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

Secretariat

Brussels, 11 July 2006

COST 258/06

MEMORANDUM OF UNDERSTANDING

Subject : Memorandum of Understanding (MoU) for the implementation of a European Concerted Research Action designated as COST Action 543 Research and Development of Bioethanol Processing for Fuel Cells (BIOETHANOL)

Delegations will find attached the Memorandum of Understanding for COST Action 543 as approved by the COST Committee of Senior Officials (CSO) at its 165th meeting on 27/28 June 2006.

MEMORANDUM OF UNDERSTANDING
FOR THE IMPLEMENTATION OF A EUROPEAN CONCERTED RESEARCH ACTION
DESIGNATED AS

COST ACTION 543

Research and Development of Bioethanol Processing For Fuel Cells (BIOETHANOL)

The Signatories 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 400/01 'Rules and Procedures for Implementing COST Actions, or in any new document amending or replacing it, the contents of which the Signatories are fully aware of.

2. The main objective of the Action is developing new technologies for bioethanol (ethanol produced from ligno-cellulose materials) that can be used effectively in small-scale fuel cell systems of electric power output between 0.5 and 10 kW. The technologies cover low-temperature bioethanol reforming in hydrogen selective membrane reactors and cleaning methods as well as their combinations with any type of low-temperature fuel cell.

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 approximately 7 million EUR in 2006 prices.

4. The Memorandum of Understanding will take effect on being signed by at least five Signatories.

5. The Memorandum of Understanding will remain in force for a period of four 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 the document referred to in Point 1 above.

COST ACTION 543

Research and Development of Bioethanol Processing for Fuel Cells (BIOETHANOL)

A. ABSTRACT

The Action focuses on developing new technologies for bioethanol (ethanol produced from ligno-cellulose materials) to be used effectively in small-scale fuel cell systems of electric power output between 0.5 and 10 kW. The technologies will cover low-temperature bioethanol reforming in hydrogen-selective membrane reactors and cleaning methods as well as their combinations with any type of low-temperature fuel cell.

Catalysts for the bioethanol reformer operating at temperatures lower than 400°C, will be developed. Different hydrogen-selective membranes will be studied to obtain a high hydrogen gas purity with a good hydrogen permeability. Theoretical and experimental research work will focus on finding and optimising appropriate operating pressures and temperatures for the microreactor to achieve a good hydrogen gas yield with a good performance. Different methods to bring oxygen without a compressor from the air to the pressurised microreactors will be studied. These studies will include appropriate use of biophysical transport processes found in nature for osmotic flows with semi-permeable membranes. The research work is linked strongly to recent studies in biophysics.

To reach the targeted operating temperatures requires the cooperation of different branches of the sciences: thermal and materials engineering, catalyst and process technologies, nanotechnology, microreactor design, electrochemistry and biophysics. Successful results will be a result of the cooperation of both scientists and R&D workers in universities, research institutes and in industry.

Keywords: Hydrogen production from bioethanol, steam reforming, fuel gas processing and cleaning, membranes, low-temperature fuel cells, biophysics.

B. BACKGROUND

The Action is focused on developing a new technology for bioenergy, particularly for a bioethanol (produced from lingo-cellulose materials), to be used effectively in fuel cells for electric power and heat production. The technology will cover bioethanol reforming processes, the corresponding product gas (or fuel gas) processing and cleaning methods as well as appropriate combinations with selected low-temperature fuel cells.

Hydrogen production

Methane, methanol and liquefied propane (LPG) gases have been studied as fuel for fuel cells in stationary and mobile systems. Because of the disadvantages of these fuels (discussed below), the interest in bioethanol as a hydrogen carrier has increased greatly all over the world, especially in Germany and Switzerland, during the past few decades.

The transportation and use of liquid ethanol is much easier and safer than that of pure hydrogen gas (H_2). Bioethanol does not pose the same health risks for humankind as methanol. Moreover, bioethanol can be produced widely, whereas methanol is usually a side-product of certain limited processes such as the reforming of non-renewable fossil fuels. (V. Fierro et al., 'Ethanol oxidative steam reforming over Ni-based catalysts'. *Journal Power Source* (2005), in press).

