# Draft Roadmap
# for the use of hydrogen
# in Ukraine in road transport

March 2021

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## Acknowledgements

This report is prepared within the scope of the UNECE implemented RPTC-funded project "Improving capacity of the Government of Ukraine to develop infrastructure for production and use of hydrogen to support green post-Covid-19 recovery". It was produced under the guidance of the UNECE Sustainable Transport Division, the Ministry of Energy of Ukraine and the State Agency on Energy Efficiency and Energy Saving (SAEE) of Ukraine.

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Cut-off date of this report is 9 March 2021.

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## List of Abbreviations

| | |
|---|---|
| BEVs | Battery electric vehicles |
| CAPEX | Capital expenditures |
| CCS | Carbon capture and storage |
| CHP | Combined heat and power |
| EU | European Union |
| FCH JU | The Fuel Cells and Hydrogen Joint Undertaking |
| FCEVs | Hydrogen fuel cell electric vehicles |
| GoU | Government of Ukraine |
| HDSAM | Hydrogen Delivery Scenario Analysis Model |
| HEVS | Hybrid electric vehicles |
| ICE | Internal Combustion Engines |
| LOHC | Liquid organic hydrogen carriers |
| NEEAP | National Energy Efficiency Action Plan |
| NREAP | National Renewable Energy Action Plan |
| NEV | New energy vehicle |
| OPEX | Operating expenditures |
| PHEV | Plug in hybrid electric vehicles |
| RES-T | Renewable energy sources in transport |
| R&D | Research and development |
| RPTC | Regular Program on Technical Cooperation |
| RFNBO | Renewable fuels of non-biological origin |
| SMR | Steam methane reforming technology |
| SDG | United Nations Sustainable Development Goals |
| TCO | Total Cost of Ownership |
| THE PEP | Transport, Health and Environment Pan European Project |
| UNECE | United Nations Economic Commission for Europe |
| WTW | Well-to-wheel models |

## Executive Summary

As public pressure is rising to limit global warming to 1.5 degrees Celsius, global leaders are grappling with how to best take on this unprecedented challenge. Full decarbonization requires a multidimensional strategy, which has spurred renewed interest in hydrogen. Governments are recognizing hydrogen's ability to decarbonize sectors that are otherwise impossible or difficult to abate – such as intensive personal or collective transport, freight logistics, industrial heating and industry feedstock – and its role in energy security. Meanwhile, industry leaders across the automotive, chemicals, oil and gas, and heating sectors look to low-carbon hydrogen as a serious alternative to reach their increasingly substantial sustainability objectives.

Hydrogen public transport (specifically buses) are being trialled in selected cities worldwide, providing practical experience in their operation and maintenance, as well as in the development and operation of associated H2 refuelling infrastructures. The aim of these demonstration projects is to gather real-world data that will help to assess the viability of hydrogen vehicles and supporting infrastructure, with a view to achieving full commercialization in the vehicle market. However, the successful introduction of these vehicles will depend not only on technical maturity, but also on public acceptability and preferences of these new fuels and technologies. The demonstration of hydrogen buses in cities across the globe will ensure that members of the public are able to directly experience the technology, providing in effect a test of acceptability in the field. Acceptance is crucial for any new technology to penetrate the market; low acceptance may result in inadequate uptake of the technology, or indeed, resistance or opposition to the technology.

Hydrogen in transport using fuel cell-electric vehicles is in early phases of commercialization worldwide and shows major potential for decarbonizing transport in a complementary fashion to battery-electric vehicles. A small contribution by 2030 and dynamic growth thereafter is anticipated for hydrogen in road transport with a focus on road vehicles for longer driving distances including passenger cars, and for heavy-duty purposes such as trucks, buses and coaches, and on non-electrified rail lines. Renewable hydrogen can also be used to produce sustainable liquid fuels for aviation, shipping, etc.

Ukraine aims to achieve the 2030 renewables consumed in transport target of 9% . In fact, significant over-achievement beyond 13% is possible. It should be noted that even with the achievement of the 2030 target of 9%, the anticipated consumption growth over the coming decade is expected to result in increased fossil fuel imports relative to 2018. Higher ambitions could thus be beneficial in economic and environmental terms for Ukraine. 2030 targets for renewable electricity production should be increased including the anticipated additional renewable electricity demand from transport (for direct use or for hydrogen production).

The report is prepared with the support of the United Nations Economic Commission for Europe (UNECE), as part of its Regular Program on Technical Cooperation (RPTC). The UNECE was established in 1947 with the aim of promoting pan-European economic integration. Currently UNECE has 56 member States in Europe, North America and Asia[1].

Through its mandate, the RPTC aims to assist developing countries and countries with economies in transition to accede to/adopt and implement UNECE legal instruments, norms, standards and regulations as means of their integration in the region and global economy. The Programme also contributes to promoting regional/sub-regional cooperation, quintessential in addressing common development challenges and resolving transboundary problems, as well as in achieving the international development goals, including the Sustainable Development Goals (SDGs). RPTC is implemented by the UNECE Regional Advisers.

[1] https://unece.org/

# 1. Introduction

This report provides an analysis and a set of recommendations for the Government of Ukraine (GoU) and specifically to the Ministry of Energy of Ukraine. These recommendations will foster and improve the capacity of the GoU to develop infrastructure for the production and use of hydrogen to support its green post-COVID-19 recovery.

Hydrogen is a renewable and clean source of energy that supports circular economy. The transition from traditional energy sources to hydrogen supports climate change initiatives, but also it influences economy due complete change of established supply chains in different sectors. At the same time investments to hydrogen production, infrastructure and use may become a new booster of economy not only in energy sector, but also in adjacent sectors.

Ukraine is experiencing an economic downturn as a consequence of the Covid-19 pandemic. Development of infrastructure to produce and use hydrogen in Ukraine will facilitate its economic recovery, increase its energy security and efficiency, improve the economic climate and create new employment opportunities.

This report contains a draft Roadmap for use of hydrogen in Ukraine in road transport, with emphasis on the urban transport component. The draft Roadmap includes analysis of best international practices and plans for the use of hydrogen, analysis of the importance of hydrogen technologies and potential for their use in Ukraine, and detailed transport oriented input to be integrated into the overall Roadmap for introduction of hydrogen technologies in Ukraine.

This report is organised in different sections according to the main issues to be considered in relation to the development of the Ukrainian hydrogen environment.

The first section provides Ukraine stakeholder mapping and focuses on identification of stakeholders relevant for the use of hydrogen in road transport and their role, type and priority of engagement.

The second section focuses on analysis of international best practices and existing hydrogen initiatives and projects in road transport, with a focus on urban transport. The section provides references to the hydrogen experience in different countries.

The third section deals with legal and regulatory framework pertinent to the use of hydrogen in road transport in Ukraine.

The fourth section covers economic and financial considerations pertinent to the use of hydrogen in road transport, particularly urban transport.

The fifth section provides a number of recommendations to set and improve the use of hydrogen in Ukraine in road transport.

### ***UNECE mandate***

UNECE as a multilateral platform facilitates greater economic integration and cooperation among its fifty-six member States and promotes sustainable development and economic prosperity through:

- policy dialogue,
- negotiation of international legal instruments,
- development of regulations and norms,
- exchange and application of best practices as well as economic and technical expertise,
- technical cooperation for countries with economies in transition.

UNECE supports countries in the implementation of the 2030 Agenda and the SDGs, a set of 17 interlinked goals designed to be a "blueprint to achieve a better and more sustainable future for all" (United Nations Resolution adopted by the General Assembly on 6 July 2017), thanks to its role as a platform for governments to cooperate and engage with all stakeholders on norms, standards and conventions.

Transport is linked with virtually all SDGs. It is fueled by energy and is therefore directly linked to SDG 7 on affordable and clean energy. Sector stakeholders can contribute to target 7.2 by increasing the share of renewables in the transport energy mix, and to target 7.3 through measures that improve passenger/freight distance travelled per unit of energy input. Targets 7.A and 7.B also have links to transport. The sector's capacity to innovate may prove increasingly relevant to these two targets for 2030 through investment in research and development (R&D) and as nascent technologies mature.

Measures to improve energy efficiency and integrate renewables into transport systems commonly diverge on the boundary between the urban scale and the inter-urban and international transport scales. It is important to take into consideration and respond to the particularities of these transport subsectors—their environments, economics and stakeholders.

At the urban scale, the "avoid, shift, improve" mitigation framework describes pathways for improving the sustainability of transport:

- reducing travel demand and minimizing unnecessary travel;
- shifting to more efficient modes of transport, such as buses;
- improving the emission performance of vehicles, e.g. using clean hydrogen.

Achieving a substantial increase of renewable energy in the transport energy mix will depend on setting ambitious targets for shares of advanced biofuels and other alternative fuels with low-carbon lifecycle emissions in the transport energy mix; deployment of higher proportions of EVs in vehicle fleets; and the expansion of renewable electricity generation capacities (on grid and decentralized). Hydrogen and fuel cells can also improve the environmental impact and energy efficiency of vehicles, providing the hydrogen is produced via low carbon primary energy sources. Technological solutions for overcoming challenges in transport and storage of hydrogen are on the horizon, while the current state of the art already has solutions for its safe use. However, several challenges remain, in particular addressing the capital costs of establishing fuelling station networks and the corresponding required infrastructure for hydrogen fuelled road vehicles. UNECE promotes energy efficient transport through UN Vehicle Regulations, developed through the work of the UNECE World Forum on Harmonization of Vehicle Regulations (WP.29), on improved fuel efficiency and by ensuring that more sustainable fuel technologies including electric, hybrid and hydrogen, become widely available.

Direct impacts of transport on progress in achieving the SDGs and their targets also include reducing road traffic deaths (target 3.6), which are a factor of the safety features of vehicles, the design of infrastructure and traffic systems and the behaviour of participants in traffic. As host to the UN conventions and agreements on road safety, UNECE supports cooperation for safer transport and works with countries to build capacities for road safety plans that save lives. UNECE also hosts the secretariat and supports the work of the Secretary General's Special Envoy for Road Safety.

Further key links are with Goal 13 on climate change (target 13.2 on mitigation), Goal 11 on cities (target 11.6 on emissions and air quality) and Goal 3 on health (target 3.9 on air pollution). UNECE helps countries reduce urban air pollution through measures to reduce harmful emissions from vehicles, through more stringent ceilings on emissions of pollutants, UN Regulations on vehicle emissions and by facilitating the availability of greener fuel sources. UNECE has also developed a modelling tool to help governments develop transport policies that minimize CO2 emissions (For Future Inland Transport Systems).

Notable links to transport are also observed in relation to SDG 8 on decent work and economic growth, as transport industry plays an important role in today's economy. Having in mind the strong projected long-term rate of increase of demand for transport-related products and services in developing countries (temporarily stalled due to the COVID-19 pandemic), the industry will be a very important element in the equation to achieve the targets of SDG 8. Through the Transport, Health and Environment Pan European Project (THE PEP) in partnership with WHO/Europe, UNECE is working with a range of stakeholders to identify and promote green jobs in the transport sector.

In a broader perspective, transport systems and energy consumption very much impact SDG 9 on industry, innovation and infrastructure and SDG 12 on responsible consumption and production, and they will in turn be impacted by measures taken by governments and industry stakeholders to achieve these goals. Through its 59 international Transport legal instruments, UNECE provides a framework for the development of infrastructure and operations to ensure safe and sustainable transport systems, by road, rail, and inland waterways, facilitating mobility of people and movement of goods. UNECE also helps countries to harness the potential of new technologies through the integration of Intelligent Transport Systems in all modes of transport.

The wording of target 7.2 of SDG 7: “by 2030, substantially increase the share of renewable energy in the global energy mix”, is quite open. As such, it presents an opportunity for countries, those that are able to dedicate sufficient resources, to define ambitious voluntary targets for shares of renewables in their transport sectors by 2030, thereby taking the lead with proactive policy examples that may be replicated elsewhere.

***Hydrogen in transport***

Investigations conducted in various cities and countries have shown that the usage of renewable fuels can significantly reduce noise pollution and emissions produced by public transport. If Europe doubles the number of hydrogen buses, it will allow decreasing the infrastructure costs per bus and speeding up the adoption of the technology in general. [1]

Fuel-cell vehicles are beneficial for public transport thanks to their ability to travel long distances (compared to electric buses), produce no tailpipe emissions but water and little noise. Powered by electrochemical cells, such vehicles can mix hydrogen contained in high-pressure tanks with oxygen from the air for generating electricity, heat, and water. The benefits are comparable with the more developed diesel, trolley and battery technologies other things being equal. [1]

This clean revolution takes slowly in European public transport. Hydrogen-fuelled buses are appearing while refuelling stations are being deployed due to several pilot projects. But this trend will undoubtedly increase in the near future, as new projects begin, trying to put hydrogen cars in a place to uphold zero emissions of transport across Europe.

There several initiatives promoting use of hydrogen buses in Europe, among them H2BUS Europe (target to supply over 600 buses until 2023), JIVE and JIVE 2 (deployment of nearly 300 fuel cell buses in 22 cities across Europe), CHIC (54 fuel cell buses were demonstrated in cities across Europe and at one site in Canada).

The hydrogen spread is not limited only to road public transport, there are various examples of hydrogen trains and ships. The hydrogen trains considered as cost competitive with diesel-powered trains and there is separate initiative Shift2Rail Joint Undertaking, which support promotion and use of hydrogen trains in Europe. The leading marine operators and vessel manufacturers also explores feasibility of hydrogen use, more than 120 companies has established the Getting to Zero Coalition with ambitious commitment to develop commercially viable zero emission vessels. The hydrogen ferries are tested in Norway, Germany and Belgium.

