



REPUBLIC OF TÜRKİYE  
MINISTRY OF ENERGY AND  
NATURAL RESOURCES

**TÜRKİYE  
HYDROGEN TECHNOLOGIES  
STRATEGY  
AND  
ROADMAP**

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## EXECUTIVE SUMMARY

It is predicted that investments in hydrogen technologies will increase even more in the coming years with the developing technology and the growing energy demand all over the world. Having a high mass energy density (120 MJ/kg) and low environmental impact, hydrogen is an important alternative as an energy carrier in the use of fossil fuel-based energy sources. Hydrogen is used in a variety of fields, including transportation, industry, renewable energy integration and green chemical production.

Our Ministry has declared hydrogen one of the priority areas due to its potential contribution to the sustainable energy future. Our aim is to create a carbon zero economy model using hydrogen in line with our economic development and 2053 net zero carbon emission targets. To achieve this aim, “Türkiye Hydrogen Technologies Strategy and Roadmap” has been developed.

The study is intended to develop a strategic roadmap for the creation of a domestic and national support and application program for research and technology development, especially by emphasizing the importance of domestic development of hydrogen technologies. The report addresses hydrogen production, storage, distribution and utilization technologies, taking into account the research and developments in the field of hydrogen in Türkiye and around the world.

Türkiye has the potential to both produce hydrogen, which is in the process of becoming widespread in many sectors worldwide, and to be a technology developer in the short, medium and long term. Taking this potential into account, the report identifies the needs for the development of hydrogen technologies in Türkiye and offers technological/supportive solutions.

Therefore, it presents targets and policies at country level. The major targets in the roadmap are listed as follows;

- Reduce the cost of green hydrogen production to less than \$2.4/kgH<sub>2</sub> by 2035 and less than \$1.2/kgH<sub>2</sub> by 2053,
- Increase electrolyzer installed power capacity to 2 GW by 2030, 5 GW by 2035 and 70 GW by 2053.

It is considered that the advantages enjoyed by Türkiye such as its high renewable energy potential and geopolitical location can enable it to both use domestically the hydrogen produced through R&D activities and export it.

For this purpose, it is of vital importance policies such as reviewing and adapting the current legislation, in terms of hydrogen, establishing incentive mechanisms and certification programs for the use of domestic components in green hydrogen production and storage, encouraging R&D and P&D to develop and produce domestic and national technologies (electrolyzer, fuel cell, etc.), establishing international cooperation, establishing public and private sector cooperation to encourage commercial demand and investments, training qualified manpower and encouraging the widespread use of green hydrogen in all sectors. In addition to gaining competence in hydrogen energy and technologies, which will play an important role in attainment of the 2053 net zero emission target in Türkiye, it is considered an important requirement for Türkiye to advance the existing fund of knowledge to a process of commercialization.

## INTRODUCTION

With the “National Energy and Mining Policy”, which was formulated by the Ministry of Energy and Natural Resources in the light of regional and global developments, announced in 2017 and built on the topics of energy supply security, nationalization and foreseeable markets, “more domestic, more renewable” approach has been adopted, making sustainability a priority. In this context, it is our primary policy to increase the share of our domestic and renewable energy resources in our energy portfolio by using more efficient, environmentally friendly, safe and domestic technologies with a sustainable approach, thereby reducing costs of imported energy. For this purpose, it is essential to diversify the resources and to nationalize this diversity, while ensuring the energy supply security of Türkiye.

It is known that the energy sector, which is an emission-intensive sector, will be one of those that will be most affected by the “Paris Agreement”, which constitutes the framework of the post-2020 climate change regime and was published in the Official Gazette on 7 October 2021. In this context, Türkiye is determined to use its energy resources effectively, efficiently and in a way that will have the least possible impact on the environment, within the framework of sustainable development goals.

“Türkiye National Energy Plan”, published by our Ministry, sets our targets in the energy sector until 2035 based on the 2053 net zero emission target. This study addresses the blending of hydrogen and synthetic methane with the natural gas to reduce emissions, and the use hydrogen energy for on-site consumption and to meet the needs of the industry initially. An electrolyzer capacity of 5.0 GW is targeted to be reached by 2035.

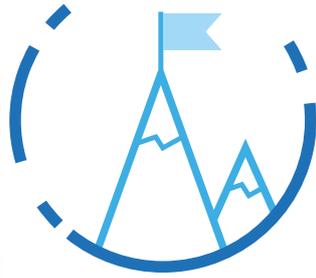
It is considered that hydrogen, as a complement to electrification-oriented development, will make a great contribution to the manufacturing sector’s achievement of net zero emissi-

on targets, with its potential uses, including as a raw material, fuel, energy carrier and energy storage material.

Hydrogen will present a new export potential to Türkiye, as it will increase the production and share of renewable energy in Türkiye, develop production, storage and utilization technologies, reduce greenhouse gas emissions in the heating sector when blended with natural gas, and enable use of domestic resources such as coal and boron.

Moreover, Türkiye has a great green hydrogen production potential due to its high renewable energy potential and lower costs of installing renewable energy-based power plants compared to Europe. Hence, Türkiye is considered to be a strong player in the global hydrogen market.

Investing in hydrogen technologies will provide great advantages in terms of energy efficiency, decarbonization and hydrogen export in the long run. Sustainable and supportive policies are needed to overcome the technological, economic, regulatory and environmental barriers faced by the hydrogen sector around the world. It is important to diversify and increase R&D supports, particularly for hydrogen technologies. In addition, the legislation and plans that will be formulated on the subject will also play an important role. The role of the strategies and policies to be implemented in accelerating the adoption of hydrogen by everyone is quite critical. Hence, it is important to reduce Türkiye’s dependence on foreign energy, to develop domestic and national electrolyzer and fuel cell technologies by making use of our current advantages, to produce green hydrogen and to use hydrogen in a variety of industries.



## VISION

Our vision is to play a leading role worldwide in the production and use of green hydrogen by developing domestic and national advanced technologies.



## MISSION

Our mission is to create an effective value chain from the production of green hydrogen to its final use based on domestic and national technologies, and to contribute to the 2053 net zero target.



## STRATEGIC PRIORITY

While the green hydrogen to be produced with our domestic resources will meet our country's own needs, exporting the surplus will provide a significant flow of income to our country.

# HYDROGEN TECHNOLOGIES

## Hydrogen Production Technologies

A primary energy source is needed for hydrogen production. Hydrogen production is diversified according to the type of such sources. It is called “green hydrogen” if it is obtained from renewable energy, “blue hydrogen” if it is produced from fossil fuels using carbon dioxide (CO<sub>2</sub>) capture systems, “turquoise hydrogen” if it is produced without CO<sub>2</sub> from fossil fuels by processes such as pyrolysis, “pink hydrogen” if it is produced using nuclear energy, “grey hydro-

gen” if it is obtained through reformation of natural gas, and “brown hydrogen” if it is obtained by gasification method without capturing CO<sub>2</sub> from coal. The production of decarbonized hydrogen is important for achieving emission reduction targets. Hydrogen methods classified by source are listed below.

Technology	Primary Energy/Electricity Source	Carbon Footprint (kgCO <sub>2</sub> /kgH <sub>2</sub> )	Cost (USD/kgH <sub>2</sub> )
 Electrolysis of water	Renewable energy	<1	4,0-9,0
 Electrolysis of water	Nuclear energy	<2	3,5-7,0
 Pyrolysis	Fossil fuel	<3	1,25-2,2
 Steam methane reforming (with carbon capture)	Natural gas, coal	<4	1,5-3,0
 Steam methane reforming (without carbon capture)	Natural gas	8-10	0,5-1,7
 Gasification	Coal	>20	1,0-2,2

Figure 1. Hydrogen production methods by source

## Hydrogen Storage and Distribution Technologies

The plans to use hydrogen in the short, medium and long term in road, rail, sea and air transport, industry, production of green chemicals, integration of renewable energy sources, buildings and in a wide range of similar fields increase the interest in, and need for, hydrogen storage technologies.

