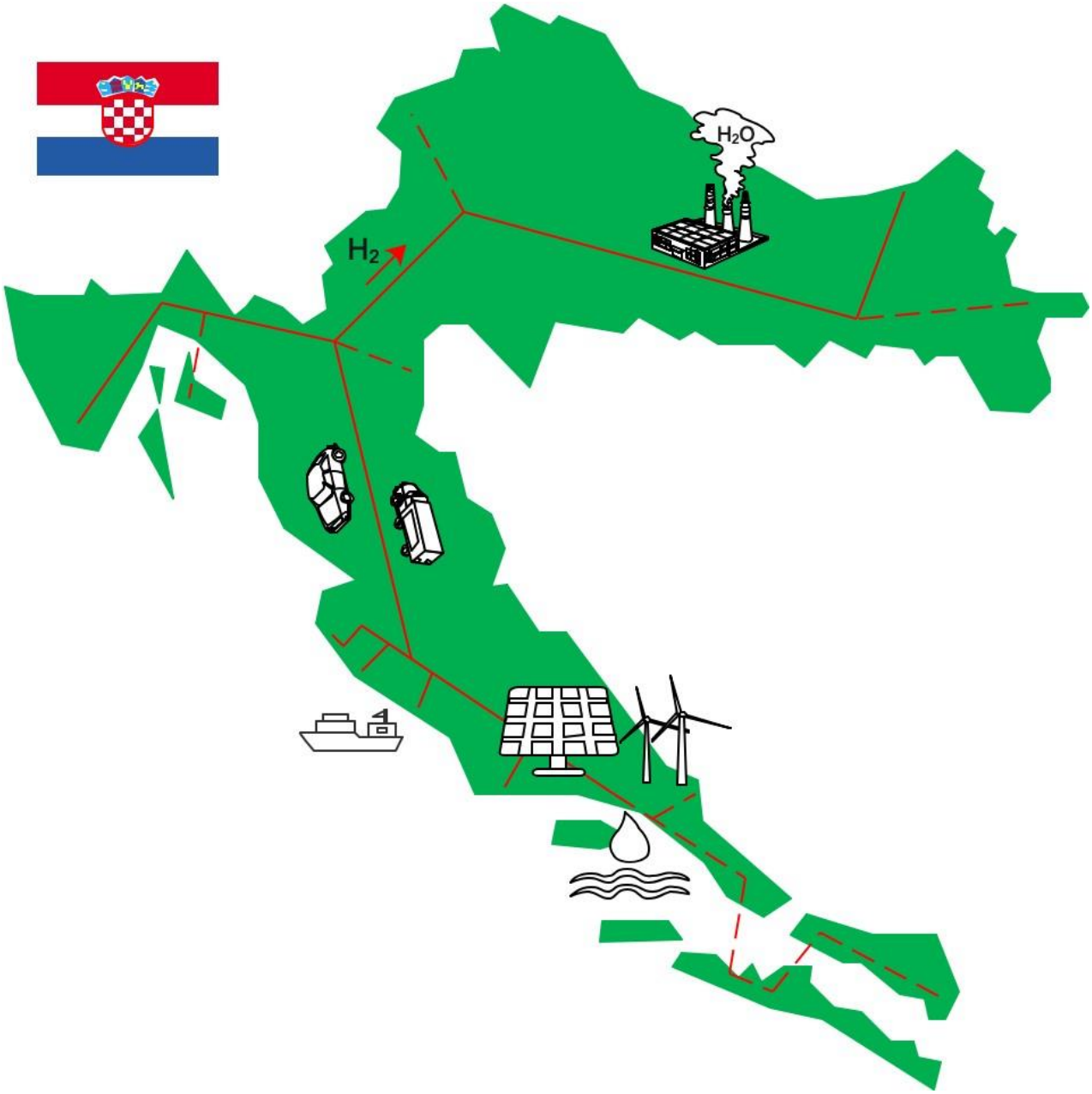
MINISTRY OF ECONOMY AND SUSTAINABLE DEVELOPMENT

HYDROGEN STRATEGY
OF THE REPUBLIC OF CROATIA UNTIL 2050



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1. VISION FOR THE DEVELOPMENT OF A HYDROGEN ECONOMY

1.1 Introduction

In accordance with Article 18(5) Of the Act on the System of Strategic Planning and Management of Development of the Republic of Croatia (Official Gazette, No 123/17), at its 45th session, held on 25 February 2021, the Government of the Republic of Croatia adopted a Decision launching the process of drawing up Croatian Hydrogen Strategy from 2021 to 2050 (hereinafter: Strategy), that is to be adopted by the Croatian Parliament on the proposal from the Croatian Government.

On the basis of this Decision, the Ministry of the Economy and Sustainable Development was responsible for drawing up the Strategy and, on 18 March 2021, the Minister adopted a Decision setting up an expert working group to draw up a proposal for the Hydrogen Strategy of the Republic of Croatia from 2021 to 2050 (CLASS: 310-02/21-01/94, REF.NO.: 517-07-1-2-21-10). The president of the Expert Working Group was the Minister for Economy and Sustainable Development. The task of the group was to prepare the analytical foundation, based on the National Development Strategy and the Energy Development Strategy of the Republic of Croatia until 2030 with an outlook to 2050, and a draft document which, after public debate and involving all relevant stakeholders, will enable the development of strategic objectives related to the hydrogen economy. On the basis of the numerous dialogue activities with all interested stakeholders and the activities of the Expert Working Group, the Croatian Government prepared the final proposal for Hydrogen Strategy of the Republic of Croatia until 2050.

Hydrogen, as an energy carrier, has for a long time been the subject of discussions and an integral part of the plans of European Union countries (hereinafter: The EU) and beyond. With a view to adapting to climate change, the European Green Deal was adopted, setting the goal of making Europe the first climate-neutral continent by 2050. With the adoption of the European Green Deal, the EU increased its ambition to reduce carbon dioxide (CO_2) emissions, raising the initial 2030 target to minus 55 % compared to 1990. The objective of reducing CO_2 emissions is to keep the temperature below 2 degrees (and, targeted, 1.5 degrees) above the pre-industrial average temperature.

In addition, in order to contribute to the objectives set by the European Green Deal, the European Commission (EC) presented two strategic documents on 8 July 2020: A Hydrogen Strategy for a Climate-Neutral Europe (hereinafter: The EU Hydrogen Strategy), which highlighted hydrogen as one of the key levers for a successful energy transition and the EU Energy System Integration Strategy.

The EU Hydrogen Strategy provides clear guidelines for cooperation with representatives of executive and legislative authorities, industry, scientific institutions and civil society through the Clean Hydrogen Alliance, which is in charge of developing investment programmes and a number of concrete projects aimed at deploying hydrogen technology. The Energy System Integration Strategy describes how current EU policy frameworks will contribute to achieving

a climate-neutral integrated energy system with a high proportion of renewable energy sources (RES).

Both the above-mentioned EU strategies contribute to achieving the goals of the UN 2030 Agenda for Sustainable Development and the goals of the Paris Agreement on climate change. According to the EU Hydrogen Strategy, for the first period 2020-2024, the strategic objective is to enable the installation of at least 6 GW of electrolysers producing up to one million tonnes of renewable hydrogen (the current installed electrolyser capacity in the EU is around 1 GW). To achieve the above objectives at the EU level, the European Clean Hydrogen Alliance will provide clear guidance on the investments needed by providing funding from the European Recovery Plan. In the second phase, between 2025 and 2030, hydrogen should become an integral part of the integrated energy system with the strategic objective of installing at least 40 GW of electrolysers for the production of up to 10 million tonnes of renewable hydrogen. At this stage, gradual regulation of the price of renewable hydrogen is expected to the extent that it becomes price-competitive with other forms of hydrogen production. Renewable hydrogen will play a significant role in balancing the RES-based electricity system by providing the necessary flexibility. Hydrogen will also be used in transport, as well as for daily or seasonal storage, thus increasing security of supply in the medium term. The third phase, between 2031 and 2050, envisages a wider scale of deployment of renewable hydrogen technology in different sectors.

In the recent years, the Republic of Croatia has made significant efforts to decarbonise the energy sector and the economy. Accordingly, the development of RES energy production is encouraged, as well as increasing energy efficiency in industry and household. Croatia targets 36.6 % of gross end-use electricity from RES by 2030. This percentage also includes an increase in RES in the transport and heating and cooling sectors.

In order to achieve the set objectives from the Integrated National Energy and Climate Plan for the Republic of Croatia for the period from 2021 to 2030, related to reducing CO_2 emissions, increasing the share of RES in total energy consumption and increasing energy efficiency, it is necessary to establish a stronger and more efficient power infrastructure (at the transmission and distribution level) which will enable the absorption of new energy from RES and enable the stability of the system. It is also necessary, in addition to sufficient quantities of biofuels on the market, to stimulate the electrification of transport (using electricity and renewable hydrogen). The Strategy therefore sets out indicative possibilities for the development of production, storage, transport and general use of hydrogen with the aim of reducing CO_2 emissions, as well as the possibility of including the economy in the equipment production sector (such as electrolyser layers and bundles of fuel cells, measuring and control equipment, sensors, etc.), thus ensuring technological adaptation and participation in the European and global market of hydrogen technologies.

1.2 Strategic and legislative framework

Croatian Hydrogen Strategy until 2050 is fully aligned with the National Development Strategy of the Republic of Croatia for 2030 (Official Gazette, No 13/21), development direction 3. “Green and digital transitions”, more specifically strategic objective 8. ‘Environmental and

energy transition for climate neutrality', priority policy area number 2. Energy self-sufficiency and clean energy transition and strategic goal 10. 'Sustainable mobility'.

In February 2020, the Energy Development Strategy of the Republic of Croatia was adopted until 2030 with a view to 2050 (Official Gazette no. 25/20) (hereinafter: Croatian Energy Strategy) that stimulates strong decarbonisation of the energy sector and growth of the share of electricity from RES. Also, the Croatian Energy Strategy encourages increased production and self-sufficiency in electricity production, which increases security of energy supply and opens up the potential for strong electrification of all sectors using fossil fuels.

In line with world-leading trends in increasing the share of RES with the possibility of using innovative technologies and consequently reducing CO_2 emissions by 2050, the EU has set clear objectives for decarbonising the economy. These objectives are related to reducing CO_2 emissions, increasing the share of electricity from RES in gross final consumption, and increasing energy efficiency. Objectives are defined at the EU level and each Member State contributes to these targets through its own national targets and in accordance with the Integrated Energy and Climate Plan.

In addition and in accordance with the Act on Climate change and the Protection of the Ozone Layer (Official Gazette, No. 127/19), the Strategy for Low-Carbon Development of the Republic of Croatia until 2030 with a view to 2050 was adopted (Official Gazette, No. 63/21) (hereinafter: Croatian Low-Carbon Strategy). These acts cover in detail the possibilities for the transition to a low greenhouse gas emission society through possible investments in green business, technologies, innovation and development with a view to contributing to enhancing competitiveness in the common European market, which is increasingly looking for green products and services.

The Croatian Energy Strategy, like the Croatian Low-Carbon Strategy, foresees a reduction in greenhouse gas emissions of around 74 % in 2050 compared to 1990 emissions.

Furthermore, the Croatian Energy Strategy recognizes hydrogen as an alternative fuel and foresees its use in traffic in order to achieve the aforementioned objectives. Hydrogen as an alternative fuel and the possibility of its use in traffic with the aim of reducing CO_2 emissions is also envisaged in the Strategy for Transport Development of the Republic of Croatia for the period 2017-2030 (Official Gazette, No. 84/17) and the National Policy Framework for the establishment of infrastructure and Development of the market of alternative fuels in traffic (Official Gazette, No. 34/17), (hereinafter: NPF).

The legislative framework implies ensuring the transposition of EU legislation into national legislation in line with the objectives set at the EU level related to the decarbonisation of the economy and the reduction of CO_2 emissions.

