HYDROGEN ACT

Towards the Creation of the European Hydrogen Economy

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Hydrogen Europe

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Executive summary

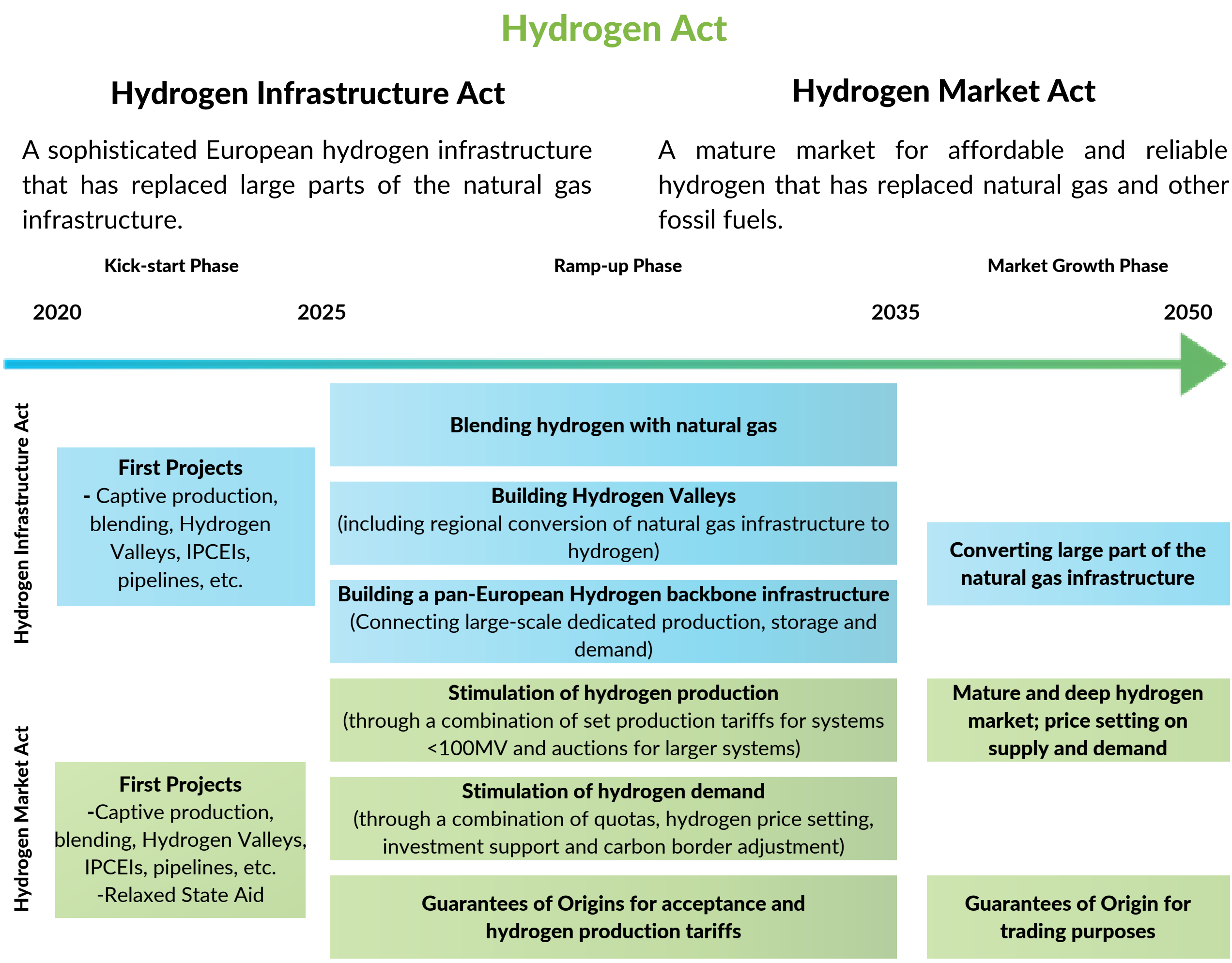
Hydrogen has seen an unprecedented development in the year 2020. From an innovative niche technology, it is fast becoming a systemic element in the European Union's (EU) efforts to transition to a climate neutral society in 2050. It will become a crucial energy vector and the other leg of the energy transition – alongside renewable electricity – by replacing coal, oil and gas across different segments of the economy. The **rapid development of hydrogen is not only important for meeting the EU's climate objectives but also for preserving and enhancing the EU's industrial and economic competitiveness.**

The European Hydrogen Strategy has set ambitious targets with a view to developing a hydrogen economy. The strategy represents the first step towards success. Now, the EU needs to "act" to turn ambition into reality. The current hydrogen policy and regulatory elements of hydrogen are distributed over gas, electricity, fuels, emissions and industrial frameworks, with limited overarching coordination. It is time that hydrogen moves from an afterthought to a central pillar of the energy system and its key role in delivering climate neutrality means it merits a dedicated framework. The proposed "**Hydrogen Act**" is not a single piece of legislation, it is **intended to be a vision for an umbrella framework aimed at harmonising and integrating all separate hydrogen related actions and legislations**. The Hydrogen Act focuses on infrastructure and market aspects, describing three phases of development: the kick-start phase, the ramp-up phase and the market-growth phase.

To meet the 2024 and 2030 targets of the EU's Hydrogen Strategy, the kick-start phase will require, for a limited period of time, exceptions and derogations from existing EU rules, such as relaxation and/or reform of EU state aid rules. Considering the challenges the hydrogen sector is confronted with in the context of the EU Green Deal, the European economy recovery post COVID19 and the Hydrogen Strategy, dedicated guidelines on state aid for hydrogen technologies should be promoted. Moving forward, the Hydrogen Act describes different methods to incentivise market functioning on the production and the demand side, including quotas targeted at the promotion of among others clean steel and ammonia. On the infrastructure side, the regulation of hydrogen networks requires a gradual approach in line with market and infrastructure developments. This ramp-up phase should start at the earliest as of 2025 to contain the funding via taxpayers' money to a minimum. The final phase describes the period where hydrogen will have achieved market growth.

Clear science-based definitions for the different production methods of hydrogen are required. To establish a robust system of carbon reduction, the CO2 content of energy carriers and vectors will become the “new currency” of the energy system and the EU economic recovery. This needs to be supported by the adoption of a methodology for the calculation of the life-cycle greenhouse gas (GHG) emissions from renewable and low carbon hydrogen, as well as transparent and robust sustainability criteria in line with the principles of the circular economy. This methodology should be the basis for relevant EU funding programs and financial support for all energy carriers, including hydrogen projects, as well as for hydrogen trade with third countries. To support this, a traceable, trackable, tradable, transparent, and trustworthy certification scheme is needed to enhance the credibility and tradability of hydrogen as a global commodity. The Hydrogen Act is a vision paper contributing to the implementation of the EU’s Hydrogen Strategy. More elaborate positions on key upcoming EU legislative initiatives will follow in separate position papers. The final goal of the Hydrogen Act is to contribute to the establishment of a proper functioning and liquid market for clean hydrogen as a new commodity in Europe, building up the backbone of a global clean hydrogen market.

The following graph contains an overview of the Hydrogen Act components and an implementation roadmap.



Introduction

Hydrogen will play a vital role in Europe's climate neutral economy, as shown in many recent scenarios. It will become a crucial energy vector and the other leg of the energy transition alongside renewable electricity by replacing coal, oil, gas and conventional hydrogen across different segments of the economy. In a system soon dominated by variable renewables such as solar and wind, hydrogen can contribute as an enabler of sectoral integration. As a direct product from renewable energy production, hydrogen can enable the transition to renewable sources by providing a mechanism to flexibly transfer energy across sectors, time and place in a more circular energy system. In addition, hydrogen is a versatile energy carrier and strategic value chain that is key to the decarbonisation of heavy industries (e.g., steel, chemicals, refining etc.), heating and transport, in particular heavy-duty trucks, lorries, as well as maritime and aviation. Furthermore, hydrogen can be seasonally stored and transported cost-effectively over long distances, to a large extent using the existing natural gas infrastructure. Besides the potential to produce dedicated hydrogen from renewable and low carbon sources, the ability to store renewable energy as hydrogen during periods of peak production contributes to alleviating curtailment of renewable electricity, bringing flexibility to the power sector, e.g., under demand-response schemes, and efficiency to the functioning of the future energy system. Predictions for hydrogen's share in the EU's final energy demand by 2050 range from 13% to 24% (FCHJU, 2019).

There is a limited market for hydrogen today, but our European continent holds unique conditions, which can facilitate market growth. Europe is leading in hydrogen technology, and European companies and knowledge institutions can be instrumental in advancing technological developments and industrial scale-up, contributing to cost-competitive renewable and low-carbon hydrogen. Coupled with the existence of an extensive gas infrastructure that can be used to transport blends of hydrogen and can also be converted to transport pure hydrogen, the EU is well placed to become the birthplace of a global hydrogen economy denominated in Euro currency. However, many other countries and regions are equally ambitious about hydrogen, and it is by no means guaranteed that Europe can maintain its leading position on a topic of growing geostrategic significance. The rapid development of a domestic European market is therefore crucial not only in terms of achieving climate neutrality by 2050 but also for preserving and enhancing EU industrial competitiveness, securing jobs and value creation in this high-tech sector.

The year 2020 has seen the emergence of hydrogen strategies in many European countries and for the EU as a whole. European countries with a hydrogen strategy include Austria, France, Germany, the Netherlands, Norway, Portugal and Spain. But most importantly, on 8 July 2020, alongside its Strategy on Energy System Integration, the European Commission released the Hydrogen Strategy for a Climate-neutral Europe (EuropeanCommission, 2020) as part of its efforts to deliver the European Green Deal. The strategy defines a target of 1 million ton of hydrogen and an electrolyser capacity of 6GW by 2024, and 10 million ton and 2x40GW by 2030. These strategies aim to create an enabling environment for the development of a secure, safe, affordable and just hydrogen economy in Europe. Although the Hydrogen Council expects hydrogen to become commercially viable in the next decade across many applications (HydrogenCouncil, 2020), the reality is that a supportive policy framework is required to bridge the cost gap with alternatives. Until sufficient renewable capacity come online to ensure sufficient running hours of electrolysers and improve the business case, a connection to the electricity grid will be required for a vast number of projects. The carbon content of the electricity mix and a sound guarantees of origin system will be key to qualify this part of the hydrogen production. For now, the European Hydrogen Strategy has set the ambition, which represents the first step towards success. Now the EU needs to “act” to realize a hydrogen economy. The Member States have given strong support via the European Council to a fast implementation of this strategy by issuing a distinguished and detailed resolution at their summit in December 2020.