Physical hydrogen storage methods are classified according to the storage of hydrogen in liquid, cold/cryogenic gas and pressurized gas form. For large-scale applications, underground storage systems are used in general. Material-based hydrogen storage systems are classified as adsorbent, sodium borohydride and chemical carrier systems.

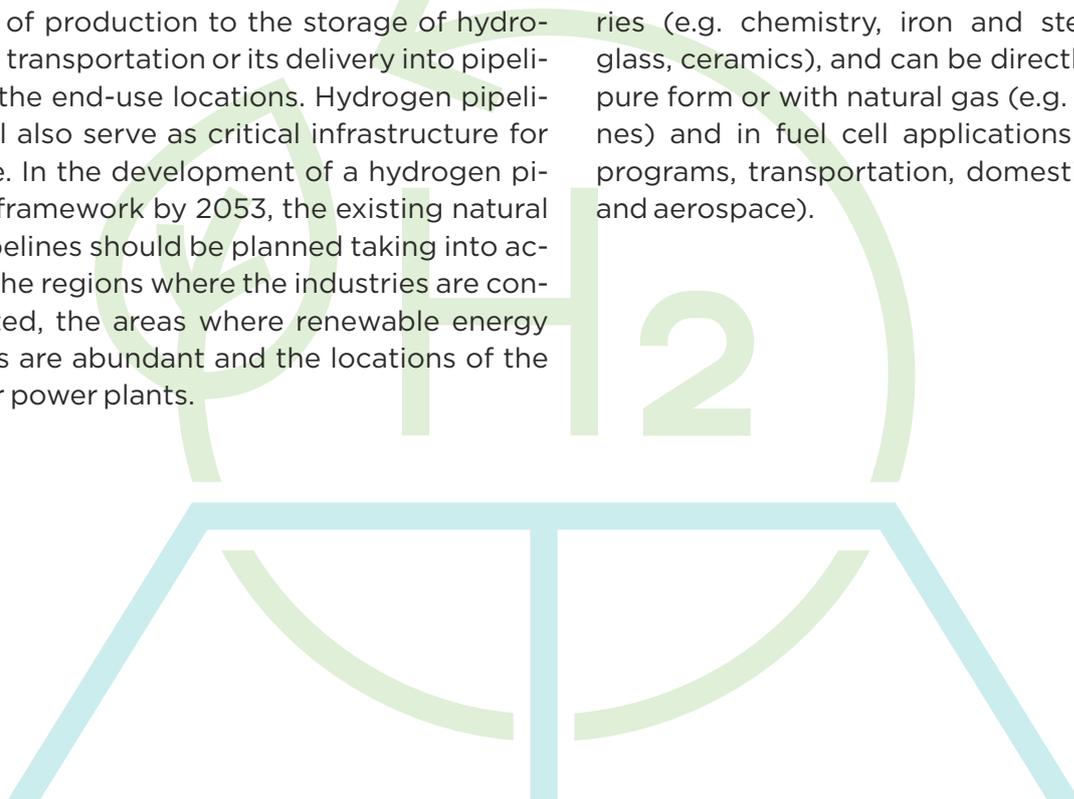
The transmission and distribution of hydrogen is crucial in that they will expand the use of hydrogen in a variety of industries and contribute to decarbonization. The entire value chain covers all of the procedures carried out from the source of production to the storage of hydrogen for transportation or its delivery into pipelines to the end-use locations. Hydrogen pipelines will also serve as critical infrastructure for Türkiye. In the development of a hydrogen pipeline framework by 2053, the existing natural gas pipelines should be planned taking into account the regions where the industries are concentrated, the areas where renewable energy sources are abundant and the locations of the nuclear power plants.

## Hydrogen Utilization Areas and Application Technologies

As a fuel and raw material, hydrogen supports many aspects of the economy, particularly in the energy and chemical industries, as well as our daily life. Considering the increased energy consumption in Türkiye and worldwide, it is clear that hydrogen will play a key role in terms of environmental impact. According to current plans, low-carbon hydrogen demand is expected to exceed 100 ktH<sub>2</sub>/year in industrial applications and gas networks by 2030.

More long-term applications are expected in the iron and steel, aviation and maritime industries. In addition to the direct use of hydrogen, chemicals produced from hydrogen, such as methanol and ammonia, have a high potential for use both as fuel and in various industrial processes. Such fuels are more attractive for some applications, as they are easier to store and transport.

Hydrogen can be used in manufacturing industries (e.g. chemistry, iron and steel, cement, glass, ceramics), and can be directly used in its pure form or with natural gas (e.g. in gas turbines) and in fuel cell applications (e.g. space programs, transportation, domestic, industrial and aerospace).



## GLOBAL VISION AND TARGETS

In its long-term plans, the EU aims to increase the share of hydrogen in Europe's energy consumption to 13-14% by 2050. In order for Türkiye, which is the EU's sixth largest trade partner and a remarkable player in the global renewable energy arena, to keep up with such goals, it needs to put forward a clear national strategy in the field of hydrogen technologies, gain competence in those technologies, and become a competitive player at global level.

In March 2022, the member states of the European Commission published the "REPowerEU Plan", which set the target of 10 million tons of green hydrogen production and 10 million tons of green hydrogen import to stop using fossil fuels by 2030. In this plan, the EU targets were revised and the installed electrolyzer capacity is planned to be increased to 65-80 GW by 2030. The current situation and the targets set in some countries are summarized below.

Country	Current Situation and Targets
Germany	The electrolyzer capacity target for 2030 is 10 GW. A 20 TWh renewable energy source (mostly wind) is needed to support this electrolyzer capacity. There are 34 gas-to-power (G-T) plants with a total installed capacity of 29 MW.
UK	It set a target of 10 GW low-carbon hydrogen production by 2030, of which at least half to be electrolyte hydrogen.
Spain	The electrolyzer capacity target for 2030 is 4 GW.
Netherlands	It aims to develop an electrolyzer capacity of 3-4 GW by 2030. It plans to install 50 hydrogen filling stations and put into use 15,000 fuel cell cars and 3,000 fuel cell trucks.
France	The electrolyzer capacity target for 2030 is 6.5 GW. As of 2020, a carbon tax of €44.6/tonCO <sub>2</sub> is levied on gray hydrogen. It is foreseen that this carbon tax will be increased to €100/tonCO <sub>2</sub> in 2030.
Other EU Countries	The installed electrolyzer capacity target of EU countries by 2030 is 65-80 GW. Denmark set an electrolyzer capacity target of 4-6 GW, Italy 5 GW, Sweden 5 GW, Portugal 2-2.5 GW and Poland 2 GW.
Australia	It is expected to reach an electrolyzer capacity of about 50 GW by 2030 based on the planned projects. Agreements have been entered into with China, Japan, South Korea and Singapore, and exports are planned to reach 3.8 Mt hydrogen (~9.5 billion Australian dollars) by 2030.

