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KOŠICE SELF-GOVERNING REGION

Hydrogen strategy for the Košice Region

The first hydrogen strategy in Slovakia

Avant propos A

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Košice Self-governing Region
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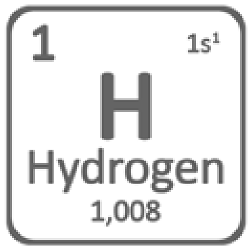

Hydrogen is among batteries, another key renewable vector undergoing considerable scientific, business, policy, and public community attention in world-leading economies. Europe as a region has unique assets that position the EU to pole position together with Japan, Korea, the US, and China. Slovakia, as an individual country doesn't implement an effective hydrogen national program yet. That is why a group of wide-spectrum authors has done this evidence-based study to discover the potential of hydrogen technologies tailor-made for Košice Self-Governing Region (KSK), helping the EU reach its environmental goals while boosting local investment. KSK, together with the 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 spillover effects on regional innovation, education, entrepreneurship, and employment. The aim was to detect areas with the 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 also contains recommendations for tourist action plans from which can benefit the public and alternative scenarios helping Košice Self-Governing Region to fit unique plans achieving a competitive position, and to set up policy decisions in the future.

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

We do not have to wait another decade in the 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 Košice Region a region with a higher quality of life for its citizens and harvest from concurrence advantage in early transformation times.

Aurel Stodola

Whether it was the introduction of steam, electricity, or automation into the production process, all activities were related to energy use, 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. Except for nuclear energy, the generation of energy from the above sources is associated with CO_2 production, which is considered one of the main sources leading to climate change and global warming. We live 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 energy production from the sun or wind. So, it is crucial to solving its storage in order to balance the supply and demand for energy. One elegant alternative and promising source of ‚green' energy is hydrogen. Its combustion generates water to release large amounts of energy and without a carbon footprint.

The idea of using hydrogen technologies in energy storage or transport is quite old, and there are 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,hydrogen technologies were 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 (H). 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 can release the energy back.

For the more extensive development of hydrogen technologies and the wider use of hydrogen in society, its 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 a long-term perspective. But the only way how to make a benefit for the public is to act together with industry, investors, universities, research institutes, and policymakers as major players.

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

January 2021, Authors

In recent years, we have been trying to find solutions in the Košice self-governing Region to contribute to greater energy independence. We are opening topics that were perhaps too complex and relegated to the sidelines for a long time.One of these topics is the hydrogen strategy and targeted research into the use of hydrogen technologies.

A Japanese proverb says: „Even a hundred-mile journey, we must begin with the first step." Research into the use of hydrogen is a complex process, but it also needs to be started and stepped up. Although Slovakia has not yet implemented the national hydrogen program, and the national hydrogen strategy has not yet been completed, we want to be helpful in this process.

The study you are holding in your hands was prepared in cooperation with a team of top scientists from the Technical University of Košice and the Pavol Jozef Šafárik University in Košice. Thanks to their work, the Košice Self-governing Region is the first in Slovakia to have a hydrogen strategy, from which we can bounce back in the implementation of green solutions. We provide answers to the questions of how to achieve and meet the European Union's environmental goals. This study maps the potential of hydrogen technologies in industrial sectors in our region from energy production, transport, storage, and research and development. We also bring recommendations for action plans that can be implemented in the territory of our region with an analysis of the need for hydrogen and the amount of investment.

Although Slovakia has limited resources for local hydrogen production, the strategic location of the Košice Region with Ukraine can play an important role in its import. We have also addressed this area as part of our hydrogen strategy. When researching hydrogen technologies, we also want to benefit from membership in the National Hydrogen Association of Slovakia.The Košice Self-governing Region became its member in 2020.As a result, we have gained access to all information and news in the field of hydrogen studies. We have the opportunity to participate in legislative changes and be invited to all dialogues related to hydrogen.

This strategy also addresses specific feasible projects that use hydrogen technologies. In the territory of our region, it is possible to set up hydrogen filling stations or provide hydrogen buses in suburban transport. You can read more about these options on the following pages of this brochure. If we connect research, industry, and self-government, it is the best way to innovate in the east of Slovakia.

Green solutions are currently one of the most discussed topics in the European Union. We do not just want to discuss this topic; we want to step forward and take an imaginary „first step" towards their implementation.

Rastislav Trnka
President of the Košice Self-governing Region
January 2021

Production

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Hydrogen Production

The difficult question regarding the utilization of 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"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 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 a clean way.

The list of possible ways of hydrogen production:

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

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

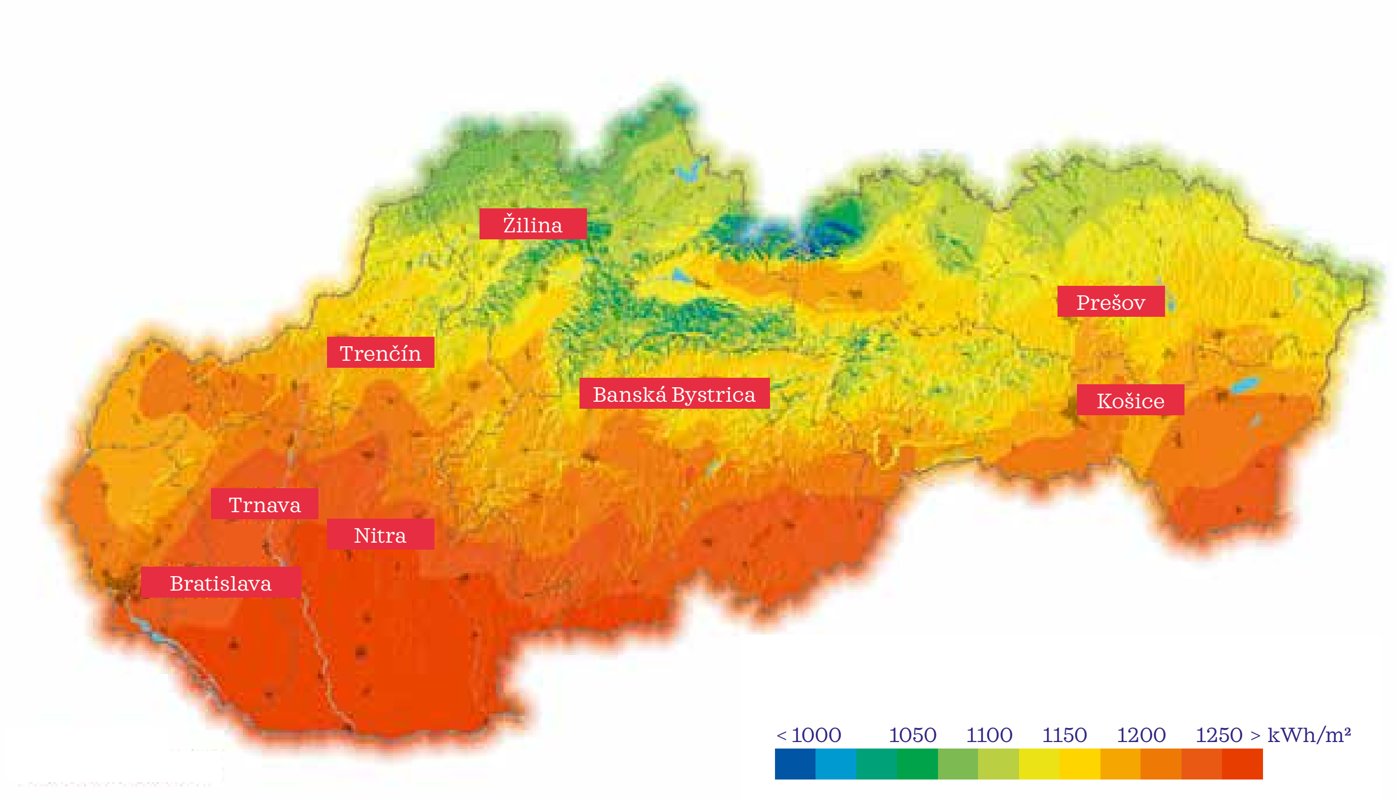
[1] Journal: Renewables and Sustainables Energy Reviews, vol.67, pp.597-611, Jan. 2017

The primary focus is to produce the "green hydrogen" or hydrogen produced on a regional level by low carbon technologies so the distribution ways will be shortened and we can achieve a 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 low emission sources have been used.

However, due to the technological progress and economic 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 2-degree target. It is expected to become increasingly less competitive over time as CO_2 emissions' cost increases, 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 the 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 green hydrogen production in the region. Recent findings suggest that the 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.



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, the scaling-up of electrolyzer systems, and the development of low-cost carbonstorage facilities.

Hydrogen production from Photovoltaics

Photovoltaics (PV) have the biggest potential for deployment in the Košice Self-governing Region. According to the irradiation map, the south area has the average energy output per m² in the range of 1000-1200 kWh/m², 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 the 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 low-quality land and buildings. The efficiency ratio of the PV panels is increasing, so 1 MW of new PV installation will require 12000 to 15000 m² 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

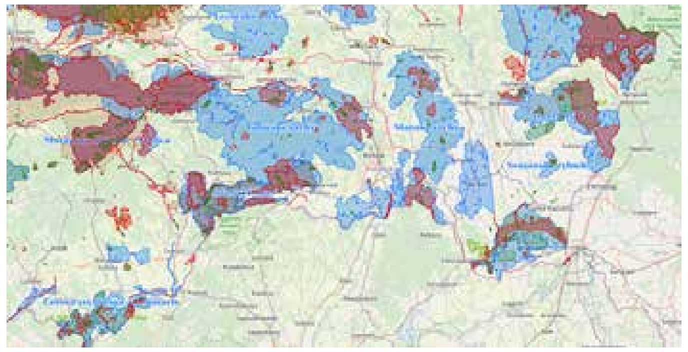
Degraded and low-quality land such as landfills, ponds, non-agricultural land could be utilized for the medium and large-scale PV installation that will provide the power for green hydrogen production. The technology innovations and smart grids for residential buildings will allow the households and 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.At the same time, we must not forget about solutions where the capture and treatment of rainwater will also be incorporated.

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

Hydrogen production from Wind

The use of wind as a source of energy for green hydrogen production is dependent on specific wind conditions. Košice valley is well known for 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). At present, turbines with an output of 1500 to 2000 kW are used globally.

