# Research and Innovation Action

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# Deliverable D6.7 - Report on the value chain analysis

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## SUMMARY

The present study is *Deliverable D6.7 Report on the value chain analysis*, resulting from *Task 6.5 Study of Value Chain*. The objective of Task 6.5 is to conduct a thorough description and analysis of the value chain to assess and optimize the entire process up to the delivery of the biopolymers in their final applications, including perspectives of logistics, and current and future value networks. As a result, *Deliverable 6.7 Report on the value chain analysis* 1) identifies and analyses existing value networks in plastics and related industry sectors and the core actors and the relevant business models in the current situation of the industry, 2) provides understanding of the market potential of the developed materials, and 3) includes a study of the existing value networks as well as of formation of new value networks to support the dissemination of the developed materials. As a part of the value chain analysis, a logistics study is carried out to optimize flows between all the steps in the value network.

The primary data was gathered during the years 2018–2021, and it includes thematic interviews and workshop data, embracing viewpoints from the NEWPACK partners and from organizations and experts involved in the plastic food packaging value networks and bioplastics industry. Based on this data, the report describes the actors, activities, and resources of the conventional plastic food packaging value network, the NEWPACK project value network, and the potential new commercial value network for NEWPACK products, as well as information about the relevant flows for producing the NEWPACK materials for the purposes of the logistics analysis. The primary data was supported by the data that was acquired through different online sources that allowed us to understand more the plastic and food packaging industries and how their characteristics influence the nature of existing plastic food packaging value networks, and the formation of new value network for the NEWPACK materials.

The data was inductively analyzed by identifying the themes emerging from empirical insights, and by following the logic of data reduction and display, and conclusion drawing. In the data analysis, the value networks for conventional plastic food packaging were identified and compared with the NEWPACK project network and the general commercial value network for the production of biobased plastic food packaging, in order to detect the differences between them, and to identify the actors, activities, and resources needed to form a new value network that supports the larger scale production and dissemination of the NEWPACK products in the future. This analysis further allowed evaluating the market potential of the developed materials. For the logistics analysis, all the flows were mapped to find the most challenging phases of the NEWPACK logistics network from the feedstock obtaining to the final disposal after the biopolymer use. The flows and processes are analysed using heuristic and qualitative methods such as analogies and scenarios for assessing the optimised logistics solutions in the value network.

Furthermore, the report detects network changes that can promote the formation of new value networks for the NEWPACK materials, and more generally, the change from conventional plastic packaging value networks toward value networks involved in production and use of biobased biodegradable plastic food packaging. The changes include: 1) *identifying and engaging new actors* to perform new value activities and provide new resources, required in transforming agro-food waste it into bioplastics, and in managing the end-of-life processes, 2) *creating new connections between new and existing actors* to distribute agro-food waste and transform it into bioplastics, develop the material for the specified needs of brand owners and produce it at large-scale, and manage the end-of-life processes, and *between existing actors* to communicate the market demands and make more sustainable and safe packaging decisions, and 3) *creating a network type of collaboration*.

The main results related to the logistics analysis underline the most critical flows taking place in the beginning of the NEWPACK logistics network where the volumes are high and durability low. Therefore,

structuring the feedstock flows between potato processor, glucose production and polyhydroxybutyrate (PHB) production has the biggest impact in minimizing the costs and environmental effects of the NEWPACK value network. The first presented scenario to optimize the flows is based on one PHB production plant with multiple potato peel sources, the second scenario presents a PHB plant close to a large potato processor, and the third scenario illustrates a decentralized pre-production for PHB close to multiple potato processors. The benefits and challenges are presented for each scenario.

Finally, if considering the increasingly growing bioplastics market and demand for polyhydroxyalkanoate (PHA) plastics, of which PHB is one example, and especially in the packaging sector, the future market potential of the NEWPACK products is relatively good. However, the developed processes and materials need still further research and optimization to be more economically and sustainably viable. Regardless of this, there are other ways in which the knowledge gained from the project can benefit the wider audience interested in this type of material. The members of the NEWPACK project can utilize the knowledge acquired from the project either by selling their knowhow to other businesses or license their intellectual property rights (IPRs) to commercial enterprises for the commercialization or further development and utilize the gained knowledge in their current operations with business actors and research organizations.

*This report has been prepared by Dr. Outi Keränen, Dr. Tuula Lehtimäki, and Dr. Timo Pohjosenperä, who work at the University of Oulu. The authors want to thank the project partners and the interviewees for their contribution to the report.*

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| bio-PA | Bio-polyamide |
| bio-PE | Bio-polyethylene |
| bio-PP | bio-polypropylene |
| bio-PET | Bio-polyethylene terephthalate |
| bio-PVC | Bio-polyvinyl chloride |
| CA | Cellulose acetate |
| $CO_2$ | Carbon dioxide |
| CTIC-CITA | El Centro Tecnológico de la Industria Cárnica - El Centro de Innovación y Tecnología Alimentaria |
| DSP | Downstream processing |
| EU | European Union |
| IPR | Intellectual property right |
| LCA | Life cycle assessment |
| LTU | Luleå University of Technology |
| PA | Polyamide |
| PBAT | Polybutylene adipate terephthalate |
| BBEPP | Bio Base Europe Pilot Plant |
| OLA | Oligomer lactic acid |
| PBS | Polybutylene succinate |
| PE | Polyethylene |
| PEDR | Plan for the exploitation and dissemination of results |
| PE-HD | High-density polyethylene |
| PE-LD | Low-density polyethylene |
| PE-LLD | Linear low-density polyethylene |
| PE-MD | Medium-density polyethylene |
| PEF | Polyethylene furanoate |
| PET | Polyethylene terephthalate |
| PHA | Polyhydroxyalkanoates |
| PHB | Polyhydroxybutyrate |
| PHV | Polyhydroxy-valerate |
| PLA | Polylactic acid |
| PP | Polypropylene |
| PTT | Polytrimethylene terephthalate |
| PVC | Polyvinyl chloride |
| SME | Small and medium-sized enterprise |
| SUP | Single-use plastic |
| UCSC | Universita Cattolica del Sacro Cuore |
| UOULU | University of Oulu |
| WP | Work package |

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# 1. INTRODUCTION

## 1.1 Context and background

The NEWPACK project intends to develop and validate new biodegradable plastic packaging films that can replace conventional plastic films of petrochemical origin. The feedstocks of the NEWPACK products are biological, coming from agro-food side-streams or waste, such as potato peels, crustaceans' shells, and wheat straw. This allows contributing to a production of value network that is in line with a circular economy approach. The project further develops advanced chemical methods that, by incorporating natural additives with antioxidant and antimicrobial properties, may extend the shelf life of packaged food products, and thus decrease food waste. As a result, two new biobased plastics that are blends of polylactic acid (PLA) and polyhydroxybutyrate (PHB) were developed in the NEWPACK project. The blends will be different from the most common conventional packaging plastic films (e.g., polyethylene terephthalate (PET), polyvinyl chloride (PVC)), which are dependent on fossil based raw materials. Furthermore, whereas other biobased plastics available on the market with similar applications (e.g., bio-polyethylene (bio-PE), bio-polyethylene terephthalate (bio-PET), bio-polyvinyl chloride (bio-PVC)) can be mechanically recycled at their end-of-life, by being biobased polymers, PHB and PLA are biodegradable and compostable at their end-of-life, which provides the potential for a blend material with a more resource efficient value chain and potentially decreased carbon emissions compared to the conventional reference technologies (e.g., Belboom & Leonard, 2016; Renewable Carbon News, 2019; VTT, 2018).

In general, the market for bioplastics is just starting, when compared with conventional plastics market. In 2020, the production capacity of bioplastics market was 2,11 million tons, including both non-biodegradable biobased plastics and biodegradable plastics, whereas conventional plastics market was producing around 368 million tons of plastics. In the bioplastics market, of the materials produced, the focus has shifted from the production of bio-PET to the development of polyethylene furanoate (PEF), which is a new polymer that is expected to enter the market before 2025. PEF is comparable to PET but 100 % biobased and is said to feature superior barrier and thermal properties, making it an ideal material for the packaging of drinks, food, and non-food products. Global differences of the bioplastics market are further remarkable. For example, Europe is viewed as one of the most potential markets for bioplastics, although that includes significant regional variation as well. In 2020, Europe's production capacity for bioplastics was around 26 % of the global production capacity, being the second largest, whereas as much as 46 % of the global production capacity for bioplastics was in Asia. (European Bioplastics, 2021.)

Our data describes the biobased plastics market in Europe as fragmented, illustrated by numerous small and medium-sized enterprises (SMEs) and relatively small production amounts for a variety of biobased plastic types. In the context of food packaging, there appears to be demand for more sustainable food packaging, but retailers wishing to use such packaging might find it hard to have a reliable supply of a suitable material for their exact use context. Furthermore, property requirements of the food packaging material are very specific depending on the packaged food, and thus, the still developing characteristics of biobased plastics face challenges in this respect. The bioplastics market, especially market for packaging made of biobased plastics, and the market for food packaging, are highly regulated, so the current and future regulations will largely affect the development of the market for biobased plastic food packaging. In addition, the value network for producing bioplastics differs in many respects from the conventional plastic value network, adding side stream feedstocks and their processors into the value network and changing the end-of-life services and technologies, as well as many other activities across the network.

Hence, there is a need to examine more thoroughly the value network for the production and the dissemination of biobased and biodegradable plastic packaging for food, and particularly, how the materials developed in the NEWPACK project could be diffused. This report focuses on those issues from the value network viewpoint, and as a result, provides understanding of the existing and potential value networks for producing and disseminating biobased biodegradable plastic food packaging by considering the specifics of the materials developed in the NEWPACK project and their market potential.

## 1.2 Approach for analysing the value chain: value network perspective

The objectives of Work Package (WP) 6 are: 1) to assess the economic viability of each product stream through the development of a technical and economic evaluation, 2) to guide the decision points throughout the project and assess economic viability, 3) to study the environmental suitability of the processes and associated bio-based plastics by means of a consequential environmental Life Cycle Assessment (LCA), 4) to ensure that the new material and their processing technology comply with the relevant regulatory landscape to achieve the biodegradability certification, and 5) to assess the market perception to ensure a market-driven research which is fully aligned with the customers.

This study follows the goal of Task 6.5 and the description for Deliverable 6.7 given in the Grant Agreement. Considering the goals for WP6, this Deliverable 6.7 contributes to the understanding of the economic viability and the market potential of the NEWPACK materials. The related Task 6.5 aims to assess and optimize the entire process up to the delivery of the biopolymers in their final applications. That includes an analysis of the value network and the related flows. In this context, optimization needs to be understood broadly because numerical data might be limited or rely on assumptions and evaluations. Therefore, the logistics analysis of this study uses more heuristic and qualitative methods, such as analogies and scenarios for assessing the logistics solutions in the value network.

Following the objectives of Task 6.5, Deliverable 6.7 presents an identification and analysis of existing value networks in plastics and related industry sectors, including packaging and food industries, and the core actors and the relevant business models in the current situation of the industry. In addition, an analysis of the existing industry data (interview data and documentary data) will contribute to the understanding of the market potential of the materials developed in the NEWPACK project. Finally, a study of the existing value networks and of the formation of new value networks will be included.

Value network is understood as a constellation of interrelated actors on the examined market, their activities and resources, and connections of these (e.g., Håkansson & Snehota, 1995). The value network includes all actors, ranging from feedstock providers to the end-of-life treatment of the packaging made of these materials. As the relationships between actors in the examined industry are complex, this study adopts the concept of “value network” instead of a more straightforward “value chain”. This is in line with the current understanding of business markets, as in today’s global and interconnected business markets it has been found to better capture the reality of the value creation and value capture processes (e.g., Dhanara & Parkhe, 2006; Peppard & Rylander, 2006; Möller & Halinen, 1999).

Furthermore, a key assumption in this report is that NEWPACK materials enter existing plastic food packaging value networks, in which conventional plastics are typically used. Hence, the new materials face the structures of the existing networks, and this report examines those structures via the actors, activities, and resources, and how they may change, if the packaging material is replaced with a biobased biodegradable packaging. At the same time, we acknowledge that the processes and materials developed in this research and innovation oriented NEWPACK project need further development and optimization before they are commercially viable. However, based on the data gathered for this report, we can make propositions now that can help in commercializing these materials, or similar materials, in the future.

The emphasis of this report is thus in analyzing the value network in question and the formation of future value networks for NEWPACK materials, and less emphasis is given on general market analysis of the current bioplastics industry, as there are already such market studies available by many organizations, of which the most referred are made by nova-Institut (see http://nova-institute.eu/), who publish their studies at http://bio-based.eu/ on an annual basis. In addition, a confidential *Deliverable 5.4 Report of the identification of residual barriers to further large-scale industrialization* is prepared within this project, and it covers market barriers and their potential solutions, and suggestions for a long-term market uptake plan for these materials. The general bioplastics market information provides important background insight for the actual analysis of the current and future value networks involved in production, dissemination and use of NEWPACK materials. Thus, information about the market situation is considered, but as a supporting element to the value network analysis. Furthermore, the closer analysis of the economic viability of NEWPACK products is presented in *Deliverable 6.1 Report on economic analysis,* which is public. Consumer perceptions are examined in closer detail in *Deliverable 1.3 Final product technical requirements, D6.5 Report on customer perception of the new packages with high performance coatings,* and *Deliverable 6.6 Customer perception of new biobased food packaging materials.*

The expert interviews and workshops represent a major source of information for this report, together with documentary data (details of the methodology are explained in Chapter 2. According to the selected approach for the value chain analysis and the underlying assumptions made in this study, the value network for the conventional plastic food packaging is first presented, followed by the description of the NEWPACK project value network, after which the possibilities for future value networks for NEWPACK materials are presented. In addition, a logistics analysis presents the related flows within the current project value network, and based on the identified development needs, presents three logistics scenarios. Based on these, conclusions about the future value networks for, and the market potential of NEWPACK materials are presented.

# 2. MATERIALS AND METHODS

## 2.1 Qualitative approach

Qualitative research methods are selected to identify and analyse the existing value networks in plastics and related industry sectors, the formation of new value network and to understand the market potential of materials developed in NEWPACK and thus facilitate their dissemination. Qualitative methods enable the investigation of the underlying qualities of entities, processes, and meanings (Denzin & Lincoln, 2011, 8) that form real-life organizations' settings (Gephart, 2004), such as business value networks. This means that qualitative researchers seek to examine the phenomenon in its natural setting through the meanings that individuals give to it to make sense of it, or to interpret it (Denzin & Lincoln, 2011, 3). Hence, qualitative methods permit analysing value networks and their differences through multiple perspectives, which tends to be difficult to measure through specific variables (Gephart, 2004), but which is important to understand the market potential and dissemination of the materials developed in the project. That is, qualitative methods enable us to explore the research phenomenon of interest through multiple perspectives and by considering its contextual details, thus creating an in-depth and holistic understanding from it.

## 2.2 Data collection

The primary data includes altogether 45 *thematic interviews* (Arksey & Knight, 1999, 7) with 65 informants, lasting from 30 to 90 minutes with the approximate length of 55 minutes. Thematic interviewing is a suitable data gathering method in this study as it facilitates the interaction between the interviewer(s) and interviewee(s), thus enabling the researchers to be more flexible during the interview. That is, thematic interviews permit the researchers to emphasize different themes depending on the interviewee's expertise and ask follow-up questions during the interview, if needed.

