National Hydrogen Strategy: Ready for the Future

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“By implementing the National Hydrogen Strategy, Slovakia joined European Union countries which established a state framework to fulfil the goal of achieving climate-neutral society by 2050.”

Juraj Sinay

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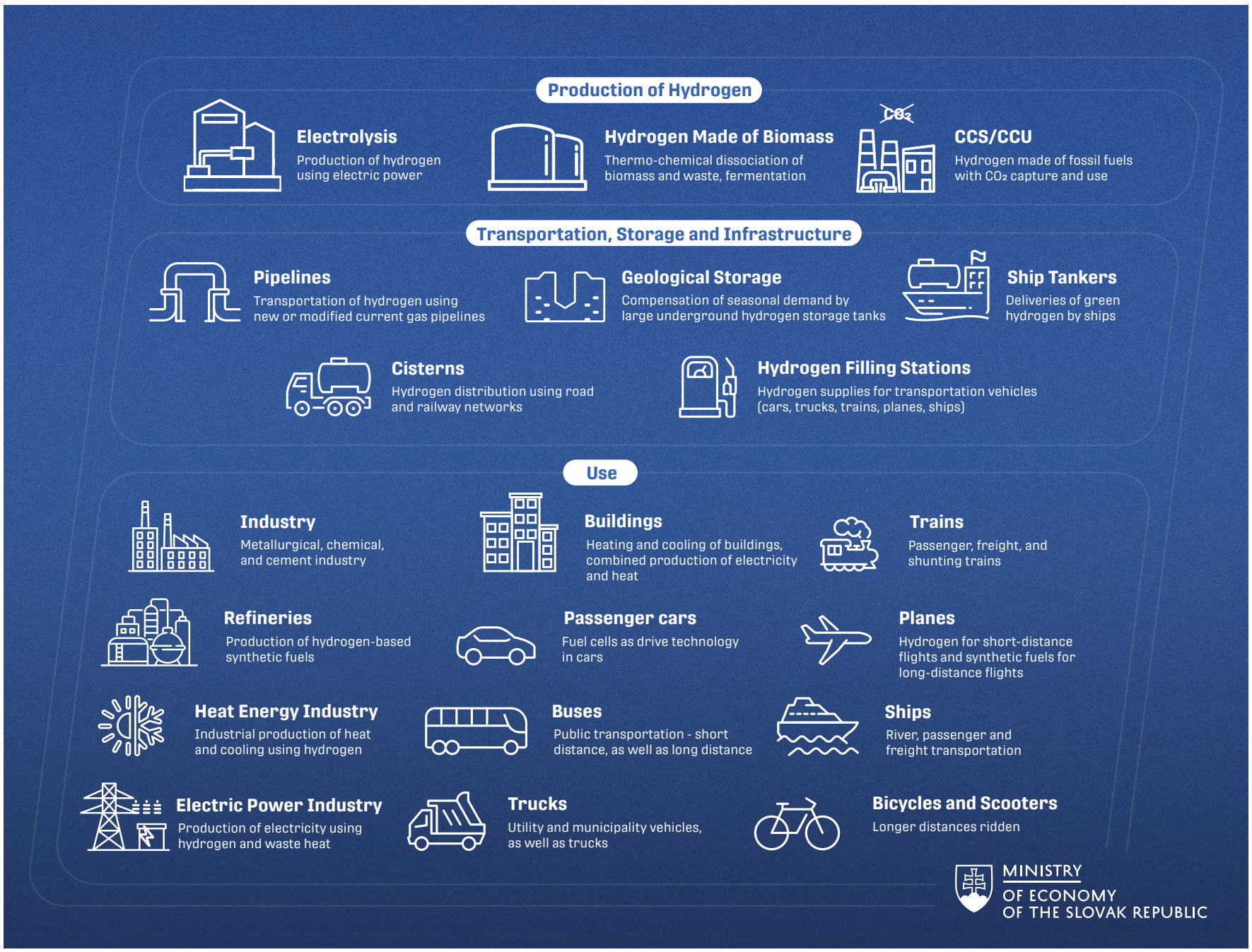
Preamble

The National Hydrogen Strategy (NHS) defines the strategic role of the state in use of hydrogen technologies in the Slovak Republic (SR) in the context of current development in the European Union (EU) member states. The goal of the NHS is to increase the competitiveness of the Slovak economy and strive for carbon neutrality, in line with the Paris Agreement, which Slovakia joined, as well as other strategic documents of the Union – in particular, the European Green Deal, New Industrial Strategy for Europe, and Europe's Moment: Repair and Prepare for the Next Generation. The strategy sets the terms for implementation of hydrogen technologies in line with the Long-Term Strategic Development Plan of SR[1,2] for 2030 and 2050. By 2030, the greenhouse gas emissions are expected to drop in the EU by 55 %. The document also recommends introduction of hydrogen activities in cooperation with other EU member states, as well as third countries.

Using hydrogen as part of the Slovak economy is in the interest of the nation. It is to be implemented by the Slovak government, working closely with various businesses and research, development, and education institutes, as well as regional authorities – in line with the measures specified in the NHS Action Plan.



1 https://www.minzp.sk/files/oblasti/politika-zmeny-klimy/nus-sr-do-roku-2030-finalna-verzia.pdf.

2 Integrated National Energy and Climate Plan /INECP/, ME of SR December 2019.

“The National Hydrogen Strategy is a fundamental document. It allows us to implement hydrogen technologies in Slovak industry.”

Richard Sulík

Baseline

Hydrogen is one of the elementary commodities of future economy. It is the feedstock at production of ammonia (NH_3), nitric acid (HNO_3), ammonium phosphate (NH_4NO_3), carbamide (CON_2H_4), and methanol (CH_3OH). Hydrogen is being largely used for hydrofining reactions in the petrochemical industry, as well as in metallurgy. Hydrogen may also be used as energy carrier.

In order to establish room for dialogue of specialists, the Ministry of Economy of the SR organised a conference titled “The Hydrogen Future of Slovakia” on 16 July 2020. The participants from industry, science, research, universities, and specialists of various areas of life supported the establishment of the platform which enabled the presentation of strategic plans and opportunities of the economy. Slovakia sent the message that it is joining the European Hydrogen Strategy for a Climate-Neutral Europe adopted by the European Commission (EC) on 8 July 2020.

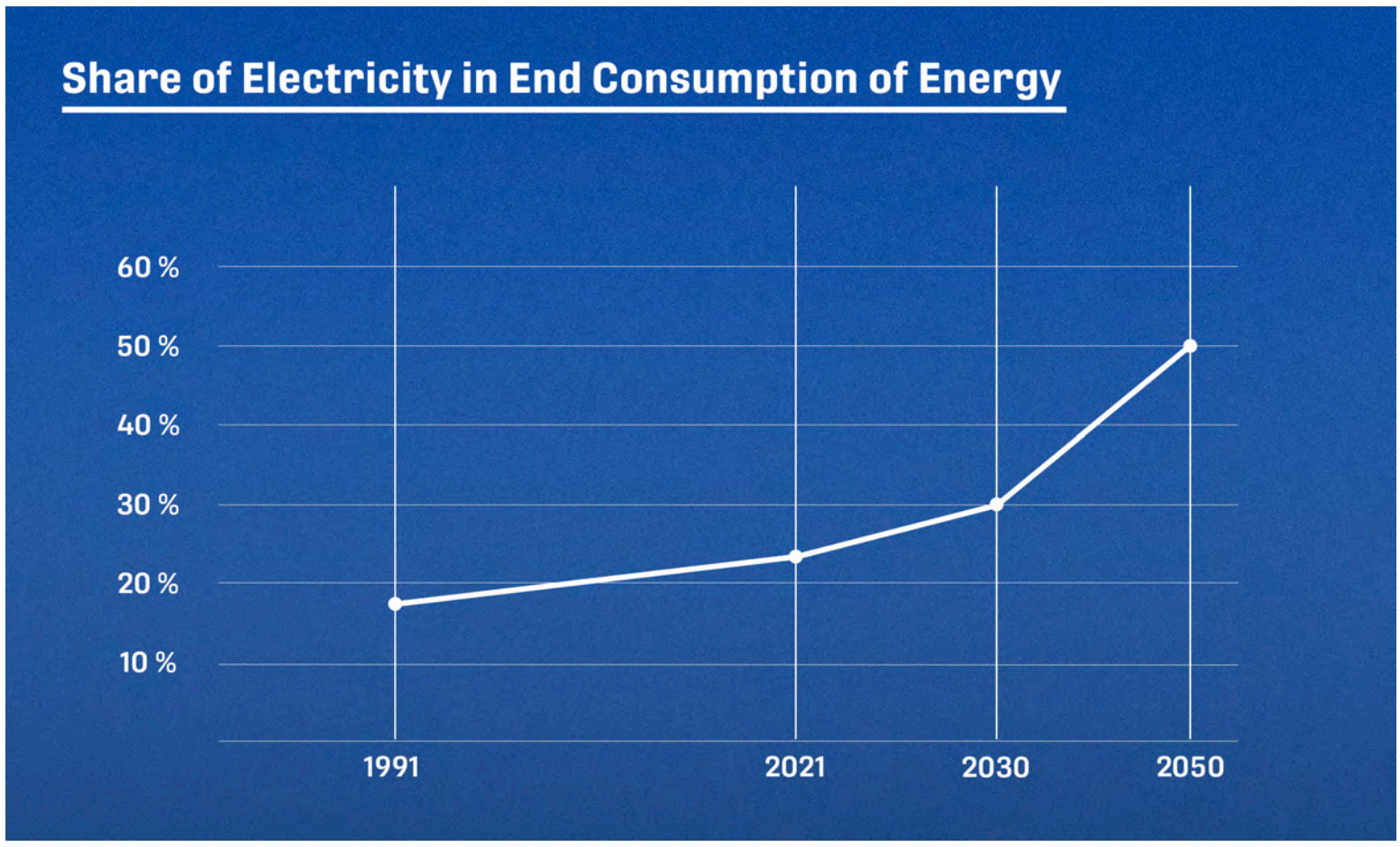
“If we want to be a carbon-neutral society by 2050, we have no choice but to focus on hydrogen-based solutions.”

