

## **Executive Summary:**

The EC project FORBIOPLAST grant agreement no. 212239, selected by EC as a star project, started on the 1st July 2008. The research activity in FORBIOPLAST have been focused on the use of by-products from wood industry as raw materials for the production of composites with biodegradable and recycled polymers as well as for the production of hard and soft polyurethane foams by innovative sustainable synthetic processes with reduced energy consumption. The materials produced in the project are devoted to applications in automotive interior parts and in the packaging and agriculture fields.

The consortium coordinated by Prof. A Lazzeri of the University of Pisa had a very positive interaction among the members as attested by the regular reaching of the scheduled deadlines. The researchers: University of Pisa (UNIPi-Italy), University of Budapest (LPRT-Hungary), the Latvian State Institute of Wood Chemistry (IWC-Latvia), University of Almeria (UAL) and Fundacion CARTIF (CARTIF) (Spain), University of Bucharest (UASVM-Romania), Organic Waste Systems (OWS-Belgium-SME), Norconserv-Nofima A.S. (NORC-Norway-SME) constantly cooperated with the producer: PEMU Plastic Processing Co. (PEMU-Hungary-IND), RODAX (RODAX-SME) and Incerplast (INCP-SME) (Romania), Ritols Ltd. (RIT-Latvia-SME), and with the end users FIAT Research Centre (CRF-Italy-IND), Neochimiki (NEOC-IND) and Cosmetic (COS-SME) (Greece) with the inputs of Wiedeman (WIED-Germany-SME) a market expert in the exploitation of environmentally friendly materials.

The FORBIOPLAST website is on line with the following address: <http://www.forbioplast.eu>. The logo of the project is visible on the Project website and aims to outline the innovation in the valorisation of forest resources perceived in the project. The website is divided into a public area for all the users and into a restricted area for beneficiaries and selected members of the Industrial Advisory Board. The public area reports a presentation of the project, abstract, objectives, and the contact details of beneficiaries as well as the news letter and the publishable news about the meetings and images of the prototypes produced.

The cooperation of researchers with industries has lead to the production of prototypes of soft and rigid foam produced by lignin and wood by-products, eventually containing wood fibres. Hard polyurethane foams were used to produce a T-node (40x40 cm) part and a spoiler (1.4 m) for automotive applications. Soft polyurethane foams produced by lignin were proposed for applications in packaging, insulation and both as support for the growth of ligninolytic micro organism.

The most promising recipes selected by researchers based on recycled polypropylene and wood fibres were used to produce the granules, by industries, shipped to the industrial partner that performed injection moulding trials and produced prototypes of a car seat.

They were produced items for agriculture and packaging applications with formulations based on biodegradable polymeric matrices and wood fibres. Materials were also prepared with wood fibres pre-treated by the addition of waxes and with wood fibres modified by enzymes. Tomato yarns were tested in trials set in green houses and in open fields. Some of the prototypes prepared fulfilled the requirements of the cultivar cycle. These tomato yarns can be collected with the organic remaining of the tomato harvest and sent to a compost plant. Tests were also organised to the transplanting pots and in packaging for the trays, and egg containers.

Some slow release fertilizers were prepared as sticks based on starch and wood fibres enriched with Nitrogen-Phosphorus-Potassium (NPK) components.

The materials produced for packaging applications were tested for properties relevant to packaging (sealing ability, permeation to gas and water, toxicity etc). The end users producers of cosmetics products and of chemicals performed tests on the containers produced for packaging on their products.

International patents were applied for the production of polyurethane and their use as substrate for growth of ligninolytic microorganism, as well as for the production of co-polymers and blends based on polylactic acid. Industrial partners and RTD are carrying on the exploitation of FORBIOPLAST products in particular for fertilizer sticks, tomato yarns and pots, biodegradable materials for packaging and composites with recycled polypropylene and wood fibres for automotive applications.

## **Project Context and Objectives:**

As reported in the Description of Work, the objectives of the FORBIOPLAST project were:

- valorisation of forest resources for bio-based products production;
- identification of the best ways for industrial exploitation of forest biomass at European scale;
- production of polyurethanes from materials based on renewable resources;
- development of improved technologies with regard to the present industrial synthesis of polyurethane and target of an industrial scale up of the process;
- replacement of glass fibres and mineral fillers with wood derived fibres in automotive interior and exterior parts;
- development of biodegradable polymer/wood derived fibre composites for application in the packaging, cosmetic and agriculture fields;
- bio-valorization of FORBIOPLAST products after their use
- eco-sustainability evaluated by LCA studies in the production chain of FORBIOPLAST products

Forest Resource Sustainability through Bio-based Composite Development (FORBIOPLAST), a Large Collaborative Project, coordinated by Professor Lazzeri, University of Pisa, supported by European Union (Grant Nr. 212239) within 7th Framework Programme, is aimed at valorization of forest biomass feedstock by development of bio-based composites and products. The project started in July 2008 and was concluded in June 2012.

FORBIOPLAST strives for developing, producing and marketing composites composed of recycled polypropylene or various bio-based and biodegradable plastics and components deriving from wood processing, such as wood flour and fibres. Additionally, lignin and tall oil, as abundant and low cost by-products entailed within pulping processes, served as raw material for different types of polyurethanes.

In FORBIOPLAST lignin was valorised for the production of polyurethane by green synthesis. Soft polyurethanes were produced by from lignin. Lignin dissolution trials were optimised by micro wave technology. The process was optimised and interesting samples produced. Raw materials for the production of hard foams polyurethane were identified, such as tall oils and fatty acids provided by Forchem, a Finnish industry leader in the production of crude tall oils. Hard and soft polyurethane foams were produced and characterized. They were selected formulations for the production of foams meeting the specification required by

applications as automotive parts, and both a T-bar prototype and a spoiler were produced in cooperation among producers and end users. The properties of these materials were reported in a Data base for the correlation between the physical-mechanical characteristics of PUR-PIR foams and synthesis and raw material parameters. The hard polyurethanes were also used to produce containers for packaging of fish. Other applications can be envisaged in building as insulation materials. As well soft polyurethane can be exploited in packaging, insulation, filling of seats, etc.

In the first two years of the project, they were selected the wood fibres to be used for composites production. Raw fibres for composite production were acquired from La.So.Le (LS), Italy, as low cost fibres (type 200/150E) and Filtracel EFC 1000 (R) (Rettenmeier AG) (R), Germany, as more expensive but higher quality fibres. An accurate characterization was performed on both wood fibres including aspect ratio, density, chemical, physical and morphological analysis.

The extensive research activity on coupling of wood fibres with recycled polypropylene and biodegradable polymers achieved positive results which were reported in the relevant deliverables of WP4 and WP5.

Thus results of WP4 were positively shifted to WP5. They were produced prototypes of items based on recycled polypropylene (rPP) and wood fibres in cooperation with the end users, and with the inputs of the researchers. The best performing formulation were selected and produced on large scale to be used for industrial trials in WP7.

The results of the activity performed in WP2 and WP4 were applied in WP6. Wood fibres from LS and from R were pre-treated with polypropylene waxes water based emulsion and compounded with polypropylene (PP), polyhydroxybutyrate (PHB), and PLA with positive results on composites modulus. The formulations based on biodegradable polymers to be produced on industrial scale have been selected and prototypes were produced. The properties relevant for packaging and agriculture applications were evaluated in green houses and on packaging equipments. This activity was reported in the deliverables of WP6.

They were produced items for packaging and agriculture on industrial scale, such as tomato yarns, pots, containers for cosmetics and for chemicals. They were also produced egg containers and food trays by thermoforming, and balcony pots by injection moulding.

The prototypes were tested for toxicity, for agriculture applications and for properties relevant to packaging. The materials were also validated for applications in food packaging, and it was evaluated the degradability and the anaerobic digestion. They were collected the data for the LCA and performed the analysis on the selected demonstrators. The positive effect on the environment of FORBIOPLAST products is mainly related to the production of compostable material and to the use of material derived by renewable resources. A LCA was performed on the production of a car seat produced with rPP and wood fibres. A lower environmental impact was observed for composites produced with 20% of wood fibres compared to a car seat produced with virgin PP and glass fibres.

They were also developed fertilizer sticks based on starch/Rettenmaier. These are environmental friendly fertilizers for flowers that promote plant growth and flowering. This material also seems to stimulate biodiversity of soil microbial population, including those microorganisms involved in long-term maintenance of fertility. Because of this property the developed starch/Rettenmaier compounds may be used for bioremediation processes as biostimulants agents.

The validation of the FORBIOPLAST demonstrators for application in food packaging, in packaging of cosmetic, in packaging of chemicals, and for application in agriculture has allowed optimising the materials produced and meeting the requirements of end users and producers. The market analysis, regularly updated, during the project, has also contributed to direct the selection of materials and targeted product to meet the needs of European and international market envisaging the industrial exploitation of FORBIOPLAST demonstrators.

Apart from components, materials and products for the core application fields agriculture, automotive and packaging, FORBIOPLAST research has created knowledge which was protected by patents, such as a heat resistant PLA/PC co-polymer, transparent films based on PLA, and bio-based polyurethane-composites for immobilization of microorganisms.

It was organised an International Conference Bio-based Polymers and Composites with the abbreviation BiPoCo 2012. A website was launched (<http://www.bipoco2012.hu>) as the primary communication channel for the public. Two types of keynote presentations were selected: two focusing on the topic covered by the plenary lecture presented before them and three presenting the FP7-projects related to the conference (FORBIOPLAST, BIOSTRUCT and WOODY), having their own dedicated block in the scientific program. In all 94 oral lectures were presented and to extend the number of presentations two poster sessions were organized where topics were extended but harmonized with oral sessions. 110 poster presentations were selected to display. A poster-award was also announced and 6 posters were selected and rewarded by an international scientific jury. As the topic of three keynote presentations were about EC founded research projects, the conference emphasized the

role of the European Commission in large scale international research projects. 8 oral and 18 poster presentations were presented by FORBIOPLAST partners and 30 from all the partners of the three projects disseminating the results and foreground knowledge obtained during the EC founded FP7 projects.

The FORBIOPLAST website is successfully online and will be kept running for next five years. Strong endeavours and the coherent collaboration within FORBIOPLAST, supported by European Union, lead to new knowledge and excellent results towards to be broadly introduced onto the market. For these reasons FORBIOPLAST is reported as a star project, and the consortium agreed to apply for FORBIOPLAST2, as demo action. This new proposal is focused on the exploitation of materials devoted to agriculture and packaging applications. Due to the stop of activity of partner INCP, the coordination of FORBIOPLAST2, is proposed under a new partner, Tecnopack, a Spanish SME, specialised in the production of packaging materials and items produced by injection moulding, thus covering also production of pots and tomato yarns.

## **Project Results:**

WP1: State of art Requirements and specification (WP Leader: 01-UNIPi) (sm1; em9)

Task 1.1 State of the art (Task Leader: 01-UNIPi) (sm1; em6)

Task 1.2 Technical requirements (Task Leader: 08-CRF) (sm1; em9)

WP1 was completed during the first year of activity in FORBIOPLAST. State of the Art Requirements Specification was performed from 1st Month to 9th Month. WP1 was divided in two tasks: Task 1.1 State of the art and Task 2.1 Market analysis on raw materials.

The objectives of WP1 were the following:

- to study the state of the art of forest derived materials;
- to study the technology for processing forest derived materials;
- to identify technical requirements of FORBIOPLAST products for end users.

Relevant Deliverables: D1.1 "State of the Art due to the 6th Month, and D1.2 Technical Specification for Targeted Products due to the 9th Month, were completed in scheduled time. A publishable part of D1.1 State of the Art was also prepared and loaded on the public area of the FORBIOPLAST website.

UNIPi coordinated the update of literature and patents on materials object of the FORBIOPLAST activity, this involved all the beneficiaries. The data on the characterization found in the literature have been relevant for the selection of the wood fibres performed in WP2. The analysis of the state of the art on polyurethanes, mainly performed by IWC, RIT, and UNIPi, considered both natural oils and methods for delignification of lignin to be later reacted to produce polyurethanes. Beneficiaries LPRT and UAL performed an update on modification of natural fibres by chemical and enzymatic pathways while LPRT reported a study on fibre properties and their effect on composite properties. It was also performed a screening of possible compatibilizers to be used for the production of composites materials.

All these data resulted of significant importance for the activity performed in FORBIOPLAST and allowed the industrial partners to enlarge their scientific knowledge and then improve their technical performances.

In Task 1.2 CRF leaded a technical analysis performed in cooperation with all the beneficiaries. The technical analysis is the basis for the risk assessment of the project. Together with the definition of technical specifications, major problems were outlined and evaluated, leading to a risk analysis outlining solutions to overcome the possible problems that could be encountered during the development phase. In particular RIT, INCP, RODAX, NORC, NEOC and COS outlined the technical requirements for packaging; with relevance to packaging of food, fertilizers, and cosmetic.

PEMU, CRF, RIT outlined hot spots for foams production and car interior components. Data were integrated with inputs from the market analysis performed by WIED at European and world level. D1.2 Technical Specification for Targeted Products is the product of this analysis.

Three main fields of applications were identified:

- agriculture;
- automotive;
- packaging;

After internal discussion and considering information enclosed in D1.1 State of the art on forest materials and processing technologies, in order to focalize the efforts in agriculture and packaging field, these products were selected to be developed at prototype level: tomato yarn, trans planting pots, encapsulated fertilizers, cream jar, chemical container, trays, foams for transport of fish.

For tomato yarn elongation over 20% was suggested by INCP and by UASVM.

