PROJECT FINAL REPORT

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Project acronym: NANOCELLUCOMP

Project title: The development of very high performance bioderived composite materials of cellulose nanofibres and polysaccharides.

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4.1 Final publishable summary report

4.1.1 Executive Summary

As a society we rely heavily on advanced materials, such as composites, made from non-renewable petroleum based products that are energy intensive and require significant use of volatile solvents to manufacture. The FP7 NanoCelluComp project was funded to address the twin issues of sustainability and environmental impact, through the substitution of high performance composite materials derived from petrochemical sources with those that are bio-based, and the development of environmentally friendly process technologies.

NanoCelluComp exploits the mechanical properties of cellulose, a natural polysaccharide which is highly abundant and in its liberated form of cellulose fibrils (known as nanocellulose or microfibrillated cellulose) demonstrates high mechanical performance, and an ultrahigh length to diameter ratio, both of which mean that its strength to weight ratio exceeds that of many synthetic fibres.

Nanocellulose can be liberated from a number of sources including plants (wood and crop waste), bacteria and algae. Of these, plants, and in particular plant waste streams, represent an abundant resource. Although these have been exploited for a number of years (wood pulp in particular), the process technologies often employ harsh chemical and/or high energy homogenisation, which detracts from their sustainability. In addition, the resultant fibrils often contain other cellular components which impair the expected mechanical properties.

NanoCelluComp aimed to address these drawbacks through a two stage process:

1. Liberation of cellulose nanofibres from vegetable food waste using an aqueous process.
2. Orientation of nanofibres (to improve mechanical properties) and mixing with bioresins to produce a 100% bio-composite.

In addition, the real substitution potential of such novel composite materials was investigated through engagement with industrial end-users and by performing a life-cycle assessment (LCA) of the materials including the manufacture, expected use and final disposal or recycling of products containing such materials.

NanoCelluComp achieved the following:

1. Development of novel enzymatic process for the liberation of nanocellulose from a variety of waste vegetable streams.
2. Novel bio-based chemistry to prevent fibril agglomeration and to introduce cross-linking motifs.
3. Technologies to align fibrils and produce macroscale fibres through spinning processes and cross-linking reactions.
4. Treatment of fibres to promote good adhesion to a variety of bioresins, and successful testing of the fibres and bioresins in a number of standard industrial manufacturing processes.
5. Processing of pilot-scale volumes of vegetable extract (30-50l) to produce fibres with the following mechanical properties: a Young's Modulus of 12.4 GPa, tensile strength of 191 MPa and strain at break of 8.9%; and epoxy composites with similar mechanical properties to those of glass fibre with the same fibre percentage (10%) (Young's Modulus of 2.4 GPa and tensile strength of 81.5 MPa).
6. Opportunities for development in niche product sectors to begin with, such as designer household goods (including furniture), lightweight vehicle components, and medical device applications.

7. Decreased environmental impact compared to composites containing glass and carbon fibres (at different stages of the life-cycle), and this expected to improve with further development of the process technologies (the largest contributing factor is electricity consumption).

Furthermore, the project has identified several exploitable results, has lodged one patent application, is in the process of finalising a second, and expects to lodge further applications following additional work.

4.1.2 Summary Description of Project Context and Objectives

Context

NanoCelluComp was funded under the NMP.2010.1.2-2 call 'Substitution of materials or components utilising "green nanotechnology" to address to contribute to reduction on the demand of scarce or non-environmentally friendly raw materials, elimination of use of hazardous substances in production processes or the reduction of non-eco waste material, utilising nanotechnology to replace existing production routes or families of products.

The demand for advanced materials in high-performance applications has rapidly increased over the past few decades. The invention of glass and then carbon fibres represented a major breakthrough in composite materials. Glass fibre reinforced plastics (GFRP) and carbon fibre reinforced plastics (CFRP) now comprise around 88% of all high performance fibre reinforced composite materials and their production continues to grow. At present there are no real alternatives to GFRP and CFRP in terms of their lightweight, high mechanical strength/stiffness ratio, toughness, high chemical resistance and many other properties. However, since the end of the last century, in terms of the next generation of materials, it has been recognised globally that fibre reinforced synthetic polymers, including glass and carbon fibre composites, suffer from three fundamental flaws inherited from their components. Synthetic polymers reinforced with man-made fibres are:

- made of non-renewable, essentially oil based components;
- manufactured through environmentally non-friendly processes consuming high amounts of energy;
- not degradable, easily disposable or recyclable.

Some of these issues have been recently addressed by replacing reinforcing fibres with nanoparticles or natural fibres. However, despite the effort undertaken with both these systems only incremental progress has been achieved regarding the fundamental issues.

Cellulose fibre based composites are the most promising bio-based materials for high performance applications. The growing interest in cellulosic fibres is mainly due to their sustainability of supply, economical production with few requirements for equipment and low specific weight, which results in a higher specific strength and stiffness when compared to randomly oriented GFRP. They also present safer handling and working conditions compared to synthetic reinforcements. Cellulose fibres are nonabrasive to mixing and moulding equipment, which can contribute to significant cost reductions.

Food processing of many vegetables produces large quantities of fibrous waste. In the EU alone sugar beet produces upwards of 7.6 million tonnes, potato 39 million tonnes and carrot/turnip 2.5 million tonnes of fibre waste each year. Much of this is used in animal feed or composted, however the cellulose fibres contained within this waste have superior structural properties that with 'green' chemistry can be put to much better use. Food waste streams have an advantage over timber as the cellular material is relatively lower in other difficult to remove compounds such as lignin, thus making processing less resource intensive. Composites containing cellulose extracted from carrot waste have already been incorporated in lightweight products such as fishing rods and steering wheels. This material (Curran), while exhibiting good structural properties, does not have the strength of GFRP and CFRP and is further disadvantaged due to limited processability.

The overall aim of the NanoCelluComp project was to develop a technology to utilise the high mechanical performance of cellulose nanofibres, obtained from food processing waste streams, combined with bioderived matrix materials, for the manufacture of 100% bio-derived, high performance composite materials to replace randomly oriented and unidirectional glass and carbon fibre reinforced plastics in a range of applications including transportation, wind turbines, biomedical, sport and consumer goods. More specifically, the project aimed to develop a manufacturing process to form a 100% bio-composite with controlled alignment of the native modified cellulose nanofibres and to evaluate this process with regards to the physical and mechanical performance of produced materials and suitability for use by industry via existing composite processing technologies. The project also studied the sustainability of the process and materials (nanocellulose bio-composites) in terms of environmental impacts and cost compared to existing materials, namely, carbon fibre reinforced plastics and glass fibre reinforced plastics.

The technology developed within NanoCelluComp included two key stages:

1. Liberation of nanocellulose fibres from vegetable food waste and stabilising these in aqueous solution using other biomolecules, to prevent gelling and to introduce chemical moieties for cross-linking and binding with matrix materials.
2. Process technologies that are compatible with existing manufacturing processes and orientate the liberated nanocellulose fibres, fix this orientation and compound the fibres with bioresin systems. At the same time investigating the technical and environmental substitution potential of this technology through engagement with industrial end-users and life-cycle assessment (LCA).

The development of the technology components was based on the principals of green chemistry and green engineering and at the end of the project, products relevant to a number of industries and using a number of different process technologies were manufactured, demonstrating the feasibility of the extraction process and materials to replace synthetic composites (at least in some applications).

Objectives of NanoCelluComp

NanoCelluComp had four main objectives:

Objective 1 - to develop a 100% bio-composite utilising aqueous based manufacturing process in which the mechanical properties of the composite have a Young's modulus exceeding 20 GPa, tensile strength 600 MPa and strain at break 2-3%. This would out-perform randomly orientated glass fibre composites and compete against randomly orientated carbon fibre composites in terms of the strength and strain at break, thereby enabling a significant reduction of demand on non-environmentally friendly materials. This was planned to be achieved by utilising liberated, intact, and purified cellulose nano-fibres from vegetable food waste. The surface of the nanocellulose would be modified utilising functionalised xyloglucans and xylans both of which are derived from plants. These surface modifiers would have the purpose of increasing the hydrophobicity of the cellulose and acting as reactive sites for either auto cross-linking or cross-linking with a bio-derived resin such as biopolyesters. By using xyloglucans and xylans and water as solvent the principles of green chemistry would be applied to create advanced nanostructured materials.

Objective 2 - to develop an aqueous based manufacturing process to form a 100% bio-composite with controlled alignment of the native modified cellulose nanofibres. Orientation of the nanocellulose dictates the final properties of the composite, and is necessary to achieve the goal of a 100% bio-composite with a Young's modulus of greater than 65 GPa (in one direction), tensile strength greater than 1600MPa and strain at break no less than 3%. In order to achieve highly orientated nanofibres, two approaches were utilised. The first introduced orientation by electrostatic alignment through spinning a solution onto a rotating electrode, producing a composite fibre with preferential orientation of the nanofibres. An alternative approach was to use a combination of high shear and strain applied to an aqueous suspension of nanofibres to align the nanocellulose followed by rapid solidification of the extrudates. The resulting materials would be in the form of a solid fibre or tape with orientation levels corresponding to an orientation parameter value of 0.5 along the axis of the composite fibre.

Objective 3 - to evaluate the manufacturing processes developed in objective 1 and 2 with regard to the physical and mechanical performance of produced materials, and suitability for use by industry via existing manufacturing processes for composites. The production of datasheets for composite samples was planned, by carrying out comprehensive mechanical testing including fatigue and impact resistance, and water adsorption. Demonstrator products utilising a range of bio-resins and existing process technologies (such as hand lay-up, vacuum moulding, resin transfer moulding and hot compacting) was planned. The target was to achieve consistency in the mechanical performance over a range of nanocellulose content up to 75 wt.%.

Objective 4 - to prove the sustainability of processes and materials (nanocellulose bio-composites) developed through objectives 1-3 in terms of their environmental impacts and cost compared to existing materials (carbon fibre reinforced plastics (CFRP) and glass fibre reinforced plastics (GFRP)) by the use of Life Cycle Assessment (LCA) approaches. These new materials are expected to lead to more environmentally friendly products in specific application fields such as biomedical, sport, consumer goods, general engineering, construction, automotive, aerospace, in respect to energy consumption (CO_2 production), the reduction of scarce or non-renewable materials (e.g. vegetable food waste as raw material), the elimination of use of hazardous substances (e.g. elimination of volatile solvents during the production phase), the reduction of non-eco waste material. In order to cover this topic in a comprehensive way, a set of specific objectives would be coordinated from a separate work package, dealing specifically with the "sustainability" aspects of the whole project. The aim was to indicate which application fields nanocellulose bio-composites might contribute to environmental sustainability, and to quantify the sustainability potential of nanocellulose bio-composites in selected applications. For example significant reduction in CO_2 emissions compared to glass fibre (estimated 2630kg CO_2 equivalents emitted per ton of glass fibre) and carbon fibre were expected. However, it is difficult to quantify the reductions in CO_2 and substitution potential, as no systematic work had been carried out in the area of nanocellulose bio-composites. The consortium set a target to reduce the CO_2 emitted by a minimum of 60% compared to glass fibre.

4.1.3 Description of the Main S&T Results

NanoCelluComp consisted of six RTD work packages (and in addition an exploitation and dissemination work package and a work package dedicated to project management). The overall scheme of the work flow is presented in the following figure (Figure 1).

