HYDAL 360°STRATEGY

Circular Economy Solution for Biopolymer Production

White Paper

July 2019
TABLE OF CONTENTS

1. HYDAL STORY ....................................................................................................................5

2. THE CHALLENGES ...........................................................................................................6
   2.1 Current Challenges .........................................................................................................6
   2.1.1 Contamination with Synthetic Plastics and Microplastics .........................................6
   2.1.2 Linear vs Circular Economy ......................................................................................7
   2.2 Replacing Synthetic Plastics with New Materials .........................................................8

3. SOLUTION IN THE FORM OF HYDAL ...........................................................................9
   3.1 Key Features of the Hydal Concept ................................................................................9
   3.2 Competitive Advantage of the Technology ...................................................................11
   3.3 R&D Ecosystem ...........................................................................................................12

4. HYDAL TECHNOLOGY DEVELOPMENT ......................................................................12
   4.1 PHA Biopolymer and Hydal Technology Description ..................................................12
   4.1.1 About PHA ..............................................................................................................12
   4.1.2 Hydal Technology ....................................................................................................13
   4.1.3 Biodegradability of Biopolymer ................................................................................13
   4.2 Independent Evaluation of the Technology and Business Strategy ...............................15
   4.3 The State of Technology Development ......................................................................15
   4.4 IPR of the Hydal Concept ............................................................................................15
   4.4.1 Strategic Collaboration and Value Chains .................................................................16
   4.4.2 IPR of the Hydal Concept .........................................................................................16

5. CURRENT HYDAL APPLICATIONS .................................................................................16
   5.1 Cosmetics Industry .......................................................................................................16
   5.1.1 Coconut Shower Milk with Natural pPolymer P3HB ..................................................16
   5.1.2 LCA of Hydal Manufacturing Process ....................................................................19
   5.1.3 Sunscreen with Natural UV Protection ....................................................................20
   5.1.4 Results of the Comparison of the Environmental Impacts of the Mineral UV filters and Niopolymer P3HB Production Using the LCA Method ..........................................................21

6. TEAM MEMBERS .............................................................................................................22

22
LIST OF ABBREVIATIONS

B2B
Business to business, also called B to B or B2B, is a form of transaction between businesses, such as one involving a manufacturer and wholesaler, or a wholesaler and retailer.

B2C
Business to consumer (B2C) refers to the transactions conducted directly between a company and consumers, who are the end-users of its products or services.

IPR
Intellectual property rights refer to the general term for the assignment of property rights through patents, copyrights, and trademarks. These property rights allow the holder to exercise a monopoly on the use of the item for a specified period.

LCA
LCA is the compilation and evaluation of the input, output, and potential environmental impact of a product system throughout its life cycle. It is sometimes also referred to as a life cycle analysis, eco-balance, or cradle-to-grave analysis.

P3HB
Poly-3-hydroxybutyrate (P3HB) form of PHB is probably the most common type of polyhydroxyalkanoate.

PBAT
Polybutylene adipate terephthalate is an aliphatic-aromatic copolyester that has the properties of conventional polyethylene, but is fully biodegradable in industrial composting facilities. PBAT is made from fossil petroleum with first attempts being made to produce it partly from renewable resources.

PBS
Polybutylene succinate, a 100% biodegradable polymer, made from (e.g. bio-BDO) succinic acid, which may also be bio-based.

PET
Polyethyleneterephthalate, transparent polyester used for manufacturing bottles and film. The polyester is made from monoethylene glycol (MEG) that can be renewably sourced from bio-ethanol (sugar cane) and (until now fossil) terephthalic acid.

PHA
Polyhydroxyalkanoates (PHAs) or the polyhydroxy fatty acids, are a family of biodegradable polyesters. As in many mammals, including humans, PHA holds energy reserves in the form of body fat. There are also numerous microorganisms that hold intracellular reserves in polyhydroxy alkanoates. The microorganisms store a particularly high level of energy reserves (up to 80% of their own body weight) for times when their sources of nutrition become scarce. By farming this type of bacteria and feeding them on sugar or starch (mostly from maize), or at times on plant oils or other nutrients rich in carbonates, it is possible to obtain
PHAs on an industrial scale. The most common types of PHAs are PHB (Polyhydroxybutyrate, PHBV and PHBH). Depending on the type of bacteria and feed, it is possible to produce PHAs with different mechanical properties: rubbery soft, stiff, or even as hard as ABS. Some PHAs are biodegradable in soil or in marine environment.

