Brussels, 13 April 2018

COST 031/18

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "Chemobrionics" (CBrio) CA17120**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action Chemobrionics approved by the Committee of Senior Officials through written procedure on 13 April 2018.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA17120
CHEMOBRIONICS (CBrio)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. “Rules for Participation in and Implementation of COST Activities” (COST 132/14 REV2);
b. “COST Action Proposal Submission, Evaluation, Selection and Approval” (COST 133/14 REV);
c. “COST Action Management, Monitoring and Final Assessment” (COST 134/14 REV2);
d. “COST International Cooperation and Specific Organisations Participation” (COST 135/14 REV).

The main aim and objective of the Action is to The aim of this COST Action is to link research groups throughout Europe and beyond to stimulate new, innovative and high-impact interdisciplinary scientific research on chemobrionics.. This will be achieved through the specific objectives detailed in the Technical Annex.

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 48 million in 2017.

The MoU will enter into force once at least seven (7) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14 REV2.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14 REV2.

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

TECHNICAL ANNEX

OVERVIEW

Summary

Self-organizing precipitation processes, such as chemical gardens forming biomimetic micro- and nano-tubular forms, have the potential to drastically enhance future materials design, as well as allowing us to develop new methodologies to explore, quantify and understand non-equilibrium chemical systems, and might even shed light on the conditions for the origin of life. The physics and chemistry of these phenomena due to the assembly of material architectures under a flux of ions, and their exploitation in applications, has recently been termed chemobrionics. Advances in chemobrionics require a combination of expertise in physics, chemistry, mathematical modelling, biology and engineering, as well as in nonlinear and materials sciences, giving rise to a new synergistic disipline. Progress is currently limited due to the lack of an efficient combination of the talents of researchers from diverse fields, but Europe is uniquely placed to develop a unique and world leading activity. The aim of this CBrio Cost action is to link research groups throughout Europe to stimulate new, innovative and high-impact interdisciplinary scientific research on chemobrionics. Our objective is to build bridges between the various communities to allow understanding and controlling physical, chemical, and biological properties of self-organized precipitation processes. This integrated fundamental knowledge will be shared with research groups focusing on specific applications to boost new technological developments, as well as with groups involved in the popularization of science and those at the interface between science and the arts.

Areas of Expertise Relevant for the Action	**Keywords**
● Physical Sciences: Non-linear physics	● chemical garden ● complex system ● origin of life ● nonlinear physics ● self-organization

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

<u>Research Coordination</u>

● To understand the relationship between the experimental conditions and morphology of these structures formed out of equilibrium.

● To combine different instrumental and analytical techniques to characterize these structures in terms of the chemical compositions and the gradient of chemical compositions and crystallinity.

● To understand the fluid dynamics during the formation of chemical gardens and biomimetic nanomaterials.

● To understand the interactions between metallic oxide-hydroxide layers in the formation of tubular forms at the atomic scale.

● To understand the thermodynamics in the interactions of the internal surfaces of these materials with water and organic molecules.

● To construct a protocol for flow-controlled synthesis of a given solid material.

● To explore the role of chemobrionics for the emergence of life at hydrothermal vents.

● To promote dissemination and science-art crossover activities related to chemical gardens.

<u>Capacity Building</u>

● To join together all these disperse Europe-wide groups into a world-leading effort that will both advance fundamental science and moreover enable the future exploitation of advances in chemobrionics by other fields.

● To bring together complementary, though diverse, disciplines and groups to form and integrate a critical mass of scientists to consolidate and expand chemobrionics into a mature and vibrant scientific endeavour.
● To improve training of early stage researchers through short-term scientific missions to groups working in different areas.

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. CHALLENGE

1.1.1. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

Self-organizing precipitation processes, such as chemical gardens forming biomimetic micro- and nano-tubular forms, have the potential to show us new fundamental science to explore, quantify and understand non-equilibrium physico-chemical systems, and shed light on the conditions for the origin of life. The physics and chemistry of these phenomena due to the assembly of material architectures under a flux of ions, and their exploitation in applications, has recently been termed chemobrionics. Advances in chemobrionics require a combination of expertise in physics, chemistry, mathematical modelling, biology and engineering, as well as in complex systems, nonlinear and materials sciences, giving rise to a new synergistic discipline. Progress is currently limited due to the lack of an efficient combination of the talents of researchers from diverse fields, but Europe is uniquely placed to develop a unique and world leading research activity.

The aim of this COST Action is to link research groups throughout Europe and beyond to stimulate new, innovative and high-impact interdisciplinary scientific research on chemobrionics. The objective is to build bridges between the various communities to allow understanding and controlling physical, chemical, and biological properties of self-organized complex precipitation processes. This integrated fundamental knowledge will be shared with research groups focusing on specific applications, as well as with groups involved in the popularization of science and those at the interface between science and the arts.

1.1.2. RELEVANCE AND TIMELINESS

Chemobrionics is a newly emerging field of fundamental nonlinear and complex systems science that intersects with physics, chemistry, biology, and materials science, and involves the study of biomimetic materials as complex systems based on self-organized structures involving semipermeable membranes and amorphous as well as polycrystalline solids. Chemobrionics encompasses the classical chemical gardens as shown in Figure 1, but the field goes far beyond this centuries-old experiment.

