PROJECT FINAL REPORT

Final Publishable Summary Report

Grant Agreement number: 207810

Project acronym: FlexPakRenew

Project title: Design and development of an innovative ecoefficient low-substrate flexible paper packaging from renewable resources to replace petroleum based barrier films

Funding Scheme: NMP3-SL-2008-207810

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Name of the scientific representative of the project's co-ordinator: David Guérin
Title and Organisation: Manager, Centre Technique du Papier
Tel: +33 (0)476 154 015
Fax: +33 (0)476 154 016
E-mail: david.guerin@webCTP.com
Project website address: www.flexpakrenew.eu

1. - Executive summary

The objective of FlexPakRenew was to develop innovative flexible functional packaging solutions, using renewable resources to replace petroleum-derived barrier films. The project focused on recyclable, biodegradable products, environmentally friendly processes and was limited to the delivery of paper based multilayer barrier material for flexible packaging.

This project combined (i) upscaling of technologies/materials that were already proven at laboratory scale and (ii) the development of new materials/new technologies. All the developments were done with a special attention paid to product life cycle and thorough sustainability assessment to prove environmental economic and social performance and potential for up-scaling from laboratory scale to pilot scale.

Upscaling of proven technologies

The core of this project was to develop a medium barrier material, applicable on paper, based on water borne coatings made from a plasticized starch matrix reinforced with pigments. Starches were combined with several candidate bentonites and plasticizers in order to optimise the bentonite dispersion and material interactions to maximise the barrier properties while getting some coating flexibility. Considerable effort has been invested in optimizing the colour rheology to match the paper coating process requirements. During the project, the solids of the colour was raised from 10 to 20% while water vapour transmission rate was cut by 3.

A breakthrough green chemistry process, named chromatogeny, that brings hydrophobicity to papers and boards, was developed at pilot scale. For the first time ever, it was proven that the combination of a reactive coating with chromatogeny could work at pilot scale on a reel to reel process to produce materials having a perfect water repellence and very low water vapour transmission rate.

New materials/new technologies

During the project, it was proven that paper for flexible packaging has to be designed to receive barrier coating. Very important properties, such as roughness of the substrate and air permeability, could be tuned thanks to the addition of MicroFibrillated Cellulose (MFC) at the wet end of a paper machine thanks to spray or curtain coating technology.

A great deal of work was dedicated to finding alternatives to starch, nanoclays and synthetic plasticizers in medium barrier coating. It was demonstrated that the use of derived hemicelluloses, i.e. xylan from birch, could be a very good matrix combining the advantages of a good barrier material, hydrophobic, heat sealable and being biosourced, not in competition with food industry. It was also demonstrated that starch nanoparticles, produced from starch granules could offer an organic, biodegradable pigment that could replace nanoclays. Microencapsulation of biosourced oils into biopolymers also showed a plasticizing effect on starch based layers and could offer an alternative to oil-based plasticizers.

Vacuum coating is a proven technology used to magnify the barrier properties of plastic films. For the first time, it was shown that this very demanding process in terms of substrate properties (stable when exposed to vacuum cycles and roughness preferably lower than 50nm) could be adapted to a coated paper to deposit an inorganic layer and magnify the barrier properties.

Successful research was undertaken to develop antimicrobial coatings that facilitate a prolonged shelf life for packed food products with releasing less quantities of preservatives on the food surface. In this way, the amount of directly added preservative to the food and thus the consumer´s exposure to preservatives can be reduced. Both the use of preservatives in the bulk of a starch layer or embedded in capsules were assessed to modulate the preservative delivery.

In the end, FlexPakRenew demonstrated at pilot scale that a set of technologies can be combined to produce performing paper based packaging materials with a demonstrated environmental gain. Some steps have however still to be climbed to get the cost performance and come to industrial production scale.

2. - Trends in packaging and barrier materials

2.1. - Introduction

The main functions of packaging are to **contain** (goods, food…), to **protect** (products from environment or environment from products), to **inform** (legal information, product information), to **trade** (sales, differentiation, competitive advantage) and to **express**, vehicle, communicate the brand values, what is inside.

3 classes of packing are commonly identified according to its uses: primary packaging, secondary packaging and tertiary packaging.

The **primary packaging** is in direct contact with the goods, has for main function to protect, inform, market, express and the adequacy product/packaging is of prime importance.

The **secondary packaging** has for main functions to pack primary packaging altogether and protect. The packaging weight, the lighter, the better, is of prime importance.

The **tertiary packaging** has for main functions to transport packaging and to protect. The cost/performance and possibility to reuse are of prime importance.

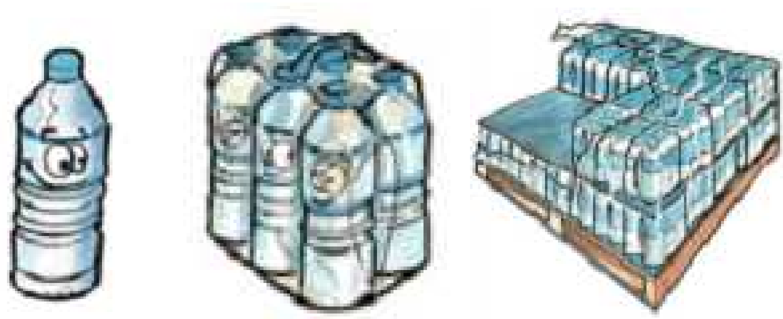

Figure 1 : Scheme of primary packaging (left).

The share of materials used for the primary and secondary packaging in Europe are reported in Figure 2. If paper still dominates plastics, it is linked to the voluminous use of corrugated board for container boxes. The general trend is a decrease of papers and boards shares at the expense of plastics.

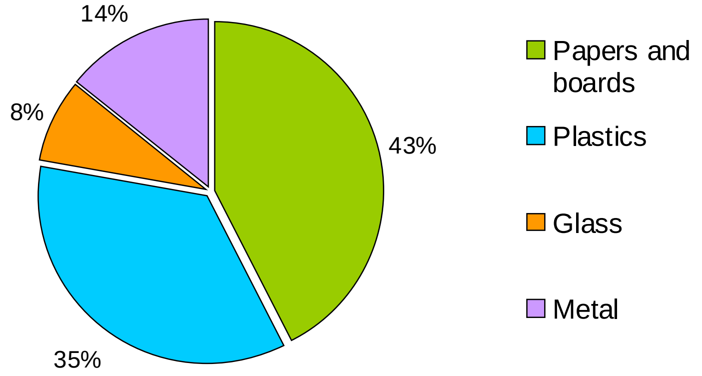

Figure 2 : European packaging material breakdown. Primary and Secondary packaging. [Source : http://www.global-packaging-alliance.com]

2.2. - Paper based packaging value chain

Packaging value chain is a complex chain involving many players. In case of paper based packaging value chain, Figure 3, five main players are active : material producers, users, brand owners, consumers and authorities. Each of these players have their own expectations in terms of environment, logistics, product protection, health, usability and economy which makes the developments of new materials very complex since it must address the requirements and expectations of all these players.

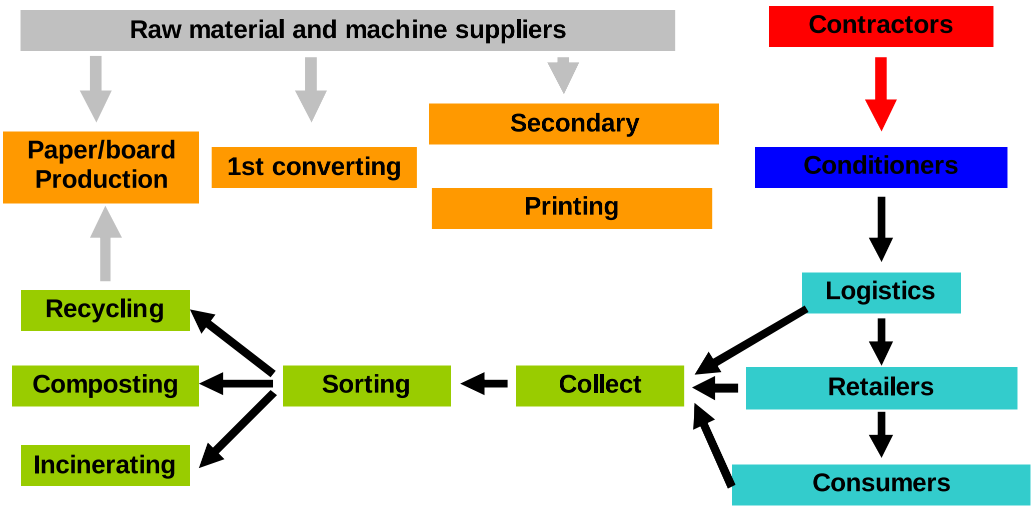

Figure 3 : Paper based packaging value chain. [Guerin, 2011]

Packaging have many advantages: they participate to the goods/food loss reduction, they protect health and increase safety of consumers, they permit to optimise the use of resource and they make life easier, inform, communicate, educate. However, generally 3 main drawbacks are identified: (i) their manufacture uses raw material, energy, (ii) they are generally difficult to reuse, to recycle and they generate voluminous wastes, (iii) they are seen as expensive or even useless by consumers.

Packaging can be seen as a paradox on several aspects since:

- Packaging are made to prolong shelf life… but are expected to vanish after use.
- Consumer would like less… but the social changes made them always more numerous.
- They are highly technical products… that are purchased only for what they look like.
- Developed countries are looking for packaging reductions… while developing countries are eagerly looking for them.

So developments of new materials for packaging are difficult for several reasons:

- The players involved in the development of materials (material suppliers) are several steps upstream from the market players (brand owners, authorities and consumers) in the value chain,
- The intermediary players (converters, printers) are generally small and medium size companies not used to R&D,
- The technical targets (barrier properties) are somehow contradictory to end of life (easy to recycle, to biodegrade…).

2.3. - Packaging materials and technological trends

2.3.1. - Trends, all packaging materials

The packaging materials are developed according to the needs of the main packaging players. Whatever the packaging materials, some global trends can be observed : (i) the developments of always lighter packaging to participate to the objective of the reduction of cost, (material cost, transportation cost, reduction of the use of resources) that shifts some packaging from rigid to flexible ; (ii) the wish to improve packaging end of life, the “green” marketing effect that pushes the emergence of biosourced monomers or biosourced materials such as biosourced PE, but also PLA, PHA, TPS, (iii) the use of LCA to accompany the developments (the material selection is based on their recyclability, compostability, biodegradability, impact on environment) and (iv) the development to increase production speeds (material strength, heat sealability…).

2.3.2. - Biosourced polymers

According to a report [Shen, 2009] issued in 2009 by EPNOE (European Polysaccharide network of Excellence) and data from papermaking industry, paper remains the first biomaterial with a world production of 390Mt/y (2010) far away ahead of plastics (245Mt/year - 2010) and bioplastics (0.72Mt/year – 2010 i.e. 0.29%). Trends in bioplastics encompass both the developments of new chemistries either to get new materials (ex PHA) or to get biosourced materials (ex : biosourced PE). Today, only 4% of crude oil is used for plastics, so the forecast oil shortage will in the next 50 years affect much more the cost of petroleum based plastics than its delivery and real stakes are on fuel and energy. In addition some plastics are made from gas (PP for example) and the chemistry is already ready for “biosourcing” most of the plastics (PE, PET, PVC, PBS, PA, PUR). So the stakes are only on cost and not really on technologies to replace petroleum based plastics by biosourced monomers. Two major issues can be pointed out :

- The synthesis of biosourced monomers of the related polymers generally consumes a lot of energy. Since in most of the countries energy mix is related to oil, then it is not expected that the cost of biosourced monomers will be lower than the cost of oil based monomers in the coming years since it will take time to change the energy mix.

- If "biosourcing" the polymers (PE for example) is of interest for converters who don't want to modify their manufacturing chains, the end of life of the polymers is not affected and biosourced PE is not more biodegradable than petroleum based one.

So it is of particular interest to find polymers directly extracted from the biomass and that requires a low amount of energy for their extraction and refining. It would also be better to use polymers that are not competing with the food industry to avoid any competition between mankind feeding and materials. Polymers that could be used for the biofuel generation should be avoided since this would probably put pressure on the material cost in the future if materials are competing with fuels.

2.3.3. - Packaging end of life

All consumer perception analyses are reporting an increased level of attention paid by consumers to the packaging waste (Figure 4).

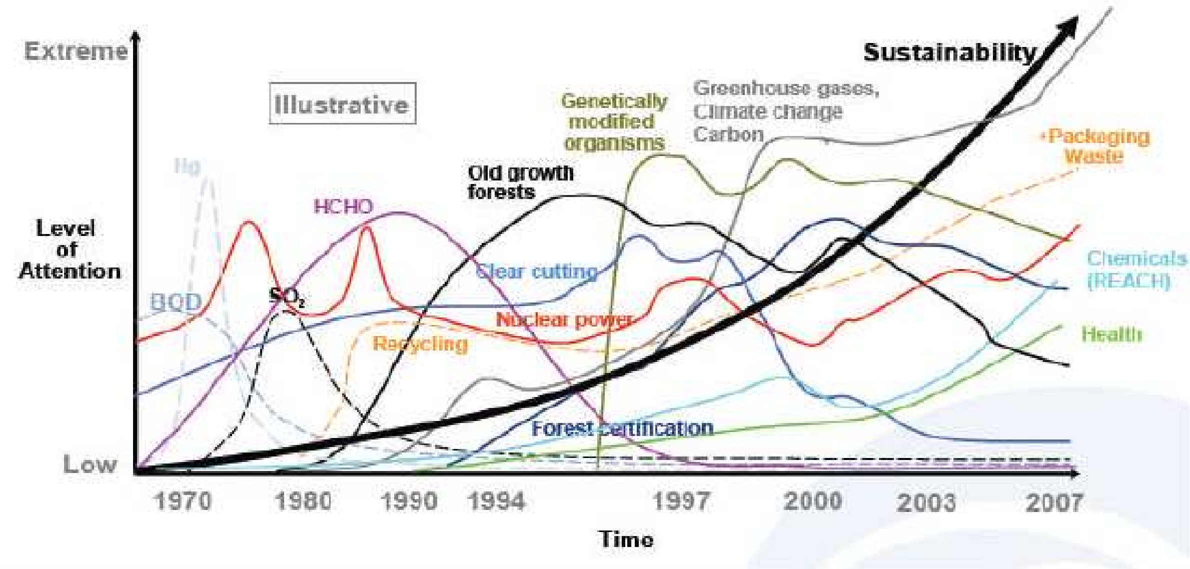

Figure 4 : consumer perception of sustainable concerns. [Clark, 2008]

The comparison of the end of life of paper and plastics of 4 major European countries showed very different situations depending on the material and country.

Table 1 : Plastic packaging waste and the end-of-life treatment in selected EU countries in 2007. [Eurostat 2009]

Largest consumers	Plastic packaging waste	Recycling		Incineration		Landfill	
	[Mt/a]	[%]	[Mt/a]	[%]	[Mt/a]	[%]	[Mt/a]
Germany	2,6	*43 %*	1,1	*52 %*	1,4	*5 %*	0,1
Italy	2,2	*28 %*	0,6	*30 %*	0,7	*42 %*	0,9
France	2,1	*21 %*	0,4	*32 %*	0,7	*47 %*	1,0
United Kingdom	2,1	*22 %*	0,5	*9 %*	0,2	*69 %*	1,4
Total	**9**	**29 %**	**2,6**	**32 %**	**2,9**	**39 %**	**3,5**

Table 2 : Paper and cardboard packaging waste and the end-of-life treatment in selected EU countries in 2007. [Eurostat 2009]

Largest consumers	Paper& cardboard packaging waste	Recycling		Incineration		Landfill	
	[Mt/a]	[%]	[Mt/a]	[%]	[Mt/a]	[%]	[Mt/a]
Germany	7,1	*80 %*	5,7	*18 %*	1,3	*2 %*	0,1
Italy	4,6	*70 %*	3,2	*8 %*	0,4	*22 %*	1,0
France	4,5	*89 %*	4,0	*8 %*	0,4	*3 %*	0,1
United Kingdom	3,8	*79 %*	3,0	*8 %*	0,3	*13 %*	0,5
Total	**20**	**80 %**	**15,9**	**12 %**	**2,3**	**9 %**	**1,8**

Table 1and Table 2 showed that the recycling is very well organised for papers and boards. So it is of interest to develop new packaging materials on paper substrate with the challenge for the new materials to be easily integrated in the existing sorting and recycling loop.

The comparison of barrier properties (permeability) against water vapour and oxygen at 23°C for a given thickness (100 µm) of film are given on Figure 5. This graph underlines that each material has intrinsic barrier properties. An untreated paper based material is very porous and doesn't offer any barrier properties and would be out of the chart. The data given for cellulose are valid for highly transformed cellulosic material which is not paper.

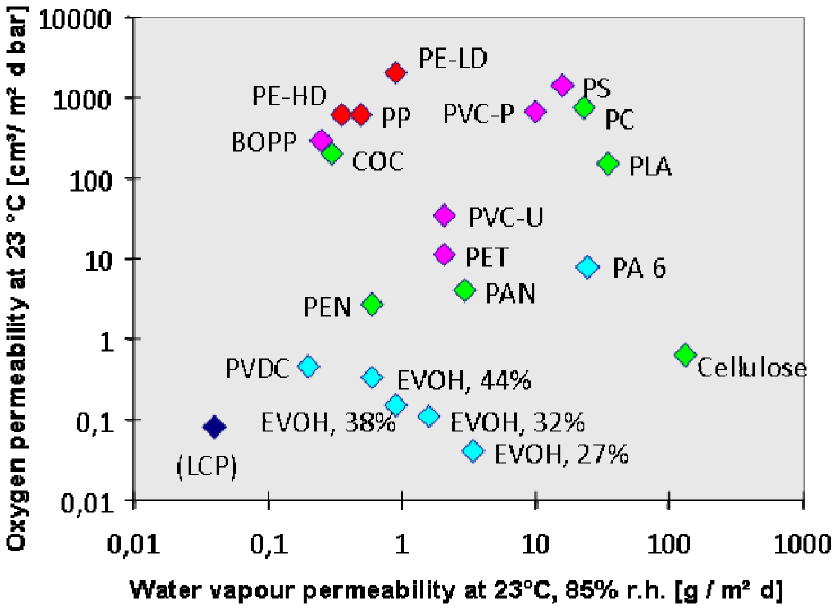

Figure 5 : Barrier properties of several materials. [Noller, 2011]

So, if it appeared of interest to develop a paper based packaging material, the first priority would be to get relevant barrier properties. It is however difficult to give ideal target barrier level since the packaging requirements are related to the packed products as illustrated on

.

Table 3 : Maximum amount of gain or loss of oxygen and water for some selected foods. [Robertson,1993]

	Max O2 gain (ppm)	Max water gain or loss (%)
Beer/wine	1-5	3 (loss)
Baby food	1-5	3 (loss)
Dried food	5-15	1 (gain)
Fruit juice	10-40	3 (loss)
Instant coffee	1-5	2 (gain)

2.3.4. - Market for functional packaging/paper based packaging

Analysis of the global market for functional and barrier coatings by geographical region as reported by Pira in its 2009 Market report "The future of functional and barrier paper and board packaging" clearly demonstrated that Europe holds the leading place in the world for functional of barrier coatings applied on paper and boards.

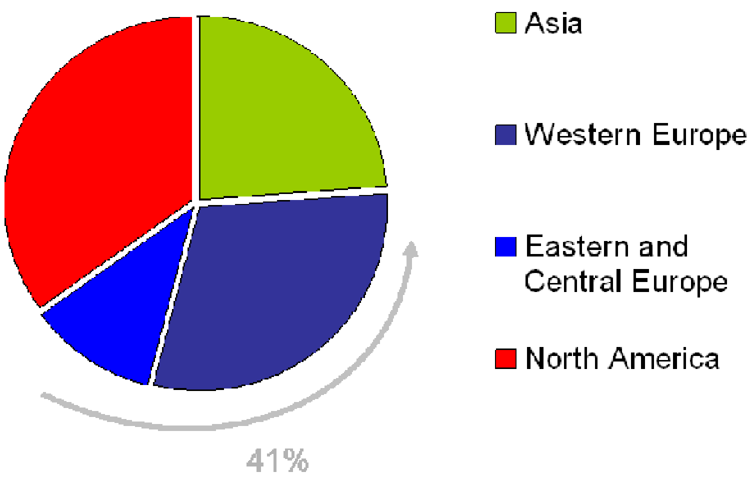

Figure 6 : Market for functional and barrier coatings by geographical region. [Pira 2009]

2.4. - Conclusions

Europe is a leading area in functional packaging and if paper has major assets (biosourcing, not competing with food industry, recyclability, biodegradability) to be one of the packaging material of the future, some developments have still to be done to really compete with plastic materials while giving a lower environmental footprint. These developments must focus first on the development of barrier properties without major impact on paper recycling.