Accordingly, the following laws of the Republic of Croatia regulate the possibilities of hydrogen use:

The Act on Amendments to the Biofuels for Transport Act (Official Gazette, No. 52/21) - envisages the introduction of hydrogen into the Croatian market. According to this Act, the

obliged entity for placing biofuels or RES on the market in transport is obliged to report on the use of hydrogen as an alternative fuel on the market.

The Alternative Fuels Infrastructure Act (Official Gazette, No. 120/16) — defines technical specifications for hydrogen refuelling points for vehicles.

Following the aforementioned, the introduction of hydrogen as a new energy carrier in the Croatian transport sector will be accompanied by legislation and subordinate legislation, which will include new standards relating to hydrogen as an alternative fuel, including new technologies that emerge in the process from production to consumption of hydrogen as a reservoir of energy and alternative fuel. It is also necessary to build an appropriate infrastructure for the production, distribution and supply of hydrogen while at the same time encouraging the procurement of vehicles, ships and trains using hydrogen as propellant in order to generate consumption.

1.3 Vision

The Strategy provides a framework for hydrogen production and use with a focus on renewable hydrogen as a substitute for fossil fuels and increasing the stability of the RES-based electricity system for energy self-sufficiency and clean energy transition and sustainable mobility.

Hydrogen and the hydrogen economy are important elements of the green energy transition to meet the EU's clean energy and greenhouse gas emissions reduction targets. Low-carbon hydrogen is considered a clean energy product and as such will play an important role in several sectors (energy, transport, industry, agriculture, etc.) to reduce greenhouse gas emissions. Investments in clean hydrogen technologies are expected to contribute to the transformation of the energy sector into low and future zero greenhouse gas emissions, to the development of the circular economy, as well as to the creation of new jobs related to energy sustainability.

In the case of electricity, hydrogen will play an important role as a storage solution resulting in more electricity generation from RES. However, renewable hydrogen will also be able to be used for electricity generation in plants based on high temperature ceramic fuel cells (SOFC-Solid oxide Fuel Cells) and gas turbines due to the far greater efficiency of such systems.

Also, in the heating and cooling subsector, hydrogen will be a viable alternative to replacing fossil fuels, to which the regulation of renewable gases and their incorporation into the natural gas transmission and distribution system will greatly contribute.

In the transport sector, hydrogen is one of the alternative and complementary solutions for electro-mobility, in particular for road freight transport, including urban logistics, road and rail transport for passengers and goods, maritime, river and air transport.

In addition to the electricity, heating, cooling and transport sectors, hydrogen will also stimulate the development and deployment of technologies in other sectors, in particular energy-intensive ones, as well as those that are not easy to decarbonise. They will all contribute to the decarbonisation of society and environmental protection through innovative hydrogen production and/or use processes.

In this context, hydrogen will play an important role in decarbonising the national economy, especially in sectors that currently have few alternative technological options and where electrification could lead to significant costs, contributing to the achievement of climate objectives.

Hydrogen is compatible with current consumption patterns and makes it possible to connect electricity and heat systems in a flexible manner, highlighting the complementarity and synergy between electricity networks and gas systems. Hydrogen technologies have developed around the world at an incredible pace in the last decade. There is now evidence that in certain contexts of hydrogen production and use it is already a viable and cost-effective solution to decarbonise some of the most difficult sectors in the economy, such as transport or heat in a number of sectors of the economy.

The Strategy sets out a national vision for the development, research, production, infrastructure and deployment of hydrogen technology, with a view to achieving climate neutrality by 2050, as well as a vision of national targets for the development of alternative fuels infrastructure. In addition, it is fully in line with the National Development Strategy of the Republic of Croatia until 2030, as reflected in Development Orientation 3 "Green and digital transition", where Strategic Goal 8 "Environmental and Energy Transition for Climate Neutrality" sets out two implementation priorities in the policy priority area "Energy self-sufficiency and clean energy transition" in the policy priority area of energy policy that coincides with the Strategy. These are 'Promoting advanced biofuels and electricity and hydrogen from renewable energy sources' and 'Investing in clean hydrogen technologies'. The Strategy represents a first step in developing the application of hydrogen in the Croatian economy and covers the possibilities for hydrogen production, storage and transport, use, as well as the potential for research, development and innovation in all parts of the hydrogen economy. The Strategy will contribute to achieving the CO_2 emissions reduction targets and enable Croatia to be more actively involved in hydrogen processes and projects at the EU level.

2. DEVELOPMENT POTENTIAL AND OPPORTUNITIES FOR HYDROGEN APPLICATIONS

2.1 Potential of hydrogen in Croatia

In line with the implementation of the EU acquis and the setting of national energy and climate targets, hydrogen has been identified as one of the significant energy sources whose use in the economy, particularly in energy, transport and other industrial sectors, will in the long term contribute to the decarbonisation of society and the reduction of CO_2 emissions.

The annual consumption of total energy in Croatia is around 100 TWh, of which energy imports account for approximately 50 %. Electricity accounts for some of the imported energy. Croatia in accordance with the National Recovery and Resilience Plan 2021 — 2026 (hereinafter: NRRP) plans to connect 1 500 MW of new RES electricity sources to the energy system by the end of 2024. According to Croatia's Energy Strategy, it is also planned to build around 2 500 MW of installed capacity by 2030, with the aim of ensuring clean energy production that should meet its own needs.

Hydrogen production in Croatia is expected to be based on research, development and deployment of all low-carbon hydrogen production options in existing industrial centres representing future demand centres for it.

Currently the world's and Croatia's most common hydrogen production process is Steam Methane Reforming (SMR) process. The listed commercial production process of fossil-based hydrogen and related CO_2 capture, utilisation and storage (CCS) technologies have been identified as significant potential with a major impact on reducing air emissions and decarbonising existing hydrogen production.

CCS technologies and infrastructures will be connected to existing industrial hubs such as refineries and petrochemical installations using the potential of oil and gas fields for CO_2 storage.

The potential of hydrogen in Croatia derives primarily from the potential of electricity production from RES, which can ensure adequate and long-term production of renewable hydrogen. However, in order to establish a hydrogen economy and encourage production itself, it is necessary to secure the demand for hydrogen and a distribution system to ensure that the hydrogen produced is delivered to end-users.

In order to establish a hydrogen economy in Croatia, it is necessary to ensure the harmonious growth of the three key elements of production, distribution and consumption, with a view to enabling the systematic and stable use of hydrogen. Figure 1 shows the general hydrogen value chain scheme (which does not exclude other hydrogen production methods).

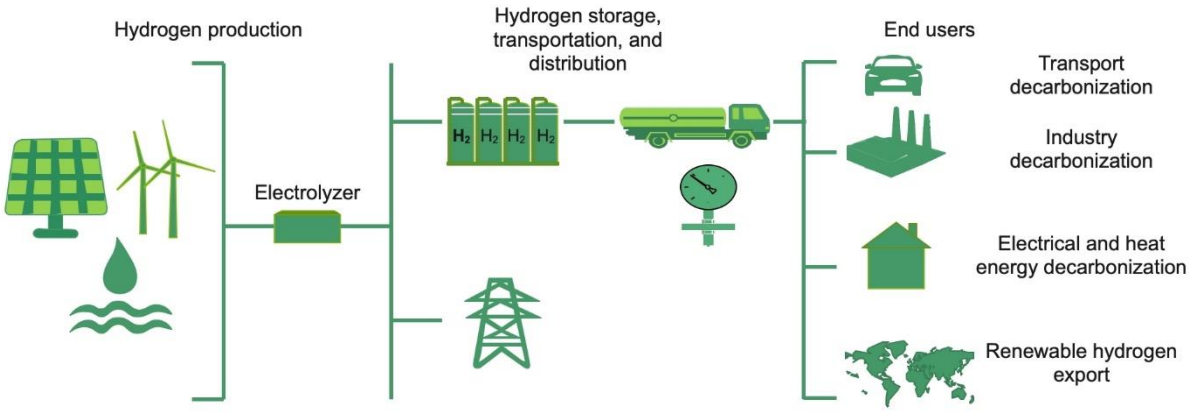

Figure 1. General scheme of the hydrogen value chain, from production to end-use

The preparation of hydrogen is also an important part of the hydrogen supply chain and the hydrogen economy. After production in the electrolyser, hydrogen undergoes processing/preparation to adapt it to safe transport and/or end use. Technologies used in the process of preparing hydrogen are dehumidification and humidification, separation, liquefaction, compression, gasification and heat treatment of hydrogen (heating/cooling), etc. Among these technologies, there is still space for developing and detecting new technologies, which opens up the possibility for Croatian companies to create new products and open up new markets.

According to the estimates in the Croatian Energy Strategy, decarbonisation of the energy sector is moving towards the installation of new RES capacity, which, depending on demand, can also be used for hydrogen production. Part of these capacities will go to end-users in the form of electricity through the Croatian electricity system, while a part may be used for the production of renewable hydrogen directly at the point of electricity production. In addition, a part of the electricity thus generated may be delivered via the electricity transmission and distribution system to the production site of renewable hydrogen provided that it is not more expensive than the electricity to be generated at the renewable hydrogen production site.

The storage and transport of hydrogen are the basis for the deployment of more hydrogen production that will focus on the needs of transport, industry, buildings and other sectors. Taking into account the developed gas network as well as existing pipelines out of service in the long term, and depending on consumption trends, it is possible to use them for the transport of hydrogen. Hydrogen can play an important role in decarbonisation by integrating different sectors, i.e. connecting end-users of energy to RES especially in areas where electricity from RES cannot be used directly or is not economically viable. Croatia's geopolitical position is also very favourable, given its links with southern EU countries as well as African countries that are moving towards more significant production of renewable hydrogen and, in the long term, Croatia is expected to position itself as an entry point for transhipment and hydrogen delivery to other EU countries.

Hydrogen is applicable in different sectors from transport use, as fuel or raw material for fuel production, through industry to heating and cooling. At present, projects in the transport sector (procurement of clean vehicles) are at a high level of preparation taking into account the possibility of co-financing the same from EU funding, which requires the provision of appropriate infrastructure for the smooth operation of these vehicles throughout Croatia.

As a next step, the industrial application of hydrogen is expected, which, with major changes, also requires logistics that, in addition to the location of production and use of hydrogen, implies an upgrade and modernisation of the electricity grid and the gas transmission system. The decarbonisation of refineries using renewable hydrogen instead of fossil-based hydrogen, as an example of industrial hydrogen applications, will require the modernisation of the gas transmission system and the electricity grid. On the other hand, a synthesis of so-called green ammonia from renewable hydrogen would allow for a wider deployment and additional tools to decarbonise industry.

2.2 Strategic orientations

The Strategy is based on four pillars, setting out the main orientations for the development of a hydrogen economy as follows:

1. Hydrogen production — enable the production of low-carbon hydrogen that will focus primarily on renewable hydrogen with the aim of producing products with low or zeroCO_2 emissions.

2. Storage and transport of hydrogen — the repurposing of existing infrastructure to transport hydrogen from the production site to the place of consumption in the long term. In the short term, production sites are expected to be in places of consumption for the purposes of industrial processes.

3. Use of hydrogen — enabling the use of hydrogen in industrial processes, agriculture, etc., as well as developing the use of hydrogen in transport by providing incentives for the purchase of hydrogen vehicles and vessels.

4. Education, research and innovation — ensuring the development and commercialisation of new technologies in the production and safe use and transport of renewable hydrogen.

I. PRODUCTION OF HYDROGEN

Hydrogen cannot be found in nature in its elementary form but linked to different chemical compounds. It should therefore be isolated from the compound in which it is located, using various technologies such as reforming (processing) natural gas (so-called grey hydrogen) or the production of hydrogen through the electrolysis of water using the RES (so-called "green" or "renewable" hydrogen). In recent years, there has been a significant development of new technologies for the production of electricity from RES, which is needed for the production of hydrogen through the electrolysis of water, but also in the production of hydrogen through other technologies (e.g. pyrolysis or waste gasification) that significantly reduce CO_2 emissions or are even zero emission.

