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HYDROGEN – BUILDING MATERIAL OF THE UNIVERSE, EARTH ANOMALY OR COMMONLY AVAILABLE FUEL?

WODÓR – BUDULEC WSZECHŚWIATA, ZIEMSKA ANOMALIA CZY POWSZECHNIE DOSTĘPNE PALIWO?

Summary: *Hydrogen is a carrier and energy store. It is becoming the energy supplier. The global energetic-climatic policy forces us to search for the alternative solutions and the sources of cheap electric energy. The implementation of RES (renewable energy sources) and the consequent legal regulations runs laboriously while the hydrogen revolution (although still ineffective) is developing dynamically and gives a chance to stabilization of the situation in energy storage, inter alia, in Poland and will make the pro-ecological activities real. Constantly increasing participation of hydrogen in energy sector, especially in global approach, forces the leading electric energy producers to increase the additional financing of the mentioned research sectors.*

Unfortunately, the development of hydrogen infrastructure is slow. It is inhibited by a lack of the need (that is, still too low demand) and the prices of hydrogen for final users are highly dependent on, for example, the number of refuelling.

The utilization of hydrogen for carbonization purposes requires, however, it obtaining in an emission-free way. At present, the discussed raw material, being mainly used in refinery and chemical industry, is generated almost exclusively in the processes of steam reforming of natural gas or coal re-gasification. The both mentioned methods are connected with CO_2 emission, therefore, the product, obtained in this way, is called grey hydrogen. On the other hand, electrolysis is the non-emission generating method; it needs only water and electric energy from the renewable sources.

The global energetic-climatic policy forces us to search for alternative solutions and for new sources of cheap electric energy. Aspects of storage and transmission of hydrogen in the industrial scale and optimization of the process of its obtaining (production?) seem to be a priority. We know what hydrogen is, we know its properties, we are able to accumulate and transform it in electric energy. The ideas of its storage are dynamically developing.

We hope that after reading this research paper, the question will be generated in the mind of the reader: when "the outbreak of the hydrogen era" is expected? In our opinion, the mentioned period was commenced at the second decade of 21st century. A lot of articles concerning the possibility of utilizing the mechanical vehicles, driven by hydrogen, the planned stations of hydrogen refuelling or construction of underground storehouses of H_2 in salt caverns are the premis.

Keywords: *hydrogen, energy carrier, storeage, decarbonisation, emission, cavern, energetic raw material*

Streszczenie: *Wodór to nośnik, magazyn energii. Staje się dostawcą energii. Światowa polityka energetyczno-klimatyczna zmusza do szukania alternatywnych rozwiązań i źródeł taniej energii elektrycznej. O ile wdrażanie polityki OZE i idących za nią regulacji prawnych przebiega żmudnie, o tyle rewolucja wodorowa (choć ciągle nieefektywna) rozwija się dynamicznie i daje szanse na ustabilizowanie sytuacji magazynowania energii m.in. w Polsce oraz urzeczywistni działania proekologiczne. Wciąż wzrastający udział wodoru w sektorze energetycznym szczególnie w ujęciu globalnym, zmusza czołowych producentów energii elektrycznej do zwiększenia dofinansowania tych sektorów badawczych.*

Niestety rozwój infrastruktury wodorowej jest powolny. Hamuje go brak potrzeby (czyli ciągle zbyt niski popyt), a ceny wodoru dla konsumentów końcowych są wysoce zależne na przykład także od liczby tankowań.

Wykorzystywanie wodoru w celu dekarbonizacji gospodarki wymaga jednak pozyskiwania go w sposób niegenerujący emisji. Obecnie surowiec ten, używany głównie w przemyśle rafineryjnym i chemicznym, powstaje niemal wyłącznie w procesach reformingu parowego gazu ziemnego lub regazyfikacji węgla. Obie metody wiążą się z emisją CO_2, dlatego wytwarzany w ten sposób produkt określono jako szary wodór. Niegenerującą emisji metodą jest natomiast elektroliza, do której potrzebne są woda oraz energia elektryczna z odnawialnych źródeł.

Światowa polityka energetyczno-klimatyczna zmusza do szukania alternatywnych rozwiązań i źródeł taniej energii elektrycznej. Priorytetowe zdają się być aspekty magazynowania i przesyłu wodoru na skalę przemysłową oraz optymalizacja procesu jego otrzymywania (produkcji?). Wiemy czym jest wodór, znamy jego właściwości, potrafimy zgromadzić i przeobrazić w energię elektryczną. Idee jego magazynowania rozwijają się w dynamicznym tempie.

Mamy nadzieję, że po lekturze tekstu w umyśle Czytelnika zrodzi się pytanie, kiedy nastąpi „wybuch ery wodoru". W naszej opinii ten okres rozpoczął się w drugiej dekadzie XXI wieku. Setki artykułów dotyczących możliwości wykorzystania pojazdów mechanicznych napędzanych wodorem, planowanych stacji tankowania wodoru czy budowy podziemnych magazynów H_2 w kawernach solnych to przesłanka.

