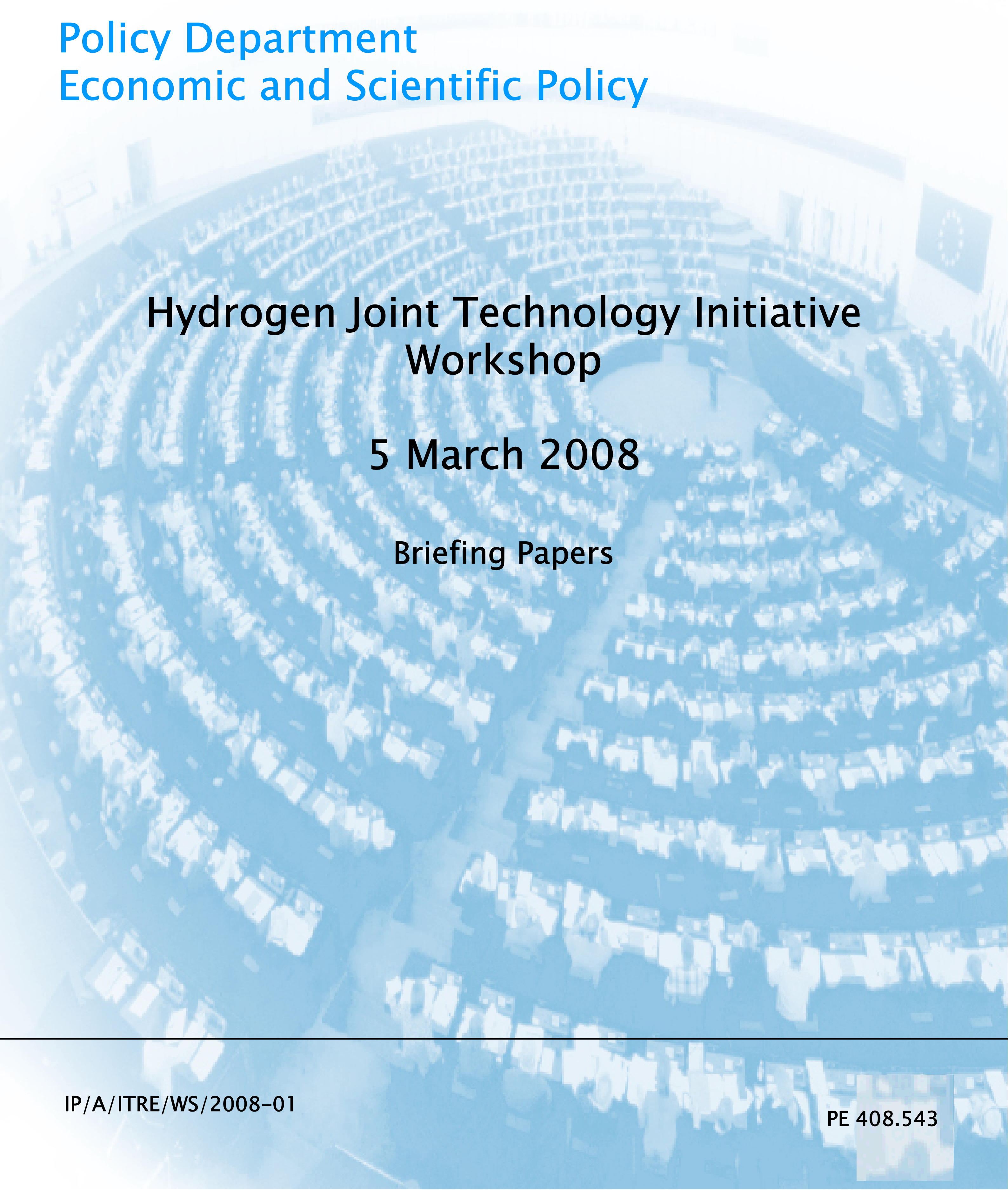
REPORT

Policy Department
Economic and Scientific Policy



Hydrogen Joint Technology Initiative Workshop

5 March 2008

Briefing Papers

IP/A/ITRE/WS/2008-01

PE 408.543

These Briefing Papers were requested by the European Parliament's committee on Industry, Research and Energy (ITRE).

Only published in English.

Authors:

Dr. Konstandopoulos (Chemical Process Engineering Research Institute (CERTH/CPERI))

Prof. Vellone (National Agency for New Technologies, Energy and the Environment (ENEA))

Dr. Serrano (Centre for the Development of Industrial Technology (CDTI))

Mr. Lucchese (New Energy Technology Programme (CEA) - Involved in the building up of the Research Grouping

Mr. Vriesman (Shell Hydrogen - Chairman of the Industry Grouping)

Administrator:

Camilla Bursi
Policy Department Economy and Science
DG Internal Policies
European Parliament
Rue Wiertz 60 - ATR 00L008
B-1047 Brussels
Tel: +32-2-2832233
Fax: +32-2-2846929
E-mail: camilla.bursi@europarl.europa.eu

Manuscript completed in March 2008.

✉ Rue Wiertz – B-1047 Bruxelles - ☎ 32/2.284.43.74 Fax: 32/2.284.68.05
✉ Palais de l'Europe – F-67000 Strasbourg - ☎ 33/3.88.17.25.56 Fax: 33/3.88.36.92.14
E-mail: poldep-esc@europarl.europa.eu

TABLE OF CONTENTS

Briefing note by Athanasios G. Konstandopoulos

Aerosol & Particle Technology Laboratory, CPERI/CERTH, Thessaloniki, Greece

htpp://apt.cperi.certh.gr

1. INTRODUCTION

The present note is submitted in response to the European Parliament's Order IP/A/ITRE/IC/2008-010 at the request of the ITRE Committee for expert opinion on the proposal from the Commission for a Council Regulation setting up the Fuel Cells and Hydrogen Joint Undertaking (COM(2007)571).

The author leads a European research consortium that has developed the HYDROSOL process for renewable hydrogen production by solar thermochemical water splitting. This achievement has received worldwide recognition through:

- The Descartes Research Prize for 2006, "for outstanding scientific and technological achievements resulting from collaborative research on Advanced Monolithic Reactors for Solar Hydrogen Production via Water Splitting" (the highest scientific award in the European Union).
- The Inaugural Technical Achievement Award of the International Partnership for the Hydrogen Economy (IPHE) in 2006, "in recognition of its leadership in forging international partnerships to deploy and test environmentally friendly hydrogen and fuel cell technology through pioneering research on solar hydrogen production featuring a two-step thermochemical water splitting process and unique reactor that holds the potential for large scale, emissions free hydrogen production"
- The Global 100 Eco-tech Award of the 2005 Expo in Aichi, Japan "in recognition of outstanding contribution to the resolution of global environmental problems and to the creation of a sustainable future"

The HYDROSOL process has been presented for the public in a recent Euronews documentary (http://ec.europa.eu/research/star/index_en.cfm?p=22_main) and in a video produced by the European Commission (http://ec.europa.eu/research/science-awards/videos/2007/research_winner_hydrosol_en.mp4).

The author has also coordinated/participated in the following European projects in solar/hydrogen technologies:

- Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants (HYDROSOL-II). (SES6-CT-2005-020030).(2005-2008). Coordinator: A. G. Konstandopoulos.
- New Method for Superior Integrated Hydrogen Generation System (NEMESIS) (FP6-2004ENERGY3-019827). (2005-2008).
- Hydrogen from Solar Thermal Energy:High Temperature Solar Chemical Reactor for Co-production of hydrogen and carbon black from natural gas cracking (SOLHYCARB) (FP6-2004ENERGY3-019770). (2005-2008).
- Solar Steam Reforming of Methane Rich Gas for Synthesis Gas Production (SOLREF) (SES6-CT-2004-502829). (2004-2007).

- Catalytic Monolith Reactor for Hydrogen Generation from Solar Water Splitting (HYDROSOL) (ENK6-CT-2002-00629). (2003-2005). Coordinator: A. G. Konstandopoulos.
- Advanced Solar Volumetric Air Receiver for Commercial Solar Tower Power Plants (SOLAIR) (ERK-CT1999-00021) (1999-2003).

Based on this expertise the note addresses the following 4 areas as stipulated in the European Parliament Order:

1. Hydrogen Technologies Technically Mature for Early Commercialization and Concrete Applications.
2. Adequacy of Srategic Research Agenda, Deployment Strategy and Implementation Plan of the HFP Platform for effectively accelerating market breakthroughs
3. Adequacy of the proposed undertaking objectives and proposed means for delivering the Implementation Plan.
4. Recommendations for addressing any possible identified shortcomings

The note also reviews recent work in the field of solar thermochemical hydrogen production via water splitting in monolithic reactors, also known as the Hydrosol process.

The Hydrosol process employs a reactor concept, adapted from the well-known automotive emission control field, and consists of multichannel ceramic honeycombs, coated with active water-splitting materials, that are heated by concentrated solar radiation to the desired temperature. When water vapor passes through the reactor, the coating material splits the water molecule by "trapping" its oxygen and leaving in the effluent gas stream pure hydrogen. In a next step, the oxygen "trapping" material is regenerated, by increasing the amount of solar heat absorbed by the reactor; hence a cyclic operation is established achieving constant hydrogen production exclusively at the expense of solar energy.

2. OPINION ON THE JOINT TECHNOLOGY UNDERTAKING ON HYDROGEN AND FUEL CELLS

2.1 Hydrogen Technologies Technically Mature for Early Commercialization and *Concrete* Applications.

Hydrogen is not a primary energy source, only an energy carrier. The term Hydrogen Technologies hence encompasses many related technologies involving hydrogen production, supply/transport/storage, use in vehicles for transportation and other off-road uses, use for stationary energy applications, use for portable energy applications, etc.

According to a certain line of thought, based on an incremental/gradual substitution of the dominant technology paradigm, new technologies that are technically mature are expected to lead to early commercialization and concrete applications, stimulating thus further growth in the area. Based on a survey of existing demonstrations of such technologies the following list summarizes technically mature hydrogen technologies that are either in commercial deployment or are close to be launched in commercial applications:

- Fuel cells for air independent submarine propulsion, such as those already installed on type 212 and 214 submarines.
- Portable fuel cells for mobile phones and other handhelds such as those introduced recently by NEC (Flask), Angstrom Power/Motorola and Toshiba.
- Portable hydrogen generators based on flexible fuel processing (e,g, such as those advanced in the European project NEMESIS, made by HyGear).

- Stationary Power Generation including combined heat and power (CHP), such as the 50,000 recently ordered units to be deployed in the Netherlands by Ceramic Fuel Cells.
- Auxiliary Power Units (APUs) that are in advanced demonstrations by many companies, including Voller Energy Group.
- Uninterrupted Power Supplies (UPS) units, that are commercially available by several companies including UPS Systems.
- Hydrogen refuelling stations such as those built by Linde, Shell and BP.
- Hydrogen internal combustion engine vehicles, such as the BMW 7 Hydrogen passenger car, exhibited in numerous demonstrations.
- Off-road utility vehicles (e.g. forklifts), that are suited to applications where zero emissions are required.

It should be noted however that **sustainable commercialization depends on sustainable hydrogen production/supply**, i.e. hydrogen from renewable sources. Among the various renewable hydrogen routes, the most promising long term option is renewable hydrogen production from solar energy.

Technology substitution can also occur through the emergence of disruptive technologies, i.e. technologies that grow in a non-incremental manner. To the author's opinion hydrogen production by solar thermochemical water splitting as embodied in the Hydrosol process, is a disruptive technology that is advancing fast in research and can be brought to commercialization within the 10 year expected life-span of the JTI, if sufficient resources are devoted. Market introduction of such technology will be greatly facilitated by the growing deployment of solar thermal power plants. The technology is fully compatible with the next generation of solar thermal tower technology.

2.2 Adequacy of Strategic Research Agenda, Deployment Strategy and Implementation Plan of the HFP Platform for effectively accelerating market breakthroughs

Securing energy supply, reducing greenhouse gas emissions and strengthening the European Economy and competitiveness are the driving forces behind the transformation of our society towards a low carbon/carbon neutral, hydrogen based economy. This ambitious vision is expressed in the Strategic Research Agenda and Deployment Strategy documents of the HFP Platform, while the current Implementation Plan (IP) anticipates most, if not all, of the above mentioned technically mature technologies, entering commercial application.

It should be remarked however that the current Implementation Plan fosters incremental advances rather than step changes. The latter triggered by technology/science innovations may also lead to market breakthroughs in a fast and disruptive fashion. For example the large potential of solar thermochemical hydrogen generation is not fully appreciated (to some extent this is expected given the rapid advances in the field) while the issue of hydrogen storage/infrastrure is addressed in isolation of its ramifications for CO_2 sequestration: important synergies involving the chemical storage of renewable hydrogen into methane or methanol exploiting its reaction with carbon dioxide (CO_2) are thus not explicitly addressed. To the author's opinion, carbon/CO_2 sequestration should be creatively combined with renewable hydrogen technologies to achieve synergies that are **extremely promising for simultaneous, sustainable hydrogen storage and sustainable CO_2 recycling/reuse.**

2.3 Adequacy of the proposed undertaking objectives and proposed means for delivering the Implementation Plan

As already mentioned the current Implementation Plan aims at incremental advances rather than steps in the hydrogen production/supply and the proposed means as distributed in the various Innovation and Development Actions (IDAs) are fully aligned with this incremental path.

To the author's opinion however it is imperative to also foster a faster, exclusively renewable and efficient hydrogen production/supply path, if the highly anticipated environmental and societal benefits of a "Hydrogen Economy" are to be realized in a reasonable time horizon. Technological developments in the Fuel Cells and Hydrogen field are very rapid and a continuously updated Strategic Research Agenda as stipulated in the JTI, offers a distinct advantage, provided that its revision will be easily accessible to inputs from innovators.

With respect to the governance aspects of the proposed Joint Undertaking it is clear that the industrial lead has many advantages, however the launching of high risk, innovative research projects should not be hindered, by over-emphasis on incremental technologies. The largest concern of a researcher active in the area, is the potential risk of exclusion due e.g. to higher barriers to enter in JTI projects than in Framework Programmes.