**PHB**
Polyhydroxybutyrate (PHB) is a type of polyhydroxyalkanoates (PHAs). Polymers belong to polyesters class, and they are of interest as bio-derived and biodegradable plastics. PHB is produced by microorganisms, primarily as a product of carbon assimilation (from glucose or starch), and is employed by microorganisms as a form of energy storage molecule to be metabolized when other common energy sources are not available.

**PHBV**
Poly(3-hydroxybutyrate-co-3-hydroxyvalerate), commonly known as PHBV, is a polyhydroxyalkanoate-type polymer. It is a thermoplastic linear aliphatic polyester that is biodegradable, nontoxic, biocompatible, and is produced naturally by bacteria. It provides a good alternative for many non-biodegradable synthetic polymers.

**PLA**
Polylactide or Polylactic Acid (PLA), a biodegradable, thermoplastic, linear aliphatic polyester based on lactic acid, is a natural acid mainly produced by the fermentation of sugar or starch with the help of micro-organisms. Lactic acid comes in two isomer forms, i.e. as laevorotatory D(-)lactic acid and as dextrorotary L(+)lactic acid. Modified PLA types can be produced by using the right additives or by certain combinations of L- and D-lactides (stereocomplexing), which then acquire rigidity for being used at higher temperatures.

**PTC**
Plant PET Technology Collaborative. In June 2012, the Coca-Cola Company, Ford Motor Company, H.J. Heinz Company, NIKE, Inc. and Procter & Gamble announced the formation of the PTC, a strategic working group focused on accelerating the development and use of 100% plant-based PET materials and fibers in their products.

**SDG**
Sustainable Development Goals is a collection of 17 global goals set by the United Nations Development Programme.

**TRL**
Technology readiness levels (TRL) is a method of estimating technology maturity of Critical Technology Elements (CTE) of a program during the acquisition process.

**WCO**
Waste cooking oil
1. HYDAL STORY

**Motto:** “The dual advantage resulting from Hydal technology and the final product makes this technology a visionary innovation from which both the environment and humanity itself will benefit.” Evaluation Report of Hydal BioTech Frost and Sullivan, page no. 4

Hydal is a technology for producing fully biodegradable and biocompatible PHA biopolymers from waste cooking oil. Biotechnology, which has global potential, meets all the criteria of so-called circular economy, and represents one of the solutions for plastic pollution. As the first technology in the history of the Czech Republic, it won the Frost and Sullivan Technology Innovation Award and other world awards. In 2012, the technology acquired its name – Hydal (abbreviation of Polyhydroxyalkanoates).
2. THE CHALLENGES

The current world is facing a number of challenges, however, they are also the engine of key innovations. At NAFIGATE, we have defined three challenges that for Hydal represent some new potential:

1. Contamination of the planet by synthetic plastics and microplastics.
2. Prevailing linear economy, in which we still operate, and the transition to a circular economy.
3. Replacing synthetic plastics with new materials that often pose a new problem, not a solution.

2.1 Current Challenges

2.1.1 Contamination with Synthetic Plastics and Microplastics

Plastic is a material with unique properties, but the amount of plastics being generated, and its insufficient processing and disposal has brought the world into a global plastic crisis. Plastics contaminated the land, rivers and seas. Every year, between 8 and 12 million tons of plastics get into the seas and oceans, and about 150 million tons of plastic waste means approximately 23 million tons of additives.

Microplastics were also detected in drinking water and even in remote areas without human activity. However, despite these warnings, plastic consumption grows exponentially, as well as the problem of plastic pollution. In fact, by 2050, there might be as much plastics as fish in the seas.

