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BIOAGROTEX

Development of new agrotextiles from renewable resources and with a tailored biodegradability

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1 Executive Summary

Increasing oil-prices, a growing threat of oil-shortages, greenhouse gases and their effect on climate change, are elements that contribute to the concern for the future of our oil based economy. The search for biobased polymers and a more extensive use of the natural resources will be needed to cope with these problems and to initiate growth in the biobased economy. Agrotextiles can offer a very attractive end market in this regard. At the moment the market is dominated by polyolefin' based agrotextiles. Other products are based on natural fibres but are degraded too fast to be very attractive. BIOAGROTEX aims at developing novel fully biobased agrotextiles with a drastically reduced impact on environment.

Different production routes are followed to develop this type of end product.
In a first route standard natural fibre based groundcovers are upgraded via application of bioresins including functional additives. For the natural fibres either recycled is used or upgraded side fractions of linseed or hemp production can be used. Properties of these fibre fractions are improved by optimising the fibre preparation process, including enzymatic retting or pretreatment. Upgrading the durability is performed via Furan based bioresins specially developed for this application in order to control reactivity of the resin and the flexibility of the woven or non-woven fibremats. An alternative route using partly oil based chemicals is developed as well with included functionality to delay degradation. It is shown in lab trials using soil burial and Q-UV tests along with field trials that the developed products have a considerable extended lifetime in normal usage (> double).

In a second route meltprocessable biopolymer formulations either starch based or PLA based are evaluated for their potential in textile extrusion processes including: staple fibre, monofilament yarns, multifilament yarns and tapes. Processes are optimised to obtain the appropriate properties.
The objective to use Starch based thermoplastic in these applications couldn't be reached. Improved formulations were developed that allows producing monofilaments, multifilaments and tapes, but mechanical properties are still insufficient for developing industrial products.
With PLA based formulations the complete range of textiles can be produced with acceptable properties for further processing, including production of non-wovens, knitted and woven fabrics. Also a range of functionalisation routes either to improve processability and properties, to control or improve the durability of the products and to introduce specific functionalities like: colour, flame retardency and anti-microbial properties. Also durability of these materials are tested in laboratory conditions and in real life leading to an expected life time of at least 3 to 5 years.

Several demonstrator products are developed including woven PLA ground-covers, knitted PLA insect screens, PLA needlefelt ground covers and natural fibre groundcovers (needlefelts or woven) with raised durability by resin application. Demonstrators are installed in several test sites in Europe for evaluating their real life performance.
For all materials produced the ecological impact of the development was analysed. It was also verified that the used products or degradation products generated are not causing toxic effect to fauna or flora.

Based on these positive evaluations the commercialisation of several products will be started.
For the natural fibre based products, woven jute fabric will be launched treated with bioresins and with an extended durability. Different PLA based products will be launched as well for the agrotextile market, including: woven groundcovers (tradename DURACOVER®), needlefelt groundcovers (HORTAFLEX®) and different types of knitted insect screens or wind break nets (FILBIO PLA®, Ultravent PLA®).

2 Summary description of project context and objectives

2.1 Context

Increasing oil-prices, a growing threat of oil-shortages, Kyoto agreements on greenhouse gases, environmental effects and climate changes, are all elements that contribute to the concern for the future of our oil based economy. Europe is gradually preparing the shift towards a biobased economy, a multistep process that will take decennia to come to its completion. Initiatives are required to start-up this process of change and to explore at an early stage the possibilities offered by products already under development.

Textiles and especially agrotextiles offer a very attractive end market. Volumes in this market area are high and fast growing. At present, products are mainly based on Polyolefin's (> 200Ktonnes/annum in Europe) and to a lesser extent other petrochemical polymers such as PA and PET are used. In most cases these agrotextiles are at the end-of-life difficult to recover from the fields and will be polluted by a vast amount of organic material and sand, making efficient recycling and even combustion with energy recovery extremely costly and not attractive.
A number of agrotextiles are based on natural fibres, but in general these products are degrading that fast in the natural environment that there lifetime is usually limited to one or maximum two years and textiles with a relatively high weight per m² are required in order to compensate a bit for the fast degradation.

Bio-based polymers in combination with natural fibres and side products can offer a good alternative, if biodegradation can be modelled and adapted according the specific end applications. Intrinsic positive properties of the bio-based polymers such as low flammability, light fastness or intrinsic preservation properties can boost technological advantages, leading to major economic and technologic benefits in industrial implementation. The proposed project envisages the research and development of new 100% renewable agrotextiles, via combination of natural fibres, bio-based fibres and bio-based resins and this respecting the economic and ecological relevance of the development.

2.2 Objectives

The BIOAGROTEX projects aims at the development of fully biobased agrotextiles with a controlled (or extended) durability as alternatives for the existing PP based agrotextiles or the natural fibre based agrotextiles with a very short lifetime.

Two routes are followed:

1. The development of biopolymers formulations (WP1) that can be melt-processed using a range of textile extrusion techniques including tape or monofilament, staple fibre, multifilament extrusion on laboratory and pilot scale (WP2) and on industrial scale including a range of further industrial processing trials such as knitting, weaving, needlefelt production (WP6). Two biopolymer families are evaluated:
    a. use of biopolyesters as meltprocessable polymers, with focus on PLA
    b. use of starch based formulations

2. Development of natural fibres, either recycled or from low value agricultural fractions and optimising properties via (enzymatic) pretreatment to optimise yield and properties (WP4). Development of bioresin (furan based) to finish the NF based products, extending the durability without jeopardizing the mechanical properties (WP3), processing the experimental fibres into non-woven structures and finishing them on pilot scale (WP5) and upscaling further to fully integrated industrial processes (WP6).

Both routes are supported by biodegradation tests on labscale and via field tests and detailed chemical analysis of the degradation routes (WP7) along with the evaluation of the ecological impact (LCA) and the possible ecotoxicity trials .

The developed production routes will be used to produce at industrial scale demonstrators to be installed in centralised field tests allowing the evaluation of the relevant performances of the developed products. (WP8). Further supportive WPs are foreseen including Training & dissemination (WP9), IPR and Knowledge Management and Exploitation policy (WP10), Project management (WP11).

Based on this approach the following specific objectives were defined at the start of the project:

A: For the thermoplastic biopolymer formulations:

- The definition of optimised starch based formulations, that can be processed on standard textile extrusion equipment to fibres, mono- or multifilaments with acceptable mechanical and processing properties,
- The definition of optimised biopolyester (PLA) based formulations, that can be processed on standard textile extrusion equipment to fibres, mono- or multifilaments with acceptable mechanical and processing properties,
- Selected range of additives to optimise processability of the biopolymer formulations and to integrate specific properties
- To define routes to vary the (bio)degradability and lifetime of end products
- Optimised industrial extrusion processes, with output similar to production processes with standard polymers.

B: For the natural fibres

- Defining alternative sources of natural fibres based on agricultural wastes or low value side products
- Development of ecological relevant (enzymatic) preparation routes to extract fibres with optimal yield and properties, including raised hydrophilicity
- Defined processing routes for pure or blended natural fibre materials into qualitative nonwovens

C: For the biobased resins with preservation activity.

- Realisation of fully biobased water dilutable resins,
- Realisations of resins with increased reactivity allowing complete curing at acceptable temperature (max 180°C) and within 2 to 3 minutes time.
- Optimised resin formulation that doesn’t alter the mechanical properties such as stiffness or drapability
- Bioresin with high preservation action that at minimum doubles the expected lifetime of the natural fibres based ground-covers.
- Routes for industrial application of the bioresins in combination with specific functionalities

- Realisation of natural fibre based groundcovers with a reduction in weight/m² of up to 50%.
- Realisation of natural fibre based groundcovers with an extended (min doubled) lifetime

D: Realisation of demonstrators and pre-commercial products

- Developed industrial production routes for thermoplastic and natural fibres and formulations via standard textile processing techniques including weaving, knitting, non-woven production, needlefelt production, …
- Realisation of at minimum 4 demonstrator products covering the different development routes and product types defined. Possible demonstrator models are:
    - Knitted biopolymer cloth for covering crops: creating micro-climate and crop protection against insects applied either out-door or in green houses, requested life time: 1 up to 3 seasons; limited degradation under standard conditions of use, compostable
    - Biopolymer based non-woven groundcovers: support for natural grass mats: to be applied in the earth strengthening the turf and/or stabilising slopes, should retain its properties during 1 up to 5 years; slow degradation under "soil burial test"- fast degradation under composting,
    - Biopolymer based woven groundcovers (prevention of weed growth and use of herbicides, support the water housekeeping of the ground) stability during minimum 3 to 5 years, fast degradation under composting conditions
    - Natural fibre based groundcovers for out-door use, weed prevention improved water housekeeping, with an extended lifetime (up to 3 years) due to the application of bioresins with preservation action
    - Other possible domains for implementation:
      natural fibres or biopolymer based agrotextiles for applications in green-houses, sun-screens, limitation of heat-loss, light reflection, … durability minimum 5 years under high temperature and high humidity conditions
      alternative out-door application (nets for bird protection, hail protection or sunscreens) minimum durability 5 years under high UV conditions.

E. Scientific proof of enhanced properties and ecological aspects of the development.

Detailed analysis of all generated materials, both on performance and ecological impacts are foreseen in order to proof the potential and the ecological relevance of the development. The following core evaluations are defined.

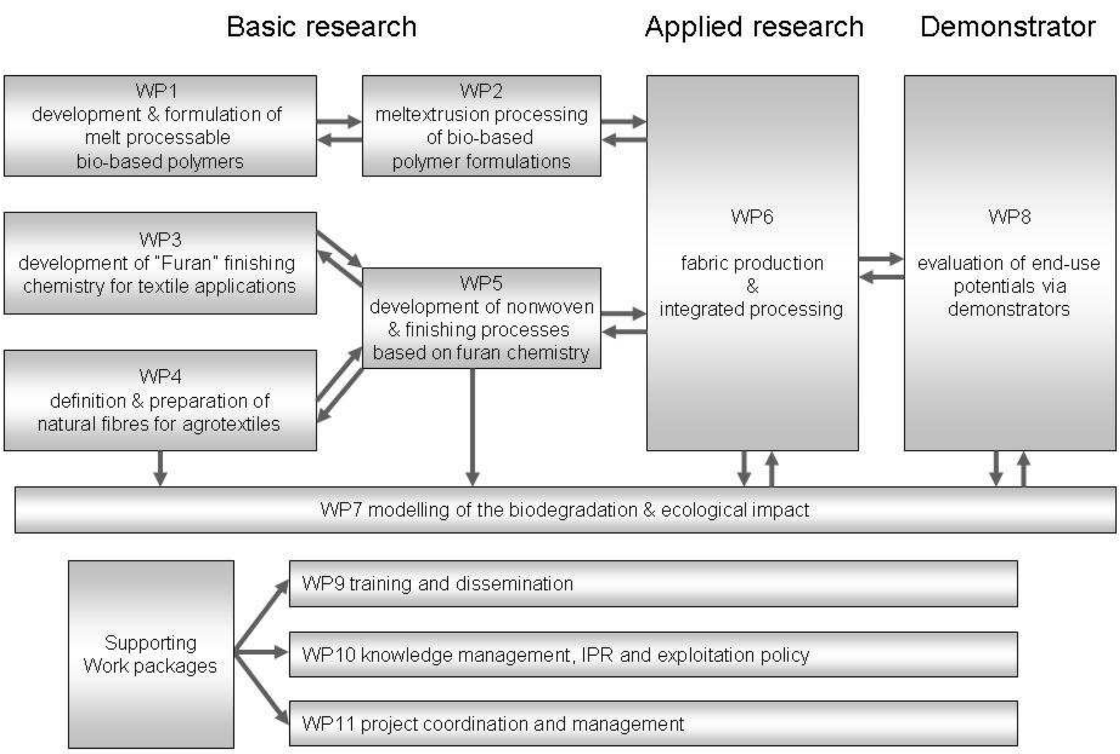
- Lab scale durability testing, via different routes simulating different routes of degradation
    - Soil- burial test (AATCC 30-2004) resistance to biodegradation (resisting minimum 56 days, doubling the durability of standard NF based groundcovers)
    - Q-UV tests: resistance against UV light (min 1500 Hours)
    - Combined Q-UV and Soil burial tests
    - Hydrolysis tests under extreme conditions
    - Analysis of mechanical properties and molecular weight as function of durability tests
    - Lab scale composting tests; industrial conditions
- Real life testing via locally installed agrotextiles and via demonstrator field tests for a minimum period of 1 year.
- Ecotoxicity tests on the developed materials and after composting; to ascertain the possibility of implementation without creating toxicological side effects.

- Detailed LCA analysis taken into account, production, use and end-of-life solutions for the newly developed end-products.