Several factors are working in unison to make a concerted research effort such as this Action both relevant and timely. It is today commonly accepted that self-assembly is an excellent way to form complex structures, indeed it is the foundation for much of modern nanoscience. Yet nature not only applies self-assembly but also self-organization that allows building complex patterns from simple building blocks. Harnessing such methods for scientific and technological applications is thus extremely promising but is currently hampered by an incomplete understanding of the underlying fundamental phenomena.

The same challenges are encountered by those interested in comprehending how these physical and chemical processes may have taken part in the emergence of life on this planet and elsewhere in the universe, as these same chemobrionic systems are found at oceanic hydrothermal vents, and the hypothesis that life may have incubated within them 4 billion years ago in a transition from abiotic geology and chemistry to biology is today the most promising theory for the emergence of life on Earth.

Figure 1: *A classical chemical garden*

Research related to these biomimetic nanotubular or microtubular systems is developing very fast and much work is appearing from individual research groups both in Europe and worldwide related with the self-organized chemical-garden phenomenon. However, the efforts of these research groups are scattered, with researchers working independently without cohesion. This impedes the construction of a strong European research effort in this area, which could bring European research in chemobrionics to a premier position. This Action will join together all these disperse Europe-wide groups into a world-leading effort that will both advance fundamental science and moreover enable the future exploitation of advances in chemobrionics by other fields.

Chemobrionics requires a multidisciplinary approach, rather than conventional more narrowly-defined research projects. This has further hampered advances in the area because research has been artificially divided along the traditional lines of physics, chemistry, biology and so on. This has been detrimental, as the distinction between these fields is blurred in the area of chemobrionics, where, as is generally the case with nonlinear and complex systems, more holistic approaches are required. There are no European efforts in this area. Therefore, there is a great and pressing need to bring together complementary, though diverse, disciplines and groups to form and integrate a critical mass of scientists to consolidate and expand chemobrionics into a mature and vibrant scientific endeavour.

This COST Action addresses that need. The COST Action will link nationally funded research projects and be an essential facilitator for world-class European chemobrionics research that will enable large-scale concerted European scale research efforts. Additionally, and very importantly, the Action will strongly improve training of early stage researchers through short-term scientific missions to groups working in different areas. This will not only train early stage researchers in interdisciplinary research but also allow them to gain experience in diverse approaches to research group organization, management and communication. Thus, the Action will be an essential component in both European research and in forming the European researchers of the future. Key features will be both networking workshops and also chemical garden demonstrations, exhibitions, and art-science installations that will involve early career researchers, giving them an opportunity not only to develop research synergies, but also to advocate for science.

1.2. OBJECTIVES

1.2.1. RESEARCH COORDINATION OBJECTIVES

The objective of this Action is to coordinate the expertise of research groups throughout Europe to stimulate new, innovative, collaborative and high-impact interdisciplinary scientific research on understanding the nonlinear dynamics of these far from equilibrium complex systems, the formation of biomimetic microtubular and nanotubular forms and the interactions with other systems including nanomaterial applications, new routes to the development of synthetic and artificial biologies, and thermodynamical implications related with the origin of life on Earth. The proposal identifies the wide range of systems that can be considered chemical gardens or to which the concepts, ideas and methods developed for chemical gardens can be applied. The identified objectives will help in generating new bridges with related systems to enhance the potential of this field. This Action will also stimulate the coordination of laboratory facilities, including the co-use of equipment and processing software. The combination of these coordination actions in expertise, laboratory facilities and applications, will stimulate a faster growth of the field of chemobrionics and its impact on society.

In particular, the Research Coordination objectives are:

1. To understand the relationship between the experimental conditions and morphology of these structures formed out of equilibrium.
2. To combine different instrumental and analytical techniques to characterize these structures in terms of the chemical compositions and the gradient of chemical compositions and crystallinity.
3. To understand the fluid dynamics during the formation of chemical gardens and biomimetic nanomaterials.
4. To understand the interactions between metallic oxide-hydroxide layers in the formation of tubular forms at the atomic scale
5. To understand the thermodynamics in the interactions of the internal surfaces of these materials with water and organic molecules
6. To construct a protocol for flow-controlled synthesis of given solid material.
7. To explore the role of chemobrionics for the emergence of life at hydrothermal vents.
8. To promote dissemination and science-art crossover activities related to chemical gardens

1.2.2. CAPACITY-BUILDING OBJECTIVES

The capacity-building objectives of this Action will be in developing general pathways for extending this fundamental research in other systems with similar structures and to transfer knowledge to other complementary networks and projects. Applied areas in which this research will have an impact include, for example, biomaterials, nanomaterial science, biosensors for environmental applications, and catalysis. The economic benefit derived from the use of such new materials in the long term would be expected to be strongly positive.

The network of groups and scientists that will be brought together and coordinated under this COST Action represents the most comprehensive means of promoting and achieving excellence in chemobrionics research across the European research area. Each group has strong experience related to chemobrionics. The scientists dedicated to this subject and the scientific equipment, research facilities and institutional support that they will bring to bear is testament to the dedication of all individual participants to this Action in meeting its objectives. While within each group research is carried out on several different topics related to chemobrionics, each group has identified at least one specific area in which it has key expertise. These areas of high-level expertise are unique and complement those of other groups in the Action. This means that there will be strong complementarity within the network with each group sharing its key expert knowledge with the others. The groups all have national and/or international funding for their research activities and, under this COST Action, will coordinate current, or modify or include new, research activities so as to maintain a cohesive approach within the network that will be mutually beneficial to all.

