Biotechnology as one of the substantial elements of the sustainable textile processing mosaic

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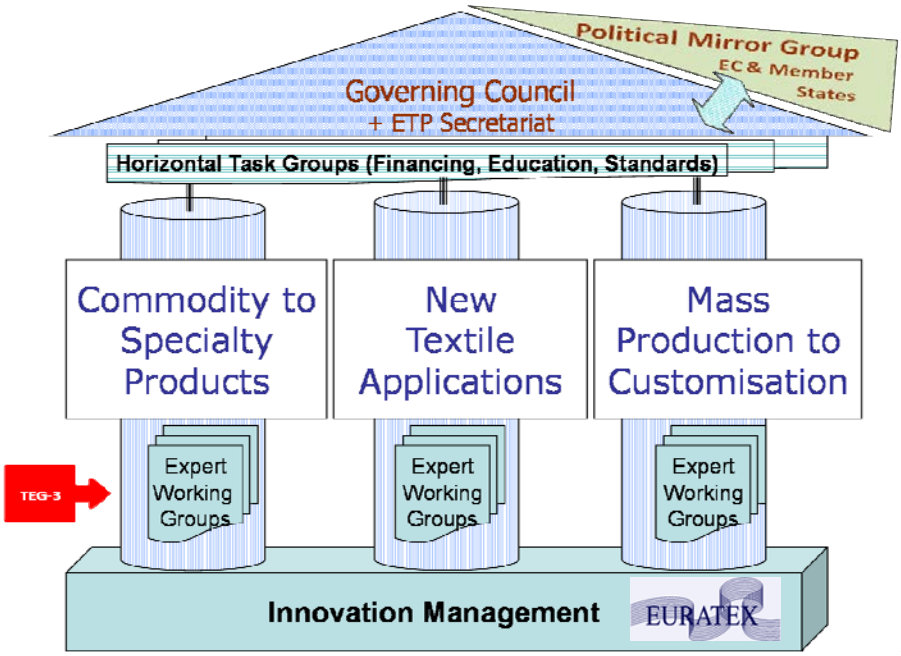
European textile and clothing sector remains one of the key manufacturing branches of national economics of many countries. Faced with globalised fierce competition of low wage countries its sustainability strongly depends on a new multidisciplinary approach of innovative movements towards new qualities and flexible, environmentally friendly technologies of production. New impulses how to influence brand new end-use areas need to be observed.
Biotechnology as one of the modern dynamic disciplines takes the relevant role of future – knowledge based economy. Industrial, or also called "white" biotechnology has a major potential to influence our textile sector employing new possibilities of selective enzymatic catalysis (as an option to harsh hammer –like chemical processings); new bio-based materials can reasonably help to launch new functional properties of textile substrate (being an alternative source of textile auxiliary agents, creating new functional properties of medical, technical, well-being etc. textiles). Natural and artificial (bio-fermented) fibrous polymers and biotechnologies as a cleaner production processes will also help by much broader utilization of natural renewable fibre sources and as an instrument of new surface architecture of hybridised fibrous matrices.
Also due to the fact that just textile industry was historically one of the first areas of industrial biotech applications (after production of foods and drinks) both sectors decided to highlight the textile biotechnology within strategic programme of existing European technology platforms. EURATEX for future of textile and clothing as well as CEFIC-EuropaBio Industrial Biotech sub-platform, supporting the Sustainable Chemistry.
The key topics of European T/C platform strategy for biotechnology and bio-based product implementation plan will be presented. Number of particular examples will be shown.

1. European Technology Platform

Only long-term visions and corresponding **strategies based on an intensive multidisciplinary approach** involving all stakeholders can help traditional manufacturing sectors like textile and clothing to find ways to sustainability, to raise competitiveness. In order to help to reach the long term objective of transforming European textile and clothing sector into a dynamic, innovative and knowledge based industry, its long term strategic priorities have been identified by European Technology Platform for the Future of Textiles and Clothing (ETP), namely:

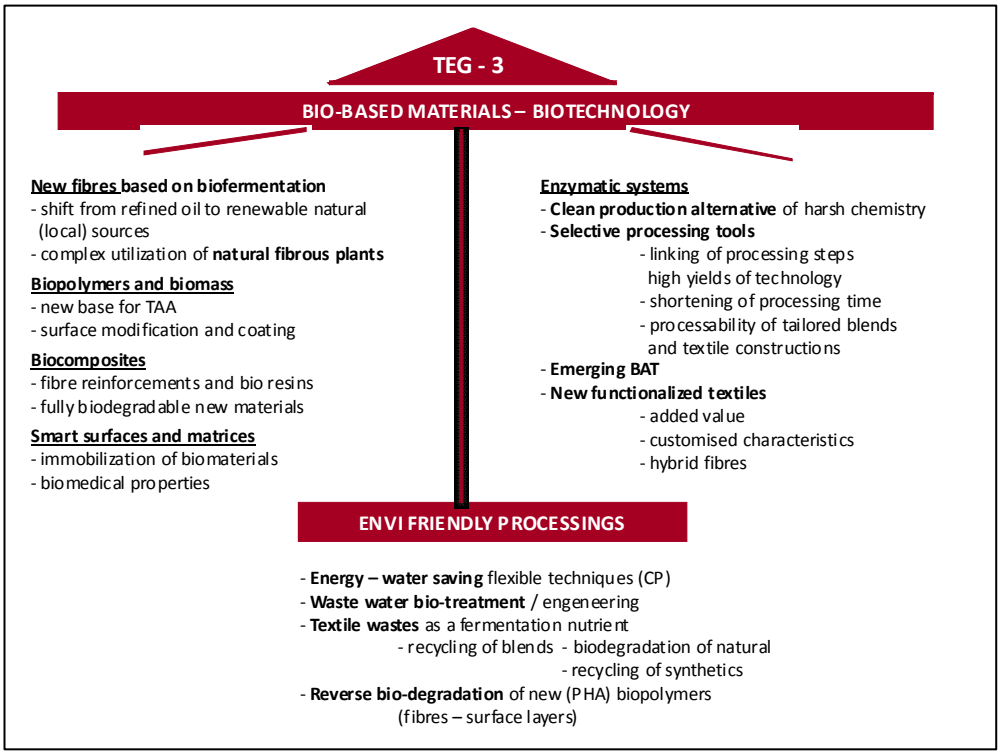
- to move **from commodities towards speciality products** made by use of high-tech, flexible processes (to launch new fibres, filaments, fabrics and final products with highly functional, purpose-targeted properties based on nano-, micro- and biotechnologies, new coatings and laminations, digital processes etc).
- to establish and extend **textiles as raw material of choice in many new sectors and application fields** (transport systems, construction, medical applications, wellness etc.)
- to prepare **end of the era of mass manufacture of textile products and to move towards the new industrial era characterized by customization**, personalization, as well as flexible, on-demand production coupled with intelligent logistics, distribution and services.

Figure 1: Structure of ETP for the future of textiles and clothing (EURATEX)



Biotechnology as modern, highly dynamic discipline takes more and more industry relevant positions to be a cleaner production based, local natural resource using alternative to conventional petrochemicals based era. Due to this fact, one of the specific part of the ETP EURATEX strategic road-map – **TEG-3**, was **focused on biotechnologies, bio-based products and environmental friendly processes**. The Knowledge-based Bio-economy (KBBE) takes one of key roles within the global economy. Industrial biotechnologies (called "white-biotechnology") have been selected as a special subject (sub-platform) of the sustainable chemistry program of CEFIC. It is evident, that a broad frame of next intensive joint cooperation exists. Now it is necessary to highlight priorities and to start work on new biotechnology based textile processing and product innovations.

Figure 2: TEG 3 – Bio-based materials, biotechnology and environment.friendly processing



Is it so difficult and something between reality and “black-magic”? Or do we have chance to speed-up this process and learn from each other what ever the textile engineers need to be done to harness the nature for textile production using existing, fast expanding skills and know-how of biotechnologists. Breaking biotechnology based news needs translating into the “textile users-friendly language” to enhance its acceptability. Intensive exchange of information and creating of joint strategy within the both platforms, these are valuable tools for shortening the R&D and innovation process.