As the actual research themes and call procedures for the Joint Technology Initiative (JTI) have not yet been put in place and given the flexibility that a continuously updated Strategic Research Agenda/Implementation Plan affords, this author is confident that eventually an adequate mechanism will be in place to ensure delivery of any updated Implementation plan.

2.4 Recommendations for addressing any possible identified shortcomings

Many of the advances anticipated in the current Implementation Plan are already occuring in the world, especially in the USA, under the influence of market forces and the Cleantech movement, in response to the increased public, government and industry interest in cleaner energy sources and the rise in concerns of global warming and adverse environmental impacts from fossil fuel utilization. To the author's opinion Europe should assume a more aggressive position and aim to lead rather than follow developments in Fuel Cell and Hydrogen Technologies, exploiting and extending any specific competitive advantages that European research has created. For this reason i**t is imperative to also foster non-incremental R&D that will lead to fast market introduction of exclusively renewable and efficient hydrogen production technologies that will also include simultaneously, sustainable hydrogen storage and sustainable CO_2 recycling/reuse.**

A certain fraction of the JTI budget should thus be devoted into higher risk/higher return, innovative research following the example of the NEST programme of FP6.

3. CLOSURE

The endless potential of solar energy among all renewable energies for Europe and the greater Mediterranean area, was reconfirmed in the recent Desertec White Paper(http://www.desertec.org/downloads/articles/trec_white_paper.pdf).

Considering that the sun is made up by 94% of hydrogen maybe we should realize that the "Hydrogen Economy" is a synonym for the "Solar Economy". **Solar thermochemical hydrogen production represents an area of European excellence that has all the potential to develop in an area of European commercial dominance.**

Briefing Note by Raffaele Vellone

Div. Tecnologie Energetiche Avanzate, ENEA, Italy

Italian Delegate of Energy Committe Programme

1. INTRODUCTION

The ITRE committee has requested expertise in order to facilitate the European Parliament report on the proposed Council Regulation (COM (2007)571) setting up a Joint Undertaking for Fuel Cells and Hydrogen and has organized a specific workshop to held in Brussels on 5th March, involving several international experts.

This paper has the aim to supply some comments and recommendations to the EU Parliament for the best assessment and full success of the Fuel Cells and Hydrogen Joint Undertaking (FCHyJU) based on the position of Italian of the Energy Committee Programme (VII FP – Cooperation) Expert in the field of Hydrogen and Fuel Cells.

2. GENERAL COMMENT

Hydrogen and fuel cell technologies promise considerable benefits in terms of reducing greenhouse gas emissions and potentially improving the security of energy supply. For these reasons the major programmes in the energy field, and in particular the programmes of the European Union, are paying a growing attention to the development and deployment of these technologies.

The European Hydrogen and Fuel Cells Technology Platform, established in 2003, has played an important role in promoting and coordinating the European activities and in making specific recommendations for the 7th Framework Programme (Implementation Plan). Moreover, the Joint Technology Initiative currently in preparation, will be established to manage the future programme of research, development and demonstration in this field.

The adoption of FCH JTU could be welcome by all stakeholders as an important new instrument which could really accelerate the process of technology innovation in the field of Hydrogen and fuel cells, by promoting early markets and allowing the EU industries to be competitive at international and word wide level.

The general approach of JTI which is expected to provide the appropriate research support to the industrial development is therefore correct. Many research institutions (EU Research Centers, Universities, etc.), will be involved in order to overcome the technological barrier and or limitation for adequate research support for the success of FCH JTI.

However, particular attention must be paid to the Governance of JTU in order to identify practical implication of the structure and the criteria of definition of the activity plan and the role of Member State Representatives clarifying the relation-ship among JTI Governing Board, Scientific Committee EU Research Consortium, Stakeholders, General Assembly.

Further care should be taken about the research for medium and long term which could suffer by the main interest for short time expressed by the industries grouping already involved in the JTI. It could easy appear that not enough funds are allocated in this field by the FCH JTI.

3. ROLE OF MEMBERS STATE REPRESENTATIVES AND THE RESEARCH COMMUNITY

The main concern in the current proposal is the role of Members State Representatives and the Research Community in the selection of the priorities over the RTD programmes and activities (especially concerning the advanced and basic research for medium and large term).

In Council Decision of 19 December 2006 concerning the Specific Programme "Cooperation" implementing the Seventh Framework Programme a specified budget and general Areas for funding priorities in the field of (non nuclear) energy (= Theme 5 ENERGY) was defined. The responsibility for implementation of these actions was given to the European Commission and representatives of the Member States organized in the programme committee (Article 8).

With the setting up of the Joint Technology Initiative in the field of fuel cell technologies and hydrogen economy (FCH-JTI), budgets will be transferred from Theme 5 ENERGY to be used by FCH-JTI to fund demonstration and research activities. But the budget will be transferred without transferring Member States responsibility in the same adequate way.

In the current proposal the decision taking processes (in the governing board) involve only representatives of the industry (= industry grouping) and representatives of the European Commission, as well as a minor group of the research sector (= research grouping, 1 seat of 12). An involvement of Member States interests in decision taking procedures is not foreseen so far. The governing board expects to hear Member States advice only as (non binding) comments of a high level group in which representatives of Member States are organized.

The transfer of budget without responsibility seems unbalanced. It could be expected that the responsibility of Member States has to be transferred in the same adequate way as the responsibility of the European Commission. This could be realized e.g. by establishing a “public grouping” representing all interest of European Commission and Member States in the same way as it is organized in the programme committee.

Even if the degree of involvement of Member States participation can’t be improved for the FCH-JTI it is important to find an adequate solution as similar structures are going to be implemented in other areas of FP7 and as well under the SET-Plan (e.g. European Industry Initiatives).

In addition considerations relating to the restrictions provided by the article about “Participation of Activities “ favours of the current members of JTI to participate to this new kind or research industry cooperation activities. It is suggested instead to follow the principles and rules of participation to the FP-7 to ensure a well-balanced and transparent allocation of the public funds in order to achieve EU industrial competitiveness and progress of the Research Community.

Furthermore it is important to clarify the financing mechanism, the role of the Governance regarding the public interest and the evaluation procedures of the in-kind contribution by the industry balancing the cash contribution of the Commission.

4. SUPPORT TO BASIC AND ADVANCED RESEARCH

Particularly attention should be considered for the basic and/or advanced research which seems to be sacrificed totally to the interest of the industry having interest on products realization in medium-short term.

In fact in the frame of the working programme on fuel cells and hydrogen for 2007 was established that basic research should be financed and management by the Energy Committee in order to assure the appropriate address to the European interest in that field.

The Commission designed to move 100 Million of Euro for basic and advanced research and allocated those funds to constitute the budget for JTI, to achieve the total budget of 470M€ as minimum level to capture the same level of in-kind contribution of the industry. The Commission officially informed the Energy Committee that in is position to guarantee the execution of advanced and basic research on fuel cells and hydrogen.

But the main question remains open: how can the members states express their evaluation on management of public funds and correctly address the development of R/D programmes? Furthermore the question of JTI and European Industrial Initiatives. concerning the technological platforms which are in progress to be open could generate the risk to cancel the role of the programme committees.

5. SUGGESTIONS FOR REVISION OF MAIN ASPECTS

Role of the FCH states representative (art.4 and art. 9)

The main aspect that should be revised is the role of the MMSS which seems to be limited to an “Advisory Group”. This limits their role in monitoring and supervising the JTI through the mechanism established in the Framework Programme, in aspects of utmost importance like the project approval for funding and the allocation of funds between the partners; organizations that should form the projects, etc.

The role of "Advisory Body" of the member states should be much more relevant in order to influence the working programme. The FCH States Representative Group must have the right of giving their opinion on the proposal to be submitted to the Governing Board for approval.

Sources of financing and participation in activities (art. 12 and 13)

Wide competitiveness should be ensured in order to allow the open participation to the FCH JTI. For a competitive call, it is recommended to delete the requirement that "at least one legal entity must be a member of Industry Grouping or the Research Grouping", in order to be in line with the principle that "Community contribution to the FCH joint undertaking used to fund projects shall be allocated following open and competitive call for proposals". It is also recommended to eliminate the requirement that "the coordinators should come form the Industry Grouping or Research Grouping".

Implementation of RTD and funding of activities (art. 14 and 15)

The implementation of RTD activities should follow principles and rules of the FP7, though competitive calls and independent evaluations. It is also recommended to consult the FCH States Representative before launching call for tenders, notably to improve complementarity and coordination with the national programmes, in particular advance research. In the current proposal no coordination mechanism or policy is proposed to stimulate or encourage the established or growing national research programmes. Such a weakness will reduce the EU potentiality and competitiveness.

With regards to the financing contribution, it should be ensured that the rules established fulfil the minimum industry contribution for operational costs but also the upper funding limits for the research community.

6. PERSPECTIVES OF ITALIAN HYDROGEN AND FUEL CELLS PROGRAMME AND SYNERGIES TO EUROPEAN TECHNOLOGY PLATFORM AND FCH-JTI

In Italy several activities on hydrogen and fuel cells are ongoing in the framework of international, national and regional programmes. Considerable resources are devoted to the development and demonstration of critical technologies, with a total spending of around 50 M€/year. To coordinate these activities and to integrate them in the frame of European programmes an Italian Hydrogen and Fuel Cell Platform has been established in 2004, with the contribution of Ministries, Regions, industries and research organizations. The priorities for research and demonstration have been defined, taking into account the strengths and weaknesses of the national industry and the possible contribution of hydrogen and fuel cell technologies to the development of a sustainable energy system. For the future, this coordination effort should be strengthened and more rapid and efficient financing tools should be defined to make an efficient use of the available resources and to seize the opportunities arising in the European Programmes and international collaborations.

Briefing note by Dr. Joaquín Serrano Agejas

Centro Para El Desarollo Tecnolgico Industrial

1. EXECUTIVE SUMMARY

The present document aims to provide some comments and recommendations for a successful Cells and Hydrogen Joint Undertaking based on the positions agreed by the Representatives of the Spanish Technologic Platform of Hydrogen and Fuel Cell.

Taking as base document the EC *Proposal for a Council Regulation setting up the Fuel Cells and Hydrogen Joint Undertaking: General Approach* (1), a detailed review of the articles considered more important for an adequate governance of the FCH JU has been commented.

Main concerns are regarded with the roles of the MMSS and the research community to contribute in the definition of the scientific priorities of the R&D activities and with the restrictions designed in Article about *Participation in Activities* in favour of the current members of the JTI to participate in this new kind of research cooperation activities.

It is proposed to follow principles and rules of participation of the FP7 to ensure fairness and transparency in the allocation of public funding to participants in the FCH JTI calls for proposals.

2. INTRODUCTION

In light of the adoption of a European Parliament report on the proposal from the Commission for a Council Regulation setting up the Fuel Cells and Hydrogen Joint Undertaking (COM(2007)571), the ITRE Committee requested expertise on the proposed Joint Undertaking. For this propose, the ITRE Committee is organising a workshop to be held on 5th March in the premises of the European Parliament in Brussels.

The present document aims to provide some comments and recommendations on the part of the EC Proposal focussing on governance (the precise set-up of the Joint Undertaking). In particular on the identification of practical implications of the proposed governance structure on the work of the Joint Undertaking (Governing Board, Scientific Committee, Members States Representative Group and Stakeholder General Assembly forum).

Especial effort has been made to describe the need to have a structure of robust and well interlinked groups: Industrial, Researching and Member States Representative Group; and with important roles in the managing of FCH JTI.

3. GENERAL COMMENTS

Most of the Spanish stakeholders, represented by the Spanish Platform of Hydrogen and Fuel Cells, welcome the presentation of the Commission of the proposal for Fuel Cells and Hydrogen Joint Undertaking due to its potential high impact on this technology area of unquestioned industrial, strategic and competitive importance in Europe.

On the other hand, it is generally considered that prior to the launch of the various individual JTIs, some issues common to all JTI initiatives should have been grouped, with the objective to ensure that the principles that have proven their validity in the various Framework Programmes are preserved.

In order to fully reach FCH JTI challenges, and to accelerate the development of hydrogen technologies to the point of commercial take off, this industrial driven initiative needs to enjoy a necessary autonomy of governance and flexible management, while maintaining their very nature as full FP7 instruments. Therefore, it is necessary to ensure that the JTIs respond to the common criteria and principles of transparency and openness, including the assignment of the whole budget through competitive calls, which should be guaranteed in any case as FP7 instruments.

Thus, it is expected that the Member States, by the FCH MMSS Representative Group, are able to monitor and supervise the JTI through the mechanisms established in the Framework Programme, in aspects of utmost importance like the project approval for funding and the allocation of funds between the partners; organizations that should form the projects, etc. In this sense, FCH JTI should adopt mechanisms to revise the Community funding commitments to the JTIs, with intermediary evaluations, as it is the rule for the whole FP7.

Likewise JTIs need to stay open to the future participation of new partners from industry. The period of operation for the JTIs is long enough as to allow some industries, which are not yet ready to participate or which have not yet perceived the JTI´s added value, to be able contribute to the activities of JTIs in the future.

Furthermore it is crucial that JTIs evolve into instruments of cooperative research, mobilizing, and not substituting, the resources of big enterprises, and integrating the capacities of public research centres and of innovative SMEs. Therefore, the public funding needs to be fundamentally directed to the activities of the latter, having the big enterprises financing the major part of their own R&D. It would be the model of financing of the IMI JTI, and it could be applied to all JTIs. Furthermore, it should also be assured that at least 15% of the total funding should go to SMEs, as it is the rule in the Cooperation Programme.

Finally, FCH JTI will channel the total amount of FP7 money to hydrogen and fuel cells, so it is important to make sure that the impact on competition of its funding is considered in the selection of the beneficiaries of the JTI's contributions, and the benefits of the funding outweigh any possible harm to competition. This is in fact inherent with the concept of market failure, one of the principles which guide the operation of all JTIs. It would not be understandable if the Community were to apply different principles for the selection of projects by JTIs from the principles it has defined – in the context of State aid policy - for the selection of projects by the Member States.