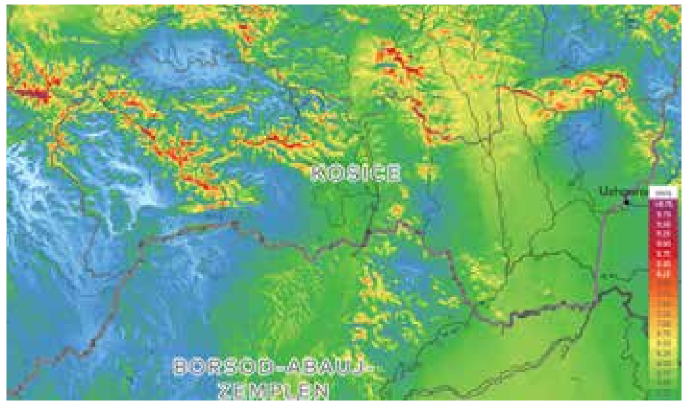
However, from the point of view of usability for wind electricity production, it is necessary to consider all protected areas, especially protected bird areas, areas of European importance NATURA 2000 and other protected areas.



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

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

Detailed environmental impact analysis (EIA) has to be provided for each locality, including detailed wind assessment.Despite these limitations, the potential of the 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.



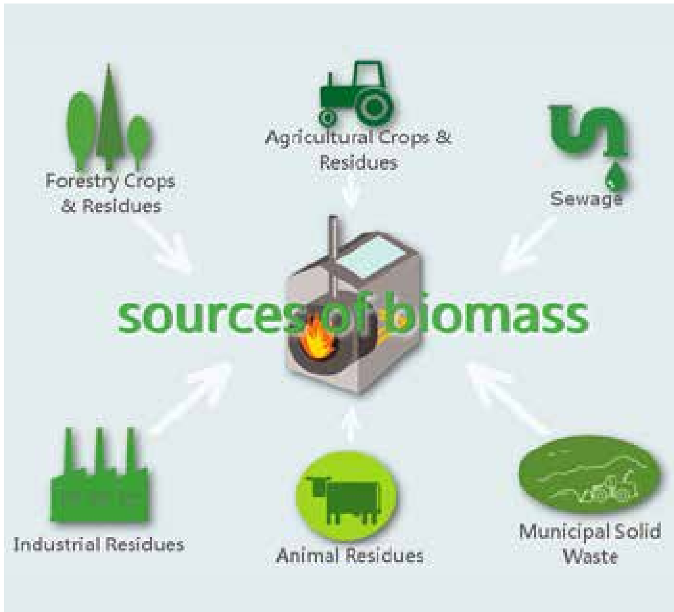
The most probable plan is to build small-scale electrolyzers of 1 MW and "hydrogen wind turbines" where an electrolyzer is incorporated in the turbine to produce hydrogen rather than power.

[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 an organic material that includes agriculture crop residues, forest residues, special crops grown specifically for energy use, organic municipal solid waste, and animal waste. These 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.



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

Fuel cell and hydrogen technologies offer 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. The conditioning removes the impurities, then sends 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 are key factors for biomass utilization 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 energy centers for processing the biomass of different origins and will combined sources for the heat, electricity, and hydrogen (or other green gas). Also, these energy centers should be built and operated close to the heat consumers so the losses on distribution will be mitigated. Hydrogen as a by-product will be the balancing factor and will be used for energy storage.

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

Hydrogen production from Geothermal

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 an 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, the 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 a detailed analysis of the economic and technical feasibility has to be provided.

Considering the current prices of the technology and electricity on 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 a decade, green electricity production from a 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 stations and storage tanks could also be available. In its pilot demonstration 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 H_2 produced. Geothermal energy is currently being used in Denmark and Iceland for hydrogen production. According to some sources, the latest technologies of H_2 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 the Košice Region, the amount of hydrogen required to meet the demand for this commodity in the industry, energy, and transport sector will be higher. Košice Region has limited potential for utilization of renewable energy sources, and at the same time, consumers such as US Steel or the transport sector will need a large amount of hydrogen for its production processes if a decision is made. Regions that 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 the 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 CO_2 costs are factored in, driven by scale in electrolyzer manufacturing, larger systems, and lower-cost renewables.

For hydrogen production 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 pressurized steam to produce syngas, which is a blend of carbon monoxide and hydrogen. Providers can easily captureabout 60 % of the total carbon by separating the CO_2 from the hydrogen; the additional must be extracted from the exhaust gas, which is relatively expensive today, allowing for up to 90% of the total capture rate. ATR combines oxygen and natural gas to produce syngas. This process can easily capture up to 95% of CO_2 emissions. ATR technology is typically used for larger plants compared with SMR technology.

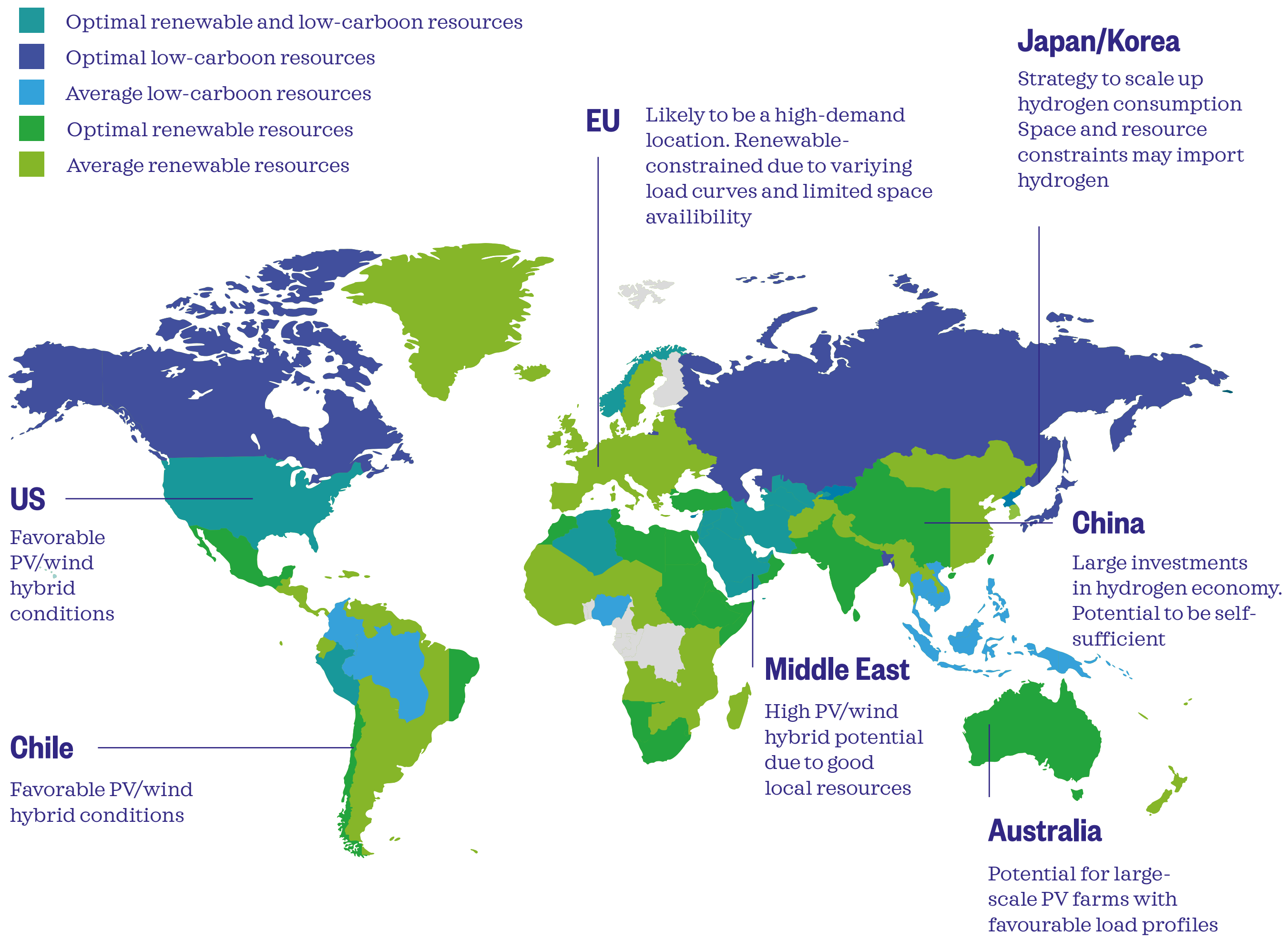
Coal gasification in Russia and Ukraine produces hydrogen by reacting coal with oxygen and steam, which like the ATR plant, allows for relatively easy capture of CO_2. However, the coal gasification plant emits about four times more CO_2 per kg of hydrogen produced than the ATR plant, increasing the amount of carbon that must be transported and stored.

Košice Region and Slovakia itself have limited resources to produce low-carbon or renewable hydrogen at scale locally. On the other side, regions have ambitious decarbonization policies plans that will require hydrogen; if local production cost is too high or unable to meet demand, we may become importers of hydrogen. The 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 2 degree target. It is expected to become increasingly less competitive over time as the cost of CO_2 emissions increase, reaching cost levels higher than all low-carbon alternatives prior to 2040.

Exhibit 12 | 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.

The Košice self-governing Region, with its strategic position on the border with Ukraine, may play a major role inthe import of green and low carbon hydrogen in Slovakia as well as the 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 long distances by trains. With the decreasing role of coal in the energy and industry sector in the EU, which is in line with the decarbonization targets, the Intermodal terminal in Čierna nad Tisou will have to be adopted to change from coal to LOHC transport.

[8] IEA, McKinsley

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 primary energy sources fossil fuels or carbon-intensive materials. In order to achieve decarbonization goals until 2030 and a zero-carbon economy in 2050, the use of hydrogen in providing ancillary services for the grid system and the required amount of energy for emission-free transport would be one of the several alternatives. (Hegeduš)

In the territory of Košice Region, it would be appropriate for important companies operating in the field of gas and electricity production, namely SPP distribúcia a.s., Nafta a.s., Slovenské elektrárne a.s., to start green activities and should actively participate in the transformation process. Under the administration of Slovenské elektrární a.s. is the Vojany coal-fired power plant, one of the most carbon-intensive producers of electricity in the region. The vision of all stakeholders should be the transformation of this power plant into the production of green hydrogen and subsequent storage in storage tanks (e.g., Nafta a.s.) and distribution by pipelines (SPP-D a.s.) near the power plant. To this end, however, it is first necessary to assess all the circumstances, to develop a vision and strategy, as well as to evaluate the obstacles and risks of this transformation. For this reason, it is necessary for Košice Self-governing Region to enter into this partnership, as is the case with such projects in the Netherlands, Germany, and France.