2.1. Biotechnologies

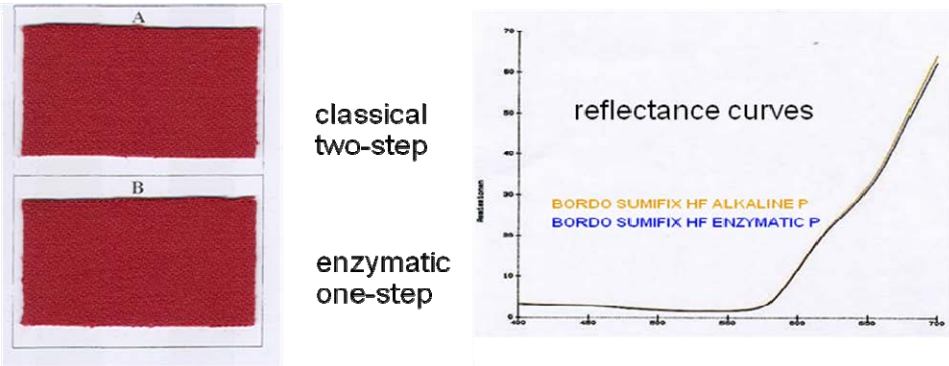
The fact that just textile was historically one of the first industries which started the industrial biotechnology applications (after food and drink production) clearly signalise, that this is the right area for further developments. In time between the first **desizing** technology, where starch size was split by pancreas *amylolytic* enzyme extract to the water-soluble oligosaccharides has been reasonably modified – new highly productive artificial technical microorganisms have been employed to produce a broad range of highly effective durable **enzymes**. Thermostability and rapid starch degradation bio-catalysts opened the possibility to speed up and intensify desizing, to realize this process as part of continual pretreatment. But this was still the beginning stage of enzymatic treatment of textiles.

Now we start new era of enzymes as selective tools which are able to help by bulk stage implementation of cleaner processing alternatives of harsh, “hammer-like” chemistry. The more we deal with tailor-made, multifibre fabric blends and special textile substrate architectures (to improve functionality, comfort, easy care etc.), the more advantageous enzyme-substrate selectivity is becoming. Enzymes in very small doses can be used in integrated processes which reasonably shorten the processing time. As bio-catalysts, they work at lower temperatures.

One of clear examples of such cleaner, environment friendly technology, based on modern enzymology is **bioscouring**. Conventional chemical saponification of natural pectine glue and wax based impurities is replaced by pectolytic enzyme. Natural pectin glue together with cotton wax protect raw cotton fibre during vegetation, but reduce significantly its water-absorptivity which is one of key preconditions of wet finishing and users-comfort. By the bioscouring process, they are selectively bio-degraded and washed out. Instead of high temperature boiling in strong alkali and high dose of detergent in the bath – bio-scouring is a near neutral pH, low temperature (50-60°C) process.

Figure 3: Single – step enzymatic desizing and bio-scouring (Texamyl BP + Texazym SC) followed by reactive dyeing. 100% Co fabric, jigger.

REACTIVE DYEING – deep shades	Classical two step pretreatment	One-step enzymatic pretreatment		
Rising height /mm/ 2 min	42	38		
Relative colour strength /%/	100	102,25		
Colour difference dE*	Ref.	D65/10	TL84/10	A/10
		0,39	0,36	0,34