The interviewees were individuals from different organizational levels and units of firms, organizations, and research institutions, participating either in the NEWPACK project network or in the broader plastic food packaging network. The interviewees were selected because they had important insights on sustainable packaging material development, bioplastics and/or food packaging, and they represented different types of organizations and roles, which is important to analyze value networks as holistically as possible. The interviewee selection relied on a snowball sampling (Biernacki & Waldorf, 1981), which means that the interviewees were asked to recommend other interviewees, but in general the interviews started with the individuals from the project, from which they were then extended to include other external experts on this subject.

Although the questions slightly varied according to the expertise of interviewees, the general interview themes related to 1) the project value network (project members), 2) the existing and future value networks in plastics and related industry sectors, and 3) current and future possibilities and threats related to bioplastics. Altogether, 33 interviews included these themes (see Tab 2.1), and they were made during August 2018–December 2020 and finished when the data did not bring any new significant information. However, these interviews were supplemented with 12 further interviews with project partners (see Tab 2.2), which were held during September 2020–February 2021, to discuss specifics of the logistics analysis. In addition, a short survey was made to project members in the late spring 2021 to gather information about how they will utilize the knowledge gained in the NEWPACK project and whether they are interest in being involved in the commercial production of the NEWPACK materials in the future.

*Tab 2.1 Qualitative interview data*

| Informant(s) | Number of informants | Informants' organization type | Interview details |
|---|---|---|---|
| Research Funding Specialist | 1 | University I | 8.8.2018, 40 min. |
| R&D Engineer I | 1 | Packaging manufacturer | 14.8.2018, 90 min. |
| R&D Director and 2 Product Technicians | 3 | Brand owner I | 4.9.2018, 30 min. |
| Senior Sustainability Consultant | 1 | Consulting of sustainable development | 12.9.2018, 55 min. |
| Innovation Manager | 1 | Brand owner II | 8.10.2018, 60 min. |
| Sustainability Manager and Project Manager | 2 | Retailer and brand owner | 5.11.2018, 70 min. |
| Head of Department of Life Sciences | 1 | Research institute I | 8.4.2019, 45 min. |
| R&D Engineer II | 1 | Packaging manufacturer | 10.4.2019, 50 min. |
| European Project Manager | 1 | Consulting of agricultural business | 16.4.2019, 30 min. |
| Technology Development Manager | 1 | Brand owner and feedstock supplier | 8.5.2019, 80 min. |
| Director of Bioprocesses Area, Researcher and Project Manager | 3 | Research and innovation center | 2.5.2019, 50 min. |
| R&D Project Manager and Researcher | 2 | Innovation center for plastics | 6.5.2019, 55 min. |
| Process Engineer and Team Leader | 2 | Scaling-up laboratory | 20.6.2019, 50 min. |
| Senior Scientist | 1 | Research institute II | 28.8.2019, 90 min. |
| CEO | 1 | Waste management facility | 24.9.2019, 40 min. |
| Associate Professor | 1 | University II | 22.10.2019, 35 min. |
| Professor of Wood and Bionanocomposites | 1 | University III | 23.10.2019, 40 min. |
| Project Manager | 1 | Technology center for agriculture | 30.10.2019, 50 min. |
| Account Manager | 1 | Industrial equipment supplier | 13.8.2020, 50 min. |
| Researcher | 1 | University IV | 18.8.2020, 90 min. |
| Head of Packaging Development | 1 | Brand owner | 20.8.2020, 40 min. |
| Researcher | 1 | University I | 25.8.2020, 45 min. |
| Development Manager | 1 | Biogas producer | 27.8.2020, 45 min. |
| IPR Specialist | 1 | University I | 28.8.2020, 40 min. |
| Key Account Director | 1 | Package converter | 1.9.2020, 60 min. |
| Professor | 1 | University V | 1.9.2020, 70 min. |
| Principal Scientist | 1 | Research institute III | 2.9.2020, 60 min. |
| Chief Sales and Marketing Officer | 1 | Package converter | 14.9.2020, 60 min. |
| Commercial Director and Public Affairs Manager | 2 | Bioplastics manufacturer | 22.9.2020, 60 min. |
| Negotiating Official | | Ministry of Economic Affairs and Employment | 2.10.2020, 65 min. |
| Company Owner | 1 | Bioplastics manufacturer and importer | 16.10.2020, 55 min. |
| Director and Ministerial Adviser | 2 | Ministry of the Environment | 4.11.2020, 65 min. |
| Sustainability Manager | 1 | Brand owner and retailer | 11.11.2020, 40 min. |

*Tab 2.2 Qualitative interview data for the logistics analysis*

| Informant(s) | Number of informants | Informants' organization type | Interview details |
|---|---|---|---|
| Sustainability Consultant I & II | 2 | Consulting of sustainable development | 8.9.2020, 50 min. |
| Associate Professor, Research Fellow, Researcher | 3 | University II | 29.9.2020, 60 min. |
| Sustainability Consultant I & II | 2 | Consulting of sustainable development | 11.11.2020 45 min. |
| Process Engineer | 1 | Scaling-up laboratory | 17.11.2020, 60 min. |
| R&D Project Manager | 1 | Packaging manufacturer | 15.12.2020, 60 min. |
| R&D Project Manager and Researcher | 2 | Innovation center for plastics | 18.12.2020, 60 min. |
| Sustainability Consultant I & II | 2 | Consulting of sustainable development | 26.1.2021, 50 min. |
| Innovation Manager | 1 | Brand Owner II | 2.2.2021, 55 min. |
| Project Manager, Area Director, Researcher | 3 | Innovation center for plastics | 12.2.2021, 60 min. |
| Project Manager (2) | 2 | Technology center for agriculture | 16.2.2021, 60 min. |
| Associate Professor, Researcher | 2 | University II | 19.2.2021, 50 min. |
| Process Engineer | 1 | Scaling-up laboratory | 27.5.2021, 45 min. |
| Professor, Associate Professor (3) | 4 | University II | 29.3.2021, 45 min. |

Besides thematic interviews, primary data was acquired through *three internal workshops* for the project members and through *five external workshops*, including viewpoints from different associations and research institutions and innovation centres related to plastic food packaging and the bioplastics market (see Tab 2.3). These workshops refined the discussions and themes of the interviews.

*Tab 2.3 Workshop data*

| Workshop number | Discussion details | Participant(s) | Organization types |
|---|---|---|---|
| 1 | 10.2.2021, 85 min. | Business Development Manager | Scaling-up laboratory |
| | | Professor I | University |
| | | Sustainability Consultant I | Consulting |
| | | Project Manager I | Technology center for agriculture |
| | | R&D Project Manager I | Technology center for agriculture |
| 2 | 23.2.2021, 110 min. | Project Manager II | Research and innovation center |
| | | Sustainability Consultant II | Consulting |
| | | Project Manager III | Packaging manufacturer |
| | | R&D Project Manager II | Innovation center for plastics |
| | | Researcher | Innovation center for plastics |
| 3 | 24.2.2021, 40 min. | Professor II | University |
| 4 | 12.4.2021, 85 min. | Project Manager IV | Biomaterial innovation center |
| | | CEO I | Packaging association |
| | | CEO II | Plastics industry association |
| 5 | 15.4.2021, 50 min. | CEO III | Plastics recycling community |
| 6 | 26.4.2021, 45 min. | Regulatory Affairs Manager | Potato trade and processing association |
| 7 | 27.4.2021, 75 min. | Founder/Consultant | PHA association |
| 8 | 29.4.2021, 75 min. | Environmental Affairs Manager | Bioplastics association |
| | | Project Coordinator | Research project I |
| | | Scientific Coordinator | Research project I |
| | | Project Coordinator | Research project II/university |
| | | Coordinator | Environmental association |

The secondary method to gather data included diverse types of online sources, which comprised bioplastic and food packaging industry related reports, journal and newspaper articles, blog posts, press releases, statistics, and directives and other policy documents. In total, the secondary data consisted of 120 items. The data triangulated the interview and workshop data and provided understanding of the plastic and food packaging industries and the bioplastics market, which was perceived important to understand the characteristics of existing plastic food packaging value networks and the potential of bioplastics in food packaging, and how those can influence the formation of new value network for the materials developed in the NEWPACK project.

### 2.3 Data analysis

The research process is inductive, meaning that the examination of the research phenomenon relies on empirical insights, from which the researchers detect broader patterns and regularities reflecting the value networks and their differences. The analysis further relied on the logic of data reduction, data display, and conclusion drawing (Miles & Huberman, 1994). In the first phase of the analysis, the existing value networks in plastics and related industry sectors, including packaging and food industries, were analyzed, and identified, primarily in terms of their actors, activities, and resources, and connections between these. Thereafter, the same analysis was made to the NEWPACK value network in order to understand the project network that developed, produced, processed, and tested the NEWPACK products. In the second phase, the identified three value networks were compared with each other in order to identify the main differences between them, and to evaluate the actions and changes needed to form a new value network to disseminate the materials developed in the NEWPACK project in the future. In the final, third phase of the analysis, all findings were brought together to draw wider conclusions about the market potential of the developed materials.

Logistic analysis, in turn, begun by mapping the logistics flows in the NEWPACK value network. During each interview the incomplete figure of the logistics flows were presented for the interviewees and further extended and elaborated by the received interviewee comments. When the figure began to include all the relevant information of the NEWPACK logistics flows, the optimization was conducted by first finding the most logistically challenging parts of the flows. These parts were further analyzed by forming three different scenarios that propose logistically optimized solutions to the identified challenging parts of the flows.

# 3. RESULTS AND DISCUSSION

This chapter begins with describing the characteristics of the plastic food packaging market to understand the context of the analysis. Thereafter, to constitute the value chain analysis, the value network for the conventional plastic food packaging is first presented, followed by the description of the NEWPACK project value network, after which the possibilities for future value networks for the NEWPACK materials are presented. Finally, a logistics analysis presents the related flows within the NEWPACK project value network, and based on the identified development needs, presents three logistics scenarios.

## 3.1 Plastic food packaging market

### 3.1.1 Characteristics of the plastics industry

The plastics industry is economically and globally significant. In 2020, around 368 million tonnes of plastics were produced globally (European Bioplastics, 2021). However, there is a limited number of large, established, international companies, who produce virgin polymers at large scale and for various industries. Examples of such large polymer producers are Dow Chemical, Hanwool Corporation, Lyondellbasell, Ihne & Tesch GmbH, ExxonMobil, Matsui Technologies India Ltd, SABIC, Acros Pvt. Ltd, BASF and Ser Rezistans A.s (Plastics Technology.com, 2021). In the European plastics market, in turn, plastics production in 2019 was around 58 million tonnes (PlasticsEurope, 2020), and the industry involves around 55 000 companies, most of them SMEs (PlasticsEurope, 2020). The five largest segments for the European plastics converters demand in 2019 were packaging (39,6 %), building and construction (20,4 %), automotive (9,6 %), electrical and electronic (6,2 %), and household, leisure, and sports (4,1 %). Furthermore, of the demand for plastic packaging, low-density polyethylene (PE-LD)/ linear low-density polyethylene (PE-LLD), high-density polyethylene (PE-HD)/medium-density polyethylene (PE-MD), polypropylene (PP) and PET represent the major part (PlasticsEurope, 2020).

Compared to the conventional plastics market, the market for bioplastics (including biodegradable and biobased/non-biodegradable plastics) is emerging, pushed by the request for sustainability, even though bioplastics are not a new invention. The first plastic materials used industrially were of natural origin, Polyamide 11 being the first technical bioplastic introduced on the market in 1947, and later followed in the 1990s by the bioplastics that we know today as PLA (e.g., NaturePlast, 2021). Furthermore, for example, PHB was invented in 1926 (e.g., Bioplastics News, 2018). The production capacity for bioplastics was 2,11 million tonnes in 2020 (European Bioplastics, 2021), and of that capacity, 58,1 % was for biodegradable and 41,9 % for biobased/non-biodegradable plastics. Of the biobased/non-biodegradable plastics production capacity, polyamide (PA) (11,9 %), polyethylene (PE) (10,5 %), polytrimethylene terephthalate (PTT) (9,2 %), and PET (7,8 %) are clearly the dominant materials, whereas among biodegradable plastics production capacity, starch blends (18,7 %), PLA (18,7 %), polybutylene adipate terephthalate (PBAT) (13,5 %) are dominating.

Bioplastics are used in an increasing number of applications, such as packaging, catering products, consumer electronics, automotive, agriculture/horticulture, toys, and textiles. Packaging is, however, the largest field of application for bioplastics with 47 % (0,99 million tonnes) of the bioplastics market in 2020. Of that, rigid packaging owned 0,44 million tonnes and flexible packaging 0,55 million tonnes. After those segments, consumer goods represented the third largest segment with 0,26 million tonnes production capacity for bioplastics. Segments, such as automotive and transport or building and construction, or electric and electronics keep growing their percentage of the production capacity of bioplastics. (European Bioplastics, 2021.)

Typically, operating in the plastics industry is capital intensive, as the machinery requires investments and is operated for a long time. Conventional plastics market is at its mature stage, where the related technologies and processes are established and working well. Any changes to the processes or machinery require breaks in production and/or investments, and thus actors want to plan such disruptions in the long term and to avoid them in the short term, to guarantee a continuing process. The growing demand of sustainability is, however, posing a challenge for the industry, and especially for the large petrochemical companies, which are largely relying on fossil raw materials. Such established, large companies producing original polymers would often benefit from keeping the market as it is, as confirmed by our interviewees. Such firms also rely on the growth of plastics use in general (Minderoo Foundation, 2021). Our interviewees reported that based on their experience, such firms will not be the first ones changing their business models because of the growing demand for biobased plastics - even though many of them have endeavors towards sustainability and circularity ongoing, they are still in a minor role in their businesses (see e.g., Minderoo Foundation, 2021). Indeed, firms focused on biopolymers are more likely to invest in research and development to drive innovation (Frost & Sullivan, 2019) than conventional plastic providers, and thus firms that have been focusing on the production of bioplastics are typically having a stronger foothold in the competition among the bioplastics market as compared to firms who are extending their synthetic offerings portfolio to cover biobased offerings (Frost & Sullivan, 2021b). However, the plastics industry is hard to enter due to the capital-intensive nature, established powerful companies, and competition among specialized plastics, for instance.

Our data shows that the sustainability pressure felt by firms operating close to consumers is not that much felt in the beginning of the plastics value network, but all firms are influenced by the tightening environmental legislation. However, criticism has been presented that so far, the legislative pressure towards sustainability, especially cutting down carbon dioxide ($CO_2$) emissions, has not been touching the petrochemical industry producing original polymers as much as those firms who manufacture products from those polymers (e.g., Charles, Kimman & Saran, 2021). Oil as a raw material for plastic is a root cause for the environmental challenges of conventional plastics and it is likely that in the near future, the sustainability pressure is increasingly felt by the established large conventional plastics providers. Based on our data, large, established plastics providers appear to prefer in-house material development programs, and it is not likely to expect that novel biobased materials, developed in smaller plastics companies would find a market path with their help in broad terms. Of course, there are exceptions and some large firms have chosen to acquire innovative new biobased material companies to complement their material portfolio. However, this means that generally the developers of new biobased plastics need to build their way to the market through selective partnerships and finding the right applications for their materials, as reported by our interviewees.

