BIOMAC

Deliverable 3.3

Delivery of agricultural applications

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22/09/2023	1	Initial version
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LIST OF ACRONYMS

ATB	Leibniz Institute of Agricultural Engineering and Bio-economy e.V.
AUTH	Aristotle University of Thessaloniki
BBEP	Bio Base Europe Pilot Plant VZW
BIOMAC	BioNanoMAterial Community
EU	European Union
H2020	Horizon 2020
MD	Machine Direction
NVMT	Novamont
OITB	open innovation test bed
PL(s)	Pilot line(s)
PPSH	Pilot Plant Surpreme Hubs
TeC	Test Case
TRL	Technology readiness level
UEDIN	University of Edinburgh
WP	Work Package

1. Executive Summary

The present report constitutes deliverable 3.3 "Delivery of agricultural applications" within the framework of the H2020 OITB BIOMAC project (European Sustainable BIO-based nanoMAterials Community) which aims, in a four-year horizon, to create an open innovation ecosystem Open Innovation Test Bed (OITB) for upscaling the processes of production and use of biopolymers and nano materials produced from biomass. The following activities refer to "WP3 - Pilot Plant Supreme Hub (PPSH) Services" and in particular to task 3.3 "Task NOVAMONT Agricultural Applications".

Herein it is reported on the validation of several intermediate materials from EU pilot lines for the obtaining of biomaterials for agricultural applications (Table 1).

Table 1. Intermediates from BIOMAC pilot lines and the corresponding biomaterials for agricultural applications.

Pilot line (owner)	Intermediate	Final biomaterial
PL8 (EUDIN)	Biochar	• Starch based biomaterial for black biodegradable in soil mulch film • Biopolyester-based biomaterial for injection molded black grow pots
PL4 (CNANO)	Nanolignin	• Starch based biomaterial for brown biodegradable in soil mulch film • Biopolyester-based biomaterial for injection molded brown grow pots
PL11 (AIMP)	Nanocomposite PLA pellets	• Starch based biomaterial for opaque biodegradable in soil mulch film
PL7 (ATB)	Succinic acid	• Biopolyester-based biomaterial for injection molded grow pots including biobased succinic acid
PL3 (AUTH)	Polyols and diols	• Starch based biomaterial including sorbitol for biodegradable in soil mulch film

For the purpose, this report on has been structured as follows:

a) Chapter 2: where the context on the validation of the intermediate materials from the PL of BIOMAC is being provided.

b) Chapter 3: where specific sheets detailing non-confidential characteristics of the final products for agricultural applications are reported.

c) Chapter 4: where conclusions and future perspectives of these agricultural products are envisioned.

2. Introduction

BIOMAC, as an open ecosystem, focuses on the creation and validation of new supply and value chains where technologies that are being scaled-up and validated to TRL 7, accelerating their exploitation potential. As a consequence, the BIOMAC OITB has been built to address 5 Test Cases (interTeCs) for the validation selected based on their complexity in order to involve different PLs as well as the supporting services and thus provide a holistic feedback for the operation of the OITB as a whole. The TeC2 "Agricultural applications" is led by NVMT and it aims at validating the use of different intermediates for the preparation of biomaterials with application in agriculture (Figure 1).

