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HYDROGEN +

STRATEGY

4 KOŠICE

REGION



Technical University of Košice
P. J. Šafárik University
Slovak Academy of Science
Promatech Centre
Slovak National Hydrogen Association
Košice Self-Governing Region



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Authors:

Maroš Halama
Vladimír Zeleňák
Tomáš Brestovič
Peter Hegeduš
Jaroslav Legemza
Andrej Oriňak
Karel SaksI
Zuzana Orságová Králová
Gabriela Baranová
Sergej Koperdák

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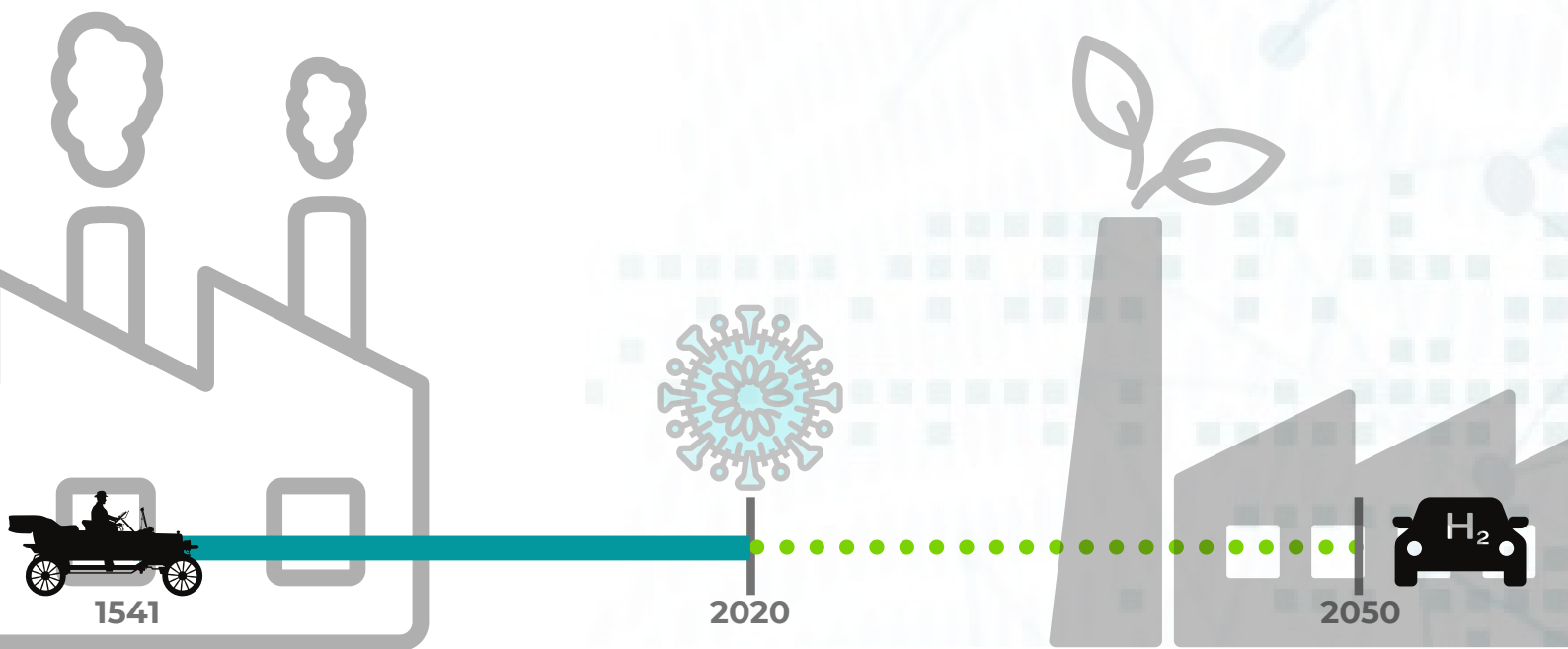
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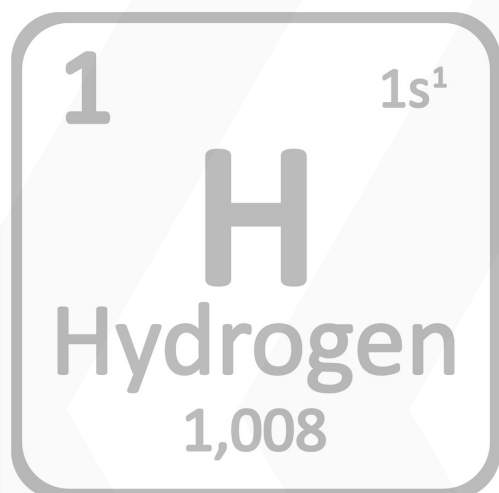
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AVANT PROPOS



Hydrogen is among batteries another key renewable vector undergoing considerable attention of scientific, business, policy and public community in world leading economies. Europe as region has unique assets that position EU to pole position together with Japan, Korea, US and China. Slovakia as individual country doesn't implemented effective hydrogen national programme yet. That is why group of wide-spectrum authors have done this evidence-based study to discover potential of hydrogen technologies tailor made for Kosice Self-Governing Region (KSK) helping the EU reach its

environmental goals while boosting local investment. KSK together with support of EU funds would like to explore further in depth the implications of greater public and private investment in hydrogen as an alternative source of energy, particularly its spill-over effects on regional innovation, education, entrepreneurship and employment. The aim was to detect areas with high deployment of hydrogen technologies across industrial sectors from energy production, transport, storage but also research and development hand in hand with education challenges fulfilled the highest criteria on safety issues. It contains also recommendations for tourist action plans from which can benefit public and alternative scenarios helping Kosice Self-Governing Region to fit unique plans achieving competitive position and to set up policy decisions in future.

Every advancement of human society, from the first industrial revolution to the current Industry 4.0 has been linked with progress in energy use and rapid changes in technology. One of the greatest inventors in Slovak history, who moved energy transition worldwide from small country in the hearth of Europe and later on from ETH Zurich was Aurel Stodola, who started his studies in Kosice region. Nowadays, with massive digitalization and smart IT solutions, parallel transformation of Society 5.0 is under development too.

We do not have to wait another decade in Košice region to find the technology to combat climate change and innovate industry in one step, but can act now instead with existing possibilities and their improvements. We can make the region of Košice a region with a higher quality of life for its citizens and harvest from concurrence advantage in early transformation times.

Whether it was the introduction of steam, electricity or the automation into the production process, all activities were related to the use of energy, which, if not counting hydro power, was obtained from the combustion of wood, coal, natural gas, oil processing or nuclear fusion. All of these commodities are a way of storing the energy that people have deliberately released and used from these commodities according to the needs and demands of society. With the exception of nuclear energy, the generation of energy from the above sources is associated with the production of CO₂, which is considered to be one of the main source leading to climate changes and global warming. We are living in times when humanity has set itself the goal of reducing its carbon footprint and moving to a carbon-free society. This is also reflected in the pressure to switch to green renewable energy sources such as solar and wind. However, their use is inevitably connected with the need to store energy, due to the fluctuation in production of energy from the sun or wind. So, it is crucial to solve its storage in order to balance the supply and demand for energy. One of elegant alternative and promising source of 'green' energy is hydrogen. Its combustion generates water to release large amounts of energy and without carbon footprint.

The idea of using hydrogen technologies in energy storage or transport is quite old and there is a long-term experiences from space and military research. However, targeted research on hydrogen technologies in the EU started after 2000 and has intensified in recent years, with improvements in fuel cell efficiency. Advanced materials and technologies make the use of hydrogen technologies more and more realistic. In Slovakia the topic of hydrogen technologies was bypassed, there was no more targeted interest of industry, investors and policymakers in this issue for many years. It only changes in the last 2-3 years.



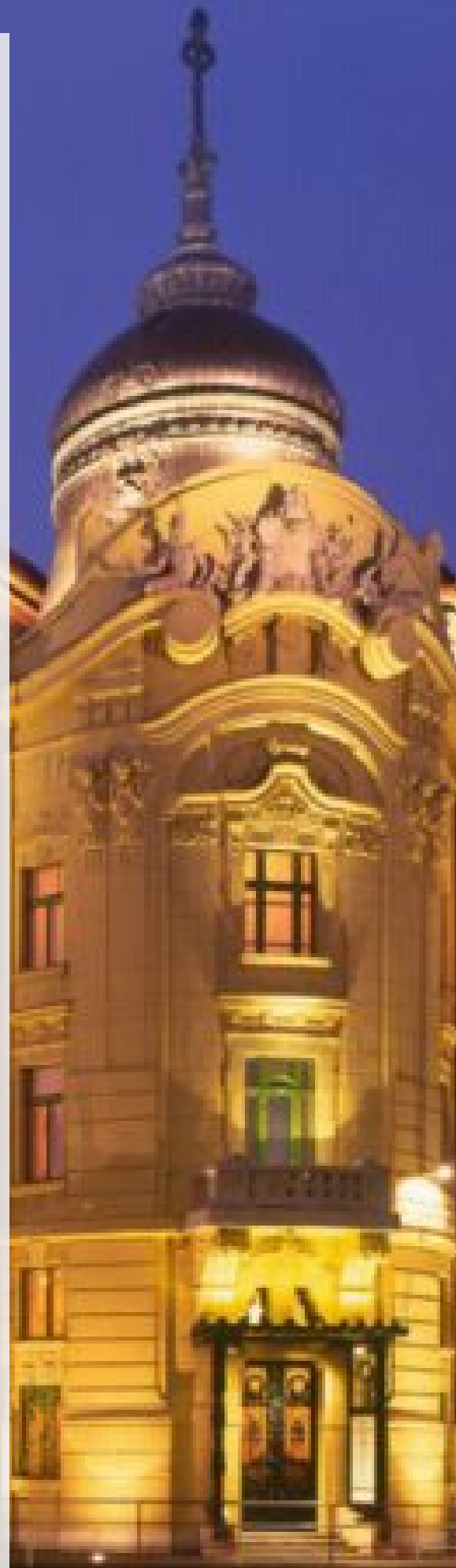
Hydrogen (H) as the lightest element on Earth weighs in 1 liter approximately 0.09 g, which is about 11 times lighter than air. It is commonly found in the form of diatomic molecules, such as hydrogen (H₂). On Earth, hydrogen naturally occurs only in the form of compounds (most common is water, but also in oil, natural gas etc.), which are the basis for its industrial recovery. However, this also results in the fact that, unlike fossil fuels (coal, natural gas etc.) in which energy is already accumulated and released from it for everyday activities, using hydrogen technologies we must first produce hydrogen by decomposing other compounds. And this requires input energy, usually in the form of work or heat and only subsequently, either by using fuel cells or by direct burning, we are able to release the energy back.

For the more extensive development of hydrogen technologies and the wider use of hydrogen in society, it's cheap and environmentally friendly production is crucial, together with way of safe transport and high-capacity storage.

The Košice Self-Governing Region can use in small scale version hydrogen and fuel cell technologies today and capture emerging opportunities which brings in long-term perspective. But only way how to make benefit for public is act together with industry, investors, universities, research institutes and policymakers as major players.

It must be said that last sentences of study has been written in times where massive coronavirus prevention was applied in Slovakia due to the announcement of WHO as pandemic disease and unprecedented historical losses at stock-market. So we hope for renaissance in application of very innovative technologies such as green hydrogen in these energy and biological labile times because world will be like never before. Hopefully smart solutions will improve quality of life of Slovaks as well as Europeans.

17th March 2020, Authors





HYDROGEN +

PRODUCTION

CHAPTER 1



HYDROGEN PRODUCTION

The difficult question regarding the utilization of the hydrogen in the Košice self-governing region is, where we can find and produce enough hydrogen to meet all requirements of industry, mobility, households or energy sector and at the same time the production of hydrogen will be sustainable, environmentally friendly, low carbon or even green.

Hydrogen can be produced from water in three main ways. One way is through a process known as electrolysis, which extracts hydrogen from water using electricity. If renewable electricity is used, this process produces zero carbon emissions. At this point we called hydrogen as “green hydrogen”. The other two ways are through thermochemical reactions, using coal (in a process known as gasification) or natural gas (in a process known as steam methane reforming). These latter two techniques are how most of hydrogen is now produced. Using fossil fuels means there are carbon emissions, but if these emissions can be captured at a high level and permanently stored, “blue” hydrogen or hydrogen made by “low-carbon” technology can be produced in clean way.



Grey hydrogen	Blue hydrogen	Green hydrogen
Split natural gas into CO ₂ and hydrogen	Split natural gas into CO ₂ and hydrogen Residual gasses also in H-vision scope	Split water into hydrogen by electrolysis powered by wind and sun
CO ₂ emitted in the atmosphere	CO ₂ stored or re-used	No CO ₂ emitted

The list of possible ways of hydrogen production [1]:

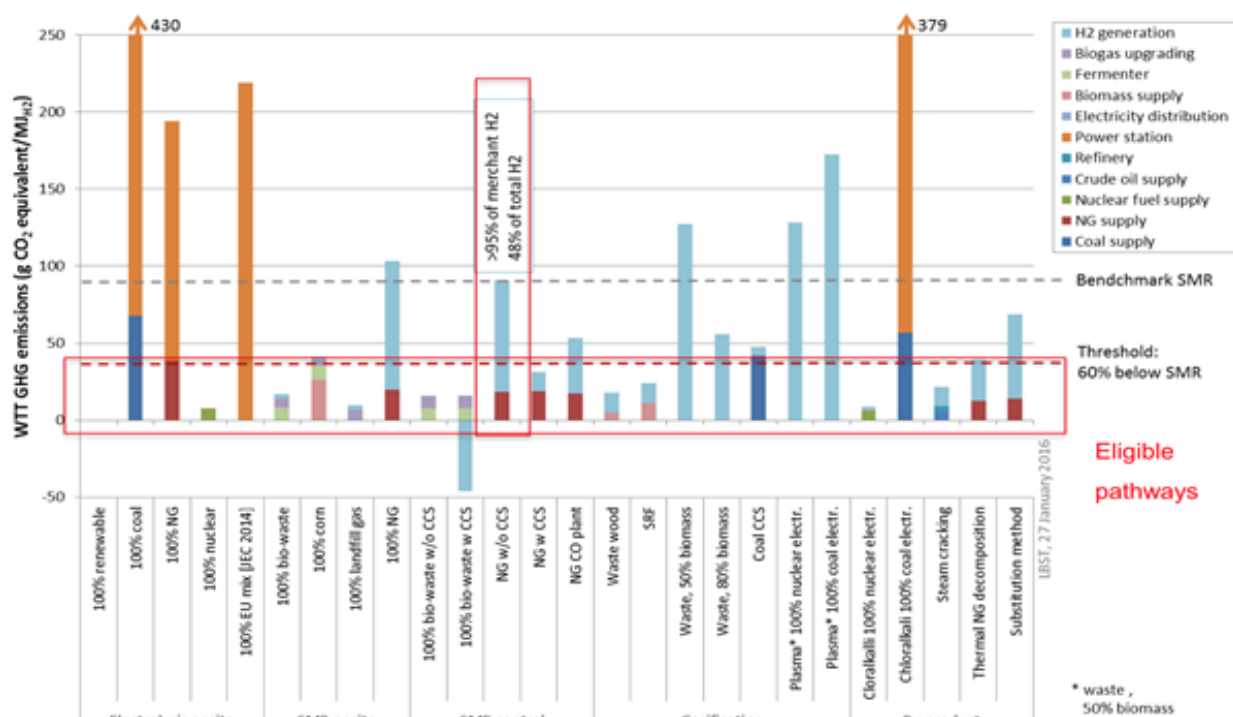
- 1 steam cracking of hydrocarbons
- 2 partial oxidation of hydrocarbons
- 3 conversion of aqueous synthesis gas
- 4 degradation of biomass by bacteria
- 5 decomposition of chlorides using water vapor
- 6 reforming of gasoline
- 7 reforming coke oven gas
- 8 electrolysis of water and acids
- 9 photocatalytic water splitting - extraction of hydrogen from water molecules
- 10 decomposition of water vapor by iron, resp. FeO
- 11 decomposition of water vapor in plasma (ionization)
- 12 decomposition of ammonia or methanol

The primary focus is to produce the “green hydrogen” or hydrogen produced on regional level by low carbon technologies so the distribution ways will be shorten and we can achieve higher possible level of efficiency in hydrogen distribution. The ultimate goal is to produce and use 100% of hydrogen for which renewable energy sources or at least low emission sources have been used.

However, due to the technological progress and economical aspects, hydrogen produced from fossil fuels - “grey” hydrogen will certainly also be used in the transition period. Grey hydrogen, the most competitive option today, should be fully phased out by 2050 to meet the 2nd degree target. It is expected to become increasingly less competitive over time as the cost of CO₂ emissions increase, reaching cost levels higher than all low-carbon alternatives prior to 2040.

Hydrogen production from renewable energy sources

Hydrogen production using renewable energy sources (RES) is determined by the geographical and natural characteristics of the region. These characteristics are the main drivers for selection of the specific RES and cost effectiveness of green hydrogen production. The amount of RES used is at the same time determined by the environmental and technical limits and by the acceptance of the public. All these specifics create the potential of the green hydrogen production in the region. Recent findings suggest that scale-up of hydrogen technologies will be the biggest driver of cost reduction, notably in the production and distribution of hydrogen and the manufacturing of system components.



