European Cooperation in the field of Scientific and Technical Research - COST -

Secretariat

Brussels, 14 December 2009

COST 277/09

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action TD0906: Biological adhesives: from biology to biomimetics

Delegations will find attached the Memorandum of Understanding for COST Action TD0906 as approved by the COST Committee of Senior Officials (CSO) at its 176th meeting on 1 December 2009.

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

COST Action TD0906
BIOLOGICAL ADHESIVES: FROM BIOLOGY TO BIOMIMETICS

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 270/07 "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 through the use of a multidisciplinary biomimetic approach to study structures, functions and principles of natural models in order to bring new bio-inspired adhesives to the market.

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 36 million in 2009 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

Biological adhesives often offer impressive performance in their natural context and, therewith, the potential to inspire novel, superior industrial adhesives for an increasing variety of high-tech applications. Using an iterative, multidisciplinary biomimetic approach, structures, functions and principles of natural models can be experimentally studied, theoretically analyzed and prototyped in order to bring innovative bio-inspired adhesives to the market. The COST Action will unite widespread and diverse European expertise in the fields of biological and technological adhesives (biology, physics, chemistry, and engineering), streamlining and pooling knowledge, methods and techniques, avoiding duplication of effort, decreasing costs, and accelerating scientific and technological progress in Europe.
Keywords: Adhesion, Bio-inspired adhesives, Organismal attachment, Bio-Hybrid Polymers, Biomimetics

B. BACKGROUND

B.1 General background

Considering the ever-increasing variety of new products comprising diverse combinations of materials, and current trends towards miniaturization in certain industrial branches, adhesive technology is challenged by the following requirements: (1) an increase in the reliability of adhesive bonds, (2) development of environmentally-friendly glues, and (3) development of mechanisms for the application of minute quantities of glue or a defined layer to a surface. An additional challenge is the use of novel substances, which (1) are reuseable, allowing multiple attachments and detachments, and (2) enable attachment to a variety of surfaces including those in aquatic or other fluid environments for a broad variety of applications.

Many biological adhesives fulfil at least some of these requirements, thereby demonstrating impressive performance and inspiration for potential solutions to technical problems. Generally, biological adhesives are functional systems, with the purpose of attachment, either temporary or permanent, of an organism to a surface. Many organisms, ranging from microscopic bacteria and fungi through much larger marine algae, invertebrates and terrestrial vertebrates, use adhesive polymers for this purpose. The performance of these adhesives can be remarkable and their diversity suggests the potential for development of glues that are markedly different from those currently available. These bio-inspired adhesives will provide more elegant solutions to contemporary engineering and biomedical adhesive requirements and will additionally provide a platform for future technological innovation that requires adhesion in hostile conditions as a prerequisite. However, our knowledge of natural adhesive systems remains distant from the engineering of innovative adhesives for specific industrial, surgical and medical needs. In order to reach this goal, an iterative biomimetic approach is needed, which requires a broad, intensive knowledge exchange and close, multidisciplinary collaboration (biology, material science, chemistry and technology) on all aspects of bioadhesion.

Due to the nature of the topic, it is imperative that an interdisciplinary approach is adopted. The aim of this Action is not to further the research of individual partners in isolation, but rather to draw on their experience, expertise, facilities and support collectively. Through cooperation and shared expertise, a fuller understanding of bioadhesives and ideas for their practical development will be forthcoming. Indeed, it is unlikely, given the cross-disciplinary nature of bioadhesives research, that any one collaborating research group will possess the resources to tackle this project alone. Instead, in the COST action network, each partner is able to make the best possible contribution to the research as a whole. To this end, the present Action unites recognized experts in the fields of biology, biophysics, chemistry and biomedical/chemical engineering towards a shared goal; the development of a new generation of bioinspired adhesives. By facilitating knowledge transfer, research visits and easy access to a wide variety of facilities, techniques and expertise not previously available to individual partners, the COST Action will prove the most effective route for moving this research forward. In addition to its direct facilitation of the research described, the COST Action will also allow fruitful networking and discussion of novel directions for the research, thereby acting as a springboard for future work and collaborative funding applications.

B.2 Current state of knowledge

Biomimetics is a relatively new science that studies nature's models and then imitates or takes inspiration from these designs and processes to develop new technological applications or new biomaterials (Benyus 1997, Forbes 2005, Nosonovsky and Bhushan 2009). Of all the biological phenomena that have been investigated with a view to biomimetics, adhesion in nature is perhaps one of the most promising ones, because recent advances in surface engineering and nanotechnology have made available a wide range of applicable research tools and fabrication techniques. These techniques allow the synthesis of biomimetic adhesive structures at the micro- and nanoscale, drawing increasingly closer to their biological models. The first generation of biomimetic fibrillar dry-adhesives, inspired by the foot hairs of geckos, have been highly successful and promise significant advances for adhesion technology. However, progress in the development of bio-inspired adhesives has been otherwise limited, remaining confined to gecko-like models while an enormous diversity of structures and principles used in biological adhesives remain unexplored. This is because, unlike most artificial adhesives, biological adhesives can be remarkably complex, involving a wide range of interactions and components with different functions. While this complexity can be daunting for researchers, its understanding will be essential for the design of improved biomimetic adhesives and will also allow a great deal of flexibility in applications. Simplification of natural systems while retaining the desired efficacy is, indeed, one of the foundation stones of biomimetics.