Richard Sulík

Hydrogen Mission of Climate-Neutral European Union

The EU member states are implementing measures to support their competitiveness in the area of hydrogen production technologies. Cumulative investments in production of green hydrogen in Europe could be up to EUR 180-470 billion by 2050, and in the range of €3-18 billion for low-carbon fossil-based hydrogen. Analysts estimate that green hydrogen could meet 24% of energy world demand by 2050, with annual sales in the range of €630 billion euros[3].

Prognoses say that the energy consumption will grow significantly on the road to climate neutrality. The share of electricity in total energy consumption will grow from today's 23% to approximately 30% by 2030 and 50% by 2050. In comparison, this share has grown only by 5% over the last 30 years.



The increase in electricity consumption will have to be – in part – covered by renewable energy sources. By 2030, energy from renewable sources will have doubled its energy share to 55-60% and to nearly 84% by 2050. The remaining part should be covered by low-carbon options.

Over the last decades, the production costs of renewable energy have grown and this trend is expected to continue. Sufficient capacity of renewable energy is crucial for production of green hydrogen. A suitable regulatory framework will stimulate the market segments to invest more in this area. The combination of these aspects will make green hydrogen more attractive. Thanks to related economy of scale, its price will drop, too.

Using hydrogen technologies will allow more and more Slovak companies to participate in the transformation. This will create new infrastructure for production and implementation of selected types of devices and equipment. Hand in hand with strong international cooperation, Slovakia will become co-author of EU projects and policies.

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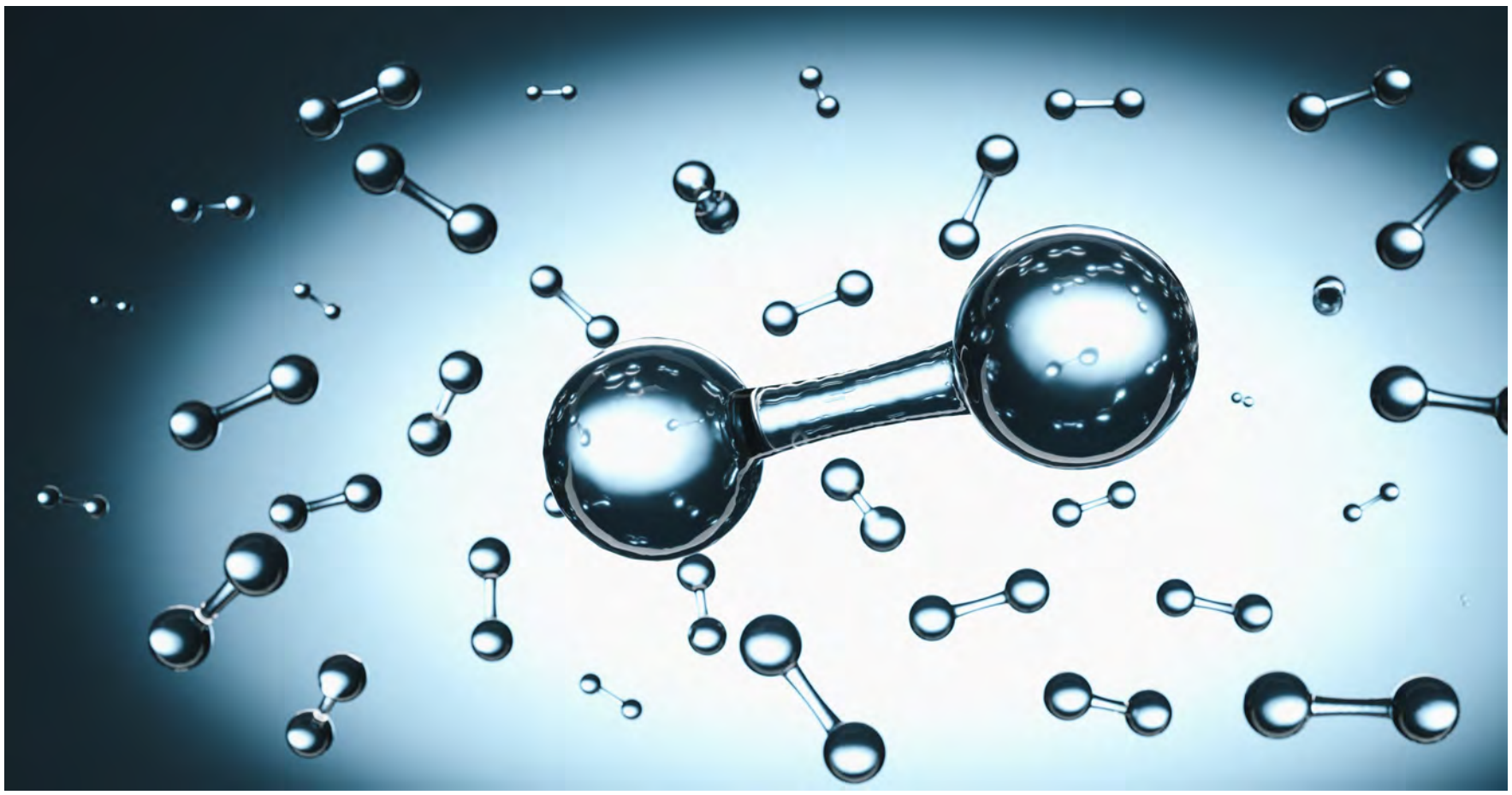
3 https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

“Slovakia should be using hydrogen as energy carrier in all its industrial branches and in public life where it is not possible to use electricity directly.”

Ján Weiterschütz

Definition of Hydrogen



Hydrogen (H) is the lightest element on Earth. It is common in its diatomic form as dihydrogen (H_2). A litre of hydrogen weighs approximately 90 mg (0.09 g), so it is 11-times lighter than air. In its natural form, hydrogen takes only the form of compounds – the most common ones being water and hydrocarbon mixtures, like oil or natural gas. Those are the base raw materials in industrial production of hydrogen. Due to this, unlike fossil fuels (e.g., coal or natural gas), which already contain accumulated energy, which can be released, when using hydrogen technologies, hydrogen needs to be produced by dissociation of other compounds. This requires initial energy in form of electricity or heat. Using fuel cells or direct burning releases energy to be used again.

In connection with the NHS, the classification of hydrogen types will be based on the production thereof:

1. Grey Hydrogen is being produced by processes based on using fossil fuels, like natural gas or coal. The greenhouse gas emissions of Grey Hydrogen are high over the course of its life-cycle[4].

2. Blue Hydrogen is produced the same way as Grey Hydrogen, but the carbon dioxide created at its production is being captured and stored, or used by means of CCUS[5] technology. Blue Hydrogen can also be produced by electrolysis of water or saline (at chloride production) using electrolysers powered by electricity from low-carbon energy sources[6]. At production of Blue Hydrogen, the greenhouse gas emissions must be below 100 g CO2eq/MJH2[7] (3.33 kg CO2eq/kgH2) over its life-cycle.