For other general packaging applications mechanical properties should be in the range: Modulus 350-450 MPa, Tensile Strength 53 MPa, Elongation 2.4-10%.

In the automotive sector car seat, insulation and spoiler were selected for development at prototype level.

Technical specifications for car seat based on recycled polypropylene (rPP) and wood fibres:

- density: 0.95-1.15 g/cm<sup>3</sup>
- flexural modulus: 1.4-3.0 GPa
- yield strain: > 2 %
- yield stress: > 25 MPa



- impact strength: > 15 kJ/m<sup>2</sup>

The other two prototypes, the spoiler and the material for insulation have been based on the green polyurethanes.

Prototypes of the following products have been fully developed:

Foams - car seat, insulation panel, spoiler; supports for growth of enzymes, fish containers.

Composite based on biodegradable polymers - food tray, egg containers, creams jars, chemical containers, tomato yarn, pots, balcony pots, encapsulated fertilizer.

Composite based on recycled polypropylene car seat, chemical containers, cream jars, pots.

WP2: Collection and pre-treatment of forest materials (WP Leader: 05-CARTIF) (sm1; em24)

Task 2.1 Market Analysis (Task Leader CARTIF) (sm1; em6)

Task 2.2 Characterization of forest materials (Task Leader CARTIF) (sm3; em15)

Task 2.3 Forest material pre-treatment Task Leader CARTIF (sm3; em24)

The objectives of WP2 were the following:

- Identification of raw forest materials providers, availability, costs.
- Characterisation of forest materials and fibres
- Pre-treatment and pre-compounding of forest materials to get fibres and pellets for the production of bio-based foams and composites.

WP2 was completed in the second year of activity in FORBIOPLAST.

During the WP2 three main aspects: market, fibres characteristics and possible pre-treatments, have been studied with the objectives of exploring and identifying the raw material components for the FORBIOPLAST products, and evaluate providers and possible modifications in the production processes. Raw materials for the production of bio-based foams and composites were identified and their relevant technical data, providers and cost were reported in D2.1 European Market Analysis and Provider Identification to perform an appropriate choice of fibres. Fibre characterizations of several woods samples were carried out with the aim of detecting differences in the fibre properties between types of wood (softwood, hardwood and mixed wood) as well as possible affections after pelletizing treatments. Results were reported in D2.2 Report on forest materials characterization. The fibre pre-treatments carried out consisted of physical (fibres pelleting) and chemical

(incorporation of specific additives), and the results related to them have been reported in D2.3 Report on forest materials pre-treatment.

The raw materials with forestry origin for producing the FORBIOPLAST products have very different characteristics and prices that can go from the 60 €/t for wood residual fibres to 150.000€/t for cellulose powder.

According to the price, an eligible raw material for reinforcement fibres in the FORBIOPLAST wood plastic composites would be those that cost less than 400 €/t. Those raw materials can be wood flour, wood fibres, wood residual fibres and cellulose pulp.

In general the purer materials are the more expensive ones. The cellulose powders are the purest materials and with a smallest size that could be used for wood plastic composite production. It is possible to use this material in the laboratory, but is too expensive for many industrial applications. The cellulose fibres have a very high price, not as high as the cellulose powders, but quite expensive for the final products expected in the FORBIOPLAST project. For this reason the research activity in FORBIOPLAST was mainly focused on wood fibres.

The cheapest materials are those that are heterogeneous or with a bigger size and worse aspect ratio, for example the wood residual fibres. Their suitability for the production of wood plastic composite is not very good because of this heterogeneity, then wood flour and fibres resulted to be the ideal raw materials for the FORBIOPLAST products.

A detailed analysis has been done for different wood flour and fibres. Relating the chemical composition, it is very similar for all the wood flours analyzed in water content, lignin and holo-cellulose. Relating to the wax content the sample from oak and beech has a very high value which could make difficult the adhesion between this filler with the plastic matrix or the coupling agents. For this adhesion it is also better to have less wax content, and in this way fibre EFC 1000 Rettemaier is the best one, having more OH groups than the others. The materials selected, to be used in the project, according with these results have been the EFC 1000 Rettemaier fibres because of its high aspect ratio, and the La.So.Le 200/150 wood flour because of its price. The first one will be used as reference material to show the ideal point to reach the required characteristics for the materials developed, and the second one will be used for developing the FORBIOPLAST products in an economic industrial procedure system.

Relating the pre-treatment required for these forestry materials, the pre-treatment of wood fibres seems to be a promising approach to improve compatibility and consequently get better properties in particular for values of the modulus. In this Workpackage it have been achieved the physical pre-treatments, such as pelleting fibres and introducing additives in the pellets of fibres.

Pellets technology seems to be a promising process to be utilized in composite manufacture in order to solve some extrusion feeding and health problems concerning the use of powdered material. Pellets could avoid feeding problems in the extruders like obstructions and vaults in the final products, whereas chemical additives can improve mechanical properties of the composites due to these additives it can be achieved a better dispersion of the fibres inside the matrices which make better adhesion between matrix and fibres.

Wood fibres pellets have showed homogeneity, which supposed to create the optimum conditions for operating in subsequent extruder for composite manufacture. In addition, pelletizing did not affect the properties of fibres, even aspect ratio, and the most important parameter for the reinforcement effect of the fibres in wood based composites. Thus, any important differences were found among different types of wood (softwood and hardwood) and among different species. However, wood fibres were too compressed that and could mix well with the polymer and consequently the composites produced achieved poor mechanical properties.

Additives used to intend improving the adhesion between the polymeric matrix and the wood fibres were Aquacer 598 and Hordamer PE 02 (HoPE). Different amount of additives were introduced in the two types of wood fibres in a range of 1-10 % (wet basis). As a results of these trials, the compounds with additives presented positive effects when were extruded with polypropylene (PP) and polyhydroxybutyrate (PHB improving the values of tensile strength, young's modulus and strain to break.

Main objectives were achieved for WP2, less quantity of chemical additives were required to obtain appropriate properties for the composites, and shorter pellets easier to be fed in the extruder were produced. Nevertheless it would be useful to improve further the pellets produced allowing their easier disintegration inside the extruder.

The activity performed in this WP was transferred to WP5, WP6, WP7, and WP8 for pilto scale and then industrial production of composites with either rPP or biodegradable polymeric matrices and wood fibres.

WP3: Developing bio-based polyurethane foams (WP Leader: 03-IWC) (sm3; em36)

Task 3.1 Synthesis of hydroxyl-containing esters (Task Leader IWC) (sm 3, em 12)

Task 3.2 Development of freon-free polyol systems suitable for long-term storage (Task Leader IWC) (sm 12, em 24)

Task 3.3 Synthesis of wood-based polyurethane (Task Leader UNIP) (sm 12, em 24)

Task 3.4 Physico-mechanical investigation of PUR and PIR foams (sm 18, em 30)

Task 3.5 Pilot scale production of PU (Task Leader RIT) (sm 18, em 36)

Task 3.6: Technical suggestions (Task Leader RIT) (sm30; em36)

### **Objectives of WP3 were the:**

- Laboratory synthesis of hydroxyl-containing esters through trans-esterification of tall oil and lignin containing compounds with polyvalent alcohols and alcanoamines; analysis of the synthesized esters;
- Development of freon-free polyol systems suitable for long-term storage;
- Development of polyurethane from lignin;
- Detailed physico-mechanical investigation of polyurethane (PUR) and polyisocyanurate (PIR) foams. Accumulation of a full set of experimental data for different foams. Recommendations for improvement of performance
- Production of Hard and soft polyurethane foams and scale up to industrial production for automotive components (T-node), bumper and packaging (fish box).

Task 3.1 was completed in the first year of the project and relevant results were reported in D3.1 a Forest derived polyols. Task 3.2 was completed in the second year of the project and the relevant results were reported in D3.1b Report on laboratory scale production of polyurethanes Freon free and with no catalyst use and in D3.2 Report on pilot scale production of forest derived polyol systems and obtaining PUR-PIR foams from these polyol systems (prototypes). Task 3.3 was completed in the second year of the project and relevant results were reported in D3.3 Report on lab scale and pilot scale production of wood-based polyurethane foams (prototypes). Task 3.4 was completed in the third year of the project and the in D3.3 Report on lab scale and pilot scale production of wood-based polyurethane foams (prototypes).

Task 3.5 and Task 3.6 were completed in year three and the relevant results were reported in Deliverables D3.4 Data base of the correlation between the physical-mechanical characteristics of PUR-PIR foams, their synthesis and raw material parameters.

Soft foams were produced using different types of lignin. In an early attempt two different types of lignin were employed, one from kraft and one from soda process. Subsequently the soda lignin was subjected to hydroxypropilation process to make the OH group more easily accessible for the reaction with isocyanate. All the lignin were liquefied using an innovative microwave process which is less time and energy consuming than the traditional liquefaction process. Through this work liquefied lignin, with suitable chain extenders, was shown to be potential replacement to petroleum polyols for the production of flexible polyurethane foams. To increase the content of liquefied lignin in foam formulation, and ultimately achieving the goal of making still flexible foam with liquefied lignin, lowering the T<sub>g</sub> of polyol phase was determined to be the most important issue.

In the attempt to produce flexible foams two type of chain extender were used in combination with liquefied lignin: polypropilenglycol triol and castor oil. The amount of lignin that was possible to introduce in the network varied from 6 to 13% and considering the renewable origin of the castor oil it is possible to state that in these samples the renewable content is more than 45%. The type of lignin did not influence greatly the structure and properties of the produced foams, hydroxypropylated lignin was easily dissolved in the liquefying agents and the characterizations of the foams produced with this material showed an intense phase mixing between liquefied lignin and chain extenders, higher than the unmodified lignin. For all the type of liquefied lignin, polypropylene glycol triol (PPG) was proven to be an effective chain extender. Samples with liquefied lignin and castor oil had phase mixed morphology and high glass transition temperature which was believed to be the factor giving rise to rigidity in those types of foams, these samples showed a density between 160-230 kg/m<sup>3</sup> that is comparable with foams made with renewable resources, like palm or soy oil.

The samples were produced with the "one shot" technique and the only blowing agent used was water. All samples were produced with a ratio NCO/OH less than one, because it is well known that it significantly reduces the degree of crosslink, resulting in higher flexibility of the material. Samples were produced in free and controlled rise expansion.

The process is environmentally friendly, based on the use of microwave technology.

The properties of the foams are compatible with application in packaging, such as packaging of furniture, and for the interior part of car seat.

The properties of these foams can be modulated by industrial producer, such as partner RIT, by the individuation of more efficient chain extenders, thus introducing flexible chains in the macromolecular structure, can reduce the glass transition temperature of the materials and generates foams with higher flexibility. It is demonstrated that controlling the phase mixing will be a key to improve the material performances in various fields of application.

Tall oil resulted a prospective raw material for polyol production for polyurethane Foams. Tall oil with rosin acid content from 2% up to 20% is prospective for polyol synthesis. It was possible to obtain esters and amides by esterification and amidization methods. The esters are more catalytically active and more suitable for spraying systems, while the amides are more prospective for moulding or pouring systems. ozone layer friendly blowing agents (water and pentane) could be used for tall oil compositions. PUR foams were obtained from tall oil characterizes with closed cell structure and low water absorption.

The laboratory synthesis process for hard polyurethane resulted completely reproducible in pilot scale reactor. The synthesis process is economically and ecologically effective. Rosin acid content in tall oil increase stability of polyol systems, flame retardants dramatically

decrease stability in long term storage process. It is possible to obtain polyol system with storage time longer than 6 month. The maximum content of renewable material (tall oil) in ready PUR foams compositions for production of automotive or packaging items achieved was 27%. From the developed and optimized recipes the first practical items were produced T-node auto part for partner CRF. There were optimized the filling conditions for selected recipe and finally obtained the perfect quality T-node, accepted by CRF.

For foams with density 25 - 30 kg/m<sup>3</sup> more prospective are the systems obtained from tall oil with rosin acid content 2 - 20%, by amidization method. Blowing agent: mix water and pentane. The target products of these systems are: refrigeration industry, incl. fish boxes, and log-house buildings. For moulding recipes for foams with density 40 - 45 kg/m<sup>3</sup> more prospective are systems obtained from tall oil with rosin acid content 2 - 20%, by amidization method. Blowing agent: pentane. The target products of these systems are: construction industry thermo insulation materials (incl. sandwich-type panels), car industry acoustic insulation. For high density molding recipes for foams with density 200 -250 kg/m<sup>3</sup> more prospective are systems obtained from tall oil with rosin acid content 20%, by esterification method. Blowing agent: water.

The target products of these systems are: different size and shape items, incl. car parts, such as spoilers, bumpers. The physical-mechanical characteristics are similar or better than conventional petrochemical foams and completely reach the industrial requirements of FORBIOPLAST Partners. Natural fibres are prospective filler for PUR foams; in this case the renewable material content (both tall oil and natural fibres) could reach 35% in end product. It must be taken into account the humidity of natural fibres, because the humidity decrease the density of PUR foams, with following decrease of physical mechanical properties. Only for high density foams (>200 kg/m<sup>3</sup>) there are improvement of mechanical properties of foams, if the fibre concentration is 3 - 6% by weight.

The optimum parameters for production of automotive parts were established and these results were transferred to activity in WP7.

