UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Towards Hydrogen Societies: Expert Group Meeting

Current advancements in hydrogen technology
and pathways to deep decarbonisation

organized by:

United Nations Industrial Development Organization (UNIDO)

Ministry of Foreign Affairs of the Republic of Poland

Permanent Mission of Japan to the International Organisations in Vienna

Ministry of Energy of the Republic of Poland

December 12th 2018

On the sidelines of the 24th Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) - COP24

Authors:
Dr. Jakub Kupecki
Dr. Marek Skrzypkiewicz
Dr. Marcin Błesznowski

Ministry of Foreign Affairs Republic of Poland

The Permanent Mission of Japan to the International Organizations in Vienna

MINISTRY OF ENERGY

Abbreviations

CTCN	Climate Technology Centre & Network
DG	Directorate General
EES	Electrical Energy Storage
GHG	Greenhouse Gases
IEA Hydrogen TCP	International Energy Agency Hydrogen Technology Collaboration Program
IPCC	Intergovernmental Panel on Climate Change
P2X	Power to X technologies (including Power-to-Gas, Power-to-Liquid, Power-to-Ammonia, Power-to-Chemicals)
PEFC	Proton Exchange Fuel Cell
SDGs	Sustainable Development Goals
SOE	Solid Oxide Electrolyser
SOEC	Solid Oxide Electrolysis Cell
SOFC	Solid Oxide Fuel Cell
UAV	Unmanned Aerial Vehicle
UNEP	The United Nations Environment Programme
UNFCCC	The United Nations Framework Convention on Climate Change
UNIDO	The United Nations Industrial Development Organization
WHEC2018	The World Hydrogen Energy Conference (organized in Brasil in 2018)

Executive Summary

Hydrogen, the most abundant chemical substance in the universe offers a way to decarbonising energy especially for industries and diversity the economy. The current advancements in its production through electrolysis and related technologies including fuel cells as well as its versatile characteristics offer holistic solutions to reduce global GHG emissions. Hydrogen supports a true paradigm shift in the area of more efficient energy storage, especially for renewable energy on industrial scale. It furthermore offers an opportunity for an integrated energy system based on renewable energy through sector coupling. While the technology is maturing, the policy and regulatory framework remains insufficient throughout the world. Consequently, the recipe for success calls for the continuous partnership between the government, industry and academia.

Background

The Expert Group Meeting, organized by the United Nations Industrial Development Organization (UNIDO), Ministry of Foreign Affairs and Ministry of Energy of the Republic of Poland and the Permanent Mission of Japan to the International Organisations in Vienna, took place on the December 12th 2018 at the 24th Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) - COP24. The event was moderated by Mr. Piotr Kociński, the director of LOTOS Lab Sp. z o.o.. The aim of this event was to provide insight into strategies of regions related to hydrogen technologies, discuss case studies, support the sustainable development and foster the cooperation with developing countries to tackle their environmental challenges.

The first session provided guidelines for the future discussion about decarbonisation of energy, industries and transport in the light of the foreseen transition to hydrogen societies. Hydrogen has an outstanding potential thanks to its energy storage capabilities. The interests in the implementation of hydrogen-based energy storage is continuously growing and these systems can support the intermittent energy sources. Electricity from renewable energies such as wind or photovoltaic faces challenges due to lack of sufficient storage to provide grid balancing. In relation to the decarbonisation, the set goals of the global energy system might be hard to achieve with other technologies excluding widespread application of hydrogen technologies.

Introduction

The level of technological advancements in hydrogen value chains should be noted. Mr. Tareq Emtairah - Director of the Department of Energy, UNIDO underlined the necessity of cooperation and knowledge exchange between public and private sectors in order to support the development of electrical energy storage systems which can be used to balance the electrical grids and to decarbonise the transportation sector. Ms. Sae Horikawa, First Secretary of the Permanent Mission of Japan to International Organizations in Vienna confirmed that the interest in the use of hydrogen is growing, as witnessed at the world's first ministerial meeting focused on hydrogen energy, held in Tokyo in October, 2018.. Hydrogen is considered to be an energy carrier which can provide the stability for the renewable energy, and therefore can couple power, industry and various sectors. She expressed their hope on the role to be played by UNIDO in stimulating world-wide discussions on hydrogen energy with its rich expertise. Ms. Horikawa underlined that, under Japan's G20 presidency discussions on the important role of hydrogen will be intensified, especially during the ministerial meeting related to energy transition and global environment for sustainable growth.