In mobile applications, bioethanol is easier to use than a solid biomass. Furthermore, the amount of different organic emissions in fuel gases is higher from solid biomass gasification processes than from bioethanol steam reforming. The demands for fuel gas processing and cleaning of solid biomass gasification systems are more problematic than for bioethanol.

In previous studies of bioethanol reforming, the reforming temperatures, which have been very high (up to 900°C) have caused severe material problems. Without the use of membrane reactors, the lowering of the operation temperatures has caused the formation of high partial fractions of methane gas (CH_4) in fuel gas, which means remarkable hydrogen losses in fuel cell applications (J. Sun et al. 'H_2 from steam reforming of ethanol at low temperature over Ni/Y_2O_3, Ni/La_2O_2 and Ni/Al_2O_3 catalysts', *Int. Jour Hydr. Energ.* 30 437-445 (2005)).

The production of bioethanol from lingo-cellulose materials such as wood and various plants is economical when compared with the production of low sulphur petrol (ULSP) as fuel for road transport (European Commission 3.2.2004, N 407/2003 - UK). As early as 1999, the National Renewable Energy Laboratory in the USA estimated that the production cost of bioethanol would drop very steeply in an order of magnitude between 25 to 35% in the next decade as a result of improved yield and performance of biotechnical conversion processes. According to the European Electrical Component Manufacturers' Association (EECA), increasing consumption, increasing crude oil prices, and the current tax-free status of bioethanol for use in fuel are making it closer to being an economic option.

Different types of fuel cell

Low-temperature (under 100°C) fuel cells (PEMFC and AFC) do not operate well with fuel gases containing hydrocarbons, and therefore hydrogen gas should be as pure as possible. Solid oxide fuel cells (SOFC) have a good tolerance of hydrocarbons but as their operating temperature is high this causes materials problems. (Siddle A. et al, Fuel Processing for Fuel Cells – A status review. ETSU F/03/00252/REP). At present, SOFCs operate with natural gas at elevated temperatures of 850-1000°C or even higher, but low-temperature (500-600°C) solid oxide fuel cells (LTSOFC) are also being extensively studied.

RELEVANT LINKS AND COMPLEMENTARITY WITH EU RESEARCH PROGRAMMES

Concerning the effective use of biomass in distributed generation (DG) and production in Europe, the Action will be in agreement with the Kyoto Protocol and with the EU White_Paper on the Security of Supply of Renewable Energy, when the decrease of CO_2 emissions in the atmosphere is taken into account. The effective use of bioethanol and biomass in power production in DG systems will improve the economies of all European countries as a result of the decreased use of fossil fuels.

These are important objectives which are named and set as certain eligible boundary conditions in the EU Power directive, the RES-E directive, and also the CHP directive that relate to power production with renewable energy sources and, especially, small-scale energy production. These background details and directives give strong grounds for this COST Action to have an interaction and synergy with the EU's FP6 Sustainable Energy Systems, and also with many ongoing national hydrogen platforms all over the world ('H_2World', *The European Journal for Sustainable Hydrogen*, 22(2005)) . Especially, the COST Action will have synergy with the EU's Seventh Framework Programme.

WHY A COST ACTION?

A COST Action meets the criteria for widely exploited technological and economical medium- and long-term research activities that are concerned with research-related networking activities and with training. The main risks to be addressed are scientific and economic rather than market and financial. The Action will lead to the generation, exploitation and dissemination of new technical knowledge that will contribute to the development of energy and associated policies and standards. The Action has its strength in non-competitive research, in flexible multinational cooperation and in solving cross-border problems with the help of a multidisciplinary approach. It will add synergy and added-value in European research cooperation.

The Action provides the changes necessary to open the way for productive and fertile cooperation, especially concerning results and technological development, from preliminary studies to technical implementation.

C. OBJECTIVES AND BENEFITS

The main objective of the Action is developing new technologies for bioethanol (ethanol produced from ligno-cellulose materials) that can be used effectively in small-scale fuel cell systems of electric power output between 0.5 and 10 kW. The technologies cover low-temperature bioethanol reforming in hydrogen-selective membrane reactors and cleaning methods as well as their combinations with any type of low-temperature fuel cell.

The COST Action aims to disseminate knowledge and to produce a practical design-support tool for a broader community, which will enable interaction between different actors (e.g. industrial players, researchers and specialists in many disciplines, and end-users of small-scale fuel cell systems).

