Nationaal Waterstof Programma

# Hydrogen Roadmap

for the Netherlands

## Colophon

This is a publication of:
**the Dutch National Hydrogen Programme (NWP)**

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This publication was commissioned by the Ministry of Economic Affairs and Climate Policy

*The NWP is a public-private partnership for the joint realisation of ambitions and agreements in the field of hydrogen. The NWP consists of representatives from the entire hydrogen sector, and relevant officials*

*The NWP stems from the National Climate Agreement of the Netherlands*

# Hydrogen Roadmap

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# Contents

# Summary of the Hydrogen Roadmap

## Introduction

The Hydrogen Roadmap describes how a broad group of stakeholders intends to progress Dutch hydrogen ambitions and climate targets in the coming years. These parties – both public and private – have committed to the Nationaal Waterstof Programma (National Hydrogen Programme, NWP). The Roadmap uses a holistic approach to developing the Dutch hydrogen market by linking supply, transport, distribution, storage, application and the requisite preconditions. It lists the objectives for the coming years and the actions needed to achieve them. In addition to concrete objectives and actions to be carried out up until 2030, the Roadmap looks ahead to the period after 2030 with a clear long-term focus.

The development of the Dutch hydrogen market is imperative if the Dutch economy is to become more sustainable. Renewable and low-carbon hydrogen and hydrogen derivatives will contribute to making industry, mobility, the built environment and electricity generation more sustainable. The need for the rapid development of the global hydrogen market is urgent because of the worldwide inertia with regard to climate action and the pressure on the security of supply. The Netherlands is willing and able to play a central role in this global market. The demand for renewable hydrogen is increasing rapidly and adequate on and offshore production and imports will be required in the Netherlands. Because of the country's experience with hydrogen, extensive port, transport and storage infrastructure, existing industry, large-scale rollout of offshore wind energy and favourable location for transit in relation to neighbouring countries, the Netherlands has an excellent starting position for the extensive upscaling of hydrogen. The size of the challenge is clear: with almost no renewable or low-carbon hydrogen supply at the present time, a speedy and significant upscaling of the entire chain – production, import, transport, distribution and use – will be needed in the period ahead. It is extremely important that the preconditions for this development are ready in good time. They include a broad safety and knowledge base, a successful rollout of renewable electricity, on and offshore infrastructure, $CO_2$ infrastructure for low-carbon hydrogen, suitable legislation and financial tools for development and rollout and sufficient qualified personnel, particularly in the technical fields.

The rapid growth of hydrogen chains will provide national and international market opportunities likely to be worth billions of euros for the manufacturing industry in the Netherlands. Around 1000 Dutch companies are already estimated to be active in these new markets. By acting quickly, Dutch companies can occupy 'control points' in various submarkets and become a force to reckon with in the international hydrogen industry. It is vital that we establish most of our energy supply chains in Europe to limit our dependence on third countries.