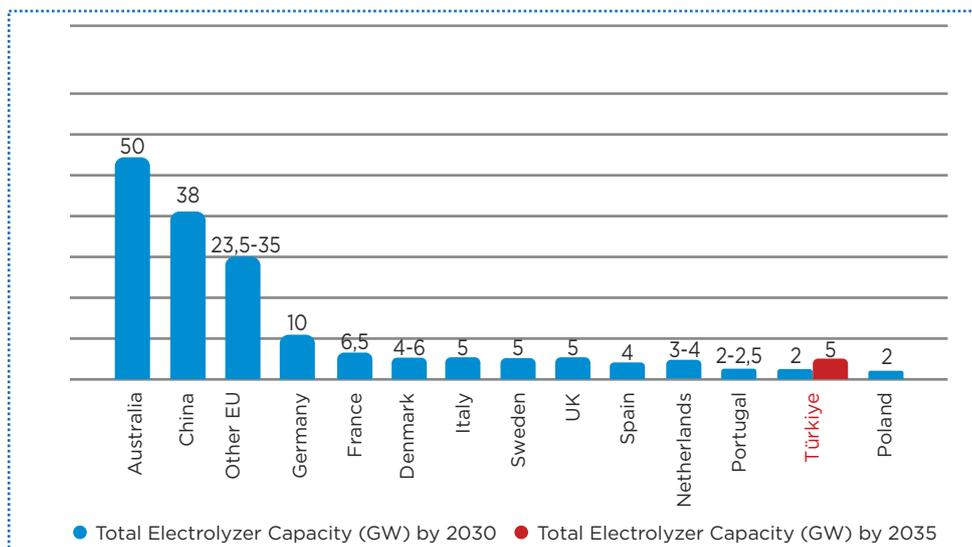


Figure 2. Global electrolyzer capacity targets

## CURRENT SITUATION IN TÜRKİYE

In Türkiye, hydrogen was cited in official documents for the first time as an alternative fuel whose use should be encouraged with the enactment of the Energy Efficiency Law in the Official Gazette published on 2 May 2007. In 2011, a regulation on hydrogen fuel cell vehicles was published. The “Regulation on Rules and Procedures for Increasing Energy Efficiency in Transport”, which includes hydrogen among the clean energy fuels that will be encouraged as an alternative to fossil energy sources in the projects by the Ministry of Transport and Infrastructure, was published on 2 May 2019.

In the “Hydrogen Exploration Conference” held by the Ministry of Energy and Natural Resources (MENR) on 15 January 2020, it was noted that hydrogen would be produced based on the following four main benefits;

- Incorporate more renewable energy into the system,
- Make the heating sector carbon-free,
- Produce hydrogen from domestic coal using CO<sub>2</sub> capture technologies,
- Increase the use of boron compounds for the storage of hydrogen.

In the conference, where the necessity of using storage technologies to balance electricity generation from renewable energy sources was mentioned, it was also stated that blending 2-6% hydrogen into natural gas distribution lines was one of the methods, the use of which would mean addition of 1 to 3 billion m<sup>3</sup> H<sub>2</sub> into the system in Türkiye.

An individual hydrogen market law can be created for the development of a hydrogen ecosystem, but it is also possible to add provisions that can serve as the basis for the creation of the regulatory framework for hydrogen to the Natural Gas Market Law (Law No. 4646), the Electricity Market Law (Law No. 6446) or the Law on the Utilization of Renewable Energy Sources for the Purposes of

Generating Electrical Energy (Law No. 5346).

The Climate Council's Recommendations published on 25 February 2022 address the development of hydrogen production, storage and utilization technologies and the creation of a Hydrogen Strategy and Roadmap.

The “Medium-Term Program (2023-2025)” published in the Official Gazette No. 31943 on 4 September 2022 highlights that necessary steps will be taken in all sectors to attain 2053 net zero emission targets in accordance with the resource-efficient and competitive green transformation policies in the EU, which is our main export market. Moreover, Türkiye will also;

- Continue to support green technology R&D projects, especially in agriculture, industry, transportation and energy sectors, with a view to establishing a green transformation infrastructure, and develop an investment ecosystem of technologies that contribute to emission reduction, such as green hydrogen and energy storage,
- Formulate a medium-term low-carbon growth strategy on the way to the net zero emission target, determine the amount of additional investment required by the sectors for green transformation, and plan a number of support mechanisms to maintain its competitiveness,
- Improve access to climate finance taking into account the needs of the private sector, and prioritize transformative investments that increase efficiency, offer high added value, limit greenhouse gas emissions and improve green skills.

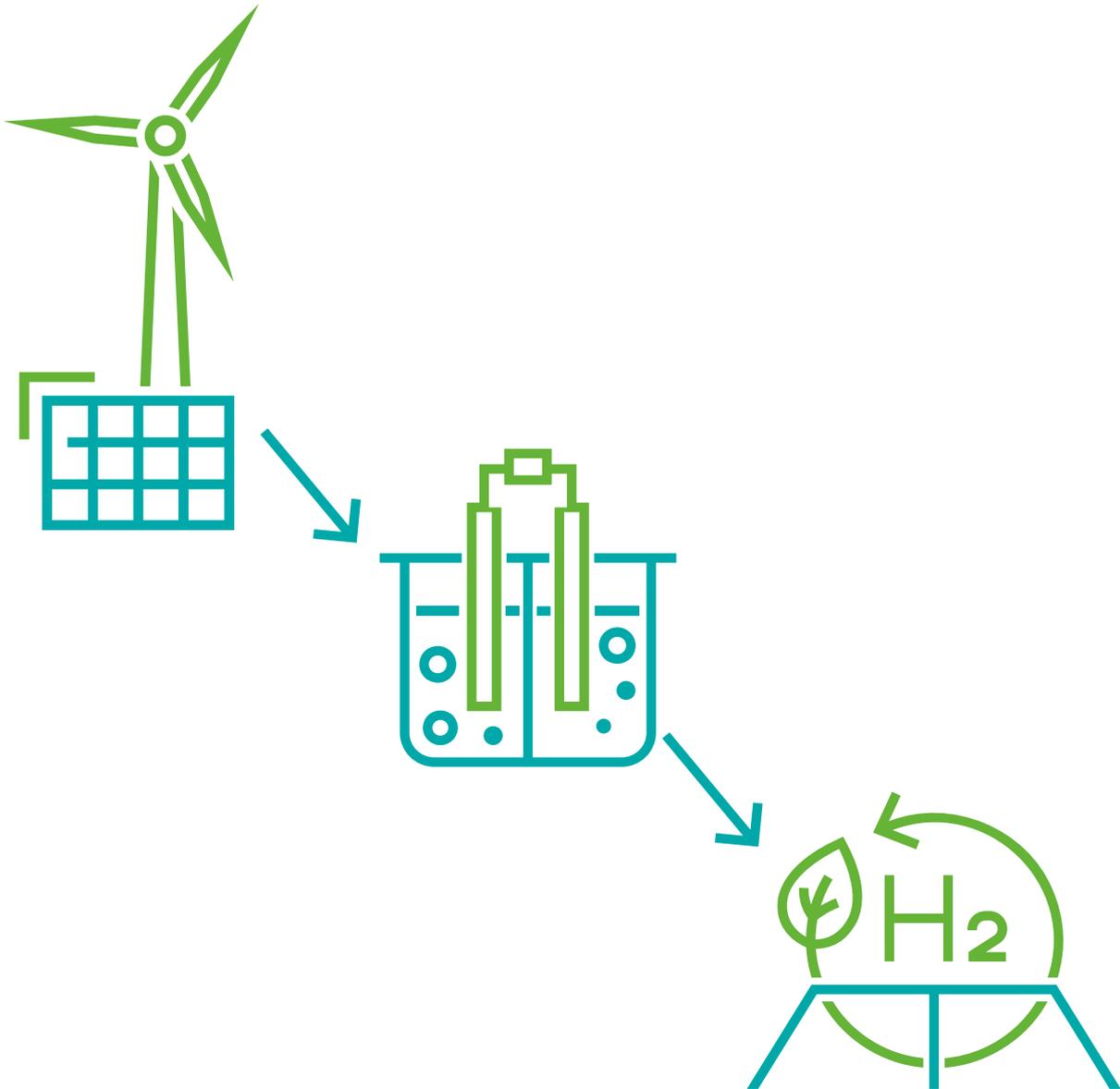
The studies carried out by the Science, Technology and Innovation Policies Board of the Presidency of the Republic of Türkiye demonstrate the importance of developments in hydrogen technologies. In order to develop policy and action proposals that will put Türkiye in a competitive position in the field of

hydrogen technologies and to ensure energy supply security/diversity, the Board drew on the “Hydrogen Technologies Policy Recommendations Report” prepared in May 2021 and offered technological/supportive solutions.