Hydrogen definitions – clean hydrogen is EU Climate Law compliant hydrogen

Definitions for the different types of hydrogen stemming from various production methods has been a topic of intense political debate. At present, these differing hydrogen production methods are commonly referred to using a colour-coded scheme, e.g., green for renewable hydrogen, blue for hydrogen produced via the steam reforming of natural gas with carbon capture and storage (CCS) technology or pyrolysis[1] (turquoise)[2].

Regional and geographic characteristics differ across the European Union, and disparities exist. Member States will have different paces of change and adaptation when it comes to hydrogen, and a mixture of different technological solutions and support schemes will be required. Today, neither low carbon nor renewable hydrogen are cost-competitive when compared to hydrogen produced via unabated fossil gas. Costs for renewable hydrogen need to be brought down rapidly to meet the strategic objective of the EU's hydrogen strategy: the development of renewable hydrogen.

The EU objective is to achieve climate neutrality in 2050, as enshrined in the EU Climate Law. As such, in order to establish a robust system of carbon reduction, the CO2 content of energy carriers and vectors will become the "new currency" of the energy system and EU economic recovery. Bringing trust and credibility to the energy system requires rapid agreement on a comprehensive and science-based uniform EU-wide terminology for renewable and low carbon hydrogen, including CCS and low carbon electricity. This needs to be supported by the adoption of a methodology for the calculation of the life-cycle greenhouse gas (GHG) emissions from renewable and low carbon hydrogen, as well as transparent and robust sustainability criteria in line with the principles of the circular economy[3]. This will enable comparability of energy sources in terms of their emissions factor and subsequent contribution to emissions reductions and meeting the objectives of the EU Climate Law. This methodology should be the basis for relevant EU funding programs and financial support for all energy carriers, including hydrogen projects, as well as for hydrogen trade with third countries.

Particular attention should be taken when defining the methodology to account for the life cycle GHG emission thresholds both for renewable and other forms of low carbon hydrogen. At present, there are different threshold values appearing across different pieces of EU legislation and/or noteworthy certification schemes, specifically:

[1] Turquoise hydrogen is hydrogen produced via the thermal splitting of methane (methane pyrolysis). Instead of CO2, solid carbon can be produced in the process. Prerequisites for the CO2 neutrality of the process are the heat supply of the high-temperature reactor from renewable energy sources, as well as the permanent bonding of the carbon.
[2] An additional pathway for clean hydrogen production is via gasification process as follows: 1. Bio-feedstock (such as biomass) based gasification process; 2. Other non-biogenic circular economy alternatives: plastics and waste gasification
[3] Such as the objectives of sustainable use and the protection of resources, the handling of waste and the increased use of raw and secondary materials, pollution prevention and control, and finally, the protection and restoration of biodiversity and ecosystems.

- Sustainable Finance: Draft Delegated Act of the Taxonomy regulation stipulates 2.256 tCO_2eq/tH_2[4] ;
- Renewable Energy Directive GHG methodology proposed foresees that hydrogen for the transport sector would have to be produced at or below 3,38 tCO_2eq/tH_2;
- CertfiHy threshold is 4,37 tCO_2eq/tH_2.

Clear definitions and clear thresholds are essential. Within the context of the renewable energy directive, the threshold should be aligned with the taxonomy in order to have consistency throughout different pieces of legislation. Indeed, as a strategic priority of the EU hydrogen strategy, renewable hydrogen should receive premium support.

As highlighted in the EU Hydrogen Strategy and recent EU Council Conclusions[5] on hydrogen, low carbon hydrogen will also be needed in the transition towards renewable hydrogen. Given the urgent need to begin decarbonising existing hydrogen production, the retrofitting of existing hydrogen production facilities/steam methane reformers (SMRs) with CCS technology needs careful consideration. If these projects can become feasible and prove commercial viability, they can offer an immediate contribution to decarbonisation and a subsequent increase in hydrogen volumes available. The extent to which CCS and pyrolysis projects could be significant now and in the future depends on technological progress and will likely require a case-by-case assessment of the economic feasibility of individual projects to avoid stranded assets and sunk costs. The CertifHy threshold should be taken as a starting point for the development of a low carbon hydrogen threshold. As technological developments advance, this threshold can be revised to take into account innovation in the industry, e.g., autothermal reforming (ATR) and high-temperature reactors (HTR) can reach up to 90-95% GHG abatement, whereas existing retrofits can reach between 60-65%. These considerations should be taken into account within the context of the 2021 Gas Decarbonisation Package.

Ultimately, in order to achieve climate neutrality in 2050, both renewable hydrogen and low carbon hydrogen produced via state-of-the-art technologies that offer high performance and the ability to abate 90% greenhouse gas emissions and above will have a role to play as “clean hydrogen”. Hydrogen Europe stands for the cleanest and highest performing technologies.

[4] This is the threshold currently proposed within the context of the delegated act, as of December 2020.
[5] December 2020 Council Conclusions / Energy Council Conclusions

The need for a Hydrogen Act

Given the importance that is being placed on the role of hydrogen in meeting EU climate objectives, the framework for a hydrogen market design merits closer attention at EU level. Hydrogen is an energy vector that, in addition to transport and chemicals, straddles both the gas world and the electricity world. It belongs neither to one or the other exclusively. In the short to medium term, the focus must be on kick-starting a hydrogen economy and ramping up production and use of renewable and low carbon hydrogen, including further replacing unabated natural gas with hydrogen. Looking to the future, once a market for hydrogen has developed, the EU needs to ensure that a fit for purpose legislative regime is in place to govern hydrogen and hydrogen infrastructure. This legislative regime could draw on certain suitable tools and mechanisms developed already in EU gas and electricity legislation and should not be a simplified mirroring exercise. The EU has a unique opportunity to develop a hydrogen economy in Europe as well as a blueprint for global hydrogen regulation.

With a view to the 2021 Work Programme of the European Commission, there are a number of legislative initiatives up for review in which hydrogen is relevant, for example: the Renewable Energy Directive, reform of the Emissions Trading Scheme and Industrial Emissions Directive, the Alternative Fuels Infrastructure Directive (AFID) as well as the reform of EU gas market legislation, to name a few. Existing infrastructure legislation at EU level such as the Trans-European Networks for Energy regulation (TEN-E), in synergy with the Trans-European Networks for Transport regulation (TEN-T) and AFID can play an important role in promoting hydrogen networks and infrastructure. Whereby it also is important to tackle other issues on the infrastructure side including harmonisation and standardisation, in particular with regard to hydrogen purity and imports.

Current hydrogen policy and regulatory elements of hydrogen are distributed over gas, electricity, fuels, emissions and industrial frameworks, with limited overarching coordination. It is imperative that hydrogen moves from an afterthought to a central pillar of the energy system. Continuing to regulate hydrogen across different legislation and patchwork will delay the necessary energy transition and can lead to fragmentation, overlapping and sometimes contradictory legislation and uncertainty for investors. It will result in failure to realise the ambitious targets for hydrogen but more essentially failure to achieve and realise a clean, reliable and affordable net zero energy system. To meet the objectives laid out in the EU Hydrogen Strategy, the EU needs to remove barriers to hydrogen investment, create a level playing field with other net-zero technologies and promote a harmonised approach to hydrogen via the development of a Hydrogen Act where infrastructure, demand and production related issues come together.

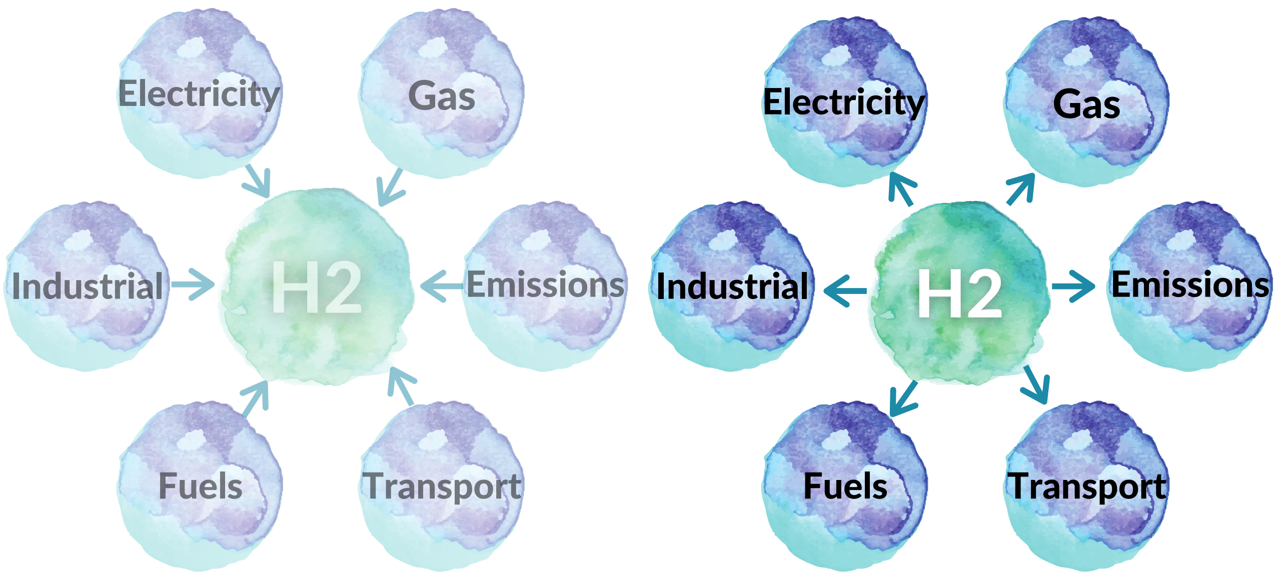


Figure 1. From a dispersed to a focused approach towards hydrogen policy

The proposed "Hydrogen Act" is not a single piece of legislation; it is intended to be a vision for an umbrella framework aimed at harmonising and integrating all separate hydrogen-related actions and legislations.

It is an innovative and novel framework whose design will facilitate the development of hydrogen as the other leg of the energy, industry, buildings and mobility transition next to electricity (or electrification). This paper outlines a Hydrogen Act, consisting of two parts, a Hydrogen Infrastructure Act and a Hydrogen Market Act. The Hydrogen Infrastructure Act is the framework for the conversion of the natural gas infrastructure into a multifunctional hydrogen infrastructure enabling the transport, distribution, storage and end-use of hydrogen and its derivatives. Moreover, it informs future regulation of hydrogen infrastructure. The Hydrogen Market Act provides a framework for how a clean hydrogen market can emerge. Furthermore, to ensure that the EU Hydrogen Strategy is effective, the EU should consider the appointment of a dedicated "EU Hydrogen Special Envoy" that would be in charge of driving forward the implementation of the EU Hydrogen Strategy and relations with third countries on hydrogen-related matters.

