The hydrogen materials community: its history and current status in the World Hydrogen Movement

Victor A. Goltsov* and Lyudmila F. Goltsova

Donetsk National Technical University
58 Artyom street, Donetsk 83000, Ukraine
E-mail: Goltsov@physics.dgtu.donetsk.ua
E-mail: Goltsova@fem.dgtu.donetsk.ua
*Corresponding author

Vasily V. Vasekin

The Federal State Unitary Enterprise Scientific
and Industrial Complex 'Supermetal'
Housing estate Andreevka, Solnechnogorsk
Moscow, 141551, Russia
E-mail: vasekin@supermetal.ru

Abstract: This review briefly summarises the history of the hydrogen materials community as an important part of the World Hydrogen Movement. It analysis the history and current status of the interrelation between the Hydrogen Energy (HE) and Hydrogen Materials (HM) communities. During the last 15 years, great advances in this cooperation have come about, thanks to the thorough activities of the Permanent Working International Scientific Committee on Hydrogen Treatment of Materials and the international conferences 'Hydrogen economy and hydrogen treatment of materials' under the auspices of the International Association for Hydrogen Energy (IAHE). The conclusion is that promoting this cooperation will be the responsibility of the World Hydrogen Movement in the 21st century, in general, and of nuclear HE technology, in particular.

Keywords: hydrogen energy; hydrogen economy; hydrogen movement; hydrogen materials community.

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Biographical notes: Victor A. Goltsov is a member of the Board of Directors of the International Association for Hydrogen Energy (IAHE), a member of the Honorary Editorial Board of the *International Journal of Hydrogen Energy (IJHE)* and the *International Journal of Nuclear Hydrogen Production and Application (IJNHPA)*, the Chairman of the Physics Department and the Head of the Donetsk State Hydrogen Laboratory of the Donetsk National Technical University, Ukraine. Over several decades, he has been elaborating hydrogen materials problems and general questions of hydrogen energy (http://donntu.edu.ua/hydrogen). As a Chairman of the triennial IAHE special international conference 'Hydrogen Economy and Hydrogen Treatment

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of Materials', he represents the IAHE and IJHE's long-term goals and activities in Eastern Europe and North Asia (countries of the Community of Independent States).

Lyudmila F. Goltsova is a Leading Scientist of the Donetsk State Hydrogen Laboratory of the Donetsk National Technical University, Ukraine, a member of the IAHE and the Associate Editor of an informative-scientific, analytical and scientific-technical journal, the *Bulletin of Hydrogen Economy and Ecology*. She is a Specialist in the informetric analysis of the world progression from hydrogen energy to hydrogen economy and the development of the World Hydrogen Movement. She was the first Scientific Analyst to work out and publish (*IJHE*, 1990) the informational structure of hydrogen energy as a novel large-scale world problem.

Vasily V. Vasekin is the Chief Director of the Federal State Unitary Enterprise Scientific and Industrial Complex 'Supermetal', Russia. As a Scientist and Manager, he is an expert in the classification, certification and analysis of noble metals and their alloys and the complex refining and nonrefining treatment of noble metals. The results of his investigations in phase equilibria and the properties of multicomponent noble metals systems are applied practically for the creation of contemporary advanced materials, technologies and goods for silicate manufacture, medicine and jewellery production.

1 Introduction

Science is not only the knowledge reflected in scientific journals and books, kept in libraries and now available on the internet. Science is, first of all, the scientific communities owning that knowledge and permanently amending it, communicating and exchanging scientific information and always functioning under the certain paradigm of the time. According to Kuhn (1970), a paradigm is a system of acknowledged scientific achievements which give *a scientific community* the opportunities to raise problems and solve them. In other words, a paradigm is a collection of interrelated and consistent scientific theories, understandings, principles and conceptions which control the thinking of the time. In accordance with this general conception, a development of science, its special fields and problems are controlled by the functioning of an appropriate scientific community.

From this viewpoint, hydrogen economy development is based on the activities of the World Hydrogen Movement consisting of two large international communities: the Hydrogen Energy (HE) community (Veziroğlu, 2000) and the Hydrogen Materials (HM) community (Goltsov, 2000; Goltsova, 2000).