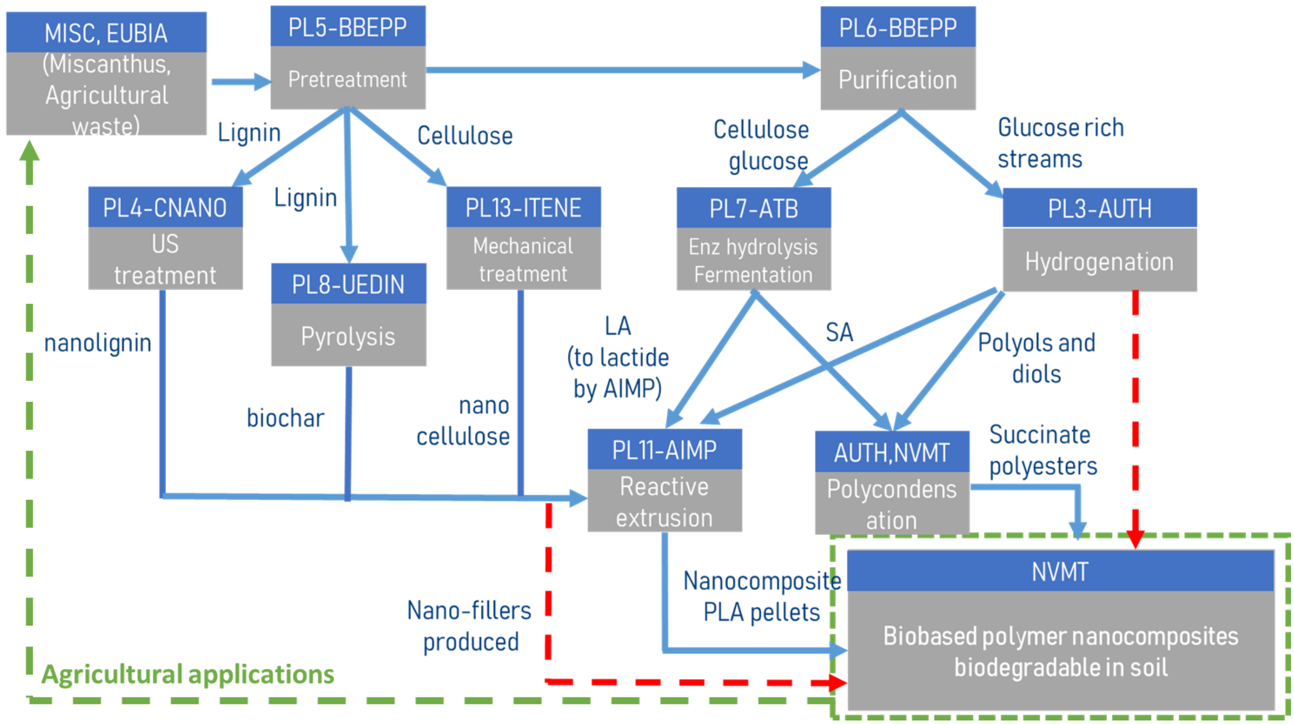


Figure 1. Overview of TeC2: agricultural applications

The value chain starts from the valorization of *Miscanthus* agrowaste into lignin and polysaccharides (PL5). Lignin is ultrasonicated to obtain nanolignin (PL4) and it is pyrolyzed to obtain biochar (PL8) while the polysaccharides are mechanically treated to obtain nanocellulose (PL13), hydrolyzed (PL6) to obtain fermentable sugars and glucose-rich streams. In turn, nanolignin has also been used for the preparation PLA-based nanocomposites (PL11), fermentable sugars for the obtaining of succinic acid (PL7), and glucose has been hydrogenated to sorbitol and other polyols (PL3).

All of these different intermediates are suitable to be processed through extrusion processes and can be effectively valorized in two categories of products: starch-based biomaterials for film blowing (e.g. biodegradable in soil mulch film) and biopolyester-based biomaterials (e.g. injection molded grow pots).