4. COMMENTS AND SUGGESTION TO THE EC PROPOSAL ON FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

In this chapter, the articles considered more important for an adequate governance of the FCH JU has been commented. Original text of the Annex I of the Statutes of the FCH JU are partially reproduced in order to clarify and to put in context the comments and proposals suggested.

4.1 Article 4: Bodies

Original text:

1. The bodies of the FCH Joint Undertaking shall be:

- *(a) the Governing Board,*
- *(b) the Executive Director,*
- *(c) the Scientific Committee.*

3. The FCH States Representatives Group, the Stakeholders General Assembly shall be external advisory bodies to the FCH joint undertaking in order to ...

Comments to Article 4:

EC Proposal Fuel Cells and Hydrogen Joint Undertaking provides a very weak role to the MMSS, represented by the FCH States representatives Group. This circumstance does not match either with the objectives of strengthening the ERA by gathering together stakeholders, public institutions, regulators and users in a joint effort to develop FCH technologies nor with the SET plan of creating a new way of working together in Europe; Member States, industry and the research community working collectively with the aim to optimise individual efforts.

4.2 Article 5: Governing Board

Original text:

1. Composition and decision-making process

The Governing Board shall be composed of six representatives of the Industry Grouping and of six representatives of the Commission….

3. Rules of procedure

The Chairman of the FCH States Representatives Group shall have the right to attend meetings of the Governing Board as an observer

Comments to Article 5:

It is of utmost importance that a Representative of the FCH Representative Group takes part in the deliberations of the Governing Board in order to assure the best coordination with national fuel cell and hydrogen programs and handling of existing regulatory barriers.

Moreover, the FCH Representative Group can play an important role for the FCH JTI strengthening the links between research and industry (and so contributing to the realisation of the European Research Area).

4.3 Article 8: Scientific Committee

Original text:

1. *The Scientific Committee is an advisory body to the Governing Board. The Scientific Committee shall conduct its activities with the support of the Programme Office.*

Comments to Article 8:

A link between the Scientific Committee and the Research Grouping must be established. Research Grouping should have a natural way to contribute in the definition of the scientific priorities of the annual and multiannual Research Activities.

To assure the close relationship between the Scientific Committee and the Research Grouping, a Representative of the Research Grouping should be encouraged to participate in its meetings.

4.4 Article 9: FCH States Representatives Group

Original text:

1. *The FCH States Representatives Group shall have an advisory role for the FCH Joint Undertaking.*

Comments to Article 9:

FCH States Representative Group must have the right of giving opinion on the ranked list of proposals to be submitted to the Governing Board for approval.

Moreover, FCH States Representatives Group will express their opinion on the Annual & Multianual Reseach Activities and the corresponding expenditure estimates.

4.5 Article 12: Sources of financing

Original text:

3. *The operational costs of the FCH Joint Undertaking shall be covered through the financial contribution of the Community, and through in-kind contributions from the legal entities participating in the activities. The industry contribution shall at least match the Community's contribution. Other contributions to co-funding of activities will be considered as receipts in accordance with the rules of participation of the Seventh Framework Programme.*

7. *The level of the in-kind contributions, calculated on a yearly basis, shall be assessed once a year. The methodology for evaluating contributions in kind shall be defined by the FCH joint undertaking in compliance with its financial rules and based on the Rules for Participation of the Seventh Framework Programme.*

Comments to Article 12

It should be highlighted that it is the Industrial Community, and not only the Industrial Groping, the one which will cover the established 50% contribution to the operational cost of the FCH JTI. This aspect is very important because it will be a heavy argument to eliminate some restrictions on participating in proposals set in Article 13.

It is stated that the Industrial Community contribution to the FCH JTI will be in kind and the EC contribution will be in compliance with financial rules on the Rules for Participation of the FP7.

According to FP7, for R&D activities Community financial contribution may reach 50% of the total cost, and in the case of SME and RTD performers it may reach 75%; and for demonstration activities may reach a maximum of 50% of the total eligible cost.

For a hypothetical RTD project presented to the FCH JTI by a consortium formed by 30% of SME, 40 % of Big Companies and 30% of RTD performers, EC contribution to the project, according to FP7 rules, would be close to 65%. In the case of demo project, EC contribution would be approximately 51%. It means that new rules must be designed in order to fulfill with the minimum industry contribution established to the JTI operational costs.

Therefore, it would be recommended to explain not only its contribution to the operational costs of the Industrial Community but also the upper funding limits for the Research Community.

In connection with the latter, one option that could be also considered is to keep the upper funding limits of the research community by mean of sharing its costs between the EC and the Industrial Community up to the target of 50% contribution of the Industrial Community to the operational cost of the FCH JTI.

4.6 Article 13: Participation in activities

Original text:

1. *Participation in projects shall be open to legal entities and international organisations established in a Member State, or any third country once the minimum conditions have been satisfied.*
2. *The minimum conditions to be fulfilled for projects funded by the FCH Joint Undertaking shall be the following:*

   (c) at least one legal entity must be a member of the Industry Grouping or the Research Grouping.
3. *The legal entities wishing to participate in a project shall form a consortium and appoint one of their members to act as its coordinator.*

   In general, the coordinator should come from the Industry Grouping or, from the Research Grouping, if such Research Grouping is established.

Comment to Article 13.

If it is assumed that the most active and compromised organisations are members of the FCH JTI, it is not necessary to establish special restrictions in order to encourage and favour their participation.

To ensure proper representation of smaller innovative companies and institutions which, due to resource and manpower limitations, are unable themselves to participate fully in this initiative. The successful of the FCH JTI initiative as a ambitious European-wide strategy to position fuel cells and hydrogen as core enabling technologies which can make a determinant contribution to energy, transport, environment and sustainable growth policies across Europe, pass through, the participation of such organisations, that could be a key actors to generate the necessary breakthroughs and speed up the introduction of these disruptive technologies.

For a competitive call, it would be recommended to delete this point 2.c in order to avoid contradictions with basic public funding principles, especially the basic principle on the main text of the resolution where it is stated that: “The Community contribution to the FCH Joint Undertaking used to fund projects shall be allocated following open and competitive calls for proposals”.

It would be fully recommended to eliminate “the coordinator should come from the Industry Grouping or for Research Grouping...”. IG and RG members will participate actively in projects and their role within the consortium cannot be prefixed by empty rules. Coordinator shall be the appropriate for achieving a successful project.

4.7 Article 14: Implementation of RTD

Original text:

The FCH Joint Undertaking shall support RTD activities following open and competitive calls for proposals, independent evaluation, and the conclusion for each project of a Grant Agreement and a Consortium Agreement.

In exceptional cases the FCH Joint Undertaking may issue calls for tenders, if it is deemed necessary for the effective pursuance of the research objectives.

Comments to Article 14:

Implementation of RTD Activities must follow principles and rules of the FP7: competitive calls and independent evaluation (likewise, it would be recommended to share the independent expert data base of the FP7).

All topics have to be open. It is not well defined what is considered as an “exceptional case”. It would be recommended to consult to the FCH States Representatives Group before launching call for tenders.

4.8 Article 15: Funding of activities

Original text:

3. The upper funding limits of the Community financial contribution in projects shall be aligned to the comply with those laid down by the Rules for Participation of the Seventh Framework Programme. In case lower levels of funding will be necessary to comply with the matching principles referred to in Article 12.3., the decreases shall be fair and balanced proportionally with the above mentioned upper funding limits of the rules of participation of the Seventh Framework Programme for all categories of participants in each individual project.

Comments to Article 15:

If EC financial contribution to the projects follows the Rules for Participation of the FP7, it will not be lower than 50% of the eligible cost of the project (always higher). In other words, Rules for Participation of the FP7, and Industrial Contribution to the project 50% in kind, do not match with the objective of sharing investment between industry and CE.

In the case of lower levels of funding of the Industrial Community, it will be recommended that the extra cost were assumed by Big Companies, keeping the upper funding limits of the 7 FP of the SMEs and RTD performers.

4.9 Article 24: Conflict of Interest

Original text:

The FCH Joint Undertaking and its bodies shall avoid any conflict of interest in the implementation of their activities.

In particular care must be taken where a conflict of interest may occur for the representatives serving in the Governing Board.

Comments to Article 24:

Public Bodies, CE and a Representative of the MMSS, should watch over to assure that any Bodies of the FCH JTI do not have any conflict of interest in the implementation of their activities.

5. CONCLUSION

The EC proposal Fuel Cells and Hydrogen Joint Undertaking presents some lacks that could jeopardize the potential impact of the FCH JTI. For this new way of realising public-private research partnerships at European level, it will be recommended to be absolutely open for all European organisations interested in the sector. This can be solved following the Framework Programmes principles that have proven their validity.

Main aspects that should be revised are:

- the weak role of the MMSS to be able to monitor and supervise the JTI through the mechanisms established in the Framework Programme, in aspects of utmost importance like the project approval for funding and the allocation of funds between the partners; organizations that should form the projects, etc;
- the role of the research community to contribute in the definition of the scientific priorities and consequently in the Working Programs of the FCH JU calls;
- restrictions stated by current members of the FCH JTI related to the *Participation in Activities*.
- In case of the Industry contribution did not match the Community's one, the decrease of funding should not be balanced proportionally for all categories of participants, but Big Companies should assume it, keeping the upper funding limits of the 7 FP for the SMEs and for the RTD organizations

6. BIBLIOGRAPHY

(1) Proposal for a Council Regulation setting up the Fuel Cells and Hydrogen Joint Undertaking: General Approach. Council Secretariat. Permanent Representatives Committee/Council. Interinstitutional File: 2007/0211 (CNS). 13843/07 RECH 260 ENER 241 + ADD 1 + ADD 2

Briefing Note by Paul Lucchese

New Energy Technology Programme (CEA)

1. INTRODUCTION

Hydrogen and fuel cells technologies are very promising techniques for sustainable development in particular for automotive and for stationary applications. However these technologies are not completely mature enough to be deployed fully at commercial level and by only private stakeholders.

It is the reason why a complete and ambitious Plan, IP (Implementation Plan) was proposed in 2006 by the so-called HFP (Hydrogen and Fuel cells Plat form) by both European Commission and Stakeholders (including research, industry, NGO etc…). The IP was planned over next 10 years and its budget was estimated at 7.4 B€.

As an expert I agree fully with the road map and proposed action plan in IP. The EC and Industry propose in 2007 an JU on the establishment of a JTI Fuel cells and Hydrogen with a budget of 940 M€. It is mainly driven by Industry and focussed on demonstration, early markets and deployment with a 1/3rd part for Research.

So I think that the main remaining issues are:

- how could fit the JTI Plan(0.94B€) with a 7.4 B€ IP ?
- Are the IP targets and IP objectives reachable despite this reduced budget?
- What are the funding possibilities outside JTI
- How could the European Research organize to be more efficient and competitive in this field
- what is the commitment of state members ? how could they organize to create synergies with JTI ?
- Role of Regions ?

2. HYDROGEN TECHNOLOGIES MOST TECHNICALLY MATURE FOR EARLY COMMERCIALIZATION AND ADEQUACY OF SRA, DS AND IMPLEMENTATION PLAN FOR ACCELERATING MARKET BREAKTHROUGHS

Hydrogen technologies are making impressive progresses since the last 7 years.

2.1 Significant examples

Regarding the PEMFC technologies, recent different estimations (DOE tech review days, May 2007) on the cost a PEMFC stack for a car (80 kW basis) including Balance of Plant gives a range of 100-120 $/kW if produced at least at 500 000 units per year. European estimation at Technical review days in Brussels, give a higher estimation at 300€/kW. Private estimation from CEA and PSA and another PEMFC for cars leads to an estimation between EC and US DOE estimation. In any case it is at least a reduction by a factor 5 compared to former estimation in the early 2000.The target for Fuel cell commercialization in automobile industry is 50$/kW or less.

The amount of platinum needed (in term of g/kW) is currently 1g/kW and at laboratory scale 0,3-0,4 g/kW (or 0,2 mg/cm2 for some of them). That's means that on a basis on a cost for platinum 30€/Kg, we could hope less than 10 €/kW for platinum. The next steps is to decrease again by a factor 3 to 4 leading to a figure 0,1 g/kW; this will be possible by using all innovative and very promising nanotechnologies, nanomaterials, for example carbon nanotubes as a support, and others nanotechnologies to implement a three dimensional structure for catalyst, support, diffusion layer and proton conductive membrane.

Another important and crucial issue is the lifetime of materials, stacks under operating conditions (severe automotive conditions, that means temperature range -30°C to +50 °C, vibrations, stop/start Cycle etc…). The target is 5000 hours (mean life time expected for a modern car today). The most recent experiment carried out in public laboratories leads to an average estimation around 1500. DOE announce 2000 h in automotive conditions.. Some car manufacturers (Honda) announced more (near target) but it is not possible to assess the performance due to confidentiality issues. New membranes are very promising (like PBI) with a higher tolerance to CO (up to 3%), low degradation rate (0,1 %/1000hours).What is certain is that considerable progress are made on availability on fuel cells, especially on water management, in order to avoid dry out conditions, on negative temperature management. More generally some impressive progresses are made on components and on auxiliaries, like pumps, or power conversion unit.

PEMFC are also promising technologies for stationary residential applications.

I am convinced that PEMFC reached now such level of performance and costs (2000 to 3000 €/kW if produced in small quantities) that it is possible to start soon the first markets: niches markets, early markets such as described in Implementation Plan, and without major technical breakthroughs.