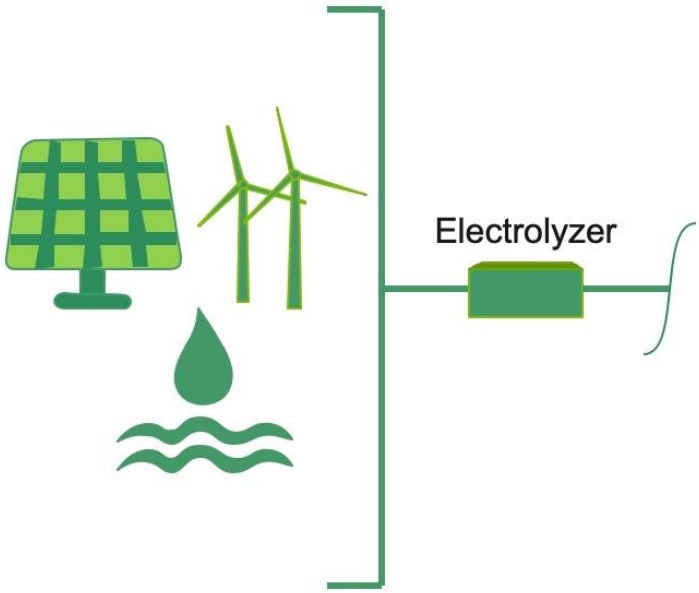

Figure 2. Hydrogen production chain

In view of the fact that Croatia aims to increase the share of electricity produced from RES, it is understandable that the production of renewable hydrogen is encouraged, which is mainly obtained through the electrolysis of water using electricity from RES. The production of

hydrogen would take place at the point of production of electricity in order to relieve the load of the electricity system, but also at a point of significant consumption with the purpose of decongesting the transmission system itself.

Furthermore, the objective is to enable the production of renewable hydrogen not only at the point of production of electricity from RES, but also through other RES using the electricity grid. Both hydrogen production models need to be implemented at the outset and the gradual development of production will take place in line with the development of new hydrogen production technologies, the capacity of the electricity grid to transport electricity to the hydrogen production site, and the possibilities for hydrogen transport through the existing gas transmission system. According to the estimates in the Croatian Energy Strategy, the decarbonisation of the energy sector is set towards the installation of new RES capacity that will be directed to end-users in the form of electricity through the Croatian electricity system, while part of these capacities can be used for the production of renewable hydrogen directly at the point of electricity production. In addition, part of the electricity thus generated may be routed to the production site of renewable hydrogen via the electricity transmission and distribution system (distributed hydrogen production). Such distributed hydrogen production allows for better utilisation of the built transmission and distribution capacity of the electricity grid, but also the use of electrolysers to provide ancillary services to transmission and distribution system operators, provided that feed-in tariffs are put in place for the use of the transmission and distribution network to transport green electricity to the distributed production site of renewable hydrogen.

In addition to the production of renewable hydrogen, a system of certificates should be provided in order to reliably demonstrate the origin of renewable hydrogen. It is also necessary to ensure that this system for the certification of renewable hydrogen is at the level of the current guarantee system for the origin of green electricity in Croatia, which would allow the flexible use of green electricity for the production of renewable hydrogen using electrolysers. There is a project in the EU dedicated to the certification of renewable hydrogen (CertifHy), so a similar model can also be introduced in Croatia.

The price of hydrogen will depend on how it is produced. In line with the EU hydrogen Strategy, the price of fossil-based hydrogen is currently around EUR 1.5 per kg without taking into account the price of CO_2 released in the atmosphere (this price depends on the price of natural gas and is subject to fluctuations). If we make it possible to capture CO_2 released in addition to hydrogen production, this price is around EUR 2 per kilogram. The cost of producing renewable hydrogen, i.e. production of hydrogen by electrolysis of water using electricity from RES, is currently around 2.5- 5.5 EUR per kg. If market forecasts and electricity prices from RES fall in the next period together with electrolyser prices, allowing profitability of renewable hydrogen production, renewable hydrogen is estimated to be cost-competitive with fossil-based hydrogen by 2030 (although an EU-wide consensus to achieve a renewable hydrogen price of 1.5 to 3 EUR per kg) is announced.

Also, while the first hydrogen production projects will be linked to electrolysers and electricity from RES, the development of projects related to new renewable hydrogen technologies (with

small or no CO_2 emissions), such as those in the waste sector or the development of other RES electricity generation technologies (e.g. wave power, offshore wind, etc.) should be encouraged. In the long term, and subject to the cessation of operation of the North Adriatic gas platforms, it is possible to develop offshore wind farm projects for the production of electricity from RES and renewable hydrogen that could be transported through the existing pipeline for the needs of Croatia and Italy.

In the period until 2026, the production of hydrogen will initially be linked to transport and industry. There are already projects at the advanced stage of preparation in the transport sector while the industrial sector is the most prepared to start renewable hydrogen applications, i.e. refineries and petrochemical plants. It is therefore necessary to enable, in addition to the production of renewable hydrogen at the point of production of electricity from RES, the development of renewable hydrogen production using electricity grid-connected electrolysers.

In the period until 2030, it is essential to ensure the production of sufficient renewable hydrogen to serve as a raw material in industrial processes. Accordingly, enabling the continuous production of renewable hydrogen will ensure its application in industrial processes primarily in petrochemicals and later in an industry that uses large amounts of natural gas or heavier forms of fossil fuels (cement, glass, metals, etc.). In this regard, sufficient electrolyser capacity is needed, but also the commercialisation of other production technologies for renewable hydrogen.

Existing industrial facilities (so-called 'brownfield investments') that are in the process of being shut down or which have the potential to repurpose and establish new, decarbonised technologies in their production processes can be used to establish more significant renewable hydrogen production in the initial period. The installation of higher-power electrolysers alone will be easier in those installations that already have the right infrastructure to do so.

After 2030, and especially after 2040, it is assumed that demand will grow and, accordingly, it will be essential to ensure the production of renewable hydrogen that is sufficient for all Croatia's needs, while also taking into account potential exports of renewable hydrogen to countries in a wider environment. In order to achieve this, it is important to ensure the development and promotion of additional electricity capacity from RES, new technologies in renewable hydrogen production and to establish high-quality cross-sectoral cooperation (agriculture, waste management, energy, transport, etc.) that will provide competitive inputs for renewable hydrogen production.

II. STORAGE AND TRANSPORT OF HYDROGEN

Storage of hydrogen at the very beginning of the development of a hydrogen economy can be in gaseous form. In long-term development, when demand for hydrogen increases, it can also be stored in liquid form that makes sense only in some special applications where compressed hydrogen cannot meet the volume requirements. Also, given the potential of hydrogen for the wider sustainable economy and the EU's 2050 objectives, scientific research capacities are expected to focus on providing new storage (storage) technologies for hydrogen.

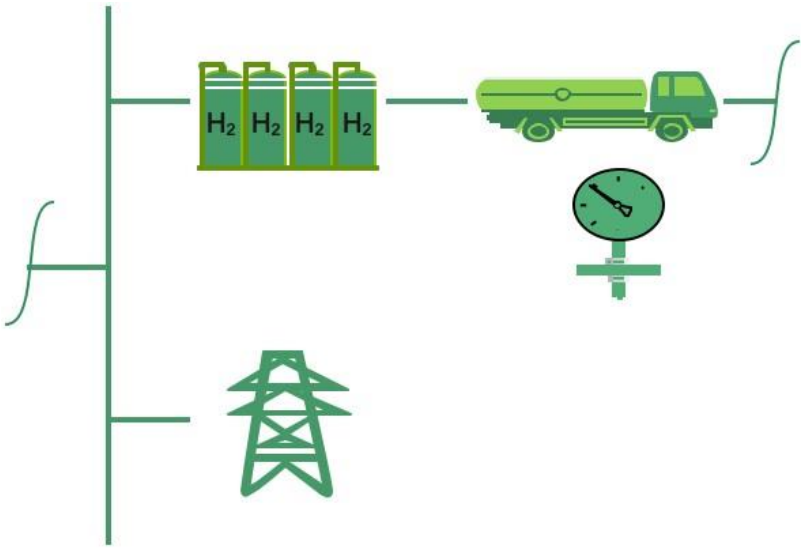

Figure 3. Chain of storage and transport of hydrogen

Hydrogen transport can be carried out in trailers with hydrogen tanks in gaseous or liquid form using road, rail, maritime and river transport. In cases where it is necessary to ensure larger quantities of hydrogen and continuous supply as is the case for industrial processes, it is important to provide adequate infrastructure through pipelines (i.e. hydrogen pipelines) from the production site to the hydrogen consumption site. The construction of direct hydrogen pipeline is technically feasible and the legislative framework for the transport and storage (storage) of hydrogen is also expected to be adopted by 2025. The transport of hydrogen is also possible through the gas transmission system by blending the hydrogen, in a certain percentage, with natural gas in the transmission system with the subsequent separation of hydrogen from the mixture, if somewhere clean hydrogen is needed. If only energy is needed, then hydrogen does not need to be decoupled.

Croatia has a developed gas transport and distribution system. The total length of the gas transmission system is over 2,500 km, and the distribution system is over 18,000 km through which more than 680,000 final customers are directly supplied with gas in 19 out of 20 counties and the City of Zagreb (directly via the district heating system, the number of final users of natural gas is significantly higher). Through interconnections with Hungary and Slovenia, the gas transmission system is connected to the regional and European gas systems, and through the LNG terminal and evacuation pipelines with the world LNG market, enabling the transport of gas, to the regional and European markets.

In the first phase, infrastructure needs for hydrogen transport will remain limited as demand will be met by production close to or on the spot of consumption. Mixing with natural gas is expected in certain areas. The planning of transport infrastructure for the transport of clean hydrogen and CO_2 capture and use infrastructure will start immediately with a view to facilitating the application of certain forms of hydrogen with low CO_2 emissions. The planning of the development of the hydrogen and CO_2 transport network will be based on the least cost principle, i.e. on the optimised use and conversion of the existing gas infrastructure into hydrogen and CO_2 transport pipelines.

In the second phase, hydrogen infrastructure (newly constructed or repurposed natural gas pipeline) will transport hydrogen not only for industrial and transport applications, but also for balancing electricity and providing heat for residential and commercial buildings. At this stage, there will be a need for transport infrastructure at the whole of Croatia and the EU. All necessary steps will be taken to facilitate the transport of hydrogen from areas with high RES potential to demand centres located in areas with lower RES potential, as well as towards other EU Member States or the Energy Community. Croatia will actively engage in the development of the backbone Transmission infrastructure. Wherever technically and economically justified, the existing gas transport system will be converted to transport renewable hydrogen over longer distances, and larger hydrogen reservoirs will be developed, which are estimated to become necessary at this stage. The EU expects the development of international trade in hydrogen and accordingly Croatia will take advantage of its favourable geographical position and potential of the existing gas transport system and, if necessary, will build new hydrogen transport pipelines with the aim of taking on the role of an indispensable link in the transport of hydrogen from Eastern Europe, the Balkans and the Southern and Eastern Mediterranean countries to the final users of hydrogen in Croatia and to the growing regional and European hydrogen market. Finally, the existing LNG site will, depending on market development and realised national hydrogen production potential, be converted to a renewable hydrogen supply location.

Finally, the biggest obstacle to faster and wider adoption of RES, i.e. green energy transition, is primarily their variability on a daily and annual basis. This requires the combination of variable energy sources and some type of energy storage if it could be used at the time when it is necessary and not when it is produced.