Słowa kluczowe: *wodór, nośniki energii, magazynowanie, dekarbonizacja, emisja, kawerna, surowiec energetyczny*

Introduction

Hydrogen is a chemical element with atomic number of 1. It is one of the most universally found elements on our Globe. The most frequent isotope of hydrogen is atom, consisting of one proton and one electron. As a standard, gas hydrogen occurs in a molecular form H_2. It is colourless, without taste or smell. It is easily flammable and is not toxic. It burns without a visible flame; the water vapour is the effect of its combustion.

If we want to write about hydrogen which is, together with helium, the main building material of our "surroundings" we should enter for a moment into a world of cosmology, construction of the Universe and realize that 95% of the Universe surroundings are made of black energy and black matter and the remaining 5% are galactic together with the Milky Way, stars, inter-galactic gas and our Solar System, including our old Planet – which seems to be the evident phenomenon, a special case, not to say anomaly. The known matter, including neutrino consist only 1%

of the mass of Cosmos; the remaining 4% include hydrogen and helium. Pure hydrogen and pure helium; it has a great energetic significance.

The probability calculus will tell us that our Solar System, Earth is many times repeatable but in the vastness of the Universe, it is the anomaly. It is perhaps more than anomaly, it is better to define it as a peculiar case because hydrogen on the earth is entrapped in the hydrocarbon and nitrogen (ammonia – NH_3 compounds) and in water. In the contrary to the Cosmos, it does not occur independently in the earthly nature.

Hydrogen is a carrier, the energy store. It becomes the supplier of energy when – in the processes of nuclear synthesis (the processes occurring, for example, on the Sun) – as a result of combination of hydrogen atoms in enormously high temperatures, it becomes a building material of helium, when releasing simultaneously enormous quanta of energy and free neutrins. Apart from the gravitation energy, the thermonuclear reaction is the main source of the Sun energy, the energy of stars. The inhabitants of the Earth are far from the possibility of controlling the mentioned process; we have learned only destruction in a form of hydrogen bomb.

The meaning of the word "HYDROGEN" is "forming water" – two atoms of hydrogen and one atom of oxygen strongly connected together. Hydrogen in two atoms is so-called as it "forms water". It is the enormous, earthly energetic resource, being practically unprecedented (according to the available today knowledge) in the Universe. We have also a hydrogen in a molecule in a form of ammonia NH_3, urea: $CO(NH_2)_2$ but also in methane (methane, the simplest hydrocarbon - carbon and 4 atoms of hydrogen, CH_4) and in hydrocarbons which had changed mankind during the recent century. But it is water, as being universally present in Earth, which seems to be the easier source of obtaining hydrogen. Today, the majority of hydrogen, utilized in technological processes of the European refinery, chemical and petrochemical industries is obtained, of course, from methane; it results from the fact that we have local electric energy plants and energy in a form of water vapour under the appropriate pressures and temperatures, we have available expensive catalysers which practically enable carrying out the reaction of obtaining hydrogen. The second and unfortunately, the greatest source of industrial hydrogen on Earth is a reaction of carbon and water (the mentioned reaction consists in generation of the so-called synthesis gas which gives high emissions of carbon oxide and dioxide), similarly as from methane to synthesis gas.

Water in Earth is a cosmic phenomenon, source of life, a special case or perhaps – anomaly (?) searched by the scientists in the Universe. We learned to perform electrolysis, i.e. utilization of electric current flow through pure water two hundred years ago; we are not able to improve the mentioned technology, or change in such a way that the molecule of water is separated non-expensively, quickly and effective in respect of energy. When speaking about electrolysis, we cannot forget the PEM method (Polymer electrolyte membrane), being an alternative to the less effective but cheaper method (alkaline water electrolysis). The only one but deciding weak point of PEM is its high cost. When speculating, we may try to lower the costs of the mentioned method by replacement of platinum with graphene in a role of catalyser. Hydrogen is universal building material of the surrounding Cosmos which we understand and experience. But it is not independently available on earth. It must be released and, additionally, transmitted to the place where it is necessary.

Future lies in hydrogen

Global energetic-climatic policy forces us to seek for the alternative solutions and sources of cheapo electric energy. The introduction of RES policy and the resulting legal regulations run laboriously whereas hydrogen revolution (although being still ineffective) is dynamically developing and gives a chance for stabilization of the situation in respect of energy storage, *inter alia*, in Poland; it would make the pro-ecological activities real. Constantly increasing participation of hydrogen in energetic sector, especially in global aspect, makes that the leading producers of electric energy increase the additional financing of the mentioned research sectors.

The most intensive work upon the properties of hydrogen is implemented, first of all, in the United States, Germany and France. Poland has also the achievements in this field, with its projects by Orlen/Lotos[1)], Gaz-System S.A.[2)] , in cooperation with higher education schools, *inter alia*, with AGH University of Science and Technology, Warsaw University of Technology and the Silesian University of Technology. A wide popularization of the discussed

[1)] Biznes Alert/Cire: President of PGE Wojciech Dąbrowski said that the company observes hydrogen technology; however, it does not intend to invest in it at this moment, as it is too expensive still. The president was asked about the application of hydrogen in energetics. He said that [...] this technology is still very expensive. It is still a lot of work, efforts in order to decrease the price to the level acceptable by our customers. The application of hydrogen in heating, in energetics would unprofitable for them. We are striving at reduction of charge from our customers. Dąbrowski did not exclude that in the future, the discussed technology would find the application in energetics. –"Our turbines in the constructed gas blocs in Power Plant Dolna Odra (Lower Oder River) would be adapted to combustion of gas with admixture of hydrogen. At present, there is no possibility to have the discussed fuel universal and available at the acceptable price. It is still connected with the high costs"

