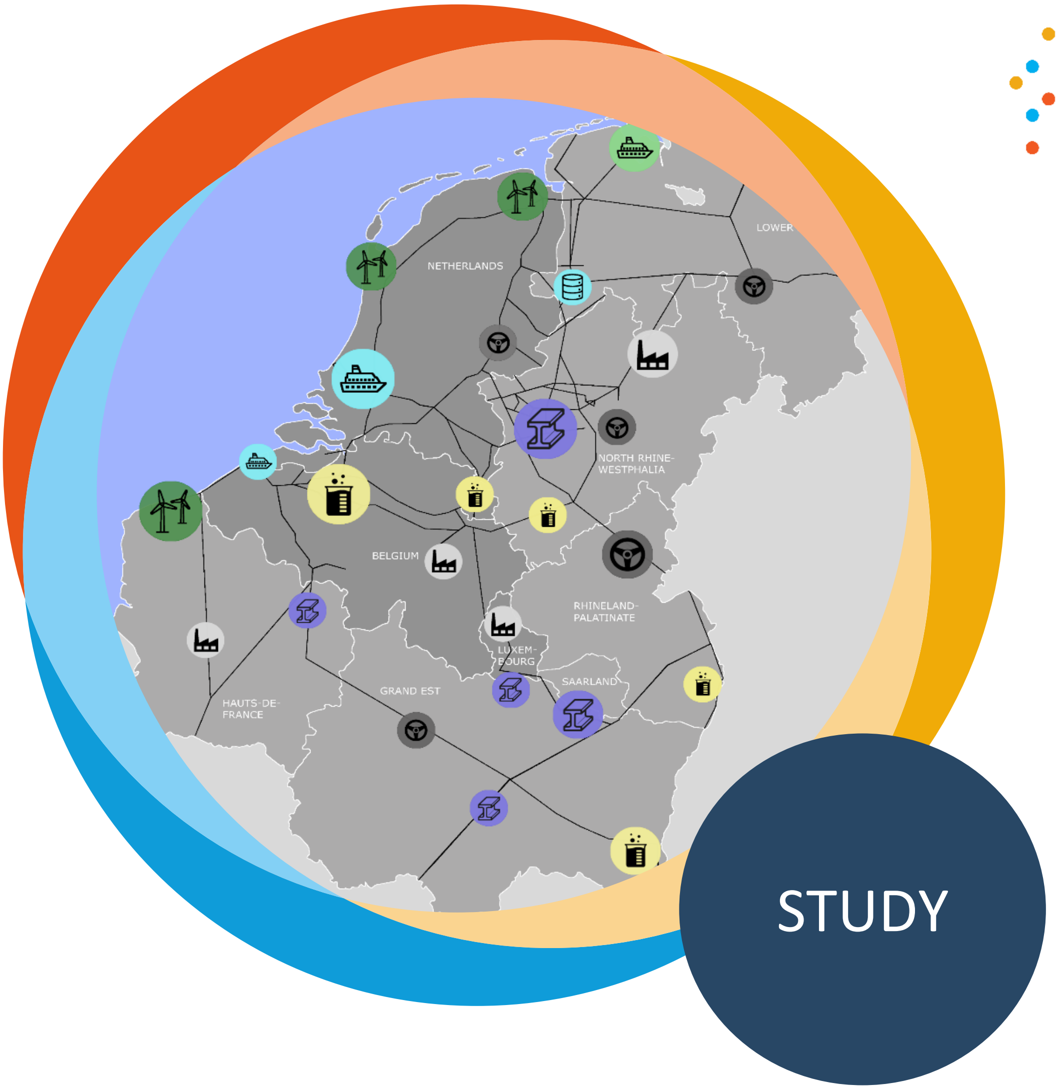


Benelux
SECRETARIAAT-GENERAAL
SECRÉTARIAT GÉNÉRAL

# CROSS-BORDER HYDROGEN VALUE CHAIN IN THE BENELUX AND ITS NEIGHBOURING REGIONS

## IDENTIFYING AND CONNECTING RENEWABLE HYDROGEN DEMAND AND SUPPLY VIA THE CROSS-BORDER HYDROGEN BACKBONE

February 2023

executed by: WaterstofNet Vzw

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# MANAGEMENT SUMMARY

**EUROPE IS ACCELERATING ITS TRANSITION TOWARDS A GREEN HYDROGEN INCLUSIVE ECONOMY.** The recent geopolitical and energy market volatilities require us to drastically accelerate the clean energy transition and increase Europe's energy independence from fossil fuels. REPowerEU is the European Commission's plan to make Europe independent from Russian fossil fuels by 2030, in light of Russia's invasion of Ukraine. In this package, next to accelerating the production of renewable electricity, there is emphasis on accelerating the production of green hydrogen, which is expected to be produced from renewable electricity. Accordingly, amongst other measures, REPowerEU has announced an ambition to reach an additional 15 million tons (Mt) of renewable hydrogen on top of the 5.6 Mt foreseen under Fit for 55 plan, going beyond the targets of the EU's hydrogen strategy[1]. The REPowerEU sets a target of 10 million tons of domestic renewable hydrogen production and 10 million tons of renewable hydrogen imports by 2030. Meeting these targets will require a rapid acceleration of the development of hydrogen demand market, production, infrastructure, storage facilities and import. Moreover, the supporting and facilitating policy and legislation need to be in place in no time otherwise meeting the targets cannot be realized.

**THIS STUDY IS FOCUSED ON THE BENELUX COUNTRIES AND ITS NEIGHBOURING REGIONS IN FRANCE AND GERMANY (HAUTS-DE-FRANCE, GRAND EST, NORTH RHINE-WESTPHALIA, SAARLAND, RHINELAND-PALATINATE, LOWER SAXONY)**. The Benelux and its neighbouring regions in France and Germany are the major industrial demand centres of Europe. Some key facts about the Benelux and its neighbouring regions are,

- The Benelux and its neighbouring regions are the **centre of the European steel and chemical industry**.
- More than **20% of Europe's production capacity for methanol, olefins, ammonia and aromatics is in the Benelux**.
- More than **30% of Europe's production capacity of the aforementioned sectors and steel is in the Benelux and its neighbouring regions**.
- All sectors combined, **14% of the Europe's capacities in the hard-to-abate sectors are in the Benelux and 27% in the Benelux and neighbouring regions which is much higher than one could expect on the basis of population** (7% and 17% respectively), **land area** (1% and 5% respectively) and **GDP** (10% and 19% respectively).
- **Major ports** are located in the Benelux and its neighbouring regions which already serve as an energy transmission hub for Europe
- The Benelux and its neighbouring regions have a **very dense gas pipeline infrastructure which have a high potential to be repurposed for hydrogen transportation**

**THE BENELUX COUNTRIES AND ITS NEIGHBOURING REGIONS IN FRANCE AND GERMANY WILL REMAIN EUROPE'S BEATING HYDROGEN HEART AS A CROSS-BORDER HYDROGEN DEMAND CLUSTER.** Figure 1 shows the hydrogen value chain in the Benelux countries and their neighbouring regions and compares them with the rest of Europe. As shown, around 15% of the hydrogen production capacity, 67% of the import capacity,

[1] https://energy.ec.europa. eu/repowereu-joint-european-action-more-affordable-secure-and-sustainable-energy_en

26% of the storage capacity, 24% of the hydrogen pipeline length, and between 19% and 41% of the hydrogen demand in Europe in 2030 is located in the Benelux and its neighbouring regions in comparison to Europe. The Benelux and the neighbouring regions are therefore a key hydrogen development centre for Europe.

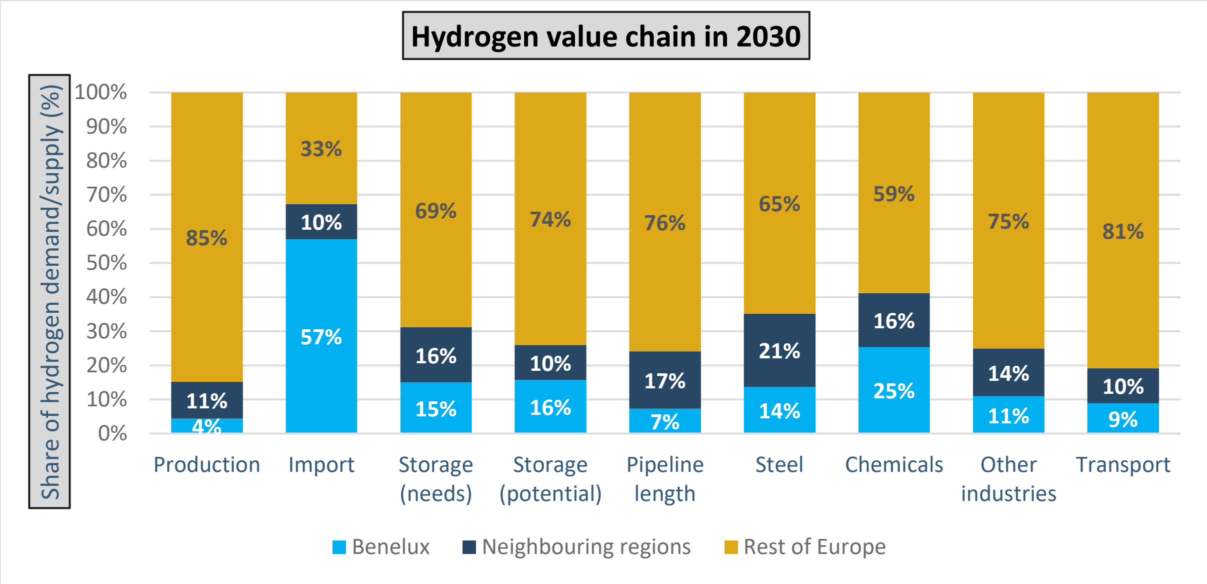


Figure 1: Quantification and shares of the hydrogen value chain in the Benelux and its neighbouring regions in 2030 (maximum scenario)

Other highlights deducted from these graphs are summarized as follows.

- **The Netherlands, Belgium and Lower Saxony foresee significant amounts of hydrogen imports** that together with the hydrogen production capacity foreseen to be deployed (based on their hydrogen strategies) **go beyond satisfying the domestic demand for hydrogen**.
- **The Netherlands and Lower Saxony** are planning to import 4 to 5 times more hydrogen than demand requires and hence they **will function as a hydrogen gateway for the neighbouring countries and regions for which their own production is not sufficient to fulfil their demand.**
- **The total amount of hydrogen imported by the Netherlands and Lower Saxony is more than sufficient to fulfil this demand in 2030.**
- **All countries and neighbouring regions foresee the development of an interconnected hydrogen pipeline system in 2030,** as can be seen in publicly available plans. For Luxembourg such public data are not yet available; the results of this study however suggest that Luxembourg has a non-negligible domestic demand potential and may offer an interesting transit potential helping to connect demand and supply centres in its neighbouring countries.
- A great amount of **undersupply of hydrogen storage capacity may exist in 2050**. It would be recommendable to develop a hydrogen storage strategy among the Benelux countries and neighbouring regions.

**THE HYDROGEN PIPELINE NETWORK IN THE BENELUX AND THE NEIGHBOURING REGIONS CONNECT FOR A LARGE MAJORITY BIG PRODUCTION AND IMPORT FACILITIES WITH LARGE HYDROGEN DEMAND CLUSTERS.** As part of this study, a graphical representation of the development of the hydrogen value chain is developed for 2030 and 2050. The map for 2030 is shown in Figure 2. As can be seen,

- local production of hydrogen is not all the time sufficient to cover the hydrogen demand in 2030, hence the need for hydrogen imports. **Hydrogen imports should take the perceived sense of hydrogen scarcity away**;
- **a large share of hydrogen production locations and big hydrogen demand centres are located near or at the hydrogen pipeline network;**
- **a small share of mainly small hydrogen production locations and hydrogen demand centres are not located at the hydrogen pipeline network**, some overlap indicating local projects where hydrogen demand is met by onsite electrolysis;
- for **some locations**, hydrogen demand centres do not yet have local hydrogen production, hence **other means to supply hydrogen need to be investigated**;
- for high temperature heat and transport, hydrogen demand may need to be supplied through alternative means too;
- **all the Benelux countries and neighbouring regions have a hydrogen pipeline network that is connected to at least 1 neighbouring country or regions in 2030**. This results in an interconnected hydrogen pipeline system. An exception is Luxembourg, which did not yet officially announce any target for establishment of a hydrogen pipeline system in 2030, even though there is a reasonable demand for hydrogen. It would therefore be recommendable to establish the interconnected hydrogen pipeline system already in 2030 to satisfy its swifter-than-expected rising hydrogen demand in Luxembourg and to create an extra interconnection with Saarland and Rhineland Palatinate.
- **a large part of the hydrogen pipeline network in the Benelux and the neighbouring regions is already foreseen to be established by 2030**, the only real expansion afterwards is a second east-west corridor that connect the Belgian harbour with North Rhine-Westphalia and Luxembourg.

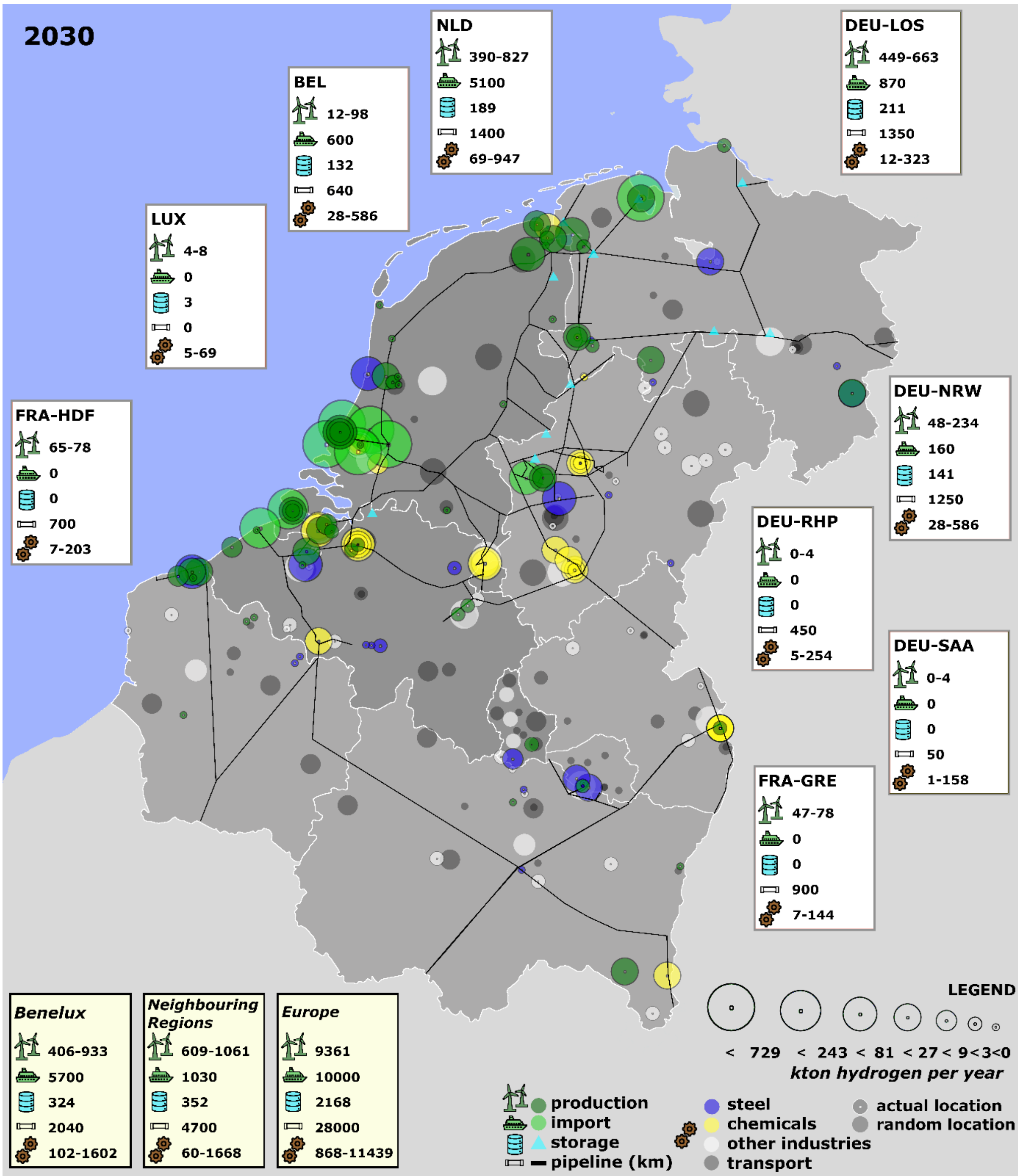


Figure 2: locations of hydrogen demand, supply, storage, pipelines in 2030 within the Benelux and its 6 neighbouring regions

During this study, we organised several workshops with main actors in the hydrogen market development from the entire value chain. During these workshops, next to verifying the collected and estimated data and strategies, the main challenges from both technology and regulatory perspective that the stakeholders are facing in the implementation of their projects and achieving their decarbonisation targets have been discussed. Stakeholders consider the **BENELUX UNION AS A KEY PLAYER IN SUPPORTING THE DEVELOPMENT OF THE REGION INTO AN OBSTACLE-FREE, CROSS-BORDER HYDROGEN HUB. A REGION THAT SERVES A KEY-PILOT LOCATION FOR EUROPE FOR CROSS-BORDER INNOVATION, DEVELOPMENT AND HARMONISATION IN HYDROGEN MARKET**.

Following the outcomes of the workshops and the discussions with stakeholders, the Benelux Secretariat and the Benelux Hydrogen Working Group, we propose **a set of recommendation for policy makers in the Benelux Union for the near-term period (2023-2026) and mid-term period (2026-2030)**. These recommendations and proposed actions are meant to further strengthen the position of the Benelux and its neighbouring regions in Europe with regard to hydrogen development and to support the region in becoming the leader in the implementation of hydrogen strategies and establishment of an integrated hydrogen market in Europe.

## RECOMMENDATIONS AND PROPOSED ACTIONS FOR SHORT-TERM (2023-2026) ARE AS FOLLOWS.

1. **Strengthened, collective voice towards influencing EU legislation and promoting the region** by strengthening the leading position of the Benelux-countries and neighbouring regions by leveraging their pioneering role as privileged interlocutors to shape EU legislation, with regards to large chemical and steel industries, $H_2$ import via seaports, $H_2$ backbone, transport sector, $H_2$ valleys; and by boosting more visibility for the Benelux and its neighbouring region in Europe and attracting more resources and funding to the region.
2. **Promoting collaboration along the hydrogen value chain** by setting up a regular dialogue and promoting institutional and regional collaboration between different public and private actors of the $H_2$ value chain and relevant Benelux authorities; by promoting closer collaboration, share of expertise and lessons learned and deepening the dialogue between stakeholders (TSOs of gas and electricity, HRS developers, technology developers, etc.) of the Benelux-countries and its neighbouring regions; and by ensuring the security of supply by coordinating the plannings for the electricity and $H_2$ infrastructure development including electrolyser plants and the repurposing of the existing gas network into dedicated hydrogen networks.
3. **Streamlined and fast-track procedures** by speeding up the permitting process to increase renewable energy and electrolyser capacity for both new and existing projects to go hand in hand with the deployment of new renewable electricity capacity; by exploring harmonisation possibilities of permitting rules; and by facilitating fast-track procedure for IP & patenting within the Benelux and its neighbouring regions.
4. **Paving the transition path** by accelerating deployment of a cross-border hydrogen backbone to facilitate hydrogen supply for hard-to-abate industries and to satisfy rising hydrogen demand; by allowing for an innovative and flexible regulatory framework for the nascent interconnected hydrogen market to accommodate the transition towards green hydrogen; and by stimulating the development of education and training programmes to have skilled labour force.
5. **Kick-start the development of an integrated hydrogen market** by harmonising system requirements, safety protocols, standards and hydrogen quality for H2 transport and consumption; by ensuring interoperability and exchanges between certification schemes and registers and integrating and hosting a trading market for hydrogen production and import; by developing a common hydrogen storage strategy; by working with combined forces at EU level to push for the clear and tailored tax and funding schemes to avoid displacement of the investment and industrial production from EU to Asia or the US; and by encouraging a joint call of the Benelux-countries and neighbouring regions for development of the supporting schemes such as European Hydrogen Bank and H2Global, and maximising the use of other EU supporting mechanisms.
6. **Uniform approach for establishing hydrogen refuelling infrastructure** by harmonising payment systems, HRS interoperability, homologation requirements, permitting rules as well as bunkering specifications and rules for waterborne and airborne applications; and by aligning HRS implementation plan and technical specifications (quality, interfaces, protocols).

### RECOMMENDATIONS AND PROPOSED ACTIONS FOR MID-TERM (2026-2030) ARE AS FOLLOWS.

1. **Advance the development of an integrated hydrogen market** by providing the means for barrier-free flow of hydrogen from production point to the end-user location through the use of the Benelux legal instruments, with extension to and alignment with the neighbouring regions by harmonising regulations for hydrogen production, import and transport; and by facilitating the market transition from a subsidy dominated system towards a competition driven system.
2. **Economic activities & education** by promoting new economic activities related to hydrogen development; and by implementing diplomas and certificates that are accepted and recognized across the Benelux region.

By working upon these actions on the Benelux level in cross-border cooperation with the neighbouring regions, the Benelux Union is able to keep its position as frontrunner in the deployment of hydrogen across all sectors and provide Europe with guidance and support on how topics of cross-border nature can affectively be tackled. In this way, the Benelux and its neighbouring regions are becoming the cross-border hydrogen hub of Europe.

# 1. INTRODUCTION AND SCOPE OF THE STUDY

## 1.1 INTRODUCTION

The Benelux Union fosters cross-border collaboration between the Benelux countries. It has recognised the key role that hydrogen has in reaching carbon neutrality for its region. It wishes to develop a cross-border hydrogen backbone in the Benelux area and its neighbouring regions. The aim of this project is therefore to facilitate cross-border cooperation, within the Benelux and with its neighbouring regions (Hauts-de-France, Grand Est, North Rhine-Westphalia, Saarland, Rhineland-Palatinate, Lower Saxony), for matters related to hydrogen and its derivatives.

Hydrogen is an important element in the current energy transition and Europe and especially the Benelux can play a leading role in the global hydrogen market. In its hydrogen strategy, the European Union mainly focuses on the application of hydrogen in industry, in ports and logistics (including freight transport, maritime applications). Moreover, import of hydrogen from locations with cheap green electricity to Europe is another important aspect of the hydrogen economy.

For the Benelux region, these three areas of application form the core of its activities:

- Several of the top 10 ports in Europe are located at a relatively short distance from each other in the region;
- The largest industrial clusters (chemistry, steel) in Europe are located at a relatively short distance from each other in the region;
- One of the busiest logistics routes (freight transport, inland shipping) runs from the ports in the Benelux region to Germany and France.

Under the impulse of European policy, together with the ambitions of the Netherlands, Belgium (both federal and regional governments) and Luxembourg to be among the leaders in hydrogen in Europe, a large number of unique hydrogen projects have already been realized in the Benelux region in recent years. It is remarkable that these projects are often also realized with the technology that has been developed in the Benelux region. This means that the application of hydrogen not only contributes to sustainability, but also to regional development and employment.

It is even more important that in recent years many, and especially relatively large, hydrogen initiatives have been announced from the Benelux countries. Industry, ports, logistics, etc., have all announced visions and concrete plans and demonstration projects. Together with the Member States, Europe has started IPCEI hydrogen (Important Projects of Common European Interest) and more than 30 projects from Belgium and the Netherlands have been also registered and qualified for that. Furthermore, new and larger hydrogen initiatives are announced nearly every day in the media, which are sometimes linked to other projects in a larger ecosystem.