2.5. - Literature cited

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[Pira 2009] : Pira Market report "The future of functional and barrier paper and board packaging", 2009.

3. - FlexPakRenew project summary

3.1. - General objectives of FlexPakRenew

The objective of this project was to design and develop an **innovative ecoefficient low-substrate flexible paper for packaging from renewable resources** to reduce the packaging industry's reliance on barrier films derived from petroleum.

According to market researcher PCI Films Consulting, "*Europe is currently the world's most sophisticated flexible-packaging region. And despite being the second smallest continent by area, Europe is one of the world's largest flexible-packaging markets, accounting for around one-quarter of global sales in 2010, at just over €12.3 billion (converted & unconverted materials)*".

The technical challenge in this project was to develop a **flexible paper, based on multilayered structure** with a total grammage between 50 and 90 g/m², that achieves **barrier properties** competitive with those of untreated plastic films (medium barrier) or to treated plastic films (high barrier). The definition of barrier properties in the current context encompasses grease, water, oxygen, water vapour and aroma barrier. The novel **functional** flexible packaging was developed using renewable materials and **latest developments in nanotechnology**, beyond state-of-the-art barrier coatings and innovative surface treatment processes.

Special attention was paid to sustainability assessment and life cycle analysis throughout the project, namely regarding **ecoefficient material processing**, optimised recycling ability and **biodegradability**. A substantial reduction in the amount of packaging going to landfill was expected, together with considerably faster environmental degradation of the new packaging materials. The development of the new packaging products for a global market should make a significant contribution towards the **reduction of the dependency** of the packaging sector on **petroleum resources** and the **reduction of greenhouse gas emissions**. The project was made to strengthen the position of **Europe** as a **lead market** in the area of packaging.

The developments made in FlexPakRenew are really matching current material global trends since they focus on light materials (between 50 and 90g/m²) ; associate paper and other biosourced polymers to develop medium barrier ; use eco-processes to develop high barrier with nanotechnologies ; develop active functionality in addition to the barrier ; include both the ease to up scale results to industrial scale and the material end of life.

3.2. - Cargill policy regarding nanotechnology

Cargill was involved in FlexPakRenew. However, all Cargill's activities in the project were following Cargill's policy related to nanotechnology.

"Cargill believes there are still many gaps in understanding nanotechnology, including the potential risks on health and the environment. While we support more detailed research, we will not incorporate or market intentionally engineered nano-materials into our products until there is a better understanding of all the potential impacts. We recognize the research objectives of FlexPakRenew are focusing on non-food applications and the research is still in the initial stages. However, we urge the participating research institutions, undertaking nanotech research within the framework of FlexPakRenew, to undertake a clear environmental, health and safety impact assessment of the activities and put in place appropriate measures to address any specific and potential issues."

All the other partners of FlexPakRenew are aware of potential risks associated to nanotechnologies and took necessary measures.

3.3. - Technical objectives and project limitations

3.3.1. - Technical objective

The objective of this project was to develop innovative flexible functional packaging solutions, using renewable resources to replace petroleum-derived barrier films. The technical target was to replace paper/polymer/foil barrier packaging with a multilayer material using renewable resources that had a Water Vapour Transmission Rate (WVTR) lower than 0.3 $g.m^{-2}\ day^{-1}$ at 23°C and 50% relative humidity and an Oxygen Transmission Rate (OTR) lower than 10 $cm^3.m^{-2}.day^{-1}.bar^{-1}$. The technical objective was defined according to paper usual conditioning (23°C-50% RH for WVTR and 23°C-0% RH f or OTR) ; an estimate of this objective under plastic usual conditioning (23°C-85 % RH for WVTR and 23°C-50% RH for OTR) is given on Figure 7.

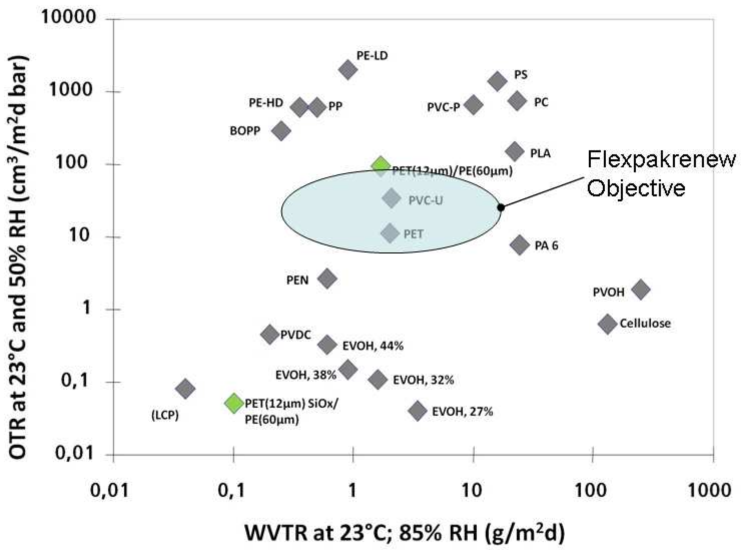

Figure 7: Barrier target of the project compared to common packaging polymers.

The project focused on the design and development of different low-weight (50 to 90 g/m²) multilayered flexible packaging products (Figure 8) with specific functional barrier properties, using selected approaches. If the applications selected do not require the complete combination of novel approaches, only those innovations required to provide the appropriate barrier level for a particular application would be utilised.

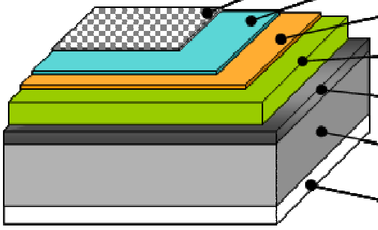

Figure 8 : Expected design of FlexPakRenew final product.

The flexible packaging to be developed within this project had to be almost entirely recyclable (> 95%) and biodegradable and use only environmentally friendly processes.

Moreover, results arising from this project were expected to be readily transferable to other packaging grades (such as folding box board, corrugated board, liquid packaging board, etc.) with additional impacts in other application fields such as biomedical and healthcare, banknotes and security documents, or as building materials.

3.3.2. - Project limitations

Due to its size, the project was limited to the development of innovative raw materials for packaging in reels and was not expected to go up to the production of bags or pouches. However, even if it was not deeply studied in the project, the partners were aware of the importance of the following points for the development of a solution for the packaging market:

- Compliance with direct food contact legislation,
- A high level of barrier (water, oil and grease, oxygen, water vapour, aroma),
- An antimicrobial action to prolong the shelf-life of products, mainly food,
- Easily processable at any stage of the life cycle of the packaging,
- Repulpable, recyclable and biodegradable,
- Compatible with standard papermaking and converting equipment,
- Free of odour and taste.

This project was expected to lead to materials that are almost ready to go into production, so the following policy was approved and followed by all the partners involved in this project :

- the raw materials from renewable resources should be available in sufficiently large quantities that their use in papermaking can be readily envisaged.
- the raw materials produced during the project should be available in sufficiently large quantities that pilot trials can be undertaken during the project.

This project combined upscaling of technologies/materials that were already proven at laboratory scale in former projects (Sub Project 4 of Sustainpack, a FP6 Integrated Project) and the development, limited at laboratory scale, of new materials/new technologies. All the developments were done with a special attention paid to product life cycle and potential for up-scaling from laboratory scale to pilot scale.

3.3.3. - Main Objectives - Scientific Advances - Progress beyond the state-of-the-art

The main expected scientific advances in the project dealt with :

- Improvement of paper substrate
- Development of bio-based coatings reinforced with nanoparticles to obtain medium barrier
- Development of nanocoatings to improve barrier performances
- Development of anti-microbial coatings to prolong shelf life of food products

In addition to the scientific advances, the project had also to fulfil two objectives to guarantee the potential up scaling and environmental benefit of the scientific advances. This was ensured thanks to :

- A Focus on up scaling the technology from laboratory to pilot scale
- Routine LCA on the proposed solutions.

To reach the objectives and guarantee the good project progress, the 10 partners organised the project as shown on the following PERT chart.

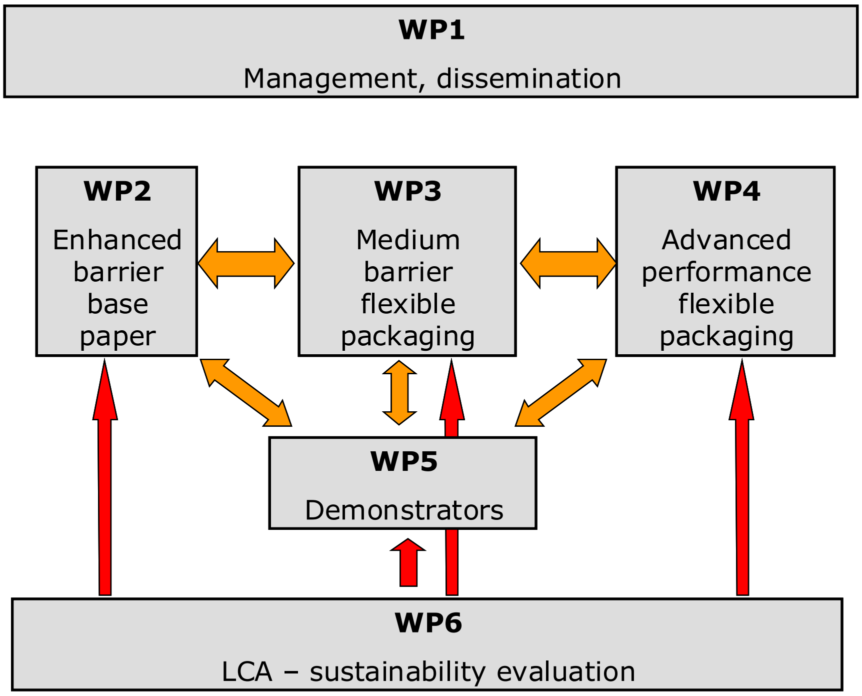

Figure 9 : Project PERT chart.

This flexible packaging paper had to be developed using renewable materials in combination with innovative surface treatment processes.

The development targets in the project focused on the improvement of paper based substrate (WP2), on the development of water borne coatings to produce medium barrier materials (WP3) and on the development of innovative coating methods and antimicrobial functionality to develop advanced performance packaging (WP4). All these developments were driven by a combination of technological feasibility at large scale (WP5) and Life Cycle Analysis (WP6) to guarantee the up-scaling of both the research and the environmental benefit.

3.3.3.1. - Improvement of paper substrate

The objective of this part was to develop a substrate with substantially improved barrier properties in comparison with standard base papers that can be produced with current technology platforms. The substrate was expected to contribute to the barrier properties of the final product as much as the barrier coating. It has to be prepared to accept a barrier coating and should help compensate the loss of barrier if the coating is damaged (crack at folds when converting the packaging). Two main research actions contributed to the achievement of the objective:

- Mechanical and barrier properties - Use of curtain/spray coating technologies and biosourced products at the papermachine wet end to promote barrier properties.
- Self healing properties - Use of microcapsules to release barrier products.

5 partners were particularly involved in this part.

3.3.3.2. - Bio-based coatings reinforced with nanoparticles to obtain medium barrier

One major objective of FlexPakRenew was the development of water borne coatings offering a medium barrier paper.
Coatings should principally be based on renewable resources, with minimal incorporation of natural fillers and other functional additives to enhance the barrier properties with respect to water, water vapour, grease and oxygen.

The coatings had to be made from renewable materials (starches, functionalised starches, starch derivatives or modified hemicelluloses) and should be reinforced by (low eco-footprint) minerals or renewable nanoparticles (starch) and additives (biopolymers) either alone or in combination to optimise the desired properties. So, if the research focused primarily on materials and procedures that actually have the potential for use in industrial scale production, new and innovative materials and approaches that have longer term applications have also been studied. An important consequence of this focus on the industrial scale meant that the processability of the materials, including for example the viscosity of coating formulations, had to receive due consideration.

By using identical base substrates for the application of biopolymers and by the use of specified testing methods, the comparison of the effects on various materials has been facilitated, as was the exchange of experiences and collaboration between project partners. 6 partners were particularly involved in this part.

3.3.3.3. - Development of nanocoatings to improve barrier performances

One objective of the project was the development of high barrier flexible paper arising from innovative surface treatments.
Two significant challenges needed to be overcome to enable successful implementation of paper based barrier packaging:

- The coatings derived from biopolymers are generally hydrophilic, thus have no water vapour barrier, and loose their barrier properties when exposed to water or high moisture atmospheres.
- Their oxygen barrier level was still two orders of magnitude lower than those of high barrier plastic films.

The developments were based on the medium barrier paper developed in the former part and the use of two innovative surface treatments, namely solvent free chemical grafting (chromatogeny) and vacuum coating that had to be developed to overcome these drawbacks and facilitate the production of a high barrier flexible paper, especially necessary with regard to products with long shelf life. 4 partners were particularly involved in this part.

3.3.3.4. - Development of anti-microbial coatings to prolong shelf life of food products

Another objective of the project dealt with development of an antimicrobial coating, that would be transferred to paper based barrier packaging and biopolymer based coatings respectively. The overall aim of antimicrobial coating is to prolong the shelf life of the product while simultaneously exposing the consumer to only a minimum quantity of preservatives.

This objective was based on:

- The development of coating formulations containing preservatives like benzoic acid or sorbic acid (first choice as they are active against a large variety of micro-organisms and are already approved to be used for food protection in Europe)
- The evaluation of two concepts of controlled release via nano-polyelectrolyte complexes or microcapsule

3 partners were particularly involved in this part.

3.3.3.5. - Development of demonstrators

One major objective of FlexPakRenew was to ensure the up-scaling of the proposed solutions. Thus a particular attention was paid to the production of prototypes of flexible packaging using the breakthrough results developed in the project. The prototype production was also used to ensure the compliance with the economic and environmental targets of the project.

6 partners were particularly involved in this task, but all the partners participated thanks to their expertise to the trials.

3.3.3.6. - LCA

Particular attention has been paid to sustainability assessment and life cycle analysis throughout the project in order to verify and quantify the significant reduction in oil-based packaging going to landfill and the rapid degradation of the waste material.

The two major objectives of this part were:

- To lead the development towards environmentally friendly renewable materials in flexible packaging paper
- To communicate the sustainability of renewable flexible packaging paper

One partner (VTT) was particularly involved in the LCA based on the data delivered by all the project partners.

3.3.4. - Conclusion

FlexPakRenew was an European collaborative, small and medium scale focused research European project ; funded under FP7 (Seventh FrameWork Programme) in the research area: NMP-2007-2.4-3 Renewable materials for functional packaging applications.

The objective of FlexPakRenew (www.flexpakrenew.eu) was to develop innovative flexible functional packaging solutions, using renewable resources to replace petroleum-derived barrier films. The project focused on recyclable, biodegradable products, environmentally friendly processes and was limited to the delivery of paper based multilayer barrier material for flexible packaging.

This project combined up-scaling of technologies/materials that were already proven at laboratory scale in former projects and the development, limited at laboratory scale, of new materials/new technologies. All the developments were done with a special attention paid to product life cycle and thorough sustainability assessment to prove environmental economic and social performance and potential for up scaling from laboratory scale to pilot scale.

4. - Main S&T results and foreground

4.1. - Project objective and structure

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The project focused on the design and development of different low-weight (50 to 90 g/m²) multilayered flexible packaging products with specific functional barrier properties, using selected approaches.

If the applications selected would not require the complete combination of novel approaches and in these cases only those innovations required to provide the appropriate barrier level for a particular application would be utilised.

The flexible packaging to be developed within this project had to be almost entirely recyclable (> 95%) and biodegradable and had to use only environmentally friendly processes.

To reach this objective, the 10 partners organised the project as shown on the following PERT chart.

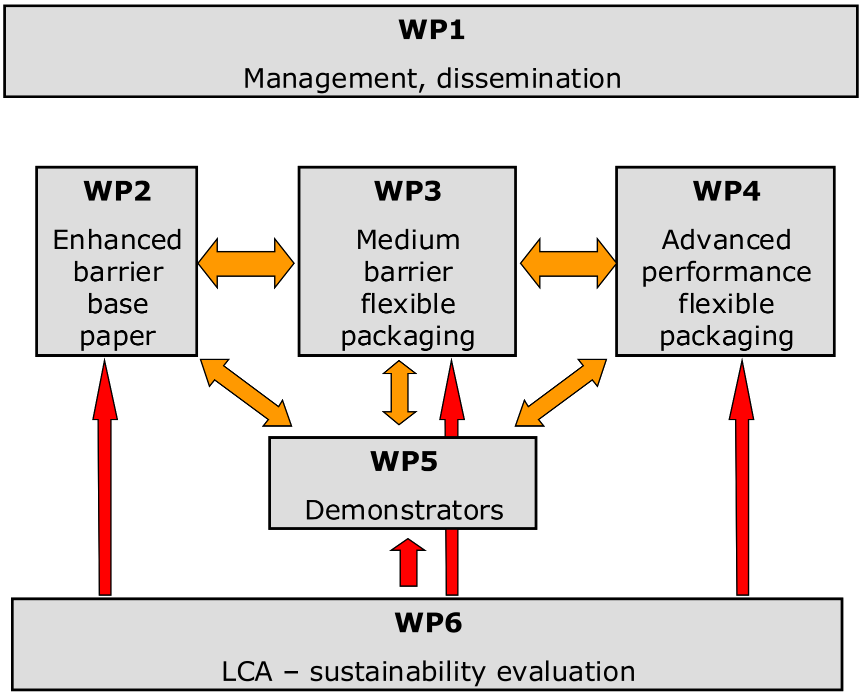


Figure 10 : Project PERT chart.

This flexible packaging paper was developed using renewable materials in combination with innovative surface treatment processes.

The development targets in the project focused on the improvement of paper based substrate (WP2), on the development of water borne coatings to produce medium barrier materials (WP3) and on the development of innovative coating methods and antimicrobial functionality to develop advanced performance packaging (WP4). All these developments are driven by a combination of technological feasibility at large scale (WP5) and Life Cycle Analysis (WP6) to guarantee the up-scaling of both the research and the environmental benefit. The expected design of the final product is described in Figure 11.

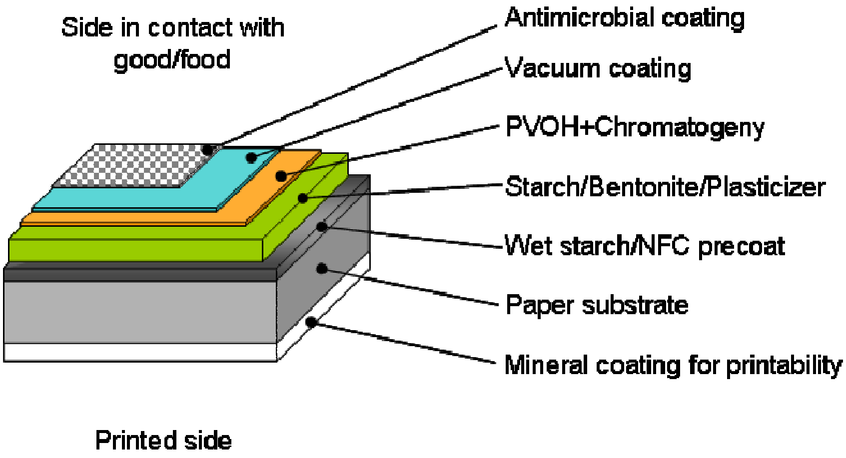


Figure 11 : Expected design of FlexPakRenew final product.

4.2. - Improvement of the paper substrate

The objective of this workpackage was to develop a substrate with substantially improved barrier properties in comparison with standard base papers that can be produced with current technology platforms. The substrate was expected to contribute to the barrier properties of the final product as much as the barrier coating. It had to be prepared to accept a barrier coating (task 2.2) and help compensate the loss of barrier if the coating is damaged (crack at folds when converting the packaging - task 2.1).