“Türkiye National Energy Plan”, published by the MENR to reach 2053 net zero emission targets, notes that natural gas will be blended

with hydrogen and synthetic methane and the percentage of hydrogen in the gas mixture will be 3.5%.

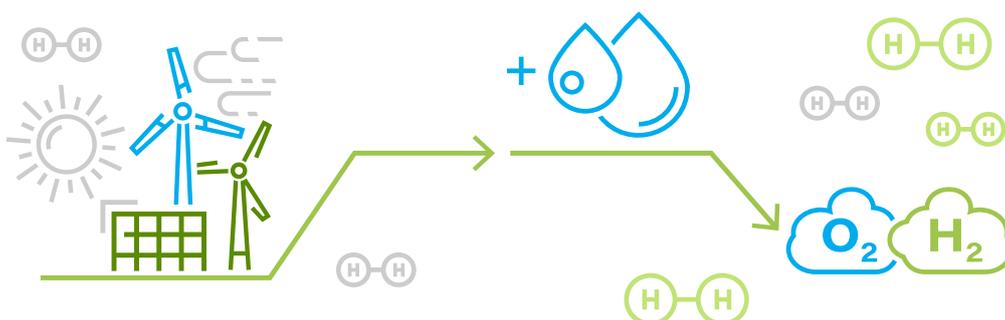
Hydrogen will also be a priority issue in the 12th Development Plan (2024-2028) and MENR's 2024-2028 Strategic Plan, which are being prepared by the Strategy and Budget Presidency and it is planned to include targets regarding the hydrogen.



## NEEDS, SOLUTIONS AND ROADMAPS IN HYDROGEN TECHNOLOGIES

In identifying the needs and developing solutions and roadmaps for hydrogen technologies, the global trends summarized below and the current situation in, and resources of, Türkiye have been taken into account.

- Upon Türkiye's ratification of the Paris Agreement, the rate of green hydrogen use will increase rapidly in industries such as transportation, petrochemistry, iron and steel, fertilizer and cement.
- In energy-intensive sectors such as iron and steel, studies will be carried out to use low-cost hydrogen at locations where it is produced.
- There will be a significant increase in the number of hydrogen vehicles for forklift and long-distance heavy freight transportation applications.
- Demand for green ammonia has an increasing trend.
- Planning and research will be undertaken on the use of hydrogen in the maritime and aviation industries, which account for a significant part of global CO<sub>2</sub> emissions.
- Projects and pilot studies will be carried out to meet the heating requirement in buildings and industry by blending hydrogen to natural gas networks or using it directly.
- The blue hydrogen that Türkiye will produce using its domestic resources will play a key role in the transition to hydrogen economy in a variety of industries, and a part of the need for hydrogen will be met in this way.
- With the use of green hydrogen produced using its energy resources, Türkiye aims to increase its energy supply security, environmental sustainability and quality of life (clean air, water and soil).
- Although Türkiye is highly dependent on fossil fuel imports in the field of energy generation, it has doubled its renewable electricity generation based on hydroelectric, solar and wind power in the last decade. Considering its potential in solar and wind power and especially low PV installation costs, it is clear that Türkiye will achieve further growth in renewable energy. However, the acceleration of efforts to develop domestic electrolyzer and the fact that significant developments have already been made in this field around the world will enable the utilization of green hydrogen through hydrolysis in every field using electricity generated from domestic renewable sources.
- Due to the increasing share of renewable energy sources such as wind and sun in the total electrical energy generation and the intermittent nature of such sources, energy storage is a necessity for both technical and economic reasons. So, hydrogen production from excess electrical energy as an alternative means of energy storage needs to be considered.
- It is predicted that the need for hydrogen in the production of hydrocarbon-based fuels and all kinds of materials will gradually increase, particularly with respect to the utilization of carbon after CO<sub>2</sub> capture in the fight against climate change.



## Türkiye's Needs with Respect to Hydrogen Technologies and Technological/Supporting Solutions to Meet Such Needs

No	Needs	Technological/Supporting Solutions
<b>Production and Utilization Technologies</b>		
1	In order to localize and nationalize the electrolyzer technology, the system sub-components are carried to the pilot plant and commercial scale with R&D/P&D studies.	<ul style="list-style-type: none"> <li>Deficiencies in the production of domestic and national electrolyzers in Türkiye will be identified, and calls for projects will be issued to ensure development of electrolyzers. Thus, Türkiye's needs for electrolyzer technologies, which are of critical importance in green hydrogen production, will be met without dependence on foreign sources.</li> <li>For mass production of domestic and national electrolyzers; <ul style="list-style-type: none"> <li>Electrolyzer cell and module designs will be developed,</li> <li>Catalyst, electrode, membrane and membrane electrode units will be manufactured,</li> <li>System control hardware and software will be developed,</li> <li>Testing infrastructure will be established in collaboration with universities and industrial associations.</li> </ul> </li> </ul> <p>International companies with a high Technology Readiness Level (TRL) will be provided with support to transfer technology for the production of electrolyzers and their sub-components.</p>
2	In order to localize and nationalize the fuel cell technology, establishment of a pilot facility with R&D/P&D studies of system sub-components and upgrade it to commercial scale.	<ul style="list-style-type: none"> <li>Firms, academics, research centers and entrepreneurs working on fuel cells will be brought together, needs will be identified and collaborations will be established. The level of available domestic resources will be identified and strengths and weaknesses will be presented. To increase TRL and expand the use of fuel cells, R&amp;D and P&amp;D calls will be issued and mass production and use of fuel cells will be promoted.</li> <li>To increase TRL regarding fuel cell technology and ensure mass production; <ul style="list-style-type: none"> <li>New fuel cell and module designs will be developed,</li> <li>Catalysts, bipolar plates, electrodes and membranes will be developed and manufactured,</li> <li>System control hardware, software and power conditioning systems will be developed,</li> <li>Prototype and mass production will be promoted,</li> <li>The necessary production and testing infrastructure will be provided,</li> <li>Project and production support mechanisms will be provided,</li> <li>Partnerships for critical technology transfer will be created.</li> </ul> </li> <li>To identify the reserves of the rare elements required for fuel cell production in Türkiye and to avoid disruption of their production in the future, it is necessary to devise plans and create a supply chain based on the identified needs. Likewise, if Türkiye's reserves exceed its needs, the precious metals will be processed and exported.</li> </ul>
3	Carry out studies on hydrogen production from domestic resources (natural gas, lignite and organic wastes)	<ul style="list-style-type: none"> <li>The current situation and TRL regarding hydrogen production from lignite will be determined and the necessary infrastructure and supports will be identified. In this way, part of the hydrogen need will be met and domestic coal gasification and hydrogen production technologies will be developed. An inventory of organic wastes that can be used to produce hydrogen by gasification will be made and necessary supports and infrastructure will be identified. Pilot plants will be put into operation to produce hydrogen using available domestic resources and organic wastes in the most efficient way. Technology level will be upgraded, sub-industry capabilities will be developed and academic research will be conducted.</li> </ul>
4	Create an industry that will produce hydrogen from renewable energy sources	<ul style="list-style-type: none"> <li>Installation of hydrogen production facilities integrated with renewable energy power plants will provide significant advantages in terms of efficiency, storage, transmission and cost. For cost-effective green hydrogen production, it is important to designate regions with high wind, solar and hydroelectric energy potential as hydrogen production sites. A large-scale hydrogen pilot site will be selected, involving refinery, cement and natural gas distribution facilities. In addition, a hydrogen production application involving a pilot pumped-storage hydropower plant where excess electricity can be stored as hydrogen will be carried out.</li> <li>To maintain the electricity supply-demand equilibrium, power plants sometimes need to reduce or completely stop electricity production. This results in Wind Power Plants (WPP) and Solar Power Plants (SPP) not being able to utilize their full capacity, thus prolonging their payback periods. Hydrogen production can be undertaken by directing a part of WPP and SPP production to hydrogen production. Domestic and national electrolyzers will be developed and produced by giving priority to domestic companies for electrolyzers to be used in hydrogen production.</li> </ul>