From the biologists' perspective, attachment devices may serve one or more of the following functions: (1) temporary attachment of body parts together; (2) attachment of one organism to another (e.g. copulation, phoresy, parasitism, epibiosis or prey capture); and (3) attachment of an organism to a non-living surface, including dynamic attachment during locomotion and maintenance of position (Gorb 2008). The evolutionary background and biology of the species, on one hand, and environmental constraints on the other hand, both influence the specific design and function of attachment systems in a particular organism. The diversity of biological attachment devices is therefore huge, but there can be no doubt that some highly successful functional solutions have evolved independently in different biological lineages (Federle 2006, Barnes 2007). Terrestrial animals that climb on plants, rocks or other types of unpredictable substrata have evolved adhesive organs on their feet. Despite the wide diversity of animals using adhesion and the variety of structures employed, adhesive organs come in only two basic designs: (1) pads densely covered with specialised, µm- or nm-sized setae, or (2) pads with a relatively smooth surface profile (Federle 2006, Creton and Gorb 2007). Due to the flexibility of the material of the attachment structures, both mechanisms can maximise the possible contact with the substratum, regardless of microstructure. Some of these attachment pads are supplemented by various kinds of fluid (wet adhesion) (Federle et al. 2002), and some not (dry adhesion) (Huber et al., 2005). Flies, beetles, large spiders, and gekkonid lizards, have feet possessing adhesive organs of the hairy type, while tree frogs, bees and grasshoppers have adhesive organs of the smooth type (Creton and Gorb 2007). Successful negotiation of natural surfaces makes a number of demands on these animals' adhesive systems (Peattie 2009). First, they need to be reusable, enabling the animal to attach and detach its feet quickly and repeatedly. The structures must also be both self-cleaning and wear-resistant (e.g. Hansen and Autumn 2005). They must be reversible, so that detachment can occur at will with negligible force (e.g. Gravish et al. 2008) and they need to be substrate tolerant, so that adhesion and, thus, locomotion is possible on a wide variety of different surfaces. Finally, they should have a non-sticky default state so that adhesion only occurs when it is required (e.g. Autumn and Hansen, 2006). All of the above features are common in climbing animals and are desirable properties for new smart adhesives. Of the two types of structure, the hairy pad is the one that has been studied the most extensively, and the gecko foot has become a model system.

The situation is rather different in the aquatic environment, especially in the sea. Because of the density of water, shear forces in the marine environment are much stronger than on land. They are also directionally unpredictable, requiring adhesion systems that are sturdy in all directions. In the marine environment, attachment devices developed by animals usually rely on highly viscous or solid adhesive secretions (Smith and Callow 2006). These adhesive secretions contain specialized adhesive proteins, sometimes associated with other macromolecules such as polysaccharides (Smith and Callow 2006). Functional convergences are also noted among marine animals, particularly in terms of the type of adhesion used, permanent or temporary (Flammang 2006). Permanent adhesion is characteristic of sessile organisms that attach strongly to a substratum by adhesives that are secreted as a fluid which then gradually solidify to form a cement possessing high adhesive and cohesive strength (*e.g.*, mussels, barnacles and tube-dwelling worms). Temporary adhesion occurs in those benthic animals that attach themselves strongly, but only temporarily, to the substratum through visco-elastic secretions and therefore retain the capacity to move (*e.g.*, limpets, sea stars) (Walker 1987, Flammang 2006). Although little information is available about marine adhesive proteins, molecular convergences have been recognized, and some adhesive motifs have been found to be shared by phylogenetically different organisms.

The above examples indicate that here has been considerable convergent evolution between organisms using different types of adhesives, suggestive of an optimal design for each system. This finding has led scientists to consider practical applications for these mechanisms even if their details remain complex and difficult to reproduce artificially. Two model systems have inspired most biomimetic approaches: the gecko foot for dry adhesion and the mussel glue for underwater adhesion. Other organisms such as tree frogs, insects, tubeworms and algae are subsequently emerging as interesting models. During the last few years, several groups worldwide have made good progress in developing biologically inspired patterned adhesives, which mimic the geometry of biological hairy systems at different scales (Geim et al. 2003, Peressadko and Gorb 2004, Crosby et al. 2005, Northen and Turner 2005, Glassmaker et al. 2007, Qu et al. 2008, Parness et al. 2009). Patterned surfaces usually have significantly higher adhesion on a smooth surface than a smooth sample made out of the same material (Nosonovsky and Bhushan 2009). An additional advantage of patterned surfaces is the reliability of contact on various surface profiles and the increased tolerance to defects of individual contacts. Materials used to make these mimics are diverse, ranging from polydimethylsiloxane elastomers (PDMS) to carbon nanotubes. The best performance has been obtained for patterns more complex than the simple micropillar arrays, for example with mushroom-like contact elements (Kim and Sitti 2006, Glassmaker et al. 2007, Gorb et al. 2007, Davies et al. 2009). Adhesives with bio-inspired patterns have already been tested successfully on small robots, allowing them to climb vertical smooth walls, as well as on living tissues for medical applications (Daltorio et al. 2007, Mahdavi et al. 2008). Recently, the company Continental has developed a winter tyre with honeycomb profiles similar to those existing on the smooth attachment pads of grasshoppers and tree frogs (Barnes 2007). The most well-characterized marine adhesive is that from the mussel. Several proteins have been identified and characterized that co-occur as a complex blend in the glue of the mussel (Waite 2002). These proteins have been used in biotechnological applications in the form of (1) crude or recombinant preparations of the proteins, (2) chemically synthesized derived peptides, and (3) biomimetic synthetic polymers (Burzio et al. 1997, Lee et al. 2006, Hwang et al. 2007). Several imaginative applications have been developed for these bio-inspired adhesives, including, among others: tissue adhesives as sealants for medical, surgical and dental applications; enzyme, cell, and tissue-immobilizing agents; anticorrosive coatings and metal scavengers (Burzio *et al.*, 1997; Silverman and Roberto 2007). More recently, two other adhesives inspired by marine glues have been described: one mimicking a tubeworm adhesive (Shao et al. 2009), and the other an algal adhesive (Bitton and Bianco-Peled 2008). The latter finds its origin in a European joint research project (FP5, G5RD-CT-2001-00542).

Despite these advances, many technological challenges remain, e.g. the development of 'smart' adhesives which can be dynamically controlled (switchable adhesives) or which modify themselves to complement specific substrata (Fakley 2001, Reddy et al. 2007). Nonetheless, the huge diversity of biological adhesion mechanisms will continuously inspire material scientists and engineers to develop new materials and systems. That is why broad functional comparative studies on biological systems must be intensified, in order to extract essential structural, chemical and mechanical principles behind their functions as a base for further developments and implementations.