In order to make the transition to hydrogen and its derivatives as efficient and as fast as possible, it is important that the coherence and complementarity between the regional hydrogen initiatives is used to the maximum and, above all, that all kinds of non-technological barriers in the Benelux region that impede this uptake are removed as effectively as possible.

To provide further support for this, the Benelux Union recognised the need to support the hydrogen developments in the region. The Benelux Union is an intergovernmental partnership based on a Treaty

(1958 and renewed in 2008) between Belgium, the Netherlands and Luxembourg, and subordinate regulations. Active on two core themes (1) internal market and economy and (2) security and society, it aims to stimulate cross-border sustainable and digital cooperation between the countries and to play a pioneering and driving role within the European Union.

In March 2021, the Benelux Directors General for energy instructed the Benelux Secretariat to come forward with a study proposal to explore the ecosystem for a Benelux hydrogen backbone. The Benelux 'Hydrogen' working group elaborated a study description, and with this current project, they would like to build on previous work and broaden and deepen the analysis to work towards a mature cross-border hydrogen market and backbone by 2050, with intermediate steps in 2030 and 2040.

The Benelux countries can become a frontrunner in Europe in the field of hydrogen. By working together and with their neighbouring regions, they can significantly increase their chances of success. It should therefore be clear that the Benelux Union can and wants to play a role in this as a cross-border connecting network. That is why the Benelux Union would like to find out where the gaps are that hinder a further transition, and where it can play a role in helping to close those gaps and facilitating cross-border cooperation between the Benelux countries and their neighbouring regions.

## 1.2 SCOPE OF THE STUDY

This study focuses on hydrogen development activities within the Benelux countries and its neighbouring regions in Germany (Lower Saxony, North Rhine-Westphalia, Rhineland-Palatinate and Saarland) and France (Hauts-de France and Grand Est). This study provides a comprehensive overview, of the quantification and location of potential demand and supply (including both domestic production and import) of hydrogen and its derivatives based on established energy policies. Next to that, it presents an anticipation of the infrastructure needs for import, transport and storage.

The data presented in this study is based on existing (long-term) scenarios, national/regional hydrogen strategies and independent literature studies as well as the accompanying discussions among experts and stakeholders, which took place in the format of several workshops with focus on different parts of the hydrogen value chain. The overview of hydrogen supply, transport and demand has been also visually represented, using maps showing the location of the production projects and demand locations. Based on these data analysis, conclusions are drawn about the efficiency and effectivity of the planned projects and strategies as well as outlining the possible shortage or mismatches between supply and demand in different areas.

Further, we have identified obstacles and opportunities on the path of hydrogen market development in the Benelux and its neighbouring regions and formulated policy recommendations accordingly. The outcome of this study together with the policy recommendations will be presented to relevant Ministers and serve as a decision support tool for the Benelux Union. This study can also serve as a base to further develop structured collaboration between the Benelux and its neighbouring regions in Germany and France for development of an integrated, cross-border hydrogen market in these regions.

## 1.3 METHODOLOGY

The methodology adopted to execute this study basically comprises two parts: data analysis and expert solicitation to derive a quantification of hydrogen supply, transport and demand between 2030 and 2050 and the execution of 6 workshops for all parts of the value chain (import, production and ports

(1); infrastructure and storage (2); steel (3); industry (4); transport (5) and policy and regulations (6) to identify barriers for implementation and areas in which the Benelux Union can take a role to reduce these barriers. Workshop participants included stakeholders from industry and governments from the Benelux countries and the neighbouring regions. The progress and the (interim) results made were presented to the Benelux Hydrogen Working Group on a monthly basis for feedback. A final workshop was organised to present the results of the study to the Benelux Union, the Benelux countries and the neighbouring regions and determine next steps on how the recommendations can be implemented.

In order to quantify hydrogen supply (production, import), transport (infrastructure and storage) and demand (steel, chemicals, other industries and transportation), a four-step approach was adopted to develop so called "information briefs" per part of the value chain. An information brief provides a synopsis of the main information that is relevant to understand the hydrogen landscape per part of the value chain. It includes for example an overview of the state of art of production capacities, main stakeholders, the role of hydrogen in decarbonisation, decarbonisation strategies of the sector, outcomes of the data analyses and scenario assessments to quantify the forecasted minimum and maximum hydrogen uptake in that sector between 2030 and 2050 for the Benelux countries, its neighbouring regions and Europe. To improve the readability of this report, all information briefs are inserted in the Annex and only the main results are described in Chapter 2. Hence, the Annex can be consulted for all details per sector.

The data analyses consist of 4 steps: an analysis of national and regional hydrogen strategies (1), assessment of the role of hydrogen in national energy and climate plans (NECPs) (2), a literature analysis to derive minimum and maximum hydrogen adoption and/or penetration scenarios until 2050 (3) and expert solicitation to confirm or modify the data derived (4).

National and regional hydrogen strategies were studied in order to determine trends, priorities and quantifications for the uptake of hydrogen in the different sectors. An overview of the strategies consulted is provided in Table 1. Often, hydrogen strategies lack the quantification of hydrogen however they may have targets, e.g., for the number of hydrogen refuelling stations to be deployed. It is however important to note that towards the end of this study new or updates of some national and regional hydrogen strategies were published (e.g., the Wasserstoffstudie mit Road Map Rheinland-Pfalz in November 2022 and the Dutch Routekaart Waterstof in November 2022, Roadmap for the decarbonisation of Luxembourg manufacturing industry in December 2022), which due to time limitations could not be considered anymore as part of this study. It is also expected that many of these strategies are being updated, for example because of Europe's increasing hydrogen ambitions through the Fit-for-55 and RePowerEU packages. So, it remains important, also after this study, to keep monitoring the status of these new sources of information.

Table 1: Overview of national and regional hydrogen strategies consulted

| Country/region | National/regional strategies assessed |
|---|---|
| **Netherlands** | Contouren van een Routekaart Waterstof (2018)<br>Kabinetsvisie waterstof (2020)<br>Fit-for-55%-pakket waterstof en Nationaal Waterstof Programma (2022) |
| **Belgium** | View and strategy Hydrogen (2021)<br>Vlaamse Waterstofvisie (2020)<br>Roadmap H2 pour la Wallonie (2018) |
| **Luxembourg** | Stratégie hydrogène du Luxembourg (2021) |
| **Hauts-de France** | Vers le développement d'un hydrogène décarboné en Hauts-de-France (2019) |
| **Grand Est** | Une stratégie hydrogene 2020-2030 (2022) |
| **Lower Saxony** | Norddeutsche Wasserstoffstrategie (2019)<br>Simulative Kurzstudie zum Einsatz von Wasserstofftechnologie in Niedersachsen (2020) |
| **North Rhine-Westphalia** | Wasserstoff Roadmap Nordrhein-Westfalen (2020)<br>Wissenschaftliche Begleitstudie der Wasserstoff Roadmap Nordrhein-Westfalen (2021) |
| **Rhineland-Palatinate** | H2R – Wasserstoff Rheinland (2020) |
| **Saarland** | Eine Wasserstoffstrategie für das Saarland (2021) |

As a second source of information, the assessment by Trinomics of national energy and climate plans (NECPs) is used to further derive quantifications of hydrogen up to 2030[2]. Other literatures have been analysed to develop minimum and maximum hydrogen penetration scenarios and to derive general growth/decline characteristics of that sector up to 2050. The results of these assessments are shown in tables and on this basis minimum and maximum hydrogen penetration scenarios are derived. The maximum hydrogen penetration scenarios can also be determined by upcoming EU legislation. It is important to note that EU legislation will have a big impact on the uptake of hydrogen along parts of the value chain. However, many of these EU legislations are still under development (e.g., update of REDII), and this study applies these drafted targets until November 2022 to the maximum hydrogen penetration scenario.

Further, the recently developed roadmap for decarbonisation of manufacturing industry in Luxembourg in 2030 shows a hydrogen demand for steel, cement and heat sector that is very close to the estimated demand for hydrogen in the maximum scenario in this study. It could be argued, similar to the drafted hydrogen targets in EU legislation, to reflect this demand into the minimum scenario. However, to stay consistent with the methodology applied in this study, it has been decided to leave it as part of the maximum scenario. For example, as shown in Chapter 2, hydrogen demand in 2030 for Luxembourg is estimated between 5 kton (minimum scenario) and 69 kton (maximum scenario) per

[2] https://www.clean-hydrogen.europa.eu/media/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans_en

year. However, based on the Luxembourg decarbonisation roadmap for 2030, the minimum demand for hydrogen will be  41 kton instead of 5 kton per year.

The results of this data analysis were applied in the information briefs, which were presented in 6 workshops to experts for validation and identification of technical and regulatory barriers for development of the hydrogen market. The quantifications of hydrogen uptake per sector are presented in tables, and a graphical representation is provided for the location of hydrogen production and demand centres. For very dispersed hydrogen demand, for example, heat or transport, hotspots are being selected (e.g., logistic hubs, industry clusters) to associate the demand to, whereas in reality that demand is much more dispersed. In Chapter 2, a synopsis is provided of the main findings and conclusion of the analysis of the value chain. Chapter 3 and Chapter 4 present the barriers and the role the Benelux Union can take remove these barriers. The final roadmap and recommendation are provided in Chapter 5.

# 2. ASSESSMENT OF HYDROGEN VALUE CHAIN IN THE BENELUX

In this chapter, the results of the data analysis for the quantification of hydrogen supply, transport and demand in the Benelux countries and the neighbouring regions up to 2050 under different scenarios are presented. All details concerning the assessment performed per part of the hydrogen value chain are shown in the information briefs in the Annex.

## 2.1 OVERVIEW OF THE ASSESSED HYDROGEN VALUE CHAIN

The hydrogen value chain assessed in this study is shown in Figure 3. It comprises hydrogen supply in terms of domestic hydrogen production and hydrogen (derivates) imports via ports, the transmission and storage of hydrogen and the consumption of hydrogen in hard-to-abate sectors. The hard-to-abate sectors assessed are steel, chemicals, other industries and transport. The sub-sectors assessed as part of the chemical sector are ammonia, methanol, olefins and aromatics, whereas refineries, cement and high temperature heat are included in the 'other industries' sector. The transport sector consists of cars, buses, trucks, trains, waterborne and airborne applications as sub-sectors.

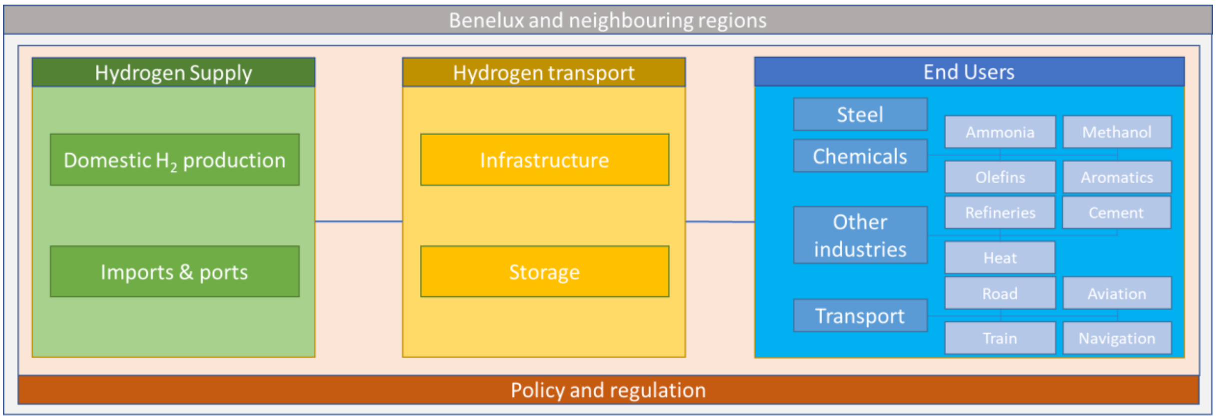


Figure 3: Hydrogen value chain (scope of study)

*How are these industries and the transport sector represented in the Benelux and its neighbouring regions in comparison to Europe?*

The Benelux and its neighbouring regions are the centre of the European steel and chemical industry. More than **20% of Europe's production capacity for methanol, olefins, ammonia and aromatics is in the Benelux** and more than 30% of Europe's production capacity of the aforementioned sectors and steel in in the Benelux and its neighbouring regions. Also, nearly all sectors are percentage-wise higher represented in the Benelux and its neighbouring regions in comparison to societal statistical parameters like population, land area and GDP (cf. Figure 4). All sectors combined, **14% of the Europe's capacities in the hard-to-abate sectors are in the Benelux and 27% in the Benelux and neighbouring regions**. This is much higher than one could expect on the basis of population (7% and 17% respectively), land area (1% and 5% respectively) and GDP (10% and 19% respectively). It shows that the Benelux and the neighbouring regions are a major industrial demand centre of Europe.

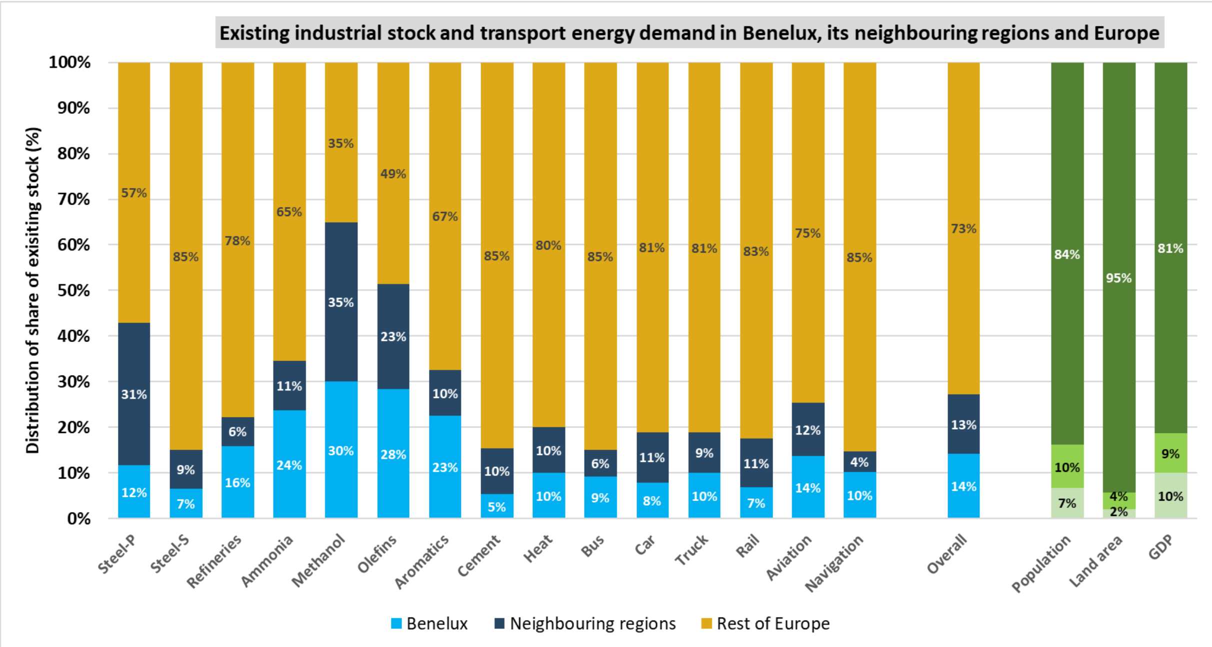


Figure 4: Overview of shares of the existing industrial stock and transport energy demand in Benelux, its Neighbouring regions and Europe

*Does this mean that the Benelux and its neighbouring regions have the potential to become the hydrogen demand centre of Europe in the near and long term?* And *will the Benelux and its neighbouring regions then have a dominant position in the whole hydrogen value chain?*

The Benelux countries and its neighbouring regions in France and Germany will remain Europe's beating hydrogen heart. This is due to the fact that:

- Next to feedstock, hydrogen is going to play an important role in **decarbonization of hard-to-abate industries, production of high-temperature heat and steam production, and decarbonisation of the transport** sector.
- The Benelux and its neighbouring regions are already **hosting six hydrogen valleys**[3], among which four of them in the Netherlands and Belgium and 2 in the neighbouring regions in Germany. These valleys will become local hydrogen ecosystems connecting the hydrogen producers to the end-users via the hydrogen pipelines.
- The region has the ambition to become a **gateway for hydrogen import** to Europe thanks to the presence of many seaports and inland ports, among which are the largest European ports.
- Because of the direct access to a large area in the North Sea, there are many plans for development of **offshore wind parks, which will be partly dedicated to hydrogen production**.
- In this region, mainly in the Netherlands and Germany, there are many **salt caverns and other forms of underground gas storage facilities (e.g., aquifers)** that are suitable and will be used for hydrogen storage.
- This region has an **existing, well-connected gas network, which is suitable for repurposing for hydrogen transport**. The gas Transmission System Operators (TSOs) in the Benelux and its

[3] https://h2v.eu/hydrogen-valleys

neighbouring regions have joined forces together with the other European TSOs to develop the European hydrogen backbone. This backbone plays an important role is connecting the production and import locations to the end-user locations.

- The Benelux countries and the neighbouring regions have announced their **ambitious strategies for hydrogen development** in different parts of the value chain and are working on supporting the projects and stakeholders with the facilitating policy and funding schemes.

In the next section, an assessment of hydrogen value chain within the Benelux and its neighbouring regions is provided and the importance of the region in hydrogen development in comparison with the rest of Europe is highlighted.

## 2.2 ASSESSMENT OF HYDROGEN VALUE CHAIN IN BENELUX AND NEIGHBOURING REGIONS

In this section, the results of the data analysis are provided regarding the uptake of hydrogen along all parts of the value chain. The results are shown for the timespan 2030, 2040 and 2050 for the Benelux and its neighbouring regions. The hydrogen demand in the four sectors (steel, chemicals, other industries and transport) are shown based on the applied minimum and maximum scenarios. These scenarios and the detailed analysis per (sub) sector are presented in the Annex Chapter.

### 2.2.1 Steel

The steel sector is considered as a large consumer of hydrogen for both the primary steel production route, which processes iron ore as a raw material into steel, and the secondary steel production route, which re-uses processed recycled steel scrap. An overview of the current state of the art in terms of plant capacities, the role of hydrogen in decarbonising the sector vis-à-vis the decarbonisation strategy of the sector and its main stakeholders are shown in Annex 6.1. The national and regional hydrogen strategies as well as the literature consulted for the development of the long-term scenarios recognise the major role the steel sector has to play in the uptake of hydrogen. An overview of the data analysis, literature consulted, and the scenarios derived as well as a geographical representation of locations of hydrogen uptake across the Benelux and its neighbouring regions are also shown in Annex 6.1.

The final hydrogen demand in the steel sector between 2030 and 2050 for the Benelux and its neighbouring regions under a minimum and maximum scenario is shown in Figure 5. The immediate observations show that,

- in 2030, a (maximum) uptake of around 80 - 160 kton of hydrogen per year is expected in the Netherlands, Belgium, Hauts-de-France, Lower Saxony, North Rhine-Westphalia and Saarland.
- This grows to approximately 260 – 450 kton of hydrogen per year in 2040 and 240 – 680 kton of hydrogen per year in 2050.
- In areas without primary steel production, the amount of hydrogen is modest (but not small) to anywhere between 10 kton (Grand Est) to 25 kton (Luxembourg) per year.
- The figure makes it very clear that a large share of the hydrogen demand in the steel sector is located in Germany, but also in Hauts-de-France.
- The need to have access to low-cost hydrogen in large quantities before 2030 has been stressed by stakeholders in the workshops organised during this project. The steel sector can therefore be considered as a prime mover of the development of the cross-border hydrogen backbone in the Benelux and its neighbouring regions.

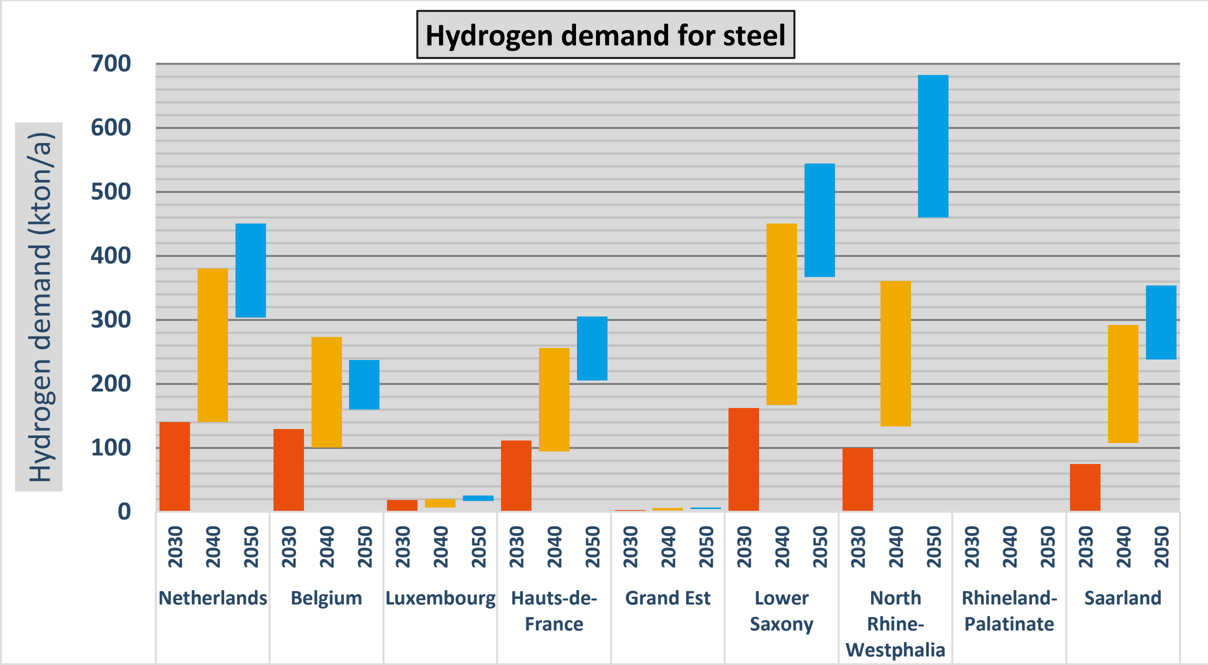


Figure 5: Overview of minimum and maximum hydrogen demand for steel in the Benelux and its neighbouring regions between 2030 and 2050

### 2.2.2 Chemicals

The chemical sector is comprehensive, and the subsectors considered in this study as part of this sector are ammonia, methanol, olefins and aromatics. An overview of the current state of the art in terms of plant capacities, the role of hydrogen in decarbonising the sector vis-à-vis the decarbonisation strategy of the sector and its main stakeholders are presented in Annex 6.2 and 6.3. Ammonia and methanol production plants are already the main consumers of hydrogen today. The upcoming EU legislation requires the replacement of this hydrogen by green hydrogen, hence these sub-sectors are considered as a replacement market. The production of olefins and aromatics can be considered as new sub-sectors for the uptake of hydrogen, since a new production route using green methanol shows decarbonisation potentials for these industries. An overview of the data analysis, literature consulted, and the scenarios derived as well as a geographical representation of locations for hydrogen uptake across the Benelux and its neighbouring regions are also shown in Annex 6.2 and 6.3.

A paradox may appear for the domestic production of ammonia and methanol as these chemicals are also being considered as a hydrogen carrier to be imported too. Recent announcements of hydrogen imports are predominantly based on the import of green ammonia as a hydrogen carrier, which poses the question whether this can be a threat to the domestic production of these chemicals in the Benelux and its neighbouring regions. Like hydrogen, it is expected that a mix of domestic and foreign production of these chemicals will exist, which is reflected in the scenarios applied. Considering the dominance of the chemical sector in the Benelux and its neighbouring regions, it is also expected the demand in these sectors are important for the initiation and expansion of the hydrogen backbone.