[2)] On 14 September 2020, the information appeared that the European Commission approved the application for accession of Gaz-System to the European Clean Hydrogen Alliance – ECH2A. It is a successive initiative, after signing the letter of intention (July 2020) about establishing the partnership in favour of building hydrogen economy in Poland, with the involvement of Gaz-System Company. The European Clean Hydrogen Alliance was established by the European Commission with the aim to support implementation of the investment and establish hydrogen economy in the European Union in accordance with the assumptions of the European Hydrogen Strategy, being published in July 2020. The Alliance is expected to play a fundamental role in the support of investment activity, carried on in the total chain of values, including production, transport, storage and utilization of hydrogen in the particular sectors of economy (e.g. transport, industry, energetics, heating system). In the case of necessity, the Alliance will undertake the activities, aiming at support of the labour market and its adaptation to the needs of local hydrogen economy. The Alliance will consist of the representatives of industry, national, regional and local authorities and the representatives of citizen society.

„Gas-System participates actively in shaping a dialogue on introduction of the assumptions of the European Green New Deal". We want to indicate, via the membership in the Alliance, how the natural gas may play a significant role in energetic transformation in Poland and in total EU. Gaz-System as the undertakes operator of transfer system, undertakes activities which may enable utilization of natural gas as low-emission energy source, supporting the implementation of the aims of climatic policy of the European Union in a long-term perspective. Besides it, Gaz-System is also strongly involved in research-developmental projects, aimed at introduction of the new methods for operation of gas infrastructure. The mentioned activities include, inter alia, adaptation of the assets for the needs of receipt and transport of renewable and decarbonised gases, including hydrogen" – citation after Tomasz Stępień, the President of the Board of Gaz-System company.

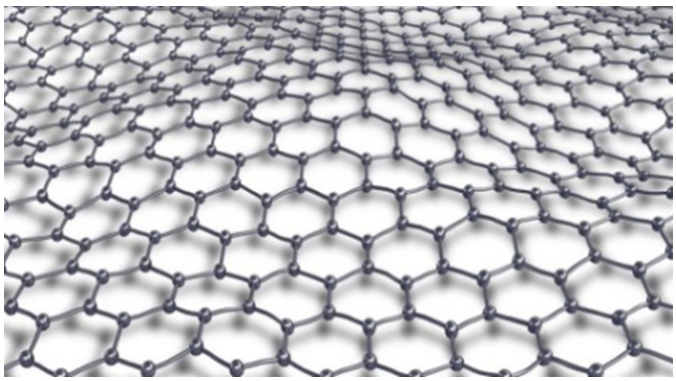
element in the Cosmos and the simple, though very expensive methods for its obtaining result in the development of energetics and rendering it a name of ecological (organic) fuel. Therefore, was the process of replacing the petroleum of natural gas inhibited until now? Whether it will be inhibited? The so-far costs of obtaining hydrogen were higher than the energy, obtained from its combustion what decided on unprofitability of the discussed process. Therefore, let's pay attention to the advantages, resulting from the increase of the hydrogen participation in the national production of electric energy. Its ecological nature, connected with the production of water (water vapour) in the process of combustion, should be confronted with the sulphur dioxide and carbon dioxide, being the by-products of fossil fuels' combustion. Moreover, hydrogen has a low ignition temperature and a relatively very high temperature of combustion in relation to the mass of the mentioned element. The cars, driven by hydrogen, are becoming more and more popular; their high performance and the application of "clean fuel" convince the users to bear higher expenses and overcome the difficulties connected the lack of fuelling station[3] [2] [3].

Aspects of storage and transfer of hydrogen in the industrial scale and the optimization of the process of its production seem to be a priority.

What may be a role of graphene in "hydrogen revolution"?

Graphene is a flat structure consisting of carbon atoms; its form resembles a thin (thickness is only one atom) plaster of wax foundation. One of its main features includes heat conductivity (thermal conductivity is equal to 4840–5300 W/mK) which is intensively employed in different industrial branches. As being a very resistant material (100 times harder than steel), it is subjected to elongation even by 25%. Graphene may play a function of a very sensitive gas detector and it is connected with its sorption properties, in which the total surface of material participates. The possibilities of applying it as insulation/dam for the smallest atoms, *inter alia*, of helium or hydrogen, is the essence of the energy storage process and its chemical neutrality to water effect allows implement the idea of catalysis of water hydrolysis process. Graphene is susceptible to modifications and to affecting its physico-chemical properties (creation of materials for construction of organic electrodes, photovoltaic cells or construction of layers of solar collectors).

Fig. 1. Structure of graphene.



Source: http://naukawpolsce.pap.pl

Some words about sorption capabilities....

Carbon-based materials may absorb well the particles of, *inter alia*, H_2. The results of physical sorption, conducted with graphene, have indicated its very high affinity to absorption of the hydrogen molecules and, what is most important (in storage aspect) owing to the mechanical tensions, the control of gas release from graphene is possible[4] [3]. Looking at these problems, it seems therefore, to be the ideal material, increasing the possibilities of energy storage in a form of hydrogen, isn't it so?