Vegetable oils offers a variety of new structures in polyols, resulting in polyurethanes with new properties suitable for a range of applications, then it is normal to expect a dramatic increase in the use of renewable resources in the polyurethane field. The development of soft and hard foams resulted challenging tasks but some formulations were identified for the production of both soft and hard foams which meet the technical requirements of producer and end user and an industrial exploitation of these materials is envisaged. The addition of wood fibres in the PU foams was also a challenging task The activity in WP3 resulted particularly successful and the positive cooperation of RTDs and INDs involved in the WP has allowed the production of interesting prototypes at pilot scale and then on industrial scale. The objectives of the WP were achieved in scheduled time. Additional exploitation of the foams developed was found in application for growth of micro-organism in cooperation with Partner UAL, as bio-valorisation of FORBIOPLAST products, as reported in the activity of

WP9. The PUR foam material usable for microorganism growing was object of a patent application by IWC, UAL, and UNIPi.

WP4: Physical, chemical and biological modification of wood fibres to improve compatibility in wood based composites. N (WP Leader: 02-LPRT) (sm3; em36)

Task 4.1 Development of a coupling technology for recycled PP-wood fibre composites (Task Leader LPRT) (sm 3, em 12, extended to 18,)

Task 4.2 Selection of coupling agents for biodegradable polymer/wood composites (Task Leader LPRT) (sm 6, em 24,)

Task 4.3 Biological modification (Task Leader UAL) (sm 6, em 24,)

Task 4.4 Development of a method for the chemical modification of wood  
(Task Leader LPRT) (sm 18, em 36)

Task 4.5 Development of coupling technology for PU foam/wood composites  
(Task Leader LPRT) (sm 18, em 36)



**Objectives of WP4 were:**

- To develop coupling technology for PP/wood composites, to select wood type, amount and type of coupling agent, recycled PP;
- To select coupling agents for wood composites with biodegradable matrices adjusted to the chemical structure of the polymers;
- To select a microbiological treatment for biological modification of wood;
- To explore methods for the chemical modification of wood in order to improve its inherent strength and to reduce the water sensitivity of the composites;
- To develop coupling technology for PU foam/wood composites.

Task 4.1, 4.2 and 4.3 D4.1, D4.2, D4.3 were concluded in the second year of the project. Objectives were reached and they were reported in D4.1 Report on the effect of component properties and composition on the properties of recycled PP-wood composites. Selection of coupling system for the targeted product and application, D4.2 Report on the selection of coupling system for biodegradable polymer/wood composites taking into account the targeted product and application and in D4.3 Method for biological modification of wood for various polymer matrix-wood composite systems. The results achieved in Task 4.4 and 4.5 concluded in the third year of the project, were described in D4.4 Report on the chemical modification technology of wood for various polymer matrix-wood composite systems and in D4.5 Report on the selection of coupling system for PU foam-wood composites taking into account the targeted product and application, respectively.

In task 4.1 composites were prepared with different elastomer content and coupling agents (MAPP, MAEPDM), while the wood fibre content was varied between 0-60 wt%. Several tests were carried out to analyze the structure-property correlations in such materials. Different elastomers and coupling agents were selected to achieve the requirements of the industry specified for the desired product. The main factors determining the properties of rPP/wood composites have been identified and a coupling technology was selected (MAPP). The main problems hindering the development were identified and most of them were corrected. The material developed in the WP was successfully used for the preparation on the prototypes of the desired product.

In Task 4.2 PLA was selected as the most common biodegradable polymer for the experiments. Composites were prepared with different coupling techniques with different wood flour content. Two of the approaches (BMI, lignin) explored for coupling Poly lactic acid (PLA) to wood proved to be successful but later lignin proved to be chemical modification agent for wood, it has been investigated in Task 4.4. Micromechanical deformation processes were determined in PLA/wood composites and they were proved to

determine the properties of the composites. It was also proved that deformation mechanisms are determined by the strength of interfacial interactions, and the properties of fillers so large aspect ratio, and small cross-section results a better reinforcement. It was found that the dominant process is the fracture of the fibre in PLA/wood flour composites that confirms that the adhesion between the matrix and the filler is strong (stronger than in PP/wood composites) but even so the mechanical properties could be improved. Both BMI and DBMI enhanced the adhesion in PLA/wood composites that improves mechanical properties so both of them are feasible to be used as coupling agent in PLA composites.

In Task 4.3 Wood fibres were treated in vivo (live microorganism) and in vitro (enzymes from microorganism) with the white-rot fungus *Phanerochaete flavid-alba* which was selected among 269 microorganisms for this purpose. In vivo treatment showed that *P. flavid-alba* oxidized lignocellulose, decreased lignin and was able to mediate secondary amine coupling to lignocellulose when hydroxytyramine was added to the culture media. Treatment of wood fibres with enzymes (in vitro treatment) produced by *P. flavid-alba* in the presence of amines such as glycine seems to cause an increase in amines on lignocelluloses matrix that may be due to couple of amine to the lignin. Treatment of wood flour with ligninolytic fungi fail to improve fibre properties for PLA-wood composites or PUR foams preparation, while lightly improved those in PP-wood composites, but as detailed in WP9 provides better quality for anaerobic digestion of materials. Thus the treatment with enzymes lowers the thermal stability of the fibres, and some degradation took place while processing with PLA. The treated fibres are to be used with processing temperature lower than 180 °C. This degradation is also the reason for the very valuable property of degradation in anaerobic environment that is not present in the raw wood fibres.

In Task 4.4 they were further investigated the results of Task 4.2 concerning the use of lignin to improve the strength of PLA/wood composites. The effect can be described with the enhancement of the inherent strength of the wood particles that led to the improved mechanical properties of the investigated PLA/wood composites.

A phenol-formaldehyde resin was selected for the chemical treatment. It was synthesized; characterized and chemical treatment was carried out with wood-flour.

Wood particles were impregnated with different resin concentration. PLA/wood flour composites were prepared with the modified wood fibres and mechanical properties were characterized. During the optimization of the resin concentration it was found that on higher concentrations the deterioration of composite occurs that is caused by the thick resin layer formed on the surface of the wood particle. At optimum (approximately 1 wt%) resin content, the inherent strength of the wood fibres increases that led to improved mechanical properties of the PLA/modified wood composites, while the water absorption of the wood flour decreased.

In Task 4.5 Model composites were prepared for the determination of the strength of interaction between PU and wood. Linear PU polymers were chosen as model materials and composites containing different amounts of wood were prepared. The characteristics of PU were varied by changing the ratio of the low molecular weight butanediol chain extender and a higher molecular weight polyether polyol, as well as stoichiometry (NCO/OH ratio). PU/wood composites were prepared and mechanical tests were carried out for characterization. The results showed that the extent of reinforcement changes with the composition of PU. Increased NCO/OH ratio resulted in stronger interaction and it was found that under the conditions of single step batch polymerization at 150 °C coupling occurred at isocyanate excess. According to this result no further coupling agent is needed, the application of NCO excess can be used as a coupling technology for PU/wood systems. Based on the results of the linear PU/wood composites, PU/wood foam composites were prepared from a commercial foam system with different wood content. Mechanical properties were investigated and structure was observed by SEM micrographs. The selected coupling technology was successfully applied to PU foam/wood composites according to the targeted products. Maximal wood fibre content was determined taking into account multiple measurements. Stiffness increased, strength and density remained constant in the practically feasible range of wood contents. No effect of the coupling was found on the mechanical properties of the PU foam/wood composites. The properties of the PU foam/wood composites are not determined by particle related mechanisms.

In conclusion a procedure for the modification of fibres was developed and samples of amino modified fibres were produced and sent to UNIPi for composite production in WP6 and WP8. The amount of wood fibres modified by enzymatic pathways by Partner UAL (WP4) did not exceed laboratory scale due to difficulties in the scale up of the production. Tests performed by UNIPi (WP6) showed that the elastic modulus of composites prepared in polymeric matrices such as PLA and recycled polypropylene rPP was larger with wood fibres provided by UAL than with raw wood fibres. Tests performed by Partner OWS (WP9) on anaerobic digestion of composites showed a higher production of biogas for composites prepared with the wood fibres modified by enzymes than from the composites prepared with raw wood fibres. The extensive research activity on coupling of wood fibres with recycled polypropylene and biodegradable polymers achieved positive results and the most relevant formulations were selected and applied for the production of composites for automotive and packaging-agriculture applications in WP5 and WP6, respectively, on pilot scale and then on industrial scale (WP7, WP8).

Work progress in WP5: Production of composites based on recycled polypropylene filled with forest-derived fibres. (WP Leader: PEMU) (sm6; em42)

Task 5.1 Melt blending of recycled PP-wood composites at lab-scale with forest-derived fibres according to the developed coupling technology (Task Leader PEMU) (sm 6, em 18)

Task 5.2 Experimental manufacturing of recycled PP/wood composites with forest-derived fibres according to the developed coupling technology at semi-industrial scale (Task Leader) (PEMU sm 9, em 27,)

Task 5.3. Compounding technology of recycled PP-wood composites. Compounds for prototypes (Leader PEMU) (sm 24, em 36,)

Task 5.4. New compounds for prototypes (Leader PEMU) (sm 36, em 42,)

**Objectives of WP5 were:**

- To develop a melt blending technology for recycled PP-wood composites with selected wood type, amount and types of coupling agent;
- To make experimental production of PP-wood composites with forest-derived fibres according to the developed coupling technology at semi-industrial scale;
- To define the proper compounding technology;
- To produce compounds for the manufacturing of prototype(s);
- To produce new compounds for the manufacturing of prototype(s) on the basis of the

Task 5.1 was concluded in the second year of the project and relevant results were reported in D5.1. Melt blending of recycled PP/wood composites on laboratory-scale with forest-derived fibres according to the developed coupling technology. Task 5.2 was completed at month 27 and the relevant results were reported in the D5.2. Experimental manufacturing of recycled PP/wood composites with forest-derived fibres according to the developed coupling technology at semi-industrial scale. Task 5.3 was concluded in the third year of the project, the relevant results were reported in D5.3 Compounding technology of PP/wood composites. Preliminary compounds for prototypes, Task 5.4 was concluded in the last year of the project and relevant results were reported in D5.4b Report on production of final composites granules and in D5.4c Report on pilot scale production and Prototypes produced.

The major achievements for WP 5 consisted of:

- Investigation of the optimal recipe of wood flour filled rPP compounds
- Selection of the suitable additives
- Development of optimal compounding parameters
- Production of suitable recipes
- Tests of mechanical properties
- Successful injection moulding trials

In the present WP, PEMU developed production technology for composites based on recycled polypropylene (rPP) loaded with forest-derived fibres and methods for their characterization. Participant UNIPi and Participant LPRT cooperated in structural, thermal and mechanical characterization of developed compounds.

Participant CRF followed the activity with inputs on technical requirements and as provider of rPP.

Revised specifications were (by Participant CRF):

- Strain at Yield: >2 %
- Yield Strength: >25 MPa
- Young's modulus: 1.4 - 3 GPa
- Density: 0,95 - 1,15 g/cm<sup>3</sup>
- Charpy impact strength: >15 kJ/m<sup>2</sup>

The goal of WP5 was the melt blending of rPP-wood composites on laboratory, semi-industrial and industrial scale as well with forest - derived fibres according to the coupling technology developed in WP4. In this WP, PEMU selected raw materials, additives, coupling system, formulation and technological parameters for the targeted products in cooperation with Participant LPRT, and determined component properties and components of the rPP/wood composites. Different formulations were selected and processed from lower amount to higher amount of compounds for injection moulding tests. This cooperation was very important for PEMU which acquired new knowledge and improved the experience of its workers.

The compounding processes were carried out on a co-rotating twin screw extruder. During compounding trials several modifications were applied on the machine. Due to low elongation properties of wood plastic compounds, the application of a strand die was presumed to be difficult. Therefore dry granulation with head cutter was applied for the initial compounding trials. Cooling of the die was not sufficient. Hence different methods (cooling with compressed air and ventilation with water-spray) were tried.

Despite of these modifications, the dry granulation process was not successful. The produced pellets were stuck together immediately after cutting.

During subsequent trials a strand die was applied to produce adequate granules (Figure 5.2). The strands were lead onto a conveyor or a water bath and latter into a grinder unit. With this method PEMU managed to optimize the processing parameters and produce continuous strands with good dispersion of components.

A side feeder was applied for dosing of wood-flour during compounding trials and optimization was carried out. This type of side feeder was suitable for compounds that have wood fibre content lower than 50 wt%.

For drying of wood fibres to be used for the trial of productions at industrial and semi industrial scale it was applied a larger hot air dryer with multiple levels. The optimal parameters for this type of dryer are 100°C temperature for 16 hours. Final optimal compounding temperature for wood flour filled recycled PP were from 170 to 190°C. During compounding trials effects of high temperatures were also investigated and above 200°C temperatures the wood fibres damaged inside the extruder.

In conclusions some difficulties, and derived delay, were encountered in the first research activity of the WP to define the recycled polypropylene to be used. After several investigations it was selected rPP material provided by CRF which met PEMU and CRF requirements and was then maintained up to the end of the project.

Difficulties were encountered to fit rPP melting temperature with wood fibres temperature of degradation, thus processing the material without incurring in fibres degradation. This problem was overcome with additive selection and processing optimization. Finally the presented recipes were optimised for the achievement of the best mechanical properties. PEMU cooperated with Partner LPRT and managed to choose the suitable recipes that were then sent to Partner CRF and used for the production of the prototype of car seat as reported in the activity of WP7.

The materials used for industrial scale production of FORBIOPLAST products are produced from the renewable resource fibres and recycle PP materials. The La.So.Le fibre is the cheaper material, and the mechanical properties are slightly lower than the Rettenmaier fibres that are more expensive. Thus both fibres can be used considering the requirements to be met for the final application.

WP6: Production of composites based on biodegradable polymeric matrices filled with forest-derived fibres. (WPLeader: UNIPi) (sm6; em36)

Task 6.1: Preparation and characterization at laboratory scale (Task Leader UNIPi) (sm6; em18)

Task 6.2: Pilot plant production (Task Leader INCP) (sm12; em36,).