Let's give some recent examples (last two years) from my personal experience and from new projects (without giving names of the companies involved) in the main market described in IP: Portable, UPS and back up system, micro-fuel cells, by-products, specialist vehicles:

- small vehicles, forklifts and utility vehicles where some companies require innovation, no pollution, low level of noise
- military applications for drone development where there is a huge need for energy autonomy and range, combined with batteries (hybrid systems)
- speciality work-vehicles in agriculture
- Back up system for computer centers and crisis centers, power for cooling system
- New use of incineration plants to produce "by-products " hydrogen and to supply urban vehicle (cleaning vehicle, municipalities vehicles etc.)
- micro-fuels cells (<50W) are ready to commercialization for cell phones, video-recorder, computer, using micro-systems, technologies derived from Silicon industry.

But RTD support is still needed because customers' requirements cannot yet be fulfilled in full. Key points for RTD are on improving stack performance, system integration and simplification, and on field testing different generations of products, from prototypes to pre-commercial systems.

2.2 Other examples

In the field of Hydrogen Storage, significant technical progress has been made. It is clear that now (CGH2) high pressure tank (compressed hydrogen at various operating pressure from 300 bars to 700 bars) are mature technologies, good performance on system capacity, ~5 wt.% (and near ~14 wt.% for Cryogenic H2 storage) and ready to commercialization from a technical point of view, even the cost is too high. Main part of the cost is due to the carbon fibers wrapping up the liner and standing high pressure level. These fibers are quasi exclusively supplied by Japanese companies and are very expensive; aeronautics industry require a large amount of the total production and give some tensions on the fibers markets. Certification must be carry out now at European level. CGH2 is near commercialization and could be apply to transport applications.

Reversible solid storage at room temperature could be used for stationary applications where weight is not an issue. Performance of 1.8 wt.% (alanates) is state of the art. Major bottlenecks include system capacity, safety, storage losses, permeability, energy losses, tank design, heat management, recycling of materials and last but not least costs. There is a need for a deeper fundamental understanding of materials properties, and therefore for basic research, for example with the potential of theoretical simulations for finding novel materials, understanding aging.. New tank design, prototype development, engineering tasks are the most relevant RTD topics in this field.

SOFC technologies operating between 600 and 800°C are very promising technologies in Europe and could be divided in two main applications :

- residential and small power applications, < 20 kW, (heat and power generation); suited design, ***mostly planar***, combined with natural gas, LPG or propane fuel, integrating a reformer: these technologies are now in different test phase. The most important issues are the reliability of the system, voltage (and efficiency) degradation (typically 1-3 % per 1000 hours) and sealing, particularly because of high temperature operation, slow start-up of up to 10 hours, limited number of thermal cycles and carbon deposition in the case of reforming. Performances are not good enough to allow early commercialization.
- decentralized power and cogeneration (hundred of kW up to 5 MW); special design is needed ***(not planar but tubular or 3D)***, could be coupled with gas turbine (combined cycle) with better degradation losses but more costly; the technology, especially Balance of Plant at scale > 250kW is no mature yet but very strong developments are carried out inside large power companies and on a multi-year basis, which is a positive signal.

MCFC are close to commercialization.

Generally speaking on fuel cells, more support is needed for developing Balance of Plant and systems integration expertise e.g. fuel processing, power electronics, air and fuel movement and circulation and heat exchangers. Off-the-shelf components that are not designed to operate under the challenging conditions of fuel cells could lead to failure in fuel cell units. It is new opportunities especially for SME to create new business for these components.

Hydrogen production and supply is in a paradoxal situation: at the contrary of fuel cells, hydrogen production, transport distribution exist yet at industrial scale. Hydrogen can be bought at different quantities needs and even could be relatively cheap if produced massively and used closed to the production location.

From this point of view hydrogen technologies could be considered technically mature. But the technologies used and primary energy are not satisfying sustainable development criteria. They are linked to fossil fuels sources and CO2 emission. The alternative is:

- at first CO2 capture and sequestration not mature before 2020
- Medium/long term processes like high temperature processes (thermo-chemical, high temperature electrolysis) or low temperature (fermentation, photo-fermentation, bio-production, photo-electrolysis) not ready at industrial scale before 2015 and for some 2020-2025; high temperature electrolysis is the most promising and medium term technology; main issues are the degradation of the cells, innovative design suited to scale-up to MW scale plants. Large HTE project in the forthcoming JTI and that there will be needed.
- Biomass to Hydrogen(BTH) by gasification process could be ready at demonstration level by 2015 and seems relatively competitive BUT one can raise the question of competition between BTL (Liquid to biofuels) and BTH; both processes are similar except the final Fisher Tropsch stage for BTL; the deployment of BTL could start around 2015 so we could imagine only some demonstration projects for BTH supplying some demonstrations projects (at the level of Refueling station); if a larger deployment is needed, BTH and BTL road map alignment are to be considered and coherent actions. Probably an unique “Biomass” road map will be needed at European level covering energy applications (biofuels, hydrogen, heat, power..) and others applications (chemistry, high value project) comparing to traditional use of land (agriculture …).
- The industrial use of Hydrogen in Refinery, heavy oil extraction, for chemistry and for Liquid second generation Biofuels, the huge resulting and growing demand of “Clean” Hydrogen for these markets will accelerate the R&D and deployment for CO2 free processes (described above) for H2 production; the new processes will be used for massive hydrogen production near or very close to industrial final use. These type of markets will play similarly the same role of “**Early market” for Hydrogen** as “early markets described before for Fuel cells; it will be a strong driver for big energy supplier
- Last but not least, renewable energy (wind, solar, waste, biomass) could very quickly produce electricity the hydrogen via classical electrolysis processes (alkaline etc..) at small scale. Technologies are mature but it will needed a large amount of research(to improve efficiency, scaling up, new low temperature electrolysis processes like PEMFC, elevating operating pressure etc…), development (system integration) and feed back from a large number of demonstration projects combining different type of Renewables (solar PV, solar concentration, biomass, wind, waste…), different size (from few kW to x MW), different configurations (small communities, grid or non-grid connected, isolated area, islands …) and different national context and reglementations (energy mix, incentives…).

2.3 Demonstration/deployment Phase and projects (SRA, DS, IP)

The demonstration/deployment coupled to a strong emphasis on commercialisation and market opportunity phase as described in Implementation Plan are necessary and will give essential feed back to future research needs. . The first demonstrations projects (more than 400 different projects in the world, according to IPHE database) allowed having good interactions between real conditions and research and developments

According to European review days in Brussels, October 2007, “the Implementation Plan envisages a substantial programme of demonstration for infrastructure. In the first phase, running to 2010, this will comprise 13 demonstration sites for road vehicles, focusing on captive fleets and comprising around 200 vehicles and nine hydrogen refuelling stations. The objective is to bridge the gap between the isolated prototype demonstrations operating now and future mass-market installation. Larger scale demonstrations are planned for the second phase covering 30 sites with 3000 vehicles and the linking of clusters of users of hydrogen. It is expected to achieve a delivered cost for hydrogen of 2.5 €/kg, excluding tax The results were combined into a Road Map that identified the critical steps along the way to large scale use of hydrogen and an Action Plan that identified necessary policy measures.

It identifies a particularly promising corridor from North West Italy through the Rhine-Ruhr into Benelux countries. The early markets appear to have been identified as middle-class car owners seeking novelty and environmental credit rather than urban bus fleets. The technical and commercial aspects of analysis predominate in the US scheme, whereas in Europe there is more attention paid to social aspects – consensus building, regional development, employment”.

I think that this part of the project will need very strong political support, policy measures (for example legal frameworks for the use of aquifers for CO2 storage), financial support. It will require good organisations, industrial capability: a major point will be to create a European Stack manufacturer like Ballard in Canada and able to supply thousands of power stack; it could be a major decision from Members States to jointly help to the creation of such company for strategic reason.

This type of project could be the contribution of the next “World Hydrogen Project: WHP” as described in IPHE organization and really accelerate the deployment of fuel cells and hydrogen technologies at world level. For example in California, 2500 cars are planned for a market introduction programme within the next 5 year

The main advantage of such big Demo projects in an integrated and iterative process is to gain operating experience and to feed back into technical development and manufacturing processes, and to demonstrate the technology to potential customers.

To summarize and considering impressive progresses made last years and the useful feed back from demonstration and first deployment, I think that:

- MCFC, PEMFC, Hydrogen storage are mature enough to start early commercialization and large demonstration/deployment in niche/early markets
- SOFC have to make more progresses on lifetime, durability and reliability. Large demonstration phase, large number of systems are needed as described in IP
- Huge demand of Clean Hydrogen for industrial use will accelerate innovative hydrogen production processes,
- Sustainable Hydrogen production for small quantities can start with renewables at local level and with classical electrolysis system for small/medium size but expensive hydrogen will be produced. By- product H2 or hydrogen produced from waste could be cheaper.
- The other main conclusion that considering the slope of progress these last years (2000-2007), we could be confident enough that IF a strong and continuous R&D effort on technological breakthroughs is done , it could lead to reach the targets of SRA/DS and IP in 2015. That aspect is not completely taken into account presently in the JTI.

SRA, DS and Implementation Plan describe a action plan well balanced between Research, Development and demonstration deployment. It will need a strong policy support from Members State not completely fulfilled now and some others commitments.

3. ADEQUACY OF THE PROPOSAL UNDERTAKING OBJECTIVES JU JTI, AND PROPOSAL MEANS FOR DELIVERING THE IP.

The Implementation Plan envisages a total expenditure over the period to 7.4 B€ - much more than the resources available to the JTI (940 M€). Bridging this large gap is critical to the execution of the Plan.

In fact, I think that JTIs must play a critical catalysing role in aligning the various sources of public funding, Members States and regional, needed to achieve the Plan's goals. This is the Key point to achieve the common goals. If it succeeds to give coherence and synergies between all European public funding, it will be the very easy to give confidence and involve the others bodies: industrial stakeholders, EIB, financial private bodies like investment bank, risk capital funds and other private sources. Another important point is to establish national coherent strategies and strong commitment in Members States. Only in a few Member States (e.g. Germany, Italy, Spain ? and Scandinavian countries) there seem to be well established coordination mechanisms at a national level.

The European Parliament could propose and call for a great european alliance, following the Written Declaration on establishing a green hydrogen economy and a third industrial revolution in Europe through a partnership with committed regions and cities, SMEs and civil society organizations.

IP suggests devoting more resources to R&D in the early stages than in following steps but also with a global major funding for demonstration and deployment. The focus shifts increasingly to demonstration and pre-commercial deployment later on, to prepare for and kick-start market entry. The JTI probably focussed on the same ratio R&D and demonstration but with eliminating drastically some entire activities (discussion in progress).

As most of activities of IP are not included in JTI, I think that important consequences can be drawn:

- **demonstration and deployment project** have to be planned and articulate with local institutions, especially some Regions candidate to welcome and fund large demonstration/Deployment projects. Germany has a large national programme (NOW, 1.4 B€ over 10 years, and some Länders very active and experienced). I agree with the idea to include external cost of CO2 for example in the final cost of transport in order to facilitate large demonstration projects for Local governments. I think that a very Large Regional Hydrogen Project including Germany, east of France and North of Italy could reach a consensus between Member States.
- Local government has an important part to play as host to demonstration projects, as planner and perhaps as owner of equipment. This is recognised and measures are in place to develop some light partnership arrangement that would let regions and municipalities participate in the work of the JTI.
- Common public procurement strategies are needed, e.g. for early market applications (examples such as the "Bus Alliance")
- Following an idea from an Italian colleague, the idea is to determine at European level a price for a ton of CO2 avoided (it could be specific for H2 and Fuel cell projects. Policy to internalise external costs could help generate revenue flows:

Building an harmonised system of policy intervention to internalise these costs) and create an European fund by national contributions or a tax on fossil fuel companies; the order of magnitude could be a few percents (5%) of oil companies annual profit during 10 years are enough to fund the whole Implementation Plan. For example, if a large demonstration project avoid thousands of tons of CO2 through H2/Fuel cells demonstration technologies, the local project could receive an amount of money corresponding to the total price of CO2 avoided. It could help significantly to fund this large type of project and initiate a real Hydrogen infrastructure. The European Investment Bank (EIB) could play a important role for such large scale demonstration plants preceding spontaneous commercialisation.

- **Research part** has to be looked for very carefully. The drastic reduction of budget in JTI gives a "sub-critical" mass to volume of R&D necessary to carry out efficient research leading to breakthroughs. JTI is rather strongly oriented towards industrial interests would distort activity and undermine basic research and training
- Therefore, JTI with a rather small part R&D budget could not address all the needs for research, especially those described in IP. Basic research, medium/long term research for PEMFC, SOFC, for long term production processes, new type of fuel cells, biological processes for example, new materials for hydrogen storage, fundamental understanding of chemical and physical mechanism are not covered by JTI action plan.
- Especially on research part, the JTI should be proactive in working with national governments to achieve central coordination of research budget. Most of research is funded through national budget and national call for proposal. It is crucial to call national programme, government and programme manager to launch joined and coherent call as soon as possible. The recent Era Net HY-CO was not completely successful because of misunderstanding of the importance of objective and also the non-representativity of project participants (Higher level will be needed next time).
- A centralized strategy supported by a central validation and assessment exercise is necessary. It could be done or coordinated through JTI office and management structure and Scientific Committee with the cooperation of the national programme agencies in charge of Hydrogen and fuel cells programme in Member States from which all can learn.
- Research Grouping could play a major role to harmonize and structure research community (following point)..

4. ASSESS APPROPRIATENESS AND EFFICIENCY OF THE PROPOSED MODEL GOVERNANCE, ESPECIALLY RESEARCH GROUPING.

The governance proposed for JTI management during the next 7 years is based on a share power and decision votes shared between European Commission and representative from Industry grouping; in addition one seat from EC could be given soon to a representative of "Research Grouping" association. Considering the main objective of the JTI, "accelerating the deployment of H2 and Fuel cells technologies in the next 7 years", the principle of governance seems globally appropriate. One major reason is that the main risk taken during this first step commercialization is taken by Industrial companies in Europe. One another reason is that 2/3 of the total budget is devoted to demonstration and deployment projects.