The demand for environment-friendly vehicles is also growing among Europeans, who want to reduce urban air pollution, decrease reliance on fossil fuels, and eliminate carbon dioxide emissions generated by their cars. And now, it is being fuelled by innovations that can give improved execution and equal comfort, range, and refuelling time compared to petroleum and diesel-controlled autos at a small amount of the ecological expense.

Like diesel or petroleum, hydrogen is stored in a car tank, but in contrast, hydrogen-powered vehicles drive by electrochemical reaction between hydrogen and that generates electricity. A comparative electrochemical cycle is utilized in batteries. While a battery discharges with time, a fuel cell can keep working as long as hydrogen and oxygen are fed into it, emitting water as the only discharge. [2]

Ukraine has the largest energy consumption and population among Contracting Parties (or members) of the Energy Community. The Energy Community is an international organization which brings together the European Union and its neighbours to create an integrated pan-European energy market.[2] In all countries oil

[2] https://www.energy-community.org/

and petroleum products are the dominant type of fuel. Significant shares of other types of fuel are electricity and biofuels. Biofuels consumed in Ukraine are not compliant with the requirements of the Renewable Energy Directive.

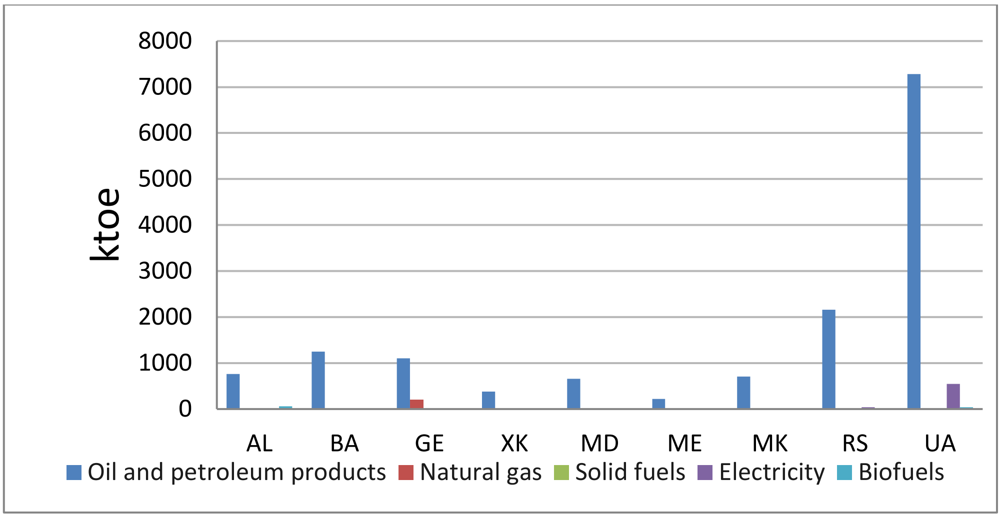


*Figure 1: Absolute energy consumption in transport by type of fuel in 2017*
*Source: Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties (2020) [3]*

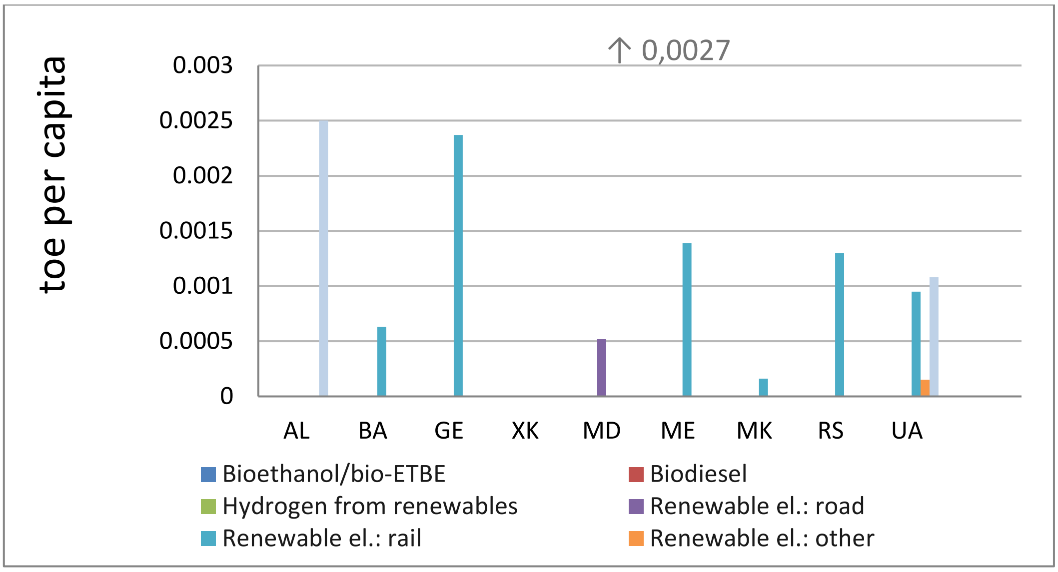


*Figure 2: Renewable energy consumption per capita by type of fuel in 2017*
*Source: Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties (2020) [3]*

Ukraine has a share of renewable energy in transport of around 2% through electricity consumption in rail. Biofuels consumption in Ukraine is low so far, but draft legislation is in the political debate that is set to establish the instruments to increase biofuel consumption.

Options for renewable fuels production including hydrogen beyond the 2030 target may open up opportunities for exports. Of the 9%, crop-based biofuels are capped at 2%, while 7% need to be achieved by other renewable fuels. Crop-based and advanced biofuels as well as renewable electricity in rail and public transport are anticipated to contribute most to the target if the renewable electricity share is to reach the 2030 target of 40%.

Electric road vehicles supported by the existing support strategy and further measures related to charging infrastructure have notable potential by 2030, which is anticipated to grow dynamically thereafter. Hydrogen and battery-electric vehicles are complementary with hydrogen enabling long driving distances and being suitable for cars and heavy-duty transport alike; development of the sector until 2030 would allow for dynamic growth thereafter.

Additional benefits of achieving the 2030 Renewable energy sources in transport (RES-T) target include the reduction of fossil energy import dependence, additional national value creation, new or enhanced national value chains with related economic benefits and job creation, export opportunities, additional contributions to the national climate targets, and further benefits.

The “National Transport Strategy”, the “Energy Development Strategy”, and the “Roadmap for the wide introduction of hydrogen energy in Ukraine” represent a solid strategic basis for policies aimed at increasing the share of renewable energies in transport based on biofuels, electricity and hydrogen. The use of renewable energies in transport should be continued and enhanced. The existing strategies should be further developed to strengthen the focus on electricity and hydrogen in transport, and should be complemented by a national strategy for the development of hydrogen energy and fuel cells in Ukraine, both for domestic use and for export using synergies between the two. Research and innovation based on state funding for basic and applied research and development in the field of electric transport and hydrogen energy should be fostered.

The energy consumption has increased since 2015. The share of transport in final energy consumption has fluctuated around 15%, being a little higher in recent years.

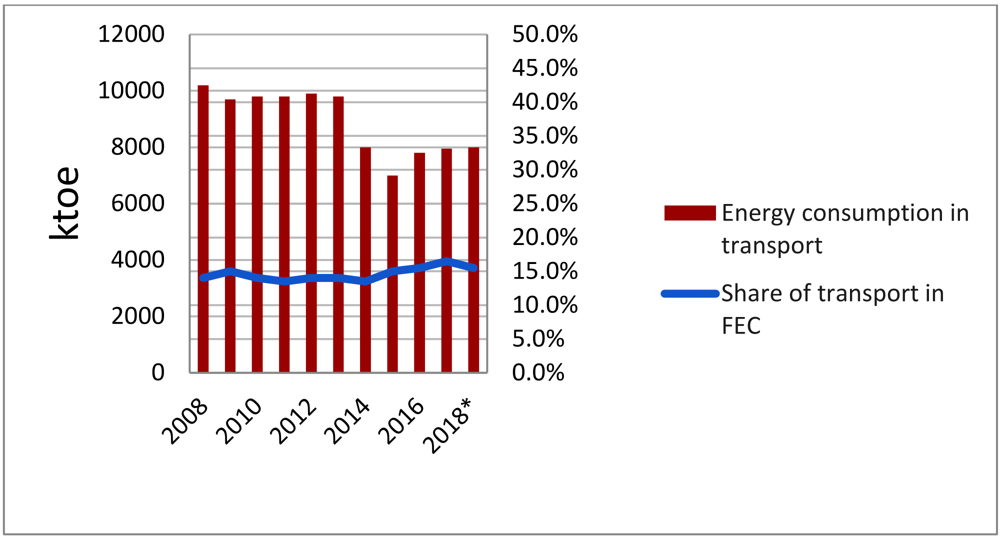


*Figure 3: Energy consumption in transport*
*Source: Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties (2020) [3]*

The majority of energy is used for road transport. The consumption in this sector has increased since 2015 after remaining roughly constant in the years before. The share of transport by rail has been fluctuating in recent years without a clear tendency. There are small fluctuating shares of consumption in navigation and non-specified transport.

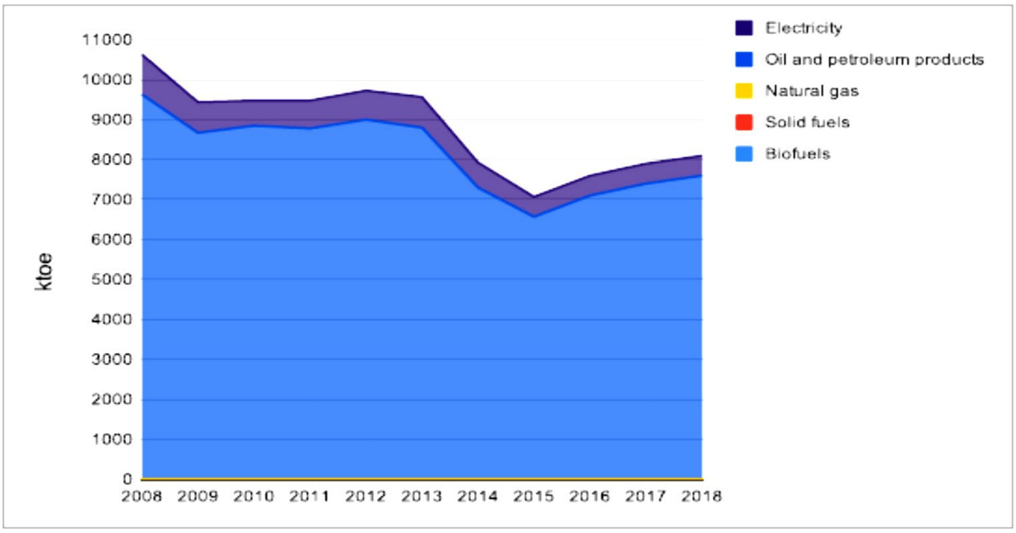


*Figure 4: Energy consumption in transport by type of fuel*
*Source: Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties (2020) [3]*

The dominant fuels in transport are oil and petroleum products. The next most important fuel is electricity in rail and to a lesser extent in other transport including trolleybuses, trams, etc. Also, there have been small shares of natural gas and solid fuels which each have remained roughly constant since 2014.

## 2. Ukraine stakeholder mapping

In light of global decarbonization efforts and new technological trends, private sector has begun to embrace hydrogen as an emerging opportunity. The productions and use of hydrogen are massively discussed among also by different Ukrainian governmental representatives during recent decade.

The mapping seeks to identify and describe the interests and relationships of all stakeholders in overall objective of the analysis of the use of hydrogen in Ukraine in road transport. The mapping is a useful and applied instrument in cases where multiple agencies are involved, such as government institutions, private sector, non-governmental institutions and other relevant institutions.

The mapping process includes several key steps:

1. Identification of the stakeholders (consideration of a list of everyone who may have an interest in the use of hydrogen in transport), during this exercise the supply chain presented below is considered;
2. Analysis of stakeholders (analysis of stakeholder perspectives, interests, roles and engagement);
3. Prioritization of engagement levels (all stakeholders are prioritized based on engagement levels into the use of hydrogen in transport).

To determine stakeholders in the context of this report, the hydrogen supply chain can be used. The supply chain includes production, supply, use and support of hydrogen economy and use in transport, industry, etc. Such approach allows to determine all possible stakeholders, describe the role and prioritize them.

Members of the Hydrogen Council (established by 92 energy, transport and manufacturing companies from across the globe) currently invest billions per year in hydrogen solutions. Previously this investment had been heavily weighted to R&D. Now however, council members are planning to increase this investment and change the prioritization of funding to focus on market introduction and deployment. The current focus is made on following hydrogen supply chain.