Based on the realisation of these objectives and on the created knowledge base regarding interaction of product parameters, processing conditions, functional additives and durability properties it should be feasible to bring at least some of the demonstrator products to the market within short term after finalisation of the project. The generated know-how should allow via further industrial developments the creation of a large range of different agrotextiles. The results obtained could be valorised further in other application fields such as textiles, composites, injection moulded articles and can therefore contribute to some extent to the overall development of the biobased economy.

2.3 Defined workplan.

For the realisation of these objectives a multidisciplinary approach is required covering the complete production chain - starting with the development of the biopolymers up to the final textile products. At the same time the project has to pass through all stages within the innovation process; starting with fundamental research aspects, through implementation and up-scaling development of adapted testing procedures and even providing complete proof of concept via full-scale and real life demonstrators.
The structure of the workplan and the interactions between work packages are highlighted in the following scheme:



3 A description of the main S&T results/foregrounds

Along the 4 year project a multitude of results are obtained in the different research domains. Results are not reported per WP since some of the WP closely interact with one another and are evaluating the same products or processes along the production chain: formulation, processing lab scale, processing industrial scale, definition of end products. Due to constant feed-back and fed-forward along this chain it's better to report the results per individual development topic. Results are therefore grouped together under the following Topics:

- Results related to starch based formulations and processability to textile yarns.
- Results related to the formulations, processability and properties of biopolyesters.
- Observations on fast degrading PLA materials and problem solving.
- Alternative natural fibre sources and processing into non-wovens
- Development of biobased resins and application to natural fibre structures
- Demonstrator development & demonstrator field tests
- Durability and ecological aspects of the developed products.

3.1 Results related to starch based formulations and processability to textile yarns.

For the starch based biopolymer formulations a range of applications are already known. At present it are these type of biopolymer formulations that have the largest share in the biopolymer market. Based. The applications are at present however predominantly in (food) packaging applications, film extrusion and to some extent injection moulding applications. In these applications the fast biodegradability of the products offers a major advantage. Since starch itself has very poor thermoplastic properties, it cannot be processed as such and always needs plasticizing and blending with other biodegradable polymers. Popular polymers for blending are amongst others the oil based PolyCaprolacton, and Ethylenevinylacetate or biopolymers such as PLA. Development of textiles made of starch based formulations is in its infancy and no commercial products were known at the start of the project.

The objective within Bioagrotex is that starch based formulations are developed that can be processed into the different textile products: tapes or monofilament and if possible multifilament. A minimum level of mechanical properties (tenacity level of 0.2 N/tex) should be reached in order that the products can be processed further.

As a starting point standard Solanyl formulations, basically used for film extrusion, were selected for first small scale textile extrusion trials. It was observed that these were totally inadequate for the textile processing route. Inappropriate stability and melt strength was observed. Either no filament structures could be obtained or only filaments could be produced without applying a cold drawing step and therefore resulting in a very brittle product.

Detailed microscopic analysis of the Starch formulations used showed an insufficient homogenisation of the formulation and insufficient compatibility between polymer products leading to deblending of the formulation and insufficient properties.

It was concluded that the formulations needed adaptations and the following elements were taken into consideration:

- Intensification of the compounding process: - leading to a finer distribution of the polymer components in one another, this is observed but deblending limits the efficiency.
- Adapting water content during extrusion; - water can have a positive plastisizing effect but also catalyses degradation and hydrolysis. In combination with (bio)polyesters the water content should be kept low.
- Lowering the extrusion temperature - as low as possible (± 160°C) - in order to avoid degradation of starch and the hydrolysis of other biopolymer components.
- Evaluation of different blend compositions and ratio's. – Raised compatibility between materials influences in a positive way the fineness of blend morphology and reduces deblending effects. A higher % of thermoplastic polymers improves processability, but final "starch" content will become low.
- Selection of high molecular weight grade of the added thermoplastic polymer (PLA) – a considerable improvement in melt strength and therefore processability and stability was observed.

Optical microscopy in combination with staining revealed an improved morphology in contrast to the previous dry blend system. The starch (dark areas in the figure below) was dispersed in a matrix of PLA and PVAc (red areas). This morphology is found to be beneficial for the mechanical properties which are mainly determined by the matrix components. PLA gives rise to toughness and PVAc brings flexibility.

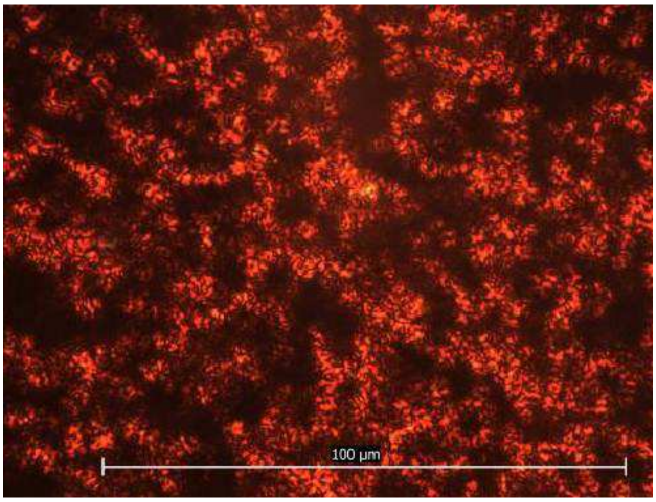


Fig. 1: Optical micrograph of stained Solanyl specialty grade. Red shows the PLA/PVAc matrix and dark dictates starch.

Using these improved formulations the processability to textile monofilamnts and even multifilaments become feasible. Secondary drawing (soli state) of the materials was feasible. Mechanical properties obtained still remain unsatisfactory (tenacity of ± 15 cN/tex) in order to start-up large scale production trials and the realisation of end products. .
Due to lack of mechanical properties no demonstrators based on starch based formulations could be defined. A further improvement in mechanical properties of about 30% is required to produce textile materials that can be considered for Agrotextile applications.

3.2 Results related to the formulation, processability and properties of biopolyesters.

PLA is one of the biopolymers available in the market for a longer time, at considerable volume (> 100kton) and acceptable price. The implementation is especially known in packaging applications and to a lesser extent for textiles or injection moulding. Although the first products are proposed a long route of developments still is needed to bring the biopolymer formulations and the processability to a similar level as the petrochemical based ones.

Within the Bioagrotex project the developments on the biopolyesters formulations are specific aiming at increasing the mechanical properties (tenacity and elongation at break, and reduction of brittleness), increase in processability (operating window at different process lines, production speed), improvement in processing stability (influence of temperature and humidity) and integrating functionalities in the biopolymer formulation. In addition the formulations are function of the different extrusion routes required for the different types of textile intermediates: tapes, monofils, staple fibre, FDY or POY.

For the different processes different pilot and industrial extrusion systems are used to explore the processability. The different lines have different configurations that have important consequences on the polymer requirements and processing conditions. One can differentiate between the following extrusion systems:

A. Monofilament or tape extrusion line.

This type of extrusion equipment is used for production of thicker textile monofilaments or tape material. Due to the diameter of the produced filaments more cooling is required and this is provided by quenching the melt coming from the extruder directly in a water bath. As an alternative the melt can also be deposited on a metal quench roll (internally cooled). After cooling the yarn is monofilament is heated again and drawn to a high degree (factor 5 to 12) in order that the polymer chains are stretched to the maximum and the material receives its highest tensile properties possible. This process is in general performed at a limited speed (100 à 200 m/min). The products produced via this route are amongst others used in knitted agrotextiles using monofilaments or tape production for production of woven tape fabrics.

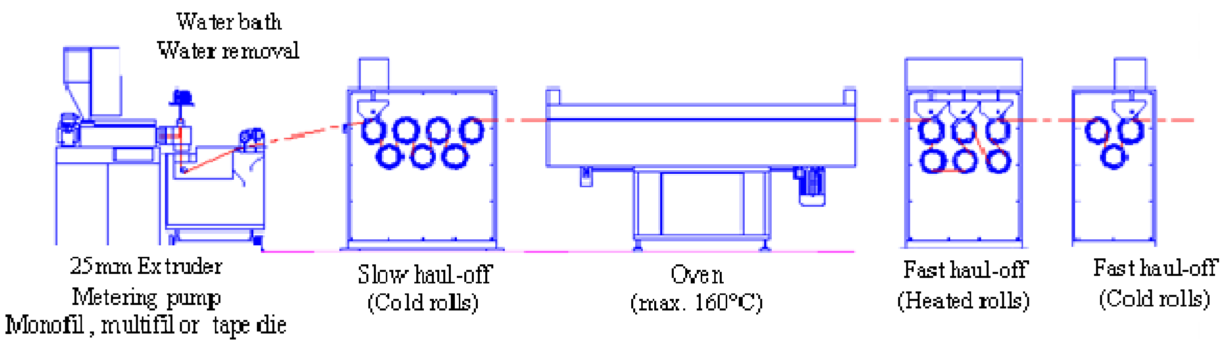


Fig. 2: scheme of semi-industrial tape line

B. POY extrusion – separate draw (texturation) step.

Fine filament yarns or staple extrusion is in general performed via air-quenching instead of water bath quenching. The production speeds are considerably higher (3000 up to > 5000 m/min) and spinerettes are much finer, making the process more critical. Especially the rheology of processed materials becomes more critical) (less viscous formulations required) as well as the fineness of any additives used should be below a few µm in order not to block filters or to disturb the built-up of mechanical properties.

Moreover the POY production process is a two stage process. In the first stage extrusion of the filaments take place at a high speed without a secondary drawing. Due to the high melt drawing ratio the filaments produced gets already an important degree of orientation and therefore stability and tenacity. Nevertheless the yarn is still only a Partly Oriented Yarn and will need a secondary drawing step to obtain it's full mechanical properties and stability. This two-step production process is especially explored for the production of very fine multifilaments, which can be used in knitted crop protection products.

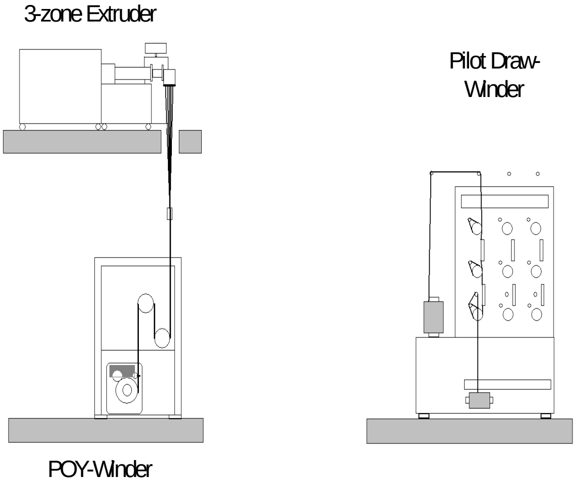


Fig. 3: Scheme of POY extrusion with second step draw winding operation.

C. FDY extrusion – integrated drawing step.

A second production method to produce fine filament yarns is the extrusion with integrated drawing resulting in a full drawn yarn in one production step. Depending on the process, 1, 2 or even 3 stage drawings are possible. Not only multifilament yarns are produced in this way but as well staple fibre production. In that final case also texturation and cutting the yarn to the appropriate length are integrated in the same process.

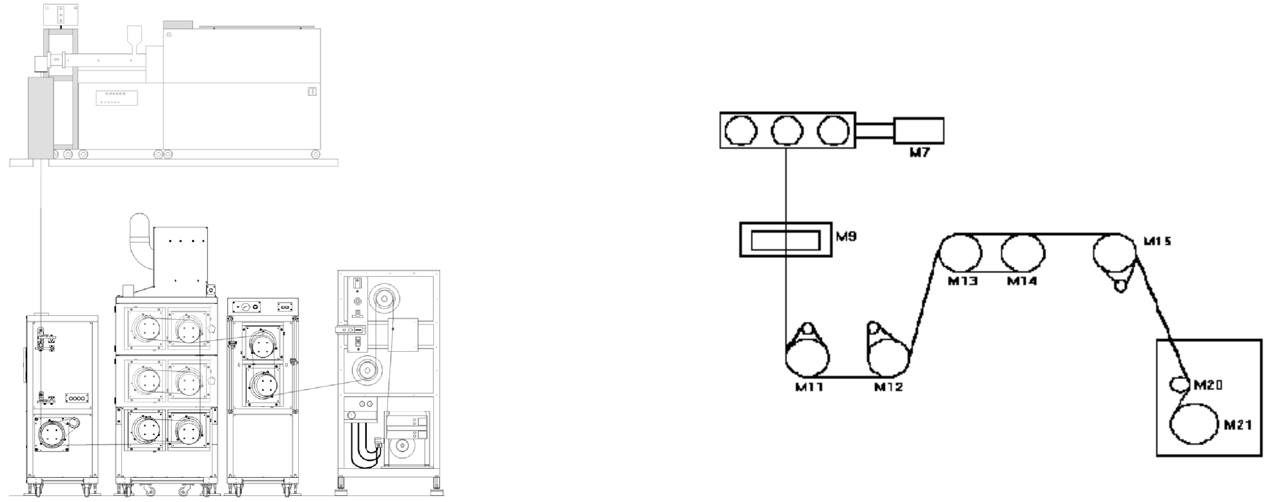


Fig. 4: Examples of filament extrusion pilot lines with integrated drawing.