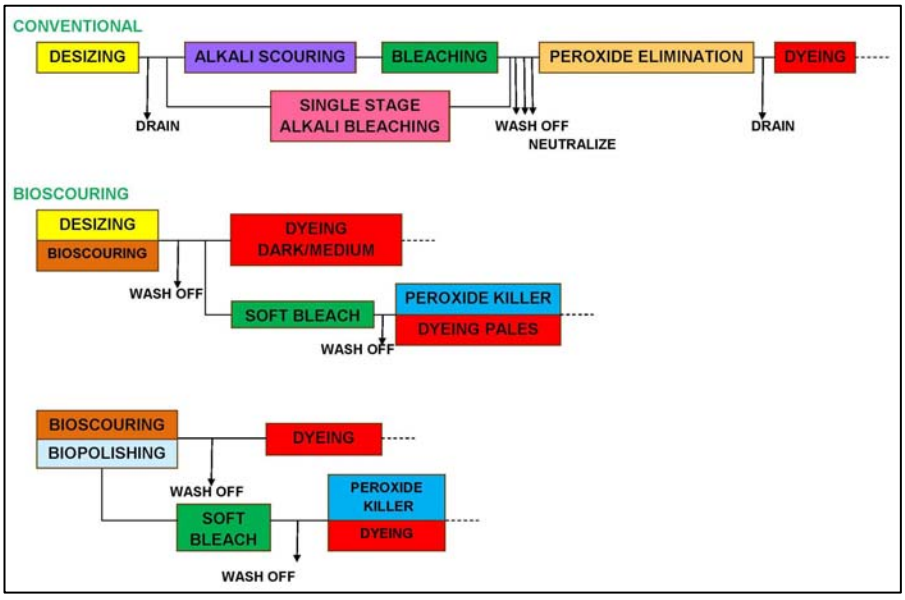


Bioscouring enzymes can be combined with other enzyme products – amylases and/or cellulolytic antipilling systems to run desizing (woven fabrics) or antipilling of knitted materials in one step. Significant reduction of costs (energy, chemicals, water pollution and shortening of processing time) is evident. Processing without harsh caustic soda also improves the fabric touch and look, eliminates the rest (internal) alcalinity problems which are often known by eco-labelling of textiles.
If deep and medium shades of fabric are requested it is not necessary to realize bleaching. In case of pales and white articles, it is necessary to add soft, lower alkali (used as activator of peroxide bleaching system only) bleaching. Followed by enzymatic elimination of hydrogen peroxide by enzymatic (*catalase* based) **peroxide killer**, dyeing process can be started immediately. Additionally in case of immediate dyeing without drying – small rest of cotton wax can be used as a natural anticreasing and soft handle lubricant. Here we have a clear example of fully environment- friendly „eco“process. After intensive lab-scale as well as bulk evaluation (examples will be presented) many additional advantages can be used. Risk of tensile strength lost is minimized – in combination with other special treatments (using resins for easy-care finishing, fixing of durable FRs etc.), pretreatment of sensitive Co- viscose heavy fabric (for furniture) should be mentioned.

Figure 4: Bioscouring for durable FR treatmentEN ISO 15025 (532) 100% cotton twill
TEXAZYM SC + TEXAMYL BP, 60°C, jigger
Bulk trial results – comparison of conventional and enzymatic pretreatment

Twill 100% cotton	loom state	desizing and alkaline scouring two-steps / two baths	bioprefreatment (desizing + bioscouring) one-step / one bath
Square weight /g/m²/	298,2	289,7	298,5
Rising height /mm/ 2min / 30min	0 / 0	50 / 108	60 / 138
Absorptivity /%/	43,9	239,4	249,3
Tensile strength /N/ warp / weft	696 / 1232	676 / 1190	705 / 1239
ADP	2 667	2 316	2 548
Fats and waxes (PEth.) /%/	0,40	0,21	0,34
Ash /%/	1,08	0,28	0,86
Ca /mg/kg/	434,0	626,0	279,0
Mg /mg/kg/	642,0	267,0	138,0
Stiffness /mN/ warp/weft	7,78 / 18,2	7,46 / 25,9	7,92 / 28,2
Desizing rate - Tegewa	-	8 - 9	8 - 9
% P fixed	-	2,26	2,29

Figure 5: Bio-scouring – reduction of processing time



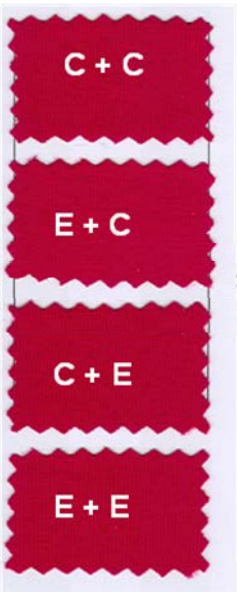
Cellulases are the next growing enzyme family visibly influencing the textile and garment sector. As an integral part of young fashion (**denim wash**, old- fashioned wash effects etc.), cellulolytic enzymes totally substitute chemical bleaching and eliminate environmental problems with stone-washing. Broadening unlimited variability of fashion effects on denims, next type of enzyme –*laccase* excel as an ideal protector against indigo redeposition.
But cellulolytic enzyme family is a key to the new generation of processing of natural renewable fibres - namely flax and hemp in European context. This will be presented in details in section „bio-based materials“ of this presentation.

Proteolytic enzymes seem to be one of challengers in the area of brand new, substrate and environment friendly processes of natural protein fibres – wool and silk. In near future new generation of bio-based recombinant proteins (PHA poly-hydroxialkanoates, PLA etc.) will certainly also bring the broad range of new enzymes for their modification and degradation.