Presentations

Japanese hydrogen policy and present activities towards hydrogen society were the subject of the presentation of Mr. Daishu Hara, Director of New Energy and Industrial Technology Development Organization (NEDO). Mr. Hara referred to Basic Hydrogen strategy, the initiative of Japanese Prime Minister. It is the World's first hydrogen strategy with clearly defined targets.

H2 production scale	300 kt/a by 2030 and 5-10 Mt/a by 2050
Affordable H2 with the following targets	$3/kg by 2030 and $2/kg by 2050
Fuel Cell Vehicles (FCV's) with the total number of	40 k in 2020 and 800 k in 2030
Hydrogen refuelling stations (HRS's):	160 in 2020 and 900 in 2030

This strategy highlights the Japanese vision of hydrogen society. It relies on developing international hydrogen supply chains and power-to-gas (P2G) technologies for green hydrogen production for districts, cities and industries. In order to harmonize and cooperate for enhancing the utilization of hydrogen at a global scale, Japanese Ministry of Economy, Trade and Industry organized the ministerial meeting (October 23rd, 2018) related to hydrogen energy. Around thirty countries, including Poland, attended the event. Declaration of cooperation named Tokyo Agreement resulted from the discussion. The following actions were agreed upon:

- collaboration on technologies and coordination on harmonization of regulation, codes and standards,
- promotion of information sharing, international joint research and development with emphasis on hydrogen safety and supply chain,
- study and evaluation of the potential of hydrogen across sector, including its potential for reducing emissions of carbon dioxide and other pollutants,
- communication, education and outreach.

Important to note is that Polish authorities acknowledged the advantages of hydrogen technologies. The next day after the meeting Polish Hydrogen Parliamentary Group (Polska Wodorowa) was established in order to analyze the potential and possible applications of hydrogen.

Actions of NEDO are oriented towards cost reduction of PEFC (Proton Exchange Fuel Cell) in the mobility sector, promotion of SOFC (Solid Oxide Fuel Cell) in stationary applications with the target of efficiency in excess of 65% in stand-alone electricity generators, the development of hydrogen refuelling stations (HRS), advancing hydrogen as energy carrier for power industry based on gas turbines, demonstration and improvement of power-to-gas systems. These actions are multi-fold, including both improvement of the R&D cycle which was established over the years, demonstration of a long term durability, improvement of the technology in order to achieve the reduction of capital expenditures (CAPEX) as well the operational expenditures (OPEX). This can potentially result in a large scale hydrogen supply chain, which can include transportation of hydrogen in a liquefied form even from distant locations. The important driver for NEDO is the possibility to showcase the progress of the technology during the Tokyo Olympic Games scheduled for 2020. The 10 MW electrolysis system located in Fukushima prefecture will provide hydrogen to the Olympic town. Hydrogen technologies not only offer the outstanding efficiency but also drive the economic growth and secure Japanese position among the developed countries. This was supported by the statement of Mr. Daishu Hara in his presentation.

Bringing hydrogen to the developing countries requires external support and cross-border collaboration. This aspect was addressed by the Regional Manager of the Climate Technology Centre and Network (CTCN), Mr. Federico Villatico Cambell. The relation between the energy consumption and the level of development is studied by numerous organizations worldwide, including UNIDO. The key finding is that approximately one third of global energy consumption and 32% of global emissions of greenhouse gases are related to industry. The role of hydrogen in the transition from fossil fuel-based economies to renewables-based is not yet widely understood. Hydrogen is still not fully recognized in the power industry and neighbouring sectors. For that reason, UNIDO promotes it with the help of three main Sustainable Development Goals (SDGs), defining the topical areas:

SDG 7 – Affordable and clean energy,

SDG 9 – Industry Innovation and Infrastructure, and

SDG 13 – Climate Action.