E. Formulation routes or PLA based materials.

Formulation routes explored are related to:

- Initial polymer grades; varying in molecular weight, d lactic acid content (homogeneity and crystallinity) – A high MW contributes to a raised melt strength and processability and is needed to reach a higher tenacity level in the textile products. A few % d-lactic monomer content contributes to the flexibility of the products and reduces the brittleness but at higher percentages the melt temperature and the overall polymer properties are reduced too much.
- Addition of “Poly D Lactide content”: A special crystal structure is generated when a fraction of Poly D LA is blended in the PolyL LA with a higher melting point (> 200 °C). The highest effects are expected at 50/50 blend ratio, but also at lower % of added Poly D LA effects can be obtained. The addition contributes to a higher thermal stability of the extruded monofilaments or tapes but little effect on tenacity is observed. Due to the limited availability and higher price of the Poly D LA polymer, this route of formulation is of interest for future industrial developments.
- Incorporation of low% of other biopolymers (PHA), - can contribute to an improved processability and has an impact on draw ratio and resulting mechanical properties especially in air quenched production. Effects are variable in function of the processing routes and should be evaluated for specific end applications.
- Addition of impact modifiers and crystallisation agents – In most cases products seems to have only minor effect on the extrusion process or on the strength of the textiles produced, but crystallisation and recrystallisation behaviour is clearly influenced, contributing to textile intermediates with a raised stability. Use of these types off additives can be considered in these processes where fast crystallisation is required.
- Control of humidity content: During melt processing partial hydrolysis of PLA will occur as function of humidity content, residence time and process temperature. Predrying of polymers to below 250 ppm is in general sufficient to avoid detrimental effects during the processing. Proccesing of formulations with higher water content, will lead to uncontrolled shifts in polymer properties.
- Use of chain extenders: Chain extenders can have a positive effect on molecular weight of the biopolymer. They can contribute to reduction of the hydrolysis effect created by processing

Biopolyesters with a too high humidity content (or the required level of predrying) and can improve properties and processability by counteracting the polymer hydrolysis. An interesting side-effect is observed namely increase of dyeability; although less important for agrotextiles this can have important benefits in other application area's such as clothing.

- Use of biodegradation promoters – It is possible to add low amounts of a biodegradation promotor during the extrusion. Concentration must be low and processing conditions must be kept well under control to limit the impact on hydrolysis and lower tenacity during extrusion. The products show clearly a much faster degradation during further durability testing, especially Q-UV artificial weathering tests, than reference products. This can be of importance for applications where a reduced lifetime is required even without entering industrial composting conditions.
- Use of hydrolytical stabilisers – PLA is vulnerable to hydrolysis at high temperature e.g. 80°C and high humidity degree. Within one or two days at these extreme conditions the polymer loses its mechanical properties and the molecular weight drops drastically. It could be proven that using selected hydrolysis stabilisers under correct processing conditions will largely stop the hydrolysis process. The additive stabilises as well the melt during the melt processing stage although it is still to be advised to dry the material well before processing.

The extrusion process of these materials into different textile intermediates: monofilaments, tapes, staple fibre, continuous filament yarns, has successfully been demonstrated at laboratory, pilot and full industrial scale with acceptable mechanical properties. Tenacity ranges from 0.25 à 0.35 N/tex for the multifilament materials and from 0.25 to 0.40 N/tex for monofilament and tapes. Also extension to break is acceptable for most processes. Although in general yarns and tapes are somewhat stiffer than reference PP materials they have a sufficient flexibility to be processed via different processing routes into a range of semi-industrial articles.

The very fine multifilament or monofilament PLA yarns defined by Inotex, needed for the production of knitted agrotextiles, could only be produced on pilot lines and not on the industrial equipment available in the consortium. The specific lay-out of the industrial equipment and throughput were not compatible with the operating window required for the PLA production. As alternative some industrial yarns could be sourced for the evaluation of the processing potentials.

3.3 Observations on fast degrading PLA materials and problem solving.

In the course of the project two difficulties were observed for instabilities of the extruded PLA textile materials:

- Shift in mechanical properties due to reorientation and crystallisation process
- Decay in mechanical properties under warehouse conditions.

3.3.1 Shift in Mechanical properties due to reorientation and crystallisation process. .

PLA is a polymer that in general crystallizes only slowly. This can create some problems during processing as illustrated in the following figure.

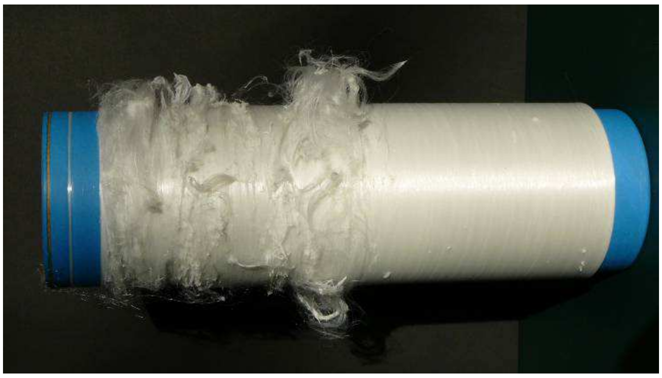


Fig.5: Destroyed bobbin by crystallisation

If insufficient crystallisation takes place during the extrusion process, the material will further post-crystallise after the production process, whether or not accelerated by heat treatment. In the example shown above crystallisation in a POY extrusion was so low that after winding, the post crystallisation process caused such an increase in temperature and in tension that the bobbin was destroyed completely. In most cases the effects are not that spectacular but shifts in mechanical properties of 10 to 20% can be observed in a number of cases if insufficient crystallisation on the extrusion line is obtained.

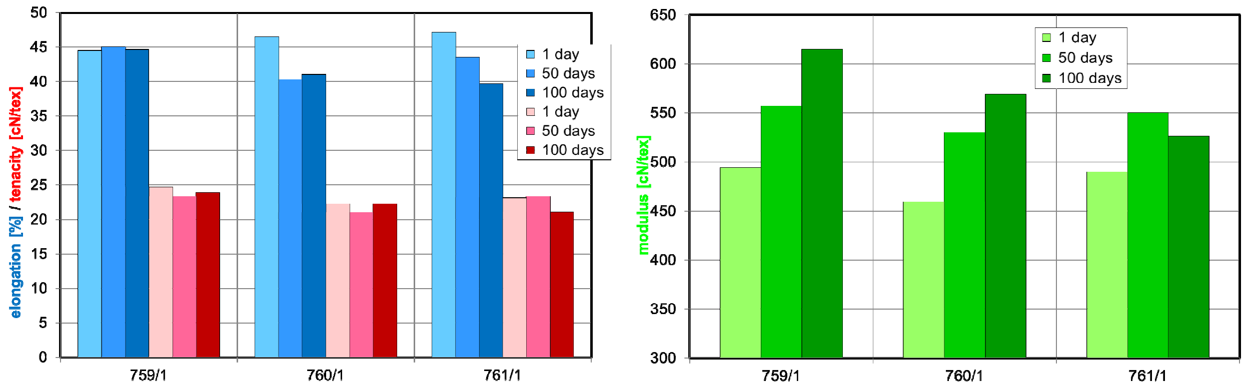


Fig.6 : Mechanical properties of yarns spun at FDY condition before and after storage

A detailed analysis of the recrystallisation process and of the extrusion parameters influencing the crystallisation before winding the yarn was performed in order to resolve these problems.
The experiences led to the following rules of thumb to optimise crystallisation of PLA yarns.
Achievement of high crystallinity and therefore high stability of mechanical properties after processing will be obtained by:

- application of low cooling rate during melt drawing,
- increased melt-drawing ratio
- additional support of crystallisation by
  - stress (winding speed, draw ratio)
  - nucleating additives
- application of secondary drawing (drawing on hot godets or oven)
- multistep drawing
- heat treatment of yarns: high setting temperatures.

3.3.2 Stabilisation of PLA against hydrolysis.

Although PLA is stable under standard conditions, it is easily hydrolysed at high humidity and high temperature. Within about 3 days the polymer looses its properties at 80°C and 80% rel. humidity. Although such extreme conditions are not occurring during real life of agrotextiles, it is still of interest to be able to stop this process.
Specialty hydrolytical stabilisers additives were evaluated and found that not only stop the hydrolysis at the extreme storage conditions but also inhibits the hydrolysis during melt processing, as can be observed in the enclosed fig. 7.

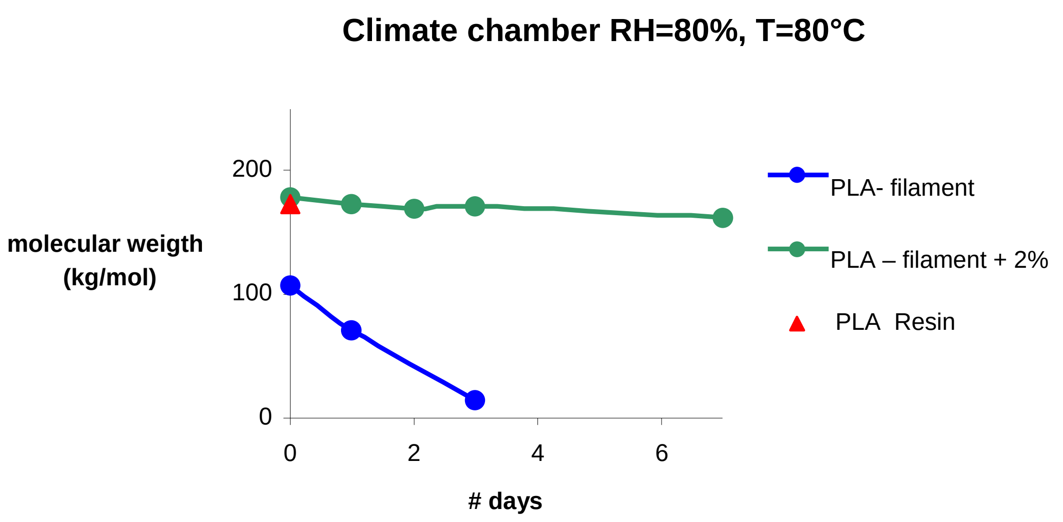


Fig.7: Effect of hydrolysis stabiliser additives in PLA materials under extreme conditions.

3.3.3 Decay in mechanical properties under warehouse conditions.

During the project it was observed in a few cases that PLA materials that normally should have a high stability and should not loose their mechanical properties under "warehouse conditions" over years started to degrade very fast. The drop in properties can occur in a few weeks to a few months' time and is totally unacceptable for commercial applications. Other materials produced under similar conditions stayed intact for several years. The phenomenon was analysed in great details.

It was observed that the direct cause of the problem is related to the growth of fungi on the material as could be observed by microscopical analyisis and microbiological tests.

Isolation of 3 fungi found on the sample T1200723

Fig. 8: Fungal species detected on fast degrading PLA material.

Further analysis indicates that although the microbiological action is the direct cause of the degradation, there are other elements contributing to the fact that these specific production samples are vulnerable for degradation. A first cause is the relatively low molecular weight of PLA used in the production of the material. A second element is the impact of the further mechanical processing of the fibre materials under harsh conditions, causing the appearance of some minor surface cracks. Degradation by the fungal enzymes will occur preferentially starting from these cracks. No proof of fast degradation is found for intact PLA materials inoculated with fungi.

3.4 Alternative natural fibre sources and processing into non-wovens.

3.4.1 Alternative natural fibre sources and upgrading of properties.

Also natural fibres are used in the development of agrotextiles. Hereby the project is focussing on NF sources either obtained via recycling, as a waste or side fraction of agricultural crops or products with a high agricultural output.
Main NF sources evaluated are recycled jute, linseed flax, hemp, hop wastes and nettle.
It was shown that hop or nettle offer no economical interesting source due to the very low fibre yield generated from these materials. Linseed and hemp offer good potential to generate fibres with high yield and good properties.

Hemp and linseed fibre fractions offer good potential to be used for technical fibre applications including agrotextiles.

Table 1: fibre yield and purity for several bast fibre types.

Reference values 2009	Unit value	Bast plants			
		Linseed	Flax (cutting)	Flax (pulling)	Hemp
Stem yield	$t.ha^{-1}$	2,952	2,390	3,130	9,867
Fibre content	%	34,59	38,49	35,78	33,38
Fibre yield	$t.ha^{-1}$	1,021	0,920	1,120	3,293
Impurities content	%	24,59	22,49	6,4	28,59

Further improvement of yield and quality of fibres could be obtained both for linseed and hemp by use of enzymatic processing (“bio-retting”) including the optimized enzyme product ”Texazym SER 7”. Especially the field spray application was developed as the most effective route for harvesting quality fibres in the most economical conditions. This enzymatic treatment process was alternatively supported by smooth (longitudinal) mechanical treatment on the new concept of the opening/cleaning device REA 120 (Rieter CZ) and led to improved fibre yield and quality.