All participants are strongly committed to facilitating the vital short term scientific missions of researchers from other groups to learn key skills and to transfer that knowledge back to the home group. This will allow the groups to make use of diverse theoretical and computational approaches, different equipment related with diverse analytical techniques, learning experimental design and experiencing the approach of other groups to solving the similar problems. Such intimate knowledge of how research is conducted in other groups will facilitate strongly enhanced communication and understanding within the network. Early-stage researchers will be favoured for these training and networking activities. Workshops will also have an extremely high priority as they will allow the interaction of many researchers with each describing their needs and as a group coming to common solutions regarding research directions to solve outstanding research problems.

Conferences, publications, targeted contacts for promotional information and a website will allow the dissemination objectives to be met with respect to the general public, outside researchers, industrial actors and policy makers. Chemical gardens will be explained and demonstrated in schools for enhancing scientific vocations in teenagers, and touring photo and video exhibitions and art-science installations based upon chemobrionics science will be set up.

In particular, the Capacity Building objectives are:

1. To join together all these disperse Europe-wide groups into a world-leading effort that will both advance fundamental science and moreover enable the future exploitation of advances in chemobrionics by other fields.

2. To bring together complementary, though diverse, disciplines and groups to form and integrate a critical mass of scientists to consolidate and expand chemobrionics into a mature and vibrant scientific endeavour.

3. To improve training of early stage researchers through short-term scientific missions to groups working in different areas.

1.3. PROGRESS BEYOND THE STATE-OF-THE-ART AND INNOVATION POTENTIAL

1.3.1. DESCRIPTION OF THE STATE-OF-THE-ART

For the past four centuries, the amazing precipitation structures known as chemical (or silica, silicate, crystal) gardens have been the subject of fascination, as well as the basis of different philosophical and scientific theories, an inspiration for literature, and the motivation for many experiments. Classical chemical gardens are the hollow precipitation structures that form when a metal-salt seed is dropped into an aqueous solution containing anions such as silicate, phosphate, carbonate, oxalate, or sulfide. The dissolving seed releases metal ions that precipitate with the anions in the outer solution, forming a gelatinous colloidal membrane enclosing the seed. There is an obvious visual similarity between precipitated chemical-garden structures (Fig. 1) and a variety of biological forms including those of plants, fungi, and insects. Moreover, in some ways, the process of formation of chemical gardens from an inorganic “seed” in a reactive solution is reminiscent of plant growth from a seed in water or soil.

These biomimetic structures and processes have from the very beginning caused researchers to wonder: Do chemical gardens and biological structures share any similar processes of formation? Can these inorganic structures teach us about biological morphogenesis, or is the similarity only accidental? Are they related to the origin of life? And, if their precipitation is affected by chemical and environmental parameters, can the process be controlled to build complex structures as biology does, to produce self-organized precipitates as useful materials? Could a synthetic biology system, using genetic material, be developed to initiate, control or manipulate a chemical garden?

There are many other reaction systems that can form analogous chemical gardens, and many details of their formation process are specific to the particular system, but the key universal aspect is the formation of a semipermeable precipitation membrane of some sort, across which steep concentration gradients may be formed and maintained, leading to osmotic and buoyancy forces. Of course, chemical gardens are by no means the only pattern-forming system in chemistry. Liesegang rings, for example, are another long-studied pattern-forming system involving chemical precipitation. However, Liesegang rings do not involve semipermeable membranes and are as such a quite different phenomenon. Chemical gardens are found in laboratory chemistry ranging from silicates to polyoxometalates, in applications ranging from corrosion products to the hydration of Portland cement, and in natural settings ranging from hydrothermal vents in the ocean depths to brinicles beneath sea ice.

The structures formed in chemical-garden experiments can be very complex. Experimental and theoretical studies of chemical-garden systems have accelerated from the end of the 20th century with the development of nonlinear dynamics, the study of complex systems, the understanding of pattern formation in chemical and physical systems, and the development of more advanced experimental and analytical techniques. Many aspects of the chemical-garden system, such as electrochemical and magnetic properties, have recently been and are being characterized. It has been observed that in certain systems, self-assembling chemical engines can spontaneously emerge. The increased understanding of the chemical-garden formation process in the past several decades has also enabled researchers to begin to control it, to produce intentional structures via sophisticated precipitation techniques that have many potential uses for materials science and technology, especially on the nanoscale. Chemical gardens on one hand show us that complex-looking structures do not have to be biotic in origin— and thus highlight the dangers of using morphology as a sign of biological origin — and on the other hand point to a possible way to arrive at a proto-cell from an abiotic beginning. We now know that the finding of a biomimetic form is not a direct indication of the existence of life, because it can be produced by organic matter, like living organisms, or by abiotic phenomena, like chemical gardens. However, modern research shows that chemical gardens at hydrothermal vents in the ocean floor are a plausible pathway towards the emergence of life on Earth.

The scientific and technological importance of chemical-garden systems today reaches far beyond the early experiments that noted their visual similarity to plant growth. Chemical garden-type systems now encompass a multitude of self-organizing processes involving the formation of a semipermeable membrane that create persistent, macroscopic structures from the interplay of precipitation reactions and solidification processes with diffusion and fluid motion.

