IEA IMPLEMENTING AGREEMENT
PROPOSAL FOR A NEW ANNEX ON HYDROGEN

WIND ENERGY & HYDROGEN INTEGRATION

Draft to be presented at the IEA ExCo Meeting, Petten (NE), 7th November 2006

1. Introduction

There is nowadays a broad interest in hydrogen production by means of renewable energy sources. Given the widespread concern with climate change and sustainable development, hydrogen is expected to be one of the main energy carriers in the near future.

Within the set of current possibilities for use of renewable energy sources in hydrogen production (some of them already studied by the IEA HIA) water electrolysis by means of wind energy ranks high in terms of technical & economical feasibility as a competitor to fossil fuel technologies for hydrogen production.

Today, both water electrolysis and wind energy technologies are considered mature technologies, although R&D efforts are still undertaken to enhance performances and cost savings in both fields.

However water electrolysis technologies have not been in principle conceived for such variable input conditions as those related to the inherent nature of wind resource. Therefore, current state of the art integration has to be upgraded largely to avoid redundant power electronics, thereby increasing efficiency and reducing capital and O&M costs.

Although hydrogen applications are virtually unlimited, transportation and early markets in portable applications are expected to be near term drivers for advancement of the hydrogen economy. At the same time, there is an interesting stationary application that arises related to wind energy and other renewable energies such as solar PV. This is because they have an inherent variable nature that may slow down their development in markets (like wind in Denmark, Germany or Spain) where it already has a non-negligible penetration, due to integration problems for market and grid operators.

Storage systems can provide a solution to this problem by allowing wind energy to be closer to conventional energies, increasing its capability to follow demand, guarantee a desired amount of energy, offer a flat curve, a more smoothened curve, etc…

The fully integrated wind & hydrogen application connects wind technology with various hydrogen related technologies like electrolysers (production), storage systems and hydrogen to electricity converters (use).

If wind farms can be coupled to such energy storage systems, wind energy will become available to offset the growth in network capacity. Furthermore, wind farms would become multi-purpose producers for either electricity or hydrogen as fuel in a decentralized configuration when the automotive industry enters mass production of hydrogen fuelled vehicles. In the short term, marginal but significant benefits can be obtained by improving dispatchability, offering reserve power and grid services. In any case, the goal is to enhance the value of the wind electricity itself.

Another important niche market will be off-grid systems relying solely on renewable energy sources. Due to the inherent high cost of power in these systems, their role as an early adopter application and the notion that most current operational wind/hydrogen applications are serving off-

grid applications, it make sense to include these systems in the scope of this Annex.

Some projects have been developed or proposed in various countries. These represent a good starting point for learning from experience since very different stakeholders from every segment of the value chain -- research institutions, equipment manufacturers, and utilities – participate in these projects.

The principal drawbacks to an economically feasible wind-to-hydrogen concept are the costs of the main equipment, the diversity of regulations and promotion of wind energy from country to country, and the gap between prototyping, and mass or niche market.

2. . Objectives

To explore in detail all possible issues (technical, economical, social, environmental, market and legal) related to hydrogen production using electrolysis with wind energy.

To explore in detail possible applications for hydrogen produced by electrolysis using wind energy, with special emphasis on full wind & hydrogen integration by means of hydrogen storage and electrical conversion that balances the original wind energy production, allowing an approach to demand that closes the gap with conventional energies.

3. Scope

The Proposal of Annex herein aims to establish a collaborative midterm R&D program among entities belonging to the whole wind-to-hydrogen production chain, as well as the wind-to-profits chain: project financiers, engineering and contractors, market regulators, grid operators and distribution companies[1].

It makes sense to establish a collaborative international framework with expected win-win results due to: the different approaches to wind energy in the different countries; the global concentration in equipment manufacturers (less than ten for either electrolysers or wind turbines, sparsely distributed on a geographic basis); the non existing optimum technological coupling between the turbine and electrolysesr technologies;, and the immature state of the art of hydrogen to electricity conversion..