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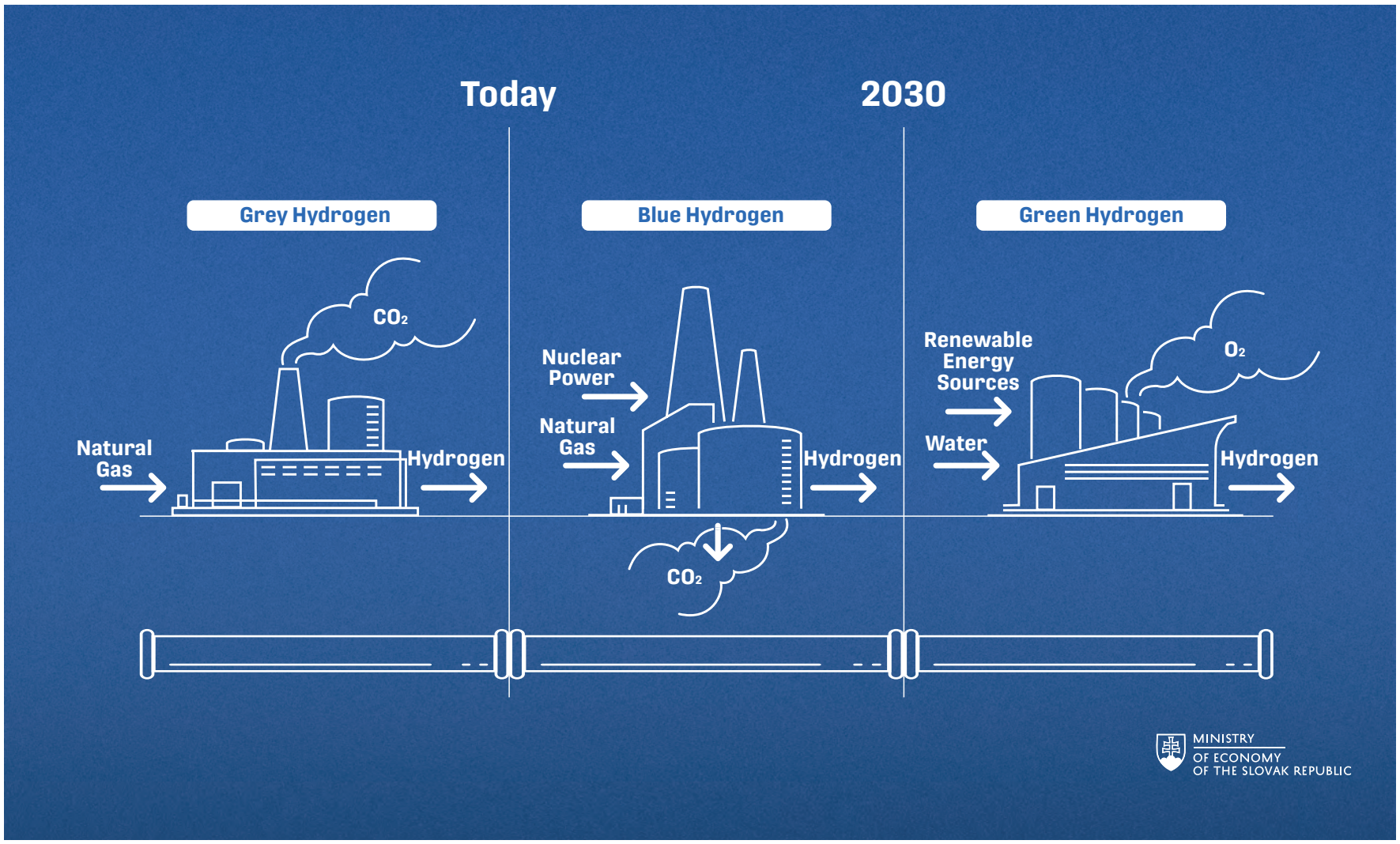
4 Hydrogen made of 237 g CO2eq/MJH2 coal = 28.4 kgCO2eq/kgH2 (Coal EU-mix, Cen gasification, Pipeline transport), hydrogen made of natural gas (NG 4000 km, Cen Ref, Pipe) 104.4 g CO2eq/MJH2 = 12.5 kgCO2eq/kgH2. Source: JRC technical reports, https://ec.europa.eu/jrc/sites/jrcsh/files/wtt_appendix_2_v4a.pdf, p. 27-30.

5 Carbon capture, utilization and storage.

6 At the production of Blue Hydrogen, it is possible to use nuclear power. Some specialised commentaries describe such hydrogen as purple, pink or yellow.

7 Sustainable Finance and EU Taxonomy: https://ec.europa.eu/finance/docs/level-2-measures/taxonomy-regulation-delegated-act-2021-2800_en.pdf.

3. Green Hydrogen is being produced by electrolysis of water using electrolyser powered by electricity of renewable energy sources[8].



In specialised application, this hydrogen is also called turquoise or white[9].

Below, we will be meaning Green Hydrogen and Blue Hydrogen when referring to hydrogen. The comparative table for hydrogen definition of the Hydrogen Strategy for Climate-Neutral Europe and the terms used in this NHS are in Annex 2 below.

[8] Production of 1 kg of hydrogen requires 9 l of water. The water does not need to be fresh. It can come from water treatment facilities, (underground) rivers or the sea. For the production of 10 mil tons of hydrogen, EU uses 0.0048% of its water sources a year. https://hydrogen.spade.be/wp-content/uploads/2021/04/Hydrogen-production-water-consumption_fin.pdf.

[9] Turquois Hydrogen – produced by thermic fission of methane – and White Hydrogen – produced by the technology of hydraulic fission.

Hydrogen Usage

Using hydrogen is one of the ways how to boost Slovak energy management, given that hydrogen:

- can be produced by water electrolysis and can be stored over long periods of time;
- is universal energy carrier;
- provides options for decarbonisation in various segments – in particular in those where using other carbon-neutral technologies is not feasible or cost-effective;
- can be effectively used as raw material in chemical and petrochemical industry, or in steel production, as (partial) replacement of solid fossil fuels and coke made of black coal, as well as in cement production;
- can be used as fuel of transportation vehicles in form of fuel cells, and can be used to produce synthetic fuel after being processed with CO_2; and
- can be used as energy carrier in heat production.

In order for the hydrogen usage actually helping decarbonising the industrial processes and replacing fossil fuels in transportation and energy, all the areas of its usage must produce only minimal or zero CO_2 emissions. Those are the processes of hydrogen production, transportation, storage and use in end technologies and products.

In order to achieve the final goal of decarbonisation, Slovakia plans to use hydrogen as energy carrier in its industry segments and public life – everywhere where using electricity is not possible or cost-efficient.

Thus, hydrogen production technology must be based mainly in renewable and – for some transition time – low-carbon energy sources. The goal of the Slovak government is to support production and use of Green Hydrogen, as well as the necessary infrastructure to implement those activities. They will also support production of Blue Hydrogen.

Based on the plans of the Hydrogen Strategy for Climate-Neutral Europe[10] and the financial support instruments of the EU, Slovakia will support the education, research, development and innovations of hydrogen usage in Slovak economy in order for it to stay competitive on the EU market.

In the mid-term and long-term, the demand for hydrogen usage horizon will keep growing and change from its current form, described in other parts of this strategy. Therefore, it is important for Slovakia to become an adequate partner in international consortiums. It will be important to set terms and goals for effective investments[11] into hydrogen economy, so that private investors can participate in its development, too.

The goal of Slovakia will be to establish terms for production of hydrogen in order for Slovak economy to be as independent as possible in terms of its import. The priorities will be aligned with the updated Strategy for Smart Specialisation for Research and Innovations (RIS3) for the programming period of 2021 – 2027.

Based on the sources at hand, at the production of Blue Hydrogen, Slovakia will focus on use of electricity from nuclear power plants as the preferred low-carbon renewable energy source.

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10 Hydrogen Strategy for Climate-Neutral Europe – COM /2020/ 301 of 8 July 2020.

11 For example: parks, clusters, joint ventures.

Usage in Chemical and Petrochemical Industry

Hydrogen is one of the raw materials of the chemical industry used by several chemical companies[12]. Next to the role of hydrogen as a chemical substance, it is anticipated that hydrogen will also play a role of energy carrier at various chemical reactions in energy-demanding segments of production.

Most of the current hydrogen production is bound to the use of fossil fuels, natural gas and coal. Thus, when producing it, CO_2 and other greenhouse gases are being produced, as well[13]. This requires the search for perspective solutions to replace this type of hydrogen production or its modification by introduction of capture technology or re-using the produced greenhouse gases. Chemical industry consumes more than 200 000 tons of Grey Hydrogen a year and is both its biggest producer and consumer.

12 For example: Duslo, a.s. Šaľa, Slovnaft,a.s. Bratislava, Fortischem a.s. Nováky, US Steel, a.s. Košice.

13 For example: CH4-methane, N2O-nitrogen oxide; GHG-global greenhouse gas emissions, F-gas – fluoridated gases.

Usage in Steel Industry and at Metallurgic Processes

The steel and metallurgic industries are major part of Slovak economy and the biggest producers of CO_2 emissions[14]. According to international statistics, steel industry produces roughly 7 % of CO_2 emissions globally, while in Slovakia, it is 13.9% (data for 2018)[15].

