The Czech Republic's
Hydrogen Strategy

MINISTRY OF
INDUSTRY AND TRADE

Czech
Republic
The Country
For The Future

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1 INTRODUCTION – SUMMARY AND MAIN OBJECTIVES

1.1 Overall summary

The Czech Republic's Hydrogen Strategy is being developed in the context of the Hydrogen Strategy for a climate neutral Europe, which reflects the European Green Deal objective of climate neutrality by 2050. The objective of the Strategy is thus to reduce greenhouse gas emissions in such a way that the economy shifts smoothly to low-carbon technologies. This is associated with **two strategic goals**:

- Reduce greenhouse gas emissions
- Stimulate the economic growth

To achieve these, **four specific goals** have been set:

- Volume of low-carbon hydrogen production
- Volume of low-carbon hydrogen consumption
- Infrastructure readiness for hydrogen transport and storage
- Progress in R&D and production of hydrogen technologies

The Hydrogen Strategy is based on **four pillars**:

- Low-carbon hydrogen production
- Low-carbon hydrogen use
- Hydrogen transport and storage
- Hydrogen technologies

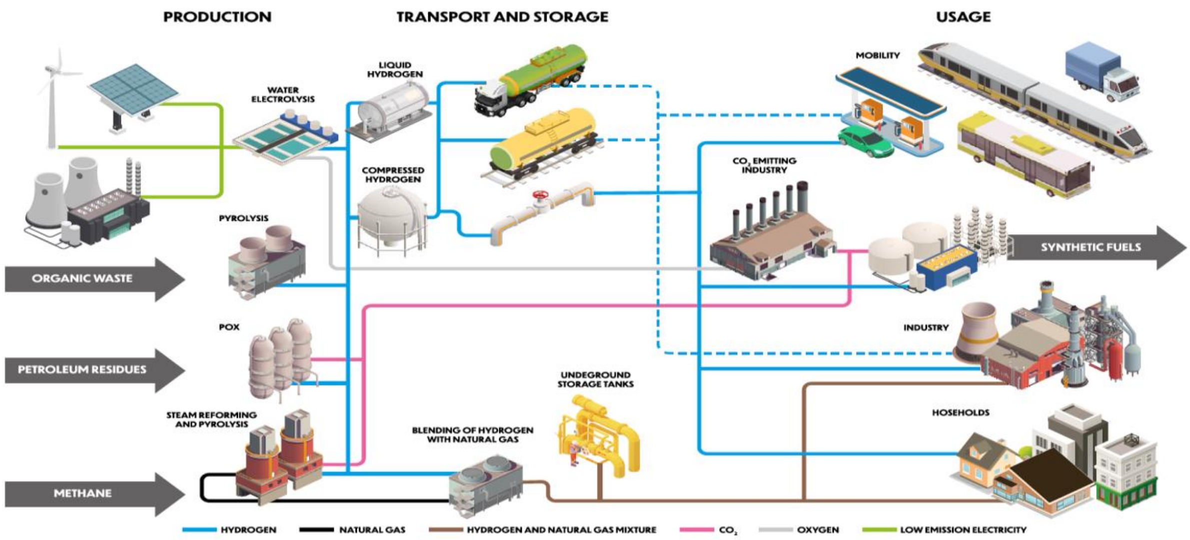
These pillars are interlinked – production and consumption must be well-balanced to achieve economic use of the respective technologies, otherwise any imbalance will be offset by imports from abroad. Each of the pillars is linked to exactly one strategic goal.

The Strategy describes the baseline situation and projects trends in the period up to 2050, which is linked to the strategic horizon of the European Green Deal. It analyses each pillar using a SWOT analysis. Each analysis results in identifying priority areas that need to be developed and, conversely, those whose development is rather discouraged. The results of the analyses are presented in the **analytical section (Chapter 2)**, which also recognises cross-cutting areas that are crucial for all four pillars and identifies barriers to developing a hydrogen economy that need to be gradually removed.

The strategic section (Chapter 3) sets out in more detail how to accomplish the specific goals and projects what hydrogen production and consumption will look like in the coming years. It is followed by the **implementation section (Chapter 4)**, which describes the phases of developing a hydrogen economy in the Czech Republic in the period up to 2050. Obviously, in the conditions of the Czech Republic, there will be no large surpluses of RES energy for which it would be necessary to find a use. Demand for hydrogen can be expected to increase as a result of gradual external pressure to reduce greenhouse gas emissions. This will initially be met by local sources and later by various forms of imports. Furthermore, the implementation section identifies the tools that will be used to meet each goal of the Strategy. These **tools** are:

- Support Schemes (Annex 5)
- Task Cards (Annex 8)

Annexes 1–4 present analyses of all four pillars. In terms of production, the most promising ways to produce hydrogen are identified. Within the transport and storage pillar, the strengths and weaknesses of the different forms of transport (in pressure vessels or via pipelines) are outlined. The analysis of the hydrogen pillar considers the deployment of hydrogen primarily in transport, which is likely to be the first area where hydrogen will become a competitive substitute for fossil fuels. In addition, deployment in industry and the storage of surplus energy are also addressed. A separate analysis aims to identify technologies in the development of which the Czech Republic could become successful. The Czech Republic as a country has a strong industrial tradition and hydrogen technologies present an opportunity to transform the industry and become involved in newly-emerging production sectors.



1.2 Context of the Strategy's creation and existence

The main reason why this Hydrogen Strategy has been prepared is to reduce greenhouse gas emissions and decarbonise transport, industry, services, households and agriculture. In these efforts, the Czech Republic coordinates its actions not only within the European Union, but also in cooperation with other countries that are preparing or already implementing their hydrogen strategies.

The target situation to which this Strategy contributes is to achieve the EU's climate neutrality. This must be achieved through gradually transforming the industry and changing technologies in a way that does not jeopardise employment, competitiveness and the overall standard of living in the Czech Republic. Hydrogen technologies will also bring a variety of growth drivers and new development opportunities and, in turn, support economic growth.

1.3 Users of the Strategy

This Strategy mainly concerns:

- Transport
- Chemical industry

- Energy
- Energy-intensive industries
- Manufacturers of hydrogen technologies and transport equipment
- Hydrogen transport, distribution and storage
- Citizens who will use hydrogen technologies and live in a healthier environment

The owner of the Hydrogen Strategy is the Ministry of Industry and Trade.

1.4 Purpose of the Strategy

Building on the European Hydrogen Strategy and the objectives of the European Green Deal, this Strategy focuses on the period 2021–2050, at the end of which we should achieve climate neutrality.

Hydrogen technologies bring a unique opportunity to use clean energy, as burning hydrogen or using it in fuel cells produces no greenhouse gases other than water vapour. While it is a key contributor to the greenhouse effect, unlike other greenhouse gases, its average amount in the atmosphere is constant and cannot be altered by adding additional water vapour, since its actual content in the atmosphere is solely a function of ocean temperature, atmospheric temperature and atmospheric pressure. This situation, i.e. the balance between the amount of water in the ocean and the amount of water vapour in the atmosphere, is related to the relationships described by physical chemistry (the Clausius-Clapeyron relation).

While the conversion of hydrogen to clean energy is relatively straightforward and does not pose any insurmountable problems (even so, it is still problematic), the production, storage and transport of hydrogen holds a number of pitfalls. Hydrogen is an energy carrier, not a primary energy source, because in all cases we need to produce it from other energy sources through processes with varying efficiencies and carbon footprints. This needs to be analysed throughout the entire life cycle from primary energy source to end use. Some future technologies are yet to be discovered, and others have yet to evolve to the point where they can be used effectively and routinely. As it is not possible today to project exactly which technologies will be the right ones, this Hydrogen Strategy is conceived as a framework that will make it possible to evaluate a range of options and – based on the interim results – choose the optimal path for further development at a given time. With the exception of the strategic goals of reducing greenhouse gas emissions and stimulating economic growth, the Strategy only sets interim milestones and defines support systems. The Strategy will be updated regularly, at least in a three-year cycle.

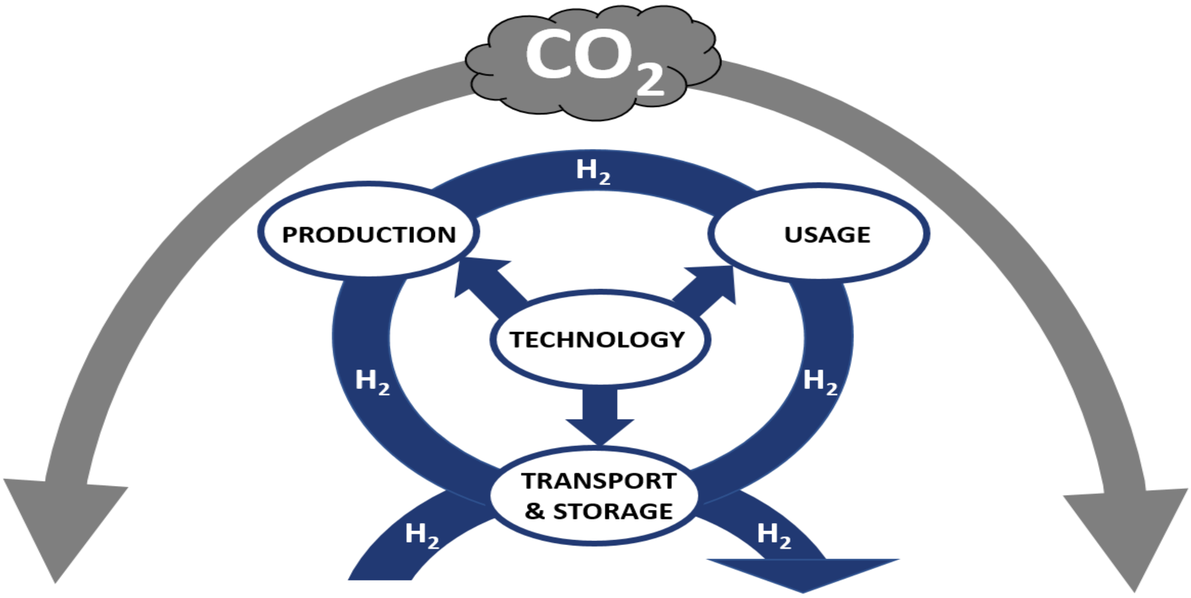
This Hydrogen Strategy builds on the European Hydrogen Strategy as described in the European Commission Communication entitled Hydrogen Strategy for a climate neutral Europe COM(2020) 301.

The Strategy aims to speed up the implementation of hydrogen technologies while minimising the associated costs. For efficient deployment, the requirements for hydrogen consumption and production must be sensitively balanced at every step to ensure maximum utilisation of capital-intensive infrastructure such as electrolysers, filling stations, storage tanks, transporters and other equipment. The Hydrogen Strategy is based on four interrelated pillars:

- **LOW-CARBON HYDROGEN PRODUCTION** – different methods to produce hydrogen

- **LOW-CARBON HYDROGEN USE** – the use of hydrogen in various industries as a fuel, chemical feedstock and energy storage medium
- **HYDROGEN TRANSPORT AND STORAGE** – different methods to transport, store and distribute hydrogen so that point of production and the point of use are efficiently interconnected. This includes imports and transport of hydrogen through the Czech Republic
- **HYDROGEN TECHNOLOGIES** – support for research, development and production of technologies for hydrogen production and use

The strategic goal of the Hydrogen Strategy is to reduce the total amount of greenhouse gases emitted into the atmosphere in the Czech Republic while maintaining the performance and export potential of Czech industry.



Many of the futuristic visions around hydrogen technology are driven by the idea that at the beginning there are renewable sources of solar and wind energy, which are seemingly free, and at the end there is energy stored in hydrogen, which can be used anytime and anywhere. However, it is important to remember that the price we pay for this hydrogen-bound energy consists mainly in the depreciation of equipment, which is currently very expensive. In order to reduce its cost, it is imperative that – in the initial phases – we support integrated projects where hydrogen production and consumption are very closely linked. This is the only way to maximise the utilisation of production, storage, distribution and consumption equipment and, in turn, to reduce the price of hydrogen for the end consumer.

In later phases, when consumption is likely to exceed production, it will be necessary to ensure cost-effective imports of low-carbon hydrogen from countries with favourable production conditions.

At present, low-carbon hydrogen (see 1.5.1) cannot be produced and consumed under economic conditions comparable to other fossil fuels. These are cheaper because they do not include the cost of greenhouse gas emissions. In the hydrogen area, we need to quickly reach the point where economies of scale make low-carbon hydrogen comparable to existing fossil fuels in terms of price. This Strategy aims to show which areas are the most suitable (from different perspectives) for hydrogen deployment at a given time. We expect that the growth of hydrogen use in one area will reduce production, storage, transport and distribution costs, thus enabling the deployment of hydrogen in other areas where the economic conditions require lower hydrogen prices.

In order to create a sustainable hydrogen ecosystem, it is essential that the production price of low-carbon hydrogen for the end consumer is comparable to the sum of the price of fossil fuels and CO2 allowances and, in the future, that it even brings an economic advantage. Therefore, when choosing the priority directions of development, it is essential that we look at the economics of the hydrogen technology in question.

1.5 Basic terms used – hydrogen classification

The hydrogen that is used in the end equipment is always made up of the same H_2 molecule. Given the different methods of production and end-use, hydrogen can be classified in several ways:

- according to CO_2 generated during production,
- according to purity.

1.5.1 Classification according to CO_2 generated during production

For the purposes of the Hydrogen Strategy, we use a classification depending on the way hydrogen is produced. There is currently no clear-cut categorisation of hydrogen types within the EU. However, with the increase in regulations, it can be expected that taxonomy within the EU will be harmonised in the coming period.

1.5.1.1 Low-carbon hydrogen

Low-carbon hydrogen means hydrogen whose production generates a maximum of 36.4 g CO2/MJ[1]. For example, this includes hydrogen produced by electrolysis using electricity from renewable or nuclear sources, hydrogen produced from biogas and hydrogen produced from natural gas or waste with CO_2 capture. **The present Hydrogen Strategy focuses primarily on low-carbon hydrogen because its use contributes to reducing CO_2 emissions.** This type of hydrogen is termed as **"blue hydrogen"**. Sometimes it is also useful to define subsets of low-carbon hydrogen depending on the way it is produced:

- **Renewable hydrogen**

  This is hydrogen that has been produced by electrolysis using electricity from renewable sources, mainly solar, wind and hydroelectric power plants. Hydrogen from renewable sources can also be produced by biogas/biomethane reforming (instead of natural gas reforming) or by biochemical or thermochemical conversion of biomass, provided they comply with

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[1] The value is based on the CertifHy methodology, where 36.4 g CO_2/MJ is 40% of the emission intensity of hydrogen production from natural gas without CCSU,
see https://www.fch.europa.eu/sites/default/files/documents/280120_Final_Report_CertifHy_publishing%20approved_publishing%20%28ID%207924419%29%20%28ID%207929219%29.pdf
Other carbon content values are also being discussed. However, the values below have not been agreed:

- The "Delegated Act of the Taxonomy regulation" proposal advocates 2 .256 tCO_2eq/tH_2
- The "Renewable Energy Directive GHG methodology" proposal assumes a value of 3 ,38 tCO_2eq/tH_2 for hydrogen used in transport

sustainability requirements. The usual goal of hydrogen strategies in different regions of the world is to maximise the use of renewable sources for hydrogen production. If the entire value chain is accounted for, including the production and disposal of solar panels or wind farms, renewable hydrogen has a carbon footprint like any other energy source. In the Czech Republic, we are trying to maximise hydrogen production from renewable sources, but these are limited due to our geographical location, because we have less sunshine and wind than countries near the sea or closer to the equator. This hydrogen is sometimes called "**green hydrogen**".

- **Hydrogen produced using nuclear energy**

  If we use electricity generated from nuclear sources to electrolyse water or use the high temperatures to directly decompose water, we obtain hydrogen with a minimal carbon footprint.

- **Hydrogen produced by the pyrolytic decomposition of natural gas**

  Another way to produce low-carbon hydrogen is by pyrolytic decomposition of natural gas without air access, where the hydrogen is separated from the carbon, which can then be processed or stored without producing CO_2 that could escape into the atmosphere. This hydrogen is sometimes called "**turquoise hydrogen**".

- **Hydrogen produced by pyrolytic decomposition or plasma gasification of waste**

  By pyrolytic decomposition or directly by plasma gasification of organic waste without air access, we can produce hydrogen with a minimal carbon footprint.

1.5.1.2 Other hydrogen

There are many other possible ways to produce hydrogen, such as from oil residues, coal and natural gas without CO_2 capture. However, these have a large carbon footprint, so such hydrogen cannot help us to reduce the amount of greenhouse gases emitted into the atmosphere in the long term. The use of such hydrogen can only serve as an interim solution for a limited period of time. This category also includes hydrogen produced by electrolysis from the grid, where electricity production has a corresponding carbon footprint given by the national energy mix[2]. All hydrogen that is not low-carbon is sometimes referred to as "**grey hydrogen**".

1.5.2 Classification by purity

Regardless of the production method, hydrogen needs to be classified by its purity. The required purity of hydrogen as fuel for proton-exchange membrane (PEM) fuel cells, but also for other applications, is determined by ČSN ISO 14687. We are mainly concerned with two categories:

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[2] While the colour coding of the different types of hydrogen is widely used by both professionals and the general public, it is not backed by any regulation. For a comprehensive overview of hydrogen colour coding see https://en.wikipedia.org/wiki/Hydrogen_economy

1.5.2.1 Hydrogen for PEM fuel cells

Hydrogen for PEM fuel cells, which are mainly used in transport, requires the highest chemical purity in order to ensure that the fuel cells do not degrade and become damaged even during long-term operation. This hydrogen is mainly produced by electrolysis of water.

1.5.2.2 Hydrogen for other uses

In other applications, the requirements for hydrogen purity are not as high. In this case, hydrogen is mainly used as a feedstock for chemical reactions or possibly for the production of heat by combustion. Therefore, requirements for purity may be defined by the specific use, which may be sensitive to the content of specific substances. Impurities must be considered in terms of the specific chemical reaction.

1.6 Scope of the Hydrogen Strategy

Given that hydrogen technology is very young and rapidly developing in many different directions, this Strategy is not intended to be limited to hydrogen alone. It should also cover its compounds such as methane (biomethane and synthetic methane), methanol, ammonia, liquid synthetic fuels, hydrides and other hydrogen derivatives or mixtures of hydrogen and methane.

Since it will not be possible to produce all necessary hydrogen by electrolysis of water using renewable energy sources alone, this Strategy must also address the possibilities for storing and using carbon and its compounds in the production of hydrogen from methane or other organic compounds.

1.7 Baseline situation in 2020

The Czech Republic is a country with a highly developed chemical industry which – in our conditions – is virtually the only producer and consumer of hydrogen. So far, the predominant production methods have been partial oxidation (POX) of heavy oil fractions, steam methane reforming (SMR) and electrolysis. If we use electricity from the grid for electrolysis, the carbon footprint of the hydrogen produced in this way is 176 g CO2/MJ in the Czech Republic, which is significantly higher compared to production by steam methane reforming, and such hydrogen cannot be considered low-carbon. The average emission intensity of hydrogen produced in the Czech Republic is currently 116 g CO2/MJ.

The 2015 State Energy policy mentions hydrogen only marginally. The Czech National Energy and Climate Plan outlines the possibility of using hydrogen in more detail. This includes low-carbon hydrogen that is produced either from RES or in combination with CCU or CCS technologies, i.e. technologies for the capture and subsequent use or storage of CO_2. It also mentions the role of hydrogen to stabilize the electric transmission system, where hydrogen could find an application.

There is a set-up of support for applied research (Horizon 2020 programme, TA CR programmes, Operational Programmes). So far, the focus has generally been on two directions – clean mobility and energy storage. Oriented and applied research in the area of hydrogen and hydrogen technologies is, in part, thematically included in the National RIS3 Strategy.

In recent years, the Czech Republic has successfully participated in research activities in the field of hydrogen technologies and has trained many experts in this area.

Plans are underway to engage in international cooperation in the hydrogen area within Important Projects of Common European Interest (IPCEI).

The Czech Republic is a founding member of the European Clean Hydrogen Alliance, which was established in early 2020 with the aim of preparing countries to build capacities for renewable-hydrogen production and, in turn, to facilitate the decarbonisation of the economy. The Alliance aims to bring together the private sector and government in coordinating hydrogen activities. Its activities are organised around roundtable discussions on various specific aspects of hydrogen use. The Alliance is open to all organisations that are active in the hydrogen area.

In Czech legislation, hydrogen is formally anchored only as a transport fuel. At this time, it is not one of the gases defined under the Energy Act. That said, this situation should change very soon.

2 ANALYTICAL SECTION

The analytical section focuses on searching for a cost-effective way to use hydrogen technologies to reduce greenhouse gas emissions and support economic growth.

The overall CO_2 savings are very difficult to measure. Any low-carbon hydrogen that is consumed replaces fossil fuels or carbon as a reducing agent. Depending on the area where hydrogen is used, it is possible to calculate the savings in greenhouse gas emissions – this will be different in the transport sector, where hydrogen will gradually replace diesel (petrol), in industry, where it will replace coal, natural gas, oil fractions and other fuels, and in the metallurgical sector, where it will serve as a substitute for coke as a reducing agent in iron production. In all cases, the more low-carbon hydrogen we use, the greater the greenhouse gas emission savings. The amount of low-carbon hydrogen that is produced and consumed is a key indicator of meeting the strategic goal – reducing greenhouse gas emissions. Therefore, maximising the consumption and production of low-carbon hydrogen is the main indicator of the implementation of the Czech Hydrogen Strategy.

The deployment of advanced hydrogen technologies and the transformation of research, development and production towards these technologies will then be an important driver of economic growth and help accomplish the second strategic goal.

The individual steps described below consist in determining a cost-effective way to maximise hydrogen production and consumption so that the path to this goal is economically sustainable in the long term and so that only socially acceptable costs are incurred. This Strategy will assess various procedures or technologies and the speed of each step, so that at all times we make optimal use of the economic and technical resources available.

2.1 Preferred areas for development

Our aim is to look for areas where the deployment of hydrogen technology can achieve an economic return as soon as possible. Areas should be found where initial support will trigger subsequent spontaneous development. A detailed analysis of the technologies within each pillar is provided in the Annex. For each technology, a SWOT table is prepared and the results are entered into bubble charts for groups of similar technologies. These bubble charts make it possible for the different technologies to be compared with each other. The results of this analysis are summarised in the priorities set out below. We expect that the priority areas listed below may change in the future depending on trends in technology, prices and energy requirements. The text of this Strategy, the SWOT analyses and bubble charts will be amended accordingly during regular updates.

This Strategy seeks to maintain technology neutrality in the application of hydrogen technologies.

2.1.1 Hydrogen production

In other countries, the development of hydrogen technologies is mostly considered along the lines of producing hydrogen using energy from solar and wind power plants. The Czech Republic is located in the very centre of Europe, where we have fewer hours of sunshine and lower wind intensity compared to coastal and southern countries.

Annex 1 (Hydrogen Production) analyses the hydrogen production options that are currently used and known. While the most common methods of hydrogen production are technically sophisticated, the incremental demands on reducing their emission intensity are likely to render these technologies inadequate or very costly over time. A number of technologies that are oriented towards low-carbon hydrogen, such as pyrolysis of organic waste or natural gas, appear to be economically viable. However, for now these solutions are technically immature. Production using nuclear energy appears to be promising, especially under the conditions existing in the Czech Republic, but even the future available capacity of nuclear facilities may not be sufficient for hydrogen production. In the analysis, production from renewable sources (especially photovoltaics) performed best along both axes, i.e. technology readiness and economic viability, however the conditions in the Czech Republic are unlikely to ever provide sufficient potential.

In the initial phase, the production of low-carbon hydrogen using electrolysers connected to renewable electricity sources is the only way forward. There are plans to continue constructing solar and wind power plants and use them for hydrogen production is planned to continue, and the use of renewable sources is one of the priorities of this Strategy. Given our natural conditions, the contribution of renewable sources to hydrogen production and the efficiency of production can never be on par with coastal countries or countries closer to the equator. In addition to solar and wind energy, we are therefore looking for areas where we will not be limited by natural conditions. That is why we want to focus first on the following low-carbon hydrogen production methods:

- from renewable sources,
- from natural gas with CCS/U,
- in nuclear power plants,
- by pyrolytic decomposition (or plasma gasification) of various types of organic waste or natural gas.

The setting of the technical and economic conditions and the technological progress in the area will determine which of these options will be the most commonly used at any given time.

In the initial stages, it is envisaged that hydrogen will be produced using existing technologies (grey hydrogen), with a gradual increase in the use of hydrogen production from renewable sources and the subsequent introduction of the other technologies that were mentioned above. In order to make the Hydrogen Strategy a success, it is necessary to use those practices that make it possible to minimise the cost of low-carbon hydrogen.

Over time, the ratio between locally produced and imported hydrogen will also change. In the Czech Republic, the possibilities for hydrogen production using existing technologies (RES, biomethane, current nuclear power plants, chemical production and decomposition of organic waste) have their limits that cannot be overcome. It will therefore be necessary to start importing low-carbon hydrogen via pipelines from abroad. Potential technologies that could produce sufficient quantities of low-carbon hydrogen directly in the Czech Republic are nuclear power plants or the pyrolytic decomposition of natural gas with the processing/storage of the resulting carbon.

2.1.2 Hydrogen transport and storage

The points of hydrogen production and consumption may not be the same, which is why it will be necessary to arrange transport from the point of production to the point of consumption alongside the development of hydrogen production and consumption. In the initial phases, it will be necessary to choose transport systems that are efficient even for smaller transported quantities. With the gradual increase in hydrogen consumption, it will be necessary to start using hydrogen pipelines that will make it possible for large quantities of hydrogen to be efficiently transported both into and within the Czech Republic. It must be taken into account that the planning of new pipelines and modifications to existing pipelines is a relatively long-term process, so the relevant plans must be prepared in advance. Preparing gas networks for hydrogen transport is essential in order to maintain and expand the Czech Republic's position as a transit country.

As mentioned above, the Czech Republic will probably never be a hydrogen exporter due to its geographical location, so it will be necessary to connect to a trans-European hydrogen pipeline system in the future. The use of imported hydrogen will not change the level of our dependence on imports, as even now we are importing the vast majority of oil and gas. The countries from which we would import hydrogen are likely to be different from those from which we import oil and gas. In the case of pure hydrogen, these can be assumed to include countries with a high RES potential (within the EU mainly the Mediterranean countries and the North and Baltic Sea countries; outside the EU e.g. Ukraine, North African countries, Russia or the Middle East), from where hydrogen would be imported via pipelines, water or railway transport. Hydrogen in a mixture with natural gas will probably be transported via pipelines from countries that are located on existing natural gas supply corridors for the Czech Republic (e.g. Germany, Slovakia, Poland, Russia).

The Czech Republic has a well-connected and reliable gas infrastructure at both domestic and European levels. For the gas industry, hydrogen is not a new topic. More than 100 years ago, gas companies started operating pipeline systems for the transport and distribution of coke-oven gas/coal gas containing 50–60% of hydrogen. With hydrogen, the gas sector is going back to its roots, but in combination with modern technologies.

The current gas sector is a natural partner on the infrastructure side to facilitate the gradual transition to a hydrogen economy. A stable and clear legislative and regulatory framework will need to be created for hydrogen transport, storage and distribution and, as with other areas of hydrogen deployment, financial and institutional support will be needed.

Gas infrastructure operators can build on several decades of experience in gas network development and they also have the technical and commercial expertise for future transport/storage of hydrogen and its mixtures, including making sufficient capacity available for domestic and cross-border needs.

Technical modifications to the gas system for hydrogen transport are manageable. While some network modifications will be necessary, the required investment in repurposing (modifying the infrastructure for pure hydrogen) and retrofitting (modifying the infrastructure for a mixture of hydrogen and natural gas) is significantly lower compared to newly built hydrogen infrastructure. Cost-effectiveness can be further improved thanks to the "natural" replacement of system components over time and at the end of the lifetime of individual system components. In order to kick-start the development of a hydrogen economy and simultaneously to reduce CO_2 emissions, the transport/distribution of mixtures of hydrogen and methane is expected to be the simplest and cheapest solution, while in later phases the transport of pure hydrogen is likely to be the best option.

The Czech transmission system operator, NET4GAS, operates about 4 000 km of gas pipelines consisting of three trunk pipelines that cover domestic demand for gas and are used for international gas transit, connecting Germany, Slovakia and Poland. In the future, it is expected to transport hydrogen and other renewable or decarbonised gases. NET4GAS is involved in planning future European infrastructure within the European Hydrogen Backbone project. Due to its geographic location in the centre of Europe, the Czech Republic will remain an important transit state in the transmission system, because it can transport hydrogen from the east (e.g. from Ukraine via Slovakia), the south (e.g. from North Africa via Italy and Austria) and the north-west (e.g. from Germany).

The analysis of hydrogen transport and storage (Annex 2) arrived at the conclusion that, at lower production volumes, the primary decision to make will be between transporting compressed gaseous hydrogen and transporting liquefied hydrogen. At higher volumes, the considerations will also need to include gas pipelines – these will need to be converted from existing pipelines or newly built. Compressed hydrogen in containers is a technologically mature and viable method. In contrast, the repurposing of the existing infrastructure for hydrogen and the construction of new pure hydrogen pipelines may encounter a number of barriers in the planning phase, but this process is inevitable in the future. Strategic decisions in this respect need to be made very early on, because infrastructure repurposing and construction (including the preparatory processes) takes a relatively long time. At large volumes, long-term underground storage of hydrogen is possible in a mixture with natural gas, which is a proven technology. Underground storage of pure hydrogen is preferable, yet still technically immature. The analysis shows that there are also alternatives that are yet to be properly tested – the transport or storage of hydrogen in the form of hydrides or other compounds.

2.1.3 Hydrogen use

Due to the cost of production, low-carbon hydrogen is currently an expensive fuel, so we need to look for areas of consumption where operating and investment costs on par with those for fossil fuels can be achieved as soon as possible.

Annex 3 (Hydrogen Use) starts by analysing the possibilities for hydrogen use in transport. As before, the technological readiness and economic viability of the various methods were examined and their potential capacity was assessed. Cars are the most technically advanced and economically viable, and the potential of this market is very high. City bus transport and road freight transport ranked very high on both axes, i.e. technology readiness and economic viability. Hydrogen internal combustion engines may also be an interim solution with a relatively large capacity.

The chemical industry already produces and consumes hydrogen. This is therefore essentially about substituting one type of hydrogen for another. Under the current conditions, oil refining and ammonia production are the most widespread uses of hydrogen and it is expected that – despite some changes – these two areas will continue to operate in a similar manner in the future. Similarly, the possibilities for hydrogen use in metallurgical production, large-furnace burners and the energy sector were analysed.

For the above reasons, it turns out to be convenient to start deploying hydrogen in the transport sector. Fossil fuels are subject to excise duties, and the various forms of this taxation will increase. There, we are able to achieve the same level of operating costs for diesel and hydrogen at much higher hydrogen prices than those required to replace natural gas with hydrogen for heat generation. In terms of planning and overall consumption, it is most efficient to deploy hydrogen in city bus transport, rail, freight and private transport. So far the high purchase prices of hydrogen vehicles have been a disadvantage. Another area where the deployment of low-carbon hydrogen could start is in chemical industry. We therefore consider the following areas as promising for the initial deployment of hydrogen:

- City bus transport
- Freight and passenger road transport
- Railway transport
- Hydrogen use in chemical industry

2.1.4 Hydrogen technologies

Involvement in the production of components and final products in the field of hydrogen technologies may act as a significant stimulus to strengthen the innovation potential of Czech companies. Hydrogen technologies brings a range of opportunities in the field of hi-tech, high value-added manufacturing. The promotion of hydrogen technologies in the different EU Member States will generate mass demand for this type of products. However, it is important to note that the window to enter this market will only open for a relatively short period of time. Hydrogen technologies may also represent a convenient stimulus for the transformation of the Czech automotive industry, which is now heavily tied to the use of fossil fuels.

As part of the analysis of hydrogen technologies (Annex 4), the various basic technological components that are required for the operation of hydrogen technologies were compared. In the comparison, the winning components are those where the Czech Republic already has a certain tradition and, at the same time, where the use is sufficiently wide (universal). One example of such a component is the battery. Many components are already very technologically mature, but the problem is the massive competition from similar cheap components produced outside Europe.

The analysis took into account the projected development of the individual technologies for which the components will be needed. While the long-term usefulness of some components is uncertain (e.g. hydrogen turbines), others are almost certain to be needed (pressure tanks). There is little difference between the components in terms of technical readiness.

Companies in the Czech Republic are unlikely to be suppliers of large integrated technical units. Supplying filling stations or high-pressure storage facilities can be considered as reasonably promising areas, where Czech companies can be assumed to have some experience with the various components. The segments of trucks, buses and handling equipment offer potential for Czech companies – the analysis assesses these segments as technologically mature, having sufficiently large market capacity and, at the same time, as economically viable.

Given the priorities for hydrogen production and consumption, the following areas can be considered to have the greatest potential for research, development and production:

- Components for hydrogen vehicles and transport infrastructure
- Hydrogen vehicles (buses, trucks and cars)
- Hydrogen production equipment (electrolysis and pyrolysis)

2.2 How much hydrogen do we need – usage scenario

As mentioned above, it is very difficult to project hydrogen quantities accurately up to 2050. The projections have been broken down by the same sectors as those used in the previous chapter.

2.2.1 Transport

In projecting the amount of future consumption, the Strategy uses the National Action Plan for Clean Mobility (NAP CM) for buses and cars. The requirements for trucks were set on the basis of the projects being discussed.

The railway transport area will have to be further refined and, for the time being, air and water transport are not included in the projections at all.

2.2.2 Chemical industry

The chemical industry will use hydrogen in two ways:

- **As a feedstock**: in this case, the strategy works with the amount of hydrogen that is processed now, with the expectation that this amount is likely to decrease in the future due to a reduction in petrol and diesel production in refineries and a reduction in ammonia production for fertilisers, which will result from implementing the objectives of the European Green Deal. However, the reduction in ammonia production may be offset by the increasing demand for synthetic fuel production. For this amount, the percentage of grey hydrogen that will gradually be replaced with low-carbon hydrogen was projected.
- **As a heat source – a substitute for natural gas and coal**: the figure for the amount of natural gas that is used for heat production was obtained from the material entitled **Overall Energy Balance of the State using Eurostat methodology for 2010–2019**. It is possible to project the percentage of this natural gas that will be replaced with hydrogen. It is not expected that the entire current natural gas consumption for energy will be replaced in this way. It will also be replaced with biomethane and electricity.

2.2.3 Iron and steel sector

In its efforts to decarbonise the iron and steel sector, the EU is relying primarily on hydrogen technologies, where the principle will be to reduce iron ore with hydrogen instead of coal or coke, which is still used today and which is the main contributor to the sector's CO_2 emissions. However, these technologies are not yet available in the market – they are still being developed or tested. In the blast furnaces that are in use today, a full replacement of coke with hydrogen is not possible, so at least partial replacement is being tested. For full replacement, completely new production units will be required.

The revolutionary Swedish HYBRIT project, which is expected to produce the first completely emission-free steel in a few years using hydrogen produced from RES, estimates that approximately 3.5 MWh of electricity will be needed per unit of steel. The study entitled Klimaneutrale Industrie states that 3.3 MWh/t of steel will be required. At the same time, most available sources estimate that 70–90 kg of hydrogen will be needed per tonne of steel. Through direct reduction with hydrogen, the Czech Republic's current (2018) annual production of 4 million tonnes of iron and 5 million tonnes of steel would therefore mean the consumption of up to 360 thousand tonnes of hydrogen, the production of which would require approximately 20 TWh of electricity (for comparison, in 2019 the electricity consumption in the steel industry was approximately 2 TWh; the total electricity consumption in the Czech Republic was 73.9 TWh). In addition to the electricity consumed to produce hydrogen in electrolysers, large additional amounts of electricity are needed to melt the iron for further processing in the steelworks. This is because reduction with hydrogen (unlike the primary process of blast furnace production using coke) does not result in a liquid metal.

The amount of hydrogen required for the Czech Republic's iron and steel industry depends not only on the future volume of iron and steel production, but mainly on the physical availability and affordability of hydrogen and hydrogen technology, which is not yet available in the market. This will also provide a better answer to the question of how much steel will eventually be produced by smelting scrap iron in electric furnaces, which can be done without the use of hydrogen, and to what extent hydrogen will be used in ore reduction. The resulting technology mix is likely to be a compromise between the two technologies. In any case, it must be taken into account that a certain amount of CO_2 is emitted both when producing steel from scrap metal and when melting hydrogen reduced sponge iron using electric arc furnaces.

2.2.4 Industry (excluding the iron and steel and chemical industries)

In industry, hydrogen will mainly be used as a substitute for natural gas for heat generation. The amount of natural gas was obtained from the material entitled **Overall Energy Balance of the State using Eurostat methodology for 2010–2019**. The percentage of this natural gas that will be replaced with hydrogen was projected. It is not expected that the entire current natural gas consumption for energy will be replaced with hydrogen. Natural gas will also be replaced with biomethane and low-carbon electricity.

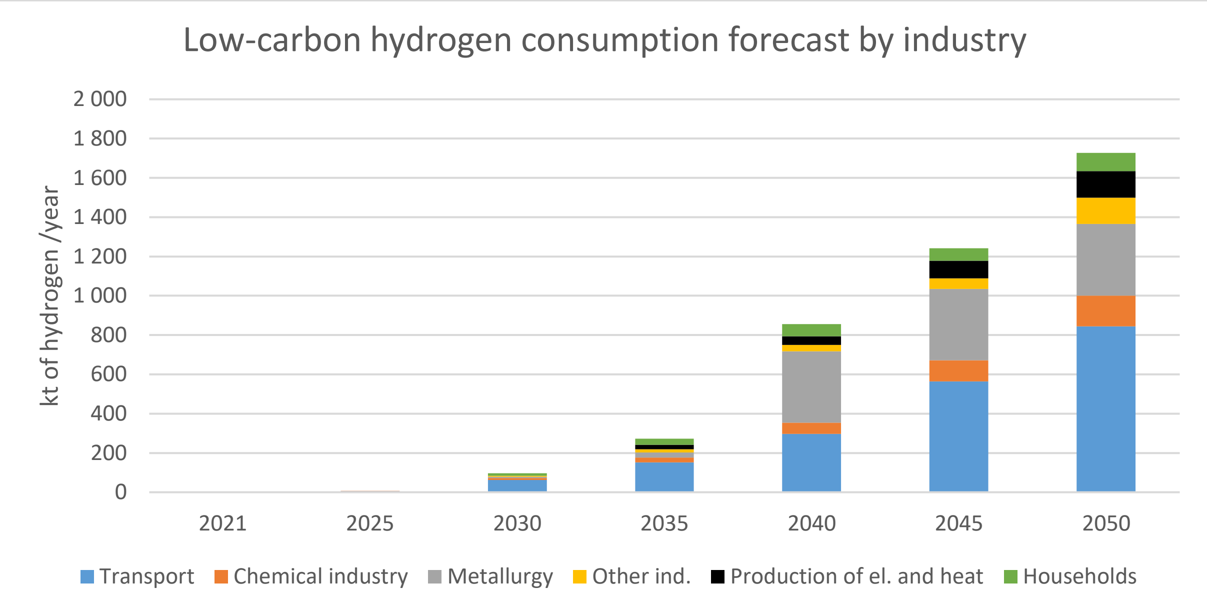
2.2.5 Households

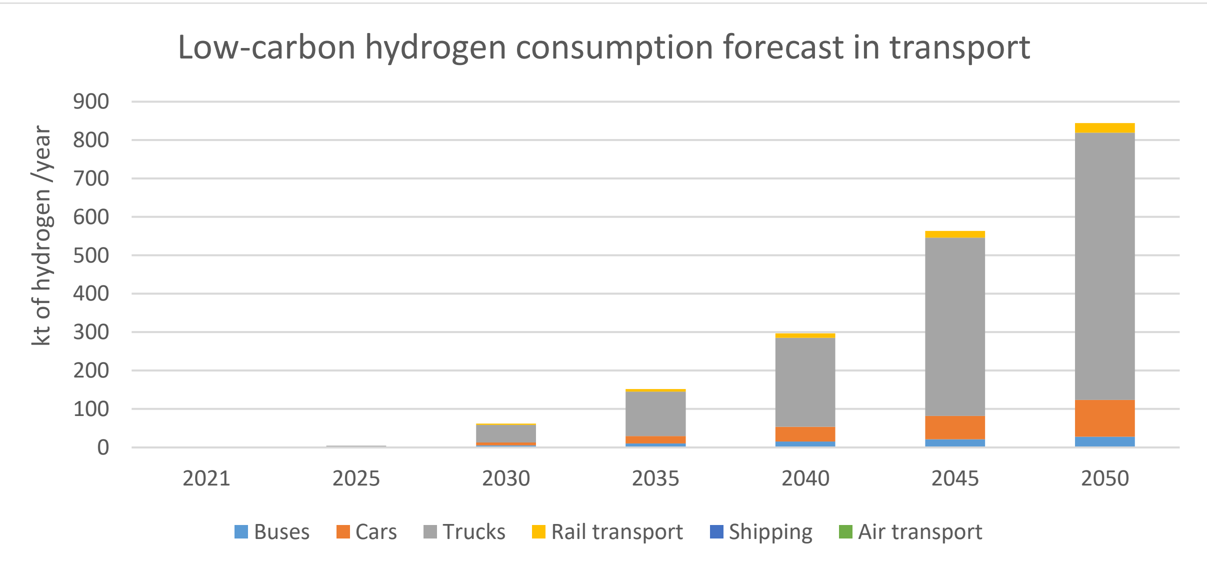
Hydrogen can only be used in households if it is blended into natural gas. The amount of natural gas was obtained from the material entitled **Overall Energy Balance of the State using Eurostat methodology for 2010–2019**. It is not expected that households' entire current natural gas consumption for energy will be replaced with hydrogen. Natural gas will also be replaced with biomethane, electricity, biomass, and partially by photothermal energy, or possibly hybrid heat pumps will be developed. At the same time, the trend of energy savings in households (insulation, low-energy houses and other forms) is expected to continue. In terms of blending hydrogen into natural gas, only small amounts of up to 2% are envisaged for the time being. This blending can also start in phases 1 and 2 as it requires minimal technological changes.