The research and development activities target the technological and economical evolution of the main equipment (wind turbines, electrolysers and hydrogen to electricity converters) and system integration concepts, as well as the prognosis on regulations (technical, environmental and from the market perspective) and business models.

[1] Although not all of the actors listed would be able to participate in the Annex, their point of view must be accounted for in order to deliver a balanced perspective of the advantages and disadvantages of hydrogen produced by wind energy. The cooperation through links to third party entities is therefore encouraged.

4. Subtasks

To accomplish the before mentioned objectives, the Participants will undertake activities within the framework of four coordinated subtasks. These aim to target separate problems.

Subtask A: state of the art

In this subtask, the goal is to conduct an in detail review of current state of the art regarding wind turbines, electrolysers and intermediate equipment, as well as a survey of market and electrical system regulation.

A detailed review of current state of the art and lessons learned relative to hydrogen production using wind energy and fully integrated wind energy & hydrogen technologies projects will also be performed.

Subtask B: Needed improvements & system integration. Technology development on main equipment and system integration concepts

In this part of the study, the scope is focused on the two main components for hydrogen production, the wind turbine and the electrolyser, as well as the intermediate connecting components. The in-depth analysis will research a future technical optima. The goal of this subtask is not to provide an enhanced design for either equipment but to develop proper specifications.

This subtask has to address the following issues:

- The dynamics of both power electronics and control (system integration) equipment. Wind turbine output normally varies depending on the variable wind resource while electrolysers are conceived to work under steady conditions. The various concepts of energy buffering should be evaluated, as well as the potential effects on performance, costs and efficiency.
- Electrolyser durability under a very dynamic workload. Until now, there has not been any systematic study on how the variability in electrical parameters can affect the long term performance of an electrolyser. Failure mode analysis methodologies should be proposed, definition of acceptance test protocols and technical specifications, as well as monitoring measures. Current output hydrogen pressures range from 1 to 30 bar on commercial equipment. Hydrogen storage pressure for most applications needs further compression with consequent efficiency losses and investment and O&M costs regarding the use of compressors. At this point, electrolysers with higher output pressures should be investigated.
- Development of specific wind turbines adapted for hydrogen production. A broad range of potential technical redesigns with synergistic benefits have to be assessed, considering the reduction in power electronics conversion stages, thus reducing costs and system power losses, so that the best-in-class proposals could be prototyped and tested by technology developers.

Subtask C: Business concept development

This subtask will deal with:

- Economic assessment with a detailed hydrogen production cost study of different concepts within representative market conditions, and prognosis of the potential market size.
- Conceptual development and validation of layouts, extending to logistics and final use of the produced hydrogen, differentiating remote applications, weak grids, and large-scale wind generation. Two applications will be specially considered: hydrogen as fuel for transportation, and on-site conversion of hydrogen to electricity for grid balancing.
- Cross-cutting issues: social and environmental acceptability of increasing wind power capacity

devoted to hydrogen production. Technical, environmental and market regulations affecting hydrogen production using wind power. An analysis of competing technologies should be included, as well as safety regulations.

Subtask D: Applications. Emphasis on wind energy management

In this subtask, near term applications for the hydrogen produced shall be studied, with a special emphasis on one of the main applications pointed out in subtask C. This application is wind energy management within the wind & hydrogen full integration concept. Given the noticeable synergy between hydrogen and wind energy regarding their integration for a further approach of renewable energy sources with inherent non continuous and random nature, it is considered appropriate to deal with this application in a separate subtask.

An analysis similar to the ones performed in tasks A to C shall be performed for those components contributing to full wind energy & hydrogen that were not previously taken into account. These components are basically hydrogen to electricity converters such as fuel cells, internal combustion engines and gas turbines.

The key issue for such system integration is the development of a control and operation software that could enable wind & hydrogen integrated plants to operate in different conditions

Cross-cutting issues: social and environmental acceptability of increasing wind power capacity versus other solutions (grid reinforcement, fossil and nuclear generation), comparative analysis of different technical, market and environmental regulations affecting wind power.