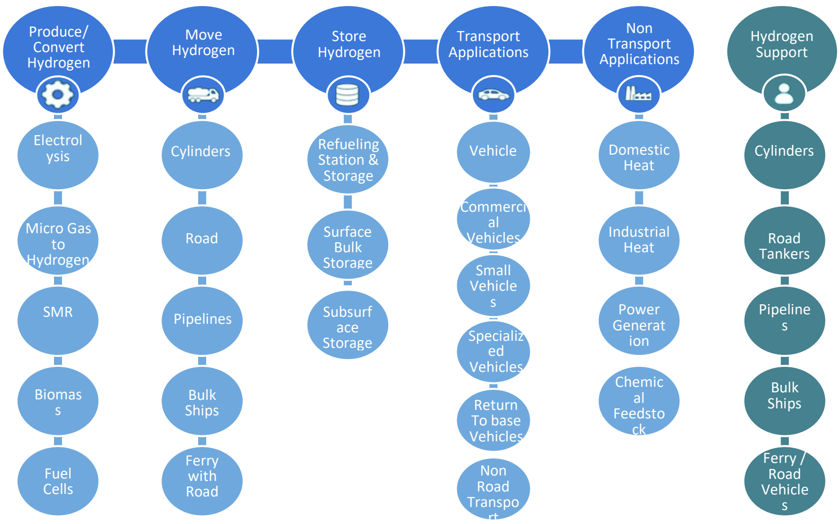


*Figure 5: Hydrogen supply chain map*
*Source: Hydrogen Supply Chain Map for the North Sea Region (2018) [6]*

***Produce/Convert Hydrogen.***

Electrolysis is performed by using electrical energy to make hydrogen from water. It allows energy from electricity to be stored in the form of hydrogen. There are many commercial and R&D initiatives that use electrolysis technology in various ways. The supply chain aspects include electrolyser creation and allotment and project installations. In the process of hydrogen creation, electrolysis plays the most s important role. The electricity supply could come either from green energy or gas grid.

Hydrogen can be made by using fossil fuel on-site or small-scale steam methane reforming (SMR) technology. This technology emits CO2, which means that low carbon is not considered. Though the technology is now ready to use, it also requires further research and development.

Carbon capture and storage (CCS) is the process of capturing CO2 outcomes from the SMR, transporting and making them constantly sequestered deep underground. The technology has already proved to be effective in many international projects, including two projects in Norway. In addition to this, it's used in several UK projects that are now in the design phase but none yet in operation. CCS is the main approach to generating low carbon hydrogen from gas and it is likely to be used in the market in the future.

Biogas is created by the anaerobic digestion of biomass such as crops, farm waste, or municipal waste. The methane generated as a result of digestion can then be turned into hydrogen. Put it another way, the biological gas may be pumped into gas grid for creating heat and/or electricity. Typically, biogas is created on farms or municipal plants on a small to medium scale. In certain countries the procedure is well-known and widely used.

Hydrogen electricity is generated by fuel cells. They come with many forms and scales and are all used under one supply chain heading. They can be transport fuel cells, stationary fuel cells for main or additional power supply), small CHP, and large power/CHP fuel cells. The supply chain aspect of the fuel cell encompasses R&D, fuel cell design and development, and later fuel cell installation, mainly in stationary applications. In addition to the production of electrical power, hydrogen fuel cells play a significant role in reducing negative carbon effect to the environment. The hydrogen industry is focused on fuel cells. They are commercially available of all sizes, though, but they still require more investigation and product development.

***Move Hydrogen***

The most common way of transporting hydrogen in EU is compressing it and placing in cylinders. This is how it's supplied to gas and oil businesses for use in specialist welding. Hydrogen delivery can be arranged in horizontal cylinders filled with compressed hydrogen or in refrigerated tankers with liquid hydrogen.

As the hydrogen market grows the role of road tankers will significantly increase. It's also possible to deliver hydrogen as a refrigerated solvent by boat in bulk carriers. It is a new segment of the industry that focuses primarily on the developing global hydrogen market. However, these two transportation approaches have proved their value. The rising hydrogen deployment is an important factor for the increased business activity.

Where the amount of hydrogen is very high, the most economic means of its delivery shall be a pipeline. For decades, pipeline of hydrogen transport was common practice at refining sites. There is substantial ongoing work to investigate the possible injection of hydrogen into the gas grid at concentrations of up to 10% or 20%. In the longer term, 100% hydrogen supply for gas heat substitution is possible.

Moving hydrogen-powered cars in ferries is possible in coastal areas. Whilst the supply chain operations are not quite distinct here, hydrogen distribution by ferry requires proper security preparation, contingency plans development, and necessary permits obtained.

***Store and Deliver Hydrogen***

The implementation of transport applications is important to hydrogen refuelling stations and storage. This supply chain aspect is directed at refuelling stations for road vehicles, but may also be viewed as having potential for marine refuelling facilities. Refuelling stations provide the processing or reception facilities, as well as equipment for hydrogen compression, storage, and dispensing, like high-pressure pipelines, pumps, metering, and related devices.

As uses of hydrogen grow, the mass storage of hydrogen is definitely important. The best solution is still being created for medium-sized storage and will depend on the location. In subterranean storage, vast volumes of hydrogen can be deposited. This is a well-established and commonly used natural gas storage approach. This storage relies on the regional geology since there is no sufficient geology in many regions.

### *Transport Applications*

The generic issues of vehicle management are taken into account by this supply chain element for all automobiles. These generic car management practices consist of automobile servicing and maintenance, turning diesel engines into hydrogen ones, and the opportunities emerging from vehicle operating experience.

This transport group encompasses a broad range of urban transport and commercial vehicles (including coaches, buses, vans, etc.). The expansion in the number of buses is contingent on public support for the capital expenditures and the creation of facilities for regional refuelling stations. The potential for buses and haulage vehicles depends on the hydrogen costs and availability of refuelling stations, as well as applied regulations for diesel autos.

The growth of small vehicles like private cars, taxis, and fleet autos mainly depends on public funds that should help to increase volume and reduce purchase costs of hydrogen-based transport. The local public subsides also impact hydrogen price and the number of refuelling stations across the region.

As for specialized vehicles, advanced equipment such as road sweepers, forklifts, and waste trucks are required in both the public and the private sectors. Vehicles for agricultural purposes are also required. A particular target for hydrogen cars may be vehicles that are normally driven within a certain area and used quite frequently. Particularly, it can be automobiles used for emergency and delivery purposes.

There are also multitude of non-road applications such as ship, train and air travel can also be fuelled with hydrogen. Hydrogen-powered ferries and hydrogen trains are the most interesting usage.

At the same time, safety issues of hydrogen use in public transport should be carefully addressed. The hydrogen is a highly flammable gas, however knowledge about it has increased and nowadays hydrogen can be used safely with proper precautions.

### *Hydrogen Support Services*

Health, safety, environmental and quality related services are required to support the emerging hydrogen market. Professional services that are needed from environmental advisors, emergency assistance, engineering providers, as well as technical service providers like lab services, specialist monitoring. The supply of special equipment for measurements and fire and gas devices are also in much need. Many of these services can be provided from other sectors, especially from the oil and gas industries.

Finance and legal support services can be provided by companies which support multiple sectors but may have professionals that are specialized in a particular automotive sector.

In order to stimulate the hydrogen industry in any specific area, training and marketing on a wide variety of hydrogen-related fields are important. This should include academic, postgraduate, and R&D activities, training for professional staff, and short-term business classes. There is also an urgent need for industry training on the level of private and public education institutions. In addition, substantial work is needed to do to include local authorities, the sector, and other stakeholders in opportunities created by hydrogen. Early educational efforts are critical to attract stakeholders and engage the wider public.

With the evolving existence of the hydrogen market, laws and requirements must both be recognized and affected. Provision of consultancy services, R&D, and testing operations, as well as advocacy and policy implementation activities, public funding application assistance provide the opportunities for the hydrogen supply chain.

In addition to these, such other supportive services as logistics, IT, or equipment, are not specialized in hydrogen but play an important part in the hydrogen distribution.

### *Non-Transport Applications*

As for non-transport applications of hydrogen, it’s worth considering the opportunity for decarbonizing centralized or decentralized heating and power generation. For these purposes, hydrogen can be used as a low carbon alternative to coal and an alternative to natural gas [6]. Based on the supply chain the following mapping can considered:

*Table 1: Stakeholder mapping*

| Name of institution | Role | Priority of engagement | Type of engagement |
|---|---|---|---|
| Ministry of Energy of Ukraine | - energy policy maker in Ukraine<br>- responsible for the development of Ukrainian energy strategy | High | - leading the process production and use of hydrogen in Ukraine<br>- develop a Ukrainian strategy for hydrogen<br>- establishing policies for production of hydrogen in Ukraine |
| Ministry of Foreign Affairs of Ukraine | - oversight of European and Euro-Atlantic integration of Ukraine and cooperation with foreign states and international organizations | Moderate | - support with international negotiations and high-level agreements<br>-develop cross countries hydrogen opportunities |
| Ministry of Infrastructure of Ukraine | - transport and infrastructure policy maker in Ukraine<br>- responsible for the air, railway transport and maritime sector | Moderate | - create implementation principles and regulation for use of hydrogen in air, railway transport and maritime sector |
| Ministry of Interior of Ukraine | - responsible for the road transport regulations | High | - create implementation principles and regulation for use of hydrogen in road transport |
| State Agency on Energy Efficiency and Energy Saving | - responsible for the energy efficiency, alternative fuels and renewables | Moderate | - support with alternative fuels policies |
| State Service of Ukraine on Food Safety and Consumer Protection | - responsible for the agriculture and special purpose vehicles | Moderate | - create implementation principles and regulation for use of hydrogen in agriculture and special purpose vehicles |
| Committee on energy, housing and utilities services of the Verkhovna Rada (Parliament of Ukraine) | - legislation initiative and approval of primary legislation | Moderate | - development of primary legislation<br>- high level public support of hydrogen use |
| Development agencies and international finance organizations | - providers of technical and donor assistance<br>- financing of various projects, public and private sectors | Moderate | - support with technical assistance<br>- financing of pilot hydrogen projects |
| Scientific and research institutions | - research and development of hydrogen technology | Moderate | - research and development, adaptation and localization of hydrogen technology<br>- stimulate the development of studies of hydrogen use and technician and technical training programmes |

| | | | |
|---|---|---|---|
| Non-governmental institutions | -support of hydrogen initiatives | Moderate | - encouraging partnering and collaboration between GoU, private sector and other stakeholders<br>- stimulate new hydrogen-based start-ups, entrepreneurial activity<br>- facilitate the arrangement of regional events and conferences on use of hydrogen |
| Private sector | - business initiative and commercial activity | Moderate | - create and deliver tangible hydrogen projects (productions, use and infrastructure) |
| Cities and communities | -responsible for local transportation of habitants<br>- local transport and infrastructure establishment in the cities and communities | Moderate | - create and stimulate hydrogen transport projects in the local regions<br>- support with financing of hydrogen transport projects in the local regions |

There are various scientific and research institutions, which examine hydrogen issues such as Institute of Renewable Energy of the National Academy of Sciences of Ukraine. Among non-governmental institutions there are several visible representatives like Energy Association "Ukrainian hydrogen council" (https://hydrogen.ua) and Association for Hydrogen Energy (http://www.aheu.com.ua). The coordination of stakeholders is essential for successful development of hydrogen transport in Ukraine. Currently every stakeholder tries to develop different strategies and solve its own problems, sometimes these initiatives are even contradicting to each other. As an example of poor coordination, the following can be observed:

- During Global e-Mobility Forum (November 2020) the Ministry of Infrastructure announced replacing existent road public transport by electric vehicles with establishment of respective infrastructure by 2030. This challenging target will be partially supported by the European Investment Bank program "Ukraine Urban Public Transport II" which includes 200-million-euro tranche to support electric public transport (trams, trolleybuses, electro buses) and respective infrastructure.
- At the same time Kyiv City Administration has recently signed the contract for supply of 200 regular petrol buses made by Minsk Automobile Plant till the 2020 end. The contract was criticized by other government institutions (such as Ministry of environment protection) as non-compliant to latest environmental standards.
- The Kharkov City Administration has already procured 57 trolleybuses in 2020 and expects to get additional 156 in 2021. The recent purchase was financed by European Bank for Reconstruction and Development and European Investment Bank.
- The Lviv City Administration has signed a memorandum with private public transport company "Ecopastrans", municipal public transport company "Lvivelectrotrans" and Ukrainian producer of electric transport «Electron» to supply new 250 electro buses during next 3 years.
- So while Ministry of Energy considers use of hydrogen in road transport, others implement own public transport projects.

## 3. Analysis of international best practices

This section provides the analysis of hydrogen projects conducted worldwide regarding road transport with the most attention on public transport and describes the best practices of hydrogen application. [7]

***European Union***

In the European Union, several big projects have already begun to promote the adoption of hydrogen as transport fuel through the creation and application of a national network. Here are some of the flagship projects across Europe:

1. H2 Mobility created a network of refuelling stations with mobile access to fuel cell electric vehicle (FCEV) drivers access in Germany. The initiative also expands to other European countries.
2. Mobilité hydrogène France is a consortium of private and public stakeholders that distribute hydrogen from energy companies to end customers.
3. Scandinavian Hydrogen Highway Partnership is a collaboration that creates a hydrogen road network with refuelling stations across Denmark, Norway, and Sweden.
4. UK H2 Mobility is a partnership of leading industrial players that lobbying for the interests of hydrogen-fuelled vehicles in the UK government.

Other EU countries such as Austria, Italy, Belgium, Finland, Switzerland, and the Netherlands are also undertaking related pilot projects.

The projects named above underline the circumstances needed for developing hydrogen as vehicle fuel:

- An existing strategy for placing hydrogen refuelling facilities;
- Strong assistance from the national government;
- Availability of industrial players in the local market of hydrogen and fuel cells;
- Opportunities for green hydrogen production.

These factors can be defined as essential increasing plans for hydrogen usage for road transport.