The above fact was developed, *inter alia*, by the research team of the University of Technology of Łódź, working upon the graphene tank, allowing riding about 800 km without the necessity of refuelling the car (hydrogen as a fuel[5]) [3]. The process of absorption and recovery of particles was performed on the principle of the change in temperatures, with the consideration of the earlier mentioned property of graphene to control the sorption-desorption cycles. The searches for methodology and materials for the increase and improvement of the currently obtained results in respect of the quantity as well as quality of the hydrogen in the reverse gas storehouses is a priority in the discussed sector of pro-hydrogen policy.

Lack of the sufficient hydrogen infrastructure

Unfortunately, the development of hydrogen infrastructure is slow. It is inhibited by a lack of the need (that is, still too low demand) and the prices of hydrogen for final users are highly dependent on the number of refuelling (let's imagine such situation at petrol station!?) Are there the stations which sell as much hydrogen per day as it is delivered? The total length of hydrogen

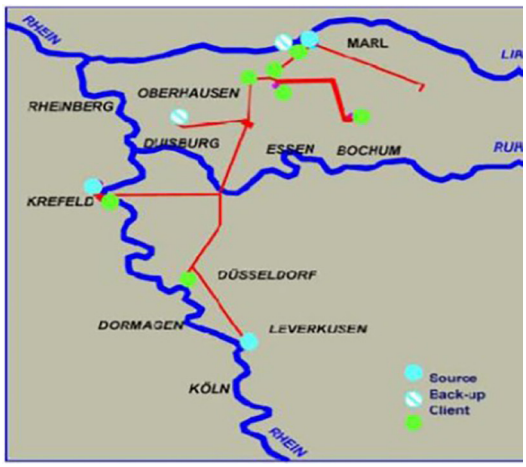
[3] „Institute of Car Transport (ITS) has prepared the plan of the project for construction a network of several stations in Poland where it would be possible to fuel the vehicles (buses and personal cars) powered by fuel links, with hydrogen. ITS is one of the institutions, implementing the European Project Hit-2-Corridors, the aim of which is to create and later on, integrate with the European infrastructural network, serving for utilization of hydrogen as fuel in road transport" – Wojciech Gis explains. One of the effects of the work on the discussed project includes plan of building the stations in Poland, mainly in the courses of the European transport corridors TEN-T. The answer to the question: "when it will be possible?" is not easy. The Institute assumes the establishment of such 9 object up to 2030, depending on the interest. "http://www.pb.pl/4365094,94750,polska-bedzie-miala-stacje-wodorowe?utm_source=copyPaste&utm_medium=referral&utm_campaign=Firefox (access 2015/12/03)

[4] The document „Graphene is a new material base on carbon", developed by Agnieszka Jedrzejczak, Multi-person post for foreign economic cooperation and entrepreneurship, as placed in portal http://www.mazovia.pl, presenting the possibilities for graphene applications in aspect of its physical and chemical properties. Separation of functions of hydrogen and aspect of its storage

[5] Vision of Prof. Piotr Kula, director of the Institute of Material Engineering of the University of Technology of Łódź, based upon the so-far obtained results of the studies on the application of graphene in the motorization revolution. The interview by Jack Krywko for wyborcza.pl

pipelines in Europe is ca. 1500 km. It is a very effective way of energy transportation – the losses in the hydrogen transfer are at least by twice lower than those ones occurring in the transfer of energy by transfer lines. The gas pipelines are constructed from a special steel (hydrogen supplants carbon) with diameter of 25–30 cm and allow hydrogen pumping under the pressure of 10–20 bar. The oldest hydrogen network in Europe is found in the Ruhr area where the 50 years old gas pipeline has a length of 210 km and joins 18 suppliers and recipients without any failure. The oldest line (400 km) combines the plants in France and Belgium.

Fig. 2. The system of hydrogen gas pipelines in the Ruhr area (acc. to Air Liquide www.airLiquide.com 2005).