5. Results

The collective efforts of these Tasks will result in the following outputs:

- D1: a report on the current state of the art of individual equipment and demo projects on S2/Y1 (preliminary review on S1/Y1 – semester 1 of year 1; and update on S1/Y4).
- D2: a report concerning the potential redesign of a system with wind & hydrogen integration, considering aspects on electrolyser durability and synergies with the wind turbine generator, on S2/Y3 (preliminary report on S2/Y2).
- D3: a report on the economic performance of the various concepts for wind systems with integrated hydrogen, market potential, and social or environmental burdens associated with the proliferation of such systems on S2/Y1 (Methodology to be adopted on S1/Y1; definition of the case studies on S2/Y1; update on the report on S2/Y4).
- D4: a report on the possible applications for the hydrogen produced with a special emphasis on the wind & hydrogen full integration with the use of hydrogen to electricity converters on site. The report will be based on a preliminary analysis for wind energy & hydrogen full integrated needs both in isolated and grid connected cases to be done by S1/Y3. The final report will be finished on S2/Y2, including a techno economical assessment as well as an analysis for market potential, and social or environmental issues related.
- Dissemination: publications of Task activities in scientific as well as industry journals and in the proceedings of international conferences. Web-publishing with interactive worldwide information dissemination.

6. Responsibilities

In addition to the obligations enumerated in Article 8 of this Agreement, each Participant shall:

1. Attend all Task and Subtask meetings (both, the in-persona ones as well as the web-based ones) to which it contributes, and present a status report of the on-going or completed work at such meetings.
2. Provide the OA with a National Participation Letter (NPL), indicating their commitment and the level of contribution to the Annex. The NPLs in aggregate represent the National Participation Plan (NPP).
3. Contribute to the collective efforts of the Task in accordance with the Program of Work (PoW) approved by the Executive Committee (ExCo) pursuant to Article 5(c) and the NPP.

Each Subtask Leader (SL) shall:

1. Assist the OA in preparing and updating the PoW.
2. Manage the Subtask work in co-ordination with the OA.
3. Lead the experts in the production of technical reports and be responsible for the final editing.
4. Organise and chair Subtask meetings as part of the Task meetings or as deemed appropriate by the Participants.
5. Provide the OA in time with an annual report of Subtask activities.

The Operating Agent (OA) shall:

1. Manage the overall Task in co-ordination with the SLs.
2. Implement decisions of the ExCo.
3. Organise and conduct expert meetings.
4. Submit a detailed PoW to the ExCo for approval not later than two months after the adoption of this Annex.
5. Provide the ExCo with written semi-annual reports of the status of the work being undertaken by the Task.
6. Assume responsibility for the timeliness and technical content of all reports produced by the Task.
7. Provide to the ExCo a final report on the work of the Task within six months after the completion date of the Task.
8. Perform such additional services and actions as may be decided by the ExCo acting by unaniity of the Participants.

7. Level of Effort and Funding

The Annex will be developed in a task-sharing basis. Each partner will bear his or her own personnel costs as well as travel expenses.

The estimated level of effort for the before mentioned tasks is shown on table 1 and explained

hereinafter:

A) State of the art: 1 person for S1/Y1 the review of the status of wind turbines, electrolysers, power electronics and demonstrations. 1 person for S2/Y1 to coordinate and edit the state of the art report. 0,5 person for S1/Y4

B) Needed improvements and system integration: 1 person during S2/Y2 for the preliminary design. 0, 5 for the electrolyser and 0, 5 for the wind turbine. 1,5 person for Y3 for the final design. 0,5 for the electrolyser and 0,5 for the wind turbine.

C) Business concept development: for the economic assessment and conceptual development, 0,5 during Y1 and Y2, plus 0,1 for each country participating to analyse Xcutting issues during S2/Y1 and S1/Y2. Then 0,5 person for the update on S2/Y4.

D) Applications. Emphasis on wind energy management: 1 person during S2/Y2 and S1/Y3. 0,5 for the study of different applications during S2/Y2. 0,25 during S2/Y2 and S1/Y3 for the detailed analysis of wind energy needs in isolated systems and 0,25 during S2/Y2 and S1/Y3 for grid connected systems. 0,5 for coordination and edition of D4 report on S1/Y3. 1 person on Y4 for the detailed analysis of wind & hydrogen full integration including technical, economic, environmental and social issues.

