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

Brussels, 24 May 2013

COST 011/13

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action ES1302: European Network on Ecological Functions of Trace Metals in Anaerobic Biotechnologies

Delegations will find attached the Memorandum of Understanding for COST Action ES1302 as approved by the COST Committee of Senior Officials (CSO) at its 187th meeting on 15-16 May 2013.

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

COST Action ES1302
EUROPEAN NETWORK ON ECOLOGICAL FUNCTIONS OF TRACE METALS IN ANAEROBIC BIOTECHNOLOGIES

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

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

2. The main objective of the Action is to grow a critical mass of stakeholders interested in understanding TM interactions in AD environments.

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 52 million in 2013 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 IV of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

A challenging area of anaerobic digestion (AD) research remains largely unchartered with respect to understanding the role of trace metals (TMs) in enabling biogas production. This major knowledge gap and scientific challenge is a multifaceted problem involving metal chemistry, physical interactions of metal and solids, microbiology and technology optimisation. Moreover, the fate of TMs, and the chemical speciation and transport of TMs, in environments - often agricultural lands - receiving discharge waters from AD is completely unknown. The Action aims to grow a critical mass of stakeholders interested in understanding trace metal bioavailability and microbial interactions in anaerobic environments and soils. Five Working Groups (i.e. Chemical speciation and bioavailability; Microbiology; Engineering; Fate of TMs in the environment; and Modelling) are defined, where cooperation between, and integration of, the Working Groups will be emphasized. The COST Action will allow the establishment of a strong European network, including Early-Stage Researchers. The problem has major environmental, economic and social significance, and the network will disseminate findings to the scientific community, water industry, policy makers and the rest of society.
Keywords: Metal bioavailability, anaerobic biotechnologies, metal speciation, environmental engineering, renewable energy

B. BACKGROUND

B.1 General background

Anaerobic digestion (AD) is an attractive bioenergy and wastewater treatment technology. The comparative advantages of AD for wastewater treatment, when compared to conventional aerobic systems, include: production of a useable fuel (biogas/methane); higher organic loads; reduced carbon footprint; lower quantities of sludge generation; and suitability for integration into a wide variety of process configurations and scales. AD is increasingly applied world-wide; in 2011, 8,760 anaerobic digesters were reported in Europe, most of which were used to produce renewable energy from organic feedstock, itself a limited resource. Internationally, the research effort to maximize biogas yield has increased 10-fold over the past decade. Yet a critical research question still remains open: How does trace metal availability limit biogas yield and how can this limitation be engineered out of the system? To answer this question with confidence, in such a complex matrix of substrates, microorganisms and chemical products, requires the synthesis of new research consortia spanning fundamental molecular sciences to engineering applications; only then will the underpinning science be coupled successfully to engineering-led systems, benefitting end-users and producing more renewable energy for Europe. The establishment of a multi-disciplinary research consortium to address this challenge is the motivation for this Action.

B.2 Current state of knowledge

The beneficial and inhibitory/toxic effects of trace metals (TM) in anaerobic treatment processes have always been an interesting topic for researchers, not only TM but chalcogens as well which includes the elements selenium, tellurium, radioactive polonium. Chalcogens, even they are not metals, would be included in the term TM in the present proposal. The roles of TM in anaerobic processes are actually also significant. The anaerobic fermentation and microbial growth is dependent on the availability and/or optimal supply of nutrients. Free metal ion availability is an important parameter that should be taken into account. The requirements of iron (Fe), nickel (Ni), cobalt (Co), molybdenum (Mo), selenium (Se) and tungsten (W) of various methanogens have already been reported. Furthermore, the effects of trace metals like Fe, Ni, Co, Zn, Mo and Cu on anaerobic treatment of various types of industrial effluents have also been investigated in detail. On the other hand, trace metal requirements of agricultural biogas digestion systems operated with solid organic matter such as energy crops, animal excreta, crop residues and the organic fraction of municipal solid wastes (OFMSW) are seldom reported in literature, despite the exponentially-increased interest in biogas production from renewable sources.

Since industrial wastewaters and sludge contain elevated amounts of trace metals, most of the previous research activity has obviously been directed towards investigating the inhibitory and toxic effects of these elements on anaerobic wastewater treatment bioprocesses. During anaerobic conversion of energy crops, animal excreta, crop residues, OFMSW or any other type of organic wastes (i.e. food wastes) to biogas-methane, the availability or lack of trace elements such as Fe, Co, Ni, Zn, Mo, W and Se definitely play a significant role in maintaining a stable and an efficient conversion process. Recently, several scientist involved in one EU FP7 project entitled "Valorisation of Food Waste to Biogas (Valorgas) (http://www.valorgas.soton.ac.uk/index.htm) showed that food waste appears to be deficient in some trace elements required by the anaerobic digestion process when operating at high ammonia concentrations. Such findings have major implications for successful - and expanded - application of AD technology.