2

Storage and transport

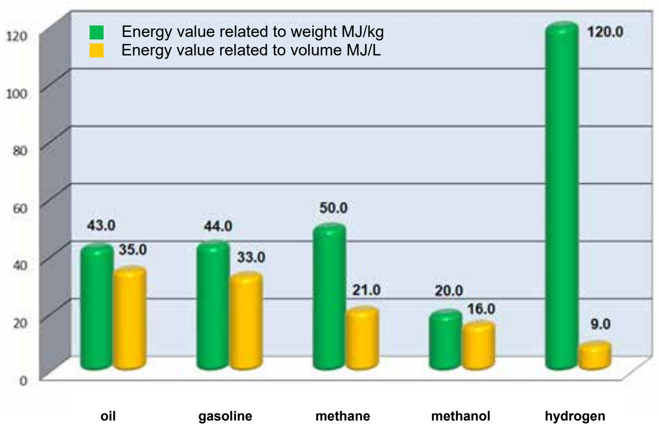
Due to the fact that the hydrogen atom is the smallest atom in the periodic table, in the form of the molecule as gas, it tends to leak and can embrittle some metallic parts of systems such as pipelines, valves, etc. In liquid form, safety issues arising due to the low temperature always is cold enough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

Hydrogen technologies are a promising alternative in clean energy transition, hydrogen is an 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 include complex data from the 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 experience and in a race in the development of novel materials which are less expensive, the assistance of several universities (TUKE, UPJŠ, STU, etc.), research institutes at the Slovak Academy of Science hand in hand in close cooperation with industrial partners is needed.

Hydrogen storage

Hydrogen, as the lightest existing molecule, has a very low density. 1 kg of hydrogen gas, occupies approximately 11 m at normal room temperature and atmospheric pressure. Thus, it takes up a large volume at a 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 less energy per volume.



Storage and transport 2

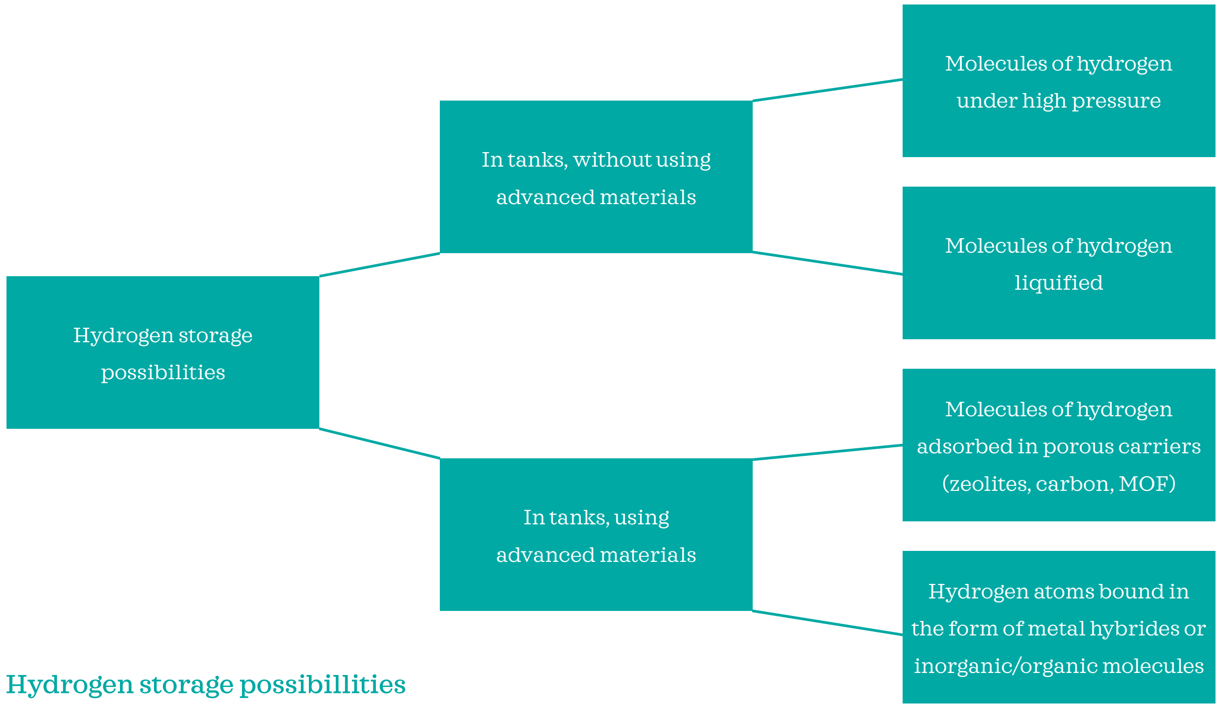


Figure: Hydrogen storage possibillities

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.

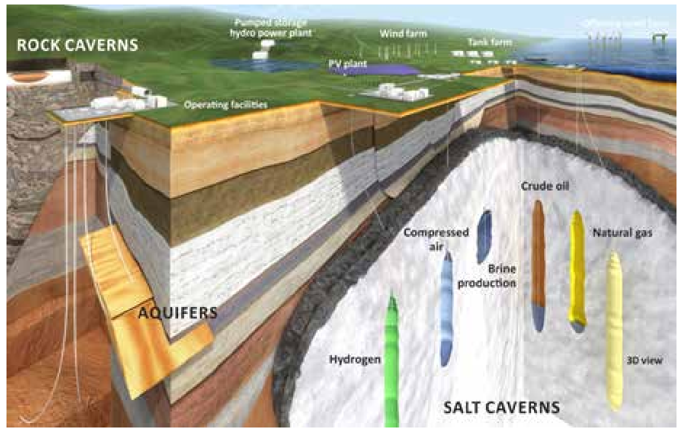
There are currently several concepts for hydrogen storage. Some have been in use for several decades, others are in the pilot stage, and others exist only on a lab scale. A schematic breakdown of the various approaches for hydrogen storage is shown in Figure (Hydrogen storage possibilities). None of the methods has the 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 isa 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.

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.

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 an 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 on a 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 is 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%.
.

Storage and transport 2

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 refueling stations.

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

Storage and transport 2

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 a chemical (ionic) bond to a metal atom (e.g., MgH_2) or are present at interstitial positions inside the intermetallic hydride structure.

Metal Hybrides

Suitable chemistry for hydrogen storage fulfill MgH_2 and AlH3, 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 of reversible hydrogen desorption/sorption. However, it has the disadvantage that relatively high energy (about 75 kJ.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 kg.m–3. For example, the atmospheric pressure desorption temperature is about 12 C for the LaNi5H6.5 alloy (1.49 wt% capacity H) and up to about 30°C for the ZrNiH3 alloy (1.49 wt% capacity). The disadvantage of intermetallic hydrides is their high price so far.

The last group is common chemical compounds, chemical hydrides such as methanol, ammonia, formic acid,or various liquid hydrocarbons. (Zeleňák)

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

Hydrogen transport

Compared to the transport of natural gas, the 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...

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 electricity through hydrogen molecules to large users. Finally, it seems to be cheaper than transporting electricity via cables. TNO is already testing existing infrastructure of onshore and the North Sea gas pipelines to transport 100% of hydrogen.

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 the 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. This is currently being tested by the Faculty of Materials, Metallurgy and Recycling of TUKEand SPP-Distribution.

An alternative could be the transport of liquid hydrogen. Although 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, largecapacity vacuum insulated multi-layer tanks for trucks, wagons, or ships that have 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 the 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 the solution for the Košice Region?

A likely perspective in the development of hydrogen technologies is that hydrogen production needs to be decentralized, and the potential of natural resources of energy must be fully used on a regional basis, such as build electrolyzers in close proximity of lakes, geothermal plants 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 also integrated 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.

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

Blending hydrogen into a natural gas distribution network

Several tests conducted in western EU countries show the potential of blends with up to 20% vol. H_2 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. Another restriction is steel pipelines, where hydrogen cracking may occur in the material itself and welds. Due to the small molecule of H_2, there might also bea higher leakage rate of pipes, welds, fixtures, and fittings. On the other hand, plastic pipes (majority of local networks in cities) are considered to be 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 comprehensive testing and demonstration on the real-world infrastructure conducted first to verify the outcomes of the foreign experience and second to raise public awareness and obtain general acceptance of the future users of safe, clean, and sustainable energy.