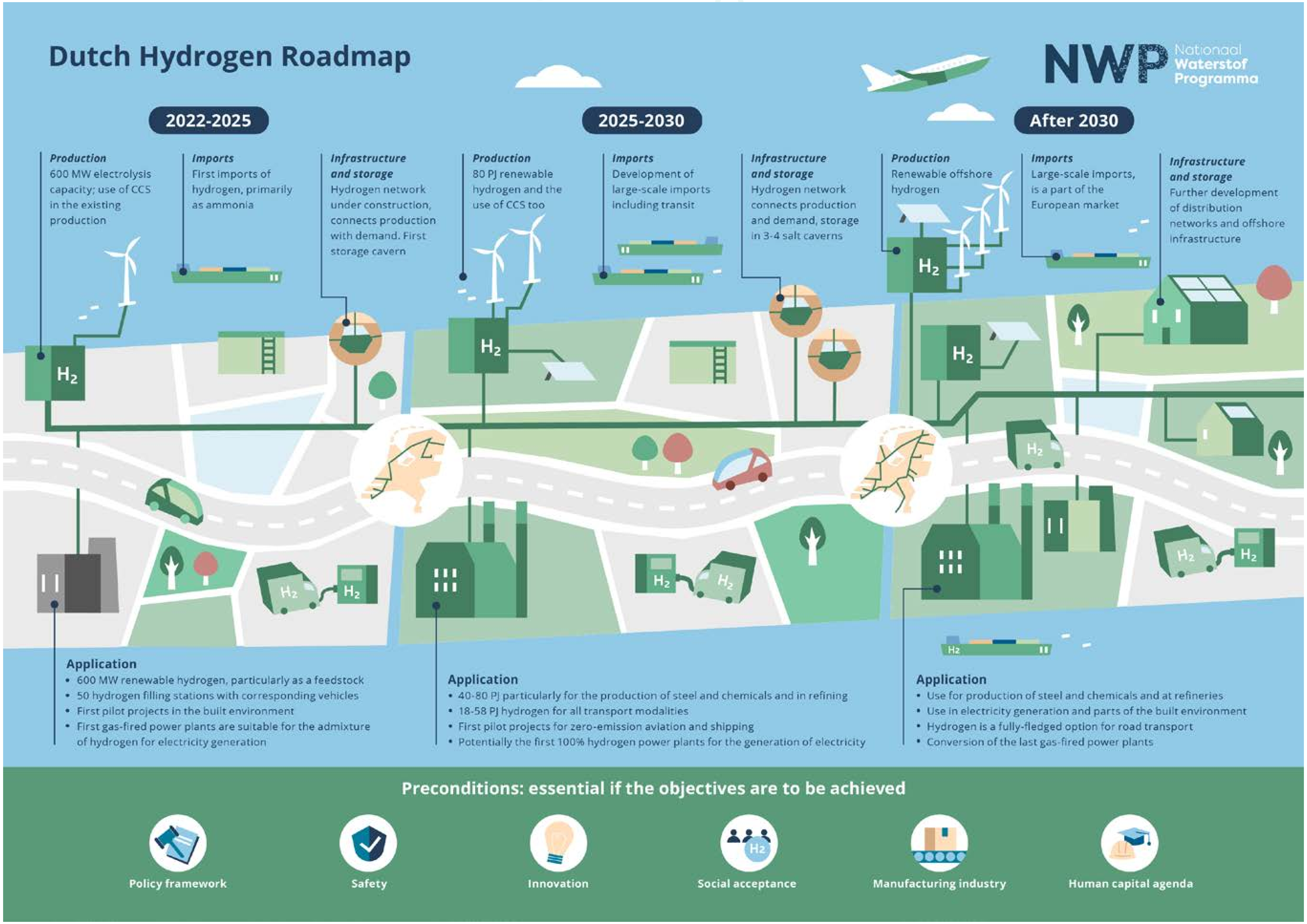
The framework within which the hydrogen market is being developed is still very much subject to change. At the time of writing of this Roadmap, negotiations are taking place in Brussels on how high the targets for 2030 should be for the use of renewable hydrogen in industry and the mobility sector. Conditions are also being laid down for the electricity used and contracted for the production of renewable hydrogen. Regardless of the precise challenges, it is clear that a considerable demand for renewable hydrogen and hydrogen derivatives will arise in industry and the mobility sector towards 2030. This will have to be met by domestic production and imports. To ensure that the Netherlands meets the European targets, NWP participants are advocating a target of at least 80 petajoule (PJ) for the domestic production of renewable hydrogen by 2030. Depending on the number of full load hours, this amounts to 6 to 8 gigawatt (GW) electrolysis. If this hydrogen may not be produced at the cost of direct electrification and the improvement of sustainability of the existing electricity consumption, the production or imports of $CO_2$-free electricity will have to be increased to meet the remaining demand for electricity.

Hydrogen will also have to be imported to supplement this and, towards 2030, offshore electrolysis will have to be scaled up. We must start the necessary actions immediately and in parallel so that we are prepared for 2030; this will entail a steep collective learning curve. The monitoring of the timing and coordination between all the activities and choices made in the years ahead form a tremendous challenge. Upscaling of production and imports will depend on and relate to various factors, including the timely presence and good working order of hydrogen infrastructure, the presence of safety frameworks and further developments in the manufacturing industry, with adequate innovations, personnel and social acceptance. Furthermore, industry and the mobility sector's ultimate demand for hydrogen will be linked to the European targets and the associated tools.

Intensive collaboration of all the players in the chain, both national and international, is therefore vital to enable the making of choices now for policy measures which will lead to investment in the short term. The government will play an important role as initiator and director of this process and in creating the preconditions.

The NWP's work will not be over on the delivery of this Roadmap. Our picture of realistic assumptions for the volume of renewable electricity needed to produce renewable hydrogen is becoming increasingly clear. This also applies to the volumes of hydrogen and hydrogen derivatives that will have to be imported. This picture is based on the outcomes of European negotiations and a growing understanding of the development of demand for renewable hydrogen and direct electrification. The NWP will share its thoughts on these developments and the policy needed. We will also introduce hydrogen interests into policy pathways such as the Nationaal Plan Energiesysteem (National energy system plan) and, moreover, monitor the progress of the objectives and actions stated in this Roadmap, adjusting them where necessary.