Slovakia uses hydrogen as inert gas in protective atmospheres at thermal processing of steel products or at direct reduction of the iron ore as replacement of blast furnace technologies in metallurgic processes[16,17,18], which all are source of high amounts of emissions.

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14 In 2020, emissions related to production of steel in US Steel Košice amounted to 37% emissions of Slovak emission allowances within the SET; in 2019, it was 19%.

15 Eurostat https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en, https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1.

16 IEA – Iron and Steel Technology Roadmap (October 2020), https://www.iea.org/reports/iron-and-steel-technology-roadmap.

17 Pei, M., Petäjäniemi, M., Regnell, A., Wijk, O.: Toward a Fossil Free Future with HYBRIT: Development of Iron and Steelmaking Technology in Sweden and Finland. Metals 2020, 10, 972.

18 LEGEMZA, Jaroslav - FRÖHLICHOVÁ, Mária - FINDORÁK, Róbert: Biomass and Carbon Fuels in Metallurgy / 1st vol. - London : Taylor & Francis Group - 2020. - 292 p. [print, online]. - ISBN 978-0-367-22242-0.

Usage in Gas Industry

The development of markets for hydrogen usage in Slovakia requires the introduction of innovative logistic solutions for its transportation, distribution and storage. We will be using the current capacity of the transmission and distribution grids of natural gas. For storage of hydrogen, we will use the current underground natural gas storages.

In the future, we will be looking for solutions for technological modification of the current Slovak natural gas transmission network, its expansion and connection to other European natural gas pipelines.

The government will inspect the options of the natural gas transmission network in order to utilize it to transport hydrogen, unless its full capacity is used for transporting natural gas. At the same time, we will be looking for solutions of technological modifications to the natural gas distribution grid for the inland distribution of hydrogen, depending on the hydrogen market development.

The gaseous hydrogen can be blended into the natural gas distribution network, which is well-developed in Slovakia. It will be possible to repurpose it and use it to transport and distribute hydrogen. Before that, it will undergo a detailed expert analysis of its technical condition. Use of hydrogen and various forms of hydrogen-containing gas mixtures will play a crucial role at decarbonisation of heat economy[19].

[19] Hydrogen in its gas state can be mixed with the natural gas distribution network, which is well-developed in Slovakia. The maximum safety limit of hydrogen to be mixed will be subject to thorough research and testing of its impact on the materials used and the gas equipment components. We will identify and implement the necessary technical modification to the natural gas network. They will be used to transport hydrogen only after a detailed expert analysis of the technical condition of the network (e.g., pipeline, equipment to reduce/increase pressure, fittings, flowmeters etc) and presentation of additional safety elements and components for hydrogen management, if necessary. Use of hydrogen and various hydrogen-containing gas mixtures will play a major role in decarbonisation of the heat economy. An important step of research and development will be identification of suitable technologies and procedures of adding and separating hydrogen to and from the natural gas mixture.

A separate group of hydrogen production is equipment using the principles of high-temperature pyrolysis and gasification which process various non-recyclable waste. Synthesis and pyrolysis gas which is rich in hydrogen and processing of (CCU) CO_2 represents a source of blue hydrogen. This gas can also be used in other energy and petrochemical applications[20]. Technology of natural gas pyrolysis plays a major role, as it is used to produce not only hydrogen, but also solid carbon.

Usage in Heat Management

In the segment of heat management, in the INECP, Slovakia committed to use the measures to reach the national contribution of the SR in energy effectiveness with the goal of increasing it to 30.3% by 2030, what is a little below the European goal (32.5%). In order to achieve this goal, the sectors of industry and construction technology will be crucial.

When compared with the conventional production of heat in heating plants and by cogeneration, hydrogen produced of variable renewable energy sources can – under some circumstances – have positive impact on reduction of primary energy consumption of the SR. One of the prerequisites is the use of seasonal accumulation – i.e., accumulation of hydrogen in times of energy surpluses in the system, and its use in the heat economy when there is electricity shortage or heat consumption peek (in winter). Due to high electricity prices and lack thereof, which are typical for the European market during the heating season, in order to achieve the desired impact of use of hydrogen on the energy end prices, the hydrogen accumulation would have to happen in summer.

The quantification of the efficient rate of replacing natural gas by hydrogen in order for it to be used in heat economy requires further analyses of the ability of the electricity grid to cover the additional electricity

[20] Waste heating with air inflow (gasification) or without air inflow (pyrolysis) allows thermic decomposition, producing gas, containing, in particular, hydrogen, CO, CO_2, and N_2. The hydrogen content is up to 55%.

consumption and of the gas network to accumulate and store the required hydrogen volumes for a long period of time.

Usage in Transportation

Introduction of fuel cells in transportation may create a market for new drive systems. Their usage is efficient for public transportation, freight and utility vehicles in inter-town transportation, as well as trains, planes, boats, and other machinery in construction, agriculture, forestry, or defence sectors. Corporate logistics also represents an opportunity for use of vehicles with hydrogen drive (e.g., forklifts and other handling machinery), and so do railway shunting locomotives, which are currently mostly powered by combustion engines[21].

The development in the area of vehicle powertrains indicates that application of fuel cells is becoming a real alternative to combustion engines and battery (accumulator) based electromobility. However, due to technical reasons,[22] they are inter-connected[23]. In order to use hydrogen in transportation, Slovakia will build a network of refuelling station based on the transportation concentration and the expected consumption of hydrogen in the given region.

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21 A potential alternative to hydrogen drives are drives using synthetic fuels.

22 Strategy of Electromobility Development in SR and Its Impact on National Economy of SR, UV-29689/2015.

23 Revision and update of National Political Framework for Alternative Fuel Market Development, UV 557/ 2019.

Decarbonisation due to hydrogen usage reduces some negative impacts of mobility on the environment. It can be reached by:

- ***use of transportation vehicles with hydrogen drive in general transportation;***
- ***production of transportation vehicles with hydrogen drive, search for innovative opportunities in domestic development; and by***
- ***transformation of production programmes of producers of parts and drive modules using hydrogen – with domestic development results being preferred.***

At the same time, this represents a big opportunity for transformation of vehicle production, which is the biggest segment of the Slovak industry.

Anticipated Hydrogen Consumption

Domestic hydrogen consumption will be covered by electrolysers to be constructed and other low-emission hydrogen production methods[24].

The biggest consumers of hydrogen in Slovakia will be the sectors of industry, transportation, and later, energy. The main goal will be to cover as much of the hydrogen needs as possible from domestic sources only. However, due to the energy demands related to hydrogen production and its anticipated consumption in the SR, in the long-term, it will be necessary to cover some of the consumption by import from abroad.

Based on the current hydrogen use, it can be assumed that by 2030, Slovakia will consume 200 kilotons of hydrogen a year. We anticipate that with intense usage of hydrogen, the consumption will reach 400-600 kilotons by 2050 – 90% of which will be covered by low-carbon sources.[25]

Increase of prices of emission allowances and reduction of hydrogen production costs may lead to partial replacement of natural gas by hydrogen in heating and cooling segment[26]. The priority interest will be the effort to cover the hydrogen needs in industry by as many domestic sources as possible.

The growth of hydrogen consumption for various intensity scenarios of its use should be taken into account when planning the expansion and modernisation of the energy infrastructure. The impact of hydrogen production on electricity consumption in the SR. The scenarios of hydrogen use will need to be taken into account in planned revisions of the Integrated National Energy and Climate Plan for 2021-2030[27].

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24 From natural gas with capture and use of carbon; from biomass or communal un-sorted waste.

25 Prognosis of hydrogen consumption and production in Slovak economy by 2050 will be part of the Action Plan of Measures for Successful Implementation of the National Hydrogen Strategy.

26 SPP-d is testing the impact of adding up to 20% of hydrogen to natural gas to the distribution network.

27 Integrated National Energy and Climate Plan for 2021-2030.

Transformation of Slovak Industry

Within the INECP and the National Political Framework of Alternative Fuel Market Development, Slovakia committed to gradual decarbonisation of its national economy. The main quantified goals of the INECP in industry for 2030 (when compared with 1990) are:

- reduction of greenhouse gas emissions in industry and energy by 43%[28] (EU ETS);
- reduction of greenhouse gas emissions in other national economy sectors (buildings, transportation, agriculture, and waste management) by 20% (non-EU ETS);
- energy efficiency goal of 30.3%;
- renewable energy sources share of 19.2%; and
- increase of renewable energy source share in transportation by 20% by 2030.