I think that considering JTi a an important but partial body in Hydrogen and fuel cell development in Europe, governance globally speaking is well balanced between Research Grouping, Industry grouping and EC. As I see the JTI as a central and catalyst role, I think that the link with members states and Regions have to be seriously reinforced. We need a more representative group from Member State and more “organic “link” between Mirror Group and Executive Board. I agree with the idea to have at first a central coordination of strategy through JTI (or HFP Plat form to gather all stakeholders including non-JTI members), supported by a central validation and assessment exercise. I expect to launch the idea of a global scientific and technological evaluation of all H2&FC programmes (including regional, national, JTI) and to help to harmonization of road mapping and comparison of road maps in Europe at different level (regional, national, european).

The JTI should be proactive in working with national and regional governments to achieve this level of collaboration.

All this task is necessary to participate actively in the SET Plan. It could be a good and first example for all energy technologies.

The research grouping is an Association under the Belgian Law. It gathers more than 50 institutes, universities from 15 countries. The Research man power is greater than 1500 people and represents a huge scientific competences pool, people and facilities, one of the most important in the world. According to its Statutes, the main objectives of Research Grouping, are:

a. providing expertise and advice to other stakeholders, e.g. industrial companies, the European Community and its Member States, including the European Hydrogen and Fuel Cell Technology Platform, about the results and needs of European research;
b. actively participating as a member in the creation and implementation of the joint undertaking for the JTI and in its decision process, in particular its highest decision making organ, or any other committees by electing from among its members representatives for such purpose and defining positions of the research community;
c. reaching a better gathering of the above-mentioned research community by mapping existing research competences, facilities and expertise and maintaining a respective knowledge base for its Members and third parties;
d. formulating joint views on existing and future needs on research infrastructures and programmes; special attention will be drawn to the interrelation and cooperation between upstream, basic and applied research, with the support of national and European programmes;
e. issuing any other coordinated positions of the research community and representation of the interests of its Members as research organisations and the research community in general towards third parties.

The first objective is to elect the RG representative in the governing board of the JTI (One vote on 12). In operational conditions, RG expect to participate actively in the definition of the Call for proposal (in progress now) for the definition of the Annual action plan and Multi annual action Plan.. Another important role will take place in chair Scientific committee (not yet approved). We think that the RG chair will represent a strategic role to represent all the scientific strategy and results and will be mandated by the whole research community to preserve R&D tasks.

Step by Step, we hope to participate actively by our work to alignment of national programme and definition of synergies between national programmes: complementarities, expression of needs, promotion of bilateral or trans-national collaboration besides JTI programme; JTI R&D programme will be for us a starting point and by knowing better each others, working more together, leads to a more efficient and structured research organization in Europe. It is a innovative way fir Energy research and lessons learned could be useful to other energy R&D field, for example in preparation of EIT (European Institute of Technology) in the field of Energy, well coordinated and addressing the very ambitious challenges in Energy in Europe.

JTI offer an unique opportunity to test a new model to carry out the research in Europe.

5. CONCLUSIONS AND SUMMARY OF RECOMMANDATIONS

The performance targets set out in the Implementation Plan are challenging.

A strong emphasis on commercialisation and market opportunity is needed in future research, whilst at the same time recognising the areas where market success still needs fundamental research.

So a global approach can be successful. JTI plan is to be the central point structuring all the others aspects.

Some conclusions and recommendations:

- Considering impressive progresses made last years, IP targets could be reach in 2015-2020;
- Some technologies (PEMFC, Hydrogen production, hydrogen storage for early markets) are mature enough to launch early and niches markets for fuel cells. Large demonstration phase (stationary and transport), large number of systems are needed as described in IP.
- Huge demand of Clean Hydrogen for industrial use in time frame 2010-2020 will accelerate innovative hydrogen production processes. This industrial market is an “Early market for Clean Hydrogen”
- Sustainable Hydrogen production for small quantities can start with renewables at local level
- BTH biomass to Hydrogen has to be coordinated with other biomass (BTL second generation)
- It is an unique occasion to create a big industrial stacks supplier supported by member states policy (public procurements…)
- Large demon project could be a part of “World Hydrogen project” recommended by IPHE

Although there is a huge gap between IP budget and JTI, JTI must play a critical catalysing role in aligning the various sources of public funding, Members States and regional, needed to achieve the Plan’s goals. The European Parliament could propose and call for a great european alliance.

But the conditions are

- strong commitment of members states and strong, long-term, public-private partnership on hydrogen and fuel; High Level group of national representative is now needed to link with JTI

- Collaboration with national governments is also important in the development of a common position on regulations, codes and standards.

Large demonstration projects needs political support and strong regional commitments supported by :

- common public procurements at European level (harmonized) and role of European Public Sector
- European Policy to internalise external costs could help generate revenue flows Policy instruments to consider include zero emission zones, capital subsidies and payments for carbon avoided (fed for example by a tax on fossil fuel). Create an European fund based on this principle to help significantly this large demonstration project European. Investment Bank (EIB) could play a important role.

Research part and training is rather low in JTI due to drastic reduction of budget and industry oriented direction of the JTI.

- Long-term research leading to new ideas and concepts is key to overcoming these challenges. It is, therefore, an integral part of this programme and must be long term funded.
- Especially on research part, the JTI should be proactive in working with national governments to achieve central coordination of research budget. Most of research is funded through national budget and national call for proposal. It is crucial to call national programme, government and programme manager to launch joined and coherent call as soon as possible.
- A centralized strategy supported by a central validation and assessment exercise is necessary. It could be done or coordinated through JTI office and management structure and Scientific Committee with the cooperation of the national programme agencies in charge of Hydrogen and fuel cells programme in Member States from which all can learn.

JTI Governance:

- a central and catalyst role, well balanced as today
- link with members states and Regions to be seriously reinforced
- more representative group from Member State
- a central coordination of strategy through supported by a central validation and assessment exercise.
- idea of a global scientific and technological evaluation of all H2&FC programmes (including regional, national, JTI) and to help to harmonization of road mapping and comparison of road maps in Europe at different level (regional, national, european).

Research Grouping

- Participate to the definition of the JTI Call for proposal;
- Chair JTI Scientific committee
- Work to alignment of national programme and definition of synergies between national programmes: complementarities
- Progressive structuration of European Research community

- Future european pioneer for more efficient and structured research organization in Europe R&D field, for example in preparation of EIT (European Institute of Technology)

Finally JTI and other European programme (regional national) have to participate actively to international collaboration like IPHE and IEA agreement in order to join the effort towards accelerating deployment of the Hydrogen and Fuel cells for the Economy.

Briefing note by Gijs van Breda Vriesman

Shell Hydrogen

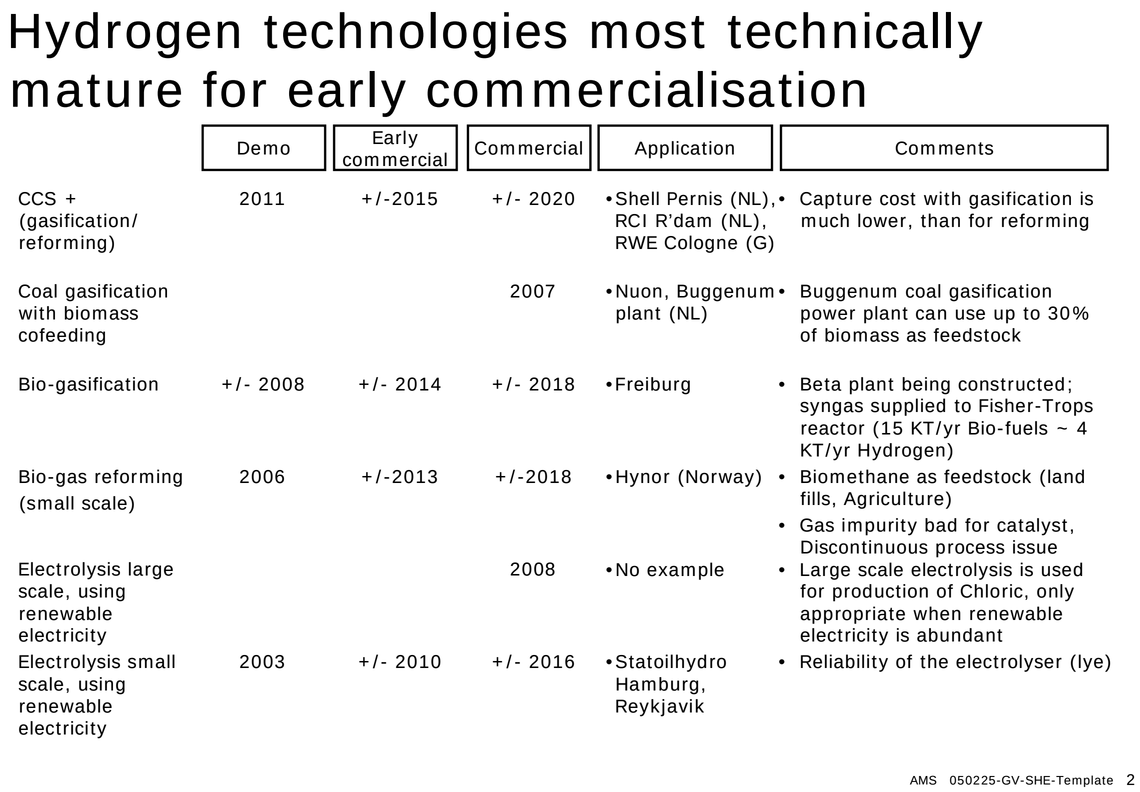
1. HYDROGEN TECHNOLOGIES CONSIDERED TECHNICALLY MATURE FOR EARLY COMMERCIALISATION

The overall objective of the Joint Undertaking is to develop a portfolio of sustainable hydrogen production processes. Sustainability encompasses cost competitiveness, low well-to-tank carbon content, high-energy efficiency and minimum dependence on fossil fuels. Although Carbon capture and sequestration (CCS) is outside the scope of the JU, production processes with CCS added need to be taken into account. If CCS technology is demonstrated and publicly accepted, it will make some the existing commercially available hydrogen production processes more environmentally friendly. Therefore, separately it makes sense to do an assessment of the maturity of CCS. The following generic processes were listed in the strategic research agenda:

1. Chemical conversion of fossil or biomass derived feedstocks via gasification or reforming processes, with CSS where appropriate
    1.1. Centralized reforming of fossil or biomass derived feedstock with CCS
    1.2. Decentralized steam reforming of biomass derived feedstock
    1.3. Centralized gasification with CCS using fossil fuels and/or biomass as a feedstock
2. Electrolysis with electricity from renewable or nuclear power
    2.1. Centralized, large scale (3000 kg/day)
    2.2. Decentralized, small scale (150 kg/day)
3. Chemical conversion of natural gas using high temperature heat from solar thermal concentrators or generation IV nuclear reactors
4. Thermo-chemical water splitting, photo-electrolysis, bio-photolysis or fermentation processes

In the table below, hydrogen production processes of option 1 and 2 will be discussed. Option 3 and 4 are still very much in a research stage and according to my assessment will not become technically mature and commercially available in the next 15 years, but that might also take longer

The hydrogen production process that is technically most feasible and commercial earliest viable and fully sustainable at the same time will be bio-gasification. Electrolysis will be earlier technically viable, but will be more expensive even when the price of renewable energy comes down. Nevertheless, for certain markets, electrolysis will be the most appropriate production process as renewable energy can be abundant (ie Iceland). Depending on public acceptance, CCS combined with existing hydrogen production processes will “green” current hydrogen production methods. First indications are that these will still be cost competitive.



Hydrogen technologies most technically mature for early commercialisation

	Demo	Early commercial	Commercial	Application	Comments
CCS + (gasification/ reforming)	2011	+/-2015	+/- 2020	• Shell Pernis (NL), RCI R'dam (NL), RWE Cologne (G)	• Capture cost with gasification is much lower, than for reforming
Coal gasification with biomass cofeeding			2007	• Nuon, Buggenum plant (NL)	• Buggenum coal gasification power plant can use up to 30% of biomass as feedstock
Bio-gasification	+/- 2008	+/- 2014	+/- 2018	• Freiburg	• Beta plant being constructed; syngas supplied to Fisher-Trops reactor (15 KT/yr Bio-fuels ~ 4 KT/yr Hydrogen)
Bio-gas reforming (small scale)	2006	+/-2013	+/-2018	• Hynor (Norway)	• Biomethane as feedstock (land fills, Agriculture) • Gas impurity bad for catalyst, Discontinuous process issue
Electrolysis large scale, using renewable electricity			2008	• No example	• Large scale electrolysis is used for production of Chloric, only appropriate when renewable electricity is abundant
Electrolysis small scale, using renewable electricity	2003	+/- 2010	+/- 2016	• Statoilhydro Hamburg, Reykjavik	• Reliability of the electrolyser (lye)

AMS 050225-GV-SHE-Template 2

2. ACCELERATING MARKET BREAKTHROUGH: STRATEGIC RESEARCH AGENDA (SRA), THE DEPLOYMENT STRATEGY, AND THE IMPLEMENTATION PLAN (IP)

Bringing hydrogen and fuel cells to market in order to exploit their outstanding environmental and economic potential should not be under estimated. The SRA, the deployment strategy and the IP are important elements to accelerate market breakthrough of the aforementioned hydrogen production technologies for three reasons.

Firstly, without commercially viable fuel cell products, there will be no hydrogen demand. Hence, a coordinated plan for both elements of the value chain with in addition cross cutting issues like socio economic analysis, education, codes and standards is vital. All elements of the value chain will need to be moved in sync from research, via demonstration to larger scale deployment, so that they are ready within a limited range of time. Large-scale private investment will only move in when products have passed consumer acceptance tests and affordable "green" or "clean" hydrogen can be made readily available. The SRA has listed all the elements and the implementation plan has prioritised them and developed a deployment planning.

Secondly, the SRA and the IP have put hydrogen and fuel cells in the right context. The world's need for energy is growing fast, but it needs to be used more efficiently, and provided from a secure source with a smaller CO2 footprint. With hydrogen production processes for the medium (clean hydrogen from fossil fuels with CCS) and the long term (green hydrogen from renewable energy and biomass), the SRA and IP set in motion the right activities for both phases.