The Action focuses on the following **specific objectives**:

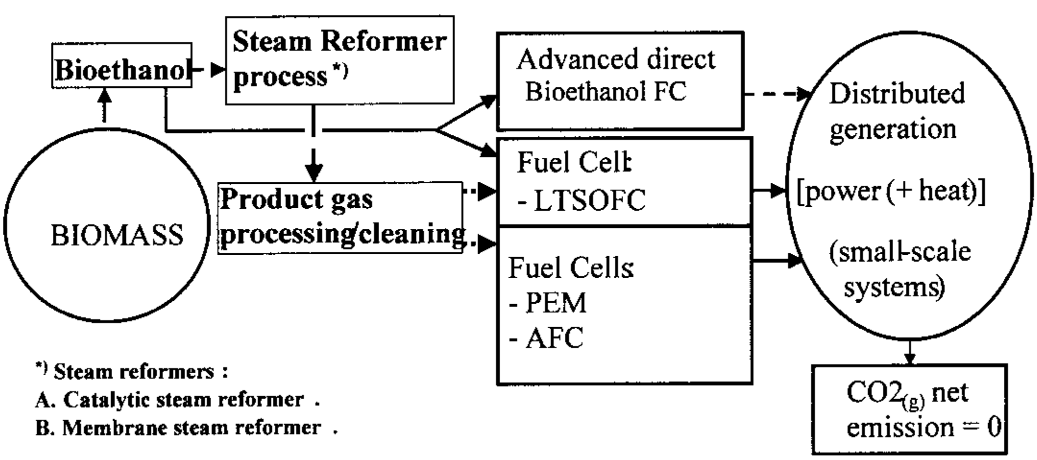
1. Increasing the awareness and commitment of different players and users to the bioethanol concept and promoting thermodynamic studies of appropriate biophysical processes for finding new models from nature for technical solutions.

2. Producing the equipment for bioethanol reforming and product gas processing and cleaning in selected small-scale fuel cell systems with acceptably low operating temperatures.

3. Producing operating low-temperature fuel cells (i.e. AFC, PEMFC and SOFC), which can be attached to the equipment mentioned in Objective 2.

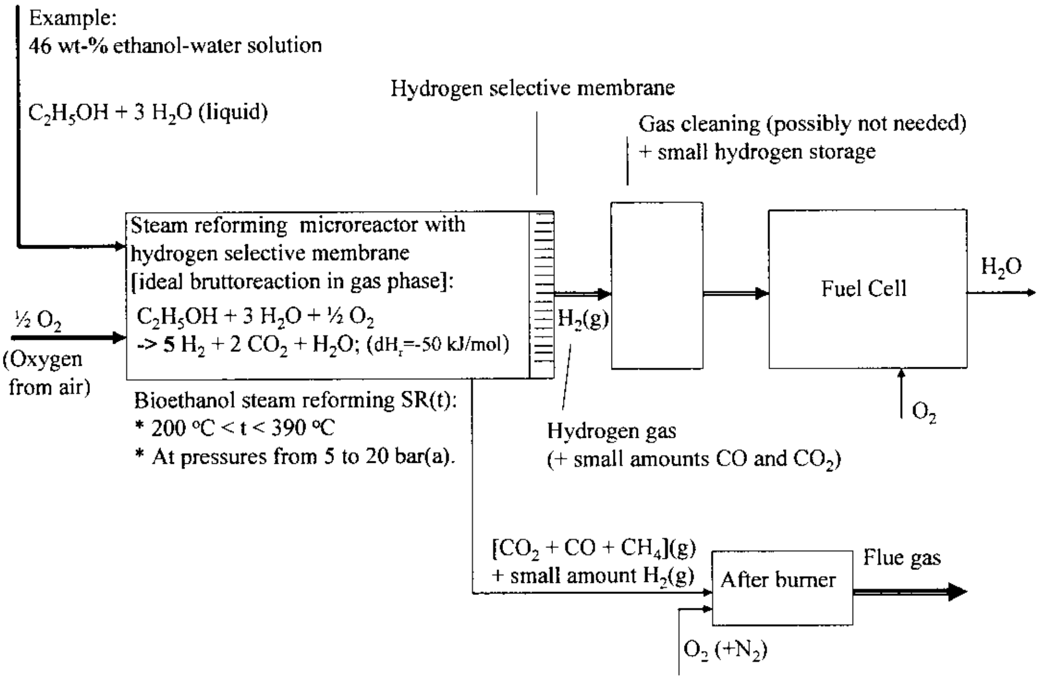
Main outcomes from the COST Action

The main outcomes are illustrated in Figure 1. As technical applications, the main outcomes include hydrogen gas production technologies from bioethanol in applied membrane steam reformers to be used in small-scale low-temperature fuel cell systems.