B.3 Reasons for the Action

Of all biological phenomena that have been investigated with a view to biomimetics, adhesion in nature has perhaps received the most interest. Yet, because of the complexity of this phenomenon and the multi-disciplinarity needed to tackle it, there has been little visible progress in the development of bio-inspired adhesives. This COST Action will immediately act as a catalyst for practical advances of recent research conducted separately in the field of biomimetic adhesives. Across Europe, there are many activities on biological adhesion in the biological, medical and materials science fields, attempting to understand biological adhesives and develop materials with similar properties. In different European countries, isolated work on biological and industrial adhesion is advancing rapidly as modern tools of analysis and measurement open up new perspectives for understanding the physico-chemical principles involved in adhesion from the molecular to the organism level. Since the variety of topics in bioadhesion research (e.g., surfaces, structure, chemistry, friction, measurements, prototyping) requires a broad range of methods and techniques (which cannot be developed completely even in the best single laboratory), it is necessary to pool knowledge, methods, and techniques together, as well as to enable an intellectual and practical exchange. Thus, the combination of various disciplines has to be intensified and streamlined for faster and cheaper technical progress. The COST Action is considered to be the most appropriate way of networking to facilitate cooperation between academic partners and technology transfer towards industrial partners in Europe.

New adhesive technologies will open up new exciting opportunities of development, especially for SME´s and spin offs. Although European academic laboratories are at the leading edge for the study of biological adhesives, Europe is lagging behind the USA and Asia in terms of technology transfer. It is therefore not surprising that the few commercial bio-inspired adhesives developed to date are being produced and marketed by non-European companies. The COST network will support European SME´s, ensuring that they have the highest level of scientific know-how available for fast and efficient product development in the global race to exploit this vast market potential. The expertise from leading European scientists and engineers in combination with the experience of industrial companies will ensure a rapid and efficient transfer of knowledge and know-how to marketable innovations. Therefore, the COST Action will address both the economical/societal as well as scientific/technical needs of the European society.

B.4 Complementarity with other research programmes

The COST Action is complementary to a number of national research activities on biological adhesives and their applications. At the European level, two projects have also been launched recently, the EBioAdI project on dry adhesives (ESF, EUROCORES Programme), and the Blue4Glue project on marine adhesives (EU, Marie Curie Industry-Academia Partnerships and Pathways Programme), both of which involve groups at the centre of this Action. However, the topics in these national and Europe-wide research projects are focussed on specific model organisms or on defined applications of biomimetic adhesives. On the contrary, the COST Action is unique in the sense that it will give the opportunity for a Europe-wide networking and exchange of information regardless of experimental models and technical applications. The Action offers the best strategic platform to promote integrated trans-disciplinary projects and to avoid duplication of effort in Europe. Its advantage compared to other EU research programmes lies in its flexible and open nature, allowing new teams to join the ongoing Action and new avenues of research to be explored as the knowledge base grows dynamically.

C. OBJECTIVES AND BENEFITS

C.1 Main/primary objectives

The main objective of the Action is to gain new understanding relating to the mode of action of biological adhesives so as to facilitate the development of synthetic counterparts with improved efficacy. This objective necessitates (1) the characterization of many different biological adhesives, (2) the screening of their effective principles and where these converge, as well as (3) the engineering of biomimetic surfaces or materials with superior adhesive performances, and (4) their evaluation.

C.2 Secondary objectives

Secondary objectives are:

- the establishment of a scientific network platform stimulating communication and collaboration between European researchers in the field of bioadhesion;
- the pooling together of resources, in particular methods and analytical techniques found in the different laboratories;
- the training of young researchers by cross-cutting exposure to all aspects of bioadhesion;
- the development of novel methods in adhesive technology and the standardization of existing methods;
- the increase in technology transfer through improvement of communication between scientific and industrial partners;
- the interdisciplinary cooperation between diverse disciplines, some of whom are not normally engaged in specific bioadhesion research and who would not normally be able to work together in this field.

From a quantitative point of view the achievement of these specific objectives can be evaluated by the following parameters:

- number of transnational collaborative research proposals prepared;
- number of groups and companies participating actively in the network;
- number of presentations, publications and patents originating from collaborative research, the latter representing experimental achievements generated in the COST Action which can be transferred to SME's for further commercial exploitation;
- number of short term scientific missions supported by the Action;
- number of training activities and number of people trained.

C.3 How will the objectives be achieved?

Members of this Action will provide all the resources and infrastructure (the personnel and the equipment) to build the critical mass needed to achieve its objectives. Active links will be established between European research groups with various scientific backgrounds working in the field of bioadhesion and related applications, in order to build scientific excellence in this field. The mechanisms of COST will be used in order to assure the full exploitation of the potential available from the member research teams. Thus interactions among the partners will be implemented by:

- Management Committee meetings (2 per year).
- Working Group meetings (1 per year/WG). By initiating specific focus groups (WG1: Chemical characterization and synthesis of adhesives, WG2: Structural characterization of natural and synthetic adhesives, WG3: Mechanical testing and theory, WG4: Fabrication of bio-inspired adhesives and their evaluation), the communication progress and technological transfer is facilitated. Each researcher or expert can participate in one or several WGs.

- Training Workshops. A seminar series (training workshop) on the fundamentals of bioadhesion will be arranged with the purpose of introducing new graduate students, post-doctoral fellows and non-specialists into the field. This will be widely announced in order to reach scientists from different disciplines. Training workshops for early-stage researchers will also be set up on specific topics like new groundbreaking technologies or standardization of measurement methods. Training in intellectual property issues will also be offered as most young scientists are not aware of the issues involved in developing ideas that have substantial economic implications.
- Short Term Scientific Missions (as many as possible). Technical training, in which especially young researchers are involved, will be carried out by visiting host laboratories for certain periods of time. STSM will take place horizontally by involving partners within each WG, working on different model objects in a similar discipline, but above all vertically, across disciplines between WGs.
- Annual conferences (1 per year)**.** No specific meetings on biological adhesives and biomimetics have taken place to date at a European level, so the proposed COST Action will provide an opportunity to build a strong scientific community centered on bioadhesives. The high quality, interactive Gordon Research Conferences (www.grc.org) will be used as a model for the conferences.
- Website. A Bioadhesion website will be created and regularly updated with information material prepared and distributed by the different partners.