Lastly, the SRA and IP articulate a clear vision from now to implementation. A deployment plan without a well-articulated vision, with hydrogen and fuel cells in the context of smart grids, renewable energy and CCS will not be very convincing.

3. ADEQUACY OF THE PROPOSED UNDERTAKING OBJECTIVES AND MEANS FOR DELIVERING THE IMPLEMENTATION PLAN

The objectives of the proposed joint undertaking are challenging, but achievable. The most important ones are listed below:

1. Aim at placing Europe at the forefront of fuel cell and hydrogen technologies worldwide
2. Support research, technological development and demonstration (RTD) in a coordinated manner to overcome market failure
3. Support the implementation of RTD
4. Aim to encourage increased public and private investment.

FCVs, stationary and portable fuel cells are being developed by a range of large and small businesses across Europe. And there is diversity of technologies that is already being trialled in Europe. Such trials are being undertaken in a range of Member States. The industry is thus moving to real use on an annual basis. Although the prospects for the industry are bright, considerable investment is required to meet the technological challenges. The majority of this investment will be made by the Private sector, but the long-term support of the Public Sector is required to provide industry with the confidence to make these investments. Co-support of the technology development, of technology validation and demonstrations are fundamental to creating confidence amongst industry and co-sharing the risk.

In terms of basic shortcomings, that the JTI would help to overcome, there are threefold:

The lack of commitment by the public sector beyond the annual calls – a JTI with committed funds and a five/six year plan would help over come this.

- The lack of funding cohesion between industry, regions, Member States and Europe – although there are considerable funds available for fuel cell and hydrogen technologies the co-ordination of these has been limited in the past – a JTI with agreed objectives and multi-annual plan would help provide a future focus for pan-European efforts;
- The lack of vision for the technologies beyond the industry and committed supporters – a JTI would provide the political commitment by the European Union, one of the world’s key regions, as well as lead the necessary public education and awareness activities required over the next few years.

Whether this would place Europe at the forefront of fuel cell and hydrogen technologies, will be hard to say. The United States and Japan have implemented their umbrella programme several years ago and have invested more than Europe. With the current JU budget, it is likely to remain so in the short term. However, if the Joint Undertaking is able to coordinate the program with the Member States well and can mobilize national and regional funds as well, this would make a real difference. The original quantitative objectives stated in the IP will still be difficult to realize but not unachievable. Some Member States have already put a robust program in place (Germany, UK, Norway). With the coming of the JU, it is only expected that more Member States will follow.

4. ASSESS THE APPROPRIATENESS AND EFFICIENCY OF THE PROPOSED MODEL OF GOVERNANCE AND IN PARTICULAR THE ROLE OF THE INDUSTRY GROUPING

The current model of governance is appropriate, but could be made more efficient and inclusive.

Currently, the Governing Board, the Program Office and the Scientific Committee are bodies of the Joint Undertaking. The FCH States Representatives Group is an advisory body to the Governing Board. This means that the Program Office supports both the Governing Board and the Scientific Committee. This is clearly described in the role of the executive Director, who also has the responsibility to regularly inform as well as respond to any specific ad hoc requests for information of the Gonverning Board and the Scientific Committee. In terms of governance, it would be clearer if the Program Office only supports the Governing Board and that the Scientific Committee is an Advisory body.

Further, currently the structure of the Joint Undertaking does only foresee in a role for the Member States but not for the regions. The Regulation as currently drafted is proposing an advisory body composed of Member States representatives. As important actors of the FCH development and deployment activities, it would be worth to consider including a direct interface of the Regions within the FCH JU structure. This direct interface could take the form of one representative from the Regions being a member of the FCH States Representatives Group.

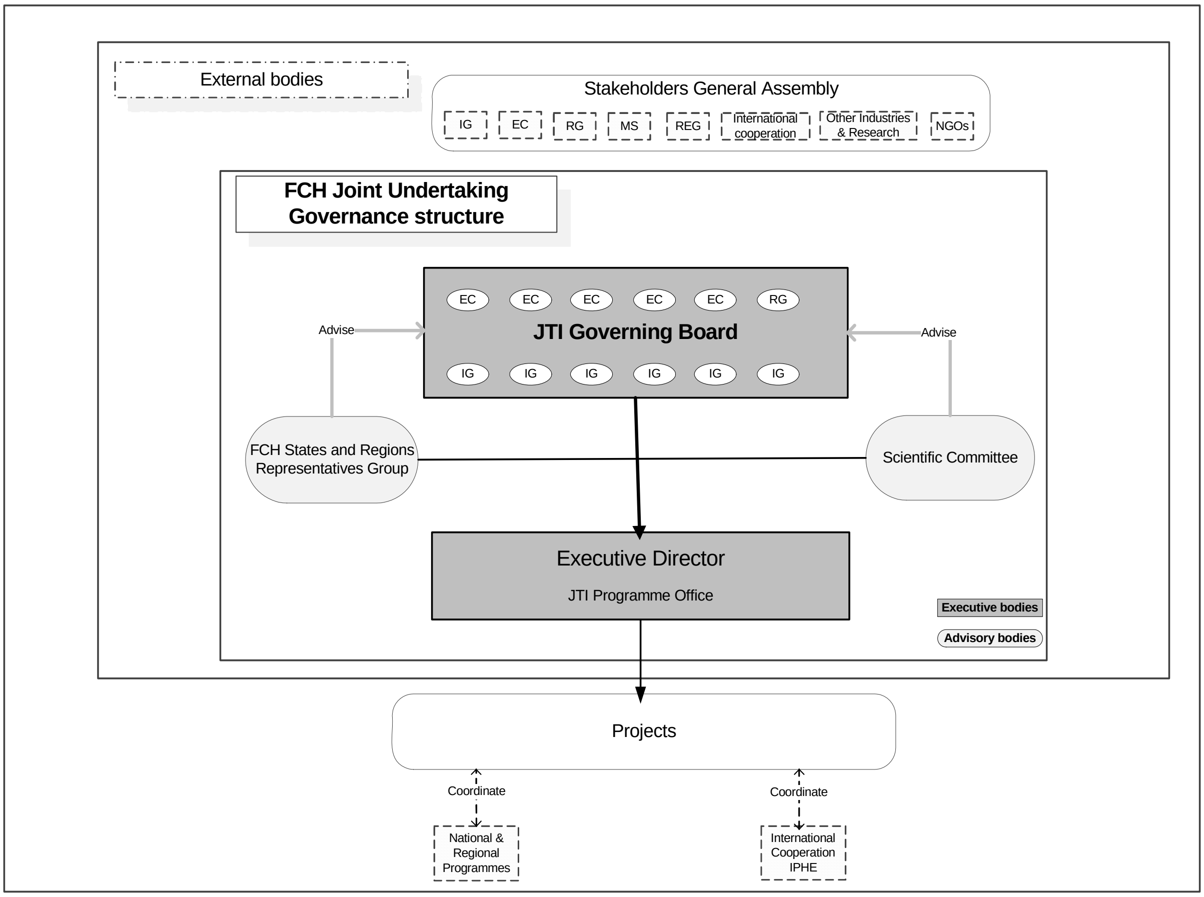
In addition, the term of the mandate of the industry positions in the Governing Board is now a period of two years, which can be renewed by another two. However, the term of the mandate of the counter parts in the European Commission is not arranged and remains at the discretion of the EC. It should be considered to keep the length of both terms the same.

Lastly, the regulation suggests that a minimum of two people in the scientific committee should have industrial background. It should be considered to increase this to a higher number reflecting the considerable amount of research that is also being done by Industry.

The role of the Industrial Grouping in light of the undertaking reflects the 50% share of the funding of the Joint Undertaking. It is an industry lead public private initiative. The last two comments above are relatively unimportant and mere suggestions to reflect the joint responsibility.

5. PROVIDE RECOMMENDATIONS FOR ADDRESSING ANY POSSIBLE IDENTIFIED SHORTCOMINGS.

Some recommendations are already hidden in the text above on governance and structure of the JTI. In the figure below, a slightly changed proposal for governance and structure is put forward. It reflects the new role of regions and changes the organisational structure of the Scientific Committee.



Further, the Regulation gives a possibility to implement preparatory actions for the establishment and initial operation of the FCH Joint Undertaking (article 16) until the JU has the operational capacity to implement its own budget. It should be recognized that an interim structure already exists and the FCHInstruct project has been co-funded by the Commission to carry out preparatory activities for the establishment of the Joint Undertaking. Whatever, preparatory action will be taken, it will be important that the current interim structure is kept alive and involved until permanent staff takes over. Currently, there are no interfaces defined between the current interim structure and the new to be set up preparatory activities. It is recommended to detail these.

In article 8, the peer reviews are introduced by means of the advise of the composition of the peer review committee. The role of peer reviews has not been discussed yet. As the Joint Undertaking, is supposed to have in house expertise to review the calls, peer review committees might not be necessary.

ANNEX 1

HYDROGEN PRODUCTION VIA WATER SPLITTING IN SOLAR REACTORS: THE HYDROSOL PROCESS

A. G. KONSTANDOPOULOS[a,b,*], C. SATTLER[c], P. STOBBE[d], A.M. STEELE[e]

[a]*Aerosol & Particle Technology Laboratory, CERTH/CPERI, P.O. Box 361, Thermi, Thessaloniki 57001, Greece and* [b] *Dept of Chemical Engineering, Aristotle University, P.O. Box 1517, 54006, Thessaloniki, Greece*
[c]*Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Technische Thermodynamik, Solarforschung, D-51170 Köln, Germany*
[d]*Stobbe Tech Ceramics, Vejlemosevej 60, DK-2840, Holte, Denmark*
[e]*Johnson Matthey Technology Centre, Sonning Common, RG4 9NH, Reading, UK*
**E-mail: agk@cperi.certh.gr*

Invited Paper at the INTERNATIONAL SYMPOSIUM ON MATERIALS ISSUES IN A HYDROGEN ECONOMY, November 12-15, 2007, Richmond, Virginia, USA.

The present paper reviews recent work in the field of solar thermochemical hydrogen production via water splitting in monolithic reactors, also known as the Hydrosol process. The process employs a reactor concept, adapted from the well-known automotive emission control field, and consists of multichannel ceramic honeycombs, coated with active water-splitting materials, that are heated by concentrated solar radiation to the desired temperature.. When water vapor passes through the reactor, the coating material splits the water molecule by "trapping" its oxygen and leaving in the effluent gas stream pure hydrogen. In a next step, the oxygen "trapping" material is regenerated, by increasing the amount of solar heat absorbed by the reactor; hence a cyclic operation is established. Multi-cyclic solar thermo-chemical splitting of water was successfully demonstrated on a pilot solar reactor achieving constant hydrogen production exclusively at the expense of solar energy.

1. Introduction

The harnessing of the huge energy potential of solar radiation and its effective conversion to chemical energy carriers such as hydrogen is a subject of primary technological interest. One of the reactions with tremendous economical impact because of the low value of its reactants is the dissociation of water (water splitting) to oxygen and hydrogen. However because of unfavorable thermodynamics interesting yields can only be achieved at very high temperatures imposing therefore technological difficulties. The integration of solar energy concentration systems with systems capable to split water is of immense value and represents an important long term goal for hydrogen production with virtually zero CO_2 emissions [1-3]. The state of the art is focusing on two-step processes, based on redox materials that can act as effective water splitters at lower temperatures [4-6].

The HYDROSOL process employs water splitting materials coated on a monolithic honeycomb solar reactor, inspired from the well-known automobile catalytic converters [7], and it was recently introduced in [8]. The HYDROSOL reactor contains no moving parts and is constructed from special refractory (Silicon carbide) ceramic thin-wall, multi-channelled (honeycomb) monoliths, optimised to absorb solar radiation and develop sufficiently high temperatures. When steam passes through the solar reactor, the coating material splits water vapor by "trapping" its oxygen and leaving in the effluent gas stream pure hydrogen (Eq. 1), without any need for expensive and complicated gas separation post-processing steps. In a subsequent step (Eq. 2), the oxygen "trapping" material is regenerated (i.e. releases the oxygen absorbed), by increasing the amount of solar heat absorbed by the reactor and hence a cyclic operation is established:

$$MO_{red} + H_2O\ (g) \rightarrow MO_{ox} + H_2 \qquad \text{(exothermic)} \qquad ...(1)$$

$$MO_{ox} \rightarrow MO_{red} + \tfrac{1}{2}\, O_2 \qquad \text{(endothermic)} \qquad ...(2)$$

The inherent advantage of two-step thermochemical cycles is that the production of pure hydrogen and the removal of oxygen take place in separate steps, avoiding the need for high-temperature separation and the chance of explosive mixtures formation. In addition, with the HYDROSOL reactor configuration, with the active redox pair materials coated upon the substrate walls, the whole process can be carried out on a single solar energy converter, the process temperature can be significantly lowered compared to other thermo-chemical cycles and, last but not least, this reactor concept does not involve any circulation of (hot) solid reactants or products and therefore has no problems with the recovery of high temperature heat. Such redox-material-coated-honeycombs have achieved continuous solar operation water splitting – regeneration cycles in the temperature range 850–1200oC demonstrating the "proof-of-concept'' of the proposed reactor design and producing the first solar hydrogen with monolithic honeycomb reactors [8,9]. The present work summarizes the work performed so far and highlights the current research efforts focussed on long-term material stability and scale-up of the solar reactor.

2. Redox Material Development

Four different routes were employed for the synthesis of iron-oxide-based redox water-splitting materials: Solid-State Synthesis (SSS), Self-Propagating High-Temperature Synthesis (SHS), Gel Combustion (GC) and Aerosol Spray Pyrolysis (ASP) [8]. These synthesis methods were chosen with the rationale to exploit particular characteristics of each one for the synthesis of products with "tunable" oxygen vacancies concentration. The synthesis details have been reported previously [8], therefore only the general reaction concepts are reported below, where A and B denote the bivalent dopant metals: Ni, Mn or Zn.