Variety of materials is typical to the current market for biobased plastics (typically more or less 20 types of biobased plastic mentioned in reports just to capture the most known materials, e.g., European Bioplastics, 2020a, and nova-Institut, 2013). In the category of biodegradable bioplastics, the production capacity for polyhydroxyalkanoates (PHAs) plastics was around 1,67 % and PLA represented 18,7 % of the total bioplastics production in 2020, PLA having the largest production capacity of all bioplastics together with starch blends (European Bioplastics, 2020b). PHAs are biopolymers based on bacteria, including biopolymers such as PHB, and polyhydroxy-valerate (PHV). Innovative biopolymers, such as bio-polypropylene (bio-PP) and especially PHAs continue to support the growth of the bioplastics production, and the importance of PHAs is expected to increase (Renewable Carbon News, 2020).

If looking back, in 2013, it was estimated that production capacity would be tripled before 2020, PET, PE/PP polymers and PLA and PHA having the fastest estimated market growth, and production be located especially in Asia and South America (nova-Institut, 2013). In 2013, the biobased production capacity represented a 2 % share of overall structural polymer production (256 million tonnes in 2013) (nova-Institut, 2013). In 2017, the markets for some biobased and/or biodegradable plastics were expected to grow significantly during the coming years (e.g., bio-PET, polybutylene succinate (PBS) and PLA), and others were expected to consolidate (e.g., cellulose acetate (CA) and bio-polyamide (bio-PA)). In overall, it was expected that by 2020 the share of biobased and biodegradable plastics will increase to 2,5 % of fossil plastics production. For most of the biobased and biodegradable plastics there were several suppliers, and most plastics were readily available. (Van den Oever et al., 2017.) In 2019, the total production volume of biobased polymers was 3,8 million tonnes (nova-Institut, 2019). Currently the production volume of bioplastics, including biobased and/or biodegradable plastics, is estimated to be around 1 % of nearly 368 million tonnes of global plastics production, the global production capacities of bioplastics being around 2,11 million tonnes in 2020, and majority of that being in Asia, Europe, North and South America (European Bioplastics, 2021).

Thus, the growth for bioplastics production has been slower than anticipated earlier, but the estimated 400 million tonnes for overall global plastics production (nova-Institut, 2013) has nearly been realized. It is estimated that partly the legislative stance to treat biobased plastics similarly to conventional plastics might have hampered market growth together with low crude oil prices (nova-Institut, 2019). Current estimates of the market growth for bioplastics represent this slower growth model, having production capacity of bioplastics to grow to approximately 2,9 million tonnes by 2025 (European Bioplastics, 2020b). Especially the amount of production capacity for biodegradable plastics (also non-biobased) is estimated to grow, more than the amount of biobased (non-biodegradable) plastics (European Bioplastics, 2020b).

Biobased plastics are currently produced largely over hundred companies over the world (Bioplastics News, 2020), which specialize in specific biopolymer types. Among our interview data, firms such as Braskem, Corbion, TianAn Biopolymer, Novamont and NatureWorks were mentioned as examples of broadly known bioplastics providers. For example, NatureWorks and Corbion have a strong hold of the PLA market, which has been growing rapidly because of the suitability of PLA for many packaging applications, whereas Braskem has developed a strong foothold based on its drop-in bioplastics that can easily be used to replace conventional plastics in existing production lines (Frost & Sullivan, 2021b). The biobased polymers market is consolidated, and in addition to those already mentioned, other large players mastering the market, include DuPont, DSM, BASF, and Biotec, among others (Frost & Sullivan, 2021a; Frost & Sullivan, 2021b; Markets and Markets, 2020).

Companies involved in the bioplastics market can be classified as 1) feedstock providers, 2) raw materials and additives producers, 3) semi-finished products producers (compounders etc.), 4) users, brand owners, applications, sectors, 5) trading (retailers and whole salers), 6) associations and federations, and 7) service providers (professional services to the bioplastics industry (Bioplastics News, 2020). Hence, when compared to the conventional plastics value network actors, the providers of feedstock are different for biobased plastics, and the processors of the biomass are added into the network (producing plastic granules, for instance). However, like conventional plastic value networks, one actor can operate one or more of these roles in the value network. The value networks for conventional plastic and bioplastic food packaging are discussed more in Chapter 3.2. and Chapter 3.3.

### 3.1.2 Characteristics of food packaging industry

The global food packaging industry size was around $ 300 billion in 2019 and it has been estimated to have 5 % annual growth rate between 2020–2027. The growing consumer demand for packaged food has a major impact on the market, and factors such as convenience and use of high-performance material are expected to accelerate industry growth. Improved shelf-life, coupled with heightened efficiency in the prevention of content contamination, is expected to further boost the growth of the market. In addition, factors, such as increasing population, rising disposable income, and shrinking households have a positive impact on the market. (Grand View Research, 2020.)

Major producers of food packaging in the market are present in North America and Europe, including Mondi Group, Amcor plc, Berry Global Inc., and Ball Corporation. For example, Mondi provides sustainable packaging and produces plastic films, pulp, and paper, and manufactures and develops consumer and industrial packaging products, and has 102 production sites in more than 33 countries. Amcor, on the other hand, develops and produces packaging for various industries that includes food and beverage, pharmaceutical, medical, home and personal care, and other products. The company has 250 manufacturing sites located in more than 12 countries, with their strategies consisting of differentiated capabilities and aspiration to be the global leader. Similarly, other key industry participants in the market have developed strong distribution channels, product offerings, and regional presence. (Fortune Business Insights, 2020.)

In Europe, the food packaging market is driven by the growing demand for extended shelf-life of a product. Fresh food packaging market is seen adopting some exceptionally wiser strategies during growing demand to stay competitive. Prominent brands are seen collaboration to increase their product portfolio or services and enter new markets. Food packaging companies are now spending heavily on research and development to maintain a competitive edge in the marketplace. Adoption of effective marketing and branding strategy is another key factor that is helping brands to position their products successfully. Some of the prominent market players of fresh food packaging market includes Ultimate Packaging, Mondi Group, International Paper Company, PP Global, DuPont, Amcor Limited, Coveris Holdings S.A, Temkin International Inc., Smurfit Kappa, Univeg Group, and others. (Allied Market Research, 2020.)

By being versatile, durable, and inexpensive material (Quantis, 2018), plastic is one of the main raw materials used in food packaging, and it is presumed to preserve its significant position in packing food products (Raheem, 2013). Often the plastic packaging is made from synthetic polymers like polypropylene and polyethylene, manufactured from natural resources. The fluctuating price of these raw materials, such as crude oil, affects, however, the packaging industry. Moreover, regulations developed by government and associations over resource conservation are surging the price of these raw materials, which, in turn, is restraining market growth. Furthermore, the limited raw material availability is hindering technological improvement in packaging solutions. High raw material costs are causing inaccessibility to many new packaging technologies and companies are thus dependent on traditional packaging solutions, which, in turn, is affecting both the economy and environment. Costly skilled manpower is further a restraining factor in market growth, as rapid changes in technologies (such as the swift from conventional to biobased plastics) require highly skilled labor, and the manufacturing of packaging materials requires highly knowledgeable and experienced workers in general. (Fortune Business Insights, 2020.)

The plastic food packaging market is expected to witness rapid growth owing to low prices and the rising usage of plastic films in secondary food packaging. The food packaging market exhibits the presence of many players, most of which operate through North America and Europe. Players are exhibiting immense interest in investing in Asia Pacific to expand their business, and it is possible due to their dedicated distribution networks and manufacturing locations across the globe. (Grand View Research, 2020.) If compared to the overall conventional plastics market, the food packaging market, especially plastic food packaging market, is described in the interviews as a more dispersed group of actors: large/small, and national/international firms. Requirements for the packaging vary, for example, depending on the type of food to be packed, and therefore the user needs might be rather specific. Hence, companies tend to offer product customization, which increases their share and augment their revenue (Grand View Research, 2020). The interview data revealed that especially the cooperation between converters, packaging suppliers and brand owners is important in this customization.

Out of plastic packaging, flexible packaging is the fastest-growing segment, exhibiting an annual growth of around 6 % from 2020 to 2027 owing to its ability to form thinner, lighter, and compact packaging. Shift in demand from rigid to flexible packing solutions is expected to boost segment growth, especially in the developing economies. Superior performance and convenience offered by reportable packages is presumed to exhibit the largest demand over the forecast period. Technological innovations in product development and increasing trend of smaller package sizes are further expected to fuel the segment growth. Similarly, cost-effectiveness and reduced raw material consumption are likely to boost demand over the projected period. (Grand View Research, 2020.) Firms offering especially biobased biodegradable flexible food packaging include, for example, Agrana Beteiligungs-AG (Germany), Biotec GmbH & Co. KG (Germany), Danimer Scientific (US), FKuR Kunstof GmbH (Germany), Nafigate Corporation (Czechia), NatureWorks (US), and Plasticos Comuestos SA (Kompuestos) (Spain), among others (Frost & Sullivan, 2020).

The other side of the growing packaging and food packaging market is that a large part of it utilizes single-use plastics, in such a degree, that of the product categories of single-use plastics thrown away in 2019, food bottles represent the largest part (25 million tonnes), film packaging (not only for food) represents the second largest part (18 million tonnes), and food packaging represents the fourth largest part (15 million tonnes) (Charles et al., 2021). In high income countries, most of this single-use plastic waste is either buried or burned, whereas in low- and lower-income countries the infrastructure is often missing or underfunded, and the single-use plastics contribute to serious environmental problems (Charles et al., 2021). In general, the demand for more sustainable packaging is strong but as sustainable development is a systemic phenomenon, providing more sustainable packaging materials does not mean only more sustainable raw materials and manufacturing processes, but also the end-of-life treatments and supporting legislation, which at this point is not yet at place (e.g., Charles et al., 2021; Keränen et al., 2021).

Against this background, it is not surprising that the plastic packaging industry has searched for ways to improve its sustainability, also by adopting biobased and biodegradable materials. Indeed, packaging sector is the largest user of bioplastics, representing 47 % (0,99 million tonnes) of the total bioplastics market in 2020, of which 0,56 million tonnes was for flexible packaging and 0,44 million tonnes for rigid packaging (European Bioplastics, 2020b). As a comparison, the third largest sector for bioplastics is consumer goods, representing 0,26 million tonnes of global bioplastics production in 2020 (European Bioplastics, 2020b). If looking at only biobased and biodegradable plastics, the packaging segment accounts for an even larger part of the market, even 77 % in 2019 (Frost & Sullivan, 2020). Especially companies involved in the plastic food packaging market strive to replace existing materials with biodegradable ones to meet changing government standards, and large number of companies in the food packaging market are integrated across the value chain and indulge in captive consumption of raw material to reduce production cost. (Grand View Research, 2020.)

The plastic food packaging industry brings together the plastic material producers and the food industry, while packaging suppliers are in the middle. Based on our interviews, it is through these packaging suppliers that the user requests reach the plastic material producers. On the other hand, the packaging suppliers have to be the ones who inform the users about the present limited options when it comes to the large-scale availability of bioplastic materials for diverse food packaging applications. Especially, the data revealed that some brand owners have felt that the plastic producers are not that interested in developing suitable bioplastic materials for them and some of them blame the packaging suppliers, too. However, we interpret these interview findings to talk about the growing and versatile demand for bioplastic packaging, whereas the supply has not yet followed the degree and variety of the demand. It also reflects the important role and inertia of established, large fossil-based companies to transform their businesses to be more sustainable. The food packaging industry is highly regulated (Regulation (EC) No 1935/2004), and some actors have uncertainties considering the forthcoming developments in regulation, which might influence their interest in adopting new more sustainable packaging materials (e.g., Single-use Plastic (SUP) directive, June 2019, entry into force July 2021). Europe, however, is considered as a leader for pushing and supporting the use of sustainable materials for packaging, that is, materials that provide environmental health, human health and safety across their life cycle, by reducing waste, pollution and toxins, and being easily managed within circular economy ecosystems (Frost & Sullivan, 2020). Innovation is a key factor in economic growth in the development of more sustainable packaging materials, also biobased biodegradable plastics, and during the recent years, SMEs have been active in research and development when compared to larger firms providing the most popular bioplastics at large-scale, but these SMEs are depending on external funding (public initiatives and investments by government bodies) for their research and development activities, and that is why collaboration between such SMEs and research organizations is called for (Frost & Sullivan, 2020). These existing network configurations for plastic food packaging are discussed next.

## 3.2 Existing value networks for plastic food packaging

### 3.2.1 Conventional value networks for plastic food packaging

The existing value networks for conventional plastic food packaging are selected as a comparative network as the developed materials are expected to replace to some extent such plastics (e.g., PE and PP) in food packaging. A value network for conventional plastic food packaging brings together multiple actors from many kinds of industries, including plastic, packaging, and food industries (see Fig 3.1). In its simplest form, a plastic food value network begins from *raw material producers*, meaning primarily oil and other chemical firms, who supply the raw material for *plastic material producers* (monomer and polymer producers) who manufacture plastic resins/original polymers. The value network further includes different combinations of *additive producers* (for example, actors providing plasticizers, flame retardants, antioxidants, acid scavengers, light and heat stabilizers, lubricants, pigments, antistatic agents, slip compounds and thermal stabilizers (Hahladakis et al., 2018), as well as ingredients for coatings) and *color agent producers*, depending on the plastic formula. Thereafter, the polymers are blended with these additives into master batches by *plastic compounders* to achieve the desired characteristics and packaging properties before the plastic is further processed by plastic *processors and converters*. Converters give the (more or less customized) form to the plastic material, fitting its use application, after which the material goes to the market through brand owners and retailers.

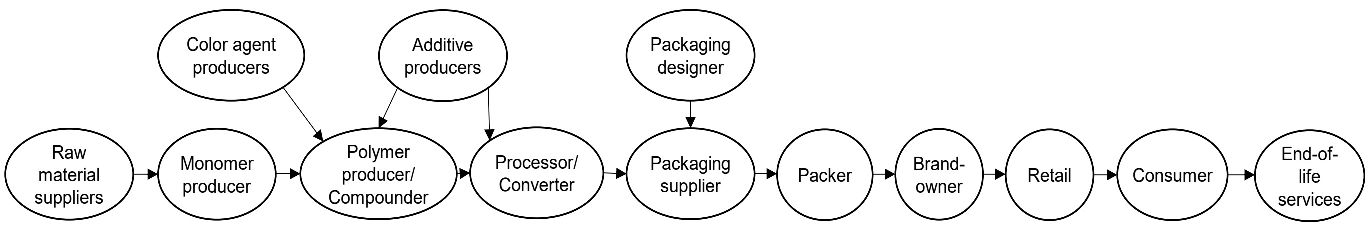


*Fig 3.1 Conventional value network for plastic food packaging*

The business models in the plastics industry are largely dependent on the actor's position in the value network, resources, and the related business strategy. In other words, the business models in the plastics industry can be thought of as combinations of handling different parts of the plastics value network to form various kinds of value for the customers. Each value chain actor builds its business model around selling their expertise and end products, and the differences in their business models rise from the scale of operations, are they focused on continuous production or customer projects, the degree of differentiation of their offerings, and the part they cover in the value network. There are firms that are focused on a small part of the value network activities, covering, for example, supply of plasticizers, or research and development of processing new types of materials. On the other hand, there are firms that cover a broader part of the value network activities, and in that way, they can offer, for example, development of a specific formula, blending, and converting it for a special application. In addition, there are actors who base their business on mass production of large volumes of undifferentiated products. To clarify the composition of the value network in question, the typical actors, and the related activities relevant to producing plastics packaging for food are described next in more detail.