C.4 Benefits of the Action

The Action will allow its members to gain improved access to the results obtained in individual laboratories and to the methods developed by the partners, thus improving the efficacy of the research of individual groups. The Action will also provide to its members, especially young scientists, additional means to spread their results to a broad scientific forum as well as specialized industry and the general public.

Ultimately, the knowledge generated by research projects in this COST Action should meet the current scientific and technological challenge of developing a new generation of adhesives for various applications (e.g. reversible pressure sensitive adhesives or adhesives working in an aqueous environment). The long-term outcome of breakthroughs and advances in this technology will be commercial benefits and increased competitiveness for European industry, affecting many fields, such as the automotive industry, medicine, micro/nano-technology, robotics, etc. A further fundamental benefit of biomimetic adhesives will be their environmentally-friendly features: biological adhesives contain neither toxic components nor volatile organic compounds, and are therefore safer to produce, use and dispose of; some biological adhesive systems also have the potential to be reversible and recyclable.

In summary, the COST Action will stimulate European cooperation, concentrate the knowledge, accelerate research progress and technology transfer, and create valuable input from and into nationally funded projects for European industry.

C.5 Target groups/end users

The target groups will be the university and research laboratories in the field of biological adhesion and biomimetic adhesives, as well as recognized experts in relevant fields outwith these disciplines, within Europe. The end users of the knowledge generated will be mainly SMEs, start up and spin off/out companies.

Target groups identified include:

a) General Scientific Groups:

- Microbiology (tubing and processes in food industry, water purification and waste water plants, oral cavity)
- Pharmacology (mucoadhesive drug development)
- Cell biology (cell attachment to biomaterials, tissue engineering)
- Biotechnology, including marine (blue) biotechnology
- Marine antifouling (anti-adhesive coating development)

b) Research Societies

- the Adhesion Society (AS)
- the Society for Adhesion and Adhesives (SAA)
- European Society for Biomaterials (ESB)
- European Society for Marine Biotechnology (ESMB)
- Tissue Engineering and Regenerative Medicine International Society (TERMIS)
- British Society for the Study of Prosthetic Dentistry (BSSPD)

c) Industry (especially SME's)

- Adhesive producers
- Biomaterial and biomedical device manufactures
- Coating industry
- Dental materials industry
- Product design/manufacturing processes

d) Public

- Foundations
- Health care institutions
- Schools
- Popular media

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The scientific programme is built around the objectives listed in section C. The COST Action is flexible enough to incorporate a variety of projects ranging from fundamental research on biological adhesives and innovative characterization methods up to processing and specific applications of biomimetic adhesives. All the projects carried out by the participating scientists and laboratories will be driven by the need to fulfil the primary objective of the COST Action.

Adhesives found in nature combine many inspiring properties such as sophisticated hierarchical organization, versatility, and adaptability. Thus, it is necessary to elucidate the basic components and building principles selected by evolution in order to propose more reliable, efficient and environmentally-friendly materials. Extensive scientific studies revealing the adhesion mechanisms of mussels, tubeworms, geckos, insects and algae have led to the successful development of biomimetic adhesive analogues. Yet, the huge potential of the biomimetic approach in the field of adhesives is far from being fully exploited. Nature offers a vast repository of inspiration in the form of organisms utilizing bioadhesives for a variety of functions. The challenge is to understand the mode of action of these systems, their unifying themes and function-specific adaptations, and to transform this knowledge into technology by developing new synthetic biomimetic adhesives with improved performance. In order to meet this challenge, this COST Action will coordinate two main research tasks: (1) the identification of potentially interesting bioadhesives and model organisms and their functional characterization, and (2) the fabrication of biomimetic adhesives with tailored properties and their evaluation in various applications. Because we are able to take an iterative approach, we will mimic, but also where possible simplify, the structures and materials we investigate to make commercialisation a realistic prospect.

1. Characterization of biological adhesives and adhesive mechanisms

Many organisms, ranging from microscopic bacteria and fungi, through macroscopic marine algae and invertebrates, to terrestrial vertebrates, use adhesive polymers. The diversity of biological adhesives is remarkable, and considerable convergent evolution between organisms must have occurred with optimal designs for each system. This task will involve broad systematic functional comparative studies on biological systems. Modern techniques will be used to extract essential structural, chemical and mechanical principles behind their functions.

2. Engineering of biomimetic systems and their evaluation

Newly discovered biological functions and principles will be analysed theoretically and transferred to models for understanding and abstraction in relation to the projected fabrication of biomimetic materials. Physical and chemical parameters will be defined and, if necessary, specific measurement methods will be developed. Wet adhesives will be produced through biotechnology or polymer chemistry. The fabrication of dry adhesives will require the synthesis (e.g., via self-assembly) of surfaces with nanostructured features, or production by lithographic techniques. Innovative designs will be tested by coupling key features from different biological models, and finally, successful developments of novel adhesives will be applied.

To complete these tasks, it will be necessary to bridge the gap between biology and engineering. Bringing together experts from different fields, intensive knowledge exchange addressing all aspects of bioadhesion, from biology, physics and chemistry to technology, and close multidisciplinary collaboration between research teams will enable the development of new adhesives.

D.2 Scientific work plan – methods and means

The course of Action is based on a value-added chain with many interactions. The scientific and technical objectives will be to review existing knowledge of adhesive systems; identify gaps in knowledge with respect to nature of adhesives employed by well-studied models; compare and contrast systems to identify unifying principles and function-specific adaptations (e.g. underwater adhesion), some of which can be merged for improved adhesive performance or new practical applications; identify possible new models based on industry requirements; fabricate innovative bio-inspired adhesives for specific technological applications. Four working groups (WG) have been designed to address these different objectives. However, to reach a maximal trans-disciplinary knowledge exchange, the scientific plans of the different WG intentionally overlap, and transversal interactions will be encouraged.