Transformation Options

In the long-term, hydrogen technologies are one of the means of how to transform industrial processes to carbon-neutral ones and to maintain the competitiveness of the Slovak industry.

Their added value lies in the fact that:

- they will allow production and industrial procedures which use hydrogen as production input or processing in form of intermediate product and reduce emissions;
- companies in the machinery and electrotechnics industry get the opportunity to produce equipment to produce and use hydrogen; this will introduce new products and industrial solutions with high added value to the production portfolio of Slovak companies – ideally, using own development; it is highly likely that they will – based on main industrial trends – operate using the principles of smart industry[29]; given the expected dynamics of hydrogen development, there is also the opportunity for industrial subjects with export potential; technological solutions require the cooperation of research capacities of universities and scientific institutions, as well;
- in chemical and metallurgic industry, as well as in the energy segment, they will allow direct implementation of hydrogen in production processes; and
- new industrial solutions using hydrogen in electroenergy, heating and gas sector will emerge; using local energy in production processes will increase the added value[30] of the final product.

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[28] Current national goal – is planned to be revised shortly.

[29] Key industrial megatrend based on the principles of Industry 4.0, as well as the Slovak strategy of Smart Industry.

[30] For example, in processing segment, establishment of new operations for primary raw material processing; production of cellulose and paper, metallurgy, foundry industry, and pressure forming, glass industry, production of primary plastic etc.

Increased Hydrogen Production and its Use

Effective and quick application of hydrogen technologies in Slovakia needs sustainable hydrogen production. Significant domestic market may be a signal to international partners, indicating the ability of the Slovak hydrogen industry to take part in international hydrogen projects. In this connection, it will be necessary to look into to the possibility of electrolyser production and their construction and use at hydrogen production.

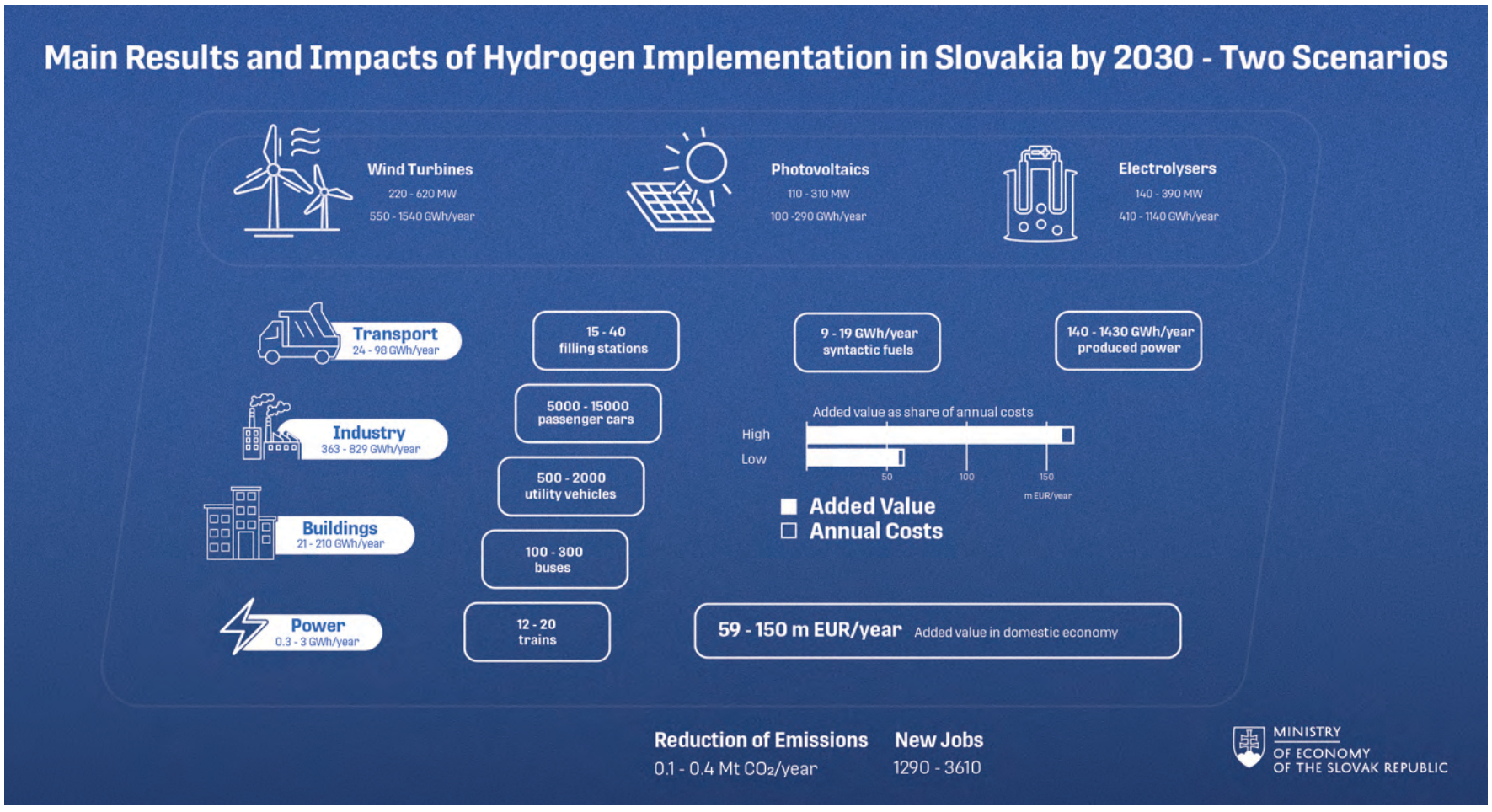
In the strategic vision on climate-neutral EU defined in the EC announcement of Clean Planet for All of November 2018, it is anticipated the hydrogen share in the energy mix of Europe to grow from 2% to 13-14 % by 2050.

Hydrogen production will require building equipment to produce electricity from renewable and low-emission energy sources. In Slovakia, this means using electricity of reserves of our nuclear power plants.

Another area in which Slovakia can potentially contribute to development of global hydrogen management is the development and production of materials for transport and storage of hydrogen.

Transformation Goal of Carbon-Neutral Mobility

The EU and Slovakia as such committed to significant cut-backs in greenhouse gases and decarbonisation[31]. The transportation sector, which is using smart technologies and new business models to transform into a more complex mobility sector, offers a large variety of options for use of hydrogen. In the areas where it is impossible or too expensive to use direct or indirect (battery) electricity solutions, hydrogen technologies represent a viable alternative.



[31] The share of energy of renewable sources in gross final energy consumption in transportation will grow from the estimated 8.9% in 2021 to 14% by 2030 (INECP 2019), Strategy for Sustainable and Smart Mobility – directing the European transportation to the future.

Government Measures

In its NHS, Slovak government creates a coherent framework for use of hydrogen in its full chain. It will include hydrogen production, transportation, distribution and storage, as well as use and production of products, technologies and components for hydrogen management, including all the necessary safety elements and components.

The possibility to use hydrogen as energy carrier offers solutions for decarbonisation of energy and industrial processes. In case of low-carbon hydrogen, it is possible to efficiently decarbonise a whole spectrum of economy – in particular, if direct electrification of industrial processes or transportation in its new forms is limited.

This allows the Slovak government to implement policies addressing the challenges related to protection of environment and decarbonisation as such. At the same time, this creates an opportunity for making industry, energy and transportation more efficient. Using science and innovations, the competitiveness in the individual economic sectors of the SR will be boosted.

In order to implement its policies, the Slovak government will accelerate the establishment of legislative framework and financial terms for implementation of hydrogen technologies. In the EU, we expect rapid growth in consumption and use of hydrogen in relevant areas of industrial technologies, energy, and gas industry. The NHS sets terms for Slovakia to become one of the countries with hydrogen technologies implemented in measures to secure competitiveness and achieve the goal of carbon neutrality of the EU by 2050.

These goals can only be achieved by efficient cooperation of research, education and innovations segments, related to use of hydrogen and hydrogen technologies, and the industry.

Their partnership will lead to transformation of several sectors as part of structural change of Slovak economy, due to the excellence of the most competitive sectors, in line with the Strategy for Smart Specialisation of the Slovak Republic 2021 – 2027 (SK RIS3 2021+).

The Slovak government will participate in:

- implementation of measures to use low-carbon hydrogen and its compounds in transportation;
- implementation of policies of use of low-carbon hydrogen technologies in the relevant areas of national economy;
- establishment of a common standard for low emissions of CO_2 as part of the implementation chain of low-carbon hydrogen;
- introduction of general terminology and criteria for certification of process quality based on use of low-carbon hydrogen over its full cycle – from production, through transportation and distribution, to its use;
- introduction of legislative and regulatory measures and safety regulations to support the readiness of the gas infrastructure for transportation, distribution, and storage of hydrogen; and
- support of research, development, and innovations related to hydrogen technologies.