Depending on the type of substrate to be digested; digester type; and the digestion procedure (mono or co-digestion) employed; trace metal requirements of digesters can theoretically be provided through the substrate, such as by co-digesting with sewage sludge, OFMSW or animal excreta, or externally by using chemical additives. Agricultural biogas plants operating with energy crops, such as maize and grass as mono-substrates, can sometimes face suboptimal digester performance without any obvious reason at first glance, but the volatile fatty acids (VFAs) concentrations could range between 3 and 5 kg m^{-3}. Then, the lack or unavailability of micro-nutrients (i.e. trace metals) should be the first reason to be questioned. In addition to the determination of the bioavailable fraction of trace elements added in digesters, the application of advanced molecular biology techniques to determine, and understand, the impact of TMs on the methanogenic, and various bacterial, species is urgently required to determine the real demand of microbial groups for these micro-nutrients. It may, in fact, be that case that different groups underpinning the successive and cooperative stages of the AD process might respond differently to, and require different concentrations of, TMs, which would present yet further complexity but also offer exciting opportunities to enhance the activity of target microbial groups. Since performance dictates the commercial viability of anaerobic digestion, more attention to managing the trace element needs of the given process would improve the overall prospects for the technology. However, the addition of macronutrients should also provide a digestate that complies with certification limits on heavy metal contents in bio-fertilizer for farmland application.

B.3 Reasons for the Action

The use of TMs to promote biogas production features prominently on the agenda for many biogas-producing companies. However, the application of the technique is often characterized by trial-and-error methodology due to the acute lack of any substantial or basic knowledge on the impact of TMs in anaerobic digestion under different process conditions. The present Action will address this problem. Thus, this Action will develop a fundamental, scientific understanding of how TMs behave and interact in AD bioreactors, and the fate of TMs released into the environment. We aim to predict bioavailability characteristics, interactions with microbial populations and the impact on biogas production. This will be translated to engineering protocols such as targeted dosing methodologies that will contribute to enhancing AD process performance while minimizing environmental contamination.

Furthermore, this Action is a valuable instrument to improve waste treatment and biogas formation as renewable energy in Europe, as well as in important markets in other parts of the world. Waste treatment and water sanitation are the major challenges in the Global South, but also in European countries where lower carbon footprints are required in the water infrastructure. The Action contribution to improve waste treatment and maximize useful biogas production, while minimizing release of TM into the environment, will have tangible environmental and socio-economic impacts. This Action embodies ‘excellence with impact’ and provides valuable new information that will underpin important technological developments.

The area of TM availability in, and supply to, AD calls for studies from several angles. Therefore, efforts from a multitude of research areas are needed and the area is by necessity interdisciplinary. Thus, the TM research draws on: physics e.g. rheology, diffusion, adsorption; organic, inorganic, physical and analytical chemistry; microbial physiology, genetics and biotechnology (lab.-, pilot- and full-scale systems); agronomy and forestry biofertilization, etc. Many of these areas are the basis for the research presently taking place within the laboratories of each of the individual partners involved in the suggested COST Action. This means that the consortium has an inherently wide competence, which will be explored jointly to achieve a much stronger momentum for the development of the role and use of TM to enhance biogas production in Europe.

B.4 Complementarity with other research programmes

There are several FP7 programs that consider the interactions between ecosystems and human activities. COST Action represents a unique means for European researchers to jointly develop their own ideas and new initiatives across different scientific disciplines relevant for renewable energy (biogas) production from almost any organic substrate, through trans-European networking of nationally funded research activities. It is an extremely attractive opportunity to create a network composed of industrial and scientific specialists from different areas, which will be working on the development and transfer of innovative treatment technologies and operation strategies that contribute towards a sustainable future. This Action will complement research carried out in more specific programmes (e.g. FP7) and constitutes a perfect starting-point of more business oriented networks, as for example Eureka. It is also an excellent platform for the creation of new and successful projects in the future EU Framework Program (Horizon 2020).

The consortium includes researchers supported by the European Research Council (ERC), and several partners of this consortium participate in Erasmus Mundus and Marie Curie Actions in order to promote training, mobility and career development of their researchers. This COST Action will complement this European Program by providing networking opportunities for the Early Stage Researchers (ESR) involved.