If the membrane reactors for bioethanol steam reforming are operated in temperatures between 200 and 390°C with high hydrogen production capacity, this would be a great success and a breakthrough in all applications of low-temperature fuel cell systems. The concept for the membrane reformer attached to the fuel cell is shown in Figure 2. In addition, the bioethanol-driven fuel cells could be an intermediate step towards glucose-driven fuel cells.

Figure 2: A hydrogen-selective membrane reactor for bioethanol steam reforming attached to a small-scale fuel cell system.



BENEFITS

It is estimated that the amount of the total distributed generation (DG) of the energy markets in Europe will increase from 11.4GW (2004) to 16GW (2007). While western European countries already show a remarkable market size, the market in central and eastern Europe is in its infancy (ElecroWatt-Ekono and Frost & Sullivan, 2002). The results of the Action will match the above recommendations for following future development and research work concerning DG systems in Europe:

- The effective use of bioethanol and biomass in small-scale DG systems
- More effective fuel cell applications for small-scale DG systems,
- Effective bioethanol reforming systems for DG small-scale systems
- Decreased net CO_2 emissions from combined heat and power (CHP) production in small-scale DG systems as a result of effective biomass or bioethanol use.

Moreover, research activities, which cover the research objectives shown in Figure 1, will also contain fundamental research targets, which will in turn lead to new technological applications. The main emphasis is on bioethanol use in small-scale energy systems, but the results from these studies can be extrapolated to systems which are based on, for example, solid biomass gasification technology. Additionally, good results from solid biomass gasification will be translated for use in the design principles of advanced bioethanol systems.

The extensive market survey conducted by ElecktroWatt-Ekono and Frost & Sullivan (2002-2003) gives a background to the recommendations, which are allocated to the three main areas. According to these recommendations, development and research work concerning distributed generation of energy systems (DGs) should be directed to:

- the design and development of products and production technology which are suitable for small-scale DG systems;
- the development of networked business models and networking among producers of DG systems and related services;
- research into and development of advanced technologies in the field of DG systems.

This Action will produce results that will serve the above conclusions of the market surveys, when the use of bioethanol for small-scale energy systems is taken into account.

D. SCIENTIFIC PROGRAMME

The work activities will include five working groups (WGs). Each working group is in line with the corresponding topics mentioned in Section C. The Action will include a WG6 specifically for dissemination. The tasks under each WG will be further elaborated during the implementation of the Action.

WORK PLAN OUTLINE IN RELATION TO OBJECTIVES

Figure 3 provides a contextual framework for the scientific programme. The research activities cover both exploitation of totally new technological solutions in the steam reforming of bioethanol and the applied technological solutions for use in effective bioethanol-driven small-scale low-temperature fuel cell systems. Combinations of nanotechnology and of microreactor design with membrane technology in particular will produce advanced technical applications for effective hydrogen production from bioethanol, which can also be applied in other energy systems.