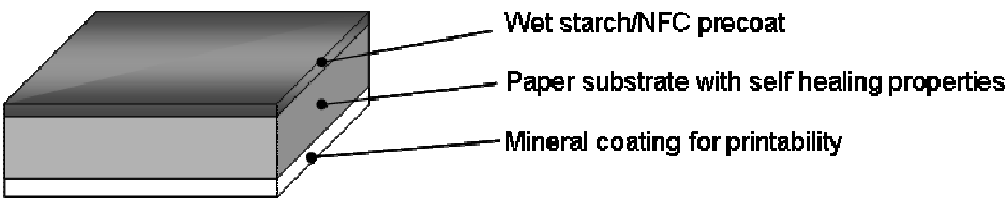
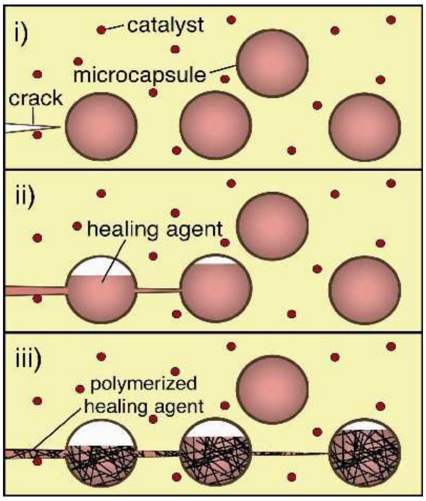
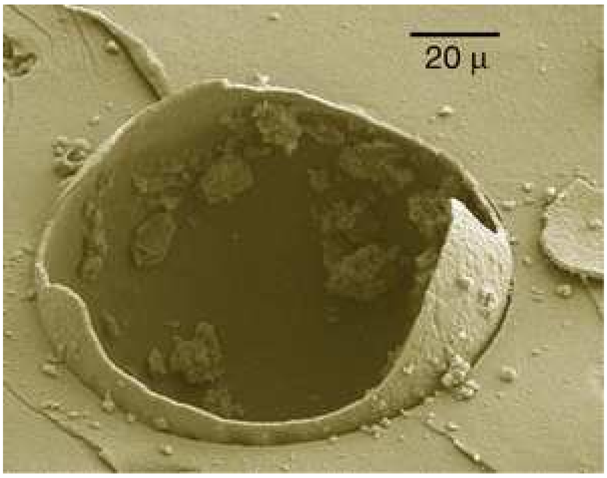


Figure 12 : Expected design of an improved paper substrate before barrier coating based on FlexPakRenew concept.

4.2.1. - Use of self healing concept in papermaking

The first objective -task 2.1, Improved barrier properties of bulk paper- was to develop a novel composite bulk paper material with improved barrier properties that also offers an additional self-healing feature. Self-healing means in this context that the material has the ability to alleviate a severe reduction in barrier properties if the barrier coating is damaged. The desired properties are achieved by introducing microcapsules into the sheet. The microcapsules consist of a hydrophobic core and an outer hydrogel biopolymeric membrane.





Right : A microencapsulated healing agent is embedded in a structural composite matrix containing a catalyst capable of polymerizing the healing agent.

(i) Cracks form in the matrix wherever damage occurs.

(ii) The crack ruptures the microcapsules, releasing the healing agent into the crack plane through capillary action.

(iii) The healing agent contacts the catalyst, triggering polymerization that bonds the crack faces closed.

Left : Scanning electron microscope image of a ruptured microcapsule

Figure 13 : Self Healing principle. According to White SR, Sottos NR, Geubelle PH, Moore JS, Kessler MR, Sriram, SR, Brown EN, Viswanathan S. Autonomic healing of polymer composites. Nature 2001;409:794–7.

The self healing concept in the project was simpler since it uses “non reactive” microcapsules that were carriers of selected hydrophobic compounds, including vegetable oils or waxes. When the paper undergoes mechanical stress, like pressure, heat or shear, the microcapsules break and, because of the hydrophobic character of the core material, the paper maintains barrier properties.

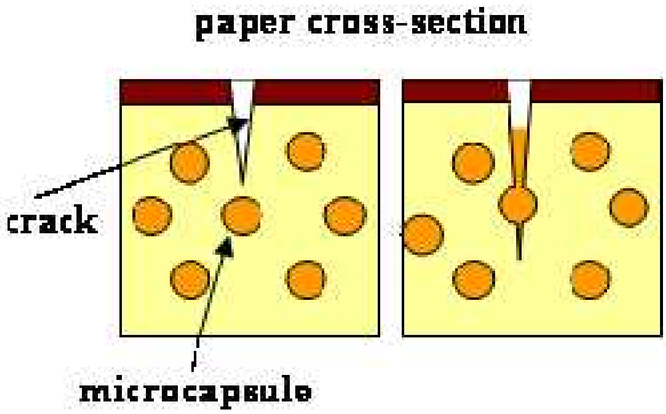


Figure 14 : Self healing concept applied in FlexPakRenew. Source A. Bartkowiak, West Pomeranian University of Technology.

During the first 18 months of activity within the project, it has been shown that it is possible to manufacture capsules to confer self-healing properties to the base paper. The best materials to manufacture stable capsules and to bring barrier properties without damaging the visual aspect of the paper (no transparency) were selected.

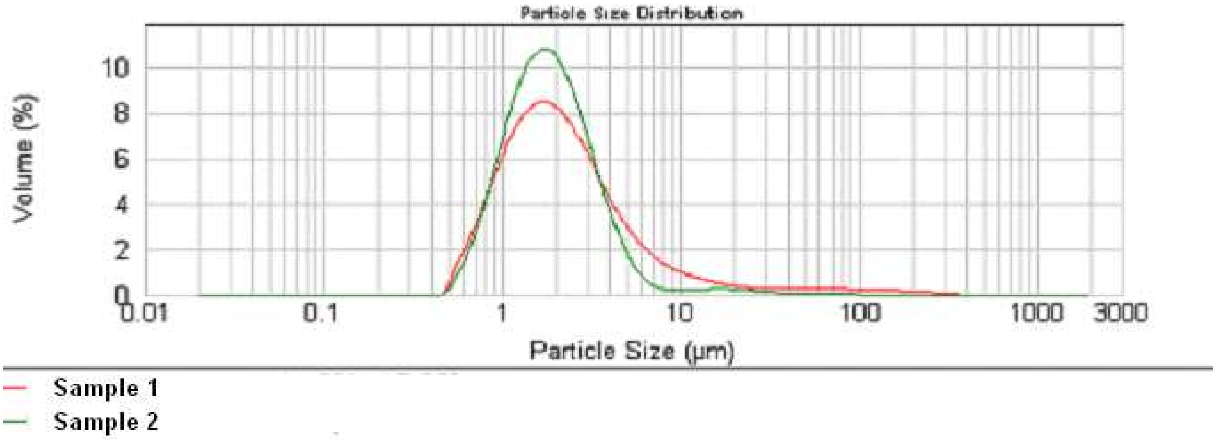


Figure 15 : Size distribution of two generations of microcapsules. Source A. Bartkowiak, West Pomeranian University of Technology.

During the second 18 months of activity within the project, it was proved that the self-healing concept by adding microcapsule in wet end was not the best method. This aspect has been demonstrated by showing that the calendering paper process (in-line) damaged capsules before the folding process. Furthermore, the capsules, even in excess, did not reduce WVTR.

Thus, it was decided to lead in parallel two separate studies. First was the continuation of optimization of microcapsule and second, the study of new biobased raw materials for reducing WVTR before coating.

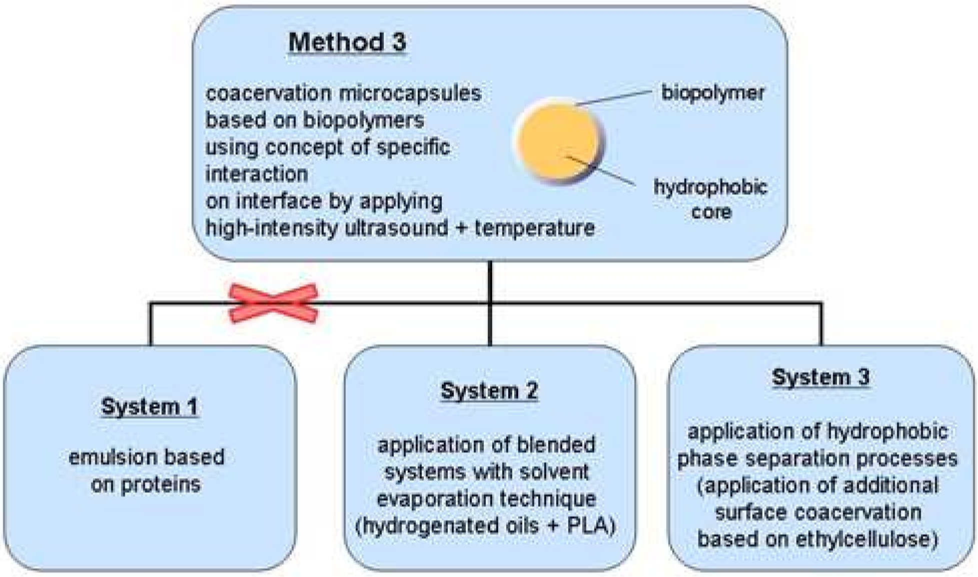


Figure 16 : Schematic representation of investigated coacervation microencapsulation systems.

As far as the microcapsule preparation was concerned two additional processes of capsules manufacturing were investigated. In that case, several interesting results proved that stability of microcapsules and particles size distribution could be possible even using safe solvent.

The self healing concept was validated with the introduction of microcapsules in a starch based coating layer that demonstrated a good efficiency to prevent loss of barrier properties after folding.

From this part of the study, several achievements were reached:

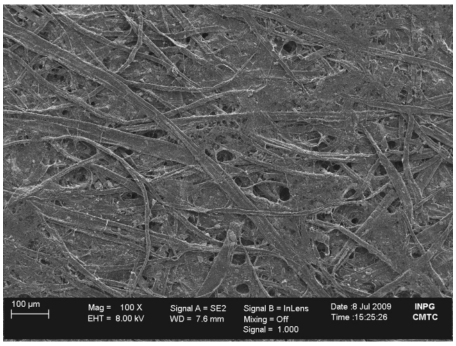
- Selection of the best techniques to manufacture micro and nanoparticles
- Selection of the hydrophobic core and hydrophilic shell
- Definition of the stresses that could be encountered in papermaking and converting processes
- Determination of the best properties of the core materials
- Improvement of capsule performances
- Validation of the self healing concept

4.2.2. - Use of wet end deposition of NFC

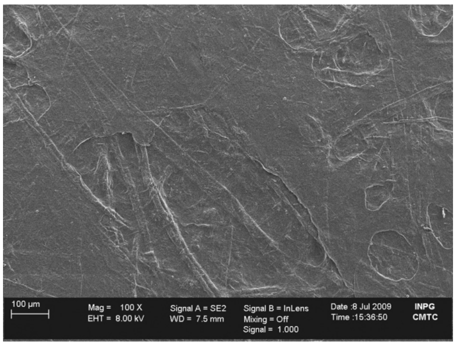
The second objective -task2.2, Improved substrate surface at the wet-end- was to develop an improved substrate prior to coating. Indeed, the quality and homogeneity of the coating layer on the paper is of major importance for the barrier effect. This task aimed at improving the paper substrate surface, as early as possible in the papermaking process, in order to ensure superior film formation when the barrier coatings are applied during the coating stage.

During the first 18 months of the project, this work focused on the selection of renewable materials and deposition method at laboratory scale to deposit a wet film of biomaterials on an un-dried paper; which simulated the papermaking process.

The best products and the best location, for colour delivery, on the paper machine were selected. It was established that the addition of a thin layer (4g/m²) of MicroFibrillated Cellulose (MFC) or NanoFibrillated Cellulose(NFC) or a combination of starch and NFC resulted in only a minor improvement in the mechanical properties, but the accompanying decrease in the air permeability of the substrate made an effective contribution to the final barrier properties.



untreated paper surface



paper surface treated with MFC

Figure 17 : SEM top views of papers. Source F. Girard, Centre Technique du Papier.

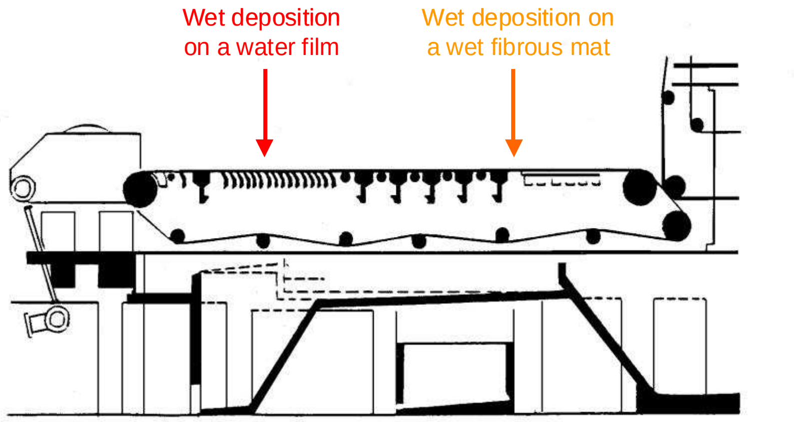


Figure 18 : Scheme of the fourdrinier part of a paper machine, with possible locations for a wet treatment. Source F. Girard, Centre Technique du Papier.

During the last 18 months of the project, this work scrutinised the implementation of the deposition method (curtain coating) at pilot scale to deposit a wet film of biomaterials on an un-dried paper.

Work was performed to determine optimal recipe that could guarantee a stable curtain and a smooth operation when the CTP's curtain coater would be installed on the Pagora's pilot paper machine. This stability was achieved after modifications of the initial recipe. Thus, pilot trials have been achieved proving that it was possible to adapt a curtain coater on the wet end of a paper machine.



Figure 19: Implementation of the curtain coater on the paper machine. Source F. Girard, Centre Technique du Papier and J. Bras Grenoble INP Pagora

From this part of the study, several achievements were gained:

- Assessment of the gain obtained when using deposition of materials at the wet end of a paper machine
- Selection of the best products to be deposited at the wet end
- Selection of the best location of the deposition on a Fourdrinier part of a papermachine
- Stabilization of a low viscosity starch/NFC blend for curtain coating application

Achievement of papermaking pilot trials at Pagora to validate the concept of wet end deposition

4.3. - Development of the middle coating layer to produce medium barrier properties materials

One major objective of FlexPakRenew was the development of water borne coatings offering a medium barrier paper. These developments were based on the concept described in Figure 20 and were done on an existing one side mineral coated paper.

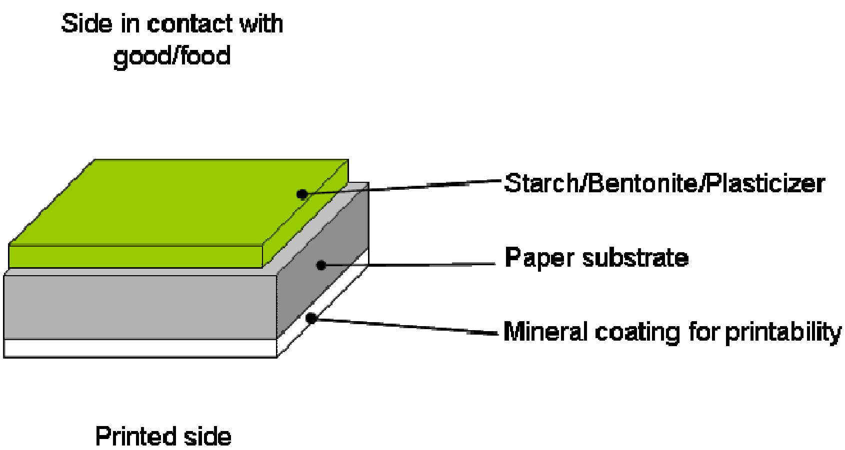


Figure 20 : Expected design of a medium barrier paper based packaging based on FlexPakRenew concept.

Coatings should principally be based on renewable resources, with minimal incorporation of natural fillers and other functional additives to enhance the barrier properties with respect to water, water vapour, grease and oxygen. The effect of adding platy particles in a polymeric matrix is known for improving the barrier performance of the materials thanks to the increase of the path length (tortuosity) that a gas molecule has to come through to migrate across the material (Figure 21).

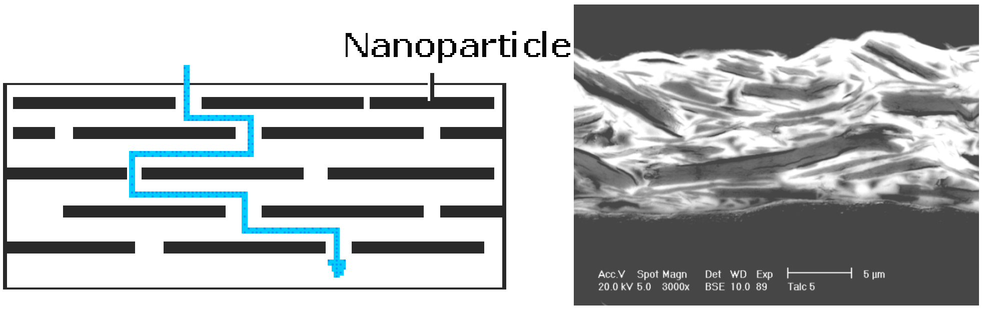


Figure 21: Improvement of the barrier properties obtained using nanoparticles (left), SEM crossection image of a highly talc-filled waterborne barrier coating (right).

The coatings had to be made from renewable materials (starches, functionalised starches, starch derivatives or modified hemicelluloses) and should be reinforced by (low eco-footprint) minerals or renewable nanoparticles (starch nanocrystals) and additives (biopolymers) either alone or in combination to optimise the desired properties. So, if the research focused primarily on materials and procedures that actually have the potential for use in industrial scale production, new and innovative materials and approaches that have longer term applications have also be studied. An important consequence of this focus on the industrial scale meant that the processability of the materials, including for example the viscosity of coating formulations, have to receive due consideration.

Starch, nanoclays plasticizers

Considerable effort has been invested in identifying the optimal combinations of starch or hemicelluloses, bentonites and plasticizers. Several starches were selected for evaluation, with a special focus on those that could be prepared at the highest solid content. The film forming behaviour of starch was particularly taken into account.

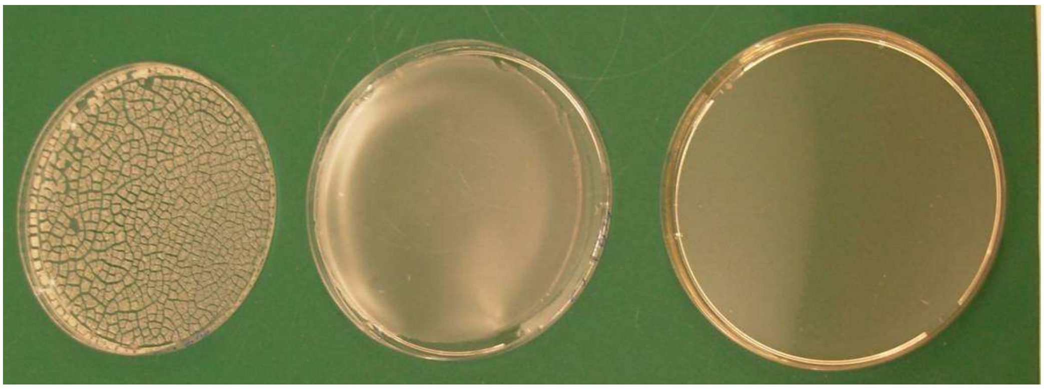


Figure 22 : Film-forming properties of starch films casted on moulds (from bad film forming on the left up to good film forming on the right). Source Lars Järnström, Karlstad University.

These starches were combined with several candidate bentonites in order to optimise the bentonite dispersion and achieve the best barrier properties. The choice of plasticizer, which is crucial for coating flexibility, was closely scrutinised in order to draw greatest benefit from its interaction with the bentonite and maximise the barrier properties of the coating.