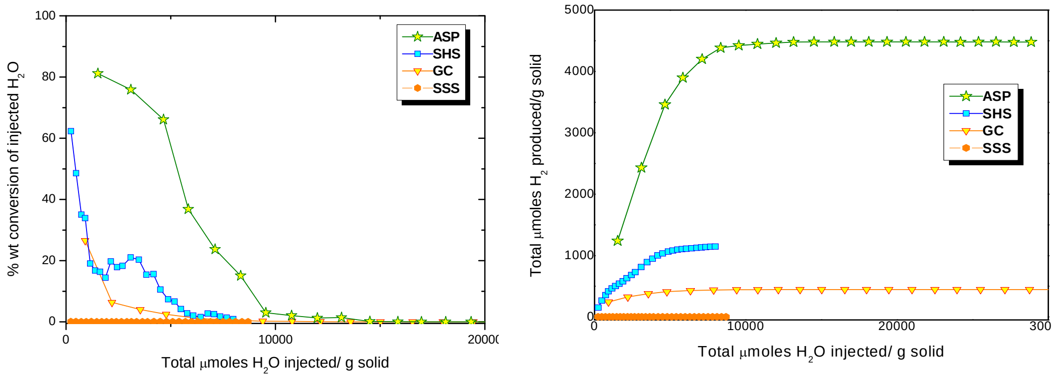
i) Solid state synthesis (SSS) involved powder mixing of the component oxides (or carbonates), pre-firing, milling, spray drying and calcination at high temperatures (≈1250oC). The products were doped spinel ferrites of the structure (AxByFez)Fe2O4.

ii) Self-Propagating High-temperature synthesis (SHS or Combustion Synthesis) of the targeted materials is based on the heat released from the reaction of iron metal powder ("fuel") with oxygen ("oxidizer") in the presence of the dopant metal oxides and of Fe2O3 powder as a "thermal ballast/moderator" to control the synthesis temperature.

iii) Gel combustion (GC) is based on the reaction in aqueous solutions of nitrate salts Ax(NO3)y ("oxidant") with amino-groups ("fuel") to form explosive ammonium nitrate; upon heating the solution is first transformed to a gel which is then combusted to produce a very fine powder of spinel structure (AxByFez)Fe2O4.

iv) Aerosol spray pyrolysis (ASP) employs the atomisation of a metal precursor salts solution in a spray of fine droplets that is subsequently passed through a hot-wall reactor where it transforms within a very short time to ultra-fine, nanostructured spherical particles [10].

The first "screening" of the synthesized material compositions with respect to water splitting activity was performed in a laboratory unit described in detail previously [11] and subsequently in a scaled-up testing rig version consisting of a 20-mm-diameter quartz glass tubular reactor enclosed within a high-temperature programmable furnace capable of reaching temperatures of 1500oC. A bed of the redox material powder to be tested was placed in the middle of the reactor and subsequently heated under inert atmosphere (Nitrogen) to the water-splitting testing temperature. When this temperature was reached, steam was introduced to the reactor. The effluent, after passing through a water trap, was diverted to the analysis rig, consisting of a mass spectrometer (MS). The quantities of unconverted water and of produced hydrogen were calculated based on the areas of the corresponding MS peaks.



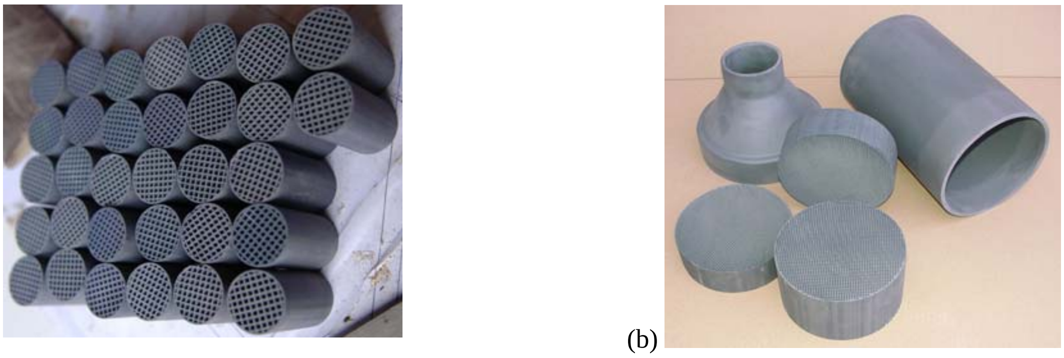
(a) (b)

Figure 1: Comparison of “best’’ redox powders from each synthesis route with respect to: (a) water conversion and (b) total Hydrogen yield.

These experiments have shown that systems from all the synthesis routes were able to split water and generate hydrogen as the only product, at temperatures as low as 800°C and could be repeatedly regenerated under inert atmospheres at temperatures below 1200°C [8]. The “best” products from each synthesis route are compared with respect to water-to-hydrogen conversion and total hydrogen yield in Figs. 1a, 1b respectively. Both SHS and ASP materials exhibited very high water conversions (amount of water converted/total amount of injected water) at 800oC – 57% and 81% respectively. Overall the ASP materials exhibited both the highest water conversion and hydrogen yield.

3. Manufacturing and coating of honeycomb solar receivers

Several series of small-scale (Ø25x50 mm) and large-scale (Ø144x200 mm) monolith extruded multi-cell SiC supports were produced (shown in Figs. 2a and 2b respectively) and coated with the synthesized materials via the “washcoating” technique employed for the coating of automotive catalysts, in which the porous supports are impregnated in a slurry of the coating powder [7]. With subsequent drying and firing at the temperature range 500-800oC, an adherent oxide layer is formed on the walls of the support. The coated honeycombs were employed for the experimental campaigns in a solar furnace to demonstrate the “proof-of-concept” of the proposed approach and to “screen” redox material formulations.



(a) (b)

Figure 2: (a) Small-size and (b) large-size, extruded SiC honeycombs and housing vessel..

4. Solar Reactors

Two reactors have been developed for different purposes. The first reactor built (Fig. 3a) was designed and constructed to monitor the performance and feasibility of solar chemical hydrogen production by the HYDROSOL process.

This receiver-reactor is operated in the the Solar Furnace at the DLR facilities, in Cologne, Germany. This reactor was mainly designed for the investigation of the general feasibility of both steps of the process and for screening different “families” and “generations” of redox pairs coated on small-scale honeycombs as depicted in Fig. 3b. Both steps of the thermochemical cycle were successively performed in the same reactor.

The first solar campaign demonstrated the in-principle-feasibility of water splitting by the proposed method. The first solar hydrogen was successfully produced by irradiating a redox material coated on a SiC monolith at 800°C in a mixture of steam and nitrogen, whereas after completion of the water splitting step and by raising the operating temperature to 1200°C under flushing by pure nitrogen, a release of oxygen was initiated. The second campaign proved the feasibility of multi-cycling, i.e. a periodic and alternating performance of water splitting and regeneration of the redox system. Not only the reactor was capable for producing hydrogen from steam at the expense of solar energy alone, but multi-cyclic operation (water splitting and redox material regeneration) at the temperature range 800-1200oC was successfully demonstrated several times and for several of the redox materials synthesized [9].

The main objectives of the third campaign were on the one hand large monolith (Ø144 x200 mm) testing for the demonstration of continuous production of hydrogen and on the other hand, further improvement of the coated monoliths with respect to multi-cycling capability and the amount of hydrogen produced. In addition, the stability of coating/support assembly was examined. The results were quite encouraging. One of the samples was irradiated in a long-term operation over five days and it maintained its activity after 40 cycles. More cycles would have been possible if more testing time had been available but the solar furnace had to be used for other scheduled projects.

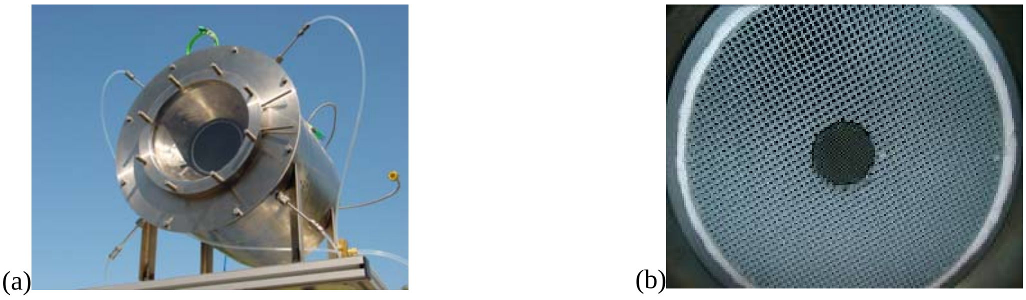


Figure 3: (a) Front view of the first solar water-splitting receiver-reactor, (b) Small-scale honeycomb coated with redox material (black) in the centre of the reactor ready for testing.

The second reactor constructed, was designed with the purpose to be capable for continuous hydrogen production [12]. Different approaches of receiver-reactors have been analysed and compared. The final decision was in favor of a multi-chamber reactor with fixed honeycomb absorber allowing a modular set-up. This is the so-called “conti reactor”, where one module splits water while the other is being regenerated, shown in Fig. 4. The test programme aimed at exploring suitable operation conditions to verify the concept of a continuous hydrogen production in the “conti reactor”.

Fig. 5 presents the quasi-continuous production of hydrogen in 13 subsequent cycles during the first day of solar testing of two large coated monoliths in the “conti reactor”. Another 10 cycles were carried out during the following day. A subsequent campaign proved the long-term stability of the redox-coated honeycomb systems: 53 cycles of solar hydrogen generation with the same redox coating were performed during a 5-day campaign, proving the capability of the “conti-reactor” to reliably operate the HYDROSOL two-step water splitting process quasi-continuously.

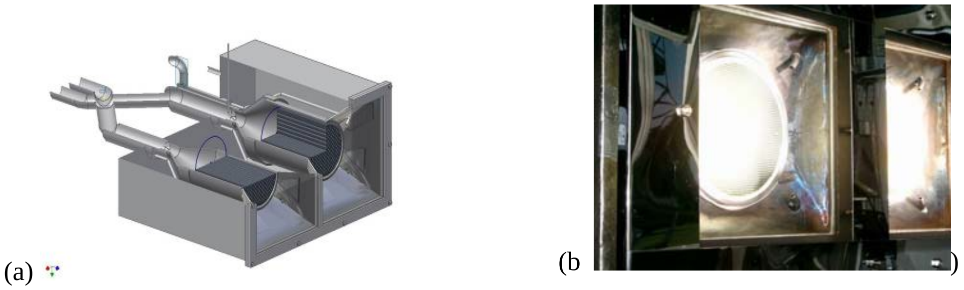


Figure 4: The dual-chamber ("conti" reactor) for continuous solar hydrogen production: (a) vertical-horizontal cut, (b) front view of the reactor, in operation at the solar furnace facility.

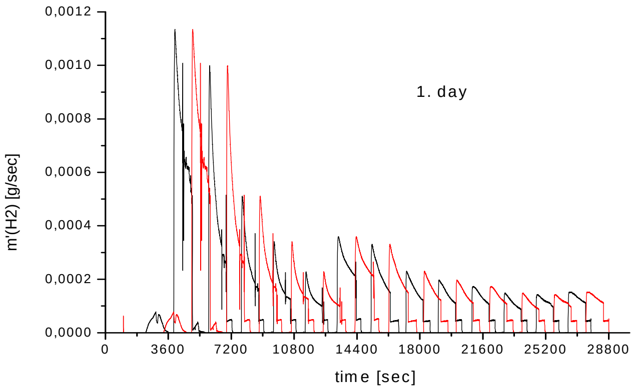


Figure 5: Campaign with the "conti" reactor; first quasi-continuous production of hydrogen: mass flow of hydrogen for 13 cycles during the first day of testing of two coated monoliths.

5. System scale-up

The next steps involve the development and build of an optimized pilot plant (100 kWth) for solar Hydrogen production based on this novel reactor concept, involving further scale-up of the HYDROSOL technology and its effective coupling with solar platform concentration systems, in order to exploit and demonstrate all potential advantages. Specific challenging problems currently addressed include:

The first scaled-up version of the solar reactor/receiver currently under construction involves a dual-reactor unit, each part assembled from 9 square-shaped SiC honeycomb pieces with dimensions 146x146 mm. The unit is going to be installed on a solar tower and coupled with the heliostat field at the Plataforma Solar in Almeria, Spain for test operation in 2008.

6. Conclusions

An innovative technology has been developed for the production of hydrogen from the splitting of water by a two-step thermochemical cycle using solar energy. Highly active water splitting (redox) materials were produced via un-conventional synthesis routes (combustion synthesis and aerosol spray pyrolysis). The HYDROSOL process was successfully put into practise in a pilot scale and the stability of the redox/support assemblies during multi-cyclic solar thermo-chemical splitting of water was successfully demonstrated: the reactor produces hydrogen by cyclic operation exclusively at the expense of solar energy.

Up to 52 cycles of constant hydrogen production were operated in a row during the five-day campaign that the solar furnace was available to us.

The HYDROSOL process represents the world's first closed, solar-thermochemical cycle in operation that is capable of continuous, pure renewable hydrogen production. It is expected that deployment of the HYDROSOL process will proceed with the ongoing commercialization of solar thermal power plants.

Due to the fact that the HYDROSOL process employs entirely renewable and abundant energy sources and raw materials - solar energy and water respectively - it holds a significant potential for large-scale, emissions-free hydrogen production, particularly for regions of the world that lack indigenous resources but are endowed with ample solar energy.

Acknowledgements
Colleagues who have contributed to this research are from the APT Lab: C. Agrafiotis, S. Lorentzou, C. Pagkoura and from DLR: M. Roeb, M. Neises, P.M. Rietbrock, J.P. Säck. The authors would like to thank the European Commission for partial funding of this work within Projects HYDROSOL (ENK6-CT-2002-00629) and HYDROSOL-II (FP6-2002-Energy-1, 020030).