C. OBJECTIVES AND BENEFITS

C.1 Aim

The aim of the Action is to grow a critical mass of stakeholders interested in understanding TM interactions in AD environments. Through the interaction between researchers and innovators from the industry sector, especially small and medium enterprises (SMEs), a fundamental scientific understanding will be developed of how TM behave in anaerobic environments and how they migrate through the environment. This will result in high quality research publications that establish an early track record for this new, but urgently necessary, interdisciplinary research community. Training of young researchers will be emphasized in order to create a creative environment where students can experience international cooperation at the highest scientific level, and alongside experienced scientists and engineers.

C.2 Objectives

- Scientific objectives:
  - Chemical speciation and bioavailability of TM in both anaerobic technologies and in the environment
  - Dynamics of the microbial populations as a response to changing concentrations of different TM
  - The impact of TM on the range and concentrations of useful microbial products
  - Assessment of the impact of technological aspects on the fate of TM in anaerobic bioreactors
  - Fate of TM in environment
  - Modelling of anaerobic digestion systems

- Networking objectives:
  - Creating interdisciplinary discussion platform where researchers will meet professionals from the industry
  - Setting-up a training network for young researchers
  - Promote the role of young researchers in the networking activities, especially during the Short-Term Scientific Missions and visits between partners
  - Acting as precursor of successful projects in Horizon 2020
  - Give clear guidance on sustainable TM management in both technological applications and in the environment (deliverables: book + Decision Support System) useful for different stakeholders

C.3 How networking within the Action will yield the objectives?

Yielding scientific objectives

All the partners involved in the Action currently have research funding for their area of expertise. The Action will draw together these different research initiatives to create a new, coherent research community that has a high level of interaction and cooperation, creating a discussion platform, and a strong focus, to integrate the research findings of these on-going projects.

Yielding networking objectives

Regular meetings (workshops) will be organized to create a **multi- and inter-disciplinary discussion platform**. Lecturers from both academia and industry will exchange knowledge in order to tackle TM related issues in their complexity.

The **training of young researchers** will be done through these workshops, where they will be encouraged to actively participate and through Short-Term Scientific Missions and visits between partners.

Support from COST will facilitate the **preparation of multi-disciplinary proposals** for strategically-relevant research funding calls, especially within **Horizon 2020**. Calls such as the ERC Synergy Grant would provide an excellent opportunity to propose high-risk-high-gain work plans to promote innovation on this topic. The coordinator of the Action is in an ideal position to apply for an ERC Starting Grant for TM supplementation. Indeed, one of the partners already holds an ERC Starting Grant. The group will identify suitable topics for the ERC Proof of Concept call, as well as to leverage matching funds from strategic industrial partners.

The Action plans to offer **guidance on sustainable TM management**, intensive cooperation with industry is foreseen, which will facilitate the transfer of the gained knowledge into practice. Each of the partners has an established network within both SMEs and larger companies. This Action enables the industrial partners to cooperate and give practical feedback to the research partners involved.

C.4 Potential impact of the Action

The Action contribution to improve waste treatment and maximize useful biogas production while minimizing release of TM into the environment will have tangible environmental and socio-economic impacts. The Action will actively promote new approaches for the conception and application of new technologies, going beyond a strict technological threshold by considering a more holistic perspective. This means that the Action has an inherently wide competence, which will be explored jointly to achieve a much stronger momentum for the development of the role and use of TM to enhance biogas production in Europe. The active collaboration among professionals from Industry, technological Centers and University will promote the effective transfer of innovative, cost-efficient and environmentally friendly technologies, thus contributing to an increase in the competitiveness of European waste treatment companies. These developments will be carried out in the frame of their economic feasibility, reliability, environmental impact (especially in terms of energy efficiency, Greenhouse Gas (GHG) footprint) and resource recovery possibilities, thus resulting in effective benefits for environment (less impact), economy (lower operational costs and maximal biogas production) and society (safer waste stabilization).

C.5 Target groups/end users

The interest of this Action for end users is demonstrated by the inclusion of industrial partners that have actively collaborated in the preparation of the proposal and that will participate in the networking activities. It is a main aim of this Action to foster the transfer of innovative technologies to full-scale applications.

Exploitation of results will be performed by companies dealing with the design, construction and management of anaerobic biotechnologies. Also water agencies will benefit from the results obtained as they will have updated know-how on the newest developments in this field.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The scientific challenge to be addressed by the Action is a multifaceted problem involving metal chemistry, physical interactions of metal and solids, microbiology and technology development and optimisation. Moreover, the fate, as well as chemical speciation and transport of TM, in the environments where anaerobically digested materials are disposed (often agricultural land) is completely unknown. The Action will grow a critical mass of stakeholders interested in understanding trace metal bioavailability and microbial interactions in anaerobic environments and soils.