Source [2]

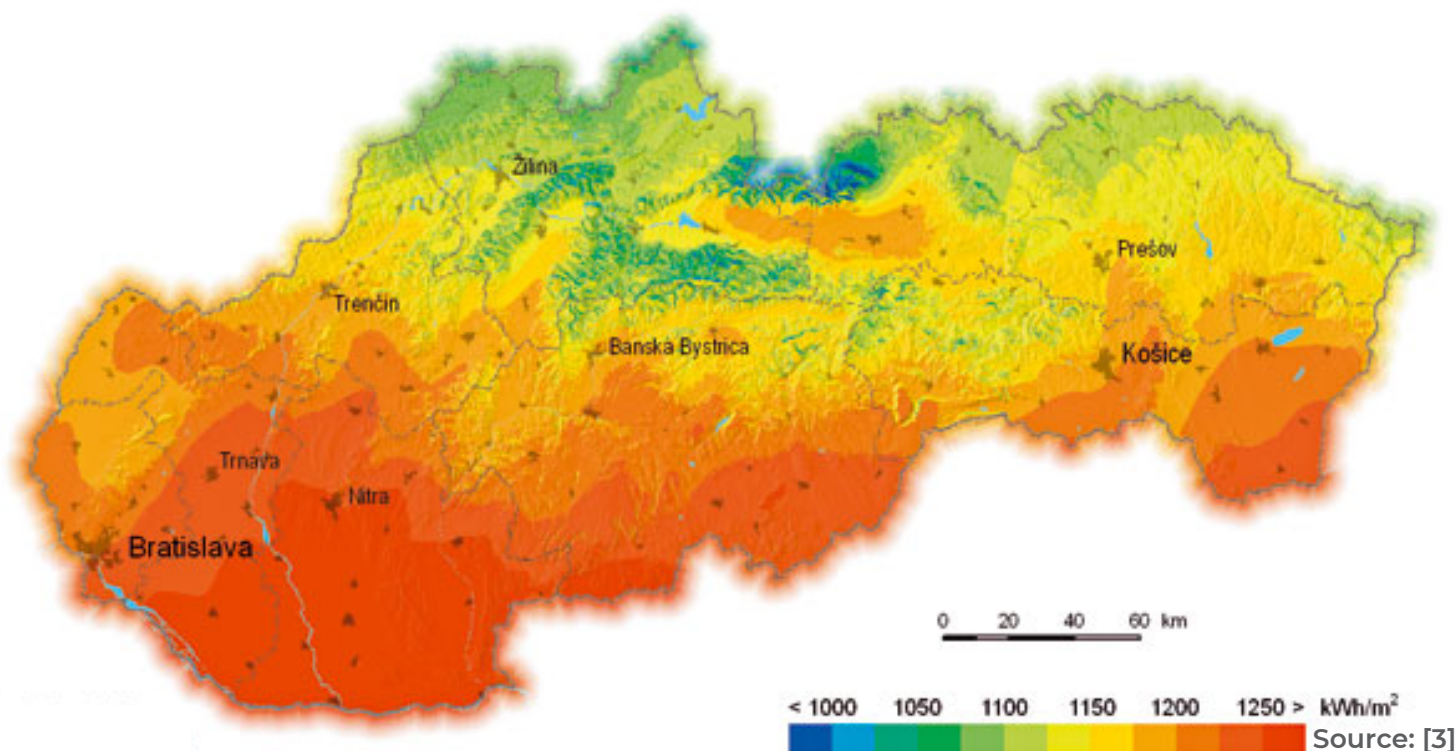
This will deliver significant cost reductions before any additional impact from technological breakthroughs is considered. The cost of low-carbon and/or renewable production of hydrogen will fall drastically by up to 60% over the coming decade. This can be attributed to the falling costs of renewable electricity generation, scaling-up of electrolyser systems and development of low-cost carbon storage facilities.

Hydrogen production from Photovoltaics

The photovoltaics (PV) have the biggest potential for the deployment in Košice self-governing region. According to the irradiation map, south of region has the average energy output per m^2 in the range of 1000-1200 $kWh \cdot m^{-2}$ as shown in the map below.

Currently there is installed around 100 MWp of PV projects with the potential of increasing up to 600 to 700 MWp in 2030 and 1500 MW in 2050 considering the technology development in PV sector. In mid and long-term period, LCOE (leverage costs of electricity) of PV installation will decrease beyond 50 EUR per MWh and lower, which enables the green hydrogen to be more competitive than hydrogen from fossil fuels.

The new PV installation should be placed on the low-quality land and on the buildings. The efficiency ratio of the PV panels is increasing, so 1 MW of new PV installation will require 12000 to 15000 m^2 of available space. Commercial buildings, production and logistic buildings have the biggest potential for the production of green electricity needed for the green hydrogen.



[3] <http://solargis.info>

Degraded and low-quality land such as landfills, ponds, non-agricultural land could be utilized for the medium and large-scale PV installation that will provide the power for the green hydrogen production. The technology innovations and smart grids for residential buildings will allow the households and communities to become the prosumer - both producer and consumer at the same time of energy and that means they will produce the hydrogen for their own consumption using the PV installation on the roof tops of the houses.

Large industrial areas such as EVO Vojany, US Steel, Chemko Strážske with good connection to the existing electric and gas infrastructure have the best potential for the deployment of Power to Gas technologies. PV as source of energy will play a major role in renewable energy mix in Košice region.

Hydrogen production from Wind

The use of wind as a source of energy for green hydrogen production is dependent on the specific wind conditions. Kosice valley is well known with its permanent wind presence. The most suitable wind areas within the Košice self-governing region are located on the tops of mountains and hills (wind speed above 7 m.s^{-1}). At present, turbines with an output of 1500 to 2000 kW are used globally.



However, from the point of view of usability for wind electricity production, it is necessary to take into account all protected areas, especially protected bird areas, areas of European importance NATURA 2000 and other protected areas.

Taking into account environmental limitations, the potential of the Košice region is limited to localities with average wind speed from 6-7 m.s⁻¹, where detailed assessment of the technology selection is necessary to ensure the economic feasibility of green energy production.

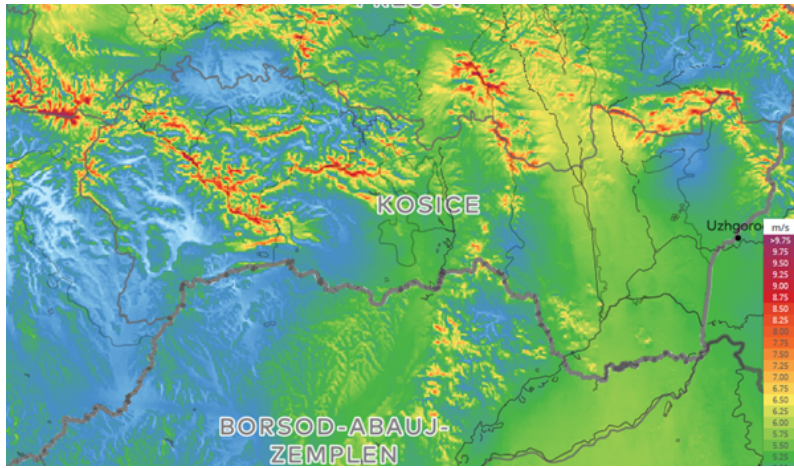


Figure: Wind speed in 100 m above surface
Source: [5]

Detailed environmental impact analysis (EIA) has to be provided for each locality, including detailed wind assessment.

Despite these limitations, the potential of Košice region is 30-50 wind power units by 2030, which means an installed capacity of 120-200 MW and, with increasing technology efficiency, an installed capacity of 500 MW by 2050.

The most probable plan is to build small scale electrolyzers of 1 MW and “hydrogen wind turbines” where an electrolyser is incorporated in the turbine to produce hydrogen rather than power.

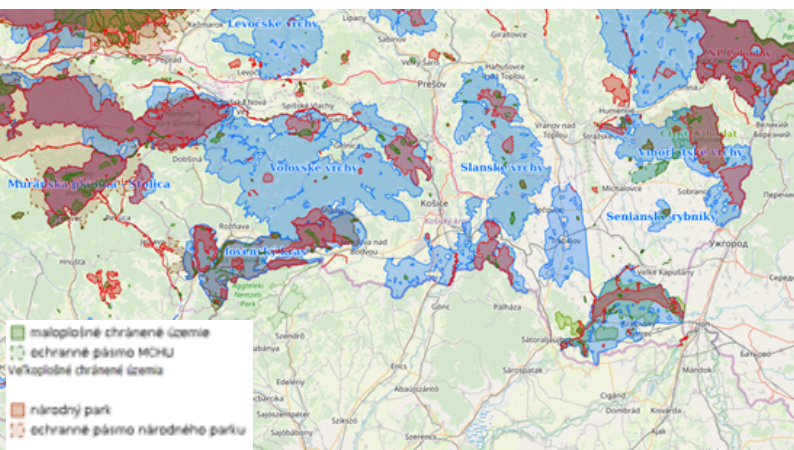
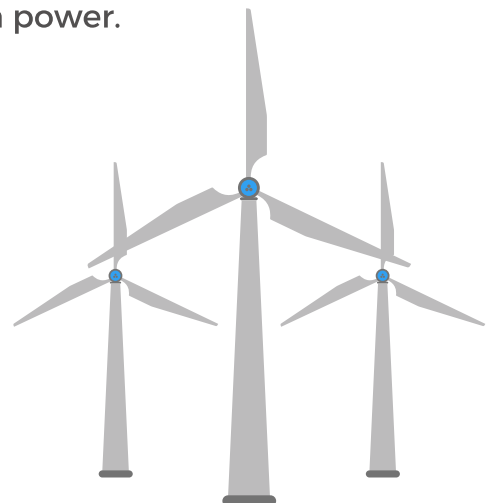


Figure: Map of environmentally protected areas

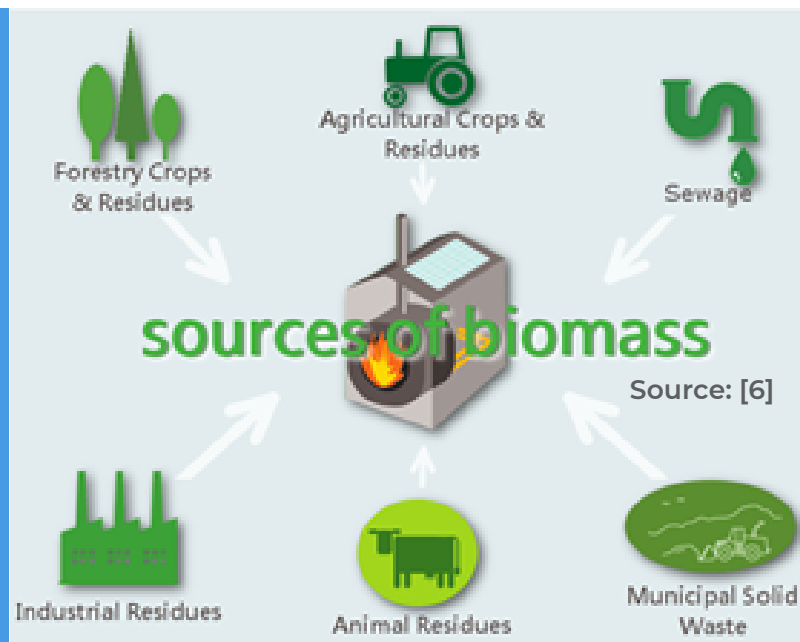
Source: [4]

Another limiting factor of wind turbine deployment is the residential areas, where the minimum distances of wind turbines from residential areas should not be less than 7 times the height of the turbine, approx. 700 - 1000 meters.



[4] <http://maps.sopsr.sk/>
[5] <https://globalwindatlas.info/area/Slovak%20Republic>

Single small turbines below 100 kW are typically used for residential, agricultural and small commercial and industrial applications. Small turbines can be used in hybrid energy systems with other distributed energy resources, such as microgrids powered by batteries and photovoltaics. These systems are called hybrid wind systems and are typically used in remote, off-grid locations where a connection to the utility grid is not available.



Hydrogen production from Biomass

Biomass is organic material which includes agriculture crop residues, forest residues, special crops grown specifically for energy use, organic municipal solid waste and animal waste. This renewable resources can be used to produce hydrogen, along with other by-products, by gasification. Biomass gasification is a technology pathway that uses a controlled process involving heat, steam and oxygen to convert biomass to hydrogen and other products, without combustion. Because growing biomass removes carbon dioxide from the atmosphere, the net carbon emissions of this method can be low, especially if coupled with carbon capture technology, utilization and storage in the long term [6].

It is highly sufficient that for transport of biomass to energy centres zero carbon footprint ways will be used such as railway wagons or in future hydrogen trucks, garbage trucks etc. It will change mind of residents looking for garbage car where waste can transform to more clean energy and has positive effect.

Fuel cell and hydrogen technologies are offering a pathway to turn environmental hazards into clean and renewable power instead, including by generating hydrogen, which can then be used in a stationary fuel cell or for other purposes, such as transportation. The fuel cell industrial products include different types of fuels cells that are able to run off various fuels and feedstocks, including methane, pure hydrogen and waste gas from biomass sources, installation of fuel cells and hydrogen generation equipment at wastewater treatment plants, generation of electricity and hydrogen from a landfill. Instead of flaring or combusting the methane, a cleaning unit is attached to the fuel cell.

Hydrogen production from Geothermal

The conditioning removes the impurities, then send the methane into the fuel cell, where it produces clean electricity that is prepared into the grid.

The technology development and cost effectiveness of biomass gasification is a key factor for the utilization of biomass for hydrogen production. As the biomass as a source of energy is used for the heat production (district and central heating system), new energy sources will be operated as an energy centres for processing the biomass of different origins and will combined sources for the heat, electricity and hydrogen (or other green gas). Also, these energy centres should be built and operated close to the heat consumers so the losses on distribution will be mitigated. Hydrogen as by product will be the balancing factor and will be used for energy storage.

Geothermal energy provides an affordable, clean method of generating electricity and providing thermal energy. In this regard, the use of geothermal energy for hydrogen production can prove to be effective option in the future hydrogen structure. Geothermal energy as one of the oldest sources of energy in the Košice valley is relatively easily accessible and not yet used. It is located in several locations near the capital of the region, city of Košice and is considered one of the most powerful geothermal deposits in Central Europe. The estimated energy potential is around 1 200 MWt, with 300 MWt practically being used directly. Ďurkov area as well as other geothermal areas in east Slovakia are low temperature sources, so the detail analysis of the economic and technical feasibility has to be provided.

The ongoing requirements on communal and industrial waste processing and separation (no landfilling, limited potential of waste incineration) will create a need to build up several such a "Biomass energy centres" across Košice region, preferably close to the municipalities or heat consumers.



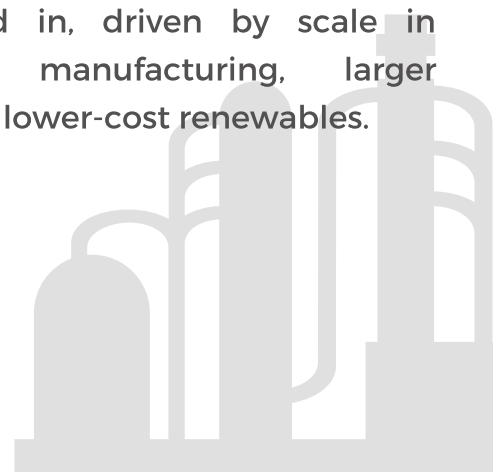
Considering the current prices of the technology and electricity in one hand and hydrogen prices on the other, the potential seems to be limited. However, calculating the long-term analysis of the electricity and hydrogen prices, in decade, green electricity production from geothermal source will be feasible. Some of this energy could be used in a geothermal power plant to power the electrolyzers that will produce hydrogen and hydrogen station and storage tanks could also be available. In its pilot demonstrator phase, it could be combined with other European projects (hydrogen trucks, buses, airport support cars, bikes, etc.)

The hydrogen produced by electrolysis (electricity and water only) consumes approximately 50 kWh of electricity per kg of H₂ produced. Geothermal energy is currently being used in Denmark and Iceland for hydrogen production. According to some sources [7], latest technologies of H₂ production and its liquefaction using geothermal steam can lead to 19% lower production costs.



Hydrogen import

Even though all the renewable energy sources will be utilized in Košice region, the amount of hydrogen required to meet the demand for this commodity in industry, energy and transport sector will be higher. Košice region has limited potential for utilization of the renewable energy sources and at the same time consumers such as US Steel or transport sector will need large amount of hydrogen for its production processes if decision will be made. Regions which have access to renewables from both wind and solar at low LCOE such as Russia, Ukraine, Romania, Bulgaria enables high load factors for hydrogen production through electrolysis. They thus offer optimal potential for producing renewable hydrogen at minimum costs. Under these optimal conditions, hydrogen production could become available at costs of about EUR 2,50 per kg by the early 2020s, declining to EUR 1,90 per kg in 2025 and perhaps as low as EUR 1,20 per kg in 2030. This is well below the average for grey hydrogen, and even close to parity with optimal grey hydrogen costs in 2030 if CO₂ costs are factored in, driven by scale in electrolyser manufacturing, larger systems and lower-cost renewables.



For production of hydrogen using low-carbon technologies from natural gas with CCS, two technology options exist: steam methane reforming (SMR) and autothermal reforming (ATR). SMR combines natural gas and pressurised steam to produce syngas, which is a blend of carbon monoxide and hydrogen. Providers can easily capture about 60 % of the total carbon by separating the CO₂ from the hydrogen; the additional must be extracted from the exhaust gas, which is relatively expensive today, allowing for up to 90 % of total capture rate. ATR combines oxygen and natural gas to produce syngas. This process can easily capture up to 95% of CO₂ emissions. ATR technology is typically used for larger plants compared with SMR technology

Coal gasification in Russia and Ukraine produces hydrogen by reacting coal with oxygen and steam, which like the ATR plant, allows for a relatively easy capture of CO₂. However, the coal gasification plant emits about four times more CO₂ per kg of hydrogen produced than the ATR plant, increasing the amount of carbon that must be transported and stored.

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Košice region and Slovakia it-self have limited resources to produce low-carbon or renewable hydrogen at scale locally. On the other side, regions have ambitious decarbonisation policies plans that will require hydrogen; if local production cost is too high or unable to meet demand, we may become importers of hydrogen. Next figure (Hydrogen production across regions) shows where hydrogen from reforming plus CCS as low-carbon technology and renewable hydrogen from electrolysis is projected to become cost competitive.

Grey hydrogen, the most competitive option today, should be fully phased out by 2050 to meet the 2nd degree target. It is expected to become increasingly less competitive over time as the cost of CO₂ emissions increase, reaching cost levels higher than all low-carbon alternatives prior to 2040.