Also biocatalysis for **dyeing** as the most sensitive wet processing step can't be avoided. However, at this moment first trials of enzymatic soaping-off process signalise that the selective decolourisation of non-fixed reactive dye hydrolyzate only isn't absolutely unambiguous. From case to case risk of dye structure change, which cause non-tolerable shift of colour shade by *laccase* treatment, exists. After all, based on our detailed studies of many dye constitution, TEXAZYM RES (Inotex) confirmed its ability to be used in after-wash process of the SUMIFIX HF (Sumitomo) range of modern reactive dyes without any significant problems. It is evident this can be way to major cutting of processing time (non fixed dye hydrolyzate is decolourised instead of long process of stepwise wash off of residual rest of colorant) and water consumption and costs reduction. Besides, waste water pollution figures significantly improve.
Positively, new sorts of *oxizymes* will facilitate colouration and yield of dye-bath based on textile substrate pre-activation in future.

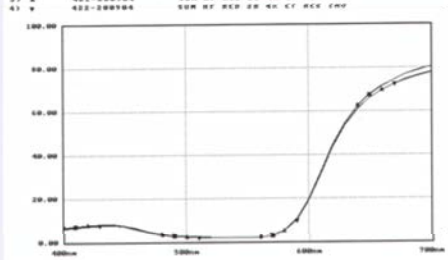
Figure 6: Enzymatic scouring and aftertreatment of cotton reactive dyeing - comparison of conventional and enzymatic processes Texazym SC 60°C, Texazym RES, C-conventional process, E-enzyme

SUMIFIX HF RED 2B



Colour fastnesses	Woven fabric		Knit	
	Clas.	Enzym.	Clas.	Enzym.
water	4-5K/4-5/4-5	4-5/4/3-4	4-5/4-5/4-5	4-5/4/3-4
washing 60°C	4/4-5/4-5	4-5K/4/4-5	4-5/4-5/4-5	4-5K/4/4-5
rubfast.dry	4-5	4-5	4-5	4-5
rubfast.wet	2-3	2	2-3	2
Sun test	4D	4D	4D	4D

Reflectance curves



Colour difference

RED 2B	dE* D65/10 wov.f./ k.	relat.depth /%/ wov.f. / k.
E +C	0,62 / 1,07	102,33 / 106,46
C + E	0,68 / 0,69	104,26 / 104,85
E + E	1,19 / 0,86	107,32 / 103,51

The end of 20th century pointed to great opportunities of enzymology in the area of **synthetic textiles modification**. It seems clear that the traditional status quo of enzyme use strictly only in the area of natural fibres has been broken. INOTEX as one of the first performers launched the industrial scale suitable system of PES modification based on *esterase* treatment of fabric. TEXAZYM PES (Inotex) increases the PES hydrophilicity and consequently its antielectrostatic property. New functional (-OH, -COOH) groups were identified in the PES polymer structure after the enzymatic process. This allows a completely new strategy of PES modification to enhance its use as a functionalised and customised textile substrate. The TEXAZYM PES based process is simple, short and reliable by use of existing processing technologies. It was confirmed that achievable hydrophilicity is fully comparable to the alkaline hydrolysis realized under the drastic conditions. On the contrary, enzymatic modification does not reduce the fabric weight and it can also be used for special types of PES like TREVIRA CS with no influence on flammability. As a pre-activation step this bio-process can be, thanks to its substrate selectivity, used for broad range of blends. First positive signals of durability improvement (FR, antimicrobial, coating adhesion) have been identified.

Figure 7: Enzymatic modification of PES, comparison with alkaline hydrolysis
PET substrate : 100% FR PET – Trevira CS, twill 160g/m^2 scoured, thermofix.
Processing : - *enzyme* : 0-2g/l TEXAZYM PES, pH=4, 30°C, 30min, 2x wash 50°C, dry
- *alkali* : 20g/l NaOH (s) 98°C, 45min, wash, dry

Enzyme conc./g/l/	Rising height 2 min/mm/	Weight loss /%/
0	12	< 1
0,1	27	< 1
0,2	32	< 1
0,5	41	< 1
1,0	42	< 1
1,5	55	< 1
2,0	54	< 1
Alkali hydrolysis	40	14,8