In order to secure sufficient volumes of hydrogen produced in Slovakia or purchased from other countries which can produce it cheaper and to use it on a large scale, the Slovak government needs to:

- draw up policies to stimulate demand in sectors of end use of hydrogen, connecting goals in the area of decarbonisation;
- implement supporting measures, making the establishment of innovative products, technologies and industrial solutions for hydrogen production and processing in Slovak industry and energy;
- participate in preparing a common standard for low CO_2 emissions during the production of hydrogen, as well as over its execution cycle, which is to be implemented in the respective regulation;
- introduce common terminology and hydrogen certification criteria;
- secure participation of Slovakia in setting-up a pilot programme to support production of low-carbon and recycled steel and basic chemicals;
- take into account scenarios of hydrogen production in national strategic documents from the perspective of impacts on electricity consumption and development of energy infrastructure, as well as the electricity source;
- as part of the legal framework of support of renewable energy sources, establish conditions for issuing guarantees of origin for hydrogen produced of renewable energy sources in form of self-consumption and create conditions for expanding the guarantees of origin for hydrogen from low-carbon production, as well; and
- evaluate and suggest supporting measures to stimulate the readiness of gas infrastructure to transport, distribute, and store hydrogen.

NHS Financial Instruments

The European Commission's European Green Deal[32] – plan of the European Commission of green transformation of the European Union's economy in order to achieve sustainable future – acknowledges the potential of hydrogen to meet the EU goals to reach climate neutrality. The development of hydrogen industry is very interesting for Europe – in particular, as an emerging market.

The EC anticipates that Europe will become world leader in use of Green Hydrogen.

At the same time, the Member States acknowledged the potential of the growing market by recommending support of hydrogen technologies on the national level. Financial instruments supporting the NHS goal implementation are:

- Recovery and Resilience Facility[33] designed for investments and reforms focusing on green and digital economy;
- European Union funds for the programming period of 2021 – 2027[34];
- Fond for Fair Transformation, which has previously been connected with coal-mining regions, and covers regions with energy demanding industry (Košice), as well;
- Strategic Investments Instrument, which is to mobilize private investments with the support of European Investment Bank and national supporting banks;
- Connecting Europe Facility – grants for financing respective infrastructure, hydrogen filling stations or the adjustments to gas networks;
- ETS Innovation Fund linked to emission trading is to mobilise investments to innovative low-carbon technologies in the volume of around 10 billion euros (depending on the price of carbon) in 2020-2030 – the first call was announced on 3 July 2020;
- Modernisation Fund which is designed to fund investments to modernisation of energy systems and increase of energy effectiveness;
- at the same time, the European Commission will promote international projects covering the full value chain by allowing state subsidies for important projects of common European interest (IPCEI);
- InvestEU Fund, which will provide 30% of its funds to support activities related to solutions for implementation of climate changes[35];
- EU mechanism of funding common projects of use renewable source energy, which will allow support of blanket introduction of innovative technologies; the mechanism can be combined with other EU instruments[36];
- Envirofond; and

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32 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

33 Recovery and Resilience Facility - https://ec.europa.eu/info/business-economy-euro/recovery- coronavirus/recovery-and-resilience-facility_en.

34 Support of activities in research, development and innovations is possible only for measures/projects which are in line with the priorities of the Updated Strategy for Smart Specialisation of the Slovak Republic (SK RIS3 2021+) and will be implemented in form of cooperation of public organisations and companies.

35 https://eur-lex.europa.eu/legalcontent/SK/TXT/PDF/?uri=CELEX:52018DC0773&from=EN.

36 https://eur-lex.europa.eu/legalcontent/SK/TXT/PDF/?uri=CELEX:52020DC0564&from=EN.

- state budget investment aid.

The implementation of hydrogen chain in the respective industrial branches in the EU member states will enable the direct and indirect creation of a million jobs[37].

In line with the EU priorities, the Recovery and Resilience Facility is designed to support the restart of economies with the priority being investments to green and digital technologies. It creates opportunities for funding new investments and reforms, priorities of which are listed in the document of Shaping Europe's Digital Future[38].

Among the other alternatives and funding options to reach the NHS goals, there are public and private partnerships, suitable for large infrastructure projects.

Another possibility of funding is venture capital, being a type of capital funding providing entrepreneurs and research organisations with the option of how to acquire funding prior to starting their activities or generating income or profit.

Other Tools of Slovak Government

Next to financial support, Slovak government focuses on other types of support of development of hydrogen technologies. According to the International Energy Agency[39], individual governments can support the development in this area by applying these following measures:

- harmonizing standards and elimination of legislative obstacles at introduction of solutions using hydrogen;
- efficient use of regulatory tools;
- support of research, development and share of knowledge in application of hydrogen technologies;
- creating long-term signals to support the trust of investors;
- stimulating the commercial demand of hydrogen;
- implementation of measures to mitigate risks related to use of new technologies in the full implementation cycle of hydrogen[40]; and
- elimination of obstacles and adopting measures to reduce the price of own electricity consumed.

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[37] http://ec.europa.eu/energy/sites/files/hydrogen_strategy.pdf.

[38] Shaping Europe's Digital Future.

[39] The Future of Hydrogen – International Energy Agency - https://www.iea.org/reports/the-future-of-hydrogen.

[40] For example, the adoption of this Strategy, being a commitment of the Slovak government to develop the use of hydrogen, amendments to legislation, standards, and other environment aspects to support business with hydrogen, adjustment to other government and economical policies and other strategic documents for consistent support of research, development and innovations, as well as other environment aspects allowing market return of investments.

Roles of Research and Development

Generally speaking, results of current research will become innovations of future. In the framework of hydrogen technologies, activities in this area will be in line with the implementation of Strategy for Smart Specialisation of the Slovak Republic (RIS3) and application of European Union policies, focusing on:

- management of key pilot projects in research and development to support the value chains of hydrogen;
- presenting proposals to calls within the Innovation Fund, which will support solutions to improve the system of glasshouse gas emission allowance trade in the EU;
- preparation of calls focusing on innovations in hydrogen technologies in regions using grey hydrogen;
- establishing international partnerships and preparation of calls for projects of bilateral/multilateral applied research and industrial development;
- establishing partnerships in hydrogen usage; and
- participation of Slovakia in EU programmes (Hydrogen Europe association, which is partner of the EU at the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)) and International Energy Agency (Technology Cooperation Programme H2 – TCP H2), Horizon Europe.

Active involvement of Slovakia in the areas above will speed up the transformation of several industrial sectors.

This will lead to establishing conditions for networks of research activities related to hydrogen in cooperation with international partners. Participation in functional consortiums to solve science and research projects will be funded by the EU. The terms should motivate universities, research institutions, as well as public and private sector in taking part in preparation and implementation of new study programmes focusing on application of hydrogen technologies in the environment of the Slovak Republic.

In order to develop initiatives to use hydrogen technologies in Slovakia, the EU will define support schemes for applied research with the goal to use the research results by businesses[41]. They will focus on motivation measures for organisations in science and research, in order to take active part in introduction of innovations and application of the achieved results in practical life[42].

Basic and Applied Research

In order to secure and focus disponible capacities on basic and applied research and innovations, the Centre for Research of Hydrogen Technologies (CRHT) of the Slovak Republic, seated in Košice, was founded. The centre will be an open organisational structure, accepting members into its structures from all academic and research institutions in the industrial and public sector of the SR, as well as from foreign entities. The CRHT will support active dialogue with the industry. Some priorities of the basic and applied research are listed in Annex 3 a.

For specific research and innovation projects, the centre will be able to establish competence centres in Slovak regions.

The CRHT's ambition is to actively participate in establishment and forming the contents of study programmes containing all stages of the hydrogen chain in the Slovak university environment, as well as in the dual education system at various levels of specialised studies in the individual hydrogen chain stages. The centre will actively co-create conditions to support excellent scientists[43] and talents of new generation of experts – for example, by using exchange programmes of the European education and research environment. It will be looking for new options to connect education and research at universities – in cooperation with partners of the industry.

CRHT will be funded by several sources (public funding, private funding, and EU funding).

Development and Innovations

We will focus on projects supporting the expansion of Slovak innovation ecosystem and leading to development of hydrogen start-ups[44] and spin-offs[45] in the area of application of hydrogen technologies, as well as significant scale-up of current companies[46]. The key goal is the use of knowledge of domestic research and development to support market competitiveness of corporate innovations.

As a result, the position in international development and innovation partnerships with high share of added value in Slovakia will grow and sustainable and well-paid jobs will be created.