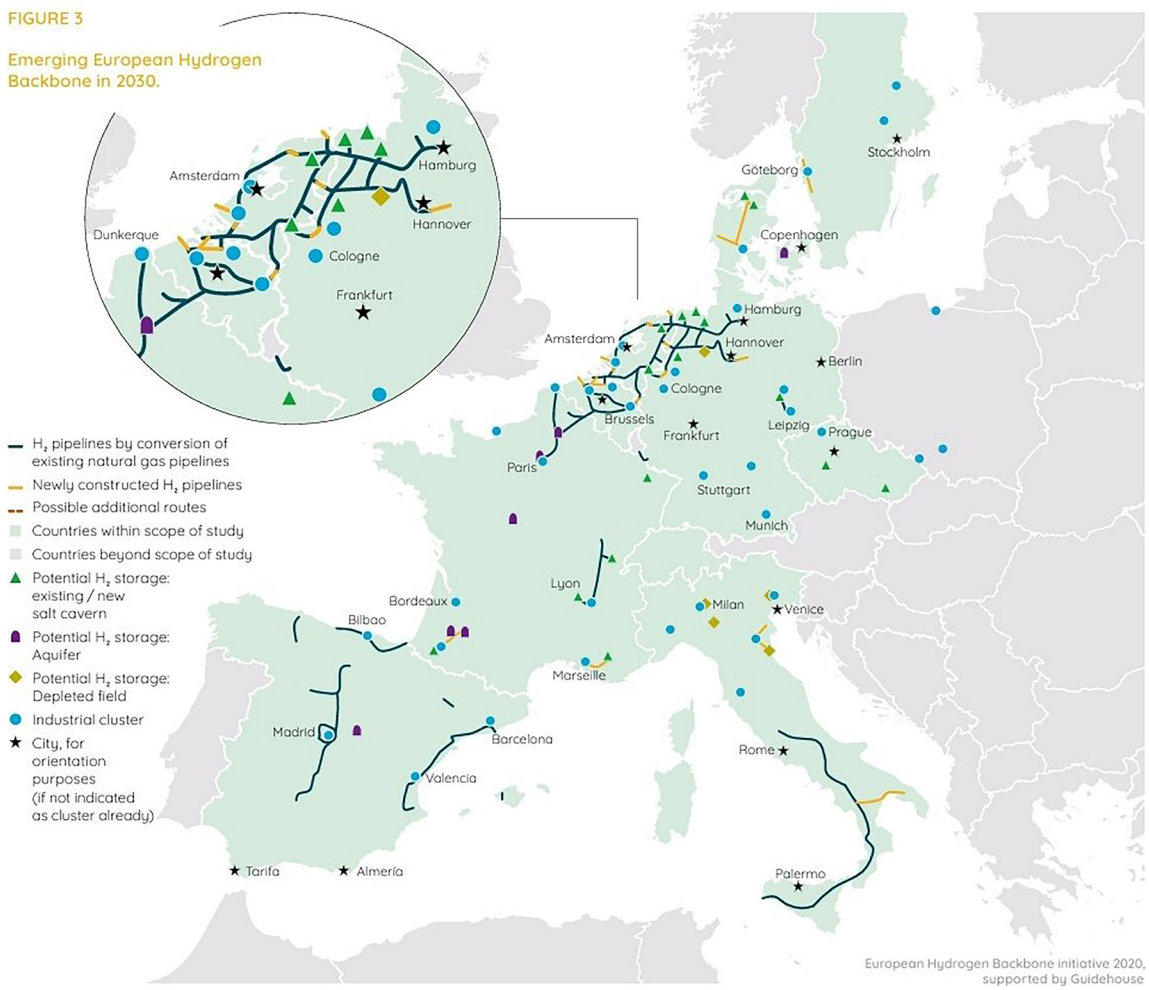


The key problem before the researchers is the application of cavern technologies for storage of hydrogen as energy and performance of salt caverns, meeting the safety requirements in respect of leak-tightness and stability. We know to-day that they should be situated in the regions, enabling utilization of brine coming from leaching and receipt of energy to the network of high tensions. The storing installations of hydrogen should be located in the vicinity of potential sites of its utilization.

In July 2020, the report entitled "European Hydrogen Backbone" [4] sponsored by some operators of transmission systems (Enagás, Energinet, Fluxys Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas, Teréga) was published. In the mentioned document, the transmission network for hydrogen in Europe was preliminarily outlined.

In the document [4], the analysis included 10 European countries (in our region, only the Czech Republic). The main thesis of the Report is the opinion that on the grounds of the existing network or *via* the so-called "upgrade", the change of the existing non-used gas pipelines, it would be possible to speak about creating the beginnings for the hydrogen backbone of Europe as early as in 2025, in the perspective of 2030. The starting point should be the hydrogen network, existing in France, the Netherlands and its development in Germany.

Fig. 3. The European planned hydrogen infrastructure. The European hydrogen backbone. Source: EUROPEAN HYDROGEN BACKBONE. Anthony Wang, Kees van der Leun, Daan peters, Maud Buseman [4] .



As it is given by the International Energy Agency (IEA), hydrogen at the global scale, in the contrary to Europe, is almost completely obtained from natural gas and carbon [5] (production of the so-called synthesis gas); water hydrolysis is considerably more expensive and requires distillation. Its production – ca. 70 million t annually in a pure form – the further 45 million t without previous separation – is responsible for the total CO_2 emission, estimated at 830 million t.

Then, IEA informs that there are huge regional differences in the costs of hydrogen production. Natural gas without CCUS (Carbon Capture, Utilization and Storage) is at present the most economic source of hydrogen production in majority of the world, at such low costs as e.g. 1 USD/kg H_2 in the Middle East region. From among the low-emission options, electrolysis requires price of electric energy at 10-40 USD /MWh to become competitive in respect of costs for natural gas from CCUS technology (depending on local gas prices). In the available literature, we may find information that the cost of producing 1 kg H_2 from fossil fuels, connected with CO_2 emission to atmosphere is about 1.5 €. For comparison, the cost of production of 1 kg of H_2 from fossil fuels in combination with sequestration of CO_2 is equal to almost 2.0 €[2]. In such situation, the plans of the European Commission concerning promotion of building and development of renewable – green hydrogen market, the costs of which are estimated depending on the price of electric energy at 2.5 – 5.5 €/kg[6], are somewhat puzzling.