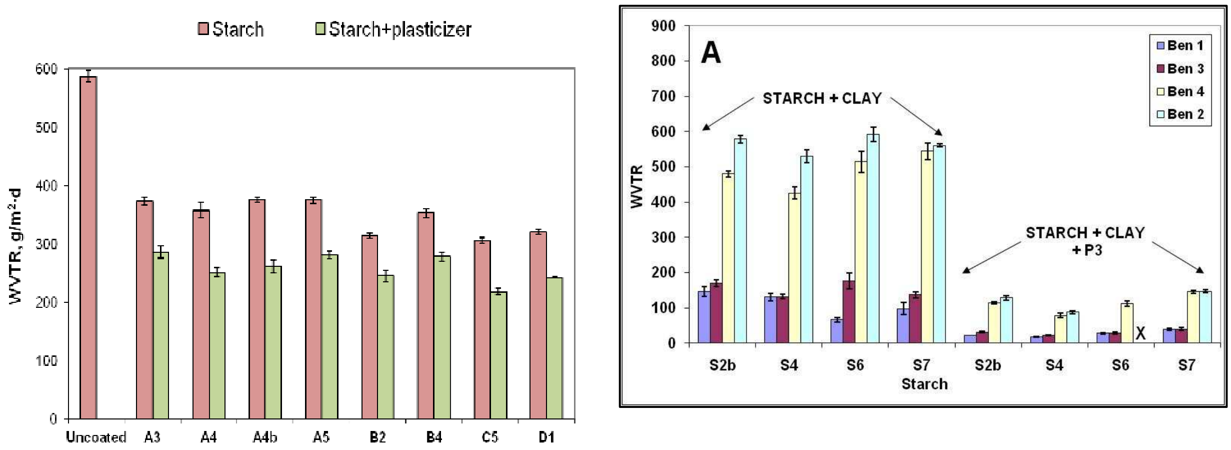


Figure 23 : Influence of plasticizer (left) and bentonite & plasticizer (right) on WVTR of different starches. Source Lars Järnström Karsltad University and Chris Breen, Sheffield Hallam University.

Optimal combinations of biopolymer, bentonite and plasticizer have been defined to get a smooth coherent and defect free layer at the surface of a paper substrate (Figure 24).

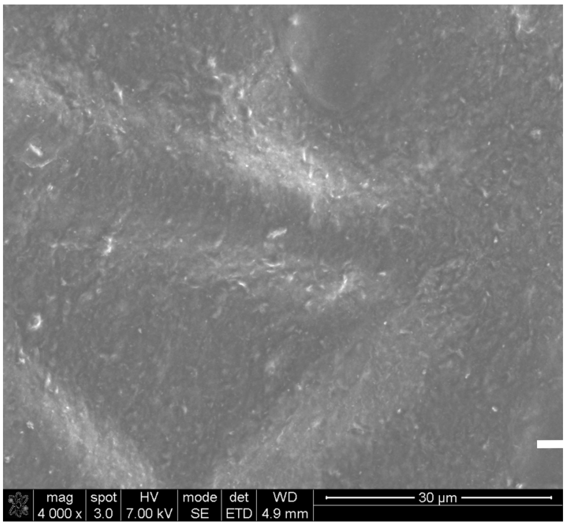


Figure 24 : Environmental scanning electron micrographs of paper coated using a biopolymer-bentonite-plasticizer formulation (scale bar = 30 µm).

At the starting point of the project, the water vapour transmission rates (WVTR) of the reference starch/nanoclay, plasticizer applied as a double coating on paper was about 200 g/ m^2.day (@23℃-50%RH) with a coating solids about 10%. After 24 months of laboratory development, a WVTR of about10 g/m².day (@23 ºC- 50% RH) was gained with a solid content of 17%. This result was validated on the pilot coating machine in the frame of the demonstration activities.

Several strategies were then employed either to improve the coater runnability or to improve further the barrier properties.

- Coatings for demonstrator samples required a higher total solid content combined with manageable viscosity. Investigations showed that this was possible by further addition of selected pigments and that water vapour barrier properties were not considerably reduced. Coatings for demonstrator samples were successfully prepared with total solids content up to 30 wt%, a WVTR value of 76 g/m².day was obtained for a coat weight of 6.1g/m².
- Several combinations of other plasticizers, pigments could lead to improvements. However, the most promising approach seems to be the use of the positive effects of phase separation between poly(vinyl alcohol) and starch. WVTR values around 10 g /m².day and OTR values around 1 cm^3/m².day.bar (both values at 50 % RH and 23 °C) were obtained in laboratory scale coatings (coat weight less than 20 gsm) without any mineral filler. Pilot-scale trials confirmed that this is possible to scale up.

Alternatives to starch/nanoclays based layers

Xylans as an alternative to starch

Amongst the most promising biomaterials lay hemicelluloses which are one of the most abundant renewable biopolymers in the world. If in the beginning of the project, simple xylan based formulations were studied and proved to be a good candidate, further investigations, used novel xylan derivatives i.e. xylan ethers and esters which were synthesized in order to receive internal plasticization and hydrophobicity. The xylan based coatings were also reinforced with bentonites and in coatings xylan was cross-linked to enhance water vapour barrier properties.

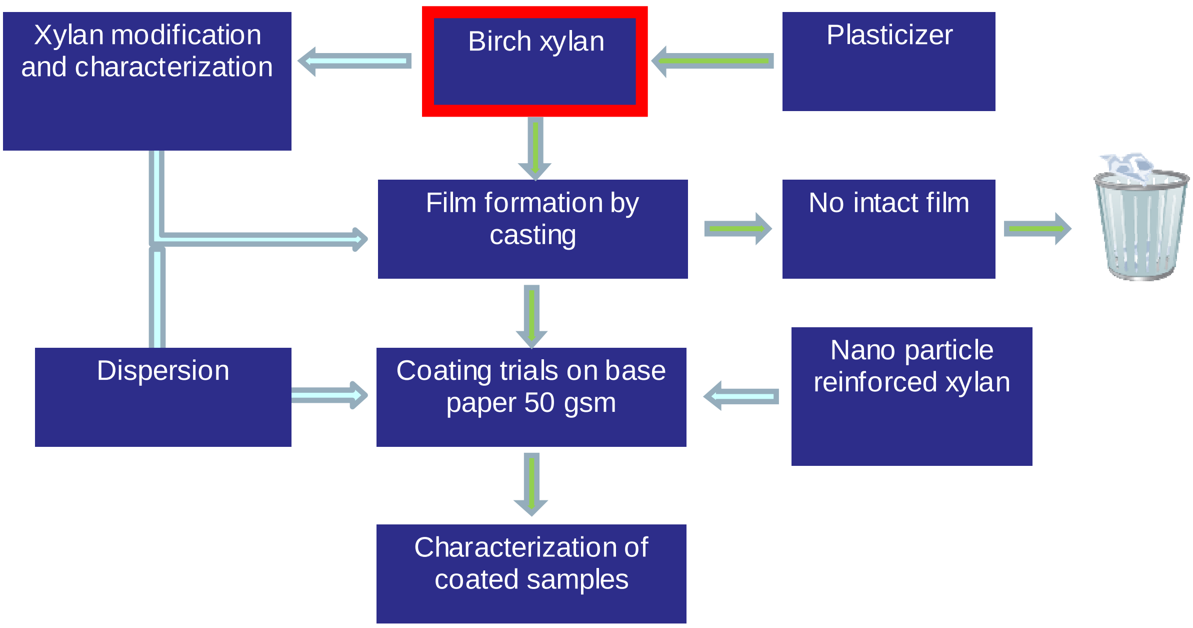


Figure 25 : Studied possibilities followed within FlexPakRenew for the use of xylans as paper coating matrix. Source R. Talja, VTT.

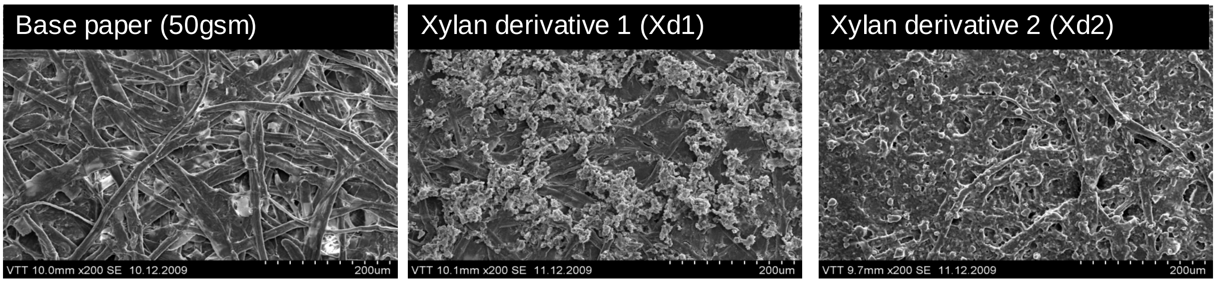


Figure 26 : Picture of uncoated paper (top left) and papers coated with xylan derivatives (top centre and top right. Source R. Talja, VTT.

Particle coalescence has occurred even though primary particles of the xylan derivative dispersions are visible (Figure 26).

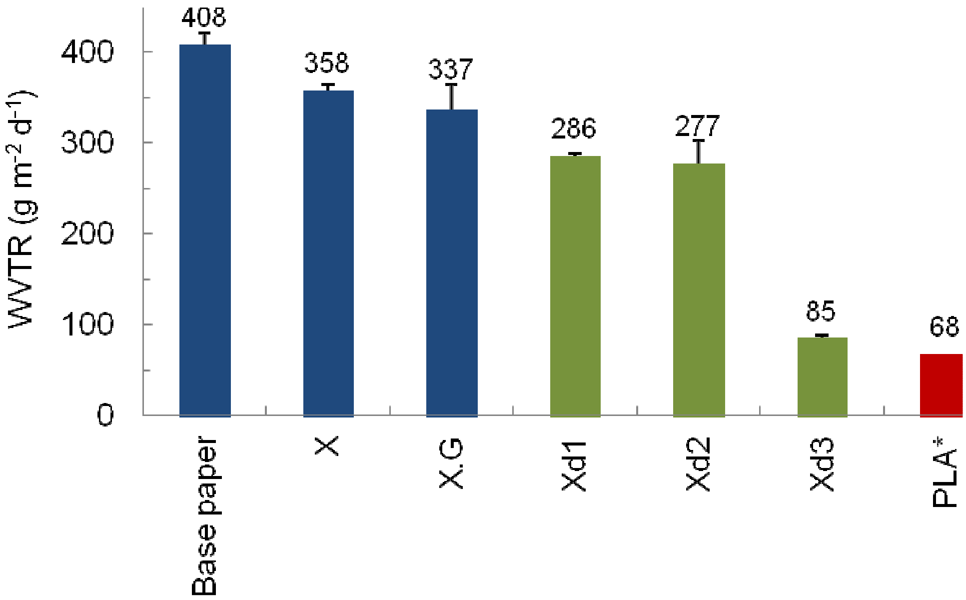


*Figure 27 : WVTR of xylan and xylan derivatives according to R. Talja, VTT. *Data for PLA from Lahtinen et al. (2009)* Packag. Technol. Sci. *22:8, p. 451.*

The present study demonstrated that one chemical modification of xylan was particularly promising even though better water vapour properties could be achieved with cross-linked and bentonite reinforced coatings.

Indeed, derivatized xylan coating (i) can be prepared by dispersion coating technique which allows higher solid content in coating process than solution based techniques; (ii) gives good water vapour barrier properties being comparable to those of PLA coating (iii) presents high hydrophobicity and repels water and last but not least (iv) gives heat sealable coating whereas bio-based barrier coatings generally do not.

Plasticizing effect of hydrophilic/hydrophobic two phase dispersion

Another strategy was developed to manufacture materials that could bring improvements of brittle layers. This work focused on the potential of two phase dispersion, which includes both types of biopolymers with hydrophilic and hydrophobic characteristics. The presence of a hydrophilic dispersion component allows the reduction of penetration of a hydrophobic substance, for example fats/oils, and the presence of a hydrophobic component leads to lower rates of water vapour diffusion WVTR.

It was decided, that the hydrophobic component would be introduced into the system in the form of microcapsules. A microencapsulated healing agent was embedded in a structural matrix, which was a hydrophilic biopolymer (polysaccharide or protein).

Following first results, sono-coacervation method was selected to microencapsulate the healing agent. The main objective of research was to investigate the self-healing effect of coatings containing microcapsules. Paper was coated by selected starch-based dispersion mixed with biopolymeric microcapsules containing vegetal oil (*Figure 28*). A reference coating (starch/nanoclay/plasticizer) that showed a high barrier to water vapour has been applied for comparison in order to investigate the self-healing effect. The self-healing effect was investigated by determining WVTR properties of modified material before and after folding test (Figure 29).

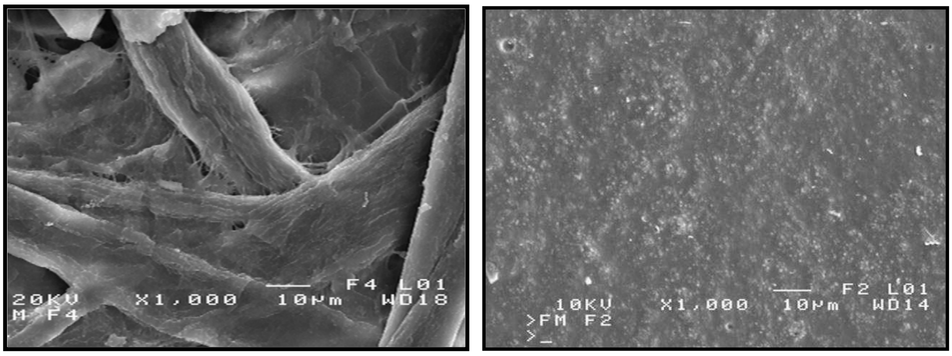
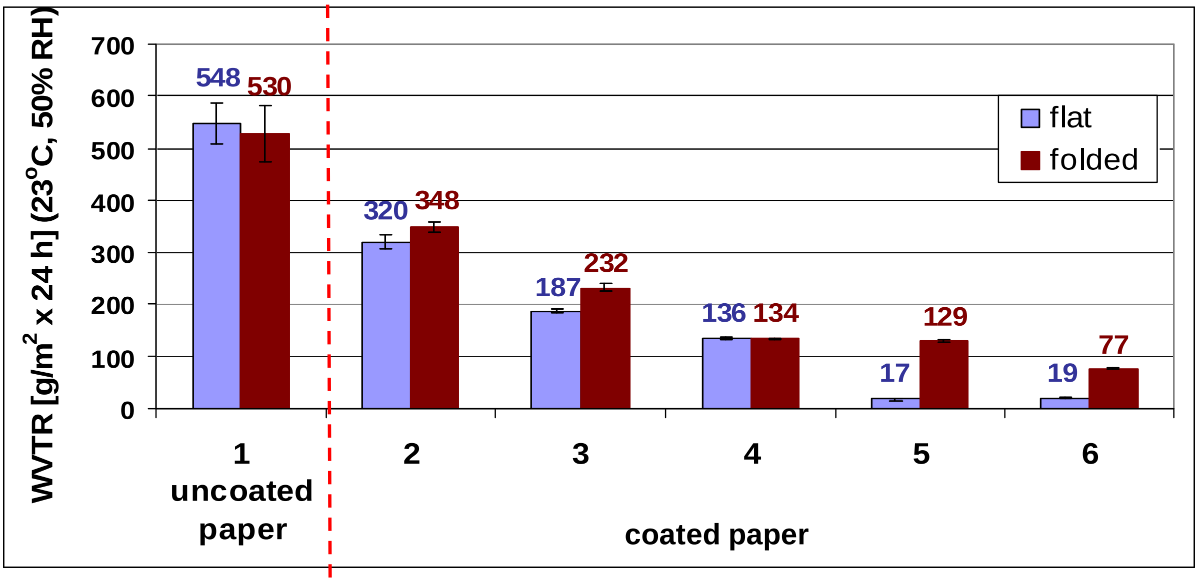


Figure 28 : SEM (x1000) of 50gsm paper: uncoated (left) and coated with dispersion of biopolymer + vegetal oil/starch microcapsules (double wet coating 40 and 4 micrometers (right). Source A. Bartkowiak, West Pomeranian University of Technology.

The results of self-healing films application demonstrated (Figure 29) the potential of this strategy to reduce dry coating layer brittleness and improve the barrier performance when folded.



1. uncoated paper
2. starch coating
3. dispersion of biopolymer/starch microcapsules
4. dispersion of biopolymer+vegetal oil/starch microcapsules
5. brittle coating
6. 1st layer: brittle coating; 2nd layer: dispersion of biopolymer+vegetal oil/starch microcapsules

Figure 29 : Determination of self-healing effect using a coating made of starch-based dispersion of biopolymer microcapsules containing vegetal oil,– WVTR analysis before and after folding of modified paper. Source A. Bartkowiak, West Pomeranian University of Technology

Starch nanocrystals as an alternative to nanoclays

All the developed medium properties coating layers contained mineral nanopigments. It seemed of interest to use biosourced nanoparticles to reinforce the polymeric matrix and get in the end a fully biosourced/renewable coating layer. In early stages of the project, starch nanoparticles appeared to be a good candidate even if the production of such materials appeared to be slow with a low yield.

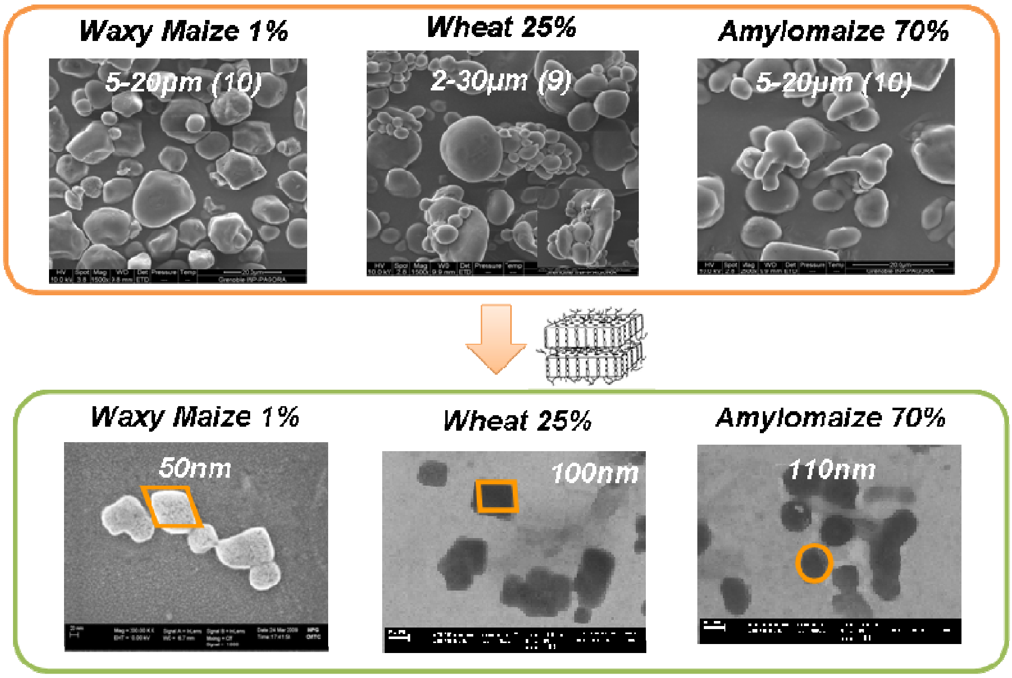


Figure 30 : Starch granules and starch nanocrystals. Source D. Le Corre, Grenoble INP Pagora.