The graphic visualisation below shows the NWP's vision of the development and upscaling of the hydrogen market in the years 2022-2025, 2025-2030 and after 2030. The purpose of the visualisation is to create a shared picture and provide a guide to what has to take place to achieve the 2030 objectives. It also shows the steps necessary to develop a mature hydrogen market which can help make the Netherlands climate neutral. The structure of the visualisation ties in with the chapters of the Hydrogen Roadmap; an explanation is given later in this summary. The first two themes (chapter 2: Hydrogen production and chapter 3: Imports) cover the supply side and the third theme examines the rollout of the required infrastructure and storage (chapter 4). Important milestones to this end can be seen at the top of the visualisation. The milestones for the applications of hydrogen in industry (chapter 5), mobility (chapter 6), built environment (chapter 7) and electricity generation (chapter 8) are shown under them. The preconditions mentioned at the bottom of the visualisation are crucial for the intended development of the hydrogen market. The policy framework (chapter 9), safety (chapter 10), innovation (chapter 11), social acceptance (chapter 12), the manufacturing industry (chapter 13) and the Human Capital Agenda (chapter 14) are decisive factors in the intended development of the hydrogen market. The Roadmap also contains an appendix on offshore wind energy. This is because the upscaling of renewable hydrogen and the intended large-scale rollout of offshore wind energy are closely linked.


Dutch Hydrogen Roadmap
NWP Nationaal Waterstof Programma
2022-2025
Production
600 MW electrolysis capacity; use of CCS in the existing production
Imports
First imports of hydrogen, primarily as ammonia
Infrastructure and storage
Hydrogen network under construction, connects production with demand. First storage cavern
2025-2030
Production
80 PJ renewable hydrogen and the use of CCS too
Imports
Development of large-scale imports including transit
Infrastructure and storage
Hydrogen network connects production and demand, storage in 3-4 salt caverns
After 2030
Production
Renewable offshore hydrogen
Imports
Large-scale imports, is a part of the European market
Infrastructure and storage
Further development of distribution networks and offshore infrastructure
H2
Application
• 600 MW renewable hydrogen, particularly as a feedstock
• 50 hydrogen filling stations with corresponding vehicles
• First pilot projects in the built environment
• First gas-fired power plants are suitable for the admixture of hydrogen for electricity generation
Application
• 40-80 PJ particularly for the production of steel and chemicals and in refining
• 18-58 PJ hydrogen for all transport modalities
• First pilot projects for zero-emission aviation and shipping
• Potentially the first 100% hydrogen power plants for the generation of electricity
Application
• Use for production of steel and chemicals and at refineries
• Use in electricity generation and parts of the built environment
• Hydrogen is a fully-fledged option for road transport
• Conversion of the last gas-fired power plants
Preconditions: essential if the objectives are to be achieved
Policy framework
Safety
Innovation
Social acceptance
Manufacturing industry
Human capital agenda

## Overarching objectives and the most important related actions in 2022-2025

This summary contains overarching objectives and the related actions considered most important by the NWP. The Roadmap elaborates on various objectives, actions and preconditions for each theme and phase.

**1. Setting clear targets for hydrogen production and use and the development of suitable tools**

Actions

- The central government sets national hydrogen targets for supply and demand and revises them with annual interim targets.
- The central government provides a robust upscaling policy: adequate subsidies for projects and clarity on incentives for hydrogen users. It evaluates whether the policy is adequate.
- The central government and NWP participants agree to exchange information on any bottlenecks in permit procedures.
- The central government facilitates the successful development of voluntary certification schemes for renewable hydrogen, including applications in countries outside the EU.

**2. Providing certainty on the essential preconditions for the import and transit of hydrogen**

Actions

- The central government collaborates with neighbouring countries to position this region as the destination for imports.
- In the interest of diversification, the central government works on relationships with countries with export potential inside and outside Europe.
- The central government strives to have the most critical preconditions for import ready around 2025.
- The central government promotes the first phase of this Roadmap via supportive tools, such as H2Global.
- The central government carries out research into the expected import volumes of hydrogen and hydrogen derivatives, partly to determine their impact on space and safety.
- The central government and NWP participants collaborate on preparing a cross-border hydrogen infrastructure for imports and transit.

**3. Setting up a national hydrogen transport network with related storage**

Actions

- The Gasunie is commissioned by the central government to realise a national transport network for hydrogen.
- The central government investigates the possibilities for an offshore public hydrogen transport network.
- The central government and NWP participants investigate how distribution networks can be developed for the timely connection of cluster 6 and filling stations.
- The central government investigates what else is necessary in terms of aboveground and underground hydrogen storage capacity.
- The central government and NWP participants investigate possible storage sites (in empty gas fields and salt caverns: storage spaces in underground salt fields).