3

Metallurgy

Metallurgy 3

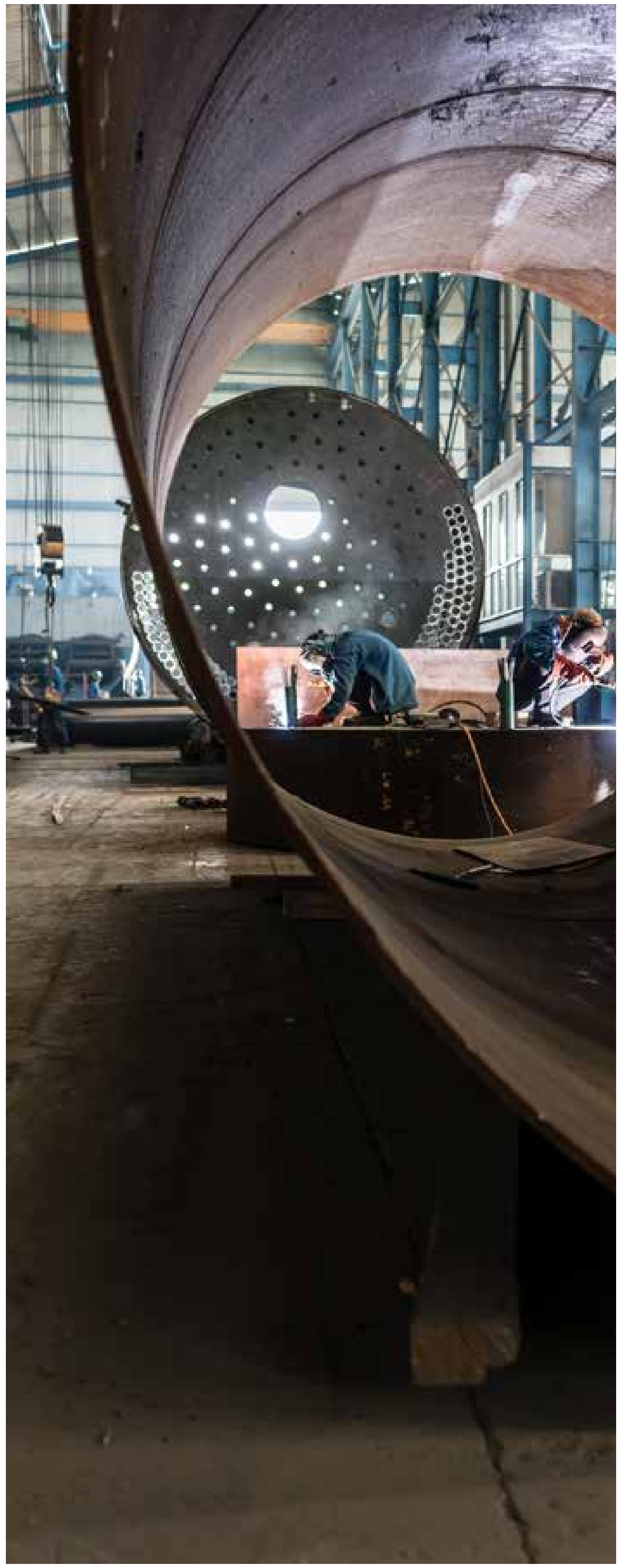
Green steel

There are already technologies on the market that use hydrogen for the 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 H_2 and CO-based reducing gases made from the 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 the old-fashioned traditional way is based on the operation of blast furnaces (BF) and basic oxygen furnaces (BOF) emitting around 1.8 tons of CO_2 per ton of steel compared to the crap-based route based on the operation of electric arc furnaces (EAF) emitting 0.3 tons of CO_2 per ton of steel. Another option is to use the direct reduced iron (DRI) technique, emitting about 0.6 tons of CO_2 per ton of steel. But due to the limited availability and quantity of suitable scrap and some well-known problems with the replacement of coke with biomass, carbon capture storage technologies (CCS) have become very relevant and actually are under observation.

One elegant carbon capture solution is an algae-fueled bioreactor that soaksup CO_2 400x more effectively than trees. Through the photosynthesis process, the aquatic plant algae soakup CO_2, water, and sunlight to produce energy. Naturally, this type of plant uses this energy to multiply, grow and later on convert intoanother form of energy. Scientists have been experimenting the ways to capture CO_2 and convert it into biofuels instead.



It is clear that the metallurgical industry is facing a dramatic energy transition and the only way is to researching practical ways of reducing CO_2 emissions by available renewable energy resources. One example is now under realization as part of the H_2 Future project in the steel plant in Linz, Voestalpine in Austria. Here, the proton exchange membrane (PEM), a 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 a large scale in the EU28 model for the steel industry.

What is the solution for the 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 the 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. The steel sector paysan enormous budget for CO_2 emissions, and hydrogen technologies are reliable for them and University partners through several EU innovative projects. One existing solution is using electrolyzer systems such as a special one for steel companies with the power of 1,2 MW (FY. Salzgitter). Demonstrator projects and pilot studies for the 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 the up-mentioned project in Austria (H_2Future). 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 for producing hydrogen at the point of consumption if transport and storage will be locally accessible and standard.

Based on information in the next chapter of Hydrogen+ Nuclear and Chemical Industry, another example is using energy from nuclear power plants for the 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 the so-called "Sulfur-iodine" process and would be considered for green production in the metallurgical industry to reduce ores in the far future.

Digitalization and next generation of hybrid metallurgical engineers

Each new massively commercialized technology needs 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 the training process of new hybrid engineers.

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

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

Another way to attract and effectively learn the young generation is to use a humanoid AI robot equipped with terabytes of information on hydrogen technologies, the theory behind, applications, manuals, legislation, etc. This approach shall be used in the learning process on the different grade levels 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, practicing questionnaire with immediate analysis, etc.

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

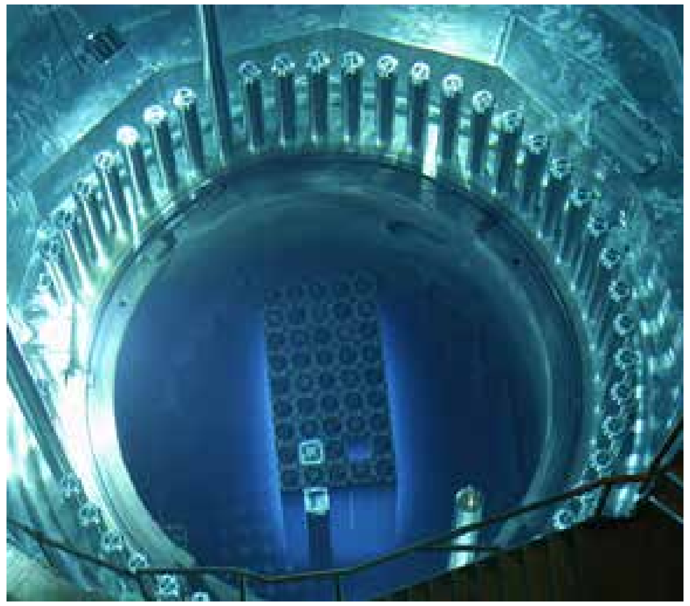
4

Nuclear and chemical industry

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 liesin decreasing the 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.

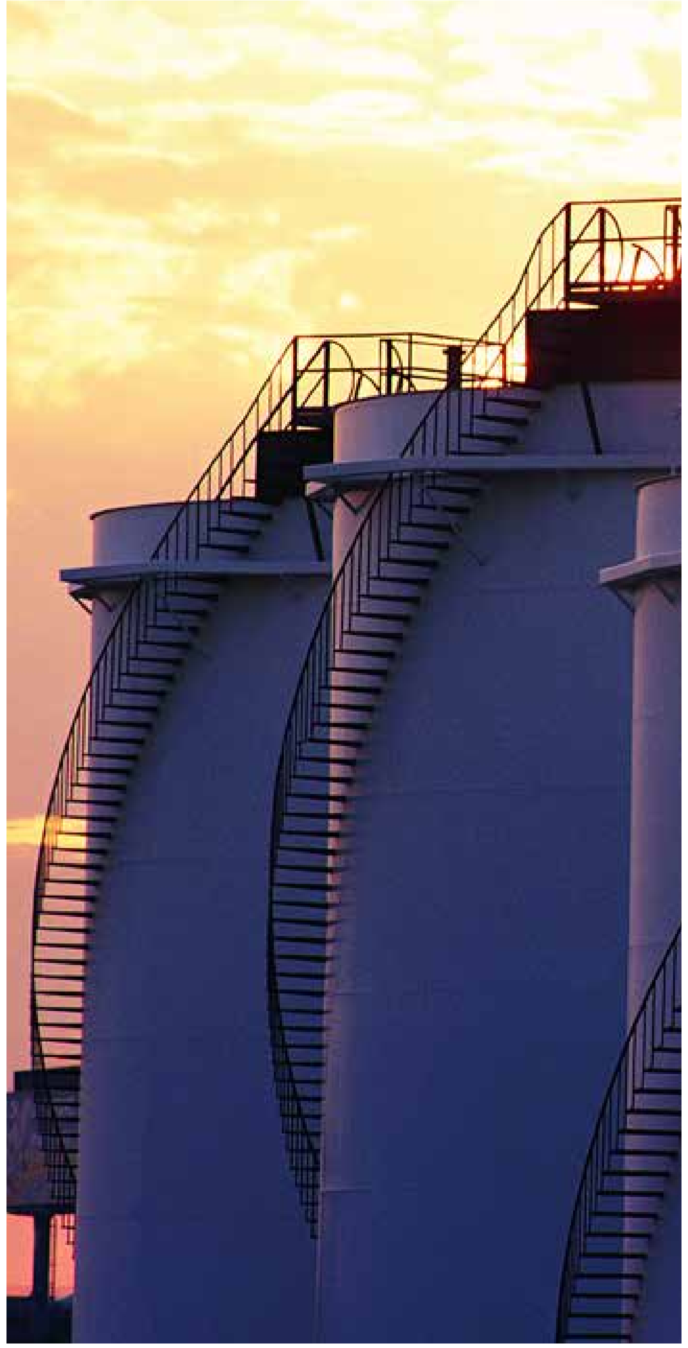


Produkcia vodíka

Ammonia could serve as an energy storage chemical for green electricity if required. It can be split into H_2 and N2 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 (University in Duisburg-Essen in cooperation with company ZBT).

93% Fossil fuels
4% Water electrolysis
3% Biomass and waste gas

Nuclear and chemical industry 4



The potential for the use of hydrogen and hydrogen technologies exist at Chemko, a.s., Strážske as a 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 the reforming process to produce fertilizer for agriculture (see also chapter Metallurgy). So small-scale chemical company at the campus of global steel producer is an effective way how to add to waste additional value in the form of a new product for other sectors and creates new jobs.

In Europe, the 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 the year 2030, it could be possible to produce it with sustainably produced ammonia. Ammonia can effectively serves as a storage medium for hydrogen, as a super battery, which was created from Slovak companies DUSLO a.s. and CHEMKO a.s. very attractive business partners for leading European companies in the hydrogen economy.

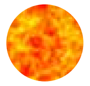
Based on predictions of world professional hydrogen alliances and associations, using nuclear power will make hydrogen production cheaper and more affordable in the future. Although nuclear power has been used for decades, newer and safer nuclear reactors are constantly being developed. Reactors of the 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 that the power plants will 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)

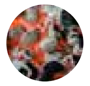
 Gas-cooled fast reactor (GFR) system

 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 CO_2 - free energy sources. Regarding hydrogen production in any volume and quantity, nuclear energy can play a crucial role, especially in Slovakia, which invested into new units billions of EUR during the last two decades.

5

Battery

Battery support

In the recent past, battery and hydrogen technologies seem to be concurrent.Nowadays, many applications arise where these two technologies' intelligent interplay made products of high everyday practicality. On the way are first cars with short refueling 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 the presence of one of these technologies solution is in many applications inpractice. This hyphenation of two green technologies createsa strategic point in fulfilling emission-free plans in mobility, heating, etc.