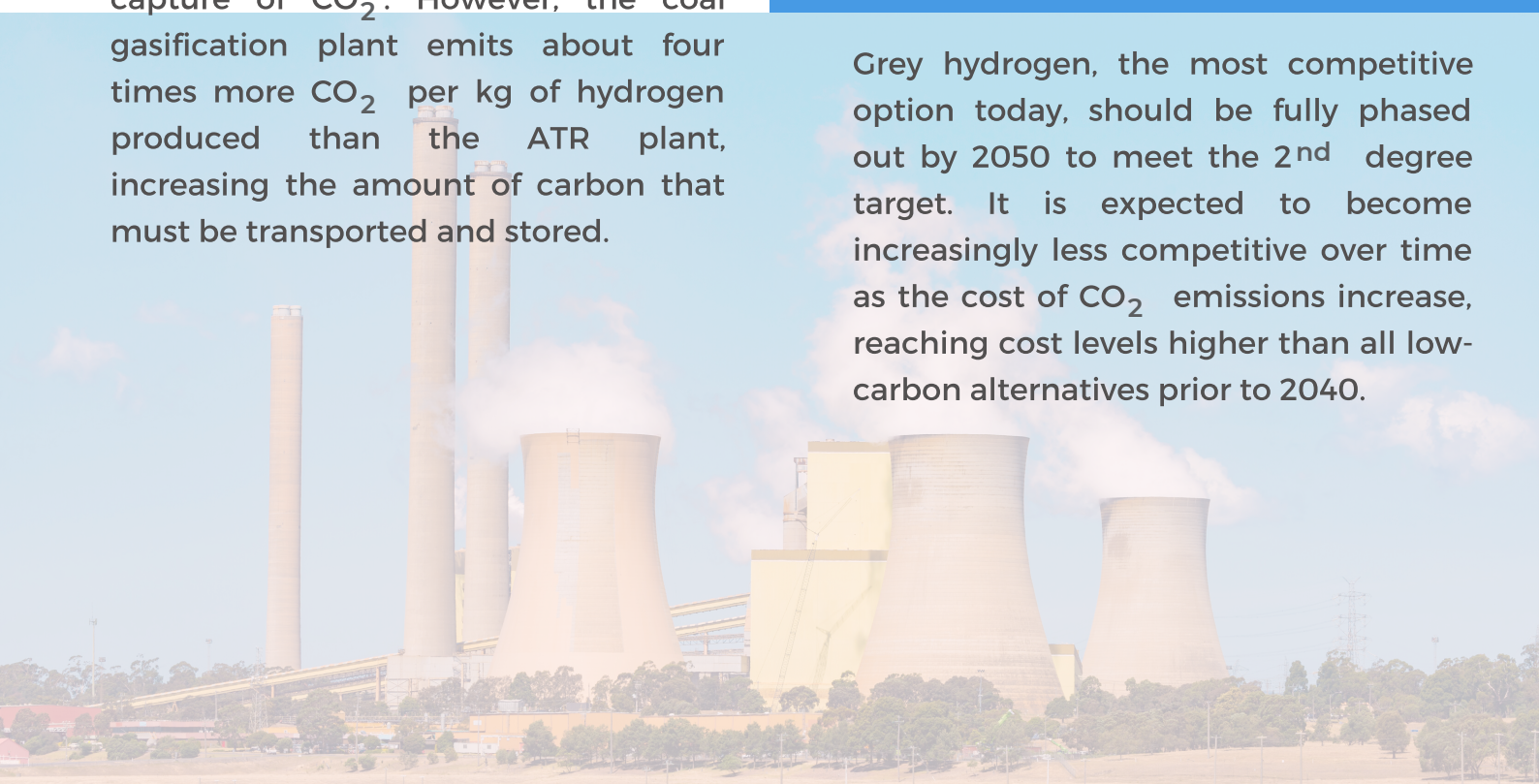
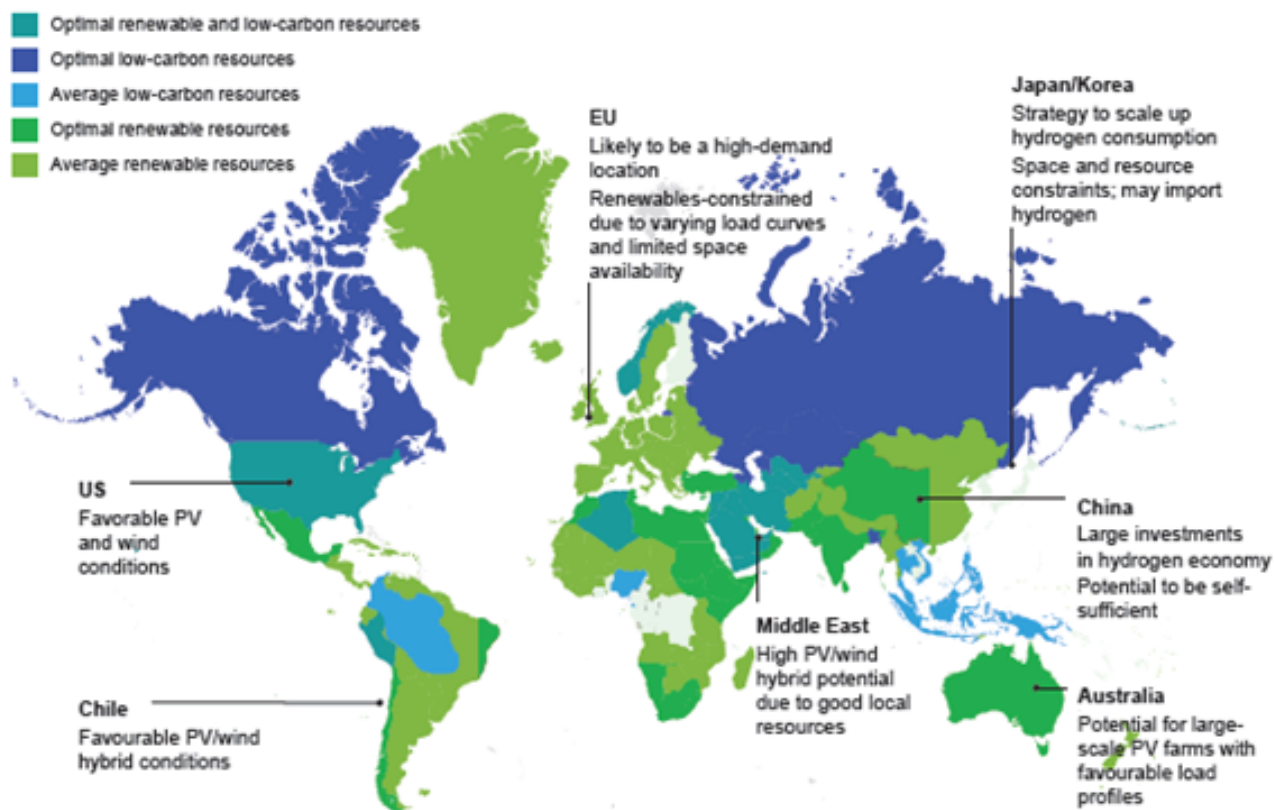


Figure: Hydrogen production potential across regions

Best source of low-carbon hydrogen in different regions



Demand centres, e.g. EU, North-east Asia, are often constrained for resources, and may not be able to self-supply hydrogen.

Countries with complementary load profiles of wind and PV can produce renewable hydrogen at very low prices.

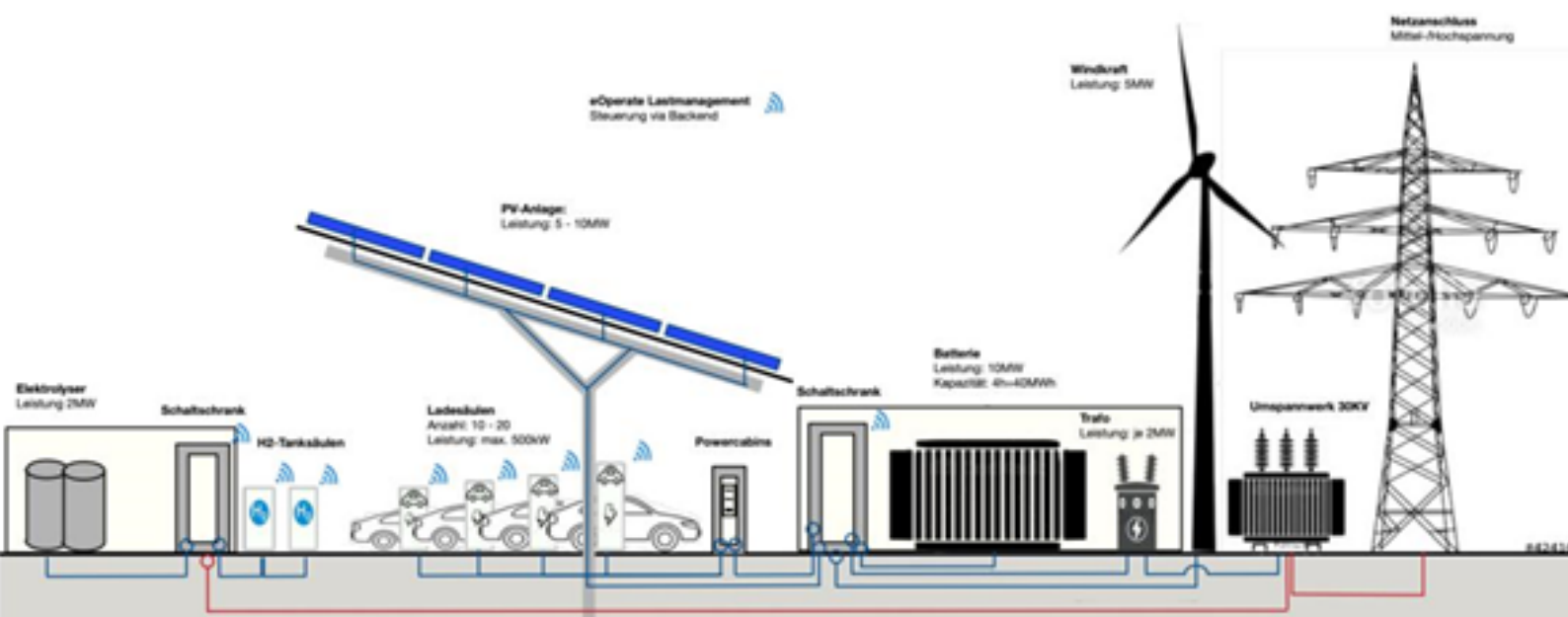
Regions like China and the US are both demand centres and have favourable RES.

Source: [8]

Košice self-governing region with its strategic position on the border with Ukraine may play a major role of import of green and low carbon hydrogen in Slovakia as well as EU. Hydrogen as an energy carrier could partially replace the natural gas in the transit and distribution gas system. The other form of distribution of hydrogen includes the liquid organic hydrogen carrier (LOHC), which is typically transported on long distance by trains. With the decreasing role of coal in energy and industry sector in EU which is in line with the decarbonisation targets, Intermodal terminal in Čierna nad Tisou will have to be adopted to change from coal to LOHC transport.

Hydrogen as a universal energy carrier, plays an important role in sector coupling and can be a tool to deliver ancillary services. Currently in Košice region, these services are mainly provided by EVO Vojany, enormous potential has US Steel s.r.o., Chemko a.s, Duslo a.s. and other large enterprises but they need to invest in innovations together with EU support. Most of these energy sources use as a primary energy sources fossil fuels or carbon-intensive materials. In order to achieve decarbonization goals until 2030 and zero carbon economy in 2050, the use of hydrogen in providing ancillary services for the grid system and required amount of energy for emission-free transport would be the one of the several alternatives.

[Hegeduš]





HYDROGEN +

STORAGE AND TRANSPORT

CHAPTER 2

Due to the fact, that hydrogen atom is smallest atom in periodic table, in the form of molecule as gas, it tends to leak and can embrittle some metallic part of systems such as pipelines, valves etc. In liquid form safety issue arising due to the low temperature, always is cold enough to freeze air and ice is often formed on components, later on causing corrosion. The decision in policy roadmap was already chosen, but care is needed on materials selection to secure compatibility with hydrogen. One of the most promising pathway contributing to development of hydrogen is electrochemical storage from renewable energy.

Hydrogen technologies are promising alternative in clean energy transition, hydrogen is attractive fuel for heavy vehicles, trucks, buses, trains, robots, drones etc. powered by fuel cells but hydrogen transport and storage still presents challenges.

Although database for materials already exists for many materials in high pressure hydrogen applications, not all cases includes complex data from manufacturing process such as microstructure, welding parameters, heat treatment on one side and on the other long-term experiences with corrosion and fatigue behavior is totally missing, esp. for new advanced materials. In this lack of experiences and in race in development of novel materials which are less expensive, an assistance of several universities (TUKE, UPJŠ, STU etc.), research institutes at Slovak Academy of Science hand in hand in close cooperation with industrial partners is needed [Halama].

HYDROGEN STORAGE

Hydrogen, as the lightest existing molecule has a very low density. 1 kg of hydrogen gas, occupies approximately 11 m³ at normal room temperature and atmospheric pressure. Thus, it takes up large volume at very low weight. From an energy point of view, the use of hydrogen is only effective if its storage capacity is high. Figure (Energy density per weight) explaining this phenomenon. It compares how much energy we can get from conventional fuels (gasoline, diesel etc.) and their comparison with hydrogen. It is evident that if we take 1 liter of these fuels (orange bars in the graph), the use of hydrogen is not interesting, since we get the less energy per volume.

The situation changes completely when we consider weight. From 1 kg of hydrogen we get significantly more energy than from other sources (green bars in the graph). Therefore, when developing materials and technologies for hydrogen storage, it is necessary to look especially at how much hydrogen is capable of storage.

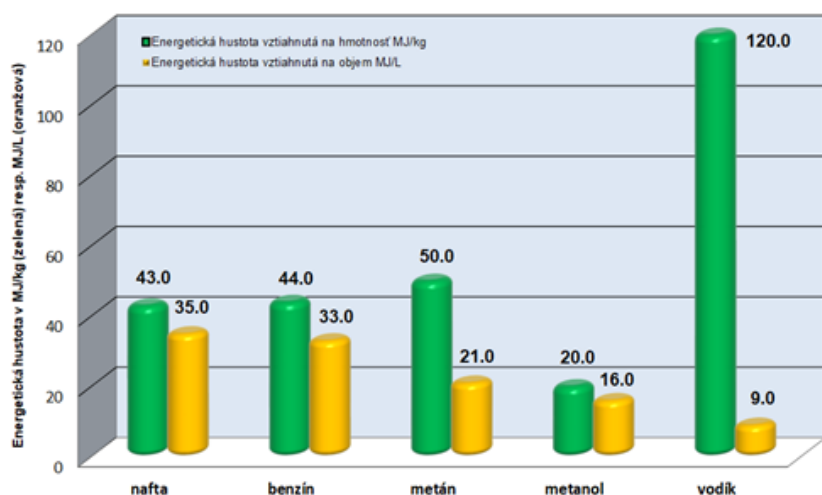
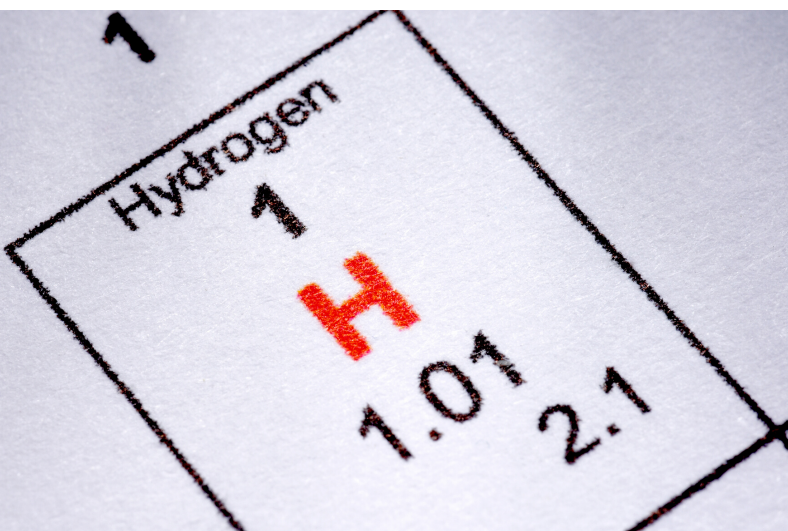


Figure: Energy density per weight

There are currently several concepts for hydrogen storage. Some have been in use for several decades, others are in the pilot stage and others exist only in lab scale. A schematic breakdown of the various approaches for hydrogen storage is shown in Figure (Hydrogen storage possibilities). None of the methods has potential to be universal and meet all the needs of a future hydrogen-based economy. More research and development activities are needed in this field and the ability to store hydrogen safely, economically, ecologically and in sufficient quantities is of major challenge nowadays.

Storing hydrogen as a compressed gas is the simplest, most natural and economical option. It is the compression of hydrogen into the pressure tanks using compressors. It is basically an analogy to how today hydrogen is normally distributed by means of cylinders. In conventional, commercially available tanks, the gas pressure is usually 100 or 200 bar (100 or 200 times higher than normal atmospheric pressure), but in the case of hydrogen the cylinders can be pressurized up to 300 bar (30 000 kPa).



Increasing the pressure goes with higher amount of gas stored, reaching also more energy density. The hydrogen density at atmospheric pressure (1 bar) at 20°C is approximately 0.084 kg.m⁻³. When the pressure is increased to 100 bar at the same temperature, the density rises to 7.8 kg.m⁻³, at 300 bar it is already 20 kg.m⁻³ and, for example, at a pressure of 700 bar almost 40 kg.m⁻³.

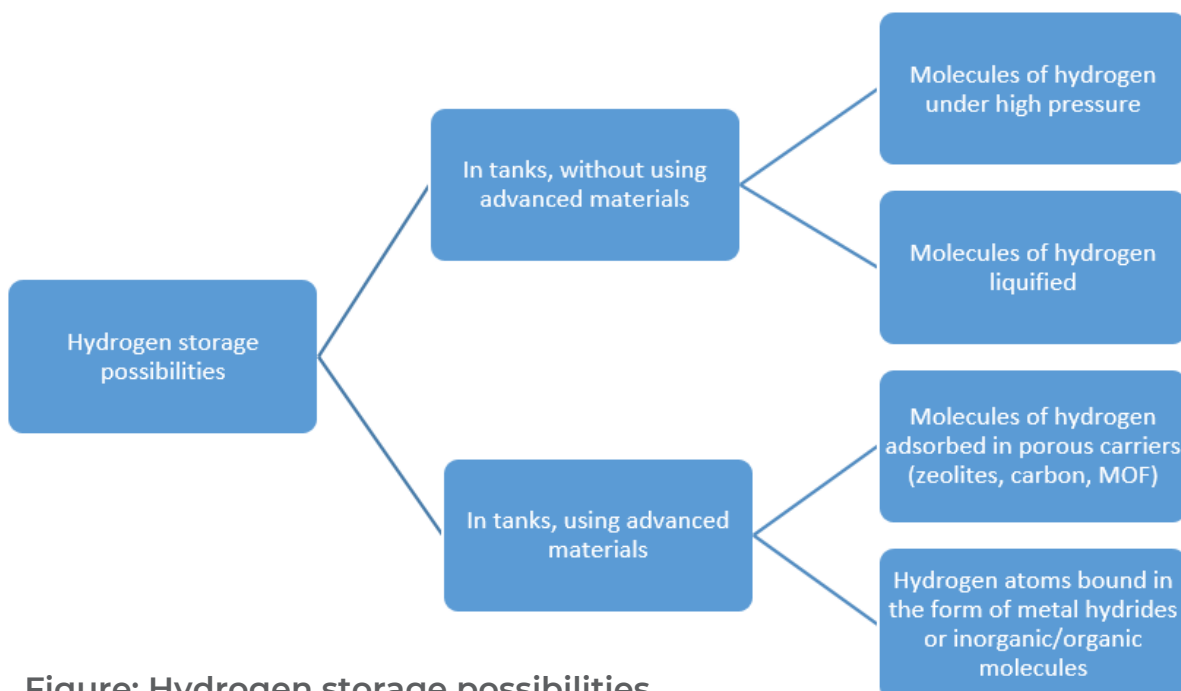
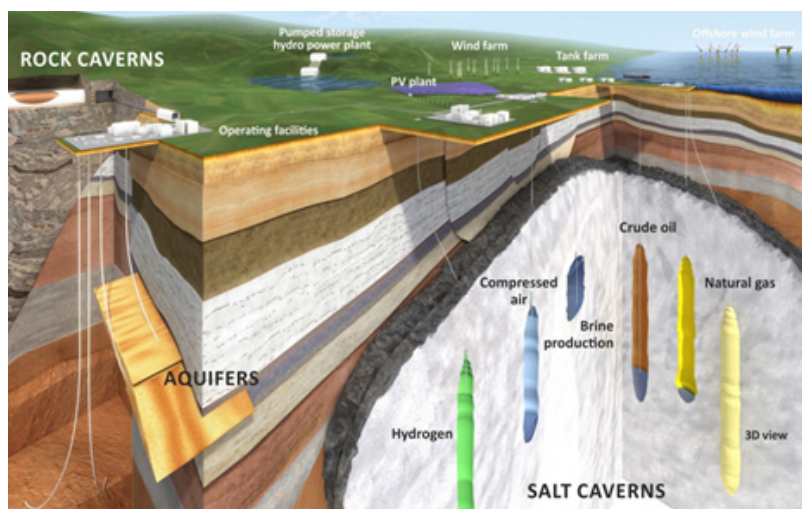


Figure: Hydrogen storage possibilities

Meanwhile, this method of hydrogen storage at high pressures has also been used in transportation in hydrogen-powered cars. An example would be cars using fuel cells. These fuel cells are powered by hydrogen stored in tanks at a high pressure of up to 70 MPa (700 bar), which, depending on the volume of the tanks used, represents approximately 5-6 kg of hydrogen. High pressure is needed to ensure high energy density and consequently the range of cars. With a pressure of 700 bar, the range of fuel cell cars is around 600 km. Commercial examples of such cars come mainly from Asia, e.g. Honda Clarity, Hyundai NEXO, Toyota Mirai but also European carmakers companies such as BMW, Mercedes etc. are also working on the development and commercialization [Zeleňák].