References

[1] Rubbia, C., *Hydrogen at crossroads between science and politics*. Conference on the Hydrogen Economy – A Bridge to Sustainable Energy, Brussels, June 16-17, 2003.

[2] Kodama, T., *High-temperature solar chemistry for converting solar heat to chemical fuels*. Progress in Energy and Combustion Science, 29 (6), 567-597, 2003.

[3] Steinfeld, A., *Solar thermochemical production of Hydrogen-a review*. Solar Energy, 78, 603-615, 2004.

[4] Tamaura, Y., Steinfeld, A., Kuhn, P., Ehrensberger, K., *Production of solar Hydrogen by a novel, 2-step, water-splitting thermochemical cycle*. Energy 20(4), 325-330, 1995.

[5] Ehrensberger, K., Frei, A., Kuhn, P., Oswald, H. R., Hug, P., *Comparative experimental investigations of the water-splitting reaction with iron oxide* $Fe_{1-y}O$ *and iron manganese Oxides* $(Fe_{1-x}Mnx)_{1-y}O$. Solid State Ionics, 78, 151-160, 1995.

[6] Steinfeld A., *Solar hydrogen production via a two-step water-splitting thermochemical cycle based on Zn/ZnO redox reactions*. International Journal of Hydrogen Energy 27, 611-619, 2002.

[7] Heck R. M., and Farrauto, R. J., *Catalytic Air Pollution Control-Commercial Technology*. Van Nostrand Reinhold, New York U.S.A, 1995.

[8] Agrafiotis, C., Roeb, M., Konstandopoulos, A.G., Nalbandian, L., Zaspalis, V.T., Sattler, C., Stobbe, P., Steele, A.M., *Solar Water Splitting for Hydrogen Production with Monolithic Reactors*. Solar Energy, 79(4), 409-421, 2005.

[9] Roeb, M., Sattler, C., Klüser, R., Monnerie, N., deOliveira, L., Konstandopoulos, A.G., Agrafiotis, C., Zaspalis, V.T., Nalbandian, L., Stobbe, P., Steele, A.M., *Solar hydrogen production by a two-step cycle based on mixed iron oxides*. Journal of Solar Energy Engineering - Transactions of the ASME, 128, 125-133, 2006.

[10] Lorentzou S., Karadimitra K., Agrafiotis C., Konstandopoulos A. G., *New Routes for Ferrite Powders Synthesis*. PARTEC International Conference for Particle Technology, March 16 –18, Nuremberg, Germany, 2004.

[11] Nalbandian, L., Zaspalis, V.T., Evdou, A., Agrafiotis, C., Konstandopoulos, A.G., *Redox materials for Hydrogen production from the water decomposition reaction*. Chemical Engineering Transactions, 4, 43-48, 2004.

[12] M. Roeb, M., Monnerie, N., Schmitz, M., Sattler, C., Konstandopoulos, A.G., Agrafiotis, C., Zaspalis, V.T., Nalbandian, L., Steele, A.M., Stobbe, P., *Thermo-chemical production of hydrogen from water by metal oxides fixed on ceramic substrates*. Proceedings of the 16th World Hydrogen Energy Conference, Lyon, France, 13-16 June, 2006.

PUBLICATIONS ON HYDROSOL TECHNOLOGY

1. Konstandopoulos A. G., Sattlerc C., Stobbe P., Steelee A.M. , (2007) "Hydrogen Production via Water Splitting in Solar Reactors: the Hydrosol Process", in International Symposium on Materials Issues in a Hydrogen Economy (ISHE – invited paper), Richmond (Virginia).

2. C. Agrafiotis, C. Pagkoura, S. Lorentzou, M. Kostoglou, A. G. Konstandopoulos (2007) “Hydrogen Production in Solar Reactors”, Catalysis Today, 127, pp. 265-277.

3. S. Lorentzou, C Agrafiotis, A. G. Konstandopoulos (2007) “Aerosol spray pyrolysis synthesis of water-splitting ferrites for solar hydrogen production”, Granular Matter, 10, pp. 113-122.

4. C. C. Agrafiotis, I. Mavroidis, A. G. Konstandopoulos, B. Hoffschmidt, P. Stobbe, M. Romero, V. Fernandez-Quero, (2007) "Evaluation of Porous Silicon Carbide Monolithic Honeycombs as Volumetric Receivers/Collectors of Concentrated Solar Radiation", Solar Energy Materials and Solar Cells, 91, pp. 474-488.

5. Agrafiotis C., Pagkoura C., Lorentzou S., Zygogianni A., Konstandopoulos A.G., Roeb M., Rietbrock P.M., Neises M., Söck J.P., Sattler C., Stobbe P., Jones D., Steele A.M., (2007) "Functional Monolithic Reactors for Solar Hydrogen Production via Thermochemical Water Splitting", in 10th International Conference and Exhibition of the European Ceramic Society, Berlin (Germany).

6. Agrafiotis C., Pagkoura C., Zygogianni, A., Konstandopoulos A.G., (2007) "Self-Propagating High-Temperature Synthesis of Water-Splitting Mixed Iron Oxides for Solar Hydrogen Production", in 10th International Conference and Exhibition of the European Ceramic Society, Berlin (Germany).

7. Lorentzou S., Zygogianni A., Agrafiotis C., Konstandopoulos A.G., (2007) "Aerosol Spray Pyrolysis Synthesis of Water-Splitting Ferrites for Solar Hydrogen Production", in 10th International Conference and Exhibition of the European Ceramic Society, Berlin (Germany).

8. Agrafiotis C., Pagkoura C., Lorentzou S., Konstandopoulos A.G., (2007) "SHS Synthesis of Mixed Iron Oxides", in IX International Symposium on Self-propagating High-temperature Synthesis, Dijon (France).

9. Agrafiotis C., Lorentzou S., Pagkoura C., Konstandopoulos A.G., Roeb M., Neises M., Rietbrock P.M., Säck J.P., Sattler C., Stobbe P., Steele A.M. , (2007) "The HYDROSOL Process: Solar-Aided Thermo-Chemical Production of Hydrogen from Water with Innovative Honeycomb Reactors", in 2nd International Workshop on Hydrogen, Ghardaïa (Algeria).

10. Hoguet J.C., Karagiannakis G.P., Agrafiotis C., Konstandopoulos A.G., (2007) "Desulphurization Technologies and Materials for Multi-Fuel Processors for Hydrogen Production", in 2nd European Fuel Cell Technology and Applications Conference, Rome (Italy).

11. Hoguet J.-C., Karagiannakis G.P., Agrafiotis C., Konstandopoulos A.G., (2007) "Gas and Liquid Phase Fuels Desulphurisation for Hydrogen Production Via Reforming Processes", in 2nd International Workshop on Hydrogen, Ghardaïa (Algeria).

12. M. Roeb, C. Sattler, R. Klüser, N. Monnerie, L deOliveira, A. G. Konstandopoulos, C. Agrafiotis, V. T. Zaspalis, L. Nalbandian P. Stobbe, A. M. Steele, “Solar Hydrogen Production by a Two-Step Cycle Based on Mixed Iron Oxides”, Journal of Solar Energy Engineering - Transactions of the ASME, 128, 125-133, (2006); also in Proceedings of ISEC 2005: ASME International Solar Energy Conference, Orlando, Florida, USA, 6 –12 August, 2005, pp. 671-678.

13. M. Roeb, N. Monnerie, M. Schmitz, C. Sattler, A. G. Konstandopoulos, C. Agrafiotis, V. T. Zaspalis, L. Nalbandian, A. Steele, P. Stobbe, “Thermo-chemical production of hydrogen from water by metal oxides fixed on ceramic substrates”, Proceedings of the 16th World Hydrogen Energy Conference, Lyon, France, 13-16 June, (2006).

14. C. Agrafiotis, C. Pagkoura, S. Lorentzou, J.C. Hoguet and A. G. Konstandopoulos "Material Technologies Developments for Solar Hydrogen", Proceedings of the 16th World Hydrogen Energy Conference, Lyon, France, 13-16 June, (2006).

15. C. Agrafiotis, S. Lorentzou, C. Pagkoura, M. Kostoglou, A.G. Konstandopoulos, "Advanced Monolithic Reactors For Hydrogen Generation From Solar Water Splitting" Proceedings of SolarPACES 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies”, Seville, Spain, June 20-23, (2006).

16. A. G. Konstandopoulos, S. Lorentzou and C. Agrafiotis: "Aerosol Spray Pyrolysis Synthesis of Water-Splitting Ferrites for Solar Hydrogen Production", The Fifth World Congress on Particle Technology, Orlando, Florida, USA, 23-27 April, 2006.

17. M. Roeb, N. Monnerie, M. Schmitz, C. Sattler, A. G. Konstandopoulos, C. Agrafiotis, V. T. Zaspalis, L. Nalbandian, A. Steele, P. Stobbe, "Thermo-chemical production of hydrogen from water by metal oxides fixed on ceramic substrates", 16th World Hydrogen Energy Conference, Lyon, France, 13-16 June, 2006.

18. C. Agrafiotis, C. Pagkoura, S. Lorentzou, J.C. Hoguet and A. G. Konstandopoulos "Material Technologies Developments for Solar Hydrogen", 16th World Hydrogen Energy Conference, Lyon, France, 13-16 June, 2006.

19. C. Agrafiotis, S. Lorentzou, C. Pagkoura, M. Kostoglou, A.G. Konstandopoulos, "Advanced Monolithic Reactors For Hydrogen Generation From Solar Water Splitting" SolarPACES 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies”, Seville, Spain, June 20-23, 2006.

20. C. Agrafiotis, M. Roeb, A. G. Konstandopoulos, L. Nalbandian, V. T. Zaspalis, C. Sattler, P. Stobbe, A. M. Steele, “Solar Water Splitting for Hydrogen Production with Catalytic Monolithic Reactors”, Solar Energy, 79, 409-421, (2005).

21. C. Agrafiotis, V. T. Zaspalis, L. Nalbandian, M. Roeb, C. Sattler, A. M. Steele, P. Stobbe, A. G. Konstandopoulos, "HYDROSOL - "Advanced monolithic reactor for hydrogen generation from solar water splitting" 8th Cologne Solar Symposium, on Solar Thermal Hydrogen and Fuel Production, Cologne, Germany, June 14th, 2005.

22. M. Roeb, C. Sattler, R. Klüser, N. Monnerie, L deOliveira, A. G. Konstandopoulos, C. Agrafiotis, V. T. Zaspalis, L. Nalbandian P. Stobbe, A. M. Steele, "Solar Hydrogen Production by a Two-Step Cycle Based on Mixed Iron Oxides", ISEC 2005: ASME International Solar Energy Conference, Orlando, Florida, USA August 6th -12th, 2005.

23. S. Lorentzou, C. C. Agrafiotis and A. G. Konstandopoulos, "Synthesis of water-splitting ferrites for hydrogen production via Aerosol Spray Pyrolysis", European Aerosol Conference Ghent, Belgium, Aug. 28th- Sept. 2nd, 2005.

24. A. G. Konstandopoulos, C. Agrafiotis M. Roeb, C. Sattler, V. T. Zaspalis, P. Stobbe, A. Steele: "Catalytic monolith reactor for hydrogen generation from solar water splitting" International Partnership for the Hydrogen Economy (IPHE) International Conference on Renewable Hydrogen, Seville, Spain - October 24-26, 2005. Invitation from EU.

25. R. Klüser, M. Roeb, N. Monnerie, M. Schmitz, C. Sattler, P. Stobbe, A. Steele, C. Agrafiotis, A. G. Konstandopoulos: "Solar Thermo-Chemical Splitting of Water Using Coated Ceramic Monoliths", 10th Mediterranean Congress of Chemical Engineering, Barcelona, Spain, November 15-18, 2005.

26. M. Roeb, R. Klüser, N. Monnerie, L.de Oliveira, P.M. Rietbrock, C. Sattler, A. G. Konstandopoulos, C. Agrafiotis, V. T. Zaspalis, L. Nalbandian, A. Steele, P. Stobbe "Development of a thermochemical process for solar water splitting", 2nd European Hydrogen Energy Conference-2nd Professional Meeting on Hydrogen and Fuel Cells, Zaragoza, Spain, November 22nd-25th, 2005.

27. L. Nalbandian, V. T. Zaspalis, A. Evdou, C. Agrafiotis, A. G. Konstandopoulos, "Redox Materials for Hydrogen Production from the Water Decomposition Reaction", Chemical Engineering Transactions, 4, 43-48, (2004).

28. S. Lorentzou, K. Karadimitra, C. Agrafiotis and A.G. Konstandopoulos, “New Routes for Ferrite Powders Synthesis” Proceedings of the PARTEC 2004, International Conference for Particle Technology, Nuremberg, Germany, March 16 – 18, (2004).

29. S. Lorentzou, K. Karadimitra, C. Agrafiotis and A.G. Konstandopoulos, "New Routes for Ferrite Powders Synthesis" PARTEC 2004, International Conference for Particle Technology, Nuremberg, Germany, March 16 – 18, 2004.

30. L. Nalbandian, V. T. Zaspalis, C. Agrafiotis, A. G. Konstandopoulos, “Redox Materials for Hydrogen Production from the Water Decomposition Reaction”, H2AG: H2age When, where, why, International Conference, Pisa, Italy, May 16-19, 2004.

31. S. Lorentzou, C. Agrafiotis, A. G. Konstandopoulos: "Combustion synthesis of spinel materials for catalytic applications", Joint Meeting of the Italian and Greek Sections of The Combustion Institute, Corfu, Greece, 17-19 June, 2004.

32. L. Nalbandian, V. T. Zaspalis, C. Agrafiotis, A. G. Konstandopoulos, C. Sattler, M. Roeb, P. Stobbe, A. M. Steele "Solar Water Splitting for Hydrogen Production with Catalytic Monolithic Reactors", 3rd European Meeting on Solar Chemistry and Photocatalysis: Environmental Applications, Barcelona, Spain, June30th- July 3rd, 2004.