The Košice Self-governing Region, together with the support of the Slovak government, set up plans that plan to builda Gigafactory for the production of batteries. A Memorandum of understanding was signed in 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 the patronage of the Slovak Battery Alliance (SBaA), where also deployment of hydrogen technologies is one of the priorities in the next years. To support strategic research and development activities, the Slovak government allocated in 2020/2021 both in basic research and application research 5 millions EUR. (Halama, Smik)

SBaA
SLOVENSKÁ BATÉRIOVÁ ALIANCIA

6

Research and innovation in the Košice Region

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 the International Hydrogen Safety Association, the direct provision of specialists for working with battery systems and hydrogen technologies is also possible by creating separate study programs.

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 is focusing on research of the most promising materials for hydrogen storage.

Carbon-based materials

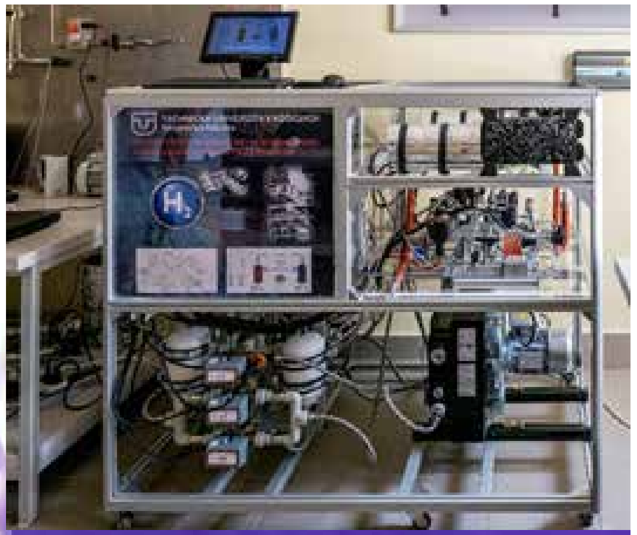
Various types of nanostructured carbon materials, such as carbon nanofibers, carbon nanotubes, nanorods, etc., are being investigated for hydrogen storage. The specific surfaces of these materials may exceed 3000 m²/g. As in the case of MOF, storage is limited to the use of low temperatures and pressures 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 of Košice for the implementation of hydrogen technologies in the energy and automotive industries. His research focuses on the 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 a 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 temperatures. The concept of a hydrogen compressor works on a principle where the heat transport and heating, and cooling are provided by a heat pump, which results in a considerable saving of electricity and is 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)



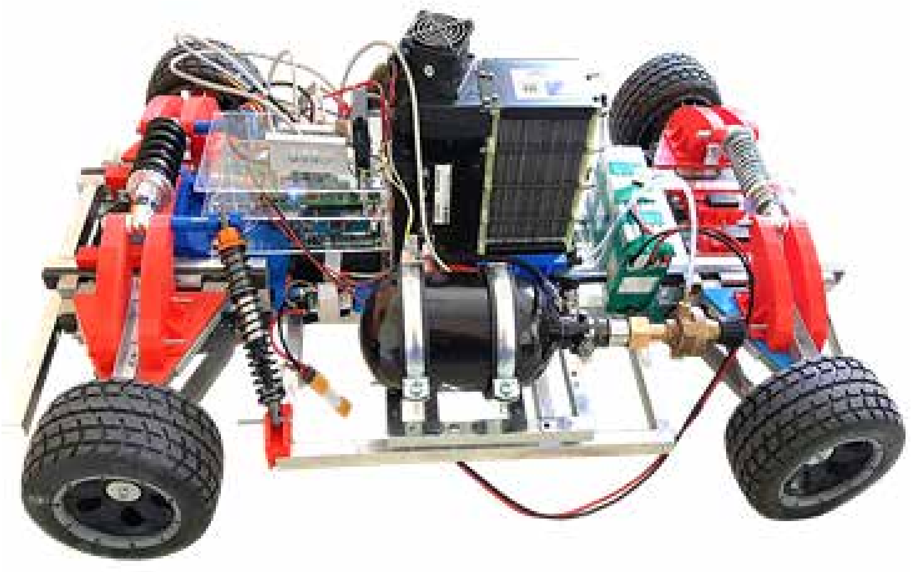
Prototype of hybrid hydrogen/ Li-ion battery car using fuel cell andmetal-hydride materials for propulsion

The prototype of a 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 a 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, Saksl)

The hydrogen car model was developed by Brestovič's team at the Faculty of Mechanical Engineering of 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 usesa 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.

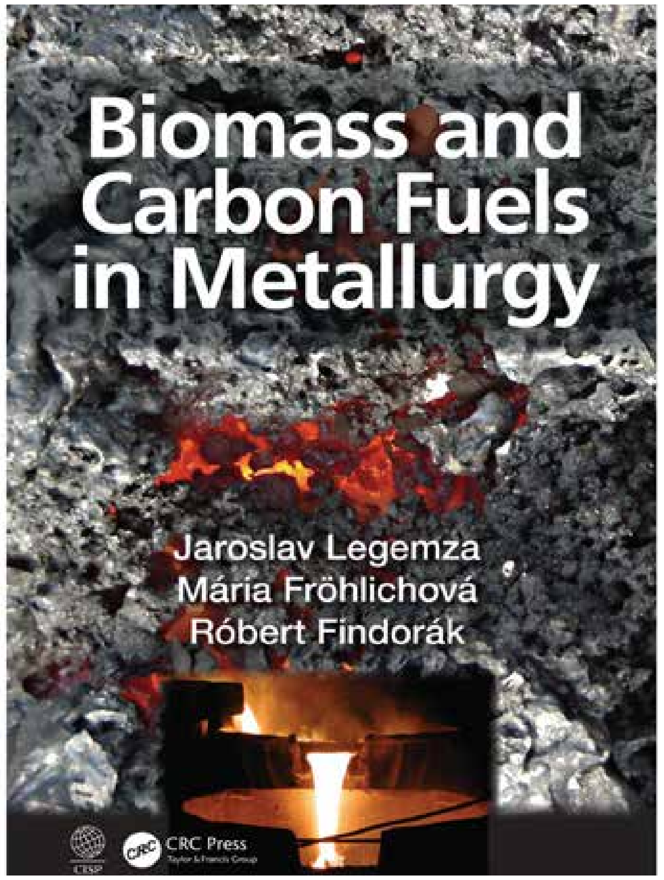


The given motor was chosen to ensure the required power for the vehicle model. Depending on the drive concept, the vehicle operating mode can be selected. The vehicle can be operated as a pure electric vehicle with a set of 16Ah Li-ion batteries. Another possibility is to use the fuel cell as the primary 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 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 the 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. The Faculty of Materials, Metallurgy and Recycling at the Technical University of Košice can offer know-how in nondestructive 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 the energy sector, working on expertise and consultancies with oil & gas companies, classical power plants, 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 and predict physicochemical properties of materials by using the power of supercomputers via modeling of properties by quantum-chemical calculations, density functional theory simulations. (Halama, 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 deciding 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 the 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 experience 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)

As part of the preparation of the EU project CARBON in cooperation with 9 Slovak entities (including the Faculty of Materials, Metallurgy and Recycling and Slovak Academy of Science), which are associated with 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.

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

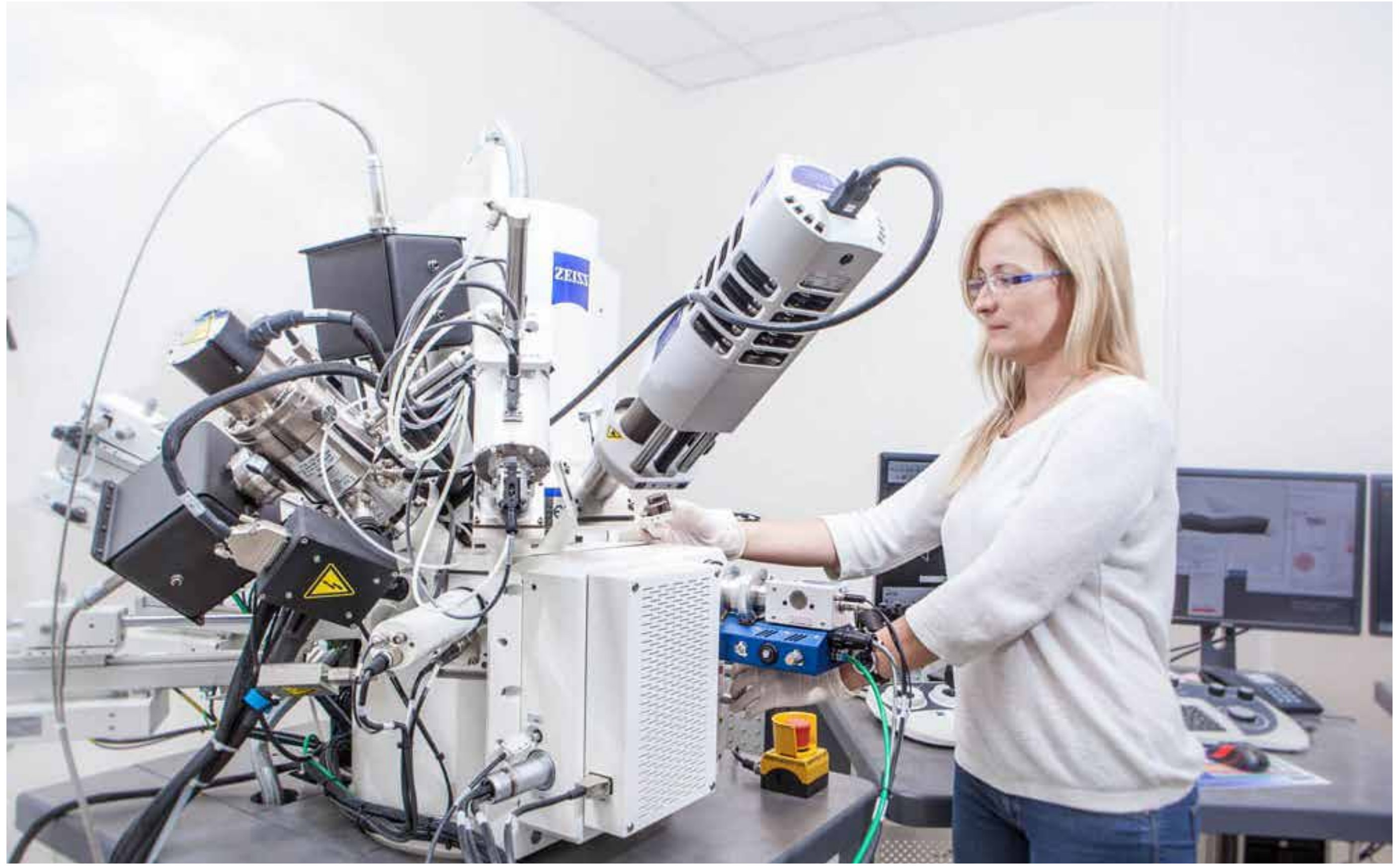
- The creation of thermodynamic models in hydrogen production by high-temperature technology - can be used to optimize existing technology or to develop new technology.
- Research related to the production of hydrogen from waste biomass.
- Research on carbonaceous substances for the storage and transport of hydrogen (e.g., coal, coke, electrode materials, graphite, selfbaking, and composite electrodes, etc.).
- Research in the field of metallurgical use of hydrogen.
- Perspective electrolytic recovery of metals from an aqueous solution and form 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 the near future, and mining companies do not have alternative production programs. The production of hydrogen from brown coal is already underway worldwide under operating conditions.
- Effect of hydrogen in natural gas on combustion properties of the 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 flammable metallurgical gases for support of hydrogen distribution in the steel plant hydrogen and pure hydrogen in combustion units. (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 XaYbHc (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 the other. The experienced research team lead by Ing. Karel Saksl, DrSc. from the Institute of Materials Research at Slovak Academy of Science, contributing to high-level European research on the 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 the Faculty of Materials, Metallurgy, and Recycling with a partner from Ukraine (Halama, Ruzickova, Slezakova, Horvathova) "Towards cross-border East-Carpathian health water chain through innovative monitoring," we set up a plan forthe autonomous collection of water samples using hydrogen drones. Another advantage of hydrogen drones equipped with physicochemical sensors is longer operation time, so it could be used for air quality monitoring too, which opens potential in atmospheric corrosion research of metallic structures and prediction of their lifetime. (Halama)