Task 6.3: Evaluation of properties essential for packaging and agriculture applications (Task Leader UNIPi) (sm18; em36,).

**Objectives of WP6 for were:**

- To produce films and composites based on biodegradable materials loaded with fibres and additive derived from forest resources on laboratory-scale;
- To characterize produced items in terms of structural, thermal, mechanical, permeability properties;
- To select best formulation to be promoted for trials at industrial scale.

The objective of this WP was the selection of the formulations to process bio-composites based on biodegradable polymers and renewable resources which will be converted into products for packaging and agriculture industry by the industrial partners of FORBIOPLAST, as reported in the activity of WP8.

Based on D1.1 State of the art, D1.2 Technical specifications for targeted products and D6.1 Report on laboratory scale production of composites based on forest derived materials and in collaboration with the project partners six targeted product were developed for agriculture and packaging applications:

- Tomato yarn;
- Biodegradable plant pot;
- Food trays;
- Egg containers;
- Cosmetic package;
- Chemical package.

Also, encapsulated fertilizers and fish boxes for thermal insulation were achieved in cooperation among LPRT, IWC and RIT.

They were developed bio-based composites that include polymers based on biomass (polylactic acid), polyesters generated by fermentation from biomass (polyhydroxybuturate), biodegradable polymers synthesized from petrochemical resources such as ECOFLEX and biodegradable fillers such as wood fibre. Also, wood plastic composites based on polypropylene and wood fibre were processed.

UNIPI, CARTIF, INCP, LPRT, PEMU, USAVM, RODAX, NORC, UAL, OWS, NEOC and COS partners were involved in the activity to establish technical requirements of items to processing at pilot scale, process technologies and to select the best formulations that were then developed at industrial scale.



Both RTDs partners and industrial manufacturers INCP and PEMU were in closer relationship in order to develop bio-based plastic materials. The relevant results of this activity were summarized in D6.2 Report on the processing of blends and composites at pilot scale.

Processing of tomato yarn was carried out on a TRUSIOMA extruder equipped with a single screw with diameter of 32 mm and length to diameter ratio of 20 on formulation based on PLA/Ecoflex/Wood fibre.

The formulations compounded by UNIPi and PEMU designed to obtain pots were processed by a VICTORY injection moulding machine, which has 2.5 tones, a screw with diameter of 30 mm and clamping force of 400 kN. INCP designed a new mould matrix with volume of 300 cm<sup>3</sup> to process pot injection moulding taking into account of processing properties of the new materials filled with fibres.

The quality of the resulting pots was adjusted by changing of the injection speed and cooling time. PEMU prepared balcony flower box, food trays and egg containers as reported in Task8.1 and detailed in D6.2.

Thermal, mechanical and morphological characterization on materials developed for scale up production and use in packaging and agriculture were performed by UNIPi and by LPRT. UNIPi optimised formulations based on Polylactic acid (PLA) testing new plasticizers such as polypropyleneglycol diglycidyl ether (PPGDGE). Composites were produced with micro cellulose fibres. Mechanical properties were valuable for the production of FORBIOPLAST demonstrators for packaging and agriculture as detailed in D6.3 Report on the description of the specifics of the produced composites related to packaging and agriculture application. In order to investigate other possible biodegradable polymeric matrices also cellulose diacetate was tested. Thus polymer would allow use of the items even at moderately high temperature (over 50°C) where PLA usually present deformation and loss of mechanical properties.

CARTIF managed to produce shorter and more easily to be broken up pellets. Nevertheless its durability is too high to be well disintegrated in the extruder. When the pelleting parameters are modified to obtain pellets with less durability, the pellets are not produced and only wood powder is obtained. The pelleting plant has been designed to obtain hard pellets so it could be necessary to make modifications in its design to obtain the pellets required for the project.

By the way analysing similar commercial products (Deliverable 6.3) we can see that they have been produced from wood flour with a particle size more than 500 micron. The wood flour required for the FORBIOPLAST project should have less than 200 micron, and with less particle size the pellet produced is harder and more difficult to be disintegrated.

Making pelleting trials with other different biomasses, CARTIF confirmed that for those materials with higher sizes, the pellets are better disintegrated than the others produced with smaller particle sizes.

In conclusions the most promising formulations were selected and shifted to activity performed in WP8. Some delay was faced in the first stage of the project for the use of wood fibres pellets produced by CARTIF since they were too hard for feeding with conventional extruders. Few samples were prepared with fibres modified by enzymes (from WP4) since this biotechnology required a long period for enzymes isolation and set up of conditions for fibres modification. It was observed an improvement in the modulus of the composite prepared with polypropylene and fibres modified by enzymes compared with those prepared with raw fibres.

WP7: Materials from forest resources for automotive applications. (WP Leader: CRF) (sm18; em45)

Task 7.1 Automotive part design and equipment set-up (sm 18, em 27 Leader CRF)

Task 7.2 Automotive part design and equipment set-up (sm 27, em 36 Leader CRF)

Task 7.3 Evaluation of automotive parts (sm 36, em 45 Leader CRF)

**Objective of WP7 were:**

- To evaluate the use of lignin and other forest resources in the formulation of composites and foams for automotive applications with specific relevance to panels and structural parts for automobile interior.
- To produce a car part prototype to verify the forming process and performance of materials based on forest resources (composites and foam).
- To test the composites and foams according to the working standards in place for automobile components.

Objective of the WP is the study and evaluation of the use of lignin and other forest resources in the formulation of composites and foams for automotive applications with specific relevance to panels and structural parts for automobile interior.

They were evaluated and assessed the automotive prototypes parts produced using new bio based materials developed in FORBIOPLAST as described in D7.2a Report on the production of automotive parts based on forest derived materials. The scope was the demonstration that technically valid automotive parts can be produced using a percentage of bio materials improving the environmental impact as described in D10.3 Life cycle analysis based results on environmental burden and impact of the newly developed materials in automotive field and comparison with commercial products.

Car part prototypes were produced and tested to verify the forming process and performance of materials based on forest resources (composites and foam).

According to the results in WP1, and in particular the FORBIOPLAST targeted products table, three different automotive applications were considered. Applications were related to interiors (seat bottom), exteriors (spoiler) and chassis (insulation material) of a car.

CRF developed a new concept of slim and ergonomic of a car seat bottom.

Computer simulation tool were used to assist the design procedure both for the part structural performances and process parameters of the injection moulding and permitted an optimisation of the part shape through an iterative process. Equipments for the production of the car seat by injection moulding were set-up by CRF. Before the final set-up of the mould, in conjunction with WP5, a series of sample sheets reproducing the main feature of the seat parts (different shaped ribs and holes, different thickness) were produced with the FORBIOPLAST composite material to verify the mouldability and possible problems. Thanks to this test it was possible also to find the best process parameters for the production of the car seat.

The prototype mould of the seat was positioned in a 1200 tons injection moulding machine. For testing and comparison purpose a first series of seats was mould based just on virgin polypropylene. After preliminary test using materials produced by PEMU containing recycled PP and fibres, four final recipes were selected and used for the final prototypes production.

The first and second material were based on PP recycled by car bumpers and Rettenmaier EFC 1000 vegetal fibres and were named: CRF\_1E\_1O\_S (10% of vegetal fibres) and CRF\_3E\_3O\_S (30% of vegetal fibres).

The third and fourth materials were based on PP recycled by car bumpers and La.So.Le. 150/100 wood fibres and are named: CRF\_1E\_1O\_LSL (10% of wood fibres) and CRF\_3E\_3O\_LSL (30% of wood fibres). As described in D5.4, also coupling agent and process additives were included in the recipes. Process parameters were optimised.

The first test after the production of the seat structure part was the dimensional stability. A measurements system detected a number of main points on the parts and compared with a 3% tolerance to the optimal design geometry. All the prototypes passed the test and their dimensions were compatible with the set tolerances. Then the prototypes were subjected to long thermal cycles according to the automotive standard conditions: no damage or deformation occurred on the parts after the thermal treatment. The parts were assembled with four screws in the side holes for the mounting of the structure on the full seat.

Materials developed in FORBIOPLAST from recycled PP and forest resources have been demonstrate to be suitable for the production of automotive parts, in particular a seat structure. All the final four materials are good with a different level of flexibility. Forest materials can be considerate an adequate form of resources in conjunction with plastic. An amount from 10% to 30% of natural resources is a reasonable value.

For the application of polyurethane, the main scope was to demonstrate the feasibility of a polyurethane material based on tall oil polyol with the same properties of traditional polyurethane produced by not renewable resources.

PEMU identified a spoiler already in production to carry on with the new material. Equipments and mould were already set-up to produce some prototypes with different formulations provided by IWC. PEMU also identified other possible applications and set-up mould and equipment to allow further processability test on the material. FORBIOPLAST polyurethane material used for the production of the spoiler demonstrate in WP3 to have properties similar to the traditional one.

The produced spoiler has been analysed and the surface quality is comparable to the reference one. Also internally, the spoiler shows a good cell structure indicating homogeneity during the dispensing process. Mechanical properties are similar to the

reference one. The spoiler was painted with standard equipment and it looks like the reference one.

A T-node steel shape was just an example of application to verify the dispensing process but the main efforts were devoted to the realisation of the bio PUR material. Comparing material developed in FORBIOPLAST with a traditional DO7/100 PUR from DOW Chemicals, it was possible demonstrate that a bio PUR containing about 27% of renewable resource has the same properties. CRF and IWC worked together in the set-up of the method to dispense the new developed foam (green PUR) into chassis steel frame. Scope of the foam is to avoid noise propagation through the chassis elements; to avoid vibration and to increase drive comfort and to create a barrier against water or dust.

Equipment for dispensing has been set-up by IWC and CRF has prepared fully welded car T-node of about 440 mm X 340 mm on which dispense the material.

The best PU final material for the production of the prototypes is named FP-45.

PEMU, Ritols and IWC produced the prototype of spoiler using polyurethane system developer in FORBIOPLAST. After some trials, in order to set-up the conditions for the process, good pieces have been carried out.

Several trials were made in order to optimise the time for the opening of the mould to reach value similar to those of a traditional polyurethane systems.

In the frame of task 7.2, PEMU tested the new developed polyurethane material also in other parts with complex shape in order to verifying fully the potentiality of the new material.

Thus high density polyurethane material developed in FORBIOPLAST using polyol from forest resources demonstrated to be suitable for the production of automotive parts, in particular a spoiler. Forest materials can be considerate an adequate form of resources for the production of polyol at 22% of content, equivalent about 8% of bio resource in the final PUR formulation.

WP8 Materials by forest resource for agriculture and packaging applications (WP Leader: INCP) (sm18; em42)

Task 8.1 Preparation of prototypes at pilot scale and industrial scale (sm18; em 42, Leader INCP)

Task 8.2 Evaluation of prototype properties relevant for packaging and agriculture applications (Task Leader UNIPi) (sm 21; em 45)

Task 8.3: Test of prototype for packaging (Task Leader RODAX) (sm 24; em 45)

Task 8.4: Test of prototype for agriculture applications (Task Leader UASVM) (sm 24, em 45)

**Objectives of the WP were:**

- To produce at pilot- and industrial- scale films and composites based on biodegradable materials loaded with fibres and additives derived from forest resources,
- To characterize the structure, thermal and mechanical properties, as well as permeability of the produced items.
- To test produced prototype in packaging applications
- To test produced prototype in open field tests

Formulations for the production of prototypes were defined in WP6 by Partners UNIPI, LPRT and PEMU. Characterization of developed materials in terms of structure, mechanical and thermal properties was performed by UNIPI and LPRT. Test of food trays for packaging in vacuum or in modified atmosphere were performed by RODAX, NORC and UASVM. Test of performance of tomato yarn were performed by Partner UAL and UASVM. Test on application of containers for chemicals and cosmetics were performed respectively by NEOF and COS.

Prototypes for agriculture and packaging applications, such as tomato yarn, pots, cosmetic containers, chemical containers, encapsulated fertilizer, fish boxes, food trays and egg containers were produced at pilot and industrial scale using extrusion, injection moulding and thermoforming technologies. In the activities of WP8, the SMEs and INDs partners worked in close cooperation with RTD partners to prepare the prototypes at pilot and industrial scale and to test their performance.

Partner INCP produced tomato yarns with flat and rounded shapes, with pellets designed and provided by Partner UNIPI and PEMU. The formulations were based on PLA/Ecoflex/wood fibres up to 30 % by weight and were selected as a result of the research activity performed in WP6.

UNIPI found that rounded yarns show higher values of mechanical properties (elongation at break, ultimate tensile strength) in comparison with flat shape yarn.

Performance of yarns on tomato plants was evaluated by Partner UAL, UNIPI and UASVM, in comparison with similar products present on the market. UAL tested both flat and rounded design of yarns with different formulations on melon (*Cucumismelocv cantaloupe*), cucumber (*Cucumissativus*), tomato (*Solanumlycopersicum*) and green bean (*Phaseolus vulgaris*) in greenhouses cultures and tomato in open field culture.

Technicians and farmers were asked to fill a questionnaire about yarn installation and handling. Flat design was one of the main drawbacks reported by the technicians.

Additionally, flat yarns were easily breakable both during installation and supporting plant growth. Consequently, rounded yarn demonstrated to be the most suitable for field application. This yarn may be used to support growth of a wide range of plants, from the heaviest such as cucumber to the lightest such as green bean.