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41 For example: EU funds, IPCEI projects, EEA Financial Mechanism, Norwegian Financial Mechanism, Swiss Financial Mechanism, Agency for Support of Science and Research of the SR, agencies of the Ministry of Education, Science, Research and Sports of the SR of VEGA and KEGA, stimuluses for support of science and research, state support schemes for research and development of hydrogen technologies, PPP projects.

42 Applied research, development and innovations in production, transportation, distribution and storage of hydrogen are described in detail in Annexes 3a and 3b.

43 For example: Erasmus+, Horizon Europa programmes.

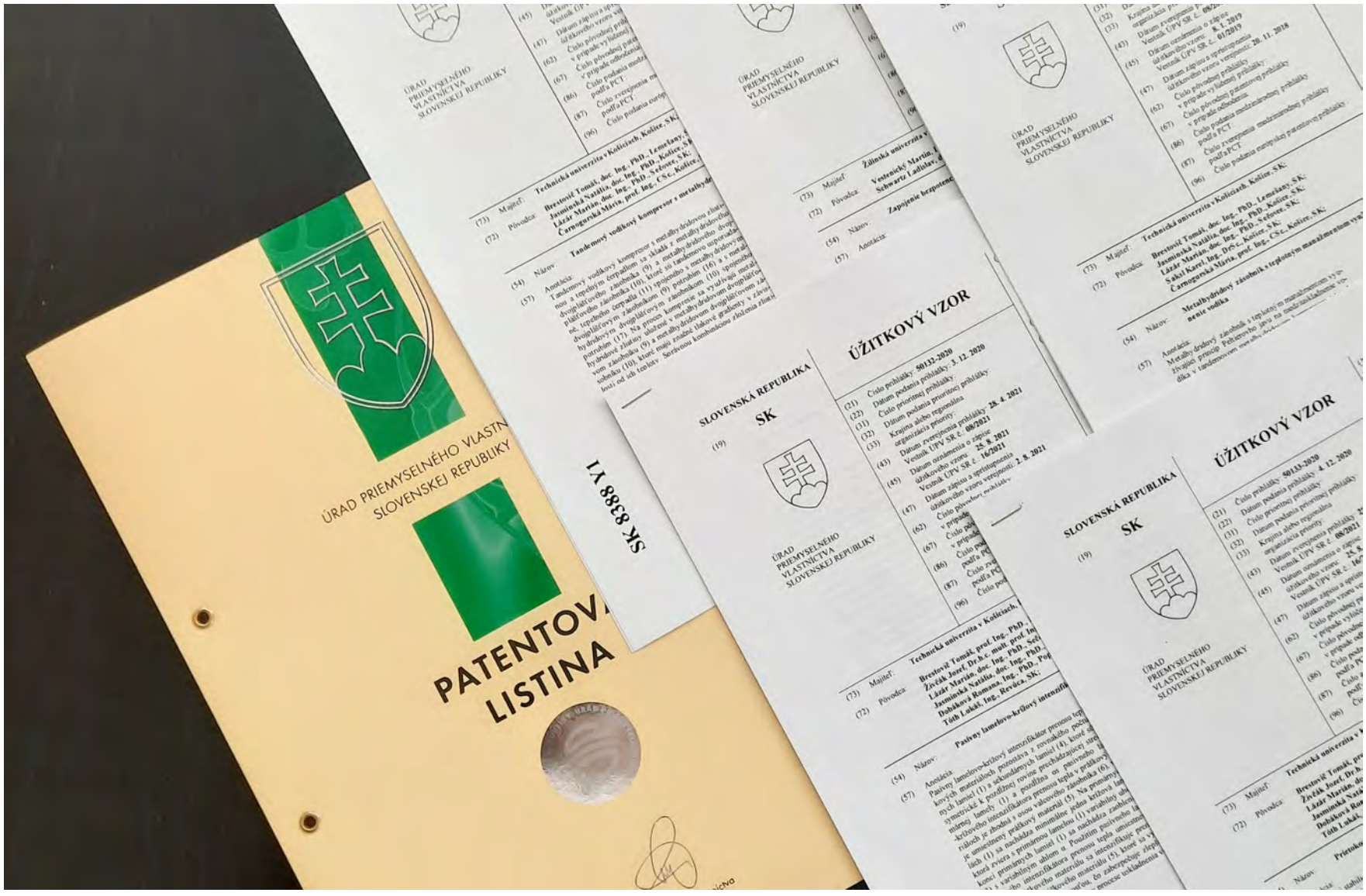
44 Start-up – a new project or starting company.

45 Spin-off – company established for the purposes of commercialisation of intellectual property established by a research organisation.

46 Scale-up – current company with the potential to expand.

Example of projects as part of innovation activities related to development of hydrogen technologies are listed in Annex 3 b.

Protection of Intellectual Property



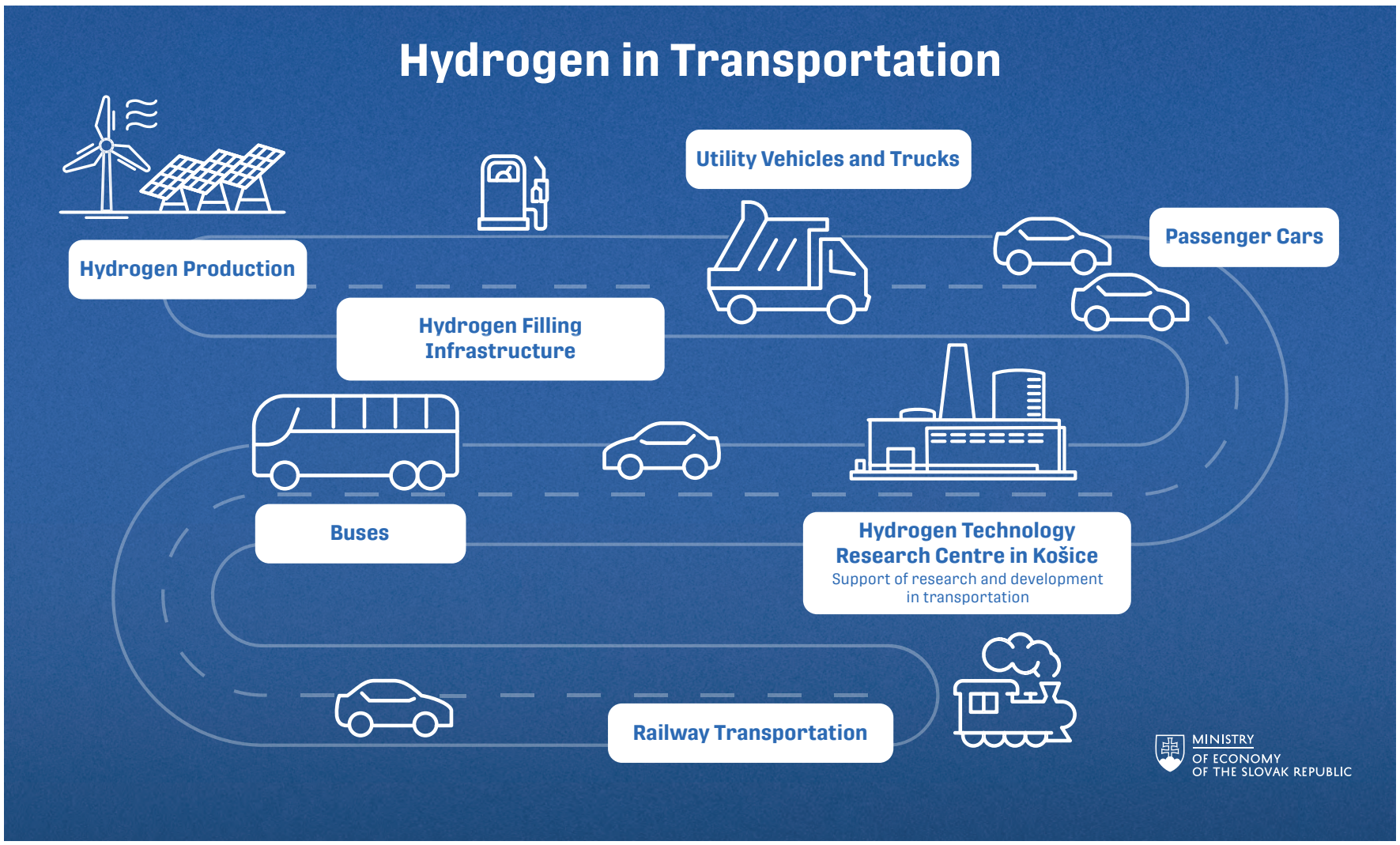
Hydrogen technologies of the SR, as one of the strategic economic interests of the country, will be supported by the Office of Industrial Ownership of the SR, which will focus on the applications of industrial ownership protection with special care. It will make best effort to process the industrial ownership protection applications as soon as possible after being filed.