The EU countries put hydrogen as an integral aspect of energy protection and transformation. The European Research Area ("ERA") project focuses on developing the European platform of hydrogen and fuel cell R&D. The Fuel Cells and Hydrogen Joint Undertaking (FCHJU) is a public private partnership supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe. In 2019, the partnership has released a roadmap for hydrogen energy development towards 2030 and 2050, considering the large-scale deployment of hydrogen in Europe. The FCH JU also established a map with real-time hydrogen refuelling stations information (available at https://h2-map.eu).

The FCH JU roadmap provided the key advice for all stakeholders:

- To define clear, long-term, and realistic approaches for reducing carbon emissions in all industry sectors;
- To stimulate private investments in hydrogen and fuel cell technology to benefit arising opportunities;

The roadmap also provided the following specific objectives by 2030 for various industries:

- **Transportation:** To place on the road the next number of fuel cell vehicles: 570 trains, 3.7 million passenger cars, 500,000 LCVs, 45,000 trucks and buses.
- **Infrastructure**: To develop about 3,700 refuelling stations and replace natural gas with hydrogen in heating by 7% to cover the demand of about 2.5 million households.
- **Industrial applications**: To apply hydrogen to refineries and ammonia production and large-scale power generation due to the development of specialized plants. [8]

***Germany***

Germany is a leading player in the hydrogen and fuel cell market in Europe. In 2018, 41% of all European hydrogen refuelling stations were located in Germany. To stipulate the fuel cell and hydrogen energy manufacturing, the German government planned to invest €7 billion in new businesses and research in 2020.

In addition to this, Germany has recently issued the National Hydrogen Strategy with their goals and ambitions regarding decarbonization and reduction of greenhouse gas emissions. Hydrogen is crucial for achieving these goals and empowering not only the chemical and steel industry but also the transport sector of the German economy.

The main objectives of this strategy include:

- Decarbonizing of industrial production by using renewable energy based on carbon-free energy sources like hydrogen.
- Creating regulatory preconditions for developing hydrogen technologies and enabling local markets to manufacture and apply hydrogen to certain industrial and transport needs.
- Reducing the expenses of implementation of hydrogen technologies and taking part in developing international market for hydrogen.
- Supporting German businesses in their ambitions to adopt hydrogen technologies by conducting R&D activities.
- Ensuring the future supply of green hydrogen and its secondary products by establishing cooperation with global partners and countries producing alternative energy for international trade and import purposes.
- Making investments in hydrogen-powered vehicles, including public transport, light and heavy-duty cars, inland and coastal navigation. In particular, Germany plans to invest €2.1 billion in purchase grants for electric cars, €0.9 billion in grants for utility vehicles powered by hydrogen technology, and €0.6 billion for buying buses with alternative drivelines.

A role model for biodiversity and climate security is Hamburg, the second largest city in Germany. The city's goal of cutting $CO_2$ emissions by 80% in 2050 is very optimistic. Fuel cell buses and other emission-free buses have the ability to eliminate pollution from public transport, so the city will buy only emission-free buses from 2020. The city of Hamburg is a leader in renewable enery buses in Germany, it currently runs 4 fuel cell buses as a part of Europe's first bus breakthrough line 109 [8] and committed to phase out diesel buses by 2030. The operator Hamburger Hochbahn has launched a tender for the supply of up to 50 fuel cell buses for the years 2021 to 2025. The tender's specifications require minimum distances of 300 km for solo buses and 230 km for articulated vehicles. (August 2020). Hamburg also announced interests in 530 electric buses to be supplied within 2021 and 2025.

Mobility Programme started in Berlin in 2016 provides steps to support the adoption of electro-mobility from renewable energy sources and decrease negative environmental impact made by public transport. The initiative of hydrogen Internal Combustion Engine buses taken place from 2006 till 2014. In 2016, Berlin cooperated with Hamburg to adopt zero-emission buses, and starting in 2020, these two cities were going to purchase up to 200 zero-emission buses per year.

Regionalverkehr Köln GmbH (RVK), the public transportation operator in the Cologne region of Germany, has set an ambitious goal to substitute its entire diesel bus fleet with alternative power-train vehicles. By 2030, RVK will be ready to buy only zero emission busses and develop the necessary facilities. The hydrogen policy for the region includes fuel cell electric buses and intends to extend the fleet to add thirty vehicles and two new refuelling stations in the Cologne region. A major portion of the fleet is to be replaced by fuel cell busses and by 2030 hydrogen refuelling stations are to be located at more distribution centres. [17]

Germany has wide network of regional trains, so also explores hydrogen use in railway. The Alstom presented the Coradia iLint, CO2-emission-free regional train, for the first time in 2016. Later in 2018 it was entered into commercial service. The Lower Saxony region has ordered 14 Coradia iLints to be commissioned in 2022. Siemens and Deutsche Bahn has announced partnership to test hydrogen powered trains and associated infrastructure, the train to be supplied in 2024 and will service Baden-Württemberg area.

***United Kingdom***

London also led the development of green bus technologies to solve the city's daunting challenges with bad air quality, resulting in premature mortality and respiratory diseases. The centre of London is planned to be an ultra-low-emission zone (ULEZ). All double-decker buses driving in the region must be hybrids that meet the Euro VI norm, and all single-decker buses serving in the ULEZ must be tailpipe prototypes with minimal environmental impact. About 4,000 Euro IV and Euro V buses will be redesigned to eliminate tailpipe NOx by up to 95 percent outside the central region. This will update them up to the most modern Euro VI norm. By attracting external investments, London plans to expand the fuel cell bus fleet in the coming years.

In 2020 the Liverpool has launched Liverpool City Region Hydrogen Bus Project covering 25 hydrogen–powered buses and hydrogen refuelling stations with £6.4 million budget.

In addition to buses, the UK also wants to remake electric trains to hydrogen ones and place them in service by 2022. The UK government is going to stop using diesel-only trains by 2040 and has already considered hydrogen as an effective solution for carbon-free trains.

Hydrogen innovation in the UK goes beyond the transportation industry. At the 2020 Construction Week in the UK, Intelligent Energy presented the ECO GH2, a hydrogen-powered product specifically designed for the construction sector. [17]

***Italy***

Italy is looking to improve its polluted air as it affects the health of people and their mobility needs, particularly in winter, with cars being excluded from the city on a regular basis. Milan opened the Congestion Charge area (Area C) in the city's historical centre in 2012. A ticket must be bought to visit Region C, while some high-emission automobiles are fully banned and low-emission vehicles are exempt from the fee.

Azienda Trasporti Milanesi (ATM), Milan's bus operator, is searching for renewable technology that provides the best balance between costs and operational performance. ATM views, along with fuel cell buses, the opportunity provided by hybrid and electric buses. ATM will continue passenger transportation with fuel cell buses for a further couple of years in partnership with the bus maker and infrastructure vendor, and explore other renewable technologies. [17]

Regional operator Ferrovie Nord Milano, the second largest train company in Italy, has ordered 6 hydrogen-fueled trains from Alstom. The trains will enter service in 2023 and the investment worth more than €160 million.

***Norway***

The environmental goals are very aggressive in Oslo and in the surrounding Akershus area. Oslo declared in June 2016 that it would cut the city's carbon emissions by 95 percent by 2030, while Akershus has a 50 percent elimination goal by 2030.

A regional hydrogen plan has been implemented for 2014-2025, which wants to make hydrogen readily accessible in the transport industry by raising the number of refuelling stations for hydrogen cars. Ruter, the regional public transport authority, is trying to ensure that by the end of 2020, all national transport in Oslo and Akershus drive on alternative fuels. Hydrogen fuel buses are included in the country's hydrogen policy and into the Carbon Free 2020 initiative by Ruter. [17]

Norway also explores hydrogen use in maritime sector, among recent projects are hydrogen ferries in Lofoten islands by 2024 or 1800 passengers ferry between Oslo and Copenhagen to start operating by 2027.

***Canada***

Canada is globally recognized as a world pioneer in hydrogen and fuel cell exploration, creation, and monetization. Being among the biggest hydrogen manufacturers and consumers, Canada is home to the largest accumulation of knowledge in hydrogen and fuel batteries. This industry in Canada is dynamic and contains all components within the distribution network. Hydrogen is mostly made by the chemical industry from fossil fuels (53%) and by the oil and gas sector (47%).

The industry consists primarily of small to medium-sized businesses and investigation firms. A well-educated workforce with technical expertise is the basis in the Canadian knowledge-based economy. A highly competitive position arising from years of R&D activities has been established by Canadian businesses.

British Columbia (BC) has the largest number of hydrogen and fuel cell companies in Canada. BC strategic plans in this sector include improving the enterprise's environmental, social, and economic accountability and continue to test vehicles that are less dependent on natural gas by 2030. The Canadian government plans to achieve net-zero in greenhouse green emissions by 2050. [17]

Toronto being biggest metropolitan area in Canada studies hydrogen fuel cell trains as a viable alternative to electric and diesel trains, the local transport company Metrolinx already completed its feasibility study. Another railway company called Canadian Pacific Railway develops first hydrogen-powered locomotive for freight trains.

### *The United States of America*

As a result of the oil crisis, the US government first began funding the hydrogen research in the 1970s. Thus, the United States was one of the first countries to introduce hydrogen and fuel cell technologies into its national energy development strategy. Afterwards in 1990 Hydrogen research, development, and demonstration program was introduced, on the basis of which a plan of research and development in the field of hydrogen energy was formed.

Later in the 2000s, the National Hydrogen Energy Roadmap was created under the leadership of the US Department of Energy, which provides a blueprint for the coordinated, long-term, public and private efforts required for hydrogen energy development. Then hydrogen fuel cell policy was revised in the United States. The US government boosted tax credit for hydrogen filling stations from one-third to one-half percent, which created a further discount to encourage high-efficiency fuel cells that use combined heat and power systems.

This Energy Program explained the leading role of hydrogen energy in the transformation of the country's transport system. Moreover, the Association of Fuel Cells and Hydrogen Energy chose the day of October 8 as the National Day of Hydrogen and Fuel Cells in 2015, and which was also established in Resolution No. 217 of the Senate.

Hydrogen and fuel cell research and development in the States was under the jurisdiction of the Department of Energy, which allocated funds to solve key technical problems, and this created the basis for a development system operated by the Department of Energy's national laboratory, as well as universities, research institutes and enterprises.

Due to the long history of hydrogen development, the United States has formed a permanent system of laws, policies and research strategies to further promoting research, development and deployment of hydrogen energy. Thus, in March 2019 the Department of Energy planned to fund $30 million for the H2@scale project, where the focus is on the production, transportation, storage and use of hydrogen in many of the country's industries. With this aim, the Department of Energy of the USA started the H2USA project, which is a partnership between public and private manufactures of hydrogen fuel cell electric vehicles (FCEV), working to implement and resolve infrastructure problems. The main focus is on developing hydrogen infrastructure to expand energy transportation options for American consumers.

The USA is definitely the leader in the global hydrogen market, so the time and finances were well worth it. In 2020 the USA had the largest number of fuel cell passenger cars in the world: the number of cars sold and leased by FC reached more than 7000 in the third quarter of 2019. It is also interesting statistics that companies such as Walmart and Amazon use more than 30 thousand fuel cell forklifts in their activities.

In the United States, California is considered the most technologically advanced and environmentally friendly state, as California represents the highest purchase rate for hydrogen fuel cell vehicles with up to 7,000 FCEVs operating in California as per data in the end of the second quarter of 2019. This is because California has a robust government support for renewable energy that other states do not. Since the introduction of the first State Energy Commission grants in 2010, more than 30 retail hydrogen refuelling stations have been opened, and another 30 stations are under development. California has become the most active and indicative market player for the development and deployment of hydrogen and fuel cells in the United States of America due to its subsidiary hub assessment plan. The California Fuel Cell Partnership has set targets for 1,000 hydrogen filling stations and one million FCEV by 2030. [8]

California also leads in hydrogen ferries, in 2021 the first fuel cell ferry will be launched to service San Francisco Bay area (project called Golden Gate Zero Emission Marine).

***People's Republic of China***

China developed into one of the world's largest market for hydrogen in 1999 when a Chinese fuel cell vehicle was first developed. China is already among the largest hydrogen producers in the world: industrial hydrogen production capacity is over 25 million tons per year. Speaking about the consumption volume, China sold over 3,000 commercial FCEVs in the period between 2017 and 2019, this distinguished China as one of the world's largest markets for FC deployments.

However, behind this title there were decades of state policy and plenty of initiatives. Since 2010 the country's government has made plans to encourage and to guide the research and development of hydrogen and fuel cell technologies, namely, “Energy Technology Revolution and Innovative Action Technology (2016-2030)”, “the 13th Five Year Plan for the Development of Strategic Emerging Industries”, “Made in China 2025" and “Energy Conservation and New Energy Vehicle Industry Development Plan (2012-2020)”. [8]

Moreover “Dual Credit Management System” was introduces for facilitating the development of new energy vehicle (NEV) and production of passenger cars. This is connected with the positive credits granted for NEV production and negative credits for internal combustion engines (ICE) production. Hydrogen was included in the list of 15 key areas of China's energy strategy and technological innovation plan.

Hydrogen is an important part of this strategy, as China is making a nationwide effort to switch to renewable energy sources. For example, hydrogen can help solve many of the security and sustainability issues in China's energy system. In 2019, at a meeting of the government of the Republic of China, hydrogen was firstly included in a government annual report.