## Türkiye's Needs with Respect to Hydrogen Technologies and Technological/Supporting Solutions to Meet Such Needs

No	Needs	Technological/Supporting Solutions
5	Domestic production of the necessary materials for hydrogen technologies and increase the capabilities of sub-industries	<ul style="list-style-type: none"> <li>There are many universities and public and private institutions working on hydrogen, electrolyzer and fuel cells in Türkiye. Their efforts are mostly independent of each other and cover topics such as design, modelling, control, testing, component production and system integration. Each of the institutions and organizations that are project coordinators are engaged in such activities at different TRLs. It is important to identify the current situation and to conduct an analysis of strengths, weaknesses, opportunities and threats so that complementary steps can be taken, the existing fund of knowledge can be drawn on and plans can be developed for the future.</li> <li>The materials required for hydrogen technologies can usually be produced with intensive and long-term research and support. It is crucial to disseminate hydrogen technologies in Türkiye and to provide the supply chain of the components required for domestic production. It is considered that in providing the supply chain, technology transfer in critical issues can be enabled and the rapid progress of domestic manufacturers can be facilitated. By creating plans that include all scenarios, domestic manufacturers will be enabled to come up with alternative solutions through supports.</li> </ul>
6	Carry out studies on the design, development, mass production, prioritization, integration and testing of components of the systems (burners, boilers, combi boilers, etc.) that enable the use of hydrogen for energy purposes	<ul style="list-style-type: none"> <li>Studies will be carried out to identify the current situation concerning hydrogen combustion technologies, to make an inventory of domestic and national mass production of the components, and to conduct an analysis of strengths, weaknesses, opportunities and threats.</li> </ul>
<b>Storage and Distribution Technologies</b>		
7	Scale up research activities for the use of strategically important boron resources in hydrogen storage	<ul style="list-style-type: none"> <li>Pilot and mass production capacity will be identified by evaluating the experience and knowledge gained from the studies carried out in Türkiye on the applications of boron-hydrogen technologies. R&amp;D activities will be carried out and project support will be provided to commercial products that can be equipped with sodium borohydride fuel cells, including; <ul style="list-style-type: none"> <li>Land, sea and air vehicles,</li> <li>Unmanned vehicles,</li> <li>Radio and battery charging equipment,</li> <li>Armored vehicles and submarines.</li> </ul> Moreover, studies on the development of hydrogen production systems that allow hydrogen production from sodium borohydride through hydrolysis and on the utilization of by-products such as sodium metaborate will be supported.</li> <li>The current situation as well as the strengths and weaknesses concerning the use of boron and boron compounds in hydrogen technologies need to be identified. Studies should be carried out to increase TRL in order to store hydrogen in boron compounds, to produce hydrogen by hydrolysis, to develop solid fuels containing boron for defense and space applications, and to put commercial applications into use. Coordination between relevant institutions should be ensured for the aforementioned studies. Strategic areas and priority R&amp;D projects for boron-hydrogen technologies will be designated by those institutions and commercial product development studies will be carried out.</li> </ul>
8	Correct the deficiencies in the production and development of storage systems with domestic components for the storage of hydrogen in gas/liquid state using solid materials as well as for its transmission/distribution	<ul style="list-style-type: none"> <li>Considering the major technologies for storage, transmission and distribution, the current situation and areas that need improvement will be determined in order to examine the technical characteristics of existing natural gas distribution and transmission lines and to make them suitable for the distribution and transmission of hydrogen.</li> <li>In the plans for transition to hydrogen, studies will be carried out on the domestic production of necessary components. In this context, support will be provided to the production of; <ul style="list-style-type: none"> <li>The components required for transportation by pipelines,</li> <li>Pressure tanks for land vehicles,</li> <li>Metal hydrides (especially boron compounds) for hydrogen storage,</li> <li>cryogenic tanks for the aviation, space and defense industries.</li> </ul> </li> <li>Manufacture of the necessary components for the production of pipes suitable for the transmission and distribution of hydrogen will both meet the domestic need and increase the variety of exported products.</li> <li>Opportunities for storing hydrogen in underground salt caves, similarly to storage of natural gas, will be explored in order to create a large volume storage capacity that will be needed with the widespread use of hydrogen.</li> </ul>

## Türkiye's Needs with Respect to Hydrogen Technologies and Technological/Supporting Solutions to Meet Such Needs

No	Needs	Technological/Supporting Solutions
9	Establish the infrastructure for the transportation, distribution and utilization of hydrogen through natural gas pipelines	<ul style="list-style-type: none"> <li>• Technical characteristics of the existing natural gas transmission and distribution lines, including their suitability for hydrogen transport as well as their permeability, fragility, useful life, etc. will be reviewed, and infrastructure investments will be made to make them suitable for hydrogen transport.</li> <li>• Sub-components required for the transportation of pure hydrogen or hydrogen-enriched natural gas, such as valves, instrumentation (sensors, analyzers, detectors, etc.), regulators and fastening materials should be produced in accordance with international standards. By providing support to the sub-industries, the production of the systems that are needed will be possible.</li> <li>• The suitability of existing systems for the use of hydrogen-enriched natural gas in Türkiye has been examined in small-scale studies. Detailed studies will be carried out for different hydrogen contents (2–20%) as part of the studies for expanded use and upgrading to industrial scale. Regarding the blending of hydrogen into natural gas; <ul style="list-style-type: none"> <li>▶ The suitability of existing natural gas systems for hydrogen-enriched natural gas will be identified,</li> <li>▶ Combustion systems for natural gas with high hydrogen content will be developed,</li> <li>▶ Efforts will be made to upgrade the developed combustion systems from pilot scale to mass production scale. A detailed life cycle impact analysis will be conducted and the environmental, social and economic benefits of adding hydrogen to natural gas lines will be determined.</li> </ul> </li> </ul>
10	Install hydrogen transmission, distribution networks and filling stations	<ul style="list-style-type: none"> <li>• Hydrogen filling stations will be installed and expanded in Türkiye in order to meet the fuel needs of fuel cell vehicles that will both be developed domestically through R&amp;D projects and placed on the market by foreign companies. International safety standards for humans and the environment will be taken into account in the installation of hydrogen filling stations. In particular, hydrogen production systems using electricity from renewable sources and filling stations will be planned in the form of integrated facilities.</li> </ul>
11	Carry out studies on portable (charging systems, etc.), stationary (microgeneration, power systems, etc.) and vehicle (land, air and sea) applications of fuel cell systems	<ul style="list-style-type: none"> <li>• The silent operation and low thermal traceability of land, air and sea vehicles offer significant advantages in military applications. To gain the technological competence to produce and expand the use of fuel cell systems, it is important to; <ul style="list-style-type: none"> <li>▶ Support and strengthen existing infrastructures,</li> <li>▶ Provide necessary R&amp;D support,</li> <li>▶ Engage in international cooperation,</li> <li>▶ Install and expand hydrogen production and filling stations, thus making the market attractive for fuel cell vehicle manufacturers.</li> </ul> </li> </ul>
12	Set a target for the export of hydrogen and hydrogen technologies	<ul style="list-style-type: none"> <li>• The hydrogen production potential of Türkiye and the areas where it can perform better in hydrogen technologies will be determined and its export potential will be evaluated. Necessary collaborations will be established in line with export targets, and design, production, operation and performance standards and targets will be set for systems, products and services that will be used in hydrogen technology.</li> </ul>
<b>Industrial Utilization Needs</b>		
13	Promote use of green hydrogen in refinery, desulfurization, ammonia/fertilizer, glass etc. industries	<ul style="list-style-type: none"> <li>• Ensuring clustering of all main and sub-industries using green hydrogen will provide significant benefits in terms of production and consumption. For example, the establishment of green hydrogen production centers will facilitate the use of hydrogen in carbon-intensive industries. Thanks to clustering, the unit price of green hydrogen produced by electrolyzers to be installed in large capacities will be reduced, thereby making it possible to export surplus green hydrogen to Europe at a price advantage.</li> </ul>