At the turn of May and June 2020, the road map was passed on to social consultations; the mentioned map was aimed at obtaining the social contribution to the EU hydrogen strategy under development. In the mentioned document, the chances and challenges before the development of trans-border market of "green" hydrogen in the EU were generally described. The mentioned document is consistent with the policy of obtaining a climatic neutrality of Europe until 2050:

- its main aims include lack of net emission of greenhouse gases to atmosphere and bringing about the separation of the economic growth and resources. The role of hydrogen in the assumptions of this ambitious climate policy cannot be overestimated. Hydrogen is expected to replace, first of all, fossil fuels in those sectors where cannot be fully electrified and allow storing the electric energy, generated from RES (renewable energy sources) during the period of excessive production. The purpose of the consultations was to submit the information on barriers and challenges which – in the opinion of the social side – do not allow creating the profitable and competitive market of hydrogen in Europe in short and long term perspective.
- they concerned the complete life cycle of "green" hydrogen, commencing from the stage of creating the legal framework and unification of nomenclature, problems connected with the wide production and integration with electric network, transmission and storage of hydrogen, ending on the requirements connected with the necessity of adapting the equipment of final users, indispensable development of new hydrogen technologies and the necessity to ensure the appropriate financial means and the suggestions for the terms of their granting.

Within the frames of the cited work [6] the obtained comments were analysed in the context of the challenges, standing before the European chemical industry, being connected with the plans for decarbonisation.

Analysis of the conclusions in the context of the countries of origin and size of the enterprises

The opinions on the road map were reported in the period of 26 May – 08 June 2020. In total, 279 remarks from 24 countries were submitted. In our opinion, the time came to utilize a potential of hydrogen. At present, hydrogen is mainly used in crude oil refining and in production of ammonia, i.e. further of artificial fertilizers; it occurs in trace amounts in transport. If the discussed universal element is to have a significant contribution to clean energy and become a bridge of energetic transformation, we have to find a place for it in the sectors where it is almost absent. It must be found in everyday life areas such as human life, transport, buildings and energy production. For this to happen, a modern technology of its effective obtaining is necessary. (Humanity has not known yet such technology, not only the cheap one. It would be fantastic if the discussed process could run as exergonic reaction requiring less energy than that one which would be obtained later when combusting hydrogen). Hydrogen is the universal element; it may be comprehensively employed. As early as two years ago, we wrote about methane hydrates [7]. It is a very interesting source of hydrogen; the question, however, arises: will we be successful in this undertaking? Whether the humanity will open new horizons? Perhaps a new Copernicus or a new Maxwell[7] will discover the new successive evidences?

In the past, the false starts for hydrogen technology had place; our time is to be different. "*In this century, we will subdue the power of the stars, the source of the energy of Gods. In a short time perspective, it means introduction of era of solar-hydrogen energy which would replace fossil fuels, and in a longer perspective, it means mastering nuclear fusion and even solar energy from the space.*" [2].

Hydrogen must begin to play a key role as a cheap, clean, safe fuel of the energy of the future. Hydrogen may help in solving different critical energy problems. Hydrogen must begin to play the main role in energetic transformation of humanity as:

- It will release a high-scale integration of RES with the so-far energy producers,
- It is the easy energy storehouse,
- It is a buffer of energetic safety,

[6] The European Commission, A hydrogen strategy for climate-neutral Europe. COM (2020) 301 final, 8.7. 2020, Brussels https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy [access on line: 14.09.2020]

[7] Maxwell proved that electricity and magnetism ate two kinds of the same phenomenon - electromagnetism. He demonstrated also that electric field and magnetic field disperse in a vacuum with the speed of light in a form of wave, i.e. light is electromagnetic wave.

- It is a clean raw material for the industry.

There is a will to have such micro-market in Poland. It seems that PKN Orlen is a leader in this respect; the enterprise specifies it quite clearly: If the fuel companies want - in the future - to exist in the market, they have to consider with what to replace oil and petrol in petrol stations. The company wants to develop also capacities of hydrogen production in electrolysis process and, also, the infrastructure for charging the vehicles, driven in Poland. It's the beginning. If we want to exist in the market as a fuel company, we must take into consideration that the mentioned oil and petroleum in the fuel stations should be replaced with something. They will contain also chargers of electric cars as they have to be. Personally, I cannot see the batteries-driven electric cars. I am more convinced to electric vehicles, driven by hydrogen. Hydrogen-driven car is the electric car. Hydrogen is not combusted. It is transformed in fuel cell and generates current. It is exactly the same what electric car but it does not possess battery but hydrogen cell. The difference between such vehicles is visible especially in the respect of their distance. In the case of hydrogen-driven Toyota cars it is 500–700 km. As far as heavy transport is concerned, i.e. buses and trucks, the battery is not an option because it would occupy a half of the truck's surface in order to pass 1000–1200 km. It could be ensured by hydrogen. In Poland, the hydrogen stations do not exist yet, but PKN Orlen wants to develop such objects in Poland[8)].