Since 2014, production of hydrogen fuel cell vehicles has increased, helping to improve technology, reduce the cost of hydrogen, and caused usage of hydrogen in other spheres. However, Battery electric vehicles (BEV) initiatives are also being implemented in parallel with the development of hydrogen technologies. As with BEVs, the government has primarily focused on commercial FCEV applications that are easier to regulate and implement nationwide. Central and local government subventions play leading role in the fuel cell automobile industry, and subventions have been applied based on the following factors:

- Every buyer of FCEV receives subvention. Even though municipal subsidies on electric vehicle are being suppressed every year, subsidies on FCEVs are expected to be prolonged up to 2025. Specialists say that step by step these FCEV subventions will be cut down and the requirements for specifications would become levelled up;
- Every start-up of hydrogen refuelling station receives subvention. For the moment no strict state-wide subventions on hydrogen refuelling stations exist. Although there are several municipal subsidies initiatives for example like in Foshan and Zhongshan cities. One of the most progressive cities in hydrogen implementation - Foshan city- proclaimed that each new built immovable hydrogen refuelling station will obtain subvention in amount up to 8 million RMB;
- Subsidies on hydrogen refuelling cost. According to government expert interviews, the goal of these subsidies would reduce hydrogen cost per 100km to be less than or on par with that of ICE vehicles. However, to whom the subsidies go to is still under discussion, which could be given to the hydrogen station operator or direct to consumers refuelling their FCEVs.

Reasonable success and political will of the country's administration provide incentives to improve the hydrogen industry in the People's Republic of China.

According to the experts, the following factors will influence the improvements in this industrial sector:

- Political and infrastructural support for the production and transportation of hydrogen;
- Deleting hydrogen from the category of hazardous chemicals;
- Increasing the volume of local and mass production of components for fuel cells in order to reduce costs;
- Implementation of procedures for approval and launch of hydrogen stations.

The National Development and Reform Commission issued a plan "to reform the circular economy of vehicles in China" in the summer 2019. Thus, initiatives to remove restrictions on NEV purchases / license plates by local governments, prolong national government subventions and permanently remove restrictions on the entry of trucks into cities emerged. Now it is planned that through such initiatives the NDRC will provoke the consumption of NEV as well as FCEV. [8]

***Japan***

Due to its geographic location and environmental limits, renewable energy sources are highly valued in Japan. This country is striving to become a leader in the hydrogen market. It was originally supposed that Japan would be able to realize its hydrogen energy potential through nuclear power. Although the accident at the Fukushima nuclear power plant forced Japanese government to reconsider national energy strategies. Thus, hydrogen was introduced at the forefront of the "national energy strategy" with the further goal of transforming the country into a hydrogen community.

Finally, Japan began the 4th Strategic Energy Plan, which distinctly outlines the usage of hydrogen. The Strategic Roadmap for Hydrogen and Fuel Cells was introduced, which specifies a comprehensive strategy for the production, transportation, storage and use of hydrogen.

Afterwards, the New Energy and Industrial Technology Development Organization of Japan issued a bulletin about Hydrogen Energy in 2015, where hydrogen is promoted to the third place in the national energy strategy.

Then in 2017 the government of Japan published the "principal strategy for hydrogen energy" with a plan to commercialize hydrogen fuel cell energy production by the end of 2030. In such a way in 2018, the Ministry of Economy, Trade and Industry invested approximately $250 million for works of hydrogen and fuel cells. It should be noted that back in 2009 Japan became famous for being the first to introduce fuel cells to generate electricity and hot water at residential premises. Thus, fuel cells for residential CHP plants were firstly commercially used in Japan, and today Japan is considered a leading country in the commercial use of fuel cells. Nowadays Japan has more than 19,000 stationary CHP systems in commercial and residential premises.

When it comes to the Japanese automotive industry, it should be noted that fuel cell vehicles are all the rage in Japan. World renowned Japanese such auto magnates as Toyota, Honda and Nissan spend a lot of efforts on the research and development of fuel cell vehicles. The first commercial car brand was Mirai in 2014, followed by Honda Clarity. As per middle of 2019 according to statistics of the Japanese Ministry of Economy, Trade and Industry, the number of fuel cell vehicles sold and rented in Japan consisted of more than 3,000 units.

However, Japan mainly uses fuel cells in passenger cars. Before the 2020 Olympics, Toyota planned to supply 100 fuel cell buses to shuttle visitors between venues. Due to this massive production deployment and interest in fuel cell vehicles, the hydrogen infrastructure in Japan is highly developed thanks to government investments as well as industrial communities which develop and open hydrogen filling stations. In 2018 a consortium of 11 companies along with Toyota and Nissan, launched "Japan H2 Mobility", which aims to build 80 hydrogen filling stations by 2021. In 2020 Japan was among world leaders with more than 125 hydrogen filling stations available across the country and plans to install additional 160 during 2020-2021. [8]

## 4. Review of legal and regulatory framework

The UNECE provides a platform for exchange of knowledge and develops standards and best practices throughout the hydrogen value chain. The key documents prepared by the UNECE are following:

- a note on "Hydrogen – an innovative solution to carbon neutrality" presents recommendations on hydrogen application. The key recommendation is expand collaboration on renewable hydrogen production; support hydrogen market stimulation programs including quotas, targets, dedicated programmes; development of guidelines, regulations and technical rules for energy industry; support deployment of electrolysers and develop dedicated financial engineering needed to scale up the hydrogen economy. [9]
- United Nations Regulation No. 134 "Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen fuelled vehicles" under the 1958 Agreement on Harmonized Technical Regulations for Wheeled Vehicle, specifies safety-related performance requirements for hydrogen-fuelled vehicles by minimizing human harm that may occur as a result of fire, burst or explosion related to the vehicle fuel system and/or from electric shock caused by the vehicle's high voltage system. The UN Regulations includes specifications for hydrogen storage systems, specific components and vehicles fuel systems using hydrogen storage systems. [10]
- United Nations Global Technical Regulation on hydrogen and fuel cell vehicles (UN GTR) No. 13 under the 1998 Agreement on UN GTRs, provides a definition of hydrogen-fuelled fuel cell vehicles and technical specifications regarding hydrogen fuelling systems, hydrogen storage systems, hydrogen fuel delivery systems, fuel cell systems and electric propulsion and power management systems. It also provides safety requirements and test procedures. [11]

Both UN Regulation No. 134 and UN GTR No. 13 are essential for an internationally harmonized legal framework for safety of hydrogen road vehicles and may be implemented in the Ukrainian legal framework.

The European Union has also approved various documents related to the use of hydrogen in transport:

- Regulation 79/2009 dd. January 14, 2009 Type-approval of hydrogen-powered motor vehicles. The regulation provides fundamental provisions on requirements for hydrogen systems and components approval, timetable and implementing measures. [12]
- Regulation 406/2010 On implementing EC Regulation 79/2009. The regulation is needed for a adoption of harmonized rules on hydrogen receptacles, including receptacles designed to use liquid hydrogen, in order to ensure that hydrogen vehicles can be refuelled throughout the EU countries in a safe and reliable manner. [13]

***Ukraine***

In 2009, Ukraine has adopted first version of the Law "On Alternative Fuels" which defines the legal, social, economic, environmental and organizational principles of production (extraction) and use of alternative fuels. The Law was amended several times in 2015, 2016 and 2019 and it also stimulates increase of the share of biofuels use to 20% of total fuel consumption in Ukraine by 2020. [15]

In accordance with the Energy Strategy of Ukraine the share of energy from renewable energy sources used in transport should increase to 20% by 2025, which is less ambitious than the objective of the Law "On Alternative Fuels" mentioned above. Coordination and control over the implementation of the Energy Strategy is carried out by the Cabinet of Ministers of Ukraine and the National Security and Defence Council of Ukraine.

In 2018 Ukraine adopted the National Transport Strategy of Ukraine 2030. One of the priorities defined by this Transport Strategy is reduction of negative impact of transport on the environment. As well, the goals of the Transport Strategy are improvement of the transport service quality and safety, as well as improvement of transport infrastructure up to the European standards. In accordance with the National Transport Strategy the level of use of alternative fuels (bioethanol, biodiesel) and electricity is expected to increase to 50% by 2030. However, Ukraine has not yet adopted a National Renewable Energy Action Plan to 2030. The competent body for monitoring of renewable energy targets is the State Agency on Energy Efficiency and Energy Saving of Ukraine.

In 2015 Ukraine has adopted National Energy Efficiency Action Plan (NEEAP) until 2020. NEEAP was developed based on the requirements of the Directive 2006/32/EC of the European Parliament and of the Council on energy end-use efficiency and energy services. The used model was recommended by the European Commission for the Member States of the European Union, and was also adapted for the Contracting Parties of the Energy Community. The reporting period of NEEAP for Ukraine to achieve the estimated goal according to the Directive is from 2012 to 2020.

The major priority tasks for improving energy efficiency in transport sector defined by NEEAP include development of a market for cleaner, more energy-efficient and safer vehicles through incentives like: easier access to city centres by public transport, creating of parking lot systems, optimizing public transport routes, development of electric transport, etc.

NEEAP until 2030 is under discussion now and the draft was submitted by the Ministry of Energy to Cabinet of Ministers of Ukraine. The experts from the Energy Community Secretariat has recently conducted a workshop on which was discussed the preliminary forecast for energy saving potential, for example measures related to buildings, industry and transport. The draft of NEEAP, including a roadmap for its implementation, will be developed in the coming months. On this basis, the Ukrainian government will make important decisions on how to enhance the energy security of its citizens.

The creation of an effective legislative mechanism for the development of a competitive market for the production and use of alternative fuels is extremely important for Ukraine. Earlier in 2000, the Law of Ukraine "On Alternative Types of Liquid and Gas Fuel" defined that the main principles of state policy in the field of alternative fuels:

- Promotion of the development and rational use of non-traditional sources and types of energy raw materials for the production (extraction) of alternative fuels in order to save fuel and energy resources and reduce Ukraine's dependence on their import. Non- traditional sources and types of energy raw materials are: vegetable raw materials, waste, solid combustible substances, other natural and artificial sources and types of energy raw materials, including oil, gas, gas condensate and oil and gas condensate depleted, non-industrial and man-made fields, heavy oil, natural bitumen, gas- saturated waters, gas hydrates, etc.;
- Gradual increase of the normatively defined share of production and use of biofuels and mixed motor fuels. The content of bioethanol in motor gasolines produced and/or sold on the territory of Ukraine will be not less than 7 percent (volume) from 2016;
- In accordance with the Law of Ukraine On the State Regulation of Production and Circulation of Ethyl Alcohol, Cognac and Fruit Alcohols, Alcoholic Beverages, Tobacco Products and Fuel, fuel production is carried out by economic entities which must have a license for such activity. The license should be obtained for retail or wholesale trading and storage of fuel, as well. Business entities that perform retail, wholesale trading or storage of fuel exclusively in consumer packaging up to 5 litres, are not obliged to have a license.

The current political discussions on use of hydrogen should be steered towards adoption of policies fostering the market uptake of hydrogen vehicles in road, rail and public transport and targeting establishment of a national hydrogen refuelling and storage infrastructure. In November 2016, the European Commission published its 'Clean Energy for all Europeans' initiative. As part of this package, the Commission adopted the Renewable Energy Directive (know as RED II). Hydrogen from renewable sources was added to the list of renewable fuels for transport sector (Annex III to RED II).

Complementary policies for battery-electric and hydrogen fuel cell-electric transport are recommended to be established in order to ensure target achievement and maximum benefits to the Ukrainian economy, including communication and information campaigns, pilot projects at local/ municipal level, the establishment of zero or low emission zones in urban areas for reduced air pollution, professional and academic training, etc.

The bill of Ukraine "On Amending Certain Legislative Acts Of Ukraine On The Development Of The Production Of Liquid Biofuels" currently in the political debate will amend laws and legislative acts relative to obligatory quotas on the bio component and alternative fuels share in the volume of sold motor fuel including responsibility for non-compliance with quotas as well as sustainability criteria. Terminology in the field of alternative fuels complying with RED II will also be introduced into Ukrainian legislation and this is the perfect opportunity for taking up the provisions of RED II including certification.

Policies fostering the market uptake of battery vehicles should be further developed, notably in view of the establishment of a national charging network including fast-chargers. Electricity use in public transport should be enhanced by policies for the extension of trolleybuses, tramways and metro, and should be extended to battery-electric buses. The same should be done for hydrogen in transport.

Key policy elements to be implemented and enforced include:

- Blending obligation on fuel suppliers for renewable fuels;
- Sustainability framework for renewable fuels;
- Sustainability certification for renewable fuels;
- Promotion of electric charging and hydrogen refuelling infrastructures and incentives for battery-electric and fuel cell-electric vehicle purchase.

All elements of the regulatory framework may be in place by the end of 2022.

Complementary policies are recommended to be established in order to ensure target achievement and maximum benefits to the Ukraine economics. These may include:

- Adjusting taxation and customs duty systems to provide incentives for renewable fuels as well as electric and hydrogen vehicles, and disincentives for fossil fuels;
- Financial incentives through grants, subsidies and loans;
- Clear permitting rules for electric charging and hydrogen refuelling infrastructure;
- Communication and information campaigns on renewable fuels and vehicles;
- Lighthouse projects at local/ municipal level, the establishment of zero or low emission zones in urban areas for reduced air pollution;
- Professional and academic training;
- Technical inspections of vehicles (both electric and conventional).

Policies should be revised and possibly adjusted around 2025 based on a policy evaluation. The regular revisions and monitoring are the appropriate instrument for monitoring success and ensuring 2030 target achievement. Additional benefits of achieving 2030 RES-T targets include the reduction of fossil energy import dependence, additional national value creation, new or enhanced national value chains with related economic benefits and job creation, additional contributions to the national climate targets, and further benefits e.g. related to green tourism. The Energy Community recommend considering following key measures:

- Including RED II into the Energy Community acquis;
- Encouraging CPs to implement all provisions of RED II into national law by the end of 2022, and defining a RES-T target for 2030 on this basis;
- Facilitating the exploitation of synergies between the CPs in introducing RES-T;
- Promoting good practices from other CPs and globally for the benefit of the CPs.