Mr. Cambell underlined that CTCN is an executive organization of the UNFCCC Technology Mechanism, hosted by the UN Environment Programme (UNEP) and UNIDO. CTCN serves the developing countries creating opportunities to open new markets. Organization welcomes various forms of collaboration. Up to now CTCN was involved in non-technical actions concerning internationalization of the Brazilian hydrogen association during World Hydrogen Energy Conference (WHEC2018), which took place in Rio de Janeiro in June 2018. Networking event was organized to promote interactions of hydrogen associations worldwide. UNIDO is also a member of IEA Hydrogen TCP (International Energy Agency Hydrogen Technology Collaboration Program) since its beginning (October 6th 1977). Key actions of IEA are important to be noted: facilitating technology transfer to developing countries, H2 roadmapping, and promoting H2 for the decarbonisation of industries. The Strategic Plan is under development in order to define the work plan for the period 2020-2025. It is currently in the final stage of preparation. This document will aid IEA Hydrogen TCP to accelerate the implementation of hydrogen and the promotion of its wide use worldwide. Within Hydrogen TCP there are forty tasks, among which the hydrogen production is the one most frequently addressed. The storage of hydrogen is also in the spotlight. Moreover the importance of hydrogen in power-to-gas, power-to-liquid, power-to-ammonia or power-to-chemicals systems is also emphasized. Organization of the United Nations are open for collaboration and are willing to support the implementation of hydrogen as a flexible energy carrier in future multi-sector energy system. Further actions from that perspective focus on cost reduction, research, development and demonstration as well as the joint discussion about hydrogen as a climate change mitigation option in light of the IPCC report. Storage of energy resolves the problem of balancing electrical grids in terms of the reduction of a mismatch between the demand and production. The continuously growing share of renewable energy sources requires storage capacities which can operate at hourly, daily, weekly, monthly and seasonal basis. Director General of DG Energy and Mining, Mr. Michael Losch put strong emphasis on the topic of the seasonal storage of renewable electricity. With an increasing share of intermittent sources such as wind or solar, flexible long- and short-term storage solutions for renewable electricity are crucial. Hydrogen serves as a perfect candidate which, when produced locally, not only supports the spatial availability of renewables, but also increases the security of energy supply. Estimations indicate that by 2050 more than 80% of the net electricity production will originate from renewables. Such a level of renewable production will result in severe challenges for electrical grids and a devaluation of e.g. PV-produced power during times, where supply will exceed demand, especially in summer day-time periods.. A large share of this generated renewable electricity could be utilized if storage or instantaneous production of gaseous, liquid fuels, or chemicals using power-to-X systems (P2X) is possible. Looking at currently available electrolysis technology, a decentralized approach with electrolysis facilities in the range from 1 MW to 5 or potentially even 10 GW allows an efficient storage option for EES and can assure electrical grid stability. It also enables the dynamic dispatch to complement intermittent renewable power and match the demand and production of electricity at the local, regional and national levels. As an energy vector, renewable hydrogen supports the further integration of renewable energies in all energy sectors, which is vital to the successful transformation of the energy system. Additionally, renewable hydrogen will pave the way for decarbonization of energy-intensive industries.

The EU Hydrogen Initiative was established by the Austrian Presidency of the Council of the EU in September 2018 in order to stimulate identification and evoke synergies in application of renewable hydrogen technology in fields of sector coupling, short- and long-term storage, production of substitute natural gas (SNG), and use of hydrogen as a new vector in industry, transport and mobility. The Initiative is supported by twenty six Member States, 2 EFTA states, the European Commission and approximately hundred European companies, organizations and institutions. However, the growth of the hydrogen market in the EU is facing challenges linked to legislation and standards. Therefore, the identification of problems and barriers as well as the definition of guidelines for their elimination are key for a successful roll out of technology. Two EU projects in that field should be noted: CertifHy and HyLAW, both funded by the Fuel Cell and Hydrogen Joint Undertaking (FCH-JU). The limiting factors, which are observed in the field of hydrogen technologies, make it possible to define EU-wide standards for gas grids to be addressed:

- security for end-use consumers,
- necessity for cross border trade in pipelines (in case of hydrogen injection to the gas grids),
- implementation of hydrogen assurance for gas quality,
- methodology for issuing certificates of origin of hydrogen, and
- development of dedicated infrastructure.