Work Group 1: Chemical characterization and synthesis of adhesives

This group will draw on the complementary expertise and facilities of members to isolate and characterise biological adhesives at both the biochemical and/or physico-chemical levels. The central tenet is to identify key features of adhesives that can be synthesised. Natural adhesives usually consist of complex blends of different biopolymers. Marine adhesives, for example are primarily composed of proteins and polysaccharides. The composition of the adhesive secretions will be initially determined using histo- and cytochemical techniques (including immunocytochemistry and lectin cytochemistry). Then, the biopolymers will be purified either from the adhesive directly, or from whole organisms, or dissected adhesive organs, fractionated into their different components which then will be characterized by biochemical analyses. Proteins will be identified by mass spectrometry-based proteomics. This same method will be used to characterize their post-translational modifications, such as phosphorylation, glycosylation or hydroxylation. These modifications are usually fundamental to the function of biological adhesives. Molecular techniques, including DNA and RNA extraction, PCR, cloning and sequencing, will be used to obtain the primary sequence of the adhesive proteins. Synthetic adhesives will be produced as recombinant proteins through expression techniques or as biopolymer mimics through polymer chemistry.

The establishment of the bond for biological adhesives starts with the adsorption of the adhesive biopolymers to the substrate. Subsequently, this may be followed by the formation of cohesive interactions with the next layer of adhesive biopolymers that are deposited/adsorbed on top of the first layer. These two fundamental processes for the adhesive build-up will be characterized by a range of surface analytical tools such as infrared ATR and Raman spectroscopies, atomic force microscopy, quartz crystal microbalance (QCM), imaging surface plasmon resonance (iSPR), and imaging ellipsometry.

Work Group 2: Structural characterization of natural and synthetic adhesives

Biological adhesives possess complex hierarchical structures from the micrometric to the nanometric scale. The structural organization of the adhesive is as important for its function as its chemical composition. Therefore, broad systematic functional comparative studies on biological systems using modern microscopy techniques will be carried out, in order to extract essential structural principles behind their functions. Natural and synthetic adhesives will be investigated by light microscopy, confocal microscopy, electron microscopy (both SEM and TEM), atomic force microscopy (AFM), and energy dispersive X-ray spectroscopy to gain understanding of their organization. The nanoscale imaging and nanomechanical measurements made in air and liquid with AFM, and other local mechanical tests used in WG 3 to characterize the material properties of adhesives (and their components) at each scale of organization, will further contribute towards the structural characterization focus of this WG.

Understanding adhesion and the interaction of adhesives with surfaces and interfaces requires an understanding of surface properties before, during and after spreading and/or curing of any adhesive. To this end, it is essential that surfaces used for testing are controlled and well-characterized. The surface sensitive methods used in WG 1 will also be applied here for the characterization of surface composition, structure, and dynamics. Marine adhesives pose particular challenges, partly because surface characterization needs to be conducted underwater, and also because surface properties are affected by immersion. Upon immersion in water, the properties of hard surfaces are changed substantially; for example through biofilm formation. However, surfaces or surface coatings may undergo solid-phase structural rearrangement and morphological changes on shorter timescales due to interactions with water or an adhesive, thus emphasising the importance of understanding the timescales involved in surface wetting/adhesion dynamics.

Work Group 3: Mechanical testing and theory

To understand the detailed function of biological adhesives, it is essential to characterize their adhesive and frictional performance, as well as their material properties and tribological interactions under standardised conditions. Biological attachment devices are typically hybrid systems consisting of complex mechanical units that are integrated with an adhesive system. The mechanical testing has to be performed at several levels, from the evaluation of the nanomechanical properties of the constituent biomolecules of the natural adhesives, to *in vivo* force measurements on microscopic and macroscopic whole organisms. To determine how some organisms control adhesive forces dynamically, their movements will be investigated. To allow comparisons between different adhesive systems (wet and dry, natural and synthetic), adhesion and friction forces will be measured under controlled conditions, in combination with optical techniques to monitor the adhesive contact. Attachment performance must be evaluated while varying a number of relevant experimental conditions such as surface energy and roughness, pulling and sliding velocity, pull-off or peeling direction, contact time, submersion and hydration.

The experimental data on the mechanical performance of adhesives will be used to test theoretical models of adhesion and friction. The models will help to identify new principles where natural systems show a different behaviour. Moreover, simplified models will also be the starting point for the design of synthesised adhesive systems. These will provide excellent physical models that can be used to test the predictions from theory.

Work Group 4: Fabrication of biomimetic adhesives and their evaluation

As understanding and predicting is not enough to engineer new adhesive systems, this WG is focused on the fabrication of biomimetic adhesives with the tailoring of the surface properties and control of those parameters that the theoretical models and the experiments have identified to be crucial in the adhesion process. The fabrication of patterned adhesives will require the synthesis and/or lithographic fabrication of surfaces with a controlled roughness or with nanostructured features such as thin pillars, bumps and domes regularly spaced to form a matrix. Innovative designs will be tested and evaluated by coupling key features from different biological models. For example, the physico-chemical properties of micro-fabricated surfaces will be further controlled by the addition of adsorbed thin polymer films (thicknesses ranging from 100 nm to 10 µm) inspired by other types of bioadhesives. To the best of our knowledge, there have been only two attempts to couple ‘dry’ and ‘wet’ adhesives in such a way, and the hybrid biomimetic adhesives presented superior performances for reversible attachment to a variety of surfaces in any environment (Lee et al. 2007, Glass et al. 2009).

The bio-inspired materials generated by this WG will meet the current scientific and technological challenge of developing a new generation of adhesives, in particular for the development of reversible pressure sensitive adhesives or of adhesives working in a fluid environment. Breakthroughs and advances in this technology would have a significant impact on the development of the following sectors: tyres in the transport and automotive industry; contact-based Micro-Electro-Mechanical Systems (MEMS); implants, adhesive bandages, sutures and drug delivering systems in the biomedical industry; denture retention systems in dentistry; labs-on-a-chip devices for the pharmaceutical and biotechnology industry; running and climbing robotic and microrobots; or coatings for the metal industry. The different biomimetic adhesives produced will be tested in these specific applications in collaboration with industrial partners.