For the large-scale storage of hydrogen, the possibility of underground storage in underground cavities is currently being investigated (analogous to the storage of natural gas underground, in geological formations). This method of storage, although advantageous, is bound to specific conditions, usually salt caverns, which can only be found at some points on the planet.



Besides considering the safe, long-term storage of large volumes of hydrogen as energy carrier, also new insights in the generation of "green" synthetic methane by Power-to-Gas technology were intended, because some bacteria can produce methane by metabolism processes from hydrogen and carbon dioxide. But this idea in large scale needs to be economically proofed at first on small pilot projects.

Liquid hydrogen is used extensively in the space industry, for rocket propulsion, where transport by trucks to the site exists at minimum losses and are well established. In the case of liquid hydrogen, losses must be taken into account during handling (pumping) and natural evaporation. For example, in the case of space shuttles used by NASA, losses were up to 45%.



Modern liquid hydrogen tanks having a double shell have an evaporation rate of less than 0.1% per day. Several hundred tons of liquid hydrogen can be stored in such tanks. It may not be rational to assume the use of liquid hydrogen in cars or freight transport but despite energy consumption, liquefied hydrogen is a suitable form for transporting it to the place of use e.g. to refuelling stations.

Hydrogen adsorption in porous carriers is based on weak intermolecular interactions (so-called van der Waals forces) between molecular hydrogen and porous material with a large specific surface area. The key is the very high specific surface. Modern porous materials can have a surface of several thousand of m^2 per gram of carrier. Thus, the adsorption phenomenon leads to the "attachment" of the hydrogen molecules to the surface and in the pores of the porous material. In this way, hydrogen can be stored very efficiently, with high density. The amount of hydrogen molecules in the porous material may be higher using high pressure. An illustrative example of the use of porous materials for hydrogen storage is on Figure (Porous materials for hydrogen storage). If the container is filled with porous material, it is possible to inject several times more gas into the container compared to injection at the same pressure as an empty container.



Figure: Porous materials for hydrogen storage

Illustrative representation of hydrogen molecules under various conditions:

- a) Hydrogen molecules in a closed vessel at normal room temperature and atmospheric pressure
- b) Hydrogen molecules compressed in a pressure vessel at high pressure
- c) Hydrogen molecules in a liquid state
- d) Atoms
- e) Hydrogen molecules adsorbed in the porous material

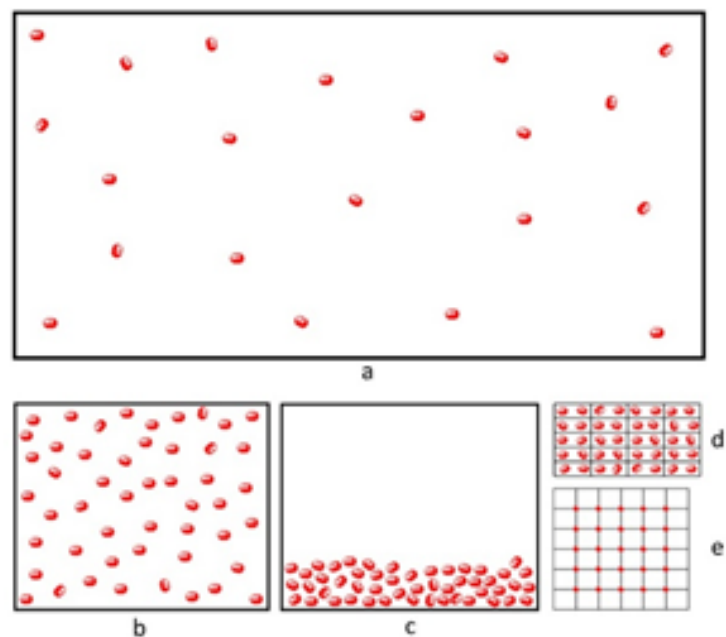


Figure: Hydrogen molecules storage

Another category of materials under investigation for hydrogen storage are hydrides (both metal and non-metal). In these substances, hydrogen is integrated directly into the structure of the solids and forms a stronger bonding interaction with the solid in the form of chemical sorption. Thus, in the preparation of hydrides, the hydrogen molecule is cleaved into atoms and these atoms are subsequently bonded by chemical (ionic) bond to a metal atom (e.g. MgH_2) or are present at interstitial positions inside the intermetallic hydride structure.

Metal Hydrides

Suitable chemistry for hydrogen storage fulfill MgH_2 and AlH_3 , which are light and contain interesting gravimetric quantities of hydrogen to be stored. They have quite different properties. The MgH_2 compound (able to store 8 wt% of H_2) is capable for reversible hydrogen desorption/sorption.

However, it has the disadvantage that relatively high energy (about $75 \text{ kJ}\cdot\text{mol}^{-1}$) is required to release hydrogen, and hence hydrogen is released from the compound at temperatures of about 300°C .

Hydrogen adsorption in intermetallic hydrides was discovered around 1960 and first applications began to be used for hydrogen storage in about 10 years later. Intermetallic hydrides have already been used commercially to produce electricity (NiMH batteries) and for drive propulsion of mining vehicles or in modern submarines.

The weight of hydrogen stored (gravimetric capacity) in intermetallic hydrides is relatively low, usually less than 2% by weight. The volumetric capacities are comparable to other materials and for some materials can reach up to $65 \text{ kg}\cdot\text{m}^{-3}$. For example, the atmospheric pressure desorption temperature is about 12°C for the $\text{LaNi}_5\text{H}_{6.5}$ alloy (1.49 wt% capacity H), and up to about 30°C for the ZrNiH_3 alloy (1.49 wt% capacity). The disadvantage of intermetallic hydrides is their high price so far.

The last group are common chemical compounds, chemical hydrides such as methanol, ammonia, formic acid or various liquid hydrocarbons [Zelevák].



We have detected that from the point of view of hydrogen storage perspective, potential within the Košice self-governing region has company Zeocem Bystré, a.s. This company is engaged in mining and processing of zeolite minerals as one of the candidate materials for effective hydrogen storage. Zeolites, which do not normally absorb notable amount of hydrogen, with a small Pd additive or ion exchange demonstrate enhanced hydrogen adsorption properties. Zeolites with Mg-ion exchange possesses a high adsorption capacity for hydrogen, up to 6.2 wt%, which is explained by its encapsulation in zeolite pores. [Zeleňák].



It is estimated that about 4.6 times more energy is needed to transport hydrogen by pipeline than natural gas. In addition, there are considerable energy losses during transport, about 10% for every 1000 km. Netherland is currently investigating the most robust and inexpensive way to transport the electricity through hydrogen molecules, to large users. Finally, it seems to be cheaper than transporting electricity via cables. TNO is already testing existed infrastructure of onshore and North Sea gas pipelines for transporting 100% of hydrogen [9].

In addition to the piping, hydrogen can also be transported in pressure tanks with pressures up to 350 bar or alternatively higher pressure. However, in the case of massive introduction of hydrogen technologies with assumed higher hydrogen consumption, such a distribution would be uneconomical. That is why all knowledge and forces must be handle to made potential distribution using pipeline infrastructure safe.



HYDROGEN TRANSPORT

Compared to transport of natural gas, transport of hydrogen through the pipeline is more complicated and expensive due to the higher energy required to push the hydrogen into the pipeline and its low bulk energy density. This requires higher gas flows. But...

[9] <https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/towards-co2-neutral-fuels-and-feedstock/hydrogen-for-a-sustainable-energy-supply/hydrogen-storage-and-transport/>


An alternative could be transport of liquid hydrogen. Although the liquefaction is a process that is time and energy consuming and takes place at a temperature of -253°C , the advantage of liquid hydrogen is high energy density and a high energy-to-weight ratio, which is three times higher than that of gasoline. Only nuclear fuel has a higher energy density [Zeleňák].

Liquid hydrogen is difficult to store due to the evaporation, but currently large-capacity vacuum insulated multi-layer tanks for trucks, wagons or ships that have a minimum evaporation are being developed. Road transport of liquid hydrogen is now carried out by tanks, which can have a capacity of more than 60,000 liters.

An alternative in near future will be the transport of hydrogen bound in the compounds, e.g. molecular hydrides mentioned above and in chapter Research & Innovations [Brestovič].

What is solution for Košice region?

A likely perspective in the development of hydrogen technologies is that hydrogen production need to be decentralized and potential of natural resources of energy must be fully used on regional basis, such as build electrolyzers in close proximity of lakes, geothermal plant to produce energy for electrolysis etc. For example, it is envisaged that the hydrogen pumping stations to be used for transport (fleet of buses, trucks, garbage cars, quadrocopters, bikes, police cars etc.) will have integrated also up-mentioned hydrogen production, whether by electrolysis of water or steam reforming, minimizing physical transport of hydrogen by tanks. Another solution is in future use existing gas transport infrastructure and in-house microgrids stations operating autonomously.



INNOVATION

Practical solutions can be reached in cooperation of universities TUKE, UPJŠ Slovak Academy of Science, where all partners using latest high-tech infrastructure at consortia Promatech - Centre for progressive materials and technologies and owners of gas transport infrastructure SPP-distribution a.s. or/and producer of freight wagons Tatravagonka a.s. Further research and development in this field is needed to help in fast and safe implementation of hydrogen technologies with high added value for region [Brestovič, Saksl, Halama].

Blending hydrogen into natural gas distribution network

Several tests conducted in western EU countries show the potential of blends with up to 20% vol. H₂ into natural gas distribution. Major restrictions for higher admissions are end-use appliances and safety characteristics of

the mixture of two gases (methane and hydrogen), which may differ from the individual characteristics of those two gases. Other restrictions are steel pipelines, where hydrogen cracking may occur in material itself and in welds. Due to small molecule of H₂ there might be also higher leakage rate of pipes, welds, fixtures and fittings. On the other hand, plastic pipes (majority of local networks in cities) are considered being able to transport 100% hydrogen (and therefore any mixture with methane), making the opportunities for future transport of renewable gases more realistic.

However, there should be a comprehensive testing and demonstration on the real-world infrastructure conducted first to verify the outcomes of the foreign experience and second to raise the public awareness and obtain general acceptance of the future users of safe, clean and sustainable energy.





HYDROGEN +

METALLURGY

CHAPTER 3

GREEN STEEL

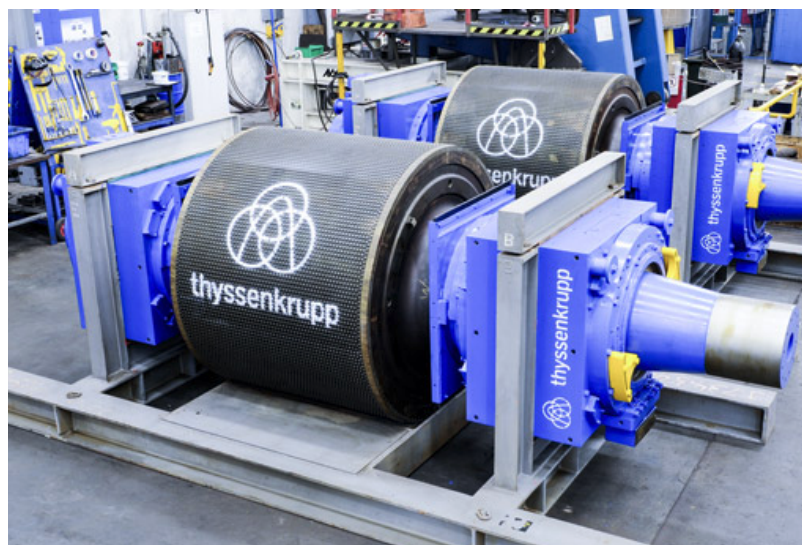
There are already technologies on the market that use hydrogen for production of metals, most often in connection with the production of steel.

So called MIDREX and HYL-based processes are gradually being developed and refined, utilizing H₂ and CO-based reducing gases made from reforming of natural gas. The aim of the new technologies nowadays is to increase the proportion of hydrogen (about 60-70%) in the synthesis reducing gas up to the use of pure hydrogen (99.9%) in the reduction process of iron ores and pellets.

The steel made by old-fashioned traditional way is based on operation of blast furnaces (BF) and basic oxygen furnaces (BOF) emitting around 1.8 tons of CO₂ per ton of steel compared to the scrap-based route based on the operation of electric arc furnaces (EAF) emitting 0.3 tons of CO₂ per ton of steel. Another option is to use direct reduced iron (DRI) technique with emitting about 0.6 tons of CO₂ per ton of steel. But due to the limited availability and quantity of suitable scrap and also some well-known problems with replacement of coke with biomass, development of carbon capture storage technologies (CCS) become very high relevant and actually is under observation.



One of elegant carbon capture solution is algae-fueled bioreactor which soaks-up CO₂ 400x more effectively than trees. Through the photosynthesis process, the aquatic plant algae soaks-up CO₂, water and sunlight to produce energy. Naturally, these type of plant use this energy to multiply grow and later on convert in other form of energy. Scientists have been experimenting the ways to capture CO₂ and convert it into biofuels instead.



It is clear, that metallurgical industry is facing dramatic energy transition and only way is to researching into practical ways of reducing CO₂ emissions by available renewable energy resources. One of example is now under realization as part of H2Future project in steel plant in Linz, Voestalpine in Austria. Here, the proton exchange membrane (PEM), large-scale 6 MW PEM electrolysis system was installed and operated. In this project global industrial partners cooperate closely with University research centers and study the replicability of the experimental results on large scale in EU28 model for the steel industry.

What is solution for Košice region?

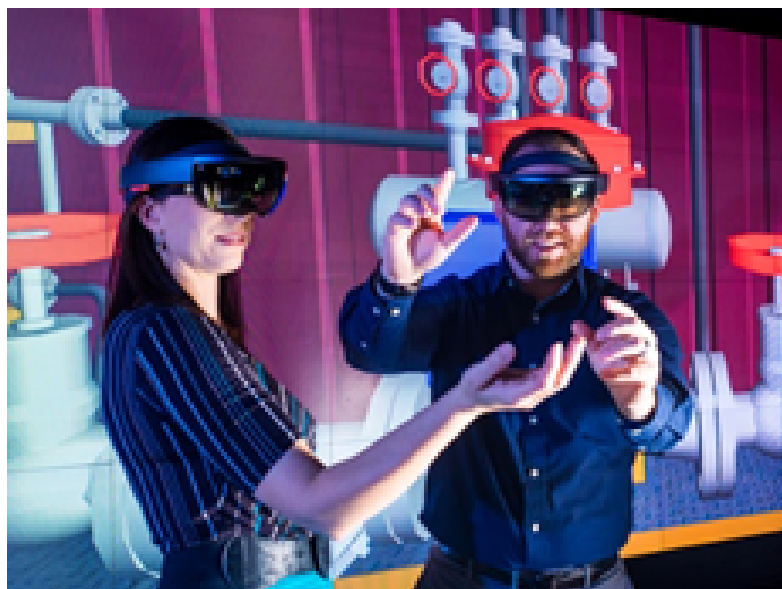
From the perspective of the Košice self-governing region in fulfilling ambitious climate plan it is critical that also global steel maker company US Steel s.r.o. will go foreground with ambitious plan implementing massive innovations, partly in production of steel which is very costly and has higher investment risk but also in energy balance, using renewable sources, battery storage together with replacing carbon sources and in no alternative ways, there is a need to apply effective carbon capture processes. Steel sector pay enormous budget for CO₂ emissions and hydrogen technologies is reliable for them and University partners through several EU innovative projects. One of existing solution is using electrolyzer systems such as special one for steel companies with power of 1,2 MW (fy. Salzgitter).



Demonstrator projects and pilot studies for production of fossil-free steel were carried out in steel companies with high innovative drive force across Europe, such as in Sweden (project HYBRIT) and up-mentioned project in Austria (H2Future). The main aim is to replace coking coal, traditionally needed for ore-based steel making, with hydrogen.

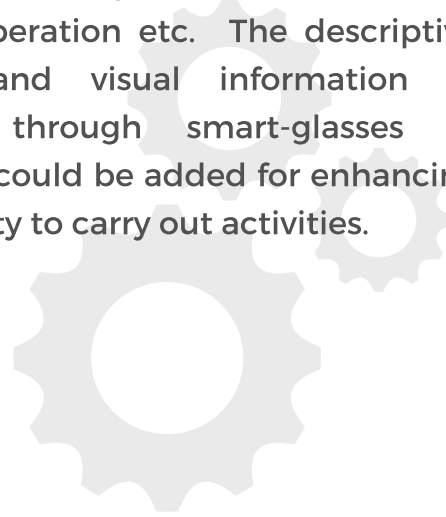
However, the development of these technologies depends on their economic demands as well as the companies innovation policy. From the point of view of these technologies, it is ideal to produce hydrogen at the point of consumption, if transport and storage will be locally accessible and standard.