There are several gaps in the Ukrainian legislation which may be filled in the future. This refers to renewable fuels of non-biological origin (RFNBO) defined in RED II. For the production of RFNBOs, no criteria related to electricity used to produce RFNBOs is defined.

Certain subjects such as public parking or public garages are obliged to have electric vehicle charging stations. Namely, in 2019 came into force amendments to the state building codes for the design of parking lots and garages. According to them, a mandatory requirement is introduced in Ukraine – to equip at least 5% of parking spaces in parking lots under construction or reconstruction with electric cars.

In 2019 was adopted the Law of Ukraine “On Amendments to Certain Legislative Acts of Ukraine Concerning the Creation of Access to the Infrastructure of Charging Stations for Electric Vehicles” [16]. One of the amendments refer to the implementation of green license plates for electric cars, and systematization of the issues of traffic, parking and charging of electric cars by changing governmental traffic and construction regulations.

Tax Code of Ukraine imposes exemption from taxation in case of import into the customs territory of Ukraine of the equipment and materials for the production of alternative fuels, materials, raw materials, equipment and components that will be used in the production of alternative fuels or energy from renewable energy sources. Also, the Custom Code of Ukraine determines tax benefits, i.e. exemption from customs duties for companies operating in the use of renewable energy sources and alternative fuels.

In the area of public transport in Ukraine, abovementioned incentives which refer to electric vehicles apply as well. The same measures need to be considered and implemented for the use of hydrogen in transport. In September 2020 the Cabinet of Ministers of Ukraine has approved the bill of Ukraine “On Amendments to Certain Legislative Acts of Ukraine concerning socially important services in transportation of passengers by automobile and city electric transport” for further submission to the Verkhovna Rada. One of the amendments refer to the new definitions such as:

- Electric vehicle (electric car) - a vehicle (electric bus, electric truck, electric car), equipped exclusively with electric motors (one or more) that drive it, charged from the charging station of electric cars, has at least four wheels, designed for movement non-rail roads and is used for transportation of people and (or) cargoes, towing of vehicles, performance of special works;
- Electric bus - an electric car, which is a type of bus;
- Electric truck - an electric car that is a type of truck;
- Hybrid electric car - a type of car equipped with an electric motor and an internal combustion engine, which drive it simultaneously or alternately. The battery of a hybrid electric car cannot be charged from an external power source;
- Plug-in hybrid electric car - a type of car equipped with an electric motor and an internal combustion engine. The battery of the plug-in hybrid electric car can be charged from an external power source;
- Electric car charging station - an element of infrastructure installed permanently or can be moved and designed to provide electricity for charging electric vehicle batteries: electric cars, electric buses, electric scooters, electric scooters, electric bicycles and other vehicles using an electric motor and battery.

Climate change mitigation and adaptation is the most important and complex challenges of modern society. Like Ukraine, countries around the world, as well as international organizations such as the United Nations, are is actively involved in efforts to address todays and future consequences of changing climate patterns and their impacts on the economy, the environment and society as a whole. As these processes move forward, it is important that local policies and measures designed to address climate changes are carefully developed taking into account local resource limitations, and to apply mechanisms existing within international cooperation platforms to overcome these resource gaps to the furthest extent possible.

The transport sector is the largest consumer of fuel in the global energy market. As countries are developing and implementing strategies to meet their and international climate targets, hydrogen is being put forth as one of the primary tools for reducing $CO_2$ emissions from transport. Hydrogen is a promising fuel for safe, reliable, and convenient use, and according to the most optimistic forecasts, hydrogen can soon be used in trucks, airplanes and ships.

## 5. Economic and financial considerations for the use of hydrogen

At the beginning of the 21st century fuel cell buses are considered to be very important public transport vehicles and widely used all over the Europe due to its economy and minimal air pollution effects. It is absolutely different transport if to compare with the vehicles based on electric batteries or the ones with diesel engines.

No use talking about technological devices without proper profound analysis and their commercial value. To understand what a fuel cell vehicle is, it is necessary to analyse its economic advantage by contrast comparison with all the other machines. Such a procedure is usually quite expensive and may lead to a certain list of consequences. Public transport service expenses should be reasonably valued and planned to avoid serious unnecessary losses and meet the total cost of ownership. The total cost of ownership (TCO) includes the purchase price of a particular asset, plus operating costs over the vehicle's lifespan. Only private transport organizations can afford capital expenditures (CAPEX) and operating expenditures (OPEX) vehicles purchase. [8]

To begin with, it is considerably important to mention the pricing. There are two significant aspects to see the difference between electrolysers and electricity outlay. The first price goes for the production equipment, it is a fundamental issue to be discussed, as at the production stage electrolysis produces hydrogen. The second price to be taken into consideration is for the used energy. Sometimes electrolysis usage is much more expansive than power supply system, despite the fact that hydrogen distributed by production requires a lot. [19]

*Table 2: Estimated cost of hydrogen production from the recent literature*
*Source: Energy prices and the economic feasibility of using hydrogen energy for road transport in the People's Republic of China (2020) [19]*

| Country/ Region | Energy Source | Type of Technology | Estimated Cost | Expected Future Cost |
|---|---|---|---|---|
| US | Grid electricity | Large-scale centralized; proton exchange membrane (PEM) electrolyzer | USD 4.20-5.11/ kg | |
| US | Grid electricity | Large-scale centralized; Solid oxid electrolysis cell (SOEC) | USD 3.82-4.96/ kg | |
| US | Grid electricity | Small-scale on-site; proton exchange membrane (PEM) electrolyzer | USD 4.23-5.14/ kg | |
| US | Grid electricity | Small-scale on-site; molten carbonate fuel cell (MCFC) | USD 2.58-3.71/ kg | |
| US | Biomass | Large-scale centralized; biomass fermentation | USD 51/kg | USD 5.65/kg (by 2025) |
| Canada | Medium-scale wind power | On-site electrolysis | USD 9.0 / kg | |
| Libya | Small-scale wind power | On-site electrolysis | GBP 9.3-10.4 / kg | GBP 6.2-6.6 / kg (by 2030) |
| US | Natural gas, solar PV, and biomass | Large-scale SMR, electrolysis, and gasification | USD 1.89/kg, 6.16/kg, and 2.5/kg, respectively | |
| US | Natural gas, grid electricity, and biomass | On-site distributed production | USD 2.03/kg, 5.75/kg, and 3.32/kg respectively | |

It has been conducted a comparative analysis about hydrogen production cost by Asia Pacific Energy Research Centre in the paper "Perspectives on Hydrogen in the APEC Region" (2018). As a matter of fact, some fundamental differences have been found. For instance:

- The price of hydrogen production via electricity from solar PV is about USD 6.65/kg, 6.02/kg, 4.12/kg, and 3.7/kg in the Republic of Korea, Japan, China and the US, respectively;
- Hydrogen production using electricity from wind power costs USD 6.65/kg, 5.66/kg, 4.21/kg, and 3.99/kg in the Republic of Korea, Japan, China and the US, respectively. Less expensive hydrogen production usage has been found in New Zealand and Canada.
- Hydrogen produced from fossil fuels costs about USD 2.27/kg in different countries. Natural gas reforming with the combined charging system has the lowest prices among the fossil fuel pathways - USD 0.78/kg (in Russia) and USD 1.49/kg (in the USA).

The International Energy Agency has made its calculation of hydrogen production worth through several pathways in China.

- Hydrogen produced from coal has the lowest cost, at USD 1.1/kg; if to apply CCS, it increases to USD 1.6/kg.
- Natural gas reforming costs USD 1.8/kg, and it increases to USD 2.3/kg with combined charging system.
- Hydrogen produced from electrolysis using renewables costs about USD 3.0/kg, while it costs USD 5.4/kg on grid electricity. [19]

The infrastructure itself and network for the transportation, storage, delivery, and refilling of hydrogen also cost a lot. Pipelines, compressed hydrogen, liquefied hydrogen, and a liquid organic hydrogen carrier are included into the hydrogen delivery package.

According to the US Department of Energy statistics the cost of hydrogen transportation, delivery, and refilling using the Hydrogen Delivery Scenario Analysis Model tool (HDSAM ) is (1) pipeline (100 km): USD 4.85/kg; (2) compressed hydrogen trailer (283 km): USD 3.30/kg; and (3) liquid hydrogen trailer (283 km). The compressed hydrogen, liquid hydrogen, and liquid organic hydrogen carriers (LOHC) usage costs from 4.5 euro/kg to 6.5/kg. The hydrogen production capacity assumption in this study is 50 tones/day, with a transportation and delivery distance of 250 km. [18]

The Asia Pacific Energy Research Centre (APERC) has made a research about Asian countries and their hydrogen export to Japan for subsequent uses in power generation applications and FCEVs applications in 2018. It turned out that the cost of transportation from Indonesia, Australia, the US, and Russia would be USD 2.23/kg, 2.51/kg, 2.3/kg, and 1.76kg, respectively. Talking about the fuel cell vehicle, the cost of hydrogen including end-user price would be USD 12.6/kg if the hydrogen came from solar PV-based production in Indonesia.

The hydrogen exported to Japan by Australia in 2019 conducted by the IEA showed USD 3.2/kg. for liquid hydrogen transportation. Due to the geographical conditions and ammonia usage could reduce the transportation cost (ammonia due to its physical characteristics allows it to transport and store hydrogen with lower costs).

To make a relevant pricing analysis it is important to consider money spent on the use of hydrogen in road transport. The question to understand is if hydrogen energy can compete with the conventional energy.

Annual research of the Fuel Cell Technology Office of the US Department of Energy demonstrated the cost requirements hydrogen energy should be competitive with:

- The total supply cost: production cost and the cost of transportation and delivery, should be lower than USD 4.0/kg, in which the cost of transportation and delivery is lower than USD 2.0/kg;
- The capital cost of the electrolyser system becomes lower than USD 300/kW, while its conversion efficiency becomes 77 %;
- The cost of the fuel cell system becomes lower than USD 40/kW by 2020, with peak efficiency up to 65% and a life expectancy of 5,000 hours. Eventually, the cost of the system reaches USD 30/kW, with life expectancy of 8,000 hours.
- Vehicles' onboard hydrogen storage - USD 10/kWh by 2020 and then -USD 8/kWh.

In accordance with the APERC investigation, the total supply cost of hydrogen should be as low as USD 1.92/kg–USD 3.23/kg to compete with coal-fired power generation (in Japan). Power generation on liquefied natural gas is pretty competitive, so hydrogen energy should be USD 2.04/kg–USD 2.64/kg with a transportation price not exceeding USD 1.32/kg, to correspond ICEVs.

Hydrogen Europe is a fuel cell association affiliated with European Union made a forecast for costs of hydrogen production in 2025-2030. The electrolyser costs expect to fall to 720 euro/kW by 2025, which can lead to hydrogen price around 5 euro/kg. The further drop of prices may be caused by large-scale use of hydrogen and the price can be around 3 euro/kg. The hydrogen storage, transportation and costs for fuel cells also expected to drop. [19].

In the power section the hydrogen price should remain at USD 0.53/kg–USD 0.85/kg to compete with coal. There are the requirements of the oriental counties which took into account the cost, insurance, freight (CIF) cost of imported energy, including hydrogen and other types of energy.

To compete with natural gas, it needs to hit USD 1.29/kg–USD 1.41/kg. For instance, in Japan, hydrogen needs to cost at least USD 1.69/kg -USD 1.99/kg to compete with natural gas with respect to the application of hydrogen in the industrial sector. Hydrogen price has to be USD 4.24/kg-USD 5.0/kg in the transport sector, if only considering the contrast of fuel prices, to compete with traditional ICEVs. In Indonesia, the cost of hydrogen is USD 3.78/kg-USD 4.53/kg.

The analysis given by the Economic Research Institute for Southeast Asian Nations and East Asia says about expensiveness of fuel cell vehicles in comparison to the ICEVs usage. Thus, to be fully competitive for commercial purposes, there must be at least 3 main aspects for hydrogen energy.

- More persistent interest in RD&D to improve specialized exhibitions and diminish costs through mechanical enhancements;
- Make the early business sectors and specialty markets for hydrogen energy applications a priority to profit by the learning impacts, the economy of scale, and the organization impact of the hydrogen energy foundation and the prices;
- Sufficient and steady approaches that favour the turn of events and reception of hydrogen energy and power device advances. In such manner, it is conceivable to allude to the approaches that nations have received to help battery electric vehicles (BEVs) as specific illustrations.

The idea is to research the financial aspects of hydrogen created from environmentally friendly power as an energy application for the public road transport area. In particular, it will appraise the expense of creating hydrogen from sustainable power, the coordination expenses of moving and putting away hydrogen, and at last the expense of refuelling vehicles with hydrogen at the hydrogen station. At that point it will contrast the use of FCEVs and vehicles with elective power trains, for example, BEVs, plug in hybrid electric vehicles (PHEV)/hybrid electric vehicles (HEVs), and ICEVs.

In order to determine key factors for evaluation of the economic and commercial feasibility of hydrogen in transport, the well-to-wheel (WTW) cost models, as well as TCO models can be used. Both models consider hydrogen supply chain and cover different factors as hydrogen production technologies, cost of primary energy inputs (like solar PV, wind power, fossil fuels, etc.), assumptions for use of hydrogen transport and some others. The various scenarios with different assumptions and sensitivities can be created to properly evaluate economic considerations [19]. Figure 6 presents hydrogen supply chain starting from production, transportation to vehicles utilization rate.