1.3.2. PROGRESS BEYOND THE STATE-OF-THE-ART

The challenge remains to elucidate the growth processes both to understand the science, and to be able to control them for the benefit of various applications. Chemobrionic processes are varied and applicable to many disciplines; specific systems and properties are being studied in fields including geology, planetary science, astrobiology, biology, materials science, catalysis, etc. Researchers from these disciplines generally do not communicate with one another and there is not yet the general knowledge that these phenomena are all very interrelated.

1.3.3. INNOVATION IN TACKLING THE CHALLENGE

The innovation in tackling the Challenge is to create an interactive network, where, for the first time, a bottom-up initiative has been taken involving leading scientists from different fields of research to work together on the research and development of the science of chemobrionics, as well as on training of young researchers in the field of chemobrionics and characterization techniques. The involvement of artists and the engagement of the public provides a new 'open' approach. This Action’s results offer high innovation potential at different levels both in fundamental science and in the development of new applications using biomimetic nanotubular materials and based on flow-controlled material synthesis. In fundamental science, it has the potential to solve part of one of the greatest scientific challenges: to understand the origin of life. In the long term, the knowledge created by it will lead to the creation of a new pool of scientists, designers and entrepreneurs in sensors, systems and related electronics, and new materials production methods will increase the competitiveness of European industry for fabrication of controlled self-assembled materials.

1.4. ADDED VALUE OF NETWORKING

1.4.1. IN RELATION TO THE CHALLENGE

Apart from writing co-authored reports and collaborative research articles, networking provides a higher level of interaction between experts in chemobrionics by means of the organization of workshops, short-term scientific missions and exchange of researchers. Besides, networking provides the possibility of research visits for early-stage researchers; this possibility enhances the maintenance of inter-relationships between groups for the future period of time when the early-stage researchers will consolidate their positions.

The Action also plans to set up 'challenge' projects whereby the network will try to achieve a certain goal in a 'X-prize' type way and then document the solution allowing other groups in the network to duplicate the challenge result thus establishing new know-how quickly. We shall ensure that networking reaches to potentially interested industries, owing to the potential technological impact of the field. Networking is not simply predicated thinking on how existing academic groups will interact. The structure of the Action is not merely a network between research groups that will develop their own specific scientific interests, but rather a global network. As a result, there is a great potential of the added value associated with networking.

1.4.2. IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

The research that will be undertaken and the coordination of activities under this COST Action does not duplicate any other efforts supported by the European Commission through its various funding instruments. Nevertheless, this Action can be related with earlier initiatives. There have been previous COST Actions related to pattern formation and non-linear dynamical systems, far from thermodynamic equilibrium. In direct relation to this proposal, an initial workshop on chemical gardens/chemobrionics was organized at the Lorentz Center, Leiden, in 2012, and proved a great success. This COST Action is a natural successor to that workshop.

We emphasize the real added value of putting forward a network on chemical gardens in Europe. The network activities in this action will be integrated with other activities in order that collaborations among groups in different work groups will lead to far greater returns than a mere series of bilateral projects. The interconnection between the different network-wide proposed activities and the specific activities proposed bring added value to existing activities in this area across Europe.

2. IMPACT

2.1. EXPECTED IMPACT

2.1.1. SHORT-TERM AND LONG-TERM SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS

The coordination of research through this Action will lead to the development of new areas of fundamental scientific enquiry through the sharing of knowledge and enhancing the research abilities of the participants. In particular the Action will coordinate research that will have significant impacts on important contemporary issues. On the side of fundamental science, new knowledge about the origin of life here on Earth and in the universe fulfils one of the most basic human necessities: to understand where we came from, and whether we are alone in the universe. On the technological side, there is the impact of the formation of new functional materials. While in the short term this is fundamental science, the knowledge derived and disseminated under this Action will have strong socio-economic impacts in the long term. It is clear that an enhanced ability for the development of new materials, with applications in diverse areas such as energy technologies or information and communications technology, is strongly positive in the long term

2.2. MEASURES TO MAXIMISE IMPACT

2.2.1. PLAN FOR INVOLVING THE MOST RELEVANT STAKEHOLDERS

This project began as a bottom up initiative involving leading scientists from the different scientific fields coming together in chemobrionics. During the preparation of this proposal representatives from the most important stakeholders in Europe have been involved. A forum will be created through this Action to discuss and perform focussed activities in the field of chemobrionics. It will be open to anyone interested in contributing to the field. As well as giving visibility to the Action and attracting interested actors in this area, the forum will identify additional members, will extend the Action limits as necessary and explore how to push the potential of the topic of the Action beyond the natural bounds set by the contacted participants. In particular, the forum will explore potentially interested industrial or technological partners.

2.2.2. DISSEMINATION AND/OR EXPLOITATION PLAN

Further milestones will be the hosting of a seminar at the end of year 2 with actors from other relevant or complementary European networks and projects to discuss modes for sharing of results from this Action and the transfer of knowledge. Furthermore, the planned publication of a book on advances in chemobrionic research based on results of this network in year 4 of the Action will also be an important milestone for the dissemination of knowledge, as well as an interactive digital version on the web. A key part of the planned book will be a chapter on demonstrations and equipment and materials to use. Alongside this we plan chemobrionics demonstration kits for teachers to be used in front of students in high schools.