2.3 Scenario of hydrogen consumption by sector

Based on projections, we should reach an annual consumption of **1 728 thousand tonnes of low-carbon hydrogen by 2050**. To produce this amount of hydrogen by electrolysis, we would need 95 TWh of electricity. If this amount were to be produced by electrolysis, it would require approximately 3.2 times the annual output of the Temelín and Dukovany nuclear power plants combined (30.2 TWh/year in 2020). Another option is to import this amount of hydrogen via the gas system from abroad.

According to current projections, transport, and especially freight transport, is the largest user of low-carbon hydrogen.





	Consumption type	2021	2025	2030	2035	2040	2045	2050	Note
Transport	Number of hydrogen buses according to NAP CM	1	100	900					NAP CM (2019)
	Number of hydrogen buses				1 700	2 500	3 500	4 600	estimated extrapolation of NAP CM total of 21 484 buses and minibuses in 2019
	Newly registered hydrogen buses (% of registrations in 2019)	0 %	2 %	13 %	13 %	13 %	16 %	18 %	newly registered 1 220 buses in 2019
	Hydrogen buses total	1	100	900	1 700	2 500	3 500	4 600	
	Hydrogen buses consumption (kt/y)	0	1	5	10	15	21	28	bus mileage 60 000 km/y bus consumption 10 kg H_2/100 km
	Hydrogen passenger cars number according to NAP CM	2	5 000	45 000					NAP CM (2019)
	Hydrogen passenger cars				120 000	240 000	380 000	600 000	estimate of extrapolations by NAP CM total of 5 924 995 passenger cars in 2019
	Newly registered passenger cars per year (% from registrations in 2019)	0 %	0,4 %	3,2 %	6,0 %	9,6 %	11,2 %	17,6 %	249 915 passenger cars were newly registered in 2019
	Hydrogen passenger cars total	2	5 000	45 000	120 000	240 000	380 000	600 000	

	Consumption of hydrogen passenger cars (kt/y)	0	1	7	19	38	61	96	passenger car mileage 20 000 km/y consumption of passenger car 0,8 kg H_2/100 km
	Number of hydrogen trucks	0	300	4 000	10 000	20 000	40 000	60 000	total of 723 678 trucks and road tractors in 2019
	Newly registered trucks (% from registrations in 2019)	0 %	0,2 %	2,4 %	4,0 %	6,6 %	13,2 %	13,2 %	30 288 trucks and light commercial vehicles were newly registered in 2019
	Number of hydrogen trucks (kt/y)	0	3	46	116	232	464	696	truck mileage 116 000 km/y consumption of truck 10 kg H_2/100 km
	Hydrogen trains consumption (kt/y)	0	0	3	7	12	18	25	local trains and shunting locomotives
	Shipping (kt/y)	0	0	0	0	0	0	0	
	Air transport (kt/y)	0	0	0	0	0	0	0	
	Consumption in transport total (kt/y)	**0**	**5**	**62**	**152**	**297**	**564**	**845**	

Chemical industry	Current capacities of hydrogen production, which are processed in subsequent chemical production (kt/y)	96	96	96	96	96	91	86	It is likely that oil refining will be decreasing after 2040 to ensure that the objectives of the European Green Deal are met. Production of ammonia is likely to remain at the same level because the current production does not cover the whole domestic consumption.
	% of grey hydrogen replaced by low carbon hydrogen	0 %	1 %	5 %	10 %	30 %	60 %	100 %	estimate
	Consumption of hydrogen in chemical production (kt/y)	0	1	5	10	29	55	86	
	High temperature heat (kt/y)	2,5	2,5	2,5	2,5	2,5	2,5	2,5	
	% of grey hydrogen replaced by low carbon hydrogen	0 %	10 %	20 %	40 %	60 %	80 %	100 %	estimate
	Consumption of hydrogen for high temperature heat production (kt/y)	0,0	0,3	0,5	1,0	1,5	2,0	2,5	
	Natural gas consumption in chemical industry (TJ/y)	10 228	10 228	10 228	10 228	10 228	10 228	10 228	data according to the Summary Energy Balance for 2019 (Souhrnná energetická bilance)

	% of natural gas replaced by low carbon hydrogen	0 %	1 %	5 %	15 %	30 %	60 %	80 %	estimate
	Consumption of hydrogen for heat production (kt/y)	0	0,9	4,3	12,8	25,6	51,1	68,2	hydrogen calorific value 120 MJ/kg
	Consumption in the chemical industry (kt/y)	**0**	**2**	**10**	**23**	**56**	**108**	**157**	
Iron and steel sector	Energy needed for iron and steel production (TWh/y)	2	2	8	10	25	25	25	Consumption of electricity planned for decarbonization of the iron and steel production is around 25-30 TWh/y
	% of energy used for hydrogen production	0 %	0 %	5 %	15 %	80 %	80 %	80 %	
	Corresponding amount of hydrogen (kt/y)	**0**	**0**	**7**	**27**	**364**	**364**	**364**	
Industry (excluding metallurgy and chemical industry)	Natural gas consumption in industry (excluding metallurgy and chemical industry) (TJ/y)	64 498	64 498	64 498	64 498	64 498	64 498	64 498	data according to the Summary Energy Balance for 2019 (Souhrnná energetická bilance)
	% of natural gas replaced by low carbon hydrogen	0 %	0 %	1 %	3 %	6 %	10 %	25 %	estimate, natural gas will be replaced not only by hydrogen, but also by biogas and electricity
	Industry (excluding metallurgy and chemical industry) consumption total (kt/y)	**0**	**0,0**	**5,4**	**16,1**	**32,2**	**53,7**	**134,4**	hydrogen calorific value 120 MJ/kg

Production of electricity and heat	Total production of electricity in the Czech Republic (TJ/y))	429 701	429 701	429 701	429 701	429 701	429 701	429 701	data according to the Summary Energy Balance for 2019
	% of electricity and heat produced by hydrogen	0,0 %	0,0 %	0,0 %	0,5 %	1 %	2 %	3 %	qualified guess
	Corresponding amount of hydrogen (kt/y)	**0**	**0**	**0**	**22**	**45**	**90**	**134**	hydrogen calorific value 120 GJ/t efficiency of cogeneration units 80 %
Households	Natural gas consumption by households (TJ/y)	75 169	75 169	75 169	75 169	75 169	75 169	75 169	data according to the Summary Energy Balance for 2019 (Souhrnná energetická bilance)
	% of natural gas replaced by low carbon hydrogen	0 %	0 %	2 %	5 %	10 %	10 %	15 %	it is about the proportion of hydrogen in the mixture with methane (e.g. natural gas, biomethane)
	Consumption of households total (kt/y)	**0**	**0**	**13**	**31**	**63**	**63**	**94**	hydrogen calorific value 120 MJ/kg
	Consumption of low carbon hydrogen total (kt/y)	**0**	**7**	**97**	**273**	**857**	**1 241**	**1 728**	

2.4 Current barriers to the development of hydrogen technologies in the Czech Republic

This chapter provides an overview of the barriers that currently hinder the development of hydrogen technologies. The Strategy aims not only to identify these barriers, but also to propose possible solutions to remove them. The proposed Task Cards (Annex 8) are one of the main mechanisms for removing barriers. In general, we assume that the production, transport, storage and use of hydrogen is affected by several laws, e.g. Act No. 458/2000 Sb., on the conditions for conducting business and public administration in the energy sectors and amending certain acts (the Energy Act), Act No. 311/2006 Sb., on fuels and filling stations and amending certain related acts (the Fuel Act), Act No. 183/2006 Sb., on spatial planning and building rules (the Building Act), Act No. 56/2001 Sb., on the conditions of operating vehicles on roads, Act No. 541/2020 Sb., on waste, Act No. 263/2016 Sb., the Atomic Act, or Act No. 165/2012 Sb., on supported energy sources. This is an illustrative list, not an exhaustive one. However, it is unclear at this time whether these laws will need to be changed based on national requirements, whether they will be amended based on newly adopted European regulations, whether they will remain unchanged, or whether new regulations will be created specifically for hydrogen. The work that is associated with the respective task cards includes conducting an analysis of the relevant laws and proposing possible changes.

2.4.1 Legislative and regulatory barriers

2.4.1.1 State Energy Policy of the Czech Republic

The 2015 *State Energy Policy of the Czech Republic* (SEP) does not deal with hydrogen virtually at all, which corresponds to the date of its preparation and the share of renewable sources proposed by the SEP. One of the main points that will have to be added to the SEP is the share of hydrogen in the Czech Republic's overall energy mix, as well as e.g. energy storage in the form of hydrogen. However, this technology is not expected to be used on a larger scale in the Czech Republic in the next 10 years.

2.4.1.2 Hydrogen is not a statistically monitored commodity

Hydrogen is not one of the commodities that are monitored by the Czech Statistical Office and the Energy Regulatory Office (ERO).

2.4.1.3 Lack of certification and tools for low-carbon hydrogen trading

There is no certification instrument to guarantee the origin of low-carbon hydrogen or possibly another certification authority based on EU directives. A proposal for a single approach will be presented by the European Commission in 2021.

2.4.1.4 The injection of hydrogen into the gas system, even in limited quantities, is not legislatively regulated

2.4.1.5 Lack of legislation, standards and safety regulations for the injection, transport, distribution and use of hydrogen

- The Energy Act, which is currently about to be amended, defines the term gas. According to the current definition in Section 2(2)(b) of the amended Act No. 458/2000 Sb., "gas" shall mean natural gas, pure coke-oven gas, degassing gas, generator gas, biomethane, propane, butane and mixtures thereof, unless used to drive motor vehicles. Hydrogen is not within the scope of the Energy Act and it is not included in the ERO's balances, which are prepared under authorisation provided for in the Energy Act, nor in the key decrees[3].

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[3] Decree No. 108/2011 Sb., on gas metering and on the method of determining compensation for damages in the event of unauthorised consumption, unauthorised supply, unauthorised storage, unauthorised transport or unauthorised distribution of gas, as amended.

- At the same time, it will be necessary to assign the governmental authorities responsible for all areas of hydrogen use (fuel, chemical feedstock, energy vector – energy carrier).
- Lack of regulations and standards for the transport and distribution and separate use of hydrogen also for ordinary consumers – analogous to the current situation of natural gas.
- Lack of a system of guarantees and certification of the origin of low-carbon hydrogen (see Legislative and regulatory barriers)
- Lack of safety regulations for installing hydrogen technologies in the public sector.
- Lack of safety regulations for installing hydrogen technologies within the premises of nuclear facilities.

2.4.1.6 Lack of measurement and laboratory capacities for experimental activities involving hydrogen

2.4.1.7 Legislative restrictions on hydrogen transported in cylinders on the road

2.4.1.8 Inadequate education in hydrogen technologies

Inadequate education and awareness raising on hydrogen technologies (a necessary condition for the acceptance of hydrogen by the general public and for increasing the number of skilled personnel for implementing and operating hydrogen technologies).

2.4.1.9 Linkage to standards and legislation in neighbouring countries

Neighbouring countries (e.g. Germany) have made more progress in defining and implementing standards, legislation and recommendations[4] in the field of hydrogen production, storage and transport. If our standards and legislation are not harmonised and put into practice in a timely manner, it may hinder cross-border cooperation.

2.4.2 Technical and economic barriers

2.4.2.1 Geographical and climatic conditions for low-carbon hydrogen production

Unfavourable climatic conditions for hydrogen production from RES result in lower performance at comparable investment costs.

Decree No. 349/2015 Sb., on gas market rules, as amended. Decree No. 545/2006 Sb., on the quality of gas supply and related services in the gas industry, as amended.

Decree No. 70/2016 Sb., on billing for supplies and related services in the energy sectors – effective until 31 December 2021.

Decree No. 207/2021 Sb., on billing for supplies and related services in the energy sectors – effective from 1 January 2022.

[4] https://acer.europa.eu/Official_documents/Position_Papers/Position%20papers/ACER_CEER_WhitePaper_on_the_regulation_of_hydrogen_networks_2020-02-09_FINAL.pdf

2.4.2.2 Current limited gas infrastructure readiness for the transport, distribution and storage of higher percentages of hydrogen/methane mixtures, current incompatibility of the system for the transport, distribution and storage of pure hydrogen

2.4.2.3 Technically viable solutions (hydrogen blending into a 2 % mixture with methane) lack legislative regulation

2.4.2.4 Insufficient resource capacity for low-carbon hydrogen production – very limited RES capacity and limits of nuclear power plants

2.4.2.5 Lack of pilot projects to acquire technological know-how


H2

3 STRATEGIC SECTION

3.1 Strategic goals

The main strategic goals and reasons for preparing the Hydrogen Strategy of the Czech Republic are:

- **Reduce greenhouse gas emissions**
- **Stimulate economic growth**

1.1.3. Reduce greenhouse gas emissions

Reducing greenhouse gas emissions is a clearly defined goal both in terms of the European Green Deal and the European Hydrogen Strategy. Within EU policies, hydrogen is defined as one of the important tools to achieve climate neutrality and to ensure decarbonisation in sectors where other means of reducing greenhouse gas emissions cannot be deployed.

Through direct measurements of air pollution, we are unable to determine the contribution of hydrogen to emission reduction. To do that, we need to use other methods. There is a direct proportionality between greenhouse gas emission reduction and the use of low-carbon hydrogen. The more low-carbon hydrogen we use, the more greenhouse gas concentrations in the atmosphere will decrease.

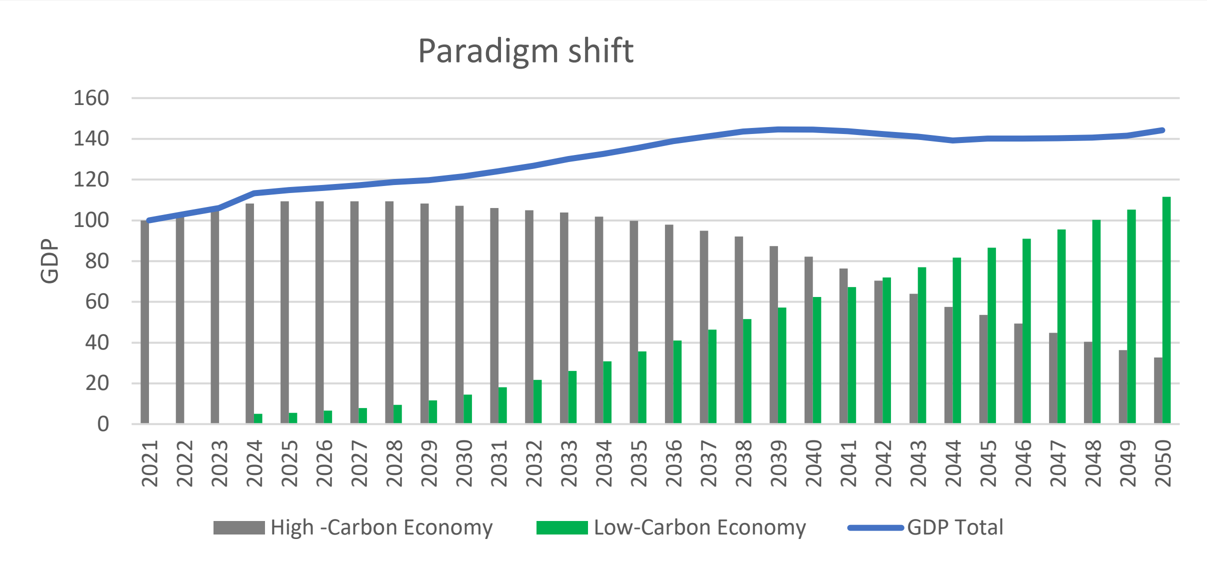
Therefore, we will use specific goals such as the amount of low-carbon hydrogen consumed to assess the achievement of this strategic goal.

3.1.2. Stimulate economic growth

The hydrogen technologies that need to be used to reduce greenhouse gas emissions are very new technologies that require a high quality of research, education and industrial production. They will require many new specialists and experts. That is why our Strategy emphasises not only the use of hydrogen, but also education, research, development, production, deployment and operational support for these technologies. Hydrogen technologies can be expected to bring many new jobs that will replace those lost in the sectors that are heavily dependent on the use of fossil fuels.

At the same time, greenhouse gas emission reduction targets have been set that will lead to phasing out fossil fuel-intensive technologies. The strategic goal of this Strategy is to kick-start the development of technologies and industries that will replace the sectors that are being phased out.

The aim is for the national economy, represented by gross domestic product (GDP), to grow or to be only affected by normal economic cycles. Such a development is illustrated, in a simplified form, in the following graph. The GDP, which is shown as the blue line, is the sum of two economies. The first one is based on emission-intensive technologies and is shown in grey in the graph. Due to the restrictions imposed by the European Green Deal, i.e. mainly due to the rising price of emission allowances and poorer financing conditions, this economy will gradually shrink. In contrast, the second economy, which is based on modern low-emission technologies and shown in green, will continue to develop. This will be due to targeted research and support schemes. We want to create an environment for the development of modern low-emission technologies so that the overall trend in GDP remains steadily increasing, or with only minor cyclical declines, as shown below. It is important to kick-start the low-carbon economy as soon as possible so that its gradual growth is able to offset the decline of the economy that is based on emission-intensive technologies. For simplicity, the illustrative chart does not include industries whose development is not associated with GHG emissions in a positive or negative sense.



While the overall economic growth is well measurable (GDP), it is not easy to determine how the activities defined in this Strategy contribute to that growth. It is safe to say that the following factors will clearly have a positive impact on economic growth:

- The amount of hydrogen produced in the Czech Republic (by contrast, significant imports of hydrogen would reduce GDP)
- The amount of hydrogen consumed in end use
- Building (construction) of infrastructure for hydrogen transport and storage
- Progress in R&D and production of hydrogen technologies

Given the already existing activities and the fundamental importance of green transition (decarbonisation) for the Czech Republic's traditional industrial regions, it can be expected that the Strategy will have a significant impact in the Ústí nad Labem, Karlovy Vary and Moravian-Silesian Regions, and possibly other regions.

These factors are already measurable and the following chapter defines how the strategic goals are linked to the specific goals for which we can define specific target values and link them specifically to the **Task Cards**.

3.2 Specific goals

The fulfilment of **both strategic goals** is difficult to measure, so we will use the following **specific goals** to evaluate the success of their fulfilment:

1. **Volume of low-carbon hydrogen consumption** that can replace fossil fuels in transport, chemical production, metallurgy, industry, heat and power generation.
2. **Volume of low-carbon hydrogen production.** The production of low-carbon hydrogen is a necessary prerequisite for its use, because low-carbon hydrogen cannot be imported cheaply in the initial period. Therefore, all requirements will have to be covered by domestic production.
3. **Infrastructure readiness for hydrogen transport and storage** so that we can connect the points of production and consumption and import low-carbon hydrogen from abroad.
4. **Progress in R&D and production of hydrogen technologies** as the last specific goal is related to the fact that in order to produce, transport, store, distribute and consume hydrogen, we need to have the appropriate technologies.

Each specific goal is based on the four pillars of the Hydrogen Strategy and supports both of its strategic goals, as shown in the diagram below.

3.2.1 Specific goal 1: Volume of low-carbon hydrogen consumption

As mentioned, the total amount of hydrogen consumed is an indicator that describes CO_2 savings well. The Strategy assumes that there is a direct proportionality between the strategic goal (greenhouse gas emission reduction) and the amount of low-carbon hydrogen consumed, which makes it possible to measure low-carbon hydrogen consumption instead of greenhouse gas emission reduction. During evaluation, it is necessary to distinguish between low-carbon hydrogen and other types of hydrogen, which should be achieved using certificates of origin. This strategy is based on a projection of the need for low-carbon hydrogen (see Scenario of hydrogen). The consumption forecast was based on various projections that, in turn, were based on the amount of hydrogen currently used and the expected substitution of fossil fuels. In the transition period, it will be possible to use hydrogen other than low-carbon hydrogen in order to encourage at least the consumption side. Therefore, consumption and production forecasts are evaluated separately here. If hydrogen mobility develops in line with the forecast but low-carbon hydrogen production is insufficient, the goal will be accomplished in terms of consumption and it will not be accomplished in terms of production.

3.2.2 Specific goal 2: Volume of low-carbon hydrogen production

In the area of production, it is necessary to maintain technology neutrality in producing low-carbon hydrogen, which is why this strategy does not prescribe any target quantities for individual low-carbon hydrogen production technologies as part of the forecast. It can be expected (at least initially) that the main technology will be hydrogen production by electrolysis using electricity from renewable sources. This technology will dominate until other low-emission technologies are more widely deployed, depending on their technological readiness, or until affordable low-carbon hydrogen can be imported from abroad.

There are no plans for the Czech Republic to become a low-carbon hydrogen exporter. Therefore, the production volume is derived from the volume of used low-carbon hydrogen. It is assumed that the volume of the Czech Republic's low-carbon hydrogen production has a limit, which will depend on the efficiency of the production technologies and the availability of renewable sources of electricity and biogas. Any additional requirements will have to be met by importing low-carbon hydrogen from abroad. Due to existing contracts, it is not likely to be possible to use existing pipeline infrastructure to import hydrogen until 2035. Other ways of transporting hydrogen over long distances are not yet very efficient, so until 2035 the main source of low-carbon hydrogen will be local production and the target figures are in line with the consumption forecast. The production forecast for the subsequent period will be updated depending on transport infrastructure readiness and the availability of low-carbon hydrogen abroad.

(kt of hydrogen /year)	2021	2025	2030	2035	2040	2045	2050
Production of the Czech Republic	0	7	101	284	tbd	tbd	tbd

3.2.3 Specific goal 3: Infrastructure readiness for hydrogen transport and storage

The main focus of this goal is to have infrastructure that is ready for hydrogen transport (transmission/distribution in the gas sector) and storage in the form of pure hydrogen or mixtures of hydrogen with methane in technical, legislative and regulatory terms, i.e. to create a stable and clear legislative and regulatory framework (including institutional support) for repurposing (modifying the infrastructure for pure hydrogen) and retrofitting (modifying the infrastructure for a mixture of hydrogen and natural gas).

The gas system and transport infrastructure will play a very important role in transporting hydrogen. In the initial phases, this will mainly involve transporting hydrogen by various road/railway transport modes within the country, so that hydrogen can be used in places other than where it is produced. This transport will make use of different methods: compressed hydrogen, liquid hydrogen or hydrogen bound in chemical compounds.

As the volume of transported hydrogen increases, it will be necessary to use pipeline transport, i.e. not only within the country but also for the transit transport of low-carbon hydrogen through the Czech

Republic. For transit transport, it will be necessary to closely coordinate development plans with all neighbouring countries that share cross-border pipelines with the Czech Republic. The gas system will have to technically prepare for the efficient transport of low-carbon hydrogen between the points of consumption and production, as well as at the sections between the various border transfer points for the purpose of importing hydrogen into the Czech Republic. Imports of low-carbon hydrogen will have to cover the difference between domestic production capacity and the requirements for low-carbon hydrogen consumption. Hydrogen import requirements will depend on the price and availability of low-carbon hydrogen that is produced in countries with abundant renewable electricity sources (sunshine, wind and water) or countries where low-carbon hydrogen can be produced from natural gas. At present, we are not able to precisely define the hydrogen transport targets for the coming years within the Czech Republic, nor the requirements for hydrogen transit, because the future quantities to be transited will depend on the development of hydrogen production in the EU and in third countries (Ukraine, North Africa, etc.). Specific measurable targets will be set as soon as possible.

The amount of hydrogen transported can be divided into three separate categories: domestic transport, low-carbon hydrogen imports into the Czech Republic, and transit transport of low-carbon hydrogen through the Czech Republic. Given the limited possibilities for low-carbon hydrogen production in the Czech Republic, it is expected that a part of the consumption will have to be imported. As far as hydrogen/natural gas mixtures are concerned, the amount of imported hydrogen will depend on the development and amount of hydrogen injected in the countries from which gas is physically flowing into the Czech Republic, which is currently Germany, more specifically its north-eastern region.

The transmission system operator NET4GAS has concluded several long-term contracts for gas transport through the Czech Republic. Two major capacity reservation contracts will terminate in early 2035 and 2039. The transport of pure hydrogen between Slovakia and Germany via the existing NET4GAS gas infrastructure could thus be implemented as early as 2035, after the necessary technical modifications to the various components of the network. Under certain circumstances, which still need to be analysed, this possibility would allow for hydrogen imports from e.g. Ukraine and North Africa, by connecting expected hydrogen sources in regions outside the EU to regions with expected hydrogen demand in the EU. In addition, the Gazela pipeline could provide an important transit link for transporting hydrogen between the northern and southern parts of Germany.

The various pre-planned specific goals for transport infrastructure readiness are listed in the **Task Cards**.

3.2.4 Specific goal 4: Progress in R&D and production of hydrogen technologies

Hydrogen production, use, transport and storage require the use of new technologies. While the basic technologies for hydrogen production and use are well known, they are relatively expensive and their cost will not decrease significantly until they are mass deployed. Also, it is expected that investment in further research and development will bring down the cost of these technologies.

If the strategic goal of **stimulating economic growth** is to be met, we must ensure that the production of these technologies also takes place in the Czech Republic and that it replaces productions that are associated with the use of fossil fuels, whose proportion in the economy will gradually decline. The production of advanced hydrogen technologies also requires extensive related research and development as well as the involvement of Czech companies and organisations in international cooperation.

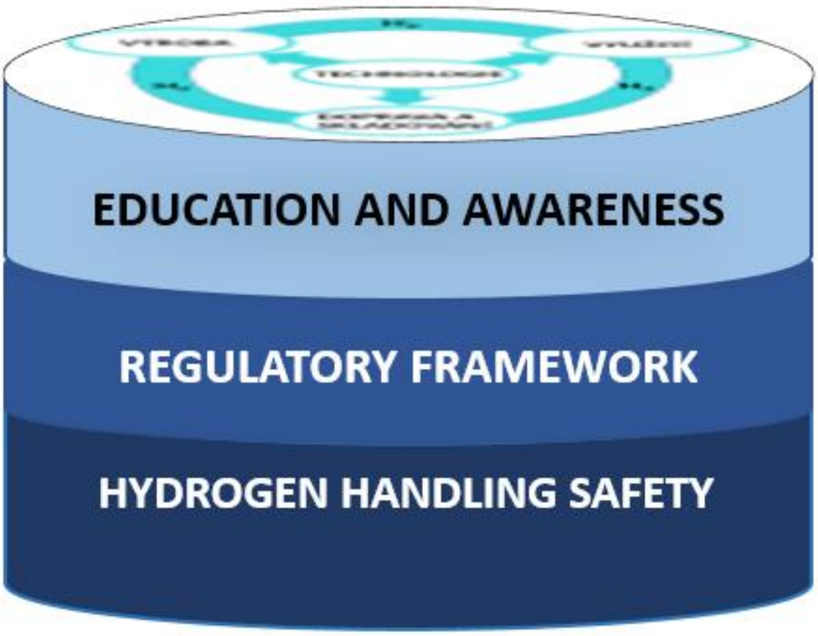
This specific goal is primarily about creating a conducive environment to support the creation of new companies and the transformation of existing ones so that they can become major players in hydrogen technologies. As mentioned above, the Czech Republic is not likely to become an exporter of low-carbon hydrogen, but it should become an exporter of hydrogen technologies. This is also why this Strategy places so much emphasis on hydrogen technologies.

Within this goal, we do not set specific target numbers of organisations in the field of hydrogen technology research, development, production and support for each year. The sub-goals are set out in the Task Cards. Here, the involvement of research teams from the different universities is expected.

3.3. Cross-cutting areas

In addition to the four main pillars underpinning the Hydrogen Strategy, it is important to highlight other cross-cutting areas that are important for supporting the Strategy. These cross-cutting areas cut across all pillars and create an environment for implementing the strategy. The success of the Strategy will depend on whether we have enough hydrogen experts, whether the overall regulatory environment makes it possible to develop these new technologies, and whether hydrogen technologies are perceived as safe by the general public.

The specific tasks for the cross-cutting areas are set out in the **Task Cards**.



3.3.1. Education and awareness raising

Hydrogen technologies are a modern and rapidly evolving field that will require many experts and workers at various levels with completely new skills. It is necessary to start training these experts and specialists. New hydrogen facilities need to be not only designed and manufactured, but it is also necessary to make sure they are serviced and maintained. It is essential to have experts for every stage of the hydrogen technology life cycle, otherwise we may reach a point where we have hydrogen vehicles but no one who is able to repair them. In this respect, adequate training also needs to be provided to actors who will come into contact with hydrogen technologies indirectly (the integrated rescue system).

It is necessary to introduce accredited study programmes in hydrogen technology and certification exams for hydrogen technicians. Hydrogen technologies need to be included in the curriculum of other fields of study that are only marginally related to hydrogen.

At the same time, it is also necessary to ensure that the general public has an understanding of hydrogen technologies. It is necessary to openly communicate all aspects of the new technologies and explain what makes hydrogen a convenient alternative to fossil fuels and what benefits it brings.

3.3.2. Regulatory framework

The regulatory framework establishes the ground rules of the environment in which the various organisations produce, plan and develop products or provide services. The correct set-up of this framework can support the development of efficient technologies and the functioning of the entire sector. The regulatory framework should be technology-neutral and it should make it possible to develop technologies based on their efficiency. Some regulatory rules must be based on the objectives that have been set pursuant to regulations and decisions of the European Commission. The introduction of the certification of origin (including functional inspection tools) will be particularly important for the application of low-carbon hydrogen. The international recognition of certificates of origin is essential for both hydrogen imports and exports. The regulatory framework must create a stable and predictable environment.

A substantial part of the regulatory framework is set by legislative measures that will be prepared and adopted pursuant to the **Task Cards** defined in this Strategy.

3.3.3. Hydrogen handling safety

Compared to other chemical production operations and the use of fossil fuels, the production and use of hydrogen does not represent a significant increase in risk to users. Its use also brings considerable advantages, because in the case of pure hydrogen the combustion gases and the fuel itself are completely non-toxic. Although there is experience with the use of hydrogen in gas mixtures (syngas and coal gas), the use of pure hydrogen is a new and, in some respects, different technology, which is always considered very sensitively by the population in terms of potential hazards. Therefore, it is necessary to make sure that all safety rules are strictly observed from the very beginning and, where relevant, to create new rules and to regularly assess whether any problems or accidents occur in connection with the use of hydrogen technologies. It is also necessary to openly inform the public about all aspects of hydrogen technology development.

Preventive training on how to deal with accidents concerning hydrogen technologies needs to be provided to employees, the police, firefighters and medical personnel. These technologies must become an integral part of occupational safety training.

The inclusion of safety as a separate cross-cutting area of the Hydrogen Strategy is an indicator of the importance given to safety and accident prevention. However, this section will be prepared in more detail in the future and it will address the statistics of possible accidents, fires and injuries in direct connection with the operation of hydrogen equipment. It will also include an indication of the improvement in the preventive preparedness of security and health personnel to successfully intervene in the event of such accidents or dangerous situations.

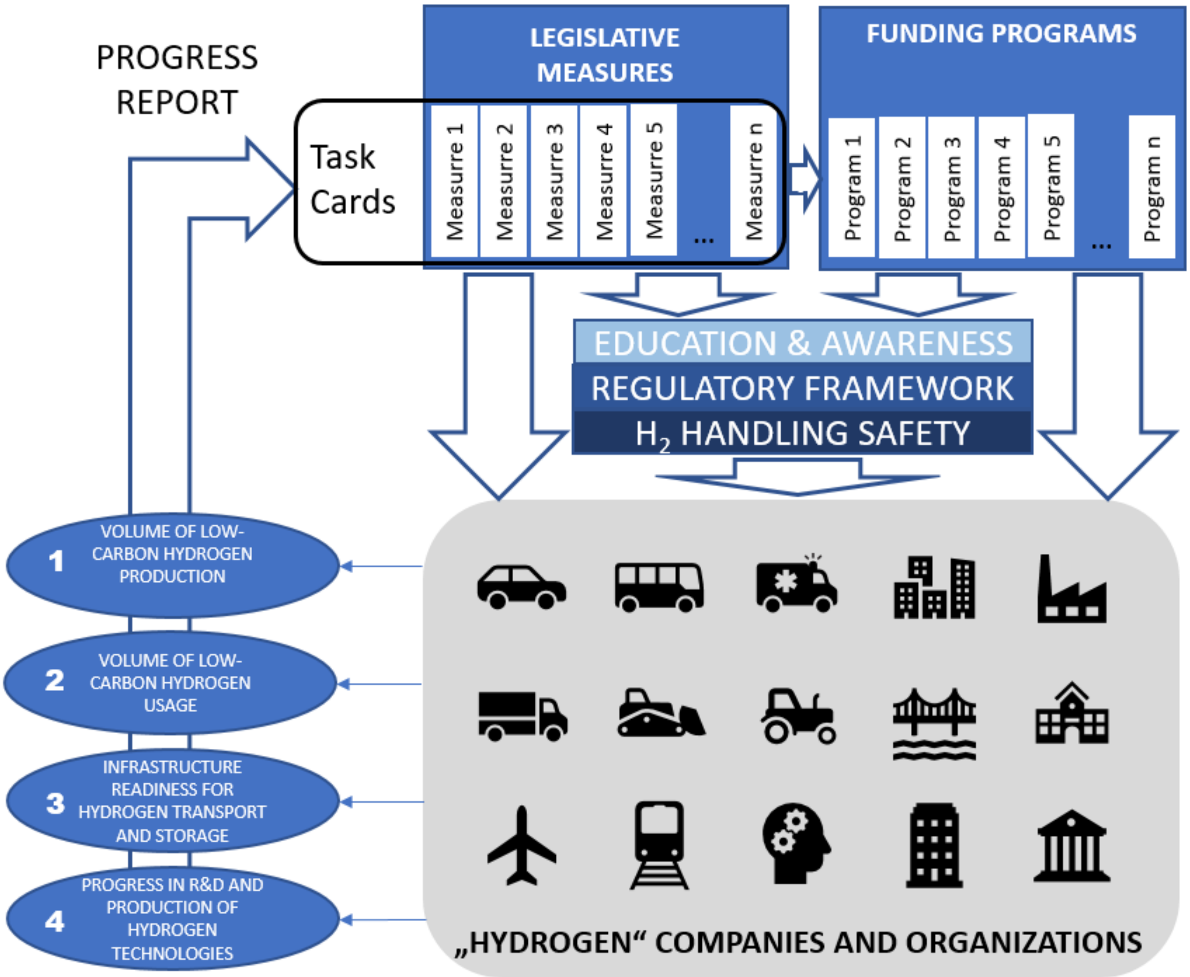
3.4. How to ensure the Hydrogen Strategy goals are accomplished

In order to promote the goals of the Hydrogen Strategy, we basically have only two types of tools that we can use to influence businesses, organisations and households:

- **Legislative and organisational measures** that define the framework in which the different businesses and organisations will operate. Such an environment must stimulate businesses and organisations to contribute to accomplishing the defined goals on their own. To support the goals of the Hydrogen Strategy, we will coordinate between this Strategy and related strategies (see Annex 6) and prepare decrees and laws that remove obstacles to implementing the Strategy (see Chapter 2.3). At the EU level, the Czech Republic aims to push for the necessary changes to EU legislation to be adopted as soon as possible so as to contribute to the development of all hydrogen technologies in line with this Strategy, and to advocate the creation of a single hydrogen market. Specific tasks to ensure legislative and organisational measures will be formulated on an ongoing basis in the Task Cards. Once the Hydrogen Strategy of the Czech Republic has been adopted by the government, the Task Cards will be further refined and specific tasks will be defined for them, including a timetable. Work on their implementation will start as soon as possible. A report on the progress of implementing these tasks will be prepared at least once a year and submitted to the Minister of Industry and Trade.

- **Support schemes** are defined schemes that direct money from the national and EU budgets to priority development areas. Support schemes are and must continue to be non-discriminatory and must allow open and equal access for businesses and organisations under clear rules so that there is competition between participants and so that the allocated financial resources are used as efficiently as possible. An overview of the different support schemes suitable for hydrogen technologies is provided in Annex 5. Where necessary, modifications to the various national schemes will be proposed in cooperation with the managers of these schemes, so that they can be effectively used to support hydrogen technologies under the rules of the scheme.

Businesses and organisations are independent entities that make decisions based on their own business strategies. Using legislative and organisational measures and support schemes, we need to create an environment that makes it convenient for them to pursue the goals of the Hydrogen Strategy as part of their own business objectives.