Also UASVM tested flat and rounded yarns on tomato hybrid SIRIANA F1 for pallising and traditional yarns from PP and PVC, for comparison in the staking process. UASVM reported the best quality for formulations of flat yarns containing 15% of wood fibres La.So.Le. and 20% Rettenmaier, the staking procedure being realized in a proper way and stated for rounded yarns that the plants can be pallisate with an average degree of difficulty.

Low and tall shapes of pots produced with formulations based on PLA/Ecoflex/wood fibres were prepared and compounded by Partner UNIPi, LPRT and PEMU and were processed by INCP using injection moulding technology.

PEMU managed to manufacture some prototypes of the balcony flower boxes with formulations based on PLA, plasticizer and Rettenmaier fibre up to 40 wt%.

INCP encountered some difficulties in the production of pots by injection moulding using formulations based on PLA, ECOFLEX and wood fibres relating to flow of melted materials and filling of the mould.

The pots were tested by UASVM in open field using Broccoli hybrid MONTOP F1 in comparison with two types of Romanian market pots. Field monitoring of pots made of PLA/Ecoflex/wood fibres revealed that the plants were stressed because no biodegradation of these were observed during more than 4 months and the roots couldn't exit out of pots. Thus, the development, growing, flowering processes were disturbed. This test confirmed that pots based on PLA are not suitable for transplanting, for this type of application they must be considered polymeric matrices such as polyhydroxyalkanoate or starch based blends which can be degraded in open field. The second experiment was conducted in laboratory conditions of UASVM and consisted of testing the pots for the production of early flowers (*Narcissus pseudonarcissus*). Observations and measurements were made on the behaviour of these biodegradable pots throughout the growing season of flower plants, observations on growth, development and growth of narcissus. It is found that plants vegetate in pots very good for pots based on PLA/Ecoflex loaded with 20% Rettenmaier compared with those provided from PLA/Ecoflex La.So.Le. formulations, for which the vegetation period ended after 92 days.

The third experiment consisted in testing of new formulation based on PHB and Rettenmaier fibre, designed and compounded by UNIPi. Trials on these biodegradable pots were made with *Petunia* sp. by UASVM.



Encapsulated fertilizer with very promising properties were prepared by LPRT from starch, wood and an industrial NKP compound (nitrogen, potassium, phosphorus). The work of LPRT was focused on improving the reproducibility in stick production, increase the nitrogen content and evaluate different wood reinforcement. The sticks produced are promising as slow release fertilizer.

The biodegradable fertilizers were tested by UASVM on the plants (*Dianthus caryophyllus* and *Petunia hybrida*). Before to organize the experiments, the fertilizers sticks were analysed for the following parameters: pH, N, P, K existent as total amount but also in soluble form. During the vegetation period, biometric they were made observations regarding growing and developments of plants, namely: height, roots length, number of shoots, number of flowers. Regarding the growth and developments of plants (height and number of shoots) all the fertilizers samples demonstrated a beneficial slow release process of the macro elements which determined a positive effect. At the same time didn't noticed any negative deficiencies for any of the NPK elements in the tested plants. All the matrices of fertilizer sticks were degraded in substrate in 2 weeks after the experiments starting point. An industrial partner, member of Bige Holding, is interested in applying the fertilizers.

INCP produced cosmetic containers using several formulations based on polypropylene/Rettenmaier fibre designed and compounded by LPRT and PEMU at 20%, 30%, 40% and 50% by weight loading of Rettenmaier wood fibres. UNIPi prepared a composition based on PHB with 20% Rettenmaier wood fibres. Different moulds were used for obtaining of cosmetic containers with capacities of 50 cm<sup>3</sup> and 100 cm<sup>3</sup>. Cosmetic containers based on PP and PHB with 20 % Rettenmaier were easily processed, the fibres being well dispersed in matrix of respectively PP or PHB.

Partner COS performed tests of cosmetic containers to assess the potential use for jar comprising: resistance to chemicals, emulsion stability, compatibility with preservatives and consumer acceptance assessment. The immersion tests clearly concluded that the prototype jars may be used only in the case of oils or possibly in water/oil creams. For emulsion stability test a commercial cream (Macrovida hand cream) with GMS (Glycerol stearate and PEG-100 stearate) was placed in the prototype jars for 10 days at 45°C. After test, there was no microscopic (micelle size, oil separation) or macroscopic difference between the control (virgin polypropylene) and the prototypes jars. The prototype jars do not affect significantly the emulsion stability of a water/oil cream. Commonly used preservation systems are not affected from the new packaging and showed similar reduction of the log of the microbial count with the control of virgin PP.

Sensory profile consisted in touching smooth, touching familiar, visual natural looking, visual attractive, smell intensity, smell pleasant, all senses evaluation were used 20 volunteers with

ages between 20 to 45 years. It is found that the prototype jars based on PP and Rettenmaier wood fibre had a strong smell of lignin which is a negative aspect for the general consumer and affects negatively the smell of the cream. Only the PHB with 20% Rettenmaier wood fibres seemed to be acceptable from the consumer tests for cosmetics packaging.

Chemicals packaging for industrial use consisting in three parts: body, lid and handle were produced by injection moulding by INCP. Several formulations from polypropylene/recycled propylene (rPP)/Rettenmaier/La.So.Le fibre were designed and compounded by LPRT and PEMU at 20 wt.% Rettenmaier/ La.So.Le fibres and respectively 30 wt.% Rettenmaier loading and at different PP: rPP ratios. Brown and black chemical containers having the size of 170x150 mm, thickness of 2.5 mm and capacity of 2 litres were obtained. Containers prepared from rPP and addition of virgin PP showed an improved processing than formulations based on just recycled polypropylene.

PEMU, LPRT and UNIPi studied mechanical properties of materials. A significant improvement in the performance of the chemical container was observed starting from the lower content of PP (25 wt %) in rPP. The values of mechanical properties increase with increasing of the content of PP in rPP but for most of the planned applications just the addition of 25% PP in rPP is sufficient to achieve the desired properties.

Representative products of the industry Neochimiki (NEOC) such as emulsions (VAM-Veova copolymers, VAM homopolymers, styrene-acrylics and all acrylics), alkyd resins and unsaturated polyester resins were packaged in the containers containing Rettenmaier fibre and the stability of the packaged products was checked regularly over a period of six months to detect any potential changes of the contents in regard to pH, viscosity, thixotropic index and optical observation for the detection of any possible defect. New packaging material is not suitable for storage of organic solvents or solvent borne products, but they can be used for storage of alcohols and waterborne products such as emulsion polymers for paints.

Chemical containers based on bio-composites have both economical and environmental advantages by replacing of amount of PP with rPP which is low cost, abundant, without affecting their mechanical performance.

Latvia's partners, Institute of Wood Chemistry (IWC-RTD) and Ritols Ltd. (RIT - SME) were involved on concept of fish boxes with thermal insulations. Thermal insulation material contains 29% of renewable raw material tall oil in ready foams. The processing of material is optimum and could be used on industrial foaming machines.

Food trays were produced by PEMU with PLA/Ecoflex in different ratios and Rettenmaier fibres. Different moulds were designed by PEMU for thermoforming lab scale trials of the food trays. Firstly PEMU produces thermoformed prototypes from pure PLA, then from PLA/Ecoflex in different mixing ratios of components and later from PLA/Ecoflex/Rettenmaier in different mixing ratios of components. PEMU tried to reduce the thickness of products, at the same time the price and the wood smell of prototypes, therefore were prepared trays with a sandwich structure in order to avoid the direct contact of wood fibres with food. The best performance was observed by RODAX, NORC and USAMV partners for prototypes produced as sandwich structure.

RODAX (SME Romania) tested the performance of food trays as following: sealing tests, seal strength tests, leakage tests, tray crash tests, package tests. RODAX manufactured the packaging equipments to make the sealing test of film over trays. Their characteristics regard the cutting and the sealing of the thermal assemblies respectively the hot cutting wire, hot sealing band or the aluminium heated plate with incorporated resistance. As film were used PLA, PLA/ECOFLEX and PP films. The best results for sealing and cutting have been obtained at temperature of 100 °C and 8 sec., at 140 °C and 150 °C for 4 sec. respectively 3 sec.

NORCONSERV-NOFIMA A.S. (NORC-SME Norway) performed test of migration of substances from packaging films provided by UNIPI, some migration was observed with acetic acid 3%. NORC tested the tray's ability to withstand deformation at different temperatures. Temperature stability is an important feature of plastic of trays in the food industry. It is found that FORBIOPLAST trays are not suited for applications and processes involving heat above 50°C.

The gas permeability of the developed trays was measured in two different ways, measuring oxygen transmission rate by the ambient oxygen ingress rate (AOIR method) or by a packaging and storage trial, comparing the FORBIOPLAST tray with standard HDPE tray. NORC stated that the developed FORBIOPLAST food trays have a slightly better barrier properties compared to a standard HDPE tray. Based on the results the tray could be used for short term modified atmosphere packaging of food products with shelf lives up to two weeks.

The sensorial analysis of products stored in the developed FORBIOPLAST trays compared to standard commercial hydrocarbon-based plastic trays commonly used by the food industry were studied by NORC using modified atmosphere packaging of salmon. The FORBIOPLAST food tray could be used for packaging food preserving their own characteristic taste and odor. However sensitive foods will take up odour and taste from the wood fibres inside the tray. The tray must be further developed to hide the characteristic woody odour, as the tray is now it will have trouble complying with European food packaging directive and good manufacturing principle (GMP). This optimisation might be performed in a possible future demonstration project.

For the food trays experiments UASVM used packaging of fish and meat and stored at chilling temperature for 7-8 days and at frozen conditions storage for 3 months. After certain preservation period in refrigeration conditions (chilling or freezing) physico-chemical and microbiological analysis for fish and meat have been performed in order to establish the shelf life and also the food trays materials were analyzed. Thermal analysis (TGA, DSC, DMA), physical and mechanical analysis (density, compression) performed showed that neither the content nor storage conditions for food trays did not lead to any significant change occurred in the composition and structure of composites used in their manufacture. FTIR analysis did not reveal the existence of major changes in surface materials. The differences between samples in terms of specific heat (Cp), enthalpy of cold crystallization (Hc) and total melting enthalpy (Hm) measured by DSC are probably due to absorption of water during the time spent in contact with meat.

Egg containers were produced by PEMU with PLA/Ecoflex in different ratios and Rettenmaier fibres. Several formulations were tested for the production of egg containers based on PLA/Ecoflex or PLA/Polyethylene glycol 4000 and wood fibres Rettenmaier in content of 5%, 10% and 15%. The best performance were observed for prototypes produced with PLA/Ecoflex (80/20) with 5% Rettenmaier.

For experiments on the egg container UASVM used packaging of eggs and stored at chilling temperature for 30 days and after that all the physical damages (defects) have been evidenced and calculated as percentage. Also the eggs were analyzed as physical, chemical and microbiological parameters for the shelf life establishing at 2-4°C storage. Thermal analysis (TGA, DSC, DMA), physical and mechanical analysis (density, compression) performed showed that neither the content nor storage conditions for egg containers did not lead to any significant change occurred in the composition and structure of composites used in their manufacture. FTIR analysis did not reveal the existence of major changes in surface materials. The differences between samples in terms of specific heat (Cp), enthalpy of cold crystallization (Hc) and total melting enthalpy (Hm) measured by DSC are probably due to absorption of water from the storage cabinets.

INCP performed tensile characteristics and compression test on egg containers. It is recorded the maximum compression load of 196 N at deformation under maximum compression load,  $\epsilon = 30\%$  and respectively 394 N at  $\epsilon = 50\%$ . The tests on the egg containers attest the possibility of their utilization on market.

The biodegradability and the compostability of all tested prototypes were performed as reported in WP9. These tests were also carried out on initial formulations and final products by partners involved in WP9.

The promising FORBIOPLAST prototypes based on bio-polymers and bio-composites could be used in agricultural and packaging fields. Testing of prototypes performance demonstrated that some formulations have the same properties as the similar products presented on

market, and in the same time they are superior to traditional products regarding the benefits on environment.

WP9 Biodeterioration, biodegradability and valorization of the developed materials (WP Leader: UAL) (sm15; em48)

Task 9.1 Biodegradability and compostability of the produced biobased materials (Task Leader UAL) (sm 15, em 45)

Task 9.2 Ecotoxicity of the newly developed biobased products (Task Leader UAL) (sm 15, em 45)

Task 9.3 Valorization of the packaging and agricultural materials produced (Task Leader UAL) (sm 15, em 45)

Task 9.4 Recyclability of the packaging and agricultural materials produced (Task Leader UAL) (sm 15, em 48)

Task 9.5 Biodeterioration of biobased products for automotive applications (Task Leader UAL) (sm 21, em 48)

Objectives of the period in the present WP were:

- to study the biodegradability and compostability of the newly developed biobased products;
- to evaluate ecotoxicity of newly developed products;
- to explore processes for microbiological valorization of the packaging and agricultural produced material;
- to evaluate the recyclability of the packaging and agricultural produced materials;
- to determine biodeterioration of the developed materials for automotive applications

The biodegradation of the developed compounds was evaluated in a broad range of environments. Also the biodegradation of the basic Rettenmaier wood fibre, used in many applications within this project, was investigated. It was observed that the biodegradation under composting conditions and soil proceeded, but at low rate due to the lignin content. A previous bio-delignification process by treatment with ligninolytic fungi induced a positive effect on biodegradation rate.