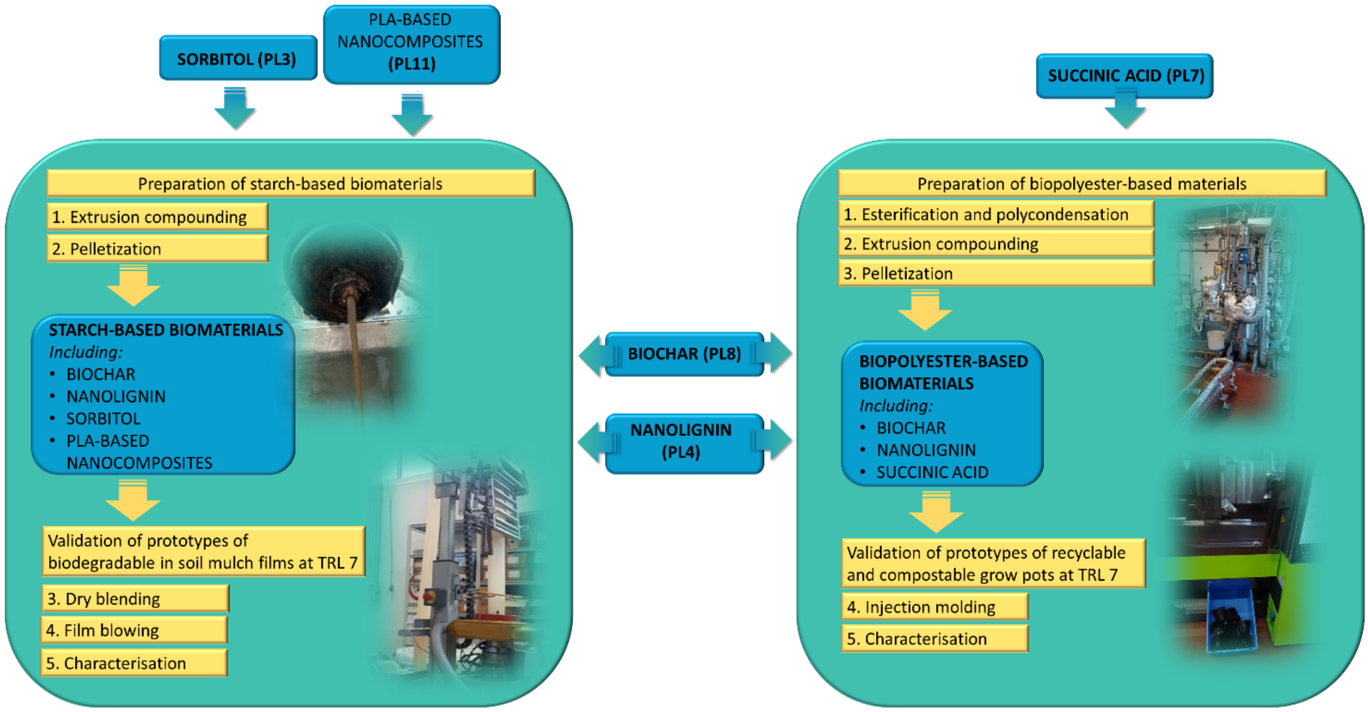


Figure 2. Valorisation of the five intermediates from the PLs into biomaterials for film blowing (e.g. biodegradable in soil mulch films) and injection molding (e.g. recyclable and compostable grow pots).

These following applications have been selected due to their potential benefits due to the introduction of intermediates materials from the PLs as well as due to favorable exploitation opportunities, as reported in D5.1 “Workflow Design and Preparatory Market Uptake actions” submitted at M18:

Biodegradable in soil mulch films: mulching is a consolidated agronomic technique used to prevent weed growth, improving soil heal and fertility, while preserving soil moisture. Mulching in large-scale farms is achieved by applying mulch films with thickness in the order of tens of micrometers that are suitably perforated to allow the growth of the desired crop, but not of the weed. The application of traditionally, non-biodegradable plastic mulch film entails two critical issues: (1) A proper disposal of the mulch films in waste management plants at the end of its life, resulting in higher cost for farmers and for the municipality; (2) Environmental pollution due to accidental dispersion of non-biodegradable plastic fragments in the arable fields (white pollution).