## Türkiye's Needs with Respect to Hydrogen Technologies and Technological/Supporting Solutions to Meet Such Needs

No	Needs	Technological/Supporting Solutions
14	Formulate the strategy and establish the infrastructure for transition to green hydrogen from fossil fuels in carbon-intensive industrial sites	<ul style="list-style-type: none"> <li>It is necessary to determine the carbon footprint and decarbonization potential of the industries whose decarbonization is a priority in Türkiye. The decarbonization of the industries has become an urgent issue, particularly within the framework of the Carbon Border Adjustment Mechanism (CBAM), which aims to impose additional obligations on carbon-intensive imports from outside the EU. One of the primary means of decarbonization is the use of hydrogen instead of fossil fuels. In this context, it is important to make an inventory of the industries that have priority as per EU regulations. Such industries will be provided with support so that they use green, blue and turquoise hydrogen.</li> </ul>
15	Correct the deficiencies in the development, prioritization, promotion and implementation of domestic and national hydrogen technologies in the defense, aerospace and space industries	<ul style="list-style-type: none"> <li>Türkiye has a high TRL with regard to fuel cells. Studies conducted by different universities usually focus on single cells. If calls for R&amp;D projects are issued in a way to target products that meet the needs in the fields of defense and aerospace, it will be possible to develop, focus on and prioritize domestic and national hydrogen technologies and create the motivation for cooperation.</li> <li>Supporting the production and storage of liquid hydrogen and liquid oxygen as well as studies involving launchers using combustion technologies and fuel cell applications will ensure that practitioners gain competence in this field.</li> </ul>
<b>Non-Technological Needs</b>		
16	Develop target-oriented plans for the hydrogen value chain (production, storage, transmission, distribution and use) and establish directly related institutions, different industrial clusters and market-based mechanisms	<ul style="list-style-type: none"> <li>The support to be provided for the expansion and development of hydrogen technologies in Türkiye is of critical importance. Such supports should be used in areas that will pave the way for the development and expansion of technology. They will facilitate; <ul style="list-style-type: none"> <li>The transition of the industries that already use hydrogen extensively to green hydrogen,</li> <li>Hydrogen production from renewable energy sources,</li> <li>The transition to hydrogen in line with 2053 decarbonization targets,</li> <li>The development of materials and equipment for the transmission, storage and use of domestic and national hydrogen technologies (electrolyzers, fuel cells, etc.).</li> </ul> </li> </ul>
17	Improve existing infrastructures (laboratory, test systems, etc.) related to hydrogen technologies in universities and public and private research centers, and ensure cooperation and coordination	<ul style="list-style-type: none"> <li>If master and doctorate programs are opened in the fields needed for hydrogen technologies, the need for qualified researchers can be met.</li> </ul>
18	Increase the number of qualified researchers in hydrogen technologies and related disciplines and ensure continuity in employment	<ul style="list-style-type: none"> <li>Türkiye aims to employ more trained personnel to keep up with the current and newly developed technologies. With regard to hydrogen technologies; <ul style="list-style-type: none"> <li>Industrial collaborations will be established for the employment of graduate and doctoral students in Türkiye,</li> <li>Transformation of PhD theses into products will be encouraged and necessary industrial collaborations will be established for commercialization.</li> </ul> </li> </ul>
19	Engage in international cooperation	<ul style="list-style-type: none"> <li>Türkiye has a critical geopolitical position. During the transition to hydrogen, cooperation between European and Asian countries in the production, transportation, export and use of hydrogen will make a significant contribution to the rapid expansion of hydrogen technologies. Türkiye will engage in cooperation with other countries in all areas from the production of hydrogen to its transmission and marketing.</li> </ul>
20	Conduct studies on safety of hydrogen technologies, their legal aspects, and social awareness	<ul style="list-style-type: none"> <li>All segments of the society will be informed through workshops, papers, television programs and training courses on hydrogen technologies. Awareness-raising campaigns will be launched to provide the necessary information for the use of hydrogen technology. To raise awareness, "promotional demonstration" projects will be carried out and communities will learn about hydrogen technologies.</li> </ul>