If hydrogen systems were to be built along with the RES systems, the surpluses of electricity, which occasionally occur, could be stored for subsequent use. This would skip the biggest obstacle to the stronger development of new power plants. The storage of electricity today takes place through reverse hydro power plants, battery systems and hydrogen.

Hydrogen containers may be strategically geographically distributed and interconnected. They're the central part of the micro network. The networking of green micro networks can cover the entire geographical area of a region or a state with one extremely flexible and robust green electric grid. It is possible to directly connect the container and the hydrogen pipeline network.

Croatia currently has an underground gas storage facility “PSP Okoli”. Construction of a new, smaller underground gas storage facility at the site of the “Grubišno Polje” exploitation field is under way. In addition, during regular activities of the gas storage system operator in Croatia, further development of the system is being pursued by continuous evaluation of new potential locations of underground geological structures suitable for storage of gas as well as their potential for hydrogen storage in the future. Since hydrogen, as one of the energy sources of the future, attracts increasing interest in the EU and worldwide because of its possible versatile application and contribution to decarbonisation, a scientifically based assessment of the possibility of refocusing existing underground storage depots for hydrogen will be carried out. This will take into account different factors, such as cost-benefit analysis from both the

technical-economic and regulatory aspects, general system integration and long-term cost effectiveness. The possibility of storing hydrogen in large quantities in the existing underground gas storage facility "PSP Okoli" will be determined, as well as in the underground gas storage facility "PSP Grubišno Polje" that is under construction. Also, during the process of evaluating new locations for underground storage of gas, the suitability of geological formations for hydrogen storage will be determined.

In the first phase, no significant need for large-scale H_2 storage is expected in Croatia. However, at this stage it is necessary to start with the planning, legal and technical regulation and development of large-scale hydrogen storage infrastructure, whether either hydrogen blended with natural gas or pure hydrogen only. Therefore, tools for effective removal of potential obstacles should be included in the content of regulations of relevance for investments and sustainability of hydrogen storage infrastructure construction projects.

Hydrogen will be used for daily and seasonal energy storage and the provision of reserves and temporary reserves, which will increase the security of supply in the medium term. At this stage, there will be a need for EU-wide logistical infrastructure and hydrogen will be transported from areas with large amounts of energy from RES to consumption centres, which may also be located in other Member States. The backbone of the Pan-European network will be planned and a network of hydrogen bottlers will be established. The existing gas network can be converted to transport hydrogen from RES over longer distances, which will require large underground hydrogen storage tanks.

After the second phase, the technologies of hydrogen production, transport, storage and use of hydrogen need to be improved and widely applied in all sectors and activities. Therefore, it will be necessary to build an appropriate underground capacities of hydrogen storage tanks in accordance with the forecasted future energy demand for this energy source in Croatia and, if necessary, the countries of the region.

III. USE OF HYDROGEN

Hydrogen is one of the elements important for the implementation of the decarbonisation of energy and the economy. In particular, because there are a number of sectors in which hydrogen can be used: as a raw material (petrochemical industry, refineries, etc.), in traffic (road, rail, ship and air transport), energy (storage of energy, system services necessary for the operation of the transmission and distribution systems). Also, it's potential as a possible direct replacement for natural gas must not be neglected, as well as his role as complementary or substitute energy generating product for sustainable liquid fuels.

The development of the hydrogen market and the strengthening of its demand should take place in parallel with the development of the capacity to use it. For example, in addition to developing renewable hydrogen production technology, an important precondition for its use in the traffic is the simultaneous development of the necessary infrastructure for hydrogen filling and transport, along with the procurement of hydrogen vehicles. A much greater challenge is the transformation of the industry that will start using hydrogen for decarbonisation, thus creating the need for large quantities of renewable hydrogen.

Croatia has significant potential within the industrial sector, especially in the refinery production and petrochemical industry, which continue to use hydrogen produced from natural gas as part of their production processes. Hydrogen can be used in other energy intensive industries that need gas in processes as raw material, but also as an energy source. However, in order to enable this, the process of switching from fossil fuels to the use of hydrogen as an energy source must be competitive and coordinated with the creation and increase of capacities for the production of renewable hydrogen.

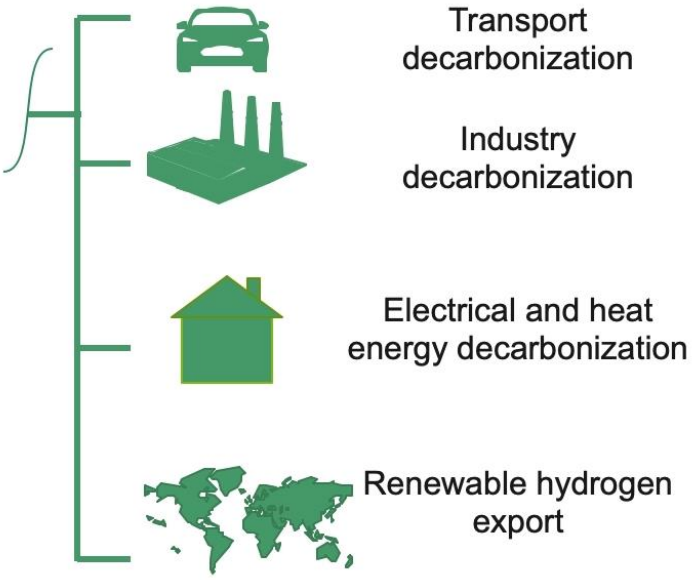

Figure 4 4. Hydrogen use chain

Use of hydrogen in transport

With regard to CO_2 emissions per sector, the leading sector with the largest CO_2 emissions is the transport sector and therefore the research, development and application of hydrogen should be directed to all its branches. Especially taking into account the potential imposition of a greenhouse gas emission trading system (ETS) on the transport sector.

The introduction of transport into the ETS system will further accelerate the transition process with lower CO_2 emissions where hydrogen, along with electricity and other alternative fuels, can be an important driver of change. Hydrogen can be introduced as motor fuel into all parts of traffic, from road through rail to maritime, and the hydrogen technology has gone so far that today there are ultralight fuel cells and hydrogen tanks used in aircraft and drones.

For a stronger use of hydrogen in the transport sector, it is important to ensure all parts of the hydrogen value chain from production, through transport to hydrogen use. (i.e. ensuring sufficient number of vehicles to be used by hydrogen). Harmonising the completion of the infrastructure with the completion of the procurement procedure and delivery of hydrogen vehicles is important for the efficient use of the infrastructure, which has a significant impact on the speed of development of the new market and confidence in the results of such investments.

Today there are already hydrogen vehicles in serial production (cars, buses, trucks, etc.) which facilitates the use of hydrogen in this part of transport. This primarily refers to public urban transport whose reduction of CO_2 emissions will improve air quality in urban environments. Accordingly, the transport sector is also the most mature for hydrogen application in Croatia. Although the share of heavy vehicles is still negligible globally, given the promising technology for the application of fuel cells for heavy vehicles and significant efforts to develop technologies in this transport industry, this can change very quickly.

The establishment of the infrastructure (hydrogen charging station) is envisaged by the foreseen in the Croatian National Policy Framework for the deployment of alternative fuels infrastructure (hereinafter: NPF) where hydrogen is one of the solutions for replacing hydrocarbons in fuels of medium and large sized vehicles. The Strategy for Transport Development of the Republic of Croatia for the period 2017 until 2030 stipulates that the reduction of negative environmental impacts on transport will be defined by the measures necessary to achieve national targets and these measures will be revised as part of the development of a new NPF for the establishment of alternative fuel infrastructure.

The establishment of the hydrogen market in road transport should start with large end users such as public procurement entities in the transport of passengers and goods in accordance with the adopted EU directives. At the same time, it is necessary to ensure the establishment of a network of hydrogen charging stations in road traffic, which, in the first steps, will be linked to larger city centres. In this step, it is important to provide conditions (for example grants) for the construction of the first network of charging stations which will not be economically viable in the first few years. The establishment of a network of ten charging stations will ensure the further expansion of the network of charging stations on a market basis.

It is particularly important to ensure the rapid transition of public urban transport from fossil fuels to electricity, i.e. batteries and hydrogen. In doing so, it should be taken into account that both technologies are equally important and necessary, but hydrogen should be especially potentiated in mountainous terrain environments, long lines or high temperature oscillations over the years that may affect battery capacity. In addition, vehicles in the waste sector have great potential to switch to hydrogen, which will ensure both the reduction of CO_2 emissions and noise abatement, which is necessary considering the timing of waste collection operations.

There are no concrete objectives in rail transport for the development and use of hydrogen, therefore it is necessary to consider the same in relation to alternative fuels. Since a number of important railway routes have not yet been electrified, it is necessary to consider the cost-effectiveness of investments in hydrogen in relation to investments in the electrification of these routes. The study “Study on the use of fuel cells and Hydrogen in the railway environment” published in 2019 by the Fuel cell Hydrogen Joint Undertaking (FCH JU) showed that hydrogen trains are competitive for long non-electrified routes of more than 100 km with low utilization — less than 10 trains per day. There are ready-made solutions for passenger railway transport, since there are already several producers within Europe offering hydrogen trains which further enhance the competitiveness of hydrogen use in rail transport. Therefore, it is necessary to

consider the advantages of using hydrogen in railway transport with a view to rapid and efficient transformation of the railway transport from fossil fuels to clean energy.

Maritime transport also has great potential for hydrogen use. Especially when it comes to traffic related to connecting the mainland and the islands. Although Croatian islands of are connected to the mainland by submarine cables, when ensuring the energy independence of individual islands, hydrogen can be used as a potential energy reservoir and also as fuel for the public insular transport as well as for ferries, especially when the ferries are stationary and when the engine works for the use of electricity. This would allow the storage electricity generated from surpluses to be used better, especially in the period when the island's settlement (outside the tourist season) decreases and the production capacity is oversized.

The second segment of ship transport is related to rivers, especially the Danube, which has become attractive for river cruisers in recent years. Adding a European initiative intended to establish the transport of hydrogen from Southeast Europe to the western part of the EU, the use of hydrogen may take precedence over other alternative fuels.

A special segment related to shipping is related to the supply of electricity to connection ships (cold ironing). This is an important element especially in ports that receive a large number of cruisers (Dubrovnik, Split, Zadar). Most ports today use aggregates on fossil fuels that emit a large amount of greenhouse gases and produce noise. For this reason, it is necessary to decarbonise this segment of port operations as soon as possible and to ensure either direct supply from RES or the use of hydrogen through fuel cells to ensure a sufficient amount of electricity for vessels in ports.

The transport sector has great potential for hydrogen use both in road, rail, ship and air transport. In particular, it is important to ensure the transition to hydrogen in the railway sector where the establishment of hydrogen supply infrastructure is far simpler than other transport sectors, and the impact on CO_2 emissions reduction is high.

Synthetic fuels (e-fuels) that have potentially lower logistics costs and higher energy density compared to compressed or liquefied hydrogen can be used in the field of air and ship transport while using known engine technologies with internal combustion. It is also necessary to develop a comprehensive planning of hydrogen use at airports.

Finally, a regulatory and normative framework is needed for faster implementation and safe use of hydrogen.

Use of hydrogen by industry

Industrial production in Croatia has great potential for hydrogen use, especially in the decarbonisation process as a substitute for fossil fuels. This primarily refers to the industry that already uses hydrogen in its processes (petrochemical industry, refineries), but the use of hydrogen should also focus on all other energy intensive industries that use fossil fuels (especially natural gas) as an energy source for their production processes.

In Croatia today hydrogen is mainly produced within industrial plants for the needs of its own production processes, and it is produced from natural gas (so-called grey hydrogen). These are also the first industrial plants in which decarbonisation can be considered in order to replace hydrogen produced from fossil sources with renewable hydrogen.

At the same time, these locations require significant quantities of hydrogen, which can ensure a uniform rise in hydrogen production and use, which will ensure the economic viability of both processes necessary for the complete establishment of a hydrogen-based economy.