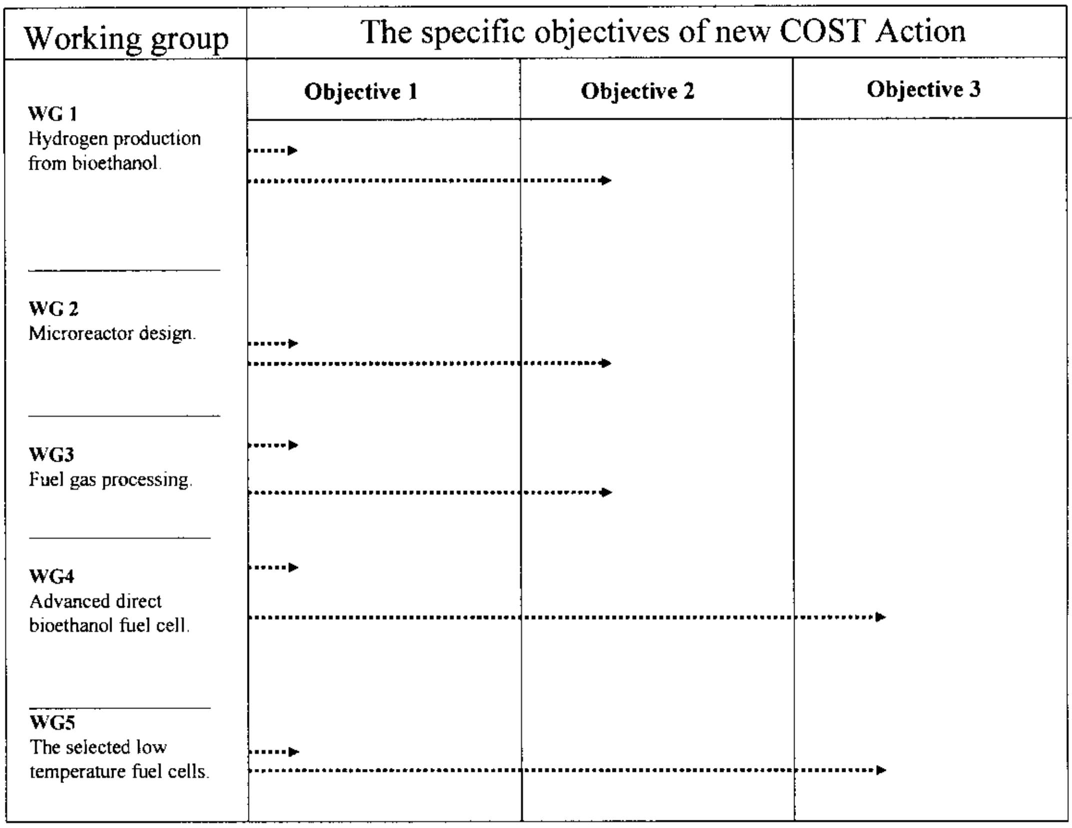


Figure 3: Relationship of Objectives 1 to 3 with Working Groups (WGs) 1 to 5

The working groups are outlined below. Each WG has several tasks, to be defined during the implementation of the Action. Essentially, these tasks reflect the research activities carried out by the participants.

WG1. Hydrogen (H_2) production from bioethanol

- WG 1 focuses on developing functional and effective hydrogen gas production devices for bioethanol by catalytic steam reforming technology at as low temperatures as possible to ensure a high H_2 production with acceptably low CH_4 content **(Task 1)**.
- The research target is the application of a membrane reactor for bioethanol (catalytic) steam reforming. The H_2 selective membrane would purge H_2 gas out from the reactor space during reforming of bioethanol. This kind of application of membrane reactor would enable very low steam reforming temperatures (in the range of 200-400°C) and still produce a high H_2 amount in fuel gas flow with an inconsiderable amount of CH_4 (which is regarded as hydrogen loss, when that fuel gas is used in low-temperature fuel cells) as a result of chemical equilibrium in reforming reactor outlet.
- WG1 undertakes the exchange of information with ongoing research on catalytic bioethanol steam reformer without membrane reactors to enable the development of effective catalytic membrane reactors for bioethanol reforming.

- WG1 has the catalytic research for membrane reforming reactor in Task 1 including the following sub-tasks:
  -Characterisation of activation of self-prepared or commercial reforming catalysts using a fixed-bed reactor (FBR).
  -Estimation of the reaction rates after evaluation of the FBR experiments.
  -Modelling and simulation of the membrane reactor (MR) in consideration of the determined reaction kinetics and of the mass transfer through the used H_2 selective membranes (measurement and description of mass transfer through the membranes will be done by the Max Planck Institute).
  -Experimental evaluation of the MR concept, varying operation parameters and determining the effect on hydrogen yield and on H_2 separation, optimising the MR.
  -Assistance in designing the after burner for combustion of exhaust gases and using the produced heat by coupling with endothermic processes (e.g. reforming).