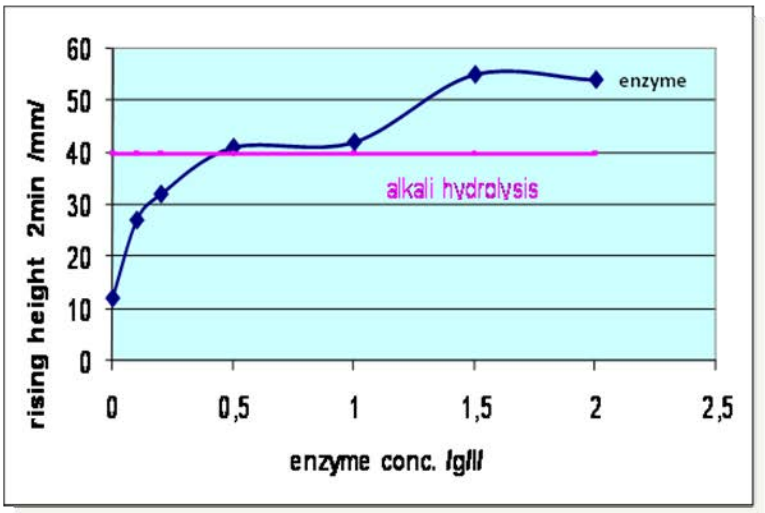


Figure 8: Enzymatic modification of PES. Durability in repeated laundry, antistatic effect, hydrophilicity. Texazym PES 1,5 g/l, 30 min, 30°C.

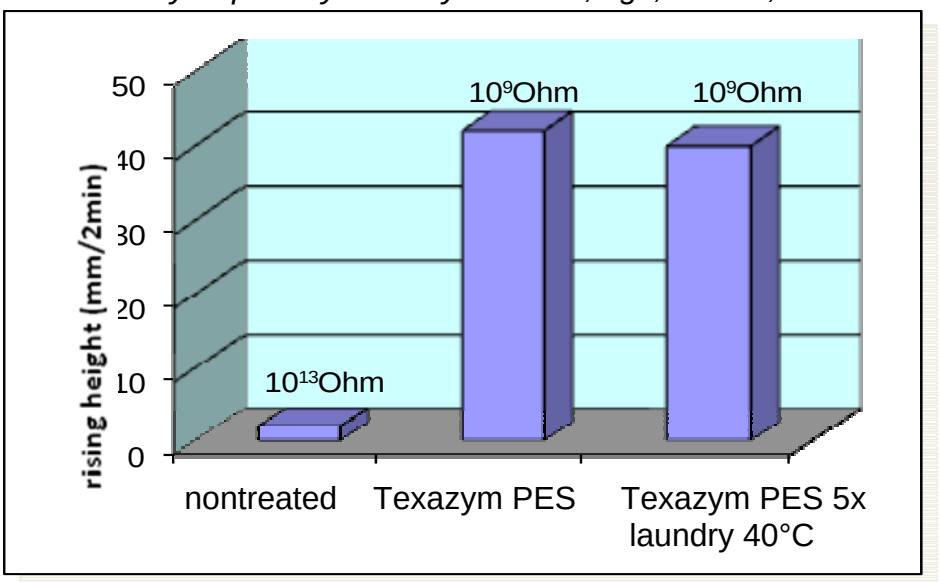


Figure 9: Confirmation of OH-groups in PES modified by TEXAZYM PES, Re dyeability and fastness properties. 0,5 % Re dyeing (C.I.Re Blue 19), after treated by soaping.

Intensive work on screening of new sources of enzymes for synthetic fibre polymer modifications (PA, PAC etc.) is started and first positive signals have been noticed as well as new preparations containing *polyesterases* of new generation. This new way of **„bio-functionalization“and hybridisation** of existing wide market of synthetic and man-made fibres will strengthen its competitiveness and reasonably widen their potential of use.
Research initiatives focussing on development of new, more effective biocatalysts and on engineering of biocatalytic processes will attract the interest of a wide audience of textile industry. New impulses of textile sector will initiate the adequate response of white biotechnology. Due to extensional use of new sizing agents (e.g. PVA, CMC) the adequate enzymes able to handle reliably imported loom state fabrics should be an example, that also the most traditional processing step is ready for next bio-based improvement (if we don’t think about future sizing by use of new biopolymers).
Novel enzymes and optimization of biocatalysts properties as well as the future new dimension of industrial use of **extremozymes** (as biocatalysts with durable activity by harsh conditions – pH, temperature, high content of chemicals etc.) will get new opportunities. It is evident that a joint activity supported by textile engineers will facilitate the biocatalysts process design, allow next multi-step bio-reactions etc.
Combination of chemical-physical and biotechnological treatments (substrate activation by plasma followed by subsequent enzymatic reactions, ultrasonic process intensification etc.) as a new tool of integrated pretreatment and functionalization, including improved dyeability (better exhaustion of dyebath and better dye fixation) need to be studied within the multidisciplinary teams.