The preferred green hydrogen in the strategy of Germany

Utilization of hydrogen in order to decarbonise the economy requires, however, obtaining it in the way which does not generate emissions. At present, the discussed raw material, used mainly in the refinery and chemical industries, is generated almost exclusively in the processes of steam reforming of natural gas or carbon re-gasification. The both mentioned methods are connected with CO_2 emission, therefore, the generated product is specified as grey hydrogen. On the other hand, electrolysis is emission-non-generating process; it requires water and electric energy from renewable sources. Green hydrogen, obtained by this way, is considered as the only one solution, which meets the needs of the sustainable development in a long perspective. Another method for hydrogen production, which is considered in the context of decarbonisation of the economy, includes its obtaining from natural gas, with the utilization of technology of CO_2 sequestration (CCS, *carbon capture and storage*), that is, the process consisting in the capture of CO_2 from exhaust fumes in order to store it e.g. in salt caverns or under the sea bottom. Blue hydrogen, as obtained by this method, is treated, however, for example in Germany, as only a transitional solution. Due to a wide availability of natural gas and lower costs of such raw material as compared to the green hydrogen, a partial decision on blue hydrogen may accelerate the process of establishing hydrogen economy. This option gives also a chance to the companies from gas sector for the adaptation to the needs of decarbonisation. Contrary to the green hydrogen, its blue equivalent is not the emission-free product because during the production and transportation of natural gas, harmful methane is released to atmosphere.

Strategy for green hydrogen in France

In September 2020, the Ministers Barbara Pompili and Bruno le Maire submitted the report on the state of the national strategy in respect of green hydrogen to the main French entities and companies, associated in the Hydrogen and Fuel Cell Association connected with the hydrogen economy. Within the frames of restructuring plan, France Relance Covid, the French Government plans to obtain 6.5 GW power in the installation for hydrogen production up to 2030. Within the frames of France reliance, 7.2 billion € will be destined for hydrogen strategy until 2030, including 2 billion € up to 2020. The French Government has defined three priorities concerning hydrogen. First one includes decarbonisation of industry, with the application of hydrogen coming from electrolysis and not from fossil fuels. According to the mentioned aim, France will commence the project concerning hydrogen in the field of sustainable production of batteries. It refers, in particular, to the projects of electrolysers with power of gigawatts. The second priority is utilization of hydrogen as a fuel in public transport, in delivery vehicles and trains. This year, the auction of 350 million € value for innovative project in the discussed area, is anticipated. Also, the project of purchase of "innovative big-scale objects of industrial ecosystem" of 275 million € is also planned. In 2021, the Government will destine 65 million € for the third priority connected with hydrogen, i.e. program of the research and development in the research institutes, universities and engineering schools. 3.4 million € assigned to hydrogen up to 2023 will be divided in a following way: 54% for decarbonisation, 27% for public transport and services and 19% for research and development, innovations and training.

Poland and hydrogen

The work upon the national strategy for development of hydrogen economy is conducted at the Inter-ministerial Governmental Team for Hydrogen Management with the participation of the Ministry of Climate. The Team works on the coherent vision of developing hydrogen utilization not only as a raw material and fuel but also as energy carrier which may be additionally stored. The hydrogen perspective should be a natural consequence, recorded in the Energetic Policy of Poland up to 2040. The mentioned document is again amended and – as we understand – subjected to comprehensive social consultations; it has not been adopted as the binding document, by the Government of the Republic of Poland. From the

[8)] Józef Węgrecki, the member of the board for operating matters of PKN Orlen during the 5th Polish Economic Summit, held in Siedlce

perspective of the authors, acting, for many years, in the domain of comprehensively understood energetics, the basic problem to be settled is a stable – cross-party – economic policy from which a clear, long-term energetic policy is resulting, without opportunism and meanness. In this context, we should mention still unsettled problem of obtaining land for linear investments, i.e. the draft law on strategic investments of public aim. We are for a quick development of hydrogen technologies.

The Team "*wants to strive at independence on the specified technological solutions, all this will be implemented with the assumption that the mentioned neutrality would not generate costs which might exceed the potential advantages coming from its reaching*". *Probably, it would be not possible in all domains; we will be striving at its obtaining in the places where there is a chance. We witnessed several times the situation where the dependence on a defined technology or on the supplier of such technology implied huge costs in a short time period. Therefore, obtaining the appropriate efficiency in green hydrogen production is the important aim but in the perspective of Polish hydrogen development, we take grey hydrogen also into account. It would create the foundation of hydrogen economy which then, owing to energy excesses from renewable source, will be supplemented with the electrolysers and completely zero-emission hydrogen. The hydrogenization as the element of energetic transformation must include also local, Polish specificity. The mentioned transformation must be the responsible process which would allow not only changing the picture of our energetics but also would contribute to development of Poland, ensuring a new economic dynamics and new work places to the local communities.*

Generation of the effect of inter-sector synergy is the element necessary for further effective work on the development of hydrogen sector in our country. The particular market tycoons may get much; however, the maximum advantages coming from development of hydrogen technologies in Poland is possible only with the assumption of possessing comprehensive know-how and resources, including energetic and fuel sectors. Such approach results from the nature of the discussed technologies and the potential of their later utilization. Therefore, the transformations in the mentioned above sectors are the answer to the needs generated by the market. We expect that they will give the appropriate stimulus to the Polish hydrogen sector and will bring advantages coming from synergy.

A private sector has also a significant role to play. It is already now involved in the link of values of hydrogen economy. A lot of the private companies develop successively the solutions in favour of hydrogen purification, storage and transport. There are also interested in commencement of producing hydrogen from RES [...].

