European Cooperation
in Science and Technology
- COST -

Secretariat

Brussels, 8 December 2011

COST 4172/11

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action FP1105: Understanding wood cell wall structure, biopolymer interaction and composition: implications for current products and new material innovation

Delegations will find attached the Memorandum of Understanding for COST Action as approved by the COST Committee of Senior Officials (CSO) at its 183rd meeting on 30 November 2011.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action FP1105
UNDERSTANDING WOOD CELL WALL STRUCTURE, BIOPOLYMER INTERACTION AND COMPOSITION: IMPLICATIONS FOR CURRENT PRODUCTS AND NEW MATERIAL INNOVATION

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4154/11 "Rules and Procedures for Implementing COST Actions", or in any new document amending or replacing it, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to improve understanding of wood cell structure, biopolymer interaction and composition and factors driving these variables, to support wood based product and process improvement and develop new biopolymer based materials.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 60 million in 2011 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter V of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

The primary objective of the Action is to build knowledge and understanding of fundamental physical (self assembly) processes and biological systems (e.g. genetic control) that drive natural structures and biopolymer composition within the plant/wood cell wall and to use new knowledge of self assembly processes to support the development of new biopolymer based materials.

The Action also aims to quantify the impact of new knowledge on our understanding of the mechanical properties of the cell wall and how processes such as pulping, bleaching recycling, cell wall disintegration methods and ongoing tree improvement and biotechnology programmes impact both positively and negatively on structure and composition of the cell wall. The intent is to explore how this knowledge can be used to support ongoing improvement in these areas of activity. An overarching goal is to develop multidisciplinary competence and capability to support these objectives and to work closely with commercial organisations to promote effective dissemination of knowledge and the development of a more economically sustainable Forest Based Sector.
Keywords: Biopolymers, new materials, theoretical physics, self assembly, plant cell wall

B. BACKGROUND

B.1 General background

For several decades scientists have looked at the structure and biopolymer composition of the wood cell wall and the role it plays in the properties of plant fibre-based materials such as solid wood, paper and composites. Recent work has highlighted some significant gaps in our knowledge which restrict our ability to accurately predict and improve these properties. Perhaps more importantly, the pulp and paper and broader forest products industry is under increasing pressure to not only improve and add value to existing products but also to:

- Utilise residuals in higher value applications and;
- Develop new game changing technologies, materials and products that can transform the traditional manufacturing base into higher value markets which can compete more effectively in global markets.

These challenges have led to the evolution of a bio-refinery concept, which requires an "in depth" characterisation of a complex package of bio-polymers and to understand the processes required to extract different components. Interest in the development of wood as a bio refinery feedstock has led to advances in our understanding of cell wall ultra-structure and biopolymer composition. Cost action FP 0901 ("Analytical Techniques for biorefineries") and COST Action FP0602 **"**Biotechnology for lignocellulose biorefineries" are examples of how analytical techniques and technologies are being developed to improve our knowledge in this area. However, as our knowledge improves there is an increasing awareness that there is much still to learn. For example, A recent paper (Turner *et al*, 2011) highlighted a new approach to viewing the crystalline cellulose structure of plant cells, that has provided important new insights into the architecture of the wood cell wall. The work indicates a complex, fractal cell wall structure. In addition to the cell structure, recent unpublished work indicates that the internal arrangement of cellulose chains within crystalline micro-fibrils is also fractal as opposed to the currently accepted model of a linear arrangement of cellulose chains). This finding offers new insights into how the tree forms crystalline cellulose within the nano-fibril.

Further complexity is added by a poor understanding of how primary industrial processes influence and change cell wall ultra-structure and overall composition, these processes may alter the assembly of the biopolymers in unintentional ways that lead to suboptimal extraction and utilisation of the residual material in whole tree utilization processes.

Within the field of biochemistry and genetics there is a growing understanding of some of the factors under genetic control but in other instances, it is clear that there is still a poor understanding of the incredibly complex phenotype (at the cell wall level). Without this understanding, it is impossible to determine the relative contribution of genes, environment and the underlying physical processes in determining the structure, and composition of the cell wall.

A hypothesis has been proposed (Turner *et al*, 2011) that the fractal structure of the tree and the cell itself along with the majority of biological and inorganic materials that are allowed to self assemble (in what is traditionally seen as a process of diffusion limited aggregation) is driven by the underlying fractal structure of space-time. This concept, has gained considerable momentum through parallel and independent research programs in theoretical physics.

The principle has been demonstrated through the use of a modified Schrödinger equation (Nottale and Auffray 2008) to model biological functions (morphogenesis, duplication, multiscale hierarchy of organization etc) and the ubiquitous fractal structures found in biological systems and the physical world. The hypothesis states that these structures are influenced by quantum mechanics and the fundamental geometric structures of space-time in a way that we are only just beginning to understand. The physics underlying this work which is also supported by string theory is already providing new, fundamental insights into the nature and structure of matter.

There is a growing interest in the mimicking of biological systems in the development of new materials. One of the challenges has been to identify the processes by which some of these structures are formed as biological processes can be very complex. However, if we can confirm that the processes that define plant wall structure are physical rather than genetically driven then it opens up opportunities for us to model and mimic these processes more easily from first principles.

Conversely, if we know that some processes are driven by fundamental physical processes then we need to understand the role of the genome in influencing these structures and the overall biopolymer composition of the plant cell wall. i.e. it is important to understand how manipulation of genes is capable of changing and modifying the cell wall. This has implications for current biotechnology initiatives in plant sciences and the Forest Based Sector.