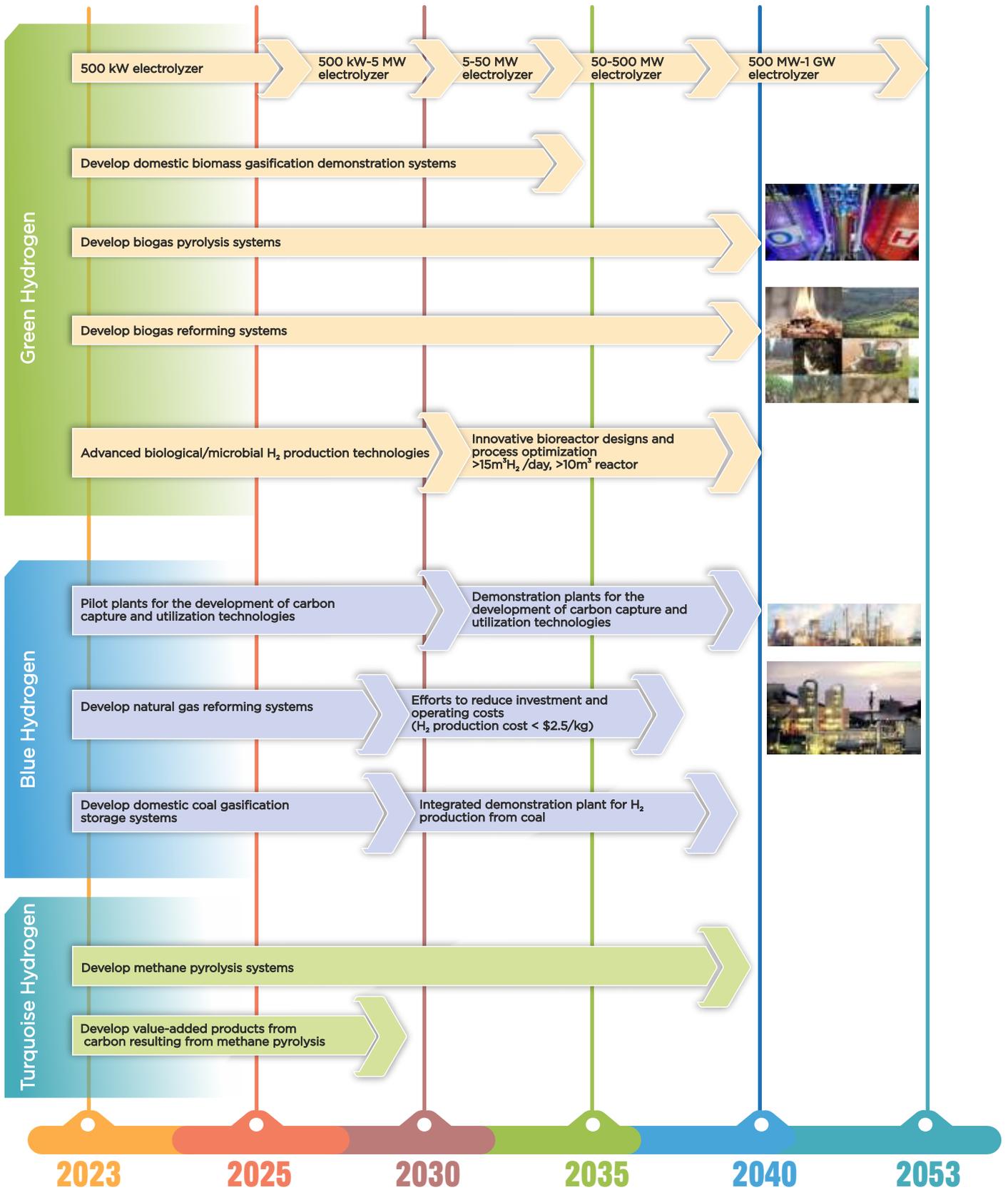


Figure 3. Hydrogen production technologies roadmap

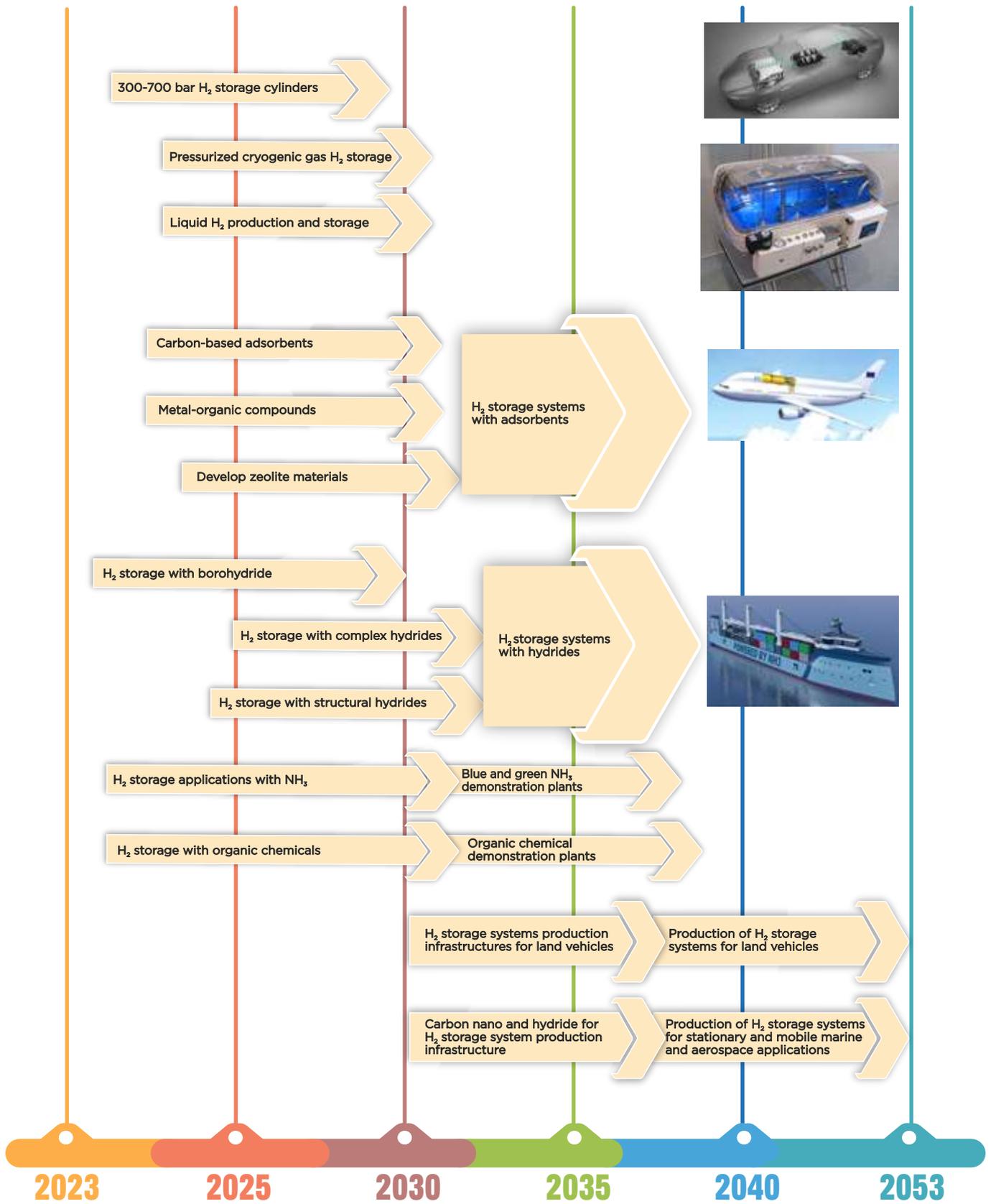


Figure 4. Hydrogen storage technologies roadmap

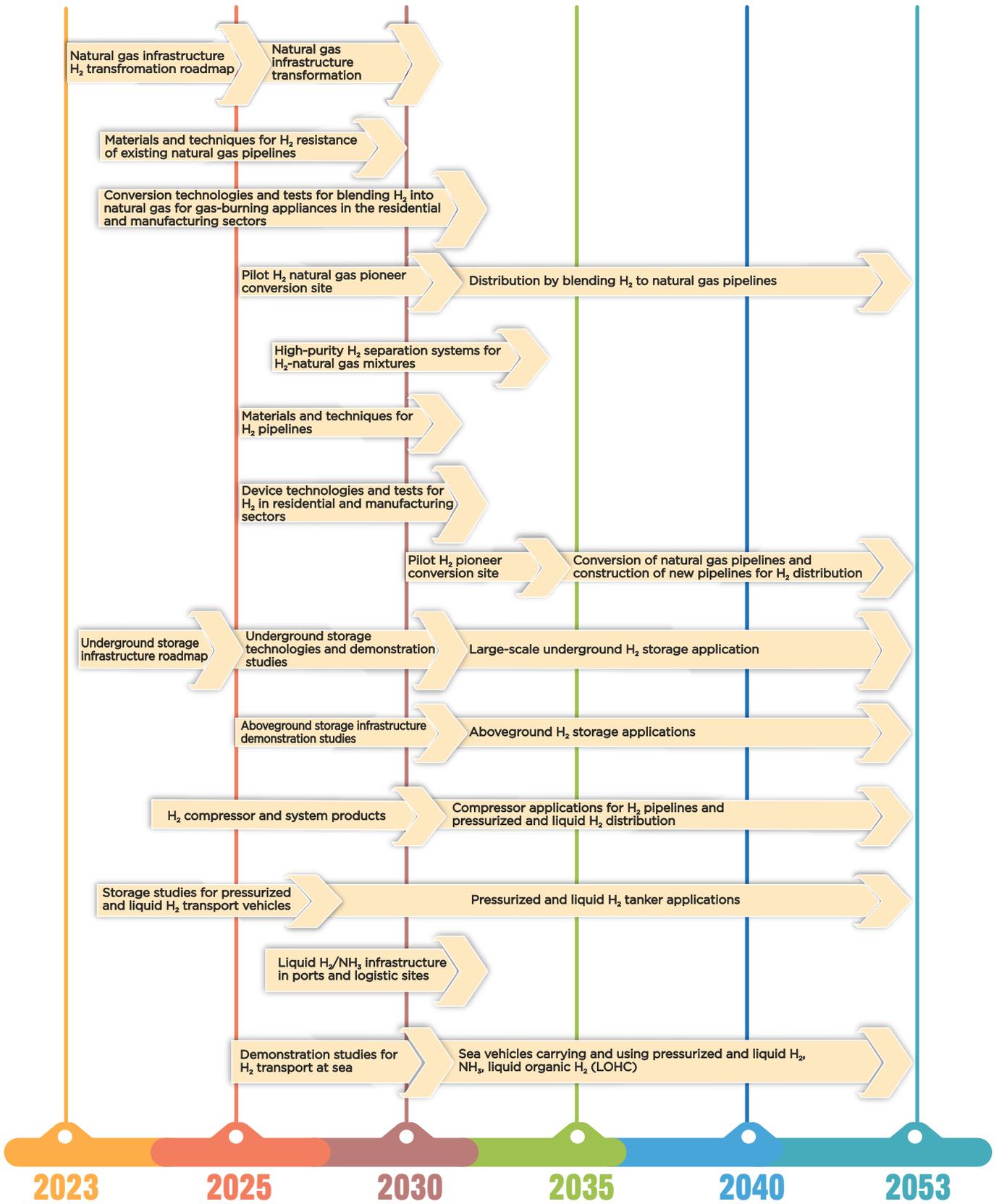


Figure 5. Hydrogen distribution technologies roadmap

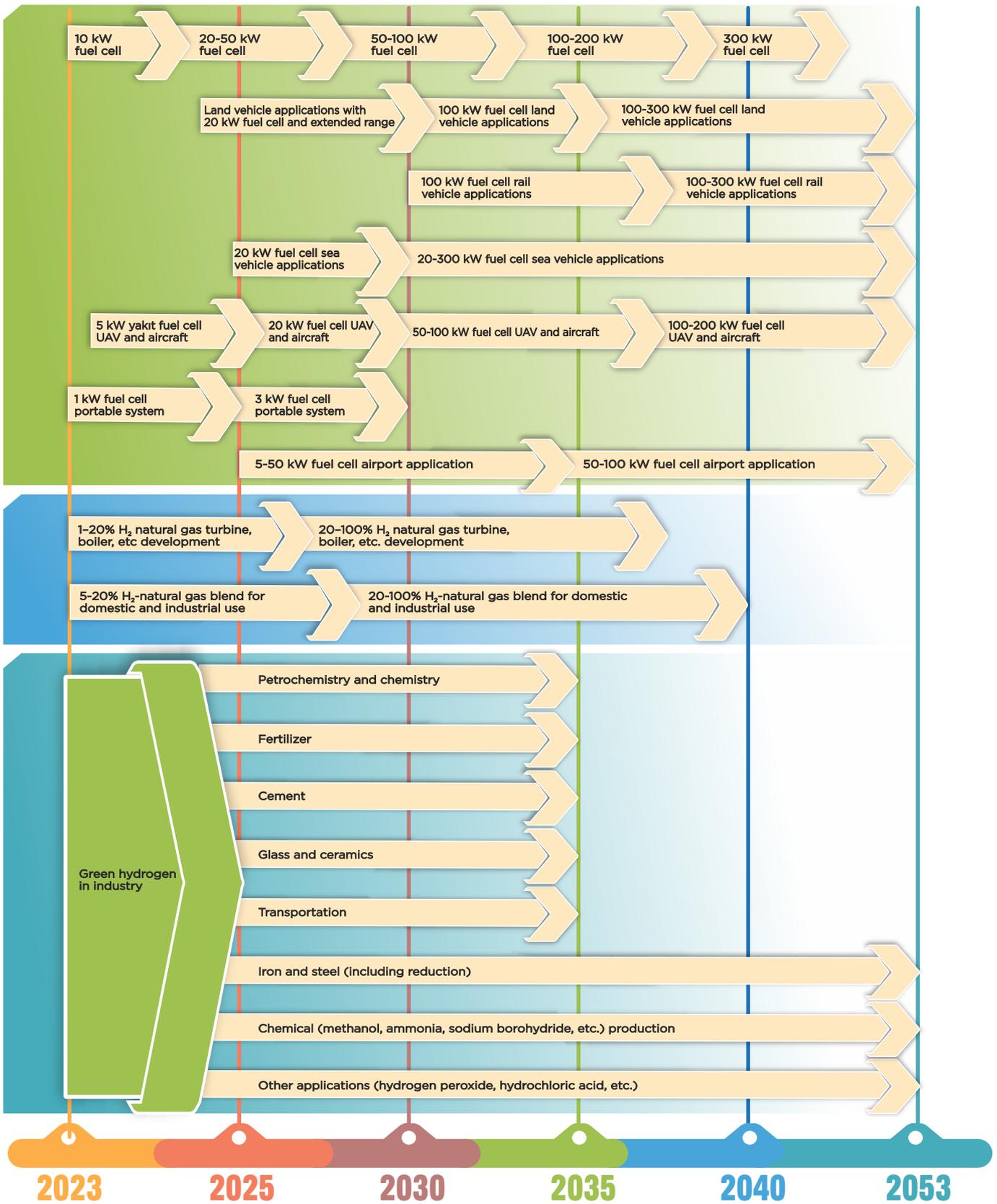


Figure 6. Hydrogen utilization technologies roadmap

## CONCLUSIONS, TARGETS AND POLICIES

The potentially critical role of hydrogen is increasing worldwide. Numerous strategy documents and regulations that will shape the future of hydrogen are being issued. Existing gaps in the value chain, covering all processes from the production of hydrogen to its final use, are being studied. It is known that hydrogen, which is one of the primary arguments for achieving net zero emissions, will add great value to our lives.

It is of great importance to establish forums for the exchange of information among all stakeholders and national and local governments on hydrogen technologies. Since hydrogen technologies concern many players in the ecosystem, it is important to engage and inform all stakeholders about them and to carry out inclusive studies. Hydrogen infrastructure can be established by effective communication among all players who will implement the regulations in the legislation, develop technologies and fund their development, and bear the responsibility for storage and distribution.

For the development of a domestic green hydrogen market in Türkiye, it is necessary to harmonize and clarify the existing legislation and to develop technical standards in line with international standards regarding the production, distribution, storage and end-use of green hydrogen.

It is essential to synergetically carry out the studies required to ensure effective adoption of hydrogen technologies in the coming years. The success of the policies in the report will also depend on the development of training programs to create a skilled workforce ready to implement new hydrogen technologies.