2 Hydrogen energy community

This community started to form in the early 1970s under the influence of an energy crisis, as a response to a permanent environmental worsening (the greenhouse effect, acidic rains, *etc*.) and a scarcity of the fossil fuel deposits in the world. The main idea of a large-scale conception of HE is replacing the fossilised organic fuels (that is, first of all,

oil and gas) in all spheres of their use with a new energy carrier: hydrogen. Hydrogen burning produces water and no harmful effluents into the atmosphere. As it was attractively described in Veziroğlu (2000), during:

> "…the first international conference on Hydrogen Energy, the Hydrogen Economy Miami Energy Conference, or the THEME Conference for short, held 18–20 March 1974, in Miami Beach, Florida, USA, when, on the afternoon of the second day, a small group got together: this group later named the 'Hydrogen Romantics', consisted of Cesare Marchetti, John Bockris, Tokio Ohta, Bill Van Vorst, Anibal Martinez, Walter Seifritz, Hussein Abdel-Aal, Bill Escher, Bob Zweig, Kurt Weil, myself and a few other enthusiasts, whose names escape me. There was a passionate, yet deliberate debate. *It was agreed that the Hydrogen Energy system was an idea whose time had arrived.* It was the permanent solution to the depletion of conventional fuels. *It was the permanent solution to the global environmental problems.* Then the discussion turned to whether there was a need for a formal organisation. International Association for Hydrogen Energy (IAHE) was established by the end of that year, and started working in earnest."

In 1975, *The International Journal of Hydrogen Energy* (IJHE) started as the official journal of the IAHE. Since 1976, the biennial World Hydrogen Energy Conferences (WHEC) were established to provide a platform for the HE community. The role and achievements of this community have been analysed by the president of the IAHE, Professor Veziroğlu (2000).

In those years, HE was also widely discussed in the former USSR at the national conferences. For example, at the Conference 'Gases in Metals' (Donetsk, September 1975), the late Professor Anatoly N. Podgorny and his co-authors reported on the main ideas of HE and found a broad response among the Soviet scientists in the sphere of materials science. In 1976, the main state journal of the USSR published an article by Legasov, 'Universal possibilities of hydrogen'. That meant an official acceptance in the USSR of a necessity to develop large-scale works in the field of 'Nuclear-Hydrogen Energy and Technology'. As a result, the USSR joined the IAHE and the Commission for Hydrogen Energy of the Academy of Sciences of the USSR began to coordinate studies in this field.

In accordance with the solution of the USSR State Committee in Science and Engineering and the Council of Ministers of the Ukrainian Republic, there was established in 1977 the State Hydrogen Laboratory in the Donetsk Polytechnic Institute (now the Donetsk National Technical University). This laboratory was charged with a mission to be a contributor to the development of HE and elaborate HM science.

By the 1980s, the concept of HE comprised (Goltsova *et al.*, 1990):

1 the primary sources of energy:
   - irrenewable sources of energy: coal, atomic energy and, in sight, thermonuclear energy
   - renewable sources of energy: solar energy, wind energy, tide energy and the like
2 hydrogen delivery, transportation and storage
3 hydrogen utilisation in the industry, transport (land, water and air) and home
4 the problems of materials and safety.

Then, more and more countries have joined the World Hydrogen Movement. As a result, for more than 30 years of its development, the HE community has covered a path from a small number of 'romantics' to a community numbering many thousands of scientists, engineers, industrialists and, nowadays, business persons too (Goltsov, 2006).

3 Hydrogen materials community

Another part of the World Hydrogen Movement is the HM community, as *materials are an absolutely important part of any field of technical development*. The HM community has had its own long history, as the industry of all the countries has had a lot of troubles with the hydrogen degradation of structural materials since World War I (see in Hydrogen in Metals, 1977; 1982). This problem keeps its importance today and hundreds of scientists and engineers are engaged in this field (Environmental Degradation of Engineering Materials, 1999).

Since the 1970s, a new HM subcommunity started to form (Hydrides for Energy Storage, 1978) around the functional materials based on hydrides and needed the successful development of a hydrogen economy. It is connected with the following. As is known from the history of science and engineering, new technologies require the development of new materials. The development of new hydrogen know-how required not only new structural materials, but new functional materials, too. It is important that in the early 1970s, some amazing properties of many intermetallics of the $LaNi_5$ type were discovered to absorb large quantities of hydrogen and then easily release it. Correspondingly, new functional materials – hydrides for hydrogen storage and transportation, membranes, electrodes and others – gained intensive development. A corresponding scientific community can be named 'hydride HM subcommunity'. This subcommunity holds conferences on different trends, which are later on united into a biennial symposium, 'Hydrogen and Materials: Fundamentals and Applications' (see Proceedings, 1999a).

At the same time (since the early 1970s), a new field of materials science and engineering, now named 'Hydrogen Treatment of Materials' (HTM), was conceived and started to develop. The idea to use hydrogen, 'a harmful element in metals', for action on materials with the aim to improve their structure and properties seemed so 'crazy' at that time that the history of the formation of this HTM subcommunity is of a special interest (Goltsov, 1997a).