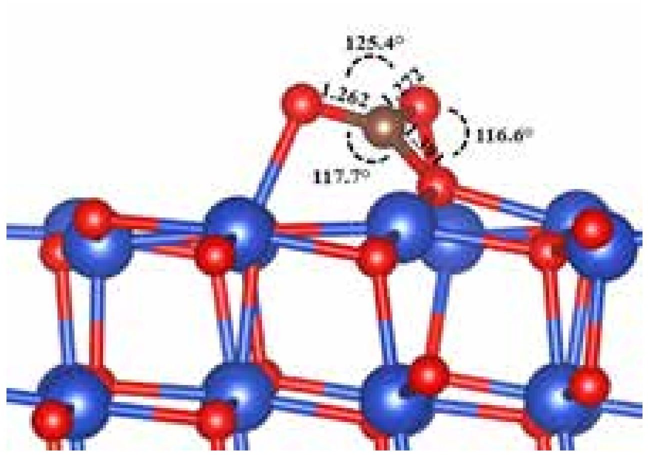
Huge scientific infrastructure at PROMATECH center

Promatech Centre, as consortia of two Universities (TUKE, UPJŠ) and three Institutes at the Slovak Academy of Science, is a center for excellence for advanced materials and technologies. It contains a huge scientific infrastructure equipped with the latest sophisticated devices in 39 labs that serve modern material science research. It helps scientists, innovators in the field of material development, complex characterization, also covering hydrogen topics (catalysts, electrodes, electrolytes, etc.), topics in battery research (electrodes, electrolytes), including usage of nanotechnologies. It allows scientiststo workon materials improvements in technical applications and has everything for achieving high-quality results. It has everything for hydrogen production using nanotechnologies, such as the latest discovery of Prof. Zhao's team, who invented a nickel-iron electrode for oxygen generation with a record-high efficiency. The idea of his concept works on an idea with relatively cheap metals such as iron and nickel. They are not good catalysts for hydrogen generation, but they radically reduce energy consumption when they join at the nanoscale. 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 environmentallyfriendly waste. A very nice example of how can Košice scientists reach comparable world-class research using 40 mil. EUR infrastructure is at the Promatech center in a lab equipped with a Nanospider device, which is able to do a similar concept.

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. The 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 nonnoble metals catalysts composed from Ni, Co, and Fe due to the electron configuration and their physical properties. A conversion rate of hydrogen production with the use of the above catalysts is over 80%, and catalytic activity is high even at very low temperatures.

Nanocatalysts for conversion of carbon dioxide

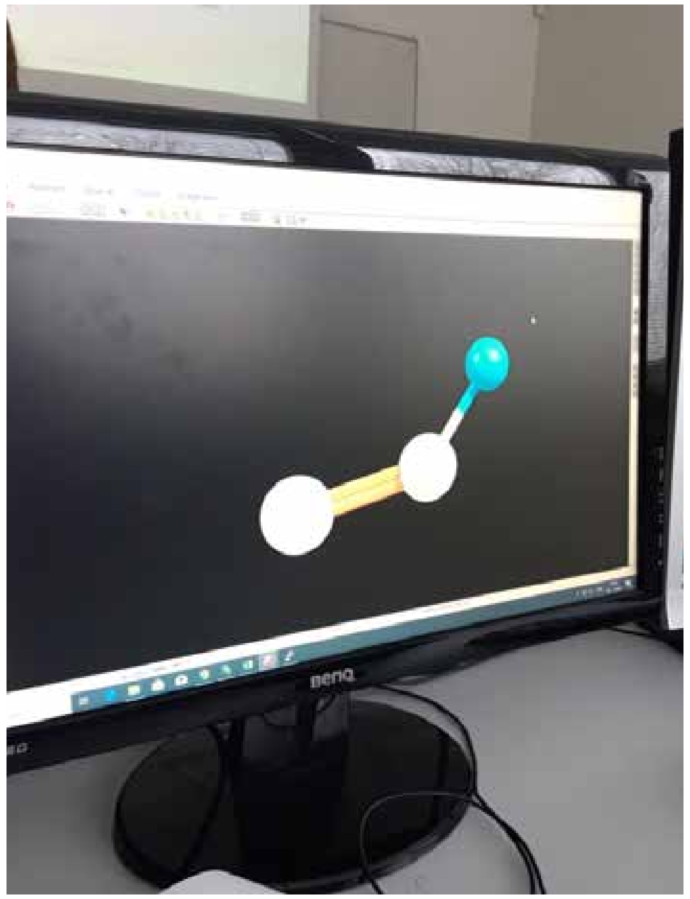


With the use of an effective catalyst, carbon dioxide can be converted to different chemicals, which can be used as a clean energy option in combustion engines, gas turbines, or fuel cells and can also lead to hydrogen formation or hydrogen storage.

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 a high impact on the number of final products, mainly alcohols, and reduced the amount of CO_2. The structure of Zn, Cu catalysts is also studied in CO_2 conversion to methanol.

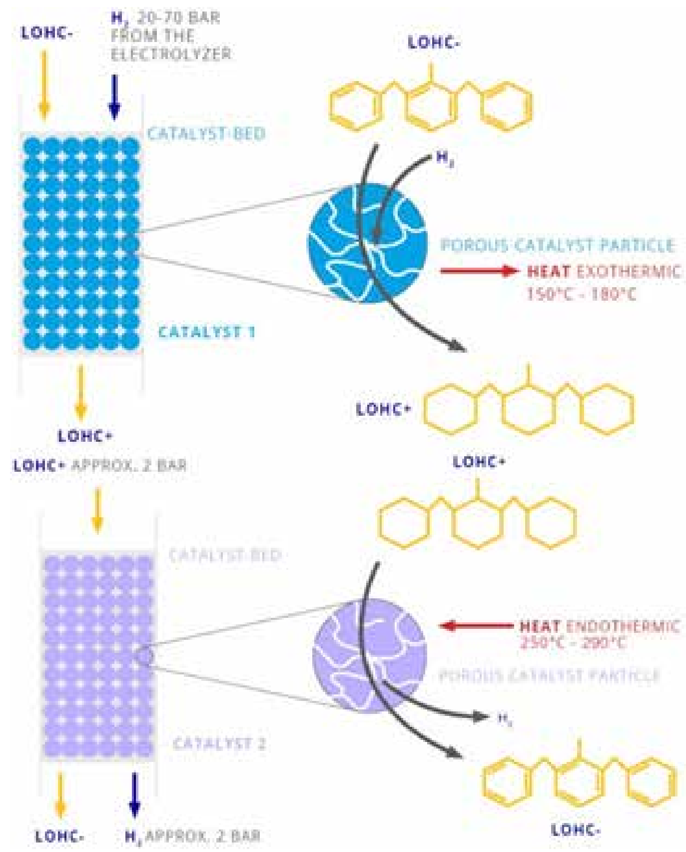
Computational calculations of catalytic surfaces

Prof. Oriňak´s Group, in cooperation with Prof. Honkala´s Group from the University of Jyväskylä in Finland, uses Density Functional Theory (DFT) for modeling of catalytic surface, optimization, and simulation of thermal decomposition of methane and carbon dioxide conversion. Theoretical calculations provide details about reactions and improve 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 of 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 kg.m–3 or >6 wt%), very selective hydrogenation, and dehydrogenation for long life cycles and low productions costs.

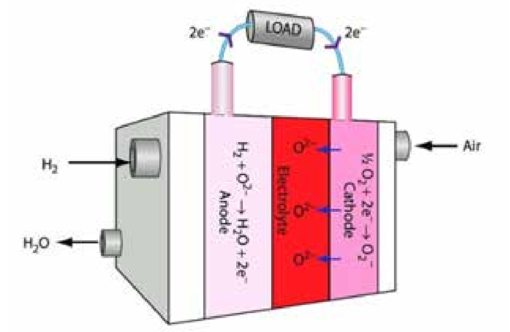


Design of electroactive carbon fibers modified by metallic nanoparticles as novel electrocatalysts for hydrogen evolution

Carbon modified fibers as potential electrocatalysts for hydrogen evolution reaction (HER) were prepared using needle-less spinning technology (NLE) by a research group at the Institute for Materials Research at Slovak Academy of Science in cooperation with UPJŠ. It was observed that the specific surface area of the fibers increased rapidly with the increasing content of metallic nanoparticles and their phosphides (Ni, Co, Cu, etc.) in the carbon matrix. They developed the 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 fibers containing the highest amount of CO_2P nanoparticles, which provided the current density of 10 mA cm-2at η10 −300 mV. The smaller Tafel slope and fastest HER kinetics were found in the samples with the highest content of CO_2P nanoparticles and the 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).