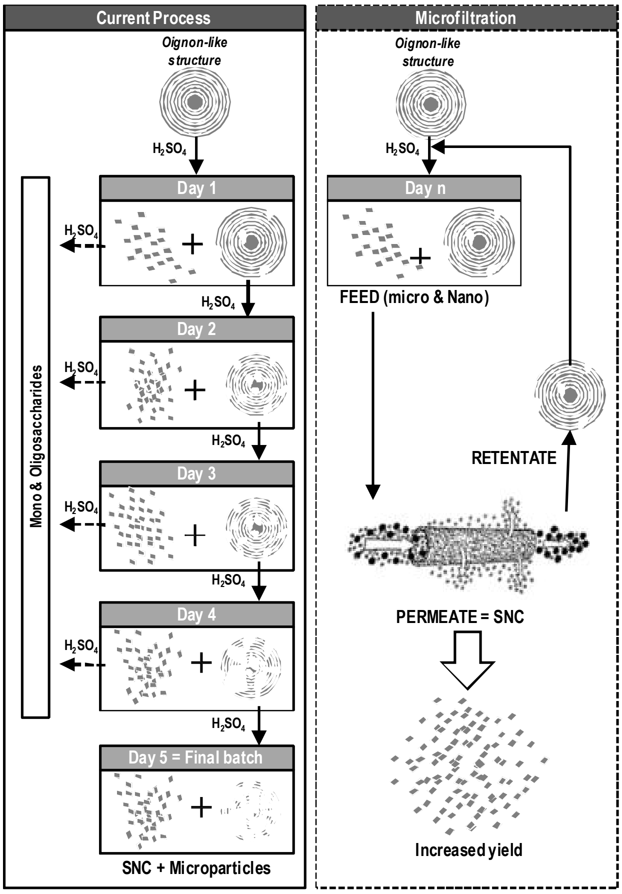


Figure 31. Schematic comparison between the current preparation process involving the progressive production of starch nanocrystals as evidenced in (Le Corre et al., Submitted), and the proposed microfiltration process.

Research suggested, for the first time, that during the hydrolysis of starch granules (i) nanocrystals are mixed together with other micro particles and that (ii) some nanocrystals might turn to sugar by the end of the batch production, underlining the need for a continuous production and extraction process of SNC. Such a manufacturing process, using a microfiltration unit equipped with ceramic membranes to filtrate the starch nanoparticles, was tested and showed promising results.

The potential use of starch nanocrystals (SNC) as fillers for organic coating material of industrial packaging had never been investigated before. In FlexPakRenew, their processability in coating has been assessed and the final properties of coated papers were measured.

Even if results were less promising than nanoclay ; improvement of properties have been observed and their renewable and biosourced nature associated to their low density could be a strong assets to push the development of such particle.

From this part of the study, several achievements were gained:

- Development of a starch/bentonite/plasticizer colour suitable for paper coating and leading to medium WVTR (10 g/m²/day @23℃-50%RH)
    - Understanding of starch properties for a wide range of starch derivatives in order to identify the most promising starch grades when used as a medium barrier coating layer that also works well as a precoating layer for subsequent high performance top coating.
    - Understanding of the effects of different plasticizers on mechanical and barrier properties of starch-based nanoclay-containing coatings applied on model and paper surfaces.
    - Understanding the effects of plasticizer on degree of dispersion and clay structural features and in starch-based nanoclay-containing coatings applied on model and paper surfaces.
- Development of xylan/bentonites/nanoclays water based colour suitable for paper coating and leading to medium WVTR (10 g/m²/day @23℃-50%RH)
    - Understanding how to produce hemicellulose dispersions suitable for water-borne dispersion coating.
    - Understanding the effects on dry coatings of interactions between hemicellulose and nanoclay in aqueous solutions of hemicelluloses that also contain nanoclays.
- Development of xylan derivatization to bring hydrophobicity and heat sealing properties of xylan layers.
- Validation of the concept of two phase separation of hydrophobic and hydrophilic polymers.
- Validation of the heat sealing effect of hydrophobic core/hydrophilic shell microcapsules to reduce the cracking at the fold of starch based layers.
- Development of a new generation of starch nanocrystals with an optimized production process.
- Demonstration of the reinforcing effect of starch nanocrystals as fillers in starch- and hemicelluloses-based composites for packaging.
- Formulation of dispersions suitable for further optimization in pilot trials.

4.4. - Development of vacuum coating and chromatogeny to produce high performance barrier materials

Two significant challenges need to be overcome to enable successful implementation of paper based barrier packaging:

- The coatings derived from biopolymers are hydrophilic, thus have very limited water vapour barrier and loose their barrier properties when exposed to water or high moisture atmospheres.
- Their oxygen barrier level is still two orders of magnitude lower than those of high barrier plastic films

Therefore two innovative surface treatments, namely solvent free chemical grafting and vacuum coating, had to be developed in FlexPakRenew to overcome these drawbacks and facilitate the production of a high barrier flexible paper, especially necessary with regard to products with long shelf life packaging. The expected design of the product was described on

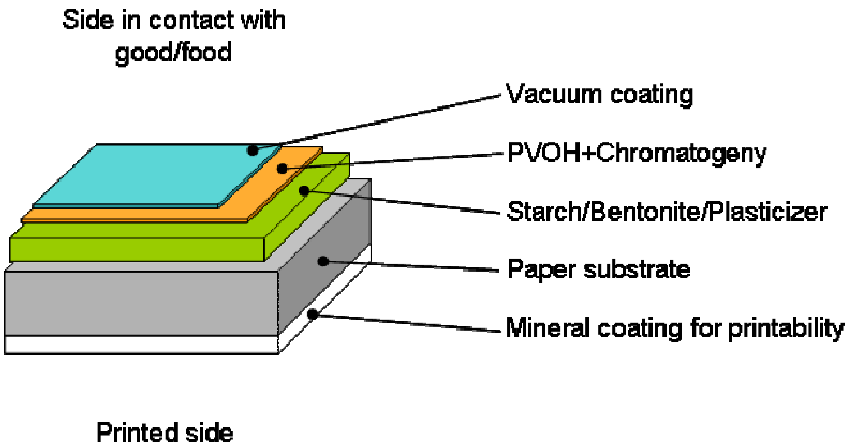


Figure 32 : Expected design of a high barrier material based of FlexPakRenew concept.

Chromatogeny to produce water repellent barrier coated paper

The chromatogenic grafting is a solvent free grafting using the ultrafast kinetics of liquid-vapour equilibrium to make efficient the acylation of cellulose, starch or polyvinyl alcohol with fatty acid chlorides (stearoyl, palmitoyl or behenoyl chloride). This technology permits to significantly reduce the sensitivity of coated layer to water and water vapour (Figure 33).

Figure 33: Droplets of water at the surface of coated and grafted paper after 5 minutes of exposure. Source D. Guérin, Centre Technique du Papier.

With carefully selected primer layers, it was possible to get perfect water repellence and very low WVTR (below 0,5g/m²/day @ 23℃ and 50%RH - Figure 34) and OTR (3 cm^3/m^2.day.bar @ 23℃ and 0%RH).

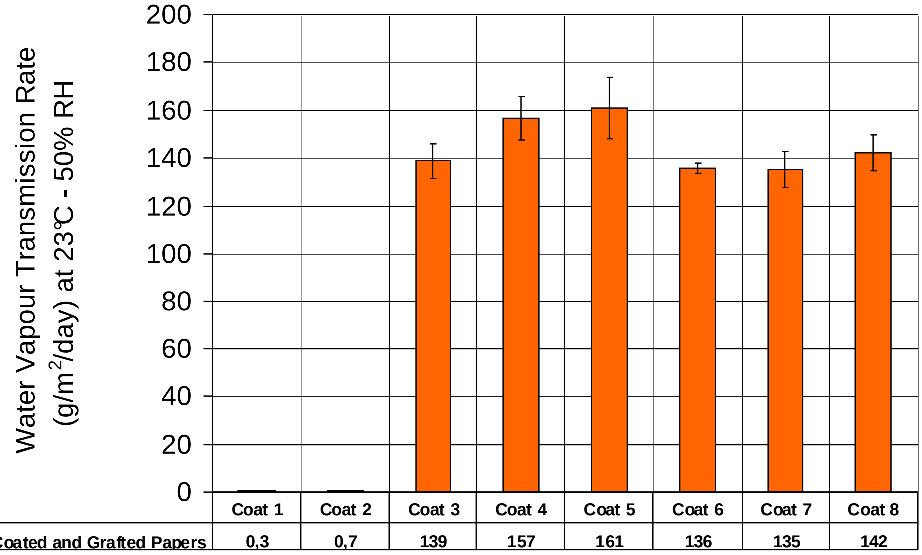


Figure 34 : Influence of primer coat on the WVTR of coated and grafted papers. Source D. Guérin, Centre Technique du Papier and C. Stinga CERMAV-CNRS.

In the midterm of the project, CTP developed a pilot machine to demonstrate (Figure 35) the feasibility of the chromatogeny grafting process at large scale. This pilot was financed outside the FlexPakRenew project by CTP thanks to FEDER funds granted by local authorities (Region Rhône-Alpes) to the technology platform Teklicell.

Figure 35 : Views of CTP's chromatogeny pilot plant.

CTP and CNRS work, done in FlexPakRenew, demonstrated, for the first time ever that it was possible to graft both uncoated and coated papers with the chromatogeny technique at pilot scale. However this work also showed that the mechanisms involved in uncoated paper grafting and coated paper grafting were very different: in case of coated materials longer reaction times (about 4 seconds -Figure 36) were required whereas the reaction takes place in very short times (about 1 second) for uncoated paper grades.

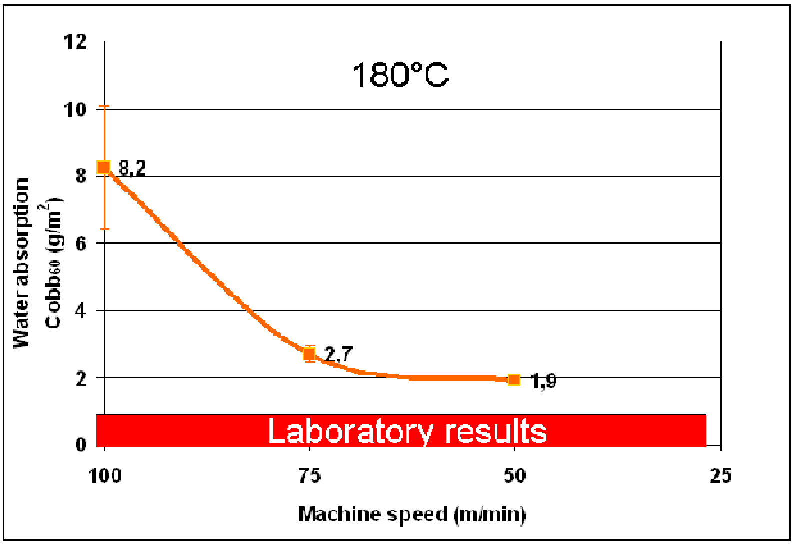


Figure 36 : Cobb60 water absorption measured for grafted samples at 3 machine speeds.

The size of the pilot being large enough, no further up-scaling is necessary to demonstrate the feasibility of this process at industrial scale. The chromatogeny grafting technique, opens new development possibilities for papers and it is now possible to develop:

- Uncoated grafted papers that will remain porous but water repellent e.g. Gore-Tex® like
- PVOH coated and grafted papers that have very good barrier to water, water vapour, oxygen, grease and water which makes a very efficient material for packaging.

This last possibility was particularly scrutinised during FlexPakRenew and a lot of work was dedicated to the development of a coating layer particularly adapted to chromatogeny grafting. Unfortunately, the most efficient material was polyvinyl alcohol, a petroleum based polymer. However, if the PVOH coated and grafted papers are not fully biosourced, they were proven to be biodegradable.

Vacuum coating to magnify the gas barrier properties

The use of vacuum coating (Figure 37) is very demanding in terms of substrate properties: The materials to be coated must be very smooth (roughness lower than 50nm) and be resistant to, or at least not modified by, the change of environment associated with entry into a vacuum chamber. These two requirements are difficult to achieve when using a paper (with roughness about 1µm) coated with a hydrophilic layer (containing water) and plasticizer.

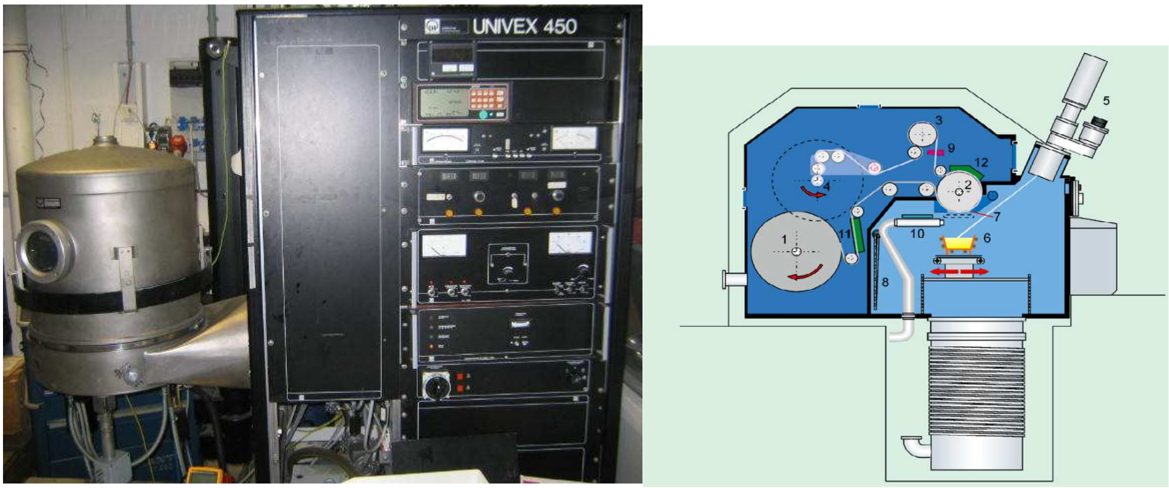


Figure 37: Vacuum coating facility and principle at Fraunhofer IVV, lab scale. Source K. Noller, Fraunhofer Institut vur Verpackung.

To achieve the barrier objective - at least an OTR < 10 $cm^3.m^{-2}.day^{-1}.bar^{-1}$ and WVTR < 1 $g.m^{-2}.day^{-1}$ at 23°C and 50% RH - the vacuum coating process was further adapted by Fraunhofer IVV with regard to avoiding or at least reducing the negative influence of humidity, which causes defects (Figure 38) in the inorganic layer and decreases the barrier properties of the vacuum coated multilayer. For that reason the developed preconditioning and rehumidification process which showed first promising results in the first reporting period was optimized, especially taking into account also the interaction of the process with the substrate. The corresponding coating trials had to be done at lab scale. Several trials were also performed in order to apply the aluminium layer in continuous reel-to-reel application (pilot plant scale).

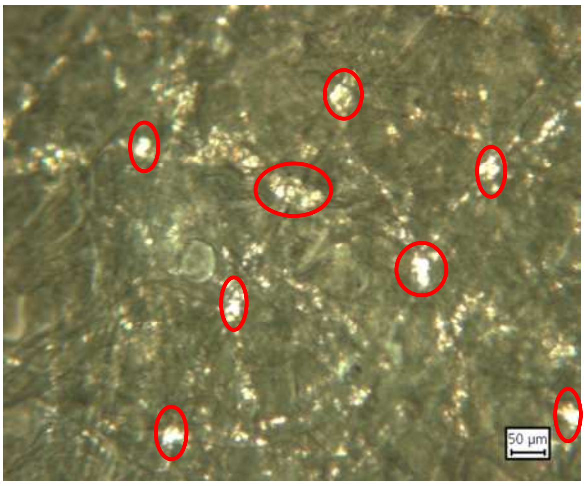


Figure 38: Transmitted light picture of coated and Al-deposited paper. Defects due to non adequation between paper composition and vacuum coater parameters. Source K. Noller, Fraunhofer Institut vur Verpackung.

It can be concluded that due to the successive optimization of the pre-coating materials and thanks to the developed PVD process, it was finally possible to improve the water vapour and oxygen barrier properties significantly. The selected materials were suitable for the developed PVD process and the material combinations seemed to provide additional synergistic effects on the final barrier properties. The adaptation of the vacuum coating process to achieve at least an OTR < 10 $cm^3.m^{-2}.day^{-1}.bar^{-1}$ and WVTR < 1 $g.m^{-2}.day^{-1}$ at

23℃ and 50% RH was successful in more than one cas e. Thus it could be shown that the positive impact of this process was reproducible. Although it was not possible to do the vacuum coating at pilot plant scale the developed PVD process can be transferred to industrial scale facilities due to the fact that these have more powerful vacuum pumps and a higher ability to freeze out the water within the vacuum chamber.

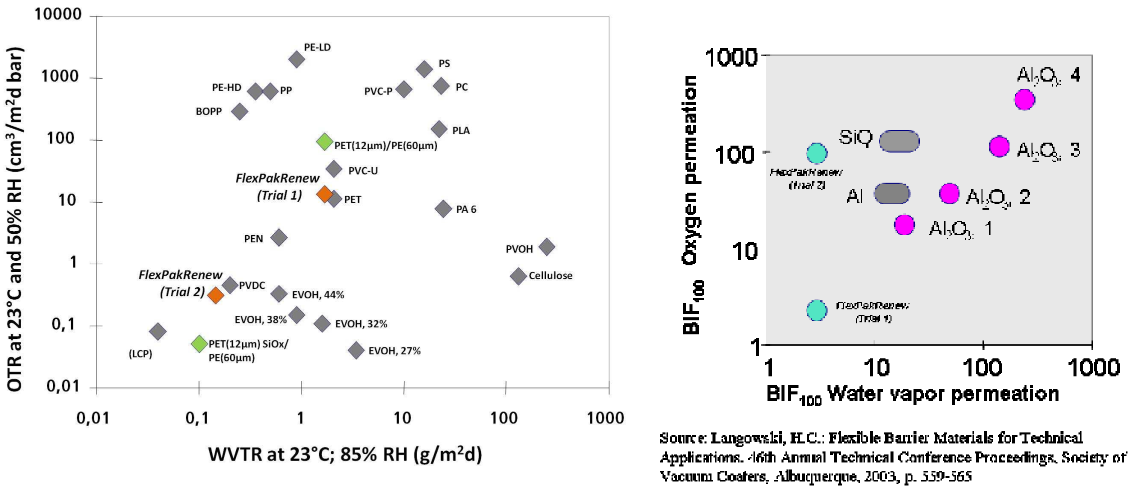


Figure 39 : Comparisons of FlexPakRenew trials with reference polymers (left) and barrier improvement factors compared to standard polymer films were observed for OTR in best performance case (right). Source K. Noller, Fraunhofer Institut vur Verpackung.

From this part of the study, several major achievements were gained:

- It was proven that vacuum coating could be used to improve barrier properties of a coated paper. With this technology, the barrier target objectiveS of FlexPakRenew were successfully passed. This is provided that:
    - Coated paper has a smooth substrate surface on which Al_2O_3 or SiO_x coatings can be applied in the vacuum for barrier purposes. Unfortunately, chromatogeny, leading to low surface energy was found to be not compatible will Al_2O_3 or SiO_x deposition.
    - The processing parameters for the vacuum coating are adapted to reduce the negative influence of humidity and to preserve the properties of the precoating.
- The use of chromatogeny to improve the water resistance of hydrophilic coated layers was demonstrated at laboratory scale.
    - The knowledge of the optimal combination between starch PVOH, nanoclay, talc, plasticizers, kind of reagent (palmitoyl chloride, stearoyl chloride, behenoyl chloride), coat weight, coating process and the barrier properties of coated and grafted paper was gained.
- It was demonstrated, for the first time ever that it was possible to graft both uncoated and coated papers with the chromatogeny technique at pilot scale. This makes possible the optimal processing conditions to develop:
    - Uncoated grafted papers that will stay porous but water repellent e.g. Gore-Tex® like
    - PVOH coated and grafted papers that have very good barrier to water, water vapour, oxygen, grease and water which makes a very efficient material for packaging. This material fulfilled the barrier target of FlexPakRenew.

4.5. - Development of antimicrobial coatings

In FlexPakRenew, additionally, another aspect of advanced performance packaging – the antimicrobial coating – had to be transferred to paper based barrier packaging and biopolymer based coatings respectively.

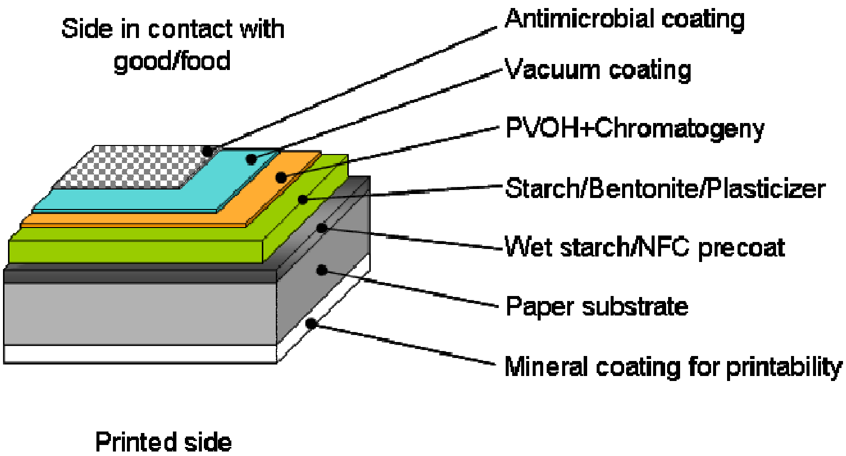


Figure 40 : Expected design of an antimicrobial barrier paper based on FlexPakRenew concept.