The lack of uniform regulations, safety codes and standards has been identified. In the field of power-to-gas technologies one of the key limitations is related to the allowable concentration of hydrogen in natural gas pipelines in various countries. The natural gas grid has the largest potential to become a main reservoir of hydrogen and simultaneously its distribution system. With respect to the volumetric content, the maximum tolerated hydrogen concentration in the natural gas grid varies broadly between Member States from less than 1% until up to 12 %. Various technical experts state that in most of the EU countries hydrogen concentration in range 10-20% can be handled by the existing infrastructure. One of the scenarios foreseen by the European Commission Long-term Strategy till 2050 highlights the key role of hydrogen in the reduction of emissions of greenhouse gases. It is believed that approximately 150 Mtoe in form of H2 will be consumed annually. European gas grids, thanks to their volume, readiness for hydrogen injection and transport capabilities which underline the large scale distribution, can indeed play a major role in the decarbonisation.

Europe's actions can be based on the experience of other regions which successfully advanced the state of hydrogen technologies. In the early days of the existence of Ballard company, its founder Mr. Geoffrey Ballard stated that it will take a combined effort of academia, government, and industry to bring the change from a gasoline economy to a hydrogen economy. Currently, Ballard operates in different markets in which low temperature fuel cells are present: fork lifts, buses and trucks, trains, ships, personal transportations and UAVs. According to Mr. Jesper Themsen, CEO Ballard Power Systems Europe electrification of transport is on its way and the efforts of car manufacturers are increasing. Moreover, fuel cells can improve the performance of electric vehicles and allow achieving complete decarbonisation of transportation. As an evidence it is worth to mention that currently about 65 fuel cell busses are in commercial operation in European Union. Ballard as the leading manufacturer of low temperature fuel cells gained operational experience equal to more than 30 million kilometres, which proves the technological readiness. Important to note is the Ballard's vision of the year 2030, which includes:

- presence of thousands fuel cell buses,
- half a million of H2-fuelled trucks,
- between 1 and 10 trains, and
- first cruise ships in service operated on H2.

Transportation sector is indeed in the spotlight regarding the decarbonisation. To accelerate the transition, in September 2018 the Hydrogen Council - a global coalition of the leaders in energy, transport, industry and utilities announced joint commitment concerning decarbonisation of transportation. The goal for 2030 is to fuel FCVs only with green hydrogen originating from renewable energy sources. Transport is the first target among others sectors. The role of government, local and national support cannot be underestimated. Vice president for Markets & Strategy H2 of Air Liquide Mr. Eric Sebellin can be quoted: "In hydrogen economy two hands are needed to clap: industry and policymakers". This announcement is a continuation of the decision which was taken two years earlier in Davos by the leading players in the sector. At that time the Hydrogen Council was founded. One year later, during 23rd COP conference in Bonn, management of the companies grouped in Hydrogen

Council presented their vision and called on governments to work together on multilateral H2 deployment, set the objectives and harmonize the actions. Presently, hydrogen-related energy topic reached the highest level of importance and the Energy Ministerial Meeting was organized in October 2018 in Tokyo. The consecutive meetings is scheduled for June 2019. Zero emission energy carrier is one of four energy pillars which aids the energy transition. Air Liquide emphasizes that hydrogen is the most attractive option which enables energy to move through time and through space. This is not possible for electricity as such and therefore hydrogen and electricity are complementary goods. To summarize, seven roles of hydrogen in energy transition can be formulated:

- integration of renewables and power generation,
- distribution of energy,
- stabilization of energy sector,
- decarbonisation of transportation,
- decarbonisation of industry,
- decarbonisation of heating and power supply for buildings, and
- use of hydrogen as feedstock and substrate in various processes.

Hydrogen market is estimated at fifty billion dollars worldwide. The amount of hydrogen which is produced in refineries would be sufficient to fuel 250 million cars. This hydrogen is currently considered as black hydrogen due to the fact that hydrocarbons are used as a feedstock for its generation in the steam reforming process. This highlights the potential role of alternative hydrogen production technologies such as high temperature electrolysis based on solid oxide cells

(SOC) in the process of decarbonisation. It can be observed that financing tools in a form of incentives or subsidies are driving the early state implementation of the technology. As a result, several flagships initiative are underway:

- Californian activities of Southern California Gas Company (SoCalGas) and the joint project of Boeing and Sunfire which resulted in the largest reversible solid oxide fuel cell system,
- Anglo-American spin-off focused on H2 technologies, o German activities of Alstom related to H2 trains,
- French Hydrogen national plant with 100 M€ investment, o Investment by Weichai into Ballard,
- H2Korea plan for wide spread H2 mobility by 2022,
- Japanese consortium for implementation of hydrogen refuelling stations resulting in 500 units by 2027.