The individual measures that have been proposed in order to accomplish the goals defined in the Hydrogen Strategy are described in the Task Cards in Annex 8.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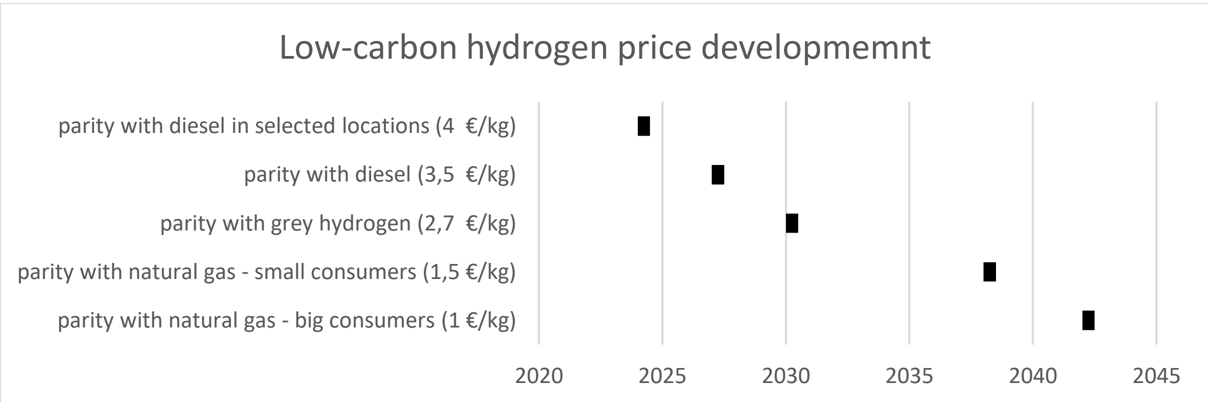
4 IMPLEMENTATION SECTION

4.1 Sequential steps by area of hydrogen use

The sequential steps are defined according to areas that are important in terms of greenhouse gas emissions and in which it is expected that the use of hydrogen can successfully contribute to reducing those emissions. Milestones (marked as "<>" in the graph description) have been set for each area, separating the different stages. The milestones are dependent on the cost and availability of low-carbon hydrogen, so their position on the timeline is merely an estimate and will be adjusted and refined as part of updates to the Hydrogen Strategy depending on actual price trends.

For hydrogen to be deployed efficiently, it is always necessary to reach the milestone where price parity with the fossil fuel being replaced is reached. The milestones are based on current prices, which may change by 2050. The price of fossil fuels may decrease, due to a decline in demand and their surplus in the market, or it may rise, due to the inclusion of a carbon tax or an equivalent of emission allowances. An early achievement of a price milestone will speed up hydrogen deployment in the given sector – this can occur either due to an increase in fossil fuel price (increased taxes and fees) or due to a decrease in the production price of low-carbon hydrogen (support for research, development and innovation, investment subsidies).

This chapter uses milestones that are based on the current prices of the fuels being replaced. Actually, the difference between the price of low-carbon hydrogen and the fuel being replaced is important and it must be close to zero when calculating operating costs. When setting the milestones, the trends in oil and natural gas prices cannot be determined and this Hydrogen Strategy is not able to influence them, although a gradual increase in these prices is likely to be expected. The milestone may thus be reached sooner. The goal of the Hydrogen Strategy is to identify and support technologies that will reduce the price of low-carbon hydrogen and, in turn, move the milestones (as shown below) further to the left. By contrast, if the price of hydrogen stagnates or even rises in the long term, it will be necessary to reassess these timetables and look for alternative solutions to achieve the emission targets defined.



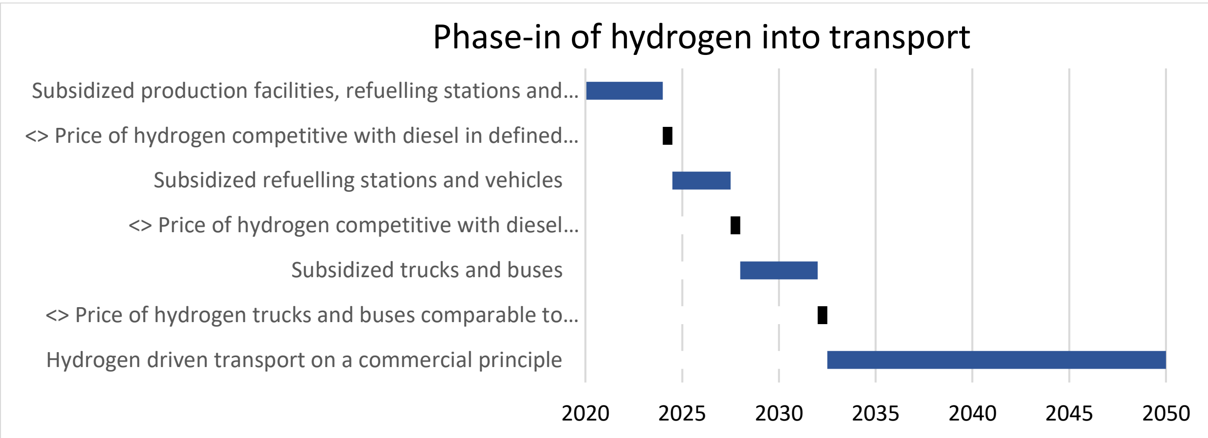
Note: "Hydrogen price parity with diesel in selected locations" means that hydrogen will only be used where it is produced, which will reduce the cost of transport and make it possible for price parity to be achieved earlier.

4.1.1 Transport (mobility) sector

The transport sector is a major contributor to greenhouse gas emissions and it is one of the very few sectors where these emissions are increasing. Hydrogen technologies make it possible to replace diesel and petrol even where the use of electric vehicles is very difficult, such as long-distance trucking. Due to the various taxes and charges that are currently imposed on fossil fuels in transport, it is possible to achieve price parity between low-carbon hydrogen and diesel at a higher hydrogen price that in the case of natural gas. The biggest constraints to the rapid deployment of hydrogen in transport are the high cost of fuel cell vehicles and the lacking infrastructure that will need to be newly built.

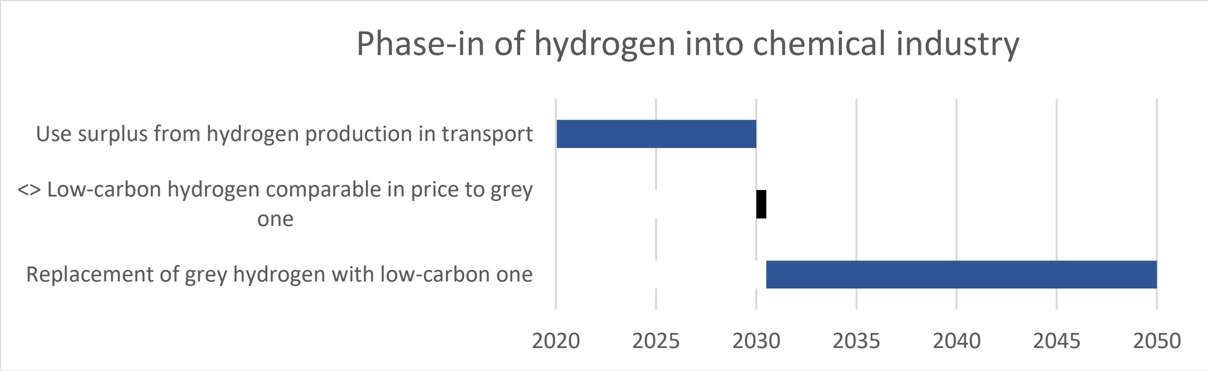
In terms of efficiency, it is advisable to use hydrogen technologies in city bus and freight transport, or railway transport, where it is possible to plan consumption relatively accurately and thus align it with hydrogen production. It is convenient to start developing hydrogen transport close to the points of hydrogen production, which will reduce the cost of transport. As the number of vehicles increases, their price will decrease. Of all the areas where hydrogen is used, transport has the best chance to reach economic sustainability where it will not need to be supported through subsidy programmes. At the same time, hydrogen transport can help eliminate a significant portion of greenhouse gas emissions.

The construction of filling station infrastructure needs to start as soon as possible in order to meet the ambitious hydrogen vehicle targets as set out in the National Action Plan for Clean Mobility.



4.1.2 Chemical industry sector

The chemical industry is currently the largest producer and consumer of hydrogen. In terms of technology, replacing grey hydrogen (which is produced from natural gas, oil or coal) with low-carbon hydrogen is easy because it means substituting one hydrogen for another. So this is merely a question of the price ratio between low-carbon and grey hydrogen. This difference is smaller than the price difference between low-carbon hydrogen and natural gas. This means that grey hydrogen, in its applications, could be replaced with low-carbon hydrogen earlier.



4.1.3 Iron and steel sector

In the iron and steel industry, hydrogen can be used not only as a fuel but also as a reducing agent for pig iron production, thus replacing coke which is currently used and which is the main contributor to CO_2 emissions. However, in order to fully replace coke, entirely new production technologies will be needed (these are still being developed and tested) to replace the blast furnaces that are currently used and where coke must be used. Two main scenarios for decarbonising iron and steel production are currently being considered. The first one will place emphasis on increasing the share of scrap iron melting, especially in electric arc furnaces, while the second one will mainly be about the use of hydrogen technologies. It can be expected that both technologies will be used in parallel, and the percentage of production will depend on many factors, including the physical availability and affordability of scrap iron, emission-free electricity and green hydrogen. In any case, the metallurgical industry will require its own low-carbon source that will be used to generate electricity or hydrogen. Another option is to convert some existing pipelines and import hydrogen from abroad, which could theoretically provide enough hydrogen for iron smelting. If it is decided to build powerful electrolysers or a hydrogen pipeline, such a hydrogen source could also benefit other sectors.

4.1.4 Electricity and heat production

Based on the analyses carried out, it turns out that the production of electricity and heat using hydrogen CHP cogeneration units will not happen in the near future due to the low economic efficiency. In technical terms, the process is well developed and can be relatively easily mass deployed. This block is included in the overview table in case the economic parameters change in the future and this hydrogen-consuming technology becomes more widely used.

4.1.5 Industrial sector (excluding the iron and steel and chemical industries)

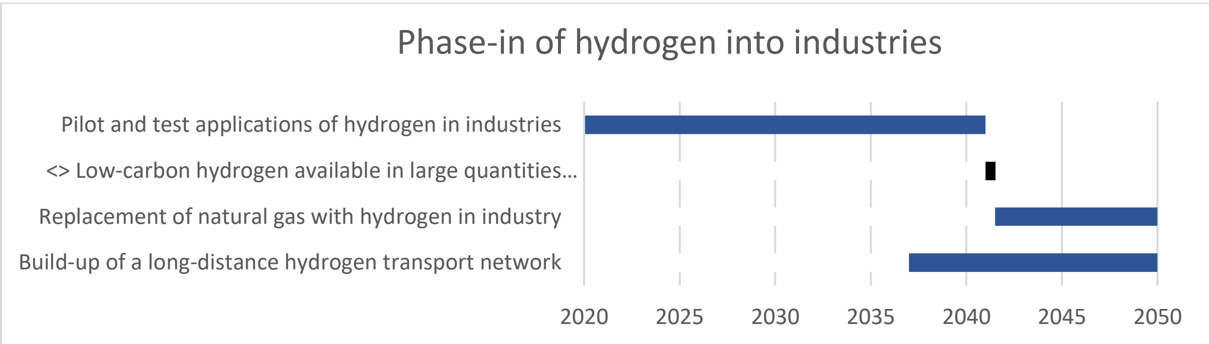
The situation in industry is probably the most complex, because in order to efficiently replace natural gas with hydrogen, the price of hydrogen needs to be close to the price of natural gas, and the price of natural gas for large consumers is lower than the price for households. This is therefore the lowest price that needs to be achieved for hydrogen. In the near term, achieving this parity is not realistic. Industry also requires large amounts of energy in many locations, which will be difficult to provide in the short term regardless of price. We will not be able to efficiently produce or purchase large quantities of low-carbon hydrogen and transport them to the point of consumption until after 2040.

In the industrial sector, it is advisable to first launch pilot projects in order to see what impacts hydrogen use can have on specific technological processes (the production of bricks, ceramics, glass, lime, cement, ...) and to test where locally produced hydrogen could be used (solar power plants and waste pyrolysis) to partially reduce the emission intensity while maintaining overall production efficiency.

For hydrogen to be massively used in industry, it will be necessary to modify the existing and possibly build a gas transport/distribution pipeline system that will make it possible for large hydrogen quantities to be transported cost effectively to the point of consumption via pipelines.

The energy-intensive industry will be extremely sensitive to trends in the prices of low-carbon hydrogen, natural gas and emission allowances. The ratio between these prices may shift the milestone for the transition from natural gas to hydrogen significantly, both towards the present and further into the future. A dramatic increase in the price of emission allowances could make the energy-intensive industry completely uncompetitive – it would cease to exist and relocate outside the EU.

The use of hydrogen in industry is conditional upon timely commissioning (i.e. modifying) the existing gas infrastructure and partially constructing a new hydrogen distribution network and connecting it to foreign hydrogen pipelines. Unless these pipelines are converted to be hydrogen-compatible or built in a timely manner, the transition will not be feasible even if low-carbon hydrogen becomes affordable. On the other hand, the conversion and construction of hydrogen distribution networks cannot begin until long-term commitments to hydrogen consumption, production and transport cost have been agreed.

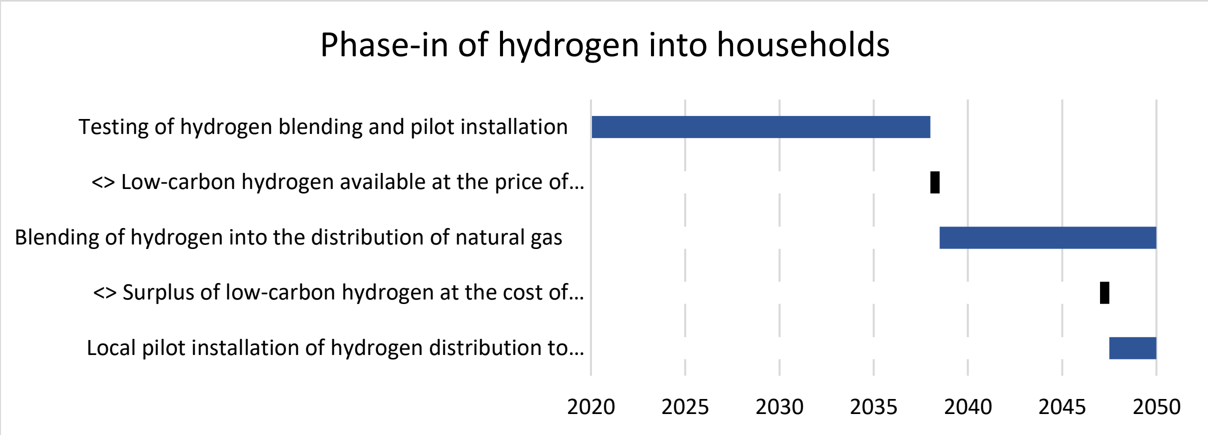


4.1.6 Households and other users

Households are major energy consumers and have a significant emission footprint, yet we have no easy way to transport hydrogen to them because the only usable supply pipes to homes are natural gas pipes. Reducing the emission-intensity of natural gas can be achieved by adding biomethane and low-carbon hydrogen. Based on the tests conducted to date, a maximum of 2% of hydrogen can be added without any need to modify the end equipment. Under well-defined conditions, higher proportions can be tested at the same time. Should this ratio increase, further testing would be required to verify that all end equipment is able to safely work with a higher hydrogen content.

Hydrogen injection into the natural gas transmission/distribution network is likely to occur when there is a surplus in hydrogen production for which there would be no other suitable use. A certain amount of hydrogen may be received in gas supplies from abroad, provided that it is technically feasible and standards and regulatory measures allow it. Intensive hydrogen blending with natural gas in order to reduce its emission-intensity is not likely to occur until the price of low-carbon hydrogen starts to decrease significantly relative to the current cost of its production and until it gets close to the sum of the price of natural gas and any carbon/environmental tax.

Once hydrogen is available in large quantities, at least in certain locations, at a price comparable to natural gas, it will be possible for household natural gas distribution to be completely converted to hydrogen. This must be preceded by the replacement of end equipment. If hydrogen was piped into homes, households could use it to generate heat and electricity in fuel cells, as long as this is economically viable, and this hydrogen would not have to be solely burned for heat. In the system transformation period, it will be imperative that all security aspects are taken into account.



4.2 Sequential steps according to time stages

In line with the European Hydrogen Strategy, we divide the steps into three stages:

- Stage 1: 2021–2025
- Stage 2: 2026–2030
- Stage 3: 2031–2050

4.2.1 Stage 1: 2021–2025

In this stage, there will be a clear focus on the use of hydrogen in transport. This is because transport is the first sector in which economic sustainability can be achieved. The main limitations are the price of low-carbon hydrogen, which is still high, and the high cost of hydrogen vehicles. In the initial phases, it is therefore advisable to create hydrogen mobility “islands” near hydrogen production sites in order to reduce the cost of transport. Due to the predicted and rapid increase in hydrogen consumption, it is advisable to start using hydrogen in local bus and freight transport. In order to achieve maximum hydrogen production efficiency, it is necessary to build large production capacities. Given the low number of hydrogen vehicles, it is unlikely that their full production can be used immediately. This production capacity should be put into operation in a way allows for any surplus hydrogen to be used in chemical production, which has a large absorption capacity and does not require large investments in technology change. When optimising the size of sources, the transport of hydrogen from the point of production to the point of consumption must be taken into account. Integrated projects, where hydrogen production and consumption are addressed together so that they are interlinked, will be the most appropriate for this stage.

The cost of hydrogen vehicles is a limiting factor for the use of hydrogen in transport, so in this stage and the next (at least until 2030), we should support the development and production of technologies for hydrogen mobility, the acquisition and operation of vehicles by operators of passenger transport services (public transport), state and local governments or business entities, and the construction of related filling infrastructure.

In stage 1, there will probably not be any pure hydrogen pipelines yet. Therefore, we need to test other methods of transporting hydrogen, e.g. transport in cylinders, transport of liquid hydrogen or hydrogen bound in organic compounds (LOHC = Liquid Organic Hydrogen Carriers) or hydrides. Each of these technologies is likely to find an area in which it will dominate.

Because of the transport costs, which further increase the price of hydrogen, we need to find ways to produce hydrogen close to the points of consumption. The use of renewable sources of electricity will play an important role in this stage. The pyrolytic decomposition of organic waste or natural gas could be a local source of low-carbon hydrogen, as long as the technological barriers are successfully overcome and the issue of accounting for the emissions associated with this production method is resolved.

At this stage, hydrogen injection into the natural gas system will also be tested, both at the end equipment and at the meters and other system components. While this injection cannot be implemented on a large scale for reasons of price, it is necessary to have practical experience with it, because natural gas with added hydrogen could be transmitted to the Czech Republic from abroad.

Another technology that warrants our attention in research and development is CO_2 capture and processing. If this technology is cost-effective, it could turn natural gas into a cheap, available and highly scalable source of low-carbon hydrogen until renewable hydrogen that is imported via pipelines becomes widely available. Even if CO_2 capture is taken care of, it is essential to find a suitable use for it, because our geological conditions only allow for a limited amount of CO_2 to be stored. Even if the carbon is captured in the form of solid soot, there is no suitable use for it yet in the quantities produced by fossil fuel combustion.

4.2.2 Stage 2: 2026–2030

In this stage, the operational verification of hydrogen use in industry could begin. The scale depends mainly on the success of the development of systems for the pyrolytic decomposition of organic waste and natural gas and the construction of large local solar or wind power plants connected to electrolysers and equipment for compressing or liquefying the hydrogen produced.

Based on the projections of future consumption and potential sources of low-carbon hydrogen, planning for the hydrogen transport and distribution method will also commence. It can be assumed that existing gas networks can be used to a large extent for the transport and distribution of hydrogen mixed with natural gas. In this period, we expect that it may be possible to start concluding contracts for the construction of any new hydrogen pipelines, or for the conversion of existing pipelines (repurposing or retrofitting) into hydrogen pipelines for both domestic transport and transit through the Czech Republic. Based on technological advancements, it will also be possible to continue discussions on the construction of new nuclear sources, potentially including small modular reactors that would use a larger portion of their output to produce low-carbon hydrogen.

In this phase at the latest, it will be necessary to start tests of supplying hydrogen to households.

Due to the energy requirements of industry and the lack of low-carbon sources of electricity, the Czech Republic will be a net importer of hydrogen, just as today it is an importer of natural gas and oil. To strengthen its position, the Czech Republic should participate in international projects for the construction of electrolysers and hydrogen transport routes. To reduce the emission intensity of households and industry, hydrogen will gradually start to be injected into natural gas in the gas system.

It is possible that, in the longer term, the Czech Republic will face a shortage of electricity. In such a case, it will not be practically possible to produce hydrogen from RES, because the energy from these sources will be primarily used to supply electricity. In addition, the requirements for grid electricity may also increase on the part of industrial companies that will be decarbonising their production. In that case, it will be difficult to produce hydrogen by electrolysis of water. Hydrogen will then be produced from other sources – that is why the strategy also considers other hydrogen production methods. Another alternative is to import hydrogen from abroad. If even imports are unable to meet domestic demand, the deployment of hydrogen in the various sectors would slow down.

In this stage, domestic mass production of vehicles could also begin, taking advantage of the growing demand in the Czech Republic.

4.2.3 Stage 3: 2031–2050

In this period, hydrogen-powered transport (mobility) should be able to operate without subsidies and gradually replace fossil fuel-based transport under economic rules. It is expected that there will be a relatively clear line between areas dominated by hydrogen and battery vehicles.

The construction and repurposing of hydrogen pipelines will begin, because large hydrogen producers and consumers will already be well established. The repurposing of existing infrastructure will make it possible for hydrogen to be transported and distributed in a relatively shorter period of time compared to the potential construction of new pipelines for pure hydrogen.

Following the subsidised pilot installations in phase 2, it will be possible to start the transition to commercial hydrogen use in industry, especially where sufficient quantities of affordable low-carbon hydrogen can be obtained locally. The true mass deployment of hydrogen technologies in industry will only be possible once a network of hydrogen pipelines has been constructed, which will supply us with cheap low-carbon hydrogen from abroad and allow for its distribution to the necessary locations.

In places with a powerful and cheap source of low-carbon hydrogen, it will be possible to start building pilot projects to convert households from natural gas to hydrogen. At the same time, local hydrogen distribution networks will be created.

4.3 Management structures

The development of hydrogen technologies and their introduction into practice is within the purview of the Ministry of Industry and Trade, under the responsibility of the **Minister of Industry and Trade**. The Minister has appointed the **Plenipotentiary of the Minister of Industry and Trade for Hydrogen Technologies** to coordinate the relevant activities, prepare and continuously update the **Hydrogen Strategy of the Czech Republic**, create the necessary management structures, cooperate with other organisations, state administration and local government bodies, the European Commission, and monitor the development of projects in the field of hydrogen technologies.

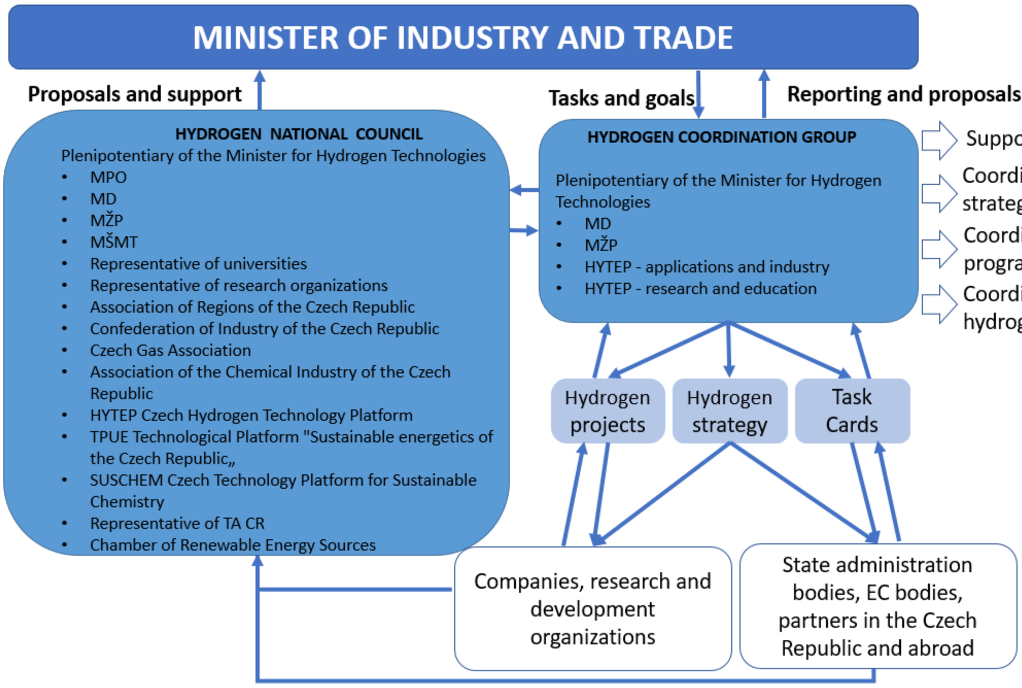
The Plenipotentiary of the Minister of Industry and Trade for Hydrogen Technologies receives tasks and main goals for the hydrogen technology area from the Minister of Industry and Trade and keeps the Minister updated by presenting regular reports on the implementation of the tasks and goals and the implementation of the Hydrogen Strategy, and submits proposals and recommendations in the hydrogen technology area.

The Plenipotentiary of the Minister of Industry and Trade for Hydrogen Technologies manages the **Hydrogen Coordination Group** that consists of representatives of the Ministry of Transport, Ministry of the Environment, a HYTEP (Czech Hydrogen Technology Platform) representative for applications and industry and a HYTEP representative for research and education. The Plenipotentiary works in close coordination with other organisational units of the MIT.

The main responsibilities of the Hydrogen Coordination Group are:

- Proposing updates to the **Hydrogen Strategy of the Czech Republic**
- Updating and monitoring the implementation of the **Task Cards** that are based on the Hydrogen Strategy of the Czech Republic
- Monitoring the portfolio of **Hydrogen Projects**
- **Monitoring the implementation of the goals** of the Hydrogen Strategy of the Czech Republic

Also, the Hydrogen Coordination Group provides support in the hydrogen technology area to other ministries, state administration and local government bodies. It coordinates other strategies and plans that are related to hydrogen technologies and are described in the Hydrogen Strategy of the Czech Republic. It coordinates with the relevant administrators of the subsidy schemes on the focus of these schemes so that they are in line with the goals set out in the Hydrogen Strategy of the Czech Republic. Together with the different regions that develop their own hydrogen strategies, it ensures that the regional hydrogen strategies are in line with the Hydrogen Strategy of the Czech Republic. It submits to the Minister of Industry and Trade and the Hydrogen National Council regular reports on the fulfilment of the goals of the Hydrogen Strategy of the Czech Republic, a report on the alignment of strategic documents and a report on the status of the implementation of the Task Cards.



The Hydrogen National Council acts as an advisory body to the Minister of Industry and Trade on hydrogen technologies and it usually meets once a year. It proposes and approves changes to the Hydrogen Strategy of the Czech Republic and the Task Cards. It is kept informed about trends and developments in the area of hydrogen projects and it prepares suggestions and recommendations for the Minister of Industry and Trade. The Hydrogen National Council is composed of nominated representatives of:

- Ministry of Industry and Trade
- Ministry of Transport
- Ministry of the Environment
- Ministry of Education, Youth and Sports
- Universities that are active in the field of hydrogen technologies
- Research organisations that are active in the field of hydrogen technologies
- Association of Regions of the Czech Republic
- Confederation of Industry of the Czech Republic
- Czech Gas Association
- Association of Chemical Industry of the Czech Republic
- HYTEP Czech Hydrogen Technology Platform
- TPUE Technological Platform “Sustainable energetics of the Czech Republic”
- SUSCHEM Czech Technology Platform for Sustainable Chemistry
- Technology Agency of the Czech Republic
- Chamber of Renewable Energy Sources

The Hydrogen National Council is chaired by the Plenipotentiary of the Minister of Industry and Trade for Hydrogen Technologies.

5 THE STRATEGY DEVELOPMENT PROCESS

This Hydrogen Strategy was prepared by the Ministry of Industry and Trade in close cooperation with and using materials and studies previously prepared by:

- HYTEP – Czech Hydrogen Technology Platform
- Ministry of Transport

The Strategy was consulted with:

- Ministry of the Environment
- Ministry of Education, Youth and Sports
- Ministry of Regional Development
- Office of the Government of the Czech Republic
- Permanent Representation of the Czech Republic to the European Union
- State Environmental Fund
- Technology Agency of the Czech Republic
- Energy Regulatory Office
- Office for the Protection of Competition
- Chamber of Commerce of the Czech Republic
- Confederation of Industry of the Czech Republic
- Association of Chemical Industry of the Czech Republic
- Czech Gas Association
- Steel Union
- TPUE Technological Platform "Sustainable energetics of the Czech Republic"
- SUSCHEM Czech Technology Platform for Sustainable Chemistry
- Automotive Industry Association (AIA CR)
- ČESMAD BOHEMIA
- ČAPPO
- University of Chemistry and Technology, Prague
- Czech Technical University in Prague
- VSB – Technical University of Ostrava
- Jan Evangelista Purkyně University in Ústí nad Labem
- Association of Regions of the Czech Republic
- Ústí nad Labem Region
- Moravian-Silesian Region
- Prague Capital City
- Czech-Moravian Confederation of Trade Unions
- Association of Independent Trade Unions
- ECHO Trade Union
- Confederation of Employers' and Entrepreneurs' Unions of the Czech Republic
- Economic and Social Council of the Ústí nad Labem Region

ANNEXES:

1. Hydrogen Production
2. Hydrogen Transport and Storage
3. Hydrogen Use
4. Hydrogen Technologies
5. Support Options
6. Related Strategies and Plans
7. Constants and Formulas Used in Calculations
8. Task Cards

1 HYDROGEN PRODUCTION

This annex shows different options for hydrogen production. The potential of these options is compared in terms of potential production capacity in the Czech Republic, the price of the produced hydrogen, technological constraints, and the readiness of the technology.

The aim is to identify approaches that represent a cost-effective way of reducing greenhouse gas emissions at any given time and to develop a system that will enable regular updates being made to this list based on the latest technological and economic developments. A simple SWOT analysis has been made for each technology. Bubble charts were created based on the SWOT analyses. They compare the selected technologies with each other in terms of:

- **technological readiness (x-axis)**, to what extent a given technology is already established on the market and how widely it is used (0 – lowest readiness, 11 – highest readiness); technological readiness refers to the current situation and position of the technology in the world (the level of technological readiness in the Czech Republic may be lower);
- **economic viability (y-axis)**, which is an assessment of the current cost-effectiveness together with the estimated future economic viability of the technology (0 – lowest viability, 10 – highest viability);
- **the potential of the technology (the size of the bubble)**, how much hydrogen or what size market the technology may concern. The bubble size captures the maximum potential from now until 2050. This means that for technologies with growth potential, the bubbles in the chart will reflect the maximum size that they can reach in 2050. Conversely, the bubble size for technologies that are expected to decline will correspond to today's state.

To assess technology readiness, we use the Technology Readiness Level (TRL) scale as defined by the International Energy Agency (IEA). It uses the following levels:

1. **Initial idea:** basic principles have been defined
2. **Applications defined:** the concept and the application of the solution have been formulated
3. **The concept requires validation**: the solution needs a prototype and application in practice
4. **Early prototype**: prototype proven in test conditions
5. **A large-scale prototype**: components proven in conditions to be deployed
6. **Full prototype at scale**: prototype proven at scale in conditions to be deployed
7. **Pre-commercial demonstration**: solution working in expected conditions
8. **First-of-a-kind commercial**: commercial demonstration: full-scale deployment in final form
9. **Commercial operation in relevant environment**: solution is commercially available, needs evolutionary improvement to stay competitive
10. **Integration at scale:** solution is commercial but needs further integration efforts
11. **Proof of stability:** predictable growth

This means that the promising technologies are in the top right corner of the chart.

The bubble charts are not based on absolute numbers, but compare the different technologies in the chart with each other.

The annexes on hydrogen use, transport and storage, and hydrogen technologies are structured in the same way.

By far the largest volume of hydrogen production in the Czech Republic is currently extracted from petroleum fractions, a method that creates a large carbon footprint. For the time being, this method also shows certain economic viability. However, this is limited by the gradually increasing price of emission allowances and administrative measures to the detriment of the combustion of carbon compounds. It is obvious that if this technology is to be used in the future, it will have to be combined with one of the mitigation processes – CO_2 capture and storage (CCS) or CO2 capture and utilisation (CCU). Efficient and cheap technologies for CCS are not yet available, and the Czech Republic does not have suitable geological conditions ready for massive CO_2 storage. CCU is even less technologically mature.

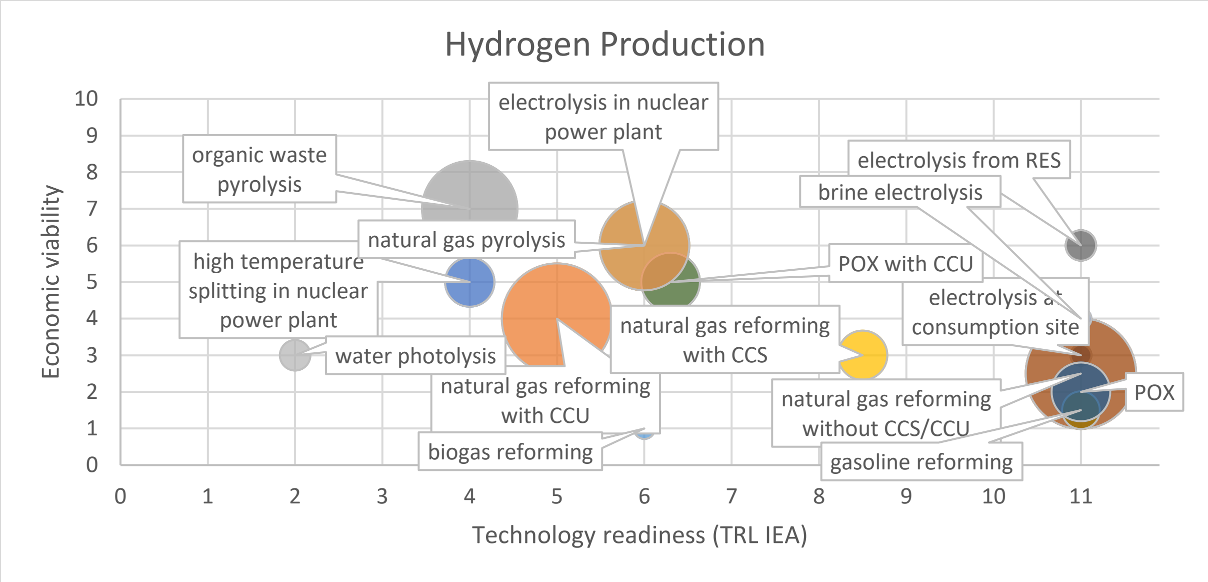
Under Czech conditions, in which the share of waste incineration plants remains low and the rate of waste energy recovery is very low, hydrogen, as one of the products of the pyrolytic splitting of waste containing hydrocarbons, may also play a role. However, the technology is still hampered both by the purity of the end product and by the amount of other waste by-products that such production generates.

Thanks to its energy mix, the Czech Republic may consider hydrogen production close to nuclear power plants and potentially in the future, also next to small modular reactors, which would bring the advantage of hydrogen production by electrolysis near the source of energy and would store surplus energy in hydrogen during times of overproduction from RES. High-temperature water splitting based on high-temperature reactors appears to be promising but is still only in the research and development phase.

In the future, another way of producing low-carbon hydrogen, namely pyrolysis production from natural gas, might also be envisaged. Within this process, natural gas is directly decarbonised. Hydrogen can be produced directly at the point of consumption if natural gas is available. The resulting solid-phase carbon could be further processed or stored.

Over time, most producers will probably choose hydrogen production via electrolysers. However, it is questionable whether the high investment costs would be acceptable for certain industries. In principle, there are two possible ways: production close to energy sources (RES, nuclear, etc.) or production from electricity at the point of consumption. The economics of transporting hydrogen compared to the cost of "transporting" electricity (distribution charges) will play a role.

Another potentially promising method is the production of hydrogen from biogas.



1.1. Production by electrolysis

Production by electrolysis is one of the methods that has been implemented rather sporadically in the Czech Republic thus far, mostly as a by-product of chlor-alkali production in the chemical industry. Given the energy mix in the Czech Republic, hydrogen produced in this manner has a high carbon footprint. However, several European countries are planning to develop hydrogen production by electrolysis. This will start to make sense after the share of low-carbon sources has significantly increased.

In this case, on-site production from low-carbon sources or on-site production at the point of consumption should be considered.

In addition to energy requirements (55 kWh/kg), high-purity water with a volume of 9 litres/kg H_2 is required for production. The presence of a water source may be limiting from the local point of view, but the total amount of water consumption for hydrogen production will have a negligible impact on the water balance in the country.

Alkaline water electrolysis is industrially well mastered, cheap and relatively easy as it takes place at low temperatures, but with lower efficiency and little flexibility.

On the other hand, a polymer electrolyte membrane is more efficient, but the electrolysers used for this purpose contain precious metals, which means they are expensive.

High-temperature water electrolysis, sometimes referred to as steam electrolysis, is characterised by the fact that part of the energy supplied is electrical energy and part is supplied as heat. The reaction that takes place in a high-temperature electrolyser is reverse compared to the reaction that takes place in solid oxide fuel cells. Steam and water enter the electrolyser. An enriched mixture containing 75% hydrogen and 25% steam by weight is discharged. From this, an oxygen ion is separated and passes through the membrane. The hydrogen is then separated from the steam in a condensing unit. While at 100 °C, 207 MJ are required for electrolysis to produce 1 kg of hydrogen; at 850 °C, only 133 MJ are required to produce the same amount of hydrogen.

1.1.1 Electricity from renewable sources

The feasibility of producing hydrogen from renewable sources and the economics of such production depend on a number of factors that have not yet been finalised.

Production on islands is without any technical or legislative constraints, as e electrolysers are directly connected to solar or wind power plants. In this case, we only have to deal with the economics of operation where the requirement for high electrolyser utilisation and the available time of electricity supply from renewable sources are in conflict. Hydrogen compression and storage facilities must be located behind the electrolysers, which further increases the cost of the hydrogen produced.

However, it is important to keep in mind the physical reality, i.e. that the efficiency of the electricity-hydrogen-electricity chain is relatively low.

It is also possible to build solar parks that would be simultaneously connected to both the electricity distribution network and to electrolysers. Surplus electricity that cannot be used on the network would be used to produce hydrogen. This solution is used, for example, in the pilot project implemented by E. ON, Salzgitter AG, and Linde.

Another option is to build electrolysers at the point of consumption. These will produce hydrogen on demand from renewable electricity supplied by the distribution network. In this case, we face legislative and economic constraints. Regulated prices and charges applied to use the electricity system substantially increase the price of electricity. At the moment, the market for certificates of origin is not fully operational. It is also unclear, given the negotiations taking place at the Commission level, whether the renewable electricity transmitted through the electricity system can be used to produce hydrogen. This is referred to as the principle of additionality, where only new dedicated renewable energy sources can be used for hydrogen production. These possible future legislative restrictions must be taken into account when assessing renewable sources for hydrogen production.

The production of green hydrogen from surplus electricity produced from renewable energy sources and its use will be a key element in decarbonising electricity production and consumption, industry and transport.

STRENGTHS	**WEAKNESSES**
• Inevitable RES development, meeting 2030 and 2050 emission targets • Preparing infrastructure for a period when demand for green hydrogen will increase and the price will decrease • This area is massively supported by the EU	• A lower RES potential in the Czech Republic compared to countries with significantly more hours of sunlight and/or countries with greater wind intensity • The cost of addressing the instability and seasonality of production • Expensive electrolysers – high fixed costs – initially more feasible for larger units • A low utilization of electrolysers depending on limited sunlight hours • Transport costs

	• Distance between sources and points of consumption – the need to transport hydrogen. Also, ECHA recommends installing electrolysers near wind farms, etc. • A missing certification mechanism for green hydrogen • Water demand at the production site
OPPORTUNITIES • Further increases in electrolysis efficiency are expected. • The use of high-purity oxygen as a by-product • Increasing the efficiency of photovoltaic panels to their physical limits • Over the long term, a decrease in production costs of electricity from RES, especially photovoltaic and wind power plants, is expected.	**THREATS** • A possible stagnation of RES prices, a lack of space for their installation, specifically in the Czech Republic

1.1.2. Electricity production at the point of consumption

Taking into account the costs and problems associated with transport, it seems advantageous to produce hydrogen as close to the point of consumption as possible. The following subsections show where this solution is actually possible and where it is not. An alternative solution would mean installing RES sources in the immediate vicinity of the filling stations or the relevant facility, which would not be feasible in practice under Czech conditions.