E. ORGANISATION

E.1 Coordination and organisation

The research carried out by this Action is funded from various sources including national and trans-national organizations. The networking and connection of researchers in this Action will be coordinated through COST. Particular attention will be paid to developing trans-disciplinary links and to the training of young researchers.

The Action will be managed by the Management Committee (MC) that will be created according to the COST "Rules and Procedures" (COST 299/06). The Management Committee will be based on the nominations by the National COST Coordinators. This MC will be responsible for the strategic planning and coordination of the Action. It will manage all initiatives such as working group meetings, short-term scientific missions, training workshops and other matters that may arise during the term of the Action. A Chairperson, a Vice-Chairperson, four Working Group Coordinators and all other functions will be elected from the MC members at the Kick-off meeting to be held at the start of the Action. The MC will meet twice a year but may also decide on urgent matters by electronic communication (email). An Action Steering Group (ASG) composed of MC Chair and Vice-Chair and WG Coordinators may meet additionally (if required) between the regular MC meetings. This ASG will form as a central core of research teams acting as scientific drivers of the Action.

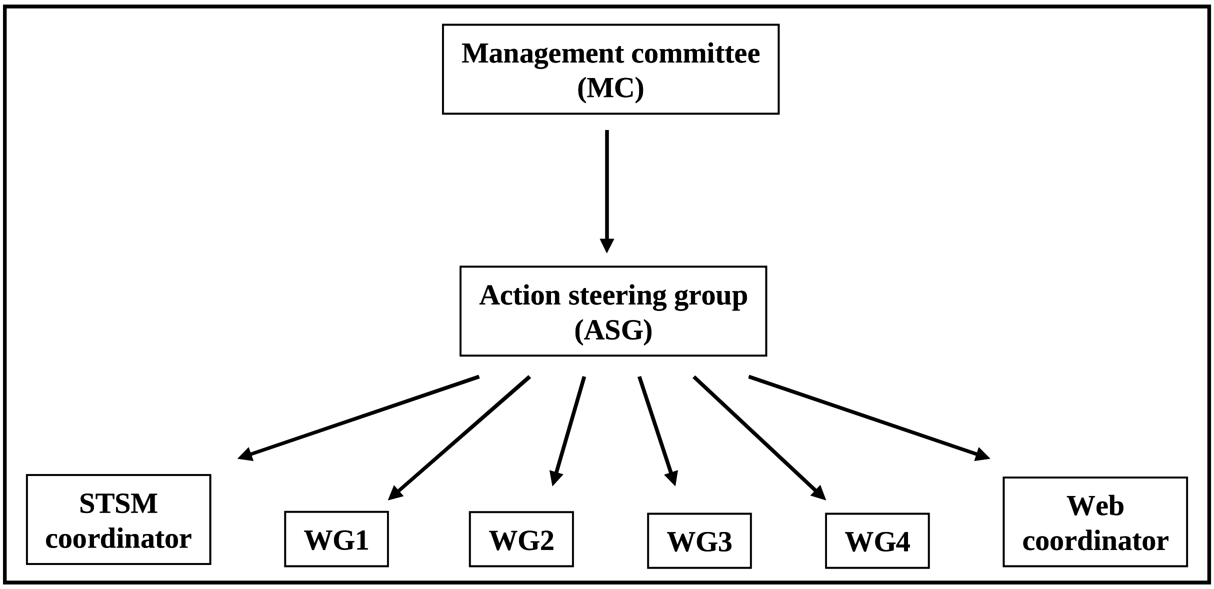

Figure 1: Organisational structure of the Action

In this COST Action, four Working Groups (WG, see E.2) act together. Each working group will be coordinated by an expert member of the MC (WG Coordinator elected at the first MC meeting) and will convene at least one meeting per year.

Short- Term Scientific Missions (STSMs) will be actively used to actively enhance information exchange and to enable young researchers and senior experts to participate in inter-group programs. STSM applications must be related to one or more of the four working groups and require approval by the relevant working group coordinator(s). A STSM Coordinator (elected at the first MC meeting) will then further evaluate the value of the STSM prior to approval by the MC. This procedure will be completed either at MC meetings or by email to avoid delays.

The opportunity to organize Training Schools offered by COST will be discussed at an early stage with experts from the Action providing the teaching resource(s). Recognizing the budgetary limitations, attention will be paid to obtaining best value for money and choosing locations that maximize the numbers of early-stage researchers who can attend.

An Annual Conference will be organized, gathering the European ‘biological and biomimetic adhesion’ community in order to discuss advances, establish new collaborations both within and outside the network and to foster new scientific directions and collaborations. It will include all aspects of the field: biology, chemistry, physics, engineering, technology and applications. Scientific highlights obtained during the past year will be communicated in an informal, open forum. Participants and invited speakers from non-European countries will keep the members of the COST Action up-dated on their most recent results, as well as on general trends within the field. Round-table discussions on topics of mutual interest will be arranged in a positive atmosphere, encouraging the exchange of knowledge, experience and innovative ideas.

There will be an Action website that will act as an intranet for the exchange of data/ideas inside the Action and respective WGs and an extranet for disclosing the main achievements both to specialists and to the general public. Information on the Annual Conferences will be made available online. A Web Coordinator, appointed by the MC, will be elected to set up and manage the Action's website. The COST initiative is the most suitable instrument for supporting this kind of open, flexible and growing networking for the generation of new collaborative projects.

E.2 Working Groups

Four Working Groups (WG’s) will be created according to COST rules based on the preliminary groups participating in the proposal preparation. The composition and arrangement of the WG’s will be approved and/or modified at the first meeting of the MC. Further modifications, proposed in the frame of the COST rules, will be discussed and, if necessary, approved during the subsequent MC meetings.

In this COST Action, four working groups (WG) will include:

Working Group 1: Chemical characterization and synthesis of adhesives

Characterization of the adhesives found in nature and, based on this information, preparation of biomimetic adhesives through various techniques.

Working Group 2: Structural characterization of natural and synthetic adhesives

Characterization of the structure of natural and biomimetic synthetic adhesives at the nano-, micro- and macroscopic level and linking these to their functional properties.