The objectives and policies formulated by evaluating the needs and solutions of Türkiye based on the studies carried out around the world are presented below.



## TARGETS

- 1 Reduce the cost of green hydrogen production to less than \$2.4/kgH<sub>2</sub> by 2035 and less than \$1.2/kgH<sub>2</sub> by 2053;
- 2 To ensure that the installed power capacity of the electrolyzer reaches 2 GW in 2030, 5 GW in 2035 and 70 GW in 2053.

## POLICIES

- 1 Review the current legislation and make it suitable for hydrogen production, transportation, storage and use;
- 2 Develop an incentive mechanism for the use of domestic components in the production and storage of green hydrogen;
- 3 Develop certificate programs for green hydrogen and ensure their traceability;
- 4 Encourage R&D and P&D for the development and production of domestic and national technologies (electrolyzer, fuel cell, etc.);
- 5 Engage in public and private sector partnerships to encourage commercial demand and investments;
- 6 Cooperate internationally on issues related to industry, technology, standards and certification development, supply chain and trading opportunities;
- 7 Promote widespread use of green hydrogen in all relevant industries, especially those where carbon emissions are difficult to reduce (chemistry, iron and steel, transportation, glass, ceramics, etc.);
- 8 Ensure continuity in employment by training qualified labor in hydrogen technologies;
- 9 Carry out R&D activities for the production of hydrogen and synthetic gas from lignite and organic wastes;
- 10 Increase the production and share of renewable energy to increase green hydrogen production;
- 11 Contribute to the gradual decarbonization of the heating sector by blending hydrogen into existing natural gas lines;
- 12 Use domestic resources, particularly boron, in hydrogen storage;
- 13 Export excess green hydrogen and ammonia to other countries, especially to the European market, with our domestic technologies



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