IEA-HIA Task 25: High Temperature Processes for Hydrogen Production – Three Year Progress Review of the Project

F. le Naour, S. Poitou, C. Mansilla, C. Sattler, M. Roeb, D. Graf, G. Kolb, A. Giaconia, R. Liberatore, P. Tarquini, A. Meier, D. Gstoehl, R. Allen, G. Karagiannakis, C. Agrafiotis, R. Moliner, I. Suelves, M. Gasik, A. Lokkiluoto, S.D. Ebbesen, U. Vogt, J. Hinkley

This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 4: Storage Systems / Policy Perspectives, Initiatives and Co-operations
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-4
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-654-5

IEA-HIA Task 25: High Temperature Processes for Hydrogen Production – Three Year Progress Review of the Project

F. le Naour, **S. Poitou**, **C. Mansilla**, CEA, France
C. Sattler, **M. Roeb**, **D. Graf**, DLR, Germany
G. Kolb, SNL, USA
A. Giaconia, **R. Liberatore**, **P. Tarquini**, ENEA, Italy
A. Meier, **D. Gstoehl**, PSI, Switzerland
R. Allen, University of Sheffield, UK
G. Karagiannakis, **C. Agrafiotis**, CPERI, Greece
R. Moliner, **I. Suelves**, CSIC, Spain
M. Gasik, **A. Lokkiluoto**, Aalto University Foundation, Finland
S.D. Ebbesen, RISOE DTU, Denmark
U. Vogt, EMPA, Switzerland
J. Hinkley, CSIRO, Australia

1 Introduction

Through the International Energy Agency organisation, CEA proposed to the Hydrogen Implement Agreement (HIA) Executive Committee that an expert group be set up to address the definition of the high temperature hydrogen production processes running either with a solar or a nuclear heat source. This project was accepted and referenced as Task No 25.

The purpose of Task 25 is to support production of massive quantities of hydrogen with zero-CO_2 emission through the use of high temperature processes (beyond 500°C) coupled with nuclear or solar heat sources. The overarching objective is to share existing worldwide knowledge on high temperature processes (HTPs) and further to develop expertise in global assessment of the HTPs that can be integrated in Hydrogen Production Road Mapping. The specific objectives are:

- To identify and classify HTPs and establish different and coherent criteria for successful application of each family of HTPs, based on a scientific/technological approach.
- To establish the state of the art and investigate the existing R&D, programs, projects on HTPs and other innovative ideas for massive production of hydrogen.

2 Task Description

2.1 Organisation

Task 25 was approved in late 2007 with a three year term of operation. This project is focused on innovative high temperature processes (HTPs) such as:

- Thermochemical cycles,
- High temperature steam electrolysis,
- Innovative direct water spitting.

More mature processes such as Steam Methane Reforming and Alkaline Electrolysis are only studied to compare them to HTPs in both technco-economic and yield terms.

Task 25 is split in four subtasks:

Subtask A: Scientific, technological review and analysis of the State of the Art of HTPs and assessment of mid to long-term HTPs deployment strategy.

Subtask B: Development of a methodology for the integration of HTPs.

Subtask C: Recommendations for HTPs deployment through demonstrators.

Subtask D: Coordination and links with other international organisations: dissemination of information.

Task 25 is led by an operating agent from CEA (French Atomic Energy Commission). The expert group is holding a meeting every semester and results from this group are presented every semester to the IEA/HIA Executive Committee by the Operating Agent.

2.2 Members

All members are recognised as experts in their field and are nominated by the representative of their respective country, belonging to the IEA/HIA executive Committee. The list of members presented below is not definitive and new members and/or new countries can always join this expert group.

Table 1: Members of the IEA/HIA task 25 project.

Australia: CSIRO: J. Hinkley	Italy: ENEA: A. Giaconia, P. Tarquini, R. Liberatore
Denmark: RISOE DTU: S. Ebbensen	Spain: Instituto de Carboquimica: R. Moliner, I. Suelves
Finland: Aalto University Foundation: M. Gasik, A. Lokkiluoto	Switzerland: PSI: A. Meier, D. Gstoehl, EMPA: U. Vogt
France: CEA: F. Le Naour, S. Poitou, C. Mansilla	UK: University of Sheffield: R. Allen
Germany: DLR : C. Sattler, M. Roeb, D. Graf	USA: Sandia National Lab : G. Kolb
Greece: APTL/CERTH: G. Karagiannakis, C. Agrafiotis	

3 Activities and Results

The scientific and technical achievements are described for each subtask below.

Subtask A - Scientific, Technological Review and Analysis of High Temperature Processes and State of the Art (Subtask Leader: C. Sattler, DLR):

A technical review of the different processes has been made through the results of the INNOHYP-CA project (European FP6). INNOHYP-CA established the state of the art in massive high temperature production of hydrogen by reviewing existing knowledge in Europe and worldwide. INNOHYP-CA provided a clear understanding of the basis for future European research.

The first aim of this subtask is to update and complete INNOHYP-CA results. For instance, apart from some international projects, INNOHYP-CA is mainly focused on European countries. The database has to be completed with other countries policies and national programs (e.g: South Africa, Korea, Japan, China).