TASKS	S1 07	S2 07	S1 08	S2 08	S1 09	S2 09	S1 10	S2 10	TOTAL
A	1	1					0,5		**2,5**
B				1	1	1,5			**3,5**
C	1	1,5	1,5	1				0,5	**5,5**
D				1	1		1	1	**4**
TOTAL	**2**	**2,5**	**1,5**	**3**	**2**	**1,5**	**1,5**	**1,5**	**15,5**

Table 1. Level of effort

8. Time Schedule

This new Annex is scheduled for a four year term, as shown on table 2, with the option for an extension of two additional years. Due to the current operating period of the H2 implementing agreement which ends in 2009, the new annex proposal shall be renewed by that date in order to fulfil the foreseen 4 years period. Within the limits of the term of the Agreement, this Annex may be extended by two or more Participants, acting in the ExCo, and shall thereafter apply only to those Participants.

TASKS	S1 07	S2 07	S1 08	S2 08	S1 09	S2 09	S1 10	S2 10
A	Preliminary review	D1 state of the art					Update on D1	

B				D2 Preliminary redesign		D2 Final design		
C	Methodology and tools	Case studies definition		D3 Business report				Update on D3
D				Definition of near term applications	Wind energy needs preliminary analysis			D4 Wind & hydrogen full integration report

Table 2. Time schedule.

9. Proposal Development for the New Annex

This Annex aims to bring together the current research, development and demonstration activities and to unify them to form a coherent framework with minimum overlapping. Specific R&D projects shall be selected based on inputs from researchers and R&D managers in participating countries.

It is proposed that a meeting be held, possibly sponsored by IEA (and Spanish institutions) to bring together participants from potentially participating countries to develop a joint R&D program, resulting in specific linkages between existing activities to be proposed for the new Annex as well as to propose additional areas of research where such collaborations should be established. The goals of this research, the timetable, the projected metrics, and overall program direction would need to be developed in detail and receive support from the participating researchers and technologists. This process would then be followed by further proposal review and decision making process by the IEA Hydrogen Program ExCo.

APPENDIX

Minutes of Project Definition Meeting – 4th October, 2006

IEA HIA Wind Energy and Hydrogen Energy Task

Following the conclusions of the 54th Executive Committee Meeting (June 16-17, 2006, Lyon, France), the Project Definition Meeting was held on Wednesday the 4th October in Brussels at the Charlemagne Building of the European Commission, Room 37, with the following attendees:

10.

11. 1	Allan Schroeder PEDERSEN	Denmark	Risoe National Laboratories
12. 2	Joaquín MARTÍN-BERMEJO	EU	DG RTD
13. 4	Suzanne SHAW	EU	DG JRC
14. 5	Thierry D'ESTAINTOT	EU	DG RTD
15. 6	Gilles RODRIGUEZ	France	CEA
16. 7	Nikos LIMBEROPOULOS	Greece	CRES
17. 8	Jon Bjorn SKULASON	Iceland	Icelandic New Energy
18. 9	Izumi USHIYAMA	Japan	Ashikaga Technology University
19. 10	Ken-Ichiro OTA	Japan	Yokohama National University
20. 11	Sam MIYASHITA	Japan	ENAA
21. 12	Yoshimitsu ISHIHARA	Japan	NEDO
22. 13	Yukio SUGURO	Japan	Mitsubishi Heavy Industries
23. 14	Antonio G. GARCIA-CONDE	Spain	INTA
24. 15	Fernando TAMAYO	Spain	Gamesa Energía
25. 16	Luis CORREAS	Spain	Fundacion Hidrogeno Aragon

26.

27. The meeting starts at 10:10. Mr Martín-Bermejo, host of the meeting, welcomes the attendees. Mrs Mary-Rose de Valladares calls from the USA to welcome and to stay available for questions and comments. All attendees present themselves.