Why COST is the best mechanism for support ?

The work identified is primarily long term and multidisciplinary in nature. A successful outcome requires the development of new networks between different scientific fields including physics, genetics, plant physiolgy, plant science, materials science, mathematical modelling, wood science and industrial processing of biopolymers. One of the key outcomes will be the development of a new European wide platform of competencies and capacities with a common goal, that can be harnessed to compile and integrate exisiting knowledge and to develop new multidisciplinary research proposals into the future. COST offers an ideal mechanism to facilitate this objective.

Key benefits of the Action will include:

1. Collective development of a new fundamental understanding of the plant cell wall structure and biopolymer composition, their interactions and what controls these variables.
2. The development of a common language of communication across a wide range of disciplinary boundaries.
3. A new multidisciplinary network and platform of synergistic competencies that can support innovation in the Forest Based Sector.
4. Better informed tree improvement programmes
5. Improved utilization and value addition to the forest resource
6. The development of new young scientists in new areas of multidisciplinary scientific research
7. The development of multidisciplinary trans European research proposals with participation from non EU institutions.
8. Creating awareness among scientists from a broad range of disciplines of key challenges in the forestry and forest products industry which would not traditionally have been exposed to this industry.
9. Development of a new platform of competencies that can support the development of new bio-polymer based materials.

B.2 Current state of knowledge

Theoretical physics and self assembly

In the field of theoretical physics, a considerable body of work has been published on the theory of "scale relativity" and impact of the structure of space-time on the potential structure of matter [Nottale (1992, 1994, 1995a, 1995b, 1997, 2003a, 2003b, 2007)]. The theory is an extension of the theories of relativity. In the general theory of relativity the geodesic curvature of space-time is smooth and differentiable. The scale relativity theory treats space-time as continuous but non-differentiable, (fractal) at all scales from the Planck scale (10-33cm) to infinity.

The length of a non-differentiable (fractal) curve is dependant on the resolution at which it is measured. For example, when measuring the coastline of Norway its length is scale dependant, with smaller scale resolutions leading to an increase in the length of the coastline measured. According to the scale relativity theory, this principle can be applied to space, and more generally to space-time. On a large scale the curvature of space-time approximates to a differentiable curve but as the resolution becomes smaller in scale these curves have an internal fractal structure with an infinite number of possibilities depending upon the scale at which it is observed. In translation, this suggests that a "wave-particle" such as an electron will have the geometric properties of a subset of the fractal geodesics of a non-differentiable space-time i.e. an electron will follow a fractal trajectory in its orbital as it travels through the complex, multidimensional fractal scaffold of space-time. Auffray and Nottale (2008) introduced pure scale laws describing the dependence on scale of fractal paths at a given point of space-time. Their work considers the radical consequences on motion of the fractal structure of space-time. The laws of mechanics constructed from the geodesic of fractal space-time become quantum type mechanics. Auffray and Nottale transformed Newton's equations of dynamics into a generalized macroscopic Schrödinger equation, which leads to a profound theory of self-organization.

A Schrödinger-type equation is characterized by the existence of stationary solutions yielding well-defined peaks of probability linked to quantization laws, of the forces applied and of the symmetries of the system. Nottale (1997) interpreted these peaks of probability as a tendency for the system to form structures. The theory doesn't predict precise organization, but rather the most probable structures among the infinity of other close possibilities. This is compatible with the large variability that characterizes living systems.

Traditionally, scientists have viewed growth as a process of "diffusion limited aggregation" while Nottale and Auffray (2008) suggest that growth processes are based upon the laws of quantum mechanics. It should be emphasized that quantum mechanics and diffusion process are opposite processes. Diffusion laws describe disorganization and entropy increase. Conversely quantum-type laws are an archetype for laws of self-organization and local entropy decrease.

In living systems, structure is driven through growth processes. According to Auffray and Nottale (2008), following their “Schrödinger process”, growth can be described in terms of an infinite family of virtual, fractal and locally irreversible trajectories. However, instead of an infinite number of possible morphologies, only some are possible due to the quantized nature of trajectories and their corresponding morphologies are also quantized. The quantum level (n) can be 0 to infinity. When *n=0;*a one–body structure results. If energy increases, no stable solution can exist before it reaches the second quantized level when a two-body structure is formed through a process of bifurcation. The passage from the fundamental level to the first excited level provides a rough model of duplication or bifurcation. As the energy levels increase further, bodies of increasing complexity result. The model provides a good hypothesis as to why we see fractal structures at both the macroscopic (tree) level and at the microscopic (within cell) level. This could also explain why we see both relatively simple, almost linear arrangements of micro-fibrils within the S1 layer in combination with increasing levels of complexity in other layers of the cell wall.

Scale relativity theory provides a fundamental explanation as to how simple through to complex structures (both organic and inorganic) can be influenced by the fundamental structure of space-time and the “Schrödinger process". In theory it should be possible to write a complete system of equations including the effects of fractality and describe the system, the environment and the interaction between them. Nottale (1995, 1996a) suggests it is possible to produce a system of equations that can be integrated in terms of a single, multisystem Schrödinger equation, which could have profound implications for the description of the relations between biological systems and their environment.

To demonstrate the principles behind the theory, Auffray and Nottale (2008) show a simple example of the use of the “Schrödinger process” to “grow” flower-like shapes, with different structures (petals, sepals and stamen) within the flower being derived from the same wave equation.