D.2 Scientific work plan methods and means

Five Working Groups (WGs) are defined. Cooperation between, and integration of, the WGs will be emphasized:

WG1: Chemical speciation and bioavailability

The total metal concentration, the conditions during digestion such as pH and redox potential, and the kinetics of reduction, precipitation, complexation, and adsorption are expected to play a key role influencing the chemical speciation of micronutrients in liquid phase and biofilms. The increasing pH decreases solubility of metals in the matrix. The precipitation of metals by sulfide (S^{2-}), carbonate (CO_3^{2-}), and phosphate (PO_4^{3-}), and their deposition in the bioreactor sludge plays an important role in the nutrient turnover of macro- and micronutrients. There is also probably a strong interaction of added Fe and the micronutrients in the matrix: micronutrients may react with the Fe-sulfide releasing Fe^{2+}. The resulting Fe^{2+} may form precipitates as hydroxides ($Fe(OH)_2$) or carbonates ($FeCO_3$). Consequently, bioreactors have a considerable ability to sequester Fe^{2+}-ions in the sludge. Simultaneously, non-alkali metals (e.g. Ca^{2+}, Mg^{2+}) form soluble ion pairs with a number of anions: HCO_3^-, CO_3^{2-}, OH^-, SO_4^{2-}, S^{2-}, Se^{2-}.

Complexation reactions play an important role in bioreactors making a particular metal either more or less bioavailable. The level of soluble metals in the presence of CO_3^{2-} and S^{2-} may be increased by a factor of up to 10^4 by complexation, avoiding precipitation as carbonates or sulfides. Several authors describe a shift of micronutrients away from mobile forms toward more stable and less reactive and bioavailable forms during AD. However, in a growth chamber experiment, it has been found that AD does not reduce the plant bioavailability of micronutrients. The relevant processes driving the underlying effects are still not well understood. Furthermore, no data were found concerning the effects of a long-term digestate field application on the heavy metal accumulation in the soil and their bioavailability to plants (WG4).

WG1 will therefore focus on the development of new, direct and speciation-preserving analytical techniques applicable to study the interactions of TM within the AD environments, especially biofilms. The main challenge is to develop techniques *for in situ* use under dynamic conditions. The transport and immobilization phenomena still need to be understood regarding the physico-chemical heterogeneity of anaerobic biofilm and suspended stirred systems.

The analytical results (e.g. quantity of single species) can then be linked with specific microbial activity rates. Similarly, advanced chemical analyses will be adapted to be suitable for AD environments and further applied to determine organic and inorganic complexation. Additionally, information on the minerals and organic phases present in the biofilm matrix is required to better assess the impact of such phases on the spatial chemical heterogeneity encountered in biofilms at the micro-meter (i.e. cell) scale.

How are the chemical forms of TM related to bioavailability? In order to answer this question, the following aspects will therefore be discussed:

- Trace metals speciation in liquid and solid phases. At this stage recent analytical techniques still need to be developed or adapted (e.g. use of DGT (Diffusive Gradient in Thin film), ion selective electrode or DMT (Donnan Membrane Technique)) (Bartacek et al., 2008). In parallel a better characterization and quantification of the soluble Extracellular Polymeric Substances (EPS) and Dissolved Organic Matter (DOM) have to be developed due to the role of such organic macromolecules in TM complexation.

- Characterization of the organic (EPS) and mineral (more especially sulfur, phosphate and iron minerals) solid phase is therefore required in order to interpret the liquid phase speciation data. Molecular information regarding the mineral phase could be accessible via X-ray absorption spectroscopy. In addition, spatial EPS heterogeneity of the biofilm could be investigated by Confocal Laser Microscopy; however, sample preparation techniques should be developed.

- The link between the TM speciation in the liquid and solid phase, respectively, require the determination of trace metals leachability (i.e. a proxy for bioavailability?). At this stage a simple procedure still need to be developed despite that the acid volatile sulfide (AVS) extraction and semi-continuously extracted metals (SEM) methodological approaches gave promising results.