There are many types of firms producing plastics. According to our interview data, there are *large chemicals companies*, who usually produce few types of original polymers at a large scale for different applications. As a response to the rising needs of emerging and growing industries, this kind of large plastic providers have adopted a larger part of the plastics value network, such as producing and adding additives and colors to the plastic compound, so that they can directly answer the needs of a certain industry, such as electronics, without the need to have additional actors between them and the customer industry. In this way, the plastic providers have been able to achieve greater margins from their products and increase the strength of their customer relationships.

The actors in the upstream of conventional plastic food packaging value network are identified to be critical because of their strong impact on what polymers are manufactured in the industry. Specifically, plastic material producers are detected to be important actors. In the data, the importance of firms producing the original polymer and the masterbatch is characterized in the following way: it is common that the original polymer or the masterbatch is processed by a limited number of firms, but then there are many other firms that process the same plastic particles, for example, to obtain multilayer materials or just to print materials. This reflects the strong influence of plastic producers on the type of polymers available in the market. The strong and powerful position of plastic producers in the value network is further supported by the fact that these firms tend to be large and established actors that might simultaneously be chemical firms, which allow them to be involved in multiple different types of phases of the plastic food packaging manufacturing process. For example, if the plastic producers are simultaneously chemical firms, they have necessary capabilities to manufacture their own additives and control plastic compounding activities.

*Smaller plastic providers*, in turn, handle more specific and experimental plastics needs of customers, for example, for purposes of product development and small-scale production. They might produce the plastic granule or also do the needed blending with diverse additives and color. These kinds of firms have usually specialized experience from certain materials, industries, or applications, and they may operate with lower scale and/or on a project basis. By serving diverse customers, the specialized knowledge base increases, and provides further business opportunities. Compounding and processing/conversion might be done by one company. Typically, *processors/converters* can produce both the semi-finished or the finished products obtained with the plastic material in the plastics value network, utilizing diverse technologies, such as blowing and film casting extrusion, thermoforming or injection molding. For processors/converters, the customers can be brand owners or their suppliers, or packaging suppliers, depending on how the roles are divided in the value network. Like plastic producers, plastic processors/converters can do multiple activities in the plastic food packaging value network; for example, design, customize and manufacture the plastic packaging for brand owners. However, their role in the value network is not described in the data to be as influential as the role of plastic producers. Instead, plastic converters are characterized to be in the middle of plastic producers and brand owners, experiencing the demands and pressure of both sides.

Food packaging can include many forms of plastic components, such as a plastic tray that is sealed with a plastic film. In many simple packaging cases, the *packer* utilizes directly the materials supplied by the processor and converter, packs the food (by sealing the plastic film tube, for example), and then the product is delivered to the brand owner, or sometimes directly to retail. However, there can be a *packaging supplier* between the converter and the packer, especially in case of more complex packaging. For example, a packaging supplier might receive plastic materials from a converter, and the packaging supplier then prints labels, and does some other finishing, combining, and customizing activities to the packaging, after which the prepared packaging is sent to the packer. The actual packing lines are often parallel to food production lines.

The primary function of packaging is to protect the food products of the *brand owner*, who is the customer in this network, before these food products reach the *retailer* and the *consumer*. Brand owners are in a key role in this value network, as they can decide on and do many of the value network activities such as packaging design, packaging, and retail. Often producing and packing the food product is done by brand-owner's suppliers when the brand owner is not necessarily directly performing operations in this simplified value network.

If plastic packaging is recycled after its use, diverse types of plastic *end-of-life service providers*, handling the gathering, sorting, and recycling of packaging waste, become relevant. Depending on the packaging type and the services available, packaging ends up either to reuse, recycling (mechanical, chemical, or biological), energy recovery, or landfill.

The actors of the conventional plastic food packaging value network are identified to be connected to each other by long-term collaborations and contracts. For example, packaging customization tends to result in long-term contracts between packaging suppliers and brand owners, which may limit the ability of brand owners to switch their packaging material. Then again, large brand owners can hinder packaging suppliers to invest in answering the specific packaging needs of their other customers, as they need to provide the same packaging solutions for all their customers in order to treat them equally and not to lose them. Similarly, the reliability and security in material quality and supply may create the need for long-term relationships and support the market position of already established materials as large brand owners need to be sure that they can receive their packaging materials on time and that the material they receive is uniform. Therefore, if brand owners are already collaborating with a packaging supplier who can provide this and whom they trust in this matter, changing that partner to somebody who may not be as reliable is a significant risk. (Keränen et al., 2021.) The problem with packaging materials made from PHB from large brand owners' point of view might relate to this because the large-scale availability of PHB is not reliable enough at this point.

In our data, the collaboration in the plastic food packaging value network is further described as linear, as its actors are not often collaborating beyond their closest partners in the value network and do not even have an explicit understanding of whom their partner is collaborating with in the same network. This might be the result of the non-transparent nature of the plastics industry, which is seen to emerge from the intense competition between plastic material producers and the secrecy related to their formulas. This may create situations in which packaging suppliers are at the crossfire of plastic producers and brand owners. That is, packaging suppliers may experience difficulties fulfilling the needs of their customers if they do not receive suitable materials from their material producers. (Keränen et al., 2021.)

However, as our workshop discussions pinpointed, the lack of networked collaboration is not necessarily an unwanted situation from the perspective of brand owners, for example. As price and reliable availability of packaging is important, it is natural that the closest collaboration of brand owners is with packaging suppliers, and for the sake of simplicity and resource management, brand owners let packaging suppliers handle the upstream of the value network. In addition, some interviewees reminded that when the packaging is not special, the relationship between a brand owner and a packaging supplier might be rather easy to replace, when close collaboration is not aimed at in the first place.

### 3.2.2 NEWPACK value network for biobased biodegradable plastic food packaging

The materials developed in the NEWPACK project are blends of PLA and PHB, of which PLA is acquired from commercial sources and PHB is produced within the project from glucose, which is extracted from potato peels. In addition, the developed blends include different sets of additives, including nanochitin from crustacean shells, natural extracts (such as olive oil extract or orange-peel extracts), and/or nanocellulose from wheat straws, in addition to commercial plasticizers. Although many different blends, based on PHB and PLA, were developed, processed, and tested in the NEWPACK project, the following description of the members and their activities aims to summarize the activities needed for all those blends – hence, it is not specific to any blend.

First, several *feedstock providers* are needed to supply the needed raw materials. In general, various feedstocks could be used for obtaining glucose for PHB production. In the NEWPACK project, potato peel providers are important for PHB production as the project works on optimizing the processing of such feedstock. In the project, potato peels are provided by a large European potato processing firm, for which potato peels are by-products of its manufacturing processes. Similarly, wheat straw providers are needed for cellulose nano-additive production, and natural extracts for active coating production or for including them into the blend. In the project, these raw materials are bought from commercial sources. In addition, crustacean waste, or chitin processed from them, is sourced for nanochitin production.

Then, several project members are needed to *process* such feedstocks. In the project, the pretreatment and enzymatic hydrolysis of potato peels into fermentable sugars, fermentative production of PHB as well as purification (developed by Tecnalia at lab-scale), is optimized and scaled up by Bio Base Europe Pilot Plant (BBEPP). Furthermore, cellulose nanowhiskers are produced with wheat straw as feedstock, where Universita Cattolica del Sacro Cuore (UCSC) and Tecnalia are involved in the extraction process, and BBEPP is upscaling the process, utilizing commercial microcrystalline cellulose. Luleå University of Technology (LTU) is responsible for the development and processing of nano-chitin production from crustacean shell waste at lab-scale and BBEPP at larger scale. Hence, the upscaling of PHB and nanowhiskers is made by BBEPP.

After producing the biopolymers and bioadditives, Proplast and LTU do the *co-blending of PHB* (NEWPACK) *and PLA (*commercial) and make the *compound* including the nanowhiskers of cellulose and/or chitin together with the PLA-PHB blend, as needed. Tecnopackaging blows the material into packaging films at pre-industrial scale, whereas other partners can do smaller scale production. For some of the blends, natural extracts are used. The processing of natural extracts, in turn, is made by UCSC, after which natural extracts are either blended into the compound or added as a coating over the PHB/PLA films at Proplast. The active coating formulations for PHB/PLA films are developed by Tecnalia, whereas UCSC tests the overall migration and antioxidant/antimicrobial activity of the coated films.

Finally, University of Oulu (UOULU) *micro perforates* the films. After this, the blends are tested by the *end users*; that is, Grupo Riberebro and Argal, together with El Centro Tecnológico de la Industria Cárnica - El

Centro de Innovación y Tecnología Alimentaria (CTIC-CITA), at optimal process conditions on a pilot line. UCSC and CTIC-CITA test and verify the food contact compatibility of the developed new materials.

Based on this description of the main actors and their roles in the NEWPACK project, a simplified value network for producing NEWPACK products can be presented. Figure 3.2 includes the sources for raw materials, the actors processing them, the actors blending PHB with commercial PLA, as well as the actors compounding the blends with different additives and film-blowing the packaging films. With the italics in actor names, Figure 3.2 illustrates actors that are not project members, and with the dashed lines circulating PHB production and nanoadditives production, the figure illustrates that these activities could be done by separate actors, but in this project these activities are covered by a single organization.

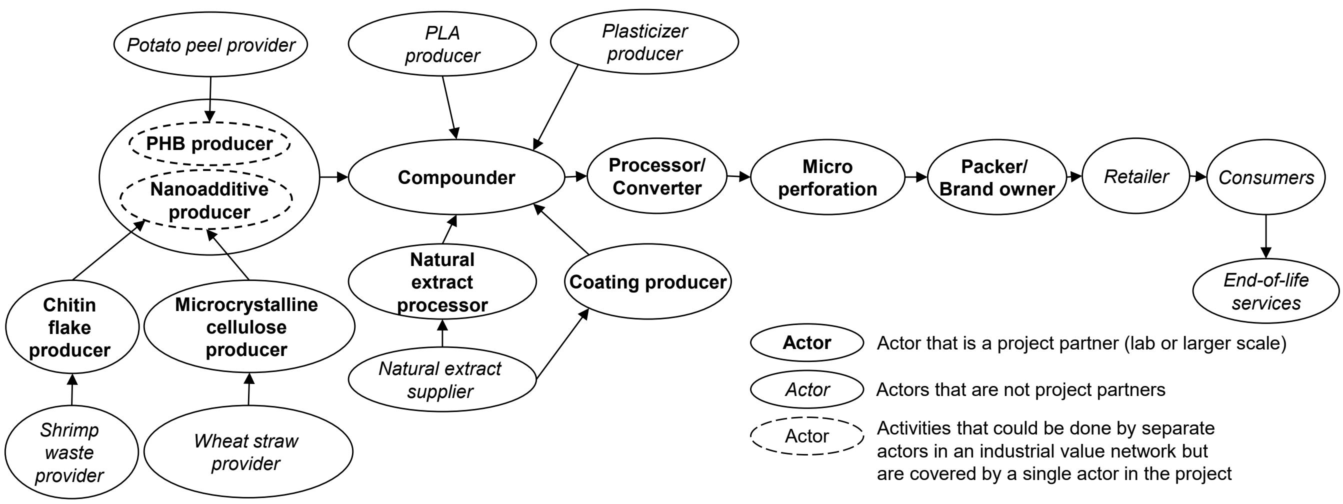


*Fig 3.2 The value network for the NEWPACK products*

The NEWPACK project value network has been developed for the organization of research and development work, and therefore, it will not function as such for commercial production in the future. Many of the project members are either non-profit organizations or universities and other research centers, and some are for-profit organizations for whose operational logic commercial production would possibly fit in some form. Furthermore, even though some organizations would be interested in being part of the commercial value chain, for example, in developing the formula and the processing of the materials further, the project network, and its resources and facilities, cannot produce larger quantities of the developed materials, regardless of the type of organizations involved. For example, Tecnopackaging characterizes them to be capable of producing small batches or 1st series of biobased materials for different applications for other businesses, and Tecnalia states in their website to be "a leading Research and Technological Development Centre in Europe" and in addition, they aim to generate business opportunities for the industry and continuously create spin off companies with interested investors and other stakeholders.

To review the intentions of project partners considering how they plan to utilize the learning and results gained from the NEWPACK project, we sent a short email survey to them. Based on the survey, the project members are, for example, planning to utilize the knowledge acquired from the project either by selling the knowhow to other businesses through their current operations (such as consulting), or licensing their intellectual property rights (IPRs) to some commercial enterprise for the commercialization. The answers supported the view *that for the developed materials are to be produced at a commercial scale, new actors capable and interested in doing that need to be identified and involved*. Further exploitation plans have been discussed within the IPR Committee of the project and discussed in *Deliverable 7.6 Final Plan for the Exploitation and Dissemination of Results* (PEDR) (confidential).

*The division of tasks is further likely to be different under commercial scale production*. For example, micro perforation is possible to be made by the same actor who blows the film, or by the packer, and it is unlikely that a separate organization would do that in a commercial network. If not thinking of tasks, but the number of organizations involved, there are many opportunities to organize the tasks between diverse organizations, depending on the organizations, and their capabilities and other resources, involved in the commercial value network. For example, as mentioned earlier, large plastic material producers might be able to handle multiple different activities, including producing and processing biopolymers and blends with their self-made additives. Similarly, the packaging converter can be involved in the activities of design and manufacturing of packages, whereas packing of food products can be either made by brand owner themselves, or a separate packer firm.

Some of the tasks might be eliminated from the commercial value network. For example, the supply possibilities of crustacean shell waste in Europe are limited, and thus it is suggested in the data that it might be more eco-friendly to produce and scale-up chitin closer to its source (e.g., Asia). Therefore, it is likely that chitin is purchased ready-made, which eliminates the processing activities of such waste from the core activities. In addition, now there is an organization providing potato peels for the project, but if the production volumes grow, there would be need for identifying and involving multiple suppliers of potato peels, located nearby the large-scale production of the developed bioplastic material, or examining the opportunities to utilize other feedstocks for PHB production in the future This raises questions of logistics and economics: how the PHB production could be best organized? Could there be several smaller locations for PHB production, or would it be more efficient to have one large facility for PHB production? There are various biomass refining facilities in Europe (see e.g., https://biconsortium.eu/news/mapping-european-biorefineries), and there are, similarly, remarkable potato processing facilities (see e.g., https://euppa.eu/members/), both having a bit different weight in different regions around Europe. *Task 6.1 Economic analysis,* and the logistics analysis included in this report examine these issues.

### 3.3 Formation of new value networks for the diffusion of NEWPACK products

Figure 3.3 presents a possible construction for a new value network for manufacturing the biobased biodegradable plastic material in the future. Furthermore, based on our data, we analyzed the changes that would support the diffusion of new biobased biodegradable plastic packaging material into the existing value network of conventional plastic food packaging. In general, *to promote the change of materials toward more sustainable packaging solutions, a more networked type of cooperation, both vertical and horizontal, is needed* between new and existing value network actors. That is largely because of the developing knowledge of bioplastics and the related bioplastics market – through cooperation, the materials could be developed more efficiently, so that they would answer the needs of a broader base of users and use applications, and on the other hand, the division of tasks could be organized effectively. Also, it is not enough to find new actors for organizing the commercial production and buyers for this new material, but to *support the market and the supporting infrastructures for these new materials* - also for biobased biodegradable plastics in general, because that contributes to the value potential of the developed material, as well. More work is needed for *identifying other possible applications for the developed material*, that is, where the biobased origin and biodegradability bring the most benefits for the user and from the sustainability point of view.