Certified renewable energy is required to produce low-carbon hydrogen from RES. The carbon footprint of hydrogen produced by electrolysis using grid electricity is determined by the national energy mix. Currently, hydrogen produced in this way in the Czech Republic cannot be considered low carbon.

STRENGTHS	**WEAKNESSES**
• Direct production at the point of consumption eliminates the cost of building distribution lines • Minimisation of hydrogen leaks and the resulting increased safety	• High-carbon footprint corresponds to the energy mix of the Czech Republic • Costs associated with strengthening the transmission network or the need to build RES sources in close proximity to electrolysers •
OPPORTUNITIES • Decentralisation and local independence	**THREATS** • A significant loss of area for RES in the vicinity of consumption points

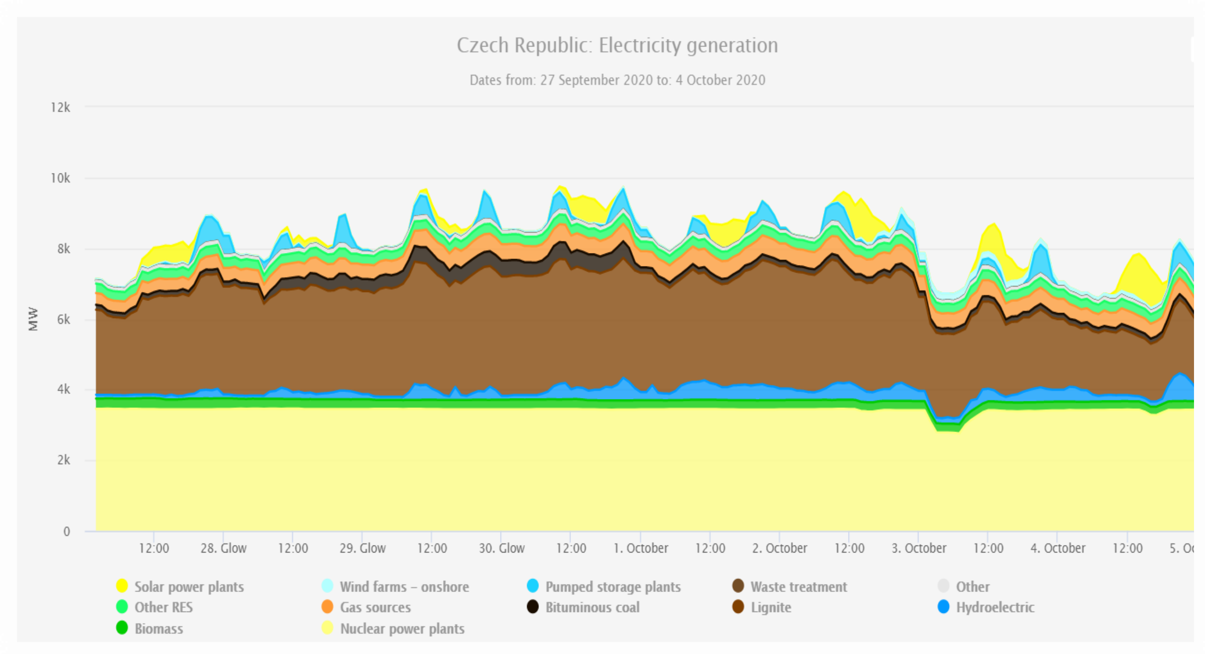
1.2. Production using electricity from nuclear powerplants

1.2.1. Electrolysis

Hydrogen technologies are being developed as one of the tools for storing surplus renewable energy that cannot be applied to the network at any given time. In the Czech Republic, we do not have to deal with this issue yet because the share of intermittent RES in the system is not high enough yet. As the installed capacity of RES increases, it may also be problematic to utilise all the energy produced from it. In order to ensure a secure energy supply, it is essential to have significant capacity installed and available even for sources that increase their output very quickly when the sun is not shining or the wind is not blowing. This can be done either by gas-fired power stations, where the output can be quickly increased, or by nuclear sources that can operate in steady-state mode and use the surplus energy to produce hydrogen. It is much more efficient to build large electrolysers and hydrogen storage facilities in one location near a nuclear power plant than to have them distributed among several small renewable energy sources. However, the necessity to transport hydrogen to the point of consumption must also be considered. As thermal power plants are being decommissioned and the output of intermittent sources has been growing, it will become increasingly necessary not to utilise renewable energy or to regulate the output of nuclear power plants, see the figure below. Hydrogen production from surplus energy could be a suitable alternative. Electrolysers are able to change their output very dynamically.

The electrolysis can be either low- or high-temperature and the energy source can be either a standard reactor or a small modular reactor (SMR). For example, NuScale's SMR project is considering high-temperature water electrolysis, assuming a process steam temperature of 850 °C in the high temperature electrolyser and steam production for one 250 MWt module of about 50 t per day.

During the transition period when there is an insufficient amount of electricity generated from RES, electrolysers can help operate the electricity system by providing support services and help optimise the operating regime of fossil resources, while balancing fluctuations in consumption. At the same time, this will also improve the operating parameters of the electrolysers in terms of their time of use.



STRENGTHS	WEAKNESSES
• Hydrogen produced in this way has a very low carbon footprint, comparable to RES • Hydrogen production and storage can be easily centralised • In the future, the use of smaller modular reactors with optimum performance is also potentially possible • It is possible to use large electrolysers and scale them well according to the surplus energy in the power plant • Hydrogen production can easily cover surplus electricity generation from renewable sources • An electrolyser can be connected to virtually any source via a high-capacity line to the nuclear power plant	• Possible problems with the certification of hydrogen produced in nuclear power plants as "pure" hydrogen • The question of legal regulations for placing other facilities near a nuclear power plant from a safety perspective • Today, the planned capacities for the construction of new nuclear power plants only serves to replace decommissioned units. • Production economics, taking into account guaranteed electricity prices • Transport of the produced hydrogen to the point of consumption, i.e. higher costs and the need to have available infrastructure in place •
OPPORTUNITIES	**THREATS**
• The Czech Republic wants to continue to use nuclear energy in the future, which creates a competitive advantage over countries without nuclear power • Combining intermittent renewable energy sources with nuclear power plants with a constant output and hydrogen production can create a very efficient and stable system	• Political and regulatory risks at the national and EU levels

1.2.2. High Temperature Splitting

At very high temperatures over 2000°C that can be reached in a nuclear power plant, thermal splitting of water must be considered. At these temperatures, a small fraction (around 3%) is dissociated and hydrogen molecules are produced among other products. At temperatures of around 3000 °C, this can affect up to one-half the mass. These temperatures can be achieved, for example, in a nuclear power plant, but also by concentrating sunlight using spherical mirrors.

STRENGTHS	**WEAKNESSES**
• A very effective solution for nuclear power plants • Utilisation of excess heat	• A source of very high temperatures and the associated materials and design requirements are needed • A low hydrogen-to-water ratio
OPPORTUNITIES	**THREATS**
• The Czech Republic wants to continue to use nuclear energy in the future, which creates a competitive advantage over countries without nuclear power	• Development of other solutions

1.3. Production from natural gas

1.3.1. Thermal gasification – use of biogas/biomethane

Biomass is convertible into other products, including hydrogen, using thermochemical reactions at temperatures ranging from 200-3000 °C. This mainly involves biomass pyrolysis, which produces gaseous products such as methane, hydrogen and carbon monoxide. However, it is possible to reform existing biogas from anaerobic digestion or biomethane generated through biogas upgrading. In practice, the addition of a large amount of water vapour is used to achieve the desired degree of conversion, allowing for operation at pressures up to 4 MPa. The waste products of this process are carbon dioxide and carbon monoxide. In practice, this method is used very scarcely and its potential is likely to be limited

STRENGTHS	**WEAKNESSES**
• The production of biogas/biomethane, together with other recoverable gases, is an efficient way of using biomass that would be waste in nature • Transporting biogas/biomethane is easier than transporting hydrogen • The possibility to produce hydrogen at the point of consumption	• Biogas stations are usually not located at the point of consumption. • The cost of further synthesis and gas processing has been and is likely to remain high.
OPPORTUNITIES	**THREATS**
• An economically viable source of hydrogen that can be produced in a decentralised manner	• Usually the need for shipping with the associated charges and risks. • It is necessary to compare when it is appropriate to use biogas/biomethane

	directly and when hydrogen produced from biogas/biomethane is better

1.3.2. Using natural gas without CCS/CCU

Hydrogen production by steam reforming natural gas is currently the cheapest and most widespread method of hydrogen production worldwide. The heat for the reforming reaction and the subsequent conversion of carbon monoxide is supplied from the direct combustion of a portion of the natural gas.

Although this method of hydrogen production is burdened by the carbon footprint of natural gas, due to the energy mix of the Czech Republic, this carbon footprint is lower than the carbon footprint of hydrogen produced by electrolysis from grid electricity.

In this way, it is possible to produce hydrogen directly at the point of consumption as long as natural gas and water are connected. Small reforming units exist that can be connected to the natural gas supply at the inlet and produce hydrogen at the outlet.

If biomethane is added to the natural gas system and transported to the point of consumption where it is processed into hydrogen by steam reforming, such hydrogen is considered renewable, provided that certificates of origin exist for the biomethane. If such biomethane is converted into hydrogen via CCS/CCU, negative CO_2 emissions can be accounted for.

STRENGTHS	**WEAKNESSES**
• Use of existing infrastructure • A simple solution for the transition period • Hydrogen can be used directly at the point of consumption if natural gas is supplied	• A high-carbon footprint
OPPORTUNITIES	**THREATS**
• The cheapest method of hydrogen production	• Hydrogen produced it this manner cannot be described as low-carbon

1.3.3. The use of natural gas with CCS

Currently, natural gas and oil deposits, salt caverns and other geologically suitable environments are used for storage. According to the IEA, the SMR and CCS technology based on separation processes alone increases natural gas consumption by 10% and economic costs by 50%. One of the main factors is the availability of sites for CO_2 storage. Unfortunately, in the Czech Republic, suitable sites are already used to store natural gas reserves and their conversion to CO_2 storage is not a realistic option. The total potential for underground storage with suitable parameters can only be estimated at 850 million tonnes of CO_2. Building CO_2 pipelines over long distances is completely unrealistic due to economic reasons. CCS methods can take advantage of being near oil fields where inert gas needs to be injected underground to increase the yield of the field.

STRENGTHS	WEAKNESSES
• A low CO_2 balance	• A lack of experience with this technology in the Central European region, especially in the Czech Republic • High CO_2 storage costs • Transport of captured CO_2 on a larger scale is not realistic in the Czech Republic; at the same time there are probably not enough suitable sites for CO_2 storage near hydrogen production sites • Low capture efficiency
OPPORTUNITIES	**THREATS**
• For the transient period, it can provide a simpler option with an acceptable carbon footprint	• Security aspects of the technology

1.3.4. The use of natural gas with CCU

Compared to the previous technology, it also counts on using the CO_2 recovered in other processes. The production of urea, its use in agriculture and possibly during the production of methanol may be a relevant technology for the Czech Republic. However, even this option does not seem to sufficiently utilise the size of sales for decarbonisation of current production.

STRENGTHS	WEAKNESSES
• A low CO_2 balance • In addition, use of the captured CO_2	• Very high costs (especially the initial investment) • Low capture efficiency
OPPORTUNITIES	**THREATS**
• For the transient period, this option is being considered by some other countries on their way to meeting climate targets. There might be room for cooperation.	• Security aspects of the technology • Demand for unutilised CO_2 is likely to fall over the mid term

1.4. Hydrogen production by pyrolysis or plasma gasification of waste

The Czech Republic is a country with a high rate of landfilling and a low rate of energy recovery from waste. From this point of view, hydrogen production from certain waste types is a reasonable alternative. So far, there has been minimal experience and it is theoretically possible to apply several different technologies, the economic viability of each of them being decisive. However, experience has been increasing and Hydrogen Europe estimates that the technology will be developed within five years.

Smaller scale projects use pyrolysis technology at temperatures up to 1000 °C or plasma gasification technology at temperatures up to 3500 °C. Multiple gases (hydrogen, nitrogen, carbon dioxide, carbon monoxide, methane, or oxygen) are produced at the output. The hydrogen is separated in the next stage.

STRENGTHS	**WEAKNESSES**
• Zero or negative price of waste as a raw material • A high surplus of waste in the Czech Republic	• Little experience • Other waste substances to be recovered (solid, gaseous, and liquid) • Carbon remains in many waste products
OPPORTUNITIES	**THREATS**
• Preferably combine the issues of a circular economy and RES • A very comprehensive approach can eventually solve the problem of landfilling, the need for solid products, etc.	• Faster development of other thermal waste treatment technologies • A loss of outlets for by-products

1.5. The use of photochemical or photo-electrochemical technology (activation by sunlight)

It involves hydrogen production by direct water photolysis using highly efficient and sunlight-absorbing substrates with an overall solar energy conversion yield of more than 14%. This value corresponds to a commercially and technically acceptable rate of mass production via this process. An advantage is the introduction of photo-electrochemical processes and the development of materials that are free of precious metals and at the same time capable of achieving at least 90% efficiency in water splitting with the simultaneous application of electro- and photoactivation.

STRENGTHS	**WEAKNESSES**
• No other source of energy except sunlight needed • A low photolysis temperature • Replacing precious metals with cheaper ones. The amounts of precious metals (Pt, Pd, etc.) needed to prepare substrates for water splitting are not as high. These metals can be replaced by cheaper, more accessible ones, such as Al and Zn • Low water purity requirements, unlike electrolysis	• Very little experience - only experimental use • Restricted by sunlight • Relatively low production intensity
OPPORTUNITIES	**THREATS**
• A combination of photo- and electrolysis	• Faster development of other technologies

1.6. Pyrolytic production of hydrogen from natural gas

Another way of producing low-carbon hydrogen is through pyrolysis from natural gas. This means the direct decarbonisation of natural gas where pyrolysis produces hydrogen and solid carbon ($CH_4 \rightarrow C + 2H_2$). Depending on the type of pyrolysis, temperatures ranging from about 800 to more than 1000 °C are required for efficient methane conversion. The separated solid carbon can then be stored or used. The storage and transport of solid carbon is simpler from the technological perspective than the handling of gaseous CO_2. The storage of solid carbon will not be so easy either if larger quantities are involved. Solid carbon is normally used as a tyre filler or as a landscaping filler. A comprehensive solution to the use of solid carbon is unlikely to be feasible until the technology has been further developed. The existence of large amounts of "waste" carbon will stimulate the search for ways to use it efficiently.

There are currently no large commercially operated projects. Experience with hydrogen production using the natural gas pyrolysis technology is limited at the present, but some major natural gas producers and academic institutions are very focused on researching and developing this technology. This technology can produce hydrogen directly at the point of consumption if natural gas is available. In the case of the Czech Republic, with limited potential for domestic renewable hydrogen production, there is space for hydrogen production from available natural gas.

STRENGTHS	WEAKNESSES
• Natural gas availability • The formation of solid carbon, which is easier to handle than gaseous CO_2 • No need to deal with CO_2 capture and transport • No water source is required for production (unlike electrolysis) • Lower input energy requirement for production compared to electrolysis and steam reforming of natural gas	• Limited experience with the technology so far • A waste substance (solid carbon) is generated which must be stored or used
OPPORTUNITIES	**THREATS**
• It can supplement the production of renewable hydrogen which may not be sufficient in the Czech Republic/EU due to the high expected demand • Future potential for transporting purified hydrogen produced by current natural gas suppliers • The utilisation of waste material as input for further industrial use	• Faster development of other technologies

1.7. Hydrogen production by partial oxidation of petroleum residues (POX)

In the Czech Republic, this technology currently accounts for the largest volume of hydrogen production. It is a technology that has been applied for years and is technically 100% mastered. The main disadvantage is the high emission footprint– 125 g CO_2 /MJ. The main purpose of this production is consumption in the chemical industry, which means no significant surpluses can be assumed for further use.

STRENGTHS	WEAKNESSES
• An established technology	• The very high emission footprint that can only be reduced by additional CCS/U technologies • A need for additional purification
OPPORTUNITIES	**THREATS**
• The use of existing technological units	• The cost of CO_2 elimination

1.8. Hydrogen production by partial oxidation of petroleum residues (POX) using CCU

The high carbon footprint of POX technology could be offset by the CCU mechanism. Capture and partial utilisation of the captured CO_2 is already taking place. There has been an ongoing search for ways to increase the CO_2 capture and to find uses for the captured CO_2 directly in chemical production.

STRENGTHS	WEAKNESSES
• A low CO_2 balance • The utilisation of captured CO_2	• High costs (especially the initial investment) • The necessity to find an efficient use of captured CO_2
OPPORTUNITIES	**THREATS**
• An opportunity to extend the life of the existing technology that is already in place and to recover waste CO_2	• Demand for unutilised CO_2 is likely to fall over the mid term

1.9. Hydrogen production by gasoline reforming

This proven and stable technology generates hydrogen with a high emission footprint in several industrial plants in the Czech Republic. During catalytic gasoline reforming, hydrogen is released together with aromatic hydrocarbons. The reforming can be continuous, cyclic or semi-regenerative.

STRENGTHS	WEAKNESSES
• An established technology	• A very high emission footprint that will not be technologically reducible • A need for additional purification
OPPORTUNITIES	**THREATS**
	• Replacement with clean technologies

1.10. Brine electrolysis

A significant amount of hydrogen is produced as a by-product of the electrolysis of aqueous sodium chloride or potassium chloride solution during the production of chlorine and sodium hydroxide or potassium hydroxide.

STRENGTHS	WEAKNESSES
• An established technology	• A very high emission footprint, which can only be reduced by changing the energy mix • A need for additional purification
OPPORTUNITIES	**THREATS**
• The use of existing technological units	• Assessing the total emission footprint of chlorine and hydroxide production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2 HYDROGEN TRANSPORT AND STORAGE[5]

2.1. Hydrogen transport

In most cases, hydrogen production and consumption sites are far apart which means that hydrogen has to be transported. This further increases its cost to the end users. The most efficient way of transporting hydrogen is through pipelines. The construction of new linear structures is relatively investment-intensive and can only take place when there is a stable and clear legislative and regulatory environment for the construction of hydrogen networks. It must also be known what quantities of hydrogen will be transported/distributed over the long term. It is necessary to take into account that the construction of a new pipeline involves several years. A more likely option would be to repurpose existing natural gas pipelines to transport hydrogen, which is quicker and cheaper than laying new pipelines. However, this repurposing must be timed to reflect the current provisions of transmission contracts that party determine the use of some pipelines in the Czech Republic.

Significant hydrogen injection into the natural gas system is not expected in the Czech Republic by 2030 and the beginning of the conversion to dedicated hydrogen infrastructure is not expected this decade. Adding 2% hydrogen to natural gas is not a technical problem as studies show.

Hydrogen storage in cylinders or larger tanks can be done in gaseous form or even in liquid form, which is a less widespread and even more energy-intensive method. Mobile storage is part of the overall technical design of vehicles.

The above shows that hydrogen production and transport/distribution are always an interconnected and quite complex problem. The choice of a particular method depends on a number of factors and should always be assessed with regard to the stated objective and the specifics of the Czech Republic. At the same time, it is obvious that the Czech Republic will most likely not be a hydrogen exporter in the next 30 years and will always have to deal with an excess of demand for hydrogen over domestic production.

To transport pure hydrogen, either a completely new infrastructure specifically designed for hydrogen must be built or the existing one, which is not used for natural gas transmission, must be modified. Modifying an existing infrastructure is always more cost-effective.

Transmission through the gas system starts to pay off at high volumes and also makes sense if multiple producers are concentrated in one region. Based on current calculations, 1 200 pressurised railcars or 82 cm wide pipelines can be used to transport 100 000 tonnes of hydrogen (the German Hydrogen Strategy).

Until a distribution network of hydrogen pipelines can be used to bring hydrogen to at least every wholesale customer, it will be necessary to use road and railway transport. Water transport is not being considered at the moment. Road and railway transport can be used for various technologies described in the chapter on hydrogen storage (compressed hydrogen, liquefied hydrogen, LOHC, and

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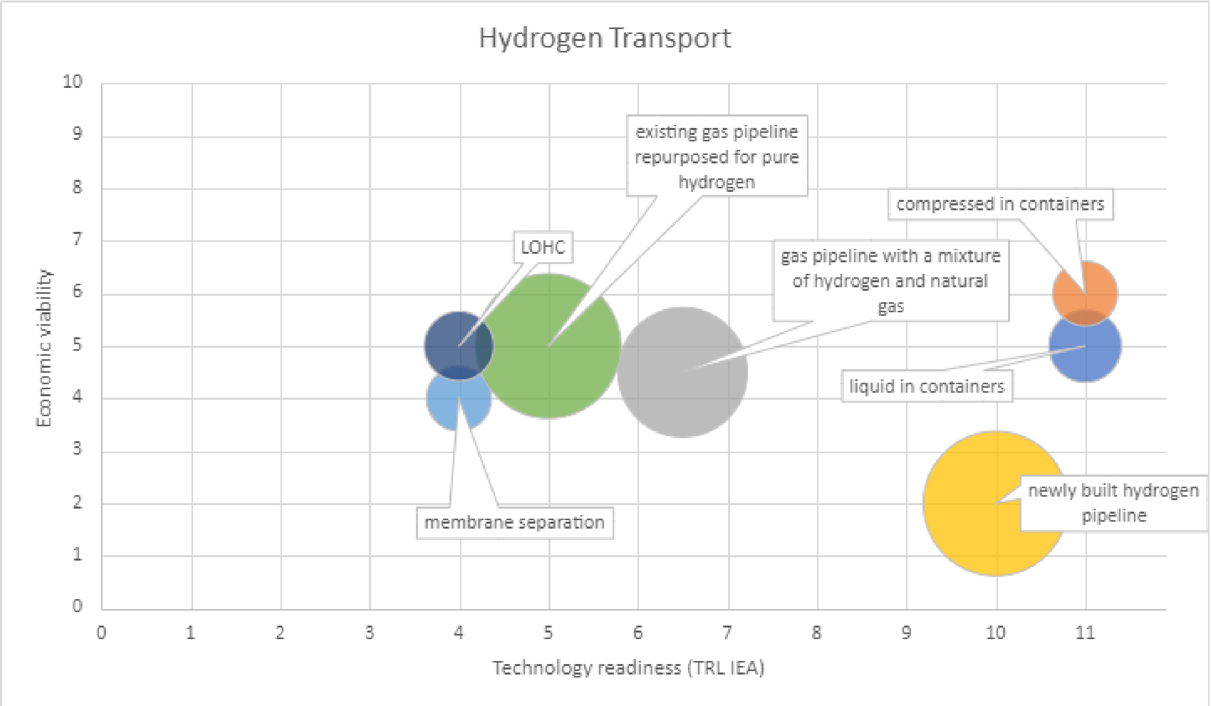
[5] A detailed description of the method by which the analysis was carried out is provided at the beginning of Annex 1.

hydride storage). These modes of transport are much more flexible but have a much higher unit cost per tonne-kilometre transported.

In the initial phase of hydrogen technology deployment, it will be necessary to look for applications where hydrogen is produced close to the point of consumption in order to reduce transport costs.



2.1.1 Transport of compressed hydrogen in containers by road or railway

Currently, hydrogen is most often transported as a compressed gas in pressure vessels made of steel or a carbon fibre composite. Hydrogen in pressurised containers can be transported in cylinders at a pressure of 200 bar[6]. Hydrogen-powered vehicles use smaller pressurised tanks of 350 or 700 bar.

A 40-tonne truck can transport 26 tonnes of gasoline to a petrol station. The same truck carrying compressed hydrogen can transport 500 kg of hydrogen (in cylinders at 200 bar). This is because the cylinders have to withstand very high pressure. A truck transporting hydrogen weighs almost the same as a truck without hydrogen, the difference is only the 500 kg. Compressed hydrogen tanks are robust. Because of the low amount of hydrogen transported in a single trailer, this method of transport is only economical up to a distance of around 150 km.

The transport of hydrogen bound by a chemical bond in a compound can also be considered, such as ammonia, methanol, other organic compounds (LOHC). In such a case, hydrogen can be transported

[6] According to the Agreement on International Carriage of Dangerous Goods by Road (ADR).

at a normal temperature and pressure. The disadvantage of this process is the cost required to bind the hydrogen into the compound and its subsequent separation.

STRENGTHS	WEAKNESSES
• No need to build any special infrastructure (pipelines) • Transport capacity can be scaled to meet requirements on a small scale	• The weight and volume of the tanks • The pipeline also acts as a hydrogen accumulator • The low weight transport capacity
OPPORTUNITIES	**THREATS**
• The use of semi-trailers as mobile filling stations	• Risk of traffic accidents

2.1.2 Transport of liquid hydrogen in containers by road or railway

An alternative way that could significantly increase the amount of hydrogen transported is to liquefy it. Liquid hydrogen is stored at a temperature of -253° C. This implies increased demands on the materials used and high energy requirements for liquefaction, a major disadvantage being the loss of around 40% of the energy during liquefaction itself (*Devinn, Irena*). Further losses occur due to leakages caused by the necessary evaporation of liquid hydrogen from cryogenic tanks that are not meant to be used as pressure vessels. This evaporation is controlled and does not affect transport safety.

STRENGTHS	WEAKNESSES
• No need to build any infrastructure (pipelines) • The possibility of transporting larger volumes	• High losses in liquefaction • The low transport weight capacity
OPPORTUNITIES	**THREATS**
• Transporting large quantities of hydrogen over long distances until hydrogen pipelines become available	• Risk of traffic accidents

2.1.3 Transport of hydrogen through pipelines in a mixture with natural gas

In the Czech Republic, the gradual addition of hydrogen to the existing infrastructure is realistic. The Czech gas supply system is technically ready for the transmission, distribution and storage of natural gas with an H_2 content up to 2% (see the *CGA*). However, higher hydrogen ratios are theoretically possible (with the current knowledge, 10% is most often discussed) with technical modifications of a smaller scale. The limitation as to the amount of hydrogen added to natural gas is mainly due to limitations on the end-user side. This form of transport would bring an advantage if hydrogen were used together with natural gas for combustion at the end of transport. Otherwise, it will depend on the technical perfection of the reverse split of the mixture, separating hydrogen from natural gas.

At the same pressure and volume, hydrogen has a lower calorific value than natural gas, around 30% of the calorific value of natural gas. When selling gas to customers, this will not cause any problems because the price for delivered gas is already charged in energy units (delivered KWh) according to its calorific value and the billing systems that are used have to change the calorific value of natural gas based on what is actually measured.

To supply the same amount of heat, more hydrogen is needed than natural gas. The advantage of hydrogen is its lower resistance to flow through the pipeline, which means that the mixture of natural gas and hydrogen can flow faster. The existing flow capacity of the pipeline is not a constraint on the natural gas-hydrogen mixture in terms of the amount of heat transported.

Pipeline transmission begins to pay off at high volumes and when there is a greater concentration of producers and consumers in one region.

According to the current calculations, 1 200 wagons, 600 ships or 82 cm wide pipelines could be used to transport 100 000 tonnes of hydrogen (The *German Hydrogen Strategy*).

STRENGTHS	**WEAKNESSES**
• The existing natural gas (and biogas/bio-methane) infrastructure • Continuity of deliveries • Lower costs compared to road/rail transport • Natural storage capacity • Reducing CO_2 emissions in a quick and relatively cheap way	• A limited admixture ratio up to a certain percentage • The maximum hydrogen concentration is determined by the compatibility of the connected end devices (e.g. CNG, domestic boilers, etc.)
OPPORTUNITIES	**THREATS**
• The necessity to transport large quantities of hydrogen for long periods of time	• In case of a failure, dependence on one pipeline

2.1.4 The separation of hydrogen from a mixture with natural gas using membrane separation

An interim solution may be to use the existing natural gas network into which hydrogen would be injected. Instead of being burnt with natural gas, hydrogen is separated by membrane separation before the subsequent branching of the transmission network. Natural gas and Hydrogen are then used separately and natural gas is used only as a transport medium.

STRENGTHS	**WEAKNESSES**
• The use of the existing pipeline network • A relatively cheap technology • A scalable technology	• Reverse hydrogen separation is not 100% reliable • It can only be used in sections without branching • A new technology
OPPORTUNITIES	**THREATS**
• A temporary solution until dedicated hydrogen pipelines are built	• The efficiency of other hydrogen transport methods

2.1.5 Transportation of pure hydrogen through an existing pipeline converted to pure hydrogen

Given the location of the Czech Republic and the current attitude of our neighbouring countries, it seems absolutely necessary to think about an international interconnection of gas systems with respect to hydrogen. The European Hydrogen Backbone[7] study (link) envisages that the hydrogen transmission system would be based three-quarters on the existing infrastructure, while the remaining one-quarter would have to be newly built.

The EU foresees a shortage of green hydrogen by at least 2030, which will mean that imports will be necessary. From the perspective of the Czech Republic, it is relevant to direct potential international hydrogen pipelines primarily from the Czech Republic's western and eastern neighbours:

- From a connection to Germany (high hydrogen production from RES, low-carbon hydrogen production from natural gas)
- From a connection to Slovakia (the possibility of importing hydrogen from Ukraine and North Africa (see the 2x40 GW Initiative) and to transport hydrogen on the Danube)
- A connection to the Danube pipeline from Austria, or connection to hydrogen pipelines from Southern Europe or North Africa.

STRENGTHS	WEAKNESSES
• Means of importing large volumes of hydrogen • Flexible balancing according to the immediate need in the country • An active TSO with the latest approach to decarbonising the EU gas sector • Experience with hydrogen pipelines in Europe, e.g. the Benelux region • Imports of "cheap" hydrogen from regions with significantly lower production costs compared to the Czech Republic	• A low level of experience with transmitting pure hydrogen in pipelines in the Central European region • Some cross-border capacities of the transmission system in the Czech Republic are largely reserved until 2035
OPPORTUNITIES	**THREATS**
• The development of cross-border cooperation, a transfer of experience • Using the experience of some countries with a more advanced preparation of the transmission system	• The safety aspects of hydrogen transport • Dependence on imports, even from less stable regions

2.1.6 The transmission of pure hydrogen through a newly built pipeline

Some European countries have operational experience with pipelines newly built to transmit clean hydrogen. However, the construction of new pipelines outside of existing routes may encounter a

[7] https://gasforclimate2050.eu/sdm_downloads/european-hydrogen-backbone/

number of typical complications associated with their construction, as is the case with various types of newly built linear technical infrastructure structures, in particular due to the requisite easements over land. Relatively high investment costs of new development can also be problematic. On the other hand, a pipeline designed entirely according to the requirements for hydrogen transmission is an advantage.

STRENGTHS	**WEAKNESSES**
• Means of importing large volumes of hydrogen • Flexible balancing according to the immediate need in the country • Experience with the operation of hydrogen pipelines in Europe, e.g. the Benelux region • Imports of "cheap" hydrogen from regions with significantly lower production costs compared to the Czech Republic	• High investment construction costs compared to the use of existing infrastructure • Problems with securing land rights, EIA, nature and landscape protection
OPPORTUNITIES	**THREATS**
• The development of cross-border cooperation	• The safety aspects of hydrogen transport

2.1.7 LOHC

LOHC (Liquid Organic Hydrogen Carriers) are organic compounds that bind hydrogen by chemical bonding. In order to be effective, the hydrogen storage and recovery process must meet conflicting requirements. Hydrogen storage must be stable so that hydrogen is not spontaneously released. On the other hand, the storage and release process must be energy-efficient, because each energy input increases the price of the transported hydrogen. A huge advantage of this technology is that the hydrogen is transported under normal pressure and temperature. Hydrogen is bound to a liquid that can be handled in the same way as diesel. In this way we can also transport large quantities of hydrogen per unit volume and weight. A tanker trailer with LOHC can carry significantly more hydrogen than a trailer of the same weight with cylinders.

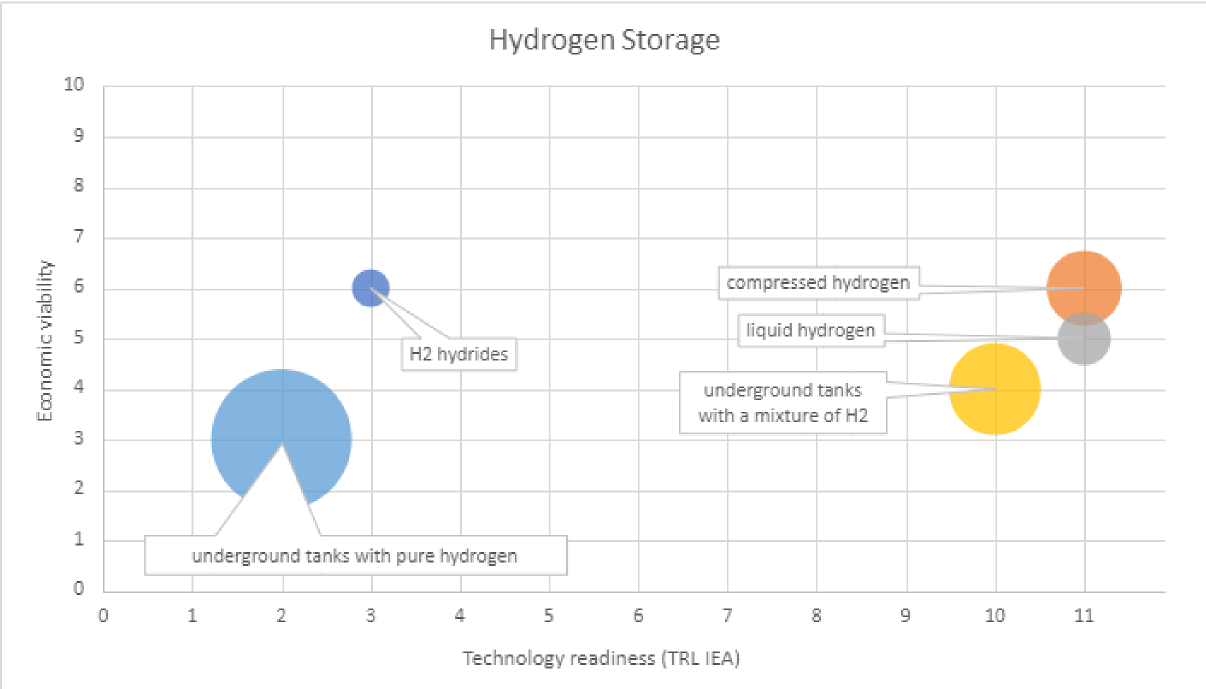
STRENGTHS	**WEAKNESSES**
• Transport at normal temperature and pressure • Easy liquid handling • A high hydrogen content in terms of both mass and volume • High flexibility in terms of transported quantity and transport distance	• Hydrogen storage and recovery is expensive • A new technology
OPPORTUNITIES	**THREATS**
• It can be the ideal technology for transportation	• Existing technical and economic problems will not be resolved

2.2 Hydrogen storage

To make up the difference between production and consumption, hydrogen must be stored. A number of technologies can be used to do this, each with its own advantages and disadvantages. No cheap, universal and highly scalable method of storing hydrogen has been developed yet.

In this chapter, we also cover the storage methods used during transport. These may not have as much scalability, but they must ensure that hydrogen is inexpensively transformed from the form in which it was produced to a form suitable for transport and then to the form in which it will be consumed. At the same time, these technologies must be very safe.

Efficient hydrogen storage and its transformation from production to final consumption is an open field for further research and development.



2.2.1 Compressed hydrogen storage

Due to its low density, hydrogen must be stored compressed in pressurised containers. These must be pressure-resistant, destruction-resistant and very tight to prevent hydrogen leakage. Hydrogen is a gas with the smallest molecule and special materials must be used to store it. When hydrogen comes into contact with steel or aluminium, it causes hydrogen embrittlement, which can impair the resistance of cylinders; this also means that special materials must be used. Hydrogen compression by itself is energy intensive. Hydrogen is a poorly compressible gas, with a negative Joule-Thompson coefficient, therefore it requires much more energy to compress than other gases. For stationary hydrogen storage, large volume steel pressure vessels are used.

Conventional methods of hydrogen storage are safe and time-tested systems, but their technological potential has been almost exhausted. Mass capacity is mainly dependent on the material of the storage vessel and a suitable material can slightly improve this parameter. On the other hand, volumetric capacity depends on the storage pressure and temperature of hydrogen.

STRENGTHS	WEAKNESSES
• Compared to batteries, it shows an increasingly convenient form of energy storage for longer periods • Long-term experience	• Losses (leakages) • Hydrogen compression is energy-intensive • Technologically, no further improvements are feasible • Route restrictions under ADR conditions
OPPORTUNITIES	**THREATS**
• As hydrogen production grows, so will the requirement for hydrogen storage	• A rapid development of other technologies

2.2.2 Liquid hydrogen storage

Hydrogen can also be stored in liquid form. In this case, high pressures are not necessary, but hydrogen must be kept at a very low temperature of -253 °C, close to absolute zero. Cryogenic storage tanks must be able to maintain these low temperatures. Evaporative losses in this type of storage are typically about 3% per day and hydrogen leaked in this way must be captured and used.

Liquid hydrogen is used in long-distance transport by ship, or even in road transport. Some car companies are experimenting with storing liquid hydrogen directly in truck tanks. Liquid hydrogen has been the only way to put the same amount of energy into a truck tank as is contained in a full tank of diesel.

It is also possible to consider another method of compression to pressures between 200-300 bar at temperatures around -230°C. Under these conditions, gaseous hydrogen has a higher density than liquid hydrogen. This cryo-compression method is still under development.

STRENGTHS	WEAKNESSES
• A higher energy concentration than in compressed hydrogen • The possibility of handling hydrogen at low pressure • A good ratio between the energy contained and the weight of the container.	• Losses (leakages) • Hydrogen liquefaction is energy-intensive • Cryogenic vessels for storage and transport are very expensive
OPPORTUNITIES	**THREATS**
• A high energy concentration for remote preparation	• A rapid development of other technologies

2.2.3 Hydrogen storage in underground storage tanks mixed with methane

Hydrogen can be stored in a mixture with natural gas in underground storage tanks that are currently used for natural gas storage. Nine underground gas storage facilities are currently in operation in the Czech Republic and their storage capacity corresponds to approximately 40% of the annual natural gas consumption of the Czech Republic. Underground storage facilities allow for large-scale storage of gas, are interconnected with the natural gas network and can build on experience with the storage of LPG, which contains a high proportion of hydrogen. The storage of higher concentrations of hydrogen in a mixture with natural gas has to be technically verified and may vary from one underground storage facility to another. The lower volumetric calorific value of hydrogen compared to methane and the need to store a correspondingly larger volume must be taken into account.

STRENGTHS	**WEAKNESSES**
• High-capacity storage • The existing storage infrastructure • Connection to the gas system • Experience with hydrogen storage as a component of coal gas	• The storage of a higher proportion of hydrogen must be technically verified and may vary from tank to tank • Losses (leakages) from storage of higher concentrations of hydrogen mixed with methane or hydrogen alone
OPPORTUNITIES	**THREATS**
• As hydrogen production grows, so will the requirement for hydrogen storage	• Demand for storage of hydrogen alone, i.e. not mixed with natural gas (or bio-methane or synthetic methane)

2.2.4 The storage of pure hydrogen in extracted oil and gas structures

The technology for storing pure hydrogen underground in extracted oil and gas structures is significantly less advanced. No experience with operations exists, even at the experimental level (an experiment with small underground storage tanks for pure hydrogen is under preparation in Germany). However, if this technology is mastered, it may offer a very efficient solution with large capacity. The storage facilities are designed to store large quantities of hydrogen, which means a hydrogen pipeline needs to be brought to them for their efficient use. They will be used mainly for the seasonal storage of energy made from RES.