- WG 1 focuses on researching different methods to bring oxygen without a compressor from the air to the pressurised microreactors.
- WG 1 has thermodynamic studies of biophysical processes in nature in order to find new technical solutions.
- WG 1 has system analysis of the bioethanol membrane reformer process with exergy analysis.
- WG1 has the energy plant simulation actions of Task 1.

WG2. Microreactor design

WG1, which is phenomena orientated, is complemented by WG2, which contains specific design methods for micro-scale systems. Microreactor design methods will be developed for H_2 production equipment in order to improve both mass and heat transfer properties **(Task 2)** of membrane bioethanol reformers (in Task 1). The microreactor design includes the microreactor design methods for membrane reformers, and for catalyst technologies in these membrane reformers. The microreactor design will also have an interaction with nanotechnology science.

WG3. Fuel gas processing

- Different product gas processing and cleaning systems will be applied and tested for product gas cleaning **(Task 3)**. The target of the research in WG3 is to produce as minimal as possible processing and cleaning systems for small-scale energy systems. The research in WG3 contains the following:
  – Research for product gas processing (i.e. CO shift reactor with water) for Task 1.
  – Fuel gas cleaning (i.e. separation of hydrogen gas from total fuel gas flow of $(H_2+CO_2+CO+CH_4)_{(gas)}$ before feed into low-temperature fuel cells).
  – The possible solid carbon (C(s)) formation and separation from membrane reformer in Task 1.
- WG3 focuses on the catalytic research for product gas processing in Task 1.
- WG3 has small-scale hydrogen gas storage.

- WG3 concentrates on setting controls for bioethanol processing.
- WG3 focuses on targeted energy plant simulation actions for Task 1.

WG4. Advanced direct bioethanol fuel cell

Advanced direct bioethanol fuel cell (ADEtOHFC) will be studied and developed for bioethanol/pure water systems **(Task 4)**. In this ADEtOHFC technology, the electrolyte is bioethanol itself, which is embedded inside the FC structure. With the aid of cation and anion selective and conducting membranes, the overall oxidation of the bioethanol is decomposed in electrochemical oxidation and reduction reactions in the anode and cathode. Task 4 also includes energy analysis with calculations and modelling of biophysical fuel cells.

WG 4 focuses on developing the conventional fuel cell, LTSOFC, for direct bioethanol feeding **(Task 5)**. In Task 5, the research target is to develop a low-temperature solid oxide fuel cell operating directly with bioethanol based on its internal reforming mechanisms.

WG5. The selected low temperature fuel cells

WG5 will concentrate on the development of conventional fuel cells that can operate with hydrogen gas from bioethanol reforming.

Task 6: LTSOFC. The research target is to develop a low-temperature solid oxide fuel cell (LTSOFC), which can operate with hydrogen gas produced from bioethanol fuels in the temperature range of 400-450^{o}C in small-scale energy systems. The research on LTSOFC should also include comparison of use of different fuels (at least syngas, biomethanol and bioethanol for use in LTSOFC in small-scale DG or combined heat and power production (CHP) systems).
Task 7: AFC. The research target is to develop alkaline fuel cell applications for small-scale DG systems. The specified target is to develop electrodes for AFCs for biomass applications. **Task 8: PEM** – PEM fuel cell applications for small-scale bioenergy DG systems.
Task 9: Nanotechnology for fuel cells Nanostructured catalysts for direct oxidation of biomass products such as ethanol will be investigated. High surface area and highly dispersed particles in nanometer dimensions will be achieved to effectively transfer biomass-generated chemical energy into electricity in the selected applications of fuel cells.

- The research activity in WG5 (Tasks 6 to 9) has active interactions with research activity in WG3 (Fuel gas processing and cleaning systems).
- WG5 also contains exergy calculation for Tasks 6 to 8 **(Task 10)**
- WG5 contains targeted energy plant simulation actions for Tasks 6 to 8.

WG6 Dissemination

Dissemination is to be carried out within WGs 1 to 5. The dissemination WG6 will provide a common framework for facilitating communication and diffusion, and for avoiding work duplication. This framework is outlined in Section E.