28. Mr Correas explains the process followed up to date for the proposal of a New Annex on Wind and Hydrogen integration, and makes a short review on the draft.

29. In a round table discussion some questions arise as:

- Desired presence of an electrolyser manufacturer: manufacturers, especially electrolysers, are welcome, and more effort must be done to attract them.
- Use of hydrogen only to produce electricity back to the grid: not the only use of hydrogen. It is the main short term application foreseen by the potential Operating Agents (OA). Other uses of hydrogen are implicitly regarded, as fuel for transportation.
- Demonstration activities are beyond the scope to the Annex: the Annex will make use of the experience of on going demonstration activities but will not promote a new one.

- Participation of US: contacts have been made and there is interest on participating.
- Competing technologies: a thorough study shall be conducted across the working program.
- Cooperation with Task 18 (Integrated System Evaluation): an approach to this Task would be helpful.
- Cooperation with Wind Implementing Agreement, Task 25 (Power System Operation **with Large Amounts of Wind Power): an approach at ExCo level will be promoted, before putting into contact the technical level.**

30.

31. Action 1: Luis CORREAS will ask the HIA Secretariat to facilitate the contact between the Chairmen of the both HIA and WIA, to agree on the potential cooperation.

32.

33. Specific presentations of every partner (either oral or with support of overheads)

4. Mr Tamayo (Gamesa Energía, pdf available): participation in three R&D&D projects related with H2 production from wind, either in cooperation or alone. Also participation in European and National Hydrogen Platforms. Potential Operating Agent in years 3 and 4 of the Annex.
5. Mr Correas (Fundación Hidrógeno Aragón, pdf available): promotion of a Wind-to-hydrogen demo facility, start-up mid 2007. Potential Operating Agent in years 1 and 2 of the Annex.
6. Mr D'Estaintot (EU DG RTD and WIA, pdf available): presentation of the projects of the EU under the 6th Framework Programme. Handing out of the publications of the WIA and EU DG RTD[2]. Participation declined (EU DGs except the JRC can not engage) but availability to contact the partners of the wind energy projects financed by the EU.
7. Mr García-Conde (INTA): availability to participate in subtasks related with revision of the state-of-the-art, modeling and preparation of test protocols.
8. Mr Lymberopoulos (CRES, pdf available): presents the current status of the demo facility in Greece and lessons learned. Available to contribute at the subtask state-of-the-art. Pending engagement of Greece at the HIA.
9. Mr Rodriguez (CEA): France is targeting wind energy as a promising renewable energy producer. Some companies, as Areva, are already developing electrolyser technology, but it is too early for them to contribute in such Annex. He will report back.
10. Mrs Shaw (EU DG JRC): currently in charge of techno-economic analysis and assessment of clean energy systems. Interested in high penetration of wind energy scenarios and the economics of these situations, and hence, very interested in the Business Development approach of the Annex. In her opinion, efficiency is too low to make profitable closing the loop (wind-electricity-H2-electricity). She will report back in order to define the involvement in the Annex.
11. Mr Pedersen (Risoe National Laboratories, pdf available): Presentation of the current energy situation and policies in Denmark, where there is a political unanimity to grow in Renewable Energy Sources, based in wind energy and biomass. Oil and gas resources will be depleted by 2025. Electrical grid is very integrated with Scandinavia, profiting of balancing (hydro pumping) but limits are foreseen. For instance, negative prices for electricity already appear. As a conclusion, new ways to use excess energy must be sought. Risoe is able to commit to this Annex.

