IEA IMPLEMENTING AGREEMENT
NEW ANNEX ON HYDROGEN

TASK 24 - WIND ENERGY & HYDROGEN INTEGRATION

Approved 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, 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 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.

4. Subtasks

To accomplish the before mentioned objectives, the Participants will undertake activities within the

[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.

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 its 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

8. Table 1. Level of effort

9. 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	Prelimin-ary review	D1 state of the art					Update on D1	
B				D2 Prelimin-ary redesign		D2 Final design		
C	Methodo-logy and tools	Case studies definition		D3 Business report				Update on D3
D				Definition of near term applications	Wind en-ergy needs preliminary analysis			D4 Wind & hydrogen full integra-tion report

Table 2. Time schedule.

10.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.