**4. Acquiring an understanding of hydrogen users and potential hydrogen users and realising conditions for the upscaling of hydrogen use**

Actions
- In collaboration with stakeholders, the central government develops guidelines to guarantee the safety of hydrogen application.
- The central government and the sector carry out a supply and demand analysis of renewable and low-carbon hydrogen towards 2030 and beyond.
- NWP participants provide clarity on the timelines for the introduction of hydrogen-fuelled vehicles and the realisation of filling stations.
- NWP participants work on production facilities for synthetic fuels and the development of hydrogen-fuelled aircraft and ships.
- The industry starts modifying industrial installations (and constructing new ones) so that hydrogen can be used in them towards 2030 and beyond.
- NWP participants share bottlenecks, such as permits and the modification of installations, relating to the large-scale use of hydrogen in industry.

**5. Putting adequate focus on innovation for the upscaling and application of hydrogen**

Actions
- GroenvermogenNL works on an R&D programme which covers the bulk of the required chain innovation for the years ahead. Innovation questions not dealt with in this R&D programme are tackled via generic energy innovation tools for the Top Sector Energy.
- In addition, GroenvermogenNL works on the elaboration of the Human Capital Agenda to ensure that there are sufficient qualified personnel.
- NWP participants and the central government evaluate the potential for reducing the cost of electrolysis and the most significant opportunities for further innovation before 2030.
- The central government and NWP participants aim at an energy hub and offshore hydrogen innovation programme.
- NWP participants collect the most important innovation tasks for the Dutch manufacturing industry and work on the first pilot projects and demonstrations of electrolysers and stacks, supported by, among other things, test facilities and a safety centre.
- NWP participants identify and list any bottlenecks for the realisation of Gigawatt-scale electrolysis.
- The sector and the central government investigate the use of hydrogen in new applications towards 2030 using pilot and demonstration projects in all sectors.

**6. Monitoring the integration of hydrogen into the energy system and taking alternative methods for improving sustainability into account**

Actions
- The central government makes a decision regarding the additional production of electricity from renewable on and offshore resources in line with the extra demand for electrolysis, among other things, in 2030.
- The central government investigates what strategic electrolysis capacity is desirable after 2030 and where electrolysis provides significant system advantages.
- The central government and NWP participants describe how the electrolysis projects realised contribute to a robust energy system and flexibility services to prevent network congestion.
- The central government and NWP participants investigate hydrogen's contribution to improving the sustainability of industry compared with other routes to this end.

## Production

At the moment, the Netherlands produces a large quantity of hydrogen from natural gas. In the future, the composition of Dutch hydrogen production will be fundamentally different. There will be a greater role for renewable hydrogen based on electrolysis, one of the reasons being the expected binding targets for its use in industry and mobility. Moreover, electrolysers will function as a means of energy storage and relieve congestion on energy networks. NWP participants therefore appeal to the cabinet to lay down a target for the production of renewable hydrogen of at least 80 PJ by 2030. This is necessary to ensure that the Netherlands achieves the European targets. A target of 80 PJ corresponds with about 6 to 8 GW installed electrolysis capacity, depending on the number of full load hours. In addition, we are committed to working on the upscaling of offshore electrolysis.

NWP participants suggest that the target for 2025 be fixed at 600 megawatt (MW) electrolysis capacity. This capacity must grow linearly in subsequent years and correspond with the realisation of the required wind and solar farms and the national hydrogen transport network. If this hydrogen may not be produced at the cost of direct electrification and the improvement of sustainability of the existing electricity consumption, the production or imports of $CO_2$-free electricity will have to be increased. This is because the planned quantity of offshore wind energy will not be enough to realise the entire potential for direct and indirect electrification by 2030. The integration of large-scale electrolysis in the onshore energy system forms a challenge too, as does the space it will occupy. Offshore electrolysis to supplement the capacity announced means that, by 2030, it may already be possible to produce more renewable hydrogen from additional offshore wind than with onshore electrolysis alone. The biggest challenge is to find a balance between the upscaling of electrolysis on the one hand and renewable electricity production on the other.

Supportive policy is essential for the upscaling of electrolysis capacity. The central government must therefore make an expeditious start with the implementation of such supportive policy if electrolysis projects are to be realised after 2025. It would be logical to have a subsidy tool available in the early years of this immature market to promote the growth of the electrolysis capacity. The switch to combinations of standards and pricing can be made around 2030.

Besides the production of renewable hydrogen from electricity, the production of low-carbon hydrogen from natural gas and industrial waste gases will be needed in the transition until at least 2030 to maintain a sufficiently stable supply of hydrogen for industrial applications and, at the same time, achieve industrial $CO_2$ emission targets. Carbon Capture & Storage (CCS) can be used to this end. Other promising production methods, such as pyrolysis, thermolysis and the gasification of residual waste, must be given the chance to prove themselves in the years to come.

## Imports

The concept of 'hydrogen imports' conceals a complex world of a yet-to-be-developed international trade in renewable-hydrogen-based raw materials and fuels for many different applications. It entails hydrogen in various forms, such as liquid and gaseous hydrogen, ammonia, synthetic fuels (such as methanol) and what are known as 'Liquid Organic Hydrogen Carriers (LOHCs)'.