E. ORGANISATION

The management of the Action will be accomplished by the **Management Committee (MC)**. The practical management of day-to-day issues is carried out by the **Management Group (MG)** involving the MC chairperson and the WG leaders. In addition, a person responsible for Short Term Scientific Missions (STSMs) will be selected in the kick-off meeting. This person will also participate in the MG. The Management Group will predominantly communicate via e-mail in between the MC meetings. The MC will meet at least once a year to review progress and to make strategic planning for the Action. Coordination and overseeing the activities in the different areas and their interactions will be the responsibility of the MC. The organisational structure of the Action is shown in Figure 4.

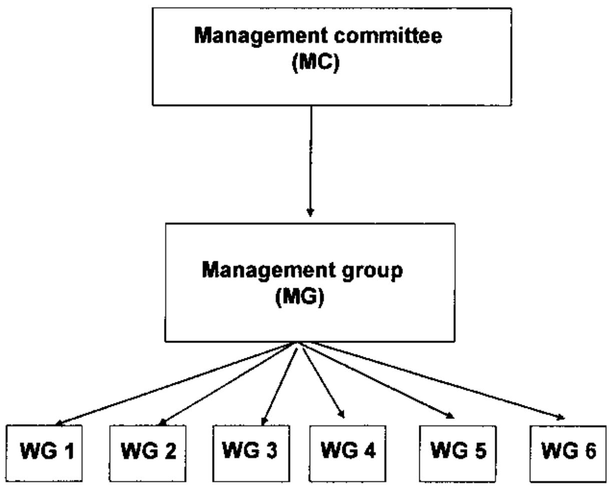
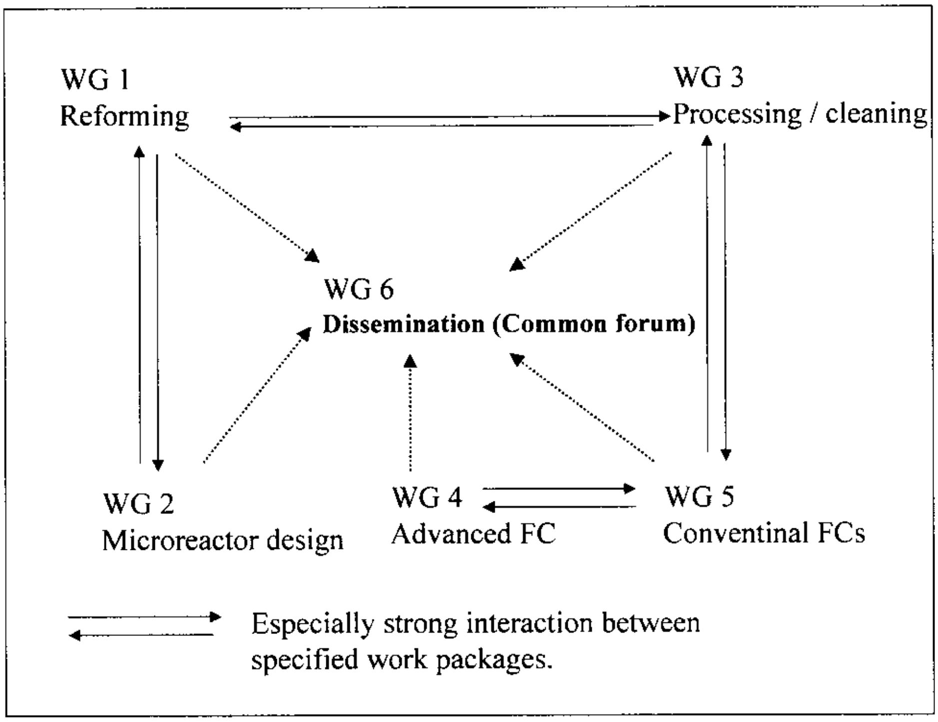


Figure 4: Organisational structure of the Action

The Action is divided into six working groups (WGs) as shown in Section D. Working group leaders will be selected in the kick-off meeting from among the most eminent scientists in the field. The WG leader will be responsible for coordinating activities and ensuring that the WG will meet the targets defined in the work plan. The work of WGs 1 to 6 will included ensuring the scientific outcome of the WG, organisation of relevant sessions during the annual workshops, and the organisation of WG meetings or smaller meetings with a selected group of experts., The interactions of the Working Groups 1 to 6 are shown in Figure 5.