The recent changes in the international policies concerning HTPs have led the group to discuss a strategy for supporting HTPs deployment through R&D studies. A report is in progress, in order to build recommendations for the future.

Subtask B - Development of a Methodological Approach to Integration of HTPs (Subtask Leader: A. Giaconia, ENEA):

The comparison between HTPs with very different levels of knowledge and maturity appears to be complex. The main challenge is to provide a good projection over a 20 year timescale.

Experts have shared the most recent research results on hydrogen production cost for various processes. A benchmark on cost investment of four simple fundamental components has been performed by three countries, in order to verify the homogeneity of the different methods.

This cross cost evaluation was encouraging. The differences between the results were easily explained by the choice of the material or the operating conditions (some methods are more open to exotic materials and flexible than others).

The next step was to define a global and common methodology for process assessment. A bibliographic study allowed discrimination between several methodologies and definition of the most accurate for our objective. The goal was to define and validate a tool for the multi-criteria assessment of hydrogen production processes, and then to perform an analysis on a couple of cases. The methodology had to take into account different viewpoints: economics, environment, multi-technology aspect, different states of development of the processes, data uncertainty, and incomparability of some of the criteria.

We chose an outranking method called Electre that was developed by the LAMSADE laboratory (Paris – Dauphine). We carried out a first multi-criteria evaluation based on processes and relevant criteria selected by the experts group. Fourteen processes and eight criteria were selected. The criteria ranking was based on two scenarios: one short-term scenario favouring economic and process feasibility and a long term scenario favouring environmental criteria. A sensitivity analysis was carried out, which permitted us to highlight the impact of changing the input data and the methodology parameters on the result evolution. The interest of this methodology has been recognized by all the experts.

Subtask C - Establishment of Benchmarks, Recommendations for HTP R&D and Future Industrial Deployment (Subtask Leader: F. Le Naour, CEA)

This subtask only started in October 2009. Its goal is to determine demonstrators' needs within the next 10 years. Recommendations will be made about demonstrators, as a complement to the report on strategy (subtask A)

Subtask D - Coordination and Links with Other International Organizations; Dissemination of Information (Subtask Leader and Operating Agent: S. Poitou, CEA):

The objective of this subtask is the development of summary sheets describing every process using the same presentation format. This includes worldwide mapping and technical review of the high temperature process studies and development, database (relevant papers, books and websites).

Beside, an Internet site has been made to have a common documentation base: **https://www-prodh2-task25.cea.fr/.** This site is an exchange place between experts of the working group.

4 Conclusions

Through IEA, the initiative of this new group of experts appears to be an efficient way to promote High Temperature Hydrogen Production Processes with an original approach that allows deep collaboration in the same expert group of two major scientific communities working on energy: solar and nuclear.

At the end of the three year period, a one year extension period was approved by the Executive Committee.

This will enable the proposal of a new strategy to support longer term HTPs deployment, in particular concerning demonstrator needs. It will also lead to the definition of a successor task according to this strategy. This work will be completed by further investigation on the multi-criteria assessment methodology, in order to refine the first assumptions and to carry out new sensitivity analysis. The final goal is to highlight the impact of each parameter and the avenue worth investigating.

References

[1] A. Noglik, M. Roeb, T. Rzepczyk, J. Hinkley, C. Sattler, R. Pitz-Paal. Solar Thermochemical Generation of Hydrogen: Development of a Receiver Reactor for the Decomposition of Sulfuric Acid. J. of Solar Energy Engineering 131, Feb. 2009, 011003.1-7

[2] M. Lanchi, F. Laria, R. Liberatore, L. Marrelli, S. Sau, A. Spadoni, P. Tarquini. HI extraction by H3PO4 in the Sulfur–Iodine thermochemical water splitting cycle: Composition optimization of the HI/H2O/H3PO4/I2 biphasic quaternary system. International Journal of Hydrogen Energy, Volume 34, Issue 15, August 2009, Pages 6120-6128.

[3] J.L. Pinilla, R. Utrilla, M.J. Lázaro, I. Suelves, R. Moliner, J.M. Palacios. A novel rotary reactor configuration for simultaneous production of hydrogen and carbon nanofibers. Int J Hydrogen Energy, Volume 34, Issue 19, October 2009, Pages 8016-8022.

[4] D. Wiedenmann, A. Hauch, B. Grobéty, M. Mogensen, U.F. Vogt. Complementary techniques for solid oxide electrolysis cell characterisation at the micro- and nano-scale. International Journal of Hydrogen Energy, October 2009.