Also, these processes can ensure hydrogen production at (or close to) the place of use, which will reduce the initial production prices due to the avoidance of hydrogen transport to other locations.

Similarly to RES, the production of renewable hydrogen can be decentralised with the aim of reducing production prices and enhancing competitiveness in industries that impose the decarbonisation pressures.

In addition to the petrochemical industry and refineries (already using hydrogen), it is also necessary to start its application in industries that need large amounts of high temperature thermal energy in the technological process (e.g. cement industry). There is also a need to explore the potential of a hydrogen switch in electricity generation as well as grid management potential.

The increase in demand for hydrogen must also strengthen industry in relation to hydrogen production and the creation of new jobs linked to decarbonisation. The decarbonisation of the industry, based on the use of hydrogen, must cover all elements of the hydrogen economy from production, through storage and transport, to the use of hydrogen in industrial processes and as an energy product.

Household

Hydrogen can also be used as an energy carrier for heating and cooling of homes, whether large or small closed systems. In addition, the incorporation of hydrogen into natural gas is encouraged as a transitional phase in the decarbonisation of the EU. Although such activities require the repurposing of existing gas systems, Croatia, as a signatory to the declaration ‘Sustainable and smart gas infrastructure for Europe’, which encourages the uptake of existing gas infrastructure into decarbonised gas infrastructure, has shown that the existing infrastructure has great potential to develop the distribution of hydrogen to a large number of final customers who today use natural gas mainly for heating and hot water.

The potential for the use of hydrogen in heating and cooling is still under development, but there are already developed hydrogen heating systems. The use of hydrogen through fuel cells to generate electricity also has additional potential, as in this process it is alongside water, one of the by-products and a certain amount of thermal energy.

Accordingly, it can be expected that hydrogen will also be used in closed heating systems, especially in smart homes where electricity and heat will be produced from hydrogen via fuel cells.

This type of hydrogen use requires the provision of a distribution network, but in the long term it can be expected that hydrogen-based systems will slowly crowd out fossil fuel systems that are now widely spread.

While a distribution system needs to be ensured for the wider use of hydrogen, the potential of these systems in modern homes (used as mini-generation systems), as well as the developed distribution system, can encourage a more massive use of hydrogen in heating and cooling in the period after 2030. Today, air conditioners, which are in fact heat pumps, are increasingly used in the area of domestic heating and cooling. An indicative third of energy needs to be invested in the process of raising the temperature level of thermal energy taken from the environment and transferring it to the heated indoor space. This amount of energy is usually electricity (because heating is carried out in winter) and is taken from the mains. However, it can be produced from solar energy in summer, stored in hydrogen and used in winter via fuel cells. Alternatively, it is possible to store electricity in batteries but with less reliability.

Security of supply/reserve systems

As an energy product, hydrogen needs to be increasingly integrated into security systems, both civil and military. Given the wide range of options it offers (storage of electricity, motor fuel), it is certainly interesting as part of the backup systems currently operating on fossil fuels (hospitals, large systems equipped with aggregates in the event of a blackout of electricity), but also for installation in residential buildings. These systems can be switched to hydrogen, which will ensure the reduction of greenhouse gas emissions, but also the safety of indoor use of such systems (e.g. ships or rooms) that may be the potential sites for carbon monoxide (CO) development when backup systems are operated, especially in situations where such systems are used as a minimum.

Such back-up systems already exist on the market, and given the number of institutions required to provide a minimum amount of energy in order to secure their activities, this may open up new economic activities related to the manufacture of equipment components and the supply of hydrogen.

One niche system is also mini-systems in remote and hard-to-reach places that cannot easily and safely deliver electricity. In a situation of strong development of digital systems, the potential of hydrogen as an energy carrier for these micro systems is particularly interesting.

The supply of military facilities is also a niche with great potential for the further development of a hydrogen economy, in particular as hydrogen can be a fuel for vehicles and at the same time a storage tank for electricity production necessary to power buildings and systems in the event of major crises.

An additional incentive for the use of hydrogen in backup systems and energy reservoirs can also be the possibility of decentralised production of renewable hydrogen that can be linked to individual sites and thus make them even less dependent on normal logistics supply systems.

IV. EDUCATION, RESEARCH AND DEVELOPMENT

Education, research and development of products and services related to the hydrogen economy can further ensure economic growth and the development of new industries in Croatia, particularly since they may be products with high added value (such as electrolysers, manufacturing and machining of vital components, etc.).

While a number of hydrogen-using systems in transport and industry have already reached a commercial stage (e.g. there are already a number of hydrogen-fuelled vehicles in series production in the transport sector), improving the potential use of hydrogen in all the listed segments requires the upskilling of existing technologies and the development of new technologies in the production, transport and use of hydrogen.

For example, hydrogen-powered robotised forklift trucks and delivery vehicles can also be a significant segment of future industrial production carried by lifts. The production of modules for electric fuel cell trucks is certainly the long-term strategic direction of Croatia's industrial transition.

It is also essential to educate and train people to cope with the development of a hydrogen economy, both in the research and commercialisation segment and in the hydrogen system use sector as part of existing processes (e.g. in the construction industry, transport, etc.). In particular, education is necessary when it comes to system safety and any negative consequences that may occur in hydrogen-using systems. The negative perception of public opinion can greatly slow down the transition process, which at a time of strong, ambitious and accelerated decarbonisation can be the main reason for insufficient hydrogen uptake in the economy and delays in decarbonisation processes. It is therefore necessary to develop and promote other, significantly more secure ways of storing hydrogen than high pressure (for example by using metal hydrides).

With regard to the production of renewable hydrogen, the potential promoted today is linked primarily to electrolysis. However, there are also more and more technologies (e.g. pyrolysis, regasification, etc.) that produce hydrogen with a minimum amount of CO_2. It should be stressed that technologies that can capture and use CO_2 or be stored in geological structures are also being developed.

The role of R & D is to upgrade already existing technologies with a focus on increasing efficiency in hydrogen electricity storage processes as well as hydrogen-based electricity generation. Minimal efficiency gains in these transformations will open up even greater potential for the use of hydrogen technologies that are now still more expensive in some branches than fossil-based technologies. There is also a need to focus on exploring materials that need to ensure better storage and transport of hydrogen using as little energy as possible for such activities.

Accordingly, particular attention should be paid to education (experts and the general public), the development of new innovative solutions and their commercialisation.

Education

Nowadays, several higher education institutions take part in courses related to hydrogen technology (Mechanical Engineering and Shipbuilding Faculty in Zagreb, Faculty of Electrotechnical, Mechanical Engineering and Shipbuilding of Split, Faculty of Chemical Engineering and Technology Zagreb and others). It is particularly important to integrate new education modules more closely into existing higher education curricula and to start creating new education programmes in higher education institutions that will focus education and training on the hydrogen economy segments and educate new generations of highly qualified professionals specialised in hydrogen technologies.

It is also necessary to develop a lifelong learning concept that would ensure adequate specialisation of existing professionals and accompany the development of all segments of hydrogen production, storage, transport and use technology.

Life-long learning is particularly important in industry, i.e. industries that see their future in the potential of hydrogen technologies and are already actively working on developing new hydrogen products and services.

In addition, hydrogen topics need to be brought closer to the general public, particularly in the area of safety and the potential offered by hydrogen to individuals (vehicles, heating/cooling systems, etc.). Here, in addition to educational institutions, associations that will develop short programmes appropriate to specific age groups can also be actively involved, ensuring that these ideas are applied faster and more strongly to formal education.

Research on new technologies

The development of the hydrogen economy needs to be linked to innovative products and services that will ensure the commercialisation and wider deployment of new hydrogen technologies.

The upskilling of hydrogen production through water electrolysis, as well as a range of new technologies for the production of renewable hydrogen, either from previously unused RES (e.g. waves) or completely new technologies (e.g. waste pyrolysis, gasification, photo electrochemical disassembly of hydrogen and oxygen, etc.) should be promoted in production.

In the area of storage and transport, technological processes should be provided for the incorporation of hydrogen into natural gas, as well as equipment and processes for the acceptable repurposing of existing natural gas-based systems. In addition, emphasis should also be placed on developing new storage methods (e.g. metal hydrides, LOHC — Liquid Organic Hydrogen Carrier, etc.).

The use of hydrogen requires further strengthening of electrolysis, but also a range of systems that use hydrogen either as an energy product, whether by means of transport or by various

devices to ensure a successful technological process. Electrolysis technology has already been verified and developed (electrolysers with proton exchange membrane, alkaline electrolysers, and solid oxide electrolysers) and, for development and demonstration, membrane-free alkaline electrolysers that allow the production of hydrogen at higher pressures, are particularly topical.

Scientific institutions should encourage applied research into the upscaling of renewable hydrogen production technology, storage and transport, and ways of using it, with particular emphasis on the development of new technological processes for industries that now use fossil fuels. One of the areas of research, development and innovation in which Croatia can make a significant step forward is to optimise the management of processes, that is to say in the management of electrolysers and fuel cells, and in particular in the management of entire systems. In addition, a step forward can also be made to convert fossil fuel vehicles into hydrogen-fuelled vehicles (especially for railways and ships as long-term means of transport where this type of intervention can be cost-effective). Further refinement of hydrogen use technology in the transport sector is needed in relation to the combustion of (chemical and electrochemical) hydrogen (which has potential for example in the aviation industry). These types of research aim to ensure a bridge between academia and industry.

Furthermore, it is necessary to encourage the strengthening of private sector research and innovation through the transfer of knowledge from academia to industry, in the context of development of new products and services that can be used both in the EU market and globally. This is important in those parts of the industry where the main activity is fossil fuel-related or are technologically dependent on the use of fossil fuels.

The scientific community needs to ensure an adequate number of experts to actively engage with industry and ensure the development of new ideas that will speed up the process of building a hydrogen economy. In addition, the scientific and economic sectors need to work closely together in so-called innovative partnerships with a view to achieving the best possible results in the development of new products and services that facilitate the faster use of hydrogen-based technologies as energy carriers.

Croatia has the potential to provide, within the scientific community and in cooperation with the industry, a range of innovations to accelerate the use of hydrogen and accelerate the establishment of a hydrogen economy, in addition to the systems already in place for the use of hydrogen.

Given that it is an energy generating product that is increasingly entering the EU economy, any solution and innovation has great potential not only within Croatia but also globally.

Regional Hydrogen Centre

As part of research activities and the strengthening of applied research related to hydrogen consideration should be given to the establishment of a Regional Hydrogen Centre (hereinafter: The Centre) in Croatia that would be a place to expand the hydrogen economy within the so-called EU 13 countries (13 youngest EU Member States) where the use of hydrogen is at the outset. The Centre’s mission would be to bring together existing research groups dealing with

hydrogen technologies in Croatia and the region, but also to establish it in terms of quality and international competitiveness within the so-called EU 13 countries.

The Centre would be run by the scientific community with the support of industry and policy from countries in the wider Croatian environment, and as such would be a meeting place for industry and research with the aim of carrying out projects related to hydrogen and the hydrogen economy. The Centre's main objective would be to become a generator of ideas and innovative solutions that will ensure that the development of a hydrogen economy is strengthened. The technical information related to the establishment and operation of the Regional Hydrogen Centre shall be defined by a separate act of the Government of the Republic of Croatia.

The Centre will also be at the heart of a consortium of scientific institutions for the implementation of Important Projects of Common European Interest (IPCEI) on hydrogen and will accelerate the development of new technologies and equipment related to hydrogen and the use of hydrogen. Accordingly, the Centre will procure appropriate equipment and coordinate the procurement of fuel cell and electrolyser testing equipment and the development of hydrogen production, transport and use technologies, as well as carry out research with a view to their further commercialisation.

The Centre's employees and associates (from all Croatian and regional scientific institutions), experts in the field of hydrogen technologies, will provide further training for existing engineers who want to upgrade their knowledge and engage in the development of hydrogen technologies.