Historically, Schleicher and Zwicker (Zwicker, 1974) were the first to conduct experiments and publish papers on the possibilities of using hydrogen for the plastification of titanium alloys and ensure their hot plastic deformation at lower temperatures. Their idea was based on the fact that hydrogen, as an alloying element, makes a more plastic high temperature β-phase of titanium more stable at lower temperatures. When plastic deformation was finished, hydrogen had to be removed from the titanium.

At the time, Schleicher and Zwicker's work was looked at as an exception, as some 'funny thing'. The hydrogen community, already numbering some hundreds of people all over the world, considered hydrogen a harmful element in steels and any materials. At the time, another way of thinking was impossible. In the 1950s–1960s and even beforehand, since World War I, there were serious accidents and even catastrophes in the industry

caused by hydrogen, such as unpredicted damages because of hydrogen degradation in the nuclear, chemical and petrochemical industries, breakings of rails and energy equipment because of flakes, aircraft crashes because of the hydrogen embrittlement of titanium alloys and so on. There are a lot of such examples in the history of engineering.

It was absolutely normal that in the 1960s and even in the first half of the 1970s, the concept of hydrogen embrittlement was the only one which was intensively worked out. Almost all the investigators were working in this direction and any other possible hydrogen effect on materials was unthinkable or, as we say now, was out of the material science paradigm of that time. That is why all information on the interaction of hydrogen and the materials generated by the world science community was considered only from one point of view.

In the early 1970s, the Hydrogen Phase Naklep (HPN) (cold work) phenomenon was discovered (Goltsov, 1981; 2000). That seemed to show at once a new possibility to use HTM. Indeed, introducing hydrogen into a metal and fulfilling hydride transformations made it possible to reach a *strong* and *controllable* strengthening of a metal and change its structure and properties. After hydrogen removal, one may have the same initial metallic article, but strengthened without changing its dimensions and shape. A wonderful thing was that even metals and metallic materials having no polymorphism can be subjected to such a hydrogen treatment. Some outstanding scientists estimated both the HPN phenomenon and the new ideas following from it. Nevertheless, only after about five years, the old way of thinking (the old paradigm) was broken down (Goltsov, 1982).

A further breakdown of the old paradigm has been achieved due to the works of many scientists and scientific groups and the hydrogen treatment of materials has attracted new and new adherents (Goltsov, 1997a–b; 1999; 2001; Proceedings, 1997; 1999a–b; 2002; 2006).

From the reasoning above, it is clear that the following conclusion can be made: nowadays, the HM community includes three subcommunities: hydrogen degradation, hydrides and HTM subcommunities.

4 History and current status of HE and HM communities

Historically, until the 1970s, the interaction of hydrogen with metals and hydrogen degradation were being investigated all over the world, but the most active scientific groups worked in France under the leadership of Professors Bastien and Azou, in the Soviet Union, under the leadership of Professors Kolachev and Goltsov, in the USA, under the leadership of Professors Wert and Birnbaum and in Poland, under the leadership of Professor Smialowski. It was very important that in 1977, during the 2nd International Congress 'Hydrogen in Metals' (1977), Professor Veziroğlu organised a roundtable meeting with the representatives of those scientific groups on the topic of future HE development. It was the first presentation of a large-scale concept of HE to the international HM community.

Then, in the early 1980s, two very important meetings were held. The first one was the Miami International Symposium on Metal-Hydrogen Systems (1981, Miami Beach, FL, USA) (Goltsov, 1982). The second one was the 3rd All-Union Conference 'Hydrogen in Metals' (1982, Donetsk, USSR). Each attracted about 300 participants and clearly showed the interconnection of a global hydrogen energy conception and hydrogen-metals problems.

In 1988, an All-Union Conference 'Hydrogen Treatment of Materials' (6–9 June 1988, Donetsk, Ukraine; Goltsova and Alimova, 1988) was held, which spread the idea of using hydrogen not only as *a good energy carrier*, but as *an agent to treat materials* to improve their structure and properties. The main scientific principles which form the basis for various types and methods of HTM were discussed. At this very conference, there were presented reports covering practically all aspects of HTM, that is, the treatment of metals having polymorphism (Ti, Zr and some Fe-alloys) and having no natural polymorphism (Pd, Nb, Ni, *etc*.), the amorphisation of intermetallics, the production of powders of a given dispersity, the improvement of the workability of steels by cutting and the pressure after hydrogen action and the like.

During these years, the communication of the HE and HM communities went ahead step by step. At the end of 1980s, the problem of materials was included into a large-scale HE conception (Goltsova *et al*., 1990). Correspondingly, the structure of the World Hydrogen Movement turned out to be completed in accordance with the current tasks and prospects (Goltsov *et al*., 2006a).

