGrail was set up to investigate if such chemical tracers and digital watermarks could provide a reliable and efficient tagging system that could eventually be deployed on a large scale, and if so how they might contribute to a circular economy for plastics.

HOW DOES TAGGING WORK?

Chemical tracers and digital watermarks tag items use the same basic principle – they introduce a machine-readable code or identifier into an item. Then, rather than relying only on the ability to distinguish one or several properties of collected items (e.g. shape, density, IR spectrum of the resin, visual identification), detecting and reading the code provides the sorting system with information unique to that item by pointing to a database where that information is stored. The information tells the system in which way to sort the item (e.g. food grade vs. non-food-grade) Such information can be updated and expanded over time, e.g. to allow for changing sorting preferences if an items recyclability improves. The main difference is in how the code is applied:

- A chemical tracer is a molecule embedded in the plastic resin or packaging component such as a label, acting as a binary 'code' as the chemical is either present or not. The molecule is detectable due to its spectroscopic properties (e.g. being fluorescent under UV light). In principle, it is possible to combine several different tracer molecules, each with unique spectra, to increase the number of possible codes. Packaging marked with such chemicals can be identified and sorted using sorting equipment that is modified with UV lighting. The chemically tagged item is insensitive to deformation or other physical stress which would otherwise reduce the detectability of many items.
- A digital watermark is an optical code the size of a postage stamp, applied directly within the item's label artwork or embossed in the mould, usually in a repeatedly-tiled manner. The code is created by subtly modulating the pixels that make up the design, or by adding micro-topological variations to the surface of the plastic as a texture - there is no need for added materials. In addition to detection by an added camera/processor on a sorting machine, digital watermarks can be detected by barcode scanners and smartphones, in practice turning the tagged items into Internet-of-Things object. The codes can provide a wide range of attributes such as manufacturer, SKU, type of plastics used and composition for multi-layer objects, food vs non-food usage, etc. The number of available codes is virtually unlimited, attributes can be added over time, and false positives eliminated.

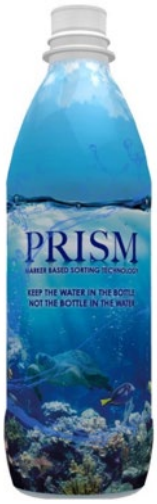
There are several intuitive advantages of chemical tracers and digital watermarks.

- The technologies enable sorting of much higher granularity and quality
- Retrofitting existing sorting equipment with add-on modules for detection of chemical tracers or digital watermarks is likely less CAPEX intensive than upgrading recycling facilities with more sophisticated detection technology based on material properties.
- The machine-readable codes could also be utilised to enable other applications throughout the value chain. For example, digital watermarks could be used in manufacturing, for faster checkout in retail applications, and to

provide information transparency and communicate with users. In principle, it could be possible to access data in real time, and to get accurate actual recycling figures broken down to format or individual product level. This could be used to inform better design choices to eliminate packaging elements that cannot be recycled.

However, it is important to investigate how these technologies fit in the broader recycling ecosystem and actually contribute to a circular economy for plastics.

Figure 1: Application of chemical tracers and digital watermarks



Chemical tracers are applied to the shrink label or plastic object and can be detected under UV lighting

For a demonstration, **click here**.

As seen by the camera, but no human recognizable pattern to code

Database holds product attributes:

- Manufacturer
- SKU/Global Trade Item Number
- Composition and percentage of plastics in layers
- Food vs Non-food
- Other attributes as desired

Digital Watermarking

For a demonstration, **click here**.

Methodology and process

At the start of HolyGrail, a small core project team was formed that looked into all available technologies in the market. A handful of chemical tracer programs were studied at that time, but none of them entered the market, likely due to lack of alignment within the full packaging chain on one technology (or several compatible ones). Digital watermarking was a completely new concept for plastic packaging recycling. The project was motivated by the belief that new sorting technology for plastic packaging truly requires first cross-value chain alignment on which technologies to use, so that they ultimately would become the "barcode of recycling", before market introduction can take place.

The project team started with organizing a public workshop (2017) to accelerate interest in the topic, which with over 85 participants was a real success. Some key items (that 99% of participants agreed to) were identified:

i. the packaging industry needs a non-permanent technology (to minimize the risk of cross contamination in the next cycle);

ii. preferably the selected technology is compatible with existing sorting assets (e.g. allowing easy retrofit of existing sorting units with add-on modules),

iii. the technology causes no issues with food safety (such as migration risks); and

iv. this "additional dimension in sorting" can solve the top 5 needs identified by the participants: 1. distinguish food from non-food (not possible with classical NIR/VIS sorters), 2. divert easily compostable packaging from Material Recovery Facilities, 3. proper identification of all kinds of full-body sleeved (PET) bottles, 4. Allow new material introductions by proper control of their after-use material flow (no risk of polluting established streams), and 5. crack the challenge on multi-layer/material components (film, tray, bottles…).