3. S TRATEGIC OBJECTIVES FOR THE DEVELOPMENT OF HYDROGEN APPLICATIONS IN THE ECONOMY

In line with the EU Hydrogen Strategy, the Strategy sets objectives in the short term until 2026, in the medium term from 2027 to 2030 and in the long term from 2031 to 2050.

The Strategy sets strategic objectives, which directly contribute to the decarbonisation of the economy as well as to the decarbonisation of Europe in line with the European Green Deal and national targets that show the potential and direction for developing the establishment and functioning of the hydrogen economy in Croatia.

The strategic objectives are linked to a common EU policy, to which Croatia directly contributes, which will ensure that the EU's headline target of climate neutrality by 2050 is achieved.

The Strategy identifies the following strategic objectives in Croatia:

1. **Increase of renewable hydrogen production;**
2. **Increase of the exploitation of the potential of RES for the production of renewable hydrogen;**
3. **Increase of the use of hydrogen;**
4. **Encouragement of the development of science, research and development of hydrogen technologies.**

Strategic objectives contribute horizontally to CO_2 reduction, which is particularly important in view of the international commitments made by Croatia as part of the EU to reduce the impact on global warming and reduce greenhouse gas emissions.

One of the tasks of this Strategy is to promote the production and consumption of renewable hydrogen in different sectors of the economy, creating the necessary conditions for a hydrogen economy. In order to secure demand, it is important to set ambitious but realistic targets for the integration of hydrogen into different sectors of the economy, which are compatible with the ambitions of different sectors in the energy transition, with current and future investment capacities and the availability of technological solutions capable of ensuring the desired level of incorporation. This stems from previous knowledge, based on studies and reports, and requires a deeper and technical discussion with the main stakeholders in different sectors.

For the purpose of the performance of the implementation of the strategic objectives, the selected impact indicators are presented in Table 1.

STRATEGIC OBJECTIVE	**PERFORMANCE INDICATOR**	**INITIAL VALUE**	**TARGET VALUE**	
		2021/2022	**2030**	**2050**
Increase of renewable hydrogen production	Electrolyser capacity Unit of measurement: MW Code: II.02.6.48	0	70	2750
Increase of the exploitation of the potential of RES for the production of renewable hydrogen	Share of hydrogen in total energy consumption Unit of measurement: % Code: II.02.6.49	0	0,2	11
Increase of the use of hydrogen	Number of hydrogen charging stations Unit of measurement: number Code: II.02.6.50	0	15	100
4Encouragement of the development of science, research and development of hydrogen technologies.	Number of patents related to the hydrogen economy Unit of measurement: number Code: II.02.6.51	0	5	50

Strategic objectives and performance indicators are aligned with the climate neutrality scenario, and the achievement of the targets set over the period under review will largely depend on a number of external factors. The climate neutrality scenario has been developed following the scenarios of the Croatian Energy Strategy, in order to align them with the European Green Deal adopted at the EU level following the adoption of the Croatian Energy Strategy and have higher CO_2 emissions reduction targets. This is complementary to the Energy Strategy of the Republic of Croatia, as it builds on the already set targets and projects provided for in the Croatian Energy Strategy and leaves considerable scope for the development of hydrogen in order to achieve the objectives in line with the climate neutrality scenario.

Achieving the objectives is possible by initiating close cooperation between the scientific community and economic entities in the area of development of hydrogen technologies and the hydrogen economy. In addition, national, regional and international cooperation on hydrogen technologies with a focus on renewable hydrogen production is essential for the development of a hydrogen economy.

It is also necessary to highlight the expectations of technological leap in the production, storage (storage) and use of renewable hydrogen after 2030, which can have a positive impact on increasing renewable hydrogen capacity.

Table 2a. Trends in hydrogen consumption and production under the climate neutrality scenario

Year	***Total energy consumption* GWh/year***	***Share of hydrogen in total energy consumption %***	***Amount of hydrogen required kt/year***	***Electrolyser capacity MW***
2020.	99.101	0,0	0	0
2025.	101.786	0,1	2,6	35
2030.	104.470	0,2	5,3	70
2035.	97.358	1,5	37	480
2040.	90.245	3,0	69	900
2045.	83.359	6,5	138	1800
2050.	76.473	11,0	214	2750

**Republic of Croatia, Ministry of Economy and Sustainable Development, Creation of scenarios for achieving higher emission reductions by 2030 and climate neutrality in the Republic of Croatia by 2050 for the energy sector, Zagreb, 28 September 2020.*

Table 2a shows the required electrolyser capacity that obtain the electricity needed to produce hydrogen from the grid. Assuming that electricity from the grid is used, the capacity utilisation of electrolysers is set at 50 %, thus a capacity factor of 0.50.

The objectives set out in Table 2a reflect the current situation and the available resources that are in line with Croatia's Energy Strategy.

However, given the growing potential of the hydrogen economy within the EU, as well as the potential expressed by Croatia with regard to RES, the above-mentioned objectives may be further increased as shown in Table 2b, which is a scenario of accelerated development of the hydrogen economy.

Table 2b shows the required electrolyser capacity that obtain the electricity needed to produce hydrogen exclusively from RES ensuring renewable hydrogen. In view of the variability of RES, the RES capacity factor was set at 0,242 over the 30-year observation period.

Table 2b. Trends in the consumption and production of renewable hydrogen in accordance with the climate neutrality scenario (*potential scenario for accelerated development of hydrogen-based economy*)

Year	***Total energy consumption* GWh/year***	***Share of hydrogen in total energy consumption %***	***Amount of hydrogen required kt/year***	***Electrolyser capacity MW (with f_{OIE} = 0,242)***
2020.	99436,50	0	0	0
2025.	101762,50	1,25	13,94	384,02
2030.	104468,80	3,75	46,20	1272,73
2035.	97357,06	8,125	106,14	2923,97
2040.	90245,30	12,50	172,60	4754,82
2045.	83358,03	13,75	216,86	5974,10
2050.	76470,74	15,00	266,03	7328,65

Taking into account the aforementioned tables, as well as a clearer definition of initial projects related to the hydrogen economy in Croatia, for which a part of the funds is secured from EU funds, the first results of implementation priorities are expected during 2026 when the implementation of projects related to NPRR will be completed.

Since in the first phase of the Strategy implementation, renewable hydrogen will be produced mainly from electrolysers using RES electricity, Table 2b shows the planned capacities of the electrolysers needed to produce the required amount of renewable hydrogen in accordance with the climate neutrality scenario.

In order to achieve these objectives, it is necessary to provide hydrogen production capacities through several projects at national level and with varying dimensions, together with an infrastructure capable of responding to the expected market developments, especially in the transport sector. It is important to ensure that investments in hydrogen are made without significantly deteriorating energy costs of final customers, which is currently possible through EU funding.

4. IMPLEMENTATION

Decarbonisation of the energy sector, in line with EU strategies, and especially in line with the European green plan, potentiates the strengthening of RES electricity production and the development of a number of technologies to ensure CO_2 emissions reduction. However, irrespective of the transition, it is necessary that energy systems continue to fulfil their basic purpose, which is to secure supply of energy to all final customers, at acceptable prices, with minimal impact on the environment. Accordingly, the development of a hydrogen-based economy should be accelerated and the decarbonisation of the entire industry strengthened, opening up a series of new opportunities that hydrogen can open up in the chain of implementation.

In order to ensure the rapid establishment of a hydrogen economy, the scientific and economic sector should be interested in a stronger involvement in hydrogen related economic activities, thus encouraging the development of a large number of projects related to all parts of the hydrogen-related economy value chain.

This will be ensured by establishing a strategic and legislative framework, raising awareness of the importance of hydrogen under decarbonisation, clearly defining the boundaries and complementarity of hydrogen with other clean technologies, ensuring the exchange of ideas and technologies, focusing on developing a hydrogen economy as a multinational priority and providing funding sources. The establishment of a legislative and strategic framework will ensure adequate hydrogen application and standardization of hydrogen production and utilisation in all sectors.

Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the management of the Energy Union and climate action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council (Text relevant to the EEA) (OJ L 328, 21.12.2018), lays down the obligation to draw up an integrated energy and climate plan which sets out the objectives related to decarbonisation by 2030 together with implementing measures, that was adopted by the Government of the Republic of Croatia. The Regulation also provides for the development of plans for the post-2030 period (2031-2040 and 2041-2050).

The revision of the aforementioned Plan is planned for 2023 and will include the corresponding objectives from the Strategy within the framework of existing and new measures. All state administration bodies whose competence the proposed measures will enter into, will be included in the definition of the measures and the necessary funds will be agreed and planned with them in coordination, which will be adequately presented and planned in the state budget.

The implementation priorities which will contribute to the achievement of the objectives of the Strategy, and which need to be covered by the legislative and strategic framework, are as follows:

1. Renewable hydrogen used in the refinery for conventional fuel processing should be included in the contribution of reducing greenhouse gas emissions in transport, which will be incorporated into the regulatory framework of Croatia. This is in line with Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on promoting the use of energy from renewable sources (EEA Text) (OJ L 328, 21.12.2018), (hereinafter "ROW II") and thus replaces the contribution of the OIE to transport by multipliers to reduce greenhouse gas emissions

2. Encouraging the construction of the whole supply chain (infrastructure)

3. Encouraging the use of hydrogen as a fuel:
    a. transposing Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles (Text with EEA relevance) (OJ L 120, 15.5.2009) into the regulatory framework of the Republic of Croatia by the Act on the promotion of pure Road Transport vehicles (Official Gazette 52/21)
    b. subsidising the price of fuels to end-users parity with conventional fuels at the initial stage of market development with the aim of generating demand

4. In order to accelerate the development of implementation priorities under points 2 and 3, it is necessary to encourage the creation of Hydrogen hubs, i.e. clusters that will ensure demand in a large scale (e.g. ports, cities or hydrogen valleys)

5. Encouraging and co-financing of pilot/demo e-fuel production projects related to renewable hydrogen

6. Harmonisation and introduction of international standards for the use of hydrogen in transport, e.g. standards for hydrogen bottlers, hydrogen quality, calibration standards, vehicle authorisations (e.g. road transport), and for ships include the Croatian Register of ships

7. Better framework for the efficient use of electricity from RES and the formation of an acceptable price of hydrogen, e.g. by supplementing the existing methodology for determining the amount of tariff lines for the distribution of electricity (Official Gazette 104/15), with a view to developing new (incentive) tariff items for the use of a transmission network for the transmission of electricity from RES to a renewable hydrogen production site using electrolysers and for the possibility of using electrolysers and fuel cells to provide services to electricity system operators

8. Encouraging the development of innovation in the hydrogen value chain by creating a positive regulatory and strategic framework.

In addition to these implementation priorities, efforts should be made to raise awareness among the general public about the role hydrogen can play in decarbonising the economy and to demonstrate that this is a technology that is safe and adequate for broad application. It is also

necessary to apply hydrogen in parallel with a series of other clean technologies that are not competitive with hydrogen but rather complement it. The best example is public urban transport where, in the promotion of clean vehicles, it is indispensable to combine hydrogen and electric battery powered vehicles and to use certain technologies on lines that prove most appropriate for the technology in question. This will avoid the negative effects of certain technologies and ensure the accelerated decarbonisation of public urban transport.

In order to implement and monitor the implementation of this Strategy, the Ministry in charge of the energy sector will, in cooperation with the Centre, ensure the adoption of the necessary legislative framework for the purpose of implementing the aforementioned priorities and monitor the fulfilment of the set objectives.

In addition, in order to meet all planned implementation priorities, it is necessary to strengthen cooperation with other Member States, in particular within the EU, and exploit the potential offered through the establishment of projects of high European importance related to hydrogen.