Forecast for plastics volume growth, externalities and oil consumption in a business-as-usual scenario:

![Forecast for plastics volume growth, externalities and oil consumption](source: EllenMacArthur Foundation: New Plastic Economy, 2016, pg. 28)
2.1.2 Linear vs Circular Economy

The world economy operates predominantly in the linear system, which simply means extracting raw materials, processing them, and manufacturing products, which is followed by their selling and consumption. The packaging and product after consumption is preferably sorted and recycled. In the worst case, it ends up in a landfill or incinerator. Thus, the linear economy depletes valuable resources and generates preventable waste.

Linear economy attitude to plastics gives rise to the fact that 95% of plastic packaging material value is lost to the economy after a short first-use cycle. Only a tiny fraction of plastics is recycled. The rest ends up as waste. Ellen Mac Arthur Foundation quotes an annual loss of $80-120 trillion each year:

Plastic packaging material value loss after one use cycle:

The opposite of the linear economy is a circular economy that is defined as a system in which resource input and waste are minimized by the use of “closing the loop” production. The aim is to prevent waste and use waste, especially in a material way (i.e. not only as an energy source).
2.2 Replacing synthetic plastics with new materials

Some new material solutions pose a high risk of potentially deteriorating plastic pollution. This is particularly the case of so-called biodegradable bioplastics. Some of the biggest risks are listed below:

1. Bioplastics are composite materials containing additives that are released into compost or/and the environment.

2. Most bioplastics, with some exceptions, need ideal conditions for their decomposition in industrial composting facilities (which are not available in most countries), i.e. the temperature between 60 and 70 degrees C, mixing, and fresh biomass (1 kg of bioplastics needs more than ten times the amount of compost).

3. Most bioplastics are made from so-called first-generation feedstock, which are rich in carbohydrates, such as corn, potatoes or sugar cane. The production is a subject to extreme energy and water consumption.

4. Despite the biodegradability certificates, bioplastics with more than 50% of PLA (polylactic acid) do not completely biodegrade, but disintegrate into microplastics.

5. When mistaken for conventional plastics, bioplastics might contaminate functional recycling systems.
3. **SOLUTION IN THE FORM OF HYDAL**

3.1 **Key Features of the Hydal Concept**

- **Material recovery of waste** – one of the priorities of the circular economy
- **Waste generation prevention** – waste is generated neither during the product development phase, nor during the production itself through the use of the remaining biomass.

- **Upcycling technology** – oil is not recycled from waste cooking oil, a completely different product is gained – biopolymer

- **Biopolymer PHA is produced by bacteria as a reservoir of energy for “worse times”** – bacteria have been part of our ecosystem for millions of years because they got to the planet from space.

- **Biodegradability in soil, water, and seas** – PHA represents food for other bacteria or other organisms. Thanks to these properties, PHA is fully biodegradable, which in other words means that it is fully utilized by nature.
Hydal brings the concept, in which PHA is produced from waste cooking oil by a simple process at affordable price, and the end of the life cycle is known already in the phase of development.

- Biocompatibility with human body and ecosystems
- Clear end of life cycle of products based on PHA – biodegradability, recycling, upcycling
- Elimination of environmental damage caused by microplastics and plastics
- “Closing the loop” strategy – collaboration with companies that agree to create the “closing the loop” concept. One such example is the cooperation with the Scandinavian giant ORKLA:
3.2 Competitive Advantage of the Technology

Unlike the competitors, the technology does not use crops or other feedstock, which requires the use of agricultural land. Hydal feedstock is primarily waste cooking oil of almost any quality. The technology solves the problem of waste cooking oil utilization, and at the same time saves water and energy production.
3.3 R&D Ecosystem

Our R&D ecosystem is based on the following features:

1. **Open Science and Open Innovation Concept** with a strong emphasis on international cooperation with all stakeholders in the value chain.

2. **Talent Management** – 3 of our chief scientists are under the age of 30, and represent the exceptional talents that make up the Hydal Concept.

3. **360° approach** – our solution is designed from feedstock to the end of life level. Each product that we develop and offer to the market underwent biodegradability tests in real conditions and LCA. All these documents are openly shared with the expert community.

4. **Education about biopolymers/bioplastics, plastics and circular economy** – educational activities are an integral part of our work.