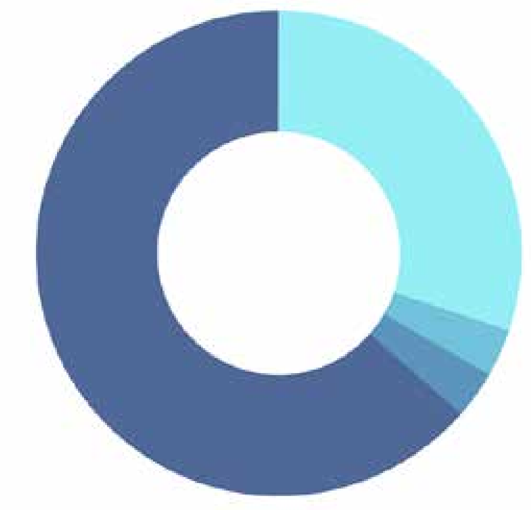
The research team lead by RNDr. Martin Fabián, PhD. from the Institute of Geotechnics at Slovak Academy of Science, is developing a novel type of nanocrystalline oxide electrolytes with modified structures and morphologies and enhanced functional properties served for high-temperature electrochemical energy conversion and storage technologies. It includes the 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 the fabrication of dense electrolyte ceramics with the controlled grain-size distribution. He studied systematic analysis of relationships between composition, microstructure, and ionic transport. The non-conventional mechanosynthesis approach is envisaged as a cost-effective and fast route for the fabrication of advanced solid electrolyte materials with controlled microstructure and improved electrochemical performance, and thus encompasses a promising pathway contributing to the development of electrochemical storage for renewable energy.

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.

Raising awareness about alternative energy sources is a major factor fostering the market growth. SOFCs are widely gaining momentum as an important source for 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 technological developments to tackle the issue. (Fabián)

Education challenge

The Košice Self-governing Region administers 63 secondary schools with legal subjectivity:



- 9 Grammar schools
- 2 Musical Academies
- 2 Combined Schools
- 40 Vocational Schools

The Košice Self-governing Region and its Education committee cooperate 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 the 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

Guidelines for 2019/2020 issued by Košice Self-governing Region itself contain a number of promising points, which indicate that the 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 are 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 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

The 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 on 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 ifnecessary. This part contains recommendations 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 cells in cars, renewables sources of energy supporting hydrogen chain, etc. The 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 of the cooperation of secondary schools with specialized departments at research universities and institutes that can support hydrogen technology with practical demonstrations in their laboratories. For pedagogues, we recommend using a simple model of a windmill 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 a source of current (for generating electricity from hydrogen). As soon as hydrogen is produced, the fuelcell 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 is during the "Day of Open Doors" at Universities and Research Institutes.

In 2018, students from Secondary School Ostrovskeho 1 won the 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 the 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 a great example of how high-quality education and practical training at Secondary School can prepare motivated students later attended more specified programs at research Universities.

Students from Košice won the world model competition hydrogen cars!

III.) Following of journals for science teachers:

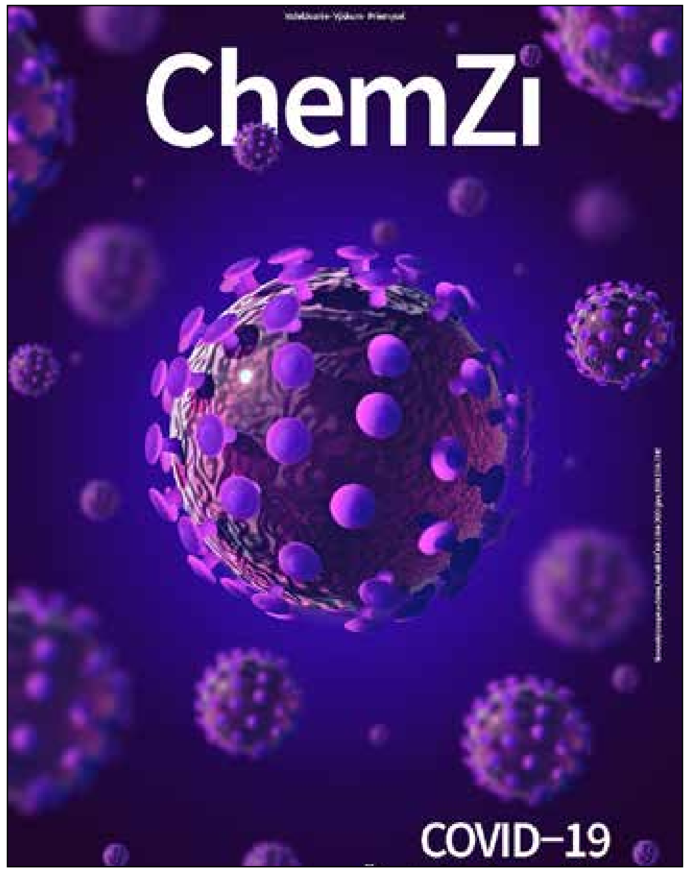
A) Today's school - man and nature:
This journal is published by the Association of Chemistry Teachers. The association is also active on the social network Facebook, where it enjoys great popularity. Teachers can quickly exchange advice, experience, focus on upcoming events such as open days in universities, 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 information about the 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 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 way how to include the areas of the latest 21st century batteries and hydrogen applications, letting students ponder how these kinds of technologies could transform the Košice Region intoa 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 a modern technology appetite at the 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 an appropriate association of the young generation in the scientific club community and attract these research domains and accelerate the next generation of energy research leaders on their journey.

ERASMUS + MOBILITY PROGRAM

HySchools
Inspiring the talent of tomorrow

The Hydrogen In Schools (www.HySchools.eu) project is an Erasmus+ program 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 promising young scientists in the Košice Region lead by a 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 the high-skilled young generation of energy research leaders. Erasmus plus program 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 the 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 TeacHy (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 researchers from Košice Universities need to be confronted with research talents abroad at world-class energy labs via a short-term stage. Industry-linked education provides access to unavailable equipment, data, and expertise.

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 training 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.

TUKE and UPJŠ universities will play a key role in education in the 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, training, summer courses necessary for a suitable position in a new kind of hydrogen and battery industry.

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 issues of fuel cells and hydrogen technologies in cooperation with the International Hydrogen Safety Association
- direct provision of specialists for working with a battery system, hydrogen technologies is also possible by creating separate study programs
- complex or specific one underthe umbrella of both TUKE and UPJS Universities with selected faculties,institutes, departments
- PhD. study programs incooperation with Slovak Academy ofScience...
- courses, training for technical staff, operators, and administratorcreation of retraining courses in conjunction with the Office for Labor and Social Affairs
- preparation and provision of retraining of emergency services to H_2-related situations using virtual reality augmented reality simulations. (Halama, Orgágová Králová, Baranová)

TECHNICKÁ UNIVERZITA V KOŠICIACH

UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH · 1959 ·

HYDROGEN+

TRAINING – COURSE – SUMMER SCHOOL

TEACH$_2$^{4}KE

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 CO_2 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

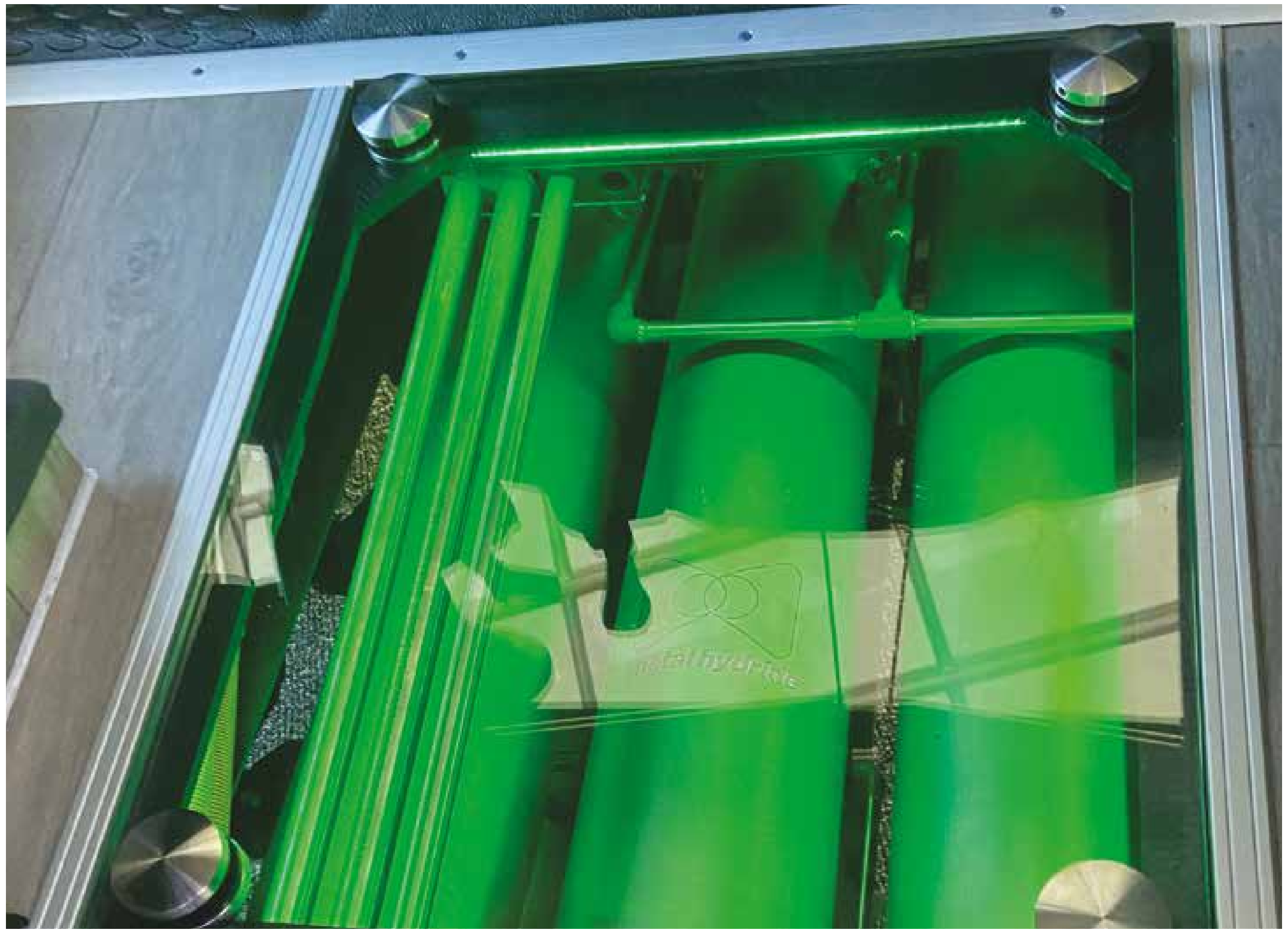
Diffusion of hydrogen in metallic structures. Hydrogen embrittlement. Corrosion monitoring of gas infrastructure. Life-time prediction using artificial neural networks.