Table 2: fibre yield of enzymatic treated bast fibre types.

Fibres	Fibre yield after 1x REA (coarse fillet cylinder used) in %	
	enzymatically untreated	enzymatically treated
Linseed	76,9	83,6
Hemp	83,8	79,7

Table 3: Fibre impurities content/cleanness/length determination

	Impurities content (%)	Shives content (%) *– part of impurities*	Fibre content (%)	Mean length (cm)	Short length cm)
Linseed enzyme	8,79	3,04	90,54	8,38	6,12
Linseed	18,59	5,79	80,49	9,09	5,08
Hemp enzyme	3,72	3,72	96,07	10,18	6,50
Hemp	2,92	0,52	96,98	10,93	6,56

Also hydrophilicity of fibre material is increased, facilitating further impregnating processing to improve homogeneity in finishing processes (fig.9).

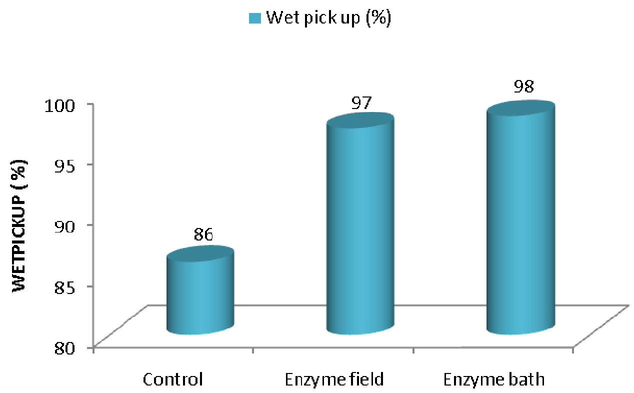


Fig. 9: Improved hydrophilicity of enzymatic treated bast fibres.

The field retting system developed can be considered for industrial exploitation for natural fibre production whether or not for agrotextile applications. The evaluated natural fibre sources have a better quality than the recycled jute, but price of these alternative sources is still higher due to the required processing. Price level is still acceptable for the application envisaged, as far as transport costs are not increasing price too much.

3.4.2 Alternative natural fibres and processing properties for non-woven production.

The processibility of the different natural fibre sources into needle felts - pure or in blends of different ratio's – were evaluated on pilot and industrial lines.

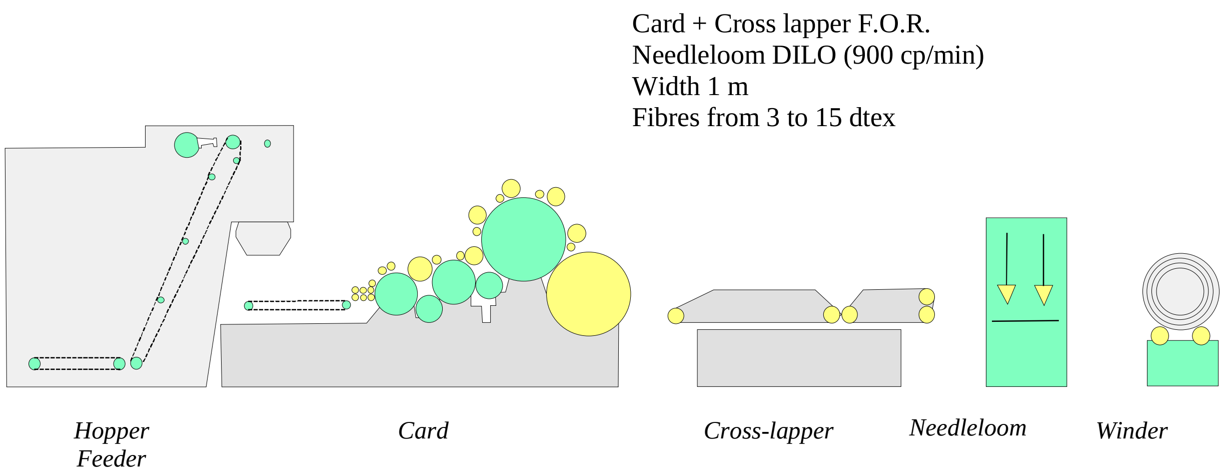


Fig.10: Scheme of pilot needlefelt line.

It was shown that pure Hemp fibres were difficult to process on pilot scale due to stiffness and hardness of the fibres. Adapting the equipment makes it possible to process also the pure hemp materials on industrial scale. On pilot scale other natural fibres or hemp/linseed or Jute blends could be processed offering good mechanical properties. Recycled jute with a high fraction of short fibres, need to be processed into felts of > 500g/m² in order to reach acceptable felt properties.

Table 4: Overview of pilot line production samples of experimental NF based needlefelts.

Ratio	Fibre	1000g/m²	500 g/m²	250 g/m²
100%	1	Not possible		
	2			
	3			
	4	1100	517	
	5	1150	533	
	6	1180	560	
	7	1095	540	300
	8	1075	505	285
70% / 30%	1 / 4			
	2 / 5	1118	537	
	3 / 6	897	535	
50% / 50%	1 / 4	1140	550	278
	2 / 5	1118	540	273
	3 / 6	1056	580	232

Samples 1-3 Hemp, 4 -8 Linseed materials; different sources and pretreatments

In addition to the pure NF based non-wovens also PLA fibre based non-wovens as well as blend of NF and PLA non-wovens (90/10) were produced. It was shown that production was feasible. Introducing PLA offered improvement of mechanical properties to a limited extent. Additional thermal aftertreatment didn't offer the expected increase in mechanical properties.

Table 5: Range of different light weight non-wovens produced on pilot line using experimental natural fibres and PLA fibres.

Ratio	Fibre	500g/m²	300 g/m²	250 g/m²
100%	Linseed	X	X	X
	Hemp (light)			
	Hemp (dark)			
	PLA	X	X	X
90% / 10%	Linseed	X		X
	Hemp (light)	X		X
	Hemp (dark)			

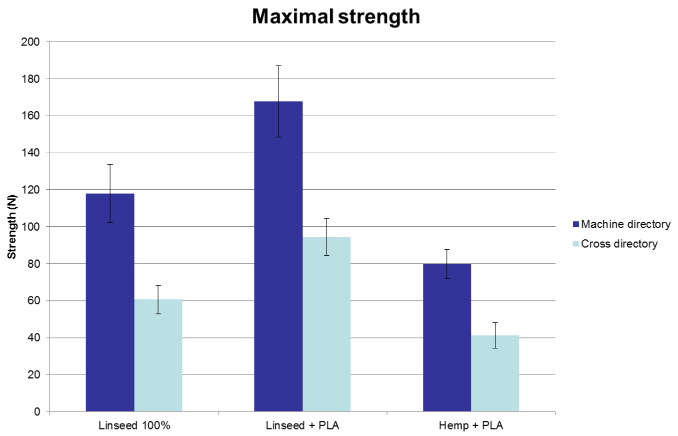


Fig 11: Strength of experimental needlefelt with and without PLA fibres.

3.4.3 Evaluation of hydrophilicity via moisture management tester.

To evaluate the interaction with water, a new test method of 3D moisture spreading through the agrotextile structure was developed by use of the MMT-SDL device. The MMT was developed to measure dynamic liquid transport properties of plain textile substrates.

Moisture Management is a method to characterize the 3D liquid transport properties of fabrics. Spread of solution applied on the top side of textile substrate during its penetration through the textile structure is electronically detected.

The limits regarding weight and fabric thickness, and test conditions (prolonged time and testing liquor dose) were studied to facilitate measurements of actual agromat constructions of different weight. This improvement of methodology facilitated the evaluation of the samples processed using bioresins, enzyme treatment, and measuring the water transmission and suction behaviour as shown in the samples below.

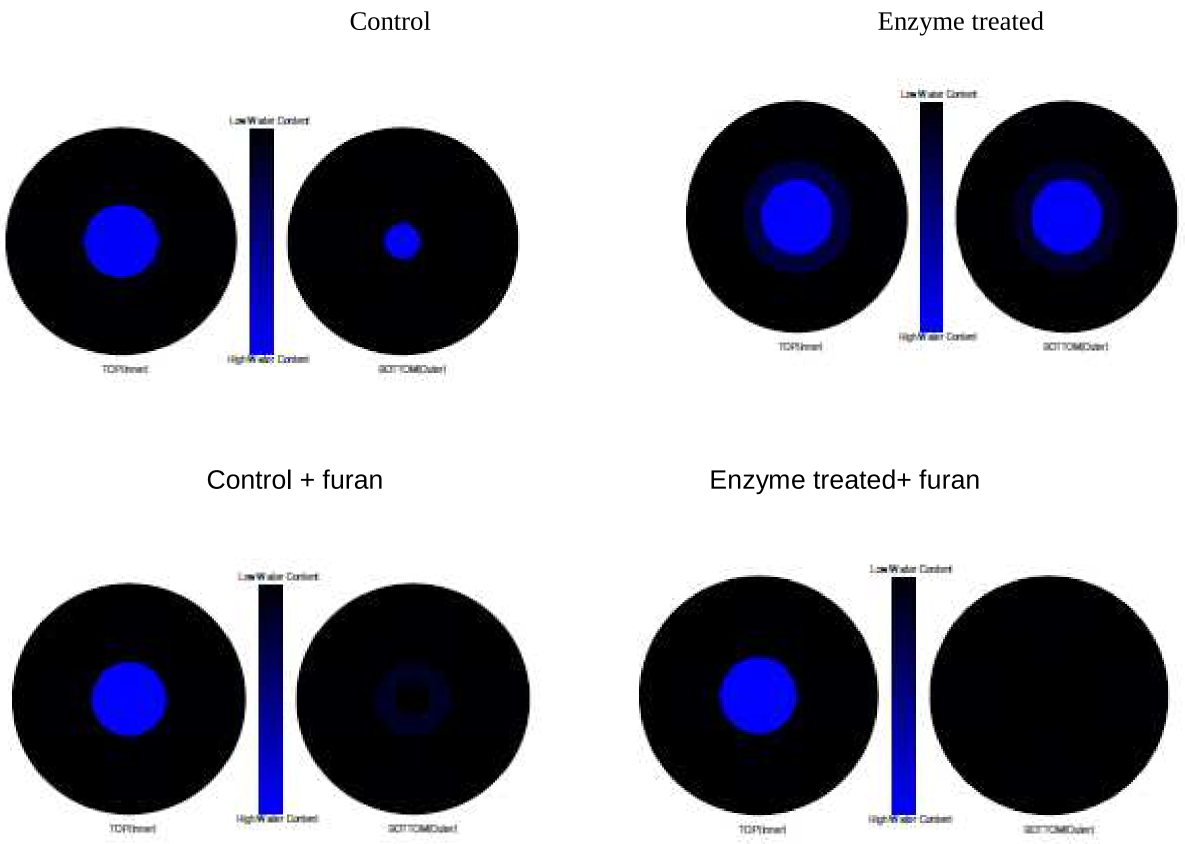


Fig. 12: Moisture management tests of different NF based needlefelts of 500 g/m2, before starting field trials.

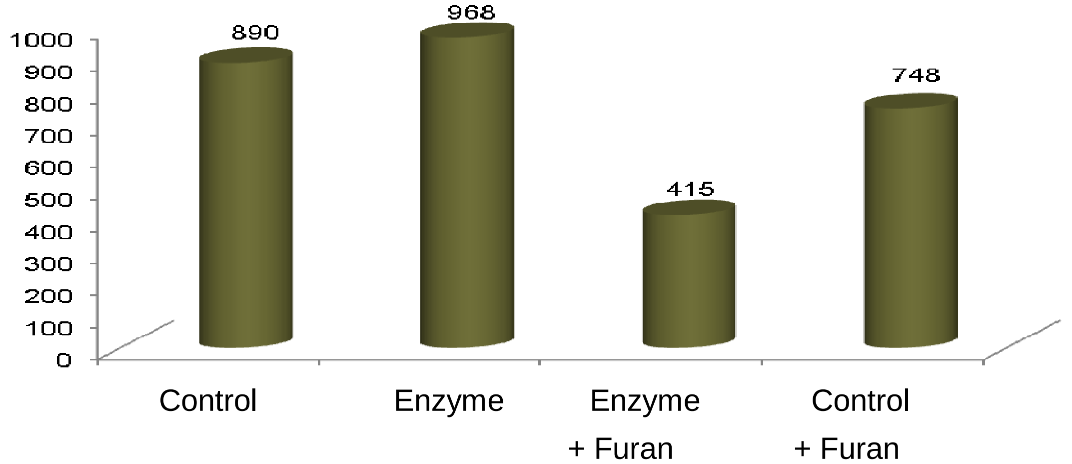


Fig. 13: Water absorption tests for experimental natural fibre based needlefelts. Hydrophobic effect of Furan treatment

It can be concluded that short fibre qualities:

- linseed fibre with the growing potential of nutrient production waste
- hemp as an alternative short bast fibre

can be identified as potential, effective sources. Positive efficiency of the new enzymatic process – preferably its field spray alternative (called "bio-retting") was confirmed by repeated seasonal post-harvest trials. Special INOTEX enzymatic product (TEXAZYM SER 7 conc.) developed and tested in real field conditions. Common and enzymatic modified fibres were tested in pilot scale production of needle punch carded nonwovens. No significant differences and limitations by process-ability of various blend combinations observed.