STRENGTHS	**WEAKNESSES**
• Experience with hydrogen storage as a component of coal gas • Pure hydrogen can be recovered, not in a mixture • The efficient storage of large quantities of hydrogen	• At the moment, it is only a theoretical possibility • A limited number of suitable sites in the Czech Republic • The necessity to connect to the hydrogen pipeline
OPPORTUNITIES	**THREATS**
• As hydrogen production grows, so will the requirement for hydrogen storage • Efficient seasonal energy storage	• Decentralised energy storage

Hydrogen hydrides

Another form of hydrogen storage in a chemical bond is the use of hydrogen hydrides, which are solid at normal pressure and temperature. Hydrogen is released from them in a chemical reaction. This technology is at an early stage of development. An example is Powerpaste, recently announced in Germany, where hydrogen is bound to magnesium hydride and then released from it by combining it with water. This compound is very stable in the solid state up to a temperature of around 200 °C. The hydride can be stored at normal pressure and temperature. The amount of hydrogen stored in this way is higher than in a 700 bar pressure tank of the same volume.

STRENGTHS	WEAKNESSES
• Transport at normal temperature and pressure • The solid form is easy to handle • A high hydrogen content in terms of both mass and volume • High flexibility in terms of transported quantity and transport distance	• A new technology
OPPORTUNITIES	**THREATS**
• Ideal for transporting smaller quantities of hydrogen; for large quantities, it is more convenient to work with LOHC	• The technology is only at the beginning of its development

2.2.5 Power to Gas - see the Use of Hydrogen Annex


22
H2
Hydrogen

3 HYDROGEN USE[8]

This chapter explains the different possibilities of using hydrogen. Their potential in terms of price, technological constraints, readiness of the technology for deployment, and possible development of consumption in the Czech Republic are compared. In terms of hydrogen use, the primary indicator for us is the price of low-carbon hydrogen. It is not important whether the hydrogen is produced in the Czech Republic or if it is imported.

The goal is to identify technologies that are optimal at a given time. This selection will be regularly updated based on technological developments and economic parameters. We use bubble charts to compare hydrogen technologies, where the size of the bubble represents the amount of hydrogen that could potentially be used in a given area. We plot the commercial readiness of a given technology on the horizontal axis and the economic efficiency of deployment on the vertical axis. We prioritise technologies in the upper right quadrant, or large bubbles that have a chance of moving quickly into the right quadrant. A SWOT table with a more detailed analysis has been prepared for each technology.

If we consider the economic criterion, the area where hydrogen can be most effectively deployed is transport. To be economically viable, a hydrogen price of around EUR 4 per kg (2021 prices) is required. In terms of planning and achieving high consumption, it is advisable to start with road freight transport and city bus transport. A basic prerequisite is the construction of the requisite filling station infrastructure. The use of hydrogen in transport has some advantages over electric vehicles, especially its longer range and faster filling. In the transport sector, it is generally assumed that only fuel cells will be used, although direct combustion of hydrogen in slightly modified internal combustion engines cannot be excluded. In parallel with road freight, bus and railway transport, there could be gradual development in the field of passenger cars. One disadvantage is the very high purchase price of hydrogen vehicles.

Hydrogen can largely replace coal and coke in smelters where it serves as a reducing agent in iron production. However, the use in smelters faces potentially very high demand for low-carbon hydrogen, which the Czech Republic is currently unable to meet, and there is a very high price for hydrogen compared to the price of coke.

Hydrogen is also widely used in the chemical industry. Hydrogen has long been used in some plants, but it is not low-carbon hydrogen. Otherwise, hydrogen would replace the fossil fuels currently used. As this would only be a replacement of existing hydrogen with low-carbon hydrogen, the associated investment costs would be relatively low. This may represent a definite advantage and therefore, the chemical industry is probably the most suitable area for early-stage hydrogen use after transport. The difference in operating costs due to the higher price of low carbon hydrogen will be problematic. Chemical companies are also likely to be the first to produce low carbon hydrogen on a large scale. They could use surplus hydrogen, primarily produced for transport, in their own production to replace existing hydrogen that has a high emissions footprint.

[8] A detailed description of the method by which the analysis was carried out is provided at the beginning of Annex 1.

3.1 Mobility

The application of hydrogen in transport results in an absolutely essential reduction of pollutant emissions in exhaust gases since the products of this process are basically only water (in case of fuel cells), and as for combustion, a minimum of secondary pollutants, especially nitrogen oxides, is generated. Mobility is a major source of greenhouse gas emissions and a segment where greenhouse gas emissions are currently increasing. The use of low-carbon hydrogen as a car fuel is one way to eliminate these emissions. Currently, fossil fuel mobility is burdened with various taxes and fees. The use of alternative fuels, including hydrogen, makes it possible to eliminate some of these additional costs and because of that, we have the possibility to achieve comparable running costs between hydrogen and diesel at a price of around EUR 4 per kg, which is a much better price from a hydrogen perspective than the price needed to replace natural gas. The use of hydrogen in transport at the moment shows a big advantage in range and filling speed compared to electric battery mobility. The price of hydrogen vehicles is still significantly higher than that of fossil fuel vehicles. Therefore, the purchase price of vehicles and the lack of infrastructure are currently the biggest obstacles to the development of hydrogen mobility. However, the prices can be expected to decrease gradually as the number of sold vehicles increases and competition between manufacturers increases. From an operational efficiency point of view, in order to be able to balance hydrogen production and consumption, it is advisable to promote the development of hydrogen transport in the long-distance freight, railway and city bus transport segments, or vehicles for in-house use and public space/utility management (waste, greenery, etc.). The development of hydrogen mobility in individual passenger transport or for in-house use and management of public space/municipal technology (waste, greenery, etc.) also has great potential. One major advantage in the development of electric battery mobility and hydrogen powered vehicles is that much of the vehicle design can be shared. Hydrogen propulsion only replaces part of the battery with a fuel cell and a hydrogen tank. As hydrogen technology is new to drivers in terms of vehicle operation and requires different principles and handling, it is also worth paying attention to the training of staff in the transport industry who come into contact with hydrogen technologies.

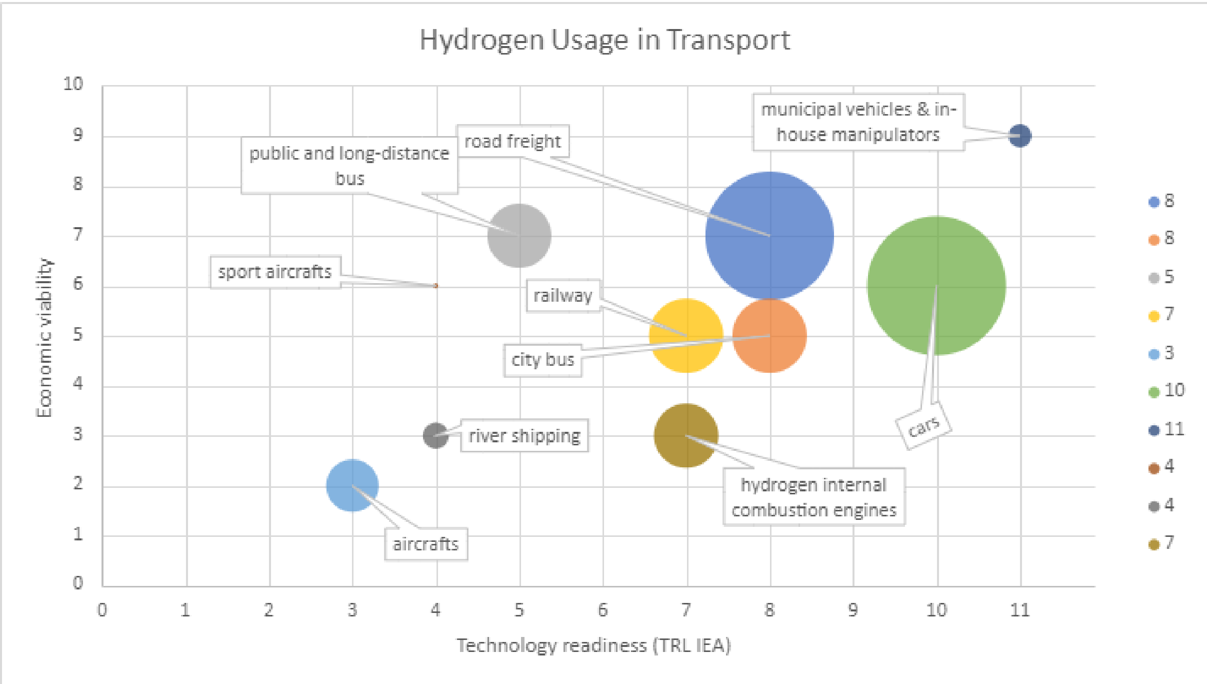
As LNG is now more widely available in heavy long-haul freight transport (a vehicle range over 1 000 km), and will probably be widely available by 2030, LNG technology will coexist with hydrogen truck propulsion technologies. The transition of transport companies to hydrogen use may be smoother and easier.

A significant role in the use of hydrogen in public bus transport and others will be played by the upcoming government legislation on the promotion of low-emission vehicles through public procurement and public passenger transport services (transposition of the EU Directive), which will impose an obligation on public contracting authorities to procure a specified proportion of low-emission vehicles when awarding above-limit public contracts and public passenger transport services. Hydrogen will not fully replace batteries, as fuel cells are slow in terms of load change and require hybrid propulsion. An internal combustion engine solution is also offered for the transient period. Tolerance to the quality of combusted hydrogen and the ability use a less conventional fuel when hydrogen is scarce make the hydrogen internal combustion engine a suitable means to support the development of hydrogen infrastructure during the transition period while building a hydrogen economy. The use of hydrogen for railway transport has its limits, but it might cover a significant segment here too. It would involve the deployment of hydrogen vehicles, particularly on local non-electrified lines and during station handling (shunting). Electric vehicles with line supply will certainly remain the dominant mode of transport. However, on non-electrified lines, hydrogen is another possible alternative to dual-source trolley/battery vehicles that use the fixed installations of electrified lines (traction substations and overhead lines) to charge batteries statically (while driving on a line-electrified line) or dynamically (while stationary in a line-electrified station).

One interesting possibility is the use of hydrogen for forklifts and material handling vehicles in large logistics centres and municipal equipment where this fuel can be very advantageous and is already being used in many cases.

The use of hydrogen in shipping and air transport is already being tested.

The National Action Plan for Clean Mobility (NAP CM) that this hydrogen builds on, addresses the issue of the transition to zero-emission transport in detail.



3.1.1 Passenger cars

As far as passenger car transport is concerned, it is still true that among car companies, the production of hydrogen-powered passenger cars is primarily being undertaken by Asian (Japanese/Korean) car companies. These include mainly Toyota, Hyundai and Honda, all producing the first thousands of vehicles.

Various studies indicate that the Czech Republic will be able to achieve 100% fulfilment of the NAP CM prediction in relation to alternative fuels (electromobility/CNG) to be able to achieve an 8-10% reduction of CO_2 emissions in transport. If, thanks to well-targeted measures, the predictions for the development of hydrogen mobility could be met, a further reduction of 4–5% in CO_2 emissions in transport could be achieved (*NAP CM*). Another possible solution is to convert an initially dual-fuel car to natural gas. However, this approach is not suitable for car manufacturers in terms of recognisable CO_2 savings.

STRENGTHS	**WEAKNESSES**
• Emission-free operation • A longer range, the lower weight of the hydrogen tank compared to a battery (2 to 5 times) • The lower weight also reduces tyre abrasion • The filling time is much shorter than the charging time for electric vehicles • Much of the vehicle is the same as an electric vehicle with the fuel cell and hydrogen tank extending the range of electric cars •	• A lack of filling station infrastructure • A limited supply of passenger cars • The price of hydrogen (transport and compression costs) • Higher vehicle servicing costs than electric battery vehicles
OPPORTUNITIES	**THREATS**
• One advantage can be the shift in technology towards new forms of hydrogen storage in passenger cars	• A reduction in gasoline or diesel prices • A faster development of batteries and other alternative drives

3.1.2 Road freight transport

A number of European and non-European car manufacturers are developing hydrogen-powered trucks. Some vehicles have already been put into operation. The advantage of freight transport is the quickly achievable effect of reducing emissions with a small number of vehicles. In particular, replacing diesel with hydrogen is economically interesting. Once the price of low-carbon hydrogen reaches EUR 4 per kg, hydrogen will become competitive with diesel.

A massive deployment of hydrogen in freight transport requires a Europe-wide network of hydrogen filling stations capable of filling large quantities of hydrogen.

In addition to the high purchase price of new vehicles, the lack of a market for used hydrogen trucks is a limiting factor in the development of hydrogen transport.

STRENGTHS	**WEAKNESSES**
• Emission-free operation • A longer range and shorter filling times • Heavy freight transport is responsible for a large amount of emissions – hydrogen-powered vehicles offer great potential for reducing them	• A lack of filling station infrastructure, trucks usually require 700 bar • A limited supply of trucks • The price of hydrogen (transport and compression costs)

• Although the fleet of trucks is very large, much of the performance is done by a relatively small group of vehicles that drive a high number of kilometres per day • Replacing diesel with hydrogen is more economically viable than replacing other fossil fuels • A shorter filling time	• More sophisticated monitoring of the technical condition of vehicles and their fuel systems • Higher vehicle servicing costs
OPPORTUNITIES • Some companies already prefer to use a "green" carrier • Possible expansion abroad • Emission limits for truck manufacturers	**THREATS** • Reduction in diesel prices • Problems with supplying the filling station network when hydrogen production is limited

3.1.3 City buses

The city bus segment was one of the first areas of focus for the private sector in hydrogen propulsion. In addition to the urgent need to reduce emissions in cities and suburban areas, buses have a signalling effect because they are highly visible. Once the price of low-carbon hydrogen reaches EUR 4 per kg (2021 prices), hydrogen will become competitive with diesel as a fuel, similar to road freight transport. The use of hydrogen as energy storage in city bus transport is optimal for capacities where continuous or occasional charging and the required range cannot be ensured with electric buses, including battery buses (e.g. due to the impossibility of building charging and supply infrastructure). According to studies to date and taking into account other hydrogen application options, even relatively low investment costs during the first phases of the Strategy will lead to significant emission savings. At the same time, most transport companies in larger cities are held by municipalities, which makes the initiation phase easier.

Due to the lower amount of waste heat in electric motors, passenger bus transport usually has heating that is designed as electric or is provided by diesel combustion. It remains to be seen what the year-round balance of hydrogen buses would look like including the winter period.

STRENGTHS	WEAKNESSES
• Emission-free operation • Shorter filling times • Existing experience and successful projects • Cooperation with foreign entities is possible • In cities, the necessity to reduce all emissions is greatest • Replacing diesel with hydrogen is more economically viable than replacing other fossil fuels • A government bill on the promotion of low-carbon vehicles through public	• Heating in winter – high energy consumption and the need to adequately size the vehicle energy system • Higher acquisition, operating and servicing costs compared to diesel vehicles • A lack of filling station infrastructure • A limited selection of buses • No serial solution for high-capacity vehicle versions (e.g. articulated bus) has been developed yet • The price of hydrogen (transport and compression costs)

procurement and public passenger transport services	
OPPORTUNITIES • Municipalities and regions themselves have ambitions to reduce emissions	**THREATS** • Reduction in diesel prices • Problems with supplying the network of filling stations when hydrogen production is restricted

3.1.4 Public and long-distance buses

So far, there has been less experience with planning intercity and long-distance bus transport with the use of hydrogen propulsion. Some similarities with city transport apply, but often to a limited extent. In case of large owners, coordination and scalability would work, depending on the infrastructure being built over time. Unlike public city buses, these buses are not usually subject to public service obligations. This makes their operation more flexible, but in general it is more problematic to obtain subsidies.

The advantage of hydrogen propulsion is the long range, but it is conditioned on having an existing transport infrastructure.

STRENGTHS • Emission-free operation • A longer range than electric battery buses, and faster filling • In terms of filling stations, the first phase should cover mainly the backbone infrastructure (motorways, class I roads)	**WEAKNESSES** • Heating in winter • A lack of filling station infrastructure • A limited selection of buses • The price of hydrogen (transport and compression costs)
OPPORTUNITIES • The development of international and cross-border cooperation (proposals for Prague-Berlin, Prague-Nuremberg routes) • A government bill on the promotion of low-carbon vehicles through public procurement and public passenger transport services • Restricting access to city centres by fossil fuelled vehicles	**THREATS** • Reduction in diesel prices • Dependence on infrastructure – in case of backbone infrastructure (D1, etc.) • Problems with supplying the network of filling stations when hydrogen production is restricted

3.1.5 In-company transport (forklift trucks and handling trolleys, municipal equipment, and work machines)

The in-company use of hydrogen propulsion for forklifts has a long history, but the number of companies adopting the technology on a larger scale is not too high. Big advantages include the longer truck range compared to battery-powered trucks and simple and quick filling. Building the infrastructure for hydrogen filling from pressurised containers is easier than building charging stations where many electric trucks have to be connected for long periods of time. The advantage of hydrogen propulsion over fossil fuels is that hydrogen-powered trucks can run smoothly in confined spaces without releasing any pollutants. The total amount of hydrogen used in this way is not large, but if enough stakeholders are involved, it can already play a role and could be an interesting pilot project.

In the future, it may also have great potential for use in fleets operating municipal waste collection vehicles and similar activities in the management of public space (such as road cleaning and maintenance, snow removal, green maintenance, construction work).

STRENGTHS	WEAKNESSES
• Emission-free operation • Fast filling is a great advantage in multi-shift operations • It eliminates the need to change batteries and increases safety • The handling of fuel cells is very hygienic and therefore suitable for food processing, etc. • Saving space in warehouses • The possibility to ride outdoors and indoors	• Benefits are more likely to be seen in larger companies
OPPORTUNITIES	**THREATS**
• A suitable pilot project • The establishment of a base in the food and pharmaceutical industries where high demands exist with respect to the cleanliness of the environment	• Battery trolleys with rapid charging • There will be impact on discharged emissions only if a sufficient number of stakeholders is involved

3.1.6 Railway transport

The development of hydrogen railway transport is also anticipated in existing strategic documents in some countries, especially in Germany. However, there is no sufficient experience with such operation, and none in the Czech Republic at all. It is advisable to use the existing experience and available data from operations abroad (e.g. Germany, Austria, Japan). In contrast to road transport, where the first companies have already invested considerable resources, hydrogen-powered railway transport has not left the stage of concepts and plans. However, railway companies can see that if they are to meet the requirements for near-emission-free operation by 2050, they must address the replacement of existing diesel units and locomotives now. Therefore, many carriers will gradually phase out the demand for diesel-powered railway vehicles altogether around 2025 (assuming a maximum vehicle life of 30 years). Two types of propulsion are now being developed – battery and hydrogen. Both technologies are considered to be low emission and differ only in the different type of charging/ filling, the power and the required range, and of course, different safety regulations. The Czech Republic has one of the densest railway networks in Europe; on the other hand, only a small part is electrified, with large reserves in the northern half of the territory. Hydrogen rolling stock should be deployed on non-electrified lines where electrification would not be economically efficient due to the nature of the operation (e.g. a low daily number of trains, the absence of freight traffic) and at the same time these lines cannot be served by BEMU battery vehicles (too long distances without any electrification). One of the promising areas in terms of deployment of hydrogen-powered vehicles is the northern part of the Czech Republic, e.g. the Liberec region, which is currently not connected to the electrified railway network.

A major player on the market is the French public transport manufacturer Alstom. After about two years of operating experience on lines in Lower Saxony, they are planning the regular operation of hydrogen-powered trains in Germany with a total volume of EUR 81 million, which should start running in December 2021. In France, too, there are already initial orders for a larger number of trains.

One interesting option could be the deployment of hydrogen-powered shunting locomotives.

STRENGTHS	**WEAKNESSES**
• Emission-free operation • A suitable solution for non-electrified lines • The possibility of temporary use until the line is electrified (there is no sense in electrifying some lines with low traffic volume) • A longer range compared to battery-powered vehicles	• Even less experience compared to bus and road freight transport • Only a few players are developing hydrogen-based railway transport • A lack of filling station infrastructure • The limited range of vehicles • The price of hydrogen (transport and compression costs)
OPPORTUNITIES	**THREATS**
• Synergies with the simultaneous development of hydrogen road transport • Using the very dense railway network in the Czech Republic • An advantage of use during ongoing traction system voltage unification • The Green Deal for Europe prioritises railway	• A decline in interest in railway transport

3.1.7 Sport aircraft

The use of hydrogen to power sport aircraft is a very under-exploited opportunity. Sport aircraft are not expected to have a long range, their average flight time is between 1 and 2 hours, so only smaller hydrogen tanks need to be used. Electrically powered aircraft are much cheaper to operate than aircraft with internal combustion engines. However, electric aircraft have a huge weight-to-battery power ratio problem; using hydrogen could be a good compromise.

STRENGTHS	**WEAKNESSES**
• Emission-free operation • Advantageous for short distances up to 1000 km • The building of hydrogen tanks at airports is not so problematic • Operating costs of electric aircraft	• The higher weight of tanks because of the material • Many small entities
OPPORTUNITIES	**THREATS**
• A small but attractive segment	• A new untested technology

3.1.8 Transport aircraft

The use of hydrogen for transport aircraft is currently showing more progress, especially with Airbus planning to develop this type of aircraft. So far, pilot projects using only hydrogen as a fuel for transporting people or goods have existed.

STRENGTHS	WEAKNESSES
• Emission-free operation • A direct hydrogen combustion technology in a jet or turboprop engine, which is similar in design to a conventional one • Kerosene substitute is cheaper • The first pure hydrogen-powered commercial aircraft took off in October 2020 • Communication with major airlines	• Large volume and very heavy tanks • The price of low-carbon hydrogen
OPPORTUNITIES	**THREATS**
• Negotiating further terms with major airlines after the coronavirus crisis	• A decline in interest in air travel or restrictive measures taken by individual countries

3.1.9 River shipping transport

Ships for river shipping transport can use fuel cells, and hydrogen could be produced by solar panels, possibly using wind power, directly on board the ships. However, so far there has been only minimal experience with this type of propulsion. Maritime transport is one step ahead and is already running on hydrogen, with the first fuel cell powered ships already in operation. Hybrid ships can be operated using hydrogen produced from RES during sunlight hours. When the ship is not sailing, the energy can be used, for example, for water purification and treatment, etc.

STRENGTHS	WEAKNESSES
• Emission-free operation • The possibility of production at the place of consumption (large ships)	• Lower potential in the Czech Republic, limited by the river network, water reservoirs and the necessary completion of infrastructure for shipping
OPPORTUNITIES	**THREATS**
• An attractive pilot project • Given the small number of ships, it would be relatively easy to transform most of this means of transport • Developing interest in a collaborative economy and a positive impact on sustainability and tourism	• A decline in interest in shipping • A rapid development of other alternative fuels (methanol)

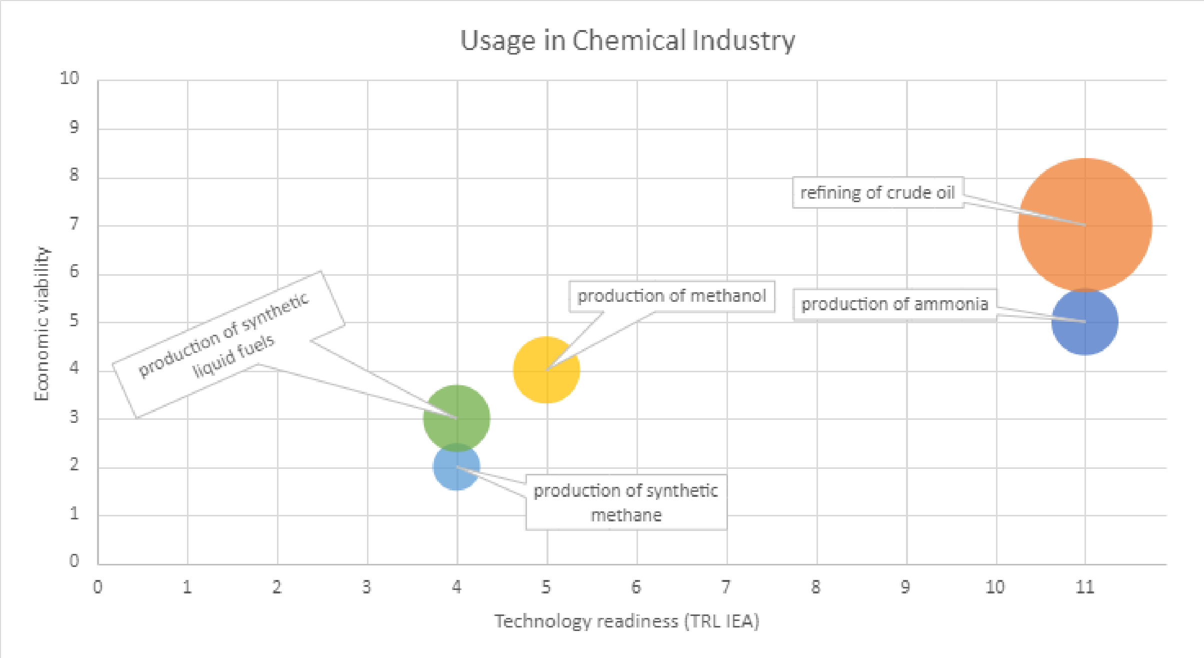
3.1.10 Hydrogen combustion in internal combustion engines

An alternative to using hydrogen in fuel cells is to combust it directly in engines. The fact that the internal combustion engine is an established technology and complete plants do not have to be significantly rebuilt is a definite advantage. Compared to other fuels, hydrogen has a wide flammability range (4-75% by volume). As a result, hydrogen can be combusted over a wide range of air/fuel ratios, even as a very lean mixture. However, partial or minor technological modifications are unavoidable for the transition to hydrogen fuel. The major disadvantages so far include significantly lower efficiency, undesirable NOx emissions, and also a shorter engine life. From an energy point of view, it is not advantageous to combust hydrogen – the calorific value/heat of combustion ratio for hydrogen is 0.83, and the oxidation of hydrogen in internal combustion engines produces steam, which removes 17% of the hydrogen's heat energy (*Chemické listy*). In the transport sector, the use of hydrogen in internal combustion engines has been experimented with by Mazda for some time. In stationary applications, it could be used under the condition that existing equipment in plants that are not feasible would still be operated for a temporary period.

STRENGTHS	WEAKNESSES
• A transitional solution for existing engines without major technological modifications • The option to combust fuel mixtures such as CNG/LPG and hydrogen • Mixtures leaner than fossil fuels can be combusted and there is a lower ignition energy	• Low efficiency – a low volumetric calorific value • A limited-service life (complications with higher thermal stress on the cylinder surface) • It requires engine design modifications • NOx emissions are generated
OPPORTUNITIES	**THREATS**
• For stationary applications, possible use as back-up power supplies	• Much higher fuel cell efficiency

3.2 The chemical industry

The chemical industry is currently the largest producer and consumer of hydrogen. Hydrogen currently produced in the Czech Republic cannot be described as low-carbon because it is produced mainly by steam reforming from natural gas without any CO_2 capture. Even hydrogen produced by electrolysis using electricity from the grid cannot be described as zero-carbon due to the current energy mix. In the chemical industry, large quantities of emission-free hydrogen can be used relatively quickly, with only minimal technology change costs. However, the biggest obstacle is the cost and availability of low-carbon hydrogen.



3.2.1 Ammonia production

Ammonia is one of the most widely produced inorganic chemicals. Worldwide, a total of 190 million tonnes of ammonia is produced annually (*OECD*). A typical modern ammonia plant first converts natural gas, LPG or petroleum diesel into hydrogen gas. The method of producing hydrogen from hydrocarbons is known as steam reforming. Hydrogen is then combined with nitrogen to form ammonia through the Haber-Bosch process. In chemical production, ammonia production accounts for the largest share of hydrogen consumption by far and is likely to continue to do so. The synthesis efficiency is up to 60% (*web.natur.cuni/anorchem*).

The widest use of ammonia is the production of artificial fertilisers. However, ammonia can be used as a temporary form of energy storage where hydrogen is recovered from it as a fuel by an additional process. Ammonia has better properties (lower volume and lower pressure required for liquefaction) for transport. Considerations are emerging for the direct use of ammonia as a fuel. There is some historical experience with its direct combustion from World War II and ammonia fuel cells for large ships and tankers are now starting to appear.

STRENGTHS	**WEAKNESSES**
• It can be easily combined with a hydrogen production process • Easier transport of ammonia	• A low synthesis efficiency (max. 60%) • The toxicity of ammonia • Ammonia stinks
OPPORTUNITIES	**THREATS**
• Wide possibilities for further use of ammonia as a hydrogen carrier • Ammonia cells	• The EU agricultural sector foresees a significant reduction in ammonia use after 2030 • China is the world's largest producer of ammonia • If the taxonomy does not allow the use of hydrogen from sources other than

	RES and nuclear, substitution in industry will not be economically viable

3.2.2 Crude oil refining

Hydrogen is also currently used in the hydrotreating refining of crude oil. During desulphurisation of the distillate diesel fraction, the mixture is mixed with hydrogen and heated to about 350 °C when, in the presence of metal catalysts, hydrogen reacts with sulphur, nitrogen and oxygen compounds to produce hydrogen sulphide, ammonia and water (*petroleum.cz, oenergetice.cz*).

Oil is now being processed at a quality that could not have been processed just a few decades ago. Therefore, all of the world's refineries are forced to use oil of different qualities, with different hydrocarbon contents and higher levels of various pollutants. This can be resolved by constant changes in production technology – one option is to add hydrogen at certain stages of the process. However, it is essential that such hydrogen is low carbon if we are to achieve greenhouse gas reductions.

STRENGTHS	**WEAKNESSES**
• A simple, proven technology that has worked for a century	• Low-carbon hydrogen is more expensive than standard hydrogen • In some cases, it is not clear how emissions savings can be accounted for by using low-carbon hydrogen
OPPORTUNITIES	**THREATS**
• A simple way to reduce overall emissions from gasoline and diesel	• A declining interest in oil • If the taxonomy does not allow the use of hydrogen from sources other than RES and nuclear, substitution in industry will not be economically viable

3.2.3 Methanol production

In addition to the production of synthetic methanol for further use in the chemical industry, the possibility of using methanol directly in fuel cells has also emerged. Methanol is commonly produced from synthesis gas that was previously obtained from natural gas, using steam and autothermal reforming. New production methods make it possible to create synthesis gas by partial oxidation of natural gas, which generates no CO_2 emissions. Subsequent steps, such as methanol synthesis and distillation, can be used almost without any changes. To ensure that carbon contained in CO_2 is not lost and can be reused for methanol synthesis, CO_2 must be brought back to the beginning of the process, for which additional hydrogen is needed.

STRENGTHS	**WEAKNESSES**
• Significant emission reductions with low-carbon hydrogen • Methanol is easier to transport because it is liquid at a normal temperature and pressure	• The combustion of methanol in internal combustion engines is not very efficient • Methanol causes operational damage to parts

	• The use of methanol in fuel cells is still an expensive technology and not well tested • The toxicity of methanol
OPPORTUNITIES • The combination of methanol and fuel cells could be the ideal combination used to power vehicles	**THREATS** • If the taxonomy does not allow the use of hydrogen from sources other than RES and nuclear, substitution in industry will not be economically viable

3.2.4 Synthetic methane production

We can produce synthetic methane from low-carbon hydrogen and captured CO_2. This methane has a similar emissions rating to biomethane produced from waste. Synthetic methane is easier to store and transport than hydrogen and can also be added directly to natural gas in the gas system without any restrictions. However, the production of synthetic methane is costly under current conditions. Synthetic methane costs many times more to produce than conventional methane (natural gas) and, with the exception of the carbon footprint, has exactly the same utility properties as normal natural gas. With the expected future trend of decreasing hydrogen production costs, the cost of synthetic methane production will also decrease.

STRENGTHS	**WEAKNESSES**
• A significant reduction in emissions (with the use of low-carbon hydrogen) • Energy conservation (a low auto-ignition temperature)	• Low efficiency – energy losses around 30% • From today's point of view, high production costs • The need for cheap CO_2 to be captured in other processes
OPPORTUNITIES • Very low investment in infrastructure – existing natural gas infrastructure (transport and storage) and existing end-use appliances can be used	**THREATS** • The advent of more cost-effective sources

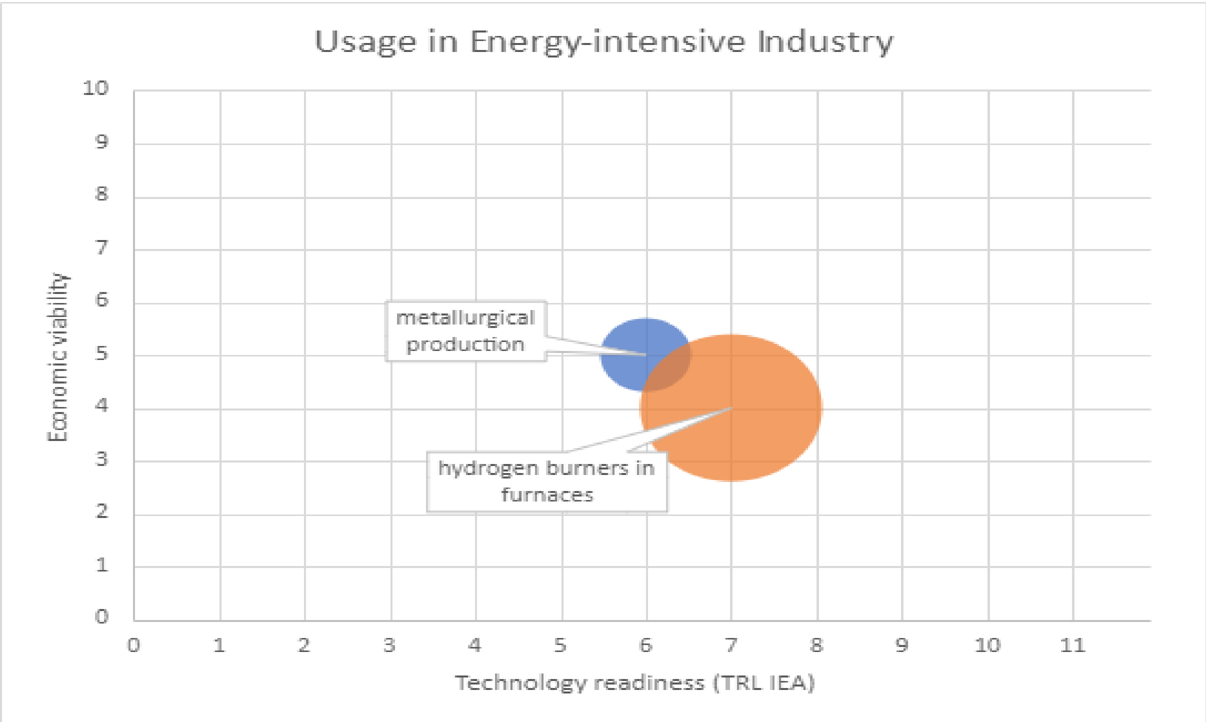
3.2.5 The production of liquid synthetic fuels

One advantage of synthetic fuels is their low emission footprint. Synthetic fuel production facilities require very high investment costs (technology). They require low carbon electricity, water and CO_2 as inputs. The great advantage of liquid synthetic fuels is their high energy content and ease of handling, as they are liquids at a normal pressure and temperature. They can be handled in the same way as diesel or gasoline. They can be used in standard internal combustion engines or aircraft turbines. Aviation applications may be one field of potential development for synthetic fuels. Synthetic hydrocarbons produced in this way can also be feedstock for further chemical processing. However, their high cost is a huge disadvantage. It is also possible to artificially produce short-chain hydrocarbons, which are gaseous at a normal temperature and pressure. These will not be included in the category of synthetic fuels in the Strategy. Methanol, which can also be considered a synthetic fuel, is described in a separate paragraph.

STRENGTHS	WEAKNESSES
• The rapid effect of emissions reduction – no need to build new infrastructure • Free from undesirable impurities • The easy transport of fuels (using the existing infrastructure) • Decarbonisation of the manufacture of plastics • It does not require any substantial additional investments on the consumer's side	• High investment costs • Little experience • Losses (lower fuel production efficiency and lower combustion efficiency) • A high price
OPPORTUNITIES	**THREATS**
• The easy replacement of fossil fuels in transport and aviation	• A reduction in demand for this type of fuel

3.3 Industry

A large proportion of greenhouse gas emissions comes from the combustion of fossil fuels (mainly coal and natural gas) that are used in industry only to produce heat. Hydrogen can be a simple substitute for such fuels. In this case, the biggest constraints are the price of hydrogen and its availability. Technological problems associated with fuel switching in boilers are relatively easily solvable.



3.3.1 Metallurgic production

As steel production is expected to continue to increase globally due to the expected growing demand, it can be assumed that there will be a continued or increasing need for hydrogen as a reducing agent in the steelmaking process where it can replace carbon in the form of coke. The Czech Republic produces about 5 million tonnes of steel every year. So far, coke from hard coal or ground hard coal

(PCI technology) has been used for production. Natural gas is also used in small quantities as a supplementary fuel in the process. The possibility of producing steel by the direct reduction of ores with natural gas is almost excluded in European countries due to the very high consumption of natural gas (the technology is mostly used in Arab countries with rich natural gas deposits). At least 1 tonne of CO_2 can be saved in the production of one tonne of liquid metal by this process. Hydrogen consumption per tonne of steel is assumed to be about 90 kg, which would mean a consumption of 360 000 t of hydrogen per year for a production of 5 million t of steel. Given the increasing pressure to decarbonise the sector, this scenario must be taken into account in the Strategy.