4.1 Inter-departmental cooperation and cooperation with the regional and local community

Given the need to develop a hydrogen economy in several sectors, high quality cross sectoral cooperation is necessary that will enrich the parallel development of hydrogen production and utilisation. For example, close cooperation between the two state administration bodies is needed in the transport sector with the aim of parallel development of hydrogen systems in all segments of transport and ensuring sufficient quantities of renewable hydrogen, in terms of energy, for these systems.

Furthermore, it is necessary to cooperate with regional and local authorities in order to ensure quality and efficient implementation of projects in accordance with all the needs of the local community. This is particularly important when we talk about developing a network of hydrogen charging station for transport, but also later when hydrogen will be produced and used in larger quantities (for example in industry). In addition, interests of the regional and local communities should be taken into account as well as the potential that certain regional and local communities possess when it comes to developing a hydrogen economy. This potential and expression of needs should be more clearly linked at the national level with the aim of creating a network of potential projects, with the aim of ensuring accelerated implementation and opening additional access to potential funds for the realisation of these projects.

4.2 International cooperation

Intensive and effective international cooperation is important for the development of a hydrogen economy, in particular in establishing large-scale production of renewable hydrogen to make it affordable for wider use while ensuring technology production and the use of clean energy.

Harmonised growth in supply and demand should be ensured at the start of the hydrogen economy, with the aim of opening up market conditions and reducing the need to subsidise projects.

At the same time, strengthening production and consumer power in the hydrogen economy requires sufficient capacity to produce renewable hydrogen, but also sufficient demand, so that the market launch process can be accelerated by several countries working together. This aspect of cooperation is also strengthened in strategic documents (e.g. the Integrated Energy and Climate Plan) and is a good instrument to accelerate the development of a hydrogen economy.

International cooperation is also essential in view of the increasing global trade in renewable hydrogen, especially when it comes to quality standardisation and defining minimum conditions for the production of renewable hydrogen in order to ensure its global accessibility.

4.3 Connecting Europe Facility

The EU has set up the Connecting Europe Facility (hereinafter: CEF) as an assistance instrument aimed at building digital, transport and energy infrastructure at the EU level pursuant to Regulation (EU) 2021/1153 of the European Parliament and of the Council of 7 July 2021 establishing the Connecting Europe Facility and repealing Regulations (EU) No 1316/2013 and (EU) No 283/2014 (Text with EEA relevance) (OJ L 249, 14.7.2021). The CEF complements Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009 (Text with EEA relevance) (OJ L 115, 25.4.2013), (hereinafter: The TEN-E Regulation) by addressing the funding gap for projects with a high socio-economic and social value. The EC presented a proposal for the revision of the TEN-E Regulation on 15 December 2020, which identified 11 priority corridors and 3 priority thematic areas to be developed and interconnected. It updates the categories of infrastructure eligible for support with a focus on decarbonisation and gives a new focus on offshore electricity grids, hydrogen infrastructure and smart grids. This will mainly be achieved through projects of common interest eligible for funding from the SEF for the period 2021-2027. The EC adopts the list of projects of common interest in the form of a delegated regulation based on the assessment of the so-called regional groups. The Council reached a general approach on the TEN-E Regulation on 11 June 2021 and a provisional political agreement on the proposal with the European Parliament on 15 December 2021.

Furthermore, achieving project status under the TEN-E Regulation is a precondition for financing cross-border infrastructure projects from the CEF. This instrument intends to co-finance projects related to the deployment of hydrogen transport and production infrastructure. It will finance the establishment of an EU wide network of pipelines for the transport of hydrogen with the aim of creating the conditions for market opening at the EU level and ensuring a sufficient amount of hydrogen for all the processes necessary for decarbonisation. On the other hand, large electrolyser installations will be financed to stimulate large-scale production of renewable hydrogen, which is needed to ensure the decarbonisation of a range of industrial processes which, in order to move away from fossil fuels, are essential to secure large

amounts of hydrogen. The opportunity offered by the CEF is particularly significant for smaller Member States that can unite and secure production that will meet the markets of all countries involved.

The CEF instrument also provides grants to finance the preparation and implementation of projects and is an important element in reducing risks and ensuring adequate support without which a number of projects would never be realised.

It should also be pointed out that this instrument has made it possible to connect individual countries in a number of different areas, such as potential hydrogen transport, adequate hydrogen exchanges and the creation of synergies between optimal hydrogen production sites and the industry that needs hydrogen to establish clean production processes.

In the area of energy, this instrument provides for the financing of so-called Projects of Common Interest (PCI) relating to cooperation between two EU Member States and Projects of Mutual Interest (PMI) relating to cooperation between a Member State and a third country, in accordance with the TEN-E Regulation. This type of projects, before adoption, undergoe rigorous analysis within the Commission and each project on the PCI list must have a direct or indirect impact on at least two Member States. Bearing in mind that the listing process takes almost two years, potential hydrogen transport and production projects should be prepared as soon as possible with a view to ensuring access to potential financing for project preparation and realisation.

4.4 Hydrogen valleys

A specific form of international cooperation is linked to the potential establishment of Hydrogen Valleys. It is a global initiative and 36 hydrogen valleys are currently established on five continents. These are regional systems located within multiple countries, linking hydrogen production, transport and various end-uses (such as mobility or industrial raw materials) and are important for building and strengthening the hydrogen economy. They also exist within EU countries such as the Netherlands, Spain, Germany, etc.

The hydrogen valleys aim to promote the opportunities and potential of hydrogen technologies in order to attract additional investments to regions and countries that have set up the hydrogen valley and to secure the value chain from hydrogen production to use. Attracting investment at global level ensures the recognition and visibility of individual regions in the area of hydrogen technologies.

Croatia is involved in the project ‘North Adriatic Hydrogen Valley’ together with the Republic of Slovenia and the Autonomous Region of Friuli, Venezia Giulia from northern Italy. The valley is in the process of being established and aims to link projects, which are an integral part of the valley, with potential partners in the valley Member States. In addition, the valley plays an important role in ensuring the visibility of Croatia, SI and IT within the EU, as well as their leading positions ahead of the 13 youngest EU Member States (EU 13), which still lack the potential to produce and use renewable hydrogen.

4.5 Projects of European Common Interest

Due to the strengthening of the hydrogen economy at the EU level, there is a growing need to establish projects of common European interest for hydrogen (IPCEI). Projects of common European interest are one of the relevant tools that support strategic value chains at European level.

The ECEI instrument is extremely important for mobilising private investment and public funds in areas where market failures exist, in particular regarding the extensive deployment of innovative technologies. IPCEI is envisaged as a key strategic instrument in the framework of the implementation of the EU industrial Strategy. IPCEI brings together knowledge, expertise, financial resources and economic actors across the EU with the aim of overcoming important market or systemic failures and societal challenges that could not be addressed without activating the knowledge and resources of several EU countries. IPCEI projects are designed as large consortia within the EU that integrate key strategic value chains with closely connected projects of individual companies. Special emphasis is placed on research and development, as well as on the first industrial applications. They are designed to combine the public and private sectors in implementing major projects that bring significant benefits to the EU and its citizens.

IPCEI requests the approval of the EC under the State aid Act (Official Gazette 47/14 and 69/17). Companies and Member States must demonstrate in the dedicated notification procedure that IPCEI follows the most important European interest and that the projects could not be realized only under market conditions. With their approval, the EC ensures that all EU Member States can benefit, that there is no major distortion of competition and that companies comply in their projects with the basic general and specific criteria set out for this type of project.

The process of establishing the IPCEI for hydrogen is under way, and its establishment opens the possibility of active inclusion Croatia in a consortium with the aim of achieving the potential that hydrogen offers to the Croatian economy.

5. MONITORING OF IMPLEMENTATION AND EVALUATION

The Strategy is a framework for the development of hydrogen economy and the implementation of new technologies related to hydrogen into the economy of Croatia.

Monitoring, evaluation and reporting on the implementation of the Strategy is an essential part of the strategic planning process. Monitoring the implementation of the Strategy will include the process of collecting, analysing and comparing indicators that will systematically monitor the success of the implementation of objectives from the Strategy. Progress and other available data will be monitored during the implementation of the Strategy, which will help provide comprehensive information on the effects of the Strategy implementation and the impact on society as a whole.

The Ministry of Economy and Sustainable Development shall submit a report on the implementation of the Strategy in accordance with the prescribed manner and deadlines, and

key holders of strategic planning at all levels shall, for the purpose of providing timely and relevant data, permanently inform on the implementation of the Strategy.

In order to improve the success of the Strategy implementation, a mid-term evaluation procedure will be carried out after 2030, evaluating all objectives of the Strategy, selected implementation performance indicators and their compliance with related strategic planning acts.

6. FINANCING

The EU hydrogen Strategy assesses the amount of total investments in production capacity by 2050, in the EU area, ranging from 180 billion euros to 470 billion euros. In the period until 2030, investments in electrolysers will range between 24 billion and 42 billion euros. At the same time, 220-340 billion euros will be needed to increase and directly connect 80-120 GW solar power plants and wind power plants to electrolysers in order to provide the necessary electricity. Investments in equipment of existing CO_2 capture and storage installations are estimated at 11 billion euros, and an additional 65 billion euros will be needed to transport, storage and hydrogen charging stations. Adjustment of the hydrogen economy use will also require significant investments, e.g. 160-200 million euros need to be invested in the conversion of steel plants into the EU, which are at the end of their lifetime, into hydrogen-powered plants. In the road transport sector, it is estimated that the introduction of an additional 400 hydrogen charging stations on a small scale could require investments of 850-1000 million euros.

The establishment of a hydrogen economy in Croatia also requires significant investments in all sectors from production, promotion and encouragement of new technologies, research, storage and transport of hydrogen to the use of hydrogen in transport (charging stations and vehicles) and industry (technological processes).

The assessment of macroeconomic effects was carried out for two development scenarios defined by the Strategy. The first scenario, in accordance with the climate neutrality scenario, implies the installed capacity of the electrolyser in the period up to 2050 in the amount of 2750 MW. The second scenario, based on the assumptions of accelerated development of hydrogen economy over the same period of time, implies an installed electrolyser capacity of 7328,7 MW.

The necessary capital investments were assessed for each of the scenarios in question in order to realise the necessary hydrogen production capacities. Investments include the cost of electrolysers, compressors and hydrogen containers. Accordingly, the first scenario requires a capital investment in the amount of 23.8 billion kuna in the period until 2050, while the second scenario in the same period requires an investment in the amount of almost HRK 70.2 billion kuna.

The macroeconomic effects of investments for each scenario are grouped over five-year periods, which are shown in the tables below.

Table 3. Macroeconomic effects of capital investments in hydrogen production infrastructure in accordance with the climate neutrality scenario

Period	*Required capital investment*	*Average annual investment*	*Average annual added value*	*Average annual GDP*	*Average annual employment*
Year	*million kuna*	*million kuna / year*	*million kuna / year*	*million kuna / year*	*Number of employees / year*
2020 - 2025	438	88	52	61	296
2025 - 2030	403	81	47	56	272
2030 - 2035	4.305	861	526	631	3.062
2035 - 2040	3.985	797	487	584	2.834
2040 - 2045	7.628	1.526	921	1.108	5.389
2045 - 2050	7.089	1.418	856	1.030	5.009
	23.848 (total)	**795 (average)**	**479 (average)**	**574 (average)**	**2.784 (average)**

In the entire analysed period, for the first scenario the average annual investment would amount to 795 million kuna. It is to be expected that the investments in question will lead to an increase in the number of new employees (for an annual average of 2784 persons from the starting year of the analysis). On average, GDP would grow by 574 million kuna per year, while the value added would amount to 479 million kuna on average per year.