3.5 Development of biobased resins and application to natural fibre structures

3.5.1 Development of bioresin formulations

For the development of the bioresins it was shown in an early stage that the furan bioresins are offering an increased biostability to the natural fibres they are applied to.

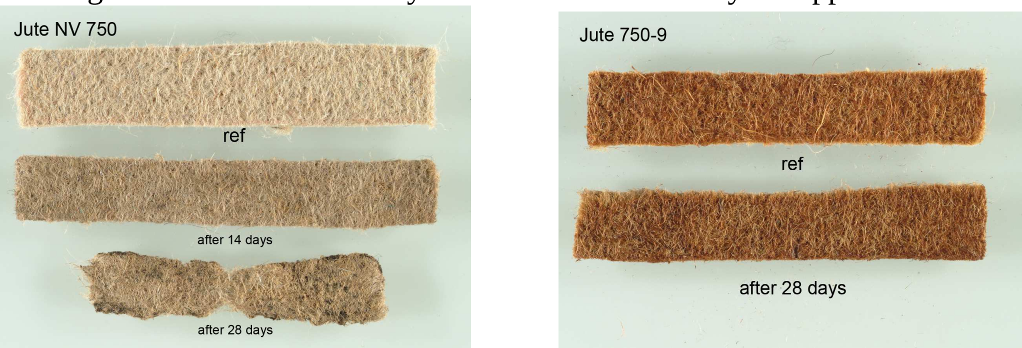


Fig.14: Comparison of jute textiles after a 28 days soil burial test: left reference material, right Furan resin treated Jute textiles.

The treated textiles showed however disadvantages including a limited reactivity, long and harsh processing and high stiffness. Therefore the following optimisation routes were explored:

- Increase of reactivity - to reduce curing temperature and time to be compatible with the application process on natural fibres, reactivity increased via adapting functional groups and catalytic system.
- Development of water dilutable furan formulation with high water content, to allow a more homogeneous application with reduced resin content.
- Reduction of brittleness and hardness after curing via:
  - development of alternative reactive monomers with longer aliphatic side chains; feasibility was tested but offers only potential at long term, due to the complex chemistry,
  - blending with long chain fatty acid esters – increase in flexibility, remaining fully biobased.
- Optimisation of stability and anti-foaming via addition of the appropriate agents.

A novel hybrid BioRez® formulation was developed taken these elements into account and resulting in a fully biobased, water dilutable and stable thermoset reactive emulsion, with appropriate reactivity, to limit curing times.

Fig. 15: examples of development of a stable water-dilutable Furan formulation

3.5.2 Application of Bioresins to natural fibres based textiles

The stable hybrid furan-fatty acid based resin is infinitely water dillutable and this makes it possible to utilise the resin in any given solid content on natural fibres and to use different resin application systems. The best suited application technology for this resin was found to be full bath impregnation with an aqueous dilution of the resin. The textile is then squeezed to remove excess resin and water and is dried and cured in an oven. This application technique allows even distribution of resin throughout the cross section of the substrate as well as in width and in length. Prior to industrial tests this technology was extensively tested on ‘’lab’’-scale coating line of Centexbel.

Fig.16: Full bath impregnation of natural fibres fabric at Centexbel

As an alternative also a spraying application could be developed at Ensait allowing that the application of resin stays limited to the surface of the material. This application system will create only a partial protection at the surface of the material.

Fig. 17: spraying device integrated in the nonwoven line.

3.5.3 Alternative formulation based on non-renewable chemicals

An alternative resin formulation (not biobased) was developed as back-up solution. The formulation is based on synthetic resin in combination with a synthetic anti-microbial additive AEGIS® that is well known and applied in other textile applications. Also in this case it was essential to find a proper balance in the ratio between resin and anti-microbial concentration. Other prerequisites are water dilutability, stability of the formulation, and non-toxicity of ingredients and degradation products.

Via the developed formulation 8% of the anti-microbial product (AEGIS®) and 4% of DPCLK acting as binder is applied to the fabric, along with an appropriate wetting agent. Also for this formulation the full bath impregnation offered the best properties. The polymerization, of the binder is realized via curing at 150°C up to 175°C during 2 to 5 minutes. Formulations were also applied at full industrial scale.

3.5.4 Additional functionalization of resin systems

In addition also functionalization of the formulation was explored via:

- Colouration with pigments
- Addition of Hydrophobic agents.
- Flame retardency.

Pigments (red, green, yellow/brown, black) were selected that can be integrated in the Furan formulation without destabilising the emulsion. Although it is feasible to define a red, green brown colour, the colouration effect is not that good due to the intrinsic colour effect of the Furan resin. In the future colouration still can be used to reduce the bleaching effect of sunlight of the treated fabrics and to stabilise the brown colour of the formulated products.

Devan PPT tested the compatibility of hydrophic agents with the Furan resin formulation. Some compatible products could be defined. Although cured Furan resin has as such already a hydrophic effect, the effect can be considerably enlarged. For most agrotextile applications, hydrophobicity is not a major property required.

It is of interest to combine a minimum level of FR properties to materials such as ground-covers. Applying furan resin in a sufficient amount improves flame retardency of the natural fibre based fabrics. For the Aegis treated fabrics or to further upgrade the flame retardency of the furan treated fabrics, Devan PPT developed an FR treatment: ECOFLAM P-128 (400 g/l), to be applied via full-bath impregnation. High level of flame retardency could be obtained.

1. Needle felted jute

2. Woven jute

Fig. 18: Natural fibre based ground-covers FR treated and perfectly resisting cigarette test.

3.6 Demonstrator development & demonstrator field tests

3.6.1 Demonstrator production.

Based on previous results, industrial production runs were performed both for the natural fibre based and for the biopolymer based, agrotextiles. Demonstrator end-products were defined and realised on industrial production equipment.
The following demonstrator products were defined:

3.6.1.1 Natural fibre based ground covers – La Zeloise.

La Zeloise produced are non-woven and woven jute ground covers against weed growth and soil stabilization. The purpose of this products family is to consolidate the terrain, suitable to resist external conditions and to avoid the growth of vegetation. Furthermore, the ground covering reduces the transpiration of ground, and reduces the necessity of water. A set of materials treated with the biobased Furan Hybrid resin (TransfuranChemicals) or with the synthetic Aegis formulation (Devan PPT) were tested along with reference materials.

Table 6: La Zeloise ground covers, product characteristics of tested materials

# Code	Fabric and treatment
1	360g/sqm Jute (woven) 8,3VR/8,3BR 190°C, 3m/min
2	360g/sqm Jute (woven) 8,3VR/8,3BR 220°C, 4,5m/min
3	460g/sqm Jute (woven) 8,3VR/8,3BR 220°C, 4m/min
4	500g/sqm Jute (felt, enzyme treated) 8,3VR/8,3BR 8,3/8,3 220°C, 2,5m/min
6	500g/sqm Jute (felt) 8,3VR/8,3BR 8,3/8,3 220°C, 2,5m/min
8	360g/sqm Jute (woven) natural, not treated
9	500g/sqm Jute (felt) natural, not treated
10	500g/sqm Jute (felt) Aegis treated

3.6.1.2 PLA based ground cover – DS Textiles.

The demo material provided by DS Textiles is a lightweight, non-woven mat made in PLA. The felt is expected to be used as an erosion protection for slopes, and to avoid the growth of vegetation. The contemporary achievement of such two functionalities makes it necessary to have a relevant strength. To avoid a too fast degradation the non-woven was calandered to limit the microbiological contamination. ,

Table 7: DS Textiles product

# Code	Fabric and treatment
1	PLA non-woven mat

3.6.1.3 PLA based insect proof nets – TEXINOV.

TEXINOV produced industrially knitted insect screens from PLA monofilament and multifilament materials. The aim of the demonstrator is to provide a physical barrier to insects that can provide problems (illness, destroying fruits, …) to plants, trees or cultures. The net is very lightweight and permeable to air; the mechanical resistance needs to be sufficient to avoid damage during installation, and must be very resistant to UV radiations.

Table 8: Texinov products

# Code	Fabric and treatment
1	PLA multifilament knitted net
2	PLA Monofilament knitted net

3.6.1.4 PLA based groundcover fabric – Bonar.

BONAR developed for the demonstrators phase a woven ground cover made in PLA as an alternative for standard PP based groundcovers. In landscaping it is used as covering of land besides highway or railways. Groundcovers are also used for weed control to reduce maintenance and the use of herbicides in public green areas or in orchards, … . Different product colours are set so as to mimic the environment (green, black, brown colours).

Table 9: BONAR demonstrator products

# Code	Fabric and treatment
1	PLA woven fabric green/black
2	PLA woven fabric brown/black
3	PP woven fabric green/black - ref
4	PP woven fabric brown/black - ref

3.6.2 Demonstrator field tests.

Demonstrators were installed at two different installation sites representing different climatic parameters; the first is in the North of Italy in Sestri Levante and the second in the Southern of Italy, in Lecce at the Botanical Garden of University of Lecce. At both sites the durability of the materials was evaluated by following up the installed materials and regular sampling of products.

In addition at the Lecce site, the mulching effects has been evaluated for the Jute based demonstrators in combination with the evaluation of plant growth (chicory growth), irrigation included.
In addition some materials were installed as-well at the premises of the industrial partners.

The following pictures give an indication of some of the installed materials.



Fig. 19: Jute groundcovers after 0,3,9 months


Fig. 20: PLA woven groundcovers / landscaping products installed at two different locations

3.6.3 Durability tests on demonstrator products.

A range of different durability tests were performed on the experimental and demonstrator materials to follow up the degradation of the products and to get an indication of the real lifetime. Tests procedures are related to:

- Soil-burial tests –simulating materials in contact with microbiological active ground samples,
- Q-UV tests, tests with UV-light source simulating sun-light,
- Combined Q-UV test with soil-burial test,
- Aging tests under warehouse conditions or under extreme temperature and humidity conditions,
- Ecotoxicity tests for used products and their degradation products after composting

The degradation is followed by visual interpretation, analysis of mechanical properties (strength & elongation), and for the PLA materials by analysis the change in molecular weight of the polymeric samples.

3.6.3.1 Soil burial test

The natural fibre based materials as well as the PLA based agrotextiles were evaluated for their durability using the "soil burial tests" according to AATCC 30-2004. This is a biodegradability test for textiles buried in a microbiological active soil at high relative humidity content and at a temperature of 29°C. The activity of the soil is tested via adding a reference cotton fabric that should be degraded completely after 1 to 2 weeks treatment. The experimental materials are tested for different periods in some cases up to 84 days in this accelerated soil burial test.

It can be clearly observed that materials appropriately treated with Furan based resins are protected to a large extent and will have an extended lifetime that is expected to be at least the double of the reference products. Also for products treated with the alternative Aegis formulation, a similar improvement is observed.

Fig 21 : Results of soil burial tests for reference Jute and Furan treated jute non-wovens in function of time.

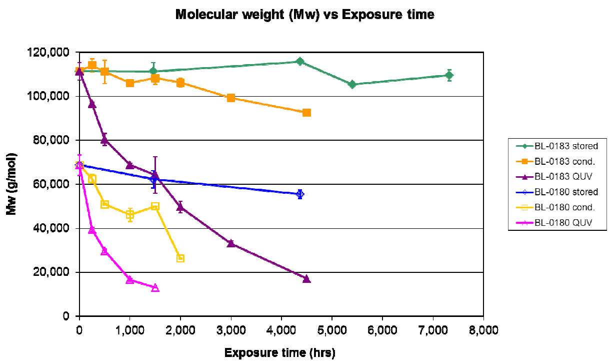
For the demonstrators in real field conditions it can be observed after 1 year that fungal attack on reference products has started considerably. The Furan treated articles are still intact except for some discolouration effect, due to the bleaching effect by the sunlight.

3.6.3.2 <u>Follow-up of molecular weight after Q-UV and outdoor exposure of PLA</u>

PLA based agrotextiles were tested both in soil-box degradation tests and in standard Q-UV tests. Exposure to ultra violet light according to ASTM G53-84 (4h at 60°C and 0.77W/m² followed by 4h at 50°C condensation) represents an accelerated exposure environment. This test is using UV-A light simulating outdoor sunlight, but temperature conditions are raised in order to raise the impact and reduce testing time.