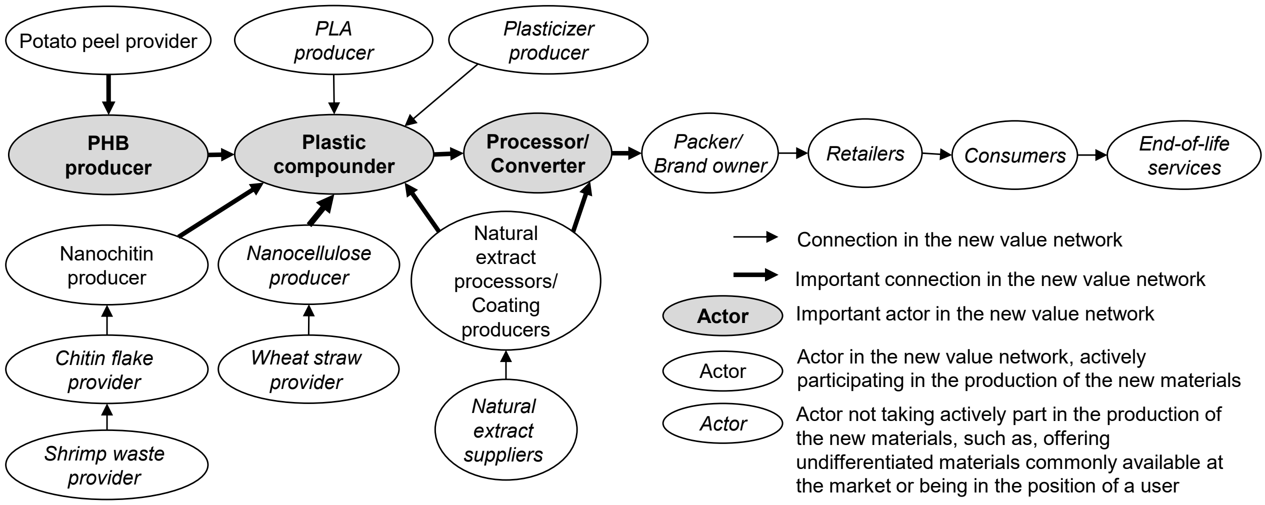


*Fig 3.3 New value network for the biobased biodegradable plastic solution in food packaging*

Providing a biobased biodegradable plastic packaging as a parallel alternative in the existing value network also means that new actors are added to the conventional plastic packaging value network. As it was noted, reconfiguring the collaborative relationships would benefit the further development and diffusion of the new materials. Figure 3.4 presents a summary of these new collaborative relationships between the actors, as suggested by our interview data (hence, the arrows do not represent material flows per se). This kind of restructuring of value networks can happen when industries face technological changes or changes in business models, for example (e.g., Keränen et al., 2021). Our data gives light to that change in context of biobased plastic food packaging starting to appear as an alternative for conventional plastic food packaging. Biobased feedstock and its processors/converters are thus key actors added to the conventional plastic food packaging value network, whereas many of the downstream actors may stay the same, making the entity a bit more complex. These potential collaborative relationships and their implications are detailed in the following chapters.

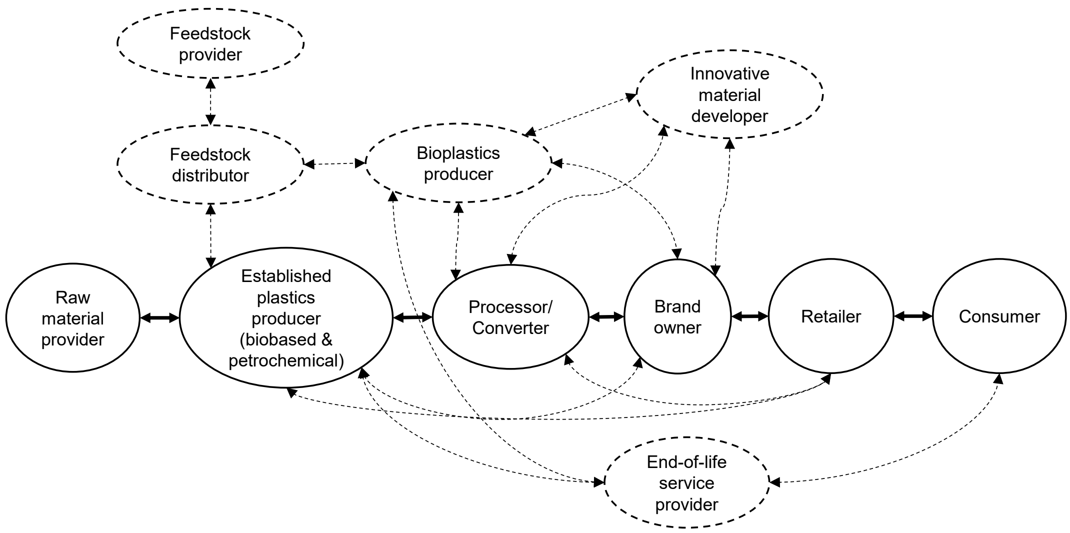


*Fig 3.4 Merging the existing and new value networks: new connections supporting the diffusion of biobased biodegradable plastic food packaging*

### 3.3.1 Actors and their roles in the new value network

Compared to the conventional plastic packaging value network and the NEWPACK value network, new actors need to be identified and included into the new value network, when manufacturing and disseminating biobased biodegradable plastic packaging. These new actors potentially include biomass feedstock providers, feedstock distributors, and biomass processors as well as bioplastic material producers, innovative material developers, and new kinds of end-of-life service providers. In addition, different associations, universities and research institutions, and policymakers are identified to have a role in supporting the dissemination of biobased biodegradable plastic packaging. (Keränen et al., 2021.) The actors and their roles in the commercial value network are described next.

In order to enable the broad diffusion of bioplastics, derived from agro-food waste, it is necessary to identify and involve multiple new *biomass feedstock providers, distributors, and processors* that can provide, both efficiently and reliably, biomass feedstocks for large-scale material producers. Large and established *plastic material producers* usually have required investment power to make necessary adaptations into their production or to invest in new processing lines to produce such biomaterials. However, such firms are identified to be more willing to and capable of producing such biomaterials, especially when the production setting for them is already optimized, and if the technologies and machinery to produce different types of plastics can be more or less the same. Thus, as process adaptations are time-consuming and costly, many of these organizations are characterized in the data to wait for “drop-in materials” that are usable as such in the existing machinery without further need for investments, major modifications or learning efforts. Specifically, these organizations are described in the data not being in the front line to learn how to use or explore new materials, at least not at this point. Therefore, it is suggested that *specialized bioplastics producers*, who have more specialized knowledge on biopolymers and how to manage them in different productions stages, might have a role in the commercial network instead of established plastic producers. (Keränen et al., 2021.)

In addition, *innovative material developers* might be needed when trying to identify and target potential applications for the new materials, as they can manufacture small scale trials and they have good contacts with the industry and understanding of the special needs among industry actors, such as bioplastic producers, packaging suppliers, and brand owners. This kind of mixed collaboration among various actors can aid in combining the material information and manufacturer and user needs, which is needed for a successful market entry of the material.

Finally, as biobased and biodegradable plastics have ever growing volumes, the question of their most beneficial end-of-life treatment becomes apparent. Even though this question cannot be solved by any single value network involved in the production of a certain material, it is good to acknowledge, that the end-of-life treatments for this kind of plastic are developing, and it is good to be in contact to such instances, industry organizations and information sources that provide the most up-to-date knowledge of the developments in the area, at least. Therefore, *end-of-life service providers* are mentioned as a part of the value network to secure proper end-of-life solutions for these materials in the long run.

*Universities* and other *research institutions* are relevant actors from the value network point of view because they can assist in examining, for example, compostability and recyclability of different materials, and in further development of the materials and their processing. It is likely that further material development work is needed in the future in order to be able to answer the varied needs of users, developing the properties of the NEWPACK materials, and to find the best combination of technical performance and costs, and then identifying the best application for the formula in question. At the same time, when investing in further development of the materials, it is possible to invest in developing the large-scale production opportunities for the PHB process developed in the project. The composition of the needed value network is, however, different in these situations. If the aim is to continue intensive material development to offer specialized solutions for varied packaging needs, there needs to be a material research and development organization in a central position in the network. In case of aiming at large scale production of PHB, for example, the development of operation efficiency, sales and distribution become crucial. One way to do that would be to find a suitable, established firm already operating in the aimed market, and interested in producing the developed material, which gives many opportunities for organizing the business logic (licensing, partnering, or selling the IPRs, for example).

To facilitate the diffusion of biobased and biodegradable plastics in general, consumers and business actors are identified to need education about such materials. Producers of biobased and biodegradable materials can work together with different *material associations* (e.g., GO!PHA), *environmental associations*, *industry organizations* (e.g., European Bioplastics), and *consultancy organization*s to provide such information and education in order to promote the environmental benefits of new sustainable packaging solutions. Especially environmental associations are identified to be capable of examining and communicating sustainability aspects in a credible way and further educating the business actors and consumers on that topic. This education should focus on providing information on the properties of different biopolymers, and for what type of applications they would be the most suitable for. For example, biodegradability is a valuable feature if it is able to solve some problems with present materials or if it enables the development of some new valuable products or services. Furthermore, if the new biodegradable material is used for consumer packaging, consumers should be educated not just about the properties and possible benefits of the developed new materials, but about their disposal, and the same applies to business end-users. However, from the viewpoint of a single commercial actor acting in the bioplastics market, the most important thing is to acknowledge the need to inform and educate business customers and consumers, to possibly cooperate with other business actors and associations in that area, and to pay attention to those viewpoints in packaging labeling, for example.

As the market for bioplastics is still developing, regulations play an important role in advancing the development and use of biobased plastic food packaging. Our interviewees reported that many actors have been withholding their investments in new biobased materials, especially those who are seeking alternatives for single-use plastic products, as there has been some uncertainties how the SUP directive will be interpreted and applied, and how diverse biobased plastics are handled in that in practice, even though the European Commission has provided some additional instructions about the implementation of the directive already. Therefore, *policymakers* are acknowledged to be an important actor group at the macro level that influences the diffusion of biobased biodegradable plastic packaging now and in the future. Hence, individual business actors involved in the bioplastic packaging value network need to keep themselves up to date about the legislative developments. Keeping contact with industry associations is one way to do that.

### 3.3.2 Central activities, collaborative relationships, and resources in the new value network

The central activities and resources in the production of NEWPACK products are strongly interlinked with each other, and they determine the organizations who can be involved in their large-scale production. That is, the organizations interested in taking part in the new value networks for the diffusion of NEWPACK products need to have, or need to be willing to acquire, new type of knowledge to perform their activities in the value network. *The central activities and resources* are identified to relate, for example, to PHB production from potato peels, and further blending that PHB with PLA, which makes sourcing and availability of PLA an important activity as well, even though PLA is not produced within the NEWPACK project. Furthermore, production and use of nanoadditives (including chitin and cellulose nanowhiskers), and natural extracts (also as coatings) with such blends is important. Specifically, the production of chitin nanowhiskers needs attention because although chitin nanowhiskers are proven to improve the properties of some blends, its availability is scarce, the production quantities remain low, and using it tends to increase the production costs and the overall environmental impact of the developed materials. Furthermore, while not perhaps among the most central activities, processing and blowing of the developed materials to produce food packaging film is important, meaning that it requires specialized know-how from the actors doing it – hence, finding actors capable of doing that at large-scale might not be straightforward in the first place.

Besides the activities and resources in the production process of the NEWPACK products, there are other types of activities and resources that become central because they can promote the diffusion of new biobased biodegradable plastic packaging solutions. These activities and resources are identified to strongly rely on a networked type of collaboration if compared to the rather linear value network (more like a chain) involved in production and use of conventional plastic food packaging (see Fig 3.1). The three most relevant collaborations identified (Keränen et al., 2021) are discussed next.

*First, it is important to organize a functioning cooperation between potato peel suppliers, actors distributing, storing, and processing the potato peels, and the PHB producer* (Keränen et al., 2021) in terms of answering the concerns related to feedstock availability, price, logistics, quality, and sustainability. Similar request for collaboration between biomass feedstock providers, distributors, and processors applies to nanochitin and nanocellulose additives production, but that appeared as less critical than the collaboration for organizing an efficient, reliable, and economic PHB production at large scale. Although there are Europe wide numbers available about the scale of processed potatoes (e.g., Euppa), which is around 19,5 million tonnes of potatoes per year (Euppa, 2021), there is less easily available exact information about the quantity of potato peel available in different areas in Europe, as that cannot be treated as equal to the number of processed potatoes per area. There are estimations that depending on the peeling method, 15 to 40 % of the first production mass ends up as peels (e.g., Sepelev & Galoburda, 2015). In addition, it has been estimated that 40 to 50 % of the potato production is unsuitable for human consumption (Charmley, Nelson & Zvomuya, 2006). In any case, many of the interviewees suggest that the availability of potato peels might not be a problem for PHB production, at least in the short run. However, potato peels are not pure waste of potato processing firms because they are at present utilized for animal feed, so besides raising ethical questions of using such biomass feedstock for bioplastic production, it makes the availability of potato peels uncertain. It was also noted in *Deliverable 6.3 Final report on Life Cycle Assessment*, that the price for potato peels varies even several euros. The different uses of potato peels increase the uncertainty related to their price development, meaning that if the demand for potato peels increases in the future, their market price is estimated to grow accordingly. Therefore, the interviewees propose that tighter collaboration, for example, in the form of a joint venture between a potato peel supplier and a PHB producer, would help to engage the potato peel supplier into the value network and thus to lower the availability and price-related risks. Collaboration between biomass feedstock suppliers, distributors, and processors is further important for logistical reasons. During transportation and storing, microbial activity can increase the growth of pathogens, thus leading to the varying quality of feedstock and challenges in processing them further. Therefore, it is important that central actors are located nearby not just to lower the carbon footprint and transportation costs of potato peels, but to cooperate in feedstock monitoring. For example, if the feedstock quality begins to deteriorate, it is important that the critical value network actors can share that information with each other in real-time in order to process the biomass earlier.

*Second, collaboration between retailers, brand owners, packaging suppliers, and even material producers* is important in order to provide the best possible solutions to the rather specified needs of food packers, and thus to communicate the market demands throughout the food packaging value network. Based on our interviews, many brand owners lack up-to-date information about biobased plastics, which would allow them to estimate and make credible and safe sustainable food packaging decisions. Thus, large and proactive brand owners are identified to be eager to increase and broaden their cooperation with firms in the upstream of the value network, particularly with packaging suppliers and plastics producers, in order to develop more sustainable products and materials for their own needs or to change their products and/or packaging to more sustainable alternatives. The point in this type of collaboration is not so much to sell the new material but to solve the brand owners' and retailers' need to find more sustainable solutions for packaging. In addition, the same brand owners, and retailers as well, are identified to cooperate vertically and horizontally to create stronger pressure for the up-stream value network firms, and to educate their suppliers, their own personnel, and consumers to act more sustainably. (Keränen et al., 2020.) Hence, for a supplier of biobased biodegradable plastic food packaging material, it is good to acknowledge, that the route to the market might start from contacting brand owners or retailers, who could be willing to try such new materials in cooperation with the material providers.