2.2. Bio-based materials

Supported by a tremendous progress and massive research in biology and biotechnology, learning form nature, new bio-based materials can reasonably help to launch new functional properties of textile substrate. **Bio-fermentation** as an alternative of refined oil based sources will conclusively produce new fibrous structures, too.
Biopolymers and biomass (inclusive extracts from rural sources of biomass produced for biorefinery and bio-fuel productions) will be available as an alternative base for new textile auxiliary agents (TAA) – bioresins, biosurfactants, FR , UV absorbers, essential oils creating new functional properties of medical, health care, well-being etc textiles. This is the future of functional, high added value, textile production supported by knowledge based bio-economy (KBBE).
New pathways engineering for **improved fermentation processes that lead to new bio-based polymers as a renewable source for textile industry** become a fundamental

area for the textile sector since availability of oil-based synthetic fibres will be more and more complicated due to the limited oil availability.

Not only the cost-effective production of degradable polymers to replace the currently used synthetic polymers, but also the development of totally new bio-based fibres, production of fibres by microorganisms, genetically engineered techniques to produce (bio)functionalised or already coloured biopolymers etc. Fermentation process improvement is essential to reach quality and cost effectiveness. In the contrary to existing synthetic fibres, new bio-based fibres can be fully biodegradable.
Our textile sector should benefit from the masive wave of **biorefinery** concept.
Broad range of new sources of biomass for bio refining contain fibrous substances – bast fibres (flax, hemp) and emerging technical plants (e.g. Spartium –Spanish broom, straw, wooden chips). These co-products have potentially high value as new materials for the composite reinforcement, new qualities of construction materials, fibrous additives in building materials etc. as mentioned, not only fibres but also bio-resins, essential oils, surface-active bio-substances etc. can be extracted from the biomass.
Biotechnologies (**bio retting**) can be part of tailor – made processing technology to enhance the effective, waste less utilization of biomass used in (rural) bio-refinery. This can be like “come-back” to utilization of local renewable sources in textile manufacturing which was one of key elements of European textile industry genesis. Nowadays for fashion garment and technical applications, too.
Direct use of **extracted fibres** as such followed by special surface (bio) modification (elementarisation, resin adhesion improvement, fibre fineness, cottonisation etc.) as well as the extrusion (co-extrusion) of natural fibre (extract) polymers can be studied.
Recent development of INOTEX, which has a range of tailor made enzymatic products specially developed for improved biocatlytic processing of bast fibres (flax, hemp), signalises that it is possible to minimize influence of climate changes using biocatalyst to bring retting procedure under the control. This process should be started in the harvest stage as well as „under the roof“during the processing stage. High yield, waste-less use of natural fibres, and customisation of fibre properties – elementarisation, cottonisation, length and fineness variability, surface compatibility with resins, can be positively influenced. Additional mechanical processing techniques have been studied.

Figure 10: Dew – retting of flax (hemp, linseed stems) versus Texazym DLG – bio-retting