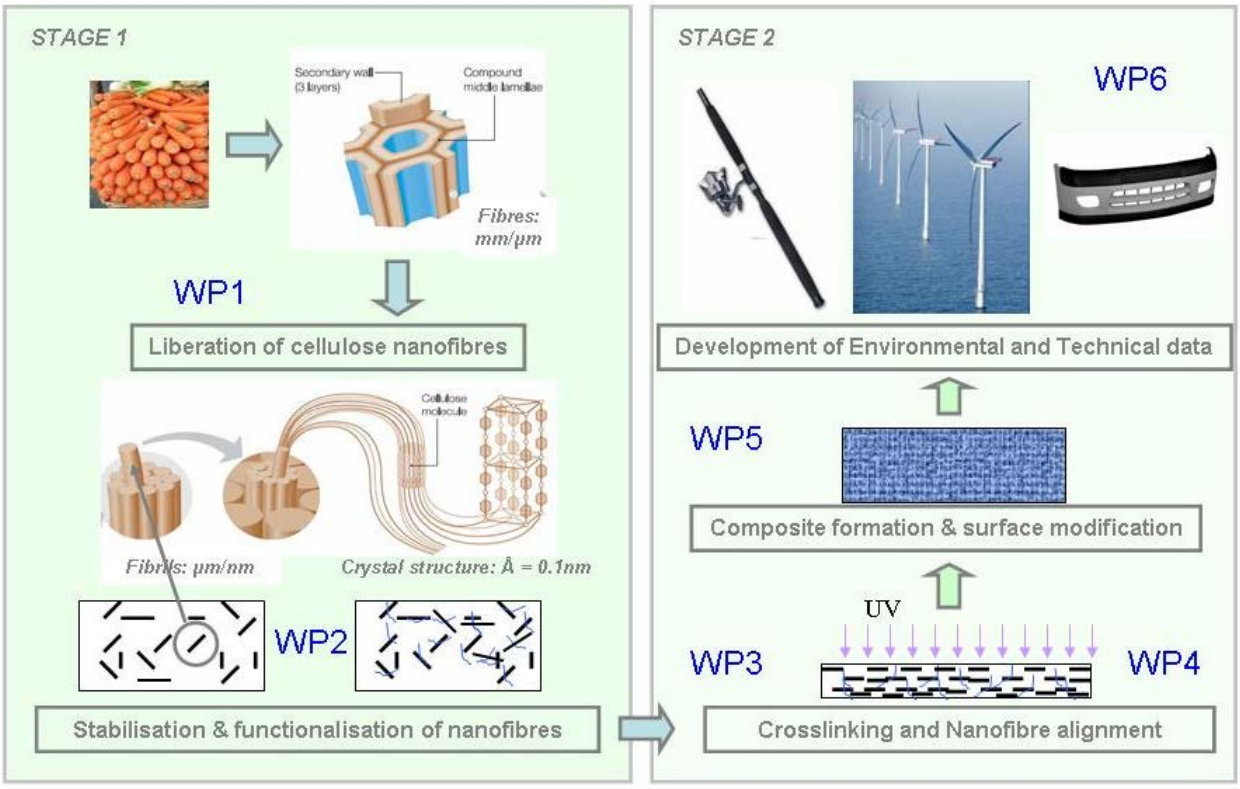

Figure 1. Overall scheme of NanoCelluComp.

<u>Work Package 1 Technology for the liberation and purification of nanocellulose.</u>

The main objective of WP1 was to develop an environmentally friendly methodology for the liberation of nanocellulose from plant materials. There were three deliverables and one milestone associated with this work package. Procedures for the liberation of cellulose nanofibres from carrot, sugar beet and potato were successfully developed, and required combined mechanical, heat and enzymatic treatment of the vegetables.

Task 1.1 Preparing reference samples of nanocellulose fibrils.

This task provided reference nanocellulose fibrils from carrots, using existing technology developed by one of the project partners to extract cellulose (producing a commercially available material known as Curran®) for the purpose of determining cellulose crystallinity, size distribution and residual polysaccharides, and comparing with nanocellulose fibrils produced via Task 1.2.

Task 1.2 Development of method for nanocellulose fibril liberation using enzymatic depolymerisation.

This task delivered an environmentally friendly methodology for the formation of liberated nanocellulose using a combination of enzymatic hydrolysis with mechanical shearing and high-pressure homogenisation (Figure 1.1). CoMPP (comprehensive microarray polymer profiling) analysis was used to determine which polysaccharides remained after enzymatic treatment. This revealed that optimal enzymatic degradation of

carrot was achieved with a combination of two different enzymes and that the chemical composition of the liberated fibrils resembled the original Curran material.

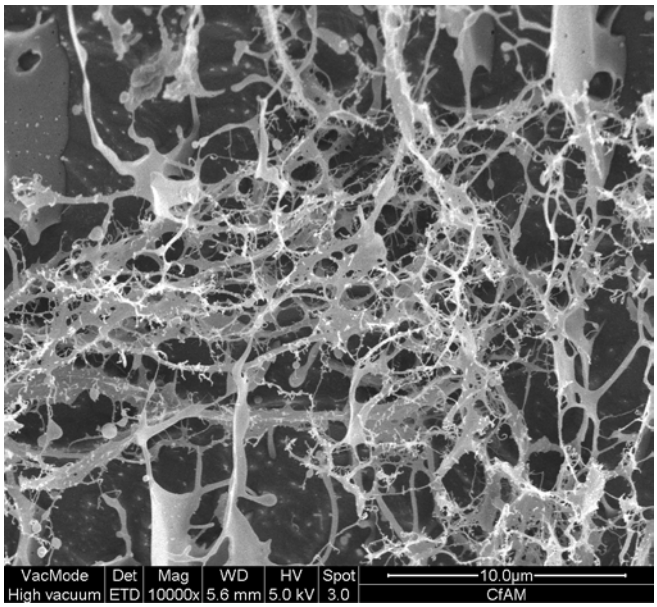

Figure 1.1 CryoSEM image of carrot extract after enzymatic and mechanical treatment.

Task 1.3 Investigation of alternative raw material streams.

Research into alternative sources (to carrot) indicated that potato and sugar beet waste streams were strong candidates. CoMMP analysis confirmed that using different enzyme cocktails it was possible to release nanocellulose from both sources (Figures 1.2 and 1.3), although certain polysaccharides remained difficult to remove.

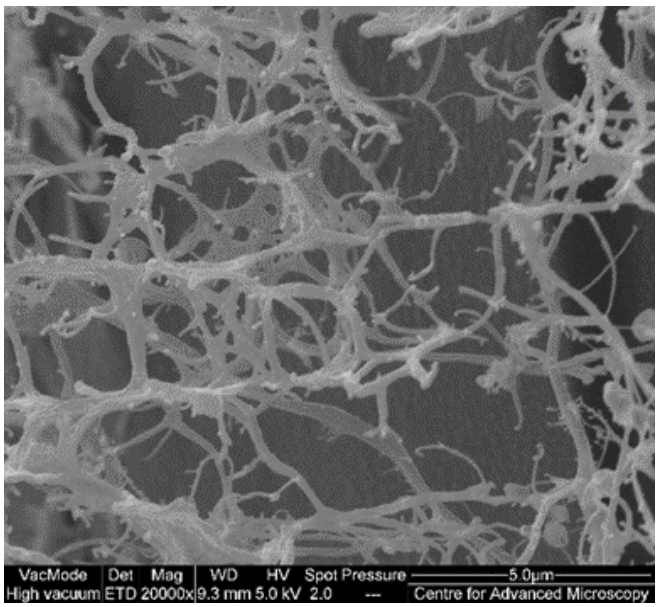

Figure 1.2 SEM analysis of the enzymatically and mechanically treated potato sample.

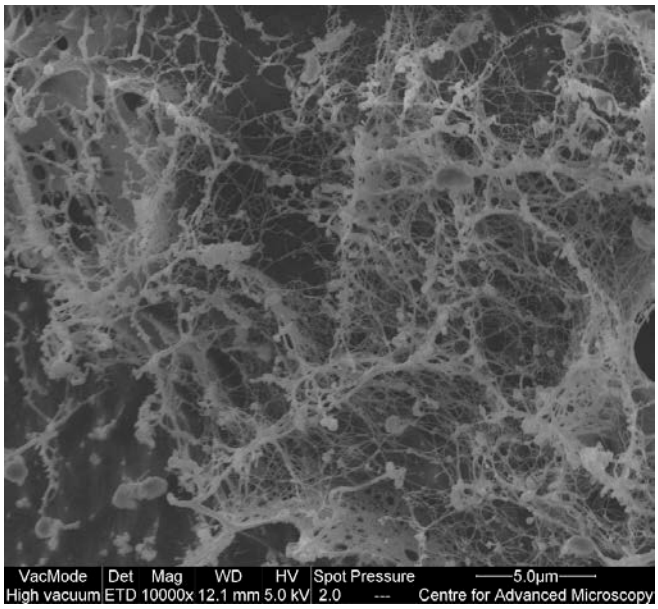

Figure 1.3 SEM analysis of the enzymatically and mechanically treated sugar beet sample.

Additional research revealed a novel enzyme that, when added to the enzymatic cocktail, further improved the liberation of nanocellulose fibrils.

Together these results are the subject of two patent applications (the first on enzymatic release of nanocellulose, which has been submitted, and a second which will be submitted in the near future).

Work Package 2 Development of technology for stabilisation and functionalisation of nanocellulose.

The objectives of WP2 were to synthesise new functional polysaccharide derivatives capable of stabilising solutions of the liberated nanocellulose fibrils, and to develop polysaccharide bearing moieties that could be employed in cross-linking processes for the surface modification of liberated nanocellulose fibrils to "freeze" nanofibrils orientation and composite formation. There were three deliverables and two milestones associated with this work package. This work exploited the natural function of xyloglucans to bridge cellulose fibrils in the plant cell wall to provide strength and flexibility, and modified this capability through the introduction of specific reactive groups.

Task 2.1 Development of xyloglucan polysaccharide derivatives for stabilisation of separated nanocellulose fibrils in the suspension.

This task delivered a number of functional polysaccharide derivatives that were able to stabilise solutions of the liberated nanocellulose fibrils, preventing aggregation and gelling. These were based on a xyloglucan backbone that was functionalised to form anionic or cationic derivatives, non-ionic surfactants or block co-polymers. Seven derivatives were tested with nanocellulose, and in each case the viscosity of the resultant suspension was measured. All derivatives were able to reduce viscosity, and the non-ionic surfactant was demonstrated to be the most effective.

Task 2.2 Development of derivatives for functionalisation of nanocellulose fibrils for subsequent crosslinking.

This task delivered 12 novel polysaccharides bearing functional moieties that could be employed in cross-linking processes for surface modification of liberated nanocellulose fibrils to "freeze" nanofibril orientation and composite formation. All of the polysaccharide derivatives were based on xyloglucans or GripX (a co-polymer of xyloglucan and chitosan, which binds cellulose with high affinity, and is manufactured by one of the project partners). The GripX compounds could incorporate 31 times more functional groups onto the nanocellulose fibrils than xyloglucan. The functional groups were chemically and/or UV reactive. Additionally, a high molecular weight GripX was synthesised to aid in the solution spinning. Furthermore, xyloglucan derivatives were synthesised bearing groups that could be enzymatically cross-linked. GripX compounds bound more effectively to liberated nanocellulose than xyloglucans in most cases, with between 70% and 90% adsorption observed.

Task 2.3 Preparation of substituted hemicellulosic glycans.

This task intended to deliver alternatives to xyloglucan based stabilisation and cross-linking polysaccharides, in the form of arabinoxylans produced through the enzymatic wet-fractionation of rye bran (and which contain ferulate groups that can be enzymatically cross-linked). This had the potential to be a low cost method for cross-linking liberated nanocellulose. Unfortunately the liberated arabinoxylans had insufficient amounts of ferulate for cross-linking to the levels required, and so this approach was not pursued any further.