Based on information in next chapter of Hydrogen+ **Nuclear and Chemical Industry**, another example is using energy from nuclear power plant for production of hydrogen followed by using hydrogen for direct reduction of iron ores. This mode is already running in fast developing countries such as India and China. The innovative process is so called “Sulfur-iodine” process and would be considered for green production in metallurgical industry to reduce ores in the far future.



Training in topics such as simulations of processes, prediction of efficiency of processes and safety issues related to hydrogen tech applications is of high importance. In cooperation with one start-up company at University Science Park at TUKE we plan to prepare training course for students, operators and new hydrogen engineers using model situation based on Virtual reality.

It provides enhanced situation awareness to them directly on virtual construction sites during simulated accidents of part of system, potential failure of components and realize service operation etc. The descriptive textual and visual information to trainees through smart-glasses or headsets could be added for enhancing their ability to carry out activities.



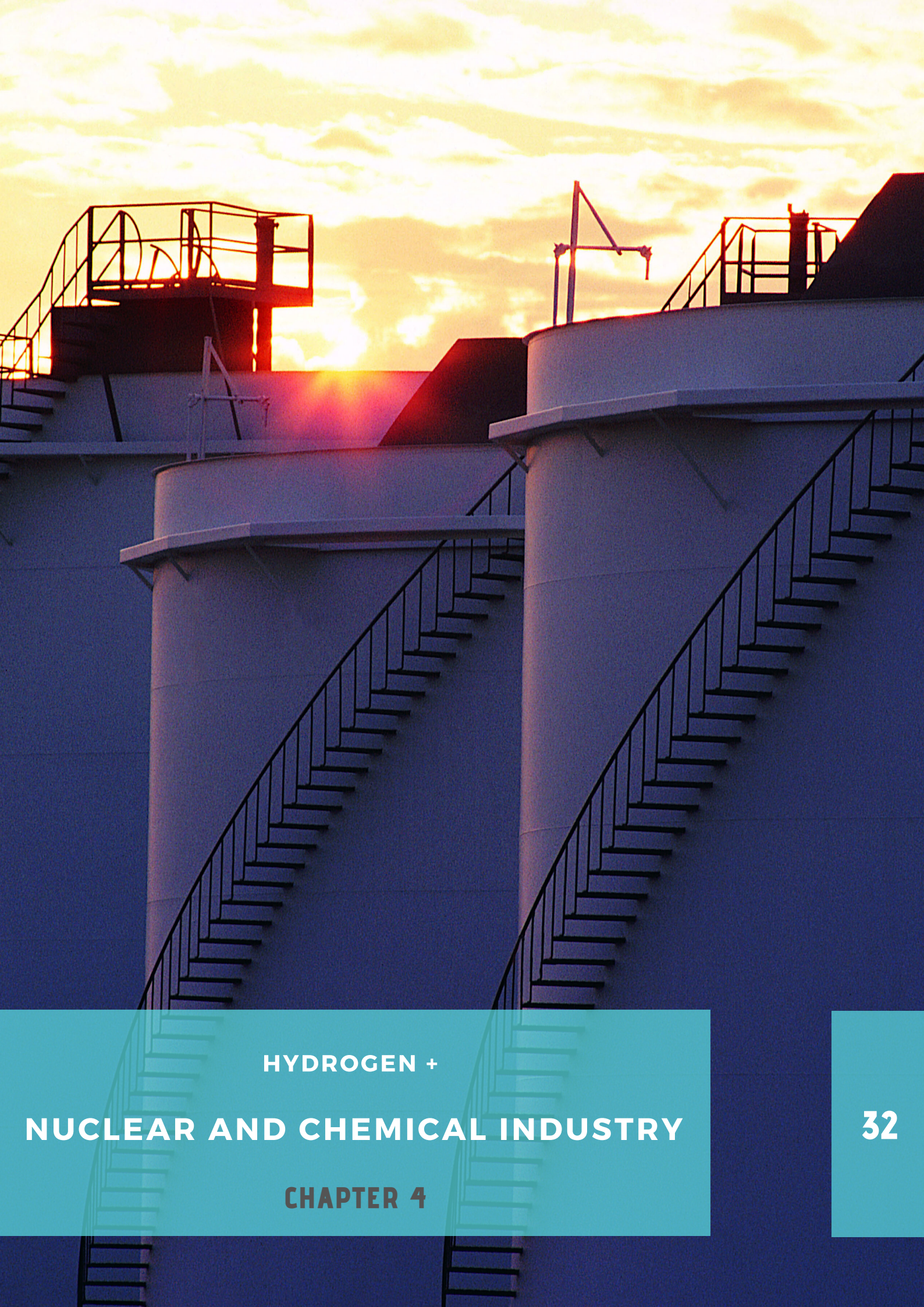
Digitalisation and next generation of hybrid metallurgical engineers

Each new massively commercialized technology need to be safe. We see that also latest IT technologies such as augmented and virtual reality (VR), artificial intelligence (AI), resp. machine learning will improve training process of new hybrid engineers.

Another way how to attract and effectively learn young generation is to use humanoid AI robot equipped with terabytes of information on hydrogen technologies, theory behind, applications, manuals, legislation etc. This approach shall be used in learning process on different grade level of schools, from basic schools, secondary grammar schools, Universities but also on expert forums, scientific events such as workshops and conferences to interact with participants and collecting and answering questions, practising questionnaire with immediate analysis etc.

Digitalization by using artificial intelligence, machine learning, augmented and virtual reality for training has special importance in metallurgical sector using hydrogen technologies and can attract young generation of future engineers in new low-carbon era. But the potential is enormous in application of hydrogen technologies also in others areas across industrial sectors [Halama, Novákova].





HYDROGEN +

NUCLEAR AND CHEMICAL INDUSTRY

CHAPTER 4

NUCLEAR AND CHEMICAL INDUSTRY

Many running projects across Europe aimed at demonstrating the possibilities of hydrogen production and applications. What is interesting about these projects is that they prove that a hydrogen-based economy produced by renewable energy sources is feasible and therefore the future of the hydrogen economy lie on decreasing costs of these technologies. Many applications are already working and under improvement. Nowadays, hydrogen is used primarily in the chemical industry for the production of ammonia, methyl alcohol (CH_3OH), nitric acid (HNO_3), hydrogen chloride (HCl) and in the petrochemical industry for oil refining.

Currently, up to 93% of the world's hydrogen is thermochemically produced from fossil fuels (mainly natural gas and coal) that contain hydrocarbons. Approximately 3% of hydrogen is produced from biomass and waste gases. Water electrolysis currently produces about 4% hydrogen (2020). Expect for the thermochemical processes, steam reforming is the most commonly used for the production of hydrogen, which consists of cleaving (reforming) hydrocarbons from fuels by water vapor, oxygen and air.

Hydrogen production

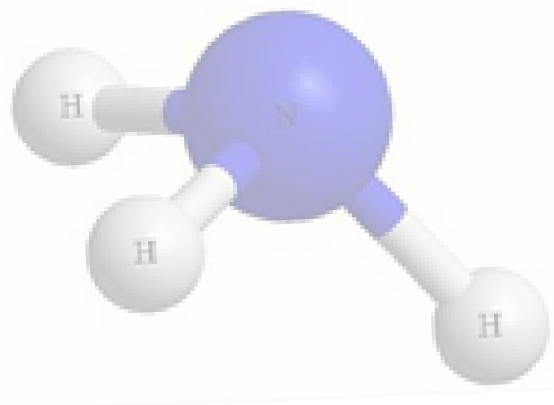
93% fossil fuels



4% water electrolysis

3% biomass and waste gas

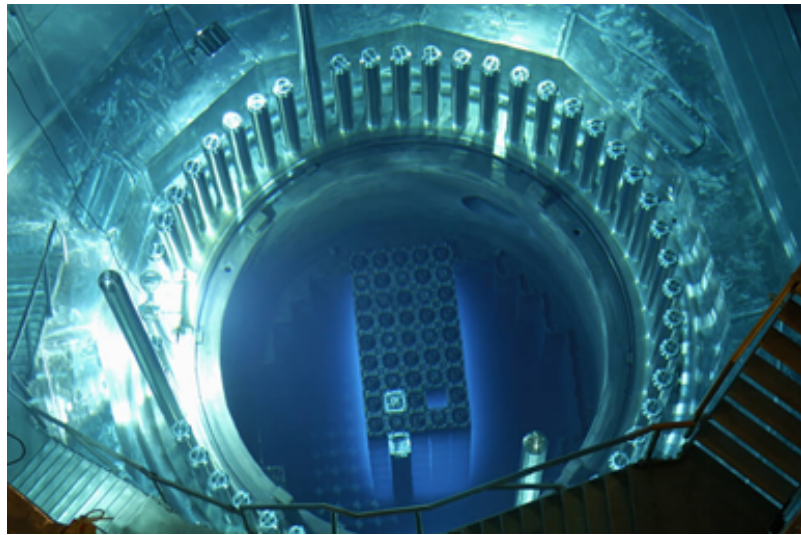
Ammonia could serve as an energy storage chemical for green electricity if required. It can be split into H_2 and N_2 and be converted back into energy in fuel cells. But if production is from carbon contain sources, also carbon capture technologies must be implemented. Scientists are currently researching such a pilot plant in Germany (Univeristy in Duisburg-Essen in cooperation with company ZBT).



The potential for the use of hydrogen and hydrogen technologies exist at Chemko, a.s., Strážske as subsidiary company owned by Duslo Šaľa, a.s. In the future, the potential for reviving ecological chemical production in Strážske is outlined, where hydrogen, its production, storage and use could have an important place.

Another potential could be revived in U.S. Steel Košice s.r.o. by using grey hydrogen in reforming process to produce fertilizer for agriculture (see also chapter Metallurgy). So small scale chemical company at campus of global steel producer is effective way how to add to waste additional value in the form of new product for other sector and creates new jobs.

In Europe, first "Power to ammonia" projects started and although ammonia is not expected to be used in this stage of the project development, converting it to hydrogen fuel represents the intermediate step to demonstrate that hydrogen could be produced using natural gas. Later on by year 2030 it could be possible to produce it with sustainably produced ammonia. Ammonia can effectively serves as a storage medium for hydrogen, as super battery, which created from Slovak companies DUSLO a.s. and CHEMKO a.s. very attractive business partners for leading European companies in hydrogen economy.



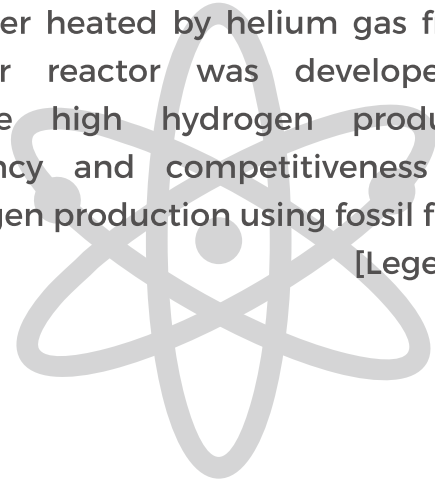
Based on predictions of world professional hydrogen alliances and associations, using nuclear power will make hydrogen production cheaper and more affordable in the future. Although nuclear power has been used for decades, newer and safer nuclear reactors are constantly being developed. Reactors of 4th Generation, which also include a thorium reactor, are currently being developed worldwide.

In this case, liquid thorium would replace the solidified uranium used in current power plants. Such a revolutionary change would mean that melting the reactors would be virtually impossible. These types of reactors have two main safety advantages. Their liquefied fuel is under much less pressure than solid fuel. This greatly reduces the likelihood of an accident, such as a hydrogen explosion. In the event of a power failure, the frozen salt in the reactor melts and the liquefied fuel is sent to the tanks where it solidifies and the cleavage reaction is stopped.

In addition to safety, thorium provides other strategic benefits. The need for huge cooling towers will be drastically reduced, so the power plants would be much smaller in size and production capacity. Based on this prediction, the construction of smaller local nuclear units can be considered in the future [Legemza].

Thermochemical hydrogen production can be efficiently accomplished by two processes: thermal decomposition of water in the core of the nuclear reactor and thermochemical decomposition (e.g. H_2SO_4) using solar energy or heat from the nuclear reactor. Hydrogen production by nuclear power is the most widespread in the world in countries that have a strong nuclear program - Japan, France, Germany, China, USA, South Korea and India. These countries using uranium reactors of 3rd Generation not only to generate heat and electricity, but also to produce hydrogen.

Prospective technologies for hydrogen production are using S-I process “Sulfur-iodine” (Japan, France, South Korea), HyS cycle “Hybrid Sulfur” (USA, China) or high temperature steam electrolysis MHR-HTSE (Japan, South Korea). Currently, thermochemical cycles based on Cu-Cl “Copper-chlorine hybrid” (Germany, USA), Fe-Cl “Iron-chlorine” (India, China) and methane reformation using HTGR steam (France, Germany) are also under development. A nuclear reactor can be used for all of these processes and are also effective for smaller production capacities. In Japan (HTTR process), a new concept of steam reformer heated by helium gas from a nuclear reactor was developed to achieve high hydrogen production efficiency and competitiveness with hydrogen production using fossil fuels. [Legemza]



The HTTR system was designed to provide approximately 4,200 Nm³/h of hydrogen production using a Ni-based catalyst, using 10 MW thermal energy.



Gas cooled fast reactor (GFR) system



Lead cooled fast reactor (LFR) system



Molten salt cooled reactor (MSR) system



Sodium cooled fast reactor (SFR) system



Supercritical water cooled reactor (SCWR) system



Very high temperature reactor (VHTR)

Water and biomass are expected to be the main sources of hydrogen in the future, with the necessary heat sources for hydrogen extraction to be obtained from CO₂ - free energy sources. Regarding the production of hydrogen in any volume and quantity, nuclear energy can play a crucial role, esp. in Slovakia, which invested into new units billions of Eur during last two decades.





HYDROGEN +

BATTERY

CHAPTER 5

BATTERY SUPPORT

In the recent past, battery and hydrogen technologies seems to be concurrent.

Nowadays many applications arising where intelligent interplay of this two technologies made products of high everyday practicality. On the way are first cars with short refuelling times and long range distance which use innovative fuel cells with battery systems (Mercedes-Benz GLC F-Cell model). Esp. in buses, heavy trucks, trains and other heavy transport without presence of one of these technologies solution is in many applications impractical. This hyphe-nation of two green technologies create strategic point in fulfilling emission free plans in mobility, heating etc.

Košice self-governing region together with support of Slovak government set up plans that plan to built Gigafactory for production of batteries. Memorandum of understanding was signed on November 2019 between Inobat j.s.a., Technical University of Košice, P.J.Šafarik university, Slovak Academy of Science and Košice self-governing region. This initiative is under patronage of Slovak Battery Alliance (SBaA) where also deployment of hydrogen technologies is one of priorities in next years.

To support strategic research and development activities, Slovak government alocated in 2020/2021 both in basic research and application research 5 millions of Euro.

[Halama, Smik]





**HYDROGEN +
RESEARCH AND INNOVATIONS
IN KOSICE REGION
CHAPTER 6**

Hydrogen storage as a key factor for the development of hydrogen technologies

Some fields of study and subjects include training in fuel cell technologies and the possibilities of using hydrogen. In order to better secure the graduates expertise, it is necessary to create new subjects directly focused on the given issue focus on education in safety issue of fuel cells and hydrogen technologies. In cooperation with International Hydrogen Safety Association direct provision of specialists for working with battery systems, hydrogen technologies is also possible by creating separate study programmes.



The storage of hydrogen in nanoporous materials is currently being investigated by Top research team in Slovakia TRIANGEL coming from P. J. Šafarik University lead by prof. RNDr. Vladimír Zeleňák, DrSc. His team focusing on research of the most promising materials for hydrogen storage.

Metal-organic networks (MOF) are solid crystalline substances that are characterized by low density (hence low weight), high porosity and specific surface area. The surface area of these substances is usually $500-3000 \text{ m}^2 \text{ g}^{-1}$, in some cases even more than $5000 \text{ m}^2 \text{ g}^{-1}$

On these materials it is possible to achieve a high weight of stored hydrogen (gravimetric amount), at pressures of 70-100 bar the adsorbed amount of hydrogen can reach up to 7-8% by weight. In the case of the most effective MOFs, such as NU-100 or MOF-210 it can reach about 15-20 weight percentage (wt%). However, these capacities are still only achieved at low liquid nitrogen temperatures (-196°C). Gravimetric capacities decrease to approximately 2% by weight at 25°C . Therefore, current research is directed to the preparation and modification of MOF to enhance adsorption interaction. This would allow the adsorption process to be brought to normal temperatures and fully exploit the potential offered by MOFs.

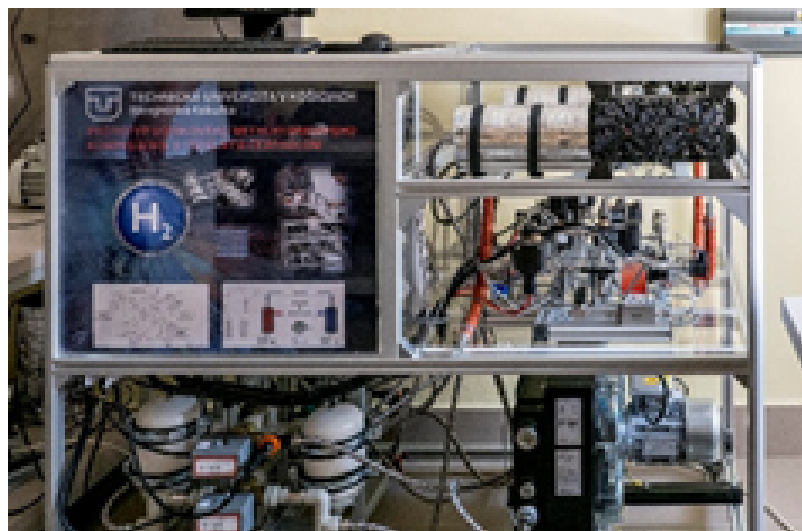
Carbon based materials

Various types of nanostructured carbon materials, such as carbon nanofibers, carbon nanotubes, nanorods etc., are being investigated for hydrogen storage. The specific surfaces of these materials may exceed $3000 \text{ m}^2 \text{ g}^{-1}$. As in the case of MOF, storage is limited to the use of low temperatures and pressures of 20-80 bar and the adsorption capacities under these conditions reach 8-10 wt%.

In addition to the up-mentioned materials another group of porous materials such as zeolites, clathrates and porous polymers are also investigated for the storage of hydrogen. However, the amounts of hydrogen stored do not yet reach those mentioned for MOF or carbon materials [Zeleňák].