The final demand for hydrogen in the chemical sector between 2030 and 2050 for the Benelux and its neighbouring regions under a minimum and maximum scenario is shown in Figure 6. The immediate observations show that,

- in 2030, a (maximum) uptake of around 150 - 450 kton of hydrogen per year is expected in the Netherlands, Belgium, North Rhine-Westphalia and Rhineland-Palatinate.
- This grows to approximately 300 – 1100 kton of hydrogen per year in 2040 and 400 – 1650 kton of hydrogen per year in 2050.
- In Hauts-de-France, Grand Est and Lower Saxony, the amount of hydrogen is modest (but not small) to anywhere between 0 - 100 kton per year.

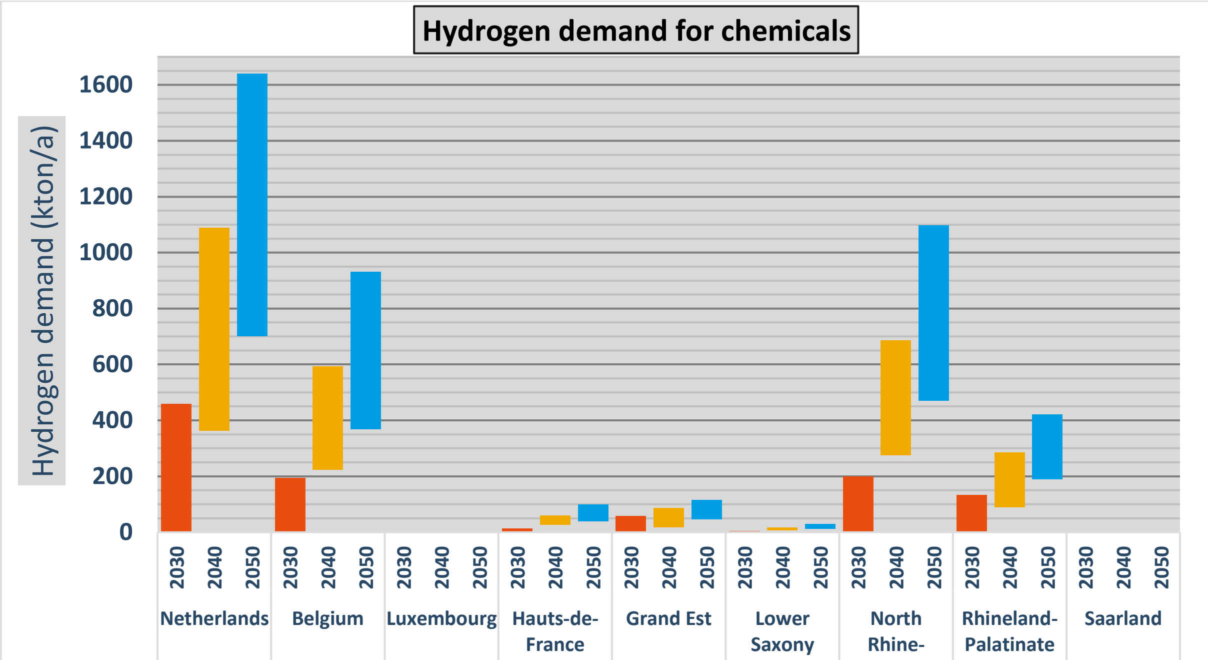


Figure 6: Overview of minimum and maximum hydrogen demand for chemicals (ammonia, methanol, olefins, aromatics) in the Benelux and its neighbouring regions between 2030 and 2050

### 2.2.3 Other industries

The other industries considered in this study are refineries, cement and high temperature heat. Refineries, like ammonia and methanol, are already an incumbent user of hydrogen (hydrocracking or hydrotreating of oil); however, its replacement by green hydrogen is currently not foreseen to be enforced by the upcoming EU legislation, and it is left to the Member States' own decision. The role of hydrogen in the cement sector can be considered two-fold, a direct demand for hydrogen coming from the provision of heat, and an indirect demand for hydrogen to convert the intrinsic $CO_2$ process emission to a synthetic fuel, e.g., synthetic methanol. The latter option is considered to be rather unlikely by the cement sector itself. Other sectors that use solid/liquid fuels or natural gas for the provision of high temperature heat are considered a prime market for hydrogen as alternative means to provide high temperature heat (e.g., through electrification) may not be that obvious. An overview of the current state of the art in terms of plant capacities, the role of hydrogen in decarbonising the sector vis-à-vis the decarbonisation strategy of the sector and its main stakeholders, an overview of the data analysis, literature consulted and the scenarios derived as well as a geographical representation for locations of hydrogen uptake across the Benelux and its neighbouring regions are shown in Annex 6.2 and 6.3. Industries that require high temperature heat are dispersedly distributed across countries and regions, and hence random locations have been assigned, whereas for refineries and cement actual locations of plants were used.

The final demand for hydrogen in the other industries between 2030 and 2050 for the Benelux and its neighbouring regions under a minimum and maximum scenario is shown in Figure 7. The immediate observations show that,

- in 2030, a (maximum) uptake of around 50 - 150 kton of hydrogen per year is expected in the Netherlands, Belgium and German regions.
- This grows to approximately 100 – 500 kton of hydrogen per year in 2040 and 200 – 900 kton of hydrogen per year in 2050.
- In Luxembourg, Hauts-de-France, Grand Est, the amount of hydrogen demand is modest (but not small) to anywhere between 0 - 100 kton per year.

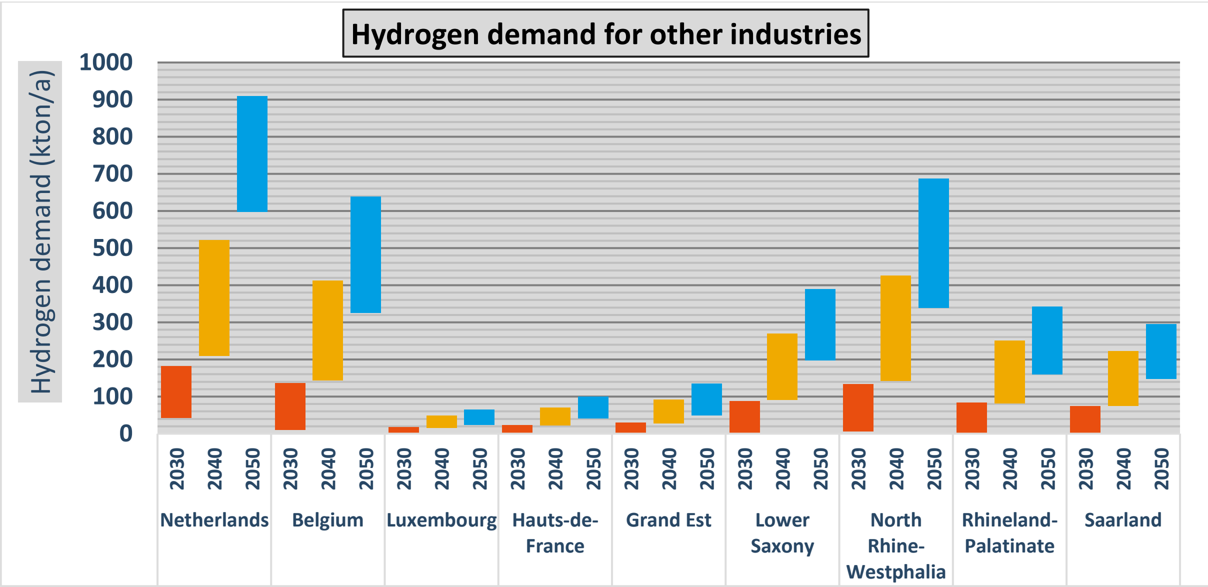


Figure 7: Overview of minimum and maximum hydrogen demand for other industries (refineries, cement, heat) in the Benelux and its neighbouring regions between 2030 and 2050

### 2.2.4 Transport

The transportation sector considered in this study comprises cars, buses, trucks, train, waterborne and airborne applications. Hydrogen plays an important, but not sole, role in decarbonising the sector, either through the direct use as fuel or indirectly through the synthesis of sustainable maritime or aviation fuels. The consumption of hydrogen in this sector is noticeable across all the Benelux countries and neighbouring regions. An overview of the current state of the art, the role of hydrogen in decarbonising the sector vis-à-vis the decarbonisation strategy of the sector and its main stakeholders, an overview of the data analysis, literature consulted, and the scenarios derived as well as a geographical representation for locations of hydrogen uptake across the Benelux and its neighbouring regions are shown in Annex 6.4.

The final demand for hydrogen in the transport sector between 2030 and 2050 for the Benelux and its neighbouring regions under a minimum and maximum scenario is shown in Figure 8. The immediate observations show that,

- in 2030, a (maximum) uptake of around 0 - 150 kton of hydrogen per year is expected for the Benelux countries and the neighbouring regions.
- This grows exponentially to approximately 50 – 850 kton of hydrogen per year in 2040 and 100 – 1900 kton of hydrogen per year in 2050.

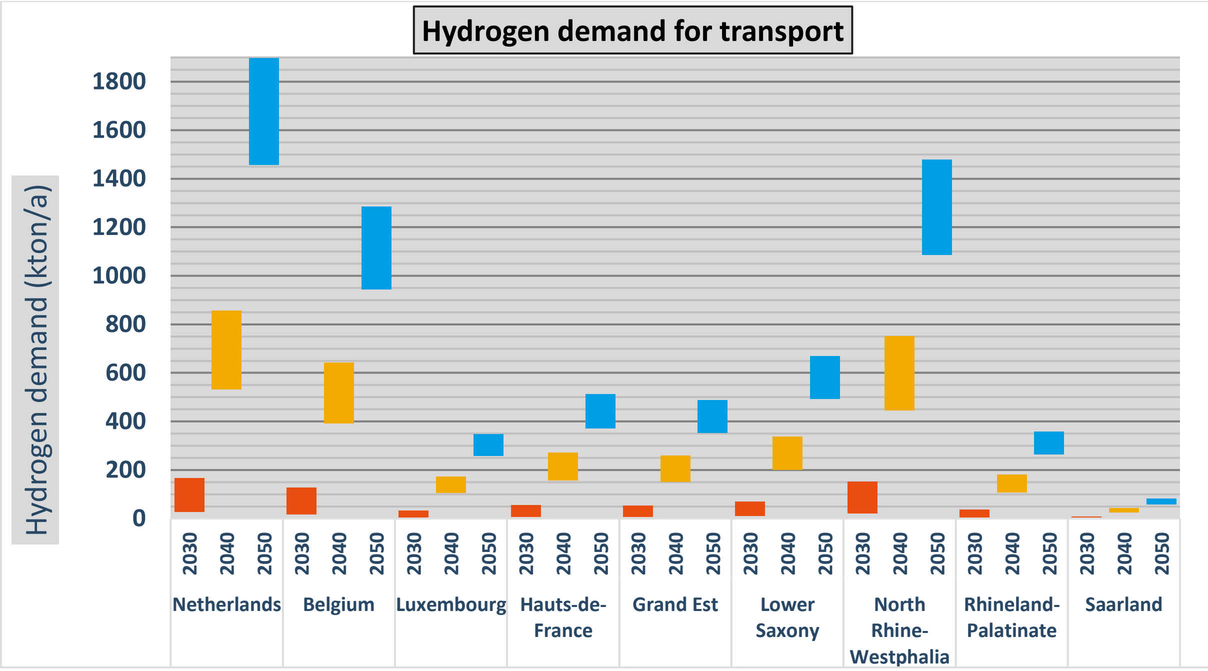


Figure 8: Overview of minimum and maximum hydrogen demand for transport (cars, buses, trucks, trains, waterborne and airborne applications) in the Benelux and its neighbouring regions between 2030 and 2050

### 2.2.5 Overview of hydrogen value chain in 2030 and 2050

The results of the quantification of all parts of the hydrogen value chain for the Benelux countries and its neighbouring regions are shown for 2030 (Figure 9) and 2050 (Figure 10). These figures enable a high-level comparison across the hydrogen value chain (supply, import, transport, storage and demand) for each country/region. A comparison is made between production and import on the one hand and the demand on the other and whether there is a transport infrastructure to connect these parts of the value chain with each other. The storage needs are assessed based on Figure 51 in Annex 6.6. A more detailed assessment is performed in section 2.2.7. *Note that since the amount of import in both 2030 and 2050 is much higher than the other values, the actual amount is mentioned directly on the related bars in the graphs*.

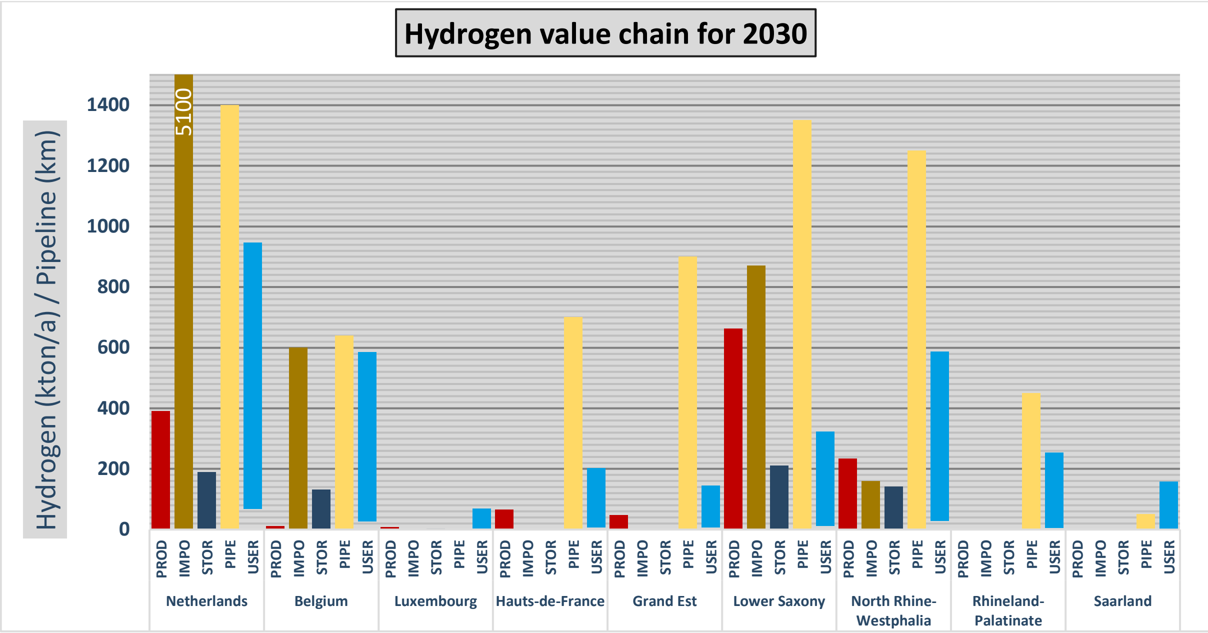


Figure 9: Quantification of hydrogen value chain in the Benelux and its six neighbouring regions in 2030

From these data, we conclude that,

- the Netherlands, Belgium and Lower Saxony foresee significant amounts of hydrogen imports that together with the hydrogen production capacity foreseen to be deployed (based on their hydrogen strategies) fulfil the demand for hydrogen.
- The Netherlands and Lower Saxony, however, are planning to import 4 to 5 times more hydrogen than demand requires, and hence, they can and will function as a hydrogen import gateway to their neighbouring countries and regions whose own production is not sufficient to fulfil their demand. Such a deficit is foreseen for the French regions, Luxembourg, North Rhine-Westphalia, Rhineland-Palatinate and Saarland.
- Yet, the total amount of hydrogen imported by the Netherlands and Lower Saxony is more than sufficient to fulfil their neighbour's demand in 2030. The development of an interconnected hydrogen pipeline network is then key to connect the import sites with the demand centres across Europe.
- An interconnected hydrogen pipeline system between almost all the Benelux countries and neighbouring will exist in 2030. It is worth noting that the foreseen network will be quite mature in 2030, and only Belgium and Luxembourg anticipate a significant expansion of the hydrogen pipeline network afterwards.
- For Luxembourg such public planning for H2 backbone is not yet available; however Luxembourg has a non-negligible domestic demand potential and may offer an interesting transit potential helping to connect demand and supply centres in its neighbouring countries.

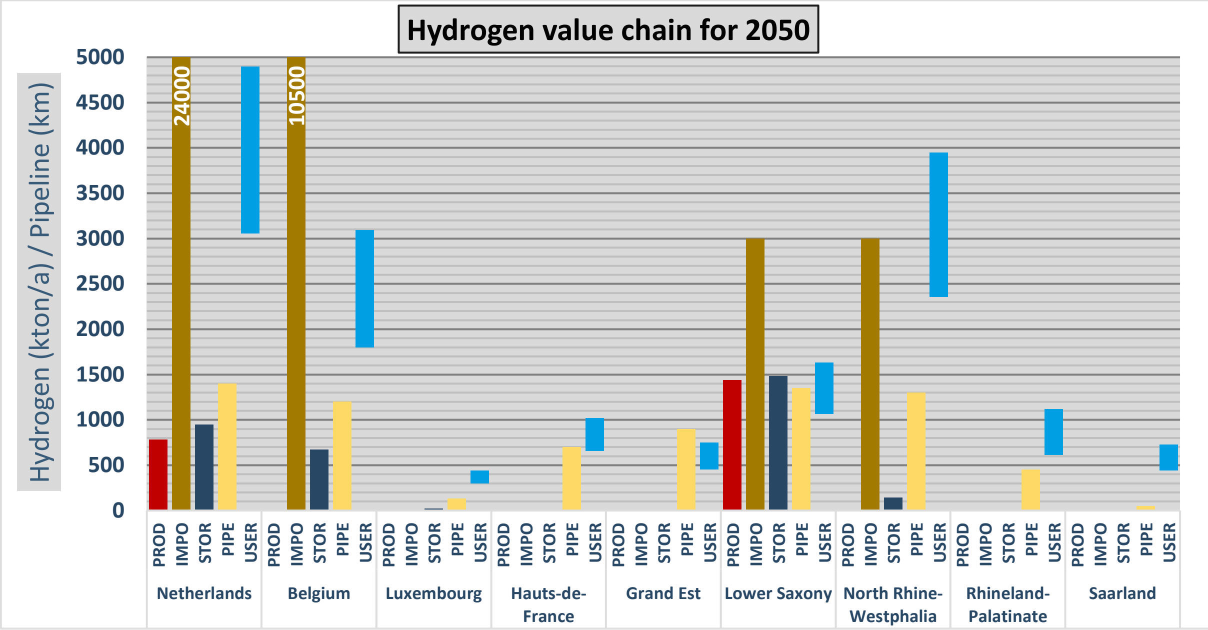


Figure 10: Quantification of hydrogen value chain in the Benelux and its six neighbouring regions in 2050

In 2050, the hydrogen landscape changes slightly, as

- Belgium and North Rhine-Westphalia are also foreseen to import significant amounts of hydrogen, next to the Netherlands and Lower Saxony.
- Although the national and regional hydrogen strategies are typically short of setting their targets/needs for domestic hydrogen production, it is expected that significant amounts of hydrogen are still going to be imported.
- The total amount of hydrogen imports exceeds the maximum demand for hydrogen in 2050, which means will be transported to the demand locations in other parts of Europe.
- In 2050, all countries and regions have a hydrogen pipeline network that is connected to at least 1 neighbouring country/region.
- Hydrogen storage potentials in 2050 will not meet the storage need.

A special need for attention is for hydrogen storage. Our assessment shows that in 2050 there is a great amount of undersupply of hydrogen storage capacity (cf. Figure 51 in Annex 6.6). Only few countries are currently foreseen to have underground hydrogen storage facilities. These include the Netherlands, Germany and France. Belgium is investigating whether its underground storage facility can be utilised for hydrogen storage. Natural storage potentials may not be available at national or regional levels, and hence, specific attention should be paid to the development and acquisition of hydrogen storage facilities. Luxembourg, for example, does not have storage facilities itself, and so it needs to strategically acquire storage capacities in the neighbouring countries/regions. It would be recommendable to develop a joint hydrogen storage strategy among the Benelux countries and neighbouring regions.

### 2.2.6 Importance of the Benelux and its neighbouring regions in Europe

The Benelux countries and their neighbouring regions in France and Germany already has a dominant position in terms of current demand for hydrogen and it is foreseen to establish, keep and expand this dominant position along the hydrogen value chain. This is shown in Figure 11 and Figure 12. Note that this assessment is based on the publicly announced strategies by the regional/national governments and the European Commission until October 2022. Any updates after this date is not reflected in this report.

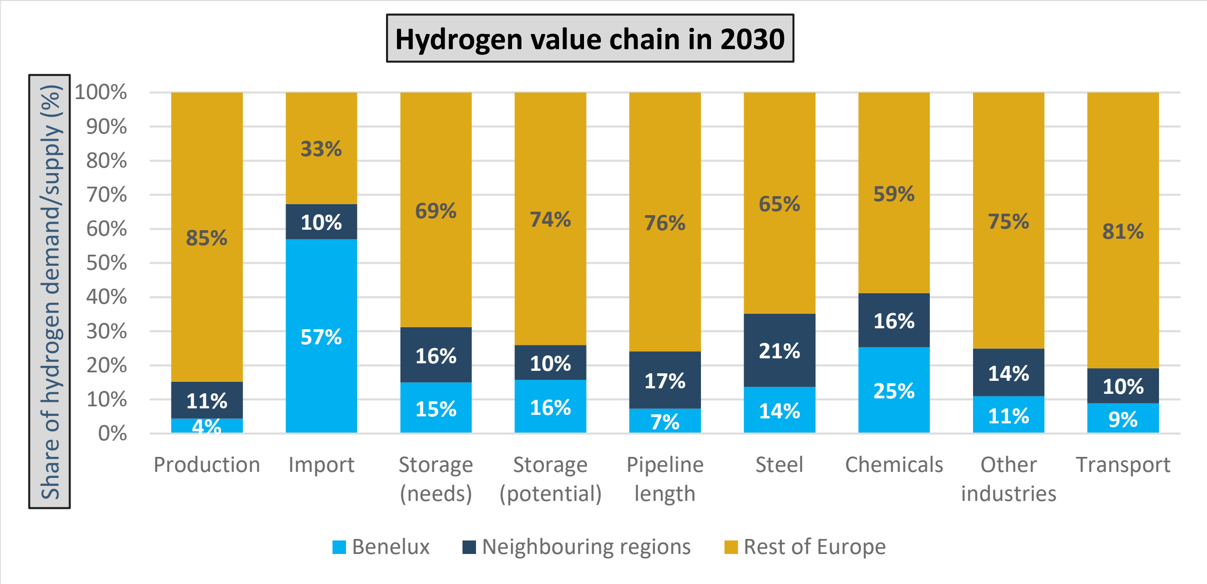


Figure 11: Share of hydrogen value chain within the Benelux and its neighbouring regions in comparison to the rest of Europe in 2030

As shown in Figure 11, in 2030,

- 67% of the hydrogen import,
- 26% of the hydrogen storage potential,
- 24% of the hydrogen pipeline length,
- 35% of the hydrogen demand for steel production, and
- 41% of the hydrogen demand for chemicals

are located in the Benelux and its neighbouring regions in comparison to the rest of Europe. Also, the **domestic hydrogen production, total pipeline length and hydrogen demand for transport, are more than 15%** of the European total.

This dominant position of the Benelux and its neighbouring regions does not change in 2050. As the domestic and European hydrogen production plans for 2050 and the total European targets for hydrogen import are not yet announced officially, there is no value for them in the graph (Figure 12). It is however not expected that the position in comparison to 2030 is changing since the demand keeps growing by 2050.