[2] http://ec.europa.eu/energy/res/sectors/doc/wind_energy/eu_wind_energy_en.pdf

http://www.ieawind.org/AnnualReports_PDF/2005/2005%20IEA%20Wind%20AR.indd.pdf

12. Mr Skulason (Icelandic New Energy): There is an initiative to promote island energy sustainability, which will promote a demonstration to produce H2 from wind energy and re-utilizing O2 at a fish farm. A second generation of electrolysers will apparently come out very soon. He will report back.
13. Mr Ota (Yokohama National University, pdf available): presentation of the background of using H2 as energy vector and the lower environmental factor obtained. Reports on electrochemical storage of wind energy in Redox batteries, where 6 MW systems are already working with a 70% efficiency.
14. Mr Ushiyama (Ashikaga Technology University, pdf available): specificities of wind energy in Japan are presented (rough wind, threat of typhoon, turbulence, lightning) as well as new wind turbine concepts (smart yaw, floating off-shore wind turbines).
15. Mr Suguro (Mitsubishi Heavy Industries): a presentation of the developments at MHI (2,4 MW double fed, variable speed or electrical buffering for wind fluctuations) and current state of affairs, focused on the allowable requirements for short term and long term fluctuations.
16. Mr Miyashita (ENAA, pdf available): overview of the current status of H2 technology and deployment in Japan, especially on hydrogen refuelling stations.

34.

35. After the presentations, attention is focused on the draft of the new Annex, in order to revise it and make complementary remarks.

6. Introduction: no remarks.
7. Objectives: no remarks.
8. Scope: there is a lack of some actors (regulators, grid operators, distribution companies, electrolyser, fuel cell or engine manufacturers) in the current team of interested entities. There is a good representation of R&D, wind turbine manufacturers and wind farm promoters. The question about the participation of Norsk Hydro arises, because their demo project at Utsira is a very valuable starting point. The message should be conveyed to potential industrial partners that the proprietary information will not endangered within the framework of this Annex, but putting in common lessons learned in order to better target a profitable business scenario. Another option is that individual partners could establish links with actors not belonging directly to the Annex. In order to clarify how to engage new partners, the following agreement is reached:

36. Agreement 1: Every partner will be responsible for the preliminary contacts with potential partners in his country. Afterwards, a more formal approach will be conducted by the ExCo representative, the HIA Secretariat and the OA.

37.

9. Subtasks:
    1. Subtask A: include survey of market and electrical system regulation.
    2. Subtask B: An electrolyser manufacturer would be necessary at this stage. Clarification on that the goal of the subtask is not designing an electrolyser but defining proper specifications.
    3. Subtask C: competing technologies should be included, as well as safety regulations and use of H2 as fuel for transportation.
    4. Subtask D: this task should be understood as one of the potential applications with a short term market entry. Other applications coming out from Subtask C could also be studied in separate Subtasks if appropriate.
10. Results: a concrete deliverable planning is agreed. Attached as Annex of these minutes.
11. Responsibilities: attendees are encouraged to propose Subtask Leaders. Attendees are asked

to fill up a matrix of participation in each Subtask. Japan expresses their intention to take part in Subtasks A and B, and assist the Annex on Subtask C, but declines participation in Subtask D. In any case, Japan declines subtask leadership.

12. Level of effort and funding: a task sharing cost basis is agreed. Every partner will bear his own costs for participation.

38.

39. Actions pending

Action 2: The OAs will refine the proposal with the comments of the meeting, including an assessment of the total man power necessary.

Action 3: The OAs will ask for contribution to the attendees. The attendees will respond with a proposal on their participation, including Subtask Leadership.

Action 4: a model of National Participation Letter will be submitted by the OAs to the potential partners. This letter must be signed by the national representative and delivered to the HIA Secretariat.

Next steps:

- The modified Draft of New Annex will be submitted to the next ExCo meeting (Petten, NE, 7th November) for consideration of approval.
- Following the results of the next ExCo meeting, a Kick-off meeting will be proposed on Q1/07. The Foundation for Hydrogen in Aragón proposes Walqa (Huesca – Spain).

The meeting ends at 16 h.

Annex: Scheduled and Deliverables agreed

TASKS	S1 07	S2 07	S1 08	S2 08	S1 09	S2 09	S1 10	S2 10
A	PRELIMINARY REVIEW	REPORT ON STATE OF THE ART					UPDATE	
B				PRELIMINARY REDESIGN		FINAL REDESIGN		
C	METHODOLOGY & TOOLS	CASE STUDIES DEFINITION		REPORT				FINAL UPDATE
D				WIND ENERGY CONSTRAINTS ANALYSIS				FULL INTEGRATION WIND TO H2 DOCUMENT