Additional work

Additional effort investigated the grafting of polyethylene glycol (PEG) directly onto cellulose nanofibrils (CNF). This stabilised the CNF suspension owing to steric hindrance of PEG, allowing CNFs to slide against each other much more easily compared to unmodified nanocellulose during stretching-induced alignment processes. In this context, the addition of an anionic xyloglucan derivative as a stabiliser to the CNFs further improved the mechanical properties to a tensile strength of 647 MPa and a modulus of 31 GPa, significantly higher than plant CNFs-based materials yet reported in the literature (see Figures 2.1 and 2.2).

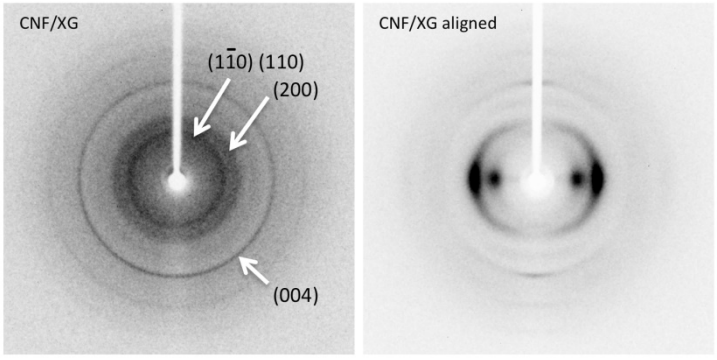

Figure 2.1 X-ray diffractograms of the in-plane direction of unstretched and stretched CNF/XG films.

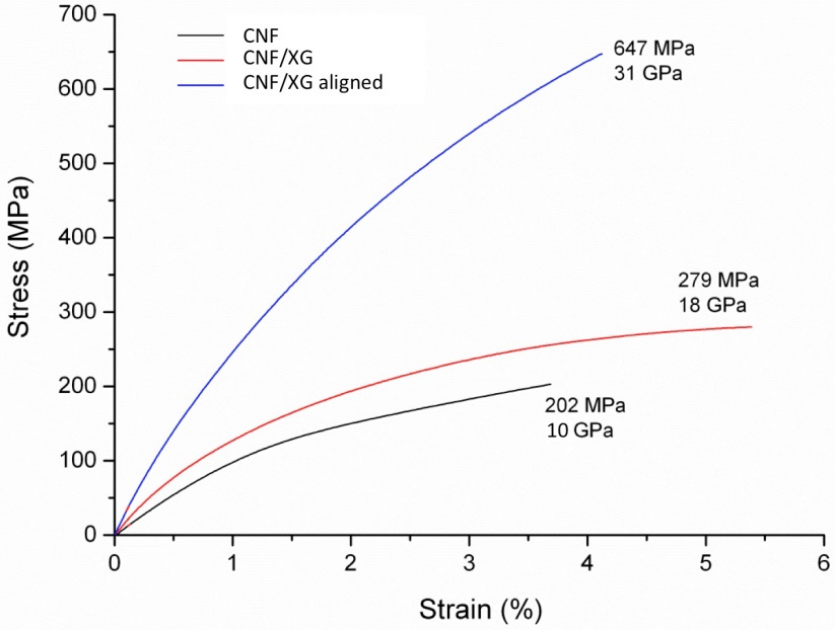

Figure 2.2 Stress-strain curves of biocomposite films of CNF/XG before and after stretching.

Work Package 3 Development of technology for the cross-linking of functionalised nanocellulose fibrils.

The objectives of WP3 were to develop methods for the chemical and enzymatic cross-linking of functionalised polysaccharide/nanocellulose fibrils. Achieving this is a critical step towards the production of mechanically strong composites, as this is expected to 'lock-in' fibre orientation. There were two main considerations: reaction rate (the cross-linking must take place within a time-span commensurate with the spinning process), and compatibility with the chemistry of the spinning process. There were three deliverables and one milestone associated with this work package.

Task 3.1 Chemical cross-linking.

This task investigated four different reactive groups, each representing different resin systems or the stabilising molecules developed in WP2:

1. Hydroxyl – present in polysaccharides, GripX molecules and synthetic systems;
2. Amine – present in the functionalised xyloglucans and GripX systems, and used in the curing of epoxy resins;
3. Acrylate – present in synthetic systems such as diacrylates PEGDA, and acrylic resins;
4. Cinnamoyl – present in the functionalised xyloglucans and GripX systems, and similar to ferulics found in arabinoxylan systems.

Various means of initiating chemical reactions were investigated: free radical initiated cross-linking, ionic cross-linking and nucleophile/ electrophile substitution type reactions (as might be found in a condensation/ step growth polymerisation) and acid base, salt forming reaction.

Experiments with these groups and the functionalised xyloglucans and GripX molecules indicated the following:

- Radical reactions could be initiated thermally, but temperatures were relatively high;
- Acrylates appeared to be better for the radical processes in terms of rate, than cinnamate-based materials;
- The reactions with activated carbonyls were hampered by competing reactivity with water;
- The isocyanate appeared to be slower than the reaction with acid chloride;
- Curing was possible using epoxide based systems, but controlling the rate was problematic;
- The possibility of a salt formation offered a much more rapid rate since the salt will be formed within a few milliseconds, but needed post curing.

In addition to these approaches, ionic cross-linking was explored. This mechanism is used within plant cell walls to strengthen structural components and relies on the presence of saccharides such as pectin and ions such as calcium and borate. Experiments indicated that calcium ions could be used to cross-link functionalised xyloglucans and GripX molecules with alginate, while borate ions could do the same for PVA (polyvinyl alcohol). Further studies indicated that a combination of calcium and borate ions with nanocellulose fibrils and pectin or guar gum or xylan at pH >7 produced gels.

From these results, two cross-linking approaches were identified that were on a timescale which met the requirements for cross-linking during the spinning process: ionic cross-linking using calcium (II) and/or borate ions, and interfacial polymerisation using a diacid chloride. Their use, however, required some modifications to the spinning process. For electrospinning, this involved the use of a co-axial needle to allow two separate phase materials to be mixed and incorporated into the fibre during spinning. This is not possible for solution spinning, and so post-spinning treatment was required to initiate cross-linking. Developments in other WPs pushed this approach towards ionic cross-linking (using calcium and borate ions, in combination with alginate and guar gum respectively) – see WP4 and WP5.

Task 3.2 Development of UV technique for rapid curing bio-based matrix materials.

This task investigated the use of UV curing (using functionalised xyloglucans and GripX molecules) to cross-link nanocellulose (both sheets cast from the extracts and spun fibres – see WP4 and WP5). This has the possibility of very rapid curing of composites (fractions of a second), which was highly appealing to the process technology being developed in NanoCelluComp (to lock-in fibril orientation within spun fibres, and even cross-link fibres). Work identified both acrylate and epoxy as potential systems, whereas cinnamate reaction times were too long to be of use. Of the acrylate and epoxy systems, the latter was more robust; however water compatibility (and therefore 'green chemistry') was an issue. UV cross-linking was used subsequently for both small fibre bundles and sheets.

Task 3.3 Enzymatic crosslinking.

This task provided a third option for cross-linking nanocellulose through enzyme catalysed reactions (offering a route to more environmentally friendly production methods and materials). Eleven different enzymes were assayed with various substrates: arabinoxylan from Task 2.3 (poor level of ferulic acid, hence not pursued); xyloglucan functionalised with ferulic acid (produced by project partners); small xyloglucans with ferulic acid, cinnamic acid or caffeic acid (produced by project partners); and a modified commercial source of arabinoxylan. Viscotek (a specialised high performance gel permeation chromatography system) was used to measure cross-linking between different substrates. From this xyloglucan-ferulic acid and the modified commercial arabinoxylan demonstrated cross-linking activity. In addition, a protocol was developed for use with the solution-spinning process in WP4. This task verified the applicability of the synthetic xyloglucans to act as cross-linking agents.

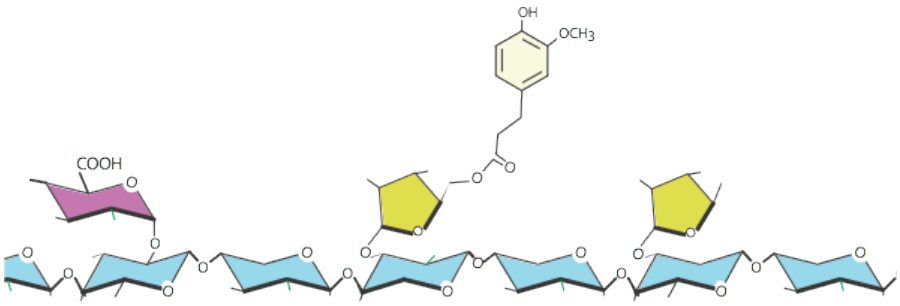

Figure 3.1 Feroylated xylan

Work Package 4 Development of methods for orienting cellulose nanofibrills.

The objectives of WP4 were to develop methods for forming fibre/sheets made from highly aligned nanocellulose fibrils. This involved characterising the rheology of vegetable extracts produced by WP1, designing systems for spinning these extracts to produce fibres and designing methods for orientating the nanocellulose fibrils. There were four deliverables and one milestone associated with this work package.

Task 4.1 Characterisation of nanocellulose fibril solutions.

This task investigated the solution properties of the nanocellulose suspensions delivered by WP1, in order to better design systems for spinning fibres from the nanocellulose in the suspensions. All suspensions showed a strong non-Newtonian and dynamic behaviour: extreme shear thinning, thixotropy or rheopexy (time dependent viscosity at constant shear rate) and yield stress. These features were more or less pronounced depending on the concentration of the suspension.

These observations indicated that suspensions of nanocellulose would need to be carefully pre-conditioned before spinning through pre-shearing, degassing, and temperature control.

The nature of the suspended cellulose was probed by environmental SEM (see Figures 1.1 to 1.3).

Task 4.2 Design/optimisation of lab scale equipment for spinning fibres/films.

This task made use of the knowledge from Task 4.1 to design and fabricate equipment required for processing nanocellulose suspensions into fibres and films. Three types of spinning were assayed (described in more detail in Task 4.3): solution, electro- and force spinning. In all cases this needed to consider the necessary process or processes to be applied after the die extrusion step to secure the effective solidification and cross-linking of the extruded fibre. The approach taken was that of a modular system, capable of switching between wet, dry and dry-wet spinning modes, with the following steps: a) mixing; b) pumping of viscous solutions; c) shearing in a purpose built shear cell; d) spinning through specific dies; e) solidification of the fibres; f) fibre stretching/drawing; g) cross-linking/curing. See Figures 4.1 and 4.2 for schematics of the systems.

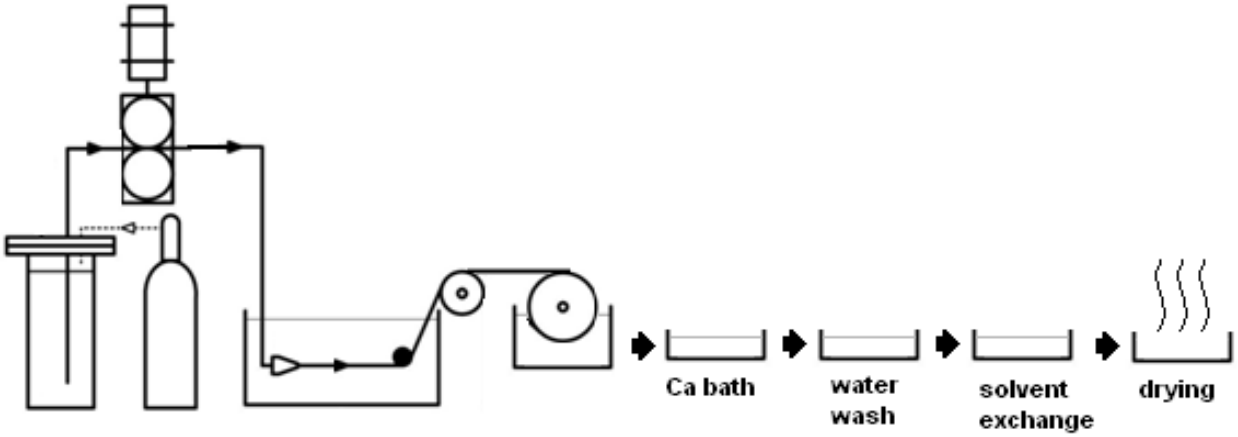

Figure 4.1 Design of lab-scale equipment for solution spinning.