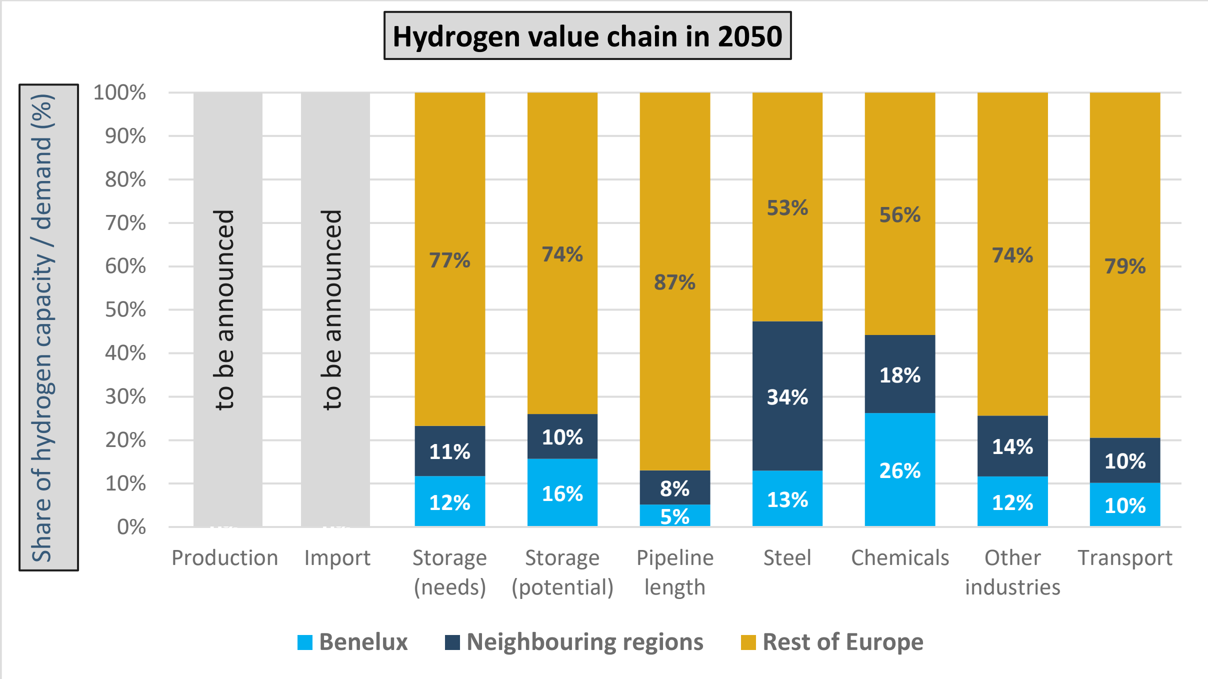


Figure 12: Share of hydrogen value chain within the Benelux and its neighbouring regions in comparison to the rest of Europe in 2050

### 2.2.7 Integrated assessment and gaps analysis

As a final result of the data analysis, two infographics (Figure 13 for 2030 and Figure 14 for 2050) have been designed, which shows the hydrogen production and import locations, the locations of the hydrogen storage facilities, the hydrogen pipeline network and the locations of the hydrogen demand for steel, chemicals and other industries (refineries and cement) for 2030 and 2050. The hydrogen demand for high temperature heat and transport is placed at random locations on the map as this demand is typically spread across the countries and regions, except for waterborne and airborne applications which are placed on airport and harbour areas. In this way, the locations for hydrogen supply and demand can be depicted in relation to the development of a hydrogen pipeline network in 2030 and 2050. Since in 2050 the hydrogen production locations and the amount of hydrogen produced are not known, the map of 2050 contain the locations of the announced projects in 2030. Info boxes are added to the map to provide a quantification of the parts of the hydrogen value chain. The range for hydrogen production is based on the announced strategies by the regional and national governments and the announced projects per region/country. In some places, there is quite a large difference between these two. For more details about the announced projects, the interested reader is referred to Annex 6.5. Moreover, the range for end-users is based on the minimum and maximum scenarios.

The maps shows that the hydrogen pipeline system is developed in the view of connecting industrial demand centres. The main observations that can be drawn from these maps are:

- Local production of hydrogen is not all the time sufficient to cover the hydrogen demand in 2030; hence, the need for hydrogen imports. Hydrogen imports should take the perceived sense of hydrogen scarcity away.

- A large share of hydrogen production locations and big hydrogen demand centres are located near or at the hydrogen pipeline network.
- A small share of (mainly small) hydrogen production locations and hydrogen demand centres are not located at the hydrogen pipeline network, some overlap indicating local projects where hydrogen demand is met by onsite electrolysis.
- For some locations, hydrogen demand centres do not yet have local hydrogen production, hence other means to supply hydrogen, such as tube trailers, containers, etc., need to be investigated.
- For transport sector, hydrogen demand may need to be supplied through alternative means, such as tube trailers or storage containers, as they will not yet be connected to the backbone or hydrogen distribution grid.
- In 2050, all the Benelux countries and neighbouring regions have a hydrogen pipeline network that is connected to at least 1 neighbouring country or regions. This results in an interconnected hydrogen pipeline system.
- A large part of the hydrogen pipeline network is already foreseen to be established by 2030, the only real expansion afterwards is a second east-west corridor that connect the Belgian harbour with North Rhine-Westphalia and Luxembourg.

There are **alternative methods to supply hydrogen to demand centres that are not in the proximity of the hydrogen pipeline system or do not yet have access to the hydrogen backbone**. These methods are: 1) through onsite electrolysis, 2) hydrogen supply by ships, and 3) last mile delivery by trucks or hydrogen tube trailers. A good example here is Luxembourg, which has not yet officially announced any plans for developing hydrogen backbone before 2030. Based on our analysis, the annual hydrogen demand for Luxembourg in 2030 is estimated between 5 to 69 kton, which under the assumption of constant demand, reflects a daily hydrogen demand of 14 to 190 ton. *Note that the minimum value for the demand is updated now to a higher value (about 22 kton) after a study has been conducted for developing hydrogen strategy for Luxembourg. However, this study has been finished only very recently and is not yet publicly available*.

Hydrogen distribution by means of one tube trailer can transfer about 1 ton of hydrogen per delivery. A 40ft hydrogen storage container that is envisaged as a standard hydrogen storage solution for the maritime sector is also about 1 ton per container, and a 4 MW electrolyser connected to wind power can also produces 1 ton of hydrogen per day. Hydrogen tube trailers or containerised hydrogen storage solutions could be replenished at hydrogen filling points located at of nearby the hydrogen pipeline network. Indicatively, **a demand up to 4 ton per day can be supplied by a hydrogen tube trailer or containerised hydrogen storage solution**, whereas for larger amount an electrolyser could be considered. Still this would mean between 14 to 190 movements of tube trailers or containerised storage solutions, which requires a significant effort in logistics. Hence, **such alternative solution, in which there is a hydrogen storage depot with several containers, is not considered a reasonable solution by this study**. Only if demand centres are very closely located to such container depots, one can use this option; however, currently this is not the case. When hydrogen production through onsite electrolysers is foreseen, **a total installed capacity of 50 to 760 MW needs to be installed to meet the hydrogen demand** in Luxembourg. Considering the portfolio of projects that are currently being planned in the Benelux and its neighbouring regions, this is a significant capacity. Therefore, seeing the envisaged developments for the hydrogen backbone in the Benelux and its neighbouring countries, **it is recommendable to develop the hydrogen pipeline network in Luxembourg earlier in time**, so that in 2030 an interconnected pipeline system exists in the region. In this case, the interconnected pipeline for Luxembourg shown in Figure 14, would appear before 2030. Another advantage of having the backbone earlier in Luxembourg is that demand clusters in Saarland and Rhineland-Palatinate can be serviced through this network as well.

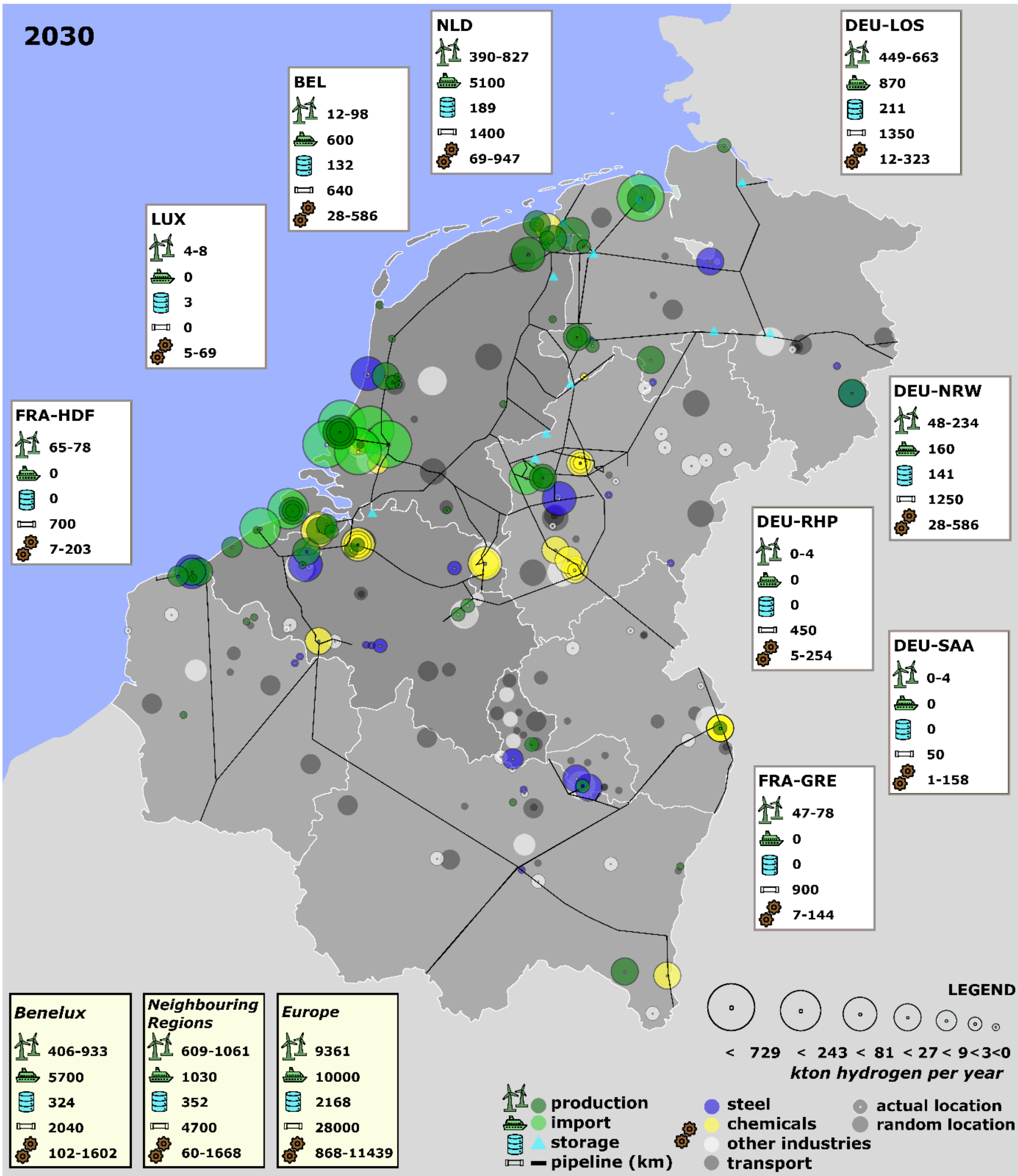


Figure 13: locations of hydrogen demand, supply, storage, pipelines in 2030 within the Benelux and its 6 neighbouring regions

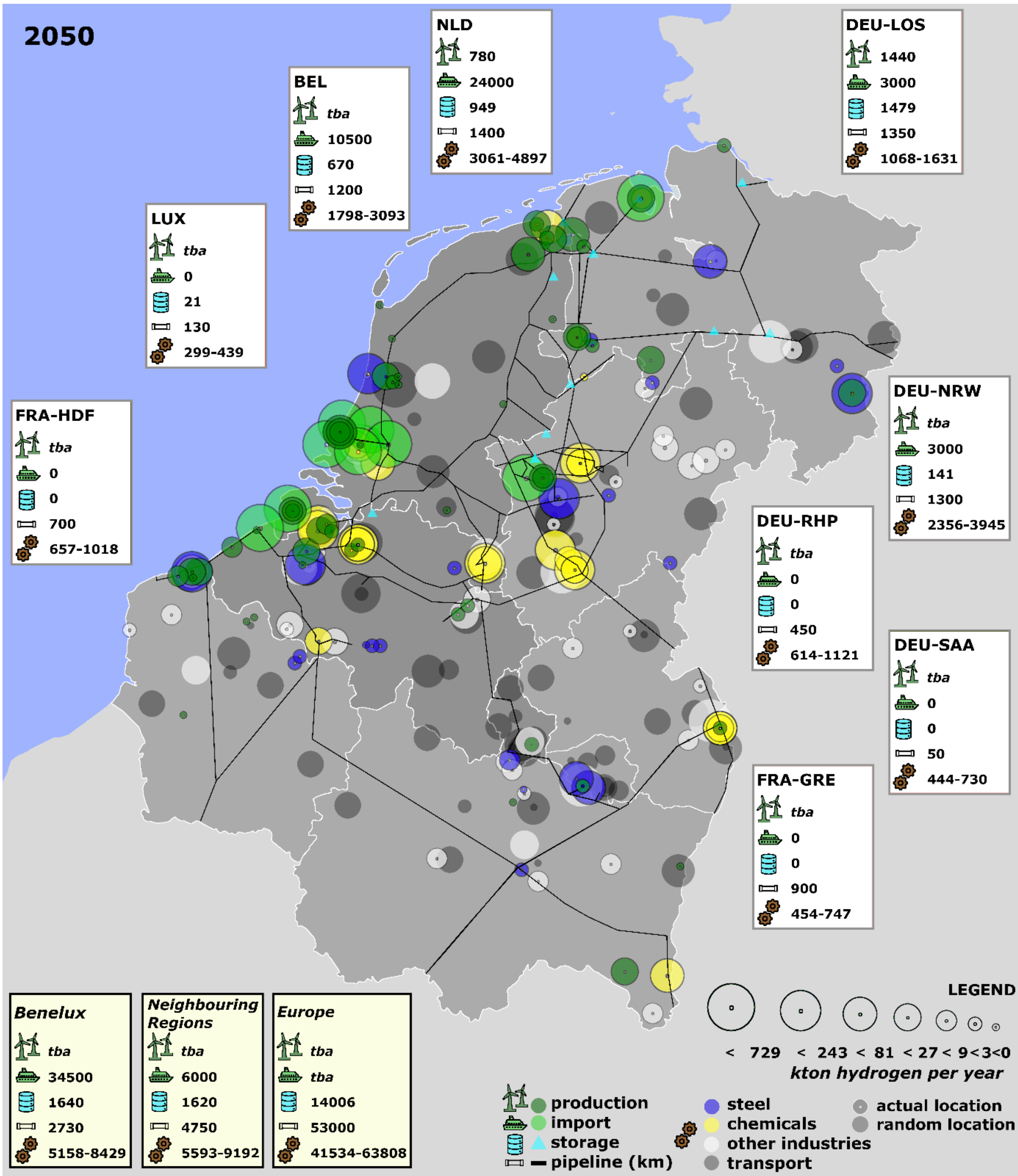


Figure 14: locations of hydrogen demand, supply, storage, pipelines in 2050 within the Benelux and its 6 neighbouring regions

# 3. TECHNOLOGY AND REGULATORY BARRIERS – STAKEHOLDERS' PERSPECTIVE

In order to verify the data presented in Chapter 2, and to discuss the technological and regulatory barriers with the stakeholders, six workshops were organised on the following themes:

1. Steel
2. Chemicals, refineries, cement, plastics and heat
3. Transport
4. Import, domestic production and seaports
5. Infrastructure and storage
6. Policy and regulations

In each workshop, several key stakeholders including governmental organizations, main industrial and transport actors, seaport authorities, federations and European/regional/national associations from the Benelux countries and the six neighbouring regions participated. The first five workshops concerned the main elements of the value chain (demand, supply and infrastructure). The workshop on policy and regulations was performed last as it builds upon all relevant barriers identified in the workshops 1 to 5 for implementation of hydrogen projects in the Benelux and its neighbouring regions. This workshops aimed, from a regulatory perspective, to define a favourable policy and regulatory framework to address technical and regulatory challenges and to foster collaboration among different stakeholders. Furthermore, in discussion with stakeholders, the role of the Benelux to support the implementation of hydrogen projects in the region and in Europe was discussed and clarified, which is presented in Chapter 4.

The main technological and regulatory challenges on the path of development of a hydrogen market in the Benelux and its neighbouring regions identified by stakeholders are gathered in 6 main categories.

1. *Research & development needs for hydrogen technologies*
2. *Hydrogen supply challenges through the entire value chain*
3. *European policy & regulation*
4. *Permitting procedures*
5. *Hydrogen refuelling infrastructure*
6. *Insufficient or absence of transnational coordination*

The rest of this Chapter is the description of these technological and regulatory challenges in each category.

## Research & development needs for hydrogen technologies

Europe so far has been the pioneer in many hydrogen technologies such as electrolysers, fuel cells, hydrogen engines, hydrogen boilers, etc. However, in the last couple of years, China and other Asian technology developers have become serious competitors to the European tech companies. In order to keep this position in Europe and remain competitive during the energy transition in the worldwide market, there is a need for more structured support on research and development (R&D) activities by the European Commission and the Member States.

During the workshops with the stakeholders, several technological challenges were identified that different sectors and industries are dealing with.

One topic that was shared by different end-users is to **remain technology neutral, i.e., using different clean hydrogen technologies (CC(U)S, pyrolysis, nuclear, etc.)**, especially between now and 2030, to enable the kick start of the hydrogen market and its consumption by industry before focusing on specific technologies. Many industries have different decarbonization pathways, in which hydrogen is one of the options. Hence, it would be beneficiary to allow flexibility in the use of different clean technologies to accelerate decarbonization of the industrial and transport sectors.

For the steel industry, there is a need for Research & Development (R&D) activities to **upscale hydrogen DRI (Direct Reduced Iron) technology** and other innovative steel production methods. DRI technologies are currently demonstrated and upscaled, but despite its level of maturity and the perception that R&D needs do not hamper the further implementation of the technology, there is still a need for R&D to develop better understanding of the effects of carbon-free metallurgic processing and better ways for carbonising direct reduced iron, to develop fossil-free agglomeration of the iron ore or the use of alternative iron oxides, carbon-free direct reduced iron melting and transport behaviour and adjustment needs of natural gas-based direct reduction towards increased hydrogen usage. Additional needs lay in the operations of the technology, such as defining the feasibility to link hydrogen production with the metallurgical process (e.g., demand, fluctuations in operation and hydrogen storage), developing economically feasible solutions for the use of oxygen as a by-product of electrolysis and providing risk assessment regarding hydrogen handling[4]. Other lower TRL technologies, like hydrogen plasma smelting reduction, alkaline iron electrolysis, molten oxide electrolysis requires **more dedicated research programmes to further improve the technology itself and to demonstrate it in a controlled environment** in order to further mature the technologies. In addition, steel upgrading through the increased use of scrap material deserves increased attention through R&D programmes.

For the transport sector, there are several challenges observed with regards to the deployment of hydrogen applications at scale. The deployment of hydrogen applications in this sector, whether these are trucks, cars, specialty vehicles, trains, waterborne or airborne applications, is limited and characterized by long lead and development times. The **scarcity of critical components is a concern** and calls for an increased awareness of the need to develop innovative components in the Benelux, supported by a skilled labour force and production and automation capacities for scaled production. This increases the possibilities to produce applications at scale. Transforming and tailoring existing production capabilities towards hydrogen requires different/additional competences in terms of

[4] https://www.estep.eu/assets/Uploads/210308-D1-2-Assessment-and-roadmapping-of-technologies-Publishable-version.pdf

organization of facilities, safety management, electrical drive line implementation, etc. As is currently observed, production facilities are organized towards developing vehicles with an electric driveline which would allow the production of and hence competition between battery electric and hydrogen electric applications. The demand for a large number of hydrogen vehicles foreseen through the uptake of hydrogen in the transport sector through RFNBOs requires the **preparation of vehicle production lines for the introduction of hydrogen applications at scale**.

The application of hydrogen in especially **waterborne and airborne applications require high gravimetric and volumetric storage solutions**. The application of high-pressure gaseous hydrogen storage solutions provides operational ranges that are much less than current practices. This can partially be overcome by changing refuelling habits (increase of frequency) and adopting an array of storage options (gaseous hydrogen, cryo-compressed hydrogen, liquid hydrogen, synthetic fuels) across the fleet that is tailored to the use cases. The current project portfolio of hydrogen applications in waterborne and airborne applications is mainly based on gaseous hydrogen storage solutions, which indicates that short ranged applications are currently targeted. To open up a significantly higher portion of the fleet for the use of hydrogen, **innovative hydrogen storage options must be developed**. The Strategic Research and Innovation Agenda[5] of the Clean Hydrogen Partnership shows great dedication towards developing liquid hydrogen and innovative hydrogen storage solutions. **Further R&D advancements in liquid hydrogen storage concepts and solutions** for waterborne and airborne applications are required to open up the direct hydrogen uptake in these sectors. Finding a suitable niche in these sectors for hydrogen is still open and sometimes undefined as these sectors are offered a variety of options to realise decarbonization, including sustainable aviation fuels, ammonia and methanol. The use of ammonia and methanol storage option will also require further R&D in system integration but less on the development of the storage solution itself.

**Hydrogen supply challenges – through the entire value chain**

Europe has high targets for the deployment of hydrogen in different sectors to be able to reach the climate goals and become carbon neutral by 2050. However, there are still many obstacles and challenges along the way regarding hydrogen supply for different sectors.

For end-users, the main challenge is related to the **availability of hydrogen in large amounts and at an affordable price**. The current energy crisis forces us to make the transition away from natural gas and coal towards hydrogen even faster than planned. The most important aspect, hence, is to have sufficient amounts of green hydrogen at cost-competitive prices available as soon as possible. This sense of urgency needs to be translated into the gas and hydrogen decarbonization package. The industrial sectors agree that a crucial point at this stage of the transition is the **prioritization of hard-to-abate industries** as first consumers of green hydrogen. The (limited) amounts of hydrogen should be allocated/sold based on tons of GHG (greenhouse gas) abated per ton of hydrogen used. Steel, chemicals and other hard-to-abate sectors would thus become prioritized.

During the workshops with different industrial sectors, it was stated that the unavailability of green hydrogen in large scale is of great concern to them. One option is to develop **temporary local production plants** at the industrial terrains until the market for green hydrogen is mature enough. However, until now, due to long permitting procedures, local green hydrogen production is not going as fast as it should. Next to local production, industrial and transport sectors expect more **flexibility in**

[5] https://www.clean-hydrogen.europa.eu/about-us/key-documents/strategic-research-and-innovation-agenda_en

**use of clean and low carbon hydrogen** next to green hydrogen, especially between now and 2030, until there is enough green hydrogen available for different end-users.