As can be observed PLA materials will be slowly degraded under the test conditions defined. However the material does resists much longer than standard polymers like PP or PET if they are not functionalised with UV stabilisers. PLA as such has clearly a higher UV stability than these reference polymers. PLA easily resists up to 2000 hours of Q-UV treatment before properties drops to halve of the original values.

In contrast it is observed that hardly any reduction in MW is observed for samples in out-door weathering tests. This can be an indication that the proposed testing methodology (used in standards for testing PP, PET, PA) might be too aggressive for the PLA material and that the Q-UV results offer an underestimation of the real durability properties of PLA fabrics.



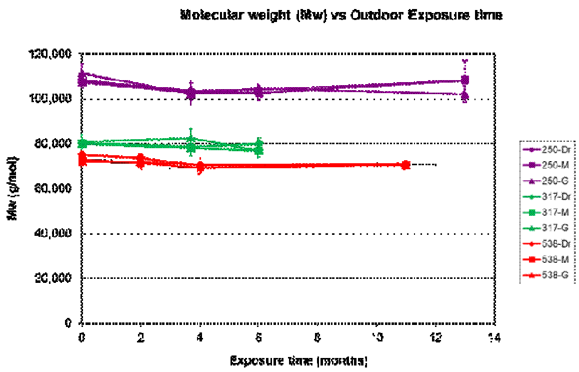


Fig. 22A: Molar mass (Mw) of PLA based fibres after exposure to QUV (QUV), exposure to similar temperature and humidity conditions without UV (cond.), and storage in the dark at 20°C and 50% RH (stored). Material containing a degradation enhancer degrades considerably faster.
Fig. 22B/:Molar mass (weight average, Mw) of PLA based fabrics tested under real life outdoor exposure during two growing seasons (April – October in 2010 and 2011) in southern France. No relevant degradation in MW and tenacity could be detected.

The soil burial test seems to have no impact at all on mechanical properties or on the molecular weight of the PLA material. Extended testing cycles even up to 12 months showed only a minor reduction in properties. Even the combination of Q-UV tests (1000 h) followed by further soil burial test didn't reveal an increased speed of degradation in the artificial soil.

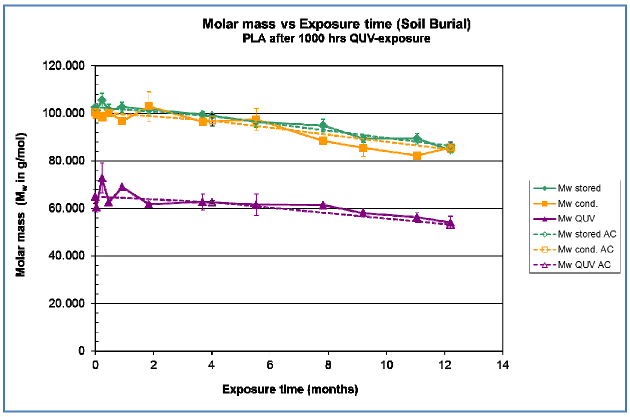


Figure 23. Molar mass (weight average; Mw) of PLA-fibres (BL-0183) during laboratory soil burial after various pre-treatments: 1000 hours of exposure to QUV (QUV), 1000 hours of exposure to similar conditions without UV (cond.), and 1000 hours of storage in the dark at 20°C and 50% RH (stored). Tests included a-biotic controls (AC).

3.6.3.3 Fast degradation test under extreme conditions

A novel test method was defined for evaluation of the hydrolytical degradation of PLA at extreme conditions. Tests were performed in an oven at 80°C and with a relative humidity > 80%. Under these conditions the PLA will be completely hydrolysed and brittled. The test is mainly used to evaluate the effect of added stabilisers. Some specific additives could be defined that not only stops hydrolysis in these conditions but as-well the hydrolysis during the melt processing as could be clearly observed for a number of tests as reported earlier (see fig 7).

3.6.3.4 Phytotoxicity tests via seed germination and plant growth tests on soil samples with partially degraded BioAgrotex demonstrator materials

Phytotoxicity tests (according to OECD 208) were performed on jute based ground-covers treated with Furan or an Aegis formulation. The samples were composted and seed germination and plant growth was evaluated using different species: Garden cress (*Lepidium sativum*), Summer barley (*Hordeum vulgare*), Soybean (*Glycine max*)

No statistically significant effects could be observed for the different composts based on the experimental products used. It could be concluded that no phytotoxicity are present in the developed agrotextiles.

Fig. 24: Ecotoxicity test set-up according OECD208

In addition to the laboratory ecotoxicity tests also the demonstrator sites were observed for any negative effects on plant growths either from weeds growing next to the installed demonstrators and of the chicory plants, planted in the middle of the ground-covers. Also in these field tests any negative effect on plant growth could be observed.

3.6.4 Conclusions from demonstrator field tests.

The installed demonstrator materials were followed-up during minimum 9 months but most materials for 15 months or more. Even then it's still insufficient to draw final conclusions on durability, since for most products a lifetime of minimum 3 years is expected.

The observations indicate already that none of the developed materials showed an unacceptable degradation level. Some of the materials clearly outperformed the reference products as was clearly the case with Jute fabrics or felts treated with Furan based or an alternative antimicrobial resin. A continued following up of the tests is performed even beyond the project timeframe. The efficiency of the reduction in weed growth is more related to the transparence of materials. Except from the lightweight woven Jute fabrics (>350g/m²) all materials were sufficiently blocking the growth of weeds.

The additional tests with the chicory growth were not fully straightforward since the tests seems to be influenced too much by local differences in the test fields and large intrinsic variations between plants. Anyhow it could be concluded that no negative ecotoxic effects were observed based on the different resin formulations used to extend the lifetime of the natural fibre based groundcovers. This is observed in the field tests and in the lab scale fytotoxicity tests according OECD208.

Also for the PLA based agrotextiles it is observed that the durability of the materials both used on top of a crop or buried in the ground is sufficiently high. UV stability is high and easily outperform standard synthetic polymers such as PP or PET unless they are functionalised with large amounts of stabilisers. PLA materials, if not degraded in advance via long term UV illumination, will resist degradation in contact with the ground for a considerably long time and therefore lifetimes between 3 and 5 years are feasible in all cases.

3.7 Durability and ecological aspects of the developed products.

The BIOAGROTEX project is an ecological driven project. Therefore it is essential that the ecological advantages generated can be clearly defined and individual products can be analysed for their ecological footprint. In this regard a detailed LCA analysis for the different production processes were performed for the different demonstrator products developed that also form the basis for the commercial products defined.

Life Cycle Assessment (LCA) is a structured, comprehensive and internationally standardised method. It quantifies all relevant emissions and resources consumed and the related impact on environment, human health and resources that are associated with any goods or services. The term “life cycle” refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product existence. The sum of all those steps – or phases – is the life cycle of the product.
LCA can be used in a number of direct applications, e.g. for product development (eco-design) and improvement, strategic planning, public policy making, marketing, etc.
In this project we undertake the following steps:

- Interview with the “Commissioner of the study” being the Owner of the technology in order to establish the goal, the scope and the boundaries of the study, to gain sufficient understanding of involved processes and products and to obtain high quality data for the LCI phase;
- Data collection based on which the LCA model is created;
- Input of the data in the software GaBi 5;
- Evaluation of both inventory and impact and interpretation of results;
- Model revision and refining with improvement of data quality.

This LCA study has been performed in accordance with internationally recognized guidelines (see e.g. ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance”) and standards (ISO 14044:2006 and ISO 14040:2006) main requirements.
Structural elements regarding the quantification of the environmental impact of the elementary ingredients both for the NF and biopolymer based materials have been defined and the specifications of the demonstrator production settings are taken into account to finalise the LCA analysis. The analysis offers a detailed overview of all aspects related to ecology including: demand on resources, energy, water and on aspects related to emission in air, water and the ground. The analysis takes into account production, real usage and end-of-life stage.
For the demonstrators generated a detailed LCA was performed and the key issues are summarised in a one page publishable report. These reports are the executive summary of the LCA analysis performed of each single product. These short publications are intended to be an exploitation of the results of the LCA analysis in order to show to the customer the benefit to produce and to use (and as a consequence, to implement in own facilities) a biobased product (fig 27).

In addition, a Bioagrotex Eco-datasheet is created in order to give to the LCA analysis output a commercial / industrial address. To have a transparent methodology to assess the carbon footprint (as the LCA) and report it to the customer could represent a plus in the marketing management of the product. In this infancy stage the Eco-datasheet is in a preliminary status that could be improved and adapted according to the textile producers needs.
The aim of the Eco-datasheet is to use the Primary Footprint as a parameter of eco-friendliness of the products and processes defined. Its calculation does not need the involvement of suppliers' or other third parties', being exclusively based on technical data. Moreover, the Primary Footprint can be also used as a marketing means of communication, being directly linked to consumption and thus interesting in the eyes of the customer both from an economic and environmental point of view.

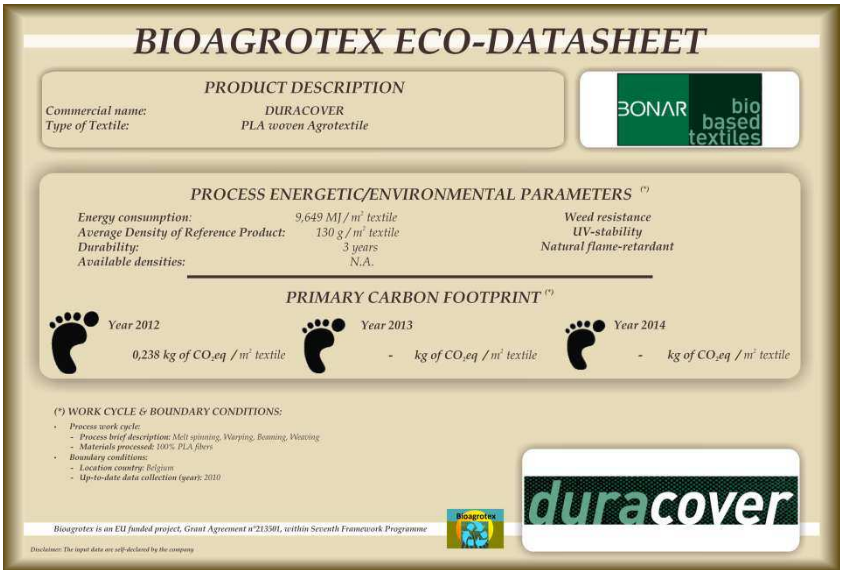


Fig. 26: Example of a BIOAGROTEX ECO-DATASHEET

Fig. 27: Example of a LCA publishable report.

LCA study on the new PLA woven groundcover – BONAR Technical Fabrics

Life Cycle Assessment (LCA) is a structured, comprehensive and internationally standardised method quantifying all relevant emissions and resources consumed and related impact on environment, human health and resources associated with any good or service.

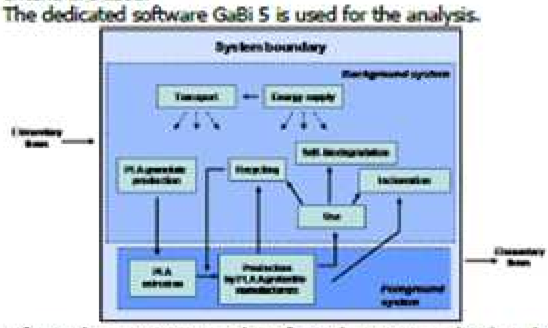
Methodology – The goal of the analysis is to evaluate performances of a plurality of geo- and agro-textile products, woven and non woven, with or without additives. The energy and environmental profiles of the 13 products are defined, and the environmental impact related to their entire life cycles (production, application, autodegradation) is assessed. The analysis does not support any business decision.

A hectare (equal to 10.000 square meters) of geotextile produced and packed has been adopted like functional unit. For each product 1,5 years of life time has been also taken into account in order to compare the solutions through a normalization of their performances. In particular, here the LCA assessment for a PLA woven ground cover is described.

The cradle to grave story is considered, from raw materials extraction through production of intermediates, finishing and assembling operations, utilization and final recovery. Post-consumer waste, i.e., PLA process waste, parts discarded during finishing utilization, are almost fully recovered.

The system has been divided into a foreground system and a background system under the specificity perspective. Processes in the background system have not been inventoried with actual data from suppliers but included and evaluated on the basis of data taken from dedicated databases. Processes in the foreground system have been instead inventoried based on data from the owner of the technology, i.e., Bonar TF. To solve multi-functionality, inputs and outputs of the foreground processes have been taken into account based on subdivision approach under attribution modelling. Where it is not possible to extract the single operation unit process from the multifunctional process of the production chain, allocation criteria are used.

The dedicated software GaBi 5 is used for the analysis.