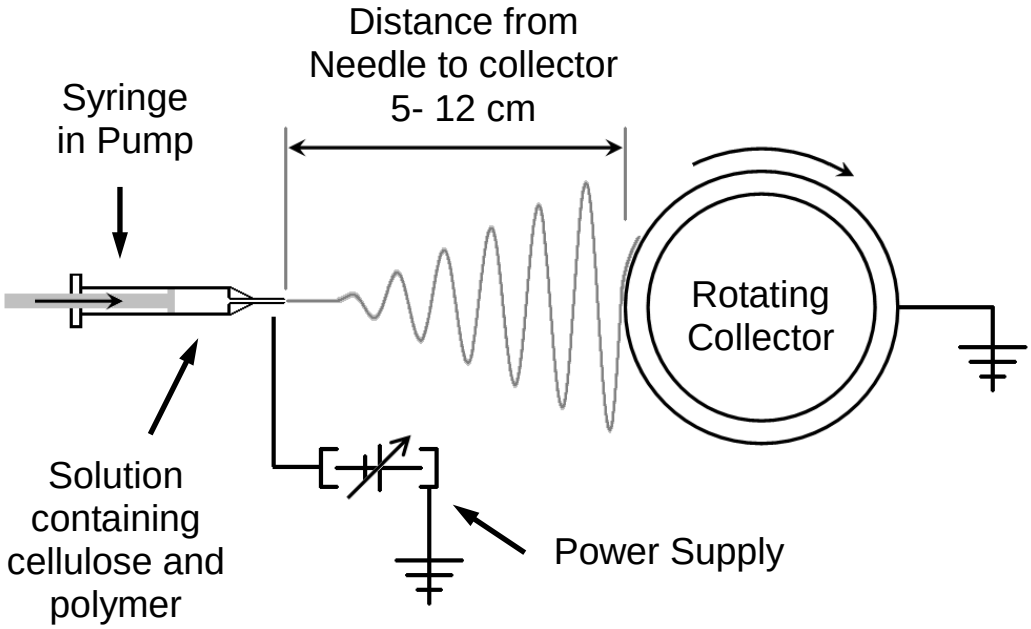

Figure 4.2 Electrospinning system for nanocellulose fibre production.

Task 4.3 Development of methods for orienting cellulose nanofibres.

This task developed methods for orienting nanocellulose using solution spinning, electrospinning and force spinning.

Solution spinning of nanocellulose extracts alone, or with xyloglucan or GripX molecules, resulted in brittle fibres. To overcome this, a carrier polymer (alginate) was included in the suspension to be spun (at various ratios) and the following observations were made:

- The total concentration of the spinning mixture strongly affected its processability and the strength of the extruded strands.

- Stronger and stiffer fibres were obtained at higher jet-stretch ratios (velocity at drum surface / average velocity of fibre at needle tip) which indicated an increased orientation of the nanocellulose fibres.
- The xyloglucan and GripX additives reinforced the resultant fibres.
- Fibres could be coagulated in a calcium chloride bath (due to ionic cross-linking), allowing continuous spinning.

Electrospinning of pure nanocellulose produced large agglomerates. This was resolved using a carrier polymer (such as polyethylene oxide – alginate cannot be electrospun). Electrospinning nanocellulose extracts also suffered from gelation at the needle tip, however the addition of a surfactant (such as Triton X-100) decreased this and improved output several fold. Electrospinning produced finer fibres than with solution spinning (however, these were collected as sheets on the drum, rather than as discrete fibres).

Initial efforts with electrospinning proved problematic and so an alternative method of force spinning was tried. The necessary apparatus was developed in partnership with an external company (Maxon). Force spinning produced fibres (at higher throughput than electrospinning), however it could not accommodate as high a concentration of nanocellulose as electro or solution spinning. Figure 4.3 provides a schematic of the equipment set-up.

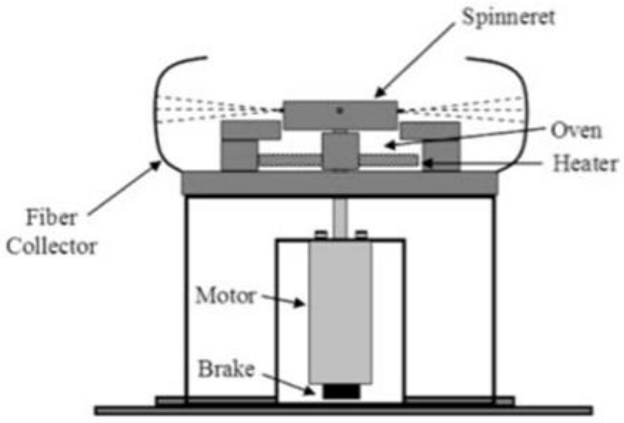

Figure 4.3 Force spinning apparatus.

As with electrospinning, force spinning also produced sheets, rather than discrete nanocellulose fibres.

The physical and chemical properties of fibres were assessed using an Instron (for mechanical properties), SEM, NMR, X-ray diffraction and neutron scattering (to measure surface characteristics and fibre dimensions, chemical composition, and orientation of fibrils within the fibres).

This revealed some alignment of nanocellulose along the fibre length and mechanical properties better than those previously reported: strain at break of 7.7%, maximum stress of 206 MPa, Young's modulus of 13.4 GPa.

Of the three approaches taken, only solution spinning was far enough advanced at the critical point in the project to produce sufficient quantities of fibre for WP5 and WP6.

Work Package 5 Integration of key technology elements.

The objectives of WP5 were to achieve integration of key technology elements developed in WPs 1-4 to form composite materials, and to upscale the technology to a pilot scale (production of Kg quantity). There were four deliverables and three milestones associated with this work package.

Task 5.1 Producing and testing composite materials with no preferential orientation of nanocellulose fibrils.

This task used the output from WP1 and WP2 to form composite samples in which the nanocellulose fibrils were randomly orientated and not formed into fibres. Two approaches were taken:

1. Liberation of nanocellulose fibrils in the presence of functionalised xyloglucans followed by mixing with bio-resins or ionic cross-linking.
2. Liberation of nanocellulose fibrils in the presence of arabinoxylans followed by enzymatic cross-linking.

The second approach was not assessed (as the arabinoxylans had insufficient ferulate content for cross-linking – see Task 2.3).

In the first approach, an optimal ratio of 80% nanocellulose to 20% functionalised xyloglucan produced transparent sheets of a few microns thickness (see Figure 5.1). These required careful drying in a specialised chamber to avoid cracking.

Figure 5.1 Sheet of nanocellulose and modified xyloglucan dried for 120hrs in drying chamber.

Further to this, suspensions of xyloglucan coated nanocellulose were mixed with water-based epoxy resins or guar gum and borate, or alginate and calcium ions, and dried to form composite sheets. A maximum nanocellulose content of 75% was achieved using guar gum. However, sheets made from guar gum and alginate did not dry well, and so sheets made from a mix of nanocellulose and the water-based epoxy were used for further development (WP6). When dried these consisted of 95% nanocellulose and 5% epoxy.

Sheets produced in this way were laminated with a conventional epoxy resin or a bio-based epoxy resin and mechanically tested (see Task 5.3). These laminates had superior properties to the resin systems alone, but did not meet the desired mechanical properties of Objective 1 (the best results were a Young's modulus of 16.9GPa, strength of 225MPa, and a failure strain of 2.3%, based on 80% nanocellulose and 20% modified xyloglucan, whereas the objective was to achieve a Young's modulus of 20GPa, strength of 600MPa, and a failure strain of 2-3%). Optical microscopy suggested that the reason for this was due to re-aggregation of cellulose fibrils with each other before they could be sufficiently coated with xyloglucans or GripX (to stabilise fibrils, thus preventing such aggregation). This essentially resulted in the formation of structures similar to those found in Curran (sub-cellular platelet structures containing cellulose). Time constraints and the desire to focus more on the spun fibres (with higher mechanical properties potential) meant this was not explored further. However, such materials were used successfully to produce the demonstrator products, confirming their compatibility with existing manufacturing processes (see Task 6.2).

Task 5.2 Development of composite materials using fibres comprising oriented nanocellulose fibrils.

This task tested the compatibility of spun fibres with a number of different conventional and bio resin systems. 34 different systems (combinations of resin and hardener) were initially tested: 20 standard epoxy, 5 bio-epoxy, 2 polyester, 3 bio-polyester, and 2 styronitrile systems. Phenolic, styrene and polyurethane systems were not tested because of potential health effects. Of these, 20 were selected for use in the production of fibre-resin test bars. Initial issues that were overcome included wetting of fibres with molecules synthesised in WP2 to improve bonding with the resins. Test bars contained typically 1g of spun fibre and 9g of resin, and were approximately 70mm by 20mm. Figures 5.2 and 5.3 provide an overview of the test procedure.

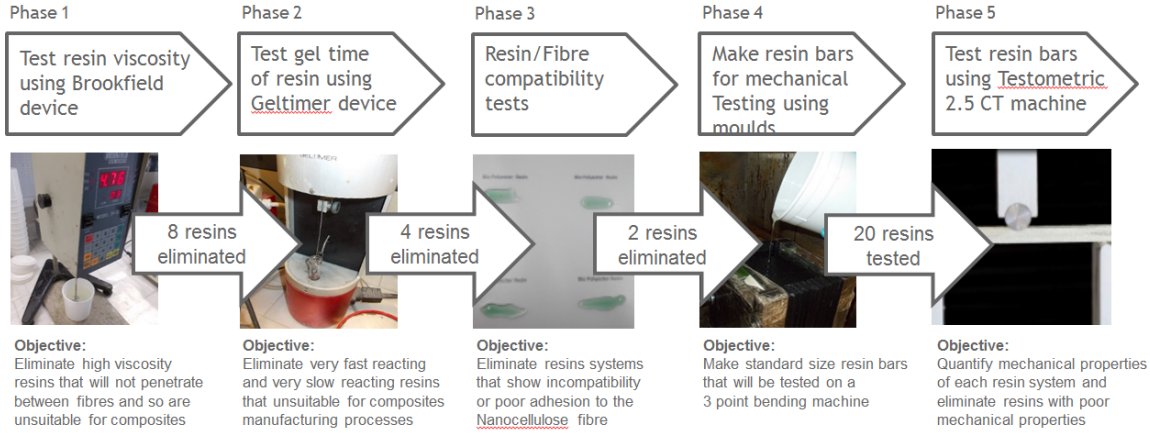

Figure 5.2 Evaluation of resin systems.