Biodegradable stackable grow pots for Home Gardens, Plant Nurseries and Commercial Farms: plant nursery in grow pots is a consolidated technique that grants ease of watering, thanks to drainage holes in the pot bottom, better plant management and increased mobility without the added weight of too much soil, soil saving in those time of the year when the plant is semi-dormant and growing slow. Grow pots are extensively used in home gardens, plant nurseries, but also commercial farms due to the reduced cost of thin, disposable plastic pots. Though, the difficulty in recycling and reutilizing the grow pots obtained from traditional non-biodegradable materials, is pushing towards the development of biodegradable grow pots that could offer improved recyclability options (including organic recycling).

More specifically:

biochar derived from EU agrowaste (PL8) is expected to replace the use of carbon black in both mulch films and injection molded articles including grow pots;

nanolignin (PL4) from the treatment of Miscanthus' lignin is expected to provide a natural brownish coloring and antioxidant properties to both mulch films and grow pots;

sorbitol from hydrogenation (PL3) is expected to act as a plasticizer in starch-based materials for mulch films;

PLA-based nanocomposites (PL11) are expected to provide an efficient and versatile way towards the introduction of nanomaterials into final products through film blowing without the need of extrusion compounding;

succinic acid (PL7) from the fermentation of glucose is expected to be an alternative to fossil-based succinic acid towards fully renewable biodegradable polyesters for injection molding.

3. Biopolyester-based biomaterial for injection molded black grow pots

Product description
A thermoplastic biobased and biodegradable (EN13432) material suitable for injection molding applications and designed to provide rheological characteristics and recyclability potential suitable for valorization in black grow pots. The grow pots could be mechanically recycled at the end of their life and industrially composted if contaminated by organic residues. These processes do not result in the generation of microplastics due to the biodegradability of the material. The biomaterial is obtained starting from Novamont's formulations including its proprietary biopolyesters and biochar from PL8 (EUDIN).
Product example
 *Biomaterial granules and injection molded grow pots obtained by NVMT and including biochar from Miscanthus straw pellet provided by UEDIN.*

<table>
<tr><td>Biomaterial and final product</td><td colspan="2">Biopolyester-based biomaterial for injection molded black grow pots</td></tr>
<tr><td colspan="3">Product functional requirements and characterization methods</td></tr>
<tr><td>Functional requirement</td><td>Test method</td><td>Required specifications/ performance</td></tr>
<tr><td>Optical properties</td><td>ASTM D1003, wall thickness 800 µm</td><td>Transmittance <10%
Haze > 95%
Clarity < 5%</td></tr>
<tr><td>Recyclability</td><td>Internal method based on re-extrusion and capillary rheological analysis (ISO 11443)</td><td>> 3 cycles</td></tr>
<tr><td>Biodegradability</td><td rowspan="2">Industrially compostable, EN13432</td><td>>90 % within 6 months</td></tr>
<tr><td>Disintegration kinetics</td><td>>90 % within 3 months</td></tr>
<tr><td colspan="3">SWOT and potential valorisation</td></tr>
<tr><td>Strength, Opportunity</td><td colspan="2">• Alternative to the use of fossil-based carbon black with exploitation opportunity in sustainable horticulture and floriculture nurseries
• No generation of microplastics during recycling or in case of accidental dispersion
• Possibility to recover pots contaminated by organic residues through industrial composting
• Reduction in cost of the final bioproduct using economically sustainable biochar grades as filler</td></tr>
<tr><td>Weakness, Threat</td><td colspan="2">• Application with a low valorisation cost
• Use of mixture of non-biodegradable recycled materials with a higher potential of microplastic generation</td></tr>
<tr><td>Indicative positioning range of biochar as filler in grow pots in the current market scenario</td><td colspan="2"><2 €/kg[1]</td></tr>
</table>

[1] Average estimate following discussion with third parties and analysis of databases such as the distributor Enchar, import and export data from Zauba and TradeMap, and the CheMondis marketplace of raw materials.