Working Group 3: Mechanical testing and theory

Testing the mechanical properties and attachment performance of natural and bio-artificial adhesives at the nano-, micro- and macroscopic level. Development of theory to model and predict the behaviour of complex, structurally and biochemically heterogeneous adhesives, as a basis for the design of new prototypes.

Working Group 4: Fabrication of bio-inspired adhesives and their evaluation.

Fabrication of adhesives with controlled geometrical structure, material properties and surface chemistry, based on the input coming from WG1, WG2 and WG3, and their evaluation in various applications.

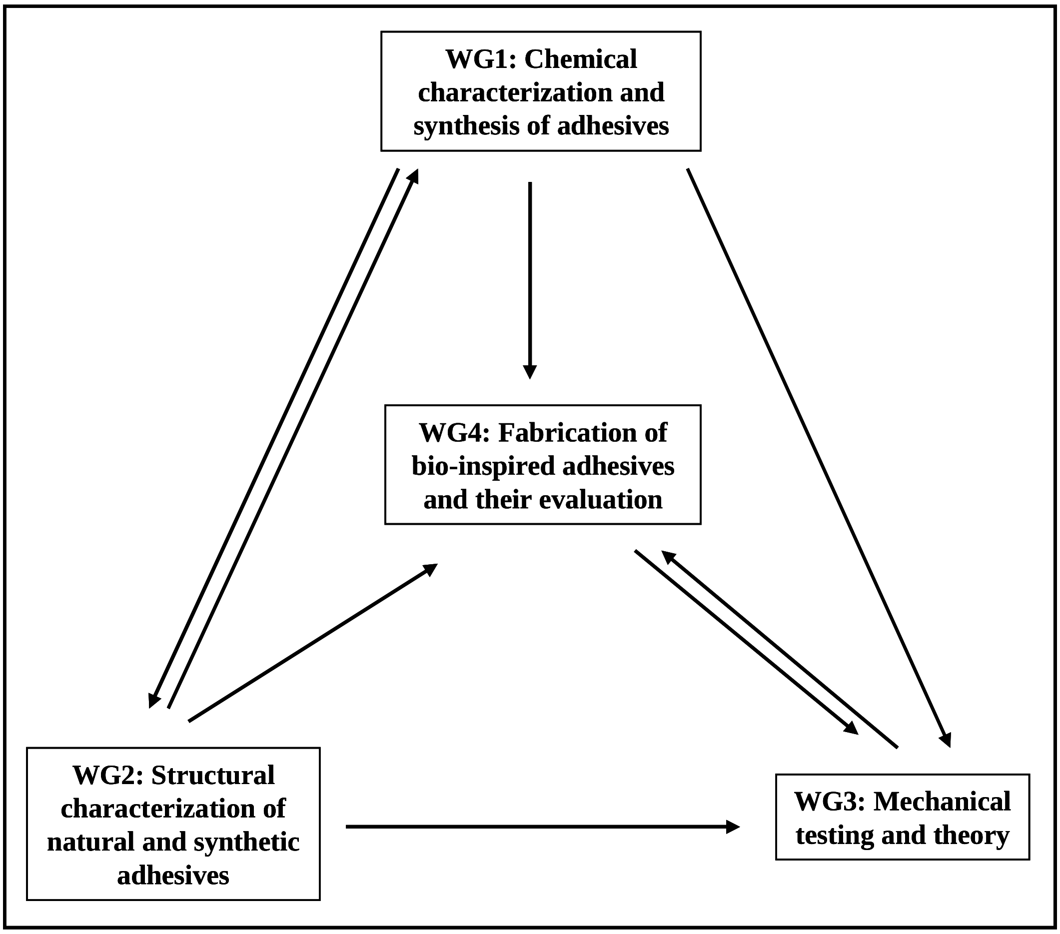

Figure 2: Organisational structure of the Action showing the interactions between WGs.

According to the iterative biomimetic approach, the WGs will work intensively on comprehensive topics along the value-added chain described in the scientific programme. Each group will include specialists from various disciplines, and each specialist will participate in more than one group, in order to enhance the information exchange in different directions. Whenever possible, partner(s) from industry will also be included to recognize opportunities for technology transfer and to consider commercialisation possibilities of the Action. When necessary, in the interests of meaningful discussions on the status of current research efforts, WG meeting participants will be asked to sign non-disclosure agreements, allowing presentation of results with actual or potential commercial implications. Close collaboration within each WG will be pursued, but intense collaboration across the whole Action will also be stimulated. The main interactions between the WGs are illustrated in figure 2. The MC will monitor the achievements of the objectives of the different working groups and, if necessary, advice on the direction which tasks should take. In this context, it will strive to support the most innovative and advanced approaches.

Each of the four Working Groups will have a coordinator (see E.1) who will organize and streamline working group activity. Together with other members of the MC, the coordinator will identify global experts and young researchers who will be invited to WG meetings. The meeting locations will be varied to disperse the work load for organisers and to facilitate attendance.

E.3 Liaison and interaction with other research programmes

At the European level, interest in biological adhesion and the development of biomimetic adhesives is growing. Some supporters of this proposal are already engaged with specific research projects sponsored by the EU: the EBioAdI project on dry adhesives (ESF, EUROCORES Programme) and the Blue4Glue project on marine adhesives (EU, Marie Curie Industry-Academia Partnerships and Pathways Programme). The involvement of these participants in the Management Committee will ensure the exchange of information between these ongoing projects and the COST network. Interaction of the COST Action with other European and national networks and initiatives will be established at the first MC meeting. In this context, the COST Action will be a strategic platform to unite widespread European expertise on biological and industrial adhesives in Europe, while avoiding duplication of efforts in the EU. Where appropriate, the Action will also hold meetings within or alongside other relevant meetings organized, for example, by professional bodies or related associations.

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

This COST Action will respect an appropriate gender balance in all its activities and the Management Committee will place this as a standard item on all its MC agendas. The Action will also be committed to considerably involve early-stage researchers. This item will also be placed as a standard item on all MC agendas.