Several countries and regions inside and outside Europe have a high capability for producing hydrogen, some of which can be exported. Initial imports will probably come from countries from which fossil fuels are currently imported: in the Middle East and North America, for example. This is because there is a great potential for renewable electricity in these countries and use can be made of existing networks, infrastructure and expertise. Preparations must also be finalised for imports from countries in Europe, such as Portugal and Spain, in this phase. The initial volumes will be small; it is therefore important that, in the coming years, preconditions are created to facilitate larger future imports. In the period after 2025, the Netherlands will import hydrogen from a growing group of countries inside and outside Europe. For this reason, the Netherlands is intensifying its collaboration with other countries by setting up bilateral Memorandums of Understanding (MoUs).

The Dutch central government is committed to providing certainty on the realisation of infrastructure, storage capacity, safety policy, regulation and certification of renewable hydrogen by 2025 at the latest. Furthermore, the initial imports will be supported via tools such as the Important Project of Common European Interest (IPCEI) framework and H2Global. It is also important that the Netherlands collaborates on an import strategy with other countries with similar import interests, such as Germany and Belgium. Collaboration with these countries can facilitate and accelerate the initiation of imports via European policy. In this way, the Netherlands can contribute to the creation of a global liquid market. This requires an energetic approach at the European level, in which space for market development goes hand in hand with certainty regarding essential preconditions.
The Netherlands, along with its neighbouring countries, can play a leading role in this.

## Infrastructure and storage

Pipelines are the most efficient way to meet domestic hydrogen transport needs; work on the development of a Dutch hydrogen transport network started in 2022. The most concrete demand for transport capacity is expected in the four industrial clusters on the coast. Fed by renewable electricity, primarily produced offshore, electrolysers will produce renewable hydrogen in the clusters. Imported hydrogen will also come into the country via these ports. The first phase of development of the transport network will connect the four industrial clusters. In the second phase of development, the demand from other parts of the country, including Chemelot, the fifth industrial cluster, located in Limburg, will be met. The timing of the construction of the transport network will depend on demand from the companies in question. This is to lead to a transport network which provides access to storage facilities and connects all the large industrial clusters to one another and the Netherlands to its neighbours in about 2027.

In parallel with national developments, preparations relating to the regional hydrogen infrastructure have also begun. Some sections of the 'major' industry (cluster 6) are connected to the regional gas network. It is important that these companies also have access to hydrogen if we are to achieve the sustainability targets by 2030. With regard to the mobility sector, as the use of heavy transport increases, the transport of hydrogen by road – for filling stations – is expected to reach the limits of what is possible. The regional infrastructure, including the requisite policy, must be ready at specific locations so that we are prepared for these developments (2025-2030). Knowledge and experience will be built up via various pilot and other projects. The infrastructure required to transport forms of hydrogen other than the gaseous form will also have to be looked at in the next few years; other modalities are eligible here.

For further expansion of the transport network capacity, efforts will have to be directed at the development of an offshore hydrogen network. A decision will be taken in the short term on market regulation and the appointment of a Hydrogen Network Operator (HNO) for this offshore hydrogen network. This will be necessary to facilitate the upscaling of offshore electrolysis.

With the growing production of and demand for hydrogen, storage will also be necessary to guarantee flexibility and security of supply. The production of hydrogen via electrolysis – linked to renewable electricity – depends on the season and the weather. This is why large-scale hydrogen storage will be needed to cushion peaks and troughs in the production and demand profiles. Variation in production can to a certain extent be cushioned by imports and underground storage of hydrogen and hydrogen derivatives. Aboveground hydrogen storage (in tanks) provides a smaller-scale alternative to underground storage. Global research is currently being carried out into the technical feasibility and potential effects of hydrogen storage in salt caverns (spaces in underground salt layers) and empty gas fields to improve the flexibility and security of supply in the energy system. Three or four salt caverns with a volume of 750 to 1000 GWh will be required for storage by 2030. Fully fledged storage locations in gas fields will probably only become available after 2030. The demand for transport and storage capacity will continue to grow beyond 2030 and a nationwide hydrogen network with adequate storage capacity will ultimately arise. This will include regional distribution networks, thus enabling it to provide the entire industrial and mobility sectors and (parts of) the built environment with renewable hydrogen. This will take place in phases, in line with the realisation of the HyNetwork Services network (HNS).

## Applications in industry

Dutch industry consumes an estimated 180 PJ hydrogen annually and is the second largest hydrogen user in the European Union, after Germany. Its current demand for hydrogen is largely met by hydrogen from natural gas and industrial waste gas. The replacement of this hydrogen by renewable and low-carbon hydrogen is an important step in improving the sustainability of our industry. At the moment, hydrogen is primarily used as a raw material. In future, hydrogen will also be used as a $CO_2$-free energy carrier for high-temperature processes.