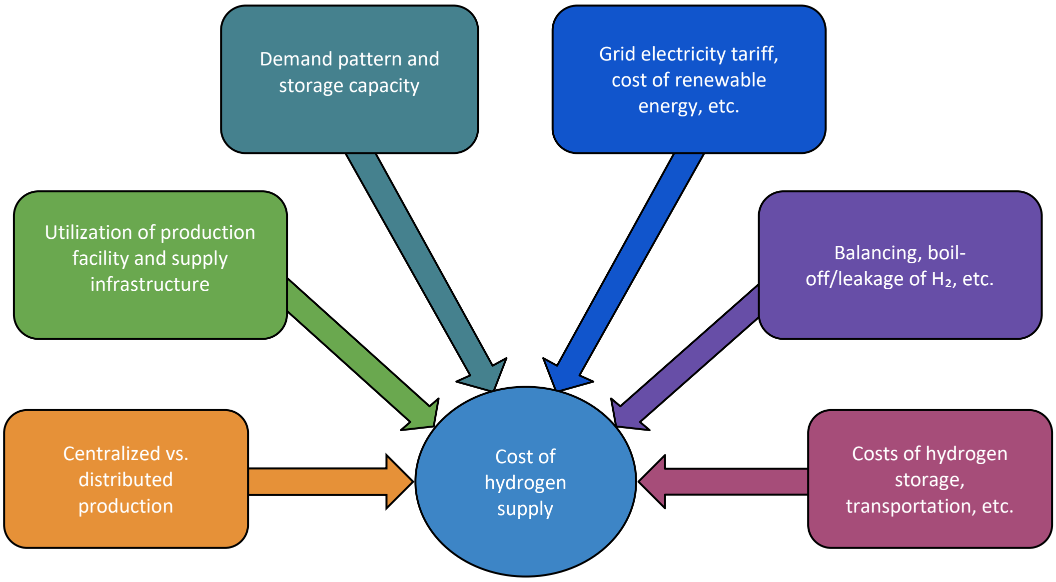


*Figure 6: Key features and factors of WTW Model influencing the Hydrogen Supply Chain*
*Source: Energy prices and the economic feasibility of using hydrogen energy for road transport in the People's Republic of China (2020) [19]*

The Figure 7 shows TCO model and concludes weighted cost of owing and driving based on estimation of operating costs over the vehicle's lifespan.

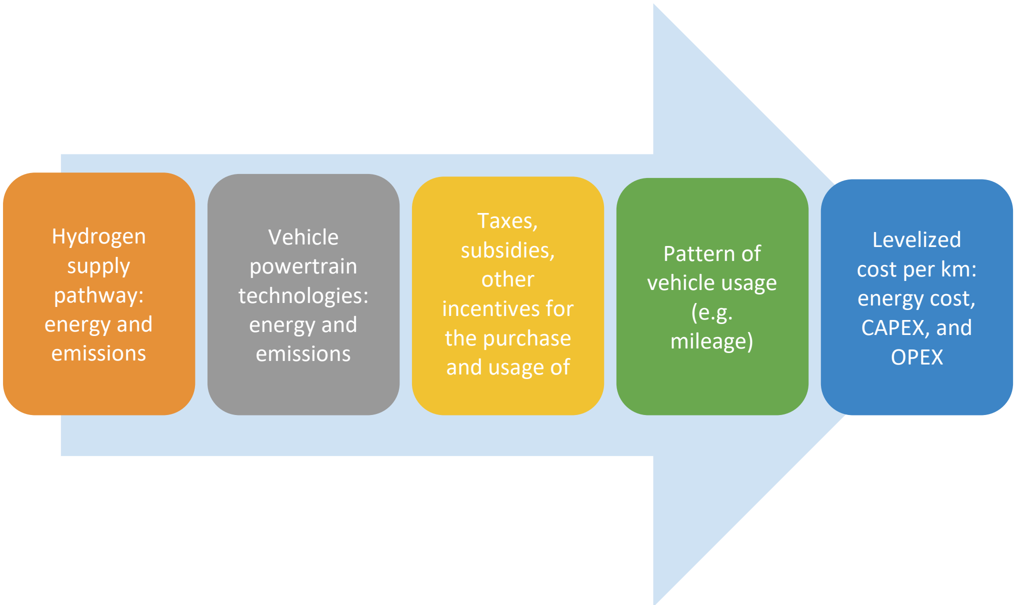


*Figure 7: Key Input and Output of a TCO Model for Vehicles*
*Source: Energy prices and the economic feasibility of using hydrogen energy for road transport in the People's Republic of China (2020) [19]*

The Asian Development Bank Institute has considered both WTW and TCO models and concluded that currently full cell buses are already competitive in China (considering hydrogen price at hydrogen refilling stations around USD 12.2/kg), however the major factors are generous subsidies available to public transport, while passenger cars without such subsidies and at current hydrogen price are questionable competitive vs. traditional cars. Another important conclusion lies in additional economic value from hydrogen use such as balancing of energy system (load management, energy storage, etc.).

The Element Energy, UK based energy consultancy firm, has reviewed EU based initiatives in hydrogen transport in the report "Commercialization of hydrogen fuel cell buses". The TCO for fuel cell buses is similar to the battery electric buses, however it can be significantly improved due to scale of hydrogen bus fleets and further development of hydrogen technologies. Additional conclusion is similar to the Asian Development Bank Institute's, policy makers needs to develop and implement favourable market conditions and policies to support hydrogen public transport.

The Figure 8 shows ownership costs for single decker buses, which is a UK equivalent of a regular standard two-axle rigid bus. The spread and mass use of fuel cell buses may decrease prices and such buses can compete with regular diesel buses.

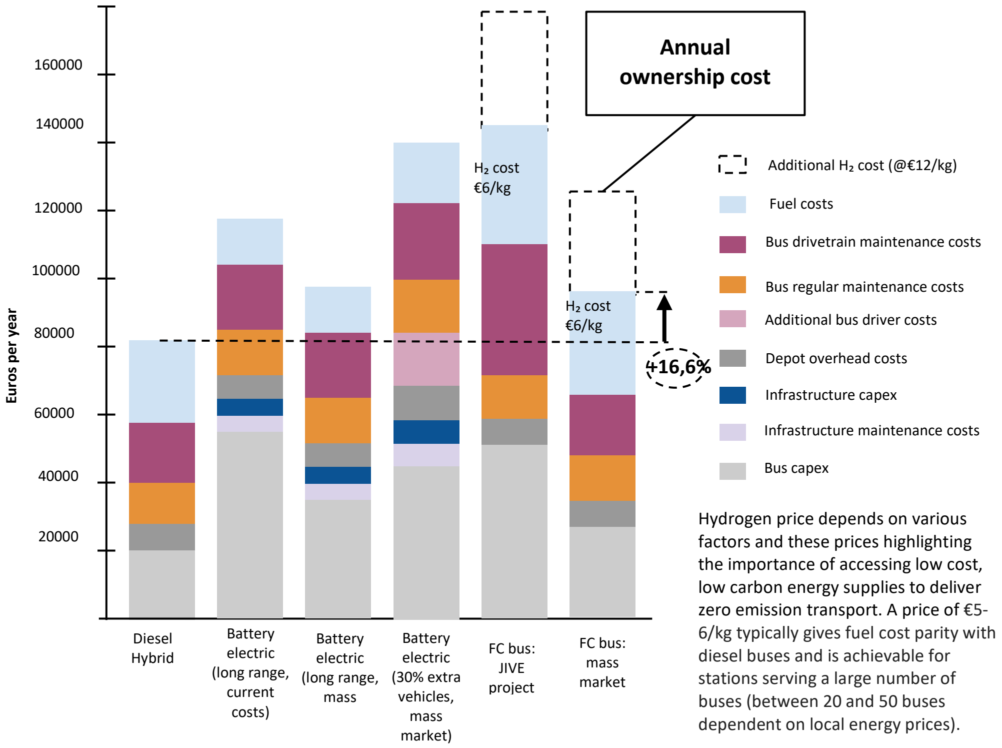


*Figure 8: Ownership cost analysis for a full cell buses (single decker type)*
*Source: Element Energy, "Commercialisation of hydrogen fuel cell buses. Discussion paper" [5]*

The mass use of hydrogen buses allows to achieve cost reductions in the whole hydrogen supply chain from hydrogen production, transportation, refuel stations to daily operational costs and fleet maintenance. This will also reduce requirement for subsidies. [5]

Currently the fuel cell buses are represented by the following manufacturers:

- Alexander Dennis Ltd, the leading manufacturer of buses in UK, supplies fuel cell bus Enviro 400;
- CaetanoBus, manufacturer of buses and coaches from Portugal, in cooperation with Toyota has developed H2.City Gold bus;
- Ebe Europa Gmbh supplies Blue City Bus;
- EvoBus, Daimler AG's subsidiary, produces Citaro NGT (natural gas drive) and Citaro Fuel CELL-Hybrid;
- Italian company Rampini has designed hydrogen bus H80;
- Safra, bus producer from France, started its production of electric buses in 2011 and later has developed its hydrogen model Businova H2;
- Solaris, a polish bus producer, premiered its Solaris Urbino 12 hydrogen bus in 2019;
- Ursus S.A., an old agriculture machinery producer, has entered the zero-emission bus market with its Ursus City Smile Fuel Cell bus;
- Van Hool, belgium bus and coaches manufacturer, supplies its hydrogen model A330 Fuel Cell;

- VDL Bus & Coach, a Netherlands based bus manufacturer, developed battery-electric bus with fuel cell range extender;
- Wrightbus, UK based company, is going to introduce its hydrogen double decker buses on 2021.
- China has various bus manufactures active in hydrogen. Among them are Yutong, Feichi, Zhongtong Bus, MAXUS;
- Japan Toyota launched production of Sora fuel cell bus in 2018;

## 6. Recommendations

The Energy Community projections until 2030 rely on the recent long-term energy modelling and forecasting study of the National Academy of Sciences of Ukraine. In this study, forecasts for energy consumption in transport are made by fuel, but not by transport sub-sector (road, rail, etc.). It is assumed for the business as usual scenario that the share of rail in transport electricity consumption remains unchanged from 2018 in 2030, which implies an 18% growth of electricity consumption in rail by 2030. The same logic is applied to trolleybuses and other electricity consumption in public transport. The remaining electricity consumption in transport according to the forecasting study is assumed to be road transport, i.e. battery cars and commercial vehicles. Overall growth in transport energy consumption from 2018 to 2030 is 23% from 7964 ktoe to 9780 ktoe. [20]

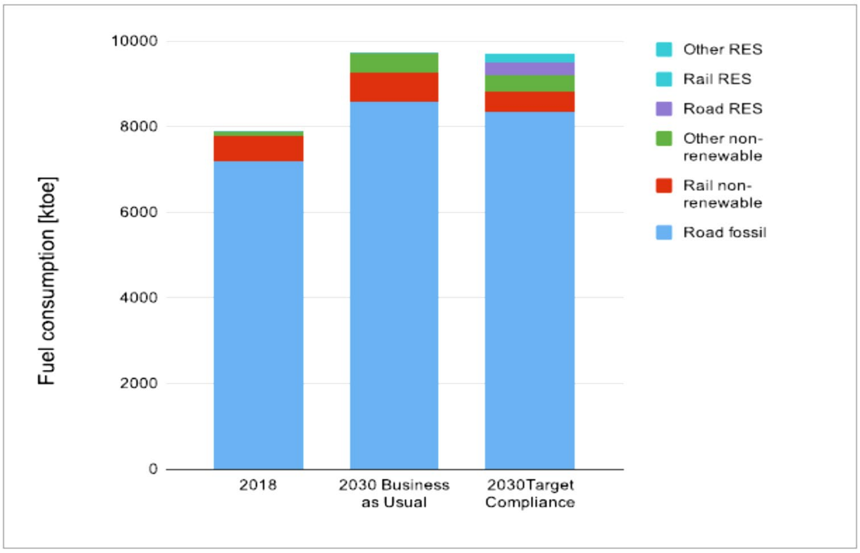


*Figure 9: Energy consumption in transport in two scenarios for 2030*
*Source: Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties (2020) [20]*

In the Energy Community's target scenario achieving the 9% renewables in transport target for 2030, has been assumed to be implemented. The 9% renewable energies are broken down by renewable energy consumption in transport in 2030.

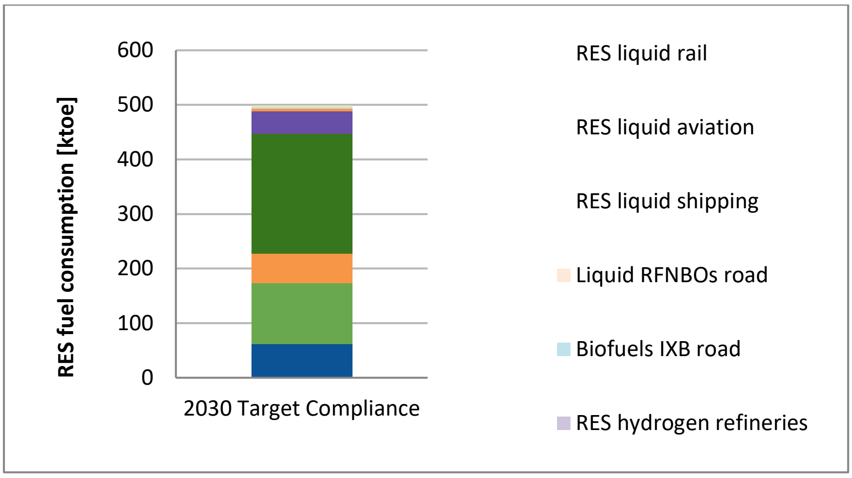


*Figure 10: Renewable energy consumption in transport in 2030 by option*
*Source: Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties (2020) [20]*

The total energy consumption in transport in the target compliance scenario is slightly lower than in the business as usual scenario as battery-electric vehicles and hydrogen fuel cell- electric vehicles are more energy efficient than internal combustion engine vehicles.