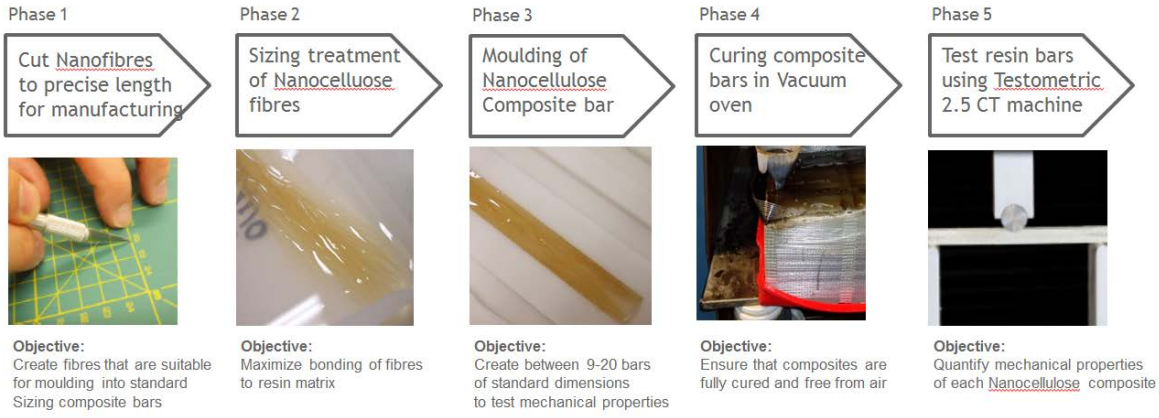

Figure 5.3 Preparation of composite test bars

The test bars were subjected to a variety of analytical procedures described in Task 5.3.

Task 5.3 Composite analysis.

This task developed protocols for testing the mechanical properties of nanocellulose composites produced in Tasks 5.1 and 5.2, in terms of their bending modulus, failure strength and strain, fibre pull-out strength and moisture uptake (which would reduce mechanical properties and thus limit potential applications).

Single fibres, fibre bundles and strips from sheets from Tasks 5.1 and 5.2 were subjected to mechanical testing using an Instron test machine. Single fibre testing showed that, although only 45% of the fibre was cellulose, reasonable mechanical properties were being achieved in the large fibre samples produced, with an average modulus of 10 GPa and strength of 180 MPa and failure strains of 10%. Multi-fibre composites formed with UV epoxy showed a 50% increase in modulus and 60% increase in tensile strength over the UV epoxy resins alone. The nanocellulose fibres formed stronger composites with bio-epoxy resins than with standard epoxy resins. One of the bio-epoxy resins, produced by a partner within the consortium and based on pine oil, was chosen to produce the demonstrator products in WP6 as composites made with this consistently demonstrated the best mechanical properties. Comparison with similar weight percentages of flax, basalt, glass and carbon fibre in epoxy resins, indicated superior properties for the nanocellulose to flax and basalt, and similar properties to glass fibre. The mechanical properties of carbon fibre epoxy resin composites were approximately 50% superior to nanocellulose epoxy resin composites (see Figure 5.4). This was a significant result, in particular considering that the cellulose content of these fibres is approximately 48.5% (due to the presence of alginate and GripX/xyloglucan). Further improvements to increase the cellulose content would be expected to further enhance these properties. Also worthy of note is that carbon fibre and glass fibre composites with bio-epoxy resins (including that chosen for WP6, based on pine oil) had inferior mechanical properties to those made with standard epoxy resins.

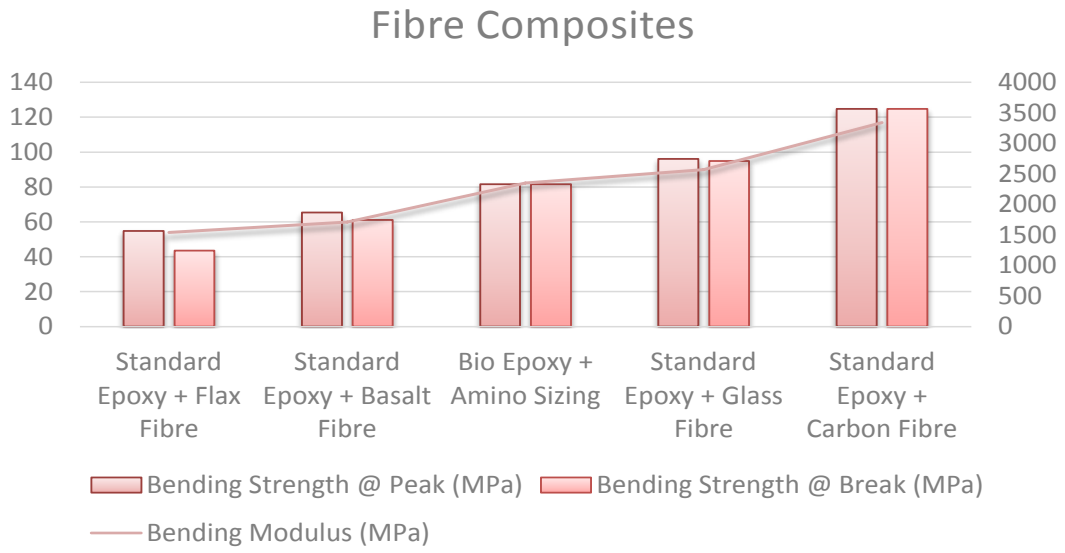

Figure 5.4 Mechanical properties of test bars comprising flax, basalt, nanocellulose, glass, and carbon fibres with epoxy resins.

The presence of nanocellulose in fibres was confirmed by compositional analysis using solid state NMR, and XRD analysis indicated that there was at least partial alignment of the nanocellulose fibrils along the fibre

length. SEM analysis revealed that nanocellulose fibres were evenly distributed through the composite samples when pre-treated with GripX or xyloglucan molecules. In contrast, untreated fibres formed clumps within the composite. Nanocellulose fibres coated with either epoxy or GripX/xyloglucan showed lower water absorption than pure nanocellulose and maintained integrity. When formed into composite test bars water absorption was further reduced to a maximum of 5% weight.

Initial studies on the mechanical properties of nanocellulose fibrils derived from sugar beet and potato indicated that these were lower than carrot. This was presumably due to a lack of optimisation in the extraction and treatment process. Within the NanoCelluComp project nanocellulose was extracted from these vegetables to demonstrate their potential as sources, not to produce fibres in parallel.

Mechanical properties of various materials produced by NanoCelluComp, comparable materials produced by others and reported in the literature, and relevant commercially available materials are summarised below.

Table 5.1 Properties of various comparable natural and synthetic materials.

Material	**Strain at Break %**	**Maximum Stress MPa**	**Young's Modulus GPa**	**Fibre content**
Sugar beet pulp			2.5-3	
Sugar beet pulp	3.2	104	9.3	
NanoCelluComp sugar beet fibre	6.5	136	7.6	40%
NanoCelluComp sugar beet sheet composite	2.6	126	5.1	51%
Softwood sulphite pulp		80-100	6	
Diacel commercial MFC	2.7	67		
Never dried kraft pulp	7.0 -7.6	222	6.2-6.9	
NanoCelluComp fibre	**7.7**	**206**	**13.4**	**40%**
pva , acrylate, epoxy		55-145		33-67%
Acrylic resin impreg	2 to 6	80 - 100	7.2 - 8.2	73-88%
NanoCelluComp sheet	**1.5**	**92**	**6**	**40%**
NanoCelluComp fibre & bio-epoxy		**81**	**23.4**	**10%**
Epoxy flax		**54**	**15**	**10%**
Epoxy basalt		**65**	**17**	**10%**
Epoxy glass fibre		**96**	**25.6**	**10%**
Epoxy carbon Fibre		**123**	**33.3**	**10%**

Task 5.4 Upscale of the composite processing method to production of kg quantities.

This task produced sufficient quantities of nanocellulose fibre for the production of demonstrator products in WP6. This necessitated the commission of a larger 30l reaction vessel to perform the initial processing of the carrot waste.

A total of 20kg of 2.42% microfibrillated cellulose solution (equivalent to 485g dry weight microfibrillated cellulose) was used to produce over 1kg of dry weight fibre from the solution spinning process. In addition, over 350g of nanocellulose sheets were produced (Task 5.1). Both materials were subjected to standard industrial manufacturing processes to produce demonstrator products as described in WP6.

Work Package 6 Development of environmental and technical data and assessment of substitution potential.

The objectives of WP6 were to develop environmental and technical data for the integrated technology to evaluate its substitution potential ("greenness"). This involved engaging with industrial end-users to identify key requirements of such a new biocomposite, and performing life-cycle assessment of potential products containing nanocellulose composite materials from production of the materials, through incorporation in products, the use of these products and their final recycling or disposal. There were four deliverables and four milestones associated with this work package.

Task 6.1 Analysis of substitution potential, through end users acceptability criteria and the selection of application cases.

This task investigated the substitution potential of nanocellulose composites through an in depth analysis with end-users (interviews) to ascertain their requirements for the technology, and performed an initial life-cycle assessment (LCA) of potential market applications (see Task 6.3 for further information).

Industrial end-users were those currently using glass and carbon fibre technology. The discussions were directed towards requirements for market acceptance of nanocellulose (e.g. mechanical performance, price sensitivity). Based on these, the following conclusions were made:

- Cost is the primary factor in deciding the suitability of a composite for a given application.
- High value composites used in high technology applications or products aimed at the affluent end of the market remain price insensitive and lucrative.
- Nanocellulose has a distinct competitive advantage in that its price is not linked to hydrocarbon prices, and this lack of volatility is something that attracts industrial customers.
- There may be an opportunity for a locally-manufactured and supplied composite in Europe, as much of the oil-based composite business is directed towards Asia.
- Nanocellulose composites should be able to be processed on existing machinery.
- Initial markets that are not subject to strict regulation and certification should be targeted first.
- Quality control across batches and expected lifespan must be assured.

Furthermore, market reports and scientific papers on nanocellulose were studied in order to evaluate a number of potential application fields for the composites being produced within NanoCelluComp. A combination of technical requirements, economic and market aspects, and LCA allowed the consortium to identify a small pool of potential products from which the following two were selected for further analysis through case studies: motorhome sidewalls and furniture. This analysis and the approach taken has been submitted as a paper to ChemSusChem.

Task 6.2 Development of technical data and evaluation of the substitution potential of nanocellulose in industrial processes.

This task assessed the substitution potential of the nanocellulose materials produced in NanoCelluComp through standard industry moulding technologies (press and vacuum moulding).

Nanocellulose fibres were successfully demonstrated to substitute existing fibres in a number of industrial manufacturing processes such as hand layup, vacuum bagging and resin transfer moulding (see Figures 6.1 and 6.2).

Figure 6.1 Hand layup using nanocellulose sheets from WP5.

Furthermore, nanocellulose fibres could be used in a variety of lengths and formats to create composites. These included very short and short chopped strands and random mats using long strands (Figure 6.2).

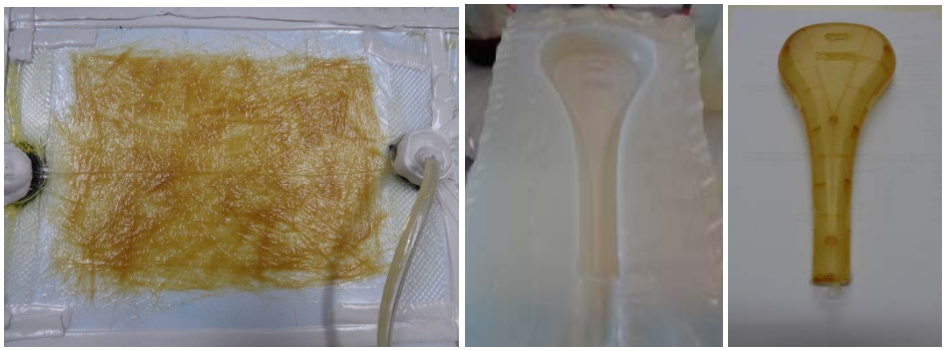

Figure 6.2 Vacuum bagging (left) and resin transfer (middle and right) using nanocellulose fibres from WP5.

Discussions with project partners and collaborations with external partners led to the creation of an industrial prototype that demonstrated the use of nanocellulose in composites and the positive collaboration between an FP7 project and industrial end-users (Figure 6.3).

Figure 6.3 Transforming an idea into nanocellulose reality (prototype of a food dish designed by Marco Goffi).