All participating partners belong to equal opportunities employers and many universities have set up measures to increase the number of women in science. Moreover, the Management Committee will strive, in so far as it is possible, to achieve an acceptable gender balance in the elected leading team members of the COST Action (Chair, Vice-Chair and MC members, WG coordinators).

Further Action will be made by the Management Committee to build and maintain diversity in all teams. The COST Action will encourage a strong participation of young women researchers, by promotion and publicity of the Action's aims among young researchers during their early training when a higher percentage of women are active in the field. The participation of women early in their careers is seen as a way to fortify their involvement in the field, increasing the possibility of achieving a better gender balance in the future.

The Action will be committed to prioritizing its activities towards early-stage researchers. Five of the possible members, who have participated actively in the drafting of the proposal, may be rated as early stage researchers, although they are already internationally renowned. Young researchers from participating groups will be encouraged to take advantage of the short term mission instrument. The training workshops will specifically target young researchers, and those researchers seeking to enter this field of research. Early stage researchers will also be encouraged to give oral presentations and/or act as chairs at all Action meetings. This will provide a unique opportunity for these researchers to gain experience in a friendly and positive environment, thereby contributing to their personal and professional development.

F. TIMETABLE

The Action will run for a total of four years and will start with a Kick-off Management Committee meeting - with presentations by all partners and the fixing of organisational issues. Regular MC Meetings will be organised in combination with WG meetings and with the annual conferences. During this conference, scientific advances obtained during the past year will be communicated. The MC will then monitor the outcomes of the Action and take necessary actions. The success of the network will be evaluated in terms of new collaborative projects submitted or funded, number of collaborative publications or patents, or new products reaching the market.

Four Milestones will beacon the course of the Action:

- Milestone #1: Effective organization of the COST Action (critical mass, balance, visibility, diversity of activities)

- Milestone #2: Scientific impact at the international level (joint publications within WG, significant presence at scientific meetings, web page as a dissemination tool, involvement of industrial partners - science/industry meeting)
- Milestone #3: Consolidation of the network and multidisciplinary approach (joint publications across WG, identification of unforeseen adhesion principles and potential application fields)
- Milestone #4: Sustainable European network in the field of biomimetic adhesion (established training network, new collaborative projects, publication of one edited book)

The specific instruments to achieve these milestones and their outcomes will be discussed and evaluated at the Annual Conferences

Table 1: Timetable and milestones for the proposed Action

Year	Month	Event	Milestone	Website update
1	1	Kick–off MC meeting		x
	6	Kick-off WG Meetings and MC Meeting		x
	9			x
	12	Annual Conference (including MC & WG Meetings)	Milestone # 1	x
2	3	Training Workshop		x
	6	MC & WG Meetings		x
	9			x
	12	Annual Conference (including MC & WG Meetings)	Milestone # 2	x
3	3	Training Workshop		x
	6	MC & WG Meetings		x
	9			x
	12	Annual Conference (including MC & WG Meetings)	Milestone # 3	x
4	3	Training Workshop		x
	6	MC & WG Meetings		x
	9			x
	12	Annual Conference (including MC & WG Meetings)	Milestone # 4	x
	3	Final Report		x

A final conference will be organised at the end of the Action. After the completion of the Action, the Final Report will be edited and published in cooperation with a recognised international publisher.

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, BE, FR, DE, IE, IL, PT, 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 36 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 main target audience for dissemination will be:

- The network partners
- Other researchers in the field (outside the COST Action)
- Research institutes and academic units (in nearly related fields)
- Industry (with a strong focus on SMEs)
- The general public

H.2 What?

The information generated during the Action will be disseminated through several routes according to the target audience.

Members of this COST Action strongly believe that any new data created should be made accessible between the partners as well as to the entire scientific community as soon as possible by expedient publication in scientific journals, public databases, presentations at meetings and workshops, etc. This will allow colleagues to use the data created within the COST Action programme in their own analyses and will facilitate the generation of new collaborative research projects.

Industry (with a focus on SMEs) will mainly be reached via personal contacts of the network partners and contacts from the different partners will be shared (e.g., intranet list on the Action website). Industry will also be reached through presence at trade fairs (stands, posters, flyers) and communications at conferences usually attracting people from the industry (WCARP, SwissBonding, EURADH, European Coatings and Adhesion Congress etc). During the course of the Action, industrial partners will be invited to actively participate in the Action meetings.

It is one of the objectives of this COST Action to raise awareness in the European population towards the timeliness of scientific research in the field of biological adhesives and bonding technology in general. Distribution of information to the general public in terms of communication through popular science articles, seminars and radio or television broadcasts will therefore be highly encouraged.

H.3 How?

Effective dissemination of the results of the Action is one the major goals the COST programme. The Management Committee (MC) will assure the exchange of knowledge and data during the course of the actions, as well as dissemination of the results by a final report to COST. Publication of the results will be carried out at partner level. For this purpose, several dissemination methods will be available, some of which are described below. This dissemination strategy will be continuously updated during the lifetime of the Action.

Website
An important tool in the dissemination of the results of the COST Action will be a website platform. Information for the public, industry, academics and stakeholders will be made available on this website, while a restricted area will be generated with access for the participants of the Action only.

Meetings and conferences
Another major communication tool between the participants of the Action will be the Annual Conferences and WG meetings. Keynote speakers will be invited to the Annual Conferences. Also, special sessions with industrial relevance will be organised. This is especially important to implement new processes, recognize industry needs and to attract representatives of industry to facilitate possible leads towards technology development.

The meetings will be organised as open forums to ensure access of the students and scientists from the organising institution. Respective proceedings and web documents will be published from these meeting, whenever indicated.

Publications

A fundamental task of each scientist is to publish high quality papers in high ranked and specialised peer reviewed journals. In this Action, the WG topics are designed in a way that will yield highly original and relevant results that should be readily publishable in leading scientific journals. The MC will stress the production of high quality, multi-group papers within the Action. Additionally, reports for appropriate journals providing general information to the broad scientific community, and those for economics and policy-making organisations targeting non-specialists will be published.

In every publication that includes data resulting from the Action, the EU financial support will be acknowledged ("work supported by the European Cooperation in the field of Scientific and Technical Research (COST)").