A key focus of the group has been on evaluating the potential of digital watermarks, given this new technology can provide benefits across the full value chain in addition to sorting (QA and inventory management at fillers, consumer engagement including anti-counterfeit, fast check-outs at retailers and packaging transparency at end-of-use, e.g. code info for high quality sorting). Proof-of-concept trials with digital watermarks both in printed materials, as well as codes directly embedded in the plastic mould, have been studied and a comparison is made with best-in-class tracer technology PRISM, which was already in development prior the start of HolyGrail and which has continued developing, resulting in high yields/purity proven in full scale industrial trials at the end of the project in 2018.

Since its initiation in early 2017, project HolyGrail has received a lot of traction from both industry and local and EU governments, in addition to associations (like Petcore Europe, PCEP, Plastic Recyclers Europe to name a few).

Further information on methodology (and most up-to-date technical results/implementation approaches) is available in the external presentation deck "Pioneer Project HolyGrail: Global project on Markers and Digital Watermarks to promote sustainable management of plastic (packaging) waste" which can be acquired upon request by writing to the project leader (email: debelder.g@pg.com) or attending one of the conferences where this project is featured.

RESULTS TO DATE[1]

Project HolyGrail has focused on 2 key activities since it was set up in late 2016.

1. Compile an overview of the existing technology and ensure that the discussion has input from the entire value chain.
2. Conduct real tests and small-scale pilots with the most promising coding technologies to establish a proof of concept.

1. Broad value chain engagement has been secured

Participation in HolyGrail has grown significantly since its initiation and now includes stakeholders from the entire value chain (including firms and organisations from outside the New Plastics Economy participant group [see below]). This is key to determining how to use chemical tracer and digital watermarking technology in practice, since the whole value chain would need to agree on a number of principles as well as technical standards. The project group notably includes leading machine vendors Tomra and Pellenc, digital watermarking pioneer Digimarc and FiliGrade, a Digimarc licensee, as well as material producers, packaging manufacturers, brands, retailers and recyclers.

2. Basic proof of concept has been established

For chemical tracers, the UK-funded project called PRISM was started in 2016. PRISM has been led by Nextek which is also part of the HolyGrail participant group and concluded in 2018. It showed encouraging results for its pilot system to sort food grade plastics from non-food grade plastics. Sorting of full-sleeve PET bottles tagged with fluorescent tracers detected using a UV lamp resulted in high accuracy and yields at industrial speed.

The PRISM proof of concept is an important benchmark for digital watermarks. However, digital watermark testing started later and is in an earlier stage of evaluation. The project group has conducted testing to understand applicability of sorting of different packaging formats (e.g. food vs. non-food grade, dark trays, multi-layer structures, full-body sleeved bottles, flexible plastics, etc.) using digital watermarks in the label or the mould itself. The preliminary tests, are so far encouraging, showing that digital watermark technology works in several different applications, in addition to sorting food-grade and non-food grade, and can be retrofitted into sorting facilities. A final round of tests within the current scope of the project is planned to conclude at end of May 2019, where watermark-enhanced plastics items mixed with true waste will be conducted.

1. As a complement to this report, the project group will produce a technical review which includes a more comprehensive technology review as well as a potential business model description. As the technology space is rapidly evolving, the technology review might also consider other options as they evolve, such as recognition-based sorting enabled by robotics and machine learning.

NEXT STEPS

Despite having made a lot of progress in the 2 years since Pioneer Project HolyGrail was initiated, much work remains to be done to understand how resin-independent codes could be used at scale. Aside from proving the technologies' robustness and actual value-adding potential, stakeholders need to agree on a common identification scheme in order to make it possible to implement codes as a basis for sorting at scale, with one option possibly being GS1-derived product attributes. Another open question is data ownership, how to finance the still significant investments required to retrofit machinery in recycling facilities. Project HolyGrail demonstrates that the science and invention aspects necessary for improved sorting are already in place, and the engineering and development aspects now need to be addressed.

For these reasons, a key remaining activity is to disseminate the findings of the project in the full value chain and engage more stakeholders in order to enable a potential roll-out of digital watermark/chemical tracer technology for plastic packaging. To take the technology further, a good next step would be a cross value chain pilot on a selected sorting technology in an industrial Material Recovery Facility. This could be conducted as a private partnership or partially EU- or regionally-funded initiative.

CONTRIBUTORS TO PIONEER PROJECT HOLYGRAIL

Pioneer Project HolyGrail was led by Procter & Gamble and facilitated by the Ellen MacArthur Foundation. The participant group consisted of representatives from the full packaging value chain, covering Brand owners, waste manufacturers, resin producers and converters, retailers, technology providers/consultants and investors.

WHAT ARE PIONEER PROJECTS?

Today's plastics system faces challenges that no organisation can address alone. Pioneer Projects are pre-competitive collaborations that are led and run by participants of the New Plastics Economy initiative. They invite stakeholders from across the plastics value chain to design and test innovations that could change the way we make, use and reuse plastics.

The **New Plastics Economy** Initiative is led by the Ellen MacArthur Foundation. The Foundation works with business, government and academia to build a framework for an economy that is restorative and regenerative by design.

The **Ellen MacArthur Foundation** is not to be held responsible for any output from the Pioneer Projects. It focuses only on facilitating the setup and engaging in the process, and on encouraging circular economy thinking and the application of a systems perspective.