*Third, collaboration between material developers and end-of-life service providers is needed* to secure and further examine the end-of-life processes and treatment of biobased biodegradable plastics and to explore, for example, their recyclability options. That is, in order to make the most of the biodegradability feature of the material, collaboration is needed with waste management and recycling facilities, as well as with other providers of biobased biodegradable plastics, and regulators, to develop the infrastructure and technologies for recycling different types of materials and thus ensure appropriate end-of-life treatment for the developed materials, especially considering that use of biobased and biodegradable plastics is expected to grow (e.g., European Bioplastics, 2021), and the options for recycling these materials when volumes start to increase, need further examination. For example, collaborative development of criteria for materials to be accepted to anaerobic decomposition of organic waste in waste management and bioenergy facilities could clarify the situation for all actors in the value network. Thus, for a single supplier of biobased biodegradable plastic food packaging, cooperation with other similar actors, as well as industry associations driving interests of the bioplastics market, and research and development organizations, could act as a bridge for a broader collaboration with waste management facility and technology developers. Another way would be to organize smaller pilots locally, among a smaller number of parties interested in developing end-of-life treatments for biobased biodegradable plastic packaging.

### 3.3.3 Drivers of and barriers to the emergence of new value networks

Our data suggests that there are many different types of forces either driving or hindering the formation of new value networks for the diffusion of the NEWPACK products. Examples of *macro level forces* that drive the demand for biobased biodegradable plastic packaging include increasing awareness of the society about bioplastics and sustainable packaging (and sustainability in general), and regulations pushing value network actors towards more sustainable packaging solutions. Specifically, increasing awareness of the society from environmental issues is identified to trigger individuals in different types of roles to make more sustainable decisions. For example, the data reveals that consumers are becoming more and more interested in and aware of the environmental issues and thus they are increasingly selecting environmental-friendly products, services, and firms. Similarly, regional, national and international governmental actors are increasingly forming different sustainability initiatives and preparing structural changes, influencing the industry through laws and regulations (e.g., European Union's (EU) plastics strategy). These forces together are detected to both pressure and encourage firms to adopt new sustainability strategies and programmes and to search for more sustainable alternatives to their products and materials to act more sustainably. (Keränen et al., 2020.)

*At the network level*, as mentioned earlier, a network-type of collaboration could enhance the market diffusion of the NEWPACK materials, but also of bioplastics in general. The data shows that a network-type of collaboration enables firms to make more sustainable decisions and generally promote sustainable development, thus acting as a driving force for the diffusion of the NEWPACK products, too. As discussed earlier, a network-type of collaboration can enable a material and packaging solution development that better meets the brand owners' specific needs. Furthermore, such collaboration can be exploited to educate business actors, policymakers, and consumers. Collaboration and information sharing with material producers can increase, for example, the transparency of product and process information throughout the value network, which allows brand owners to make more sustainable and safe food packaging decisions. Brand owners and retailers can further cooperate, both vertically and horizontally, to educate actors they are in contact with (e.g., suppliers, personnel, and consumers) and to promote sustainability initiatives. Specifically, the data shows that brand owners cooperate with environmental associations and universities in sustainability education. (Keränen et al., 2020.)

As the NEWPACK materials and their production processes are likely to benefit from further development, *collaboration with research organizations and firms* already operating in the market (packaging suppliers, bioplastics suppliers, converters, users) would be important. Not only for further material and process development but collaboration is needed also to educate the value network actors about the new materials, to support their adoption. Even if these materials would not be commercialized soon after the project, still the new knowledge developed in the NEWPACK project continues to be utilized in the operations of the project partners, many of them who are intensively working in the area of biobased materials and packaging, then benefiting many new organizations in the industry, and potentially leading to the development of new packaging solutions that are then taken to the market.

Barriers, hindering the diffusion of more sustainable packaging materials, primarily relate to existing industry regimes and network structures and collaboration. Specifically, *industry regimes*, which refer to intricate systems of technologies, market practices, cultural meanings, infrastructures, policies, and industry structures, which set the framework for behavior of actors within the industry (Köhler et al., 2019), may prevent the value network actors from adopting more sustainable solutions. This is the situation in the plastic (food) packaging value networks, in which the technology related to producing conventional plastics and their further processing is mature and the related business processes are thus working well. Similarly, past investments into machinery, manufacturing know-how, processes and relationships can further diminish organizations' interest to make necessary changes needed when adopting new materials. The long-term, but linear cooperation in the plastic packaging industry is further suggested to create barriers for new market entries by making it difficult for new and/or small actors to find customers and develop channels for distribution. In addition, as mentioned, long-term collaboration and contracts can limit the material changes in short term by influencing the ability of the brand owner to switch their packaging supplier or packaging material, and packaging suppliers to invest in answering the specific packaging needs of their customers. (Keränen et al., 2021.)

Other potential barriers relate to *the availability and logistics of feedstocks*, which was discussed earlier more thoroughly, and *credibility issues* in terms of performance and sustainability claims related to biobased and/or biodegradable plastics, which require material development work and education of the value network actors in the future. Furthermore, the value network actors are described in the data to have rather *thin or even outdated knowledge of bioplastics* and their different properties and benefits, and sometimes even wrong prejudices, which might hinder their interest to try and adopt new biobased and/or biodegradable plastic materials. Some interviewees describe that the bad experiences in the past lowered their interest in testing new bioplastics even now. Finally, the question of *recyclability of biobased biodegradable plastic packaging* was raised many times in the interviews, and whether a biodegradability feature is something what firms are really looking for and valuing in food packaging, especially when the options to recycle such materials are yet considered to be limited in many regions. Hence, these issues represent potential questions that the providers of biobased biodegradable packaging materials may need to answer when introducing their materials to potential users.

To summarize, from the perspective of the NEWPACK materials, the general growing demand for biobased biodegradable plastics is supporting their market diffusion, whereas the challenges for the market entry of these materials relate to the general challenges faced by new biobased biodegradable plastic packaging at the moment, building the commercial value network, and for developing the materials and their production processes to be yet more economic and sustainable. In addition, the simplified answer for many of these hindrances is to continue the development work and market trials in collaboration with actors who are already operating in the market.

### 3.4 Logistics analysis

As a part of the value chain analysis, a logistics study is carried out to optimize the flows between all the steps in the value chain (from the feedstock to the final disposal after the biopolymer use). In the context of a new product with no existing commercial production, optimization needs to be understood broadly because numerical data may not be available at such an early stage. Therefore, flows and processes are analyzed using more heuristic and qualitative methods such as analogies and scenarios for assessing the logistics solutions in the value network. The logistics analysis helps to analyze further the questions raised above concerning the formation of new value networks for the NEWPACK materials.

Logistics is described as the task of coordinating material and information flows across the supply chain (Harrison & van Hoek, 2005). Logistics includes a wide range of activities associated to the transformation and circulation of goods, such as the material supply of production (inbound flows), the core distribution and transport function, wholesale, and retail (outbound flows) (Handfield & Nichols, 1999). Therefore, management of logistics requires planning and coordinating all those activities necessary to achieve desired levels of the delivered service and quality at the lowest possible cost (Christopher, 1998) and environmental effects (Grant et al., 2017).

This section firstly describes the logistics flows related to the production of the NEWPACK materials and secondly it presents three logistically different scenarios to optimize the logistics solutions in the value network. In the analysis, the main streams are divided roughly to inbound and outbound flows (see e.g., Kerin & Peterson, 2013). The former stands for the incoming raw material flows such as potato peels that are transported into PHB production site whereas the latter means the flows after the PHB production. The data is collected through discussions and interviews, mainly with project partners (included in Tab 2.1), and multiple additional questions were presented for the interviewees for elaborating the needed information during the analysis. Finally, the figures and texts were cross-checked by the project partners.

#### 3.4.1 Description of the NEWPACK logistics flows

The main biomaterial for producing PHB in the NEWPACK project is potato peels. BBEPP tested production with 15 tons of potato peels that were delivered from a nearby (max 100 km) plant that produces potato products and provides peels as a side stream. The availability of potato peels appears not to be a major limitation, at least in the short term. Multiple potato processors produce their products in Europe throughout the year that is likely to ensure continuous supply of the feedstock. Potato processors buy the potato straight after harvest and collaborate with the farmers who store the potatoes in their own facilities. Therefore, the potatoes can be transported to the plant in pull control by the demand of potato products.

One potato processor can output multiple 30–35-ton silos of peels in a day. The peels that are wet after steam peeling are transported as bulk material in a horizontal silo on a semitrailer. The time window for transporting and handling the material is quite narrow as the peels stay fresh for only 1–2 days at room temperature. Drying and perhaps freezing or cold conditions would lengthen the time window, but on the other hand it would require a lot of energy and having new facilities. Hydrolyzing the potato peels increases durability but in current form it takes place in the further steps of the value network. The material flow from the feedstock is illustrated in Figure 3.5.

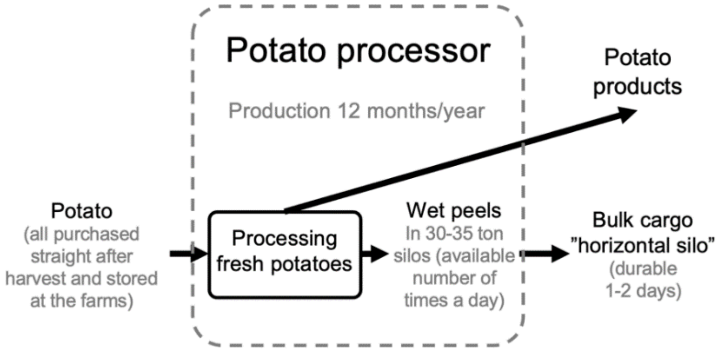


*Fig 3.5 Material flow from the feedstock*

In the beginning of the manufacturing process (see Fig 3.6) the potato peels are transformed into glucose syrup that can also be dried to glucose powder to increase its storability. Glucose production has multiple phases (e.g., hydrolysis and evaporation) that usually take place in the same facilities. Together with the main output, glucose syrup, the process outputs water, proteins, fibers, and salts that are not needed in the NEWPACK production. It is good to note that there are also other possible materials for producing glucose instead of potato peels such as cane sugar or corn depending on what is available in the geographical area, but this project focused on the use of potato peels. The process continues with PHB production that includes fermenting and downstream processing (DSP). Technically, parts of these processes could be outsourced but are practical to be operated in one plant. The output of the process is PHB that is in the form of dry, grinded flakes (5 mm diameter) that are very light and durable with no need for any other special conditions than cover from direct sunlight. The PHB flakes are packed into e.g., 25 kg cartons. Overall, these features make PHB very easy to transport that offers good possibilities to use logistics services that are very common among the European logistics service provider markets.

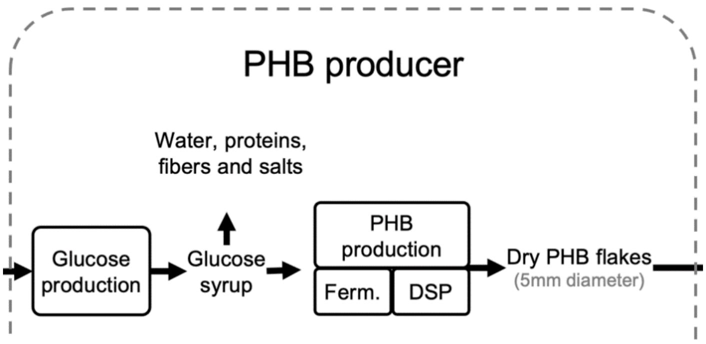


*Fig 3.6 Glucose and PHB production*

In further steps of the NEWPACK logistics network, small portions of nanoadditives and natural extracts are needed (Fig 3.7). NEWPACK 1 blend requires a small amount of nanowhiskers that were provided by BBEPP in the form of wet particle gel that was produced of chitin flakes (from Thailand) that are produced of shrimp shells that is a by- product of shrimp processing industry. The dry flakes are durable but storing the wet particle gel requires cold conditions (4°C) to keep it durable for 2 weeks. An option for or an addition to shrimp waste (depending on the type of the film) are wheat straws that are run through cellulose production to create microcrystalline cellulose (from UK). BBEPP did the nanoparticle production offering the output of dry cellulose nanowhiskers and nanochitin (dried powder) for the compounding process performed by Proplast. Also, orange peel extracts is tested to be used as a natural extract in compounding instead of cellulose nanowhiskers or wet particle gel. Orange peel extract is powder that is light and has no durability issues at room temperature, making it easily transportable in plastic containers. The needed amount of the orange peel extract is very small.

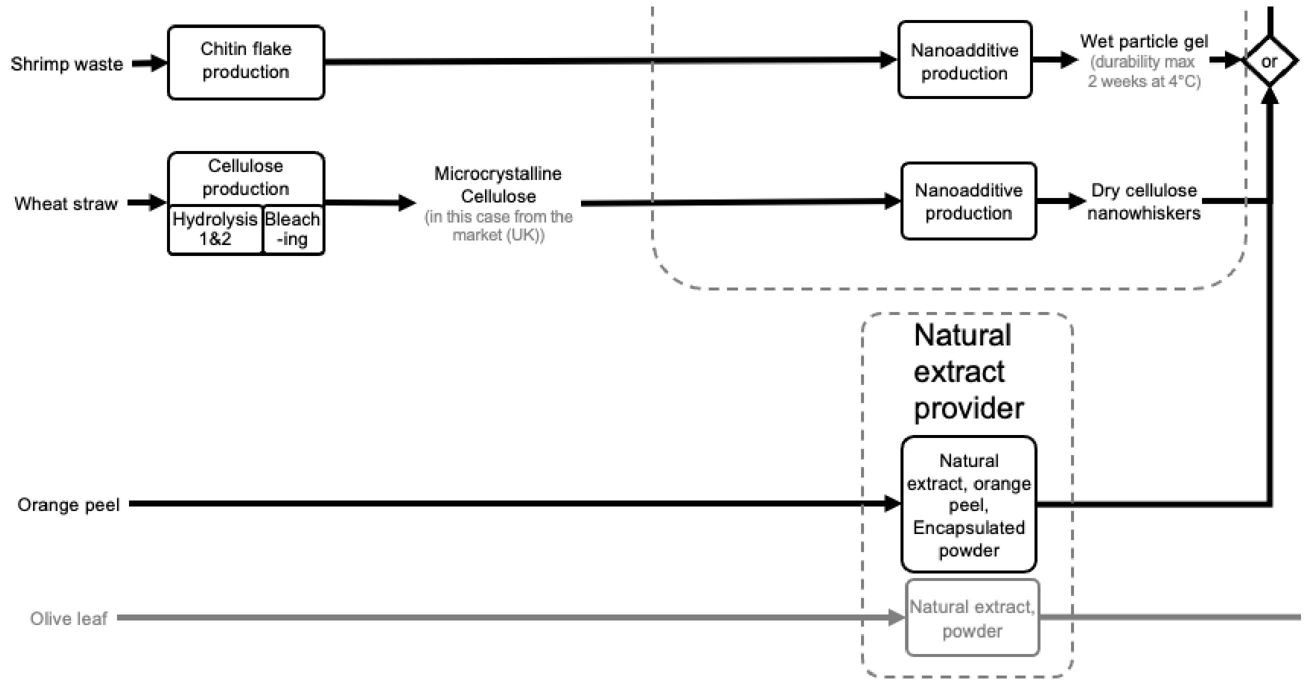


*Fig 3.7 Flows of the nanoparticles and natural extracts*

The PHB, nanoparticles and natural extracts are sent to plastic compounder (see Fig 3.8) such as Proplast, that mixes them with plasticizer (durable liquid in containers, type oligomer lactic acid (OLA) 2 (transported from Spain) and PLA (shipped from the United States). The amount of PLA needed is significant. Basically, the blend needed for the NEWPACK film consists of more PLA than PHB whereas plasticizers, nanoparticles and natural extracts are needed only in small amounts. The compounding process at Proplast outputs extruded plastic pellets. The pellets are stored, vacuum sealed and transported in aluminum containers that protect them from direct contact with the sunlight to avoid potential chemical degradation. Otherwise, the pellets are very durable without any need for special conditions (standard storage conditions are dry places with no direct contact with the light).