Recent work published by Turner et al (2011) has indicated that the traditional models of internal structure of cellulose microfibrils and the way in which they are laid down in the wood cell wall needs review as these structures are fractal. These structures are analogous to those formed by inorganic materials indicating that they are not genetically driven. The Schrödinger process published by Nottale and Auffray (2008) provides a new mechanism to help in understanding how these structures are formed. It may also provide new insights into self assembly processes that can lead to the development of new platform for materials development.

Cellulose synthesis

At least 3 different cellulose synthase (CSA) proteins are required to make a cellulose synthesising complex (CSC) in a plant primary cell wall. It has been suggested that these proteins differ in the chemistry and/or geometry of protein-protein binding sites, so that each protein structure has a unique role in the self-assembly of a CSC (Scheible et al. 2001, Taylor 2008). Electron microscope images show hexagonal CSCs, interpreted as 6 subunits each self-assembled from 6 CSA protein molecules. Identical CSCs might be expected to produce identical cellulose nanofibrils, so the conventional model for a CSC does not fully account for the fractal nature of nanofibrils. It is possible that the hexagonal CSC is an ideal shape, and that typical products of self-assembly are better described by a fractal model.

When plants start constructing a secondary wall, they switch to a different set of 3 or more CSA proteins (Timmers et al. 2009). The new set of 3 or more CSA proteins is self-assembled into hexagonal CSCs that look identical to the CSCs in primary walls, and yet they biosynthesise cellulose in distinctly different fibrillar structures. Here again, a fractal model might be helpful in developing a theory for assembly of the plant cell wall. The new CSA proteins might promote the assembly of loose clusters of CSCs, so that cellulose microfibrils can be assembled from clusters of nanofibrils.

Cell wall characterisation

Advanced techniques have proved successful over recent years, but the greatest gains in knowledge will emerge from synergies between these new techniques.

Synchrotron radiation provides the X-ray beam brilliance needed to reveal the detail of packing in cellulose nanofibrils, e.g. through calculation of diffractograms from first principles (Newman 2008), or through precise measurement of diffraction angles (Hill et al. 2010). Synchrotron radiation has provided insights into wood drying, through demonstration of partly-irreversible interactions between water and cellulose nanofibrils (Hill et al. 2010).

Solid-state ^{13}C NMR provides information about the molecular conformations of biopolymers, and can therefore be used to distinguish between cellulose chains enclosed in the core of a nanofibril and those exposed on surfaces (Newman and Davidson 2004). This information can be used to characterise the role of water in cell-wall architecture (Hill et al. 2009), interactions between non-cellulosic biopolymers and cellulose nanofibrils (Booten et al. 2009), or interactions between nanofibrils during wood processing and product aging (Newman 2004).

Over the last 5 years there has been significant progress in the development of new micro and nano-scale testing technologies that can be used to characterise the mechanical properties of individual wood/plant cells and crystalline microfibrils. These tools form an important part of the Armoury available to validate mechanical models of the structure of cells and microfibrils.

B.3 Reasons for the Action

The European Forest based sector has a big challenge to maintain and grow its economic competitiveness and create new markets. A key to its success will lie in the development of new game changing technologies that can lead to higher value products and materials which can compete in a broader market against non-renewable materials and products.

The primary reason for the launching of the Action is to form a new multidisciplinary network of experts. The main end goal of the action is the development of new high value materials with some important spin-offs and synergies with traditional with the existing pulp and paper industry and the tree improvement and biotechnology research communities. One way to do this is through the development of a new science and technology platform. This Action is an important catalyst that can start the process of capacity building and renewed research investment.

One of the key outcomes of the Action will be the coordinated development of research proposals at National and European levels to push the forest based sector into the lead in the development of new sustainable materials for the future.

The Action is mainly aimed at scientific/technological advance with a key focus on capacity building to support a more competitive Forest Based Sector.

B.4 Complementarity with other research programmes

The Action will be based on a broad range of past current and ongoing research programmes including:

An extensive body of work in the field of theoretical physics highlighted in section B2.

University of California at Davis - Neale Lab: The "Douglas fir genome project (DFGP)". In this project, they propose to use a population genomic approach called association mapping to identify the specific genes (i.e. loci and alleles) that are responsible for phenotypic differences in adaptive traits of Douglas-fir. (http://dendrome.ucdavis.edu/NealeLab/dfgp/overview.php).

The Action will be also based on achievements of existing and already terminated international and European work and will benefit from synergies with current research activities. The following COST Actions are of particular relevance:

COST Action FP0802 (FP0802; Experimental and Computational Micro-characterisation Techniques in Wood Mechanics) currently deals with many of the techniques used in this Action but will end in June 2012. It is proposed that the Action collaborates closely with this Action and take the best practice forward. It is anticipated that a number of participants from this COST Action will join the new Action ensuring continuity.

COST Action FP0602 **"**Biotechnology for lignocellulose biorefineries". Close links will be developed with this action which will form an important component of the research programme.

COST Action E20 "*Wood fibre cell wall structure*" (1999-2004): The tools, techniques and knowledge developed under this Action provide an important base for the new Action.

COST Action E35 "*Fracture mechanics and micromechanics of wood and wood composites with regard to wood machining*" (2003-2008): Results related to wood microstructure and micromechanics obtained in this Action will serve as the starting point of the new Action. Existing contacts between research groups established in the framework of this Action have already been made and will further on be very helpful in developing and managing the current Action.

