GO!PHA
Global Organization for PHA

The Global Organization for PHA - GO!PHA
Oudebrugsteeg 9
1012JN Amsterdam
The Netherlands
info@gopha.org
www.gopha.org

What about recycling of PHA-polymers?

Exploring the end-of-life options of PHA

GO!PHA White Paper #7 – 15 May 2020

Jan Ravenstijn, Co-founder of GO!PHA,
Phil Van Trump, Chief Technology Officer, Danimer Scientific

The PHA-platform consists of products that meet the needs of all known end-of-life options. In this article we shall explain the details behind this statement and its implications.

In numerous countries and geographic areas people are rightfully fed-up with the plastic waste streams they see everywhere, including on land and in rivers, lakes and oceans. This plastic waste mountain is growing rapidly year after year. While the visible part of our plastic waste is readily apparent, the non-visible part is even larger.

There are at least two main reasons driving the increased rate of this invisible waste: first, more than 90% of the plastic waste in our water streams sinks to the bottom due to fouling of the plastic waste surfaces; and second, plastic micro-particles from our clothes and a large variety of products we use daily not only end up in water streams, but also show up on land and in our food chain in unseen ways. Needless to say, action is long overdue.

There are excellent initiatives in place to retrieve plastic waste from oceans and rivers, but that retrieval can lead to a simple recycling of those plastics to make articles that people then throw back into the oceans again. We can subsequently retrieve that waste again from the ocean, and while that is technically a circular economy, it certainly is not one that we should aspire to create.

Also many legislative efforts around the globe aim to curb undesired plastic waste streams. The approach taken by legislators in different geographic areas all want to stop the use of large volume fossil-based polymers for many single-use plastic articles to avoid visible or environmentally harmful pollution on land or in water.

Some legislators aim to replace the currently used polymers by biodegradable polymers, but are still in the process to define what that means. Others tend to only allow the use of natural materials for single-use applications, since those “are biodegradable in nature”. However, natural materials like wood are not biodegradable in water. Wood consists of cellulose and lignin, while lignin is not biodegradable in a marine environment, since it needs fungi to biodegrade and those are not present in water. Shipwrecks lie on the bottom of the ocean for centuries already.

So the question is: “How can we remedy the challenge lying before us?”

In the ideal situation we are looking for innovative, new materials that can be used in a large variety of applications and for which all known end-of-life options are a possibility. After taking steps to the reduce use and redesign plastic articles, legislators, manufacturers, retailers and communities should consider the following end-of-life options:

Recycle articles to be used again	→	re-use the article
Recycle articles back to the polymer	→	use the polymer for new applications
Recycle articles for raw materials	→	use renewable carbon as feedstock
Recycle to environment composting	→	industrial or home composting
Recycle articles for incineration	→	produce renewable energy
Recycle to nutrients for living organisms	→	full biodegradation, denitrification

One cannot be selective and use just a few of these end-of-life options; they are all important and critical to ensuring as much material as possible is responsibly recycled, reused or composted. If this can be accomplished with new, innovative materials that account for all these options, then manufacturers can ensure their products minimally impact the environment regardless of whether people are disciplined enough to recycle material the way it is supposed to be. If people instead are purposely or accidentally wasting material by throwing it away on land or in water streams, then full biodegradation is a must-have.

Perhaps it is good to make a few additional remarks on each of the end-of-life options mentioned:

1. <u>Recycle articles to be used again</u>

   We all know the large soft drink bottles, the sturdy plastic shopping bags, the beer crates and many other examples that are used time and again. Although it is very good we use these articles many times, it should also be realized that wear can generate primary micro-plastics that end up in the world oceans.

   A good example is the use of synthetic fibers for products like T-shirts. Yes, T-shirts are used and washed several times, but every time in the laundry it loses fibers to the waste water stream. According to the International Union for Conservation of Nature synthetic fibers are responsible for 35% of the primary micro-plastics that end up in the world's oceans. This adds up to many thousands metric tons of plastic.

   Wouldn't it be nice if these synthetic fibers could be made from material that is biodegradable in the oceans?

2. <u>Recycle articles back to the polymer</u>

   This is done for polymer based articles that are sold in very large volumes, so the logistics to get the used articles back into a polymer processing plant are worth organizing. In this case the polymeric material is molten and put into a different form. An example is the use of PET bottles to recycle this polymer which is then used for spinning synthetic fibers.

   All thermoplastic can be recycled this way provided they can be obtained relatively pure. However, re-melting and re-processing polymers can only be done 2 or 3 times. Every time the polymer molecular weight will reduce, so the physical properties will deteriorate some. Eventually one has to go to the next step.

3. Recycle articles for raw materials

   This can be done for all carbon containing materials, so also for most thermoplastic and thermoset polymers. The material could even be “contaminated” with other organic waste streams. It is used as feedstock for the manufacturing of chemicals. This source of renewable carbon is called “Renewable Carbon from the Techno-sphere” in a report from the nova Institute.