Prototype of metal hydride compressor with heat pump

The Science and Technology Award 2018 for the best scientific-technical team was awarded to Assoc. prof. Ing. Tomáš Brestovič, PhD., from the Faculty of Mechanical Engineering at Technical University in Košice for the implementation of hydrogen technologies in the energy and automotive industries. His research focuses on development and application of the latest trends in the field of hydrogen and hydrogen technologies by implementing new programming techniques and simulation tools.



His team has developed unique prototype of a compressor using the chemical-thermal cycle of hydrogen absorption and desorption into the intermetallic structure of metals by compressing hydrogen at low temperature. The concept of a hydrogen compressor works on principle where the heat transport, and heating and cooling is provided by a heat pump, which results in a considerable saving of electricity and operated at autonomous control design. The control software is written in C++ in the Qt Creator environment, equipped with a touch monitor for control and visualization of measured data. The device is protected by two utility models (SK 8388 Y1, SK 8320 Y1) [Brestovič].



Prototype of hybrid hydrogen/ Li-ion battery car using fuel cell and metal-hydride materials for propulsion

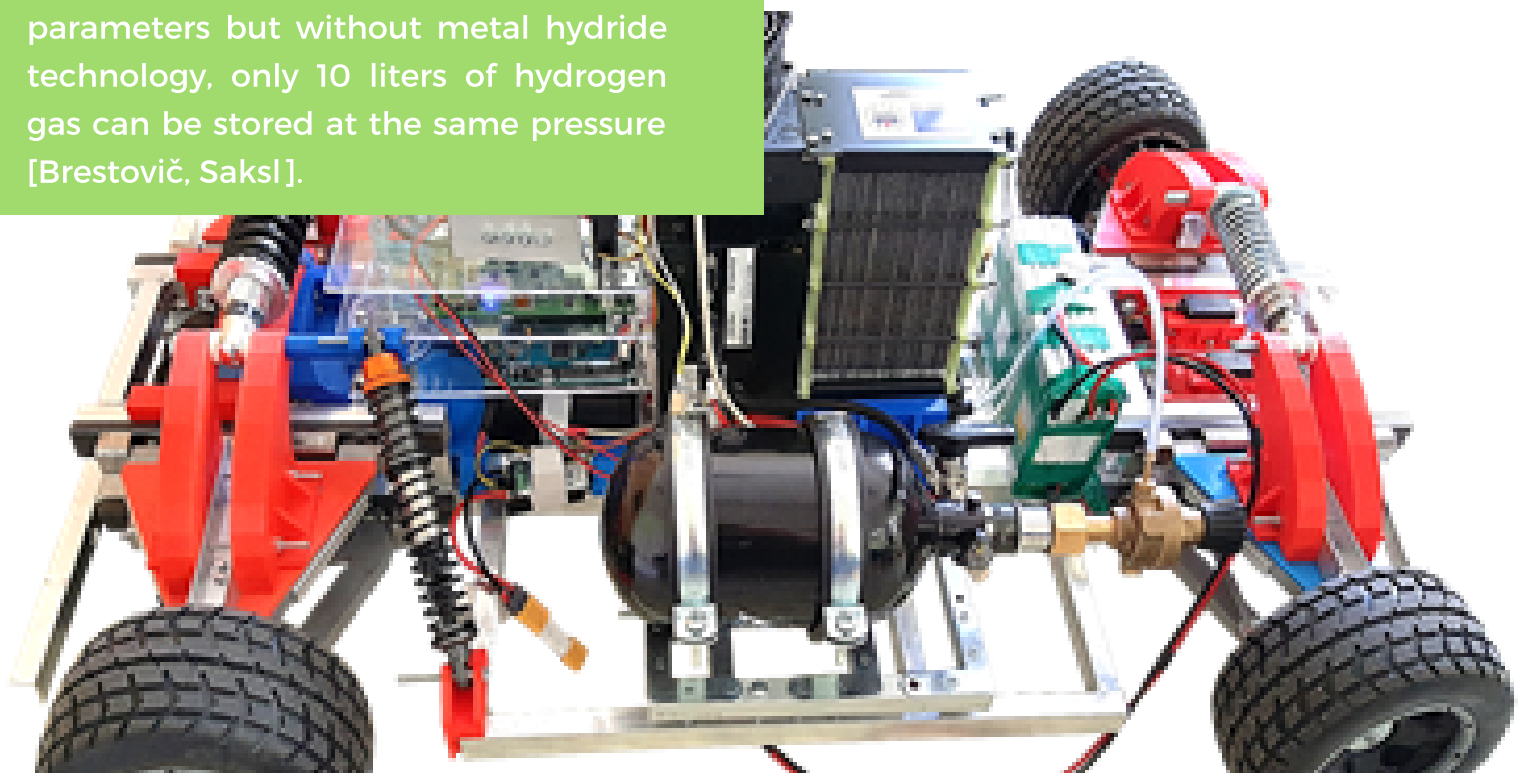
The prototype of vehicle is designed to accommodate hydrogen in low pressure metal hydride tanks (volume 1l) using 0.4 kg of LaCeNi intermetallic alloy with a hydrogen storage capacity of 42 l.

The fuel cell generates electricity from hydrogen stored in pressure tank. Compressed hydrogen must be supplied from special pressure tanks. The necessary oxygen is consumed directly from the ambient air. Only pure water is a waste product during power generation in the fuel cell.

It is possible to store 42 liters of hydrogen gas at a pressure 1 MPa at 1l metal-hydride container. This capacity allows approximately 40 minutes of vehicle operation. In a standard pressure tank with the same parameters but without metal hydride technology, only 10 liters of hydrogen gas can be stored at the same pressure [Brestovič, Saks].

Hydrogen car model was developed by Brestovič team at the Faculty of Mechanical Engineering at TUKE. The chassis of the vehicle is based on welded construction made of aluminum alloy EN AW6060 with T6 heat treatment profiles of rectangular cross-section. The arms were made using additive technology by 3D printing. The connection of the arms to the main structure is ensured by clamping elements made of steel grade E295. Suspension of the chassis used bike shock absorbers with springs tailored for the vehicle. The concept for drive force use fuel cell, electric motor and lithium-ion batteries. The mechanical concept of the drive consists of a DC motor with an output of 200 W at 12 V.

A fuel cell is a device enabling the direct conversion of chemical energy bound to hydrogen into electrical energy. Energy is released by a controlled chemical reaction of hydrogen and oxygen based on proton exchange.



The given motor was chosen to ensure the required power for the vehicle model. Depending on the drive concept, the vehicle operating mode can be selected. The vehicle can be operated as a pure electric vehicle with a set of 16Ah Li-ion batteries. Another possibility is to use the fuel cell as the primary source of electric power for the electric engine. Fuel cells are suitable for mobile applications operating at low temperatures. They also have the advantage of achieving a higher thermodynamic efficiency of the electrochemical reaction compared to the efficiency of converting the energy of a chemical bond into electrical energy by means of thermal engines. The PEM DEA 0.5 fuel cell with a power of 500 W was used to drive the vehicle model, providing a voltage of 12 to 16 V [Brestovič].

Prediction techniques

Hydrogen safety

Failure analysis

One of the alternative solutions in the distribution of hydrogen is using existing gas infrastructure. Although the hydrogen distributed in the pipeline requires perfect quality of isolations and extra tightness requirements, the highest priority must remain safety. Faculty of Materials, Metallurgy and Recycling at Technical University of Košice can offer know-how in non-destructive corrosion monitoring of gas infrastructure potentially used for fast transport of hydrogen on the site of interest and safety issues join with

diffusion control of hydrogen in metallic structures (Devanathan-Stachurski experiments), advanced material development and characterization, hydrogen embrittlement of steels and failure analysis. This research group lead by M.Sc. Maroš Halama Phd. has long-term experiences with failure analysis in energy sector, working on expertise and consultancies with oil & gas companies, classical power plant, nuclear plants etc. In strong interdisciplinary cooperation with other European universities his group is developing prediction models for assessment of life-time of materials using artificial neural networks [Halama] and predict physico-chemical properties of materials by using power of supercomputers via modelling of properties by quantum-chemical calculations, density functional theory simulations [Makowska-Janusik].

All these advanced techniques minimize errors in predictions, help to achieve more precise variable impact analysis of influencing factors and finally save project money (value for money) before decision what kind of costly experiment in labs to realize.



Thermodynamic models of combustion processes

Another area of expertise lead by Assoc. prof. Jaroslav Legemza Phd. from the Faculty of Material, Metallurgy and Recycling focused on development of thermodynamic models in which the areas of stability and concentrations of gaseous components (including hydrogen) during combustion or co-combustion processes (hydrogen and biomass etc.) and high-temperature sintering of iron-bearing materials. Factors that affect the amount of hydrogen during combustion and process gas formation should be optimized. His research group has experiences with in-field biomass utilization in the sintering process. Thermodynamic models were created in which the areas of stability and concentrations of gaseous components (including hydrogen) during biomass combustion and high-temperature sintering of iron-bearing materials are specified. Factors that affect the amount of hydrogen during combustion and process gas formation were also specified [Legemza].

Another expertise coming from development of model for solid waste gasification plant. In addition to the quality of the produced gas based on the composition of the input waste, whose process gas was based on CO and H₂, the solution included calculations join with the flow through the feed layer.

As part of the preparation of the EU project CARBON in cooperation with 9 Slovak entities (including Faculty of Materials, Metallurgy and Recycling and Slovak Academy of Science), which are associated in the National Technology Platform for Research, Development and Innovation of Raw Materials the task was "Use of volatile substances arising from the processing of carbonaceous materials for the production of synthetic gases and hydrogen". The basic research and development framework in the present topic concerned the material recovery of gaseous components from the processing of carbonaceous materials with the aim of developing products with higher added value, not only synthetic or reducing gases but also hydrogen production.



Biomass and Carbon Fuels in Metallurgy

Jaroslav Legemza
Mária Fröhlichová
Róbert Findorák



CRC Press
Taylor & Francis Group

Future research interest at Faculty of Materials, Metallurgy and Recycling will cover also:

- Creation of thermodynamic models in hydrogen production by high-temperature technology - can be used to optimize existing technology or to develop new technology.
- Research related to the production of hydrogen from waste biomass.
- Research on carbonaceous substances for the storage and transport of hydrogen (e.g. coal, coke, electrode materials, graphite, self-baking and composite electrodes etc.).
- Research in the field of metallurgical use of hydrogen.
- Perspective electrolytic recovery of metals from an aqueous solution and from molten slag (ULCOWIN process) or iron production by direct hydrogen reduction (ULCORED, HYBRIT process. Development of a completely new technological process using hydrogen.
- Research in the field of brown coal gasification in Slovakia and production of hydrogen. This area would be worth at least an experimental study, as brown coal mining for power plants will be reduced and stopped in near future and mining companies do not have alternative production programs. The production of hydrogen from brown coal is already under way in world-wide under operating conditions.



- Effect of hydrogen in natural gas on combustion properties of mixture.
- Effect of hydrogen in natural gas on the energy intensity of transit.
- Development of burner systems for the use of enriched natural gas with hydrogen and pure hydrogen in combustion units.
- Hydrogen and its utilization in small compact cogeneration units.
- Enrichment of metallurgical flammable gases for support of hydrogen distribution in the steel plant

[Legemza, Jablonský, Džupková]

Advanced materials for high hydrogen absorption capacity

Nowadays, intermetallic hydrides are very promising composite materials from the point of hydrogen storage, often non-stoichiometric chemicals with general formula $X_aY_bH_c$ (a, b, c may not be in the ratio of small integers). They may contain two metals (X, Y e.g. TiFe) or more, one of which binds hydrogen stronger than other. Experienced research team lead by Ing. Karel Saksl, DrSc. from Institute of Materials Research at Slovak Academy of Science contributing on high-level European research on development of materials with high hydrogen absorption capacity such as TiVZrNb-X alloys (X=Ag, Ta, Hf, Mo, W, Cu, Cr, Fe, Ni). For characterization of these novel materials powerful synchrotron radiation and neutron source facilities were used (DESY Hamburg, ILL D4 Grenoble etc.) where Dr. Saksl served as Scientific Secretary of the Commission for Cooperation with XFEL since 2006.



Monitoring quality of atmosphere and water



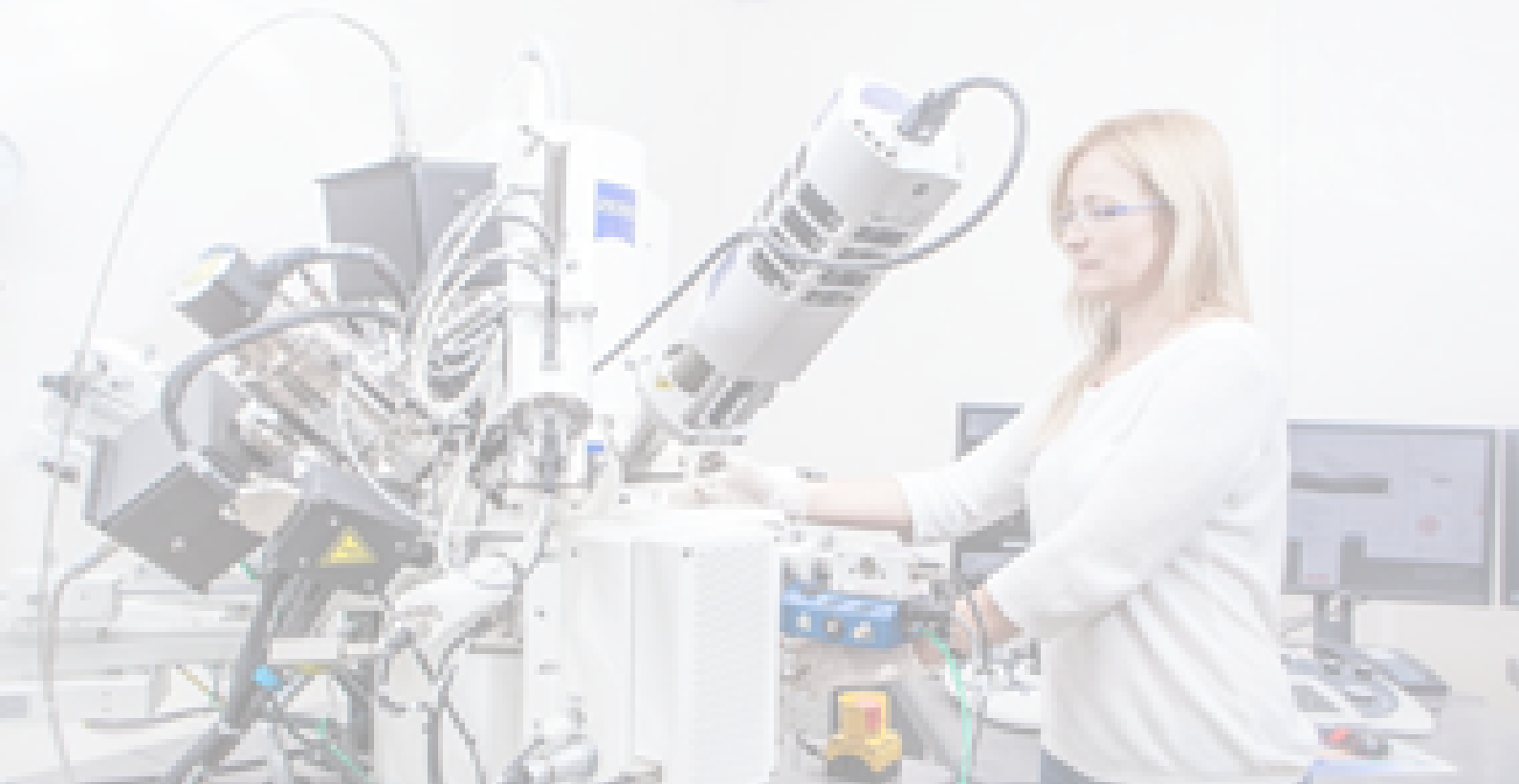
The hydrogen drone can start a new era of collecting samples hyphenated with in-situ monitoring of water quality analysis by measuring pH, conductivity, oxygen content, presence of microorganisms etc. using sensors. In one project proposal of Faculty of Materials, Metallurgy and Recycling with partner from Ukraine [Halama, Ruzickova, Slezakova, Horvathova] "Towards cross-border East-Carpathian health water chain through innovative monitoring", we set up plan to autonomous collection of water samples using hydrogen drones. Another advantage of hydrogen drones equipped with physico-chemical sensors is longer operation time, so it could be used for air quality monitoring too, which open potential in atmospheric corrosion research of metallic structures and prediction of their life-time [Halama].

Huge scientific infrastructure at PROMATECH centre

Promatech Centre as consortia of two Universities (TUKE, UPJŠ) and three Institutes at Slovak Academy of Science is centre for excellence for advanced materials and technologies. It contains huge scientific infrastructure equipped with latest sophisticated devices in 39 labs served modern material science research. It helps scientists, innovators in the field of material development, complex characterisation, covering also hydrogen topics (catalysts, electrodes, electrolytes etc.), topics in battery research (electrodes, electrolytes) including usage of nanotechnologies. It allows working scientist on improvements of materials in technical applications and has everything for achieving high quality results. It has everything for hydrogen production using nanotechnologies such as latest discovery of Prof. Zhao's team [10].

who invented a nickel-iron electrode for oxygen generation with a record-high efficiency.

The idea of his concept works on idea with relatively cheap metals such as iron and nickel. They are not good catalysts for hydrogen generation, but where they join at the nanoscale, it radically reduce energy consumption. On this catalyst there is a tiny nanoscale interface where the iron and nickel meet at the atomic level, which becomes an active site for splitting water. This is where hydrogen can be split from oxygen and captured as fuel, and the oxygen can be released as an environmentally-friendly waste. Very nice example how can Košice scientists reach comparable world-class research using 40 mil. Eur infrastructure is at Promatech centre in lab equipped with Nanospider device, which is able to do similiar concept.