The intention of this paper is not to provide a strict and rigid blueprint or timeline for hydrogen legislation. Instead, this paper is aimed at putting forward a vision for a fully-fledged hydrogen economy in Europe and a proposed roadmap for its implementation. The final goal should be to establish a proper functioning and liquid market for clean hydrogen as a new commodity in Europe, building up the backbone of a global hydrogen market.

To achieve this, three phases can be distinguished:

1. The kick-start phase (2021-2025)

During the kick-start phase, the foundation of the European hydrogen economy will be laid. At the end of the kick-start phase, 1 million ton of clean hydrogen will be produced per annum, and at least 6GW of electrolyser capacity will have been installed. Given the absence of a clear and harmonised EU framework for hydrogen and the initial lack of competitiveness in key applications, a fast-track approach will have to be adopted to achieve the goals.

Focus will be on projects that demonstrate the scalability of hydrogen and projects that have sufficiently matured, such as the European Clean Hydrogen Alliance projects, pre-registered IPCEIs, Hydrogen Valleys, blending and initial pipeline and storage pilot projects. Also, research, development and demonstration (RD&D) projects that support commercialisation, scale-up and increased European competitiveness will be prioritized. Additionally, projects in line with National Energy and Climate Plans (NECPS) and submitted under Recovery and Resilience Facility (RRF) plans will contribute to a considerable scaling up of hydrogen production and demand. To facilitate growth in the number of projects and close the initial cost gap, State Aid rules are relaxed in this phase, allowing support by the European Commission and the Member States up to 100%.

An appropriate sunset clause for these extraordinary support measures is proposed, providing an incentive for immediate and urgent action. Furthermore, in the kick-start phase, it is imperative to ensure that relevant EU legislation is adapted to recognise and facilitate the important role of hydrogen whilst also removing barriers and hurdles to hydrogen uptake.

At the end of the kick-start phase, key elements of the Hydrogen Act will have been fully implemented.

2. The ramp-up phase (2025 - 2035)

During the ramp-up phase, the supporting framework aims to facilitate crucial elements of the European hydrogen economy, with the purpose to eventually achieve commercial competitiveness of hydrogen. Large scale storage and hydrogen backbones will be constructed, captive solutions and hydrogen valleys will be realised, supported by appropriate measures to stimulate supply and demand. For most applications, hydrogen will require some sort of regulatory support, including for example through tariffs, auctions/tenders, quotas, investment support, tax relief, supported by Guarantees of Origin (GO). Most hydrogen production and applications will have achieved commercial competitiveness at the end of the ramp-up phase. The Guarantees of Origin will have become a tradable commodity, much like green electricity GOs today.

A GO can prove that the underlying power or gas for the production of hydrogen has been produced from a specific source. GOs do not necessarily apply to renewable production only, which is why the inclusion of a life cycle assessment of GHG emissions will be important. It is recommendable that the GO system fulfils the following 5 T-requirements: traceable, trackable, tradable, transparent, trustworthy.

3. The market-growth phase (2035 - 2050)

After hydrogen has achieved commercial competitiveness with conventional production and alternatives, much of the support frameworks of the previous phases will have become obsolete. Hydrogen will continue the replacement of unabated fossil fuels by converting a large part of the natural gas pipelines and further integration of the European hydrogen system. The hydrogen market will be transparent and liquid, and price-setting will largely be governed by mechanisms of supply and demand. As network integration deepens, the market will require regulation, e.g., to ensure interoperability and market rules to avoid monopolistic behaviour.

The hydrogen infrastructure transition roadmap

Clean hydrogen can be transported using the natural gas grid and can be stored in salt caverns and depleted gas fields[6] to cater for seasonal mismatches in the supply and demand of energy. Like with natural gas, underground storage would be seasonal, while line-packing flexibility provides some short-term storage. It should be noted that low-carbon hydrogen can play an important role in an intermediate period, helping to kickstart hydrogen as an energy carrier alongside the introduction of renewable hydrogen by bringing necessary volumes to the market quickly and replacing grey hydrogen.

Infrastructure

Hydrogen is at the centre of energy system integration, bridging electricity and gas infrastructure to make the system more efficient and flexible.

In Europe, the cheapest renewable resources are hydropower in Norway and in the Alps, offshore wind in the North Sea and in the Baltic Sea, onshore wind in selected European areas, whereby the best solar resource is in Southern Europe. The current electricity grid was not built for this, it is not fit for the energy transition and needs to be drastically modernised. Renewable electricity generation from solar, wind and hydro is expected to take up a much larger share of the final energy mix in the future causing more variability. This puts pressure on the grid capacity, requiring a higher degree of system integration to avoid expensive expansions of power grids across Europe. In 2020, an estimated €1.35 billion worth of offshore wind energy was curtailed in Germany due to insufficient transmission grid capacity (Schultz, 2021). In addition, the development of new renewable energy capacity is slowed down due to the lack of grid capacity. Unfortunately, overhead power lines are difficult to deploy due to environmental concerns, popular opposition and typically take more than a decade for planning, permitting and construction. In addition, a gas grid is much more cost-effective than an electricity grid: for the same investment, a gas pipe can transport 10-20 time more energy than an electricity cable (James, DeSantis, Huya-Kouadio, Houchins, & Saur, 2018). Also, Europe has a well-developed gas grid that can be converted to accommodate hydrogen at a minimal cost. Recent studies carried out by DNV-GL (DNV-GL, 2017), KIWA (Kiwa, 2018) and Gas for Climate (GasforClimate, 2020) concluded that the existing gas transmission and distribution infrastructure is suitable for hydrogen with minimal or no modifications. So instead of transporting bulk electricity throughout Europe, a more cost-efficient way would be to transport clean hydrogen and have a dual electricity and hydrogen distribution system.

[6] https://forschung-energiespeicher.info/wind-zu-wasserstoff/projektliste/projekt-einzelansicht/74/Wasserstoff_unter_Tage_speichern/ (in German)

In addition, hydrogen, like natural gas, can be stored over seasons and can hence serve as a dispatchable source of bulk energy, a distinctive advantage over electricity. Flexible consumption such as Power-to-X (PtX) coupled with hydrogen infrastructure will reduce overall infrastructure costs, thereby increasing the utilization of renewable energy generation. A holistic, more coordinated approach to infrastructure planning is needed for electricity, gas and hydrogen in the future.

Hydrogen can also play a key role in enabling the EU Offshore Renewable Energy Strategy. The strategy highlights, in particular, the role of PtX in the production of hydrogen and ammonia and recalls its role in fostering energy system integration. PtX could be used to partially make up for the limits of large-scale deployment of high voltage direct current (HVDC) as outlined by the European Commission. Offshore pipelines and depleted oil and gas fields can be used on the one hand to transport renewable hydrogen produced directly offshore and on the other hand to store hydrogen. At present, European companies and public authorities are investigating the feasibility and potential of combining an offshore wind turbine directly with an electrolyser and transporting renewable hydrogen to shore (S&PGlobalPlatts, 2021). In these types of projects, infrastructure for desalination and water treatment needs to be considered to allow for seawater to be used as a feedstock for electrolysis.

The nature of European demand in certain sectors necessitates bulk transport of energy. Firstly, it would not be possible to construct several GW of, e.g., wind power and electrolysers close to every steel plant in Europe. Secondly, even if space were available on those sites of concentrated demand, producing lower-cost hydrogen elsewhere and using pipelines to the demand centres would be much cheaper.

The European transmission grid for natural gas is approximately 200,000 km long, with a distribution grid that is a multiple of that. Figure 2 gives a schematic view of the natural gas system and infrastructure. In addition to the natural gas grid, there are 10,000 km pipelines that carry other substances such as oil, kerosene, hydrogen, ethylene, nitrogen, etc. Most of these pipeline systems are privately owned and captive, e.g., linking oil refineries to chemical parks. It should be noted that in certain areas of Europe, mainly North-West, there is already a dual gas grid at present for lower-calorific and higher-calorific gas. The lower-calorific gas, or L-gas, originates from the Groningen gas field in the Netherlands and is used in the Netherlands, Belgium, France, and Germany. High gas, or H-gas, originates from the UK, Norway, Russia, Algeria and from liquified natural gas (LNG) imports. Since the Netherlands will stop producing L-gas by 2022, discussions related to gas grid conversion are already underway. The L-gas and H-gas systems are separate and many elements of the grid, meters, end-use systems, etc., require conversion. When converting from natural gas to hydrogen, a similar playbook can be used.

Conversion of large parts of Europe's natural gas infrastructure to hydrogen infrastructure is an important element in the transition to a hydrogen economy. Furthermore, to maximize the decarbonisation potential of hydrogen across the economy, due attention should be given to the need to deploy alternative fuels infrastructure for the use of hydrogen inland transport, maritime and aviation applications and to the need to synchronize the uptake of the hydrogen economy with the end-use applications in buildings. Furthermore, the revision of the upcoming trans-European networks for energy regulation (TEN-E) should promote and ensure synergies with the upcoming legislative review of the trans-European networks for transport regulation (TEN-T).

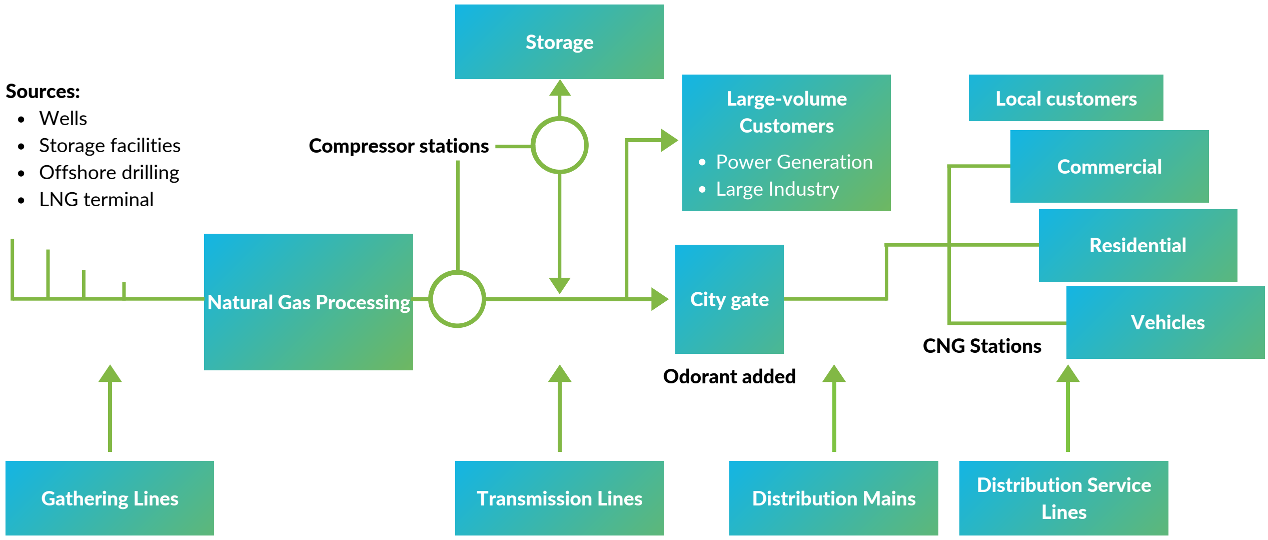


Figure 2. A schematic view of a natural gas system.