WG2: Microbiology

Successful AD requires long-term, stable and efficient metabolic conversions to be maintained, despite real-world process fluctuations. Further development and optimisation of AD requires better knowledge of the mechanisms occurring on a microscale, which should in turn be linked to the macroscale system performance and behaviour. Despite this, the relationship between the dynamic behaviour of microbial communities and environmental parameters in AD has hardly been studied . Indeed, there is a pressing need for more and better information on the biology, rates and limitations of microbially-mediated processes. Thus, the weakest component of many AD bioreactor operations is the available information on the structure, dynamics and functions of the microbial community underpinning digestion and biogas production. WG2 will focus on the microbial populations comprising AD biofilms and the impact of TMs, and of changing TM concentrations in bioreactors, on community structure; population dynamics; and the metabolism of individual trophic groups and the meta-community. An innovative and holistic approach is the basis for this task, integrating polyomics (genomics, transcriptomics, metabolomics and fluxomics), microfluidic cell counting and sorting, and ecological modelling will be explored.

System approaches such as this determine the DNA sequences of the meta-organism under study; the collectively-transcribed RNA; the translated proteins; and the metabolites resulting from cellular processes. Ultimately, the goal is to allow for *in silico* prediction of ecosystem attributes, which, in the AD context, should support process optimisation with reference to TM concentrations and bioavailabity, and the development of new applications. Metagenomic data accounts for the functional potential of the ecosystem, but does not provide many insights into microbial activity. Metatranscriptomics is one step closer to the identification of active metabolic pathways, but does not allow for translational regulation to be taken into consideration. Metaproteomics provides significant insights into microbial activity together with metabolomics, which is the study of the intermediate and end-product of cellular processes. The application of proteomics in conjunction with metabolomics has been demonstrated in an acid mine drainage ecosystem. In turn, the analysis of metabolites strengthens metaproteomics results with respect to the identification of active metabolic pathways, but it can also, through the application of labelled substrates, elucidate the metabolic fluxes of cells and interactions taking place within microbial populations. Finally, Flux Balance Analysis (FBA) is used to find a set of fluxes through the network that satisfy this stoichiometry. FBA is well established for single species but how best to extend these models to a multi-species community is still an active area of research. In AD, ***ecosystems biology models*** have great potential for predicting, and hence supporting optimisation and management of, microbial community function. Thus, the focus of WG2 represents a comprehensive strategy to understand the develop probabilistic models incorporating the stochasticity necessary to reflect the environmental conditions in bioreactors that can be used to identify functionally-important groups of microbial individuals in AD systems, and the impact of TM on those microbes. Finally, WG2 will focus on developing and commercializing quantitative, molecular diagnostics tools to monitor the metals-related ‘health’ of those functional groups.

WG3: Engineering

The influence of reactor features, such as mixing, hydraulics or operational mode (e.g. continuous or batch), has not yet been properly investigated. In completely mixed anaerobic reactors, precipitation of metals confers no advantage in terms of metals retention in the digester and hence dosing of metals as soluble complexes could be advantageous to improve their availability for microbial uptake before the metals are washed out. Conversely, anaerobic reactors that decouple the biomass retention time from the hydraulic retention time, such as UASB (Upflow Anaerobic sludge Blanket) and SBR (Sequencing Batch Reactor) digesters, are likely to benefit from being dosed with metals in a non-complexed form so that the metals will precipitate and accumulate within the biomass sludge fraction, from which they can be assimilated more slowly by the microorganisms as they are required. This is highly likely to be more cost effective than dosing complexed metals that remain in the soluble phase and are washed out of the reactor in a matter of hours, even if there is a trade-off in bioavailability. Another engineering aspect that is particularly relevant to CSTR-type digesters (representing the vast majority of sewage sludge and agricultural slurry digesters) is the mixing pattern present in the vessel. These reactors are rarely well-mixed and hence often consist of different zones; research is in its infancy to understand how mixing patterns might influence the microbiology of a digester and to relate this to biogas output. It is likely that the creation of micro-environments within a digester affects the microbiology of that mixing zone and also the chemistry and hence, logically it could be proposed that the speciation and bioavailability of metals within a CSTR will differ depending on the mixing regime and the particular mixing zones created within the vessel. WG3 will combine the knowledge gained by WG1 and WG2 for better understanding of the impact of technological aspects on the speciation and hence bioavailability of TM in anaerobic bioreactors. This information will be translated into engineering outputs, such as targeted dosing methodologies to enhance AD process performance.