All of the above made use of the bio-epoxy resin based on pine oil described in WP5. Hand layup was used with nanocellulose sheets to coat aluminium honeycombs for building panels and part of a catamaran rudder. Vacuum bagging was used to produce a small panel from nanocellulose fibres produced through solution spinning. Resin transfer moulding was used with chopped fibre to produce a shower head, and with the long fibres for the food presentation dish (Figure 6.3). This demonstrated the compatibility of the nanocellulose produced by the project with bio resins and standard industrial manufacturing processes.

Task 6.3 Development of environmental data and evaluation of the substitution potential.

This task performed an environment, health and safety analysis, an LCA for material production, and a full LCA for the two selected case studies (Task 6.1).

A review of the published peer-reviewed literature suggested that although there were data gaps (because little work had yet been performed, and the nature of (mechanically) isolated nanocellulose fibrils to form a gel), it was expected that the environmental, health and safety impacts for nanocellulose would be far lower than those of inorganic fibres. There have been no published studies on the unintended release of nanocellulose particles or fibres from composites and products; so possible release scenarios of the nanomaterial during the life cycles of the selected application cases were evaluated (see Figure 6.4).

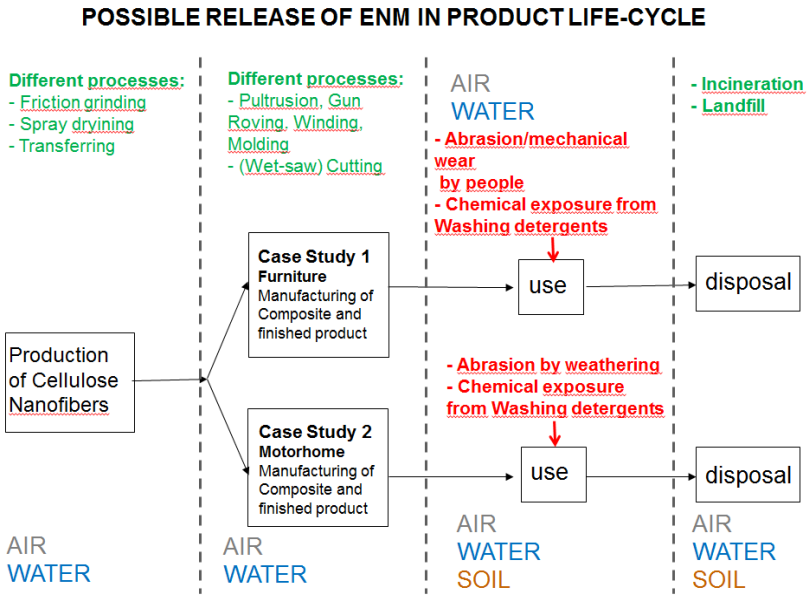

Figure 6.4 Product life cycle and exposure for selected nanocellulose application cases.

Life-cycle inventory (LCI) data for both glass and carbon fibre was derived from ecoinvent database according to the ReCiPe endpoint method. This database has information on a large number of conventional and bio-polymers and resins, and includes data on glass and carbon fibres. It provides data on global warming potential, non-renewable resource consumption, impacts on human health, ecosystem quality and resources.

LCA of nanocellulose epoxy composites produced within the project compared with carbon and glass fibre epoxy composites, indicated an improvement over carbon fibre at the projected industrial scale levels (based on data from partners and extrapolation from the ecoinvent database), but with a higher LCA impact than

glass fibre composites. Electricity requirements had the largest influence on this (e.g. heat required for enzymatic depolymerisation of the vegetables). See Figure 6.5 for an overall view of the LCA performed.

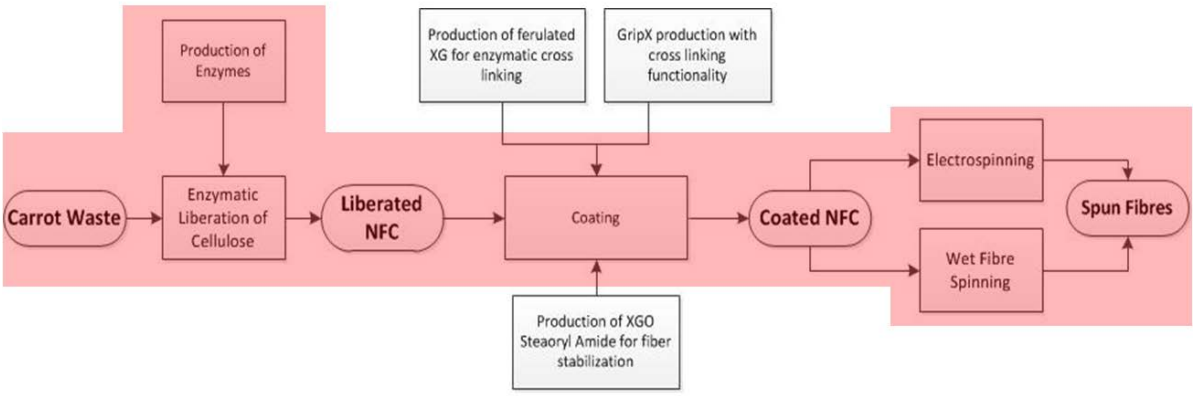

Figure 6.5 LCA schematic for the nanocellulose production process.

A new method was developed to upscale LCA from lab to industrial scale and used to determine impact over the life-cycle of the two case studies. The use phase of motorhomes containing panels made from nanocellulose composites is expected to have a lower impact than glass fibre composites due to decreased weight and therefore fuel costs. For the furniture case study, the use phase is expected to have a lower overall impact compared with conventional plastics, but this is outweighed by a higher resource requirement for the production phase.

The upscaled LCA results for the production of nanocellulose are based on a small industrial scale, and therefore better results would be expected for a higher production output due to economies of scale. These results have identified environmental impact hotspots and as a result the production process can be further optimised. Such improvements are expected to be greater for nanocellulose than glass or carbon fibres, as these are already produced using well-established and optimised processes.

Additional work

In addition to the work reported above, the project partners also collaborated with an external organisation (NOBIL BIO RICERCHE) to explore the biocompatibility of the nanocellulose fibres produced. This work indicated that the fibres were not cytotoxic, in fact cells were observed to adhere and grow on the fibres. There were a number of different cytokine responses to fibres, which is possibly due to the presence of bacteria from handling the fibres (they were not handled under sterile conditions). This suggested a potential application for such fibres as surgical meshes and scaffolds for regenerative medicine, and possibly to coat titanium implants and improve tissue integration. Shape and chemistry would be important aspects to study further (including nanoscale surface topography).

4.1.4 Potential Impact and the Main Dissemination Activities and Exploitation of Results

The main purpose of NanoCelluComp was to develop new environmentally friendly process technologies for the production of sustainable composites that could compete with glass and carbon fibre reinforced plastics.

This was an integrated process involving:

1. Extraction of nanocellulose in as pure a form as possible (removing compounds that naturally coat and bind fibrils together) from suitable vegetable waste;
2. Coating the liberated nanocellulose fibrils with a biomolecule to both prevent re-aggregation, and to provide a means of controlled cross-linking of fibrils;
3. Orientating the fibrils mechanically through a spinning process to produce cellulose fibres, and at the same time locking-in that orientation through the use of the coating biomolecules;
4. Mixing fibres with bio-resins to form composite materials, and testing the mechanical properties of these;
5. Producing suitable products from these bio-composites;
6. Assessing the material and energy flows at each stage of the production process and in addition the use and final recycling/disposal of the product to determine whether the environmental impact is indeed lower than conventional processes and materials.

This is depicted in Figure 7.1 below:

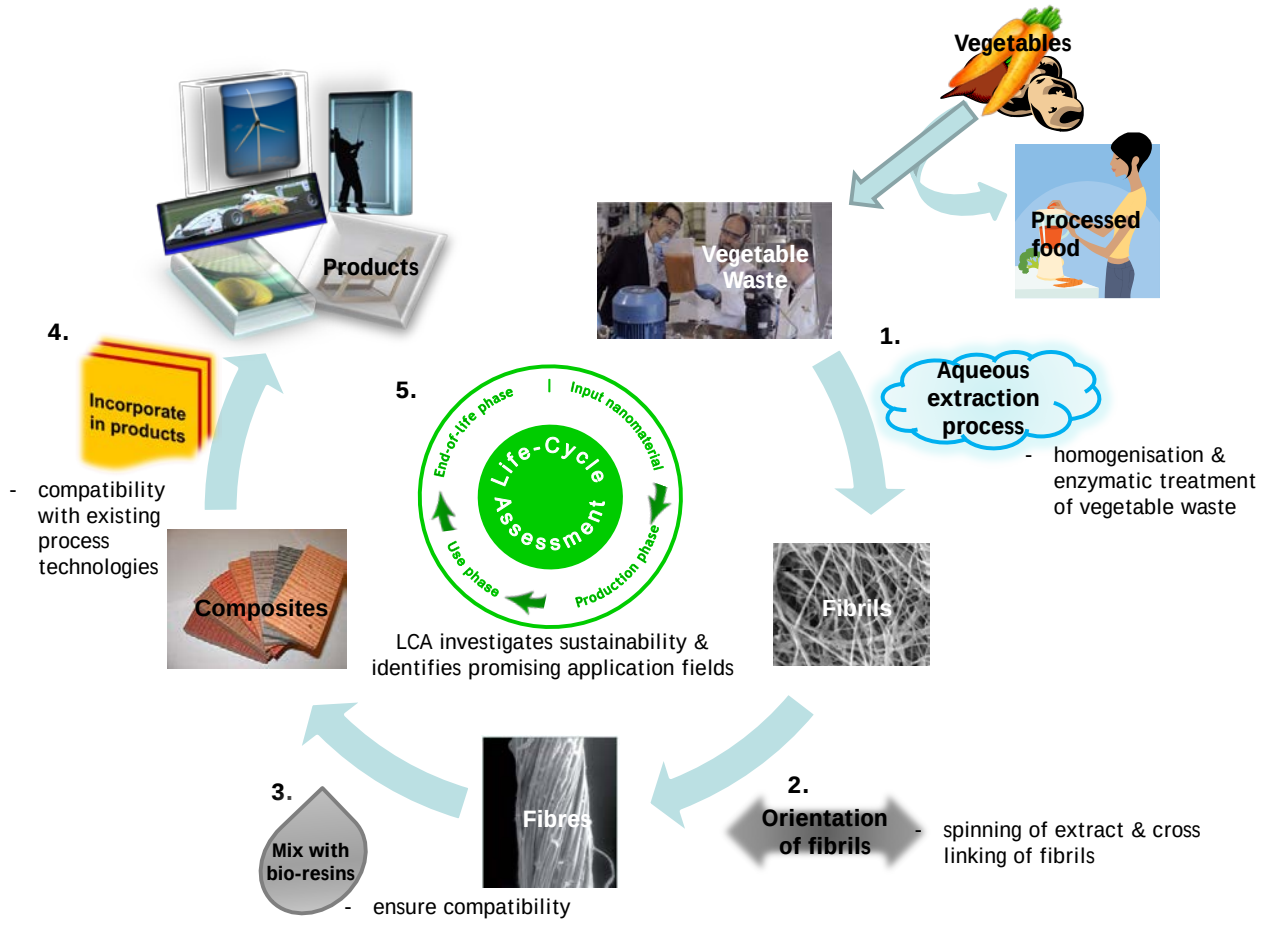

Figure 7.1 The NanoCelluComp process, from vegetable waste to product.

What did NanoCelluComp achieve?

NanoCelluComp demonstrated that it is possible to liberate nanocellulose fibrils from suitable vegetable sources (e.g. carrot, sugar beet, and potato) without the need for harsh chemicals, or organic solvents. Furthermore, through the selection of appropriate commercially available enzymes and the application of sequential mechanical steps (such as homogenisation, filtration and centrifugation) it is possible to remove most of the other cell wall constituents that could detract from the mechanical properties of cellulose.