It is important to note that local green hydrogen production is considered next to use of hydrogen from the hydrogen backbone, which brings the end-users to another challenge related to **availability of hydrogen infrastructure**. According to the stakeholders, hydrogen infrastructure should follow this principle: connect the large industrial hydrogen consumers *first* to the backbone. This will lead to a kick-start of the hydrogen economy, which will then later be beneficial for all other hydrogen users as well. Considering the announced plans by TSOs, **the infrastructure development is still too much cost driven and too slow in its development**, while the industrial targets for decarbonisation should start today to make sure it will be achieved. Moreover, industrial sites are not always directly on the backbone route and concerns are geared towards the last miles connection with the site. The industrial stakeholders believe that this issue should be enforced by the backbone developers accountable for hydrogen supply, which can lead to creating responsibility for the gas transport companies to the industrial sites. Furthermore, most of the industrial sites are located near ports; hence, direct hydrogen shipments from ports to the sites could be an option, without a need to wait for the hydrogen backbone. Of course, this can only be the case if hydrogen import happens sooner than the development of the hydrogen backbone. Certification mechanisms such as guarantees of the origin as well as a certification of the quality/purity of hydrogen, can make this possible, as hydrogen quality for certain industries, such as steel, is of great importance.

Another challenge that is affecting different parts of the hydrogen value chain is the **large scale production of green hydrogen** and access to **large scale green electricity** for that matter. So far, the policy and regulations that are in place (e.g., Carbon Contracts for Differences, Hydrogen and Gas Market Decarbonisation Package, etc.) are not sufficient for, or even preventing, the production of green hydrogen in large scale. This issue is connected to availability of offshore and onshore wind and solar farms dedicated for hydrogen production in Europe, and specifically in the Benelux and its neighbouring regions. It is still unclear how much capacity can become available for green hydrogen production and the process of building new green electricity production plants (wind and solar farms) are not as fast as it is expected to be. On the other hand, the unclarity about **import of hydrogen and its derivatives** adds to these challenges. Of course, many Member States and seaports, including the ones in the Benelux and its neighbouring regions, have announced their plans for import of green hydrogen from the countries with cheap green electricity; however, the unclarity about the possible and available amount of import, the means of import (ships, pipeline, etc.), the form of import (gas or liquid hydrogen, ammonia, methanol, LOHC, etc.) and the regulation (guarantees of origin, certificates, etc.) that need to be in place makes it quite challenging to count on hydrogen import as a reliable source in the short term.

Development of **hydrogen transport infrastructure and storage** is another point of concern not only for end-users, as mentioned above, but also for hydrogen producers and seaports. In order to have a reliable hydrogen supply network, a well-established and well-connected hydrogen network across Europe, and in particular in the Benelux and its neighbouring regions, is needed. As shown in Chapter 2, many countries and regions rely on hydrogen import to meet their hydrogen demand between now and 2050. This requires a solid infrastructure, similar to what exists now for natural gas transport, to transport hydrogen from seaports and other production locations inland to the end-users within the Benelux and/or its neighbouring regions in Germany and France. Also, for large scale hydrogen production and import, storage infrastructure needs to be in place. As shown in Chapter 2 and in Annex

6.6, at this time, there are not many storage options available in the Benelux and its neighbouring regions, which raises a serious challenge, especially for long term, to have the required storage capacity available. Next to inland infrastructure and storage, offshore hydrogen production is facing similar challenges, as there is a need for establishing the hydrogen pipelines (or repurposing the existing offshore gas pipelines) as well as providing offshore storage facilities. No need to mention that beside all these, there is a great need for having enough capacity in the electricity grid for transport of green electricity to the hydrogen production plants. The gas TSOs are developing the hydrogen backbone onshore with proper coordination; however, the offshore electricity and hydrogen production coordination is missing to align the production plans for both electrons and molecules.

Finally, several important points pop out while different stakeholders work on the establishment of a connected hydrogen network in the Benelux and its neighbouring regions, such as

- System adaptation for hydrogen transport
- Choice of gas – hydrogen or hydrogen-based carriers
- Hydrogen quality standards

**In stakeholders' opinion, these issues need to be addressed both at technical and regulatory levels not only in each country and region but also at cross-border levels**. Every country has certain mechanisms in place. Planning and permitting needs to be aligned at cross-border level, the same for hydrogen quality (impurities) and hydrogen mix allowance.

**European Commission policy & regulation**

It is obvious that large scale hydrogen production and import have direct impact on its **production cost and its final price**. For the end-users, it is of great importance to have access to cost-competitive hydrogen and green products. Hence, if Europe cannot manage to provide the right regulatory tools and supporting schemes for hydrogen supply, there is a chance that investments move outside of Europe, for instance, to the USA or East Asia where such supporting schemes do exist. To this end, having a stable regulatory framework and cross-border harmonisation in Europe, and in particular in between the Benelux countries and its neighbouring regions is of great importance.

During the workshops, many concerns were raised by different stakeholders from the entire hydrogen value chain regarding the current European and national policy and regulations. The main discussion points are summarized in this Chapter.

The first challenge comes from the **Renewable Energy Directive (RED)** of the European Commission. According to the new targets, 50% of industry requires a transition to green hydrogen by 2030 (and 70% by 2035). This will help ramp up the sector and make hydrogen a key component of Europe's green energy strategy. However, it makes it quite challenging for the industries to achieve this target, especially for the Benelux, as the Renewable Energy Sources (RES) potential in this region is limited and will not be sufficient for green hydrogen production. That is why industrial stakeholders request more flexibility in the regulation, in the absence of sufficient amount of green hydrogen, to allow for clean hydrogen consumption too. Moreover, stakeholders request for flexibility in the use of RES from other EU countries for the local production of green hydrogen.

In the meantime, the **RED III voting of the European parliament in September 2022 has had a good effect**. In this voting, the additionality principle has become less stringent in the proposal, Power Purchase Agreement (PPA) for electrolysers over quarter year based has been added to the articles, and there is no more requirement for the electrolyser plants to use electricity produced from a new infrastructure without subsidies. These adjustments will certainly facilitate the production and supply of green hydrogen. Although the new changes in RED III is removing the limitations imposed by additionality but it also creates more competition for hydrogen consumption, due to increasing the targets for transport and other heavy $CO_2$ emitters in the industry, e.g. refineries and petrochemicals (renewable fuels of non-biological origin (RFNBO) at least 5.7% of all fuels by 2030, including 1.2% in the hard-to-abate maritime sector). **That is why prioritization of the hard-to-abate industries as first consumers of green hydrogen is of importance for these industries,** in part to also stimulate the development of the hydrogen backbone, otherwise they will face many difficulties to meet the required targets.

As confirmed by many stakeholders in the workshops, **additionality** is very complicated and restrictive. If companies/entities are going to invest in green hydrogen, they need clarity and central coordination. In the USA, China, or India the regulation is more flexible and therefore, is a more attractive investment option. The Inflation Reduction Act (IRA) issued by the USA provides clear instructions to subsidise clean hydrogen, without focusing on its colour, but instead focusing on its carbon footprint. Similar mechanisms to IRA is what stakeholders would like to see in Europe, and in the Benelux region, to accelerate the deployment of hydrogen in the industry and transport sectors.

For hydrogen refuelling station developers and operators, challenges are voiced with the mandatory implementation of hydrogen refuelling infrastructure in the road transport and shipping sector through the upcoming regulation on the **deployment of alternative fuels infrastructure (AFIR)**[6]. The draft AFIR passed the first reading stage of the European Parliament in October 2022. The main challenges that are perceived are the current lack of guidance on the minimum requirements regarding technical specifications for gaseous and liquid hydrogen refuelling stations that are used to guarantee interoperability. A standardization mandate[7] was issued to the European standardization organisations to develop standards containing technical specifications with a unified solution for:

- hydrogen refuelling points dispensing compressed (gaseous) hydrogen for heavy-duty vehicles by 31 December 2023
- hydrogen refuelling points dispensing liquefied hydrogen for heavy-duty vehicles by 31 December 2025
- compressed (gaseous) hydrogen refuelling points and bunkering for maritime and inland waterway hydrogen fuelled vessels by 31 December 2026
- liquid hydrogen refuelling points and bunkering for maritime and inland waterway hydrogen fuelled vessels by 31 December 2028

Besides a perceived lack of timely guidance for these specifications through the AFIR, there are also technological uncertainties as the industry itself is still in the process of defining its own specifications as to what and how high-capacity refuelling infrastructure should look like. There is currently a lack of available station hardware (refuelling components) that enables fast flow, high-capacity refuelling, a lack of harmonisation among truck developers about how the refuelling interfaces should look like, and a lack of mature hydrogen refuelling protocols (only on project level e.g., PRHYDE). Besides, the draft AFIR foresees the uptake of 700 bar gaseous and liquid hydrogen refuelling station at least, whereas the majority of the applications currently being demonstrated refuel hydrogen at 350 bar.

[6] https://www.europarl.europa.eu/doceo/document/TA-9-2022-0368_EN.pdf
[7] https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=606

Additional clarity on how hydrogen refuelling infrastructure can be implemented would be very beneficial in rolling out a consistent network of refuelling stations.

Another challenge that is raised concerns the targets set in the EU regulation for **$CO_2$ emission performance standards** for new heavy-duty vehicles[8]. In 2030, manufacturers will have to reduce their fleet-wide average $CO_2$ emissions of their new lorries registered by 30% percent in 2030. This requires zero-emission trucks to be introduced by that time. Operators of these trucks are concerned that they will face much a higher total cost of ownership in comparison to the state of the art. The challenge is to keep the transition towards zero emission trucks affordable with the right support mechanisms that orients towards the operators.

Another regulatory challenge is related to the **Carbon Contract for Differences (CCfD)** policy. Carbon Contracts are one way to minimize the future carbon price uncertainty. A Carbon Contract is a contract by which a government or institution agrees with an agent on a fixed carbon price over a given time period. During the contractually agreed period this agent can then sell any carbon emission reductions (or allowances) at that given price. If formulated as a strike price over a carbon market price (a two-sided option) then they become Carbon Contracts for Differences (CCfDs), as first proposed by Richstein (2017). If the market price is lower than the strike price, the agent receives the difference. If the market price is higher, the agent has to return the additional revenue to the government[9]. Although this mechanism provides certainty, it also affects hydrogen supply as the carbon price in EU is much higher than the USA or Asia.

Another challenging regulation is the **Hydrogen & Gas Market Decarbonization Package**[10]. Although this package is meant to provide supportive legislation for hydrogen production and development, there are still unclarities regarding the timelines, network planning, tariffs, blending allowance, etc. Stakeholders, including TSOs, believe that until 2030, it is important to have no, or limited restrictions put in place to kick start the hydrogen market. The market is going to be started under scarcity and the gas package needs to install mechanisms that can steer the uptake of hydrogen in the short term. Next to this, import of hydrogen derivatives (ammonia, methanol), as a means of transport may affect local job markets drastically, as the local production of ammonia or methanol will not be cost-competitive with the imported products. The relevant industries are concerned about these impacts and expect that there will be supporting regulations in place for the local market.

Other **supporting mechanisms such as H2Global**[11] are useful too, especially if they are supported at EU level. The initiative for establishing the **European Hydrogen Bank** sounds promising, but the concern is that it may not be in place soon enough to support the production of green hydrogen at large scale.

**Permitting procedure**

One of the common challenges that stakeholders are facing through the entire value chain and in all the Benelux countries as well as the neighbouring regions is the permitting procedure. **Accelerating**

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[8] https://climate.ec.europa.eu/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles/reducing-co2-emissions-heavy-duty-vehicles_en

[9] https://climatestrategies.org/wp-content/uploads/2021/03/Carbon-Contracts_CFMP-Policy-Brief-2020.pdf

[10] https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en

[11] https://www.h2-global.de/

**the development of cross-border infrastructure requires substantial simplification and shortening of planning and permitting procedures**. It was mentioned in all the workshops that the duration and process of permitting for different activities creates serious delays for the implementation of projects; These activities include, but not limited to, obtaining a permit for local electrolyser installations and hydrogen production, the permitting procedure for developing dedicated hydrogen network (both at regional and national level), and obtaining permits for developing wind and solar farms. Industrial stakeholders consider it necessary to have **more integrated permitting procedures among the Benelux countries, and possibly in alignment with the neighbouring regions**, as the existing differences in the procedure from one region or country to the other creates obstacles and delays in the implementation of cross-border projects.

Approval procedures for applications are mainly set at European level, however the challenge perceived is that there are knowledge gaps to apply these procedures for hydrogen applications. For instance, for hydrogen ships dedicated guidance documents provide at least minimum requirements and considerations for the approval process; however, such guiding documents and information are generally speaking hardly existing and best practices are only gained through experiences. In order to speed up homologation processes and address knowledge gaps, educational and training materials as well as exchange platforms for lessons learned are required to increase the competence level of approval organisations.

**Hydrogen Refuelling Infrastructure**

The challenges currently perceived by the stakeholders with the deployment of hydrogen refuel infrastructure for heavy applications (road transport, waterborne, airborne applications) is the lack of maturity in the development of hardware components and industry consensus on how interoperability criteria should be approached in a harmonised manner. The draft AFIR regulation foresees a roll out of at least 700 bar gaseous hydrogen and liquid hydrogen high-capacity refuelling infrastructure, whereas currently the applications that are being demonstrated are mainly 350 bar gaseous hydrogen applications that refuel at low capacity, low to medium flow hydrogen refuelling stations mainly designed for light vehicles. **The development and standardisation of refuelling components (connectors, dispensers, hoses, fittings), refuelling protocols and application interfaces (receptacles, vehicle system components) is currently progressing but is still at an early stage of development**. The experiences with liquid hydrogen refuelling station are hardly existing, but at least a liquid hydrogen infrastructure exists in the Benelux. Nowadays decisions have to be taken regarding the hydrogen refuelling structure specifications which makes it challenging without a clear view on how (cross-border) interoperability is achieved.

**Insufficient or absence of transnational coordination**

In the Benelux and its neighbouring regions in particular – spread over several provinces and countries – cross-border issues arise where hydrogen is produced, transported and consumed across-borders. Cross-border issues concern the transport and tradability of hydrogen, differences in procedures for issuing permits and subsidies, hydrogen quality, safety regulations, etc.

One important topic is the **development of a cross-border hydrogen infrastructure**. Every country has certain mechanisms in place, while planning and permitting needs to be aligned at cross-border level, as well as standards for hydrogen quality (impurities) and hydrogen mix allowance in the gas network. Moreover, construction of hydrogen pipelines has an important spatial aspect: connections of roads, rails and pipelines are usually constructed in the same corridor and there is by definition a scarcity of space there. **Several crucial connecting points for the hydrogen backbone** will be established between the Benelux and its neighbouring regions with a cross-border perspective. **It is important that the phasing of such connections on both sides of the borders is coordinated**. In that respect it is also important to strive for a level playing field with regard to subsidies in cross-border projects. Currently the synchronization between the timing of financing in the Benelux countries is not optimal, which delays projects.

To build cross-border hydrogen infrastructure, a **stable regulatory framework is needed**. The recent Hydrogen & Gas Market Decarbonization Package provides guidance, but the finalisation of the process and implementation in the Member States will not be done until 2024/2025. Hence, until then a flexible and practical regulatory framework is needed for the operation of the infrastructure and the third-party access, which addresses the issues regarding timelines, network planning, tariffs, blending allowance, etc. This can be done at the Benelux level in harmony with its neighbouring regions. Furthermore, **exchange and trading of Guarantees of Origins and green hydrogen certificates** can be started at the Benelux level but should be aligned with Germany and France, according to the stakeholders.

Another cross-border issue which needs to be integrated is $CO_2$ taxation. Currently, this is regulated differently in the Benelux countries and its neighbouring regions, which creates obstacles in the field of cross-border carbon capture and decrease of $CO_2$.

Development of **cross-border roadmaps, integrated regulations, harmonised funding and investment schemes** are crucial aspects from stakeholders’ perspective. For stakeholders in the Benelux and its neighbouring regions, it is important to make transportation of hydrogen between country A and B within the Benelux and its neighbouring regions as easy as possible, with as limited technical and regulatory barriers as possible. The stakeholders expect that in the near future, once the first shipment of hydrogen arrives at, for instance the Port of Rotterdam or the Port of Antwerp-Bruges, there exist no hurdles to transport hydrogen cross-border. Policy makers at different levels need to **anticipate the problems that can arise a priori** to have harmonised regulation for smooth hydrogen flow in the Benelux and its neighbouring regions.

# 4. ROLE OF THE BENELUX – STAKEHOLDERS' PERSPECTIVE

As mentioned in the previous chapter, during the organised workshop with key stakeholders from all parts of the hydrogen value chain, the possible role for the Benelux Union was identified and discussed. The stakeholders see many possibilities where the Benelux Union can play a facilitating role to bring more structure and harmony in the hydrogen development activities, not only among the Benelux countries themselves but also among the Benelux and its neighbouring regions. The implementation of national and regional hydrogen strategies in the area of production, infrastructure, transport, and sectors decarbonisation (industry, transport, power, heat, etc.) can significantly benefit from the development of overarching, cross-border implementation roadmaps in which topics of common interest are addressed.

A variety of topics of common interest have been identified which could benefit from, but not necessarily depend upon, a systematic, overarching framework or work plan in which these topics are addressed. These topics of common interest have different orientations and could include functions like monitoring, facilitation, specification and/or coordination to accelerate the cross-border implementation of hydrogen in different parts of the value chain. The main areas, in which the stakeholders have foreseen a role for the Benelux Union are,

1. *Integrated regulation for hydrogen production, import and transport within the Benelux and its neighbouring regions*
2. *Harmonisation of permitting rules, especially for hydrogen refuelling infrastructure*
3. *Geographical and time alignment of the development of hydrogen refuelling infrastructure*
4. *Harmonisation of technical specifications for hydrogen refuelling including interoperability*
5. *Common payment and certification systems for hydrogen refuelling*
6. *Promote/motivate exchange of information of lessons learned and use similar protocols*
7. *Harmonisation of approval/homologation requirements*
8. *Harmonisation of refuelling requirements for waterborne and airborne applications*
9. *Creating more competition instead of subsidies*
10. *Promoting new economic activities related to hydrogen development*
11. *Tailored regulatory framework for short-term period to kick-start the hydrogen market*
12. *Supporting mechanisms within the Benelux and its neighbouring regions*
13. *Education & economic activities*
14. *IP issues and patents regarding the new technologies*
15. *One voice towards influencing EU legislation and promoting the region*

These topics are elaborated upon in more detail in the rest of this chapter.

**Integrated regulation for hydrogen production, import and transport within the Benelux and its neighbouring regions**

This recommendation keeps coming back from different groups of stakeholders, which emphasizes its importance for the development of a hydrogen economy in the Benelux and its neighbouring region and the role that the Benelux Union could play in it. The stakeholders foresee a pioneering role for the Benelux Union to accelerate the establishment of the required regulations in alignment with the European Union.

From the stakeholders' perspective, **an integrated regulatory system for hydrogen in the Benelux and its neighbouring regions consists of** the following:

- Integrating hydrogen production and import regulations by recognising green hydrogen certificates, and allowing exchange and trade of GO's (guarantees of origin) in the region. This effort can be started on the Benelux level in alignment with Germany, where the largest projects are currently located.
- Integrating hydrogen pipeline networks and transnational connection and transport regulations by harmonizing the system requirements, safety protocols, standards, hydrogen quality and hydrogen mix allowance at cross-border level.

The Benelux Union can apply its legal instruments to create harmonisation and integration in the abovementioned areas. By kick-starting the development of an integrated regulation for hydrogen production, transport and import, **especially on specific cross-border corridors** within the Benelux and its neighbouring regions, not only the development of the hydrogen market will be accelerated in the region but also the Benelux and its neighbouring regions will become a pioneer in the development of an integrated hydrogen market within EU, which can be followed by other Member States as one of the best practices.

Further, the **Benelux Union can promote and facilitate** regular dialogues between different stakeholders within the hydrogen value chain (e.g., gas TSOs, port authorities, industries, etc.) and the Benelux authorities, which can result in fostering pilot projects on concrete cross-border connections. This can be done, for instance, via organizing yearly conferences and workshops. These activities will additionally promote closer collaboration between different stakeholders within the Benelux and its neighbouring regions.

**Harmonization of permitting rules, especially for hydrogen refuelling infrastructure**

One of the main issues that different stakeholders are dealing with is **the long process to obtain permits for different activities**, including but not limited to, developing wind and solar farms, developing electrolyser plants for hydrogen production, building hydrogen refuelling stations, developing hydrogen backbone, etc.

As such, although from the national and regional governments' point of view the permitting procedure is within their jurisdiction, the industrial stakeholders would really appreciate if there were a **harmonized permitting procedure in place at the Benelux level**. This is especially important for the cross-border projects when they need to develop different infrastructure in different regions and countries. The current permitting system and the existing differences between different regions and countries have created noticeable delays and obstacles for the implementation of these projects.

Hence, **the stakeholders foresee the following roles for the Benelux Union regarding the permitting procedures**:

- Speed-up permitting process in the Benelux and its neighbouring regions to increase renewable energy production and electrolyser plant capacity
- Maximise harmonisation possibilities of permitting rules within the Benelux and its neighbouring regions

Even though the Benelux Union may not be able to oblige its member states and the neighbouring regions to have uniform permitting procedures, it is still of importance that they provide strong recommendations and facilitate the process by any means possible. This could be seen as short-term and temporary exemptions for issuing permits for certain developments by the Benelux Union to accelerate the deployment of green electricity and green hydrogen production in the region.

At the European level, there has been some activities recently to solve the permitting issues. In November 2022, **the European Commission drew up new emergency measures to speed up the realization of renewable energy projects**. For example, the permit procedure for solar panels on roofs must be shortened to one month and for large wind farms to six months. Although this is a desirable decision by itself to further accelerate development of renewable production projects, renewable energy companies complain that this only concerns new projects for which no permits have yet been applied. As a result, projects that are already in the pipeline risk not benefiting from it. According to the sector, this could involve **hundreds of gigawatts of solar and wind projects that cannot be accelerated** through administrative procedures. Representatives of the solar and wind energy sectors are therefore also asking for an accelerated procedure for projects that are already in the pipeline. Next to the energy companies, environmental organizations have also criticized the plans, as they fear that within these fast tracks, there will not be sufficient respect for nature conservation laws.

Next to issues for permitting procedure of renewable production and hydrogen infrastructure projects, development of hydrogen fuelling stations also suffers from these issues. **For hydrogen fuelling stations, in particular,** permitting is predominantly a national activity; however, from stakeholders' point of view, there is a significant opportunity for harmonisation of underlying assumptions, scenarios, safety distances and procedures at the Benelux level in alignment with the neighbouring regions. The **approaches towards permitting are currently heavily fragmented** across the Benelux countries and the neighbouring regions. As such, deploying the same hydrogen refuelling infrastructure across countries can result in differences regarding how refuelling infrastructure equipment is perceived against other refuelling equipment and its surroundings, which can lead to the same equipment being accepted or rejected across areas of jurisdiction. Therefore, in order to create an equal level playing field across countries and regions, it should be considered to apply fixed safety distances for hydrogen refuelling equipment. **Experiences from the permitting of existing hydrogen refuelling sites across the Benelux show that there are not insurmountable differences in approaches and methods**. However, permitting of hydrogen refuelling infrastructure for high-capacity stations (order of magnitude of tonnes per day), which are typically needed for heavy-duty, maritime, aviation and rail applications, is relatively new and could present new barriers for implementation.