In this regard, let us pay attention to some positive changes in the HE community's way of thinking. It is significant that in the 1990s, some questions on the safety of hydrogen interaction with materials became the subject matter of the Japanese Project 'WE-NET: World Energy Network': The 'Materials and Safety' topic has become a usual subject matter of the World Hydrogen Energy Conferences since 1996 (Stuttgart, Germany).

The Permanent Working International Scientific Committee on Hydrogen Treatment of Materials was established (10 June 1997) by the Memorandum of IAHE President Professor T. Nejat Veziroğlu. The main aims and tasks of the created committee are to propagate HM ideas and actively support the development of cooperation of the HE and HM communities.

The committee functions on the base of the Donetsk National Technical University under the auspices of the IAHE. These organisations have been holding the international conferences 'Hydrogen economy and hydrogen treatment of materials' (Proceedings, 1997; 1999b; 2002; 2006; Hydrogen Economy and Hydrogen Treatment of Materials, 2007), which are a platform for the cooperation of the HE and HM communities.

In 1998, honorary gold and silver diplomas have been instituted, which have been presented triennially at the international HTM conferences to acknowledge scientists for their outstanding achievements and great activities in the World Hydrogen Movement.

5 Platinum metals – 'a further narrow neck' of hydrogen economy development

The future transition to a hydrogen economy and then a hydrogen civilisation will be a historical epoch-making transformation and cannot be serene in principle. But most of the members of the world hydrogen community do not perceive that. For example, they do not perceive that platinum metals will play a key role in the development and commercialisation of the world hydrogen economy.

The late Professor E.I. Rytvin was just the first who understood in full the novel key role of platinum metals in the development of the world HE and hydrogen economy. He initiated analytical work on this problem and initiated the international conferences

'Platinum Metals in the Modern Industry, Hydrogen Energy and Life Maintenance in the Future'. These conferences (Goltsov *et al*., 2006b; 2008) and HTM 2007 have discussed in detail a future key role of platinum metals in the development of the world HE and hydrogen economy. There were analysed scientific bases and prospects of the use of platinum and its alloys in fuel cells and in electrochemical hydrogen production, of palladium and its alloys in membrane technology for pure hydrogen (and its isotopes) production and for the separation of industrial hydrogen-containing gases, of platinum metals in the production of power hydrogen from natural gas, oil and the like. It had been displayed that already in 2010, ~20 t of platinum for the world industry of vehicles on fuel cells will be demanded. In future prospects, the hydrogen economy demand of platinum will grow up to 180–200 tonnes per year.

In the near future, platinum metals will be a 'bottleneck' in the development and commercialisation of hydrogens economy: the future world deficit of platinum metals (tens and hundreds of tonnes of platinum per year) will lead to a world crises of the platinum metals market and hydrogen economy commercialisation.

We must give Professor E.I. Rytvin (Goltsov *et al*., 2006b; 2008) credit for seeing a new key role of platinum metals in the development of a hydrogen economy. He was the first who initiated the steady cooperation of two world communities:

- the platinum community (producers, technologists, consumers and others)
- the hydrogen community (ideologists of hydrogen economy, HE technologists, specialists on hydrogen-materials problems and the like).

In 2007–2008, the Scientific and Industrial Complex 'Supermetal' and Donetsk National Technical University proceeded with informing the World Hydrogen Movement about future platinum metals' key role in the world hydrogen market economy's development at international hydrogen conferences: Istanbul (2007), Montecatini Terme (2007) and Moscow (2008). IAHE has been paying attention to this 'future bottleneck' of hydrogen economy development and has been publishing systematically in IJHE the announcements of this new series international conferences series 'Platinum Metals in the Modern Industry, Hydrogen Energy and Life Maintenance in the Future'. Without a doubt, the platinum metals problem is one of the most important challenges of HE and the hydrogen economy at present.

6 Conclusion

HE and hydrogen economy development is based on the activities of the World Hydrogen Movement including two large international communities. The first one is the HE community. The second one is the HM community. The HM community consists of three subcommunities: hydrogen degradation, hydrides and hydrogen treatment.

As a materials problem forms (a very important part of any global vector of human development), more and more close cooperation of the above-mentioned communities, which already have almost two and a half decades of history, is necessary for the future hydrogen economy to come to life. The promotion of this cooperation is greatly welcome for the hydrogen movement's development in the 21st century. The latter is an absolutely important point for a future transition to a hydrogen civilisation, the only sustainable environmental future for humankind.

The future transition to a hydrogen economy and then to a hydrogen civilisation will be a historical epoch-making transformation and cannot be serene in principle. Beyond any doubt, the platinum metals deficit will be 'a future bottleneck' of hydrogen economy development.

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