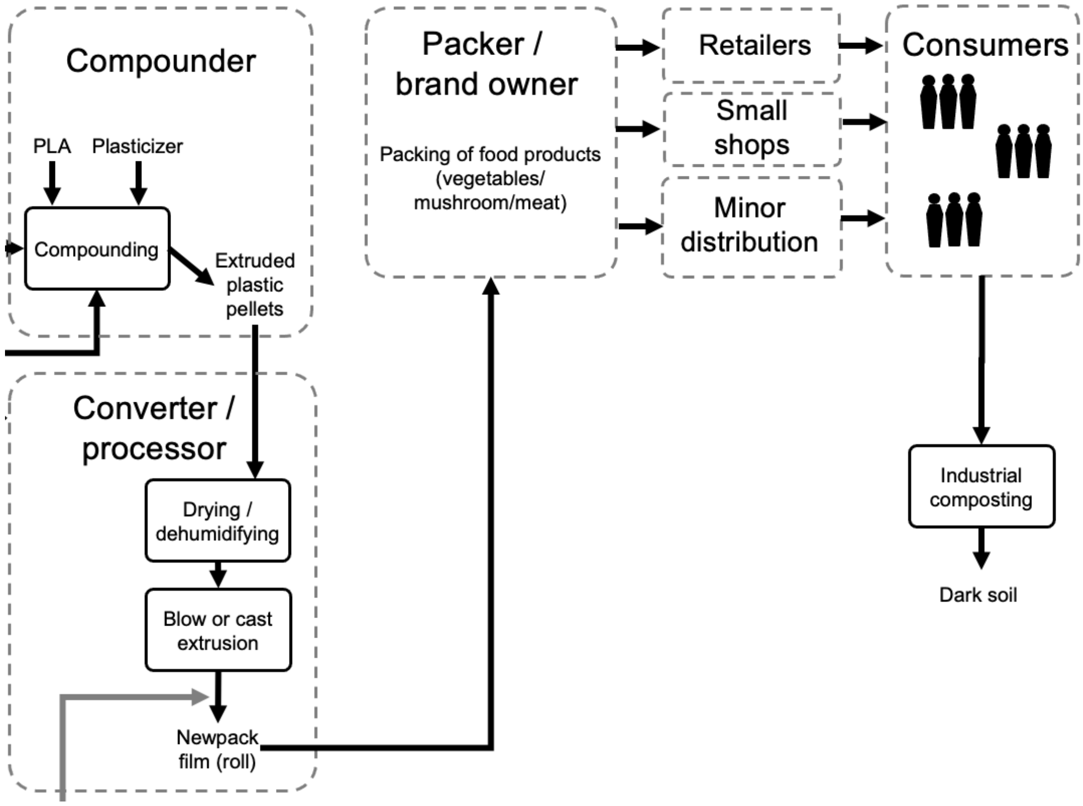


*Fig 3.8 Compounding, converting and streams towards packers, end users and disposal*

The pellets are sent to a plastic processor/converter, such as Tecnopackaging. The film production process begins by dehumidifying the pellets before heating and melting to remove the excess humidity and to avoid possible hydrolysis of the PLA. Afterwards, the pellets are extruded (melted) and transformed by extrusion film blowing (NEWPACK 0 and NEWPACK 1) or extrusion sheet casting (NEWPACK 2) to produce the different types of NEWPACK film. Also coating with olive leaf extract is tested for NEWPACK 0 that has no additives in its blend. The same extract was also added to the biopolymer formulations during the compounding process, in the preliminary trials. In large scale production the possible coating will be added on the film after blowing/casting process. Overall, the process outputs NEWPACK film rolls (width 30 to 35 cm) that are very light and durable, making them easy to transport to the customers.

The primary function of the NEWPACK film is to protect the products of the food processing companies, who are the packers, customers, and brand owners in the NEWPACK value network. In the NEWPACK project, these types of companies are represented by two companies and their products selected for this project: Grupo Riberebro with their fresh mushrooms and vegetables, and Argal with their meat products. Both companies' core function is managing the incoming material flows, production, and the distribution of their products for the retailers. Therefore, these companies have very suitable competence and facilities (docks, storages etc.) for ordering, receiving, storing, and using the needed NEWPACK film.

The finished goods such as vegetable, mushroom, and meat products with NEWPACK cover, are further packaged on pallets and distributed towards the end users through retailers, small shops, and minor distribution. Usually, these three actors take care of the transport costs and arrangements, whereas the brand owners prepare the goods ready to be delivered in their own facilities. After the usage of the products, the end users can take the packaging material into industrial composting where the material is transformed into dark soil that can be used for landscaping, farming or gardening purposes, for instance.

The complete NEWPACK logistics network including all the material flows between the feedstock towards production, usage and disposal is illustrated in Figure 3.9. Together with the material flows, the figure contains logistically relevant information about durability, needed storing and transport conditions and notable frequencies.

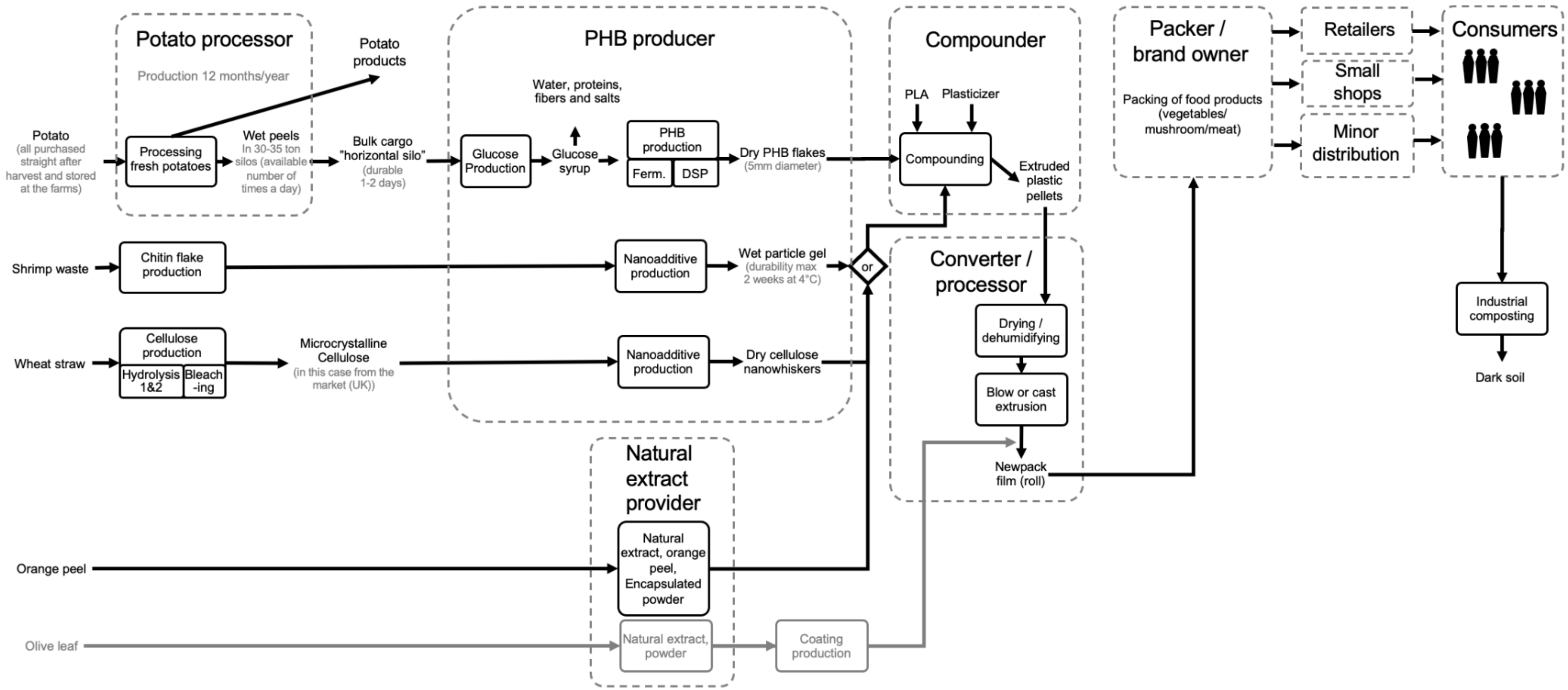


*Fig 3.99 Material flows between all the steps to produce and deliver the NEWPACK products (from the feedstock to the final disposal after the biopolymer use)*

### 3.4.2 Main issues in NEWPACK logistics

Logistics features of the goods change dramatically in the different stages of NEWPACK logistics flows. Firstly, the weight of the material is higher in the first phases of the logistics network and drops fast as the potatoes are peeled and glucose syrup is produced. That is due to the notable amount of water in potatoes and their peels. Again, if peel loss in potato processing is estimated to be around 6 % (e.g., Pathak et al., 2018), there is more than a ton of potatoes needed for each kilo of PHB. Peel loss may be more, depending on the peeling procedure applied, and the total loss of fresh biomass is even greater because of selection and grading of potatoes before peeling (e.g., Pathak et al., 2018; Schieber et al., 2001). Regardless, the volume of potatoes is significant compared to the other logistics flows in the NEWPACK network. For one kilometer of NEWPACK film the needed amount of potato peels differ roughly from 1 to 3 tons depending on the product, whereas the plasticizers, nanowhiskers and natural extracts all together are needed only a few kilos per 1 km of the film. Furthermore, the needed volume of peels for 1 km of film originates from around a truck load of potatoes. Due to the notable changes in material volumes, the first parts of the logistics flows are the most challenging for optimizing the flows of the NEWPACK supply network.

Secondly, the durability of different materials diverges considerably in the NEWPACK logistics network. As mentioned before in the description of the flows, after PHB production most of the materials are very durable, light and thus easily transportable. Also, glucose is durable. Dried glucose can be used after months of storing and in the form of glucose syrup (0,6 kg of glucose in a liter) the durability is around one week at room temperature. The durability is critical with potato peels that are usable for only 1–2 days at room temperature after the peeling process. Therefore, logistically the main durability issues lie in between potato processing (peeling) and glucose production where the time window for the transportation and storing of potato peels is only 1–2 days. That sets limits for the location of the planned production and gives room for logistics solutions with high cost and environmental effects by optimizing the locations of potato processing, and glucose and PHB production.

### 3.4.3 Logistics scenarios

The analysis of the logistics flows addresses the aforementioned critical issues in the beginning of the logistics process. These include the low durability, and big volumes of transported material that result in high frequencies of the potato peel feedstock transportation and thus both high transportation costs and environmental effects. Next, three scenarios are presented offering alternative approaches to manage these issues in the future. Accordingly, the scenarios that are presented concerning the main logistics decisions pertain mostly to the distance between the potato processor(s), glucose production and the PHB plant(s).

**SCENARIO 1: One PHB plant with multiple potato peel sources**

The first logistics scenario is adopted from the initial assumptions made for the NEWPACK *Deliverable 6.1 Report on economic analysis,* where a new PHB plant with 10 000-ton processing capacity is established and located in Belgium due to high potato processing volumes and growing demand for PHB in the market (these assumptions were changed later for a revision of D6.1). A total distance for handling the incoming primary biomass is 150 km, with no reduction in water content prior to transport.

The strength of this scenario is having optimal facilities for large scale PHB production. Also, the location in Belgium with high potato production and multiple potato processing companies would ensure the needed feedstock of 700 000 tons of peels annually that is 1 900 tons everyday if the production is continuous. This scenario is the same as the process illustrated in Figures 3.5 and 3.9.

Due to the high processing capacity the feedstock needed is remarkable. Operated with 44 tons five-axle road haulage combination (tractor + horizontal silo semi-trailer) with 30-ton payload capacity, the transportation of potato peels would require 63 daily trips between potato processors and the PHB plant. If the trip takes four hours back and forth with loading and unloading altogether, the transportation requires at least 10 vehicles running continuously. The efficiency of the transport would be low because of the high amount of water transported due to very moist potato peels and low possibilities for utilizing the empty transport capacity on the way from the PHB plant back to the potato processors. Also, the low durability of potato peels (1–2 days at room temperature) sets high requirements for logistics planning and demand management to avoid shortages in production and biomass getting deteriorated.

**SCENARIO 2: A PHB plant close to the potato processor(s)**

In the preliminary Life Cycle Assessment done in the NEWPACK project (see *D6.2 Preliminary report on Life Cycle Assessment*), transportation is not seen as a hotspot in the project setting. However, the distance comes with multiple logistics challenges related to, for example transportation costs, needed transportation equipment, and durability issues as the peels stay fresh for only 1–2 days at room temperature. Thus, scenario 2 minimizes the transportation of potato peels by locating the PHB plant close to a potato processor(s) (see Fig 3.10). This decreases the most notable transportation volumes in the NEWPACK logistics network.

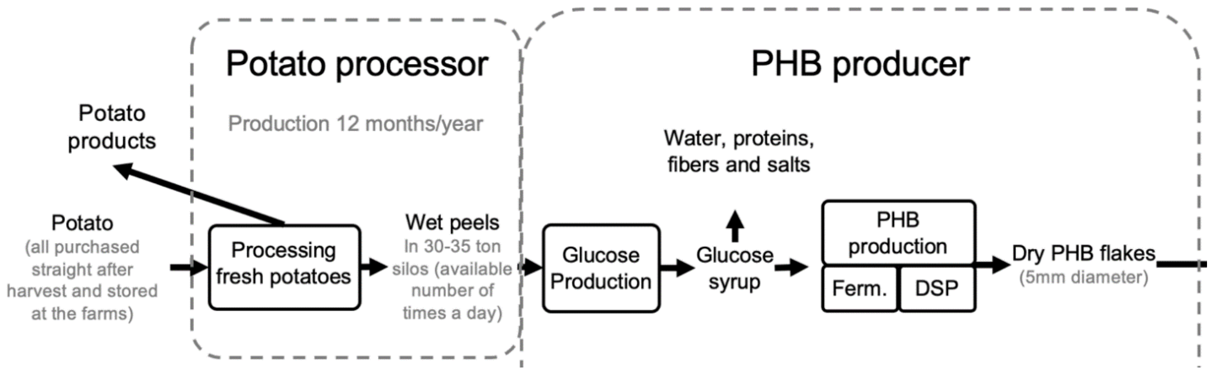


*Fig 3.10 Logistics scenario 2 with a PHB plant close to the potato processor*

The short distance between the potato processor and the PHB producer minimizes the transportation volumes but assumes the potato processor to be large in scale to be able to produce all the peels needed for the PHB production. Otherwise, there is a need to have multiple PHB plants close to several potato processors. This setup would be beneficial only in a geographical area with multiple potato processors close to each other that would allow one PHB plant to operate close to multiple potato processors.