The overall aim of antimicrobial coating is to prolong the shelf life of the product while simultaneously exposing the consumer to only a minimum quantity of preservatives as well as to antimicrobially stabilize the paper itself.

In the project two strategies were followed (i) the use of preservatives in the bulk of a starch layer – to be used in the medium barrier packaging; and (ii) the deposition of an additional layer at the outermost surface to act as a protection layer for the vacuum coating - to be used in the advanced performance barrier packaging. The release of the antimicrobial agents was done using two mechanisms:

- Coating formulations containing preservatives like silver, benzoic acid or sorbic acid had to be developed. These should be based on a composition of modified starch and clay thus potentially offering the possibility of controlled release of the active agent over long timescales.
- With respect to controlled release another subtask focussed on microcapsules. A suitable concept of configuration and generation such microcapsules containing antimicrobial substances e.g. also plant extracts should be developed and evaluated.

Coating formulations containing preservatives like benzoic acid and potassium sorbate proved their efficiency (Figure 41 and Figure 42) but some additional work had to be done to optimize their minimum necessary concentration to be active against bacteria, moulds and yeasts taking into account also the storage of the packaging material itself.

Figure 41 : View of an inhibition zone due to preservative action (left cup) compared to reference cup (right). Source P. Muryani, Fraunhofer Institut vur Verpackung.

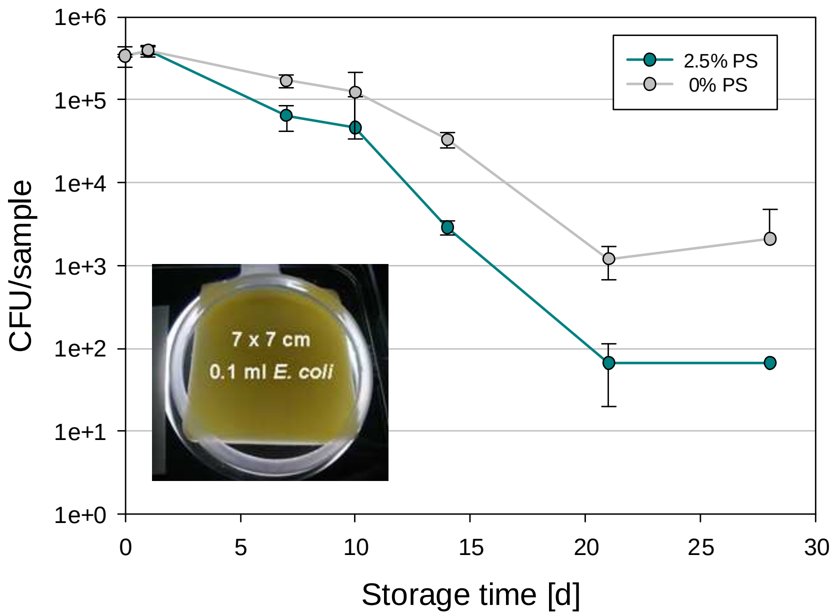


Figure 42 : Antimicrobial effect of a starch coating with 2.5% (w/w) potassium sorbate against E. coli DSM 498 on the surface of Gouda cheese as a function of storage time. The cheese samples were artificially inoculated on a certain surface (7x7 cm) with approx. 10^5 cfu and stored up to 28 days at 8℃.

The active substances like benzoic acid, potassium sorbate, essential oils and silver could not only be incorporated as pure substances in a certain matrix but were also very good candidates for being included in microcapsules or clay to optimise their release and thus the efficiency of the active agent over time.

Different materials for the formation of stable microcapsules were investigated as carrier for antimicrobial substances (Figure 43). It was demonstrated that e.g. the homogeneity of the coating influences the antimicrobial efficiency. The most effective bioactive coatings were based on formulations containing benzoic acid in the starch/PLA/oil matrix showing a significant activity against the bacteria *Escherichia coli* (DSM 498) and *Listeria monocytogenes* (DSM 15767).

Figure 43 : Microcapsules after crosslinking with transglutaminase (drying at 70 ^{0}C). Source A. Bartkowiak, West Pomeranian University of Technology.

From this part of the study, 3 main achievements were gained:

- It was possible to develop antimicrobial coatings that demonstrated their efficiency against several strains *Escherichia coli* (DSM 498), *Listeria monocytogenes* (DSM 15767), *Aspergillus niger DSM 1957*
- The use of preservative in a starch-based coating colour demonstrated its anti microbial efficiency. This required a direct contact between film and food (e.g. vacuum or skin packaging) but the measured concentration of the food approved preservative was below prescribed values.
- The use of benzoic acid encapsulated in a starch/PLA/oil matrix demonstrated its antimicrobial activity and a controlled release of antimicrobials from microcapsules that could result in more effective protection of food with lower active substance concentration.

4.6. - Up-scaling manufacturing technique from lab scale to pilot scale

This work package aimed at producing prototypes of flexible packaging using the breakthroughs developed in the project. It also aimed at checking that the scale up of each development done in other work packages would be possible. A step by step strategy was followed and several trial sessions organized during the project made possible to deliver a continuous feed back to the project partners.

During the project, one laboratory demonstrator associating all the findings was produced (Figure 44).

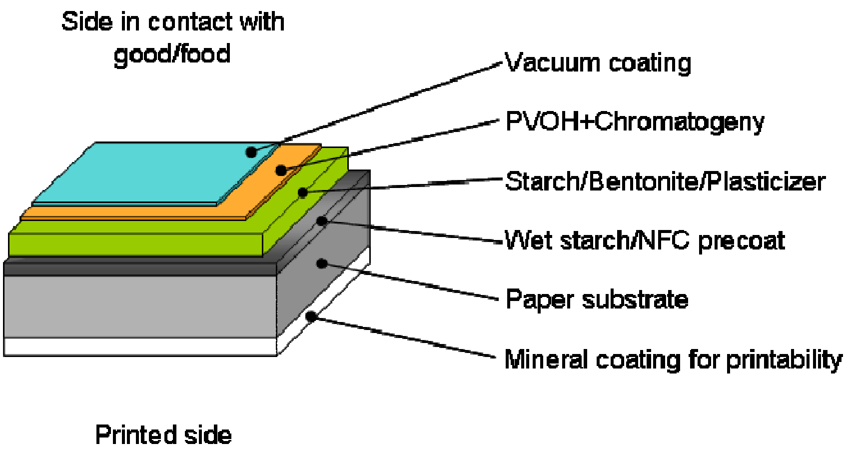


Figure 44 : Design of the laboratory demonstrator.

Several pilot scale demonstrators were developed as soon as the laboratory work was mature enough to perform trials.

A first pilot demonstrator, focused on starch based coating colour was manufactured at pilot scale and confirmed that it was possible to upscale the first developments achieved in the project. The success of this first demonstrator clearly underlined the key issues that were to be addressed during the project.

Following conclusions gained with the first demonstrator, two new series of trials (pilot demonstrator 1 and pilot demonstrator 2) were performed on Ahlstrom's pilot machine to optimize : (i) coating colour formulations, (ii) preparation processes, (iii) coating processes and strategies, (iv) drying strategies, (v) calendering strategy to get better products, with higher runability of the machines and in the end processes more adapted to the industrial scale.

Extensive work was paid to find the optimal combination of products to make the middle layer giving a "medium barrier" material.

The medium barrier material was further converted to bring better barrier performance and high performance coatings were applied at pilot scale either by grafting, vacuum coating, dispersion coating or a combination of these processes. All these high-tech methods were proven to be compatible with the medium barrier material leading to different final demonstrators (Figure 45 and Figure 46) obtained at the end of the project.

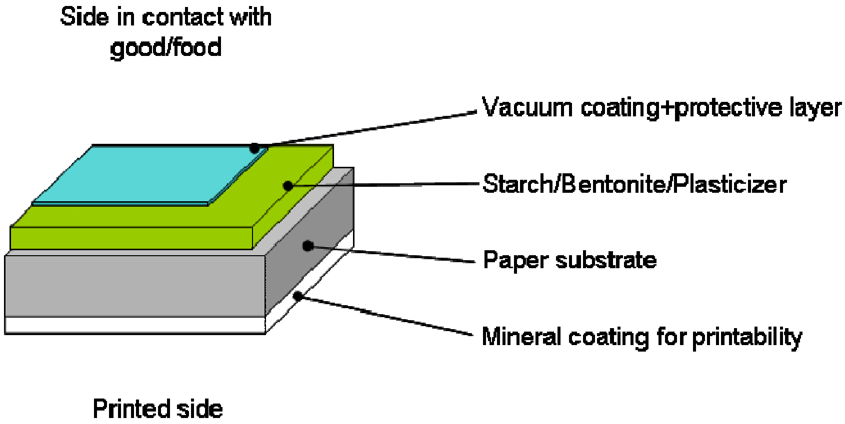


Figure 45 : First concept of demonstrator.

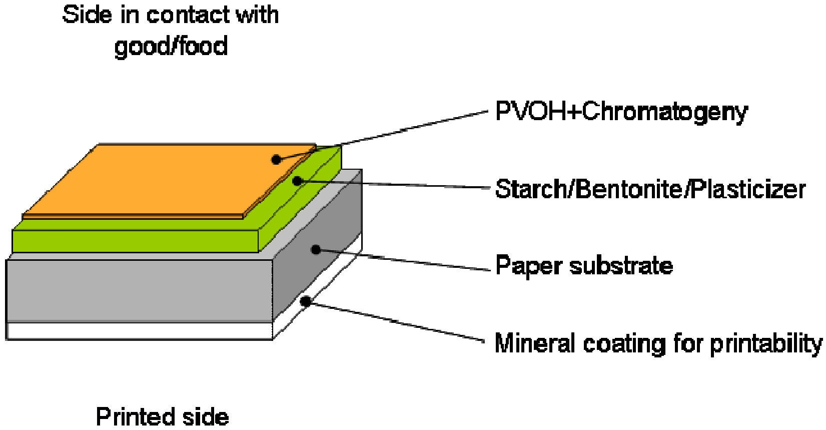


Figure 46 : Second concept of demonstrator.

Characterizations of the final pilot demonstrators proved that low values of WVTR and OTR were achieved. However, further work is still required to fully optimize processes and guarantee defect free, reproductive and competitive materials asked by industrialists.

In the frame of this workpackage, several achievements were gained:

- Delivery of all the necessary raw materials to the partners (starch, papers and other biomaterials).
- Manufacture of a first laboratory prototype to identify the most difficult challenges to overcome when producing the final demonstrator.
- Development of several pilot demonstrators to develop medium barrier coated paper and advanced barrier coated paper:
    - Increase of starch based solids from 10 to 30% during the project at equivalent barrier performance
    - Demonstration of the potential of chromatogeny to graft PVOH coated paper at pilot level
    - Fulfilment of FlexPakRenew barrier target achieved with mixed pilot and laboratory scale (OTR < 10 $cm^3.m^{-2}.day^{-1}.bar^{-1}$ and WVTR < 1 $g.m^{-2}.day^{-1}$ at 23℃ and 50% RH)
    - Evaluation of the technical performance of the demonstrators
    - Evaluation of the food contact regulatory
    - Evaluation of the biodegradability and recyclability
    - Evaluation of the economical viability

4.7. - Assessment of the environmental impact of the developed solutions

The two major objectives of this work package were:

- To lead the development towards environmentally potential renewable materials in flexible packaging paper
- To communicate the sustainability of renewable flexible packaging paper

In the forest industry, sustainable development addresses issues such as renewable raw materials, recyclable products and bio-energy. Sustainability (Figure 47) is a combination of environmental, social and economic evaluations. The assessment is based on the integration of different sustainability and LCA tools and it is always customized to suit specific products and value chains. Sustainability assessments can be applied e.g. in the evaluation of new technologies, and the evaluation can be conducted at a process, product or business concept level.

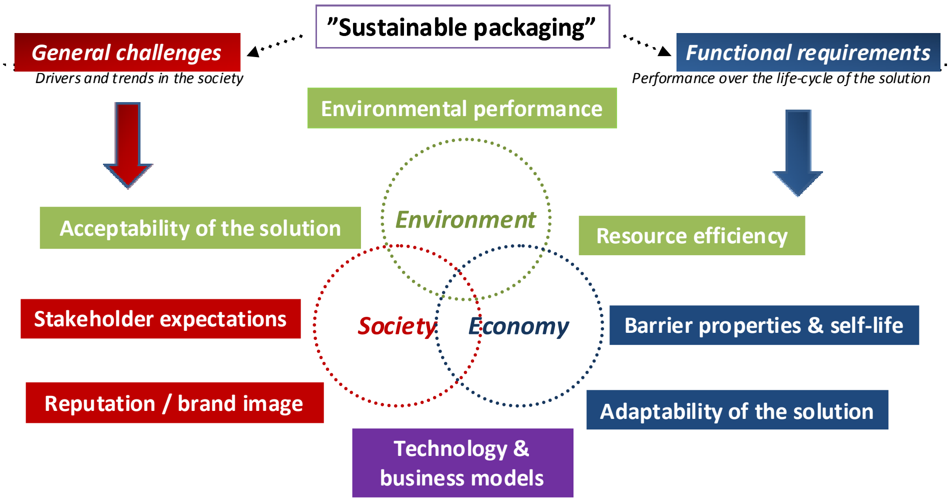


Figure 47 : A simplified visualization of the multiplicity of challenges and requirements faced by packaging solutions, and their links to the different aspects of sustainability. Source C. Hohenthal, VTT.

During the first part of the project, this activity was dedicated to:

- Define the sustainability methodology.
- Establish a list of data to be delivered.
- Collect all the data.
- Search for information to replace missing data.
- Prepare a first LCI calculation on existing products and FlexPakRenew product.

The objective was to deliver preliminary conclusions to the partners to make them orientate their research according to sustainability criteria.

In the second part of the project, this activity was focused on the Life cycle assessment of the cases developed in the demonstrator part (Figure 48).

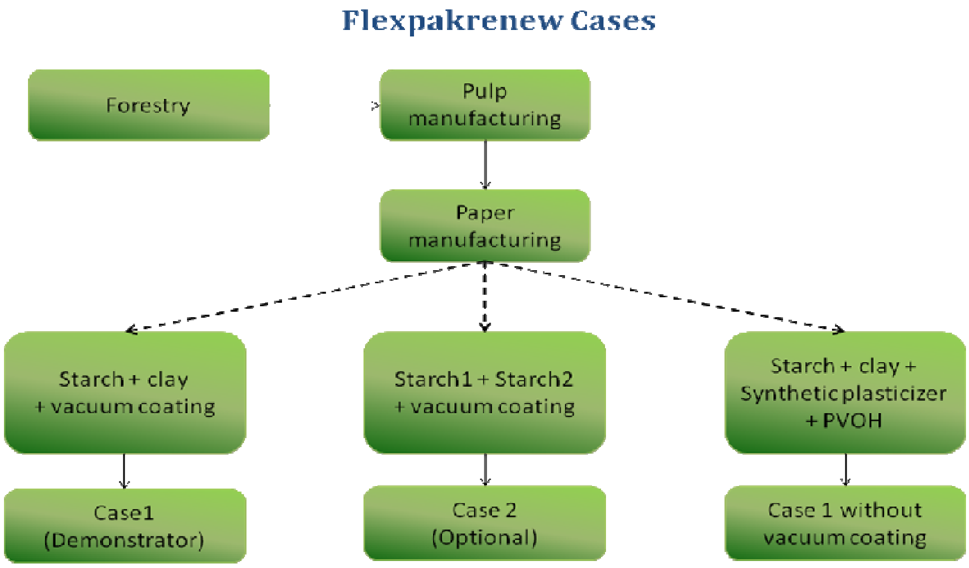


Figure 48 : FlexPakRenew cases. Source C. Hohenthal, VTT.

The environmental performance of the demonstrator cases was assessed according to 14 criteria (Figure 49 and Figure 50).

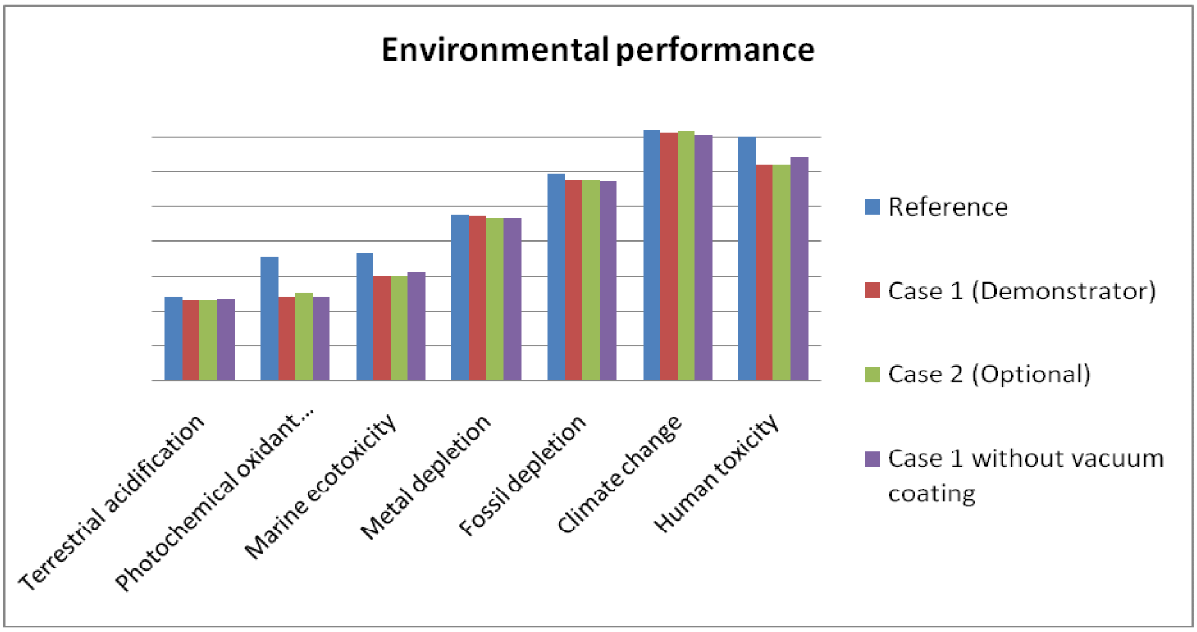


Figure 49: Weighted impacts with 7 midpoint indicators. Source C. Hohenthal, VTT.

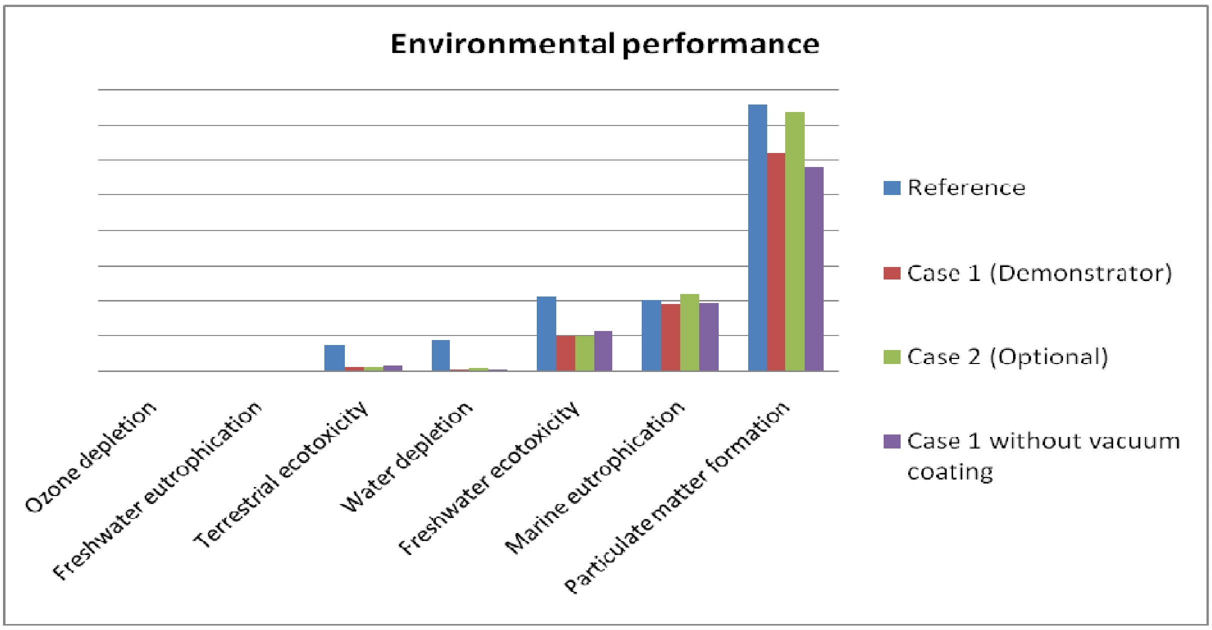


Figure 50: Weighted impacts with 7 midpoint indicators. Source C. Hohenthal, VTT.