The **suggested starting point of a harmonised approach towards permitting** should be to arrive at fixed safety distances for the most common (reference) classes of hydrogen refuelling infrastructure options. To embark on such a trajectory, the framework of underlying assumptions regarding failure frequencies and hydrogen release scenarios relevant for the (quantitative) risk assessment would need to be consented upon at the Benelux level together with its neighbouring regions and ideally at European level. In additional, the need for additional documentation required during the permitting process (e.g., environmental impact, noise, protection, soil reports etc.) could also be harmonised. Permitting procedures are slightly different across countries and regions, however, the foreseen time to permit is relatively similar (approximately 6 months). Harmonising these requirements could also significantly shorten the time to permit as delay do often happen due to the submission of incomplete permitting dossiers and lack of specific knowledge and guidelines at permitting authorities. Upfront transparency at the Benelux level, and preferably in alignment with its neighbouring regions, regarding these requirements could be key in achieving a synchronized planning of hydrogen refuelling infrastructure development. New hydrogen refuelling concepts as being developed, e.g., for maritime and aviation, require a similar but more careful approach towards harmonisation as limited experiences exist in applying these methods. That, however, provides also **opportunities towards developing a harmonised approach** already now and update approaches collectively as experiences are gathered over time. In this way, the Benelux can become a frontrunner and a pilot area for a harmonised implementation of high-capacity hydrogen refuelling infrastructure. The permitting approaches applied in the Benelux and its neighbouring regions show that especially Germany has a different approach towards the determination of safety distances which may make the harmonisation of fixed safety distances challenging, but not undoable. Historically, Germany has led the way in setting the scene for establishing permitting requirements for light duty hydrogen refuelling stations and hence the timing is now right to develop a common approach in which the neighbouring regions could lead the way towards harmonisation with the Benelux and French regions.

Another, rather interesting, perspective towards permitting is provided by Europe in its effort to shorten the permitting process time through **the (temporary) promotion fast track permitting routes based on classifications of critical energy infrastructures** to reduce its foreign dependency on (predominantly Russian) fuels. Regardless of whether hydrogen refuelling infrastructure could be considered under this framework, having a transparent and standardised approach towards permitting could reduce the time to permit to 4 months. Time gains can be obtained during the assessment of the submitted permitting dossiers by permitting authorities. Experiences from permitting processes for existing hydrogen refuelling stations show that knowledge transfer within and among stakeholders involved in the process is difficult to achieve. As such, the Benelux could develop and provide harmonised means for education and training for officials involved in the permitting process.

**Geographical and time alignment of the development of hydrogen refuelling infrastructure**

According to the stakeholders, a strategic geographical and time planning for the development of hydrogen refuelling infrastructure for all modes of transportation is currently missing at national and regional level, and hence, alignment and synchronisation of cross-border hydrogen refuelling infrastructure development is not taking place. It is often implicitly assumed that the quantitative targets set in the Member States provide for a sufficiently dense coverage of refuelling infrastructure in its jurisdiction and near-border areas. Whereas the development of hydrogen refuelling infrastructure is currently limited in the Benelux and its neighbouring regions and has mainly focussed on facilitating passenger vehicles, speciality vehicles and return-to-base applications, its (further) development towards facilitating applications that rely on cross-border hydrogen refuelling (heavy-duty road transportation, maritime, aviation and to a lesser extent rail) is considered imminent and urgent. **A cross-border alignment of the geographical development and planning of a connected**

**network of hydrogen refuelling infrastructures for all modes of transport is therefore necessary** and can only be addressed at the Benelux level and/or with the neighbouring regions.

**The geographical alignment could be supported by traffic data analysis and modelling, sales figures of alternative fuels at forecourts and logistic hubs, operator preferences, site implementation and business case assessments** in order to determine key locations for hosting hydrogen refuelling infrastructure. It could well be considered that existing insights into the development of alternative fuels refuelling infrastructure for road transport can be used as a starting point for the geographical alignment. For maritime however, among the refuelling methods envisaged for the shorter to medium term (swapping vs non-swapping) are methods that are fundamentally different from the traditional way inland shipping is being bunkered. Hence, geographical alignment of hydrogen refuelling infrastructure for the maritime sector may therefore require the assessment of new hydrogen refuelling/replenishing sites. Existing knowledge within consortia (e.g., H2Rhine) regarding the development of hydrogen refuelling infrastructure should be tapped into in order to support the development of the strategic geographical roll-out of such infrastructures. For aviation and rail, the geographical planning of infrastructure is less challenging as potential sites or locations are well known. The time alignment of the synchronised realisation of hydrogen refuelling infrastructure is also key as these developments are currently characterised by significant delays. Applying (harmonised) conditions to enforce timely deployment could be considered in areas of jurisdiction of the Member State and could relate to prerequisites regarding permitting, budgeting and investment decisions.

**Harmonisation of technical specifications for hydrogen refuelling including interoperability**

The European Union, through the adoption of the Alternative Fuel Infrastructure Directive (AFID), has taken an early lead in defining **minimum technical specifications for hydrogen refuelling infrastructure** to ensure its interoperability with hydrogen road vehicles across Europe. In the beginning, a significant degree of animosity was voiced by hydrogen refuelling station operators as few of the standards referenced to in the AFID were outdated or obsolete. **The process of introducing Delegated Acts to accommodate changes to the technical specifications turned out to be cumbersome and lengthy**. Hence, using EU Delegated Acts (e.g., delegated regulation 2018/674 and 2019/1745) did not provide enough flexible means as was required by industry to adapt the technical specifications to the latest state-of-the-art. In the draft proposal from the European Commission, as the follow-up regulation of the AFID, the AFIR, a similar approach is taken by defining minimum technical requirements in a technical annex related to the hydrogen refuelling station itself, the quality of hydrogen it dispenses, the refuelling algorithms it applies and the connectors (nozzle and receptacles) it uses. Whereas the AFID was mainly oriented at light hydrogen vehicles, the AFIR shows its commitment to heavy-duty hydrogen vehicles. However, the technical standards that are referred to in the draft AFIR mainly refer to international or European standards that were used as baseline for the AFID and hence orient to gaseous hydrogen refuelling for light vehicles. For road transport applications, the AFIR refers to gaseous hydrogen refuelling for light vehicles and heavy-duty vehicles as well as liquid hydrogen refuelling for heavy-duty vehicles. In its current version, the segregation of referencing to different standards to accommodate these different refuelling options, is only recognised for the connectors. While valid, this segregation may also need to be applied to the general requirements for the hydrogen refuelling stations and refuelling algorithms. In its current draft version of the AFIR, reference is made to non-existing (refuelling station itself), out-of-scope standards (algorithms, ISO 19980-1 is designed for light duty refuelling stations and serves only as a guidance document for heavy-duty refuelling stations) and it is an open questions whether the industry has found a compromise for refuelling pressure (350 vs 700 bar) and hydrogen quality specifications (high purity for fuel cells or medium purity for combustion). **Standardisation efforts are currently ongoing** to define refuelling algorithms for high flow gaseous hydrogen dispensing, to update specifications for hydrogen connectors and efforts may need to be undertaken to review the specifications of high capacity gaseous and liquid hydrogen refuelling stations for heavy-duty applications. The AFIR leaves the technical specifications open for connectors for heavy-duty vehicles receiving gaseous or liquid hydrogen as standards currently do not exists. The standardisation mandate M/581 is partially addressing the abovementioned concerns as it requests the European standardisation organisations to develop European standards for general requirements for gaseous and liquid hydrogen refuelling stations and its connectors to be adopted by respectively 31 December 2023 and 2025. It is specifically mentioned that the state-of-art for dispensing hydrogen to light vehicles (EN ISO 17268 and EN 17127) is taken as a basis for developing specifications for gaseous hydrogen refuelling stations for heavy-duty applications.

It is possible that once introduced as EU regulation, updates of the technical specifications in view of the progressing state-of-art and the standardisation mandate are imminent and the updates through Delegate Acts long, despite the Parliament urging the Commission to have changes implemented maximum 6 months after the European standard is adopted. **This may create an impetus for heavy-duty hydrogen refuelling stations that are currently being designed**, ordered or build. However, in case the required changes cannot be implemented quickly enough at the European level, the Benelux Union can step in to accelerate the process.

Stakeholders believe that the **Benelux Union has a unique opportunity to use its legislative framework** to provide the heavy-duty transport sector clarity early on how it perceives the uniform uptake of technical specifications and standards for heavy-duty hydrogen refuelling infrastructure. This may even go beyond the interoperability areas highlighted by the AFIR (general requirements, hydrogen quality, refuelling algorithms and connectors), e.g., metering or uniform payments systems. **This should go hand-in-hand with the neighbouring regions of Germany and France** as these countries are currently also very active in rolling out heavy-duty hydrogen refuelling infrastructure. As such, the Benelux could then provide the European Union guidance with its experiences in setting technical specifications or guidance for the heavy-duty sector and assist the Member States with uniformity in adopting implementation guidelines. Member States and neighbouring regions may consider providing implementation guidelines on these technical specifications on their own, but its impact would clearly be less effective considering the cross-border nature of the applications.

The draft AFIR also mentions the technical specifications for hydrogen bunkering for maritime transport and inland navigation, but these will be addressed in the upcoming section on shipping. Also in this area, the Benelux has a clear opportunity to lead the way by using its legislative framework to provide the shipping sector clarity early on how it perceives the uniform uptake of technical specifications and standards for hydrogen bunkering infrastructure.

**<u>Common payment and certification systems for hydrogen refuelling</u>**

The early deployment of hydrogen refuelling infrastructure was mainly characterised by the use of operator specific fuel cards to enable payments. With the increased roll-out of hydrogen refuelling infrastructure, the array of payment methods at individual refuelling stations has increased, allowing payments with the use of bank, credit and fuel cards. It is however noticed that not all hydrogen refuelling stations provide this flexibility and that there is a trend to move towards stand-alone payment solutions due to complications with dispenser certification, metering and arrangements with payment system providers. **It is critical that uniform and common payments systems exist that enable customers with refuelling opportunities on an ad-hoc basis in order to create a true public hydrogen refuelling station network**. One of the new elements of the AFIR, in comparison to the AFID, is the requirement that *operators of hydrogen refuelling stations shall ensure that all hydrogen refuelling stations operated by them accept electronic payments through terminals and devices used for payment services, including at least payment card readers or contactless devices that are able to read payment cards.* This requires the certification of hydrogen dispensers based on a verification of accuracy of hydrogen metering equipment (OIML R139). While the certification of hydrogen dispensers is currently taking place in the Netherlands through approvals of dispensers and verification tests at the refuelling site, the lack of availability of test equipment and optimised test set-ups have caused animosity between regulators and operators. In Germany, an optimised system is in place for certification of dispensers however payments are only made through fuel cards and do not allow payments with bank cards. In Belgium, a certification system for hydrogen dispensers is not yet in place, but payments can be made with bank and fuel cards. In France, a certification system for hydrogen dispensers is in place, but payment can only be done with fuel cards. Cross-border refuelling is perceived challenging due to unclarity of how payments are expected to be made. Additionally, the lack of suitable measurement equipment for certification and recalibration of hydrogen dispensers for heavy-duty hydrogen refuelling is a big concern.

Considering the upcoming AFIR requirement at EU level and the challenges that currently exists for certification and payments, **the Benelux region is in a unique position to serve as a pilot region for the harmonised introduction of certification and payments systems, according to the stakeholders**. A common Benelux approach towards uniform certification and payment systems that is aligned with approaches from adjacent German and France regions would provide an example for Europe how cross-border uniformity can be achieved. Similar to alignment for interoperability specifications, uniformity cannot be created standalone and hence it is very clear that the Benelux Union together with the neighbouring regions can give practical means as an example to Europe and the Member States on how to create uniformity for certification and payment systems.

**<u>Promote/motivate exchange of information of lessons learned and use similar protocols</u>**

In an upcoming market, characterised by limited practical and operational experiences of how to deploy hydrogen refuelling infrastructure and vehicles, especially in view of the high capacity gaseous and liquid hydrogen refuelling stations and heavy-duty vehicles that are being expected, **information exchange on best practices and lessons learned can be very useful to increase the knowledge level of all stakeholders involved in the deployment of this infrastructure**. Generally speaking, cross-border exchange of information is happening mainly on an ad-hoc and functional basis but not systematically using similar formats and protocols. Member States do organise information exchange platforms and events on sharing of lessons learned in order to improve the state- of-art and seem open to exchange this information with neighbouring countries and among hydrogen (mobility) platforms on international fora, however a systematic, bottom-up exchange through a cross-border platform, for example through an H2Mobility or H2Transport Benelux platform, does not exist. The Benelux Hydrogen Working Group however facilitates information exchanges among Ministerial representatives on matters related to, for example, (EU) legislation.

The creation of an **H2Mobility or H2Transport Benelux platform** consisting of key industrial stakeholders (HRS operators and hydrogen application providers) and policy makers could provide means to facilitate the sharing of lessons learned and provide a key recommendation to policy makers and regulatory authorities. The information exchanged could among others range from lessons learnt on permitting, operational complexities, applying business models, harmonisation of certification and payment systems and interoperability requirements.

**Harmonisation of approval/homologation requirements**

Application approval processes are a necessity to put applications into operation. Applications going through one-off, or type-approval processes require experienced organisations to conform compliance with applicable regulations. Although compliance regulations are mainly set on European level, the application of these regulations requires dedicated expertise in applying them for innovative applications, like hydrogen. Hence, gaps may exist along the process that can be filled through experience or associations providing practical implementation guidelines. Organisations that went through the approval process gain experience in applying these regulations and making them suit for the application considered. This may lead organisations to use experienced approval organisations over organisations that have to build up this experience. As an example, it has been witnessed that some manufacturers choose to have an application approved through a country with a higher expertise level than the country in which the application is supposed to be operated in, and once completed apply for fast-track approval route with a limited set of additional tests to get it approved for operation in the designated country of operation, instead of going directly through an approval route in the country of operation. **It would be of interest that all requirements for the approval process are harmonised in the Benelux and that best practices are shared across countries**. This holds for trucks, speciality vehicles, trains and also waterborne applications. The Benelux Union has an opportunity to provide a level playing field for approval requirements for applications, share information on lessons learned and good practises through educational materials.

**Harmonisation of refuelling requirements for waterborne and airborne applications**

Although the refuelling of light vehicles is slowly maturing and the refuelling framework for medium- and heavy-duty trucks is in preparation, hydrogen refuelling of waterborne and airborne applications, which require refuelling conditions that are significantly different from what is currently the state-of-art, is currently undefined. However, in the draft AFIR, the European Parliament makes its intention clear that it requires the deployment of hydrogen refuelling stations at the TEN-T core maritime ports. Hence, the standardisation mandate M/581 requests European standardisation organisations to **develop European standards that contain technical specifications for gaseous and liquid hydrogen refuelling points for maritime and inland waterway hydrogen fuelled vessels** by 2026 and 2028 respectively. While the deployment of hydrogen in the waterborne applications with ditto refuelling infrastructure is commencing, there is a void to be filled for hydrogen refuelling infrastructure that will not be covered soon by standards. Leading consortia, like the H2Rhine consortium, have identified legislative gaps that provide barriers for hydrogen implementation for waterborne applications and gaps for bunkering of hydrogen fuels. The gaps it identifies for hydrogen bunkering include the lack of standards, procedures and checklists for bunkering, lack of rules for the shipside of the bunkering process, a missing EU wide harmonised risk assessment approach for small scale establishments and bunkering activities (e.g. truck-to-ship and ship-to-ship bunkering), missing indicators for determining common operational safety distances for hydrogen bunkering and requirements for simultaneously bunkering, (un)loading of passenger and (dis)embarking processes.

From the stakeholders' perspective, the Benelux Union is ideally positioned to develop together with leading consortia like H2Rhine, guidelines and lessons learned from best practices on the refuelling of hydrogen for waterborne applications. This is extremely relevant as the development and introduction of European standards is not foreseen soon. It would not be recommended that Member States themselves develop guidelines as this is a typical cross-border activity in which the Benelux and its neighbouring countries are very strong at. It could well be envisaged that this is an integral part of the H2Transport Benelux platform. The Benelux Union and its neighbouring regions can take a leading role and sample setter for Europe.

**Creating more competition instead of subsidies for roll out of hydrogen refuelling stations**

The transition towards zero-emission transport is characterised by higher upfront costs, which requires additional means of funding to enable shorter-term investments in innovative technologies. Subsidies are a means to decrease the TCO of these applications. In order to open up markets, providing subsidies is a means to do so, but care should be given to the way in which these subsidies are provided. **Stakeholders expect support schemes to become less subsidy intensive and more competition oriented as the market evolves**. Demand-led support schemes may create competition among technology suppliers to standardise products and bring down costs, whereas public authorities may exercise their authority to specify in their future concessions for refuelling forecourts the need to deploy hydrogen refuelling infrastructure. Competition can then be created among bidders for these concessions to actively contribute to the roll out of a hydrogen refuelling network without requiring subsidy schemes. Members States can learn from each other's support practices on how to stimulate the roll out of refuelling infrastructure and deployment of hydrogen applications in a cost-effective manner. Member States are themselves in the lead in which support schemes they want to apply and which transition in type of instruments they foresee. **The Benelux Union can facilitate information exchange among public authorities**, e.g., through the Benelux Hydrogen Working Group, regarding ideas that facilitate creating a more competition-oriented support package.

**Promoting new economic activities related to hydrogen development**

Maturing the hydrogen value chain provide lots of opportunities for new or renewed business development. The Benelux takes currently a leadership role in the development and deployment of transport activities related to, e.g., hydrogen combustion engines, application of hydrogen in the heavy-duty sector and waterborne applications. **Strengthening economic activities in the Benelux and neighbouring regions** is important for the stakeholders, not only to keep this area at the forefront of the innovative radar but also to enable the development of trained and educated (young) professionals. The Benelux Union could stimulate the development of economic activities with a strong cross-border dimension. For example, one of the options considered to refuel hydrogen in waterborne applications is swapping of standardised gaseous or liquid hydrogen fuel containers. These containers need to be standardised in terms of interfaces and methods for refuelling and hoisting. Also, locations need to be developed in which these containers are stored and transferred. The application of container swapping opens us new business opportunities as the business model is very new to the sector. Such opportunities are well suited to be developed in the Benelux and its neighbouring regions as the majority of the demand for hydrogen may stem from this region for this activity. The Benelux

Union may therefore consider working together in facilitating the further development of innovative concepts and economic activities with a clear cross-border dimension that may strengthen the region.

**Tailored regulatory framework for short-term period to kick-start the hydrogen market**

One of the key issues mentioned by stakeholders, especially the end-users, is **the lack of availability of green hydrogen at large scale in the near future**. Energy crisis forces us to make the transition away from natural gas/coal towards hydrogen even faster. The most important thing is that there are sufficient amounts of green hydrogen at cost-competitive prices available as soon as possible. This sense of urgency needs to be translated into the EU gas and hydrogen decarbonization package.

**According to the stakeholders, the current regional and national legal instruments are not yet sufficient to meet the demand**. At the European level, too, the establishment of the required and supporting regulations takes a long time and is not aligned with the deadline the industry has to decarbonize. Furthermore, regulations under development such as the RED II (including additionality) and RED III, and Hydrogen & Gas Package are still work in progress and very unclear, complicated, stiff such that they create more barriers for the deployment of green hydrogen than supporting it. Furthermore, the end-users say although recent RED III voting of parliament has had a good effect and is removing the limitations imposed by additionality, **it creates more competitors for hydrogen consumption**, due to increasing the targets for transport and other heavy $CO_2$ emitters in industry, e.g., refineries and petrochemicals.

Hence, the hard-to-abate industrial stakeholders (e.g., steel, chemical, etc.), followed by the transport sector, demand for prioritization in the use of green hydrogen. The (limited) amounts of hydrogen should be allocated/sold based on tons of GHG abated per ton of hydrogen used. Steel, chemical and other hard-to-abate sectors would thus become prioritized. Although it is important to consider all sectors equally, but due to scarcity of supply of green hydrogen at this moment (and most probably also in the years before 2030), the hard-to-abate industries and transport sector will not be able to achieve their goals if there is no prioritisation in place. This is while the other sectors such as built environment or power can use alternative solutions for decarbonization in the meantime until green hydrogen become available in large scale.

Hence, the stakeholders believes that **the Benelux Union can play different roles in this phase of transition to kick-start hydrogen market in the Benelux and its neighbouring regions**. The concrete areas where stakeholders foresee a role for the Benelux Union are:

- Offering exemptions for hydrogen supply for hard-to-abate industries, without focusing on the colour, but instead on carbon-footprint
- Allowing the use of clean hydrogen until 2030, where there is no other decarbonization options or enough green hydrogen available
- Gradual transition from grey to green hydrogen by allowing more flexibility in the regulation related to hydrogen certification and GOs - no strict rules from the beginning as this market is going to be started under scarcity
- For cross-border transport of hydrogen, the Benelux Union can set basic standards as a practical example for the rest of EU
- Promoting technology neutrality, at least in the short term, to support different transition paths of the industries

**The Benelux and its neighbouring regions host 30-40% of the EU industrial clusters**, so they can be the frontrunner in creating an example for the rest of the EU by legislations the Benelux Union and its neighbouring regional authorities are going to put in place.

**Supporting mechanisms within the Benelux and its neighbouring regions**

The recent **Inflation Reduction Act in the US has upended hydrogen economics**, making "green" hydrogen — electrolyzed from renewable electricity and water — suddenly cost-competitive with its natural gas-derived counterpart. The Inflation Reduction Act offers a 10-year production tax credit for "clean hydrogen" production facilities. Incentives begin at $0.60/kg for hydrogen produced in a manner that captures slightly more than half of SMR process carbon emissions, assuming workforce development and wage requirements are met. The production tax credit's (PTC) value rises to $1.00/kg with higher carbon capture rates before jumping to $3.00/kg for hydrogen produced with nearly no emissions.

The **energy transition in the end is all about cost-effectiveness**. The Inflation Reduction Act offers great opportunities for the production of cost-effective clean hydrogen in the US, which can be seen as a threat to the hydrogen producers and industries within Europe. Investments in energy intensive industries will be shifting abroad; for example: green ore — production may be moved to the US because it is subsidized there and will then be imported back to Europe.

Stakeholders believe that the **EU should as well speed up with providing similar supporting schemes**. The current funding schemes in EU have enormous administrative issues right now. To be able to remain competitive with the US and not to lose the investments and production opportunities within Europe, the stakeholders are calling out the Benelux Union for support. The **several areas in which stakeholders believe that the Benelux Union, as a pioneer or complementary to the European Union, can play a role** are:

- Providing subsidy schemes that are based on $CO_2$ footprint, which is more important than the colour. This will solve the issue of co-produced hydrogen, which is not yet regulated.
- Using IRA as an example to provide clear tax funding scheme – simple and effective
- For supporting methods such as single buyer-H2global, The Benelux Union can be the voice to the EU to accelerate the process. Already in REPowerEU, within the hydrogen accelerator measures, the European Commission proposes[12] to establish a global European hydrogen facility to create investment security and business opportunities for European and global renewable hydrogen production.

Europe, and specifically the Benelux and its neighbouring regions, has been so far pioneer in different aspects of hydrogen development, from technology development to establishment of European hydrogen backbone and import schemes from different countries across the globe. Hence, **it is important not to lose this position because of lacking the right supporting schemes to incentivize the industries and investors to continue their greening activities within Europe**. The Benelux Union can play a crucial role here to be the voice of the stakeholders to EU Commission and to kick-start the establishment of the right tools and supporting mechanisms in the Benelux and its neighbouring regions, as an example for the rest of Europe.

[12] https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en

**Promoting education & training programs**

As mentioned before, the Benelux and its neighbouring regions are playing a major role in the hydrogen economy of the EU. Not only about half of the hydrogen demand comes from this region, but also the main hydrogen import locations, a significant part of hydrogen backbone, and many pioneering hydrogen technology developers are from this region.

All these new developments offer opportunities for the creation of new economic activities and new jobs, for which skilled and specialized labour work is needed. **To provide more integrity and harmonization in educating the labour force and developing the required skills, stakeholders suggested that the Benelux Union take a leading role** in

- Stimulating the development and implementation of education programs to have skilled labour force
- Providing diplomas and certificates that are accepted and recognized across the Benelux region

These activities can be aligned with the regional and national education programs, but then in a more coordinated and harmonized way. Having a labour force with skills that are accepted in the Benelux region make their mobility much easier and the different regions will not suffer from lack of the right labour force.