Figure 5: The organisational structure of the Action with specified interactions between WGs 1 to 6



Interactive WG meetings are an essential part of the Action and will be held once or twice per year. In order to maximise interaction, the WG meetings will preferably be organised as joint meetings with at least two other WGs that have a strong interaction. (see Table 1). These interactions are shown in the Figure 5. The annual workshop will be the forum to discuss and share the latest developments with industrial participants and invited speakers. If appropriate, inter-COST workshops with related Actions will also be organised with a focus on interactions with specific COST Actions.

This Action has close links with another COST Action: C24 COSTeXergy, These two COST Actions have a technical focus and a strong long-term focus, which can produce synergy when energy efficiency and energy analysis methods are taken into account. This Action will have also synergy with projects in EU FP6 Sustainable Energy Systems, and in a longer perspective, with hydrogen-related projects in FP7. And, when the economic issues are taken into account, the Action will have synergy with projects in EUREKA.

A number of organisations are already cooperating in terms of devising other research projects. The Action provides a framework continuing and expanding these presentation activities, to be integrated with both industry and end-users.

F. TIMETABLE

The Action will last four years Activities related to WGs 1 to 5 are rather time-consuming as the research will produce fundamentally new technological applications.

The following activities will be organised during the course of the Action (Table 1). The **Kick-off meeting** will start the Action and during the kick-off meeting the WG leaders will be selected.

WG meetings are an essential part of the Action and will be held once or twice per year. The annual workshop will be a forum to discuss and share the latest developments with industrial companies and scientists in the area. The Action will consist of internal (only for members of COST Action) and public activities to be carried out as outlined in Table 1.

Action	*Public or internal*		*Year 1 (FH)*	*Year 1 (SH*	*Year 2 (FH)*	*Year 2 (SH)*	*Year 3 (FH)*	*Year 3 (SH)*	*Year 4 (FH)*	*Year 4 (SH)*
Annual workshop	P			P		P		P		
The final meeting	P									P
PhD/D.Sc. meeting	P			P		P		P		P
WG meeting	I		I	I	I	I	I	I	I	I
MC meeting	I		I	I	I	I	I	I	I	I
First half of year (FH): Extended WG + MC meeting. Second half of year (SH): WG meetings embedded in conference workshops + short MC meetings.										

Table 1: Overall timetable of project meetings with public (P) or internal (I) seminars

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: Bulgaria, Denmark, Finland, Germany, Hungary, Ireland, Italia, Netherlands, Spain and Sweden.

On the basis of national estimates provided by the representatives of these countries, the economic dimension of the activities to be carried out under the Action has been estimated, in 2006 prices, at approximately 7 million EUR.

This estimate is valid on 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

The Action outcome will be disseminated as shown in Table 2. The primary dissemination tool between partners will be WG meetings, annual workshops and a protected web site; the public web page will contain newsletters, information of WG activities and general information on upcoming meetings. The Action will run a web site, http://www.tkk.bioethanol.fi, which will serve as a dissemination tool.

Method of dissemination	*Main targets groups*	*Quantity*
Brochure	Industry, academia, public	1
Collaborative scientific papers	Academia	Several
Workshops	Participants, other	4
WG meeting	Partners	Several
Scientific conferences	Academia	Several
Newsletters	Industry, academia, public	1-2 / WG
www-page	Industry, academia, public	1
www-page restricted	Partners	1

Table 2: Dissemination of the Action's outcome

The present target audience of the Action includes: other researchers working on bioethanol for small-scale energy systems/applied fuel cells; researchers working in other disciplines (e.g. chemical engineering, mechanical engineering, chemistry, thermodynamics; research institutes and academia; service represented by manufacturers and service providers). The COST Action will help to enhance the visibility of bioethanol-related research among planners, policy makers and standardisation bodies.

E-mail network

Past contacts with individual countries have already generated a number of e-mail networks, which will be merged and expanded.

Education

Action members working at universities have the opportunity to integrate results from 'bioethanol for small-scale energy systems' research into their teaching curricula. For example, at the Helsinki University of Technology, lectures have been introduced in graduate courses on bioenergy. A network of PhD researchers also has an educational dimension and contributes to dissemination, including spin-off effects in the longer term. Increasing the awareness and commitment of industrial players to the bioethanol concept is also an important objective of this Action (Objective 1). Educational activities will also be targeted at educating the general public about bioethanol-based small-scale energy systems in DG or CHP.