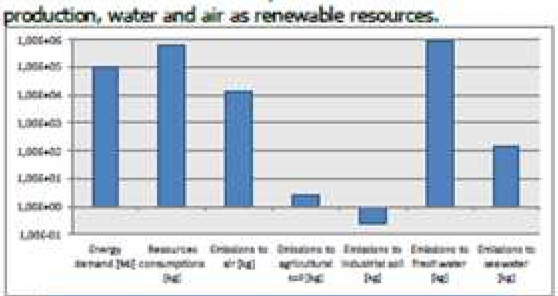


Life Cycle Inventory – The Life Cycle Inventory (LCI) is the LCA phase that involves the qualitative and quantitative identification of all inputs and outputs for a given product throughout its life cycle.

The figure and the table below represent results of the LCI linked to the entire Life Cycle of the PLA woven ground cover.

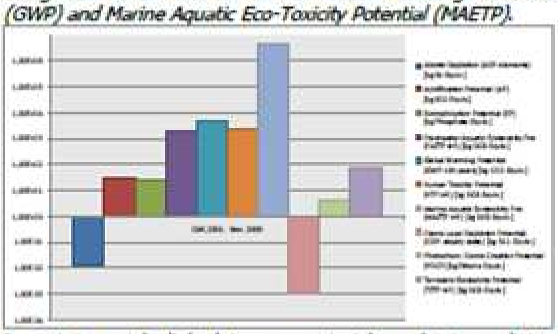
Analyzing elementary flows and comparing the results, it comes out that:

- Being the most complex and articulated phase, the PLA granulate production for PLA products is obviously the "heaviest" phase for all chosen indicators.
- *The fabric counts for higher levels of emissions to air and to fresh water*. Most of the emissions are either inorganic gases (mainly steam and carbon dioxide) or exhaust gases. Most of the emission is waste water needed for PLA granulate production process.
- *The product counts for negligible levels of emissions to industrial soil, agricultural soil and sea water.*
- *The non-woven ground cover counts for higher demand of resources* in terms of non-renewable energy resources and both non-renewable and renewable material resources. Energy resources are mainly crude oil, hard coal and natural gas. Material resources are mainly natural material for the PLA production, water and air as renewable resources.



Indicator	*PLA woven*
Resources consumption (kg)	601.000
Emission to fresh water (kg)	943.000
Energy demand [MJ]	96.487,66
Emission to air (kg)	12.500

Life Cycle Impact Assessment – The Life Cycle Impact Assessment (LCIA) evaluates the amount and significance of the potential environmental impacts arising from the LCI. Inputs and outputs are assigned to impact categories and their potential impacts quantified according to characterization factors. CML2001 with characterization factors from November 2009 is used as impact assessment method. *Relevant impact categories have resulted to be Global Warming Potential (GWP) and Marine Aquatic Eco-Toxicity Potential (MAETP).*



Impact is mainly linked to raw materials and intermediates production processes and to electric energy production processes. Transportation has negligible impact.

Impact category	*PLA woven*
GWP [kg CO2-Equiv.]	2.378,49
MAETP [kg DCB-Equiv.]	2.389.324,87

This LCA study has been performed by D'Appolonia in accordance with main requirements of international standards (ISO 14040:2006 and 14044:2006) and internationally recognized guidelines (i.e., ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance).
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4 The potential impact

4.1 Exploitation approach

BIOAGROTEX is an industry driven initiative where all partners have contributed in ideas and concepts. It builds on feasibility assessment by industry and key RTD organizations in the consortium of the ideas presented. It is a major objective to bring these ideas forward and to develop technology which can be used and exploited.
The basic IPR rules is laid down in the Consortium Agreement (CA), signed at the start of the project. The CA also indicates the background knowledge of individual partners. Access to this background knowledge will be given to the other partners on a "need to know" basis for the execution of the project. This access offered implies no transfer of ownership or right to use the information for items outside the project without written consent of the partner owing the background knowledge.
Foreground knowledge whether or not developed in joint actions is to be handled with great care. To avoid discussion concerning ownership of foreground knowledge developed during the project, the partners are instructed on good practices (logbook, lab recordings) and are described in the Quality Manual. Foreground knowledge, offering potential for commercialisation, is to be protected in an adequate and effective manner, in conformity with the relevant legal provisions and in regard to the legitimate interests of all participants. In order to maximize commercialisation potential within the consortium access rights on background and foreground knowledge will be offered on favourable conditions.
The Consortium Agreement also carefully governs issues related to the disclosure of confidential information in accordance to applicable laws and EC regulations. It further recognizes the fact that the EC Model Contract requires the use of results (commercial exploitation or further research). The Consortium Agreement specifies the responsibilities of the Partners to meet this requirement. Since it is in the benefit of all partners that the developed know-how, products and processes will be applied on a large industrial scale, access to the foreground knowledge will be offered to third parties outside the consortium on a commercial basis.

An IPR tracking system has been developed within the project during last months which collect all relevant exploitable results information and publicly available information. This tool will allow defining the freedom-to-operate and will be of assistance in defining the most appropriate way to protect the developed foreground knowledge. Non confidential information, such as analytical techniques that can be implemented into standards, or foreground knowledge once protected in an adequate way, will be released for dissemination. As the importance of dissemination is growing, strong emphasis is placed on the dissemination and promotion of results achieved in Bioagrotex. A multifaceted dissemination strategy is put in place going beyond standard academic publications and conferences by including measures for dissemination of results to industry to ensure take-up of the developments by industry and the market.

At an early stage of the project potential exploitable results were identified. The consortium has not limited themselves to define exploitable end products, but as well exploitable processes and products to be generated as intermediates. The following table reports the exploitable results defined during the course of the project with the company responsible and the other project partners involved.

Table 10: Possible exploitable results as defined at the beginning of the project

N°	*Exploitable Results*	*Exploitable Result Manager*	*Partners Involved*
1	Chemical formulations of starch based polymers	RODENBURG	
2	Starch based compounds for melt processable polymers	RODENBURG	DPPT, ITCF, DLO/FBR,
3	Biopolyester based compounds for melt processable polymers	TECNARO	DPPT, ITCF, CENTEXBEL,
4	Extrusion process for melt processing of the above bio-polymers	ITCF	DPPT, CENTEXBEL, ENYA, DS, BONAR
5	Biopolymer based textile fibres, yarns, filaments and tapes	ENYA	DS, BONAR
6	Furan Based Prepolymers	TFC	
7	Water based furan formulations for application to textiles	TFC	DLO/FBR, CENTEXBEL, DPPT, LA ZELOISE, ENSAIT
8	Upgrading process of natural fibre wastes	INOTEX	AGRITEC, DLO/FBR
9	Modified natural fibres	INOTEX	AGRITEC, ENSAIT, DLO/FBR, LA ZELOISE
10	Biopolymer textile: processing into knitted, woven, non woven structures	CENTEXBEL	DS, LA ZELOISE, BONAR, TEXINOV, ENSAIT
11	Non woven products based on natural fibres	ENSAIT	LA ZELOISE, AGRITEC
12	Furan finishing technology in production lines	CENTEXBEL	TFC, DPPT, LA ZELOISE, AGRITEC, ENSAIT
13	Furan finished products with integrated functionalities	TFC	LA ZELOISE
13a	Application of DPPT finishes to agrotextile to increase biodegradation resistance	DPPT	LA ZELOISE
13b	Application of DPPT Flame Retardant (FR) finishes to agrotextiles	DPPT	LA ZELOISE
14	Analytical technique for biodegradability control	DLO/FBR	CENTEXBEL
15	Design for textiles with tailor made biodegradability	DLO/FBR	DAPP
16	LCA Analysis	D'APPOLONIA	DS, LA ZELOISE, BONAR, TEXINOV
17	Industrial textile applications: natural fibres based ground-covers	LA ZELOISE	TFC, DPPT, AGRITEC
18	Industrial textile applications: biopolymer based fibre mats	DS TEXTILES	RODENBURG, TECNARO, DPPT

N°	*Exploitable Results*	*Exploitable Result Manager*	*Partners Involved*
19	Industrial textile applications: biopolymer based woven ground covers	BONAR	RODENBURG, TECNARO, DPPT
20	Industrial textile applications: biopolymer based crop protection textiles	TEXINOV	RODENBURG, TECNARO, DPPT, ENYA

For each exploitable result a summary table has been prepared as well as a preliminary business plan has been provided. Finally a patents scenario analysis has been performed focusing on the most relevant patents, for which a detailed description has been provided. Suggestions regarding patenting possibilities and/or strategies have been provided.

The summary table contains general information of the exploitable result as the innovation content of the result, potential customer and expected benefit, current achievement status and if necessary expected date; commercial and financial information as the time to market, evaluation of the cost to be sustained after the project, price range of the result or price of licenses, potential market size, competition against other products in terms of price or performance and the competitors; collaboration and exploitation information as partners involved, industrial partners interested in the result (partners, sponsors, etc…) and IPR strategy.
The business plan consist in 27 questions organized in eight different sections: general organisation description (current and future business activity, legal form of ownership, goals and objectives for the specific Exploitable Result), info on the management team (core assumptions of the business model and managerial objectives, business manager for the specific Exploitable Result, need for external management resources), technology information (technology as business opportunity with added value to offer new solutions to customers, development work needed to bring the technology to the market and associated costs, reaction from the competitors, bottlenecks to be overcome, standardization (reference materials - reference methodologies or regulation etc…), intellectual property rights strategies (IPRs clear within the project consortium, technology protection, comprehension of the of the state of the art current situation, including patents), products and services (stage of development of product(s)/service(s), product(s) dependence on other technologies or IPRs of 3rd parties, unique selling proposition of the product(s)/service(s) offered, competitive advantages), market analysis (market size and market growth, market segment(s) and drivers of growth, competing products and companies), preliminary marketing plan (sales targets for the Exploitable Result, strategy for pricing issues, sales methods and distribution channels) and tentative financial plan (break-even and cash flow calculations, capital needed over a period of time and level required of external funding).

As outcome of the work performed, here after, resumes of the current status, the valorisation potential and the strategies for the exploitation of the project results is presented, according to the progress of RTD work performed up to the end of the project.

Table 11: Analysis of exploitation potential at finalised project.

Exploitable result	**Current Status – Valorisation potential**
1. Chemical formulations of starch based polymers	Improved formulations and routes to prepare them were defined and offer potential for other application fields.

2. Starch based compounds for melt processable polymers	Know how generated can be implemented for other application fields
3. Biopolyester based compounds for melt processable polymers	Can be commercialised, can be improved by stabilizers and chain extenders. There is no potential for patenting.
4. Extrusion process for melt processing of the above bio-polymers	Industrial processability has been demonstrated for most extrusion processes except POY/FDY. Processes are used by partners – Patenting difficult, Consulting and use in further developments possible by industrial extrusion and by research partners.
5. Biopolymer based textile fibres, yarns, filaments and tapes	
6. Furan Based Prepolymers	The base technology has been patented in 2007. Extensions of the patent (EU, US, WO) are programmed. New formulations are to be decided, to be evaluated the palm oil formulation. Products are close to the market testing.
7. Water based furan formulations for application to textiles	
8. Upgrading process of natural fibre wastes	There is no space for patenting; it's quite difficult to get patent specifications. The process is between farmers and end-users and it's difficult to be accepted and to enter in the market, up to now. Process and related properties are well known. Fibres at the moment not yet used in the NF needlefelt production within bioagrotex).
9. Modified natural fibres	Possibility to valorise the enzyme field spray formulation Possibility for use and consulting of know how on enzyme treatment and alternative fibre sources
10. Biopolymer textiles: processing into knitted, woven, non woven structures	Only minor adaptations are required within the processing. Only internal use of individual generated know-how – limited external valorisation potential
11. Non woven products based on natural fibres	Different combinations of fibres including enzymes need to be done. For the next years, producers near Ensait could be contacted for the raw materials supply
12. Furan finishing technology in production lines	Not patentable. Needle felt and woven textile are finished using existing equipment. Generated know how: Use and eventually consulting
13a. Application of DPPT finishes to agrotextile to increase biodegradation resistance	The listed products are currently on the market in different sectors, transfer to natural fibres is a direct one with testing already completed. Middle term exploitation route foresee to identify possible end users for this application. Next actions are technical testing for new substrates
13b. Application of DPPT Flame Retardant (FR) finishes to agrotextiles	
14. Analytical technique for biodegradability control	Achieved, to be used in-house Exploitation of testing facilities and interpretation (consulting)
15. Design for textiles with tailor made biodegradability	Achieved, to be used in-house

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	Use and consulting
16. LCA analysis	Available, used for consultancy
17. Industrial textile applications: natural fibres based ground-covers	Available, pre-commercial status, industrial productions can start-up
18. Industrial textile applications: biopolymer based fibre mats	Available, Some products at commercial status, other pre-commercial status
19. Industrial textile applications: biopolymer based woven ground covers	Available, commercial status, the product is available in the market.
20. Industrial textile applications: biopolymer based crop protection textiles	Available, commercial status

4.2 Specifically generated and commercialised agrotextiles based on the project result.

Based on the results mentioned above a range of demonstrator products were defined and tested in the field. In addition durability testing was performed at lab scale conditions via soil burial tests, composting tests and fast degradation in oven or under UV-illumination. It was clearly shown that the lifetime of the natural fibre based ground-covers is at least doubled after application of the bioresin and also the PLA based agrotextiles will easily resist 3 to 5 years under outdoor conditions. No eco-toxicity effects of the materials or the products generated during degradation could be observed. Also a detailed LCA of the different demonstrator products was performed showing the ecological relevance of the products.