4. Biopolyester-based biomaterial for injection molded brown grow pots

Product description
A thermoplastic biobased and biodegradable (EN13432) material suitable for injection molding applications and designed to provide rheological characteristics and recyclability potential suitable for valorization in brown grow pots. The grow pots could be mechanically recycled at the end of their life and industrially composted if contaminated by organic residues. These processes do not result in the generation of microplastics due to the biodegradability of the material. **The biomaterial is obtained starting from Novamont's formulations including its proprietary biopolyesters using nanolignin PL4 (CNANO).**
Product example
 *Injection moulde**d** grow pots based on NVMT's biopolyester and including nanolignin*

Biomaterial and final product	Biopolyester-based biomaterial for injection molded brown grow pots	
Product functional requirements and characterization methods		
Functional requirement	**Test method**	**Required specifications/ performance**
Optical properties	ASTM D1003, wall thickness 800 µm	Transmittance <10% Haze > 95% Clarity < 5%
Recyclability	Internal method based on re-extrusion and capillary rheological analysis (ISO 11443)	> 3 cycles
Biodegradability	Industrially compostable, EN13432	>90 % within 6 months
Disintegration kinetics		>90 % within 3 months
SWOT and potential valorisation		
Strength, Opportunity	• Nanolignin shows a thermoplastic behaviour in a narrow processing window (160-180 °C) suitable for obtaining injection moulded parts with an even distribution of color • The natural colour of lignin provides a natural coloring to the final product • No generation of microplastics during recycling or in case of accidental dispersion • Reduction in cost of the final bioproduct using economically sustainable nanolignin grades as filler	
Weakness, Threat	• Application with a low valorisation cost • Availability of cheaper thermoplastic lignin not nanostructured from mayor pulp and paper companies	
Indicative positioning range of nanolignin as filler in grow pots in the current market scenario	<2 €/kg[2]	

[2] Average estimate following analysis of databases such as import and export data from Zauba and TradeMap, and the CheMondis marketplace of raw materials.

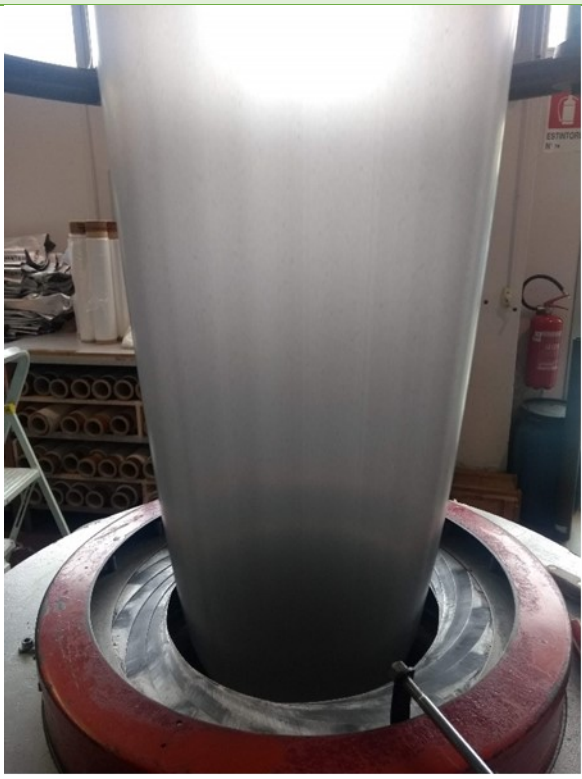
5. Biopolyester-based biomaterial for injection molded grow pots including biobased succinic acid

Product description
A thermoplastic biobased and biodegradable (EN13432) material suitable for injection molding applications including a biopolyester derived from biobased succinic acid from the fermentation of *Miscanthus'* sugars. The grow pots could be mechanically recycled at the end of their life and industrially composted if contaminated by organic residues. These processes do not result in the generation of microplastics due to the biodegradability of the material. The biomaterial is obtained from Novamont's formulations including its proprietary biopolyesters prepared from succinic acid PL7 (ATB).
Product example
 *Injection moulded grow pots based on NVMT's biopolyester derived from biobased succinic acid*