Table 4. Macroeconomic effects of capital investments in hydrogen production infrastructure in accordance with the scenario of accelerated development of the hydrogen economy

Period	*Required capital investment*	*Average annual investment*	*Average annual added value*	*Average annual GDP*	*Average annual employment*
Year	*million kuna*	*million kuna/ year*	*million kuna/ year*	*million kuna / year*	*Number of employees/ year*
2020 - 2025	4.810	962	566	674	3.250
2025 - 2030	10.231	2.046	1.204	1.434	6.913
2030 - 2035	17.338	3.468	2.119	2.541	12.331
2035 - 2040	17.370	3.474	2.123	2.546	12.354
2040 - 2045	10.333	2.067	1.247	1.501	7.301
2045 - 2050	10.108	2.022	1.220	1.468	7.142
	70.191 (total)	**2.340 (average)**	**1.409 (average)**	**1.690 (average)**	**8.193 (average)**

In the scenario of accelerated development of hydrogen economy, the average annual investment would amount to 2.34 billion kuna. Accordingly, the growth in the number of newly employed persons would be on average 8,193 from the starting year of the analysis. GDP would increase by 1.7 billion kuna on average per year, while the value added would amount to 1.4 billion kuna on average per year.

Table 5. Macroeconomic effects of capital investments for the scenario of developing the hydrogen-powered vehicle charging infrastructure

Period	***Required capital investment***	***Average annual investment***	***Average annual added value***	***Average annual GDP***	***Average annual employment***
Year	***million kuna***	***million kuna / year***	***million kuna / year***	***million kuna / year***	***Number of employees/ year***
2020 - 2025	36	7,2	4,2	5,0	24,3
2025 - 2030	234	46,8	27,5	32,8	158,1
2030 - 2035	306	61,2	37,4	44,9	217,6
2035 - 2040	230	45,9	28,0	33,6	163,2
2040 - 2045	325	65,0	39,2	47,2	229,6
2045 - 2050	325	65,0	39,2	47,2	229,6
	1.456 (total)	**49 (average)**	**29 (average)**	**35 (average)**	**170 (average)**

The Strategy envisions installing 100 charging station for hydrogen-powered vehicles. It is estimated that the above-mentioned infrastructure requires a capital investment of almost 1.5 billion kuna in the period up to 2050. Accordingly, the average annual investment amounts to about 49 million kuna. By realizing the above mentioned, GDP would increase on average by 35 million kuna per year, Average annual by 29 million kuna per year, while employment would increase on average by 170 persons from the starting year of the analysis.

It is particularly important to provide grants in the first years of implementation of hydrogen projects, as this is a relatively new technology that is not commercial and is directly oriented towards decarbonisation. A larger share of the necessary funding needs to originate from EU funding sources, whether they are investments in capital costs (including project preparation) or operating costs related to renewable hydrogen manufacturing, while some of the funds need to come from national funds.

Capital costs (CAPEX) require EU funding to invest in the first electrolyser projects, as a sufficient number of electrolysers in the EU are needed to make the project viable, which is expected by 2030. There are EU funds from which it is possible to draw funds for such projects and this is one of the objectives of the realisation of the European Green Plan. In addition,

incentivising operating costs (OPEX) should also be considered, as the price of renewable hydrogen is now 2.5 to 5.5 times more expensive than grey hydrogen.

A part of this funding relates to the establishment of hydrogen economy in Croatia. Figure 5 shows Croatia's planned financial investment in hydrogen technology for the installation of hydrogen charging stations, introduction of hydrogen vehicles and vessels, the transition of industry to hydrogen as well as for education, research and development.

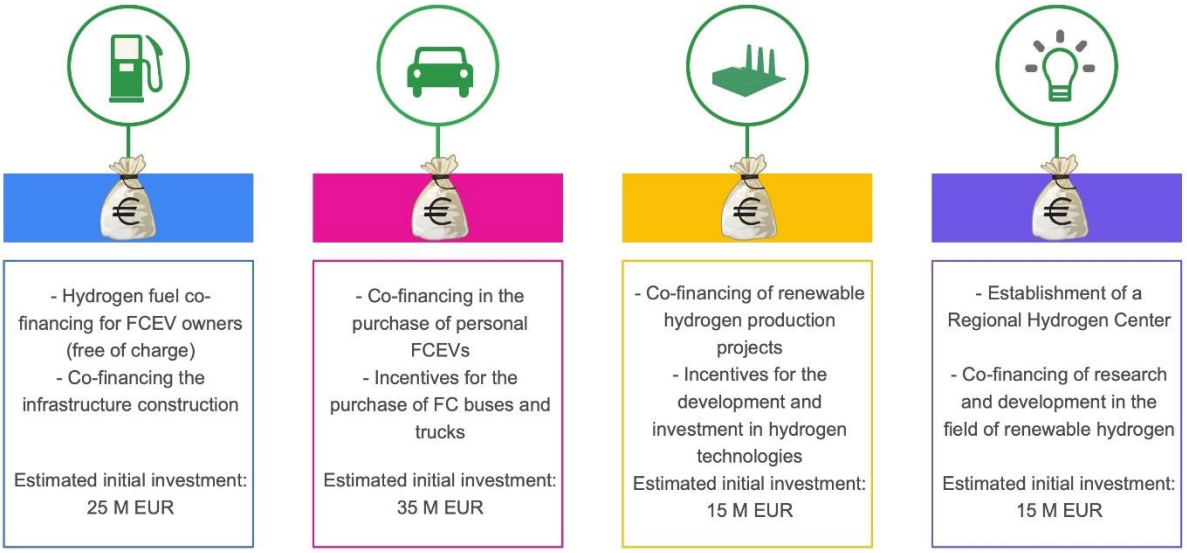

Figure 5. Planned financial investment in hydrogen technology in the Republic of Croatia

In the sector of hydrogen transport, it is necessary to analyse the possibilities of using EU funds, credit lines and/or national schemes to support businesses to facilitate the transition to a green economy. As an example of good practice, a model of subsidising excise duty on blue fuel used in public coastal maritime transport, which could be used to subsidise kWh of electricity produced from hydrogen via fuel cells to be used for the propulsion of ships.

Since it is necessary to establish a model for the creation of prices for renewable hydrogen in the initial stage of the development of hydrogen economy in Croatia, and with the aim of stimulating growth in consumption and introduction of hydrogen technologies in transport, it is proposed that the excise duty, as for clean biofuels, amount to 0.00 kuna. Potential forms of market stimulation can also be vouchers for end users, toll benefits, parking, etc.

In order to introduce new technologies and build hydrogen infrastructure in the transport sector of Croatia, it is necessary to provide financial resources for co-financing such projects which are not feasible at the very beginning of development due to their low level of volume economy.

Co-financing of both stages of the introduction of hydrogen into the transport sector of Croatia should be supported over a period of up to ten years, as it is expected that all technologies should mature in that time as well as and a sufficient level of economy volume of these technologies to make them commercially viable for all operators in the hydrogen supply chain

on the market. The level of co-financing must be sufficient to make new technologies replacing existing ones commercially viable for all actors in the hydrogen supply chain.

In the coming period, it is essential to provide sufficient sources of funding to boost the growth and development of the hydrogen economy. These can be national funds, EU funds and private investment, and a combination of all these options.

The establishment of a hydrogen economy needs to be financed for the most part by EU funds, not only those allocated at the EU level, but also EU funds allocated on the basis of national programmes.

Of the programmes with no national allocations, the most important is certainly the Innovation Fund and Horizon Europe. The Innovation Fund offers funding for projects in the construction phase but also in the deployment of technology. The Innovation Fund offers financing to large projects above 7.5 million euros and smaller projects with a value not exceeding 7.5 million euros, which finance demonstration and innovative low-carbon technologies and thus hydrogen.

Horizon Europe may finance research projects aimed at commercialisation of research and synergy projects involving in itself joint work of scientific institutions, local communities and economy operators.

Also, EU funds are available as national programmes financed by EU funds under the European Structural and Investment Funds (ESIF), NRRP, Modernisation Fund, etc.

The NRRP will finance electrolysers, hydrogen charging stations and the procurement of hydrogen vehicles. In addition, similar investments are planned in the new Operational Programme Competitiveness and Cohesion, with plans to finance the development of new technologies and the commercialisation of new products, and the Modernisation Fund has a wide range of opportunities, one of which is linked to the transport sector.

National funds, which can finance hydrogen projects, relate to the state budget and revenues generated from the sale of emission allowances.

In the plan for the sale of allowances in 2021. —2025 funds were allocated to the low-carbon energy transition, within which a part of the funds was directed towards energy and a part towards transport. This appropriation may serve as a good generator of hydrogen projects especially in the context of the procurement of hydrogen vehicles and the establishment of renewable hydrogen production systems.

Regarding private investment, which is increasingly oriented towards the green transition, hey will largely depend on possible models of co-financing and the cost-effectiveness of such projects.

The use of national and EU funds should encourage much greater investments primarily in the first decade of renewable energy production, renewable hydrogen production, transport and

storage and research and development of new products, as well as the introduction of a new segment of the economy which will ensure an adequate transformation of the industry.

Accordingly, it is necessary to consider introducing additional incentive mechanisms through other strategic documents and plans in the next period at the time of their adoption, all with the aim of bridging the time period between infrastructure construction and market development to the level of economic viability of the investments.

7. CONCLUDING CONSIDERATIONS

The establishment of an economy based on hydrogen is necessary for the realization and implementation of the decarbonisation process in Croatia. At the same time, the opportunities arising from the hydrogen economy represent an additional incentive for the transition of Croatia's current economy to a green and advanced economy that will set the foundation for the development of clean technologies and open new opportunities.

Consequently, it is necessary to start the process of establishing an economy based on RES and renewable hydrogen in its entirety, i.e. from production to hydrogen use, provided that an appropriate pool of experts is ensured, which will, inter alia, be ensured through the established Centre.

It is also necessary to start an organized and informative campaign with the aim of raising public awareness of all advantages of development of green technologies and hydrogen economy in Croatia. The price of the entire hydrogen production system, from an operational point of view, is mostly influenced by electricity prices (> 50%). Consequently, for the operation of the electrolyser it is necessary to ensure a competitive price of electricity.

The connection of the electrolysers to the grid, in the direction of receiving electricity from the grid, should be done according to real and not administrative cost. In operational activity, such electrolyser, which also offers services to the system, should be linked to wholesale electricity prices, i.e. it must not have the status of final customer. Furthermore, the price of electricity should be directly linked to the electricity exchange at the wholesale price, i.e. such a system should not have the status of final customer.

The Strategy sets strategic objectives that will contribute to reducing CO_2 emissions in line with commitments undertaken by Croatia as part of the EU with the aim of reducing the impact on global warming. The achievement of the objectives will result in an increased share of hydrogen consumption in the period until 2050, as well as in the production of renewable hydrogen that needs to be achieved following the projected share in consumption.

In the following period, capacities for the production of renewable hydrogen will be provided through several projects at the national level, together with the infrastructure that will be able to respond to the expected market development, especially in the transport sector. The proposed incentive mechanisms through the various EU funding options will enable the realisation of projects on a commercial basis in the coming period, with the aim of bridging the time period

between infrastructure construction and market development to the level of commercial viability of the investments.

8. GLOSSARY

Electrolyser – a system or device that performs electrolysis

Electrolyser Stack – set of electrolysers

ETS – greenhouse gas emission trading system

GHG –Greenhouse gas

Fuel Cell– source of electrical charge where chemical energy is transformed into electric energy through cold combustion hydrogen with oxygen supply and catalyst action

Hydrogen Economy – a sustainable energy system in which clean hydrogen replaces fossil fuels based on hydrocarbons

Climate neutrality – signifies human activity without affecting the climate

Low-carbon hydrogen – blend of fossil hydrogen using CO_2 capture and storage technologies and hydrogen obtained by water electrolysis from electricity

Renewable hydrogen – hydrogen produced with zero or low levels of GHG releases

Fuel Cell Stack – set of fuel stacks

Hydrogen – chemical element, atomic (order) number 1 and atomic mass 1,00794 (7)