As approximately twenty Short Term Scientific Missions are anticipated, the completion of the first ten and a mini-review of their progress is an important milestone to assess their success and to make any modifications to the scheme so as to enhance their effectiveness.

The end users of the research will, in the first instance, be scientists working in all fields related with chemobrionics research. However this project will attract the attention of researchers working in other fields of complex systems origins of life, and nonlinear science, as well as environmental and materials science, especially early career investigators, who can easily join and contribute to this emerging field. More indirect impacts in areas such as, for example, nanomaterials for controlled drug delivery are also envisaged. In the long term, on a more applied level, the results of investigations into designing new biomimetic pathways for creating novel functional materials with new or enhanced properties is likely to generate strong interest from small and medium enterprises, as well as from larger firms. The scale-up and commercialization of new self-assembling complex materials would strengthen the competitiveness of European industry in many areas with a strongly positive corresponding social impact, particularly from the perspective of employment.

Thanks to the fact that chemical gardens are easy to grow and produce beautiful patterns that are visually very appealing for photos and videos, we plan to use this advantage to work on the promotion of science via the following tools:

- Dissemination of protocols and kits for easy demonstration of patterns and chemical garden growths for science fairs and classroom demonstrations.

- Printed and digital science-art book, DVDs and videos gathering the most beautiful images and films of precipitations patterns obtained in all groups involved.

- International art-science exhibition travelling in Europe in science and natural history museums.

- General public conferences on synthetic biology, origin of life and societal related implications of chemobrionics research.

- An X-prize type competition for the use of chemobrionics for new application developments e.g., fuel cells, electrolysers, and so on.

- Touring installations linking chemobrionic science to art.

We plan to organize demonstrations and seminars related with chemobrionics and chemical gardens in European high schools. Previously, such activities have been performed in Spain and the USA. This Action is the natural successor to these efforts, which can awaken and encourage scientific vocations among teenage students.

Beyond the fact that the network itself will facilitate the collaboration among groups with different backgrounds, benefit of generating this network will be to maximize impact with the proposed network activities.

2.3. POTENTIAL FOR INNOVATION VERSUS RISK LEVEL

2.3.1. POTENTIAL FOR SCIENTIFIC, TECHNOLOGICAL AND/OR SOCIOECONOMIC INNOVATION BREAKTHROUGHS

The immediate, short term interest in chemobrionics is at the level of fundamental scientific research. The research that is being carried out in this very active field today is of great interest within the disciplines of complex systems and nonlinear science. There are large, active scientific communities in physics and chemistry that would certainly be interested in further results in this field. Moreover, the question of how life began in the universe is perhaps the greatest challenge of complex systems, self-assembly and self-organization. The linking together of research with this proposal would certainly spur efforts towards putting together the pieces of this question; an answer to which would surely reverberate beyond science.

From a technological perspective, chemobrionics can be used to learn about physico-chemical systems that in some ways mimic biological systems, and, if these systems are mastered, may lead to the development of new self-assembling technologies that could operate from nanometre to metre scales. The richness and complexity of these chemical motors and chemical batteries, to name two already foreseen developments, and the fact that they emerge from simple, mostly two-component chemical systems, indicates that their formation is an intrinsic physical property of the specific chemical systems.

By simply changing concentrations or reactants and other experimental parameters we may arrive at a collection or library of these chemical “engines”. And by expanding on the self-assembling nature of these out-of-equilibrium chemical systems, we may eventually be able to form larger functioning structures. One of the main challenges is to control the morphology, size and thickness of these structures. Related to this, another important challenge and a great technological development opportunity is the application of micro- or nano-probes to analyse chemical compositions of internal and external fluids, micro-electrical potentials, fluid dynamics, and thickness of layers.

In overcoming these hurdles, a great research opportunity can be opened to produce homogeneous and tailored micro- and nanotubes for industrial applications. However, for these last opportunities to become possible, it will be necessary to overcome another challenge, that is to optimize these structures in order to improve their plasticity and mechanical strength.

We highlight some of the possible technological applications of chemobrionics in the longer term:

- Organic and bio-materials: It is a challenge to extend chemical gardens to organic and mixed inorganic-organic chemobrionic systems. This can open a great opportunity to create nanostructures for biomaterials with high biocompatibility with living cells and tissues. Chemical gardens may also be worth considering with regard to selective adsorption--desorption processes with interest, for example, for the slow release of drugs.

- Electrochemistry: The electrochemical properties of self-assembling chemobrionic membranes are poorly understood and further studies of these phenomena in laboratory experiments will help us understand the larger-scale energy generation that occurs in natural chemical-garden systems. During their formation process, chemical gardens produce an electric potential across their interfacial membrane, which has a clear technological applications to fuel cell technology.

- Catalysis and adsorption: Chemical gardens are controlled crystal growth at an interface, not unlike electroplating material onto a surface or growing thin solid films. Taking into account that chemical-garden micro- or nano-tubes can have reactive internal surfaces with chemical and adsorption properties, these structures can have interesting applications such as nanocatalysts or nanosupport for catalysts.