A phased gas transition infrastructure roadmap up to 2050 could have the following structure:

- Fast-tracking initial projects that achieve the European 1 million ton target by 2024
- Building hydrogen valleys with regional and local hydrogen infrastructure (2021-2035)
- Building a pan-European hydrogen backbone infrastructure (2021-2035)
- Blending hydrogen with natural gas (2021-2035)
- Converting large parts of the gas infrastructure to hydrogen (2035-2050)

Building hydrogen valleys with regional and local hydrogen infrastructure (2021-2035)

Development of regional hydrogen valleys with hydrogen production and consumption. Conversion of renewable electricity to hydrogen could also contribute to alleviating electricity grid constraints.

Over time, regional hydrogen valleys will be connected to the national and European hydrogen backbones. Balancing hydrogen supply and demand can then be realised via the hydrogen backbone, including salt cavern hydrogen storage facilities.

A "hydrogen valley" is a geographical area where several hydrogen applications are combined into an integrated ecosystem that covers the entire value chain: production, storage distribution, and final use. The concept of hydrogen valleys has led to many initiatives around Europe, which are among the first European hydrogen projects at scale. The regional natural gas infrastructure (medium-pressure transport and distribution pipelines) can be converted to a regional hydrogen infrastructure. Hydrogen demand in industry (e.g., bakeries, laundries, paper industry, food industry, glass, and ceramics, etc.), mobility and heating buildings is connected to the regional hydrogen infrastructure. Balancing hydrogen supply and demand is accomplished via local storage or import/export of hydrogen by truck, train or ship. Eventually, these hydrogen valleys will be connected to a hydrogen backbone, which enables the balancing of regional production and demand more cost-efficiently by integrating salt cavern storage facilities. Also, the import of cheap renewable hydrogen could reduce the energy cost in that particular hydrogen valley.

In synergy with the EU Offshore Renewable Energy Strategy and the subsequent development of offshore hydrogen hubs, European ports are also prime locations for the development of hydrogen valleys, given their location and potential for providing economies of scale. Besides port-related infrastructure and the associated maritime sector, ports are often closely integrated with hard to abate sectors, including refineries and/or chemical plants. At these locations, hydrogen and hydrogen derivatives can be received by offshore pipelines, produced or imported, converted, stored, and distributed for use in different applications.

Hydrogen-based fuels (e-fuels) such as ammonia or methanol are promising for the maritime sector since they can be burned in internal combustion engines. The potential to use hydrogen-based fuels in existing ships needs to be further investigated. The focus on small zero-emissions vessels now will lead to the dedicated hydrogen supply chains for larger ships taking into account that the largest emitters, namely deep-sea vessels, will very likely make use of hydrogen-based fuels for their main engine power, which will require different supply chains and production of e-fuels on a massive scale.

Several European marine engine manufacturers have started developing dual-fuel engines that can run on ammonia.

These hydrogen valleys are set to become key hubs of the emerging hydrogen economy, also enabling the entry of cheaply produced clean hydrogen into the European internal energy market.

Building a pan-European hydrogen backbone infrastructure (2021-2035)

Construction of national hydrogen backbones, connecting large-scale low-carbon and renewable hydrogen production, salt cavern storage facilities to large-scale industrial hydrogen demand in the chemical, petrochemical, and steel sectors. Connecting these national hydrogen backbones on a pan-European level and to hydrogen production in neighbouring countries.

Hydrogen as a feedstock in the chemical, petrochemical and steel industry and for mobility requires pure hydrogen. For that reason, infrastructure for pure hydrogen needs to be developed. Such hydrogen infrastructure, however, is not only necessary to physically transport hydrogen but also crucial for a liquid hydrogen gas market and is, therefore, a prerequisite thereof. So-called hydrogen backbones connect areas of low-cost clean hydrogen production with large scale storage and demand centres elsewhere. These backbones should be made available as soon as possible, and their development prioritised so that by 2035 a pan-European hydrogen backbone system is in place with connections to neighbouring countries. Such backbones can be new pipelines or converted natural gas pipelines. The European gas infrastructure can, with few exceptions, be used to transport 100% hydrogen. Gas transmission pipelines can accommodate pure hydrogen, but compressors and flow meters need to be adjusted or replaced. Salt caverns can be used for hydrogen storage, and Europe is blessed with considerable potential for that. Most natural gas distribution pipelines, typically made from polyvinyl chloride (PVC) or polyethylene (PE), can accommodate 100% hydrogen as well. Germany and the Netherlands have already planned to convert part of their natural gas transmission system into a dedicated hydrogen backbone; see figure 3 on the right side. Several other European countries have developed roadmaps for a hydrogen infrastructure, which could eventually be integrated into a pan European Hydrogen infrastructure, also connected to neighbouring countries as shown in the 'Green Hydrogen for a European Green Deal, A 2x40 GW Initiative' report, see figure 3 the left side (van Wijk & Chatzimarkakis, 2020).

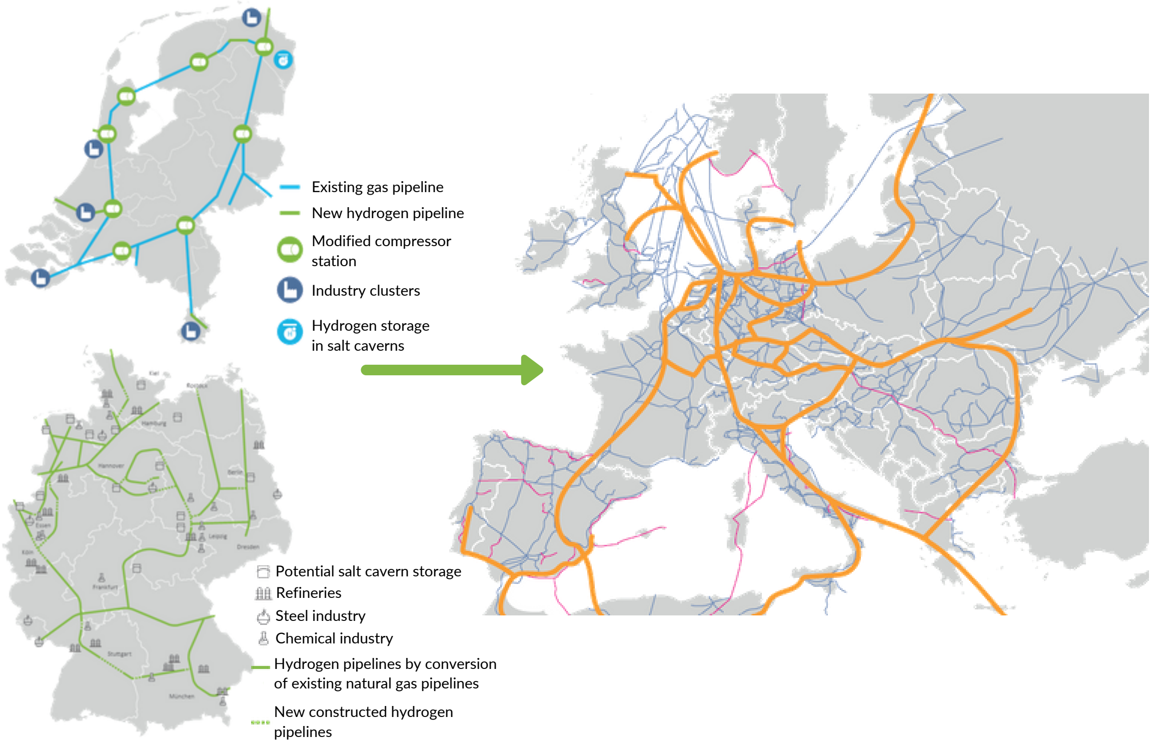
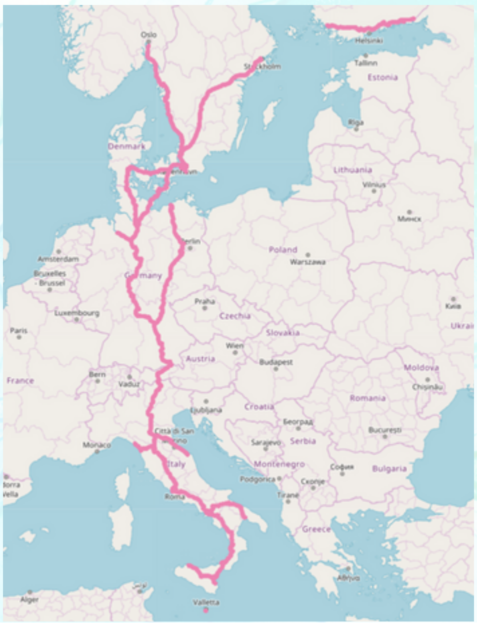


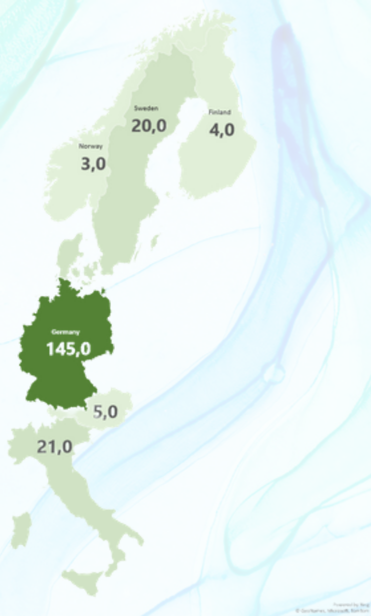
Figure 3. National hydrogen backbone infrastructures evolving into a pan-European hydrogen backbone infrastructure

With regard to the better integration of TEN-E and TEN-T networks, synergies between energy and transport networks can facilitate the flow of hydrogen from its production point to key parts of the European transport and logistics network, enabling rapid decarbonisation in the transport sector. As an example, in 2030, if 50% of all heavy-duty transport conducted annually along the Scan-Med TEN-T corridor was powered by hydrogen, it would imply: approximately 40,000-50,000 H2 heavy duty vehicles, 218 H2 refuelling stations, 328,000 million ton of renewable H2 needed per year and 4.6 million ton of CO2 emissions saved per year.

TEN-T core network corridor Scan-Med



Hydrogen refuelling stations in 2030



Blending hydrogen with natural gas (2021-2035)

Blending of hydrogen into natural gas. When there is no hydrogen infrastructure available or foreseen over a period of five years, blending into the regional mid/high-pressure gas pipelines is possible if a set of requirements is met. Blending enables kick-starting hydrogen production without the need for dedicated customers or hydrogen infrastructure. It is expected that after 2035 new blending projects may no longer be required.