WG4: Fate of TM in environment

Metal species are formed exclusively in the extremely reducing, organic and metal rich conditions during AD, either as microbially formed inorganic-organic precipitates (so called biominerals) or as organically complexed species. After AD, TM are released into the environment (i.e. soils and composts) via different routes of entry (i.e. suspended / dissolved in effluents or in solid as excess biomass). Once outside the reducing conditions of AD fermenters, they face oxidizing conditions that may favour their transformation to other thermodynamically stable species. WG4 will use the tools and knowledge gained in WG1 to study the fate (redox-stability, sorption, mobility, and bioavailability) of these TM species in different relevant environmental compartments, such as fresh waters, sediments and soils. As special focus will be given to biominerals that occur as result to different dosing strategies (WG1, WG3), since they may bear a considerably different environmental fate in contrast to chemically synthetized analogues. For instance, biominerals of zinc sulfide (regularly formed in AD), were shown to have a unique environmental distribution due to extracellular protein modifications on the mineral surface - a result of the microbial origin (Moreau et al., 2007). Due to their altered physico-chemical properties, biominerals can thus not be appropriately assessed by standard speciation and transport modelling or risk-assessment methodologies. WG4 will study:

- TM speciation together with WG1 (i.e. oxidative dissolution, phase transformations, complex stability), distribution, and eventually bioavailability to model organisms using the latest state-of-the-art methodologies. For speciation, a special focus will be given to direct, species specific methods in solid (i.e. XFAS) and liquid phase [e.g. (LC)-ICP-MS/AFS; high-resolution MS] (WG1).

- Biominerals distribution will be studied in model systems (water – sediment/soil) using pristine (i.e. freshly prepared in anaerobic conditions) and deteriorated (i.e. oxidatively degraded) state. Bioavailability will be studied both in model in vivo (e.g. *Daphnia, Danio rerio*) and *in vitro* (cell lines) systems.

- Direct information on metal speciation in changing redox conditions and data on bioavailability and toxicity may thus serve as input to state-of-the-art methods for risk assessment of heavy metals in the environment for policy makers. For instance, oxidative dissolution data may be included in the biotic ligand models (BLM) as a second-tier risk assessment tool, recently approved by the Scientific Committee on Health and Environmental Risks (2010).

WG5: Modelling

The anaerobic digestion (AD) of biomass is a multi-stage process involving different types of microbial species. In addition to macronutrients such as carbon, nitrogen, phosphorus and sulphur, specific TM such as cobalt, nickel, tungsten or molybdenum play a crucial role in the growth and metabolism of anaerobic microorganisms where they are essential for many physiological and biochemical processes. The speciation can influence both kinetics and physics of anaerobic digestion as there is a different metal uptake rate and a different diffusivity of TM in biological biofilms depending on the TM speciation (WG1).

WG5 aims at developing an up-grading of the anaerobic digestion model N°1 (ADM1) capable to describe and simulate the effects of TM and TM speciation on AD biochemical processes.

The mathematical model will present the following peculiarities:

- Differential dynamic equations capable to describe the speciation of all TM present in the biological system taken into account. In particular these equations will give the dynamic concentrations of each TM species.

- Differential mass balance equations for substrates, products and bacterial groups involved in the anaerobic digestion process, including the biochemical reactions of the substrates conversion and the kinetics of microbial growth and decay that take into account the speciation effects.

- A redox potential modelling to determine the redox potential of the biological system, which is needed for the two above objectives.

- A differential parabolic equation able to model the diffusivity phenomena in a biofilm system. In particular this equation will consider the different diffusivity constant of each TM species.

The experimental data obtained by WG1, WG2, WG3 and WG4 will be used to calibrate and validate the mathematical model.

E. ORGANISATION

E.1 Coordination and organisation

The "Rules and Procedures for Implementing COST Actions" (doc. COST 4154/11) will be followed when defining the composition and the responsibilities of the Management Committee (MC). The Steering Committee (SC) will be constituted by the Chair of the Action and the Leaders of the five Working Groups (WG) ensuring fluent interactions. The role of the SC is to ensure that the advices and recommendations arising from the MC are taken into account by, and integrated into the tasks of, the different WGs. Each WG will be coordinated by two persons (Chair and co-Chair), when possible with Scientific and Industrial profiles, and supported by a secretary, who will be represented by an Early-Stage Researcher (ESR). Continuous inter-WG discussion will be encouraged: optimum use of file-sharing platforms and an internal ‘members area’ of the Action website will facilitate discussions and data sharing. Early integration of the literature pertaining to each WG’s activity will also support the production of novel, interdisciplinary literature reviews, which will set the tone for the Action and also define the field for other interested research groups and consortia. In addition, WG Leaders will meet once or twice in each year to review progress, develop strategy and to respond to an unforeseen problems or opportunities. Meetings with all partners will be scheduled each year.
Young researchers involved in the Action will be strongly encouraged to attend these meetings and to make short research visits within the partners of the consortia in order to facilitate ESR training and the transfer, and exchange, of knowledge. The industrial partners involved in the Action will take part actively for implementation of the research. Defined end-user-relevant topics will be addressed via ‘industry-meets-academia’ symposia and short training courses. Already some exciting formats for this aspect of the management have been identified and discussed. The consortium will take a proactive approach to exploit opportunities as they arise. The Action will be open to other research groups/SMEs that express interest and who offer strategic and complementary skills. Additional SMEs, such as those engaged in marketing TM cocktails for bioprocesses, or those involved in AD of feedstocks not already covered by the consortium, will be encouraged to join the Action to help enhance and expedite the potential for translational research. COST Action is implemented through a concerted action, which means that the research is carried out in and funded by the participating countries by means of their own research projects financed by