Composites based on wood fibres (Rettenmaier) and biodegradable polymeric matrices such as PLA, PBAT (Ecoflex), starch and PHB were evaluated for biodegradation. These composites are suitable for compostable packaging and products (EN 13432). The PLA compounds also degraded under thermophilic, anaerobic conditions, but the rate was too low to yield complete degradation within industrial digestion process for treatment of waste. No complete biodegradation was observed for PLA/Ecoflex/Rettenmaier compounds at room temperature in compost, soil and water. This material is not suitable for home composting applications. The PLA component needs a certain temperature trigger (typically around 55°C) before the hydrolysis and biodegradation starts.

The starch/Rettenmaier compounds proved to be completely biodegradable in soil conditions. Together with the slow, but steady disintegration in soil the developed starch/Rettenmaier based fertilizer sticks are an environmental friendly fertilizer for flowers that promotes plant growth and flowering. This material also seems to stimulate biodiversity of soil microbial population, including those microorganisms involved in long-term maintenance of fertility (test still running). Because of this property the developed starch/Rettenmaier compounds may be used for bioremediation processes as biostimulants agents.

PHB based composites (80%PHB/20%Rettenmaier) showed biodegradation in soil (test still running) and is a valuable compound for agricultural application as flower pots. Cellulose diacetate samples proved to degrade under controlled composting conditions. The rate seemed to be triggered by addition of diacetin and triacetin. Also quick degradation was observed for cellulose diacetate under thermophilic, anaerobic conditions.

Compostability is not only determined by biodegradability, but as stipulated by EN 13432 (2000) also the disintegration during composting and effect on compost quality, including ecotoxicity tests. The whole range of testing requirements was evaluated for food trays produced by PEMU in a thickness of 0.9 mm with composition 42.5%PLA/42.5%Ecoflex/15%Rettenmaier fibres. The material did fulfil all requirements. Depending on the thickness also other developed products of PLA/Ecoflex/Rettenmaier have potential to be compostable, such as yarns, flower pots, sheets. Also CDA/Rettenmaier materials are promising for compostable applications.

None of the tested samples either as biocomposite materials extraction or composting process, demonstrated phytotoxicity effect or acute toxicity to *Vibrio fischeri*. In the case of phytotoxicity tests a positive effect was evidenced for the seeds germination or plants growth. The most toxic material was found to be PP food trays and a slightly negative influence was also evidenced for samples which contain a higher composition in Rettenmaier fibre EFC 1000. As a general trend, the phytotoxicity was a bit lower for the sample based on PLA in comparison with the cellulose and PC. None of the tested materials

produced released ecotoxic compounds into water as evidenced by acute toxicity test to *Vibrio fischeri*.

Three different approaches were attempted for materials valorization: Biogas production by anaerobic digestion, immobilization of microorganisms for ligninolytic enzymes production and production of single cell protein from materials hydrolysates.

The PLA based compounds were degraded under thermophilic, anaerobic conditions, but the rate was too low to yield complete degradation within industrial digestion process for treatment of waste. Products based on cellulose diacetate have the potential to be treated after their life-time in anaerobic digestion plants, yielding biogas for energy production.

Polyurethane (PU) rigid and soft foams were used as support for growth of microorganisms that produce ligninolytic enzymes, mainly laccase. In general enzyme production was enhanced when the fungus was immobilized in PUR foams with open cells structure and filled with wood fibres. Small size soft foams made of hydroxypropylated lignin and castor oil gave higher laccase production than those made of lignin and PPGTriol hydroxypropylated lignin or PPGTriol.

Production of single cell protein of the yeasts *Pichia pastoris* and *Rhodotorula* sp. to be used as additives in animal feed was attempted by hydrolysing several developed composites under different conditions. The highest quantity of yeast biomass was obtained for (PLA:Ecoflex 50:50):Rettenmaier 85:15 compound hydrolysed using H<sub>2</sub>SO<sub>4</sub> and high temperature treatment.

The yarn prototypes based on PLA/Ecoflex/Rettenmaier blends were used to fasten different types of cultures in one cycle production. After crop, the plants together with the yarn were used to perform a semi-industrial-scale composting. Yarns were used to fasten cultures of melon, cucumber and tomato in greenhouses cultures and tomato in open field culture (as reported in WP8). The yarn made of (PLA:Ecoflex 20:80):Rettenmaier 70:30 was the most suitable to be composted at semi-industrial scale because besides of being the most adequate for field application it disintegrated after composting and the final compost was of high quality.

The materials developed for within this project developed polyurethane (PUR) with 20% rosin acid and recycled polypropylene with Rettenmaier fibres were quite resistant to biological degradation. PUR materials prepared for fish-box industry and automotive applications were highly resistant to microbial attack. Also polypropylene/wood composites for automotive applications and materials intended for chemical and cosmetic containers based on formulations containing PP and rPP with wood were heavily colonized by fungi but not impact on materials properties was evidenced. These characteristics are essential for long term outdoor applications such as insulation or automobile parts. In general the

increase of wood content in materials favours the microbial colonization. All selected materials can be considered very durable from the point of view of susceptibility to microbial attack and biodeterioration.

WP 10: Life Cycle Analysis (WP Leader OWS) (sm 12, em 48)

Task 10.1 Scope definition for LCA study (Task Leader OWS) (sm 12, em 48)

Task 10.2 Performance of LCA on packaging materials (Task Leader OWS) (sm 18, em 48)

Task 10.3 Performance of LCA on automotive components (Task Leader CRF) (sm 18, em 48)



**Objectives of the present WP were:**

- To assess the hot spots in the production chain in order to make recommendation for future production of FORBIOPLAST materials.
- To assess the environmental burden and impact originated from the life cycle of the packaging (comparison with commercial packaging) and automotive parts (comparison with actual car components).

An environmental assessment has been made by using the eco-indicator 99 (H) method on 5 different applications containing wood fibres:

- Fertilizer sticks
- Food trays
- Tomato yarn
- PHB pot
- Automotive car pan

These materials have been chosen because of their different applications and compositions. The starting point in this assessment was the data inventory of the wood fibre production. This data inventory was based on a literature review, where it was assumed that the fibres are made from sawdust and afterwards transported to the production site in Germany. The production of sawdust, including the tree harvest steps seemed to be the most dominating step representing 46% of the total impact, mainly caused by land use, whilst energy use during further processing to fibres and transport to destination account for 29 and 25% respectively. Although it is expected that the used fibres in the studied application origin from sawdust, a sensitivity check was performed comparing the exact source of the wood biomass. From this analysis it can be concluded that the different types of wood chips found in the LCI database generally have a lower impact, especially concerning land use, compared to the used sawdust dataset. In some cases more fossils are used, but this impact seems to be low compared to the total impact of the wood fibres.

In general, adding wood fibres to plastic applications is an environmentally benign strategy. The overall environmental impact of the wood chips according to the eco-indicator 99 method is lower compared to any fossil or non fossil based material used in the studied materials, such as PE, PP, PVC, PS, PBAT, PHB, starch. Therefore, apart from material properties, it is clear that adding more wood is a good strategy to achieve a better environmental performance compared to reference products.

When studying the fertilizer sticks, the main impact is caused by the fertilizer itself (32%) and the starch material (54%). The main impact from starch is caused by the softening step

where glycerol is needed (29%). The production of wood fibres in the sticks in a composition ratio of S/W 70/30 causes only 7% of the total impact. In more advanced materials such as food trays and tomato yarn, a combination of PBAT, PLA and wood is used. In these applications wood is responsible for only 2 and 4% of the impact respectively. In both these cases the production of PBAT, including the required adipic acid in its production chain, seems to be dominant with 50 and 76% of the total impact, with a higher relative impact in the tomato yarns because of the larger fraction of PBAT in the total composition. Also in the PHB pot case study, the production chain of the 20wt% wood fibres has a relatively low impact (4%), whereas the PHB production chain accounts for 48%. In general, the energy needed for the final processing steps (mainly drying, compounding, extrusion and moulding) from resins to final applications contributes low to moderate to the total impact; results vary from 7% (fertilizer sticks), to 13% (tomato yarn), to 20% (food trays) to 48% (PHB pot). In the studied cases, data was used from lab/pilot scale setups which are used at their average efficiency. Large scale production would significantly reduce the impact of these final steps.

The different materials were compared with reference products. Generally, these products seem to be competitive. Both in the case of fertilizer sticks as in the case of tomato yarns the environmental impact is average compared to market products, while the PHB pot performs better compared to the PE alternative. The Forbioplast food tray however, performs worse compared to PET, PP and PS food trays. It seems that the production of the biodegradable PBAT and PLA is a more intensive and energy demanding process, therefore having a more severe environmental impact compared to the more straightforward production routes of fossil based plastics.

A large advantage of the materials produced in FORBIOPLAST is their biodegradability. This end of life scenario of the studied materials however, was too difficult to model with the current methodologies used in LCA. In the case of fertilizer sticks, tomato yarn and the PHB pot, the biodegradability is positive because of the fact that they often end up directly into the natural environment. It would be even possible to assign carbon credits because of the potential soil enrichment effect of these materials. At the other side, the direct emission of a non biodegradable plastic is impossible to assess because no sound fate/exposure/effect models of these materials exist for LCA. In the case of food trays, the interaction with nature is less direct. A scenario has been analysed where the PBAT/PLA/wood material is composted compared to the reference products which are incinerated. Even when implementing this end of life scenario, the life cycle impact of the FORBIOPLAST material is higher. A careful recycling of the fossil based materials would enhance this effect. Nevertheless, the biodegradable food tray may be preferred in cases where they are highly contaminated with organic matter or in cases where a direct contact with the environment can be expected (e.g. festivals).

The recycled materials reinforced with natural fibres show good technical performances, as well as significant environmental advantages, so as the LCA has been able to highlight. While the environmental impacts are quite similar for the use and end of life phases, the FORBIOPLAST solutions show remarkable advantages in the production phase mainly concerning the avoided burdens due to the polypropylene recycling and the use of vegetable fibres instead of the mineral ones. Thanks to benefits in using recycled material and wood fibres and to other improvements due to a logistic optimization (transports), the FORBIOPLAST solutions deserve to be considered as good alternatives to those currently used.

## **Potential Impact:**

European citizens tend to have an increasing positive attitude towards buying and using green and renewable technologies, especially because they reduce the impact on the environment. In the future, more people are expected to follow this behavior because of the increased advertising and policies applied in this area so the market of green technologies seems to look very bright.

The results and the prototypes produced in FORBIOPLAST attest for the possible valorisation of forest biomass for the production of environmentally compatible materials to be applied in packaging, agriculture and automotives. These materials include composites based on biodegradable polymeric matrices, or recycled polypropylene with lignin or wood fibres and hard and soft polyurethane, eventually loaded with wood fibres produced by green synthesis from tall oils or lignin.

Roughly 30% of earth's surface or around 4 billion hectares, respectively, are covered with forest land. From the total area in European Union (2008), 177 million ha (~130 million ha for use) which equals 42% are documented as wood. Forest land in EU is to ~ 60% under private ownership with typical individual holdings of less than 5 ha.

About one third of global round wood production takes place in Europe. From 170 million tons of pulp, approximately 40 million tons (2006) are generated in EU-27. Leading global wood and pulp manufacturers (e.g. Stora Enso) and specialists in engineered wood fibres (e.g. Rettenmeier) are headquartered and located throughout European Union.

More than 50 million tons of lignin annually derive from different pulping processes, while the Kraft process takes the lion's share of 76%. Merely 1 million t of the lignin is under commercial use. Hence, FORBIOPLAST research treats lignin for various materials, such as PUR soft foams. As a by-product of the Kraft pulping process, tall oil is available for further industrial use. The total yield is estimated on 1,5 million tons per year. Tall oil is primarily utilized for developing bio-based rigid polyurethanes and composites in FORBIOPLAST project.

European strategy on clean and energy efficient vehicles has been set up in 2010. The strategy proposed the European action where it can have distinct, value-added and complement the actions by the industry, national and regional public authorities.

The main objectives of the European Commission concerning the automotive sector are: to strengthen the competitiveness of the Automotive Industry, To complete, adapt and simplify the Internal Market regulatory framework, to promote globalization of the technical regulatory framework through UNECE. In order to achieve these ambitious goals, legislation in the European Union is focused on sustainable automotive industry. With regard to 8-9

million tonnes of waste deriving from end of life vehicles in European Union, the (Directive 2000/53/EC - the "ELV Directive") has been officially adopted by the European Parliament and the Council in September 2000.

FORBIOPLAST works with recycled materials as well as biopolymers and responds to depletion of fossil resources. For example, the world's crude oil reserves were estimated on 184 billion tons in 2009. Assuming that annual consumption may vary between 3.7 and 3.9 billion tons (as occurred between years 2003-2009) and no significant reserves will be discovered, the resource will be exhausted in less than 50 years. From a total demand of 52.5 million tons of plastics, 18% of this request was polypropylene in 2007. Considering the environmental issues of plastics in Europe (EU27/NO/CH), it has been reported that 50% of the plastics have been recovered either for materials (20,4%) or for generating energy (29,4%). Recycled polypropylene plays a crucial role in development of ecological automotive parts (seat system) within the project. As a further part of cars, in FORBIOPLAST a seat has been designed to be produced from fully ecological material (rPP/wood fibre). PP is a very important polymer in automotive industry and as it has been recorded, from a car in the range of 1100 kg, 130 kg are plastics. From the plastics 45 kg (more than 1/3) are PP. At European scale, it means 600.000 t. The potential amount of plastic composites in a seat system is estimated on 10 kg per car. Moreover, replacement of metal by plastic composite entails reduction of weight of the seat and the car. FORBIOPLAST research and development has generated composites which exhibit economic and ecological advantages and its potential in seats in European cars is estimated on 80.000 t.