STRENGTHS	**WEAKNESSES**
• Low-carbon substitution of coal is an absolutely crucial advantage, both in terms of emissions and in terms of the future abandonment of coal mining.	• The continued low price of hard coal so far • The need for large amounts of hydrogen • The availability of low-carbon hydrogen • The price of low-carbon hydrogen
OPPORTUNITIES	**THREATS**
• Transformation of the metallurgical industry • The use of hydrogen energy to produce high-potential (technological processes) and low-potential (heating and water heating) heat – steam, electricity, hot and warm water, blown and compressed air, industrial water	• The termination of metallurgical production • Shifting production to countries with less stringent environmental limits

3.3.2 The use of hydrogen for heat production (hydrogen burners in furnaces)

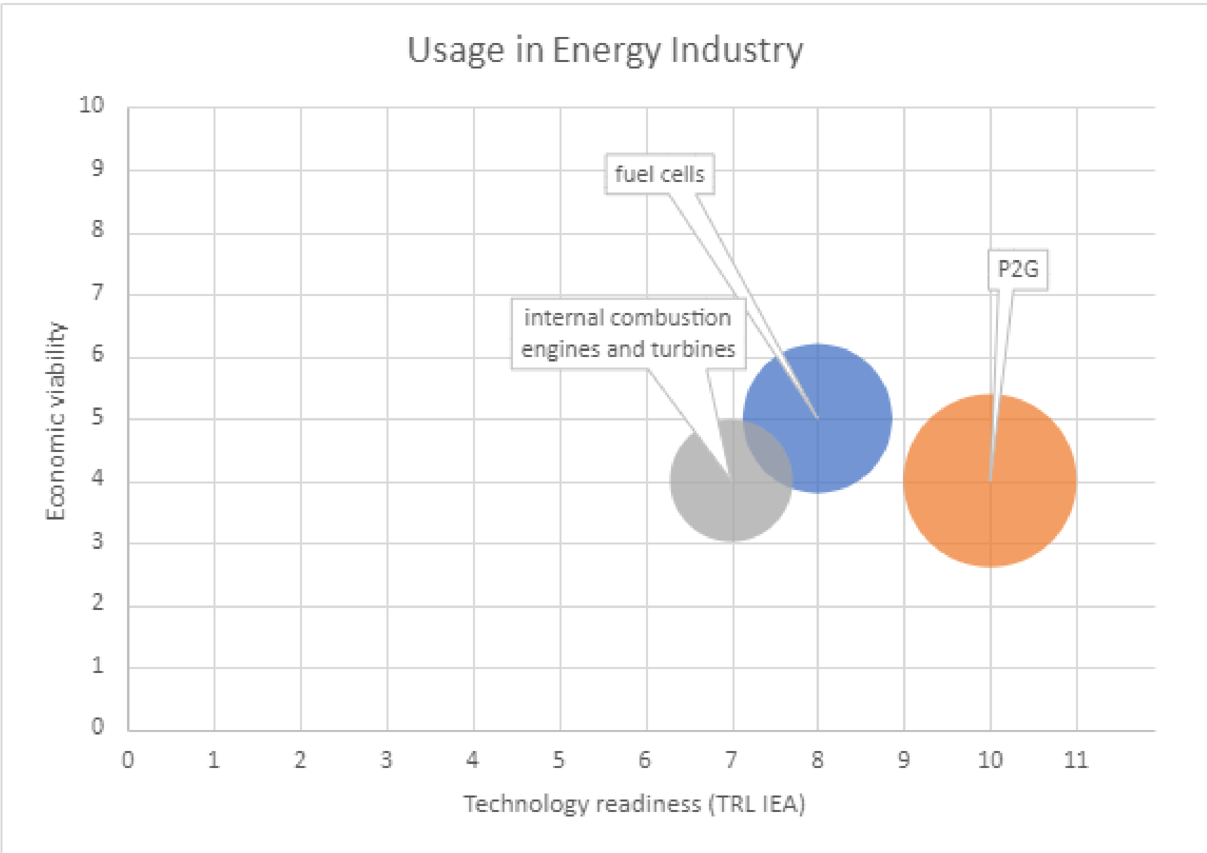
In some countries, there are plans to use hydrogen as a fuel for burning in furnaces to make bricks, lime, cement, and ceramics. There is not much practical experience with this process, but it may have the advantage of reducing emissions in otherwise non-decarbonised production. However, it is important to note that, for example, the production of lime and cement also generates process emissions (2/3 of total emissions), so even the use of hydrogen in these cases will not reduce greenhouse gas emissions to zero.

STRENGTHS	**WEAKNESSES**
• A reduction of emissions	• A lower calorific value • The high price of low-carbon hydrogen • Process emissions are not removed
OPPORTUNITIES	**THREATS**
• Reducing emissions in sectors that would otherwise be very difficult to decarbonise	• A decline in the production of construction materials • Safety risks of storing large quantities of hydrogen

3.4 The energy sector

The energy sector was one of the first areas where the use of hydrogen was considered. Its main role would be in using the surplus electricity produced by solar and wind power plants. The electricity produced in this way could be converted into hydrogen, which would be injected into natural gas pipelines to reduce its emissions footprint. Technologies are currently being developed whereby energy produced from renewable sources could be stored in hydrogen and then used to generate electricity again. This energy storage process (electricity -> hydrogen -> electricity), while highly scalable, has low efficiency. We expect that with the development of new technologies, this efficiency could be further increased. The overall efficiency of the process would improve if we could find a suitable use for the heat generated during the process.

Finding solutions for energy storage at the scale of electricity networks is crucial for the future of renewable energy. 94% of all current storage capacity is pumped storage plants; however, these, including batteries, flywheels and other technologies, have their shortcomings and none of them is yet able to offer a satisfactory solution at a sufficient scale to store large amounts of energy efficiently in the seasonal summer and winter modes.



3.4.1 Power to Gas (P2G)

The Power to Gas process is used to transform electricity into chemical energy, which is bound in gases that are then usable as a medium. The electricity and gas industries are linked in this way. The first step is always the production of hydrogen by electrolysis. From 1 GWh of electricity, almost 18 tonnes of hydrogen can be produced using 159 cubic metres of water.

The hydrogen produced in this way can be added to natural gas pipelines. Based on research conducted abroad, it is possible to inject up to 2% hydrogen into natural gas without any problems. Hydrogen injection reduces the carbon footprint of natural gas combustion but, on the other hand, reduces the calorific value of natural gas, since hydrogen has a calorific value of about one-third at the same pressure. As we do not have any surplus renewable energy in the Czech Republic that we would not be able to apply directly to the electricity network, this technology does not look very promising in the Czech Republic so far. At the same time, it should be tested in the Czech Republic and, based on the results, the relevant standards should be adapted so that, for example, we are ready for natural gas containing added hydrogen which may be imported from abroad. Any produced low-carbon hydrogen is likely to be used more efficiently in the transport or chemical industries than as hydrogen added to the natural gas system.

STRENGTHS	**WEAKNESSES**
• Used to stabilize the transmission system • Increased efficiency • A very low carbon footprint • A simple way to apply surplus low-carbon hydrogen • Injection can be carried out in many locations of the gas network and hydrogen production sites can be located close to the gas network	• So far only pilot projects exist • There is no low-carbon hydrogen available in the Czech Republic that could be injected into the gas network on a large scale • Economic efficiency depends on low electricity prices • The need for a suitable location within easy reach of sufficient electricity, gas and water supplies
OPPORTUNITIES	**THREATS**
• The strategic importance of P2G is attributed to Germany and Austria, countries that have more experience with this technology. There is potential for cooperation and Germany, at least, has expressed its interest in it. • A cheap way to get hydrogen into circulation	• Low effective use of the low-carbon hydrogen produced

3.4.2 The use of hydrogen in combustion engines and turbines for electricity and heat generation

Hydrogen turbines have already been in operation in power plants, but their use in commercial operation is still questionable, mainly due to their low overall efficiency caused by the lower calorific value of hydrogen. The development of hydrogen turbines to date shows that it is possible to design and manufacture turbines for different mixtures of hydrogen and natural gas that can operate as hydrogen fuelled from 0% to 100%. Similarly, it is possible to generate electricity in modified internal combustion engines supplied with hydrogen.

Hyflexpower is a project funded by the European Commission as part of the Horizon 2020 Framework Programme for Research and Innovation. A consortium consisting of Engine Solutions, Siemens, Centrax, Arttic, the German Aerospace Center (DLR), and four European universities are taking part in it. The experimental power plant in France is expected to save 65 000 tonnes of CO_2 per year (*Hyflexpower*).

Burning 1 kg of hydrogen in the same processing plant where natural gas is burned saves about 6.7 kg of CO_2 (*HYTEP*).

STRENGTHS	**WEAKNESSES**
• The technology will often allow for small amounts of hydrogen to be gradually delivered to turbines and engines in a mix with natural gas, with the amounts of hydrogen being gradually increased • A relatively high reduction in CO_2 emissions	• Low energy efficiency • Other sources will continue to compete in price
OPPORTUNITIES	**THREATS**
• Replacement of existing natural gas turbines and a gradual reduction of the emission footprint	• A rapid development of fuel cells that brings greater efficiency in converting hydrogen into electricity

3.4.3 The use of hydrogen in stationary fuel cells for electricity and heat generation

Stationary fuel cell technologies are emerging on the market and allow the supplied hydrogen to be transformed into electricity and heat. The majority of the energy generated is in the form of electricity. This is much more efficient than burning hydrogen in gas turbines. This solution is suitable where there are local sources of low-carbon hydrogen, which can then be used at the precise moment when energy is needed.

Similar stationary fuel cells are used for natural gas.

STRENGTHS	**WEAKNESSES**
• High efficiency • Mainly for electricity production • Quiet operation and no emissions and beyond hydrogen production	• A new technology • The necessity to bring hydrogen to the point of consumption • The maximum electricity supply is limited by fuel cell capacity
OPPORTUNITIES	**THREATS**
• Efficient production of electricity and heat as required on site	• A price comparison with the direct supply of low-carbon electricity

4 HYDROGEN TECHNOLOGIES[9]

In the Czech Republic, the production of technological components and complete plants can also be launched in connection with the development of hydrogen use. These can cover different phases of the hydrogen life cycle, from production through distribution to consumption. When Czech entities focus on technology development, they tend to focus on individual components, typically those that build on the Czech engineering tradition. In some places, production has already started (cylinders), in others it is being considered (components for fuel cells, valves, or entire fuel cells). Czech companies are also slowly getting involved in international cooperation in connection with hydrogen technology.

It is important to note that hydrogen technologies also bring a number of related technological challenges, especially for measuring equipment, safety technologies, various types of batteries, pumps and equipment components.

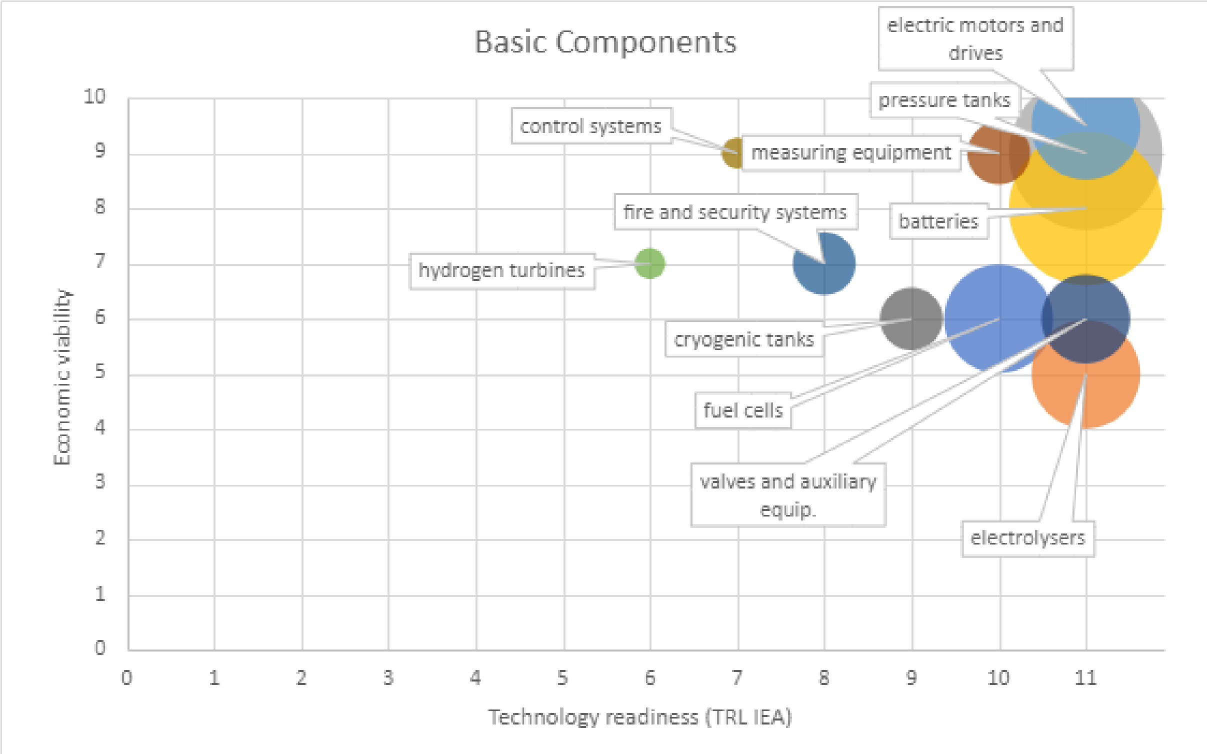
If the production of units can be anticipated for a specific location, then taking into account the Czech tradition in the production of buses, cars and trucks, the Czech Republic would a candidate. However, such production involves considerable uncertainties and the need for high initial investments, and it would necessarily face significant competition from abroad, especially from Asia.

The advantage of manufacturing integrated devices is the possibility to match individual components into a functional unit. Component manufacturers often wait for the technological solutions of downstream parts and develop them directly as needed to suit particular purpose.

Hydrogen technology involves cutting-edge equipment that requires a great deal of research, development and innovation to produce. The production of these technologies is only possible if we develop a research and development base. The work of research organisations, universities and manufacturing companies must be effectively interlinked. Suitable support schemes are listed in Annex 5.

It is necessary that individual components or direct units be available and affordable in the Czech Republic. A secondary objective is that as many components as possible are either manufactured in the Czech Republic or that Czech entities participate in their development. This is the only way to ensure that the Czech Republic remains, to some extent, among the countries that actively influences technological progress in the field of hydrogen.

[9] A detailed description of the method by which the analysis was carried out is provided at the beginning of Annex 1.



4.1 Basic components

4.1.1 Electrolysers

The European Commission envisages installing 40 GW of electrolysers by 2030 as part of the European Hydrogen Strategy. So far, most electrolysers are made in China. China is able to produce electrolysers significantly more cheaply, at up to one-fifth the cost. However, the European market could also benefit from economies of scale in the future with the introduction of the mass production of electrolysers.

Three main methods of electrolysis exist: PEM, alkaline and high temperature. PEM electrolysers are more suitable for operation using electricity from renewable sources. They start and stop faster than alkaline electrolysers. One advantage is the flexibility of the operating temperatures of PEM electrolysers, which range up to 90 °C. Alkaline electrolysers require a temperature of 80 °C and solid oxide electrolysers up to 900 °C.

With regard to intermittent and unstable renewable electricity generation, this is a major advantage.

STRENGTHS	**WEAKNESSES**
• Electrolysis is an essential part of hydrogen production from RES • Demands for new electrolysers will grow very rapidly	• The high price of electrolysers manufactured in Europe and the USA
OPPORTUNITIES	**THREATS**
• The significant development of RES brings the possibility to focus on PEM electrolysers within the EU	• Competitive production mainly in China

4.1.2 Fuel cells

Fuel cells enable emission-free electricity generation. However, the amount of emissions over the entire cycle depends on the source and method from which the hydrogen is produced. The overall cycle efficiency is most commonly estimated at 26%.

Limitations of fuel cells include their slow start, low power, a lengthy response to power change requests, low load resistance, small power range, short lifetime, and high costs. As with batteries, fuel cells decrease in power output over time and the cell pack gradually loses its efficiency (this is particularly noticeable when compared to an internal combustion engine, which shows virtually no loss of efficiency but has lower efficiency from the start).

The functioning of a fuel cell can be described as a process that is contrary to electrolysis.

Currently, the following types of fuel cells are mainly used:

- Polymer Membrane Cell (PEMFC) – transport
- Alkaline Cell (AFC) – military and missile technologies

Other relevant types are:

- Fused carbonate cell (MCFC) – the highest performance and a high price
- Phosphoric Acid Fuel Cell (PAFC) – optimal for CHP units
- Solid oxide fuel cell (SOFC) – universal use
- Methanol direct reaction cell (MCFC) – very low efficiency

So far, European operators see mainly solid oxide fuel cells (SOFC) as the future as they have universal applications and represent the most affordable solution.

Current fuel cells need higher operating temperatures and are expensive due to the necessary presence of platinum or palladium. The development of alternative fuel cells with a much lower operating temperature and lower amounts of precious metals based on photostimulation are envisaged.

STRENGTHS • Demands for fuel cell production will grow rapidly • Different applications will require different types of fuel cells	**WEAKNESSES** • Fuel cells are still very expensive • Some technologies require precious metals in their production
OPPORTUNITIES • An entire industry related to the development, production and maintenance of fuel cells is likely to emerge	**THREATS** • With large segmentation of the fuel cell market, there is a risk of a drop in interest in some types of them • The requirements for fuel cell production can increase dramatically. Companies that are unable to respond quickly enough to these demands will disappear from the market

4.1.3 Hydrogen turbines

Pure hydrogen turbines are still experimental devices that burn hydrogen and convert its energy into motion. Hyflexpower is a project funded by the European Commission as part of the Horizon 2020 programme. A consortium made up of Engie Solutions, Siemens, Centrax, Arttic, the German Aerospace Center (DLR) and four European universities are involved in its implementation. The SGT-400 turbine would save up to 65 000 tonnes of CO_2 per year if used in continuous operation.

Attention is turning to combined cycle turbines, where hydrogen can be used in a mixture with natural gas in the range of 0 to 100%. Manufacturers include Siemens and Centrax.

STRENGTHS	**WEAKNESSES**
• They allow for direct hydrogen combustion where a fuel cell cannot be used • Significant emission savings	• Experimental operation only • Unclear effectiveness
OPPORTUNITIES	**THREATS**
• Combined turbines	• Fuel cells can dominate most of the market due to their greater efficiency

4.1.4 Electric motors and drives

Hydrogen-powered vehicles are essentially electric vehicles with a “hydrogen battery” that can store significantly more energy than a conventional battery. Electric motors are actually used to propel hydrogen-powered vehicles, using the energy generated in fuel cells.

A number of electric motors for hydrogen propulsion face technical challenges involving the size or space in the device, as well as the rate of speed (design problems are manifested at high speeds). Electric motors designated for hydrogen propulsion will need to be developed for specific locations; on the other hand, the production technology can flexibly respond to developments in other areas.

STRENGTHS	**WEAKNESSES**
• Use for multiple drive types – versatility • There are a lot of players on the market • Tradition in the Czech Republic	• When hydrogen is used, the overall efficiency is lower than other propulsion systems
OPPORTUNITIES	**THREATS**
• A universal use of the production line if another technology is developed	• The advent of completely new technologies where the form of the electric motor would not be relevant. However, this is not likely to happen.

4.1.5 Batteries

A battery is an essential part of a hydrogen or electric vehicle. A battery must always be present in a hydrogen vehicle and is used to quickly compensate for energy requirements when the fuel cell is not able to respond as quickly. A battery is also used to recover electrical energy during braking, thereby increasing the efficiency of operation. However, current batteries have an unfavourable power-to-weight ratio, so hydrogen is used to significantly increase the range of vehicles.

STRENGTHS	WEAKNESSES
• Universal use for electric vehicles, hydrogen propulsion and other devices	• Heavy weight and a short battery life without recharging • Slow recharging • A limited number of recharge cycles
OPPORTUNITIES	**THREATS**
• An advantage if both electromobility and hydrogen technologies are developed	• A lack of materials for production (especially the availability of precious metals)

4.1.6 Valves and auxiliary equipment

The use of hydrogen places special demands on the tightness of the equipment. Hydrogen causes steel to become brittle so special requirements must be placed on valves, pressure lines and other auxiliary equipment and their manufacture requires precise technological procedures. Hydrogen equipment such as electrolysers and fuel cells also include a wide variety of pumps, heat exchangers, water and air purifiers, all which represent great potential for various manufacturers.

STRENGTHS	WEAKNESSES
• Hi-Tech manufacturing with high added value	• Demands on the production and quality of alloy steel • The need for special knowledge and technological procedures
OPPORTUNITIES	**THREATS**
• The development of hydrogen technology will require a large number of different auxiliary devices. • A high demand potential	• Security aspects

4.1.7 Pressure vessels

Pressure vessels can be used for both stationary and mobile hydrogen storage. For static applications, seamless low carbon or alloy steel cylinders are typically used. They are manufactured in a range of volumes depending on the intended use. In mobile applications, composite pressure vessels are typically used. These are made in volumes from tens of litres up to approximately 300 litres. The typical operating pressure is 350 bar, with 450 to 700 bar in the latest applications (the current technological limit is 1 000 bar).

12-metre-long cylinders with an outer diameter of about 80 centimetres can be used as storage tanks for filling stations for hydrogen-powered vehicles or as storage tanks for surplus energy from RES.

STRENGTHS	WEAKNESSES
• Proven technology • Increasing hydrogen storage requirements	• Security aspects • Technological limits (pressure, material, volume)

• Suitable for storage of smaller quantities and irregular deliveries	
OPPORTUNITIES • With the development of hydrogen technology, hydrogen storage requirements will increase dramatically	**THREATS** • Developing technologies that will not require high-pressure hydrogen for storage and transport

4.1.8 Cryogenic tanks

Cryogenic liquid hydrogen tanks are another form of hydrogen storage. Compared to pressure vessels, they allow for much larger quantities of hydrogen to be stored. The main disadvantage of this technology is the huge energy requirements for liquefying hydrogen and keeping it at an extremely low temperature. Hydrogen storage in liquid form also results in gradual evaporation.

STRENGTHS	**WEAKNESSES**
• The ability to store large amounts of hydrogen	• Security aspects • The energy intensity of liquid hydrogen storage
OPPORTUNITIES • With the development of hydrogen technology, hydrogen storage requirements will increase dramatically	**THREATS** • The development of technologies that will not require cryogenic hydrogen for storage and transport

4.1.9 Measuring equipment

Reliable and efficient hydrogen sensors and other measuring equipment are essential to ensure the versatile use of hydrogen technology. The use of hydrogen in fuel cells requires high purity, which places high demands on the analytical methods that must control the quality of produced hydrogen. Hydrogen containing too many impurities would cause permanent damage to the fuel cell. Measuring equipment and sensors are extremely important to ensure the safety, reliability and efficiency of hydrogen plant operations.

STRENGTHS	**WEAKNESSES**
• A very fast-developing technology • Versatile use in various hydrogen processes	• Advanced methods are still very costly in terms of investment
OPPORTUNITIES • A very fast growing area; without adequate measuring equipment, it will not be possible to develop hydrogen technologies	**THREATS** • Competition outside Europe

4.1.10 Control systems

The control system of the process involving energy production from the source (fuel cell, vessel, pipeline) to emission control is a crucial link in the chain that can influence the overall efficiency and emission savings. Precise balancing and control of the purity of inputs is essential in hydrogen technology. Control systems are a decisive added value for complete delivery units (see below).

STRENGTHS	**WEAKNESSES**
• They can significantly affect the efficiency of the entire system	• They are not yet made in the Czech Republic • High investment costs (research) • A long experimental phase
OPPORTUNITIES	**THREATS**
• Equipment necessary for the efficient functioning of a hydrogen eco-system	• Competition outside Europe

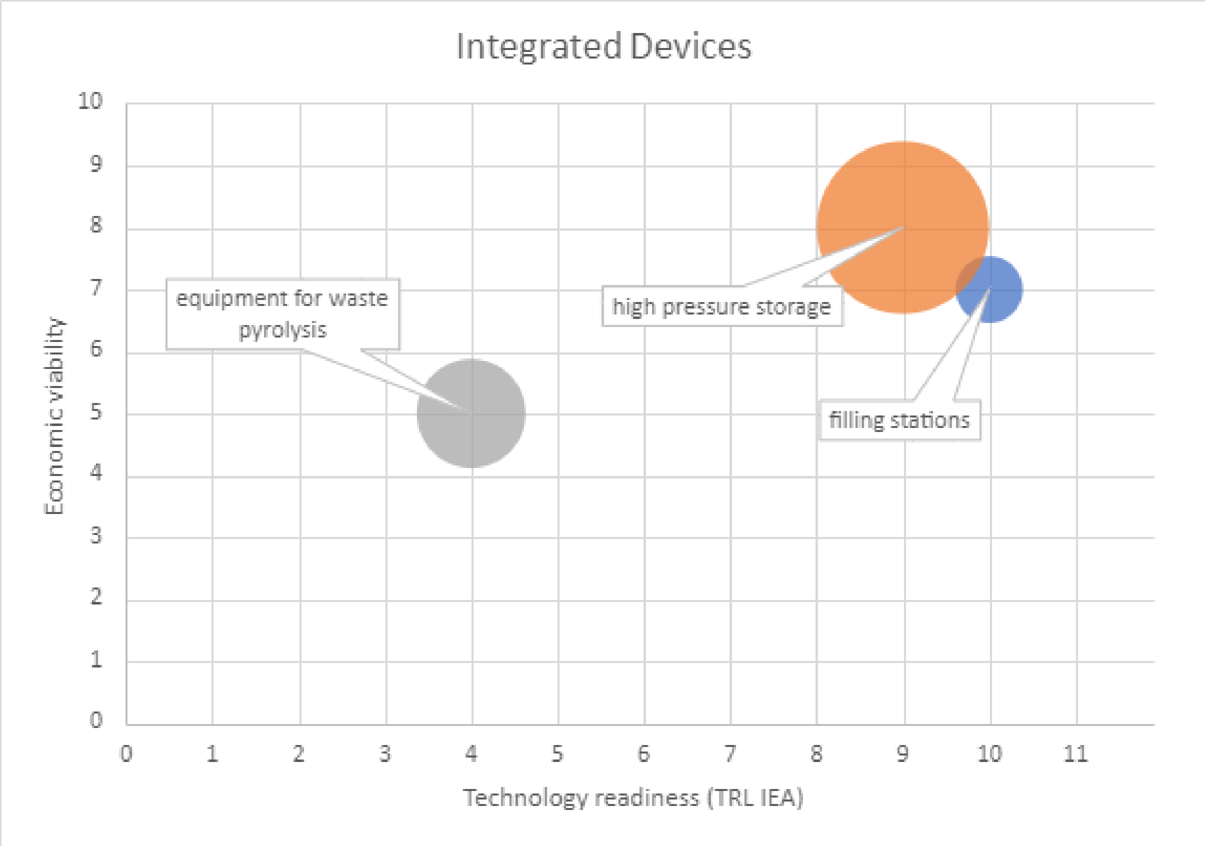
4.1.11 Fire and security systems

The production, distribution and consumption of hydrogen will require innovation in safety and security systems. Based on the utilisation of existing production, distribution and storage technologies, there is extensive experience in handling other gases and much of this know-how can be applied to hydrogen, which has a number of additional unique requirements. New technologies need to be very closely combined with safety standards and staff training. Fire and safety systems will need to keep pace with the rapidly developing hydrogen technologies.

STRENGTHS	**WEAKNESSES**
• An existing tradition in the Czech Republic • Similar technologies to secure other gases (e.g. methane)	• Hydrogen technologies by themselves are expensive. Safety measures and development can make them even more costly
OPPORTUNITIES	**THREATS**
• Demand for these systems that are necessary for the safe development of hydrogen technologies	• A rapid development of hydrogen technologies, without perfect safeguards, can slow down further development in the event of an accident

4.2 Integrated devices

They cover units consisting of several technological components, with the exception of transport equipment, which is covered in a separate section.



4.2.1 Filling stations

The first public filling stations are now being built in the Czech Republic. Individual entities carrying out the construction typically already have experience with the construction of CNG, LNG and biomethane filling stations. Many more public and non-public filling stations are expected to be built in the context of the NAP CM. Filling stations will be given strategic importance, as their development must go hand in hand with the development of hydrogen mobility.

STRENGTHS	WEAKNESSES
• Using experience from the construction of CNG and LNG stations • Opportunities for international cooperation	• A new technology • Security aspects • High initial investment
OPPORTUNITIES	**THREATS**
• filling stations will be of strategic importance for planning further hydrogen mobility activities	• A lack of hydrogen vehicles on the market

4.2.2 High pressure storage facilities

High quality and technologically advanced large volume hydrogen cylinders are produced in the Czech Republic. High-pressure large dimension storage facilities currently exist in Germany (Mainz).

However, they only make economic sense if they are located at the point of hydrogen production by electrolysis or at the point of high consumption that cannot be served by pipelines.

STRENGTHS	**WEAKNESSES**
• Storing large amounts of hydrogen in a small space	• High investment intensity • It only makes economic sense at the point of mass production or consumption • Requires hydrogen compression and an energy loss
OPPORTUNITIES	**THREATS**
• A strategic area absolutely necessary for the further development of hydrogen technologies • Economy of scale	• Security aspects

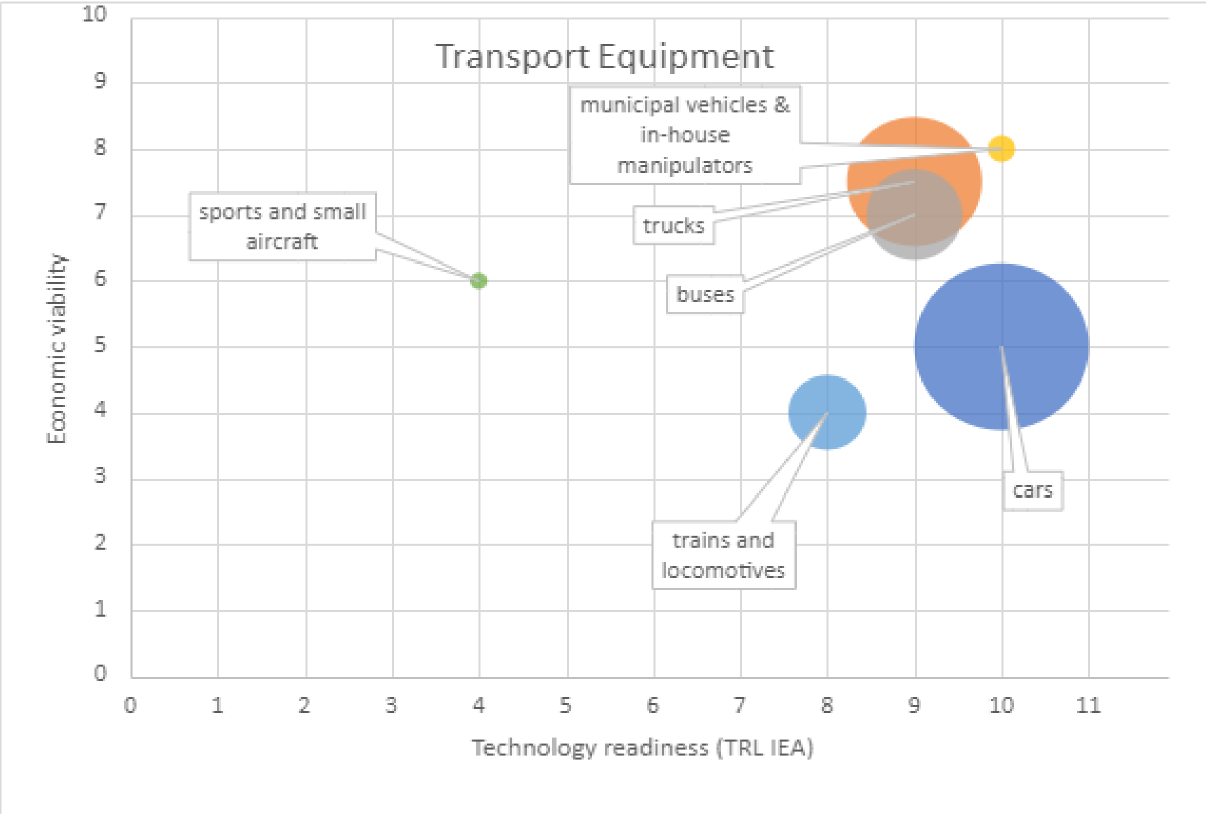
4.2.3 Waste pyrolysis and plasma gasification equipment

In many countries (Germany, France, the Netherlands, Norway, the USA, Australia), a great deal of attention is being paid to projects aimed at producing hydrogen from residual organic compounds in waste. New technical challenges are emerging in the deployment of these systems, especially in the form of additional waste products generated by pyrolysis. These can be found in all states of matter, and finding a relevant use for them will be a major challenge. The results are also strongly dependent on the composition of the input waste, which in many cases is very difficult to influence. It is also difficult to quantify the emission footprint of the whole plant. As with all integrated devices, there is a certain advantage in manufacturing the entire plant where the technical requirements of individual components can be matched. In the case of a complex plant with many inputs and outputs, the advantage of integrity is even more apparent.

STRENGTHS	**WEAKNESSES**
• Energy recovery of waste – raw materials for which a company is willing to pay for disposal • Good energy efficiency	• A complicated technology involving several phases • A problem with different waste composition • Greenhouse gases can also be an output, and they need to be eliminated
OPPORTUNITIES	**THREATS**
• The use of new materials whose waste would be rich in hydrogen • Growing pressure to maximise energy recovery from waste • Exports to Eastern Europe, the Middle East (where waste-to-energy is practically not used)	• A decrease in demand for soot and other waste products from waste pyrolysis (actual)

4.3 Transport equipment

The use of hydrogen in transport is a priority area. The greatest obstacles to this development are the high cost of hydrogen vehicles and the lack of infrastructure. It is expected that as the number of manufactured vehicles increases, their price will gradually decrease and should reach that of internal combustion vehicles in the future. The Czech Republic has a huge tradition of developing and producing motor vehicles. The production of hydrogen-powered vehicles could help transform the future of the Czech automotive industry.



4.3.1 Passenger cars

It is assumed that no domestically produced hydrogen cars will be built for the Czech market, at least not in the initial stages. However, over the short term, there has already been the possibility of cooperation and involvement in the creation of complete passenger cars targeting foreign markets.

Both electric battery vehicles and hydrogen powered vehicles are being developed in connection with emission-free individual passenger transport. Each group has its advantages and disadvantages and it appears that both groups will continue to work side by side in the future.

STRENGTHS	WEAKNESSES
• Tradition of the automotive industry in the Czech Republic • Individual components can be easily manufactured in the Czech Republic	• Competition from abroad already has a significant lead • Large foreign producers may seek to produce within their own territory

	• The lower purchasing power of the population in the Czech Republic compared to Germany and Austria • Dependence on subcontracting • Declared support by the largest Czech car manufacturer for electromobility
OPPORTUNITIES • Cooperation with large manufacturers abroad • Export opportunities to countries where the Czech automotive tradition is already established	**THREATS** • A rapid development of electric battery vehicles and other alternative fuels

4.3.2 Trucks

As the replacement of diesel with hydrogen is probably the most advantageous of all the options for deploying hydrogen technology, the production of hydrogen trucks also appears to be a promising sector. In the future, a large number of existing fossil fuel trucks will have to be replaced. For a number of reasons, this is where hydrogen mobility could find a major application. For long-distance freight transport, LNG technology is currently the most widely available alternative propulsion technology with a range of more than 1000 km, which is sufficient even for heavy truck transport. Hydrogen propulsion can smoothly replace this technology. Therefore, it is appropriate to prepare support for the introduction of hydrogen in freight transport to overlap and build on the support of LNG technology, which according to the current selection of vehicle manufacturers, will dominate until about 2030.

STRENGTHS • A tradition of truck manufacturing in the Czech Republic • Freight transport is one of the first areas with great potential for hydrogen deployment • Hydrogen propulsion can replace and build on gas (LNG) propulsion	**WEAKNESSES** • Components remain very expensive • More complex vehicle operation, more fuel system maintenance • Unknown purchase prices of vehicles, more complex investment decisions
OPPORTUNITIES • Hydrogen-powered trucks will have to be used to achieve the planned emission targets • Emission limits for truck manufacturers will speed up hydrogen vehicle development and deployment	**THREATS** • Freight transport stopping (unrealistic, but could happen with the arrival of another pandemic) • A rapid development of railway and river freight transport • A lack of filling station infrastructure • A lack of a clear government strategy in terms of support for the introduction of hydrogen-powered vehicles and the prospect of hydrogen taxation over a 10-year investment horizon

4.3.3 Buses

Replacing diesel with hydrogen also favours buses for city and regular public services. The Czech Republic is a major producer of buses, and in fact is the most successful in Europe on a per capita basis. It would be possible to take advantage of this tradition and build on it. Planning hydrogen consumption for buses is also much easier than for any other transport segment. Buses allow hydrogen production to be easily aligned with planned consumption, and hydrogen filling is concentrated in one place. Hydrogen-powered buses are already being made in a number of countries. There is more practical experience with the production and operation of hydrogen buses than with hydrogen trucks. A prerequisite for the use of hydrogen buses is the construction of filling station infrastructure.

STRENGTHS	**WEAKNESSES**
• Bus transport is one of the first sectors for large-scale hydrogen deployment • A tradition of bus manufacturing in the Czech Republic – currently the largest production per capita in the EU • A prestigious thing, hydrogen-powered city and public buses will be highly visible and people are likely to appreciate their quiet and emission-free operation	• Strong competition from foreign companies that have already started production • A lack of filling station infrastructure
OPPORTUNITIES	**THREATS**
• Both battery and hydrogen bus services will have to be used to achieve the planned emission targets • For the vast majority of people, hydrogen buses may be the only hydrogen technology they may come into personal contact with in the near future • A government bill on the promotion of low-carbon vehicles through public procurement and public passenger transport services (No. 1121 currently in the Chamber of Deputies of the Czech Parliament, transposition of the EU directive) will require that public contracting authorities procure a specified proportion of low-emission vehicles when awarding above-limit public contracts and public passenger transport services.	• A hypothetical rapid development of other forms of transport (railway, airplanes) •

4.3.4 Handling equipment (forklift trucks, etc.), municipal equipment and work machines

The manufacturing of forklifts and handling equipment for warehouses, logistics centres and similar facilities has already begun in the Czech Republic. Experience gained to date is not extensive, but for logistics centres, hydrogen-powered forklifts can be an attractive option because of their long range, fast filling and the possibility to operate them in confined spaces.

STRENGTHS	WEAKNESSES
• Attractiveness for companies with limited space • High hygiene standard • Fast filling	• Little experience thus far • A small market in the Czech Republic
OPPORTUNITIES	**THREATS**
• The existence of a large number of logistics centres in the Czech Republic • The possibility of international expansion	• A rapid emergence of other technologies

4.3.5 Hydrogen-powered railway vehicles

The manufacturing of hydrogen-powered railway units and traction vehicles is a very extensive and investment-intensive process. However, hydrogen-powered railway vehicles can be one of the few solutions to decarbonisation for lines where electrification is not cost-effective, as well as for shunting. To deploy hydrogen-powered railway vehicles, a system of filling stations and related infrastructure needs to be built. Supplying the infrastructure appears to be easier than supplying filling stations on the roads.

STRENGTHS	WEAKNESSES
• Use on non-electrified lines • The issue of very heavy hydrogen cylinders is not as critical in railway transport as in road transport	• High capital intensity for the construction of filling stations, hydrogen distribution and hydrogen-powered railway vehicles • Non-existent infrastructure of hydrogen filling stations on railways
OPPORTUNITIES	**THREATS**
• Shunting at stations – especially where electrification is limited or non-existent • Use on lines where electrification is currently not economically efficient or not realistic in the foreseeable future (e.g. areas without any connection to an electrified railway) • Neighbouring countries (Germany, Austria) will soon have more extensive experience.	• Reduction of railway transport

4.3.6 Sport and small aircraft

Under the Czech conditions, large transport aircraft will not be produced, but given its manufacturing tradition, the production of small aircraft for sport, meteorological, agricultural and other purposes is not excluded.