During the 2020-2030 decade cooperation has to take place at the global level to bridge the gap between current status and deep decarbonisation, energy transition and sustainable economic growth expected by 2050. To understand the challenges one should refer to the status in countries which are among the leaders. Germany which has the largest number of demonstration systems with fuel cells and electrolysers is still away from the targets set by the Paris Climate Agreement.

Greenhouse gases are emitted mainly from energy and transportation sectors although the country has invested a lot in power generation from renewable energy sources. Hydrogen as a zero emission energy carrier can significantly improve this situation. According to Mr. Geert Tjarks, Head of Division International Cooperation, NOW GmbH it can foster the integration of renewables inside the energy sector and enhance energy transfer from the north of country where excess green energy is being produced to the south of Germany. Potential applications of hydrogen lay also outside the field of energy generation and the automotive sector. Hydrogen can become an important feedstock and key substrate in methanation processes and synthesis of liquid fuels as well as chemicals. Rather than being considered as a competing technology, hydrogen should be considered complementary to batteries. It offers advantages which overcome the limitations of the most advanced lithium-ion batteries and electrical energy storage (EES) systems of other types. For example trains are foreseen as a good application for the initial deployment of large scale hydrogen, because of high volumes and high predictability of the consumption. Under such conditions the uncertainty of business models is reduced and the value chains can be assessed with high precision. Germany currently aims at activation of the market for industrialization of water electrolysis by 2025. The goal of reaching the installed capacity of approximately 2 GW can be achieved on conditions that actions start now. The foundation for scale-up is based on the existing pilot plants with the cumulative capacity of 20 MW in 2018.

Key challenges are related to the cost, lifetime and the political framework which affect the eagerness of transportation sector and industries. Mission Innovation IC8 was established in May 2018 in order to accelerate the cooperation for large scale projects which will prove that hydrogen is not yet another tool but effective solution to decarbonise societies. To conclude the discussion related to the development of hydrogen technologies in emerging markets, the Polish potential was presented by Mr. Tadeusz Uhl of AGH - University of Science and Technology. His presentation addressed the development of low- and high temperature fuel cells, including the discussion of activities of Polish teams. Selected projects focused on lightweight vehicles and actions oriented at e-mobility were presented. It was highlighted that the status of high temperature fuel cells was recently summarized in a comprehensive publication of more than forty scientists (Status report on high temperature fuel cells in Poland – Recent advances and achievements, International Journal of Hydrogen Energy, 2017). The joint publication presents the substantial progress related to materials, manufacturing techniques, and the first Polish power units with fuel cells. Conclusions of this work emphasize that the technology of stacks with solid oxide cells which can operate either in fuel cells mode (SOFC) or electrolysis mode (SOE) exists and is under intensive development at the Institute of Power Engineering (IEN). Discussion on the heavy duty transportation included the presentation of the locomotive platform that will allow testing various energy sources such as battery, fuel cell and diesel generator at the industrial scale.

Discussion

Final conclusions were formulated jointly by the participants of the discussion panel which closed the session. Seven panelists - international experts in hydrogen technologies defined the take away message concluding from the first session of the event. Key technical challenges are currently related to understanding the role of hydrogen which instead of competing with batteries must be considered as a complementary technology. In that field technical challenges are related to the onboard storage of hydrogen, including both the tanks and containers as well as the control

and safety systems. Mr. Jesper Themsen emphasized that the onboard hydrogen offers the advantage to utilize the surplus heat which can be valorized in automotive applications (heating the interior). On the other hand, hydrogen is widely produced, mostly using steam reforming of hydrocarbons. Countries such as Germany are expected to significantly increase the share of electrolysis as an efficient and economically viable technology for delivery of hydrogen to various sectors. This means that in the time frame of five years the demand for electrolysis will grow and will be driven by the increasing share of renewable energy sources.