national and European calls, while COST provides the necessary co-ordination by means of the networking activities described below. A dedicated, interactive website will be launched in which all relevant documents will be placed, thus facilitating further discussions on particular topics. This web site will be up-dated after the semi-annual meetings. The Action will also exploit social media, including Twitter, YouTube, LinkedIn and Facebook; all of those will be strategically linked to the social media accounts of the participating research centres, universities, companies and professional bodies (e.g. International Water Association, etc.), for maximum impact and dissemination of the findings. At the end of the Action a final Congress, open to the scientific and industrial community, will be organized. Short-Term Scientific Missions (STSM) and exchange visits mainly among ESR of the network presenting different backgrounds and belonging to different WGs will be encouraged as a way of fostering effective interactions (around 10 STSM + 10 visits during the Action). The aim is to increase the mobility of researchers across Europe in order to share techniques, instruments and knowledge among partners and to avoid duplicity. The whole set of networking activities will not only allow the establishment of scientific excellence, by building a strong network on the topic, but also the dissemination of the scientific results created during the Action to the scientific community (scientific papers, communications in congresses, etc.), water industry (workshops, engineering journals, leaflets, etc.) and policy makers (policy recommendations, press releases, news flashes, etc.).

E.2 Working Groups

The coordination of the WGs is attributed to a Chair, co-Chair and a secretary. To favour discussion among experts with Scientific and Industrial profiles, both will be represented in the coordination. The WGs will meet each year during the first day of the annual MC meeting, when the specific issues of each WG will be discussed (e.g. research topics, main results, interaction possibilities with other WGs, possibility for applying jointly to European projects). Additionally, semi-annual distance meetings of each WG will be held (videoconference, Skype, etc.).

E.3 Liaison and interaction with other research programmes

Research carried out by the participants during the COST Action is financed by national and European projects. The aim is to share the relevant outcomes of these projects with COST Action partners during the workshops and meetings. The knowledge developed in the European Research Programs will also be included in the Training School programs. Mobility of ESR during the Action will be combined with mobility of partners participating in Marie Curie programs during the STSM. The active collaboration among Industry and Universities promoted in this Action will be a key issue for enabling future collaborations through specific Programmes (e.g. Marie Curie Industry-Academia Partnerships, Research for the Benefit of SMEs, etc.).

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

ESRs will be actively involved in the coordination of the WG as secretaries, thus participating in all WG meetings. Additionally an ESR Board will be created, with responsibility for organization of networking activities targeted to young researchers (e.g. on-line forum on the web-site as think tank, get-together during workshops, etc.) as well as to communicate their concerns and opinions during the WG meetings. Training Schools and STSM will be especially targeted to ESR. The network will encourage and actively support ESR during the preparation of collaborative projects to be presented to the EU Framework Programme.

F. TIMETABLE

		Year 1				Year 2				Year 3				Year 4			
WG1. Speciation and bioavailability	Liquid phase	X	X	X	X	X	X	X									
	Solid phase		X	X	X	X	X	X	X								
WG2. Microbiology						X	X	X	X	X	X	X	X	X			
WG3. Technology						X	X	X	X	X	X	X	X	X	X		
WG4. TM fate in environment								X	X	X	X	X	X	X			
WG5. Modelling											X	X	X	X	X	X	X
MC meetings and workshop		X[1]				X			X				X				X[2]
STSM and visits		X	X	X		X	X	X		X	X	X		X	X	X	
Training Schools									X				X				

1) Kick off meeting. 2) Final Congress

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, CH, CZ, DK, ES, FR, IE, IT, NL, PL, SE, TR, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 52 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?