STRENGTHS • Tradition in the Czech Republic	**WEAKNESSES** • A small market in the Czech Republic
OPPORTUNITIES • Opportunities for export	**THREATS** • Other competing solutions

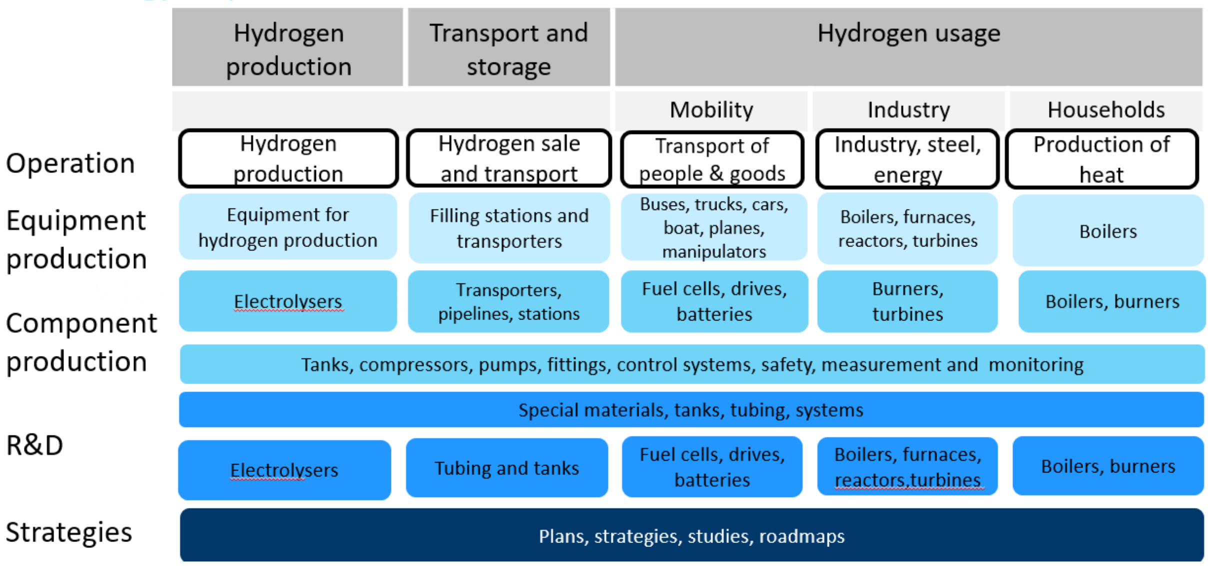
5 SUPPORT OPTIONS

One of the tools to support achieving the objectives set out in this Strategy is the appropriate targeting of support programmes. Primarily, we would like to use existing schemes and programmes. We believe that there are more advantages both for applicants and the organisations providing support by using specialised processes and programmes for which financial resources are allocated or planned. Unless absolutely necessary, we do not want to create any special programmes to support the Hydrogen Strategy. On the contrary, we would like to establish closer links between the programmes and the objectives of the Hydrogen Strategy so that any calls are made in line with the priorities of the Hydrogen Strategy. When modifying the support system, it is imperative to proceed with knowledge of the original intent and objective of the existing support and make sure that once it has been extended to hydrogen, it can still be used for its original purpose (e.g. the support for biogas production, which has a number of limitations).

For each area, we have prepared a technology map that corresponds to the four pillars of the Hydrogen Strategy. The production, transport, storage and use of hydrogen form the pillars of this map, and the individual technologies are then assigned to these two columns according to their life cycle. If a programme supports an area, it is highlighted in red on the map; light red indicates that the programme only partially covers that area.

The aim of this analysis is to identify whether there are areas that are currently not covered sufficiently or not at all by the support programmes. Where such areas are identified, we need to update the relevant programmes to align them with the agreed-to priorities.

Technology map



Information on the relevant programmes is characterised by the following information:

- Main focus

- Providing organisations
- Link
- Period
- Method and intensity of aid
- Restrictions
- Technological map

5.1 Programmes of the Technology Agency of the Czech Republic

5.1.1 Transport 2020+

Main focus: Modernising the transport sector with regard to sustainability, safety and societal needs

The main themes of transport research, development and innovation – sustainable transport, interoperable transport, safe transport, economic transport, intelligent transport, and spatial data in transport.

Four essential elements: (1) transport infrastructure, (2) the means of transport, (3) transport users, and (4) the actual management of traffic and the transport process

Priorities:

1. "A competitive knowledge-based economy"
2. "Sustainability of energy and material resources"
3. "Environment for the quality of life".

Priorities identified in RIS 3 - Automotive; Railway and rolling stock, and Aerospace. The research specialisation corresponds to the knowledge domains identified by the National RIS3 Strategy.

Specific goals: Accessible and interoperable transport; Sustainable transport – increasing the efficiency of existing vehicle drive units and searching for hybrid and combined drives

Providing organisation: TA CR (MT)

Link: www.tacr.cz/program/program-doprava-2020/

Period: 2020–2026

The first competitive tender in 2019, with support starting in 2020. Further competitive tenders are expected to be launched in 2020, 2021 and 2022. The expected duration of projects under the Programme is 36 months, with a maximum duration of 48 months.

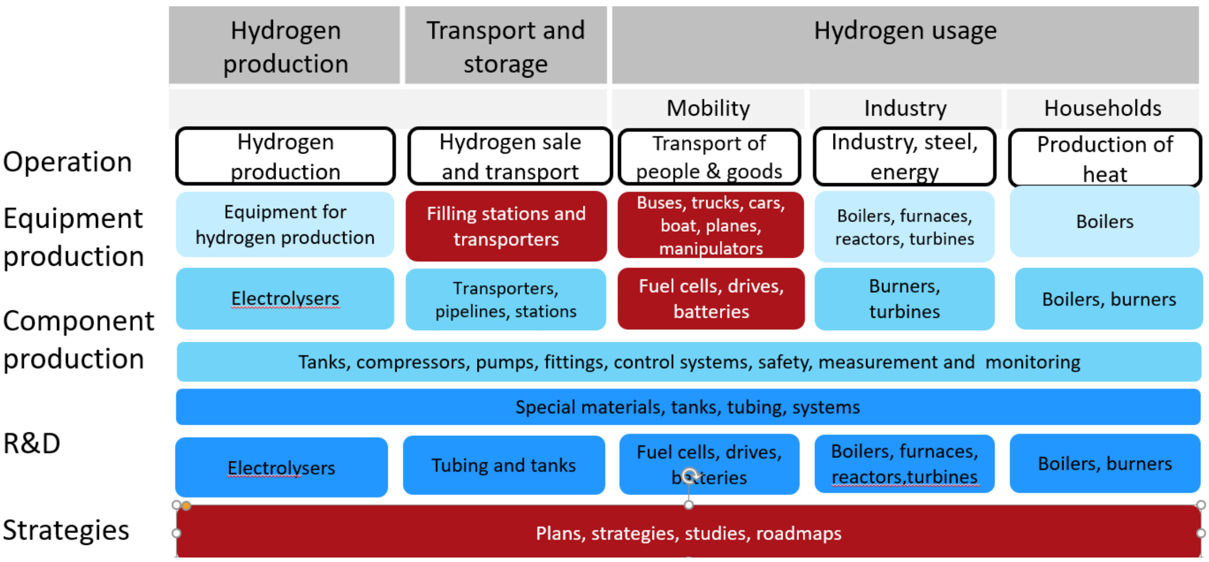
The method and intensity of aid:

Estimated intensity per programme: 80%; maximum intensity per project 100%.

Restrictions:

The aid will be provided in the form of a subsidy to legal or natural persons or by increasing the expenditures of organisational units of the state, organisational units of territorial self-government units, or organisational units of ministries.

Technology map



5.1.2 Theta

Main focus: Contribution to the vision of energy sector transformation and modernisation in accordance with the approved strategic materials. This objective will be achieved through support for research, development and innovation in the energy sector with a focus on:

1. support for projects of public-interest research;
2. new technologies and system elements with high potential for rapid application in practice;
3. promoting long-term technological perspectives.

Sub-programme 1: Public-interest research

Sub-programme 2: Strategic energy technologies

Sub-programme 3: Long-term technological perspectives (2021 will be the last year of competitive tenders in Sub-programme 3)

Links to the State Energy Policy of the Czech Republic (2015), the National Action Plan for the Development of Nuclear Energy in the Czech Republic, the National Action Plan for Smart Grids, the National Action Plan for Clean Mobility, the National Action Plan for Energy Efficiency of the Czech Republic, the Action Plan for Biomass in the Czech Republic 2012-2020, and the Multiannual Programme for the Promotion of Further Application of Sustainable Biofuels in Transport for the 2015-2020 Period .

Provider: TA CR (sponsored by MIT)

Link: https://www.tacr.cz/program/program-theta/

Period: 2018 to 2025

A competitive tender in applied research and experimental development and innovation was announced for the first time in 2017. A competitive tender is planned to be announced every year thereafter from 2018 to 2023. The maximum duration of projects under this programme is set at 8 years. On average, projects can be expected to last 36 months as a rule.

The method and intensity of aid:

Average aid intensity per programme: 70% (large enterprises up to 50%, SMEs more, research organisations up to 100%).

Maximum aid intensity allowed for industrial research and experimental development is determined by the category of the participant:

- A small- or medium-sized enterprise is defined as set out in Article 2(2) and Annex 1 of the Regulation and a large enterprise is defined as set out in Article 2(24) of the Regulation.
- A research organisation is defined under Article 2(83) of the Regulation. This aid intensity is intended for the non-economic activities of research organisations.
- Aid to large enterprises for process and organisational innovation is compatible only under the conditions set out in Article 29(2) of the Regulation.

Types of projects:

The programme aims at supporting projects that fall into the category of applied research under Art. 25 (2) b) and c) of the Regulation and Art. 1.3 e) of the Framework (including industrial research, experimental development or a combination of both), the results of which have high potential for application in many areas of the social life of the Czech population. The projects may result in patents, technically implemented results, prototypes, functional samples, industrial and utility models, semi-operation, as well as certified methodologies, etc.

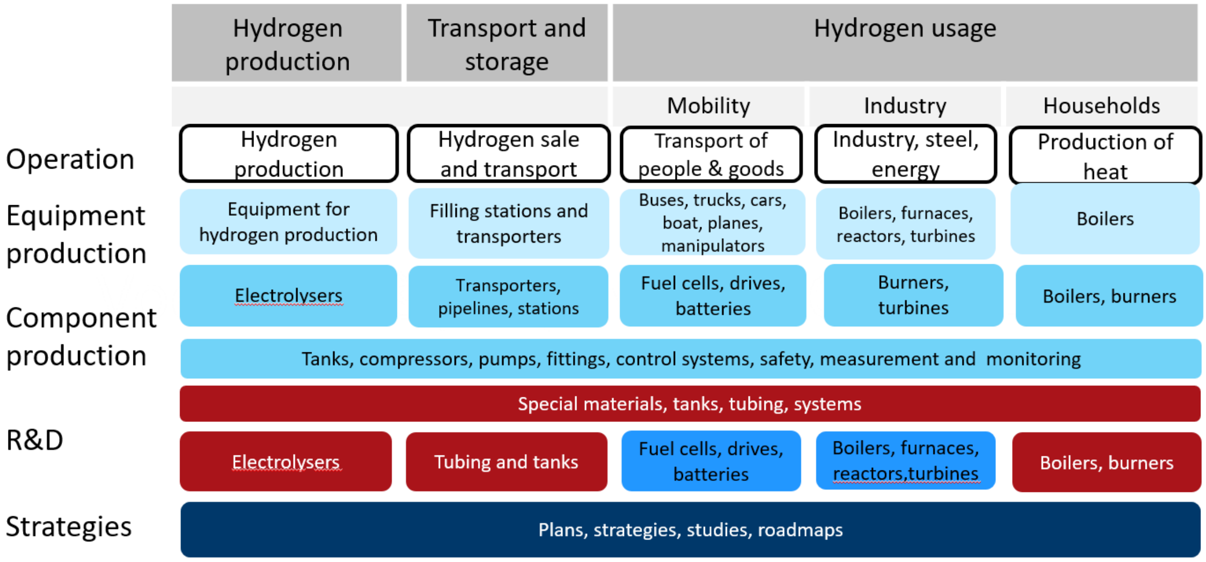
Applicants:

Applicants or beneficiaries of project support in all sub-programmes under the Act on Support for Research, Experimental Development and Innovation, the Framework and the Regulation may include: enterprises, research organisations and other natural and legal persons.

Programme budget:

Total expenditure (CZK): 5.7 billion, state budget expenditure: 4 billion, non-public resources: 1.7 billion.

Technology map



5.1.3 Trend

Main focus: Results with potential for competitiveness – new products, production processes and services

The programme is based on the National Policy of Research, Development and Innovation of the Czech Republic 2016-2020, the National Priorities of Oriented Research, Experimental Development and Innovation, the RIS 3 Strategy of the Czech Republic, and the Industry 4.0 Initiative.

Sub-programme 1: Technology leaders (successful past beneficiaries)

Sub-programme 2: Newcomers (a significantly smaller portion of the budget)

Providing organisation: TA CR (MIT)

Link: https://www.tacr.cz/program/program-trend/

Period: 2020 to 2027

The first competitive tender was in 2019 with the provision of aid from 2020. Subsequently, competitive tenders will be announced annually between 2020 and 2023, with the provision of aid starting between 2021 and 2024. The expected duration of projects in the Programme is a maximum of 60 months.

The method and intensity of aid:

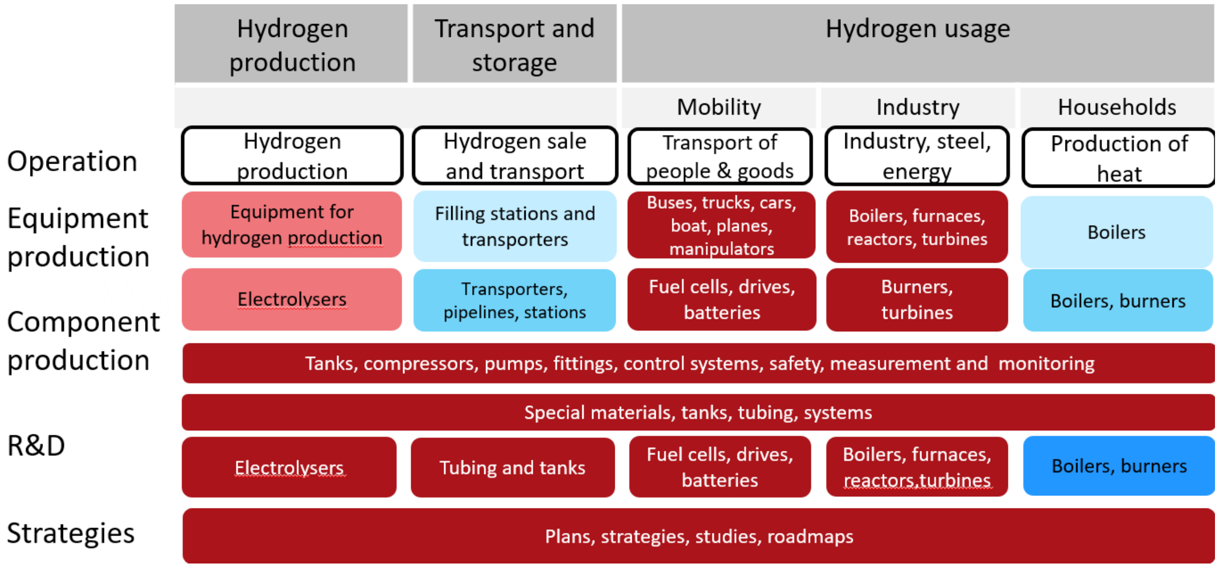
The maximum support per project can be:

- 70% of the total eligible costs of the project in sub-programme 1,
- 80% of the total eligible costs of the project in sub-programme 2.

Restrictions:

Applicants or beneficiaries of project support in all sub-programmes under the Act on Support for Research, Experimental Development and Innovation, the Framework and the Regulation may include: enterprises, research organisations and other natural and legal persons.

Technology map



5.1.4 Environment for life

Main focus: A healthy and quality environment and sustainable use of natural resources

OP E 2030 priorities with a view to 2050

In order to improve the quality of environmental protection in the Czech Republic and to fulfil the obligations assumed by the Czech Republic in this area within the European Union and international conventions, applied research, experimental development and innovation will focus on the priority thematic areas of the State Environmental Policy, i.e. the protection and sustainable use of natural resources, climate protection and improvement of air quality, improvement of waste management and its use, protection of nature and the landscape, and a safe and resilient environment, including the prevention and reduction of the consequences of natural and anthropogenic hazards.

Other departmental strategies – hydrogen can be related to several of them (air, drought)

Areas:

1. Climate
2. Air
3. Waste management
4. Protection of water, soil and subsoil
5. Biodiversity
6. An environmentally friendly society, a safe and resilient environment, specific tools for environmental protection and sustainable development

Except for the Waste Management field, all areas are mainly projects resulting in a plan, strategy, methodology, etc. There is very rarely a tangible result.

Specific goals:

1. Contribute to adaptation to climate change and to the implementation of cost-effective mitigation measures

2. Contribute to the improvement of environmental components and promote the implementation of circular economy principles

3. Promote a resilient and safe society and nature

Providing organisation: TA CR (MoE)

Link: https://www.tacr.cz/program/program-prostredi-pro-zivot/

Period: 2020–2026

A competitive tender for the selection of projects will be launched for the first time in 2019, with support starting in 2020. Subsequently, it is planned to announce competitive tenders annually between 2020 and 2024.

The method and intensity of aid:

The average aid intensity for the whole programme is 85%. The allocation for the entire programme is CZK 900 million, with CZK 135 million allocated under the fourth competitive tender.

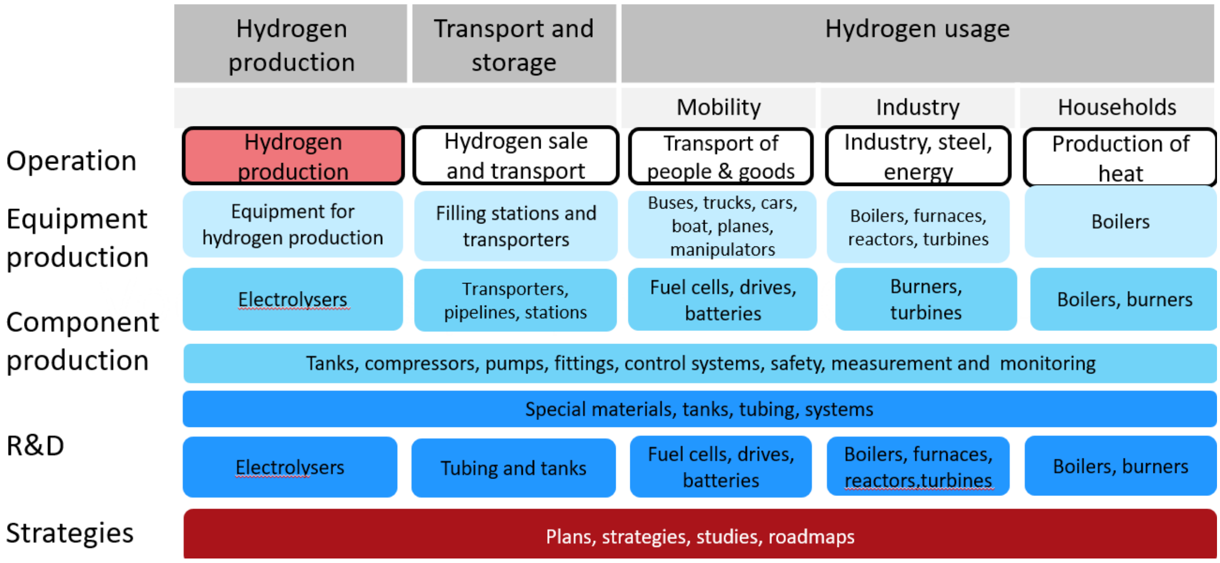
Types of projects:

Projects in the field of alternative fuels, clean mobility and climate protection are oriented towards strategies, comprehensive assessments and more general documents that can be used at the level of the Czech Republic and its regions. Projects focusing on waste treatment technologies could also cover the practical level – the purchase of incineration equipment.

Restrictions:

Applicants or beneficiaries of project support in all sub-programmes under the Act on Support for Research, Experimental Development and Innovation, the Framework and the Regulation may include: enterprises, research organisations and other natural and legal persons.

Technology map



5.1.5 Delta 2

Main focus: A programme supporting applied research, experimental development and innovation

Increasing the number of tangible results of applied research in areas where there is a consensus with a foreign partner, which will be successfully implemented and help strengthen the competitiveness of participating companies and research organizations by supporting bilateral or multilateral cooperation between Czech and foreign participants.

Priority countries (current status): Canada, Brazil, China, Korea, Taiwan, Israel, Vietnam

Providing organisation: TA CR

Link: https://www.tacr.cz/program/program-delta-2 /

Period: The duration of the programme is foreseen to run from 2020 to 2025. A competitive tender was first announced in 2019. Subsequently, competitive tenders are planned annually from 2020 to 2023.

The method and intensity of aid:

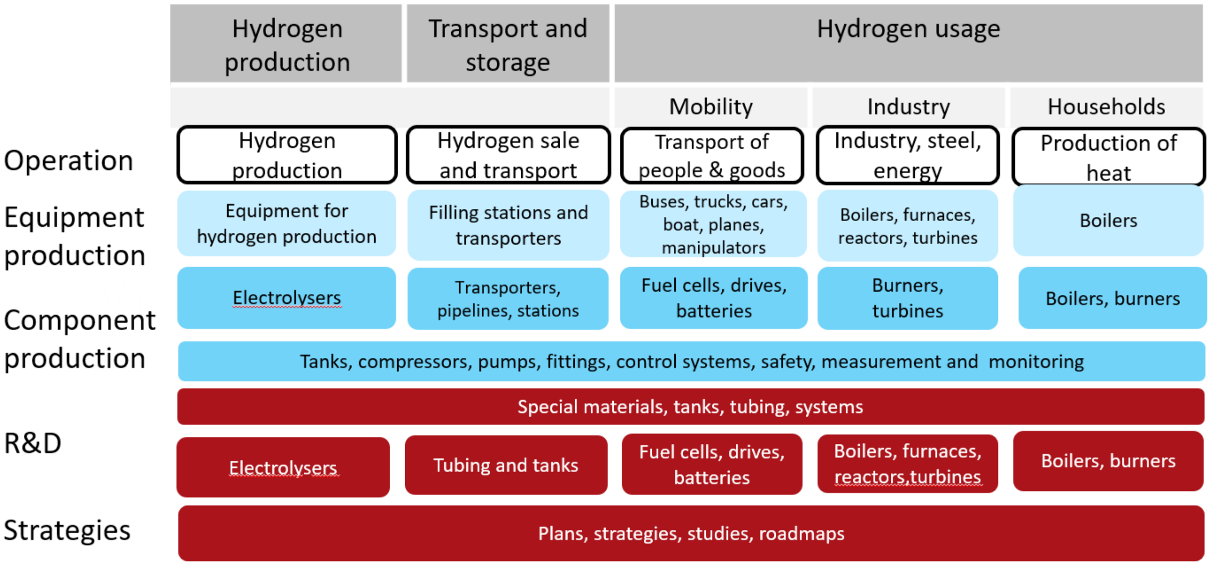
The estimated average aid intensity for the programme as a whole is 74%. The estimated maximum amount of financial support per project: CZK 25 million.

Restrictions:

Applicants or beneficiaries of project support in all sub-programmes under the Act on Support for Research, Experimental Development and Innovation, the Framework and the Regulation may include: enterprises, research organisations and other natural and legal persons.

Projects can cover a very wide area, but the key condition is consensus.

Technology map



5.2 Programmes of the Ministry of the Environment and the State Environment Fund

5.2.1 The Modernisation Fund

Main focus: Reducing the emissions intensity of GDP generation. Utilising resources generated by the sale of emission allowances. Carbon reduction, energy efficiency and security, the internal energy market and research, innovation and competitiveness. Carbon emission reduction, energy efficiency and security, the internal energy market and research, innovation and competitiveness.

Priorities:

1. Modernisation of heat energy supply systems
2. New renewable energy sources in the energy sector
3. Improving energy efficiency and reducing greenhouse gas emissions in industry in the EU ETS
4. Improving energy efficiency in business
5. Transport modernisation in the business sector
6. Modernisation of public transport
7. Energy efficiency in public buildings and infrastructure
8. Community energy
9. Modernisation of public lighting systems

Providing organisation: SFŽP

Link: http://www.modernizacni-fond.cz

Period: 2021–2030

The method and intensity of aid: Not specified, intensity will vary according to the priority areas

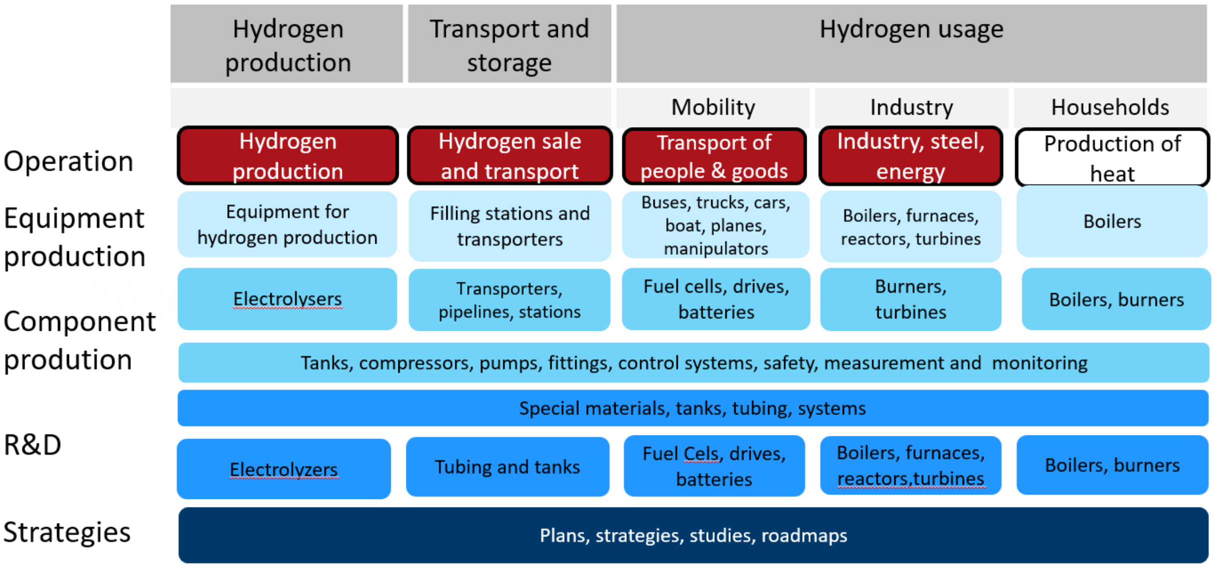
Types of projects:

Limitations: demonstration of a link to priorities – CO_2 emission reduction, energy savings, energy efficiency and new RES, entities and projects are rather large

Programme and sub-programme budget (update):

The total budget of the programme will amount to approximately CZK 150 billion. By far the largest allocation will be reserved for the first two priorities (modernisation of the heat energy supply and heating system and new RES). Together with the third priority area (energy efficiency), they will cover over 70% of the total allocation.

Technology map



5.2.2 The Innovation Fund

Main focus: Supporting large innovative projects demonstrating low-carbon technologies and practices in energy-intensive industries, renewable energy, energy storage, carbon capture and storage

Providing organisation: Commission (DG CLIMA); the SEF only as an advisor

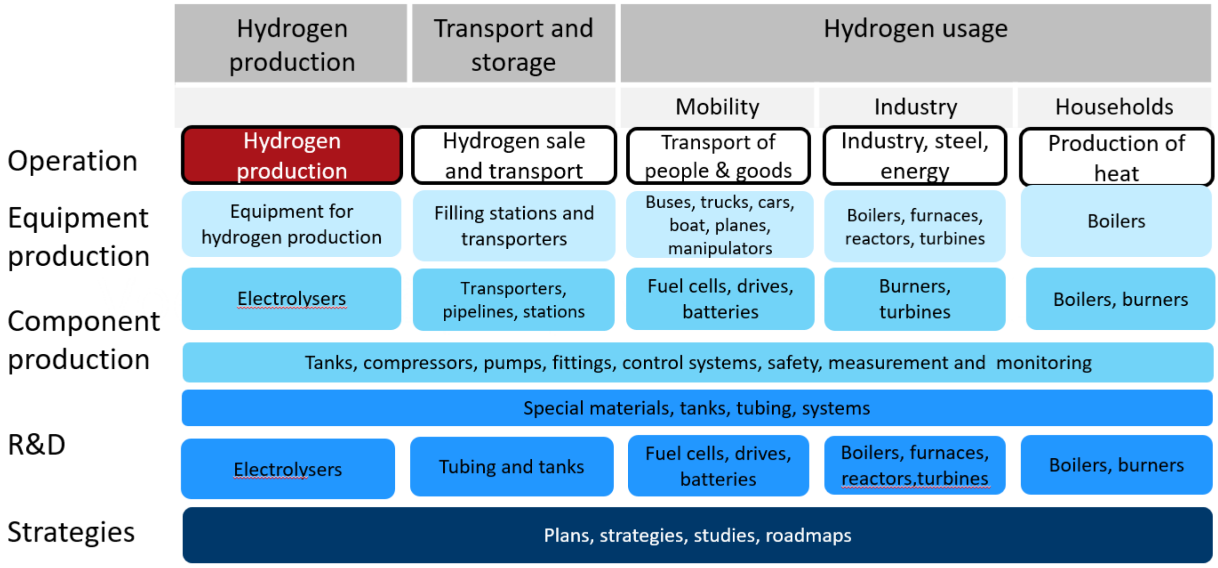
Link: https://www.sfzp.cz/dotace-a -pujcky/inovacni-fond/

Allocation:

Depending on the price of emission allowances in the period between 2020 and 2030, the Innovation Fund will have around EUR 10 billion at its disposal. Under the call for large-scale projects, proposals must meet the minimum eligible cost of EUR 7.5 million; otherwise they will be directed to the call for small-scale projects. Selected projects will be eligible for a subsidy of up to 60% of the additional investment and operating costs associated with innovation. 40% of the subsidy may cover the preparation phase.

Period: Funding is assumed to come from ongoing revenues under the EU ETS. The last call for large projects ended in October 2020, for small projects it will continue until 10 March 2021.

Technology map



5.2.3 Operational Programme Just Transition

Main focus:

As one of the pillars of the new Just Transition Fund, the Operational Programme Just Transition (OPJT) focuses on mitigating the negative impacts of the shift away from coal in regions that will face serious socio-economic problems because of the transition to a climate-neutral economy in the European Union by 2050.

The OP JT funds are mainly directed towards:

- support for small- and medium-sized enterprises,
- research and innovation,
- digitisation,
- clean energy and energy savings,
- a circular economy,
- reclamation and reuse of an area,
- retraining and job search assistance.

The programme is focused on three regions: the Karlovy Vary, Moravian-Silesian and Ústí nad Labem Regions. These regions will face the greatest socio-economic and environmental challenges in the coming years that are associated with the transition to a climate-neutral economy. In this respect, the OP JT will provide targeted support to these regions over and above other EU funds.

At the time the Hydrogen Strategy is being prepared, there is no detailed information available regarding the allocation of funding envelopes for each theme in the regions. Therefore, it is not possible to describe exactly how much funding will be directed to the hydrogen production, processing and consumption sector.

Providing organisations
MoE

Link:www.spravedlivatransformace.cz

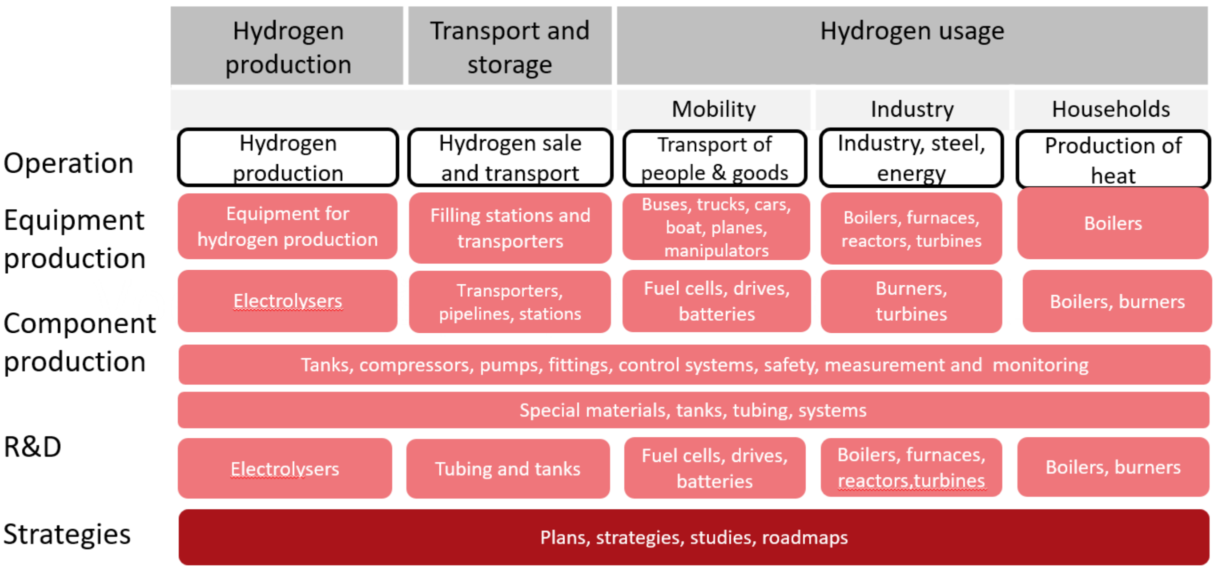
Period: 2021–2027

The method and intensity of aid:
The intensity of aid may vary for different types of measures. However, it must always comply with the current public aid rules. The OP JT budget is EUR 1.58 billion, i.e. about CZK 41 billion not including technical assistance. 15.3% of this amount is allocated to the Karlovy Vary Region, 38.6% to the Ústí nad Labem Region, and 46.1% to the Moravian-Silesian Region.

Restrictions:

- The aid is directed only to the Karlovy Vary, Ústí nad Labem and Moravian-Silesian Regions.
- Aid must be based on the Territorial Just Transition Plan and meet its objectives

Technology map



5.3 Programmes of the Ministry of Industry and Trade

5.3.1 The Country for the Future

Main focus:

The main objective of the programme is to increase the international competitiveness of companies by linking cooperation between academia, the business sector, the innovation environment and a larger use of R&D results in practice, including facilitating entry into new markets or moving up global value chains.

The programme covers the nine defined pillars (e.g. Digitisation, Mobility, Smart Marketing) and is defined for the 2020–2027 period. It is linked to the specific goals of the RIS3 strategy. Often more than one ministry is responsible for each pillar. The Smart Investment, National Start-up and Spin-off Environment, Polytechnic Education, Intellectual Property Protection and Smart Marketing pillars are co-administered by the MIT.

The sub-programmes “Start-ups” and “Innovation into practice” are relevant for hydrogen.

Providing organisation: MIT

Link: https://www.countryforfuture.com/

Period: 2019-2027

In April and May 2020, the second competitive tender of the programme, dedicated to the Innovation into Practice sub-programme, took place. Its total budget was CZK 300 million, of which CZK 120 million was intended for 2020.

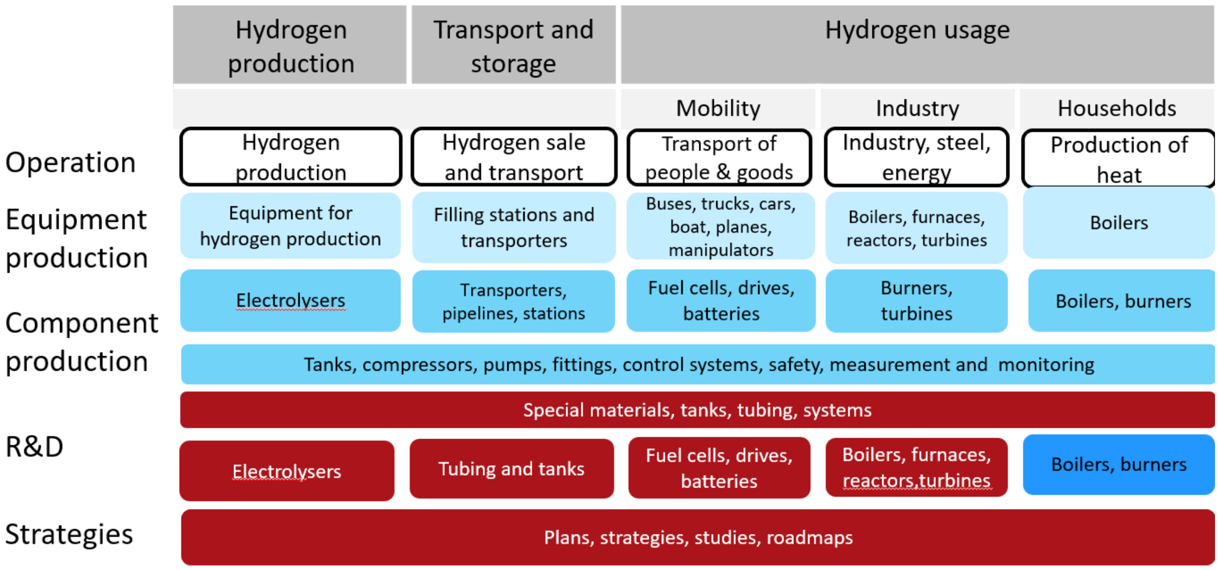
The method and intensity of aid:

The budget of the Start-ups sub-programme is CZK 1.8 billion. The budget of the Innovation into Practice sub-programme is CZK 6.1 billion. This is the total maximum allocation for the 2019–2027 period.

Restrictions:

Applicants or beneficiaries of project support in all sub-programmes under the Act on Support for Research, Experimental Development and Innovation, the Framework and the Regulation may include: enterprises, research organisations and other natural and legal persons.

Technology map



5.3.2 IPCEI (Important Project of Common European Interest)

Main focus:

Supporting large-scale projects that:

- contribute significantly to the level of research and development in the EU,
- introduce highly innovative and cutting-edge products or services into production,
- create major European infrastructure or help meet major EC climate, transport and/or energy targets.

IPCEI aims to address market failures in the relevant development area.

The programme requires close cooperation between organisations in several countries. Research and development and the introduction of new production must result in a world-class discovery, product or service. Organisations supported under the IPCEI must disseminate the results of their developments and ensure the “spill-over effects” that are also relevant for organisations in other member countries and other business sectors. R&D results that are licensed or protected by intellectual property must be further disseminated on fair, reasonable and non-discriminatory (FRAND) terms.

Projects are approved at the Commission level (DG COMP). The entire approval process is quite demanding, takes about one year and requires intensive cooperation from the project promoter. Projects concerning an announced theme are jointly coordinated and submitted to the European Commission for evaluation under the leadership of one EU Member State. All project documentation and project negotiations are in English.

Providing organisation: MIT

Link: Strategic Projects | MPO

Period: 2021-2025

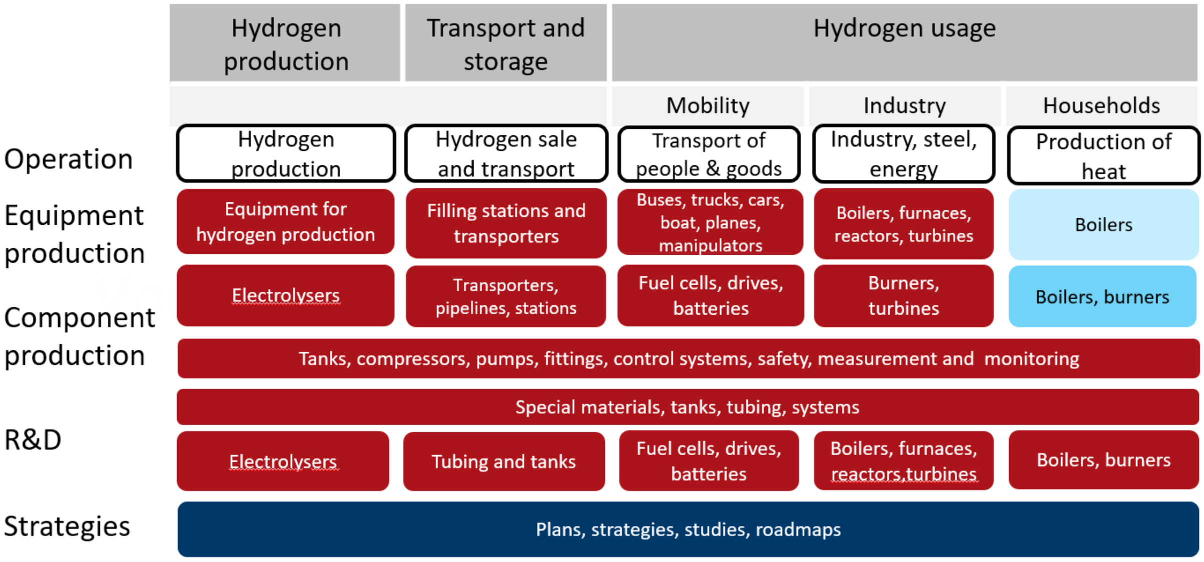
The method and intensity of aid: The intensity of aid is calculated based on the Funding Gap, which is the difference between the present value of a project using current technologies and a project deploying new cutting-edge technologies under development. The aid intensity can reach up to 100% of the funding gap.