Wider societal implications

As a society we are increasingly reliant on composite materials derived from petrochemical sources. These make up many consumer goods from hand-held devices to the fabric of our buildings and transportation. Such materials have been developed over decades to achieve the high mechanical properties they now enjoy, and consist of reinforcement materials such as glass fibre, carbon fibre or Kevlar, bound within a resin matrix. Composite materials derived from biological sources are unfortunately at the beginning of this process. Many of those that are currently on the market use macroscopic fibres (such as flax, cotton, silk) or mechanically liberated sub-cellular plant components (such as nanocellulose from wood pulp used in speciality paper products). These are not uniform structures and therefore fail to harness the inherently high mechanical properties of cellulose, with failure occurring at the weakest link. These weak points can arise from compounds present in the cell wall that naturally bind to cellulose, and by doing so weaken or prevent the interaction between cellulose fibrils or between the cellulose and the resin matrix.

Work within NanoCelluComp has moved us further along this journey. We are not at a point to directly compete with GRFP or CRFP, however we have identified the means by which to process nanocellulose from vegetables and have a better understanding of the steps that need further development to improve these mechanical properties. We have demonstrated that the materials produced within the project are compatible with existing manufacturing processes, and that in cases where high mechanical performance is not so critical, that there are energy and material savings to be made by using nanocellulose based composites. Furthermore, since the nanocellulose is extracted from vegetable waste, there is no impact on land-use.

This, in a small way (at present), contributes to sustainability and is a necessary step towards the development and manufacture on a large scale of mechanically strong biocomposites.

How did the project engage with policymakers and other key stakeholders?

NanoCelluComp maintained a project website which was updated with news items and information from within the project and from relevant external sources (including a project flyer and overview of processes used in NanoCelluComp). In addition to this, there was regular activity in terms of publishing of articles, presenting results at relevant meetings, publishing newsletters and briefings for media, and organising two project workshops. There have been a number of presentations made by project partners at academic and industrial events and to a wide international audience (including policy makers). One peer-reviewed paper has been submitted to ChemSusChem: 'Identifying sustainable applications for new materials on the example of cellulose nanofiber reinforced composites' (Fabiano Piccinno, Roland Hischier, Andrew Saba, Stefan Seeger, and Claudia Som), and a further fourteen are planned (see Table A1) covering all aspects of project RTD work. In total there were six project newsletters (released every 6 months).

Two workshops were organised, the first an internal project workshop open to members of staff (in particular junior members of staff) in the participants' organisations to learn more about the practical aspects of the project RTD programme. The second project workshop took place at JEC Europe 2014 (Paris, March 11-13). This is the largest composite trade show in Europe, attracting 1,239 companies and 35,727 individuals in 2014. NanoCelluComp's presence at the exhibition was promoted through a programme of mailshots, messages to relevant LinkedIn groups and professional/trade organisations, and news items on the NanoCelluComp and partner websites. Over 50 individuals visited the NanoCelluComp stand, and discussed project activities and results with partners. Most of these were from industry and had interests ranging from the mechanical properties of the biocomposites and their applications, to the extraction and

process technologies developed within NanoCelluComp (see Figure 7.2 for a collage of images from the JEC show).

In addition to this, the project consortium engaged with industrial end-users through WP6 (to determine their requirements and needs from a new bio-composite), and various other industrial organisations which exhibited interest in different aspects of the project during its course. This will potentially lead to new business for some of the industrial and academic partners.

Figure 7.2. Visitors to the NanoCelluComp exhibition stand at JEC Europe 2014.

How will the results from NanoCelluComp be used?

Analysis of the competitive patent landscape revealed very few that had relevance to the developments within NanoCelluComp (3 out of 366). This strongly suggests that there is both novelty in the approach taken within the project and freedom to operate. In total, 16 potentially exploitable results were identified. Of these one has been submitted as a patent application (title – 'Formation of microfibrillated cellulose from herbaceous plants'), a second will be submitted within the coming months, and there is at least one more possible future patent on fibre preparation and composition. The other developments within the project are more likely to be exploited by individual partners in terms of knowledge and improvement to RTD and services.

In addition to this, various partners have established some bi-lateral agreements to explore aspects of the developed process technologies that align with their business/research interests in greater detail. For example, a new proposal has been submitted by UCPH to the Danish Strategic Research Council entitled 'ASSEMBLY: Reverse engineering the cell wall for high-performance biocomposites' that also includes Cellucomp, Novozymes, KTH and USTRATH.

4.1.5 Project Website and Contact Details

Background information to the NanoCelluComp project and relevant news from the community are available through the project website: www.nanocellucomp.eu

A recent screenshot is shown below:

Partners and main contact details:

Partner	Country	Website	Person	Email
IoN	UK	www.nano.org.uk	Mark Morrison	mark.morrison@nano.org.uk
Cellucomp	UK	www.cellucomp.com	Eric Whale	eric.whale@cellucomp.com
USTRATH	UK	www.strath.ac.uk	Simon Shilton	simon.shilton@strath.ac.uk
UCPH	DK	www.plen.ku.dk	Bodil Jørgensen	boj@plen.ku.dk
KTH	SE	www.kth.se	Qi Zhou	qi@kth.se
UREAD	UK	www.reading.ac.uk	Fred Davis	f.j.davis@reading.ac.uk
STT/CTECH	SE	www.cellutech.se	Marcus Ruda	marcus@cellutech.se
ALPAS	IT	www.alpas.eu	Andrew Saba	asaba@alpas.eu
EMPA	CH	www.empa.ch	Claudia Som	claudia.som@empa.ch
NZ	DK	www.novozymes.com	Pierre Cassland	PRRC@novozymes.com
BV	SE	www.biovelop.com	Mark Lawson	jml@teknologisk.dk

4.2 Use and dissemination of foreground

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) shall be established at the end of the project. It should, where appropriate, be an update of the initial plan in Annex I for use and dissemination of foreground and be consistent with the report on societal implications on the use and dissemination of foreground (section 4.3 – H).

The plan should consist of:

- Section A

This section should describe the dissemination measures, including any scientific publications relating to foreground. **Its content will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

- Section B

This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential **will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

Section A (public)

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.

- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

No.	Title	Main author	Title of the periodical or series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)[1]	Is/will open access provided to this publication?[2]
1	Identifying sustainable applications for new materials on the example of cellulose nanofiber reinforced composites	Piccinno F. et al	ChemSusChem				Submitted		DOI: 10.1002/cssc.201	no

No.	Title	Main author	Title of the periodical or series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)[1]	Is/will open access provided to this publication?[2]
2	Life cycle assessment of cellulose nanofibers production derived from vegetable food waste (provisory title)	Piccinno F. et al	ACS Sustainable Chemistry & Engineering				Target: 2014			
3	Modeling the scale-up of laboratory production to industrial quantities for comparable lifecycle assessment	Piccinno F. et al	To be decided (TBD)				Target: 2014			
4	Rheological characterization of suspensions containing microfibrillated cellulose (MFC): effect of pre-treatment on processability (Draft title)	Magueijo V. & Shilton S.J.	TBD	---	---	---	Target: 2014	---		

No.	Title	Main author	Title of the periodical or series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)[1]	Is/will open access provided to this publication?[2]
5	Production of microfibrillated cellulose / alginate / adjuvant fibres via wet spinning. Part I: Maximization of mechanical strength by compositional optimization (Draft title)	Magueijo V. & Shilton S.J.	TBD	---	---	---	Target: 2014	---		
6	Production of microfibrillated cellulose / alginate / adjuvant fibres via wet spinning. Part II: Morphological and thermal characterization of produced fibres (Draft title)	Magueijo V. et al	TBD	---	---	---	Target: 2014	---		
7	Orientation of cellulose nanofibrils grafted with poly(ethylene glycol)	Tang H. et al	Advanced Materials				To be submited			

No.	Title	Main author	Title of the periodical or series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)[1]	Is/will open access provided to this publication?[2]
8	Orientation of cellulose in the nanocomposites films from nanofibrillated cellulose and anionic xyloglucan	Tang H. et al	Biomacro-molecules				To be submitted			
9	Enzymatic crosslinking of nanofibrillated cellulose adsorbed with feruloylated xyloglcuan.	Zhou Q. et al	TBD				To be submitted			
10	High performance biocomposites from nanofibrillated cellulose, xyloglucan, and rhamnogalacturonan I mimicking primary plant cell wall.	Zhou Q. et al	TBD				To be submitted			
11	Rheology of nanofibrillated cellulose from carrot and xyloglucan derivatives.	Zhou Q. et al	TBD				To be submitted			

No.	Title	Main author	Title of the periodical or series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)[1]	Is/will open access provided to this publication?[2]
12	Interaction of a Hypocrea jecorina Cel12A endoglucanase with polymers tightly bound to cellulose microfibrils	Jorgensen B. et al	PLOS ONE				To be submitted within 12 months			
13	Measurement of nanocellulose orientation in composite fibres	Mitchel G.R. et al	Macromolecules				Target: 2014			
14	Electrospun composite fibres containing microfibrillated cellulose	Mohan S. et al	Biomacromolecules				Target: 2014			
15	Orientation development in force spun polymers and composites	Mohan S. et al	Nanoletters				Target: 2014			

A2: LIST OF DISSEMINATION ACTIVITIES

No.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed
1	1st project newsletter	Sergey Gordeyev (IoN)		Aug-11	online	Scientific Community, Industry, Policy Makers		International
2	2nd project newsletter	Sergey Gordeyev (IoN)		Feb-12	online	Scientific Community, Industry, Policy Makers		International
3	conference, oral presentation	Sergey Gordeyev (IoN)	The Development of Nanocellulose-based Composites for High Performance Applications	Mar-12	Nano Enhancers for Plastics Conference 2012, Brussels, Belgium	Scientific Community, Industry		Europe
4	conference, oral presentation	Fabiano Piccinno (EMPA)	Sustainability of nanocellulose bio-composites derived from vegetable food waste	May-12	The 6th International Conference on Life Cycle Management – LCM 2013, The 1st conference of COST Action FP 1003, Barcelona, Spain	Scientific Community, Industry		Europe

No.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed
5	3rd project newsletter	Sergey Gordeyev (IoN)		Aug-12	online	Scientific Community, Industry, Policy Makers		International
6	4th project newsletter	Mark Morrison (IoN)		Feb-13	online	Scientific Community, Industry, Policy Makers		International
7	Open day	Bodil Jørgensen (UCPH)	Open day in the green houses for the community	May-13	Copenhagen University	Civil society	1000	
8	FRIMS	Peter Ulvskov (UCPH)	Seminar at departmental level	Jun-13	PLEN, Copenhagen	Scientific community	70	Denmark
9	conference, poster presentation	Mark Morrison (IoN)	The Development of Nanocellulose-based Composites for High Performance Applications	Jun-13	EuroNanoForum 2013, Dublin, Ireland	Scientific Community, Industry, Policy Makers		International
10	conference, oral presentation	Saheed Mohan (UREAD)	Nanoparticulate-containing Nanofibres	Jun-13	EPF 2013, Pisa, Italy	Scientific Community		International

No.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed
11	conference, poster presentation	Fred Davis (UREAD)	Incorporation of Intractable Materials into Electrospun Polymer Fibres via Post Reaction and Other Techniques	Aug-13	APME 2013, Durham, UK	Scientific Community		International
12	conference, oral presentation	Fabiano Piccinno (EMPA)	A decision support method for new materials during early innovation phase to find sustainable applications on the example of cellulose nanofibre reinforced composite	Aug-13	LCM 2013, Gothenburg, Sweden	Scientific Community, Industry, Policy Makers		International
13	5th project newsletter	Mark Morrison (IoN)		Sep-13	online	Scientific Community, Industry, Policy Makers		International
14	workshop, oral presentation	Bodil Jorgensen (UCPH)		Sep-13	FPS COST Action FP1205 (Innovative applications of regenerated wood cellulose fibres)	Scientific Community		Europe
15	Workshop	Dennis Jones (UCPH)	FPS COST Action FP1205: Innovative applications of regenerated wood cellulose fibres	Sep-13	Vila Real, Portugal	Scientific community		