   Several global companies developed technology and built manufacturing plants to produce renewable chemicals from these recycle streams. Contaminated plastic waste from the oceans is one of the very good sources for this process.

4. Recycle to environment composting

   Industrial composting takes place at elevated temperatures and was originally developed to manage agricultural and forestry waste streams and turn these into a useful product: compost. Standards have been developed to demonstrate whether polymers are industrially compostable. These standards usually define a part thickness for the material that is tested. It should be noted that thicker parts take (much) longer to fully biodegrade under the test conditions and might take too long to fully biodegrade.

   Home composting is done at ambient temperatures, so materials that biodegrade under industrial composting conditions, might not (sufficiently) biodegrade under these conditions. For this there are also standards available.

   Polymers that qualify for environment composting are usually aliphatic polyesters, cellulose and starch. However, some limited aromatic structure can be allowed in the polyesters.

5. Recycle articles for incineration

   If there is no option to recycle polymeric materials according to any of the abovementioned methods, one can always use the energy captured in these polymers for making electricity. Here a similar reasoning applies as mentioned under point 3, albeit that in this case one doesn’t make new chemicals, but energy instead.

   However, it’s always better to gain energy from non-carbon sources, like sun, wind, tidal, white water or nuclear.

6. Recycle to nutrients for living organisms

   Living organisms like bacteria and fungi feed on nutritious materials, so when polymeric materials end up on land or in water streams either by design or accidental they should serve as nutrients. There are several polymers that biodegrade on land, but the number of polymers that also biodegrade in sweet and salt water is limited. The polymers of the PHA-platform that are currently produced industrially meet this requirement though.

   There is an additional functionality of the PHA polymers here, since they are known to denitrify waste water streams, because they act as a solid-state carbon source in converting nitrogen compounds, like nitrates, nitrites and ammonia, into nitrogen gas. A **GO!**PHA white paper written by Anindya Mukherjee describes this in detail.

Polymeric materials that can fully meet a comprehensive combination of end-of-life options include cellulose, a large number of PHA-polymers and starch or combinations of each of these. All these materials already occur in nature as they are made by biological synthesis through bacteria based on natural nutrients or feedstock.

A large variety of micro-organisms are known to make several different PHA-polymers in nature using different sources of nutrients, i.e. depending on their environment. These polymers serve as nutrients and energy sources and are known to be part of the metabolism of living organisms (plants, animals, humans).

Polyhydroxyalkanoates or PHA's are a series of natural bio-benign materials that have appeared in nature for millions of years, similar to other natural materials like wood, other cellulose based products, proteins and starch. During the last 20-30 years dozens of initiatives from all over the world have been started to make PHA materials useful for durable and structural applications as an alternative to the chemically synthesized polymers and by mimicking nature in a consistent way.

Today one has demonstrated the conversion of many different feedstock sources, like gas, liquid or solid waste streams to PHA polymers. After-use value chains are being created for several waste streams this way, resulting in a contribution to the circular economy.

PHA materials can substitute petroleum plastics for one-time-use applications that often by design or improper waste management end up in the environment (e.g. micro-beads in cosmetic products or drinking straws). Biodegradation of PHA materials in all environments (compost, soil, water) is comparable to or faster than cellulose (i.e. paper).

PHA materials can partly substitute any of the traditional fossil-based polymer families, so the accessible market for PHA materials is very large. Depending on type and grade, PHA materials can be used for injection molding, extrusion, thermoforming, foam, non-wovens, fibers, 3D-printing, paper and fertilizer coating, glues, adhesives, as additive for reinforcement or plasticization or as building block for thermosets in paints and foams. Also, their use in medical applications like sutures and wound closures is already commercial, since the material is bioresorbable.

A variety of PHA-polymers are currently made at industrial scale and these polymers have been demonstrated in at least 24 product-market combinations. Although PHA polymers cannot replace all existing fossil-based polymers, they technically fit in a large number of applications as a first step. The PHA-platform is an emerging new polymer platform and the major world producers today are small to mid-size enterprises. Industrialization of this new polymer platform started in 1992 and currently moves from the embryonic to the early-growth stage, while several companies around the globe have built and are building new large-scale manufacturing capacities.

GO!PHA
Global Organization for PHA

The Global Organization for PHA is a member-driven, non-profit initiative to accelerate the development of the PHA-platform industry. Polyhydroxyalkanoate polymers (PHAs) provide a unique opportunity as a solution for reducing greenhouse gases and environmental plastics pollution, and establishing a circular economy, by offering a range of sustainable, high-quality and natural products and materials based on renewable feedstocks and offering diverse end-of-life options.
GO!PHA provides a platform for creating and sharing experiences and knowledge and to facilitate joint development initiatives.

Become a member or sponsor to start sharing, contributing and collaborating to accelerate the PHA-platform industry.

www.gopha.org