Hydrogen technologies are facing numerous issues related to both technological challenges as well issues originating from the lack of uniform and harmonized legislation. In that perspective, visible progress can be made in large transportation sector such as trucks and trains, instead of passenger vehicles. In the opinion of Mr. Uhl just a few hydrogen refuelling stations are needed for the introduction of fleet of heavy duty vehicles. No matter which scenario will be chosen and supported by policymakers, Poland can expect a growing number of hydrogen busses and trucks by 2025. As recalled by Mr. Campbell it is important not to forget that hydrogen technologies have been present in ammonia production and in form of electrolysis since 1950s and 1960s, even in less developed countries. This can guide to a conclusion that the problem does not lay in the technological area but rather in the field of standards, safety codes and legislation. Beside the advantages offered by fuel cells and electrolysers in the fields which were discussed in the session, the hydrogen systems are currently positioned as the 3rd most interesting technology for the public. The creation of new markets, ability to drive economies and improve the sectoral integration explains the increasing meaning of the gas. As Mr. Turk states, this aspect must not be neglected. Transition towards hydrogen economy can be potentially challenging in regions and countries with abundant sources of fossil fuels. For that reasons alternative paths for hydrogen production are being discussed. This includes coal gasification which was in the agenda since the oil crisis of the 1970s. Moreover, production of hydrogen from coke gas is currently attracting the attention of developing countries. According to Mr. Brzozowski, JSW Innowacje S.A. sees the potential to produce approximately 2,000 kg of hydrogen per hour. Successful completion of the project can be an interesting case study for replication elsewhere. One should not neglect the fact that absence of transportation and energy systems based on hydrogen in developing countries does not mean that the production of the gas is minor. For example Poland produces nearly 1 Mt of hydrogen annually (for chemical and fertilizers industries) as reported by Mr. Tomoho Umeda.

Conclusions

Transition to Hydrogen economy offers a way to mitigate GHG emissions worldwide. Thanks to its versatile applications such as power-to-gas, power-to-liquid, power-to-ammonia, power-to-chemicals, known under common name of P2X technologies, hydrogen is a great candidate for sector coupling. It provides a transformative decarbonising opportunities especially to the industries. The raise of renewables urgently needs reliable energy storage technologies at the industrial scale. One of the most promising technologies is the solid oxide electrolysis – the most efficient, already available way to split water molecules to produce hydrogen and oxygen. High temperature electrolysis can be economically viable since, together with fuel cell technology, it overcomes the limitation of batteries regarding the volume of stored energy and possibility to send it on a long distance through the gas grid.

Well-known for the industries steam reforming of methane, a technology for hydrogen production already generates black hydrogen which soon will not be accepted in all the sectors. Transition to green hydrogen produced using renewable energies is in the spotlight. While the developing countries can benefit from the technologies and experience of the pioneers in the sector, however the advent of hydrogen stimulates growth and creates new market opportunities.

The advances in fuel cell and electrolysis technologies are a perfect starting point for national-level demonstration projects and scale-up of the technology. However, a robust policy framework is necessary to effectively support the large scale implementation. Furthermore, the determination and continuous cooperation of academia, industry and government is the recipe for success.

Special thanks to the distinguished speakers who contributed their expertise and time to this event

Daishu Hara	Director, Fuel Cell and Hydrogen Technology Group, Advanced Battery and Hydrogen Technology Department, New Energy and Industrial Technology Development (NEDO)
Federico Villatico Campbell	Regional Manager for LAC, West and Central Africa at the Climate Technology Centre and Network (CTCN)
Michael Losch	Director General for Energy and Mining in the Austrian Federal Ministry for Sustainability and Tourism
Jesper Themsen	CEO & President, Ballard Power Systems Europe
Eric Sebellin	Vice President, Markets & Strategy H2, Air Liquide
Geert Tjarks	Head of Division International Cooperation, NOW GmbH
Tadeusz Uhl	Professor of AGH University of Science and Technology
David Turk	Head of the Strategic Initiatives Office, International Energy Agency (IEA)
Bartosz Brzozowski	Associate Director of International Cooperation and Analysis, Breakthrough Technologies Division in Warsaw JSW Innowacje S.A
Tomoho Umeda	Founder of ENVISIO Foundation, The owner and CEO of TOMO Group