Based on these results a range of commercial products were developed and are commercialised:

4.2.1 Woven PLA Ground covers - DURACOVER® -Bonar Technical fabrics)

Woven groundcover fabrics, based on extruded PLA tapes, were developed by Bonar Technical Fabrics and are commercialised under the commercial name DURACOVER®. Products have a high UV resistance and the durability is guaranteed for at least 3 years. They are light weight and can be easily installed. Products are available in different colours. Several pre commercial and commercial installations have already be realised (cfr www.bonartf.com/en/x/159/duracover)

Fig. 28: Examples of installed Duracover® materials: test field and first commercial installation.

4.2.2 PLA fibre needelefelt groundcovers – “HORTAFLEX” & “WEED CONTROL®” - DS Textiles

Another set of groundcovers were defined by the Belgian company DS Textiles and are commercialised under the tradename “HORTAFLEX®” and “WEED CONTROL®”. These are based on PLA staple fibres processed into needlefelts, whether or not with an additional calander treatment. Products are also available that are containing the necessary seeds and can be used as seed mat. (www.dstextileplatform.com)


Fig. 29: Examples of installed HORTAFLEX® & WEED CONTROL® materials:

4.2.3 Knitted PLA insect screens – FILBIO®PLA and ULTRAVENT®PLA -TEXINOV

A third type of products are brought on the market by the French company TEXINOV. They are producing is specialty range of crop protection products (against insect, wind, hail, intense sunlight) via well-defined knitted fabrics based on mono- or multifilaments yarns. A special range of PLA based products are now commercialised under the trade names FILBIO®PLA and ULTRAVENT®PLA. Due to the high UV resistance of the newly developed articles the products can outperform the present products based on PO or even on PA. (www.texinov.fr)

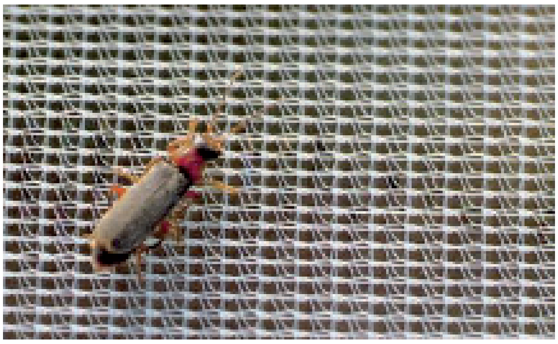


Fig. 30: Illustration of the use of FILBIO®PLA

4.2.4 Natural Fibre based ground covers treated with bioresins - LONGLAST – La Zeloise.

A final set of groundcovers were developed based on Jute fabrics and non-wovens treated with bioresins from the Belgian company: Trans Furan Chemicals. The products are produced and commercialised by the Belgian Company La Zeloise. The major advantages of the materials developed are the extended durability of the natural fibre based fabrics (double or triple lifetime) this combined with the fully biobased character, the final compostability and the absence of any eco-toxicity effect. (cfr www.lazeloise.be) .

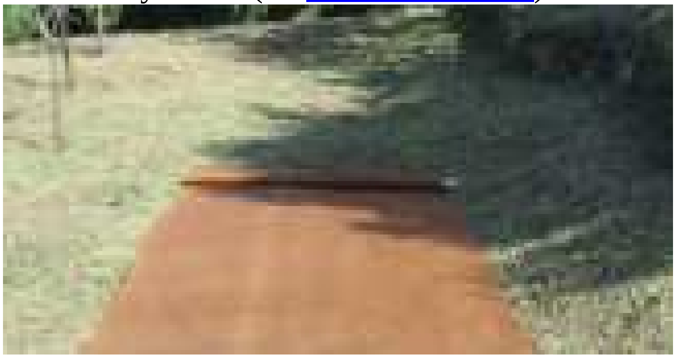
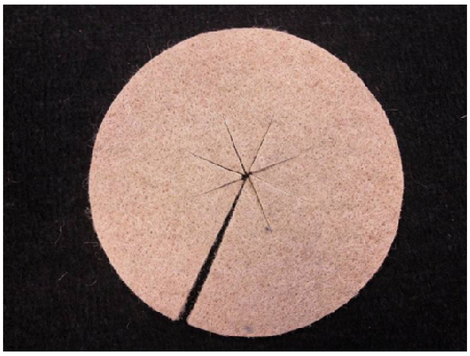

Fig. 31: Illustration natural fibre based groundcovers from La Zeloise with extended durability.

4.2.5 Commercialisation of intermediates.

It's obvious that in order to allow the commercialisation of the above defined agrotextiles end-products, there is also commercialisation actions required for all intermediates and specialty formulations defined. Partly the materials are based on existing commercial products but also new special formulations are brought on the market. A specific example of such a product is the Hybrid BIOREZ®, but also biopolymer formulations or textile intermediates can be valorised.

4.3 Dissemination of the project results

Within the consortium it was decided to disseminate as much as possible the project approach, objectives and results as far as they don't interfere with IPR and exploitation possibilities. Dissemination is seen as a key element to visualise the novel eco-friendly products developed and to create a market demand.

During the whole course of project, 44 dissemination actions have been performed by the consortium partners.

They comprises conferences and congress (among which Aachen-Dresden International Textile Conference, European Textile Platform conference - Euratex, TEXCHEM -21st TCC CZ conference), fairs (among which Techtextil, Saint Selve fair, On the Road to a Bio-Based Economy: International event on Renewable Plastics, Textiles and Composites, Salon Vert), meeting with potential industrial partners or end user groups. These activities were supported by the posters and the flyers designed within the project.

At the end of the project a successful International Symposium: "European Research & Innovation for a Biobased Economy" has been organized to disseminate project results, to launch the new products ain the market and to position the development towards other research initiatives towards the generation of a biobased economy.

Table 12: List of Disseminations

#	Event	Location	Date	Partner	Contents	Type and Media
1	European Textile Platform conference - Euratex	Brussels	01-02 / 04 / 2009	Centexbel	General overview of project and consortium	Speech, presentation
2	48th Man Made Fibre Congress	Dornbirn	16-18 / 09 / 2009	Centexbel	General overview of project and consortium	Speech, presentation
3	m-tex, technical textiles ETRforum	Czech republic	8-10 / 06 / 2010	INOTEX	General overview of project and consortium	Speech, presentation
4	TEXCHEM -21st TCC CZ conference	Czech republic	14/10/2009	INOTEX	General overview of project and consortium	Speech, presentation
5	Meeting with potential industrial partner	Denkendorf	20/04/2010	ITCF	General results and possible applications	Speech, Discussion
6	Internal Lectures	Wageningen	2010	WUR	General overview of project and consortium	Internal lectures, presentation
7	Meeting with potential industrial partner	Zele	2010	BONAR	General results and possible applications	Speech, Discussion
8	I-sup 2010 (eco-economy symposium	Bruges	19/04/2010	Centexbel	Positioning Bioagrotex within biopolymer developments	Speech, presentation
9	Meeting with potential industrial partner	Denkendorf	8/10/2010	ITCF	Biopolyester blends for fibre and non-woven application	Speech, presentation
10	Cooperation form "Biopolymers" @Bayern innovativ	Munchen	11/11/2010	Centexbel	Positioning Bioagrotex within biopolymer developments	Speech, presentation
11	Aachen-Dresden International Textile Conference	Dresden	25/11/2010	ITCF	Biopolyester blends for fibre and non-woven application	Poster, info flyer
12	Stuttgarter Kunststoff-Kolloquium	Stuttgart	16/03/2011	ITCF	Development of fibres with improved properties based on PLA	Speech, presentation
13	Natex workshop	Poland	22/03/2011	Centexbel	General overview of project and demonstrators	Speech, presentation
14	TECHTEXTIL 2011	Frankfurt	24-26/05/2011	INOTEX	Nat fibres bio-retting, enzymes for nat. fibres, textile biotech poster – exhibition boat CLUTEX/INOTEX	Poster, info flyer
15				Centexbel	General overview of project, consortium and demonstrators	Speech, presentation
16				Centexbel	General overview of project presentation of sample materials to be used as demonstrators	Poster and Flyers : Demo booth
17	Tech-Textil Meeting	Frankfurt	05 / 2011	BONAR	Presentation of industrial materials	
18				DS Textiles	Presentation of industrial materials	Commercial samples/ company booth
19				TEXINOV	Presentation of industrial materials	
20	50th Man Made Fibre Congress	Dornbirn	14-16 / 09 / 2011	Centexbel and industrial partners	General overview of project and demonstrators	Speech, presentation
21	Fair	Saint Selve	21-22 / 09 / 2011	Bonar	Presentation of the new bio-based textile	Product presentation - Small demosite

22	On the Road to a Bio-Based Economy: International event on Renewable Plastics, Textiles and Composites	Elewijt	40843	Centexbel	General overview of project and consortium - Demo of samples	Speech, presentation
23				TFC		
24				Tecnaro		
25				Bonar		
26				DS-Textiles		
27	Research activities towards a bioeconomy	Gent	jan/12	Centexbel	Situating the developments in the bioeconomy with link to Bioagrotex project and results - for local authorities	Speech and discussion forum
28	Euratex symposium	Brussels	30-31 / 03 / 2012	Centexbel and Bonar	General overview of project, demonstrator materials – woven PLA groundcovers	Speech, presentation
29	Research activities towards a bioeconomy	Zwijnaarde	29/02/2012	Centexbel	Situating the developments in the biopolymer processing – delegation of GB entrepreneurs	Speech and discussion forum
30	Meeting with German extrusion machine producer	Chemnitz	8/01/2012	ITCF	Processing of synthetic and biopolymers and effect on structure formation and properties	Seminar on comparison of standard polymers and biopolymers
31	Meeting with French end-user group		feb/12	La Zeloise	NF based agrotextiles with extended lifetime	Product presentation and discussion
32	Textiles for the 3rd millennium	LIBEREC	2/05/2012	INOTEX	Project presentation, results achieved	Speach
33	Trade Fair Spoga	Köln - Germany	02-04/09/12	La Zeloise NV	Presentation of Bioresin based Jutecloth and Juteneedle felt	Commercial contacts for the retail market
34	Salon Vert	Saint-Chéron	20/09/2012	NV	Demonstration	Product presentation
35	Salon Vert	Saint-Chéron	20/09/2012	Bonar	Demonstration	Product presentation
36	International Symposium European Research & Innovation for a Biobased Economy	Gent	26/09/2012	TFC	applications	Speech, Presentation
37				Rodenburg	Starch based formulations	
38				Tecnaro	Melt processable biopolymer formulations	
39				Centexbel	objectives	
40				La Zeloise	Bioresin treated natural fibre based groundcovers with extended lifetime	
41				Bonar TF	Woven PLA groundcovers	
42				Texinov	screens	
43				DS Textiles Platform	Biopolymer based needlefelt groundcovers	
44				D'Appoloni a	Ecological aspects of biobased polymers and products	
Disseminations planned after finalisation of project.						
45	*Symposium -EURATEX*	*Brussels*	*22/11/2012*	*Centexbel*	*Overall results Bioagrotex*	*Lecture*
46	*Symposium – UP-TEX*	*St -Quentin Fr.*	*22/11/2012*	*Centexbel*	*Overall results Bioagrotex*	*Lecture*
47	*Publication in Unitex*	*Belgium*	*1/12/2012*	*Centexbel*	*Commercialised products*	*publication*

5 Conclusion.

The FP7 Bioagrotex project was to a large extent successful and most of the objectives defined at the start of the project were successfully realised. In a few cases alternative production routes needed to be applied to be applied in order to allow the realisation of the envisaged group of end products. This was the case for the starch based formulations, that were clearly improved but only textile products with insufficient mechanical properties could be generated. The focus was there for shifted towards the implementation of biopolyesters.

A range of optimised biopolymer resins or thermoplastic formulations were defined that could be processed on existing machinery and offer good processability and properties. Based on these results a set of different types of agrotextiles could be defined and can be directly implemented in the field. The first commercial results are already obtained and already a few hundred thousand m² of specialty agrotextiles based on the present development are sold to the market.

6 Project public website and relevant contact details.

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Overview of partners logo's

Project co-funded by the European Commission within the Seventh Framework Programme