4. **HYDAL TECHNOLOGY DEVELOPMENT**

4.1 **PHA Biopolymer and Hydal Technology Description**

4.1.1 **About PHA**

Polyhydroxyalkanoates (PHAs) or polyhydroxy fatty acids are a family of biodegradable polyesters. PHAs have unique properties, which are similar to synthetic polymers.

*Microphotography of bacteria with PHB granules*
4.1.2 Hydal Technology

Hydal technology enables the conversion of waste cooking oil into a high added-value product – biopolymer PHA. The conversion takes place in the following steps:

- Microbial fermentation, where bacteria “consume” waste cooking oil and transform it into granules of PHA stored inside the bacterial cell. This process is commonly called the upstream phase.
- Isolation of polymer from microbial cells is called the downstream process. This process involves the disintegration of microbial cells from which PHA granules are released.

The final polymer in the form of powder flake may be processed into granules, to which additives are added for stabilization, processing, and desired final product properties. Each blend is unique depending on the use in final products (cosmetics, medicine, agricultural products, etc.).

4.1.3 Biodegradability of Biopolymer

The “family” of biopolymers PHA was recognized as completely biocompatible and biodegradable with zero toxic waste (biodegradation residues are only water and CO₂). Their degradation occurs in humid conditions such as in soil, compost, fresh water or sea water in the presence of microorganisms, while the speed of degradation varies from a week to years, depending on the conditions (it may not degrade at all in dry conditions).

Hydal Powder represents particles for our cosmetics products. The study of biodegradation provided the evidence of biodegradability in fresh water. Independent testing of biodegradability in fresh water has proven excellent biodegradability of Hydal PHA. The concentration of bacteria in sewage treatment plants is about 10 times higher. The biodegradation of PHA Powder in the open environment lasts for several days. Biodegradation in seawater is significantly slower than in fresh water.
Comparative biodegradability test in fresh water:

Source: Institute of Chemistry and Technology of Environmental Protection, Laboratory of Biodegradability of Bioplastics, 4-8/2018; Based on ISO standard 14851: 1999

Comparative biodegradability test in fresh water:

Source: Institute of Chemistry and Technology of Environmental Protection, Laboratory of Biodegradability of Bioplastics, 4-8/2018; Based on ISO standard 14851: 1999
4.2 Independent Evaluation of Technology and Business Strategy

Excellency of know-how in converting toxic waste into high quality biopolymer was appreciated by significant awards:

- 2017 Seal of Excellence Horizon 2020
- 2016 Top 10 Product Award – Shenzen
- 2016 EASTERN EUROPEAN BUSINESS ELITE AWARDS
- 2016 Seal of Excellence Horizon 2020
- 2015 the 2015 Frost and Sullivan Technology Innovation Award for Hydal BioTech

4.3 The State of Technology Development

Hydal is currently in the TRL 9 phase. Based on the cooperation between NAFIGATE and Bochemie, the first factory for PHA production with the capacity of 1,000 t of biopolymer is being built in the Czech Republic. In 2019, we verified the suitability of another waste material – sludge palm oil for PHA production.

4.4 IPR of Hydal Concept

- Abrasive particles for cosmetics
- Bio UV protection
- New material base for 3D printing
- Bio-solvents
- Bio-based flavours and fragrances
- PHA-based fibers
- Medical applications
- Closed the loop bioplastics
4.4.1 Strategic Collaboration and Value Chains

We prefer a limited number of strategic collaborations with institutions and businesses that meet the following criteria:

1. **Hydal’s Synergy with the strategy of relevant company or institution.**
2. Willingness to share the risks of joint innovation projects.
3. Adopt long-term innovation projects.
4. Respect for the closing the loop concept – every new product must have a clear end of its life cycle, either by recycling or otherwise, before launching the R&D phase (no new waste concept).
5. Real projects with a clear and measurable goal – not marketing or so-called greenwashing PR projects.