All the industrial clusters have indicated in their Cluster Energie Strategie (Cluster Energy Strategy, CES) that renewable and low-carbon hydrogen will play a significant role in their sustainability strategies. An outright total switch from hydrogen from natural gas to renewable hydrogen is deemed unrealistic in the short term, given the maximum rollout speed of electrolysis projects, the capacity of offshore wind hydrogen production and the current state of the supportive infrastructure. Furthermore, the large-scale use of hydrogen requires far-reaching modifications to industrial installations. For long-term success, various steps are therefore needed: the central government must lay down clear policy targets for the use of renewable hydrogen by 2030 and develop suitable tools for the use of renewable and low-carbon hydrogen in industry. Industrial players must simultaneously prepare projects involving the use of hydrogen and, in collaboration with research institutes, further develop and perfect the necessary new technologies. By 2025, renewable and low-carbon hydrogen will be used as the raw material in existing applications of hydrogen, particularly for refining and chemical processes. Towards 2030, the use of hydrogen will be further upscaled to meet the European targets, primarily for the production of transport fuels and in the chemical sector. Industry and the central government will monitor the supply of and demand for hydrogen to prevent imbalance and take targeted measures to remove bottlenecks.

## Applications in mobility

The potential applications of hydrogen in the mobility sector can be divided into road transport, shipping and aviation. The Climate Agreement stipulates a target of totally emission-free mobility by 2050. The road and inland shipping mobility sectors are collectively responsible for approximately 26% of Dutch $CO_2$ emissions. International aviation and shipping are also responsible for substantial emissions. Hydrogen and fuels derived from it will play a significant role in sustainability improvements of the mobility sector, but the tasks in the various sub-sectors differ greatly from one another.

When it comes to road mobility, for example, there is a great potential for the use of hydrogen for transport over long distances and/or with heavy loads. Battery-driven electric vehicles are a more obvious solution for lighter, short-range applications. To reduce the $CO_2$ intensity and achieve the European targets, renewable hydrogen will also be used in refineries for the production of conventional fuels via the refining route and for the production of biofuels and synthetic kerosene. In time, the intention is basically to use hydrogen directly in heavy road transport and possibly also in inland shipping; hydrogen-based renewable fuels will primarily be used in maritime shipping and aviation. In the phase up until 2025, the concrete objective for road transport is to realise a basic network of at least 50 hydrogen filling stations with related vehicles. To utilise hydrogen's potential fully and in good time, substantial upscaling is required in the field of hydrogen production, the rollout of transport and distribution infrastructure and the development of hydrogen-fuelled vehicles and filling stations. The public sector is collaborating with the private sector on actions to promote the application of hydrogen in mobility. If the market for vehicles develops adequately, a nationwide network of hydrogen filling stations for different modalities is expected to be realised by 2030.

Hydrogen can also play a key role in improving the sustainability of shipping. Ships consume a great deal of energy and frequently cover long distances; this means that hydrogen can provide a solution by supplementing electrification and other clean fuels. The Green Deal Zeevaart, Binnenvaart en Havens (Green deal on maritime and inland shipping and ports) stipulates a target of 150 zero-emission inland vessels by 2030. In addition to liquid and gaseous hydrogen, various hydrogen-carrying fuels, including ammonia and synthetic fuels, can be used. Work is also being carried out in the RH2INE programme on the transition to hydrogen-powered inland vessels in Northwestern Europe. The objective is to realise almost emission-free and climate-neutral inland shipping by 2050. The maritime shipping fuel transition is still in its infancy, possible transition pathways only now being elaborated. The focus is on research, development and the demonstration of renewable fuels and technologies that will ultimately help achieve this objective.

As regards improving the sustainability of the aviation sector, the focus is on the use of renewable fuels and technological innovations. Renewable hydrogen will be used for the production of these renewable fuels, i.e. both biofuels and synthetic kerosene. The current Dutch national aim is to blend 14% renewable fuels with fossil fuels ('known as admixture') by 2030 and, finally, fossil-fuel-free flight by 2050. The Netherlands is actively targeting the implementation of a blending obligation at the European level. Moreover, parties are also working on the development of hydrogen-fuelled aircraft, the first of which is expected by early 2030.

### Applications for the built environment

There is still a great deal of uncertainty as regards how big a role hydrogen will have in improving the sustainability of the built environment. Up until 2030, its role as an alternative to natural gas is not expected to be very large. This period will be used to examine the various hydrogen applications in said built environment. To this end, various technologies will be considered, including individual and collective solutions for a building or area, making use of the existing natural gas network. The possibility of using waste heat from electrolysers is also being investigated. In addition, pilot projects are being carried out in the built environment which are yielding knowledge and experience on the applicability of hydrogen techniques.