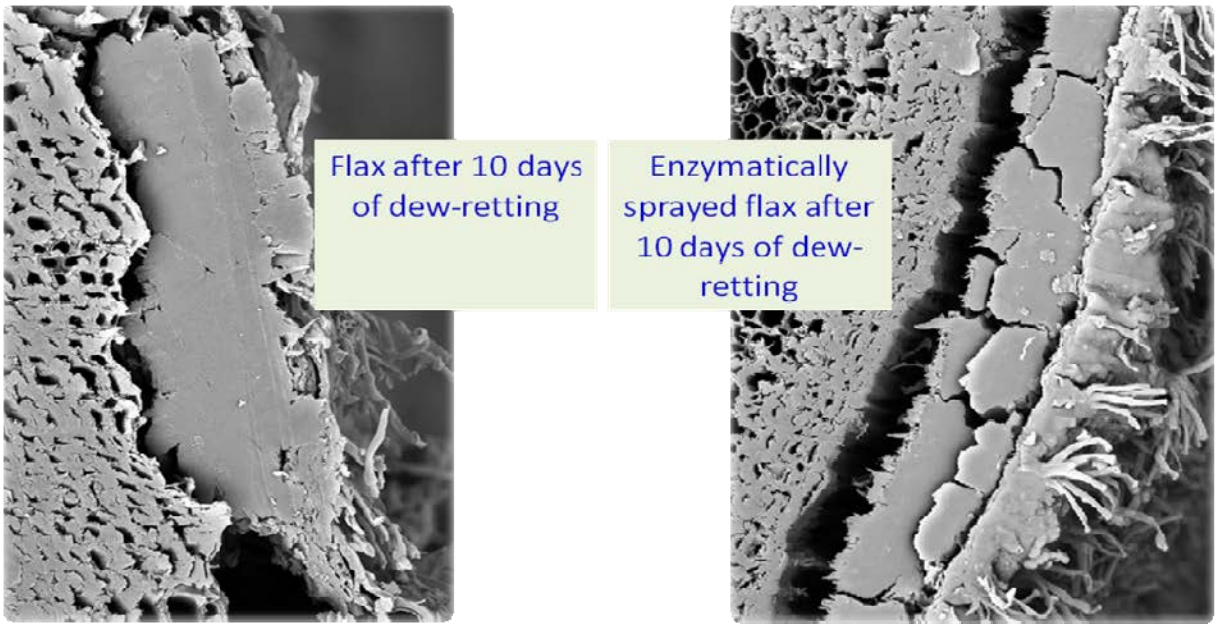


Figure 11: Natural renewable bast fibre tratment by use of enzymes
Demonstration of the enzyme impact on the flax fibre surface

Composites as a specific area of new material development broadly open space for biotechnologies. **Biocomposites** as a fully biodegradable or recyclable new materials play a significant role within the sustainable development of our planet. In this case not only fibre reinforcement but also resins and other additives will be made by use of natural sources.

It is known, that many of bio- based materials have **bioactivity** which is an essential element of **health and body care**. Smart surfaces and matrice will overtake a visible role in the whole textile branch orientation – on the way from volumes to special – high-added value products. We need to learn more about biomedical properties of biopolymers. However, this new, long-lasting activity will bear a totally new positron of textile based substrates in wound dressing, surgery, transplantation of scaffolds etc.
Textile substrate will surely find its position as an important **host of immobilised biomaterials** – enzymes, bio-active polymers etc. In the common macro-, micro- as well as in coming nano-dimension.
Surface coating as a specific tool of biofunctionalization of existing (limited range of European origin) synthetic and natural fibre substrates will speed the maturity time of new, customised functionalities (bringing new material qualities e.g. moisture management and thermo-regulation, breathability, stain removal-self cleaning, wellness and health care etc.) –comprised of recombinant protein, silk-wool protein based systems.

2.3. Environment friendly processing based on biotechnology

It seems to be evident that most of mentioned biotechnologies using **enzymes** as a low volume dose of catalyst against harsh chemical processes, working by low temperature conditions pass requirements of **cleaner production systems**.
Exchange of chemicals with biocatalysis and utilization of biomaterials made by biofermentations will make the consequent eco-labelling and eco-design processes easier.

Textile **waste water biotreatment,** decolourisation in particular, seems to make large space for biotreatments. Existing theoretical skills and model experience need to be engineered into the industrial scale.

Last but not least, **textile wastes** could be studied as one of large volume **waste feedstock for biorefinery – biofuel program**. Synthetic part of blends will be recycled separately (where just the natural, namely cellulosic part will be utilized as fermentation feedstock).

3. Conclusions

In this presentation, real bio-based tools ready for their immediate use within the textile (wet) processings have been presented. Faced with fierce problems of global environment, energy and raw material situation, new enzymatic processes will gather more and more positive arguments. It is evident that cleaner production based on biocatalysts is here to simplify the technology, to bring new parameters and to sustain the textile manufacturing sector which was one of the pioneers of biotechnology industrial scale use.
However, new bio-based materials will dramatically extend the range of innovative substrates, functional treatments and functional materials made by use of textile technologies. Thinking about biotechnologies we also support the ultimate need to „go green“ as an imperative of textile manufacturing branch sustainability since it needs to pay attention to REACH and IPPC implementation as essentials of coming days. In this context - biotechnologies have been judged as part of emerging techniques.
No fear to follow new ways of textile biotechnology!