4.4.2 IPR of the Hydal Concept

Intellectual property protection is an integral part of our concept. Our company is the so-called knowledge-based firm, which means that we create the know-how, which we sell and which creates our income. Our Hydal business model is based on:

- Selling licences in the form of project documentation for the construction of Hydal plants
- Selling (application) know-how
- Selling expert services

5. CURRENT HYDAL APPLICATIONS

5.1 Cosmetics Industry

5.1.1 Coconut Shower Milk with Natural Polymer P3HB

Hydal biotechnology might be used in various fields, and one of the applications is in cosmetics industry. In October 2018, NAFIGATE Cosmetics, a.s. in cooperation with NAFIGATE Corporation, a.s. introduced to the market Coconut shower peeling milk, in which microbeads are replaced with natural polymer P3HB.
Microplastics are solid plastic beads of less than five milimeters. In cosmetics, they are used as peeling particles in the form of polyethylene microbeads of less than one milimeter in their largest dimension that peel off dead skin cells. Once microbeads are washed off from skin, they get into water, where they do not biodegrade. Microbeads can cause plastic water pollution and be harmful to aquatic life because wastewater treatment plants cannot capture all such small particles.

According to the Institute of Hydrodynamics of the Czech Academy of Sciences, drinking water contains microplastics. Up to 30% of these very small particles of plastics, i.e. microplastics, remain in the water from which they cannot be removed.

Natural polymer P3HB is added to the shower peeling milk in the form of white particles, replacing the abrasive function of microbeads. Unlike other artificial abrasive materials used in cosmetics, the biopolymer is fully biodegradable. In contrast to other substances, it dissolves in water completely. According to our tests, biopolymers biodegrade in wastewater treatment plant within several days, in the open environment up to several dozen days. It does not harm nature and provides a solution to one of the most serious challenges in the cosmetics industry.
We prepared a concept called "Dedicated to You and Nature" for improving awareness among the target groups. The brand ambassador to the topic of microplastics is hawksbill turtle.
5.1.2 LCA of Hydal Manufacturing Process

The LCA quantified to what extent the Hydal manufacture process is positive or negative in relation to the environment. We have provided the LCA author with all necessary data from Hydal PHA production. The comparison with PE and PLA is based on available data. PE was chosen because we replace the ground PE in cosmetics with our output from Hydal production process.

Thanks to Hydal concept, excellent results have been achieved. The use of waste leads to so-called “avoided sources”. I.e. the positive impact of the production process on the environment is generated by the fact that thanks to the usage of waste, we do not consume natural sources, and thus save the necessary sources for production.

LCA – Environmental Impact Categories:

Method: CML-IA baseline V3.05/EU25/Characterization
Comparing 1kg Hydal PHB, 1kg Polyethylene (LDPE), granulate, and 1kg Polyactide, granulate
5.1.3 Sunscreen with a Natural UV Protection

In April 2019, NAFIGATE Cosmetics, a.s. in cooperation with NAFIGATE Corporation, a.s. introduced to the market a sunscreen, in which natural P3HB polymer fulfils the role of a chemical UV filter.

The new sunscreen with natural UV protection responds to the contamination of water with oxybenzone and other chemicals released from conventional sunscreen with chemical UV filters. Around 14,000 tons of sunscreen end up in the sea annually, but it does not harm only the marine ecosystem but also humans. Oxybenzone, which is an endocrine disrupter, penetrates organisms through the skin and is accumulated in adipose tissue.

In the case of mineral UV filters, the environmental impact of the production, which is classified in the next chapter, is the major issue.

**P3Hb natural polymer protects the skin from both UVA and UVB rays**, and also works right after the application. It is biodegradable and fully biocompatible, thus it harms neither humans nor nature, in contrast to chemical UV filters.
5.1.4 Results of the Comparison of Environmental Impacts of Mineral UV filters and Biopolymer P3HB Production Using the LCA Method

Methodology: ReCiPe Midpoint (E) V1.13 / Europe Recipe E
Comparing 1 kg Hydol PHB; 1 kg Titanium dioxide, chloride process; Titanium dioxide, sulphate process; 1kg Zinc oxide
6. TEAM MEMBERS

Motto: „The difference between good and excellent are team members”

Lenka Mynářová – Member of the Board

Stanislav Obruča – Chief Hydals scientist and author of the idea

Daniel Pohludka – Bio division president

Radek Přikryl – Chief scientist in the area of applications development