The potential of hydrogen use in the built environment depends on a number of factors, including the availability and distribution of the hydrogen across the various sectors, cost price and degree of reuse of local networks. After 2030, hydrogen may be applied in situations in which alternative heating methods, such as heat pumps and heat networks are not feasible or desirable.

### Applications for electricity generation

Hydrogen is the obvious solution to the demand for $CO_2$-free fuel when it comes to the flexible generation of electricity. It meets the inflexible demand for electricity which is not covered by the generation of electricity from the sun and wind. Dutch natural gas-fired power plants have a good starting position for the switch to hydrogen. Subsidies for the conversion of gas-fired power plants have been included in the coalition agreement, although the form they will take is not yet clear. Conversion to power plants which admix hydrogen to gas or are 100% hydrogen-fired is an option. The possibility of admixing hydrogen to natural gas is already being investigated at a number of natural-gas-fired power plants. The ultimate reduction achieved in this way will depend on the use of $CO_2$-free fuels in the power plants in question. Given the still extremely limited availability of hydrogen at the moment and the increasing demand that can be expected from industry and the mobility sector, the actual large-scale use of hydrogen in power plants is only likely to take place after 2030. Gas-fired power plants must be converted by 2030 because the European Emissions Trading System (EU-ETS) will then be applicable to the electricity sector. Based on the tightened emission reduction target proposed by the European Commission, the entire electricity sector – along with the major industries in the EU – will, on balance, no longer be expected to emit $CO_2$ in 2040.

### Policy framework

Both European and national policy will be key to the development of the Dutch hydrogen market. The revision of the Renewable Energy Directive (RED), in particular, will affect the Dutch hydrogen market. At the time of writing of this Roadmap, negotiations between the European Commission, European Council and the European Parliament are still in progress. Finalisation of these negotiations is expected in late 2022. They concern a binding target for the use of what are known as 'Renewable Fuels of Non-Biological Origin (RFNBOs)' in industry and the mobility sector.

The European Commission aims at 50% of the total hydrogen use in industry and 2.6% of all the energy consumption in the mobility sector by 2030. Member states want lower binding targets (35% in industry by 2030 and 50% by 2035, and an indicative target of 5.2% in the mobility sector), whereas the European Parliament is committed to higher binding targets (50% in industry by 2030 and 70% by 2035, and 5.7% for the mobility sector). Negotiations are also still taking place regarding the 'delegated acts'; these acts will determine the definition of 'renewable hydrogen' and, in turn, the conditions Dutch hydrogen projects must meet to be eligible for subsidies. The definition of 'low-carbon hydrogen' will depend on the Hydrogen and Gas Market Decarbonisation package. The proposals by REFuelEU (aviation) and FuelEU Maritime (maritime shipping) will also play a major role in the production and application of fuels based fully or partially on hydrogen. Besides existing or recently announced policy, the pathways proposed by the EU in REPowerEU are important too. These include the Green Hydrogen Partnerships, Global Hydrogen Facility (Hydrogen Bank) and Hydrogen Corridors.

As regards Dutch market regulation, the question 'who is allowed to do what?' was largely answered in June 2022. Important choices will, however, still have to be made in various fields in the years up until 2025, including the following:
- the offshore hydrogen market regulation;
- the regional distribution network market regulation;
- cross-border $CO_2$ transport and storage infrastructure;
- the European market regulation for hydrogen as element of the EU Hydrogen and Gas Market Decarbonisation package;
- rules on third party access and tariffs for infrastructure;
- space, obligations and powers for regional network operators in the field of hydrogen;
- the setting up of large and small trading markets.

Policy for $CO_2$ reduction by means of the European ETS and the Dutch $CO_2$ tax is also important. It is expected that the related targets will be further tightened in the coming years. This can promote the use of renewable and low-carbon hydrogen in these sectors. There are various existing and recently announced supportive policy tools (subsidies) which will contribute to market development.

### Safety
The energy transition – and in particular the upscaling of hydrogen as energy carrier – entails new situations and the resulting safety risks. The question of safety touches on all sectors and, consequently, all hydrogen-related themes. The central government has now drawn up a generic set of basic principles for dealing with safety issues in connection with the energy transition. These principles will be elaborated in a series of guidelines for hydrogen safety. For the time being, these guidelines concern gaseous hydrogen. There are developments in the field of liquid hydrogen and hydrogen derivatives, such as ammonia and LOHCs and guidelines will have to be developed for these too. It is important for policymakers and the competent authority to acquire a greater understanding of the safety risks. The safety policy must be anchored in the regular legislation and regulations (for example, those falling under the Omgevingswet (Environment and Planning Act) and practical implementation. Temporary frameworks (such as the generic guideline and/ or certain supplementary guidelines) can then be allowed to lapse. New developments will be monitored and incorporated into the energy system in line with the tested starting points.