**IP issues and patents regarding the new technologies**

One of the challenges that the innovative technology developers are facing is with issuing IP (Intellectual Property) rights and patents both in terms of duration and cost of the process. The Benelux Parliament has mentioned in its recommendation[13] on hydrogen to **support and award patents to innovative companies** in order to promote and facilitate development of a common strategy for the protection of the intellectual property rights related to hydrogen in the Benelux countries.

It is proposed by stakeholders to receive support in this area from the Benelux Union to explore and facilitate fast track procedures for issuing IP rights and patents.

**One voice towards influencing EU legislation and promoting the region**

Each regional and national government with the Benelux and its neighbouring regions is already well-represented at the EU. However, to **increase the visibility for different hydrogen developments in the Benelux and its neighbouring regions, especially for the cross-border projects**, the Benelux Union can be the voice of the region towards the EU. To this end, stakeholders foresee the following roles for the Benelux Union:

- Continuously indicating the importance of the Benelux and its neighbouring regions for hydrogen developments, both historically (large chemical and steel industries), and now (hydrogen import via seaports, hydrogen backbone, dense transport sector)
- Creating more visibility for the region in Europe and attracting more resources and funding to the region

[13] https://www.beneluxparl.eu/wp-content/uploads/2022/06/BNL935-1.pdf

# 5. ROADMAP & RECOMMENDATIONS

The Benelux countries and the neighbouring regions in France and Germany are historically main users of (grey) hydrogen in Europe. As shown in Chapter 2, there is a large (green) hydrogen demand in the future too to both replace the grey hydrogen in the current market and to decarbonize the industry and transport sectors, mainly, by replacing natural gas and other fossil fuels. Hence, the Benelux Union can play an important role to become a European pioneer in developing the hydrogen market and facilitating it by setting the required actions, policy and regulations in place. The European Union is ultimately the level at which many of the regulations and standardisations should take place; however, the process is often considered slow and does not seem to progress at the expected and required speed. So, the question is whether the Benelux and its neighbouring regions can afford to wait for the European Union or can the Benelux Union together with its neighbouring regions do something momentous beforehand. If actions are taken at the Benelux level, it can also give directions to ongoing or upcoming actions at EU level.

In this final chapter of the report, we, as WaterstofNet, provide a set of recommendations for policy makers in the Benelux Union. *These recommendations are formulated based on the discussions with stakeholders, the Benelux Secretariat and the Benelux Hydrogen Working Group*.

Reading guide:

✓ : already happening, ✓ : recommendation, ✗: little/no direct impact

The table below summarizes the possible roles for the governments and policy makers at different levels (regional, national, the Benelux and EU). The **blue tick** is the current situation, while the **green tick** is what is proposed based on the stakeholders' expectations and based on what we believe could be a feasible action for different political levels. The **red cross** indicates the infeasibility and/or low impact of the certain level for applying certain policy and regulations.

For most of the recommendations there are green ticks for both the Benelux and European levels. This means that these actions are proposed to be done at these levels, **with the Benelux being the frontrunner and complementary to the EU level**. Obviously, it is up to the Member States to make the final decision at which level the proposed actions are most suitable to be taken place. Furthermore, the sub-national level refers to regional levels, such as local and regional governments, provincial authorities, etc. This level naturally includes the neighbouring regions as well. Wherever we propose an action to be taken place at the Benelux level, it is also recommended to be in alignment with the neighbouring regions. The Benelux Union needs to further discuss these points with the authorities of the neighbouring regions **to strengthen the collaboration in and harmonization of the hydrogen development in the region**.

These recommendations are to be considered by the Benelux Hydrogen Working Group. Considering the interlinkage between all the Benelux countries and neighbouring regions for the development of hydrogen in the region, it is important that close collaboration is maintained between all countries and regions. It is therefore recommendable to **consider expanding the scope of the Benelux Hydrogen Working Group to all neighbouring regions**. In this way, the progress and developments can be monitored directly and the alignment be established. Such a collaboration can be further enhanced by facilitating common events (e.g., once per year) in which topics of common cross-border interest are discussed.

Furthermore, a large amount of data was generated as part of this study. Yet still updates of the national and regional hydrogen strategies are being published or will be published soon, e.g., because of Europe's increasing hydrogen ambitions through the Fit-for-55 and RePowerEU packages. So, it remains important, also after this study, to **keep monitoring the status of these new sources of information**. A public dashboard in which KPIs are being monitored enables a close monitoring of progress and developments in the Benelux and its neighbouring regions.

| Timeline | Key Recommendations | Proposed Actions | Sub-national Level | National Level | Benelux Level | EU Level |
|---|---|---|---|---|---|---|
| Short-term (2023-2026) | **Strengthened, collective voice towards influencing EU legislation and promoting the region** | • Strengthening the leading position of the Benelux-countries and neighbouring regions by leveraging their pioneering role as privileged interlocutors to shape EU legislation, with regards to large chemical and steel industries, $H_2$ import via seaports, $H_2$ backbone, transport sector, $H_2$ valleys<br>• Boosting more visibility for the region in Europe and attracting more resources and funding to the region | ✗ | ✓ | ✓ | ✓ |
| | **Promoting collaboration along the hydrogen value chain** | • Setting up a regular dialogue and promoting institutional and regional collaboration between different public and private actors of the $H_2$ value chain and the relevant Benelux authorities<br>• Promoting closer collaboration, share of expertise and lessons learned and deepening the dialogue between stakeholders (TSOs of gas and electricity, HRS developers, technology developers, etc.) of the Benelux-countries and its neighbouring regions<br>• Ensuring the security of supply by coordinating the plannings for the electricity and $H_2$ infrastructure development including electrolyser plants and the repurposing of the existing gas network into dedicated hydrogen networks | ✓ | ✓ | ✓ | ✓ |
| | | • Speeding up the permitting process to increase renewable energy and electrolyser capacity for both new and existing | ✓ | ✓ | ✓ | ✗ |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Streamlined and fast-track procedures** | projects to go hand in hand with the deployment of new renewable electricity capacity<br>• Exploring harmonisation possibilities of permitting rules | | | | |
| | | • Facilitating fast-track procedure for IP & patenting | ✗ | ✓ | ✓ | ✗ |
| | **Paving the transition path** | • Accelerating deployment of a cross-border hydrogen backbone to facilitate hydrogen supply for hard-to-abate industries and to satisfy rising hydrogen demand<br>• Allowing for an innovative and flexible regulatory framework for the nascent interconnected hydrogen market to accommodate the transition towards green hydrogen<br>• Stimulating the development of education and training programmes to have skilled labour force | ✓ | ✓ | ✓ | ✓ |
| | **Kick-start the development of an integrated $H_2$ Market** | • Harmonising system requirements, safety protocols, standards and hydrogen quality for $H_2$ transport and consumption<br>• Ensuring interoperability and exchanges between certification schemes and registers and integrating and hosting a trading market for hydrogen production and import<br>• Developing a common hydrogen storage strategy<br>• Working with combined forces at EU level to push for the clear and tailored tax and funding schemes to avoid displacement of the investment and industrial production from EU to Asia or the US | ✓ | ✓ | ✓ | ✓ |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | • Encouraging a joint call of the Benelux-countries and neighbouring regions for development of the supporting schemes such as European Hydrogen Bank and H2Global, and maximising the use of other EU supporting mechanisms | ✗ | ✓ | ✓ | ✓ |
| | **Uniform approach for establishing hydrogen refuelling infrastructure** | • Harmonising payment systems, HRS interoperability, homologation requirements, permitting rules as well as bunkering specifications and rules for waterborne and airborne applications<br>• Aligning HRS implementation plan and technical specifications (quality, interfaces, protocols) | ✓ | ✓ | ✓ | ✓ |
| | | | | | | |
| **Mid-term (2026-2030)** | **Advance the development of an integrated $H_2$ Market** | • Providing the means for barrier-free flow of hydrogen from production point to the end-user location through the use of the Benelux legal instruments, with extension to and alignment with the neighbouring regions by harmonising regulations for hydrogen production, import and transport | ✓ | ✓ | ✓ | ✓ |
| | | • Facilitating the market transition from a subsidy dominated system towards a competition driven system | ✗ | ✓ | ✓ | ✓ |
| | **Economic activities & education** | • Promoting new economic activities related to hydrogen development<br>• Implementing diplomas and certificates that are accepted and recognized across the Benelux region | ✓ | ✓ | ✓ | ✓ |

### Recommendation for short-term (2023-2026)

**Strengthened, collective voice towards influencing EU legislation and promoting the region**

The Benelux countries and its neighbouring regions in France and Germany are historically, currently and in future leaders in Europe for both hydrogen demand (due to feedstock, heavy-duty transport, large industrial clusters) and hydrogen supply (via the seaports in the Benelux region, hydrogen import and hydrogen backbone). The Benelux Union can be **the collective voice for the Benelux countries towards the European Union** by communicating and profiling the importance of this region in Europe, and by creating more visibility for the region in Europe to attract more resources and funding to the region. The **Benelux Union can be a significant weight to influence the European Union legislations in favour of the needs of regional stakeholders** to fast track and facilitate their transition towards a carbon-neutral future. This not only will benefit the Benelux and its neighbouring regions, but also will benefit Europe as a whole since this region is one of the main gateways for hydrogen import and transport to Europe. Hence, **having a harmonised and established hydrogen market in the region as soon as possible needs to be placed on the priority list** of the European Commission, with the effort of the Benelux Union.

**Promoting collaboration along the hydrogen value chain**

The Benelux Union can facilitate and promote collaboration along different parts of the hydrogen value chain. Collaboration happens already on a large scale at regional and national levels, and on a smaller scale, although it is enlarging, at cross-border and international levels. Especially on the topics of hydrogen import and transport, different stakeholders are working together on international levels.

Yet, the Benelux Union can **set-up a regular dialogue and create institutional and regional collaboration between different public and private actors of the hydrogen value chain and the Benelux authorities** to identify the current and future issues and provide the right supporting mechanisms in time. Further, the Benelux Union should **promote closer collaboration between the stakeholders** (gas and electricity TSOs, HRS developers, technology developers, etc.) within the Benelux and its neighbouring regions, leading to **fostering pilot projects on concrete cross-border connections**. Next to this, the Benelux Union can play an important role in **ensuring the security of supply by coordinating the plannings for the electricity and hydrogen infrastructure development** including electrolyser plants, in alignment with its neighbouring regions.

Finally, the Benelux Union can establish means to **promote and motivate exchange of information and lessons learned**. This can be done by organizing information sessions for the ongoing projects to bring in different stakeholders and policy makers together to exchange their ideas and experiences.

**Streamlined and fast-track procedures**

Smooth and quick permitting procedures are important preconditions for the (accelerated) introduction of hydrogen projects. Given that the trajectories and, in particular, the timing of the permitting processes in the Benelux countries and their neighbouring regions are different, **cooperation between regional and national governments is needed to facilitate the cross-border activities**. For example, when the cross-border hydrogen backbone needs to be established or hydrogen needs to be imported to a seaport and then, transported to another region in another country, it is important that governments cooperate in the permitting procedures. **Simplifying existing rules for planning and permitting in the Benelux countries and its neighbouring regions**, for instance by rapid mapping, assessment and allocation of suitable land for renewable energy projects, will play an important role in accelerating the development of hydrogen market in the region. Although in most of the cases, permitting procedures are coordinated at regional and national levels, the Benelux Union can facilitate and maximise harmonisation possibilities of permitting rules among the Benelux countries and possibly with its neighbouring regions as well.

Furthermore, the Benelux Union can **support innovative technology developers** by facilitating fast-track procedures for issuing IP and patenting.

**Paving the transition path**

The **Benelux Union can work alongside the European Union** to facilitate and accelerate the formation of a hydrogen market in the Benelux region and maximise the collaboration and harmonisation with its neighbouring regions in France and Germany.

One of the possible actions in the short term is to **provide additional support to accelerate development of hydrogen backbone in the industrial areas**, so that hard-to-abate industries can be among the first groups who have access to green hydrogen. To this end, there is a need for alignment of plannings between the TSOs and the industries to guarantee the accessibility to (green) hydrogen in time, in order for these sectors to achieve their decarbonization targets. The Benelux Union can monitor, and if needed facilitate, the permitting process, certification, and other requirements for swift connection of the industrial regions to hydrogen backbone.

Furthermore, to support the formation of a hydrogen market in the Benelux, there could be **more flexibility offered by the Benelux Union regarding the use of clean hydrogen (e.g., from biomass or with CCUS) in the short term**, to both minimize $CO_2$ emissions and to support the hard-to-abate industries and transport sector achieving their goals. The use of clean hydrogen will be complementary to green hydrogen to ensure end-users' access to sufficient amount of non-grey hydrogen until there is adequate green hydrogen available for different sectors. This requires flexible regulatory framework – in the context of REDII and III – at the Benelux level (and possibly in alignment with the neighbouring regions) to gradually complete the transition from grey to green hydrogen and from fossil fuel to carbon-free energy sources. Strict policy and regulations from the beginning, which is happening now at EU level, slow down the transition and can result in shifting the investments in and productions of green hydrogen and green products outside of EU, where the regulations are more flexible (such as in the USA, China, India, etc.).

Another action that can be promoted and supported at the Benelux level is **using different technologies (SMR+CCUS, biomass, nuclear, etc.) for clean hydrogen production**, to support different sectors with their various decarbonisation pathways. By only focusing on green hydrogen at the start of the market, there is a risk that production of green products will be moved to outside of Europe due to insufficient availability of green hydrogen in the coming period before 2030. Hence, using different technologies, at least in short term, has many benefits not only for industries and transport sectors, which allows them to use different hydrogen technologies to meet their targets, but also for development of innovative technologies in the region, and eventually in Europe.

Finally, the Benelux Union needs to **stimulate the development and implementation of education programmes** to have skilled labour force in the region. Such activities mobilise the skilled labour forces across the Benelux and provide a more harmonised and integrated expertise level among the Benelux countries.

**Kick-start the development of an integrated hydrogen market**

Having an integrated hydrogen market in Europe is an ultimate goal, which requires lots of effort and coordination between different Member States to provide **uniform standards and policy for hydrogen production, transport, and consumption**. The European Union is working hard in the last few years to develop adequate policy and regulations for deployment of RES as well as green gases including hydrogen. However, **the legislation process at EU level progresses slowly** since the laws needs to be evaluated by every Member States.

Here is where the **Benelux Union can step in and accelerate the policy making process** by developing the first set of regulations, in line with European Commission. The **juridical process of law-making at the Benelux is much faster compared to European Union**, and hence, it provides a great window of opportunity for the Benelux Union to be the frontrunner in certain areas (e.g., harmonisation of system requirements, safety protocols, standards, hydrogen quality requirement for transport and consumption of it, HRS protocols, clean hydrogen certificate, permitting for renewable energy and hydrogen production) and the European Union can follow afterwards and take learnings from the experiences gained. Other actions that support the formation of an integrated hydrogen market in the Benelux and its neighbouring regions is **actively working on coordination of certificates and permitting procedures for green hydrogen production**, in the short term. A platform can be developed for **establishing standards for the exchange and trade of certificates for green hydrogen production and import and ensuring interoperability** within the Benelux, and in alignment with its neighbouring regions. The more harmonisation and integration of regulations among the Benelux countries are in place, the faster the hydrogen market can be developed in the Benelux region and the faster different sectors can decarbonise.

A good example of a collective support scheme is **H2Global**, which is originated by Germany and now is picked up at European level. Of course, such supporting schemes are not suitable to be organized at the Benelux level, and European level is the most suited. However, **the Benelux Union can still encourage its Member States to join such schemes**. Another similar supporting is the **European Hydrogen Bank**, where **the Benelux Union can encourage a joint call of the Benelux-countries and its neighbouring regions** towards the European Commission for development of the European Hydrogen Bank.

**Other supporting schemes** such as offering subsidies based on carbon footprints of hydrogen production methods instead of its colour can be an effective approach offered at the Benelux Union level. The example of such tax and funding schemes is the one offered in Inflation Reduction Act by the US government, which makes hydrogen production more cost competitive. The **Benelux Union can apply such taxation schemes in the short term, to kickstart the hydrogen market in the region**, while the European Union is working on more integrated regulations. In this context, the Benelux Union can promote a favourable investment climate between the EU and the US, as well. Of course, the introduction of such schemes needs to be aligned with the broader industrial, energy and climate policies, such as electrification, national and European climate targets, etc., so the climate targets of each Member State can be achieved.

Further, the **Benelux Union can work together with the gas TSOs to develop a well-interconnected, cross-border hydrogen network** between the Benelux countries and its neighbouring regions. Having a strong cross-border hydrogen infrastructure, especially on strategic cross-border corridors, is key for a strong hydrogen economy in the region. Hence, it is important that the **Benelux Union in close collaboration with both electricity and gas TSOs identify the possible bottlenecks** after establishing the hydrogen network and anticipate the required juristic tools in time to prevent any possible future delays or obstacles for hydrogen import, transport and delivery in the coming years. This close collaboration should also result in a **joint approach for hydrogen storage**, due to the perceived lack of natural storage potentials and lack of developed storage facilities in the majority of the region.

**Uniform approach for establishing hydrogen refuelling infrastructure**

The Benelux and the neighbouring regions have a real opportunity to become a pilot region for the introduction of a harmonised approach towards establishing hydrogen refuelling infrastructure. The cross-border nature of heavy transport (road, waterborne, airborne) justifies collaboration at the level of the Benelux and its neighbouring regions. Although the European Union has started the process of organising a minimum level of interoperability among hydrogen refuelling infrastructure and the heavy transport applications it needs to refuel, there seems to develop a misalignment between the preparations, procurement and deployment of hydrogen refuelling infrastructure and the technical requirements they have to fulfil to enable cross-border refuelling.

The requirements for the **maritime applications** are defined even further ahead in time, whereas the first hydrogen refuelling stations for waterborne applications are already deployed and the further roll-out is foreseen in the near term. Hence, with these heavy-duty sectors well represented in the Benelux and the neighbouring regions, a **common effort can be initiated** at the level of the Benelux Union and its neighbouring regions in which industrial stakeholders together with policy makers develop guidelines and recommendations on specifications of hydrogen refuelling infrastructure for different application areas, in anticipation of and as example for European harmonisation efforts.

The **development of a uniform approach for establishing hydrogen refuelling infrastructure is however much wider than defining interoperability characteristics**, it also contains e.g., harmonisation of payment and certification systems, permitting requirements and refuelling procedures, systematic exchange of lessons learned, approval procedures. Another very relevant topic is the **geographical and time alignment of the development of hydrogen refuelling infrastructure** with the deployment of applications within the Benelux and its neighbouring regions.

It is therefore recommended to **establish a H2Transport Benelux platform** in which key industrial stakeholders of hydrogen refuelling infrastructure developers, operators and hydrogen application developers and operators and policy makers (e.g., through the Benelux Hydrogen Working Group) are organised together along an application area (heavy-duty road transport, waterborne transport) to **create a uniform approach to establishing hydrogen refuelling infrastructure**. Close collaborations should be established with H2Mobility platforms in Germany and France to ensure alignment with neighbouring regions. **Consented guidelines and recommendations stemming from the H2Transport Benelux platform can then be proposed** to be taken up by one of the legislative framework options of the Benelux Union. In this way, the European Union is provided an excellent example and lessons learned from implementing a uniform approach in the Benelux.

### Recommendation for long-term (2026-2030)

**Advance the development of an integrated hydrogen market**

As mentioned before, an ultimate goal is to have an integrated hydrogen market at European level. By taking the first steps in formation of an integrated market among the Benelux countries, and possibly with its neighbouring regions, the Benelux Union can support Europe in long-term to develop such market at the EU level.

Once the formation of such market is kick started in the Benelux region, it can **be further advanced to other neighbouring regions/countries, including other members of the Pentalateral Energy Forum**[14]. In agreement with the Benelux countries and members of Pentalateral Energy Forum, the Benelux Union can further provide the means for barrier-free flow of hydrogen within the Benelux, its neighbouring regions and other Penta members (from production point to the end-user location), and further harmonise and (possibly) integrate regulations for hydrogen production, import and transport within the Benelux, its neighbouring regions and other Penta members. Having consensus and agreements among fewer countries could be much faster and more efficient compared to the ones at European level. Nevertheless, these activities are expected to be complementary, and wherever possible pioneering, to the European policy development for hydrogen market.

**Economic activities & education**

Finally, the Benelux Union can play an important role in **promoting the new economic activities** connected to the development of the hydrogen market in the Benelux region in the long-term. Developing projects to produce renewable hydrogen and to develop hydrogen technologies creates high-quality jobs and spurs economic growth in the Benelux countries. To support the new economic activities and to deal with the shortage of skilled labour force, the Benelux Union can **develop education programs** in the long term to provide diplomas and certificates that are accepted and recognized across the Benelux region.

[14] The Pentalateral Energy Forum, a regional cooperation framework steered by energy ministers from the Benelux nations (Belgium, Netherlands, Luxembourg), France, Germany, Austria, and Switzerland stimulates energy cooperation inside Europe since 2005

# 6. ANNEX – HYDROGEN VALUE CHAIN IN BENELUX AND NEIGHBOURING REGIONS

In this Chapter, each individual element of the hydrogen value chain is assessed in order to determine the quantities of hydrogen that are associated with that part of the value chain. Prior to that, the methodology is explained that is being used to derive the quantities of hydrogen in the period 2030 – 2050 for the Benelux, the neighbouring regions and Europe.

Note that in the tables if there is no data available from the sources consulted, then the value is marked as "-".

## 6.1 STEEL INDUSTRY

### Status steel sector in the Benelux and neighbouring regions

The steel sector is well represented in the Benelux and its neighbouring regions (see Table 2). EUROFER provides an overview of the list of plants and its capacities in Europe[15]. The Benelux hosts 2 Blast Furnace/Basic Oxygen Furnace (BF/BOF) plants in the Netherlands (IJmuiden) and Belgium (Ghent), while there are 6 such plants in the neighbouring regions (France (Dunkerque) and Germany (Duisburg, Bremen, Salzgitter, Dillingen and Völklingen). These **8 plants** combine 19 furnaces. The combined capacity of these plants in the Benelux and its neighbouring regions is **45.810 kton of finished steel production**. This is **43% of the total BF/BOF capacity in Europe**. Europe hosts in total 25 BF/BOF plants with 54 furnaces.

The Benelux and its neighbouring regions also host 17 Electric Arc Furnace (EAF) plants with 19 furnaces and a total plant capacity of **13.040 kton steel**. This is **15% of the total capacity of EAF plants in Europe**. Europe hosts 122 EAF plants with 143 furnaces.