No.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed
16	conference, oral presentation - won prize	Geoff Mitchell (UREAD)	Novel Nanocomposites: Controlling the Morphology of Polymers on Multiple Scales	Oct-13	International Conference on Advanced Polymer Materials, Mahatma Gandhi University, Kottayam, Kerala, India	Scientific Community		International
17	conference	Qi Zhou (KTH)	Preparation and characterization of cellulose nanofibrils grafted with poly(ethylene glycol)	Oct-13	3rd EPNOE International Polysaccharide Conference, Nice, France	Scientific Community, Industry	450	International
18	conference, oral presentation	Fabiano Piccinno (EMPA)	Cellulose nanofibres towards sustainable products	Oct-13	PhD Student's Symposium 2013, Dübendorf, Switzerland	Scientific Community		Switzerland
19	conference, poster presentation	Fabiano Piccinno (EMPA)	Identifying sustainable applications for new materials - the case of cellulose nanofibres	Nov-13	SETAC EUROPE 19th LCA Case Study Symposium, Rome, Italy	Scientific Community, Industry		Europe
20	conference, oral presentation	Saheed Mohan (UREAD)	SANS study of electrospun polymer fibres	Dec-13	Electrospinning Principles, Practice and Possibilities 2013, London, UK	Scientific Community		International
21	conference, oral presentation	Fred Davis (UREAD)	Nanofibres and nanoparticulates	Dec-13	Electrospinning Principles, Practice and Possibilities 2013, London, UK	Scientific Community		International

No.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed
22	Presentation	Qi Zhou (KTH)	Promises, possibilities and challenges with nanocellulose materials	Jan-14	Copenhagen, Denmark	Scientific Community	30	Denmark
23	6th project newsletter	Mark Morrison (IoN)		Feb-14	online	Scientific Community, Industry, Policy Makers		International
24	exhibition	Mark Morrison (IoN)	NanoCelluComp - Nanocellulose-based Composites	Mar-14	JEC Europe 2014, Paris, France	Scientific Community, Industry	>30,000	International
25	exhibition	Andrew Saba (ALPAS)	NanoCelluComp - Nanocellulose-based Composites (co-organiser)	Mar-14	JEC Europe 2014, Paris, France	Scientific Community, Industry	>30,000	International
26	exhibition	Vitor Magueijo (USTRATH)	USTRATH was present at JEC Europe in Paris and helped in the dissemination activities (distribution of information, one-to-one discussions with visitors)	Mar-14	JEC Europe 2014, Paris, France	Scientific Community, Industry	>30,000	International

No.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed
27	exhibition	Marcus Ruda (CTECH)	CTECH was present at JEC Europe in Paris and helped in the dissemination activities (distribution of information, one-to-one discussions with visitors)	Mar-14	JEC Europe 2014, Paris, France	Scientific Community, Industry	>30,000	International
28	exhibition	Qi Zhou (KTH)	KTH was present at JEC Europe in Paris and helped in the dissemination activities (distribution of information, one-to-one discussions with visitors)	Mar-14	JEC Europe 2014, Paris, France	Scientific Community, Industry	>30,000	International
29	exhibition	Eric Whale (Cellucomp)	Cellucomp was present at JEC Europe in Paris and helped in the dissemination activities (distribution of information, one-to-one discussions with visitors)	Mar-14	JEC Europe 2014, Paris, France	Scientific Community, Industry	>30,000	International

No.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed
30	exhibition	Bodil Jorgensen (UCPH)	UCPH was present at JEC Europe in Paris and helped in the dissemination activities (distribution of information, one-to-one discussions with visitors)	Mar-14	JEC Europe 2014, Paris, France	Scientific Community, Industry	>30,000	International
31	conference, oral presentation	Fabiano Piccinno (EMPA)	Sustainable chemical production of cellulose nanofibers	Mar-14	247th ACS National Meeting & Exposition, Dallas, USA	Scientific Community, Industry, Policy Makers		International
32	conference, oral presentation	Fabiano Piccinno (EMPA)	Holistic assessment of cellulose nanofibre reinforced composites to obtain sustainable products	May-14	NANOSTRUC2014, Madrid, Spain	Scientific Community, Industry		Europe
33	conference, exhibition	Qi Zhou (KTH)	Combinations of nanocellulose, polymers and nanoparticles to create new materials and new functionalites	Nov-14	AVS 61st International Symposium & Exhibition, Baltimore, Maryland, USA	Scientific Community, Industry		International

Section B (Confidential[1] or public: confidential information to be marked clearly)

Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

Template B1: List of applications for patents, trademarks, registered designs, etc.					
Type of IP Rights[1]:	**Confidential (Y/N)**	**Foreseen embargo date**	**Application reference(s) (e.g. EP123456)**	**Subject or title of application**	**Applicant (s) (as on the application)**
Patent	Y	18 months	GB1409047.6	Formation of microfibrillated cellulose from herbacious plants	CelluComp, NZ, UCHP
Patent	Y		Due for submission next 180 days	Improved method microfibrillated cellulose from herbacious plants with	NZ, CelluComp, UCHP
Patent	Y		Potential future patent	Fibre preparation and composition	USTRATH

[1] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[1]	Description of exploitable foreground	Confidential (Y/N)	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[2]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Enzyme formulation	Y		Enzymes formulation for liberation of nanocellulose	C10.3.9 - Other processing and preserving of fruit and vegetables	3 years	patent & potential license to non-competing sectors	NZ, Cellucomp, UCPH, UREAD
Commercial exploitation of R&D results	Breakdown of vegetable materials into nanocellulose	Y		Method for liberation of nanocellulose	C10.3.9 - Other processing and preserving of fruit and vegetables	3 years	patent & knowledge exploited by Cellucomp	NZ, Cellucomp, UCPH, UREAD
Commercial exploitation of R&D results	Surface modification of cellulose with polysaccharides	Y		Methods for incorporating nanocellulose fibrils with polysaccharides	C22.2.9 - Manufacture of other plastic products	3-4 years	know-how	STT/CTECH, BV
Commercial exploitation of R&D results	Method of crosslinking cellulose/modified cellulose	Y		Protocols for chemical cross-linking	C22.2.9 - Manufacture of other plastic products	4-5 years	know-how, KTH have previously patented modified polysaccharides	Cellucomp, UREAD

Type of Exploitable Foreground[1]	Description of exploitable foreground	Confidential (Y/N)	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[2]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Method of crosslinking cellulose/modified cellulose	Y		Protocols for enzymatic cross-linking	C22.2.9 - Manufacture of other plastic products	4-5 years	know-how & potential patent	UCPH, NZ, BV
Commercial exploitation of R&D results	Method of crosslinking cellulose/modified cellulose	Y		Method for cross linking of polysaccharide modified nanocellulose	C22.2.9 - Manufacture of other plastic products	3-4 years	know-how & potential future patent	KTH, UCPH, NZ, Cellucomp
Commercial exploitation of R&D results	Procedure for spinning fibres	Y		Electrospinning process	C22.2.9 - Manufacture of other plastic products	2-3 years	know-how, potential licence	UREAD
Commercial exploitation of R&D results	Procedure for spinning fibres	Y		Solution spinning process	C22.2.9 - Manufacture of other plastic products	2-3 years	possible patent	USTRATH
Commercial exploitation of R&D results	Manufacture of composite materials	Y		Process for composite making with randomly oriented nanocellulose particles	C22.2.9 - Manufacture of other plastic products	2-3 years	know-how, internal exploitation	Cellucomp

Type of Exploitable Foreground[1]	Description of exploitable foreground	Confidential (Y/N)	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[2]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Manufacture of composite materials	Y		Process for composite making with highly oriented nanocellulose particles	C22.2.9 - Manufacture of other plastic products	2-3 years	know-how, internal exploitation	Cellucomp
General advancement of knowledge	Information on nanocellulose for LCA analysis	N		Life-cycle assessment	C22.2.9 - Manufacture of other plastic products	1-2 years	know-how & database	EMPA and ALL
Commercial exploitation of R&D results	Library of functionalised polysaccharide derivatives	Y		Functional polysaccharide derivatives for enzymatic cross-linking	C22.2.9 - Manufacture of other plastic products	4-5 years	library (know how) & potential licence or sale of products	KTH, STT/CTECH, BV
Commercial exploitation of R&D results	Formation of composites with industrial resins	Y		Composites with different resins	C22.2.9 - Manufacture of other plastic products	2-3 years	know-how, internal exploitation	ALPAS, Cellucomp
Commercial exploitation of R&D results	Equipment for aligned samples	Y		Spinning equipment	C22.2.9 - Manufacture of other plastic products	4-5 years	know how & potential licence	UREAD, USTRATH

Type of Exploitable Foreground[1]	Description of exploitable foreground	Confidential (Y/N)	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[2]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Formation of structurally sound cellulosic composites	Y		Protocols for combining spinning and crosslinking	C22.2.9 - Manufacture of other plastic products	2-4 years	potential future patent	UREAD, KTH, Cellucomp, UCPH, USTRATH
Commercial exploitation of R&D results	Formulations for forming extruded cellulose materials	Y		Optimal composition for extruded fabrication	C22.2.9 - Manufacture of other plastic products	4-5 years	possible patent	USTRATH, KTH, Cellucomp, STT/CTECH

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	263017
Title of Project:	The development of very high performance bioderived composite materials of cellulose nanofibres and polysaccharides.
Name and Title of Coordinator:	Dr Mark Morrison

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? * If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
* Did the project involve children?	
* Did the project involve patients?	
* Did the project involve persons not able to give consent?	
* Did the project involve adult healthy volunteers?	
* Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
* Did the project involve Human Embryos?	
* Did the project involve Human Foetal Tissue / Cells?	

* Did the project involve Human Embryonic Stem Cells (hESCs)?	
* Did the project on human Embryonic Stem Cells involve cells in culture?	
* Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
* Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
* Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
* Did the project involve research on animals?	
* Were those animals transgenic small laboratory animals?	
* Were those animals transgenic farm animals?	
* Were those animals cloned farm animals?	
* Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
* Did the project involve the use of local resources (genetic, animal, plant etc)?	
* Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	No
* Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	2
Work package leaders	1	7
Experienced researchers (i.e. PhD holders)	3	17
PhD Students	0	1
Other	7	15

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	9
Of which, indicate the number of men:	8

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ Yes
⊙ No

6. Which of the following actions did you carry out and how effective were they?

	Not effective at all				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

⊙ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

⊙ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

⊙ Yes- website and flyers explaining the process technologies involved.

○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

⊙ Main discipline[2]: 1.3, 2.3

○ Associated discipline[2]:

○ Associated discipline[2]:

[2] Insert number from list below (Frascati Manual).

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ ⊙	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
Education, Training, Youth		Foreign and Security Policy		Space	
Employment and Social Affairs		Fraud		Taxation	
		Humanitarian aid		Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**1 (further 14 planned)**
To how many of these is open access[3] provided?	**0**
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[4]: ……	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**1**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

[3] Open Access is defined as free of charge access for anyone via Internet.

[4] For instance: classification for security project.

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
☑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs: Difficult to estimate / not possible to quantify	*Indicate figure:* 30.05 (based on the total project PMs claimed) ❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ⦿ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ⦿ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☑	Press Release	☑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
☑	Brochures /posters / flyers	☑	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	☑	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]