Restrictions:

IPCEI projects must be integrated international projects involving at least two member countries. A major advantage of IPCEI projects is that they do not restrict the size of the enterprise or the business region. They allow for reimbursement of most types of eligible costs up to the stage of completion of the first industrial deployment. From this point of view, the IPCEI programme is very flexible and interesting.

IPCEI requires co-financing from the project promoter. Co-funding from other programmes at the national or European levels is considered an advantage.

Technology map



5.3.3 OP TAC (The Operational Programme Technologies and Applications for Competitiveness)

The OP TAC programme document is still undergoing changes.

Main focus:

1. A more competitive and smarter Europe by promoting an innovative and intelligent economic transformation

2. A greener, low-carbon and resilient Europe by supporting the transition to clean and fair energy, green and blue investments, a circular economy, climate change mitigation and adaptation, and risk prevention and management

A link-up to the RIS3 Strategy (https://www.mpo.cz/cz/podnikani/ris3-strategie/)

and Industry4 .0 (https://www.spcr.cz/prumysl-4 -0)

Mainly, the following specific goals/activities of the OP TAC may be relevant for hydrogen:

Specific goal 1.1 **Developing and strengthening research and innovation capacities and introducing advanced technologies**

- Support for industrial research and experimental development projects (except for basic research) where the main objective is the development of new knowledge needed for the development of new products, materials, technologies and services. Measures will be aimed at supporting R&I projects (implemented mainly in cooperation between enterprises and ROs) whose focus corresponds to the priorities of the National RIS3 Strategy.
- The introduction of new products and services into production and their launch on the market, as well as increasing the efficiency of production processes with advanced technologies

Specific goal 4.3**Developing smart energy systems, networks and storage at the local level**

- The development of Power-to-Gas conversion facilities to convert electricity from RES to new types of gases, the development of methanation units (for the production of synthetic methane or biomethane from hydrogen and CO_2), the connection of both facilities to the gas system (used for the production of hydrogen by electrolysis, or the subsequent production of synthetic methane or biomethane from hydrogen and CO_2);
- The construction of CO_2 capture equipment/stations (CCS/CCU technology);
- The development of conversion plants/facilities for new types of low-carbon gases (e.g. the production of hydrogen from natural gas by steam reformation, pyrolysis);
- Connecting production and conversion facilities to the gas system (measurement of the quantity and quality of the new types of produced gas, the construction of connection pipelines, injection facilities for new produced gases into the gas system, bidirectional pressure reduction stations for the possibility of connecting new gas production facilities to lower pressure levels, etc.);
- The installation of gas expansion turbines in RS associated with electricity production;
- The construction of liquefaction stations;
- The modernisation and modification of the gas system, the construction of gas pipelines and the modernisation of gas storage tanks, including the installation of new underground probes, modern compressors and safety elements compatible with new types of gas, fitting gas storage tanks with biological methanation

Specific goal 4.4**Enhancing biodiversity, nature conservation and green infrastructure in the urban environment and reducing all forms of pollution**

- The purchase of alternative fuel vehicles (electricity, hydrogen, CNG, LNG and plug-in hybrids) in enterprises, with the following categories of road vehicles being supported – L (two- to four-wheel vehicles), M1 (passenger), M2 and M3 (minibus/bus), N1 and N2 and N3 (freight), SS (special machinery);
- building charging and filling stations in enterprises;

Providing organisation: MIT

Link: https://www.mpo.cz/cz/podnikani/dotace-a -podpora-podnikani/optak-2021-2027/

Period: 2021–2027

The Czech government is currently engaged in intensive preparations and negotiations on the final form of individual subsidy programmes. The first calls are expected to be announced in the second half of 2021.

During 2021, calls under the OP EIC will expire, some of which also concern innovations in the field of energy savings.

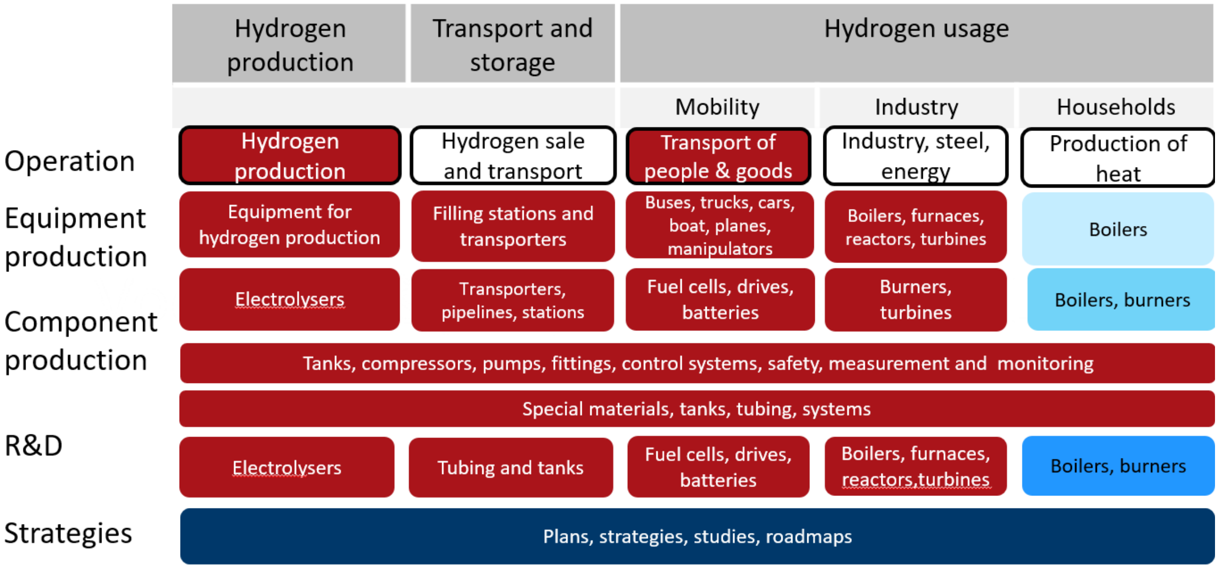
The method and intensity of aid:

The target groups are business entities (especially SMEs). The target group will also include research and knowledge dissemination organisations, research infrastructures, high performance computing centres and digital clusters.

The total budget has not yet been confirmed.

Restrictions: Aid beneficiaries will be the owners or managers of the infrastructure and means of transport in question, or other relevant entities.

Technology map



5.4 A programme of the Ministry for Regional Development – The Integrated Regional Operational Programme

Main focus:

To ensure balanced development throughout the territory, improve public services and public administration to increase competitiveness and ensure sustainable development in municipalities, cities and regions

The IROP supports 11 areas, of which modern, safe and environmentally friendly regional transport also covers hydrogen (e.g. the purchase of electric or gas-fuelled buses, trolleybuses, smart bus stops, transfer terminals, cycle paths, etc.) In terms of hydrogen, objective 2 – a low carbon and greener Europe is relevant

Hydrogen is also specifically included in Priority 2 (Development of urban mobility, revitalisation of towns and villages, protection of the population)

Providing organisation: MRD

Projects are evaluated and selected for approval by the Centre for Regional Development of the Czech Republic.

Link: www.irop.mmr.cz

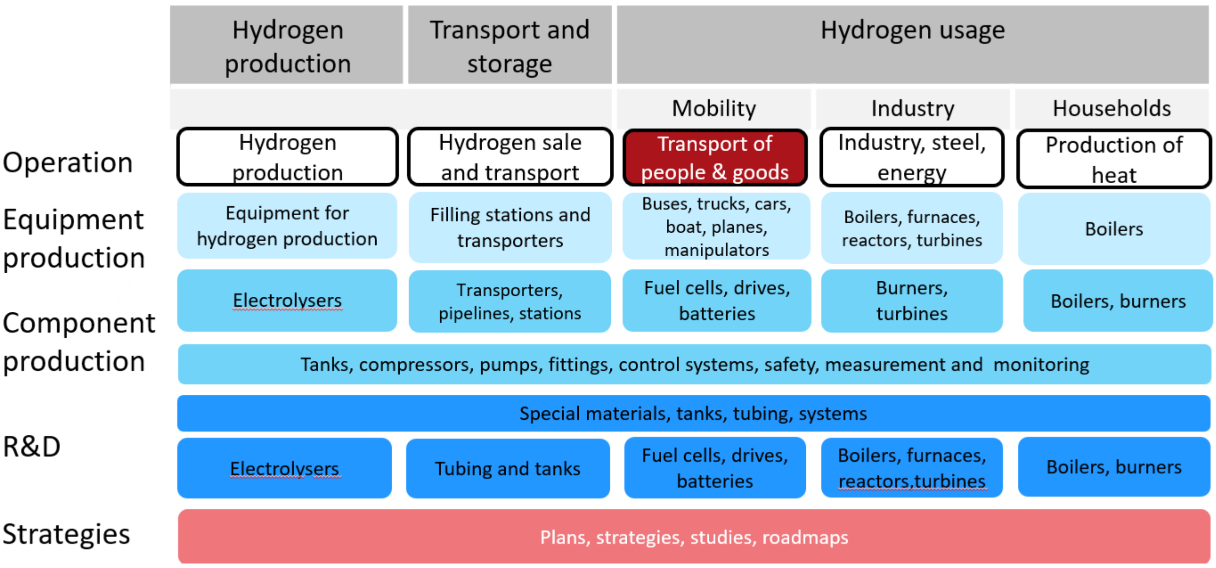
Period:

2014–2020 (EUR 5.4 billion)

2021–2027 (proposed allocation of EUR 4.8 billion)

Restrictions: In public aid, subsidies are mostly intended for carriers who operate under a public passenger service contract. Restrictions may vary according to the specific call.

Technology map



5.5 A programme of the Ministry of Transport – OP Transport

Main focus:

The objectives of the programme are based on the Commission White Paper – Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system

Hydrogen-relevant targets:

1. Promoting sustainable multimodal urban mobility
2. Developing sustainable, smart, climate-resilient and intermodal national, regional and local mobility, including better access to the TEN-T network and cross-border mobility
3. CF: Sustainable urban mobility (and alternative fuels)

General continuity with TEN-T priorities and the National Action Plan Clean Mobility.

Providing organisation: MT

Link: www.opd.cz

Period: A new Clean Mobility 2021-2027 programming period

Recently, two calls have been announced until the end of June 2021 and six more by mid-2023.

The method and intensity of aid:

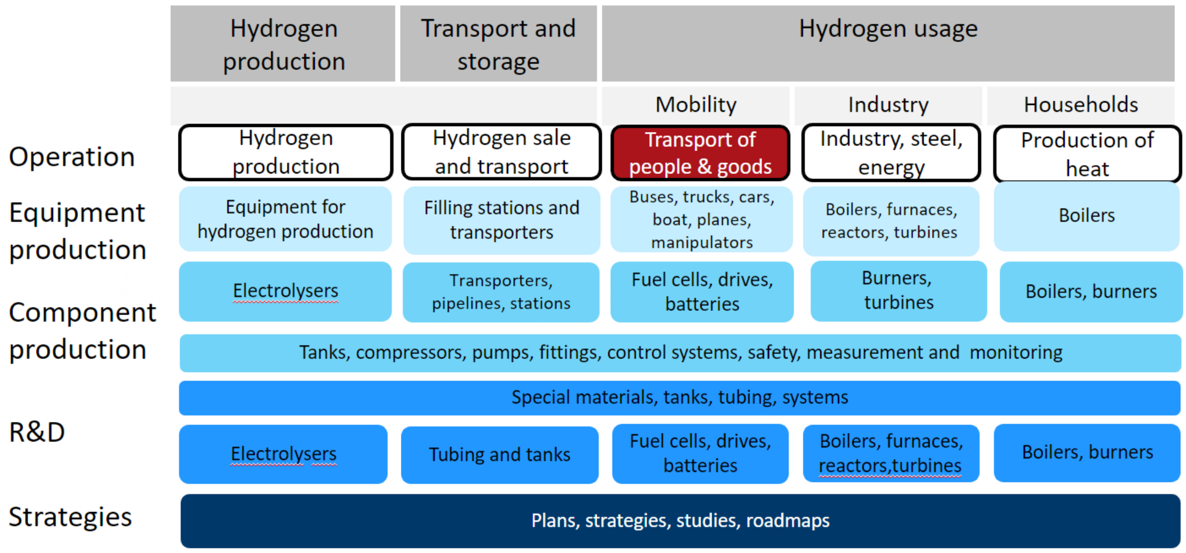
Total programme allocation: EUR 5.364 billion (the previous period was EUR 4.56 billion). The OP Transport is financed from two funds: the European Regional Development Fund (ERDF) and the Cohesion Fund (CF).

Large projects (over EUR 75 million) and small projects. There are no limits in terms of the amount of support for OP T projects, the only actual limit is the definition of possible applicants for each given specific goal.

Restrictions:

Aid beneficiaries will be the owners or managers of the infrastructure and means of transport in question, or other relevant entities.

Technology map



6 RELATED STRATEGIES AND PLANS

There is a number of other strategies, concepts and action plans that partially address hydrogen technologies. This Strategy is neither subordinate nor superior to those plans. However, it is necessary to ensure consistency between such plans and strategies. This chapter lists the main documents that overlap with the Hydrogen Strategy, and under the heading "coordination" defines working groups that will be responsible for consistency. We anticipate regular meetings between the Hydrogen Strategy authors and the relevant employees from institutions responsible for the documents listed below. The progress of aligning individual documents will be assessed at least once a year and will be part of the report submitted to the Minister of Industry and Trade.

6.1 Communication from the Commission COM(2020) 301: A hydrogen strategy for a climate-neutral Europe

https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2020:0301:FIN:CS:PDF

- **Owner:** European Commission
- **Link-up:** this strategy is based on the Communication from the Commission
- **Coordination:** is ensured through the standard process of approving and updating Commission documents
- **Note:** we do not expect frequent changes in the Communication from the Commission

6.2 The National Action Plan for Clean Mobility (2020 Update)

https://www.mpo.cz/cz/prumysl/zpracovatelsky-prumysl/automobilovy-prumysl/aktualizace-narodniho-akcniho-planu-ciste-mobility--254445/

- **Owner:** MIT/MT
- **Link-up:** an independent document, some trends and projected figures are included in both documents, so it is necessary to ensure that any changes are consistent
- **Coordination:** HYTEP Hydrogen Mobility Working Group
- **Note:** The NAP CM is regularly updated (every 2 years), therefore it is necessary to update the Hydrogen Strategy as well.

6.3 The State Energy Policy of the Czech Republic (2015)

https://www.mpo.cz/dokument158059.html

- **Owner:** MIT
- **Link-up:** A basic document for the Czech Republic where hydrogen is mentioned very marginally (with regard to the date of its creation) - however, it leaves room for further specification as an RES resource
- **Coordination:** a direct link between the relevant departments at MIT and the Hydrogen Coordination Group
- **Note:**
  - It needs to be updated.

- To be taken into account during the next update to the implementing National Action Plans (NAPs, etc.)

6.4 The Czech National Energy and Climate Plan (2020)

https://www.mpo.cz/cz/energetika/strategicke-a -conceptual-documents/international-plan-of-the-republic-in-energy-and-climate-areas-252016/

- **Owner:** MIT
- **Link-up:** The obligation to inform the Commission on RES, other plans; define energy targets, RES, etc.
- **Coordination:** a direct link between the relevant departments at MIT and the Hydrogen Coordination Group
- **Note:**

6.5 RIS3 strategy

https://www.mpo.cz/cz/podnikani/ris3-strategie/

- **Owner:** MIT
- **Link-up:** A document defining the main lines of innovation and research
- **Coordination:** hydrogen strategies concern the 2 NIPs (National Innovation Platforms) defined in RIS3 where hydrogen coordinators will work:
    - Advanced machinery and technology
    - Means of transport for the 21st century
- **Note:** The RIS3 strategy is updated every 3 to 4 years based well-defined rules when prospective areas for further development are assessed.

6.6 Transport Policy

https://www.mdcr.cz/Dokumenty/Strategie/Dopravni-politika-CR-pro-obdobi-2014-2020-s -view

- **Owner:** MT
- **Link-up:** A document defining the directions of development in the field of transport, including the use of hydrogen in transport
- **Coordination:** a direct link between the relevant departments of the MT and the Hydrogen Coordination Group
- **Note:**

6.7 The National Environmental Policy 2030 with a view to 2050

https://www.mzp.cz/cz/statni_politika_zivotniho_prostredi

- **Owner:** MoE
- **Link-up:** A document that defines guidelines for environmental protection, including priority areas for reducing greenhouse gas emissions

- **Coordination:** a direct link between the relevant departments at the MoE and the Hydrogen Coordination Group
- **Note:**

6.8 The National Action Plan for Smart Grids

The National Action Plan for Smart Grids 2019 - 2030 - NAP SG Update | MIT

- **Owner:** MIT
- **Link-up:** The document sets the direction for the development of decentralised, especially renewable sources of electricity, storage and electromobility in accordance with the requirements of the National Energy and Climate Plan of the Czech Republic.
- **Coordination:** MIT
- **Note:**

6.9 The National Action Plan for the Development of Nuclear Energy in the Czech Republic

The National Action Plan for Nuclear Energy Development in the Czech Republic | MIT

- **Owner:** MIT
- **Link-up:** The document determines the direction of nuclear energy development in the Czech Republic. Following an update to the State Energy Policy, NAP NE will be updated to include both small modular reactors and the potential for hydrogen production.
- **Coordination:** MIT
- **Note:**

6.10 The Climate Protection Policy of the Czech Republic

https://www.mzp.cz/cz/politika_ochrany_klimatu_2017

- **Owner:** MoE
- **Link-up:** The document defines the basic direction of the Czech Republic in the area of decarbonisation and emission savings.
- **Coordination:** MoE
- **Note:**

6.11 Re:Start, a strategy for the economic restructuring of the Ústí nad Labem, Moravian-Silesian and Karlovy Vary Regions

https://restartregionu.cz/

- **Owner:** MRD
- **Link-up:** The document defines priorities and tools for the transformation of the three regions.
- **Coordination:** MRD

- **Note:**

6.12 The Innovation Strategy of the Czech Republic 2019–2030

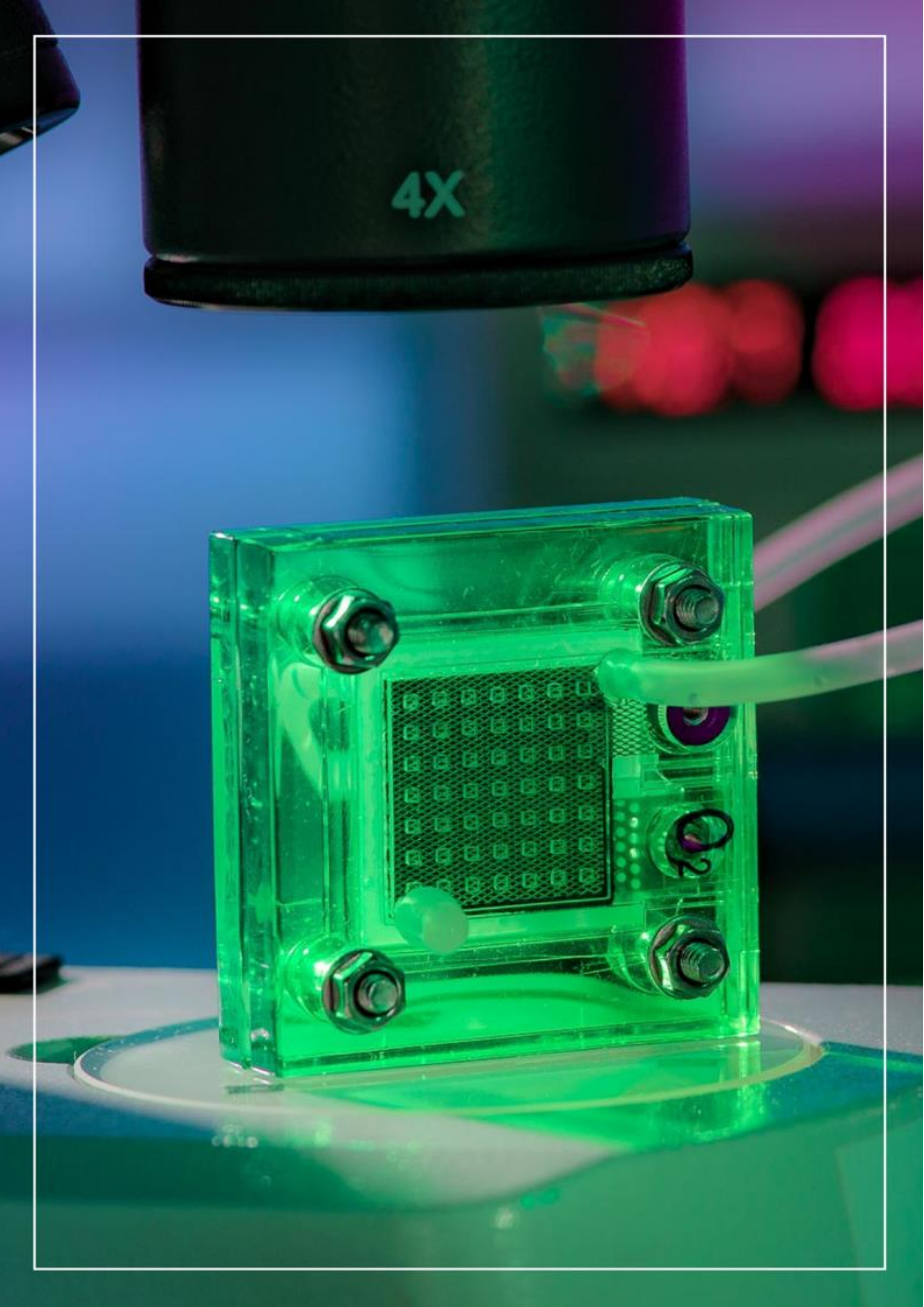
https://www.vyzkum.cz/FrontClanek.aspx?idsekce=866015

- **Owner:** Chairman of the Research, Development and Innovation Council (prepared mainly by the MIT)
- **Link-up:** The document summarises the innovation activities of the Czech Republic.
- **Coordination:** Chairman of the Research, Development and Innovation Council
- **Note:**

6.13 SMART Cities – Resilience through SMART solutions for municipalities, cities and regions

https://mmr.cz/cs/microsites/sc/metodiky/koncepce-smart-cities

- **Owner:** MRD
- **Link-up:** One of the elements of Smart Cities is the energy sector and sustainable urban mobility, to which hydrogen technologies will also contribute
- **Coordination:**
- **Note:**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7 Constants and Formulas Used in Calculations

Hydrogen

calorific value	33 kWh/kg, 120 MJ/kg
the amount of energy required to produce hydrogen by electrolysis	55 kWh/kg

Buses

average annual mileage	60 000 km per year
average hydrogen consumption	10 kg per 100 km

Trucks

average annual mileage	116 000 km/year
average diesel consumption	33 l /100 km
average hydrogen consumption	10 kg per 100 km
diesel-to-hydrogen conversion	3.3 l diesel / kg H_2

Passenger cars

average annual mileage	20 000 km/year
average hydrogen consumption	0.8 kg/100 km

8 Task Cards

For English abbreviations of organizations see the list at the end of this section

Task ID: 1	
Objective of the measure	To align the Hydrogen Strategy of the Czech Republic with conceptual documents in the field of clean mobility, such as: the NAP CM and others.
Description of the measures	Different analyses use different input data and different coefficients to calculate consumption (mileage, average consumption, etc.). We need one data source for future estimates, but this may change over time.
Responsibility	MIT, MT
Cooperation	AutoSAP, the Chamber of Commerce, the Confederation of Industry and Transport, CGA
Deadline	Continuously
Record of performance	

Task ID: 2	
Objective of the measure	Align the Hydrogen Strategy of the Czech Republic with conceptual papers in the field of energy and climate, such as: the SEP, the National Energy and Climate Plan of the Czech Republic, NAP SG, POK, relevant national strategies, etc.
Description of the measures	Hydrogen is not mentioned at all in the SEP. It is necessary to synchronise the Hydrogen Strategy with other strategic documents in the field of energy that were published before the Hydrogen Strategy of the Czech Republic. A more precise forecast of hydrogen consumption will be added to the SEP.
Responsibility	MIT, MoE
Cooperation	
Deadline	Continuously
Record of performance	

Task ID: 3	
Objective of the measure	To ensure certification for low-carbon hydrogen (legislation, a certificate registration system, auditing organisations) and to create a system for registering low-carbon hydrogen certificates.
Description of the measures	To ensure certification for hydrogen according to CO2eqv., regardless of its production method. The deadline may be accelerated by European legislation.
Responsibility	MIT
Cooperation	OTE
Deadline	2025
Record of performance	

Task ID: 4	
Objective of the measure	To define hydrogen quality measurement capacities for transport according to the relevant technical standards, incorporate quality checks into legislation and establish a control body.
Description of the measures	At present, there is no possibility of accredited hydrogen quality measurement for inspection purposes and no control body has been identified.
Responsibility	MIT
Cooperation	CTIA
Deadline	2023
Record of performance	

Task ID: 5	
Objective of the measure	To analyse the possibilities of using nuclear facilities in the production of low-emission hydrogen in the Czech Republic.
Description of the measures	To analyse the potential applications of hydrogen production from nuclear facilities (existing sources, new nuclear sources and potentially small modular reactors). Namely the applicability, potential, economic, legislative and technical aspects, including specific recommendations in relation to existing and new nuclear sources and possibly R&I in the field of nuclear energy. The results of this analysis should be subsequently incorporated into the Hydrogen Strategy of the Czech Republic and the State Energy Policy and the National Action Plan for the Development of Nuclear Energy in the Czech Republic or other relevant documents during their next update.
Responsibility	MIT
Cooperation	ČEZ
Deadline	2024
Record of performance	

Task ID: 6	
Objective of the measure	To analyse the possibilities of hydrogen production from natural gas and related processes.
Description of the measures	For the SMR (steam methane reformation) technology, the focus needs to be on CO_2 emissions, their capture, recovery, transport and storage. For the natural gas pyrolysis technology, the focus needs to be on the recovery/storage of solid-state carbon.
Responsibility	MIT
Cooperation	CGA, HYTEP, SCHP, TA CR, research institutions and universities
Deadline	2026
Record of performance	

Task ID: 7	
Objective of the measure	To create conditions for the construction and operation of new hydrogen stationary facilities to support the development of such facilities and to update technical and safety standards.
Description of the measures	To create conditions for the construction and operation of stationary hydrogen facilities such as electrolysers, filling stations, hydrogen storage, fuel cells, boilers, etc. To analyse safety risks and their mitigation in the introduction of hydrogen technologies. To develop standards and safety regulations for the production, storage, transport and use of hydrogen.
Responsibility	MIT, MT, GD FRS
Cooperation	CMI, SLI, COSMT, ČAS, CGA
Deadline	2024
Record of performance	

Task ID: 8	
Objective of the measure	To develop opportunities to support research, development and innovation in hydrogen technologies.
Description of the measures	To use, or update existing support programmes for research, development and innovation so that they correspond to the main directions defined in the Hydrogen Strategy of the Czech Republic, including building testing and research capacities.
Responsibility	MIT, MT, MEYS, MoE
Cooperation	TA CR
Deadline	Continuously
Record of performance	

Task ID: 9	
Objective of the measure	To prepare a methodology for the intervention of the Fire Rescue Service and the Integrated Rescue Service in hydrogen-related accidents.
Description of the measures	The Fire Rescue Service and other units of the Integrated Rescue Service will come into contact with the issue of hydrogen systems, their operation, failures and accidents. The aim of this methodology is to facilitate the work of the FRS and IRS.
Responsibility	MoI
Cooperation	GR FRS
Deadline	2025
Record of performance	

Task ID: 10	
Objective of the measure	To clarify the current conditions for the operation of existing/new natural gas supply and take-off facilities (intended primarily for natural gas) to allow for the operation of such facilities to support the hydrogen market.
Description of the measures	1. To specify current technical and legislative conditions for the operation of existing gas supply and take-off facilities, such as compressor stations, pipelines, other parts of the gas system and gas appliances, and to specify the current conditions for the construction and operation of any new transmission and distribution facilities. 2. To examine the readiness of the current legal framework for the use of existing gas facilities for the transport/distribution/storage of hydrogen and its mixtures with natural gas, both at the public and private legal levels, and to take appropriate measures to enable such use, if necessary.
Responsibility	MIT, MT, GD FRS
Cooperation	MoE, CMI, SLI, TA CR, EGÚ Brno, CGA,COSMT, ČAS
Deadline	2024
Record of performance	

Task ID: 11	
Objective of the measure	To prepare infrastructure for hydrogen transport and storage – technical measures.
Description of the measures	1. To determine critical points for hydrogen distribution along the natural gas flow chain from transportation/distribution/storage to final consumption: • Technological elements (pipelines, compressors, regulators, valves, gauges, etc.) • Materials • Appliances • Underground storage tank bearings 2. To verify the technical and operational options of the existing natural gas infrastructure, take-off facilities, and gas appliances with regard to the use of hydrogen, including technical conditions for the construction of new infrastructure. 3. The dynamic monitoring of gas quality in the system. The injection and addition of hydrogen (not only) into the system requires a more intensive monitoring of gas quality at the inlet/outlet and at the nodes of the system (in terms of technical operation – counters, safety, correct invoicing, etc.). 4. Safety aspects when working on gas equipment operated with a mixture of natural gas and hydrogen or pure hydrogen. 5. The preparation of testing for injection of higher quantities of hydrogen or pure hydrogen into the gas system. 6. Testing the connection of households to hydrogen instead of natural gas – it is necessary to test what adjustments will need to be made to the distribution system and to the terminal equipment.
Responsibility	MIT
Cooperation	CGA, NET4GAS, IRS, TACR, EGÚ Brno, COSMT, ČAS
Deadline	2025
Record of performance	

Task ID: 12	
Objective of the measure	Infrastructure readiness for hydrogen transport and storage – legislative measures.
Description of the measures	1. To guarantee legislative readiness for the entry of hydrogen into the Czech gas industry. To amend existing legislation and regulations while adhering as much as possible to the principles of the legislative framework in the gas industry that have been proven in practice (e.g. the Energy Act, Act on Dedicated Technical Equipment, relevant decrees, technical standards, TPGs, and others). 2. To enable by law the establishment of test plants / pilot projects with higher hydrogen concentrations up to 100% hydrogen content, also with the participation of existing gas system operators.
Responsibility	MIT
Cooperation	ERO, MLSA, CGA, CMI, COSMT, ČAS
Deadline	2024
Record of performance	

Task ID: 13	
Objective of the measure	Infrastructure readiness for hydrogen transport and storage – regulatory measures. Preparation of a draft of the Czech regulatory framework in the field of hydrogen with respect to applicable EU directives and regulations.
Description of the measures	1. Extending the existing regulatory framework for natural gas to include hydrogen, including hydrogen infrastructure, to create a stable regulatory environment to enable the development of the hydrogen infrastructure. It is important to take into account the cross-border dimension of the hydrogen market. It can be reasonably assumed that the geographical position of the Czech Republic will stimulate the need to transport hydrogen across the Czech Republic before the hydrogen market can be fully developed at the national level. Facilitating cross-border trade between neighbouring and EU Member States can encourage a more efficient development of the hydrogen value chain in the Czech Republic and the EU. For this purpose, it is important to ensure consistency across markets and to encourage the development of a single market based on the convergence of rules. 2. To take the hydrogen standard into account when building new or renovating existing infrastructure. 3. To apply the repurposing and retrofitting of existing infrastructure when planning the development of the gas (i.e. including hydrogen) system in the Czech Republic. 4. A tariff model for hydrogen system regulation: the use of the existing natural gas system for hydrogen transport and the further development of the gas system for hydrogen needs brings challenges in the form of incentive-based and economically sustainable tariff rules for hydrogen transport so that the system is incentive-based for all users. The task should follow immediately after the form and scope of regulation at the EU level has been determined. 5. A tariff model for the interconnected electricity and gas sectors: the use of the gas system as a storage medium for hydrogen produced through the electricity system will require the creation of new products so that any costs incurred are allocated correctly to the users of both systems.
Responsibility	MIT
Cooperation	ERO, CGA, regulated entities in the gas sector
Deadline	2025
Record of performance	

Task ID: 14	
Objective of the measure	Developing a comprehensive methodology for island solutions for low-carbon hydrogen production and distribution, and strengthening the support for these projects.
Description of the measures	The production of hydrogen associated with its consumption at or near the point of production must be addressed in a comprehensive manner where the timing of supply can be optimised, the need for storage minimised, and appropriate volumes and facilities selected. An island approach to hydrogen production and use will be necessary at least in the initial stages to reduce overall costs (no hydrogen transport required). It is advisable to modify existing support programmes to support these types of projects.
Responsibility	MIT
Cooperation	MT, TRC
Deadline	2022
Record of performance	

Task ID: 15	
Objective of the measure	To support strategic pilot projects for efficient hydrogen production and transport.
Description of the measures	To modify existing support schemes to enable the implementation of strategic pilot projects aimed at potentially geographically separated sources of hydrogen production and consumption and their interconnection, in particular using gas infrastructure and other efficient means of hydrogen transport.
Responsibility	MIT
Cooperation	CGA, NET4GAS
Deadline	2022
Record of performance	

Task ID: 16	
Objective of the measure	To develop scenarios for potential sources of hydrogen imports to the Czech Republic.
Description of the measures	To analyse potential sources of hydrogen abroad and transport routes for importing hydrogen to the Czech Republic.
Responsibility	MIT
Cooperation	CGA, NET4GAS
Deadline	2026
Record of performance	

Task ID: 17	
Objective of the measure	To ensure statistical monitoring of hydrogen as a fuel.
Description of the measures	Hydrogen is currently not reported as a fuel in the statistical reports submitted by enterprises. Only its production is statistically monitored. For the purpose of calculating CO_2 savings and also to further specify the strategic documents, it will be necessary to design and approve a system for reporting the amount of consumed hydrogen, especially low-carbon hydrogen.
Responsibility	MIT
Cooperation	CSU, ERO
Deadline	2025
Record of performance	

Task ID: 18	
Objective of the measure	Financial support for the purchase of fuel cell vehicles and the building of infrastructure (filling stations) for the operation of fuel cell vehicles.
Description of the measures	To provide funding and to announce relevant calls for proposals according to beneficiaries: - entrepreneurs - municipalities - public passenger transport
Responsibility	MIT, MT, MRD, MoE
Cooperation	AutoSAP
Deadline	Continuously
Record of performance	

Task ID: 19	
Objective of the measure	To propose a way to add the fuel cell vehicle commodity or its appropriate assignment to an existing commodity in the NIPEZ Code that contains approved items of goods and services which are subject to the public procurement market, if not resolved at the European level for the entire EU.
Description of the measures	It is advisable to include the commodity fuel cell vehicles in the NIPEZ Code in order to be able to classify this commodity under the correct code item, which will define the subject matter of a public contract more precisely. Given that the NIPEZ Code is based on Regulation (EC) No 2195/2002 of the European Parliament and of the Council of 5 November 2002 on the Common Procurement Vocabulary (CPV) establishing a common classification system for public procurement purposes, this objective will only be met if the classification of fuel cell vehicles under the correct heading is resolved at the European level, which would then be reflected in the NIPEZ Code.
Responsibility	MRD
Cooperation	
Deadline	2023
Record of performance	

Task ID: 20	
Objective of the measure	To inform the public about the possibilities of hydrogen technology.
Description of the measures	To promote hydrogen among the general public as one of the possible technologies that will help decarbonise industry, transport and energy. To focus namely on the issue of the operational safety of hydrogen technologies.
Responsibility	MIT, MoE, MFA
Cooperation	HYTEP
Deadline	Continuously
Record of performance	

Task ID: 21	
Objective of the measure	To actively promote Czech companies and create opportunities for networking and know-how transfer across borders.
Description of the measures	To promote knowledge transfer in the industrial sector to the maximum extent possible and to promote Czech companies developing hydrogen technologies, including abroad in foreign workshops.
Responsibility	MIT, MFA, CzechInvest
Cooperation	HYTEP
Deadline	Continuously
Record of performance	

Task ID: 22	
Objective of the measure	To analyse the necessity to update technical standards for the acquisition and operation of fuel cell rolling stock.
Description of the measures	The promotion of hydrogen mobility brings with it the need to update the technical standards for the acquisition and operation of rolling stock with fuel cells. Similarly to electric and CNG/LPG vehicles, detailed technical parameters for the definition of fuel cell vehicles must be set. In many cases, national standards will need to be aligned with those of neighbouring countries. It may happen that rolling stock from neighbouring countries will come to us earlier than rolling stock operated on Czech railways.
Responsibility	MT
Cooperation	
Deadline	2024
Record of performance	

Task ID: 23	
Objective of the measure	To analyse the necessity to update technical standards for the purchase and operation of hydrogen ships.
Description of the measures	Ships are a specific area of transport, especially for cruise passenger transport, the operation of hydrogen-fuelled ships can be an interesting alternative; therefore, it is necessary to prepare legislation and operating conditions for this area.
Responsibility	MT
Cooperation	
Deadline	2024
Record of performance	

Task ID: 24	
Objective of the measure	Support for a degree programme focused on hydrogen technology at universities.
Description of the measures	A prerequisite for the development of hydrogen technologies and their development in the Czech Republic is the existence of educational capacities at universities and the training of teaching staff. New degree programmes can be accredited or existing ones identified where there is potential to include hydrogen technologies. The accreditation of new degree programmes or the modification of existing ones falls within the autonomous decision-making of individual universities, or within the competence of the National Accreditation Bureau for Higher Education.
Responsibility	MEYS
Cooperation	MIT, MLSA, Council of Higher Education Institutions, Czech Rectors Conference, NAB
Deadline	Continuously
Record of performance	

Task ID: 25	
Objective of the measure	Accreditation of retraining in hydrogen technology.
Description of the measures	A prerequisite for the development of hydrogen technologies and their development in the Czech Republic is the existence of opportunities for retraining and further education for professionals in the field of hydrogen technologies.
Responsibility	MEYS
Cooperation	
Deadline	Continuously
Record of performance	

Task ID: 26	
Objective of the measure	To raise awareness of hydrogen technology at secondary schools by including it in curricula (physics, chemistry, etc.).
Description of the measures	To develop methodological support for hydrogen technology in schools to reflect current hydrogen production and use depending on the type of school. To include information on hydrogen, which is one of the important tools for achieving climate neutrality, into science education.
Responsibility	MEYS, regions, MIT
Cooperation	The Association of STS CR, The Association of Secondary Grammar School Directors, NPI
Deadline	2025
Record of performance	

English abbreviations of organizations used in the Task Cards:

CGA – Czech Gas Association

CSO – Czech Statistical Office

COSMT – Czech Office for Standards, Metrology and Testing

ERO – Energy Regulatory Office

IRS – Integrated Rescue System

MEYS – Ministry of Education, Youth and Sports

MFA – Ministry of Foreign Affairs

MIT – Ministry of Industry and Trade

MLSA – Ministry of Labour and social Affairs

MRD – Ministry of Regional Development

MoI – Ministry of Interior

MT – Ministry of Transportation

MoE – Ministry of Environment

NAB – National Accreditation Bureau for Higher Education

NPI – National Pedagogical Institute

TACR – Technology Agency of the Czech Republic

TRC – Transport Research Centre

The Association of STS CR – The Association of Secondary Technical Schools of the Czech Republic

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