Hydrogen can be blended with natural gas, offering an easy entry point into the hydrogen economy, allowing for quick deployment of electrolysers to kick-start the industry and assure a European leadership position. Although the energy content of hydrogen per m3 is about a factor three lower than that of natural gas, and physical-chemical properties differ, blending a small percentage of hydrogen with natural gas is possible without major investments, or compromising gas specifications and downstream user equipment. Hydrogen blending can be especially a cost-effective transitional option in those regions without parallel or duplicated networks, or without (potentially) available gas infrastructure capacity which can be easily converted/repurposed to hydrogen in the short-term.

Methanation of renewable hydrogen is also an option. Such projects combine renewable hydrogen with CO or CO2 from biomass or from fossil flue gasses to produce synthetic methane, which is fully compatible with natural gas. Such projects can be implemented in the current system quickly and without significant investments. However, considering the impending conversion of the natural gas system to hydrogen in the foreseeable future, potential developers may risk investing in future stranded assets.

According to a study by the French gas transmission system operators (GRTGaz, 2019), gas specifications of carriers, storage units, and distributors currently allow a maximum hydrogen level of 6% by volume in France. This rate can be reached on most of the French network's subzones in the short term, except for some end-use equipment or certain sensitive customer installations (e.g., compressed natural gas (CNG) stations, where tanks are currently certified for a maximum of 2% hydrogen, or glass manufacturing facilities). The study further concluded that in the future, with more knowledge and practical experience, and after network and downstream equipment have been adapted for hydrogen, the hydrogen blending percentage can go up to 10%, eventually rising to 20%. The 20% threshold seems to be the upper limit, above which significant investments are required, in particular for downstream uses. Besides France, tests and studies for the injection of hydrogen into the gas grid at both transmission and distribution level are ongoing across different European countries, notably in Germany (DVGW, 2020), Italy and the United Kingdom.

Dynamic simulations of injecting hydrogen from solar electricity into a gas distribution grid in Italy show that, even with very low yearly average blending percentages, the hydrogen percentage varies widely and can be up to 100% downstream from the injection point (Cavani, April 2020). We can conclude that blending hydrogen in natural gas grids has some advantages as well as limitations. It is advisable to set the right blending percentage and only inject in carefully selected locations in the high or mid pressure transport natural gas pipelines or inject into salt cavern hydrogen stores and meter it into the gas grid at the required rate when needed.

Completing the hydrogen infrastructure (2035-2050)

Between 2035 and 2050, large parts of the natural gas infrastructure need to be converted to hydrogen, based on a European rolling 10-year gas infrastructure conversion roadmap.

Fossil fuels, including natural gas, must be largely phased out to achieve a net zero-emission energy system by 2050. Together with renewable electricity, hydrogen and other renewable/low-carbon gases will have substantially replaced natural gas, oil and coal demand by then. Europe will have an integrated system of hydrogen backbones, which covers the entire continent and connects to neighbouring regions. Hydrogen valleys, in turn, are going to be connected to these backbones.

In the medium to long term, on-site conversion of renewable electricity into hydrogen (i.e., hydrogen offshore production directly by the offshore renewable plant) and its shipping or on-site fuelling will become more and more relevant both for use in industry, maritime and heavy-duty transport. From 2035 to 2050, the remaining natural gas infrastructure, transport pipelines, salt cavern storage, and distribution pipelines need to be converted to hydrogen. This also implies that end-use appliances and equipment have to be converted or adapted to hydrogen. Especially fuel cell technology will become important for electricity balancing and heating applications, e.g., combining fuel cells with heat pump technology.

Regulation of hydrogen infrastructure

The European Commission recently published a proposal for the revision of the regulation on trans-European energy infrastructure in order to bring it more into line with the EU Green Deal and the EU Climate Law. The revised proposal highlights support for new and repurposed dedicated hydrogen networks and electrolysers above 100MW under respective categories for "hydrogen" and "electrolysers". In addition, the injection of renewable and low carbon gases into the gas grid is covered under the new smart gas grid category.

From a grid planning perspective, the TEN-E proposal proposes that planning for hydrogen projects be integrated into the Ten-Year Network Development Planning (TYNDP) of the European gas and electricity network transmission system operators (ENTSO-G and ENTSO-E), under stricter supervision from the European Commission and the Agency for Cooperation of Energy Regulators (ACER). Investments in repurposing of natural gas infrastructure need to go hand in hand with a robust cost benefit analysis and ensuring that developments are in line with projected demand patterns. In this respect, and to complement the TYNDP process, the EU could mandate Member States to prepare hydrogen outlooks every two years which would include demand and production trends. These plans could be developed with a view to 2030, 2040 and 2050 and according to a new set of EU guidelines. The TYNDPs would integrate these national hydrogen outlooks in order to help identify minimum capacity requirements for cross-border gas infrastructure between member states and third countries.

The TEN-E proposal and hydrogen's role therein are a solid indicator of the European Commission's intention to follow through on the Hydrogen Strategy and develop a hydrogen economy that needs to leverage the existence of Europe's extensive and strategic pipeline infrastructure. Today, the use of hydrogen is largely captive and private, with hydrogen infrastructure being unregulated. However, with a clean hydrogen market set to emerge, a distinct legal framework at EU level for the regulation of hydrogen networks will become necessary once hydrogen is considered as a widely traded commodity in order to avoid monopolistic behaviour. A market test is necessary to determine the specific market situation in each case. The development of the hydrogen market will not be identical to natural gas market development. However, a hydrogen market framework should respect the same principles of unbundling, third party access and transparency for consumers. With regards to the blending of hydrogen, rules for hydrogen injection can feature in the upcoming revision of the Gas Package.

Within the context of ongoing discussions on this topic, Hydrogen Europe welcomes the recent White Papers presented by ACER published in February 2021 (ACER1, 2021) (ACER2, 2021)

Overview of the gas infrastructure transition roadmap (2021 – 2050)

The block diagram shown in Figure 4 shows an overview of the gas infrastructure transition roadmap from natural gas to hydrogen.

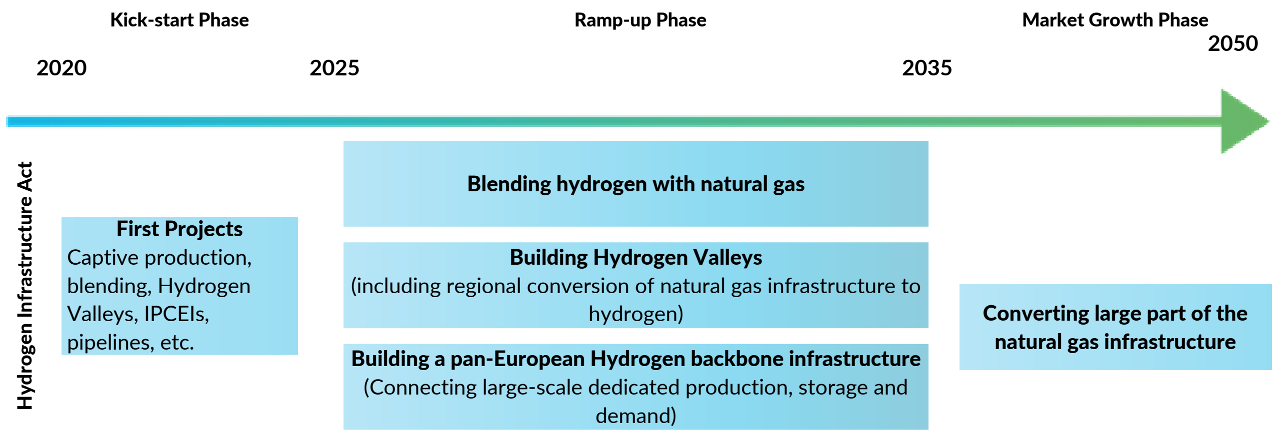


Figure 4. Gas infrastructure transition roadmap

The hydrogen market development roadmap

At present, Europe has a natural gas market with dedicated institutions, regulations, open-access infrastructure, trading platforms, multiple suppliers and off-takers. An open and transparent market is essential to achieve the lowest cost through dynamic coupling between supply and demand. Over time, continental and intercontinental markets for hydrogen and hydrogen derivatives will emerge and are expected to take over the role of oil and natural gas as the primary globally traded energy commodities.

As a global frontrunner in hydrogen, the EU can take the lead in the design and development of a common hydrogen market, incorporating standards and regulations, rules for access to infrastructure, trading platforms for the energy content of hydrogen and other qualities such as CO2 intensity, price-setting mechanism, system services, and other elements. Europe has the potential to become the birthplace of a global hydrogen economy, where hydrogen is traded across borders and seas via pipelines and ships.

As the EU strives to promote this market and enhance its industrial leadership in this sector, new value chains will emerge together with new opportunities for the European industry. Hydrogen technologies made in Europe will be exported to EU trading partners, opening up new commercial opportunities for European businesses while also facilitating EU partners in meeting their own climate targets and, overarchingly, the global climate agreement reached in Paris at COP21. In this way, Europe will emerge as the birthplace of a global hydrogen economy, not only for its technological leadership but also in terms of regulation. Other continents will look to the EU regulation as a blueprint for their own market and infrastructure developments. Ultimately, the EU should endeavour towards a level playing field and the promotion of a global hydrogen market by 2050, denominated in the Euro currency.

The question is, how could such a hydrogen market be designed and implemented in the European Union from the current situation, where there is no real market, no infrastructure and only captive suppliers and off-takers? We need to begin laying the foundations of a hydrogen market design in Europe. As an energy vector that can transport renewable energy worldwide, hydrogen is set to play a systemic role in the transition to renewable sources by providing a mechanism to flexibly transfer energy across sectors, time and place. A hydrogen market design can, as a starting point, take the best traits of both the electricity and gas markets. In the long run, today's natural gas market can evolve into a hydrogen market. The infrastructure is there, and a large part of the hydrogen use cases will replace natural gas, in addition to coal and oil products. That transition will use policies that have proven to be effective in previous energy transitions, especially until hydrogen is competitive.

After the initial kick-start phase from 2021 to 2024, a system to calibrate volumes and pricing requires due consideration during the ramp-up phase from 2025 until 2035. We propose various options inter alia a procurement system with elements of pricing and volume control through set tariffs and auctions, and a system of demand creation through quotas and incentives, enabling a balancing of the market. After 2035, hydrogen is expected to be competitive across various if not most sectors and the hydrogen market is mature enough to operate on basic principles of supply and demand.

Kick-start hydrogen supply and demand (2021-2025)

The kickstart phase is the period in which the tectonic change towards clean hydrogen and a more cyclical approach with regard to non-fossil feedstock will be initiated.