COST Action E50 "*Cell wall macromolecules and reaction wood*" (2005-2009): The tools, techniques and knowledge developed under this Action provide an important base for the new Action.

COST Action E54 "*Characterisation of the fine structure and properties of papermaking fibres using new technologies*" (2006-2010): Knowledge acquired in this Action in relation to automatic characterisation techniques and to the ultrastructure of fibres will be considered in the new COST Action.

There are also some Actions in other COST domains that are related to fine structural studies on synthetic polymers and other non-wood materials, e.g. Action P12 "*Structuring of polymers*" (domain Materials, 2003-2007), and Action P19 '*Multiscale modelling of materials*' (domain Materials, 2006-2010). Possible links with these Actions and/or individuals from these Actions will be considered.

C. OBJECTIVES AND BENEFITS

C.1 Main/primary objectives

The main objective of the Action is to increase understanding of the factors controlling wood cell structure, biopolymer interaction and composition by exploring and evaluating emerging theories and techniques in the fields of theoretical physics, analytical chemistry, plant physiology, plant genetics, biotechnology, materials science and mathematical modelling. The most important goal is to utilise this understanding to support the development of self assembly processes which could lead to new biopolymer based materials.

C.2 Secondary objectives

The secondary objectives of this COST Action can be split into two main categories:

1. Improvement of the knowledge base by:

- Modelling mechanical properties of the cell wall using the new knowledge of its structure and composition to support understanding of cell wall mechanical characteristics.
- Improving our understanding of the impact of different processes (eg pulping, bleaching and pulp recycling) on cell wall structure and biopolymer composition and to use this knowledge to support improvement in existing products and processes such as pulping, bleaching and paper recycling.

2. Development of new and existing cell wall disintegration processes. This will include:

- Using the knowledge of cell wall structure and composition developed in the primary objective to developing new and more efficient mechanisms for how to take the plant cell wall apart and to fractionate/refine the individual components so that they can be used as a raw material resource in the development of new materials. This approach is expected to include mechanical, chemical and enzymatic approaches to fibre wall disintegration. This objective is partially addressed under COST Action FP0602 **"**Biotechnology for lignocellulose biorefineries" and close links will be developed with this action as well as bringing together alternate mechanical and chemical processes.

C.3 How will the objectives be achieved?

The objectives of this Action will be achieved through collaborative exchange of ideas and knowledge in basic and applied research from both academia and industry. The means to reach the objectives will be:

- Assembling experts and young scientists from European academia and industry as well as from other non EU countries. Meetings will encourage dissemination of the latest work, exchanging and developing ideas as well as visiting sites with recognised expertise;
- Coordinating research activities, ensuring best practical use of resources, i.e. minimising duplication creating a common development programme;
- Joint collaboration among the different institutions and research activities, including the development of joint research proposals, exchange of personnel and the provision of access to specialist equipment. This will encourage greater synergy between institutions.

Networking between scientists from different disciplines is essential to address the proposed game changing approach to the challenges identified. More specifically:

The creation of a network of physicists, modellers (from fundamental principles), biotechnologists, analytical chemists and plant scientists is essential in meeting the main objective of the Action, which is to piece together a new, more holistic understanding of the key factors contributing to structure, biopolymer composition and polymer interactions within the cell wall. Integration of these competencies with mechanical modelling is essential if we are to improve our knowledge of how cell wall structure impacts on its mechanical properties.

Knowledge, analytical techniques and mechanical characterisation techniques, shared and developed within the Action are essential to support an understanding of the impact of different processes on cell wall structure and biopolymer composition.

The expertise, knowledge and understanding of cell wall structure developed in the Action will provide an invaluable background to assist in the development of new and more efficient mechanisms to take a fibre wall apart.

The understanding of physical processes involved in determining plant cell wall structure will form important baseline knowledge for use in developing new self assembly processes and subsequent biopolymer based materials.

C.4 Benefits of the Action

Scientific benefits:

- Collective development of a new fundamental understanding of the plant cell wall structure and biopolymer composition, their interactions and what controls these variables.
- The development of a common language of communication across a wide range of disciplinary boundaries.
- A new multidisciplinary network and platform of synergistic competencies that can support innovation in both the growing and processing industries. This includes focussing scientists not traditionally involved in the forestry and forest products industry on addressing research and development challenges within the industry.
- Potential for the development of new biopolymer based materials

Technical benefits

- Improve utilization and value addition to the forest resource
- Improved knowledge of the impact of different processes on end product properties. This is expected to lead to potential improvement in traditional products and processes
- Improvements in analytical and synthesising facilities traditionally not used in plant research

Societal benefits

- The COST Action is expected to contribute to the longer term competitiveness and economic sustainability of the European forest based sector through the development of higher value products and processes.
- The COST Action could lead to the replacement of products traditionally manufactured from non renewable materials. This could also lead to increased employment opportunities in European countries.

C.5 Target groups/end users

The target audience of the Action is mainly researchers interested in basic and applied research from universities, research Institutes and forestry and forest products companies and supporting industries both within Europe and from all over the world. There is already widespread participation in the development of this proposal from a range of stake holders with a number of International and European based companies involved.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The scientific focus of this COST Action is aimed at bringing together a number of the latest developments and thinking in theoretical physics, systems biology, biotechnology, plant physiology, analytical chemistry, microscopy and material science to improve our understanding of plant cell wall structure and biopolymer composition and what drives it to support a number of challenges:

- Understanding the role of structure and composition in cell mechanical characteristics and chemical reactivity and its impact on existing processes and products and how this knowledge can be used to improve on current state of the art

- Development of new and existing mechanisms for breakdown of cell wall components

- Provide support for genetic improvement/modification programmes through improved phenotype characterisation at the cell wall level. This includes creating knew knowledge of how to improve the processability of the cell wall and increase the proportion and quality of high value components for different end use applications.