- Gas adsorption: The porosity and the large surface area of these tubes could be advantageous for selective adsorption--desorption of gaseous pollutants and gas exchange processes. For these potential applications, other challenges should be overcome, such as the necessary mechanical properties, plasticity, and morphology control.

-Microfluidics and controlled branching and tubular networks: If we can control branching in chemical-garden tubes, we can construct tubular microfluidic networks for fluid processing, mixing, and so on. Important advances have already been achieved in this sense in recent years, but more remains to be done.

- Sensors and filtration: Semi-permeable membrane materials are of great interest for many applications and chemical gardens have already been shown to semipermeable properties. Choice of starting components, or incorporation of functional molecules, in these soft materials could open new avenues in hybrid membrane research for small-molecule sensing or water recycling.

- Chemical motors: Chemical motors may be defined as structures that move using chemical reactions to produce the required energy. In chemical gardens the motors first self-construct spontaneously, and then they may move in many different modes. Examples of the motion include linear translation, rotation, periodic rupturing, periodic buoyancy oscillations, periodic waving or stretching of the entire structure, and periodic ejection of complex tubes.

- Back to cement: The application of chemical-gardens ideas to understanding the hydration of Portland cement has lain mostly dormant since a burst of activity from the 1970s to the 1990s. With the fresh insights and new analytical techniques available today, determined researchers could make a large contribution to this sub-field with obviously high industrial impact.

- Complex materials: A possible outcome of experiments where one reactant solution is injected into the other one at given concentrations is to be able to control the composition and structures of the precipitates and crystals formed. For instance, layered or complex materials could be synthesized upon successive injection of solutions of different composition. This provides a route to the design and growth of complex materials.

In order to stimulate the transfer of fundamental knowledge developed by the Action to the applied beneficiaries, we shall invite industrial representatives with interests in the fields of identified above to our seminars and meetings. This will allow an efficient direct transfer of knowledge to applications of high-impact to society.

We have described a significant number of potential applications and fields that can benefit from the outcome of the Action and where the perspective and insight gained from a better understanding of chemical gardens can provide new perspectives and also new bridges between currently disconnected areas of scientific and technological interest. We shall promote those links and proactively help to establish new contacts between fields related to the main topic of the Action.

3. IMPLEMENTATION

3.1. DESCRIPTION OF THE WORK PLAN

3.1.1. DESCRIPTION OF WORKING GROUPS

The participants of this Action are experts in chemobrionics and in tools applicable to these processes. In this initial stage there are 14 groups from different institutions belonging to 12 European countries, and more groups will be encouraged to join.

Here is the list of already involved European groups and their expertise:

I (Belgium): hydrodynamics of reactive fluids and 2-D chemobrionics.

II (Denmark): formation of these systems in gels and nanomaterials; organic/inorganic hybrid chemical gardens.

III (France): educational aspects of chemobrionic systems; photo and video exhibitions with both scientific themes and the artistic aspects and divulgation of these biomimetic morphologies.

IV (Germany): growth, characterisation, and reactivity of thin films.

V (Greece): formation of organic materials containing chemical gardens.

VI (Hungary): dynamical aspects of chemobrionics.

VI (Italy): thermodynamics related with the origin of life in confined spaces.

VII (Portugal): membrane and porous material characterisation, adsorption/desorption, catalysis, separation and reaction engineering.

VIII (Slovakia): complex chemical mechanisms related to periodic precipitation systems.

IX (Slovenia): chemobrionic science-technology-art collaborations.

X (Spain): mechanisms of formation of chemobrionic systems.

XI (Spain): mathematical modelling and chemobrionics.

XII (UK): mathematical approach of fluid dynamics in the interactions of fluid flow and chemical kinetics.

XIII (UK): micromorphology of cements and nanomaterials based on polymers.

XIV (UK): non-equilibirium chemistry, digital control of the dynamics of self-assembly and self organisation of chemical gardens, polyoxometalates and nanomorphologies with these materials.

Many of these participants maintain collaborations in some aspects of chemobrionics with extra-European experts including researchers from ICP countries from the USA, Mexico and Japan. These external scientists will be invited to the Action Workshops. Therefore, this Action will enhance the international as well as European scientific networking and collaborations in chemobrionics.

The Action will comprise four Working Groups (WG) focusing on different aspects of chemobrionics research, including experimental aspects, theoretical questions, applications, and dissemination. These WGs will be formed by participants from different groups to enhance the international collaborations. There is strong overlap between the various scientific areas, reflecting the multidisciplinary nature of the subject, and participating experts will be able to be members of more than one Working Group. This will facilitate a more intimate integration of scientific research and enhance knowledge transfer. The Working Groups will be coordinated by Working Group leaders, selected from those members who are not members of the Management Committee so as to allow better distribution of workloads and to enhance cooperation within the network of participants. The Working Group leaders will have high-level knowledge and experience in the topic of each Working Group. They will set the style and content of the workgroups to ensure that they do not become merely research projects, and oversee the relationship with the network activities and the nature of the Action. The Working Group leaders will ensure the relationship between wide actions in the network and the possibility to bring in the whole community in this area.

The following WGs will be established:

WG-1.- Morphology and Nanocharacterization

Objectives: Two main objectives can be defined in this WG: a) to understand the relationship between the experimental conditions and morphology of these structures formed out of equilibrium; and b) to combine different instrumental and analytical techniques to characterize these structures in terms of the chemical compositions and the gradient of chemical compositions and crystallinity.