Research and development within FORBIOPLAST in the packaging area has resulted in prototypes like food tray, egg container, fish box, cosmetic container and chemical container. The FORBIOPLAST project has developed the process of a new generation of packaging solutions using renewable and fully recyclable materials that also respond to the growing packaging market. The future for fibre-based packaging will require the re-engineering of the packaging value chain to deliver increased, capital efficiency, product innovation and more competitive packaging materials. The main trend in modern packaging is the utilization of the biodegradable materials which enable the protection of the environment in accordance with the European legislation.

As it has been recently projected and published, the global packaging sales will upraise from 670 billion \$ in 2010 to 820 billion \$ in 2016. Apart from economic growing, there are further trends and drivers which effect the growth and quality of packaging sector. They include: Older population, Smaller households, Convenience, Health awareness, Brand enhancement/differentiation, New packaging material development, Smaller pack sizes, Recycling. FORBIOPLAST addressed these trends, particularly regarding health awareness, new materials and recycling.

Food trays and egg containers resulted from FORBIOPLAST research have clear advantages: lower ecological footprint, produced partly from renewable materials, greener product, completely biodegradable during industrial composting.

In 2010, the production of eggs (hen eggs in shell) has reached a quantity of around 112 billion pieces in the European Union. An egg production of 14,5 billion pieces was documented in Italy, an amount of 13,5 billion pieces in France, 13,3 billion pieces in Spain and in Hungary an amount of 2,7 billion pieces. Following these figures, FORBIOPLAST egg cartons could serve a large market in Europe. FORBIOPLAST egg container compete with traditional plastic such as PET and recycled PET or high impact polystyrene as well as egg cartons produced by fibre moulding.

Cosmetic is a very important industry sector in Europe. Following a market study of Global Insight, the European market size of cosmetics and toiletries was 63.5 billion in 2006. That means about the value of the combined market size of USA (38.2 billion) and Japan (23,7 billion). The Chinese market was valued with 8.2 billion in 2006. Cosmetic packaging should grow 4.2% per year to reach \$24 billion (PIRA, 2012). North America has the largest share at 66% followed by Europe at 63%. The largest categories using rigid plastics are hair care, bath & shower, facial skincare and deodorants. Cosmetic containers which includes cosmetic compacts and lipstick and mascara cases, is growing at 3% a year but in Asia Pacific, Latin America and the Middle East and Africa it is expected to grow at 5-6% a year to 2014. The top performing rigid plastic pack is expected to be plastic jars growing at 5% a year ([http://www.rexam.com/files/pdf/packaging\\_unwrapped\\_2011.pdf](http://www.rexam.com/files/pdf/packaging_unwrapped_2011.pdf)). It is suppose that the innovative FORBIOPLAST cosmetic container can replace around 10% of packaging in cosmetics. FORBIOPLAST research and development in the cosmetic packaging area and its outcomes offer bio-based and sustainable solutions for cosmetics industries. The advantages of properties which could be promoted within the FORBIOPLAST cosmetic container are the followings: ease of moulding into complex shapes, rigid enough, impact toughness, abrasion resistance and chemical resistance that reduces scalping and permeation of valuable ingredients, a superior barrier against oxygen, fragrance and contamination, the chemical and aroma barrier properties keep volatile and valuable ingredients inside the package where they belong, making sure product value and quality reach the consumer intact, anti-static properties, 100% eco friendly, unique design, gloss surface, easy to print with high-quality graphics to increase the visibility and the attractiveness of the package, and cost-efficient decorative effects, best price with top quality. FORBIOPLAST has produced an environmentally friendly cream jar based on traditional polymers and natural fibres while commonly PP, PE and PET is used for that purpose. Like any new product, packaging materials products resulted from FORBIOPLAST project require special promotion supported by adequate advertising and improved functional qualities. Demands in cosmetic container applications will be supported by growth in production, as well as by expansion in all age population body and beauty care segments, which comprise many of the most intensive consumers of cosmetics. Traditional 200ml jars from PP are sold in the range from 0.18 --

0.40 per piece. The container produced in FORBIOPLAST could be competitive in terms of price and environmental issues.

Partner INCP has produced a prototype of a chemical container that was tested by Partner NEOC. The chemicals, plastics and rubber industries belong to the most dynamic and most relevant industrial areas in the European Union. In more than 60.000 companies are around 3.2 million persons employed, which have created a turnover of 537 billion in 2007 (~30% of global chemical sales). Sustainable development is a topic which is set out in the Treaty on European Union and the chemicals industry will contribute to solve the problems like global warming and decline of natural resources with new materials and technologies towards increasing sustainability. Bio-based chemical containers as generated within FORBIOPLAST are tailor-made for offering sustainable solutions to chemical industries. The advantages of properties which could be promoted within the FORBIOPLAST chemical container are the same as reported for the cosmetic containers. While by using of PP/rPP/Fibres composites with application as chemical containers the main advantages consist in: elimination of sources of environmental pollution with non-biodegradable material; reintroduction in economic circuit of materials with high potential for reuse (both rPP and fibres); reduce consumption of the raw materials (PP). The mechanical properties correspond to the end-user requirements however physical properties such as appearance, transparency and color need further improvement.

Toward 2014 the growth of chemical container demand in the world will increase with 2.9% and will be driven by performance advantages over alternative packaging media, which will stimulate ongoing opportunities in a broad range of applications. It is expected that 15% from total chemical packaging can be replaced with FORBIOPLAST products. Certainly, the incorporation of a percentage of recycled polypropylene in the formulation has a positive cost impact and helps to re-use polypropylene. Price of polypropylene versus price of polyethylene is not expected to make a big difference since both are widely used plastics. The mixture of recycled polypropylene with pure polypropylene without affecting the mechanical properties will offer a price advantage as well as the incorporation of up to 30% of wood fibres in the formulations.

With regard to the FORBIOPLAST materials devoted to agricultural market segment, questionnaires were prepared by Partner WIED and evaluated striving for the best opportunities of market entrance for the agriculture product portfolio. From this portfolio, tomato yarn, plant pots and encapsulated fertilizer, which have been developed at pilot scale, were treated within market analysis.

Within FORBIOPLAST, bio-based and biodegradable yarn for trellising tomatoes has been evolved at pilot scale. After potato, tomato is the second most important vegetable plant in

the world. With a total amount of 17.9 million t harvested on 314209 ha in 2009, around 12% of global tomato production occurred in EU-27.

Since requested amount of yarn is approximately 350 kg per ha, the amount of string for that purpose which could be substituted in EU-27 would exceed 100.000 tonnes. Materials currently under use are polypropylene, polyethylene, raffia and other natural fibres like jute. Applications beyond tomato could be for other crops like cucumber and paprika, flowers and ornamental plants, trees grafting, tying of grapes and straw bales. Biodegradable plant pots have been manufactured and tested within the project.

The main advantages of the FORBIOPLAST tomato yarn comparative with tomato yarn based on traditional petrochemical products are: It is derived from sustainable resource; Help in preserving non-renewable resources like petroleum, natural gas and coal; Toxic free; Compostable; Environmental protection; Best suited for short shelf life products; Low barriers of oxygen/water vapors transfer.

Crucial requirements for pots to be marketed in horticulture are no negative impact on plant growing, suitable for potting machines, no negative effect on workflow, stability, low weight, low costs, printable and bondable (EAN-Code). Apart from horticulture, possible applications could be ornamental and flower plants, breeding perennials, tree nursery and aquatic plants. A possible demand in Buzau/Romania exceeds 10.000 pieces p.a.

Advantages of FORBIOPLAST pots compared with traditional pots are: Compostable;

Can be planted directly in the soil, saving time if based on polymers degradable in soil such as polyhydroxybutyrate; Eliminating stress to planting to induce the earlier production, achieving a savings in terms of manual labor; Reducing waste since the pots decompose in the soil; Easier application; Labor force concentrated in a smaller area; Ability to manage growing conditions, less climatic risk; Smaller area needed for the same production numbers; Greater success rate in comparison to traditional bare root.

As a further product devoted to the agricultural market segment, an encapsulated fertilizer with a bio-based and biodegradable coating is created within the project.

The global market for coated fertilizers shows tremendous growing rates and this type of fertilizer is more and more applied in major agriculture crops like cereals and potatoes. Among the advantages of these fertilizers are a possible reduction of fertilizer application quantity and full nutrient supply for plants under plastic cover. Moreover, with the bio-based and biodegradable coating, the drawback of plastic residues (up to 50 kg/ha/year) can be avoided.



The Common Agricultural Policy is also integrating environmental concerns as a most sensitive objective and it aims to head off the risks of environmental degradation and enhancing the sustainability of agro-ecosystems. Around half the EU's land is farmed and farming is important for the EU's natural environment, so, farming and nature influence each other. Inappropriate agricultural practices and land use can have an adverse impact on natural resources, like pollution of soil, water and air, fragmentation of habitats and loss of wildlife. The Common Agricultural Policy (CAP) has identified and set three priority areas for action to protect and enhance the EU's rural heritage which can be achieved through solutions given by biocomposite materials: biodiversity and the preservation and development of 'natural' farming and forestry systems, and traditional agricultural landscapes; water management and use; dealing with climate change. FORBIOPLAST Project helps reaching these policies by aiming the valorisation of forest resources for the production of bio-based products with the additional contribution to solve the problems related to materials produced by petro-derived resource, to waste disposal, to the use of energy consumption and polluting chemical pathways and to the use of hazardous substances. The project helps in meeting the European agriculture policies: CAP. The main topic of the research activity will be focused on the use of wood and paper mill by-products as raw materials for the production of polyurethane foams by an innovative sustainable synthetic process with reduced energy consumption. Efforts were devoted to the promotion of the use of wood derived fibres in the agriculture sector (mulching, greenhouse, tomato clips, different types of pots and yarns etc) as in FORBIOPLAST Project, 2012.

Polyurethanes (PUR), often described as the most versatile plastics materials, are produced with remarkable share from bio-based feedstock (tall oil and lignin) within FORBIOPLAST research towards end uses in automotive acoustic insulation, spoilers and packaging such as fish transport boxes (Hard PUR). Lignin-based Soft PUR can be applied e.g. in furniture industry as the biggest consumer of PUR in Europe (2005) as well as in automotive sector. Opposed to bio-based polyols from vegetable oils already introduced onto the market, FORBIOPLAST polyols are generated from waste material of pulp industry and their raw materials are commonly not grown on agriculture crop areas. Positive impact is expected from the exploitation of hard polyurethane produced by tall oils since tall oil is prospective raw material for polyol production for polyurethane foams. A spoiler, partly deriving from renewable resources has been produced by partner PEMU. As it is emphasized, the properties and the price of this automotive part which is primarily devoted to sports- and luxury cars, are comparable to traditional crude oil based materials. Following appraisals, Green PUR could achieve 300.000 t for spoilers.

Partner IWC has developed a prototype of Fish Transport Box from bio-based polyurethane. Fisheries and aquaculture products are important components in European diet. The average consumption of fish in EU-27 was 21.4 kg per capita in 2006. Opposed to the fisheries catching sector, European Union is a leading player in fish processing industries where a turnover of around 18 billion has been achieved in 2006 and 129.500 people were

employed in 2005. Taking into account, fish have no borders in sea and contemplating, fishing fleets have an impact on other fleets, the European member states have determined to collaborate in their fisheries affair, through the common fisheries policy (CFP). This policy assembles a variety of measures tailored to accomplish a prosperous and sustainable fishing industry in Europe. Pursuing the objectives mentioned above, a range of Regulations and Directives has been decided by European Union. One of the most important regulations is: Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Concerning hygienic requirements, EU Directive 91/493/EEC contents important health conditions relating to fishery production and placing on the market for human consumption. By developing bio-based PUR-insulation for thermal insulated fish transport boxes, foreseen to be deployed where no cooling facilities are available or the temperature is either too low or too high, FORBIOPLAST addresses these requirements. Thermal insulated PUR containers are under use when the temperature for transport of fish or aquatic food has continuously to be kept at the same level, usually -18 °C. Main benefit of FORBIOPLAST fish box is the green PUR foam as insulation instead of hydrocarbon based. FORBIOPLAST bio-based PUR-insulation contents more than 20% of raw materials based on natural resources.

A part from the FORBIOPLAST targeted core applications Agriculture, Automotive, and Packaging, the excellent research of the project generated knowledge to be exploited in the area of polymer processing and materials for immobilization of microorganisms (Application Number EP 12172851.3, 21.06.2012, Polyurethane rigid and flexible foams as composite obtained from wood origin raw materials and used as support for immobilization of microorganism that produce ligninolytic enzymes U. Cabulis, M. Kirpluks, U. Stirna, Maria J. Lopez, M.C. Vargas-Garcia, F. Suarez-Estrella, J. Moreno, A. Lazzeri, P. Cinelli). Ligninolytic enzymes are highly versatile in nature and they find application in a wide variety of fields of industry and environment: textile, food, paper and wood processing, bioremediation, pharmaceutical, chemical industries and nanobiotechnology. They have been proposed for bioconversion of lignocelluloses into value added-products (e.g. biofuels and chemical feedstocks in biorefinery), pulp delignification, dye bleaching, improvement of the whiteness in conventional bleaching of cotton, biostoning, detoxification of wastewaters and other bioremediation processes, preparation of musts and wines, polymerization of lignin and lignosulphonates, detergent manufacturing, modification of biopolymers for the production of derivatives suitable for incorporation as copolymers in synthetic polymers for paints, plastics, and films, tailoring of lignocellulosic materials by laccase-assisted biografting of phenols and other compounds and transformation of antibiotic and steroids. The biotechnological significance of laccase enzymes has led to a drastic increase in its demand in the recent time. Industrial enzyme market is valued at \$2.000 million per annum with a potential annual growth rate of 3 to 5%. Laccase stake in this market is about 4% thus making it a potential \$800 million market cap mainly in the textile industry and enzyme bleaching of pulp. Energy-saving of ligninolytic-based biocatalysts fit well with the development of highly efficient, sustainable, and eco-friendly industries. Also, there is a broad field of investigation that is almost entirely open to new findings and it is quite reasonable that many new applications will be found in the near future.