The growth of fuel consumption leads to a higher fossil fuel consumption in 2030 even in the target compliance scenario. In order to reduce fossil fuel imports and CO2 emissions from transport, either the growth in transport energy consumption could be reduced, or the target for renewables in transport could be more ambitious.

The renewable share in the national electricity mix anticipated for 2030 is used in this report. On the one hand, this tends to overestimate the renewable share as values for the year 2028 that should be applied are not available but should in general be lower than the 2030 values. On the other hand, dedicated renewable power plants may be erected that are counted as 100% renewable for transport.

Ukraine considers establishing methane use in road transport. This can be utilized by introduction of biomethane based on feed stocks, which have a suitable potential in Ukraine. Electric and hydrogen vehicles can already make small contributions by 2030 and have a strong growth potential thereafter.

| | | Contribution to RES-T target (%) incl. multiple counting | Amount of renewable fuel used (ktoe) |
|---|---|---|---|
| Biofuels and liquid RFNBOs | 1. Crop-based biofuels in road transport | 2.00% | 188.6 |
| | 2. Liquid fuels produced from Annex IX B feedstocks in road transport | 3.40% | 160.3 |
| | 3. Liquid advanced Biofuels (based on Annex IX A feedstocks) in road transport | 2.30% | 110.4 |
| | 4. Liquid RFNBOs in road transport | 0.03% | 2.90 |
| | 5. Renewable methane in road transport | 1.20% | 54.6 |
| | 6. Renewable liquid fuels in shipping | 0.00% | 0.00 |
| | 7. Renewable liquid fuels in aviation | 0.00% | 0.00 |
| | 8. Renewable liquid fuels in rail | 0.00% | 0.00 |
| Electricity | 9. Rail electrification | 3.45% | 217 |
| | 10. Electric public transport | 1.12% | 42.43 |
| | 11. Electric road vehicles (passenger cars and trucks) | 0.19% | 4.55 |
| Hydrogen | 12. Hydrogen in rail | 0.01% | 1.11 |
| | 13. Hydrogen bus and coach (urban bus, long distance coahes) | 0.006% | 0.60 |
| | 14. Hydrogen road vehicles (passenger cars and trucks) | 0.05% | 4.55 |
| | 15. Hydrogen in refineries | 0.00% | 0.00 |
| Total | | 13.80% | 787 |

*Figure 11: Potential RES-T contributions from all options in Ukraine*
*Source: Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties (2020) [20]*

The following high-level recommendations can be suggested, considering best international practice and Ukrainian actuality to implement hydrogen in transport.

### *I. Cooperation with international community*

To adopt best international practice, Ukraine should intensify real cooperation with its international partners. Various countries already approved its hydrogen national strategies and road maps, Ukraine needs to be recognized a reliable partner in its implementations.

The international organizations also consider hydrogen as an opportunity for decarbonization and green economies. Among them, the Energy Community, who has developed roadmap for Ukraine to achieve the 2030 target for renewable energies in transport. This involves key policies to be developed and adopted in the coming few years, building on the existing regulatory framework and policy elements already under development. The development of the regulatory framework so far focuses on biomass-based fuels and on battery-electric vehicles. In parallel, renewable hydrogen is being discussed as an opportunity for Ukraine both for domestic use and for export. The rail sector and public transport are a stronghold in Ukraine of electricity use. Increasing the share of renewable electricity in the national power mix will benefit also the transport sector. The roadmap foresees that the last elements of the regulatory framework should be in place by the end of 2022.

The European Union has developed the European Green Deal, which aims to make Europe climate neutral by 2050 by turning climate and environmental challenges into opportunities, and making the transition just and inclusive for all. Based on a set of policy initiatives by the European Commission, climate ambitions by 2030 are anticipated to be increased, which includes adjustments to RED II.

Such strategies and road maps to be considered by the Government of Ukraine and become a basis for concept (strategy) on development of hydrogen economy in Ukraine.

### *II. Strategy and local policies development*

The Government of Ukraine must develop appropriate, effective and efficient policy framework to support hydrogen development. The framework may include concept, strategy, road map, local policies (including sectoral policies). The unification and common terminology will assist to find common language with international partners.

In Ukraine, renewable hydrogen is currently in political discussions both for domestic use and for export. The "Ukrainian Hydrogen Council" established in 2018 developed a roadmap for the wide introduction of hydrogen energy in Ukraine together with the Institute of Renewable Energy of the National Academy of Sciences of Ukraine. It contains recommendations to governments and industry until 2035. Hydrogen for transport should be integrated into the transposition of RED II - hydrogen can be included in the obligation on fuel suppliers as an option, as provided for in RED II, including hydrogen consumption in refineries for conventional fuel production. Further key policy elements are rather similar to electricity in transport: developing a national hydrogen strategy including applications in transport, defining an additionality framework, increasing renewable electricity capacities for hydrogen production, supporting the market uptake of vehicles, and supporting the establishment of hydrogen refuelling stations.

The stakeholder map (Table 1) shows variety of stakeholders who should be involved in this process, however the leader is needed and the Ministry of Energy may become a focal point to do coordination of all stakeholders, including international partners.

Not only new policies should be developed, but also existent documents and commitments to be revised. For example, the above-mentioned Energy Community's road map provides some targets by 2030, they need to be monitored and supported in its achievement.

In Ukraine, the current political discussions on hydrogen both for domestic use and for export should be continued and should lead to the adoption of policies fostering the market uptake of hydrogen vehicles in road, rail and public transport and aiming at the establishment of a national hydrogen refuelling infrastructure. Hydrogen for transport should be integrated into the transposition of RED II as an option for fuel suppliers for fulfilling their renewable obligation. Synergies between domestic use and export of renewable hydrogen should be actively developed and used. The option provided by RED II of renewable hydrogen consumption in refineries for conventional fuel production should be assessed for implementation in the short-term.

The existing policies for increasing renewable electricity production should be adjusted to include additional renewable electricity demand from transport (for direct use or for hydrogen production) benefitting both the electricity sector and transport covering rail, public transport and road.

Additional attention may need to be given to criteria on production of liquid RFNBOs, alongside the rules on hydrogen (below) as these do not appear to be covered within existing activities. A unit within the relevant government authority must be designated responsible for implementing, reviewing and updating the policy as a whole, ensuring sustainability certification of fuels, administering the scheme, data collection and reporting.

Hydrogen in transport using fuel cell-electric vehicles is in early phases of commercialization world-wide, and shows major potential for decarbonizing transport in a complementary fashion to battery-electric vehicles. On non-electrified rail lines, first commercial hydrogen trains are in operation, and fuel cell vehicles are coming onto the market. A focus will be on vehicles for longer distances and for duty purposes such as trucks and buses.

### *III. Stimulate hydrogen market via pilot projects and other incentives*

Ukraine needs to consider successful hydrogen projects (including related lessons learned) and try to replicate it in Ukraine. This relates not only to hydrogen production, but also to hydrogen use.

The hydrogen transport may be focused, as there are many possible partners (hydrogen transport manufactures, infrastructure providers, EU hydrogen transport initiatives, etc.) to whom Ukraine may appeal and propose cooperation (joint ventures or alliances).

In hydrogen urban transport, the cooperation with local municipalities is highly advisable. Such municipalities are key clients in fuel cell-electric vehicles (buses), so the Government of Ukraine (Ministry of Energy and Ministry of Infrastructure) should promote hydrogen transport to them.

The successful pilot project with 1-2 municipalities may capture the attention to hydrogen transport advantages. This not limited to information campaigns, lighthouse projects, zero-emission zones, professional and academic training, technical inspections of vehicles, etc.

### *IV. Improve access to hydrogen*

Ukraine needs to improve access to hydrogen, at this stage this is all about access to financing. The Government of Ukraine should lead in negotiations with international financial institution and examine possibilities for grants and other types of development financing to hydrogen projects.

Also, the complementary policies are similar to electricity including incentives for vehicles uptake and refuelling infrastructure development (zero VAT and import duties, local taxes exemptions).

Research and innovation based on state funding for basic and applied research and development in the field of hydrogen energy would foster the national economy in this area. The related policies should be established together with those for biofuels and electricity, while the market may take up a few years later based on an earlier status in commercialization.

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## Annex A: Input to the draft Roadmap for the production and use of hydrogen in Ukraine addressing road transport

The proposed draft contains high level actions to be done by the Government of Ukraine to consider and develop use of hydrogen in road transport. The relevant actions are included into the comprehensive draft Roadmap for the production and use of hydrogen in Ukraine. The draft Roadmap proposes three phases up to 2029 and includes various actions relating to legislation, economic measures, support for R&D and fostering public awareness.

| Field | Actions | Stakeholders |
|---|---|---|
| I | II | III |
| a) Legislation | 1. Identification of necessary legislative changes in the field of hydrogen technologies not limited to:<br>– Analysis of legislation and formation of a list of legislative changes in order to promote the development of hydrogen technologies in the road transport area;<br>– Analysis of policies and mechanisms of EU countries on the introduction of hydrogen energy in the road transport sector. | • Ministry of Energy<br>• Ministry of Infrastructure<br>• State Agency on Energy Efficiency and Energy Saving<br>• Non-governmental institutions |
| | 2. Development of primary legislation relevant for use of hydrogen energy in road transport:<br>– Developing and amending legislation and regulations to ensure the use and extension of the list of alternative energy sources in road transport, including the hydrogen value chain | • Ministry of Energy<br>• Ministry of Infrastructure<br>• Committee on energy, housing and utilities services of the Verkhovna Rada (Parliament of Ukraine)<br>• Non-governmental institutions |
| | 3. Development of relevant policies and strategies for use of hydrogen energy in road transport:<br>– Action Plan on Improvement of the transport network and public transport routes planning<br>– Development of the Plan on use of environment friendly transport and micro mobility in cities;<br>– Optimization of the structure of passenger and cargo flow by increasing the share of passenger traffic by public transport<br>– Alternative (Renewable) Fuels Action Plan<br>– Hydrogen and electric vehicle promoting policies;<br>– The Program for maximum re-equipment of the fleet of vehicles with internal combustion engines for electric, hydrogen vehicles and cars on fuel cells that meet the criteria for sustainability and environmental friendliness; | • Ministry of Energy<br>• Ministry of Infrastructure<br>• State Agency on Energy Efficiency and Energy Saving<br>• Ministry of Interior of Ukraine<br>• State Service of Ukraine on Food Safety and Consumer Protection |
| | 4. Development of Standards, Regulations, Certification and Monitoring for use of hydrogen in road transport:<br>– Performance standards;<br>– Fuel cells;<br>– Vehicle safety;<br>– Fuel economy;<br>– Fuelling stations; | • Ministry of Infrastructure<br>• Ministry of Interior of Ukraine<br>• State Service of Ukraine on Food Safety and Consumer Protection<br>• Scientific and research institutions |

| Field | Actions | Stakeholders |
|---|---|---|
| I | II | III |
| b) Economic measures | 1. Development of state mechanisms to support measures and projects of hydrogen use in road transport, including improvement of access to hydrogen. | • Ministry of Energy<br>• Ministry of Infrastructure<br>• State Agency on Energy Efficiency and Energy Saving<br>• The Ministry for Development of Economy, Trade and Agriculture<br>• Ministry of Finance<br>• Ministry of Foreign Affairs of Ukraine<br>• Development agencies and international finance organizations |
| | 2. Market development, including implementation and demonstration of pilot projects:<br>– Implementation of hydrogen technologies in road transport;<br>– Construction of local (regional) pilot transport networks, including the purchase of vehicle fleet, construction of fuelling stations and their technical maintenance. | • Ministry of Energy<br>• Ministry of Infrastructure<br>• State Agency on Energy Efficiency and Energy Saving<br>• Development agencies and international finance organizations<br>• Private sector<br>• Cities and communities |
| | 3. Development of economic incentives for use of hydrogen in road transport, including a specific focus on urban transport:<br>– Direct subsidies;<br>– Fiscal incentives. | • Ministry of Energy<br>• Ministry of Infrastructure<br>• State Agency on Energy Efficiency and Energy Saving<br>• The Ministry for Development of Economy, Trade and Agriculture<br>• Ministry of Finance<br>• Development agencies and international finance organizations |
| c) Support for R&D | Strengthening and deepening cooperation between science, policy makers, civil society and business | • Ministry of Energy<br>• Ministry of Infrastructure<br>• State Agency on Energy Efficiency and Energy Saving<br>• Development agencies and international finance organizations<br>• Private sector<br>• Cities and communities |
| d) Public awareness | Public awareness campaign and actions dedicated to promotion of use of hydrogen in road transport, including a specific focus on urban transport. | • Ministry of Energy<br>• Ministry of Infrastructure<br>• State Agency on Energy Efficiency and Energy Saving<br>• Development agencies and international finance organizations<br>• Private sector<br>• Cities and communities<br>• Non-governmental institutions |