Biomaterial and final product	Biopolyester-based biomaterial for injection molded grow pots including a biopolyester derived from biobased succinic acid	
Product functional requirements and characterization methods		
Functional requirement	**Test method**	**Required specifications/ performance**
Recyclability	Internal method based on re-extrusion and capillary rheological analysis (ISO 11443)	> 3 cycles
Biodegradability	Industrially compostable, EN13432	>90 % within 6 months
Disintegration kinetics		>90 % within 3 months
SWOT and potential valorisation		
Strength, Opportunity	• Potentially >95% RRM biomaterial from EU feedstock • No generation of microplastics during recycling or in case of accidental dispersion • Opportunity in implementing a chemical recycling process for the recovery of added-value monomers	
Weakness, Threat	• Application with a low valorisation cost • • Use of mixture of non-biodegradable recycled materials with a higher potential of microplastic generation	
Indicative positioning range of biobased succinic acid in the current market scenario	<7 €/kg[3]	

[3] Average estimate following analysis of databases such as import and export data from Zauba and TradeMap, and the CheMondis marketplace of raw materials.

6. Starch-based biomaterial for black biodegradable in soil mulch film

Product description
A thermoplastic biobased and biodegradable (ISO 17556, EN17033) material suitable for film blowing applications and designed to provide mechanical properties suitable for in-field deployment compatible with standard agricultural machinery. The mulch film is tilled in the soil at the end of the crop cycle and it undergoes biodegradation in soil without the generation of microplastics. The biomaterial is obtained from Novamont's proprietary formulations including thermoplastic starch and biochar.
Product example
  *Film blowing of biomaterial by NVMT including biochar and final film roll*

Biomaterial and final product	Starch based biomaterial by NVMT for black biodegradable in soil mulch film	
Product functional requirements and characterization methods		
Functional requirement	**Test method**	**Required specifications/ performance**
Optical properties	ASTM D1003, film thickness 15-20 µm	Transmittance <80% Haze > 90% Clarity < 10%
Tensile properties	ASTM D882, film thickness 15-20 µm (MD)	Tensile strength at break >20 MPa; Elongation at break > 350 %; Young modulus < 250 MPa
Barrier properties (WVTR)	ISO 15106 - 23°C; 85%RH; film thickness 15-20 µm	<400 g/(m^2·24h)
Biodegradability	Biodegradability in soil, ISO 17556, EN17033	>90 % within 2 years
SWOT and potential valorisation		
Strength, Opportunity	• Alternative to the use of fossil-based carbon black with exploitation opportunity in 100% biobased agrofilm for biological agriculture applications • Valorisation of biochar from EU biomasses for agricultural applications in a circular bioeconomy case study.	
Weakness, Threat	• The use of biochar in thin films (< 14 micrometers) requires the development of processes to obtain micropowders with a granulometry characterised by D50 values around 1-2 micrometers. • Biobased carbon black from biogas could be an alternative to the use of biochar from biomass pyrolysis.	
Indicative positioning range of biochar in the current market scenario	<5 €/kg depending on final granulometry[4]	

[4] Average estimate following discussion with third parties and analysis of databases such as the distributor Enchar, import and export data from Zauba and TradeMap, and the CheMondis marketplace of raw materials.