- Use of fundamental physical (self assembly) processes to develop new biopolymer based materials

Some of this work is already established and ongoing within a number of institutes participating in the COST Action. However, a significant proportion of the proposed work is new. One of the key focus areas of the Action will be to coordinate the development of new research proposals and collaborative programmes at National and European levels in collaboration with a number of experts from non COST countries.

D.2 Scientific work plan methods and means

The scientific programme and the required methods and instruments for achieving the objectives are presented in relation to the three principle scientific areas which will form the basis for three working groups. So far, the main tasks and aims are specified. A more detailed description of the work will be developed at the kick-off meeting and will be adapted in the course of the Action. Other topics may then be included to accommodate additional perspectives and activities not forseen during the preparation of the proposal.

Scientific area 1: Understanding cell wall structure, biopolymer composition and polymer interactions and their impact on cell wall properties.

Proposed activities to include:

Develop an understanding of the role of fundamental physical processes in defining cell wall structure and chemical composition. A key focus of work over the course of the Action will to investigate the use of the different approaches to modelling the fractal structures observed in microfibrils, and the cellulose skeleton of the cell wall. Attempts will also be made to model interactions between structural cellulose, lignin and amorphous polysaccharides. This will be supported by ongoing work to study wood structure and composition.

As recent work indicates that many of the structures observed in the plant cell wall are driven by physical processes, it raises a key question around the role of genes and how they influence these structures. To date much of this new information on cell structure is not common knowledge within the tree/plant breeding and biotechnology community. A scientific programme will be developed to improve understanding of the role of genes, enzymes, macromolecules and environmental factors controlling microfibril and cell wall formation and how they influence the underlying physical processes. This in turn should inform genetic improvement and biotechnology programmes that can more effectively support the existing Forest Based Sector as well as enhancing plant cell wall material as a resource for new biopolymer based materials.

Theoretical studies will be complemented by ongoing development of our knowledge of the structure and composition of the plant cell wall using state of the art analytical and characterisation techniques. The Action aims to build strong links with Cost Action FP0901 ("Analytical Techniques for biorefineries") and COST Action FP0802: (Experimental and Computational Micro-Characterisation Techniques in Wood Mechanics) to ensure efficient transfer of knowledge and to build on what has being done to date.

Models of microfibril and cell wall structure will be related to the mechanical properties of the cell. As an example, recent insights into cellulose structure offers new knowledge to support the development of improved models to predict wood, pulp and paper and other wood based materials properties. It appears that the existing model of a highly oriented S2 layer and its impact on issues such as wood strength, stability and creep needs a re-think. Work is required to develop new mechanical models to reflect newly reported fractal structures and better understand the role of the micro fibril and the different cell layers on structural performance of the cell. This understanding is important if we are to manufacture different potential end products (of the best quality) in the most efficient and effective manner. Specific areas of work proposed include:

1. Development of Finite Element Models of micro-fibrils and whole cell structures.

2. Modelling fibre interactions in pulp from first principles to improve understanding of factors that determine the structural performance of the cell in products such as pulp and paper

3. Sharing macro, micro and nano-scale testing techniques for micro-fibrils and cells to validate models. Recently finished cost action E54 (Characterisation of the Fine Structure and Properties of Papermaking Fibres Using New Technologies) and an ongoing COST Action (FP0802; Experimental and Computational Micro-characterisation Techniques in Wood Mechanics) has played an important role in creating an established network of competencies that this new Action will build on.

Scientific area 2: Fibre processing

This area of research will involve two key components.

1. Focus on the impact of different processes such as conventional pulping (chemical, mechanical and recycling) and non-conventional processes (such as acid hydrolysis, enzymatic and thermal treatment) on cell wall structure and biopolymer composition and to use this knowledge to support improvement in existing forest products processes. The Action will also explore how phenomena such as pulping, bleaching and recycling (which leads to hornification), impact on cell wall structure and biopolymer composition and interactions and subsequently on end product characteristics. Characterisation methods and tools used in Scientific area 1 will provide valuable information for this section particularly for the characterization of materials after processing. Other useful methods would include the utilization of techniques that quantify the surface chemistry of fibers including X-ray photoelectron spectroscopy and the surface topography of fibers after conventional and non-conventional pulping processes such as atomic force microscopy. It is anticipated that this work will have practical application, supporting our understanding of how to improve these processes through mitigation of any negative impacts. This will involve close collaboration between theoretical studies and applied studies to be investigated by pulp and paper scientists.

2. Development of new and more efficient mechanisms to take a fibre wall apart. This is expected to incorporate mechanical, chemical and enzymatic approaches to fibre wall disintegration, taking into account new knowledge of cell wall structure and composition. The state of the art techniques listed at the end of this section will yield useful information, to establish a knowledgebase of the biopolymer interaction within the cell wall and serve as support for the subsequent work on development of new and existing mechanisms for breakdown of cell wall components. Mechanical processes will include micro and nano-fibrilation and potential pre-treatment processes to enhance the disintegration processes. Chemical processes will include acid hydrolysis, disolution in ionic liquids, supercritical fluids and other state of the art approaches to be determined.