We should also mention multi-level cooperation not only between the ministries, on public-private or even cross-nation level but also between the government and self-governing organs. The units of territorial self-governing authorities as being close to local market possess the most precise knowledge about the local needs and potential. Therefore, they will be able to direct the governmental support and indicate the appropriate investments. The cooperation at this level may obtain a form of financing the purchase of hydrogen –driven buses or in the support of building the heat power plants, based on the hydrogen technologies; they would constitute the effective source of heat and, at the same time, would have a great influence on the improvement of the air quality.

What foreign partners are taken into consideration?

We are open to any possibilities and solutions. We perceive a foreign cooperation as cooperation at the EU forum. We look also at the countries outside the Community and the non-governmental organizations which utilize developed hydrogen engineering. We plan to base the cooperation on four pillars: exchange of technology and experience, elaboration of common European and international standards in the field of hydrogen technologies, active participation in developing the EU regulations and finally, financing of hydrogen transformation in the European Union. As far as the EU is concerned, we look especially at our main commercial partners who- similarly as Poland- perceive a considerable potential in hydrogen. Simultaneously, we are open to any possibility of cooperation. In the non-European scale, we count first of all, on the countries, rich in the acquired experience in this respect, i.e. Japan, Australia and the South Korea. We do not exclude also the cooperation with our American allies."

What should the hydrogen strategy contain – the key assumptions

Global consumption of gas (certainly), oil (probably) and carbon (probably) will be still increasing in absolute values for the next two decades, even gradually with the increase of the share of renewable energy sources in the energy market. Taking the above fact into consideration, probably there is no way for reaching the global aims in respect of CO_2 emission and global increase in temperature which is not connected with a considerable increase of the electric energy production from nuclear and water energy.

Further combustion of big quantities of fossil fuels will have to be connected with a wide introduction of modern low-emission technologies in order to equalize the supposed increase of the emission; together with the development of renewable energy sources and other source of energy, oil and gas will follow carbon and will be forced, more and more frequently, to compete in prices with other sources as to maintain their role in the energetic mix.

Carbon preserved its high role in energetic system in the second half of the 20th century and at the beginning of the 21st c., as being, unfortunately, cheaper than its alternatives.

Oil and gas will follow, probably, by the same way. Together with the development of alternatives such as renewable energy sources, oil and gas will have to remain relatively cheap to maintain their markets.

The future changes in prices will accelerate the passage to competitive energy sources and will cause a loss of the to-

day levels in energetic mix. In particular, the consumption of oil will be more and more forced to the competition between the sources, when considering the possible higher prices and costs of CO_2 emissions.

Position of OPEC will have to evolve from the current attempt to maximize the incomes via limitation of production and increasing the prices for protection of its participation in the market. In the second half of the twenties and in the thirties of the 21st century, OPEC will be more occupied with the allocation of production and investing in new, not completely developed sectors and itself will probably be suffering from chronic surplus of manufacturing capacities; a cheap source of grey hydrogen will appear which – without regulations – will be effectively supplant and delay the development of green hydrogen technology.

Summing up

I would like to cite Prof. Konrad Świrski: "Unfortunately, it seems that to-day in Poland there are no possibilities of reasonable "social agreement" and compromised solution of the problem. Everything is going, unfortunately, towards a serious economic and social problem – perhaps one of the greatest problems during the recent 30 years. The successive directives and resolutions of the European Parliament will be pressing on quicker departure from carbon (during the coming days, even increase of the aim of emission reduction up to 2030 to 50–55% or even 60% is expected) what would be slowly unattainable technically for Poland, not speaking about economic costs. The attempt of strong restructuring of mining industry, being a consequence of energetic transformations (as in the new PEP 2040) will be stopped by resistance of the current carbon sector what , in consequence, will lead to dramatic discrepancy between the European and Polish policy (and the problem with the cost of emissions which will be quickly increasing in Europe). A real change will occur, alas, not as a result of "social mini-agreement" but in the period of a strong economic crisis which perhaps may occur in our country in the coming 10 years and automatically, it will force closure of the coal mines. As it usually happens in the history of the world, certain processes are unavoidable and unfortunately, the interests of individuals always fall in confrontation with the new changes in technology[9].

The international energetic-climatic policy forces us to seek for the alternative solutions and sources of cheap electric energy. The aspects of storage and transmission of hydrogen on the industrial scale and optimization of the process of its obtaining (production) seem to be the priorities. We know what hydrogen is, we know its properties we are able to collect and transform it into electric energy. The ideas of its storage are dynamically developing.

We hope that after the lecture of this paper, the Reader will have a question: when the "outburst of the hydrogen era" will take place. In our opinion, the mentioned period was commenced in the second decade of the 21st century. Hundreds of articles concerning the possibilities of utilizing hydrogen-driven mechanical vehicles, planned hydrogen refuelling stations, or construction of underground storehouses for H_2 in salt caverns are the premise of this trend. Perhaps it is enough that some would lie down under the apple tree or enter the tub with water and cry: "Eureka"!! (The motto for today is: to introduce graphene revolution and RES into the era of hydrogen!).

Economic aspects in such approach include optimization of manufacturing processes, storage and transmission of hydrogen in the industrial scale. The key may be the so-called wax foundation – the "leaven" of chemical honey plaster – Graphene.

And perhaps the future belongs to sorbents with a high capacity! And perhaps the future will be completely different?

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