Tasks:

1.1.-Growth of precipitation patterns in 2-D flow conditions.

1.2.-Growth of chemical gardens in gels.

1.3.-Growth of tubular forms from osmotic membranes.

1.4.-Growth of tubular morphology in 3-D flow conditions.

1.5.-Characterization of tubular precipitation patterns at a nanoscale level.

Milestones:

1.5.1.-Identified conditions for 3-D X-ray tomography imaging.

1.5.2.-Optimized growth conditions in a gel.

WG-2.- Fluid Dynamics and Complex Systems Modelling

Objectives: Four main objectives can be established: a) to understand the fluid dynamics during the formation of chemical gardens and biomimetic nanomaterials; b) to understand the interactions between metallic oxide-hydroxide layers in the formation of tubular forms at the atomic scale, c) to understand the thermodynamics in the interactions of the internal surfaces of these materials with water and organic molecules; and d) construct a protocol for flow-controlled synthesis of given solid material. All of these objectives have as part of their basis the interest in these questions for the emergence of life at hydrothermal vents.

Tasks:

2.1.-Monitoring the fluid dynamics during pattern formation with laser-induced fluorescence and particle-image velocimetry experiments.

2.2.-Molecular dynamics simulations of a semipermeable membrane model.

2.3.-Exploration of interactions of organic molecules in a confined space of tubular structures and extrapolation to the origin of life both on Earth and for astrobiology interests.

2.4.- Characterization of the precipitation patterns and tubes as a function of concentrations and flow conditions.

2.5. Control of garden formation using external fields and control feedback.

Milestones:

2.1.1.- Constructed model for simulations.

WG-3.- Natural and Technological Applications

Objectives: This WG aims to investigate natural and technological objectives including: a) to investigate applications of these tubular materials as adsorbents of heavy metals from wastewaters; b) to explore the adsorption of biopolymers in these inorganic tubes for possible biosensors and biocatalysts; c) to study fuel cells based on chemical gardens; d) to explore the natural application of chemobrionics to the emergence of life at hydrothermal vents.

Tasks:

3.1.-Characterise the tubular materials in terms of permeability, surface area, adsorption capacity, separation and catalytical support.

3.2.-Applications of the tubular materials as adsorbents for cleaning polluted wastewaters.

3.3.-Application of tubular forms based on transition and rare earth metals as chemical sensors and photoluminiscent devices.

3.4.-Application of the organo-composites of these tubular forms as biosensors and immobilized biocatalysts.

3.5.-Application to fuel cell and electrolyser technologies.

3.6 –A chemical garden setup to investigate the emergence of life at an alkaline submarine hydrothermal vent.

WG-4.- Dissemination

Objectives: to promote dissemination and science-art crossover activities related to chemical gardens.

Tasks:

4.1.- Organization of activities for high schools in the different countries of the network, explaining the formation of biomimetic structures and enhancing the scientific vocations among teenagers.

4.2 – Organization of touring photo and video exhibitions.

4.3 – Organization of a touring science-art installation of chemical gardens with sound.

4.4 – Digital content including interactive website, blogs and wiki pages.

4.5 – Dissemination to industrial beneficiaries, by inviting key leaders in a wide range of applications identified above to seminars and meetings.

3.1.2. GANTT DIAGRAM

Timetable (months)	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Kick.off meting	X															
MC meetings				X				X				X				X
Thematic workshops				X				X				X				X
WG1 meeting	X				X				X				X			X
WG2 meeting	X				X				X				X			X
WG3 meeting	X				X				X				X			X
WG4 meeting	X				X				X				X			X
Training Schools						X				X				X		
STSM calls	X		X			X				X				X		
Deriverables				D1				D2				D3				D4

Deliverables

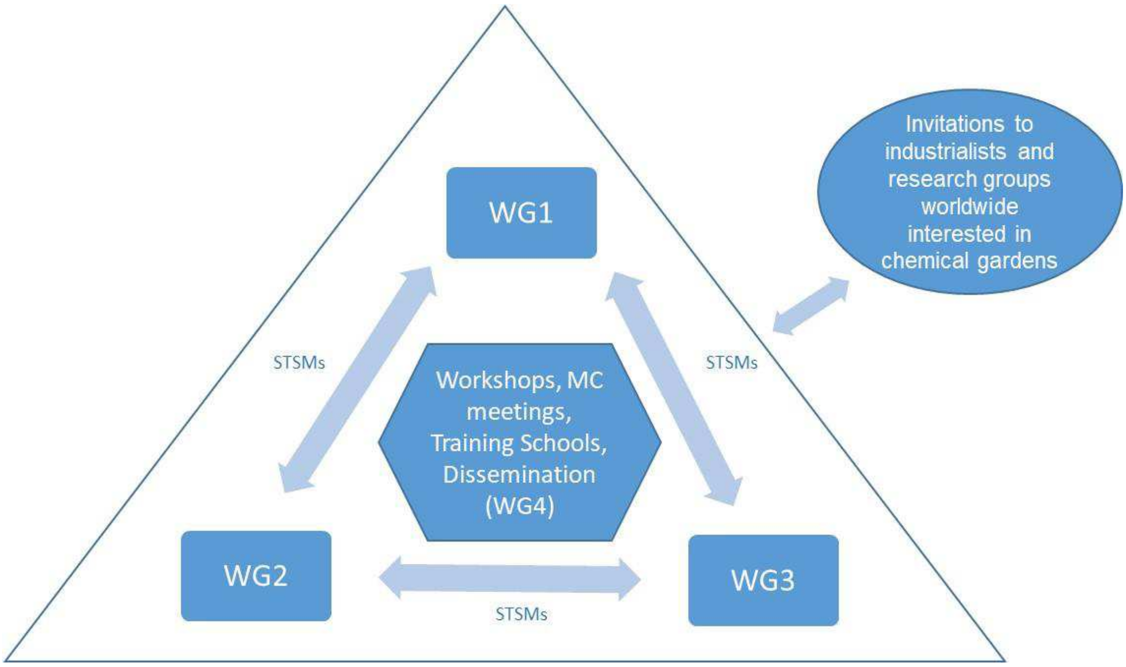
D1: Report of the Action activities of the first 12 months and planning for next months (month 13).