Enzymatic approaches to fibre wall disintegration are at least partially addressed under COST Action FP0602 **"**Biotechnology for lignocellulose biorefineries" and close links will be developed with this Action.

Scientific area 3. Use knowledge of physical self assembly processes to develop new biopolymer based materials.

Materials scientists are currently focused on understanding and mimicking biological processes. Many biological systems may well turn out to be purely physical processes. Understanding how these systems work could lead to new insights into the development of self-assembly processes at molecular, nano-meter and macro scales. The focus would be on the use of plant cell wall biopolymers (cellulose nano-fibrils, amorphous polysaccharides, and lignin) as a platform for the manufacture of new materials. One component of the work will involve determining the viscoelastic characteristics of fibers including thermal testing using differential scanning calorimetry (DSC) and dynamic mechanical thermal analysis (DMTA) to determine the influence of cell wall organization and the composition of lignin, cellulose and hemicellulose on the macroscopic cell wall properties.

Within this area, extensive characterization of the anticipated self-assembled bio-polymers will be required. Techniques include those listed in addition to gel permeation chromatography for the various polymeric fractions in order to evaluate the molecular weight and polydispersity of the lignin and carbohydrate based fractions isolated from fibers to understand the effects of heterogeneity of cell wall biopolymers on end product quality. The mechanics of anticipated polymers should also be investigated through dynamic mechanical analysis. Other tests should be related to final material properties, such as for example rheology, strength properties, barrier capabilities etc.

Initial work in this area will focus on reviewing and evaluating existing self assembly processes at all scales from molecular to macro scales. Ongoing work will be closely linked to Scientific area 1. Joint workshops will be required to develop an appropriate work programme and a set of research proposals to fund ongoing development work.

Methods and instruments

The methods and instruments that will be employed in this Action will include:

- Microscopic methods: Field Emission Scanning Electron Microscopy (FE-SEM), Transmission Electron Microscopy (TEM), Transmission Light Microscopy, Reflected Light Microscopy, Atomic Force Microscopy, Scanning Acoustic Microscope (SAM)
- Spectroscopic methods: Solid-state 13C Nuclear Magnetic Resonance (NMR).

Biochemical analysis methods: High-Performance Liquid Chromatography (HPLC), molecular biological methods, immunolabelling. There will be a review of methods in this area including the development of tools using enzymes to probe wood structure and composition. These tools can assist in discovery of the accessibility of polysaccharides and their fine structure, which influences their interactions with other components.

- X-ray scanning techniques: Small-angle X-Ray Scattering (SAXS), Wide-Angle X-Ray Scattering (WAXS), Synchrotron
- Moisture related equipment: Dynamic Vapour Sorption (DVS)
- Computational methods: Finite Element Analysis, homogenisation, Molecular Dynamics, Computational Molecular Kinetics, material point method (MPM).
- Mechanical characterisation techniques: "Small clear test and micromechanics testing devices", Digital image correlation (DIC), Video Extensometry and a range of custom developed nano-scale devices for mechanical testing of cellulose nano-fibrils.
- In addition to the methods described above, various methods that could be useful here include more simplistic yet informative measurements including the fiber quality analysis (for fiber size), water retention value measurement as an estimate of hydrophilicity, Simons staining and pulp viscosity as an estimate of cellulose degree of polymerization.

This list contains the equipment that is currently available at the participating institutes. It will be updated and amended in the course of the Action according to new acquisitions of current partners and to the equipment of new partners in the Action

E. ORGANISATION

E.1 Coordination and organisation

The Action will bring together expertise and resources of its partners. In order to organize the activities of the Action, it is led by a Management Committee, supported by a Steering Committee. The Steering Committee consists of the Chair and Vice-chair of the Action and the Working Group leaders and co-leaders. The Steering Committee prepares Management Committee meetings, monitors the activities of the Working Groups between Management Committee meetings and facilitates coordination and outreach among the Working Groups. Regular meetings of Steering Committee, individual Working Groups and biannual meetings of all Working Groups together will ensure coherence across Working Groups. The Steering Committee will also act as the assessment panel for Short-Term Scientific Missions and facilitate the development of proposals to integrate competencies and different disciplines to address specific areas of research. The Action will target National research councils with an emphasis on European wide collaboration. The Action will also consider European framework proposals and Marie Curie fellowships to support the development of early stage researchers.

As outlined, three working Groups will be established, each with a Working Group leader and co-leader. These will be elected at the kick-off meeting of the Management Committee, although not restricted to the participants of the kick-off meeting. Working Groups will start working after the first workshop. If required, external experts will be invited to some of the WG meetings.

The effective interaction of the Action with the national and international research projects and networks will be ensured by pro-active promotion of the workshops, conferences and training schools as well as STSMs. It is planned that the workshops will be organized twice a year. At the same time all Working Groups will have meetings in parallel. Two workshops will be arranged in the form of open conferences with invited plenary presentations. The Action has several multidisciplinary aspects, so it is supposed necessary to hold an Exploratory Workshop in the second half of the year two, about half time through the Action.

The principal publicity tool for dissemination and documentation will be the Action specific website. This will be regularly updated, once a month as a minimum, in order to serve the needs of the participants. Also a private interactive website will be arranged for exchange of the preliminary and unpublished results by Action participants.

E.2 Working Groups

Three working groups will be formed according to the principle scientific areas described in section D2. This section provides more detail on activities within the different areas of focus.