7. Starch-based biomaterial for brown biodegradable in soil mulch film

Product description
A thermoplastic biobased and biodegradable (ISO 17556, EN17033) material suitable for film blowing applications and designed to provide mechanical properties suitable for in-field deployment compatible with standard agricultural machinery. The mulch film is tilled in the soil at the end of the crop cycle and it undergoes biodegradation in soil without the generation of microplastics. The brownish color is compatible with local regulations favoring “naturally-colored” mulch films over traditional black mulching. The biomaterial is obtained starting from Novamont’s proprietary formulations including thermoplastic starch using nanolignin PL4 (CNANO).
Product example
  *Film blowing of biomaterial by NVMT including lignin at different concentration*

Biomaterial and final product	Starch based biomaterial by NVMT for brown biodegradable in soil mulch film	
Product functional requirements and characterization methods		
Functional requirement	**Test method**	**Required specifications/ performance**
Optical properties	ASTM D1003, film thickness 15-20 µm	Transmittance <80% Haze > 90% Clarity < 10%
Tensile properties	ASTM D882, film thickness 15-20 µm (MD)	Tensile strength at break >25 MPa; Elongation at break > 300 %; Young modulus < 250 MPa
Barrier properties (WVTR)	ISO 15106 - 23°C; 85%RH; film thickness 15-20 µm	<400 $g/(m^2 \cdot 24h)$
Biodegradability	Biodegradability in soil, EN17033	>90 % within 2 years
SWOT and potential valorisation		
Strength, Opportunity	• Nanolignin shows a thermoplastic behaviour in a narrow processing window (160-180 °C) suitable for obtaining mulch films with low unmelts and improved mechanical properties due to a more homogeneous distribution. • The natural colour of lignin offers the opportunity for the valorisation of brownish mulching in those local communities where the use of more visually impacting black mulch films are banned. • Valorisation of lignin from EU biomasses for agricultural applications in a circular bioeconomy case study.	
Weakness, Threat	• Nanolignin bears a quite distinctive odour which made its use not suitable for products with indoor applications. • Competitive thermoplastic lignin not nanostructured are being developed by mayor pulp and paper companies.	
Indicative positioning range of nanolignin for mulch films in the current market scenario	<5 €/kg[5]	

[5] Average estimate following analysis of databases such as import and export data from Zauba and TradeMap, and the CheMondis marketplace of raw materials.

8. Starch-based biomaterial for opaque biodegradable in soil mulch film

Product description
A thermoplastic biobased and biodegradable (ISO 17556, EN17033) material suitable for film blowing applications and designed to provide opaqueness and shielding light to prevent the growth of weed. The addition of a combination of titanium dioxide and nanolignin provides UV resistance through the life of the mulch film. The use of PLA-lignin nanocomposite as a masterbatch in a dry blend for film blowing offers a wider flexibility in tuning the amount of nanolignin in the final film. The biomaterial is obtained starting from Novamont's proprietary formulations including thermoplastic starch and titanium dioxide using nanolignin PL4 (CNANO).
Product example
 *Film blowing of biomaterial by NVMT including lignin and titanium dioxide*

<table>
<tr><th>Biomaterial and final product</th><th colspan="2">Starch-based biomaterial for opaque biodegradable in soil mulch film</th></tr>
<tr><th colspan="3">Product functional requirements and characterization methods</th></tr>
<tr><th>Functional requirement</th><th>Test method</th><th>Required specifications/ performance</th></tr>
<tr><td>Optical properties</td><td>ASTM D1003, film thickness 15-20 µm</td><td>Transmittance <70%
Haze > 95%
Clarity < 10%</td></tr>
<tr><td>Tensile properties</td><td>ASTM D882, film thickness 15-20 µm (MD)</td><td>Tensile strength at break >22 MPa;
Elongation at break > 350 %;
Young modulus > 200 MPa</td></tr>
<tr><td>Barrier properties (WVTR)</td><td>ISO 15106 - 23°C; 85%RH; film thickness 15-20 µm</td><td><400 g/(m²·24h)</td></tr>
<tr><td>Biodegradability</td><td>Biodegradability in soil, EN17033</td><td>>90 % within 2 years</td></tr>
<tr><th colspan="3">SWOT and potential valorisation</th></tr>
<tr><td>Strength, Opportunity</td><td colspan="2">• The PLA nanocomposite enhance the rigidity of the final film and could improve the deployment of the mulch film.
• Titanium dioxide improve on the optical properties of lignin offering more opacity to limit the photosynthetic active radiation needed for weed growth.</td></tr>
<tr><td>Weakness, Threat</td><td colspan="2">• Need to select specific titanium dioxide grades certified according to EN17033.
• US and Asian countries are largely investing in industrial plant for the production of PLA, making EU dependent on this biopolymer.</td></tr>
<tr><td>Indicative positioning range of PLA nanocomposites in the current market scenario</td><td colspan="2"><6 €/kg[6]</td></tr>
</table>