**SCENARIO 3: Decentralized pre-production close to multiple potato processors**

The third scenario assumes that glucose production can be decoupled from the PHB production (see Fig 3.11) that might be an option according to the expert interviews. These two processes differ from each other, for example, by the needed equipment and by the amount of mass handled during the procedures. Glucose production is also a simpler process than PHB production. Separating these two processes into two different plants would allow having glucose production plant close to potato processing facilities.

Counted in transport volumes, this scenario offers the biggest savings as transportation of peels, and thus of water, is minimized. Potato processing and glucose production being very close geographically would allow also transport modes with lower energy consumption and environmental effects such as pipes or conveyers instead of truck transportation. With this operational model the transportation of peels would transform into transportation of glucose syrup decreasing the weight of the transported material into one tenth of its original form without adding any extra energy consuming drying phases into the process.

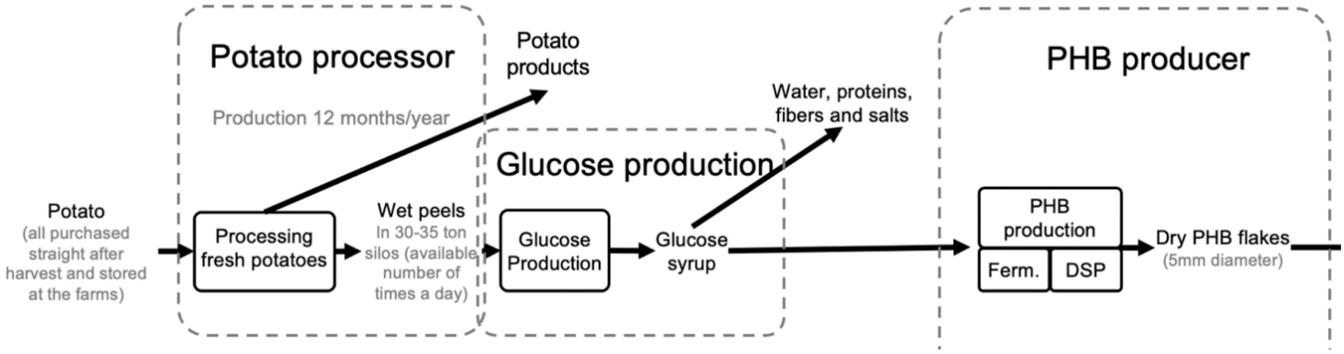


*Fig 3.11 Logistics scenario 3 with decentralized glucose production close to potato processors*

Also, from durability perspective the decentralized pre-production close to potato processors would be beneficial. The 1–2-day durability of potato peels sets high requirements for transportation when the driving distance requires several hours on the road, in addition to the loading and unloading procedures. Longer distance sets also requirements for the safety stock to keep glucose production running that, again, is challenging due to low durability of potato peels. Glucose syrup is durable for PHB production for one week that is a notable addition compared to potato peels' 1–2 days. Durability can be further improved by concentrating the glucose syrup that would increase the durability into months but on the other hand would be energy consuming keeping in mind that water would later be added into glucose powder anyway in the PHB production process.

Due to the decreased transportation volumes and increased durability, decentralized glucose production close to potato processing plants would open possibilities for multiple potato processors to provide their side streams of peels for PHB production. The transportation of glucose or glucose syrup would then be technically and logistically reasonable from several hundreds or even thousands of kilometers distance from the PHB plant(s). This allows the use of possible free capacity of returning transportation units that are a result of imbalanced transport market that occurs in many geographical areas (see Liimatainen et al., 2012). In addition, the geographically close operation with potato processors and glucose production opens possibilities for new type of collaboration between the actors. For example, potato processors and PHB producers would both have interest in having joint ventures for logistically most efficient glucose production. All three presented scenarios are illustrated in a simplified Figure 3.12.

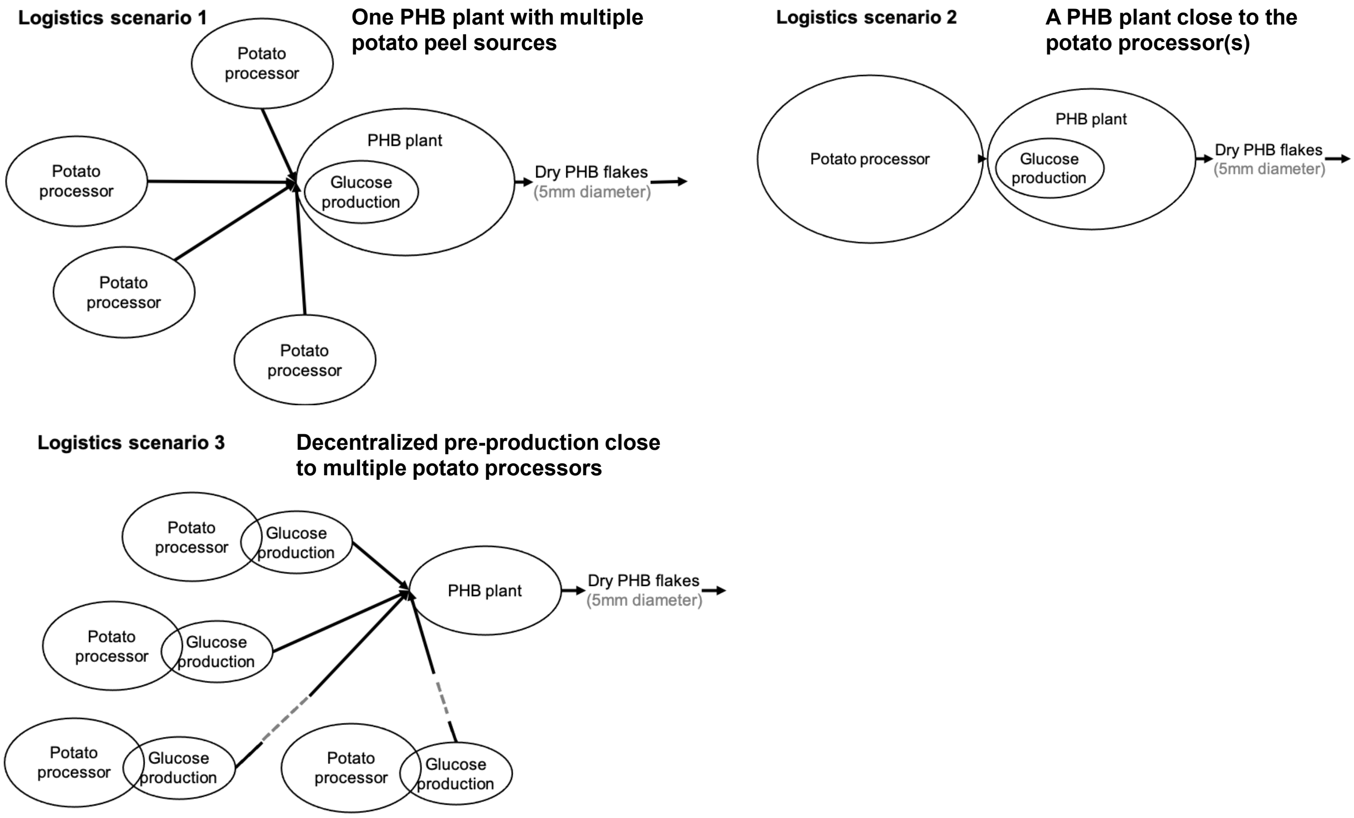


*Fig 3.12 Logistics network scenarios for organizing the flows from feedstock to PHB production*

# 4. CONCLUSIONS

The objective of Task 6.5 was to make a value chain analysis to assess and optimize the entire process up to the delivery of the biopolymers in their final applications, including the logistic study optimizing the flows in this process. Therefore, according to the objectives of *Deliverable 6.7 Report on the value chain analysis*, this report described the existing value networks in plastics and related industry sectors, including the core actors and the relevant business models, in Chapter 3.2, and further analysed the formation of future value network for the dissemination of NEWPACK products in Chapter 3.3. The logistic study was described in Chapter 3.4.

To summarize the key findings of this value chain analysis, the existing value networks and the new value network for the NEWPACK products is now compared to identify the main differences between these networks that may contribute to the formation of a new value network for the NEWPACK products. Finally, with the support of analysis of existing industry data, we evaluate the market potential of the materials developed in the NEWPACK project.

## 4.1 Comparing existing value networks and the new value network for NEWPACK products

When the conventional plastic and project network and general bioplastic packaging value network are compared with the new value network needed in the diffusion of the NEWPACK products, the following network changes are identified to promote the formation of the new value network (modified from Keränen et al., 2021):

- *Identifying and engaging new actors* to perform *new value activities* and provide *new resources*, required in transforming agro-food waste it into bioplastics, and in managing the end-of-life processes
- *Creating new connections* 1) *between new and existing actors* to distribute agro-food waste and transform it into bioplastics, develop the material for the specified needs of brand owners and produce it at large-scale, and manage the end-of-life processes, and 2) *between existing actors* to communicate the market demands and make more sustainable and safe packaging decisions
- Creating *a network type of collaboration*

Considering that the NEWPACK materials are likely to replace conventional plastic packaging materials that are currently widely used, the new value network for the NEWPACK products requires an addition of new value activities and resources, which primarily relate to distributing and processing agro-food waste streams (especially potato peels for PHB production and other feedstocks for nanoadditives production) for large-scale production. In addition, the development of the end-of-life processes of the biobased biodegradable packaging material would support the market potential of the NEWPACK materials. The actors that can perform these activities and provide necessary resources are new to the conventional plastic food packaging value network, including biomass feedstock providers, distributors and processors, and new kinds of end-of-life services. For example, firms focused on bioplastics production are innovative and eager to adopt external research and development results to try new feedstocks and processes, and one potential option is to try to involve such firms into adopting the knowledge developed in this project to produce PHB. In addition, compounders, processors, and converters, having good connections to the industry and who are already familiar with formulating and processing comparable bioplastics, could be involved into the commercial value network. Involving new actors into the value network can lead, however, to new connections between new and existing actors. For example, potato peel providers, distributors and processors would become connected with bioplastic producers – either new or already existing companies.

One option to build the new value network is to build a new organizational entity around the developed knowledge, a new firm, or a joint venture, who then takes the responsibility of building the value network and identifying and involving the needed actors. However, it is not likely that the NEWPACK products are reaching the market at this point, so to facilitate their diffusion in the future, project members can sell the knowledge acquired from the project to other businesses or license their IPRs to commercial enterprises, for example, to innovative material developer firms. Alternatively, the project partners can utilize the developed knowledge in their current businesses with other commercial actors or research organizations, in order to push the developed knowledge further and to be utilized commercially. However, then there would not be any new value network formed yet that would be focused on producing these materials.

New connections are not needed just to organize the production and dissemination of the materials but to support their dissemination in a more indirect way. For example, it might be necessary that packaging suppliers and brand owners start to cooperate with innovative material development firms to develop the material further for their own specified needs and later with specialized bioplastic material producers to produce such a material if conventional plastic producers are reluctant to accept the new bioplastic packaging material and the changes that it would create to their production lines. In addition, creating new connections between the existing value network actors are identified to enhance the possibility of restructuring the existing industry value network by breaking its non-transparent and linear structure. That alone could facilitate the development of more sustainable packaging solutions, affecting the growth of the market for biobased biodegradable packaging. We identify that a networked type of collaboration, which connects different actors more holistically together across the value network, to be beneficial, because the network of actors is expected to be more powerful than the influence created by individual actors, also when they aim to educate the market about the new packaging materials – not only to advance the material development as such. Specifically, new connections between actors in the upstream and downstream of the value network seem to be relevant. For example, collaboration between brand owners and packaging and material suppliers is identified to be important for transparent information sharing, which would allow communicating the market demands throughout the value network and for brand owners to make more sustainable and safe packaging decisions.

On the logistics analysis, after mapping all the flows it was noted that the first parts are the most challenging for optimizing the flows of the NEWPACK supply network in the future. Therefore, three logistics scenarios were presented that focused on building alternatives for organizing the potato peel supply for PHB production. The first scenario presented one PHB plant with multiple potato peel sources, the second illustrated a PHB plant close to the potato processor(s), and the third scenario presented a decentralized pre-production close to multiple potato processors. Each scenario has its pros and cons, but it can be noted that the key question in each of them is to try to minimize the amount of transported water in peels, as transportation of large amounts of wet peels is rather inefficient, and the limited durability of peels sets limitations for these scenarios. Decreasing volumes and increasing durability of the transported materials offer interesting possibilities to use feedstock from a larger geographical area and to utilize cheaper and more environmentally friendly transportation options. Finally, an important conclusion is that optimizing logistics is not separate function in planning the value network but strongly linked to the chosen business strategy and economic viability of different options.

### 4.2 The market potential of the NEWPACK products

The market potential of the NEWPACK products is promising, considering the increasingly growing bioplastics market, for which packaging sector (including flexible and rigid plastic packaging) is an important market segment. Specifically, due to PHA's significant growth rates and investments in PHA production in the United States and in Europe (European Bioplastics, 2021), the global production capacity of PHA materials, including PHB, is expected to grow from 1,7 % of the total production capacity for bioplastics (including biobased/nonbiodegradable and biodegradable plastics) to 11,5 % by year 2025 (European Bioplastics, 2020b). Indeed, the interviewees characterize that every PHA material that has been produced so far or is planned to be produced soon has already been sold, which reflects the high demand of PHA materials.

However, the products and their production process developed within the NEWPACK project might not be as economically and sustainably viable just yet as needed for a successful market entry directly after the project, which is due to the research and innovation-oriented nature of the project. Similarly, the properties of the developed packaging solution might benefit from further research and testing, as they might influence its attractiveness in the eyes of customers, including both business actors and consumers. Also, further development of the PHB and nanoadditives production processes would not only be beneficial for cutting the costs (see *Deliverable 6.1 Report on economic analysis* for details) but to target the identified environmental hotspots (see *Deliverable 6.3 Final report on Life Cycle Assessment*). Therefore, even though the developed NEWPACK materials appear as an appropriate alternative for conventional packaging solutions, according to the validation results gained in the project, more development work would further help in the future in order the NEWPACK materials to be a competitive replacement for fossil-based plastic food packaging in a broader market, and to develop their properties to suit a wider selection of food products. This development work can be made by the project members who may be interested in starting new research activities and collaborations in funded international and national projects. Alternatively, innovative material developer firms or existing PHB producers might be interested in trying out new feedstocks for PHB production and in optimizing the production process for the developed material. Each project actor can also take the development work further in their own current operations. Useful collaboration parties to promote the material and facilitate its wider diffusion in the market are PHB producers and material associations, for instance.

Indeed, many project members are planning to utilize the knowledge acquired from the project either in their current businesses, or by selling their knowhow to other businesses or licensing their IPRs to some commercial enterprise for the commercialization or further development, for example, to innovative material developer firms or PHB producers. In this way, there is a great market potential for different technologies developed within the project. Besides primary food packaging, also secondary packaging is a potential use target, and not only films, but in theory, also thermoformed trays, or other injected components could be produced from the developed materials in the future. In addition, the results of the project have raised interest among diverse types of manufacturers across industries who are searching for biobased and biodegradable materials to be used in their products.

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