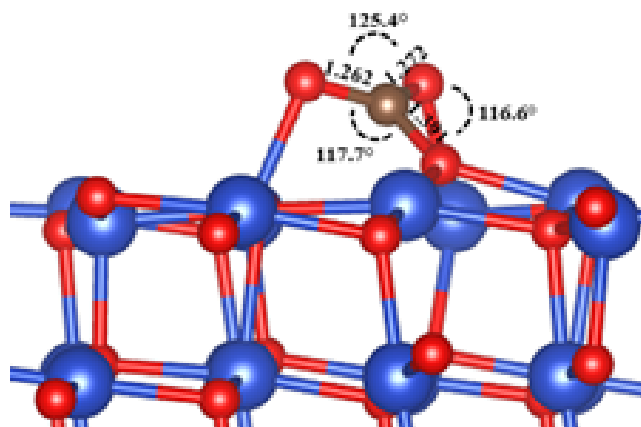
[10] Ch. Zhao, In: Nature Communications, Overall electrochemical splitting of water at the heterogeneous interface of nickel and iron oxide, 6 December 2019

Nanocatalysts for thermocatalytic decomposition of methane

Thermal decomposition of methane (TCD) is used for high purity hydrogen production where methane decomposes into hydrogen gas and solid carbon. Various catalysts are used to lower the temperature and increase the efficiency of the reaction. Research group of Prof. RNDr. Andrej Oriňak PhD. at Department of Physical chemistry, P. J. Šafarik University in Košice (Sisáková, Podrojková, Macko, Oriňaková) is oriented towards preparation of non-noble metals catalysts composed from Ni, Co and Fe due to the electron configuration and their physical properties. Conversion rate of hydrogen production with the use of above catalysts is over 80% and catalytic activity is high even at very low temperatures.

Nanocatalysts for conversion of carbon dioxide

With the use of effective catalyst carbon dioxide can be converted to different chemicals which can be used as a clean energy option, in combustion engines, gas turbines or in fuel cells and can also lead to hydrogen formation or hydrogen storage.



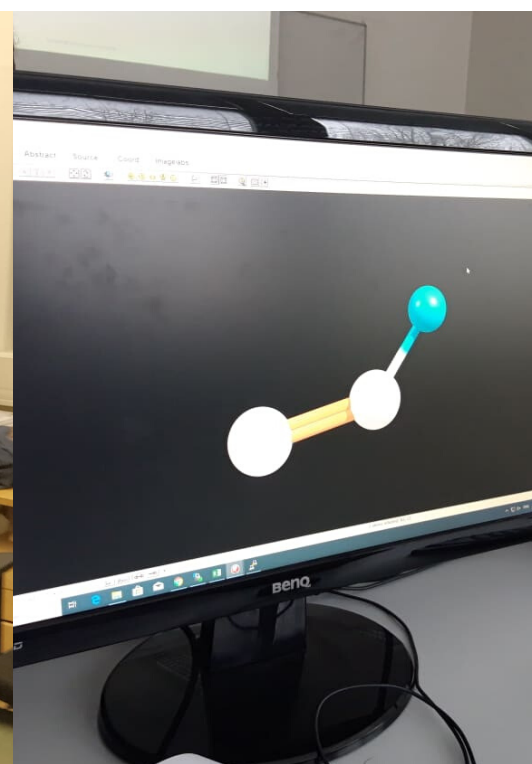
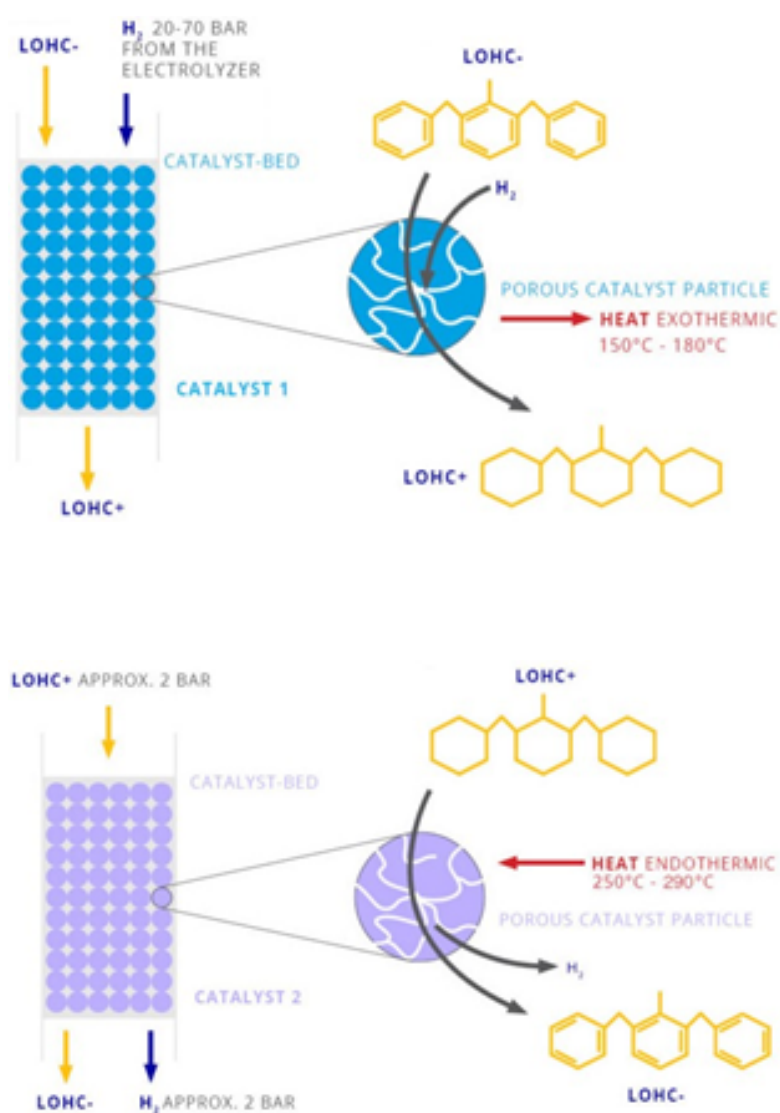
The research group prepares nonnoble catalysts composed of Cu, Zn. In their recent studies different structures of ZnO catalyst doped with Cu in biomass thermocatalytic conversion had high impact on the amount of final products, mainly alcohols and reduced the amount of CO₂. The structure of Zn, Cu catalysts is also studied in C₂O conversion to methanol.

Computational calculations of catalytic surfaces

Prof. Oriňak's Group in cooperation with Prof. Honkala's Group from University of Jyväskylä in Finland uses Density Functional Theory (DFT) for modelling of catalytic surface, optimization and simulation of thermal decomposition of methane and carbon dioxide conversion. Theoretical calculations provide details about reactions and improve the catalyst fabrication.

Catalysts for liquid organic hydrogen carriers (LOHC) system for hydrogen distribution

An alternative option for the storage and transportation of hydrogen is the use LOHC systems which consist of a pair of one hydrogen-lean organic compound (LOHC-) and one hydrogen-rich organic compound (LOHC+). Hydrogen is stored by converting LOHC- into LOHC+ in a catalytic hydrogenation reaction and it is released by converting LOHC+ into LOHC- in a catalytic dehydrogenation reaction. Andrej Oriňak's group studies catalysts for LOHC systems which would lead to high hydrogen storage capacity ($>56 \text{ kg.m}^{-3}$ or $>6 \text{ wt\%}$), very selective hydrogenation and dehydrogenation for long life cycles and low productions costs.



Design of electroactive carbon fibers modified by metallic nanoparticles as novel electrocatalysts for hydrogen evolution

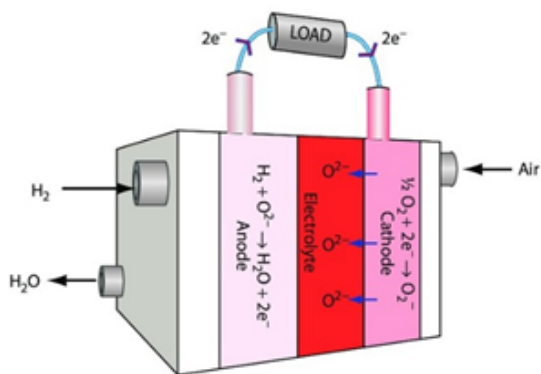
Carbon modified fibers as potential electrocatalysts for hydrogen evolution reaction (HER) were prepared using needle-less spinning technology (NLE) by research group at Institute for Materials Research at Slovak Academy of Science in cooperation with UPJŠ [Strečkova, Mudra, Dusza, Orinakova]. It was observed that the specific surface area of the fibers increased rapidly with increasing content of metallic nanoparticles and their phosphides (Ni, Co, Cu etc.) in the carbon matrix. They developed formation of large quantities of multi-walled carbon nanotubes (MWCNTs) perpendicular to the carbon matrix. The highest electrochemical activity for HER performance was found in the fibres containing the highest amount of Co_2P nanoparticles, which provided the current density of 10 mA cm^{-2} at $\eta_{10} -300 \text{ mV}$. The smaller Tafel slope and fastest HER kinetics were found in the samples with highest content of Co_2P nanoparticles and highest specific surface area.



Solid oxide fuel cells devices for hydrogen to energy conversion

A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions. There are several types of fuel cells including i) Phosphoric acid fuel cell (PAFC), ii) Solid acid fuel cell (SAFC), iii) Alkaline fuel cell (AFC), iv) Molten-carbonate fuel cell (MCFC) and v) Solid oxide fuel cell (SOFC). A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions. There are several types of fuel cells including i) Phosphoric acid fuel cell (PAFC), ii) Solid acid fuel cell (SAFC), iii) Alkaline fuel cell (AFC), iv) Molten-carbonate fuel cell (MCFC) and v) Solid oxide fuel cell (SOFC).





Among all types of fuel cells, solid oxide fuel cells (SOFCs) are one of the most attractive systems offering significant advantages for residential, large-scale transport (e.g. tankers) and auxiliary power units to large scale industrial power applications because of high efficiency (up to 70 %), reliability, modularity, fuel flexibility and environmental safety.

Research team lead by RNDr. Martin Fabián, PhD. from Institute of Geotechnics at Slovak Academy of Science is developing novel type of nanocrystalline oxide electrolytes with modified structures and morphologies and enhanced functional properties served for high-temperature electrochemical energy conversion and storage technologies. It includes preparation of complex perovskite-type oxides with designed compositions employing calcination-free mechanochemical synthesis optimized for a short reaction time, development of sintering procedures for fabrication of dense electrolyte ceramics with controlled grain-size distribution. He studied systematic analysis of relationships between composition, microstructure and ionic transport. Non-conventional mechanosynthesis approach is envisaged as cost-effective and fast route for fabrication of advanced solid electrolyte materials with controlled microstructure and improved electrochemical performance, and thus encompasses a promising pathway contributing to development of electrochemical storage for renewable energy.

Rising awareness about alternative energy sources is a major factor fostering the market growth. SOFCs are widely gaining momentum as a important source for the backup power options, primarily due to their ability to generate electricity by using a variety of fuels such as hydrogen, natural gas, and biogas. The energy crisis has been a long-standing global issue and governments around the world are supporting the technological developments to tackle the issue [Fabián].



HYDROGEN +

EDUCATION CHALLENGE

CHAPTER 7

52

EDUCATION CHALLENGE

An important part of efficient and safe use of green energy technologies in the Košice Self-governing region go only hand in hand with comprehensive education in this field at all qualification levels, including vocational education at secondary schools, universities, via trainings, courses, summer schools and raising public awareness of battery systems, fuel cells and hydrogen technologies. Quality of education is essential for next generation of engineers tackling the biggest energy challenges and facing latest improvement of technologies in renewables, batteries and hydrogen. An effective journey will go only in partnership via international networking of research intensive Universities, Academy of Science together in close cooperation with the Košice self-governing region and industrial partners with strong innovation drive.



The ideal model for education of industry required hybrid engineers would cover strong interdisciplinary skills development and training in an international level. The preparation of attractive and knowledge-based teaching process and training materials is very important to deliver it for different levels of qualification .

Early stage education

When you ask young children how they imagine the future, their answers will be full of flying cars, driverless vehicles and magic fuel. And they are not far from the truth. These little kids already know that it is time for change.



How to prepare our young generation
of students for what awaits us?

For the green future?

Do we have time?

Isn't it too late to start just now?

People are already encountering the emerging trend of new alternative fuels, which undoubtedly include hydrogen. However, these are only short reports, often without explanatory context. Hydrogen cars, trucks, trains, bicycles... But how do they work? What are their advantages? All these questions should already be explained to secondary school students. It is essential that students are led to think about technologies that will change the world once. Not to stay in the traditional and conventional learning of hydrogen as a chemical element, maximum level of knowledge ended with electrolysis in many cases. But we need to face latest research results in labs with high potential to scale it up into innovative applications, which are already in demonstrations, also those students have never dreamed.

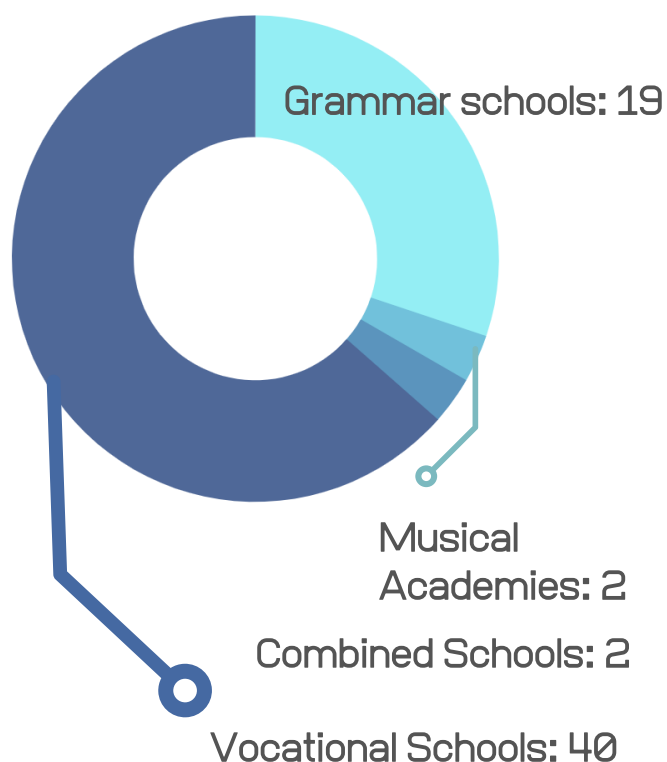


How to achieve such a change?

Crucial role will play synergic
cooperation between innovative
industry - research universities - region -
teachers clubs.

The actual secondary school system saturated with elementary curriculum without focusing on its practical use and application, requires methodical guidance and subsequent control from the administrator of secondary schools, from the Kosice self-governing region.

Košice self-governing region administrators 63 secondary schools with legal subjectivity:



The Košice Self-governing Region and its Education committee cooperates with state and self-government bodies in the field of education and upbringing, with non-government organizations and other legal entities engaged in the interest of children, youth and sport. In its founding competence, it creates conditions for education of gifted and talented children as well as children with special educational needs. The Education committee of the Košice Self-governing Region is responsible for:

- the quality of management of the educational process
- analysis
- effective planning and follow-up control

- observations in the educational process and their objective evaluation and generalization to the pedagogical council

The Educational and Organizational Guidelines for 2019/2020 issued by Košice self-governing region itself contain a number of promising points, which indicate that region is trying to think about the future, draws attention to the activities of methodological bodies in secondary schools and their mission in the area of methodology and teaching process, supports continuous education of pedagogical staff and methodologically the best teachers in order to improve the overall pedagogical process. Topics linked with energy transformation such as battery systems, hydrogen must be implemented in the process. The basic knowledge of battery and hydrogen technologies can be included in the teaching process of primary and secondary schools to an appropriate extent and in an appropriate form within the Slovak State Educational Program (ISCEC 3), where 25 to 35% part of the teaching process is available at secondary schools to implement new subjects, resp. thematic units. The extent and content of this section is determined by the school management (over 25% from own resources). Part of this capacity may be dedicated to the article whose content would be battery systems, fuel cell technology and hydrogen and the possibilities for their use.

What specific procedures should be chosen?

Whom to focus on disseminating the latest knowledge of the hydrogen technology?

Educators

After a number of interviews with secondary school science teachers, their intention and the effort to educate themselves and to pass on the latest knowledge of the 21st century to their students is very positive. On the other hand, they expect to feel strong support in their work, which should not only be based on the headmasters of their schools, but also on the role of methodological centers, associations or educational clubs. Today, information that educators acquire leads through

I.) Chemistry Teachers' Club

Educational club led by assoc. prof. Maria Ganajová, from the Department of Didactic Chemistry at the Faculty of Science, University of P. J. Šafárik in Košice. Meetings organized by this Club are already well established and held at irregular intervals. However, the interviewed teachers praised the quality of the lectures with a high impact for their subsequent work in chemistry lessons. The knowledge they brought from the lectures enriched their knowledge and outlook.

One of our recommendations is to support these lectures also from the position of KSK to introduce regularity in lectures (to determine the interveinal of meetings after agreement with teachers) and to support lecturers in their active performance at the meetings of the Chemistry Teachers Club.



II.) Methodological sheets

By introducing methodological sheets into science teaching it is possible to speed up the flow of information. After asking for a specific topic, in our case about hydrogen technologies, it is possible to provide educators methodological sheets composed of two parts:

A) Educator's part:

Basic knowledge of the topic with attached references where they can find further knowledge if necessary. This part contains recommendation on how to explain the topic to the students so that it is best understood and also suggests practical exercises on the topic.

B) Student worksheet

This part includes a graphical abstract on a top containing a simple scheme explaining, for example, the principle of water electrolysis, fuel cell in cars, renewables sources of energy supporting hydrogen chain etc. Section also includes additional questions to verify whether the student has understood the content of the curriculum, giving the teacher feedback, whether the topic has been learned effectively.

Our recommendation consists in cooperation of secondary schools with specialized departments at research Universities, Institutes that can support the topic of hydrogen technology with practical demonstrations in their laboratories. For pedagogues, we recommend using a simple model of a wind mill or better hydrogen car with incorporated reversible PEM-fuel cell (proton exchange membrane). This works in both directions: as electrolyte (generating hydrogen from water) and as source of current (for generating electricity from hydrogen). As soon as hydrogen is produced, the fuel-cell can convert it into electrical energy, to power this car.

Methodological letters should include contact with selected university teachers and researchers with whom secondary school teachers would cooperate. The close cooperation of secondary schools with Universities is recommended within the limits of laboratory and teaching at universities.

The ideal timing to propagate new green technologies are during “Day of Open Doors” at Universities and Research Institutes.

In 2018, students from Secondary School Ostrovskeho 1 won RC hydrogen car model competition in Chemnitz, Germany “Hydrogen Horizon Automotive Challenge”, in concurrence with teams from around the world. The students created the wi-fi based telemetry to communicate with the server and get data from car. So they have a constant view of how much power it consumes, what is the status of batteries, hydrogen bombs and so on. This competition expands students' knowledge in the field of renewable resources, as these cars are powered by a fuel cell in which hydrogen and oxygen are converted into electricity and this electricity is used to drive the car. This is great example how high



quality education and practical training at Secondary School can prepare motivated students later attend more specified programmes at research Universities.

Students from Košice won the world hydrogen car model competition!



III.) Following of journals for science teachers

A) **Today's school - man and nature.** This journal is published by the Association of Chemistry Teachers. The association is also active on the social network Facebook, where it enjoys great popularity. Teachers can quickly exchange advice, experience, focus on upcoming events such as open days in universities, or they can follow various science competitions.