D2: Report of the Action activities of the first 24 months and planning for next months (month 25).

D3: Report of the Action activities of the first 36 months and planning for next months (month 37).

D4: Final Assessment report of the Action (month 49).

3.1.3. PERT CHART (OPTIONAL)



3.1.4. RISK AND CONTINGENCY PLANS

The main risks, as well the means to address and mitigate them by careful contingency plans are summarised in the table below.

Risk description	Prob.[1]	Cons.[2]	Contingency plans
Some important characterization techniques will not be available or a technology turns out to be too expensive to permit its use in these researches.	2	4	There is no one technique that is on its own critical. Look for alternative availabilities of the technique within and outside Europe.
Lack of interest from young scientists to join the training schools.	2	3	Promotion of the initiative among participating universities. Cooperation with other events to raise awareness.
Limited interest of analytical techniques labs for organizing training schools.	2	3	Focus on limited number of technologies to keep volumes in each field.

Limited interest from industries.	3	2	Not a serious issue with regard to fundamental research; nonetheless special invitations to companies to participate in the workshops.

[1] Probability to occur, 1-5, 1=very low probability, etc. [2] Consequence on occurrence, 1-5, 1=no serious consequence, etc.

We do not believe there is a risk of reduced added value of the network. The main added value is in the advance of the fundamental science and we feel confident that the network will contribute significantly in this area.

3.2. MANAGEMENT STRUCTURES AND PROCEDURES

The COST Action will have a Management Committee comprised of members from each of the participating countries, and will be chaired by an Action Coordinator (Action Chair). The Management Committee will continuously develop networking activities giving a clear direction to the sharing and transfer of knowledge. Expansion of the network to any interested party across Europe or partner countries is envisaged and encouraged. The Action Chair will be responsible for the running of the Action as a whole and will oversee the various activities under the Action. Four Working Groups will be set up, based on the areas identified, and each will be comprised of experts in the task and will be led by a Working Group Leader. Each Working Group will organize annual meetings to coordinate activities for that task and monitor the achievement of milestones.

The Management Committee will appoint a Dissemination Manager whose responsibility will be to coordinate all tasks related to the dissemination and publication of results from scientific activities and to promote the activities of the Action to the public. The Dissemination Manager shall oversee the writing of reports arising from the collaborations as well as managing the implementation of an Action website. The Dissemination Manager will arrange for the website to be kept constantly updated and will ensure that its full functionality, both the part of the website for general public access and the secure area only for Action participants, is maintained.

The Management Committee shall appoint a Conference Manager who will bear responsibility for overseeing the organisation of conferences and seminars, expected to be held at locations from which there are also groups participating in the Action, in association with those local participants. For the inter-group transfer of knowledge through short-term scientific missions of scientists between research centres, the Management Committee will appoint a Short Term Scientific Mission Manager who will coordinate those short-term scientific missions with the partners involved. Within this remit will be responsibility for arranging and coordinating workshops and training schools for broader groups within the network of participants.

We are absolutely committed to rectifying the current gender imbalance in research. During the Action, female researchers will be especially encouraged to attend, participate in, and present their work at conferences, and to participate in STSMs.

Young scientists' careers will be given special attention by providing extra opportunities for oral presentations at conferences and seminars to present their results.

A key problem with multidisciplinary research is that researchers from diverse areas often do not understand the needs or capabilities of those researchers working in different areas. Therefore, while workshops will be focused on more high-level, specialized topics, a key goal of training schools will be to offer an overview on the current understanding and the needs of specific expertise from other areas of science. This will foster new thinking between researchers working in different areas and will also strengthen the Action by opening new avenues of communication and knowledge transfer among participants.

Major milestones during the Action will include the implementation of the Action website, the first Management Committee meeting for senior researchers, the first training workshop for early-stage researchers and the first hosting of a targeted seminar with the participation of key industrial actors and policy makers.

3.3. NETWORK AS A WHOLE

The network includes the leading scientists from all different aspects of chemobrionics, from both all areas of Europe (see Section 3) and the world, covering every scientific aspect of chemobrionics and including its extension to the arts. Expansion of the network to any interested party across Europe or partner countries is both envisaged and encouraged. The exchange between working groups and workshops will promote the network as a whole. The structure of the network ensures balance between different research areas and between different European zones.