Working Group 1: Understanding cell wall structure, biopolymer composition and polymer interactions and their impact on cell wall properties.

Working Group 2: Fibre processing

Working Group 3: Use knowledge of physical self assembly processes to develop new biopolymer based materials.

Research communities for these areas already exist and can be easily integrated into the working groups. This will facilitate and accelerate the establishment of efficient communication channels and research networks in the Action. Subordinate task groups may be set up during the life span of the Action related to specific scientific or technical issues. Also the further subdivision of a working group or the introduction of an additional working group will be considered if it turns out to be necessary or reasonable in the course of the Action.

E.3 Liaison and interaction with other research programmes

A key role of the Action will be to collate, assess and share existing expertise from ongoing research initiatives including national, European and institution specific activities. It is planned that this will include presentations from representatives of all interconnected current cost actions so that we can build on existing European networks and research activities. The first workshop will focus on presenting and collating this information and the production of a web based document summarising past, current and ongoing research activities amongst the participants within the COST Action.

E.4 Gender balance and involvement of early-stage researchers

The Action will provide focussed support for the development of early-stage researchers by facilitating the development of both specific and multidisciplinary proposals at National (Research Council) and European (FP7, Eranet and Marie Curie)level. The Action will also actively seek funding for PhD and Post Doctoral research projects outside of these funding sources. The over arching goal of the Action is to build new capacity. The Action offers the opportunity to attract a new cohort of young scientists. In all activities, it will be committed to supporting gender balance.

F. TIMETABLE

The Action is planned for four years. The Action website will be active from the beginning of the second quarter of year one. It will be used as the information and communication platform to all researchers and general public interested in the activities of the Action. After the first Workshop the website with a password will be arranged for internal use among the Action's participants (unpublished and preliminary results, etc.). An Action brochure will be produced and disseminated during year 1 and 3, with a COST Action book produced at the end of the Action.

The WG's will have their first formal meeting during the first Action's Workshop and before the second meeting of the MC. The Working Groups are planned to run in parallel over four years. Each WG's outputs will be released at the end of the year and presented in Action's Workshops and Conferences. Workshops will be held twice a year. It is planned that two Conferences will be organised instead of Workshops during the Action's lifetime, preferably at the end of year two and year four. A cross working group workshop is planned with an aim to share knowledge and deliberate the factors which influence the wood cell formation and properties. The Action's publication base will be launched in year two.

Key events and milestones of the Action are listed below

Proposals will be submitted to a range of funding sources depending on the proposed activities. One of the outputs from each workshop will be identification of potential funding sources for research funding applications. A number of STM's have been proposed. However, the total number will be dependant upon the amount of funding available. A key milestone common to all working groups will be annual report on progress, which will be collated into an annual report on the Action. Across the Action a summer school will be held during year 2,3 and 4. At the end of year 1 a coordinated research road map will be published that identifies :

- New research areas
- Shows how the activities of the different working groups can most effectively integrate and support one another
- Identifies research opportunities

A number of research proposals will be prepared within the different working groups. Where possible these will be integrated to form larger multidisciplinary proposals.

Specific Working group events and milestones include the following :

WG1 "Understanding cell wall structure and composition"

Theoretical physics

•Bi-annual workshops on theoretical role of physics on cell and microfibril structure

•Joint research proposals to develop modelling of cell structures from first principles (18 months).

•2 Marie Curie proposals at 18 and 24 months

•Start 3 PhD students at month 6 and 12 and 18

Genetics vs. physics

• Bi-annual workshops on role of genetics and biological processes vs. physics in defining cell wall structure and composition.

•Joint proposals to address this issue at 24 months

•1 STM per year

•Marie Curie proposal at 18 and 36 months

•PhD students starting at 12 at 24 months

•Paper on state of the art understanding on Genetics vs. physics at 24 months

Analytical techniques

• Bi-annual Workshops to review collective knowledge to characterize structure and composition of the cell wall.

•Joint proposals to develop/refine analytical techniques (18 months)

•1 STM/year

•Summer School in year 2, 3 and 4

•Marie Curie proposal 18 months

•1 PhD students at 12 months

Materials testing

•Bi-annual workshops to share best practice on testing of nano-fibrils, cells and hand sheets to validate theoretical models

•Report on state of the art at 18 months

•1 STM per year

•1 Marie Curie proposal at 18 months

Microscopy techniques

•Review document on state of the art to characterize the structure of micro-fibrils and the cellulose skeleton of the cell wall (End of year 1) Review to include current limitations and future potential

•Preparation of Joint research proposals to develop/refine microscopy techniques (18 months)

•Summer school in year 2,3 and 4

•1 Marie Curie proposal at 18 months

WG2 "Implications for current products"

• Bi-annual workshops to share knowledge of impact of current processes including pulping, bleaching, recycling on cell wall composition and impacts on downstream products

•Workshop and report at 12 months to specifically identify opportunities to improve current processes and develop research strategy

•Joint research proposals to explore potential to improve existing processes and products (18 months)

•Marie Curie proposals at 24 and 36 months

Cell wall disintegration

•Bi-annual workshops to share best practice on cell wall disintegration

•Annual progress report

•Joint proposal development at 12 months

•1 STM per year

•Marie Curie Proposals at 12 and 24 months

WG3 "Self assembly"

•Share state of the art knowledge on self-assembly processes

•Documented review of state of the art in self-assembly processes across a broad range of disciplines at 18 months, 36 months and in COST Action book.