New efficient methods of processing and new materials are generated as a result of the activities undertaken within the project. Saving raw materials and reducing costs for manufacturing and logistics will supply competitive products and secure employment. Energy consumption and effects of greenhouse gas emissions will be reduced by the exploitation of the new materials and commodities. Due to the new technologies customers benefits will be the availability of items with improved quality and lower prices related to environmentally friendly waste disposal. Renewable resources are continually renewed by the cycle of nature and are considered to be practically inexhaustible.

The research activity performed in the project had a significant impact on the RTDs performers in terms of increased knowledge, new contact, positive cooperation and experience acquired in working with industries. Problems from the perspectives of the industrial users and producers were evaluated, and with these impressions the RTDs were able to attend the necessities required by the local industries. FORBIOPLAST research and development lead to gaining new knowledge in the area of biopolymers and biocomposites and provides new options for promotion of bio-based materials and products. Furthermore, due to conduction of market analysis, new market opportunities for innovative composites were identified.

The end users were very satisfied if the results and of the positive cooperation with the RTDs and producers. The use of biodegradable packaging for cosmetics is in its infancy. Poor barrier properties, higher price and low general public awareness are the major reasons for the limited use of biodegradable packaging in cosmetics. Partner Cosmetic (COS) had the opportunity to get an inside industry knowledge of the biodegradable packaging. The dissemination of FORBIOPLAST results to Cosmetic's customers has stirred conversations about the potential use of biodegradable packaging in this industry sector. COS is offering formulation and production services to other companies. It is to the company's advantage to offer the best advice to its customers especially the ones that have more green products. 1 billion \$ world market for plastic cosmetic containers by injection moulding and 8 million is the corresponding Greek market. The above numbers are estimates based on the assumption that the cosmetics packaging produced by injection moulding corresponds to the 1/7 of the total. One fifth of the above could be replaced by the type of packaging developed in FORBIOPLAST. If biodegradable packaging becomes more widely-used, it is possible that the green certification bodies such as ICEA or Ecocert may require its use for providing the green label to cosmetic products. It is very likely that such a development will give more value to biodegradable packaging and raise general public awareness. The participation of COS to a large European consortium involving academic experts in the area has also been very beneficial towards improving the company's image and reinforcing its R&D profile, both within Greece and abroad. It has at the same time provided the basis for future research activity in the company in the area of biodegradable packaging or packaging materials in general. The industrial manufacturers could be some of the major plastic

container producers in Greece e.g. Supremeplast, Argo and abroad e.g. Bormioli, PET Power, M&H etc. The end user can be companies that have green marketing claims e.g. Korres, Macrovia, Apivita sold mainly in pharmacies and brands like Olivella, Kalliston, Ollivelonic etc. sold in the touristic shops of Greece.

Testing of the newly developed chemical containers in Neochimiki premises for the packaging of alcohol solvents commonly used in the chemical industry such as for the synthesis of polymers demonstrated their suitability and showed that they can substitute the currently used packaging materials. In particular, ethanol and isopropanol were tested and after three months storage the packaging material retained its integrity and no discoloration of the ingredients was observed. However, storage of other organic solvents such as styrene, toluene, acetone, ethyl acetate, methyl methacrylate and xylene was not successful. If the new containers meet all the requirements set including appearance, it is possible for the new chemical containers to gain a significant market share and Neochimiki through its wide network of contacts will help in disseminating the results to its suppliers and beyond. The industrial producer (s) of the FORBIOPLAST chemical container will be the suppliers of Neochimiki and similar companies producing and distributing chemicals and the end-user (s) will be companies like Neochimiki who buy the containers to package their chemical products.

For the end user CRF Materials developed in FORBIOPLAST from recycled PP and forest resources have been demonstrated to be suitable for the production of automotive parts, in particular a seat structure. All the final four materials are good with a different level of flexibility. Forest materials can be considered an adequate form of resources in conjunction with plastic. An amount from 10% to 30% of natural resources is a reasonable value. Car seat is a very critical system due to its heavy weight. The trend is to move from metal to plastic for the realization of parts of the seat system in order to reduce total weight. Potential amount of plastic composites for car seat system (front and back seats) material could be estimated in an average of 10 kg for each car. Considering the material developed in FORBIOPLAST for its peculiarity could be useful for low/medium class vehicle, it is expected for the European cars a total amount of around 80.000 tons for year.

High density polyurethane material developed in FORBIOPLAST from using polyol from forest resources have been demonstrated to be suitable for the production of automotive parts, in particular a spoiler. Forest materials can be considered an adequate form of resources for the production of polyol at 22% of content, equivalent about 8% of bio resource in the final PUR formulation.

IWC plan the funding of the Spin Off SME Plant PolyLabs, for the production of polyols, four additional jobs are planned in this enterprise.

All the partners of FORBIOPLAST were extremely active in dissemination by participation to conferences, workshops, meetings, events open to school or industries. FORBIOPLAST was selected for the Innovation Convention 2011 Bruxelles, 5-6/12/2011.

UNIPi had a stand at the PLAST2012, Milano, 8-12.05.2012, where the prototypes of FORBIOPLAST were shown (egg containers, trays, cosmetic and chemical containers, tomato yarns, spoiler etc) and got a huge interest from University but mostly from industries which enquired for the possibility to buy or produce the materials in particular for tomato yarns, tray and egg containers, cosmetic containers and for the spoiler. IWC participated to the Exposition Hall coordinated by Wood Producer Association, and the foam samples were presented there. IWC have good contacts with PU-EUROPE (<http://www.pu-europe.eu>), IWC presented them FORBIOPLAST materials, and they invited IWC to present them in the nearest association meeting. UNIPi was invited to present FORBIOPLAST as an example of success story at a Press Conference, Rome, 09.07.2012 at the Italian representative of European Community. UNIPi and other partners were interviewed about FORBIOPLAST as a project with success story. For example Prof. Cabulis from IWC presented FORBIOPLAST project in meetings of Latvian Investment and Development Agency and in Information Days of Latvian FP7 Contact Point as success story.

UNIPi was invited to present FORBIOPLAST at the PLASTICE conference Europe for sustainable plastics, Bologna 24-25.10.2011; at the Niche markets for speciality industrial crops 2.09.2011, Thessaloniki, Greece; at the Plastiche intelligent in una filiera Agricola di qualita, organised the Gruppo24ore, Milano 11.05.2012, and to present it at the Crete2012 3rd International conference on industrial and hazardous waste management, 12-14.09.2012, Chania, Greece.

A list of the scientific publications derived by FORBIOPLAST is reported in Table A1 of the final report. Several more papers are under preparation. Most relevant activity of FORBIOPLAST was finalised and optimised in the last year of the project. Partner focused mostly on the production of materials and their validation and the writing of scientific papers was postponed, also taking in consideration the possibility of exploitation and patent applications. There was large participation in conferences, meetings etc since this allows for more strict selection of the data to be presented, thus not affecting patents.

It was organised an International Conference "Bio-based Polymers and Composites with the abbreviation BiPoCo 2012. The organiser was partner 02-LPRT but main milestones were discussed with the project coordinator UNIPi. A website was launched (<http://www.bipoco2012.hu>) program was carefully composed; four types of presentations were selected: Plenary lectures, Keynote lectures, Oral presentations, Poster presentations. Invited speakers were selected to cover the scope of the conference. Internationally well known authorities presented the latest work of their fields on the highest level:

Lars Berglund (KTH Royal Institute of Technology, Sweden) Biocomposites from small building blocks learning from plant structures; Claudia Crestini (University of Rome, Italy) Cellulosic composites from low to high tech versions; Ramani Narayan (Michigan State

University, USA) The promise of bioplastics understanding the value proposition for biobased and biodegradable-compostable plastics; Balazs Imre (Budapest University of Technology and Economics ) Biopolymer blends: miscibility, compatibility, performance. Two types of keynote presentations were selected: two focusing on the topic covered by the plenary lecture presented before them and three presenting the FP7-projects related to the conference (FORBIOPLAST, BIOSTRUCT and WOODY), having their own dedicated block in the scientific program. In all 94 oral lectures were presented and to extend the number of presentations two poster sessions were organized where topics were extended but harmonized with oral sessions. 110 poster presentations were selected to display. A poster-award was also announced and 6 posters were selected and rewarded by an international scientific jury. As the topic of three keynote presentations were about EC founded research projects, the conference emphasized the role of the European Commission in large scale international research projects. 8 oral and 18 poster presentations were presented by FORBIOPLAST partners and 30 from all the partners of the three projects disseminating the results and foreground knowledge obtained during the EC founded FP7 projects.

As it was declared in the Annex I., proceedings should be published in a special publication on Bio-based materials by forest resources. Due to the change of the form of the event from workshop to conference and because of the large diversity of the topics covered, this type of special issue did not make sense any more. The goal was to provide publishing possibility to as many presenters as possible that required a wider range of journals. Based on the topics of BiPoCo 2012, four issues were planned where manuscripts could be submitted for publication: Composite Science and Technology (Elsevier, Impact factor: 2.865), Cellulose (Springer, Impact factor: 2.817), The European Polymer Journal (Elsevier, Impact factor: 2.517), Composite Interfaces (Springer, Impact factor: 0.573). Conference attendees submitted more several publications which will be published in these issues. Many of those are from partners of FORBIOPLAST. 29 manuscripts were submitted for the special issues dedicated to FORBIOPLAST, of which 5 were features articles, and 12 were accepted for publication.

Future dissemination activity includes the organization of the second edition of the Conference on Bio-based Polymers and Composites in May, 2014, organized as well in Hungary.

Several papers are under submission and revision, since most of the partners were so involved in research activities and preparation of the deliverables that they did not find the time to prepare manuscripts.

The FORBIOPLAST website will be kept active for next 5 years by UNIPi, and updated with the new papers accepted for publications, and other dissemination of FORBIOPLAST results at conferences, interviews etc

For the industrial exploitation of the results of FORBIOPLAST we report some previsions for CRF and PEMU.

CRF main interest for the products developed in FORBIOPLAST relies in the possibility to use the new eco-friendly materials based on wood fibers and plastics from post-consumer recycling and polyurethane formulations by lignin materials in automotive applications. The materials have been technically evaluated by CRF and demonstrated a good solution for semi-structural automotive parts and from the economic aspect they are also a cost effective solution. CRF also through its company Magneti Marelli - Plastic Components is interested to further strength its environmental sustainability approach also through the use of materials such as those developed in FORBIOPLAST.

From a technical point of view the materials coming out from FORBIOPLAST are almost mature but some adjustments are needed to be made by internal resources in order to provide technical optimization and achieve mature results for industrialization. In addition in order to arrive to a fully exploitation and commercialize the result, is important to continue to work on the whole supply chain with particular attention to the procurement of recycled material from end of life vehicle parts. This is a topic in which CRF is strongly committed.

It could be estimated the use of the material, based on wood fiber and plastics from recycled material, in a car for the developed of demonstrators as an amount of 1,4 kg for each car, but it is also possible to think to enlarge the use to other parts for a total amount around 5 kg for each car. That means for a production of an average model of 300.000 cars for year an amount of 1500 tons per year (500 tons of wood and 1000 tons of recycled plastic).

Instead for the green polyurethane it can be estimated a larger amount in a vehicle, for example 20 kg, but it is adopted in low production vehicle (20.000 cars/year) for an annual amount of 400 tons. It is important to add, considering CRF target on weight reduction for 2020, that polyurethane could find more applications in automotive than in the present situation and the total amount needed could growth even in medium production vehicles.

Time scale for exploitation of FORBIOPLAST materials in automotive production is predicted between 2015 and 2020.

A part the specific materials and demonstrators developed by CRF for automotive, FORBIOPLAST project allowed CRF to get experience in bioplastics. Such materials were developed in FORBIOPLAST for agricultural and packaging applications, but they could be even employed with minor modifications in the future in automotive field. And this road will be investigated by CRF in future European projects (i.e. EU BRIGIT project).

PEMU is strongly interested to the industrialization of the materials developed in FORBIOPLAST, in particular for composites produced with recycled polypropylene and production of polyurethane for automotive applications. As well as CRF, PEMU feels the need for minor optimization of the production process. Also for PEMU the exploitation of FORBIOPLAST materials in automotive production is predicted between 2015 and 2020. CRF and PEMU consider the production of the car seat, and of the spoiler enough advanced, and the performances already meeting CRF requirements. These two partners considered not justifiable to go to a demo action for materials devoted to automotive applications.

FORBIOPLAST SMEs partners (excluding INCP which stopped activity) involved in the development of products oriented to biotechnology, agriculture and packaging, decided to apply for a new proposal (FP7-613902) FORBIOPLAST2 Valorisation of forest resource for biotechnology, packaging and agriculture market. This is a demo action in FP7-KBBE-2013-7-single-stage, under the coordination of a Spanish SME, Tecnopack, which joined the consortium together with other three new SMEs, attesting for the high industrial interest towards FORBIOPLAST products.

Partner LPRT and UASVM are promoting the exploitation of fertilizer stick with Buzau/Romania, and Nitroganmavek Zrt. , and are preparing a patent on the production of fertilizer sticks.



**List of Websites:**

<http://www.forbioplast.eu>

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