The European Clean Hydrogen Alliance could establish the appropriate framework for large scale integrated projects that would serve two aspects: on the one hand, the projects could be first of its kind projects with the intention to be duplicated elsewhere; on the other hand, they could unveil the regulatory obstacles and bottlenecks for the bankability and market introduction of projects of this kind. These projects would be backed by a special quality seal. Additionally, the presented projects could be the basis for the upscale of hydrogen production targeting 1 million ton of renewably produced hydrogen and 6 GW of electrolyser capacity until 2024.

Existing legislation might need to be adapted or changed to remove regulatory obstacles. One important example is the revision of the Renewable Energy Directive (RED II), which, in its current form, limits the use of renewable electricity for the production of hydrogen to a very high extent. Proposals focusing on an all-electric scenario need to be reopened to create a level playing field between clean energy sources and enabling a balanced and smooth integration of hydrogen production in the context of smart sectoral integration.

Such a disruption needs massive investment, at a time when the European Union is discussing the future Clean Hydrogen for Europe Partnership as well as future funds such as the Recovery and Resilience Facility among others under the Next Generation EU Fund. From a research and development perspective, as the successor of the Fuel Cells and Hydrogen Joint Undertaking, the Clean Hydrogen for Europe Partnership has a critical role to play in kick-starting the hydrogen economy. Economic incentives for hydrogen also need to be introduced during this period and they should aim at compensating the higher cost of renewable and low carbon hydrogen production, as well as end-users' higher costs due to the change to renewable hydrogen and for transforming industrial technologies and processes to hydrogen. Business as usual will not be enough to achieve the objectives of the EU Green Deal.

A real shift will be needed to unlock the potential of the National Resilience and Recovery Plans in the light of the EU Green Deal. This is particularly important for the development of the clean hydrogen sector while a European supportive regulatory framework is not yet in place. An enhanced regime is therefore needed -and is essential at an early stage- to allow state aid into hydrogen projects -individually or through dedicated Member State schemes- for the production, transmission and use of renewable and low carbon hydrogen.

In addition to EU funding programs, a new approach to European and national competition law will be a precondition as the investments will require high involvement of state aid. Fortunately, the underlying necessary reforms related to state aid are already under the microscope in 2021 with a view to making them applicable as of 2022.

The support to pilot tests, demonstration plants and then ramp up needs to be accelerated so as to allow these energy intensive sectors to rapidly decrease CO2 emissions. When technology is already largely available, state aid should no longer consider the degree of innovation, but rather the market failure and far-reaching reduction in greenhouse gases.

Given the current cost gap, it is clear that for many hydrogen applications, CAPEX support alone will not suffice for an investable business case and the attainment of the EU Hydrogen Strategy targets. The eligible costs should therefore be defined as the funding gap, to be defined as the difference between the positive and negative cash flows over the entire lifetime of the investment, i.e., considering CAPEX as well as OPEX and revenues. Infrastructure is also another key element that the state aid framework needs to further consider ensuring the transmission, distribution and storage of hydrogen, including the import of hydrogen, and connect offer and demand.

Considering the challenges the hydrogen sector is confronted with in the context of the EU Green Deal, the European economy recovery post COVID19 and the Hydrogen Strategy, and as a recognized European strategic value chain, dedicated guidelines on state aid for hydrogen technologies should be promoted, including transport and storage, with more tailored and flexible eligibility conditions, more favourable maximum aid intensities and higher aid amounts. Priorities would include:

-eligibility of large-scale demonstrations projects and roll-out of hydrogen production, transmission/distribution and end-use applications in line with the Hydrogen Strategy and EU Recovery Plan objectives and expectations,
-aid intensity up to 100% of additional costs for hydrogen technologies and applications in first-of-its-kind large scale installations,

- a more flexible definition of eligible costs, with a stronger OPEX support, including in hydrogen production/conversion and end-use application projects,
- presumption of market failure for hydrogen projects,
- notification thresholds for hydrogen technologies increased to €200 million,
- faster and simpler notification procedures,
- need for clearer rules on the cumulation of aid namely with EU funding, and coherent approach of the available tools with higher funding and larger eligibility costs on OPEX (e.g.: ETS Innovation Fund, Invest EU, CEF, Horizon Europe...).

Regarding Important Projects of Common European Interest (IPCEIs), until the IPCEI framework is finetuned, an ambitious and forward-looking interpretation of the current IPCEIs rules should be supported to deploy the full effect of IPCEIs in the roll out integrated hydrogen projects across the EU. There is a clear potential for hydrogen IPCEIs to go beyond the practice and use all the flexibilities that the 2014 Communication offers in terms of support to transport and energy projects, coverage of 100% of the funding gap and also in terms of OPEX eligibility. Alternatively, provisional measures could be analysed to provide extra incentive to first hydrogen IPCEIs.

As the coming years will be crucial for the uptake of hydrogen and project engineering, project developers could definitely start developing projects on the basis of IPCEI rules and revised EU state aid guidelines. Funding should be intensive but equipped with a sunset clause. Finally, the kick start period should be the period when key legislative elements of the Hydrogen Act are designed and implemented.

EU Hydrogen Special Envoy

The European Commission should also consider the appointment of a European Hydrogen Special Envoy who would be in charge of ensuring the implementation of the EU Hydrogen Strategy. Just as the EU did with the EU Battery Alliance, the interaction between the European Clean Hydrogen Alliance, hydrogen stakeholders and the relevant tools and mechanisms at the EU's disposal would benefit from the appointment of a single point of authority and responsibility within the European Commission. Such a position is needed to ensure that the EU remains in the lead with regard to hydrogen developments. Furthermore, it would reinforce efforts to ensure the EU keeps on track to meet the objectives outlined in the European Hydrogen Strategy. Within the context of the European Commission's Better Regulation agenda, pooling all relevant hydrogen legislation under the umbrella framework of the Hydrogen Act, coupled with a dedicated Hydrogen Special Envoy would contribute to ensuring coordination and streamlining legislative efforts intended for the promotion and support of clean hydrogen.

Ramp up hydrogen production (2025-2035)

In a ramp-up phase, until the hydrogen production costs can match fossil fuel plus carbon prices, a hydrogen set production tariff mechanism, auctions or a combination thereof are required to create hydrogen volume in the market, leading to lower cost.

Currently, clean hydrogen is more expensive than unabated fossil fuels, even considering a carbon price. However, most analyses predict renewable hydrogen to be the lowest-cost clean gas option by 2050 due to the learning curves of electrolysis and renewable electricity (BloombergNEF, 2020) (HydrogenCouncil, Path to Hydrogen Competitiveness, A cost perspective, 2020).

To ramp up hydrogen production volumes and reduce its cost, it is necessary to stimulate demand and hydrogen production for a certain period until a mature market has developed. Two options for procurement mechanisms that can be applied to stimulate hydrogen production are widely used: set production tariffs and auctions. In a set production tariff mechanism, potential producers are guaranteed to receive a set production tariff over a fixed time period. Such a tariff is usually fixed (flat) but may be indexed to adjust for inflation or have a tapered structure, and the height of a tariff guarantees bankability and an acceptable return on investment. Auctions are procurement schemes in which the tariff is determined through competitive tendering, but usually results in a similar contractual arrangement with the developers as is the case for set production tariff schemes, e.g., a 25 year offtake agreement, similar to a power purchase agreement in the case of green electricity. Also, hybrid systems, e.g., auctions for larger systems and set production tariffs for smaller systems are common.

A brief overview of the pros and cons of these procurement systems is given in Table 1.

Procurement mechanism	Pros	Cons
Set production tariffs (based on price of alternative, carbon price and CCfD), allowing attractive return on investment for producers	• Solid bankability • Proven framework for fast growth • Lowest transaction costs for public sector	• Difficult to control volume and consequential fiscal burden • Difficult to assess price level dynamically: risk of overpaying (windfall profits) or underpaying (slow build-out)
Auctions	• Control of volume • Control on location • Price finding based on market	• Relatively high costs for public sector • Complex
Hybrid: auctions for large and complex systems, fixed production tariffs for smaller systems	Price finding from auction can inform production tariff	• Complex • More costly than set production tariffs

Table 1. Procurement mechanisms for hydroge

The set production tariff, which can be derived from an assessment of the hydrogen production cost, the market price of the fuel that is replaced and the carbon price, could potentially include a Carbon Contract for Difference (CCfD) to arrive at an attractive enough tariff to incentivise the investment for hydrogen production and use. The CCfD in such a mechanism could be either derived from an independent market cost assessment or be derived through an auction mechanism. Alternatively, the CCfD could be given to a potential off-taker, bridging the cost gap between the higher production price of the hydrogen, a carbon price and the alternative (including the switch to a hydrogen-based production process if needed). Applied in such manner, CCfDs can be an effective instrument to levelise higher cost during a transition phase for renewable and low-carbon hydrogen at the demand side and avoid overcompensation. In the kick-start phase, this instrument might be used in the context of state aid with regard to OPEX support whilst CAPEX will be tackled by dedicated funding programs.

Over the last two decades, set production tariffs have stimulated market growth of renewable electricity across the globe and led to the current competitiveness of most notably solar and wind. Such schemes provided certainty for investors and developers and have stimulated the development of local competitive markets. However, auctions have recently evolved as the preferred mechanism to procure solar and wind electricity in many countries, which provides more control on the volume and short-term fiscal burden to society. Many countries have gained much experience on how to best structure mechanisms of set production tariffs and auctions, much of which can be found in literature (Gabriela Elizondo Azuela, 2014). A good example is China, which initially set a production tariff for solar and wind projects that were too low, leading to a plodding start of the market. A consecutive set of auctions, which are best to find the correct market price if done well, enabled the government to finetune the set production tariff scheme, which was consequently much more successful. Another example is Brazil, whose open auction system initially attracted frivolous bids from developers, some of whom won auctions but later struggled to build projects. And in Europe, several countries with set production tariffs failed to respond to falling costs quickly enough, leading to windfall profits for developers, after which certain governments decided to introduce retroactive tariff cuts or taxes.

Learning from these renewable electricity experiences, a smart combination of auctions and set production tariffs would most probably ramp up hydrogen production at the lowest societal cost.

The European Hydrogen Strategy refers to the 2x40 GW electrolyser target by 2030, with an intermediate 6GW target by 2024. More needs to be done to push renewable hydrogen development including the removal of barriers in existing legislation. As such, in addition to these targets for renewable hydrogen, low carbon hydrogen volumes may be required in parallel to meet the 1 million ton and 10 million ton hydrogen targets by 2024 and 2030 respectively.