[5] D. Wiedenmann, U.F. Vogt, O. Patz, G. Schiller, WDX Studies on Ceramic Diffusion Barrier Layers of Metal Supported SOECs, Fuel Cells, special issue, Fuel Cells, 09, 2009, No. 6, 861-866

[6] D. Wiedenmann, A. Hauch, B. Grobéty, M. Mogensen, U. Vogt, Complementary techniques for solid oxide cell characterisation on micro- and nano-scale, (in press, Hydrogen and Energy)

[7] J. Leybros, T. Gilardi, A. Saturnin, C. Mansilla , P. Carles. Plant sizing and evaluation of hydrogen production costs from advanced processes coupled to a nuclear heat source. Part I: Sulphur-iodine cycle. International Journal of Hydrogen Energy (2009), Volume 35, Issue 3, February 2010, Pages 1008-1018.

[8] S. Haussener, D. Hirsch, C. Perkins, A. Weimer, A. Lewandowski, A. Steinfeld. Modeling of a multitube high-temperature solar thermochemical reactor for hydrogen production. ASME J. Solar Energy Eng. 131, 024503, 1-5 (2009).

[9] T. Melchior, N. Piatkowski, A. Steinfeld. H2 production by steam-quenching of Zn vapor in a hot-wall aerosol flow reactor. Chem. Eng. Sci. 64, 1095-1101 (2009).

[10] L. Schunk, W. Lipinski, A. Steinfeld. Heat transfer model of a solar receiver-reactor for the thermal dissociation of ZnO – Experimental validation at 10 kW and scale-up to 1 MW. Chem. Eng. J. 150, 502-508 (2009).

[11] R. Rivera-Tinco, C. Mansilla, C. Bouallou, F. Werkhoff, Hydrogen production by high temperature electrolysis coupled with EPR, SFR, or HTR: techno-economic study and coupling possibilites, Int. J. Nuclear Hydrogen Production and Applications, Vol. 1, No. 3, 2008.

[12] M.G. McKellar, J.E. OBrien, C.M. Stoots, J.S. Herring, Demonstration and System Analysis of High Temperature Steam Electrolysis for Large-Scale Hydrogen Production Using SOFCs, 8th EUROPEAN SOFC Forum, 2008, Lucerne

[13] Sigurvinsson J., Mansilla C., Lovera P., Werkoff F., Can high temperature steam electrolysis function with geothermal heat? Int. J. Hydrogen Energy 2007;32 (9):1174–82.

[14] W. Doenitz, R. Schmidberger, E. Steinheil, R. Streicher, "Hydrogen production by high temperature electrolysis of water vapour", International Journal of Hydrogen Energy, Vol. 5, pp. 55-63, 1980.

[15] O'Brien, J. E., McKellar, M. G., Harvego, E. A., and Stoots, C. M., High-Temperature Electrolysis for Large-Scale Hydrogen and Syngas Production from Nuclear Energy – system Simulation and Economics, International Conference on Hydrogen Production, ICH2P-09, Oshawa, Canada, May 3-6, 2009.

[16] U.F. Vogt, J. Sfeir, J. Richter, C. Soltmann, P. Holtappels, B-site substituted lanthanum strontium ferrites as electrode materials for electrochemical applications, Pure Appl. Chem., Vol. 80, No. 11, pp. 2543–2552, 2008
S.H. Jensen, P.H. Larsen, M. Mogensen, Hydrogen and synthetic fuel production from renewable energy sources, Int. J. Hydrogen Energy 32 (2007) 3253-3257

[17] W. Doenitz, E. Erdle, “High temperature electrolysis of water vapour – Status of development and perspectives for application”, International Journal of Hydrogen Energy, Vol. 10, pp. 291-295, 1985.

[18] A. Hauch, S.D. Ebbesen, S.H. Jensen, M. Mogensen, Highly efficient high temperature electrolysis, J. Mater. Chem., 2008, 18, 2331-2340

[19] Meng Ni, Michael K.H. Leung, Dennis Y.C. Leung, Technological development of hydrogen production by solid oxide electrolyzer cell (SOEC), Int. J. of Hydrogen Energy 33 (2008) 2337-2354

[20] W. Dönitz, E. Erdle, R. Streicher, High temperature electrochemical technology for hydrogen production, chapter 3, Electrochemical Hydrogen Technologies, edited by Hartmut Wendt, Elsevier 1990

[21] E. Erdle, J. Gross, V. Meyringer, Possibilities for Hydrogen production by combination of a solar thermal central receiver system and high temperature electrolysis of steam, Solar thermal central receiver systems, Proceedings of third int. workshop, June 23-27, Konstanz, Springer-Verlag, Vol. 2, pp. 727-736, 1986

[22] G. Tsekouras, J. T.S. Irvine, (La,Sr)TiO3 perovskites as cathode for solid oxide electrolysis cell, International Workshop on High Temperature Electrolysis Limiting Factors, 2009 Karlsruhe

[23] T. Ishihara, T. Kannou, S. Hiura, N. Yamamoto, T. Yamada, Steam Electrolysis Cell Stack using LaGaO3-based Electrolyte, International Workshop on High Temperature Electrolysis Limiting Factors, 2009 Karlsruhe

[24] H. Matsumoto, T. Sakaia, S. Matsushitab, T. Ishihara, Intermediate-temperature steam electrolysis using proton-conducting perovskite, International Workshop on High Temperature Electrolysis Limiting Factors, 2009 Karlsruhe