•Development of a research strategy for investigation and development of self-assembly processes (work shop at 18 months)

•Joint research proposals to national research councils at 24 and 36 months

•Marie Curie proposals at 12 and 24 months

•1 STM per year

2 PhD students at 12 and 24 months

Summary of milestones and events.

Milestones/Events	**1st Year**				**2nd Year**				**3rd Year**				**4th Year**			
MC Meetings	**x**	**x**		**x**		**x**		**x**		**x**		**x**		**x**		**x**
Workshops/Conferences		**x**		**x**		**x**		**x**		**x**		**x**		**x**		**x**
Exploratory Workshop							**x**									
WGs Meetings		**x**		**x**		**x**		**x**		**x**		**x**		**x**		**x**
SG Meetings		**x**		**x**		**x**		**x**		**x**		**x**		**x**	**x**	
Summer training schools					**x**				**x**				**x**			
Set up of Task Groups/ Meetings of TG					**x**			**x**			**x**		**x**		**x**	
Publicity Brochure of the Action			**x**						**x**							
Website set up		**x**														
Website update			**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Co-ordinated Research Roadmap				**x**												
Update Roadmap									**x**							
STM				**5**				**5**				**5**				**5**
Res Proposals WG1							**3**		**1**			**1**				
Res Proposals WG2					**1**		**1**									
Res Proposals WG3									**1**			**1**				
Marie Curie proposals					**2**		**6**		**5**			**2**				
PhD starts			**1**		**3**		**1**		**2**							
Interim reports				**x**			**x**					**x**				
Action Annual reports				**x**				**x**				**x**				**x**
Book																**x**

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, DE, EL, ES, FI, FR, HR, HU, IT, LV, NO, PT, RO, SE, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 60 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The primary dissemination tools between the partners will be the **WG meetings**, **annual workshops** as well as a **web-site** established by the Action**.** The need to establish a restricted area, only accessible for Action members will be considered. The public area of the web-site will contain newsletters, information of WG activities and general information on coming events.

Scientific and technical knowledge coming out of the COST Action will be presented in **International Conferences** in order to promote the European know-how and expertise in the area.

The major events of the Action will be two workshops per year, to which key international experts in the field will be invited as speakers, when appropriate. Original research results generated through the Action will be published in **international peer-reviewed journals** as joint papers between the participating universities or institutes.

Given the wide-reaching implications associated with the activities within the COST Action, there will be a wide Primary target audience for dissemination, typically:

• the network partners,
• other researchers in the field (outside the COST Action),
• research institutes and academic units (in related fields),

• stakeholders from industry (forest products industry and paper industry as well as chemical companies and equipment manufacturers),
• Relevant European and national associations and confederations
• the general public.

H.2 What?

The Steering Committee (SC) will make efforts to disseminate the objectives and progress of the COST Action not only to the participants, but also to the wider scientific community and to the public. The MC will ensure the organization of WG meetings, workshops, and scientific conferences. The conferences, which will allow the congregation of academic and industrial researchers to discuss the progress achieved to date, will be an important place for dissemination. These conferences will also facilitate communication on a personal level between researchers from different communities, thereby enhancing creativity and problem-solving ability of the participants. It is anticipated that this intellectual collaboration results in new developments key to furthering the objectives of the Action.

Other more conventional methods of dissemination will be enacted and promoted by the MC, including publications in peer-reviewed journals and presentations at international conferences and workshops. The MC will particularly support papers co-authored by various research groups at these conferences. Furthermore, the proceedings of the workshops and conferences of the Action and a COST Action Book at the end of the Action will be prepared and made available electronically on the Action's website. COST will be acknowledged for its support in publications associated with research performed under this Action.

The Internet will be the most valuable tool of all dissemination methods, as it is very flexible and accessible to a large audience. The Website Manager will develop the website and ensure its maintenance, as well as updating the site as information about events and meetings becomes available. The public domain of the website will include a 'static' section about the Action that covers:

1. general information on the Action's programme and objectives,

2. basic information on participating groups (contact person, available equipment, scientific focus and expertise, current and optionally completed research projects) with a link to the group's website,
3. information and forms to be used for STSM applications,
4. information for scientists willing to join the Action,

and a 'dynamic' section with

1. up-to-date timetables of the Action activities (planned conferences and meetings, etc.),
2. information on recent scientific and technical achievements and related links,
3. full technical presentations given at meetings/workshops,
4. electronic reports of past activities and achievements.

Some of the sections envisaged within the dynamic section of the website will be within a password-protected domain to allow access to internal parties of the Action to post draft reports and publications. This system will also facilitate the rapid and efficient transfer of documents between researchers and other participants of the Action.
In order to enhance the reach and accessibility of the website, links will be established on the website, along with other related sites which relevant parties—such as researchers, industry stakeholders, and policy makers—would be anticipated to frequently visit.

H.3 How?

The website will feature extensive information concerning the Action, including its research agenda, activities, reports, and publications. It will be kept up-to-date to inform the public about meetings, conferences, Training Schools, and past and upcoming events, not only within the COST Action but in related subjects. Particular care will be made by the Website Manager to ensure the accuracy and availability of the most current information on the website. Furthermore, once the Action is completed, the website will remain open and the information available.

The scientific conferences will be of great importance to reach a broad audience and to increase the external visibility and publicity of the Action. The MC will finalize the details regarding the activities and publications of the Action, and a Dissemination Group will be nominated in the early phase of the initiative and held responsible for the development and maintenance of all methods of dissemination.