B) **ChemZi**

The journal issued by the Slovak Chemical Society (SCHS), which is intended for SCHS members who are mainly from the university environment, therefore the topics discussed in it are conceived in a more professional and detailed way. On the other hand, it provides an excellent overview of the latest research in Slovakia and abroad, too.

Our recommendation is to provide information about the journals published to secondary school educators to learn about current topics that they can then teach on their subject. It is also advisable to use social networks where they can quickly get to the information about latest knowledge about hydrogen technologies, batteries systems of the 21st century.

Students

Today's generation of secondary school students has no problem with the availability of information. However, they need to be directed towards making the Internet an educational tool rather than a source of entertainment. An appropriately set learning process must arouse interest and curiosity in them. There is the possibility of extending education by project teaching. This way of teaching is very appropriate for extending of information that is not included in the basic science curriculum and hydrogen technologies are a very good example.

Project teaching consists of a 4-level plan:

1

IMPULSE

2

JOINT
PLANNING

3

IMPLEMENTATION

4

EVALUATION

Education Committee could take responsibility for the first level and be the initiator of project support and of initiating a project competition for secondary schools on selected topics.

Interviews with high school students have shown that students need strong motivation to perform better. Placing in the first three places of such a competition should be attractive to both students and educators.

Among the project topics, the best wayst how to include the areas of the latest 21 century batteries and hydrogen applications, letting students ponder how these kind of technologies could transform the Košice region in more healthy, low-emission environment and complement these topics with practical laboratory exercises in collaboration with universities.

Scientific communities clubs

It is necessary to capture students with a natural interest in science with modern technology appetite at secondary school level early on. As the statistics showed, the number of students applying to study vital natural and technical disciplines after secondary school is decreasing. There is a need for appropriate association of young generation in scientific club community and attract these research domains and to accelerate next generation of energy research leaders on their journey.

ERASMUS +
MOBILITY
PROGRAMME



The Hydrogen In Schools (www.HySchools.eu) project is an Erasmus+ programme that aims to deliver hydrogen education in secondary schools. Educational and online resources have been created for use in schools across the European countries, aimed at providing teachers with increased confidence to teach students about Hydrogen Fuel Cell Technology. HySchools aims to help schools enhance the quality of HFCT teaching to equip students with the future skills required by this growing energy sector.

We recommend creating a regularly meeting community of young promising scientists in the Košice region lead by top scientist. This community concept would include lectures on selected topics, provide space for demonstrating state-of-the-art science, cover competitions for secondary school teams and organize excursions and workshops. Scientific clubs can accelerate high-skilled young generation of energy research leaders. Erasmus plus programme via participating in international project HySchool can improve it.

Proper marketing and overall presentation to the modern high school generation and attractive places, gives an excellent precondition for a successful way. It goes only by implementing IT technologies to education related to energy transformation including batteries system and hydrogen with novel approaches using virtual reality, augmented reality, humanoid robots or artificial intelligence, participating in international projects such as HySchool etc.

Higher Education and new hybrid engineers

In today's European space, none of the Universities can offer a separate program for the education of engineers in latest energy systems such as hydrogen technologies or batteries system.

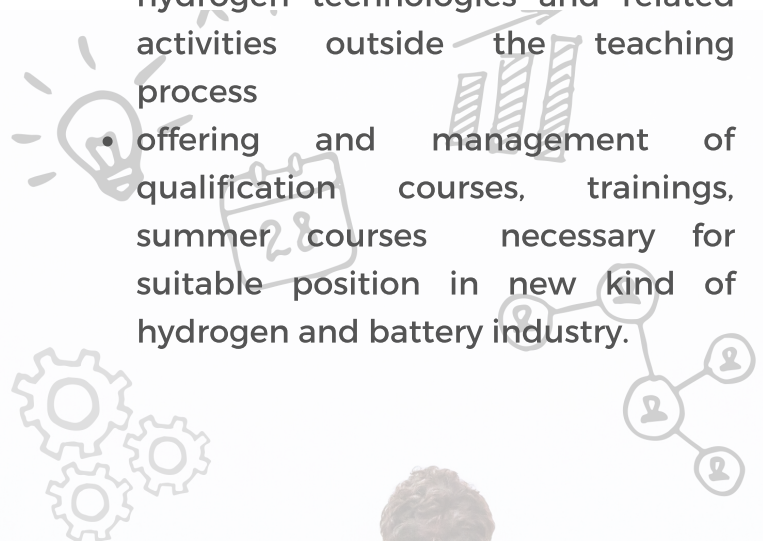
Broader training will be considered, preferably industry-linked. It is extremely important that local research Universities participate in joint European cooperation programs such as network TeachHy (coordinator University of Birmingham), which focuses on preparing materials, designing and conducting training courses for students in the field of fuel cells and hydrogen. The project consists of a core group of highly experienced institutions working with a network of associated partners (universities, vocational training bodies, industry and networks). The Teachy program offers solutions for accreditation and peer review of courses and allows institutions to offer training courses that would otherwise not be available, while providing students with access to a mix of personal and e-learning content. Each institution involved partly contributes to the overall content of the project.

The Phd students and young researcher from Kosice Universities need to be confronted with research talents abroad at world-class energy labs via short-term stage. Industry-linked education provides access to unavailable equipment, data and expertise.



TUKE and UPJŠ universities will play a key role in education in energy transformation era including battery systems, hydrogen and related technologies:

- training of highly qualified workers (Bc., Ing./ M.Sc., RNDr., PhD.)
- gaining latest experiences and up-to-date knowledge during research projects,
- mentoring young scientists, researchers and innovators,
- preparation of future teachers,
- provide mentoring in professional support to secondary school students in developing knowledge about hydrogen technologies and related activities outside the teaching process
- offering and management of qualification courses, trainings, summer courses necessary for suitable position in new kind of hydrogen and battery industry.



UNIVERSITY OF BIRMINGHAM

Being part of such a group of experienced institutions in an international network of other associated partners (universities, vocational training institutions, industry, etc.) brings enormous benefits in sharing experience. The Teachy program offers an accredited program and allows institutions to offer training courses and trainings that a single university would not otherwise be able to self-confuse while providing access to e-learning content. Each institution involved contributes in part to the overall content. That is why TUKE with UPJŠ prepared Training-Course-Summer School on Hydrogen.

Teaching in connection with hydrogen, hydrogen technologies and fuel cells at universities TUKE and UPJŠ:

- some fields and subjects include training in fuel cell technologies and the possibilities of using hydrogen. In order to better secure the graduates expertise, it is necessary to create new subjects directly focused on the given issue
- focus on education in safety issue of fuel cells and hydrogen technologies in cooperation with International Hydrogen Safety Association
- direct provision of specialists for working with battery system, hydrogen technologies is also possible by creating separate study programmes



- complex or specific one under umbrella of both TUKE and UPJS Universities with selected faculties, institutes, departments
- PhD. study programmes in cooperation with Slovak Academy of Science...

- courses, trainings for technical staff, operators and administrators creation of retraining courses in conjunction with the Office for Labor and Social Affairs
- preparation and provision of retraining of emergency services to H₂-related situations using virtual reality, augmented reality simulations.

[Halama, Orságová Králová, Baranová]





TECHNICKÁ UNIVERZITA
V KOŠICIACH



HYDROGEN+

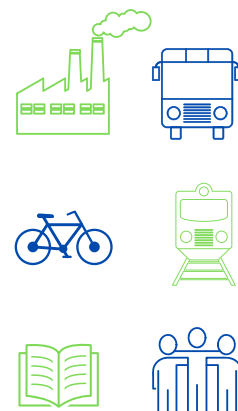
TRAINING - COURSE - SUMMER SCHOOL

TEACH₂⁴KE



I. POTENTIAL ACROSS INDUSTRIES (in cooperation with Slovak National Hydrogen Association)

Small scale electrolysis using renewable energy sources for green production of hydrogen. Transport and usage of hydrogen via natural gas infrastructure. Transport via wagons. Potential of chemical companies producing ammonia and fertilizers. Hydrogen in global steel maker company. Bike sharing, local buses, water sport scooters, tourist ship and much more. Fuel cell technologies in waste treatment. Education challenge and public awareness.



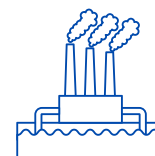
II. HYPHENATION OF HYDROGEN & BATTERY TECHNOLOGIES (in cooperation with Slovak Battery Alliance)

Unique combination as intelligent interplay between batteries and fuel cells for long range and short refueling times make usage e.g. of a vehicle of high everyday practicality. In many other applications can fuel-cell/battery system offers maximum efficiency and comfort.



III. GEOTHERMAL ENERGY AND HYDROGEN

Geothermal energy as one of the oldest sources of energy in the Košice region is relatively easily accessible. This energy could be used in a geothermal power plant to power the electrolysis systems that will produce hydrogen.



IV. LATEST TRANSPORT & STORAGE TECHNOLOGIES

Good practice in transport from highly gasified countries across Europe. European projects Black horse and hydrogen trucks in Košice region. Transport of hydrogen using wagons made by global producer. Hydrogen storage using nanoporous materials. Theory behind metal-hydride technologies etc.



V. LARGE-SCALE PRODUCTION OF AMMONIA

Large scale production of ammonia and its contribution to hydrogen economy. Ammonia as hydrogen carrier. Electrochemical oxidation of ammonia for production of hydrogen and nitrogen. Low-cost catalysts. Case study with TWI, UK.



VI. HYDROGEN IN METALLURGY

Example from Voestalpine in Linz how to fight against CO₂ emissions in greener production of steel. On-site potential at global producer US Steel Kosice. Transformation of “grey” hydrogen in steel production process into “green” one.



VII. RECYCLING & LIFE CYCLE ANALYSIS OF FUEL CELLS

Crosscutting activities. Close-loop principle. Environmentally friendly recycling of fuel-cell membrane electrodes. Life-cycle assessment of fuel cells and supporting hydrogen technologies in management processes etc.



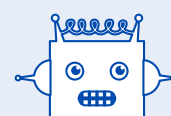
VIII. HYDROGEN & SAFETY ASPECTS

Diffusion of hydrogen in metallic structures. Hydrogen embrittlement. Corrosion monitoring of gas infrastructure. Life-time prediction using artificial neural networks.



IX. AUGMENTED & VIRTUAL REALITY SIMULATION TRAINING

The descriptive textual and visual information to trainees through smart-glasses or headsets enhancing their ability to carry out activities and simulate processes. Another way how to attract and effectively learn operators, students and in general young generation is to use humanoid AI robot equipped with terabytes of information about hydrogen technologies applications, theory behind, manuals, legislation etc.



X. HYDROGEN TECH IN TOURIST ACTION PLANS

Potential of mobile small scale production of hydrogen via electrolysis using local renewable energy sources (combination of small wind turbines, water mills and photovoltaic panels close to water sources (rivers, lakes). Charging station for hydrogen bikes without being connected to the grid. Hydrogen water scooters and cruise ship with support of alternative sources. The fleet of small hybrid buses (fuel cell/Li-ion batteries), supporting vehicles at Kosice airport, electro and hydrogen shared fleet of bikes etc. Coexistence of old water smithy in existing Museum of metallurgy vs. exemplary latest technology using direct reduction of iron ore by hydrogen.





HYDROGEN +

COMMUNITY BENEFITS

ACTION PLANS

CHAPTER 8

Public way to Košice airport

The public transport to Košice international airport do not use trams. The idea is to combine the most accessible way of city public transport with hydrogen bus.

Vehicles should be equipped with 60 kW fuel cells and batteries. The batteries will be the main source electric power for electric motor. It therefore does not drive energy directly to the engine from the fuel cells (or to the engines, because the cars will be equipped with two wheel hubs with integrated power engines- 2x 125 kW), but first stored in batteries. Waste heat from the fuel cells will be removed by heat pump and will serve for heating the interior. The hydrogen bus is able to run 350 km range on one charge, which is in our case 350/2 km distance, which equal to more than 100 ways without refueling hydrogen. The standard package is 8-year vehicle maintenance and service package. The hydrogen bus can connect city district with an airport where tram is accessible at The Pope Statue at Barca station. It is opportunity how to start propagate clean technology which will be rentable, due to the acceptable price per journey at app. 4 Eur (still 3 times cheaper than taxi). Fuel costs of hydrogen buses from 2017 (Bolzano, Italy) are € 0.90 per km and maintenance costs even astronomical € 2.60 per km, but still the total cost is max. € 3.62 per km [10].

KOŠICE INTERNATIONAL AIRPORT



Another more futuristic variant will be small version of hybrid tram, which can transform from pure electric version tram into “bus version tram” equipped with additional wheels and for part of journey on road used hydrogen fuel cells to produce electricity for electric engine when is on off-grid.

A 3D rendering of a futuristic hydrogen fuel cell bus. The bus is dark grey with light blue accents. The words 'FUEL CELL BUS' are written in light blue on the side of the vehicle. The bus has a modern, aerodynamic design with large windows and a prominent front grille area.

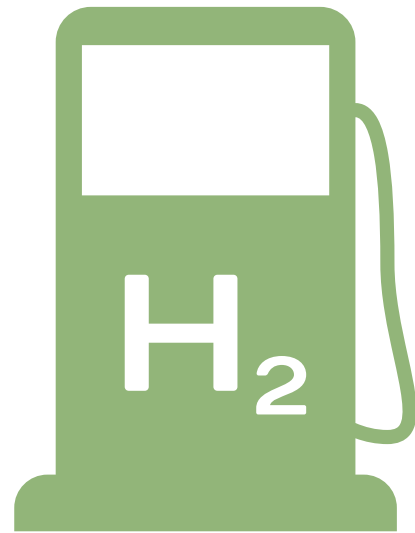
FUEL CELL BUS

Fleet of hydrogen bikes

A year ago company ANTIK started sharing of fleet of bikes to attract green way of healthy public transport. Another step is expansion with fleet of electrobikes which need charging and quite a considerable investment into maintenance service. That is why potential of hydrogen bikes by maximizing range to 300 km and refueling into 2 minutes make it attractive. The critical as elsewhere is if Košice self-governing region will support initiative with built hydrogen refueling station. In this case, very attractive and prospective is thing about off-grid version solution, to be applicable in cyclo-tourist attractive areas across region. Here, interest of potential operators for maintenance service, technical service is crucial, e.g. employees of residual waste & recycling pickup companies, waste management companies etc.

The plan to build first hydrogen refueling station in Košice city is essential and can be strategic decision for whole Slovakia in first phase of deployment of hydrogen technologies.

It could be first regional hydrogen station in country. The position in Kosice is ideal due to the closest refueling station in Vienna (Austria) in 600 km distance, so in range accessible for hydrogen car for one charge.



It will create opportunity for deployment of another types of small vehicles, esp. low-cost, high fuel-efficient, hybridized, light-weight vehicles specifically designed for usage inside big companies with high CO₂ emissions, airport etc. and later for fleet of highly specialized cars such as police car, garbage trucks etc. There are two ways how to do it. One is to build high-standard filling station with high capacity (100 - 200 kg/day) and high performance (70 MPa) refueling technology such as in Holland (Wallonia, Weser-Ems), or build on existing smaller stations of lower capacity and pressure such as in UK (Midlands and Plymouth).



Košice Children's Historical Railway

Košice Children's Historical Railway is a single-track narrow-gauge railway with a length of 3.9 km. It is located in the suburban recreational zone in the valley of the Čermel' brook, in northern part of Košice city. Historical locomotive is very nice nostalgic way how to meet with history and try to feel how steam engine move first industrial revolution using burning of coal for propulsion. On the other hand it produce certain amount of CO₂ emission in a visible way (must say attractive to children). If one of veteran locomotive will be rebuilt into hybrid one, the public can compare traditional technology vs. latest green technology approach. Nowadays, in times of energy transformation, this is one of highly relevant action and investing into locomotive which uses both hydrogen fuel cell and battery can help to attract public awareness.



Off-grid self-sustainable university dormitory for students



The concept could be based on using solar panels on the top of low-cost housing block which convert sun into energy. Energy will be collected in a battery that will be used to power an electrolyzer. The electrolyzer produces hydrogen gas by splitting water molecules into hydrogen and oxygen. Additionally, rain water could be collected into tank and later on distilled for use in electrolyzer. The hydrogen can be stored to 300 bar pressure tank.

When energy is needed, the hydrogen can be converted cleanly and efficiently back into electricity by way of a hydrogen fuel cell. The only emissions from the system are oxygen and pure water. The proposed concept is also city water friendly and calculated with water retention measure plan which is in line with water management Košice-self-governing region strategy.

Water tourist action plans

Another enormous potential we see in development of mobile small scale production of hydrogen with electrolysis using renewable energy (combination of small wind turbines, water mill and photovoltaic panels close to water source (river, lake) for charging station of hydrogen bikes, small cruise ships, water sport scooters etc. without being connected to the grid. Potentially it can be used in several places where bike roads for tourists served during season. This can deliver hydrogen for local seasonal fleet of hydrogen-powered shared bikes, scooters etc. In this way it could be one provider as of electro bikes, scooters in Kosice city and can expand to another cities or tourist locations. One of critical issue in this business model is that source of stable electricity is missing, so small scale electrolyzer, hydrogen storage using pressured vessel and fuel cell will be elegant solution.

Mobile version of electrolyzer could be installed in area with the highest fluctuation of bike tourists where existing infrastructure or minimum investment for bike road is needed. One of the top places for that is Jazero lake and Bukovec lake directly in Košice city, Zemplínska Šírava, Vinnianske lake and also Domaša lake where other supporting activities exists or are under development, such as water sport centers have also great potential.



Attractive will be both hydrogen water scooters and cruise ship with alternative sources such as photovoltaic panels in combination of fuel cells. Since establishment of sport parks or cruise ship number of tourists can increase rapidly. Another solution preferring Domaša lake area where added value is historically existence of metallurgical industry (old water smithy with Museum), so coexistence of exemplar latest technology using direct reduction of iron ore by hydrogen will be very interesting to educate visitors how we can help Earth with climate change reducing CO₂ and Green house gases and thus increase public awareness.

Sightseeing tour flights

Another tourist action plan how to widespread latest clean technologies to the public in very near future should be is hydrogen quadrocopter for visitor sightseeing flights around Kosice site (not only). Hydrogen fuel cell propulsion meet the requirements for speed, range, and payload. Each pound of compressed hydrogen contains over 200 times the amount of energy that could be stored in a 1-pound lithium ion battery. This weight reduction is essential to fulfill flight performance. It has more than 500 km range and app. 170 km/h top speed. Additionally, hydrogen quadrocopter can be refueled with liquid hydrogen in around 10 minutes and liquid hydrogen fuel can be more mobile on the ground.





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