The initial 6GW electrolyser capacity will be realized by fast-tracking current project initiatives, including IPCEIs, etc. From 2025 onwards, however, a hybrid market stimulation approach for hydrogen production is proposed, consisting of auctions for larger volumes and capacities, covering approximately 50% of the demand, in addition, to set production tariffs for smaller systems, e.g., 100MW or less in a specific location.

Ramp up hydrogen demand (2025 - 2035)

In a ramp-up phase, until a hydrogen market can replace price setting and balancing supply and demand, hydrogen demand has to be created beyond traditional feedstock demand. Quotas, additional investment support and a carbon border adjustment mechanism are all promising options to create hydrogen demand and to develop into a hydrogen market.

The ramp-up phase needs carefully designed mechanisms to stimulate hydrogen production and demand, while a hydrogen infrastructure consisting of storage and transportation facilities needs to be developed accordingly. Several important issues need to be considered, addressed and taken into account in designing these mechanisms. In the end a political decision-making process will determine what, when and how hydrogen production and demand will be stimulated. Let us discuss some of the relevant issues. The proposed hydrogen quotas for all sectors together give an estimate of the total hydrogen demand volume. When ambitious hydrogen quotas are set, clean hydrogen production volumes could be lagging behind demand. Ambitious hydrogen quotas will be necessary to accelerate the switch from unabated fossil fuels, not only to bring down the clean hydrogen production cost but also to make hydrogen application technologies more affordable.

Hydrogen quotas

Hydrogen quotas could be imposed on specific materials or products such as steel, fertilizers, chemical products, cement, kerosene, gas and on fuels such as transport fuels, including in aviation and maritime. Setting these quotas requires an intelligent customized process for each product, material or fuel. One of the issues is, whom these quotas apply to: is it the customer, the producer, the production sector as a whole or the fuel supplier? We discuss three examples on whom to impose quotas.

- Ammonia is one of the main fertilizer components, made from hydrogen and nitrogen. Hydrogen today is produced from fossil fuels, in the EU mainly from natural gas in SMR plants. The EU has more than 120 ammonia production locations and the fertilizer sector produces and consumes 3.1 million tonnes of fossil-based hydrogen per annum (FertilizersEurope, 2020). Changing to clean hydrogen does not require changes in the ammonia production process. It is simply another source of hydrogen; therefore, it would be relatively straightforward to impose equal quotas on all ammonia producers. Quotas can also be imposed on the customer, for example on the farmers that produce cereals or even the bakeries that produce bread. However, there are millions of farmers in the EU and tens of thousands of bakery companies, which makes it complex to impose a quota on them.

- Crude steel production in blast furnaces occurs in 25 locations in the EU (including the UK). Production capacities on these locations vary between 1.3 and 11.6 million ton steel per year, with a total production capacity of about 100 million ton crude steel per year (Eurofer, 2020). Hydrogen can be used for the direct reduction of iron ore (DRI) and replacing coal used in a blast furnace. About 50-65 kilo of hydrogen is needed to produce 1 ton of crude steel from iron ore, depending on the ratio of hydrogen and electricity used in the reduction cycle. The question is on whom to impose a quota, the producer, the sector or the consumer? It is difficult to impose a quota on each of the production locations because a DRI plant has to be built to use hydrogen and will need a certain minimum size and, therefore, minimum amount of hydrogen to become economically viable. It is difficult to match such a step-change with the quota, which is normally a percentage. A quota could also be imposed on the entire sector, but how to divide quota and additional cost between the production locations or companies? It seems that for steel, a quota can best be set for large steel customers such as car manufacturers, construction companies and wind turbine manufacturers.

- Gas is one of the major fuels used in the EU, and demand was 4,577 TWh in 2018, mainly used in buildings, industry and power generation (GasforClimate, Gas Decarbonisation Pathways 2020-2050, 2020). About 170 TWh bio-methane is part of the gas mix, but the vast majority of the gas supply is natural gas. Hydrogen can be blended in a methane gas grid, or hydrogen can be fed into a separate hydrogen gas grid. Hydrogen quotas for gas need to include both options and are therefore not physical blending quota but virtual. It is difficult to impose quota on the gas consumers since there are millions of gas consumers, making it a complex undertaking. It is also difficult to impose a quota on the gas producer, although in principle, they could convert natural gas or even bio-methane into hydrogen. When gas producers would do that at the gas field and capture and store the CO2 directly in the gas field, it could accelerate the conversion of the natural gas infrastructure into a hydrogen infrastructure and the uptake. However, for gas, it seems the least complex way to impose quota on the gas suppliers. They can supply a mix of blended hydrogen and pure hydrogen to their client base in a way that they can meet their hydrogen quota target.

Additional measures

Carbon border adjustment mechanism

If the EU implements clean hydrogen quotas on materials and products, while other countries and regions outside the EU do not, there is no level playing field for import and export of these materials and products, leading to so-called carbon leakage. Therefore, it is necessary to implement a carbon border adjustment tax mechanism for import and maybe also carbon border adjustment premiums for export.

Hydrogen transition investment support

Using hydrogen for e.g., the production of steel, to produce high temperature heat or in fuel cell electric drive trains means that present production installations, equipment, engines, gas turbines and end-use appliances have to be replaced or adjusted. To stimulate the uptake of hydrogen, financial support, investment subsidies, grants, incentives or tax rebates are likely required to accelerate a change to hydrogen use.
Portugal has proposed to the European Commission the use of the instruments provided for in the Directive 2018/2021, during the decade of 2020 to 2030, for the establishment of agreements between member states to support cross border mechanisms.

Who will pay?

An important question is who will bear the cost difference between higher production costs of renewable and low-carbon hydrogen and conventional alternatives, until such time as the clean alternatives are cost-competitive. The government can of course cover the gap through a fiscal mechanism, or a more direct mechanism is applied, whereby the cumulative cost gap is spread out over all or a selection of energy users in a fiscally neutral way. Both systems have distinct advantages and disadvantages and require due consideration. Also, in either mechanism, a European system of harmonisation is required to avoid market distortion.

Market growth towards a deep, fluid, and transparent hydrogen market (2035-2050)

As the cost of renewable hydrogen decreases over time, more and more applications will become feasible without monetary policy support. From 2035 onwards, hydrogen will become increasingly competitive, and policy support can be reduced to transparency on the carbon content and geographical origination of hydrogen.

In the study “Path to hydrogen competitiveness - a cost perspective” carried out by the Hydrogen Council, an analysis of 35 representative use cases predicts that hydrogen will become competitive sooner than often thought. In 22 of these applications, the total cost of ownership will reach parity with other low-carbon alternatives by 2030, and nine will also be competitive with conventional options by then. For example, this will be the case for heavy-duty trucks, coaches with long-range requirements, and forklifts (HydrogenCouncil, 2020).

As more and more hydrogen applications become commercially viable, the policy framework needs to be adapted. It is expected that by 2035 a tipping point is reached, from when hydrogen can be produced at a price point at which the majority of applications is competitive with fossil alternatives plus carbon tax. If hydrogen can be produced competitively, the tariff system and/or auction system can be replaced by a market system potentially combined with auctions. A deep, transparent, and fluid market for hydrogen shall develop. Various hydrogen products and services shall be traded on multiple market platforms.

Hydrogen Guarantees of Origin

Guarantees of Origin (GOs) can provide transparency on the GHG foot-print of the produced hydrogen, the hydrogen production technology, temporal and geographical origin of the hydrogen volumes and other potentially relevant attributes. GOs with a certification system enable the administration and eventually trading of certain qualities of hydrogen, irrespective of the physical delivery of molecules.

Hydrogen Guarantees of Origin, system development

A GO must exhibit the primary energy sources and the GHG footprint of the produced hydrogen, as well as other characteristics. The EU must develop a harmonised and distinct system of Hydrogen GO, enabling the trade of the GHG foot-print associated with hydrogen production. A reliable and robust system of GOs requires that GOs are traceable, trackable, tradable, transparent, and ultimately trustworthy.

The European CertifHy project (certifhy) has elaborated a European certification system that includes GOs for hydrogen. It currently comprises definitions for so-called "CertifHy Green Hydrogen" and "CertifHy Low-carbon Hydrogen". CertifHy low-carbon hydrogen sets a threshold for the GHG footprint of hydrogen (initially calculated considering CO2 emission reduction of at least 60%, but one that may be raised, in line with regulatory developments) while "CertifHy Green Hydrogen" requires the hydrogen to be both "low-carbon" as well as from renewable energy sources.

CertifHy's labelling system reflects the current regulatory environment and can be adapted. However, it is not at all clear which production pathways and thresholds will be legally applied to determine what is "clean" hydrogen that will be valued in the future. This is another reason why it is very important to have clear definitions, established legally, which guarantee which schemes can be adopted. The European Commission should apply a Europe-wide system of GOs, with a distinct scheme for hydrogen, and the CertifHy project could be a starting point.

However, if the aim is to decarbonise the energy system and provide transparency about the greenhouse gas emissions, the main “currency” must be the carbon content of the energy carriers and vectors based on a lifecycle assessment. Additional work is required to ensure that GOs accurately capture the attributes resulting from different pathways that may be used to produce renewable and low-carbon hydrogen from electricity, biogenic residues, biomass, and fossil fuels etc. Special attention must be paid to hydrogen production from biomass and biogenic residues, processes that produce renewable CO2, as well. If this renewable CO2 is either captured and stored or used as feedstock, the net CO2 emissions can even be negative.

Hydrogen Guarantees of Origin in the ramp-up phase (2025 to 2035)

GOs will be necessary to determine the production attributes of hydrogen. The information contained therein can then be used to determine inter alia whether the produced hydrogen meets a certain GHG threshold for acceptance to be blended in the natural gas or feeding in the hydrogen grid. In addition, the GOs will be used to determine the LCA GHG emissions related to hydrogen production. When transported via pipelines, GOs may be redeemed when hydrogen is fed into the gas or hydrogen grid. TSOs/DSOs are responsible for administering the determination of annual average greenhouse gas emissions for both the blended gas and pure hydrogen systems.

A hydrogen GO system needs to be in place at the start of a set production tariff system for hydrogen. Since the aim is to decarbonise the energy system, especially the molecules, the carbon footprint of the hydrogen that is allowed to be blended in the gas grid or fed into the hydrogen grid shall be below a certain threshold, which will be measured and validated through the GO system. In addition, the GO system enables determining the tariff based on the hydrogen production technology and temporal and geographic origin. These GOs will be issued at the time of production and will be redeemed immediately when the hydrogen is blended into the gas grid or fed into a hydrogen grid, except when there is a direct contract between the producer and the consumer. In this case, the GO can be transferred to the consumer connected to the transportation grid. It is advisable to use a blockchain-based ledger for this, enabling tamper-free transparency. In the ramp-up phase, it is proposed that infrastructure companies, including TSOs/DSOs, will be responsible for the administration of both the hydrogen fed in the natural gas grid and the hydrogen fed into a hydrogen grid. At the end of every year, TSOs/DSOs will publish the total hydrogen blended into the gas grid and fed into the hydrogen grid, together with the average and cumulative carbon content. These values can be used by companies and installations for carbon emission administration and reporting.