Final Provisions

The NHS represents a document which will be used to prepare implementation materials – in particular, the NHS Action Plan. The Slovak government will task the Ministry of Economy of the SR to prepare and coordinate the action plan.

The action plan will lay down the terms, goals, schedule and performance indicators of the individual measures of implementation of the NHS contents in the Slovak economy – in particular:

- evaluation of contribution of the measures to the declared goals;
- evaluation of impact of the individual measures to the public budget and other areas (business environment, environment, informatisation of society, and services for citizens);
- setting the terms for individual measures and the anticipated deadline for preparation and implementation of investment projects; and
- in case the investment exceeds 1 million euros or 40 million euros (10 million euros in IT), evaluation made by the Ministry of Finance of the SR in line with the tasks C.5 and C.6 of the resolution of the government No. 649/2020 and pursuant to Section 19a of Act No. 523/2004 Coll. on budget rules of public service.



Annexes

Annex 1 – Definition of Abbreviations Used in Text

EC	European Commission
EU	European Union
SR	Slovak Republic
NHS	National Hydrogen Strategy
CRHT	Centre for Research of Hydrogen Technologies
OIO	Office of Industrial Ownership
Wh, KWh, TWh	watt-hour, kilowatt-hour, terawatt-hour
gW	gigawatt
t, kt	ton, kiloton
POWER to Gas	technology using electricity to produce gas fuel
SPP	Slovenský plynárensky priemysel
SET Plan	Strategic Energy Technology Plan
ETS Fund	Emission Trading System investment fund
Best Practice	best practice
Power-to-X	ways of transformation, storage and transmutation of electric energy using excess power
SK RIS3 2021+	Strategy for Smart Specialisation of the Slovak Republic[47]
	[47] https://www.mirri.gov.sk/sekcie/cko/strategia-vyskumu-a-inovacii-pre-inteligentnu-specializaciu-sr/institucionalna-struktura-riadenia-ris3/index.html.

Annex 2 – Comparative Table of Definitions of Individual Hydrogen Types

Terms Used in National Hydrogen Strategy of SR	**Terms Used in Hydrogen Strategy for Climate-Neutral Europe of 8 July 2020**
Green Hydrogen is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources (solar and wind energy – wind turbines, photovoltaic panels). The full life-cycle greenhouse gas emissions of the production of this hydrogen are close to zero.	"Clean Hydrogen" refers to renewable hydrogen, also described as Green Hydrogen. "Renewable Hydrogen" is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. The full life-cycle greenhouse gas emissions of the production of renewable hydrogen are close to zero. Renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas) or biochemical conversion of biomass, if in compliance with sustainability requirements.
Grey Hydrogen refers to hydrogen produced through a variety of processes using fossil fuels as feedstock (natural gas, coal gasification). The life-cycle greenhouse gas emissions of the production of this type of hydrogen are high.	"Fossil-Based Hydrogen" refers to hydrogen produced through a variety of processes using fossil fuels as feedstock, mainly the reforming of natural gas or the gasification of coal. This represents the bulk of hydrogen produced today. The life-cycle greenhouse gas emissions of the production of fossil-based hydrogen are high; also called Grey Hydrogen.
Blue Hydrogen refers to hydrogen produced through a variety of processes using fossil fuels as feedstock with CO_2 capture, with significantly reduced full life-cycle greenhouse gas emissions compared to Grey Hydrogen.	"Fossil-Based Hydrogen with Carbon Capture" is a subpart of fossil-based hydrogen, but where greenhouse gases emitted as part of the hydrogen production process are captured. The greenhouse gas emissions of the production of fossil-based hydrogen with carbon capture or pyrolysis are lower than for fossil-fuel based hydrogen, but the variable effectiveness of greenhouse gas capture (maximum 90%) needs to be taken into account (Blue Hydrogen).
	"Low-Carbon Hydrogen" encompasses fossil-based hydrogen with carbon capture and electricity-based hydrogen, with significantly reduced full life-cycle greenhouse gas emissions compared to existing hydrogen production (Blue Hydrogen).

Annex 3.a – Projects of Basic and Applied Research

Material Research:

- new metal-hydric and absorption materials for hydrogen storage;
- new nano-pore and metal-organic materials for hydrogen storage;
- impact of hydrogen on distribution and transportation pipeline systems and elimination of adverse effects, taking into account the costs of transition from natural gas to hydrogen in pipeline systems;
- research of ceramic materials for high-temperature electrolysers and fuel cells; and
- research on impact of hydrogen on geologic structures, minerals, and geochemical and biochemical processes.

Fuel Cells:

- methods of low-energy hydrogen compression;
- optimisation and efficiency increase of hydrogen burning equipment;
- development of fuel cells and equipment for hydrogen burning; and
- implementation of fuel cells to drive units of mobile equipment.

Production, Transmission, Distribution, and Storage of Hydrogen:

- development of electrolysers and equipment for hydrogen production;
- production of green hydrogen;
- separation of hydrogen of synthesis gases;
- research of options of use and adjustment of current gas infrastructure for transmission and distribution of hydrogen and mixtures of hydrogen and other gases;
- research of large-capacity energy storage in form of mixtures of hydrogen and methane (and CO_2) in underground geological structures;
- processes of storage of energy gases in cryogenic conditions;
- research of options of geological storage of CO_2 (CCS) for production and use of Blue Hydrogen;
- research of options of energy gas storage in dug out underground mining areas;
- development of equipment for natural gas pyrolysis for production of carbon-free hydrogen; and
- research and development of technologies for hydrogen separation from mixture of gases.

Other Areas:

- development of systems of risk management in production, operation, maintenance, and liquidation of hydrogen technology equipment;
- energy and material optimization of use of hydrogen in metallurgical and chemical industry; and
- research and development in hydrogen detection equipment and safety systems.

Annex 3.b – Innovation Projects

Production, Transmission, Distribution, and Storage of Hydrogen:

- methods of production of Green Hydrogen;
- progressive recovery of hydrogen focusing on its separation from synthesis gases;
- increasing the efficiency of hydrogen production by electrolysis of water and water vapour;
- increasing the efficiency of transmission and distribution of hydrogen;
- innovative technologies of hydrogen storage in depleted underground gas deposits;
- thermal eFusion excavation using hydrogen; and
- other uses of hydrogen (like production of synthetic methane from biogas).

Hydrogen Use Technologies:

- hybrid systems (hydrogen technologies and other forms of energy sources);
- implementation of hydrogen for various areas of industrial technologies, increasing of efficiency of the latest Power to Gas, Power to X, and X to H2 technologies;
- application in energy and environmental policies of the SR in its current domains and goals of SK RIS3 2021+, with the long-term goals for 2030;
- use of clean hydrogen in waste management;
- replacement of diesel drive in regional trains with electric ones using hydrogen fuel cells;
- application of hydrogen in production/energy processes in metallurgic industry and chemical industry; and
- synthetic fuel made of hydrogen.

Notes

MINISTRY
OF ECONOMY
OF THE SLOVAK REPUBLIC

The National hydrogen strategy was approved by the government of Slovak Republic on 23rd June 2021.

Authors of NHS

Juraj Sinay

Professor with the Faculty of Mechanical Engineering at the Technical University in Košice and coordinator of hydrogen technologies in Slovakia. He considers hydrogen the medium of the future and is the author of the main ideas of the National Hydrogen Strategy. He has participated in the establishment of the Hydrogen Technology Centre in Košice, which will be combining the interests of politics, practical appliance of the technology, and science, as well as research, development and innovations in the field.

Ján Weiterschütz

He is the Chairman of the National Hydrogen Association of Slovakia. He intends to initiate close cooperation with the European Commission and central European agencies, like FCH JU or Hydrogen Europe, in order to support national and international hydrogen projects. His priority is to cooperate on modification of the legislation and regulatory framework in order to eliminate barriers of hydrogen technology implementation.

Martin Jesný

He is an industrial analyst and member of the working group focusing on developing hydrogen technologies in Slovakia. He participates in several activities related to decarbonisation of the society, which intend to use research, development and innovations to achieve the green commitments and establish Slovak industry as a strong player on the market.

Peter Blaškovitš

He is the Director General of the Slovak Innovation and Energy Agency (SIEA). Apart from innovation and energy, his priorities are the hydrogen technologies and support of projects in this area. He is in charge of presentation and promotion of hydrogen infrastructure and preparation of various subsidy schemes of the H2 technologies in Slovakia.

Richard Sulík

He is the Minister of Economy and Chairman of the Sloboda a Solidarita party, as well as the initiator of the nation-wide discussion about hydrogen technologies and establishment of perspective foundation of their use. He considers hydrogen the energy carrier of the future and Slovakia as a country with huge long-term potential in hydrogen technologies.