The sustainability goals of the FlexPakRenew project have not been fully met. The product was not as market-ready as planned, due to either insufficient barrier properties of the full pilot solutions or due to the use of still laboratory steps in the manufacturing process : The barrier capacity can be improved by adding an extra layer to the developed product, but this reduces the environmental performance of the product. One of the leading goals, the amount of bio-based material utilised, has not been fully achieved in all cases.

However the results of the SWOT analysis of the FlexPakRenew Case 1 (Demonstration) and Case 2 (Optional) showed some clear positive trends in terms of ecological sustainability. In both cases, the product's climate change impact was shown to decrease, its biodegradability to increase, and its petroleum use to be reduced compared to the reference case.

During this work several achievements were gained:

- Collect the data for LCA from partners.
- Calculate the Life Cycle Assessments for the new flexible packaging demonstrators and compare to the chosen existing reference.
- Inform the partners on the research direction to improve product LCA.
- SWOT analysis from environmental social and economic point of view.
- Assessment of the environmental, social and economic effects; linking these together.
- Communicate the sustainability of renewable flexible packaging paper.

4.8. - Conclusion/Executive Summary

The objective of FlexPakRenew (www.flexpakrenew.eu) was to develop innovative flexible functional packaging solutions, using renewable resources to replace petroleum-derived barrier films. The project focused on recyclable, biodegradable products, environmentally friendly processes and was limited to the delivery of paper based multilayer barrier material for flexible packaging.

This project combined (i) upscaling of technologies/materials that were already proven at laboratory scale in former projects and (ii) the development, limited at laboratory scale, of new materials/new technologies. All the developments were done with a special attention paid to product life cycle and thorough sustainability assessment to prove environmental economic and social performance and potential for up-scaling from laboratory scale to pilot scale.

Up-scaling of proven technologies

The core of this project was to develop a medium barrier coating applicable on paper and based on water borne coatings made from a plasticized starch matrix reinforced with nanoclays. Starches were combined with several candidate bentonites and plasticizers in order to optimise the bentonite dispersion and material interactions to maximise the barrier properties while getting some coating flexibility. Considerable effort has been invested in optimizing the colour rheology to match the paper coating process requirements. A special focus was set on the selection of starch, the use of additives and the preparation protocol to get the colour at the highest solid content. During the project, the solid content of the colour was raised from 10 to 20% while water vapour transmission rate was cut by 3.

A breakthrough green chemistry process, named chromatogeny, that brings hydrophobicity to papers and boards, was developed at pilot scale. For the first time ever, it was proven that the combination of a reactive coating with chromatogeny could work at pilot scale on a reel to reel process to produce materials having a perfect water repellency and very low WVTR.

New materials/new technologies

During the project, it was proven that paper for flexible packaging has to be designed to receive barrier coating. Very important properties, such as roughness of the substrate and air permeability, could be tuned thanks to the addition of MicroFibrillated Cellulose (MFC) at the wet end of a paper machine using a spray or curtain coating technology.

A great deal of work was dedicated to finding alternatives to starch, nanoclays and synthetic plasticizers in medium barrier coating. It was demonstrated that derived hemicelluloses, i.e. xylan from birch, could be a very good matrix combining the advantages of a good barrier material, hydrophobic, heat sealable and being biosourced, not in competition with food industry. It was also demonstrated that starch nanoparticles, produced from starch granules could offer an organic, biodegradable, alternative pigment to replace nanoclays. Microencapsulation of biosourced oils into biopolymers also showed a plasticizing effect on starch based layers and could offer an alternative to oil-based plasticizers.

Vacuum coating is a proven technology used to magnify the barrier properties of plastic films. For the first time, it was shown that this very demanding process in terms of substrate properties (stable when exposed to vacuum cycles and roughness preferably lower than 50nm) could be adapted to a coated paper to deposit an inorganic layer and magnify the barrier properties.

Successful research was undertaken to develop antimicrobial coatings that facilitate a prolonged shelf life for packed food products with releasing less quantities of preservatives on the food surface. In this way, the amount of directly added preservative to the food and thus the consumer exposure to preservatives could be reduced. Both the use of preservatives in the bulk of a starch layer or embedded in capsules were assessed to modulate the preservative delivery.

In the end, FlexPakRenew demonstrated at pilot scale that a set of technologies can be combined to produce performing paper-based packaging materials with a demonstrated environmental gain. Some steps have however still to be climbed to get the cost performance and come to industrial production scale.

5. - Expected impact

5.1. - FlexPakRenew in the paper based packaging value chain

As mentioned, FlexPakRenew is a project limited to offering new material solutions for flexible packaging industry. It means that its activities concerned papermakers, converters and papermaking raw materials suppliers who are all in B2B activities (Figure 51).

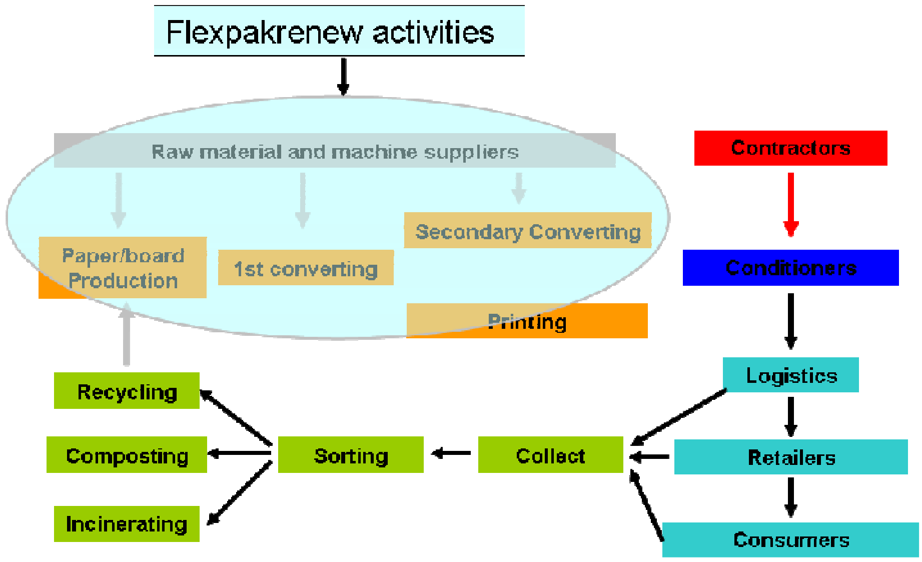


Figure 51 : Place of FlexPakRenew activities in the paper base packaging value chain.

5.2. - Flexible packaging, uses, materials, market and players

There could be many foodstuff or good that uses flexible packaging : Baking, Bread, Butter & margarine, Cheese, Coffee & tea, Confectionery, Dairy, Fast food, Pet food, Pharmacy, Soap, Soup…It is generally estimated that 75% of flexible packaging is used for food market.

The flexible packaging can either be converted or not (Table 4).

Table 4 : Example consumer goods and their corresponding flexible packages.

Consumer good[1]	Corresponding packages[1]
Coffee beans	Bags
Coffee portions	Sachets (=small, disposable bags)
Teabags	Sachets
Pet food	Bags
Sweets, chocolate	Wrappers
Chewing gum	Wrappers
Biscuits	Bags
Dehydrated food	Pouches, Bags
Sugar portions	Pouches, Bags
Yeast	Bags

The market is influenced both by small contractors (bakeries for example) or large companies such as Danone, Kraft, Mars, Nestlé, P & G, Unilever, Pepsico... that are generally considered as key market players.

The share of the 10 leading converters, according to applied market information ltd, are however limited to 25% showing the large share of small companies and a fragmented industry.

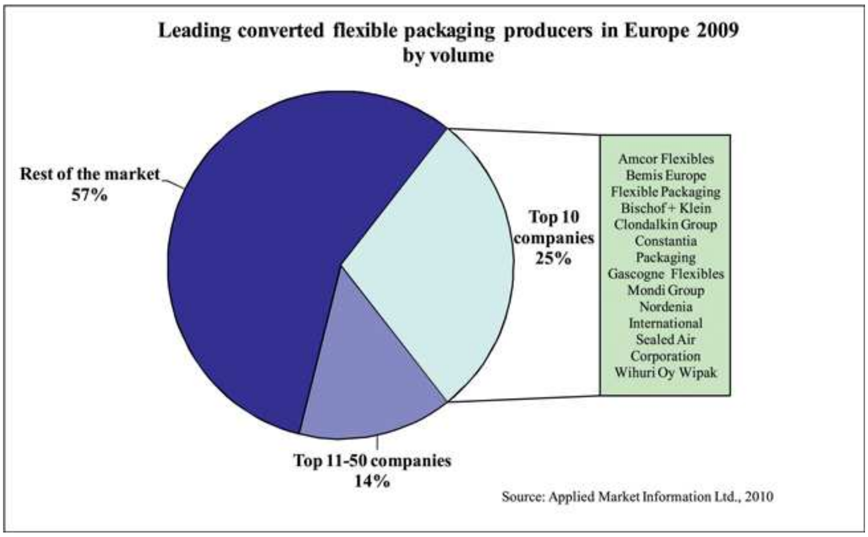


Figure 52 : Converter split per production volume. Data from applied market Information ltd.

The longer shelf-life and attractive appearance of plastic films means that they command 68 volume % of the global market for flexible packaging (Figure 53). PE and PP are the most commonly used materials.

[1] Source: Ahlstrom: http://www.ahstrom.com -> by product line -> flexible packaging papers

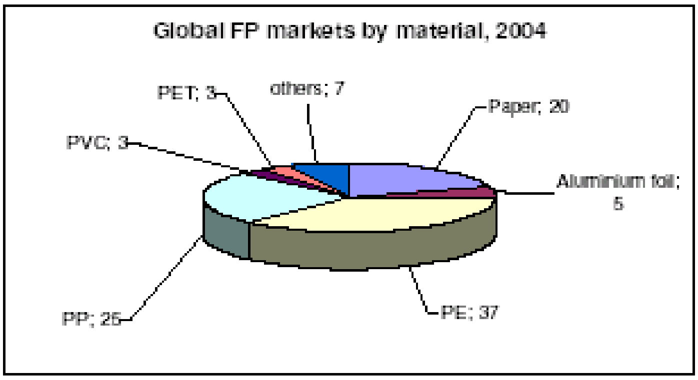


Figure 53 : Flexible packaging market share for selected materials. Source [Pira Ltd.].

FlexPakRenew developed solutions to set on the market some paper based materials that could compete with plastic materials. Its results were mainly disseminated to the scientific community and the sustainability of the solutions developed in FlexPakRenew were assessed in comparison with extrusion coated papers that is a product market leader.

5.3. - Project dissemination

5.3.1. - Website

The project uses a public website, http://www.flexpakrenew.eu/, that will be open during 18 month after the completion of the project to make the dissemination of the public documents issued during the project.

Table 5 summarizes the connection statistics about the project.

Website	Number of connection June –December 2009	Number of connection January-December 2010	Number of connection January-July 2011
Public	1847	6483	4730
Secured (extranet)	1550	2244	1200

Table 5 : FlexPakRenew, website statistics.

A increase of the visits can be seen at the beginning of 2010 which is probably linked to the dissemination done in “Emballage Digest”. The 2011 figures are probably due to the workshop and to the first disseminations about the project that were done in 2010.

5.3.2. - Dissemination thanks to publications and presentations

The dissemination of the most prominent results of the project during the second period were made either thanks to publications (about 10 papers have or are being issued) or thanks to presentations. 36 presentations were given in conferences or symposium to an estimated audience of 3500 specialist of the fields.

5.3.3. - Patents

During this project two applications of patents were reported to the coordinator :

- A patent application entitled « Machine et procédé de traitement par greffage chromatogénique de susbtrat hydroxyle » was prepared by CTP and CNRS and submitted to INPI -the French patent office – on November 16th, 2011. This patent described the processes used on CTP’s chromatgeny pilot machine.

- A patent application was prepared by VTT and submitted on August 5, 2011 to protect the invention described in D3.10 related to the heat sealability of xylan fatty acid esters layers.

5.3.4. - FlexPakRenew public Workshop

A public workshop was organized in Lyon Airport on May 10th, 2011 to disclose the main results of the project. The event was entitled “FlexPakRenew – Latest results and main advances – Innovating in fibre based flexible packaging through water based barrier coatings, antimicrobial coatings, nanotechnologies and life cycle analysis”.

The marketing of the event was done by all the partners who was responsible for marketing the event in its own country. Fraunhofer-IVV has covered Austria besides Germany. CTP has covered Italy / Spain / Belgium / Netherlands besides France. The event was advertised several thousands of specialist of the field.

FlexPakRenew workshop was made of 4 sessions during which 13 presentations were disclosed (Table 6).

#	Title of talk	Authors
1	Trends in functional and barrier paper-based packaging	David Guérin / CTP
2	Introduction to FlexPakRenew	David Guérin / CTP
3	The role of LCA in guiding projects	Catharina Hohenthal & Sini Veuro / VTT
4	Biomaterials in current uses and the focus in FlexPakRenew	David Guérin & Florence Girard / CTP, Julien Bras / Grenoble INP Pagora
5	Xylan from wood biorefinery – A novel approach	Riku Talja & Kristiina Poppius-Levlin / VTT
6	Starch Nanocrystals: the new Bionanoparticles ?	Déborah Le Corre & Julien Bras & Alain Dufresne / Grenoble INP Pagora
7	Biobased microcapsules improving the converting properties of packaging	Artur Bartkowiak & Agnieszka Romanowska-Osuch / West Pomeranian University of Technology
8	Starch coatings – Striking a balance between the benefits and the drawbacks	Hanna Christophliemk & Henrik Ullsten & Caisa Johansson & Lars Järnström / Karlstad University, Chris Breen & Francis Clegg / Sheffield Hallam University, Frédéric Bébien / Ahlstrom
9&10	Positive outcomes from FlexPakRenew / The challenges remaining	
11	Upscaling laboratory studies to pilot processes	
12	Antimicrobial coatings: state of the art and recent advances	Peter Muranyi /Fraunhofer IVV, Artur Bartkowiak & Patrycja Suminska / West Pomeranian University of Technology
13	Organic & inorganic nanolayers to improve barrier properties	Klaus Noller & Markus Schmid / Fraunhofer IVV, David Guérin / CTP, Camélia Stinga / Cermav-CNRS

Table 6 : Conferences disclosed during the workshop.

5.3.5. - Conclusions on dissemination

The dissemination was mainly addressed to specialists which is quite logical since the project was centered around the production of new unconverted paper based material for packaging.

Partners were really committed to deliver their results to the scientific and engineer community involved in flexible packaging.

One must notice that this project has reinforced two patents existing before the project starts, has led to two new patent application and to one patent in application preparation.

5.4. - Sustainability of FlexPakRenew products

This chapter is a copy extracted from the public report issued at the end of the FlexPakRenew project.

The references of this report are : "D6.6: Sustainability Assessment for Renewable Biopolymer-Based Flexible Packaging Paper", Hohenthal Catharina (VTT),Veuro Sini (VTT) and Kuisma Mika (Aalto). This report will be made available on FlexPakRenew public website www.flexpakrenew.eu.

5.4.1. - Sustainability targets of the FlexPakRenew project

The objective of the FlexPakRenew project was 'to design and develop an innovative eco-efficient low-substrate flexible paper for packaging from renewable resources to reduce the packaging industry's reliance on barrier films derived from petroleum'. The technical challenges of the project were related to all dimensions of sustainability, namely economic development, social development and environmental protection. As a consequence, the sustainability goals of the project could not be met without successful scientific as well as technological development.

While achieving the technological goals was a prerequisite for the success of the project, technological development does not automatically lead to improved environmental performance. This is due to the fact that changes in the production process or raw materials may have unintended consequences in the life cycle of a product. A sustainability assessment therefore needed to be conducted as part of the project.

The most important sustainability goals and competitive advantages related to the new packaging material were defined in the project plan and are listed in Table 7.

Table 7 Sustainability targets of the FlexPakRenew project.

SUSTAINABILITY TARGETS			
Environmental goals	Economic goals	Social goals	Technical goals
Recyclable product *Biodegradable in less than 6 months* *Reduced amount of packaging going to landfill* *Reduced use of petroleum-based materials in packaging* *Increased use of bio-based materials in demonstrated package (barrier layer 70% bio-based)* *Reduced greenhouse gas emissions* *Improved environmental performance during the product life cycle*	*Competitive compared to petroleum-based solutions* *Improved process efficiency* *New business opportunities for fibre-based packaging* *Europe strengthens its position as lead market in the area of fibre-based flexible packaging*	*Compliance with direct food contact legislation* *Free of odour and taste* *Increased shelf life of (food) products* *Reduced amount of packaging going to landfill* *Promotion of sustainable packaging*	*High barrier level* *Antimicrobial action* *Easy processability* *Compatibility with standard papermaking and converting equipment* *Transferability to other packaging grades*

The performance of the new material related to environmental, economic and social goals was evaluated during the project.

In the sustainability assessment framework, the specific sustainability goals of the FlexPakRenew project are complemented with more general sustainability demands related to fibre-based packaging. Potential environmental aspects and impacts have been evaluated applying life cycle assessment. Furthermore, screening of the potential economic and social impacts and evaluation of the competitiveness of the new packaging material have been conducted.

The sustainability assessment methodology applied in the FlexPakRenew project is presented in one project deliverable D6.3 'Definition of the sustainability methodology' (Pihkola & Kuisma 2010 – Public). Environmental evaluation is based mainly on life cycle assessment (LCA). The LCA approach applied in the FlexPakRenew project has been described in project deliverables D6.1 and D6.2 (Hohenthal 2009 - Restricted; 2010 - Public). The guidelines for data collection were presented in deliverable D6.4 'List of data to be delivered by other WP partners in order to carry out sustainability assessment' (Restricted).

5.4.2. - Results of the environmental assessment

Results of the LCA calculations are presented in this chapter. Three LCA indicators have been selected based on the sustainability goals of the FlexPakRenew project. The indicators are: impact on climate change; impact on fossil resource depletion; and the total weighted impact assessment results showing the improvement in environmental performance.

To be able to evaluate the sustainability of a raw material or a product, the whole life cycle must be considered. The life cycle of a product consists of '*consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal*' (ISO14044). Life cycle thinking means that the producer should consider the potential impacts of the product through all stages of the product life cycle. By conducting a systematic overview, the risks of shifting potential environmental burdens between different life cycle stages or individual processes can be recognized and possibly avoided (ISO 14040).

The principles of life cycle thinking have been emphasized in many EU policies. Examples of recent policies include the Integrated Product Policy Communication, the two Thematic Strategies on the Sustainable Use of Natural Resources, and the Prevention and Recycling of Waste (for more information see, e.g., http://lct.jrc.ec.europa.eu/).

End of Life and Material Recycling are excluded from the LCA calculations. However, raw materials have been evaluated separately for their biodegradability and recyclability and the results are presented in Deliverable 6;6 and LCIA – ReCiPe method.

Once the project goal and scope have been determined and the data has been collected, an inventory result is calculated. This inventory result usually consists of an exhaustive list of emissions, consumed resources and other possible items, and can be difficult to analyse and interpret. Life cycle impact assessment (LCIA) procedures, such as the ReCiPe method, are designed to facilitate the interpretation of this inventory data.