Hydrogen Guarantees of Origin in a hydrogen market system (after 2035)

Clean hydrogen GOs can be traded on an emissions trading marketplace.

In addition to a market for hydrogen, expressed in volumes, other elements can be traded, including storage capacity, futures, and other grid services.

Meeting the EU objective of climate neutrality in 2050 implies that total greenhouse gas emissions stemming from hydrogen production need to be net-zero in 2050.

Hydrogen Guarantees of Origin, import and export

An international GO system, initiated by the EU, is required for import and export of hydrogen.

An additional element to consider is international governance for imports and exports of hydrogen. Europe will increasingly rely on imports of hydrogen and hydrogen derivatives, necessitating a globally functional system of assessing the carbon content of the molecules and sustainability criteria. GOs can serve to certify the quality of imported hydrogen or hydrogen products such as renewable ammonia. It is proposed that the European Union initiates the development of a global system for Hydrogen Guarantees of Origin (HGOs), with track-and-trace and auditing functionality. Companies or countries that want to export their hydrogen to the EU need to be able to redeem HGOs that are approved and validated by an EU body at the EU point of entry.

In the period up to 2035, when a set production tariff/auction system for hydrogen is in place, but a market for hydrogen does not yet exist, a procedure must be in place to determine how much hydrogen at what price is being imported. One approach could be that bilateral agreements with neighbouring countries could agree on annual volumes and hydrogen prices. Hydrogen Guarantees of Origin are required to determine whether the produced hydrogen is allowed to enter the EU market.

The international HGO system needs to be mature, fraud-free, and transparent if it is to serve as the basis for a solid, international emissions trading system and to impose a carbon border adjustment tax (when this is implemented).

Overview of the hydrogen market roadmap (2021 – 2050)

Development of a hydrogen market is foreseen to take place in three phases, a kick-start phase till 2025, a ramp-up phase from 2025 to 2035 and a market growth phase from 2035 to 2050. Figure 5 provides an overview.

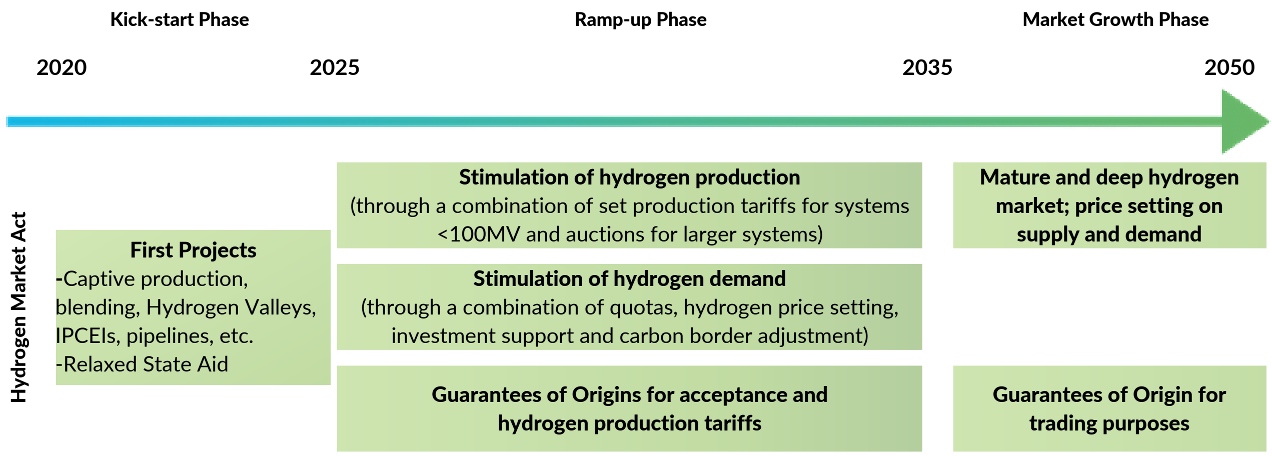


Figure 5: Overview of the hydrogen market roadmap (2021-2050)

Overview
The Hydrogen Act: a novel European policy framework

To do justice to the future central role of hydrogen in the European economy and to support above mentioned roadmap, a robust and proprietary framework for hydrogen is required encompassing existing and new legislation. The framework, aiming to replace natural gas and other hydrocarbons with clean hydrogen by 2050, should cover legal, commercial, and technical aspects of the transition. Therefore, a Hydrogen Act is proposed, consisting of a Hydrogen Infrastructure Act and a Hydrogen Market Act. The table below outlines the different existing and new initiatives and legislations needed to be brought under the umbrella of the Hydrogen Act.

Hydrogen Act	
Hydrogen Infrastructure Act	**Hydrogen Market Act**
Legal framework to convert natural gas transport infrastructure into a pure hydrogen infrastructure (TEN-E – ongoing and gas decarbonisation package Q4 2021).	Clear scientific thresholds for renewable, low carbon and clean hydrogen (RED and gas decarbonisation package – Q2 2021 and Q4 2021)
Legal framework to construct new hydrogen transport and storage infrastructure (TEN-E – ongoing, TEN-T – Q2 2021 and Directive on alternative fuels infrastructure Q2 2021).	Harmonised standards and guidelines for hydrogen quality, safety and procedures including hydrogen purity, pressures and flow speeds as well as measurement and control (new hydrogen initiative). A new European technical standard could be issued, reporting the design criteria to be adopted to engineer new hydrogen pipelines and retrofitting existing pipeline to hydrogen transport (new initiative).
Legal framework to develop hydrogen valleys by converting regional transmission and distribution gas networks into hydrogen infrastructure and networks or construct new infrastructure (TEN-E – ongoing).	Guarantees of Origin for hydrogen to be developed (revision of the renewable energy directive).
Hydrogen Outlooks can complement the TYNDP process, contributing to the governance of hydrogen network planning in an integrated energy system.	Relaxation and exemption from EU State Aid guidelines in the kick-start phase (Revision of Energy and Environmental Aid GuidelinesQ4 2021) as well as IPCEIs.
Legal framework to govern blending of hydrogen into the natural gas grid (gas decarbonisation package Q4 2021).	Demand-side quotas for hydrogen (EU Fuel maritime, EU proposal for sustainable aviation, revision of RED to include a quota for RFNBOs...), revision of the industrial emissions directive and a pilot and implementation schemes for CCfDs.
Legal framework for the regulation of hydrogen networks (new initiative).	LeHydrogen market design – clear roles for market participants, GOs and thresholds for all types of hydrogen to be merged (new initiative).
Governance framework for relations with third countries on hydrogen infrastructure development and standards (TEN-E; through the newly created Projects of Mutual Interest mechanism).	Carbon border adjustment mechanism to create a level playing field (CBAM proposal Q2 2021).

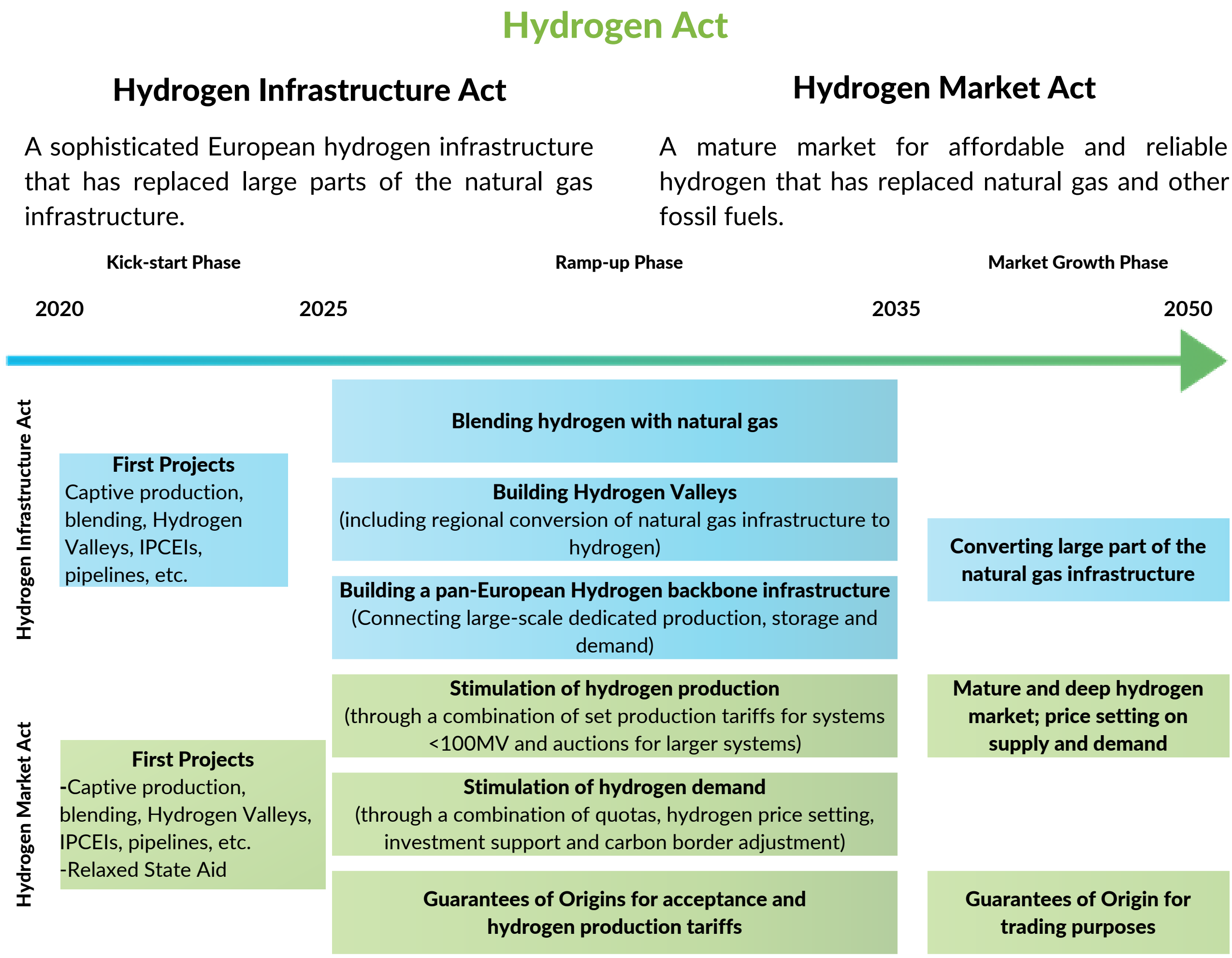


Figure 6. Hydrogen Act with roadmaps for hydrogen infrastructure and hydrogen market development

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