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.



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Community benefits, action plans

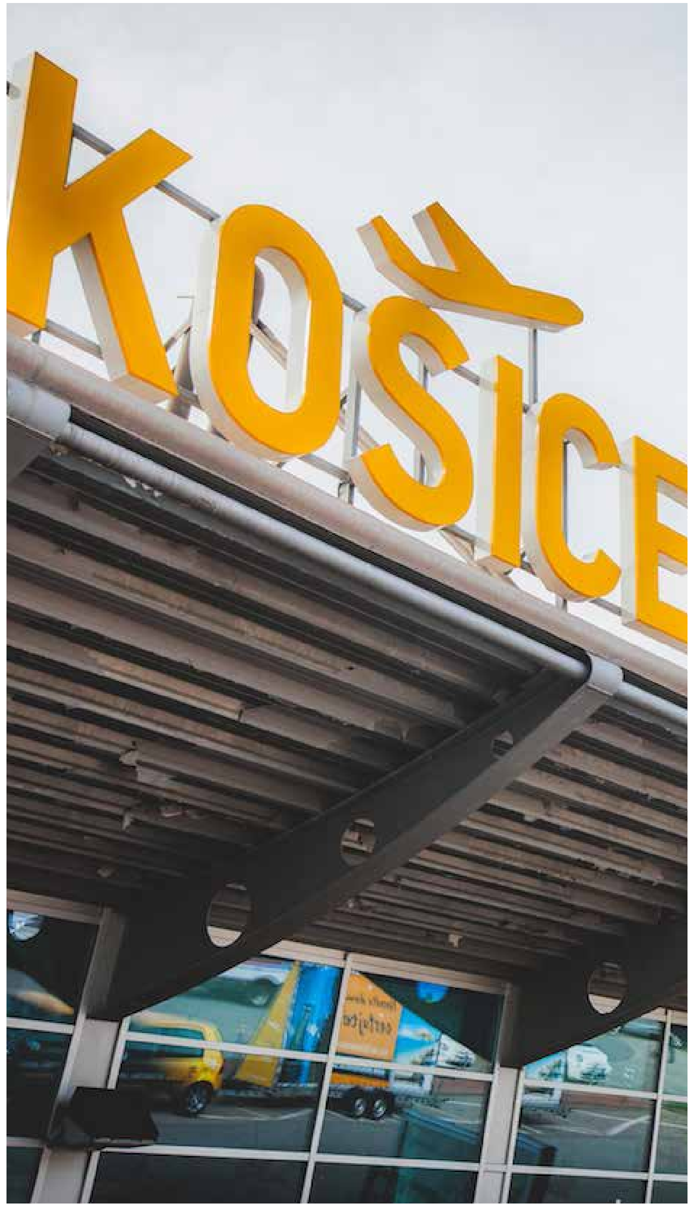
Attractive emission-free public transport to Košice International Airport

Trams are not yet used in public transport to Košice International Airport. Combining this most accessible mode of urban public transport with a hydrogen bus would create zero-emission transport.

Vehicles should be equipped with 60 kW fuel cells and batteries. The batteries will be the main source of electric power for an 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 a 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 is 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 the city district with an airport where a tram is accessible at The Pope Statue at Barca station. It is an opportunity to start propagating clean technology that will be rentable due to the acceptable price per journey at app. 4 Eur (still 3 times cheaper than a 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.

KOŠICE INTERNATIONAL AIRPORT

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



Community benefits, action plans 8

A fleet of hydrogen bicycles for green and efficient mobility of tourists

A year ago company ANTIK started sharing of the fleet of bikes to attract green way of healthy public transport. Another step is expansion with a fleet of electrobikes which need charging and quite an inconsiderable investment into maintenance service. That is why the potential of hydrogen bikes by maximizing range to 200 km and refueling into 2 minutes make it attractive. The critical as elsewhere is if Košice Self-governing Region will support the initiative with a built hydrogen refueling station, e.g.,at an attractive water area. In this case, very attractive and prospective is a thing about off-grid version solution, to be applicable in cyclo-tourist attractive areas across the region. Here, the 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 the first hydrogen refueling station in Košice city is essential and can be a strategic decision for the whole Slovakia in the first phase of deployment of hydrogen technologies. It could be the first regional hydrogen station in the country. The position in Košice is ideal due to the closestrefueling station in Vienna (Austria) in 600 km distance so in the range accessible for hydrogen car for one charge.

It will create an opportunity for the deployment of another type of small vehicles, esp. low-cost, high fuel-efficient, hybridized, light-weight vehicles specifically designed for usage inside big companies with high CO_2 emissions, airports, etc. and later for fleer of highly specialized cars such as police car, garbage trucks, etc. There are two ways how to do it. One is to build a 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 the UK (Midlands and Plymouth).

The first option in the Košice Region would be considered if in the near future they decide for a large-capacity electrolyzer and hydrogen production and recovery US Steel Košice, or Vojany power plant with nearby underground storage, or SPP-Distribution will be able to transport a mixture of hydrogen and natural gas in existing pipes. The second variants are more feasible even today.

Hydrogen infrastructure near water bodies and tourism

Another considerable potential is the development of small-scale mobile hydrogen production by electrolysis using renewable energy (photovoltaic panels, a combination of small wind turbines, a water mill, etc. near a water source (river, lake) to charge hydrogen bicycles, small cruise ships, jet skis, etc. in „off-grid" mode, i.e., without connection to the mains.It can potentially be used in several places where bike paths serve tourists during the season.In this way, hydrogen can be supplied to the local seasonal fleet of shared bicycles, cruise ships, and scooters.One provider would thus manage the fleet of hydrogen, electric bikes, and scooters not only in Košice but can variably change the location of the infrastructure in other localities near the water area with tourist activities.

One of the critical problems in this action plan may be the lack of a stable source of electricity. In this combination, a small cell, hydrogen storage in a pressure tank, storage of excess RES in a battery, and a fuel cell provide an elegant solution.

The mobile version of the cell can be installed in areas with the highest turnover of cyclists, where existing infrastructure or minimal investment in the bike path is needed. The best places for implementation are water areas such as Nad Jazerom, Bukovec near Košice, Zemplínska Šírava, Vinianske Lake, and Domaša on the border of Košice Region and Prešov Region, where there are or are developing other support activities, such as water sports centers.

In addition to bicycles, hydrogen cruise ships could be attractive. With the establishment of sports centers, parks, the number of tourists can increase rapidly.

Visualization

Another possible combination of preferred solutions is, e.g., in the broader area of Domaš (also the adjoining municipalities of the Košice Region), where the added value is the historical existence of the metallurgical industry with the old water mill as part of the museum.

Also,comparing the latest green technology such as hydrogen ore reduction with hydrogen vs. conventional iron production using coal and coke can be very interesting to teach visitors how we can help the Earth fight climate change and reduce CO_2 and greenhouse gas emissions, raising public awareness.

The above-mentioned green transport solutions for tourists require the so-called „Offgrid" solution. We already have highly specialized technical teams in Slovakia, which can offer „know-how" and have references from implementing successful projects with hydrogen and batteries abroad.A purely Slovak implementation is also possible (Antik Košice, Tesla Blue Planet Liptovský Mikuláš) in cooperation with renowned foreign manufacturers of electrolyzers, hydrogen storage tanks, and other technologies. At the same time, the proposed modular method would be an elegant, fast, and sufficiently advantageous action step near the reservoir Zemplínska Šírava.

Image: Visualization of off-grid hydrogen infrastructure at the water surface (source: Tesla Blue Planet s.r.o.)

The advantage of such a solution is clearly the modularity of such a system, while it can be adapted to the capacity and performance, the possibility of connecting RES (wind), or can also serve to share the infrastructure with electric cars, electric buses, etc.

Community benefits, action plans 8

Estimated price including a covered station for bicycles with an installed 10 kWp photovoltaic system with an area of 40 m², annual production of 10.2 MWe, a battery system for storing surplus energy with a capacity of 20 kWh, electrolyzers with an output of 2 x 2.4 kW, production of 45 g H_2 per hour ., the capacity of 5 kg with a tank volume of 2m³ and a filling stand for 20 hydrogen bicycles and 4 cruise ships is under an investment of 100,000 Euros.

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 Čermeľ brook, in the northern part of Košice city. The historical locomotive is a very nice nostalgic way how to meet with history and try to feel how the steam engine movesthe first industrial revolution using the burning of coal for propulsion. On the other hand, it producesa certain amount of CO_2 emission in a visible way (must say attractive to children). If one of the veteran locomotivesis rebuilt into a hybrid one, the public can compare traditional technology vs. the latest green technology approach. Nowadays, in times of energy transformation, this is one of the highly relevant actions, and investing in the locomotive which uses both hydrogen fuel cell and the battery can help to attract public awareness.Not to mention that, in addition to the track, hydrogen bicycles can be reconnected in the event that the cycle route is extended to the Aplinka recreational area.

Off-grid self-sustainable university dormitory for students

The concept could be based on using solar panels on the top of low-cost housing blocks which convert the 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, rainwater could be collected into a tank and later on distilled for use in an electrolyzer.

The hydrogen can be stored in 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 a water retention measure plan which is in line with the water management Košice Self-governing Region strategy.

Sightseeing tour flights

Another tourist action plan how to widespread the latest clean technologies to the public in the very near future should be is a hydrogen quadrocopter for visitor sightseeing flights around the Košice site (not only). Hydrogen fuel cell propulsion meets 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 fulfilling flight performance. It has more than a 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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