### Innovation
Mission-driven innovation is crucial for the realisation of successful hydrogen chains. Many of the products and services that will make up the hydrogen economy do not yet exist, have yet to be optimised and scaled up, are not yet marketable or are still too expensive. Innovation involves technology, economy, ecology, policy and human capital and their integration in the system. Innovation is therefore not solely technological in nature; social innovation is at least as important. Support is required on all the Technology Readiness Levels (TRLs), from fundamental to applied research, experimental development and pilot and demonstration projects. In the period ahead,

support will be needed both in terms of investment (Capital Expenditure, capex) and exploitational (Operating Expenditure, opex) funds to accelerate upscaling. Furthermore, it is important that a strong innovation ecosystem is built up which can set up and further develop competitive hydrogen chains. This ecosystem must have strong connections with other groups inside and outside Europe. The abovementioned points are reflected in TKI (Top consortium for knowledge and innovation) Nieuw Gas's multiannual hydrogen innovation programme. The updated version of the mission-driven innovation approach was delivered in October 2022 after the programme had been rigorously revised. TKI Nieuw Gas's revised innovation agenda lists the following priorities:

- Priority 1 - Development of renewable hydrogen chains in industry, comprising hydrogen production linked to offshore wind, infrastructure and storage and application in industry for energy purposes and as raw material, including the required system integration.
- Priority 2 - Import of hydrogen-containing energy carriers, such as hydrogen derivatives and LOHCs, and both liquid and gaseous hydrogen.
- Priority 3 - Application of hydrogen in heavy transport, such as road transport, construction and excavation, inland and coastal shipping and in aviation.
- Priority 4 - Regional, decentralised production and use of hydrogen in regions where congestion in the energy network hinders the realisation of renewable energy projects or where the local use of hydrogen can be efficiently served.
- Priority 5 - Development of technology clusters for hydrogen components and chains, including links with the manufacturing industry.

### Social acceptance

Hydrogen is currently the most socially 'visible' alternative to fossil fuels in the mobility sector. Furthermore, pilot projects have already commenced in the built environment, as have publicly coordinated projects for the construction of elements of a hydrogen transport network. In time, the impact, and particularly the spatial impact, of hydrogen will become clearer due to its growing role in the energy and raw material system. The space that renewable and low-carbon hydrogen infrastructure will occupy is being taken into account in various spatial programmes. Good environmental management is of the essence for establishing and maintaining public support, as is looking for linkage possibilities in the ultimate spatial integration of hydrogen. The development of a code of conduct by the sector will contribute to this. In addition, it must be made clear to the general public why hydrogen is an indispensable energy carrier and raw material in our future climate-neutral energy and raw-material system. By developing a narrative and public communication, the facts about the various hydrogen themes can be shared and the consequences of the growing hydrogen market explained. Acceptance by the general public must be monitored. Alignment is sought with the vision on citizen participation, in which an integrated vision of citizen involvement in the energy transition is being shaped.

### Manufacturing industry

The energy transition and the emergence of a hydrogen market provide a great many opportunities for the Dutch manufacturing industry, which is already responding to these opportunities. Collaboration between the Dutch process and manufacturing industries must get underway if they are to produce the best possible new-generation electrolysers and/or components. Dutch parties in the manufacturing industry currently have a good starting point in the field of new-generation scalable and replicable electrolysers, fuel cells, measuring systems, compressors, etc. and components for this equipment. At present, there are still no commercial Dutch production parties operating as system integrators for electrolysers although there are a few start-ups and manufacturers of small-scale systems (0.5 to 1 MW). The objective is to realise the first pilot projects and demonstrations of Dutch-manufactured electrolysers and stacks by 2025 and to support research with test facilities, a safety centre and suchlike. After 2025, the Dutch manufacturing industry will be further developed into an international player with key positions for both electrolysers and other installations/components.

### Human Capital Agenda

It will not be possible to scale up hydrogen in the Netherlands rapidly and safely enough without sufficient well-qualified personnel. This is why we must invest in training people and companies who, for example, can construct electrolysers and installations and know how to transport hydrogen safely. There are still too few of these professionals because of the extreme shortages in practically all sectors relating to the energy transition, and especially of technically trained specialists.

GroenvermogenNL is a research, demonstration and investment programme which is financed by the Nationale Groeifonds (National Growth Fund). This programme also forms the basis for the Human Capital Agenda for Hydrogen, which contains plans for the period 2022-2025. It consists of five parts:
1. charting the need for knowledge;
2. setting up Learning Communities in the regions;
3. setting up a national digital knowledge platform;
4. developing a national package of educational programmes;
5. promoting innovation and training in small and medium-sized enterprises (SMEs).