[6] Average estimate following analysis of databases such as import and export data from Zauba and TradeMap, and the CheMondis marketplace of raw materials.

9. Starch based biomaterial including polyols and diols for biodegradable in soil mulch film

Product description
A thermoplastic biobased and biodegradable material (ISO 17556, EN17033) suitable for film blowing applications and designed to provide improved mechanical properties suitable for in-field deployment compatible with standard agricultural machinery thanks to the use polyols and diols (e.g. sorbitol) as the plasticizer of starch. The biomaterial is obtained from Novamont's proprietary formulations including thermoplastic starch, using poyols and diols from AUTH (PL3).
Product example

Film blowing of biomaterial by NVMT including polyols and diols (e.g. sorbitol) from PL3

Biomaterial and final product	Starch based biomaterial including polyols and diols for biodegradable in soil mulch film	
Product functional requirements and characterization methods		
Functional requirement	**Test method**	**Required specifications/ performance**
Tensile properties	ASTM D882, film thickness 15-20 µm (MD)	Tensile strength at break >26 MPa; Elongation at break > 450 %; Young modulus < 200 MPa
Barrier properties (WVTR)	ISO 15106 - 23°C; 85%RH; film thickness 15-20 µm	<400 g/(m^2·24h)
Biodegradability	Biodegradability in soil, EN17033	>90 % within 2 years
SWOT and potential valorisation		
Strength, Opportunity	• The polyols and diols including sorbitol act as plasticizer of starch and results in a biomaterial and film with enhanced elongation at break (> 450%) and strength at break (>26 MPa) suitable for deployment with mechanized systems. • Valorisation of sugar sidestreams from EU biomasses for agricultural applications in a circular bioeconomy case study.	
Weakness, Threat	• Complex profile of components in the hydrogenated sugar mixtures that might be sensible to seasonality. • Large offer from other biobased polyols.	
Indicative positioning range of polyols and diols in the current market scenario	<2.5 €/kg[7]	

[7] Average estimate following analysis of databases such as import and export data from Zauba and TradeMap, and the CheMondis marketplace of raw materials.

10. Conclusions

In the previous Chapters, the dedicated effort of Novamont in validation tests towards delivering agricultural applications for the intermediate materials obtained from the EU pilot lines of the OITB BIOMAC has led to the demonstration of the valorisation of **biochar** from pyrolysis of Miscanthus (PL8), **nanolignin** from Miscanthus (PL4), **biobased succinic acid** from the fermentation of sugars (PL7), **nanocomposite PLA pellets** including nanolignin (PL 11**), polyols and diols** including sorbitol from the hydrogenation of sugars (PL3).

Going forward, the demo activities implemented with these first samples provided by the PLs within WP3 provide a valuable feedback for the activities linked to the Validation Services Hub (WP4), Market Uptake Hub (WP5), Value Chain assessment Hub (WP6), Exploitation & Sustainability (WP8), Dissemination Communication & Clustering (WP8).

With insight, the delivery of biodegradable in soil mulch films and recyclable and compostable grow pots:

- could be further enhanced by the development of biomaterial grades and final products which combine together several intermediate materials from the PLs (e.g. a biodegradable in soil mulch film plasticized with polyols and diols and additivated with nanolignin for a natural brown color);
- could be at the basis of EU bioeconomy circular case studies for the valorisation of agro-biomasses into agricultural applications.