The primary objective of the ReCiPe method is to transform the long list of inventory results into a limited number of indicator scores. These indicator scores express the relative severity of an environmental impact category. In ReCiPe, the indicators are determined at two levels: the midpoint (18 indicators) and the endpoint (3 indicators).

The midpoint method contains factors in accordance with the Hierarchic Cultural Perspective, which is a consensus model that assumes a long-term perspective. Here, we concentrate on the midpoint indicators as the uncertainty of the end point indicators is much higher. For the KCL-ECO software, the following (14) midpoint impact categories were chosen [units in brackets]:

- Climate change as GWP100 [kg CO2 eq.]
- Ozone depletion as ODPinf [kg CFC-11 eq.]
- Human toxicity as HTPinf [kg 1,4-dichlorobenzene eq.]
- Freshwater ecotoxicity as FETP inf. [kg 1,4-dichlorobenzene eq.]
- Marine ecotoxicity as METP inf. [kg 1,4-dichlorobenzene eq.]
- Terrestrial ecotoxicity as TETP inf. [kg 1,4-dichlorobenzene eq.]
- Photochemical oxidant formation as POFP [kg NMVOC]
- Acidification as TAP100 [kg SO2 eq.]
- Fresh water eutrophication as FEP [kg P eq.]
- Marine eutrophication as MEP [kg N eq.]
- Water depletion as WDP [m3]

- Metal depletion as MDP [kg Fe eq.]
- Fossil resource depletion FDP [kg oil eq.]

The ReCiPe method was chosen as it is recommended for most of the indicators by the EU Commission ILCD Handbook. For more information on the ReCiPe method, see http://www.lcia-recipe.net/.

5.4.3. - Results of the life cycle assessment

One of the key environmental goals of this project was to reduce greenhouse gas emissions (GHGs). GHG emissions minimisation was therefore a prime focus of the flexible packaging options examined. This target goes hand-in-hand with minimisation of fossil resource depletion, i.e. the use of fossil resources, and, consequently, increased use of bio-based materials.

5.4.3.1. - Impact on climate change

Whereas water vapour is the main greenhouse gas, carbon dioxide (CO_2), methane, nitrous oxide, chlorofluorocarbons and ozone are also important GHGs. The impact on climate change is calculated by multiplying each GHG emission by a characterization factor and adding them together. The impact on climate change is expressed as CO_2 equivalents.

The following Figure 54 shows the impact on climate change in four different cases according the ReCiPe LCIA-method. 3 variations of FlexPakRenew product were compared to one reference (conventional extrusion coated paper). PLA is added as an extra reference in order to see how the flexible packaging compares to an existing competitive packaging product.

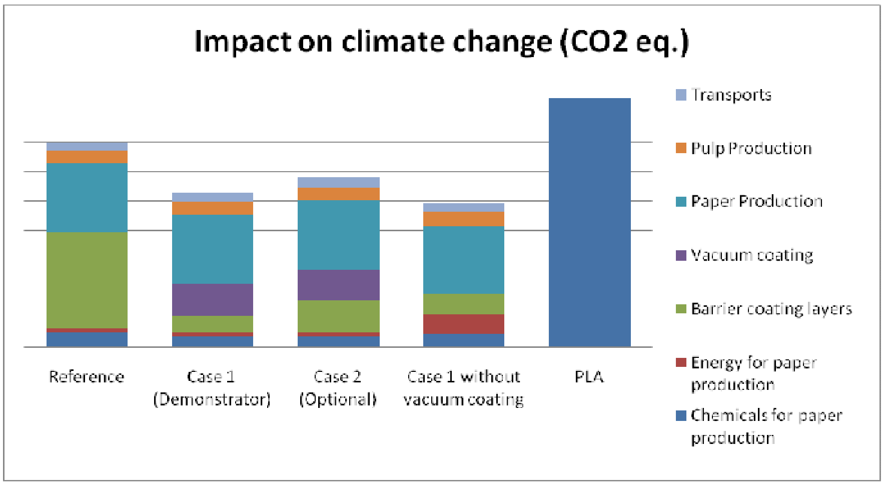


Figure 54 Impact on climate change.

As can be seen from Figure 54 above, the reference case has the biggest climate change impact. Case 1 (Demonstration) of the FlexPakRenew cases has a lower impact on climate change than Case2 (Optional). The differences arise from the barrier coating layers, as starch production causes more GHG emissions than clay production. In the FlexPakRenew cases, the most energy-intensive phase of production is the production of the substrate (paper production). Vacuum coating accounts for the second biggest share of the impact on climate change. The FlexPakRenew case without vacuum coating therefore has the lowest negative impact on climate change. In the reference case, the production of lamination materials has the biggest share.

Broadly speaking, use of electricity itself cannot be stated as a source of GHGs, but the fuel mix used to produce the electricity affects the GHG emissions result. For example, if French electricity is used instead of German, the climate change impact result is lower since in France the electricity fuel mix contains more nuclear energy, which has lower GHG emissions compared to the German fuel mix, which uses more coal.

5.4.3.2. - Impact on fossil depletion

As shown in Figure 55, the fossil depletion impact category is highest in the reference case. Case 1 (Demonstration) has the lowest fossil depletion effect. Case 1 without vacuum coating is higher than Case 1 (Demonstration) due the differences in the barrier layers. In Case 1 without vacuum coating, instead of vacuum coating SiO_2 and potassium sorbate are used. These materials also increase the energy usage in the chemicals/fuels for paper production stage.

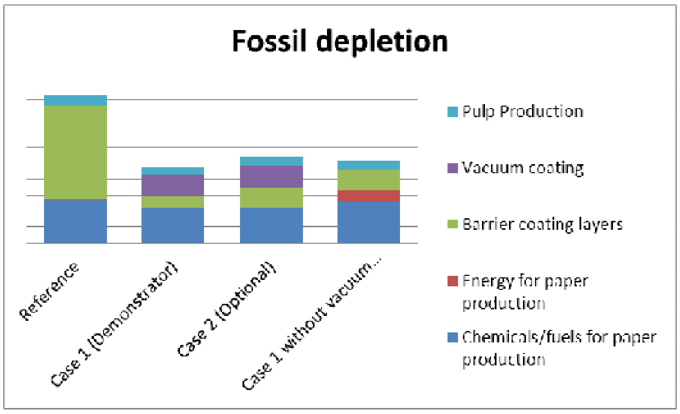


Figure 55 Impact on fossil depletion.

5.4.3.3. - Environmental performance improvement: Weighted impact assessment results

The total environmental performance of the cases are presented in Figure 56 and Figure 57. The performance is presented with weighted impact assessment results. The figures are not presented on the same scale: the scale in Figure 56 is greater than in Figure 57, with the environmental performances of the first seven indicators being higher than the last seven indicators.

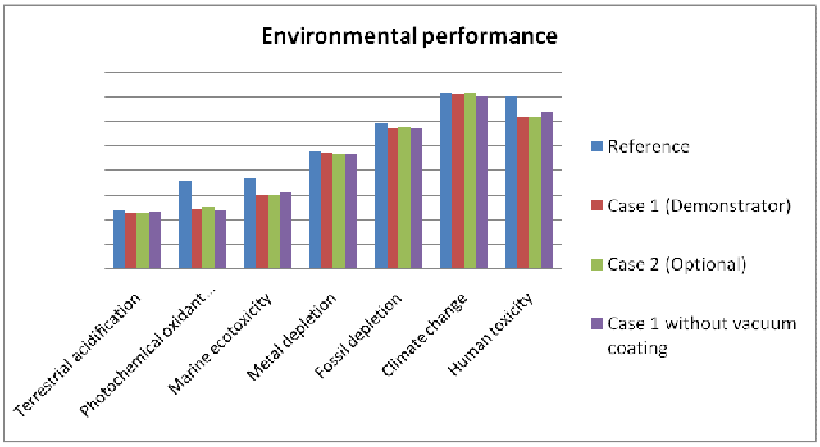


Figure 56 Weighted impacts with 7 midpoint indicators.

As can be seen from Figure 56, according the ReCiPe LCIA method, the biggest impacts of both the reference and the FlexPakRenew cases are on climate change. The second highest impacts are on human toxicity and third highest on fossil depletion. The reference case has the highest impact on marine ecotoxicity due to the manufacture of lamination materials.

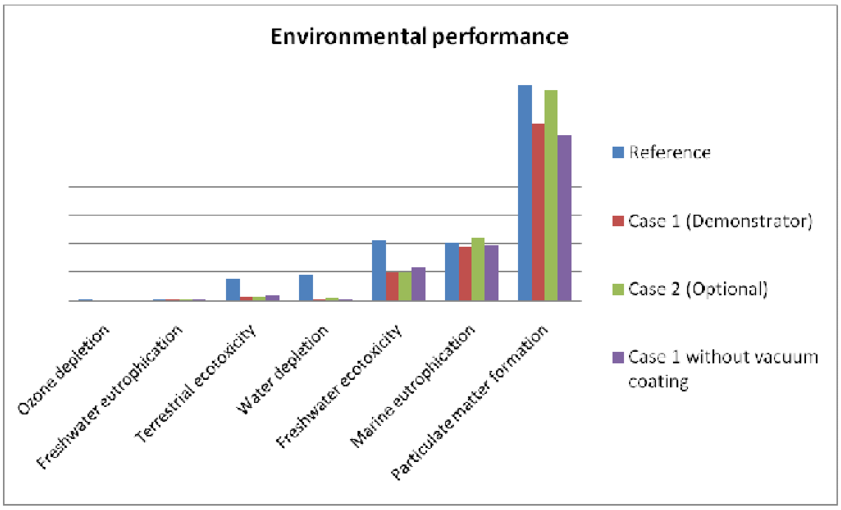


Figure 57 Weighted impacts with 7 midpoint indicators.

Furthermore, particulate matter formation and marine eutrophication are also affected by these cases. Case 2 (Optional) has a greater impact on these categories than Case 1 due to NO_x emissions from starch cultivation and production.

Case 1 (Demonstration) seems to be the best alternative according to this midpoint assessment. It has the best results across the 14 categories and performs worse than the reference only in one category. Case 2 (Optional) and Case 1 without vacuum coating also perform better than the reference case. Case 2 outperforms the reference case in 13 categories and Case 1 without vacuum coating in 14 categories.

5.4.4. - Cost evaluation

The cost of production is a key consideration in sustainability assessment. The investment costs have not been analysed in detail, but according to the questionnaires returned by the FlexPakRenew project partners, investment costs will not be high. One technical goal of the project was ‘Compatibility with standard papermaking and converting equipment’. This has guided the development work and the pay-back time for investments is estimated to be relatively short.

Figure 58 compares the evaluated price of the coating layers and total product based on raw material costs. This assessment includes three models: the reference case, Case 1 (Demonstration), and Demonstration 3. Demonstration 3 is the addition of non biosourced polymers to Case 1 to get exactly the same barrier properties than Reference case. Demonstration 3 has not been produced during the demonstration activity of the project.

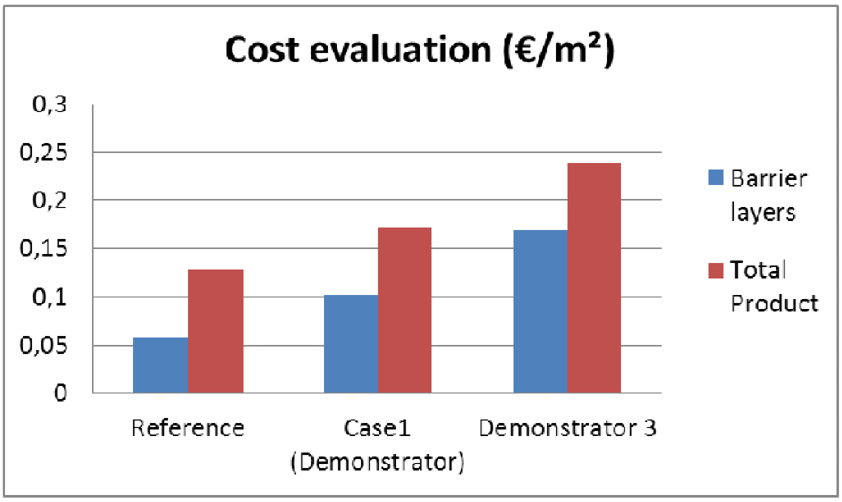


Figure 58. Cost evaluation of the reference case, Case 1 (Demonstration) and Demonstration 3.

The cost information can change according the production scale. Currently, it appears that the production cost for the reference case is lower than for both Case 1 (Demonstration) and Demonstration 3. The data for the reference case comes from public data sources and for other two cases conducted by the project partners. This might also have an effect on the final cost result. The cost for Demonstration 3 is highest due to the extra coating layer.

As expected, the cost of the FlexPakRenew cases is also higher. In development projects a new product is often more expensive because it includes all negative externalities of production. The production of products which have been on the market for a long time is usually highly optimised. This has not yet happened for this production system as it is still in its development phase, but it must be noticed that the cost evaluation of FlexPakRenew products are not extremely far from the market.

5.4.5. - Conclusions on Sustainability assessment of FlexPakRenew products

The sustainability goals of the FlexPakRenew project have not been fully met. The product was not as market-ready as planned, due to either insufficient barrier properties of the full pilot solutions or due to the use of laboratory steps in the manufacturing process : The barrier capacity can be improved by adding an extra layer to the developed product, but this reduces the environmental performance of the product. One of the leading goals, the amount of bio-based material utilised, has not been fully achieved in all cases.

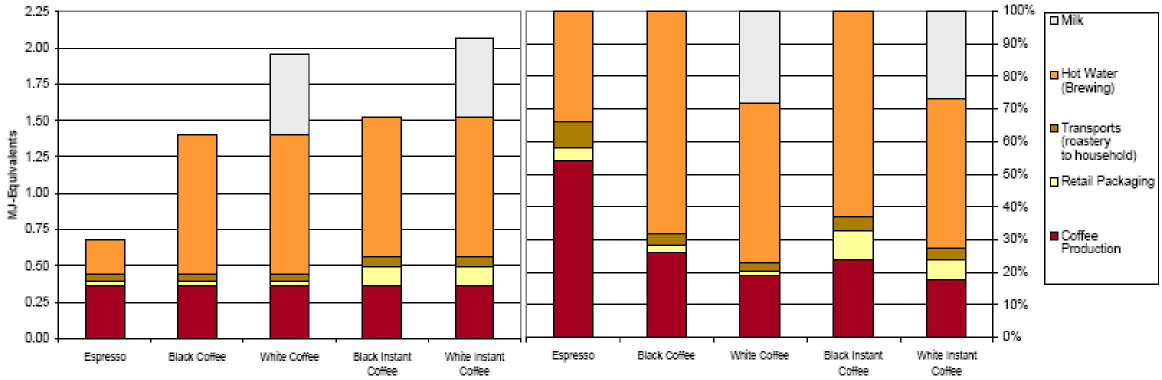
However the results of the SWOT analysis of the FlexPakRenew Case 1 (Demonstration) and Case 2 (Optional) cases showed some clear positive trends in terms of ecological sustainability. In both cases, the product’s climate change impact was shown to decrease, its biodegradability to increase, and its petroleum use to be reduced compared to the reference case.

There seems to be considerable uncertainty, and thus weakness, in terms of the economic and technical dimensions of the solutions. The barrier properties of some FlexPakRenew cases were insufficient and the positive effect of the antimicrobial layer was uncertain. The technical barrier targets could be achieved but at the expense of some of the environmental advantages of the product.

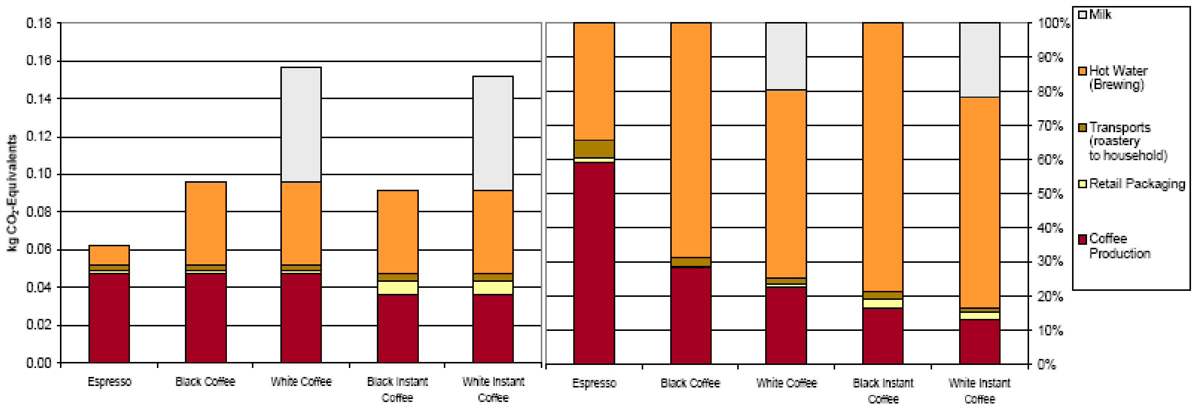
The Demonstration and Optional cases both offer several opportunities for increased material efficiency in society: reduced landfill waste and increased shelf life are likely to bring about favourable developments at the household level and in society in general. Increased material efficiency combined with reduced petroleum use and higher biodegradability is in line with the modern consumer trends that value health and sustainability. The increasing proportion of health and sustainability conscious consumers amongst the adult population may also pose a threat to the acceptance of the new materials as long as there is uncertainty regarding the health and ecological impact of the materials used.

The new packaging materials assessed in the two cases offer opportunities to improve the image of packaging in several ways. If successful, they may even create new business opportunities for the European fibre-based packaging industry.

Current public opinion is not favourable towards packaging in general, despite the fact that it is necessary for the delivery, storage and protection of all products. It is thus often reported that most environmental impacts occur during primary production of the foodstuff and can not be attributed to the packaging as illustrated by



Results of the standard case for a cup of coffee with regard to the non-renewable cumulative energy demand. Left are shown the absolute values and on the right side the results are scaled to 100 %.



Results of the standard case for a cup of coffee with regard to the global warming potential. Left are shown the absolute values and on the right side the results are scaled to 100 %.

Figure 59 : Impact of products, transports and packaging on the energy demand and global warming of a coffee cup. Source Sybille Büsser, Roland Steiner, Niels Jungbluth, "LCA of Packed Food Products - the function of flexible packaging", ESU-services Ltd., Uster, Switzerland, January 2008. Report commissioned by Flexible Packaging Europe (FPE) ; www.flexpack-europe.org

According to Sybille Büsser, Roland Steiner and Niels Jungbluth : "*The study shows: the most relevant environmental aspects for a cup of coffee is brewing (i.e. the heating of water) and coffee production compared to transport and retail packaging which are of minor importance. Brewing and coffee production have a considerable impact share between 82 percent (ozone layer depletion, black instant coffee) and 99 percent (eutrophication, black coffee) In the case of white coffee the milk added is of great environmental relevance*".

When launching a new packaging solution, effective communication will be necessary to inform consumers about the positive sustainability features of the solution and to avoid consumer uncertainty regarding the new materials. Only a comprehensive sustainability assessment can lead to a truly sustainable product.

6. - List of all beneficiaries/Contact Names

Beneficiary name	Country	Contact person
Centre Technique du Papier	**France**	David Guérin, project coordinator David.Guerin@WebCTP.com
Ahlstrom Research and Services	**France**	Frédéric Bébien frederic.bebien@ahlstrom.com
Cargill Industrial Starches	**Germany**	Timo Mäkärainen Timo_Makarainen@cargill.com Andreas Becker Andreas Becker@cargill.com
Fraunhofer Institüt vür verpackung	**Germany**	Claudia Schönweitz claudia.schoenweitz@ivv.fraunhofer.de
Karlstad University	**Sweden**	Lars Järnström lars.jarnstrom@kau.se
Sheffield Hallam University	**United Kingdom**	Chris Breen c.breen@shu.ac.uk
West Pomeranian University of technology	**Poland**	Artur Bartkowiak artur-bartkowiak@zut.edu.pl
Valtion Teknologian Tutkimuskeskus	**Finland**	Kristiina Poppius-Levlin kristiina.poppius-levlin@vtt.fi
Centre National de la Recherche Scientifique	**France**	Camelia Stinga Camelia.Stinga@Cermav.Cnrs.Fr
Institut Polytechnique de Grenoble	**France**	Julien Bras julien.bras@Pagora.Grenoble-Inp.fr