There are four stakeholder groups that will participate in and benefit from research into the fate and bioavailability of metals in the AD process. These are: the academic research community; industry; legislators and policy makers and the general public. The academic research community is key to the success of this research, from elucidating the fundamental understanding of the processes to developing innovative practical applications of the research outputs. Both require cooperation of a critical mass of academics working in the fields of microbiology, engineering, waste and wastewater treatment, modelling and the natural environment; currently, critical mass in this field is small, hence outputs from this COST Action will be targeted from early on in the process, to grow this research community. Industry is the end-user of any innovation but will also be involved in the research and development process so that there is a rapid and accurate feedback loop. Policy makers and legislators are likely to have an influence on the application of research outputs to market, particularly where there are implications for metals to be carried over into the natural environment. All researchers have a duty to inform and engage the general public about research and related social and environmental issues. As the subject of this COST Action has direct relevance to bioenergy, waste production and ultimately, climate change, it is important that dissemination methods are chosen to publicize the research within these more recognizable themes; particularly targeting school-age children to develop their environmental awareness and knowledge of technology and research.

H.2 What?

Academic research community: Although the physico-chemical environment of an anaerobic digester is recognised as being a vitally important influence on the process and ultimately the extent of biogas production, understanding these processes lags behind the biochemical and microbiological processes. It is important to excite the imagination of the big AD research groups in the world so as to generate the required critical mass of thought and cooperation. To do this it is needed to be very pro-active in promoting this research area in an inclusive fashion, through workshops and Working Groups. There are already well established conferences in the field of anaerobic digestion, for example the IWA conference AD13 to be held in Spain in June 2013, where it will be possible to hold a workshop meeting to publicize this COST Action network and to facilitate international research cooperation. The COST Action network will provide a framework to enable the coordination required to tackle this multidisciplinary problem. Through the IWA it is also possible to set up specialist groups; it already exists an AD specialist group and the Action will set up a sub-group for research relating to the biogeochemistry of trace metals in anaerobic digestion and to promote this through the young water researchers programme to draw new researchers into the area and the already established newsletters. This dissemination route will be linked to a website set up and maintained by the COST Action researchers, which will act as the central point for linking researchers and enabling discussion and sharing of information. All traditional routes for publication, e.g. conference and academic papers and presentations will be used to communicate with the research community and will be publicized and accessible through this website.

Industry; legislators and policy makers: all industry participants will be linked with the anaerobic digestion community and it hence makes sense to use collective bodies to widely disseminate research outputs to the full remit of potential users. For example, in the UK there exists ADBA (the Anaerobic Digestion and Biogas Association) which is a very active trade association with a wide range of industry members (including nutrient supplementation companies, the water industry, bioenergy and biogas companies, environmental consultants, policy makers and legislators, as well as the academic research community). ADBA will publicize related research articles through its monthly newsletters and holds a national conference and annual research forum to identify research needs and disseminate research findings that relate to the AD industry. Similar bodies have already been identified for other regions, e.g. Biogaz Vallée in France (http://www.biogazvallee.eu/) and IBBK in Germany (International Biogas and Bioenergy Centre of Expertise, http://www.biogas-training.co.uk/). These and other collective AD bodies will be actively targeted by the COST Action for dissemination of research through articles, papers, presentations, attendance of workshops and membership of technology groups and research forums.

The general public can be reached through a variety of media. Some of the most effective are through radio shows and development of podcasts. For example, through a radio station/website such as The Naked Scientist (http://www.thenakedscientists.com/) that welcomes and aids scientists to disseminate their research into a form that is interesting and accessible to the general public. This includes development of on-line scrapbooks that communicate complex research ideas in an accessible, interesting format, through simple animation. These are particularly suitable for school-age children. For example, at some universities, doctoral researchers are being specifically media trained to disseminate their research to the general public and being encouraged to go into schools and talk to the children, with the aim of disseminating research and encouraging the next generation of scientists. As part of this, doctoral students can undertake training and get funding to make short video clips of their research. Additionally, the social media tools (Section E) will be used to further reach public audiences. Many of these more innovative dissemination methods will also be very effective in reaching other audiences (industry, academia) and anticipating a cross-fertilisation of ideas which will make optimum use of all the available technology and opportunities for dissemination.

H.3 How?

The dissemination programme will radiate from the COST Action website, which will form the central point, and launching pad for all tools used by the dissemination effort and for all the material produced and be key to engaging and developing networks of interested parties. It is intended that dissemination will commence early on in the COST Action as it is vital to grow the critical mass of the research community and to attract interest and funds from industry. The website will publicize events, workshops and provide links to all published material, as well as providing opportunity for discussion throughout the duration of the COST Action.