Table 2: Number of plants, plant capacities and plant capacity shares for steel production in the Benelux, the neighbouring regions and Europe

| Country | # of Plants / # of Furnaces | | Plant capacity | | % Share of Capacity | | | |
|---|---|---|---|---|---|---|---|---|
| | BF/BOF | EAF | BF/BOF | EAF | BF/BOF | | EAF | |
| | # | | kton/y | | % | | | |
| Netherlands | 1/2 | 0 | 7,500 | 0 | 7 | 16 | 0 | 0 |
| Belgium | 1/2 | 4/5 | 5,000 | 3,400 | 5 | 11 | 4 | 26 |
| Luxembourg | 0 | 1/2 | 0 | 2,250 | 0 | 0 | 3 | 17 |
| France | 2/5 | 13/14 | 11,850 | 7,030 | 11 | | 8 | |
| 2 French states | 1/3 | 4/4 | 6,750 | 2,790 | 6 | 15 | 3 | 21 |
| Hauts-de France | 1/3 | 2/2 | 6,750 | 1,530 | 6 | 15 | 2 | 11 |
| Grand Est | 0 | 2/2 | 0 | 1,260 | 0 | 0 | 1 | 10 |
| Germany | 6/14 | 18/22 | 28,960 | 14,770 | 27 | | 17 | |
| 4 German states | 5/12 | 8/8 | 26,560 | 4,600 | 25 | 58 | 5 | 35 |
| Lower Saxony | 3/5 | 3/3 | 9,000 | 2,720 | 8 | 20 | 3 | 21 |

[15] https://www.eurofer.eu/about-steel/learn-about-steel/where-is-steel-made-in-europe/

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| North Rhine-Westphalia | 1/4 | 3/3 | 11,560 | 1,230 | 11 | 25 | 1 | 9 |
| Rhineland-Palatinate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Saarland | 2/3 | 2/2 | 6,000 | 650 | 6 | 13 | 1 | 5 |
| Benelux | 2/4 | 5/7 | 12,500 | 5,650 | 12 | 27 | 7 | 43 |
| Benelux + Neighbouring regions | 8/19 | 17/19 | 45,810 | 13,040 | 43 | 100 | 15 | 100 |
| Europe | 25/54 | 122/143 | 106,830 | 86,770 | 100 | 233 | 100 | 665 |

## The role for hydrogen/derivatives for steel production

Steel is produced through 2 routes: the primary route which processes iron ore as a raw material into steel via a BF/BOF plant, whereas the secondary route re-uses processed recycled scrap into steel via an EAF plant. 78% of the steel capacity in the Benelux and its neighbouring regions is using the primary route to make steel.

**Hydrogen is foreseen to play a major role in the production of steel in the primary route**. In the traditional process of the primary route, the iron ore is reduced through carbon as reducing agent to form $CO_2$. The majority of the emissions in the steel sector are stemming from this process. The main carbon-bearing material used is coal/coke, which is also used to generate the high temperatures required to smelt the iron ore. The iron ore can also directly be reduced through hydrogen and/or natural gas as a reducing agent in a direct reduced iron (DRI) plant. DRI plants instead of BF/BOF plants are therefore providing an important means for decarbonising steel sector. **The DRI-$H_2$ route is generally seen as the prime solution to decarbonise primary steel making, which is confirmed by major steelmakers in Europe such as SSAB, Salzgitter, Voestalpine, Thyssenkrupp steel and Liberty Steel[16].**

The hydrogen demand is estimated in several studies and range between 51 (HE[17]) and 75 (IEA[18]) kg of hydrogen per ton steel, with intermediate values of 54[19], 58[20,21]and 60[22]. To estimate the maximum potential of hydrogen demand (see Section E), it is assumed that **0,06 kton of hydrogen is required to produce 1 kton of steel in a DRI-$H_2$ plant**.

**Hydrogen is foreseen to play an indirect and very minor role in the production of steel in the secondary route.** The secondary route uses scrap steel primarily to produce steel via an EAF. This process relies predominantly on electricity, is therefore much less carbon intensive as the primary route, and hence the use of green electricity already provides a clear route towards decarbonisation. However, a very limited amount of natural gas or coal is needed for its carbon content. These fuels can be replaced by **biomethane of synthetic methane which could provide an indirect, additional demand for hydrogen** to produce these fuels.

The hydrogen demand for the production of synthetic natural gas which is used in an EAF is estimated at **0,008 kton of hydrogen in order to produce 1 kton of steel in an EAF plant**. This is based on the

[16] EHB#2_report_part1_210614.indd (gasforclimate2050.eu)
[17] Hydrogen Europe, STEEL FROM SOLAR ENERGY, Study_Steel_from_Solar_Energy_Report_2022.pdf, p. 43.
[18] IEA (2017) - Renewable_Energy_for_Industry.pdf, p. 41
[19] Hydrogen in steel production: what is happening in Europe – part two - Bellona.org, end references.
[20] policybrief-green-steel.pdf (teriin.org), p. 5.
[21] MIDREX H2 – The Road to CO2-free Direct Reduction (primetals.com)
[22] A. Bhaskar, R. Abhishek, M. Assadi, H. Nikpey Somehesaraei, Decarbonizing primary steel production : Techno-economic assessment of a hydrogen based green steel production plant in Norway, Journal of Cleaner Production, Volume 350, 2022

assumptions that 0,5 kg of hydrogen is needed to produce 1 kg of synthetic natural gas[23], and that 0,77 MJ of natural gas (= 0,015 kg) is needed to produce 1 kg of steel[24].

## Sector's decarbonisation perspective

The EU Steel industry is responsible for 5% (= 190 Mt) of the EU $CO_2$ emissions, with approximately 1.9 t $CO_2$ emission coming from the BF/BOF route and 0.1 t $CO_2$ emission coming from the EAF route per 1 ton of steel produced. Decarbonisation strategies applied in the steel sector range from optimising current processes, fuel/reducing agent replacements, CCUS, increasing secondary steel production and the application of DRI with natural gas and/or hydrogen as summarised in the Figure 15[25].

| | $CO_2$ reduction | | | Full decarbonization possible | | |
|---|---|---|---|---|---|---|
| | **Blast furnace efficiency (BOF)** | **Biomass reductants** | **Carbon capture and usage** | **Electric arc furnace (EAF)** | **DRI plus EAF using natural gas** | **DRI plus EAF using $H_2$** |
| **Strategy** | Make efficiency improvements to optimize BF/BOF operations | Use biomass as an alternative reductant or fuel | Capture fossil fuels and emissions and create new products | Maximize secondary flows and recycling by melting more scrap in EAF | Increase usage of DRI in the EAF | Replace fossil fuels in DRI process with renewable energy or $H_2$ |
| **Examples** | Optimized BOF inputs (DRI, scrap), increased fuel injection in BF (e.g., hydrogen, PCI) | Tecnored process | Bioethanol production from $CO_2$ emissions | EAF – usage to melt scrap | Current DRI plus EAF plants using natural gas (NG) | MIDREX DRI process running on $H_2$<br>HYL DRI process running on $H_2$ |
| **Current outlook** | Technology readily available at competitive cost | Process possible in South America and Russia, due to biomass availability | Not available on an industrial scale | Technology readily available at competitive cost | Technology readily available | Technology available at high cost |

SOURCE: McKinsey analysis

Figure 15: Decarbonisation strategies applied in the steel sector

Some of the major stakeholders have shed light on elements of their strategies towards decarbonisation. The summary provided in Table 3 is a non-exhaustive list of interpretations of announcements found in the public domain.

[23] (PDF) Production of Synthetic Natural Gas From Carbon Dioxide and Renewably Generated Hydrogen: A Techno-Economic Analysis of a Power-to-Gas Strategy (researchgate.net)
[24] Decarbonisation options for the Dutch steel industry (pbl.nl)
[25] https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

Table 3: Decarbonisation strategies of stakeholders

| | Owner BF/BOF Plant | Glance of company (short term) strategies announced for decarbonisation |
|---|---|---|
| | Company | |
| Netherlands | TATA Steel | DRI with $H_2$, no CCU. Until 2030 partially on gas. Replacement of BF on H2 |
| Belgium | ArcelorMittal | 1 plant replaced by DRI, 1 BF plant remains in operation: smart processing technology, CCU/S |
| Luxembourg | - | - |
| France | | |
| Hauts-de France | ArcelorMittal | 2 BF plants to be replaced by DRI combined by submerged arc furnace |
| Grand Est | - | - |
| Germany | | |
| Lower Saxony | Arcelor Mittal, Salzgitter | DRI/EAF plant in Bremen; SALCOS-project, from 2025/26 on DRP+EAF+ electrolyser (500 MW by 2030) In Salzgitter[26] |
| North Rhine-Westphalia | ThyssenKrupp | $H_2$ use in BF first, then DRI. |
| Rhineland-Palatinate | - | - |
| Saarland | Stahl-Holding-Saar, ROGESA, Dillinger Hütte, Saarstahl | DRI-Plant and two new EAF until 2027 |

**At nearly all BF/BOF plants in the Benelux and its neighbouring regions, projects are announced/taking place** to reduce $CO_2$ emissions through the hydrogen route[27,28,29]. These would typically orient at the **local production of hydrogen with electrolysers up to 100 MW**, with a perspective of up to a GW. The use of natural gas as a transition fuel is explored in which the share of hydrogen can be increased when available at large scale. Projects involving CCU are typically

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[26] https://www.bgr.bund.de/DE/The men/Min_rohstoffe/Veranstaltungen/Rohstoffkonferenz_20 22_Rohstoffversorgung_Deutschlands/Redenius.pdf?__blob =publicationFile&v=3
[27] https://www.eurofer.eu/assets/Maps/eurofer-low-carbon-projects-map.pdf
[28] https://www.industrytransition.org/green-steel-tracker/
[29] Hydrogen in steel production: what is happening in Europe – part two - Bellona.org

taking place in partnership with the chemical industry to make chemicals. Iron ore electrolysis is currently at a very low TRL level and is not foreseen to be market ready before 2040[30].

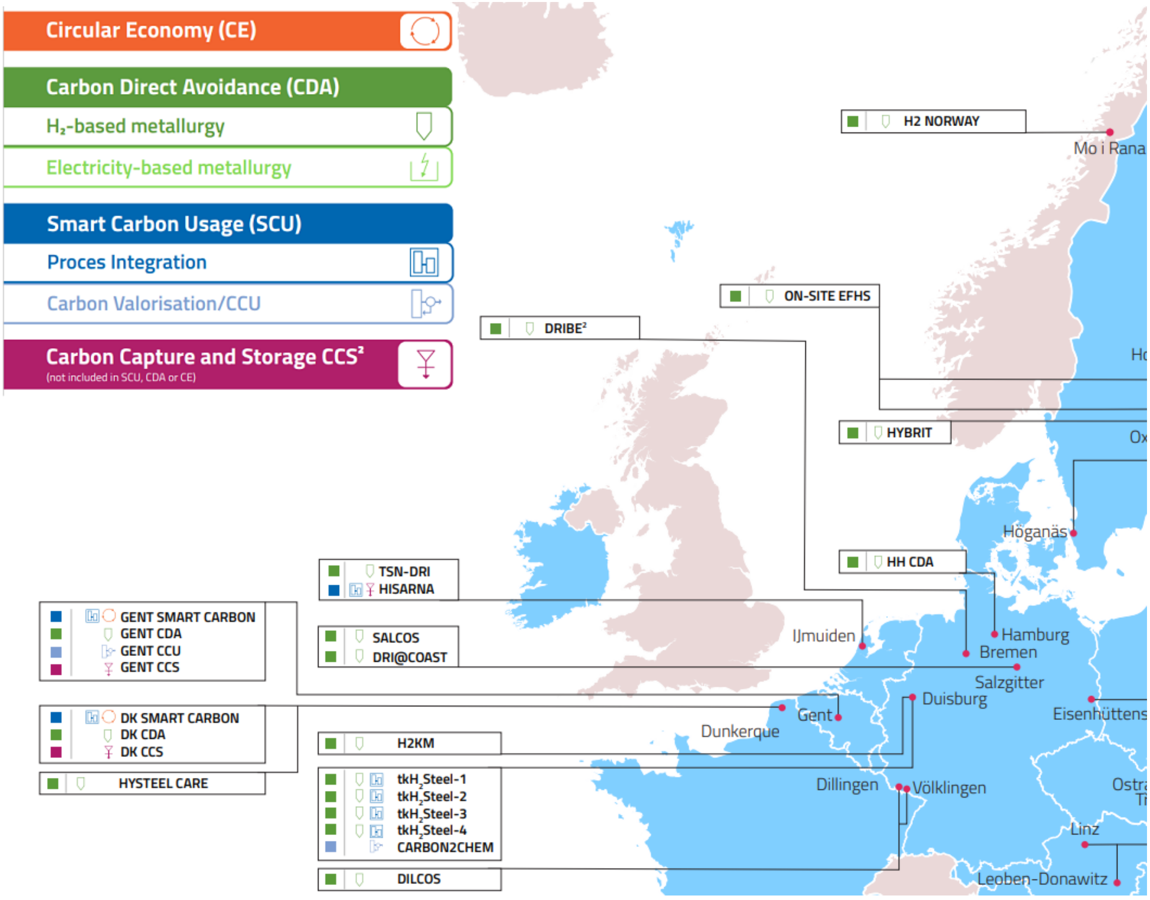

Figure 16: Different decarbonization projects for steel industry in the Benelux and its neighbouring regions

30 JRC Publications Repository - Technologies to decarbonise the EU steel industry (europa.eu)

## Quantification hydrogen demand for steel making in national/regional hydrogen strategies and studies in 2030 – 2050 timeframe

Decarbonisation of the steel sector is predominantly visible in national and regional hydrogen strategies, typically based on existing plans and perspectives of the industry for the decarbonisation of the primary steel production route itself. Identifiable quantifications of hydrogen demand are however scarce[31,32,33] and an extract of it is provided in Table 7. In this table, also the quantification of potentials of hydrogen demand for steel making up to 2030 is provided based on an interpretation of Member States' National Energy and Climate Plans (end November 2019)[34], performed by Trinomics.

Long term projections (2040–2050) are generally developed as part of literature studies. The studies assessed are European Hydrogen Backbone[35], Materials Economics[36], GreenSteel[37], CLIMACT[38] and Jülich[39] (see Table 4). The assessment was carried out to identify several scenarios and accompanying conditions to show trends in the future demand for steel, the increased use of secondary steel production route, efficiency evolutions up to 2050 and hydrogen penetration rates, assumed fuel mix and technologies applied. The European Hydrogen Backbone study is considered as a reference as it received much support from the steel sector to develop it. It should however be noted that during the workshops it was voiced that more recent estimates are available but difficult to share due to confidentiality. Although some numbers were confirmed, the general tendency however is that the estimates are significantly (+/- 20%) higher than stated in the hydrogen backbone study.

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31 Impact Fit for 55 voorstel voor herziening RED op de vraag naar groene waterstof in Nederland | Kamerstuk | Rijksoverheid.nl

32 https://www.fz-juelich.de/de/iek/iek-3/aktuelles/meldungen/wasserstoff-roadmap#:~:text=Wissenschaftliche%20Begleitstudie%20der%20Wasserstoff%20Roadmap,somit%20weitestgehend%20Treibhausgasneutralit%C3%A4t%20zu%20erreichen

33 https://www.arbeitskammer.de/fileadmin/user_upload/---------------AK_Download_Datenbank-------------/Publikationen/Sonderpublikationen/AK-Analyse/Analyse_Wasserstoff_BS_Internet.pdf

34 https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans

35 https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021.pdf

36 https://wupperinst.org/fa/redaktion/downloads/projects/INFRA_NEEDS_d4-4.pdf

37 https://www.estep.eu/assets/Uploads/D1.7-Decarbonisation-Pathways-2030-and-2050.pdf

38 https://www.vlaio.be/nl/media/1502

39 https://www.fz-juelich.de/de/iek/iek-3/aktuelles/meldungen/wasserstoff-roadmap#:~:text=Wissenschaftliche%20Begleitstudie%20der%20Wasserstoff%20Roadmap,somit%20weitestgehend%20Treibhausgasneutralit%C3%A4t%20zu%20erreichen.

Table 4: Overview literature analysis for hydrogen penetration scenarios steel

| Study | Parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Scope | Demand | 1st/2nd route | Efficiency | H2 penetration | | | Fuel mix | Technology |
| | | % change 2050 | 2050 | 2050 | 2030 | 2040 | 2050 | 2050 | 2050 |
| **European Hydrogen Backbone (2022)** | **EU, MS** | **+20** | **50/50** | **+35%** | **8%** | **27%** | **43%** | **32% electricity, 25% PCI coal/biogas** | **H2-DRI/EAF** |
| **Material Economics (2019)** | **EU** | **+17** | **2nd up** | **-** | | **-** | | **-** | **-** |
| **GreenSteel for Europe (2021)** | **EU** | **+20** | **60/40** | **-** | **1-5%** | **-** | **29-46%** | **-** | **H2-DRI, BF/BOF-CCUS** |
| **CLIMACT (2020)** | **Flanders** | **+10** | **85/15** | **+15%** | **0%** | **6%** | **15%** | **22% electricity, 67% coal/waste/biomass** | **BF/BOF+IGAR, EAF** |
| **Jülich (2021)** | **NRW** | **-10** | **60/40** | **+35%** | **0%** | **10%** | **43%** | **28% electricity, 29% natural gas/coal** | **H2-DRI** |
| **Low H2 penetration scenario** | | **+20** | | | **0%** | **10%** | **29%** | | |
| **High H2 penetration scenario** | | **+20** | | | **8%** | **27%** | **43%** | | |

The final minimum and maximum green hydrogen penetration scenarios selected are shown in Table 5.

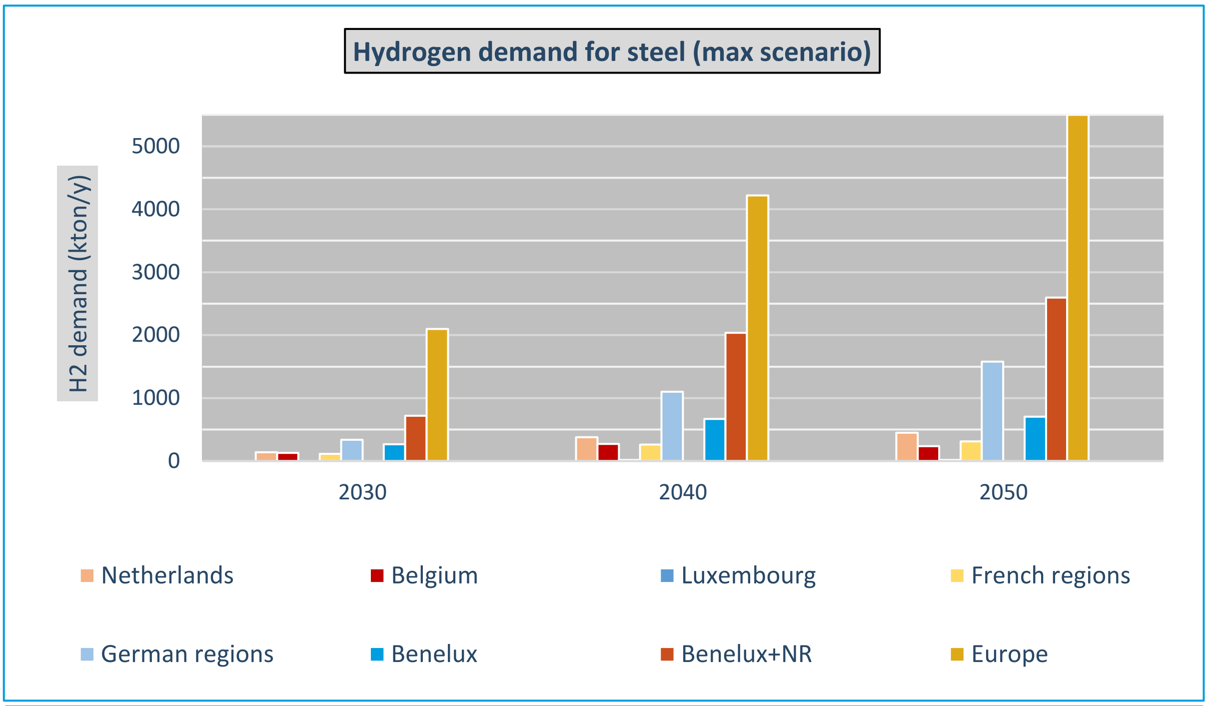
Table 5: Overview of minimum and maximum scenario selected for the calculation of the final hydrogen demand for steel production

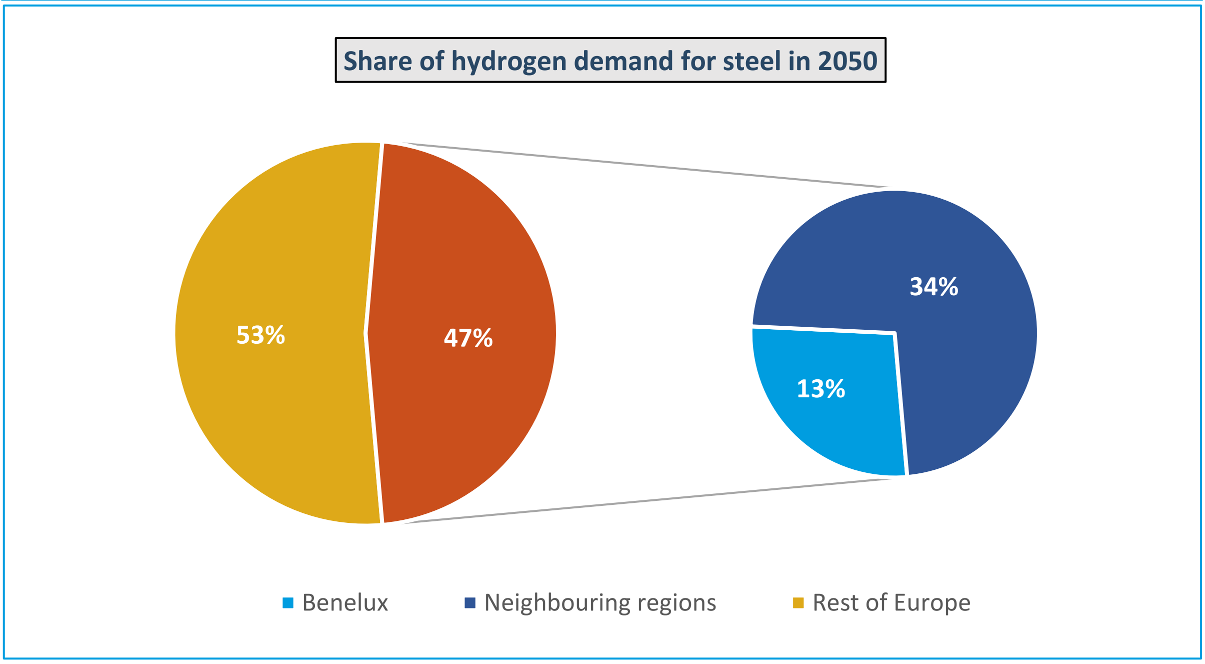
| | | Demand | | Green H2 penetration | | |
|---|---|---|---|---|---|---|
| | | % change 2050 | | 2030 | 2040 | 2050 |
| **Steel** | | | | | | |
| **Minimum penetration scenario** | | **+20%** | | **0%** | **10%** | **29%** |
| **Maximum penetration scenario** | | **+20%** | | **8%** | **27%** | **43%** |

Based on these scenarios, the national hydrogen strategies, the assessment of the National Climate and Energy Plan and the feedback from the workshop, the final demand for green hydrogen is shown in Table 6. A geographical representation of the hydrogen demand for steel in 2050 is shown in Figure 17. As shown below, the demand for hydrogen in the Benelux and its neighbouring regions for steel is 47% of the total European hydrogen demand for steel.

Table 6: Final demand growth selected for steel

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Steel | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 141 | 303 | 140 | 380 | 450 |
| Belgium | 0 | 101 | 160 | 129 | 273 | 237 |
| Luxembourg | 0 | 7 | 12 | 18 | 20 | 25 |
| France | 0 | 174 | 379 | 204 | 471 | 562 |
| 2 French states | 0 | 97 | 211 | 114 | 262 | 313 |
| Hauts-de France | 0 | 95 | 206 | 111 | 256 | 305 |
| Grand Est | 0 | 2 | 5 | 3 | 6 | 7 |
| Germany | 0 | 551 | 1315 | 610 | 1,488 | 1,799 |
| 4 German states | 0 | 408 | 1065 | 337 | 1,102 | 1,580 |
| Lower Saxony | 0 | 167 | 367 | 162 | 450 | 544 |
| North Rhine-Westphalia | 0 | 133 | 460 | 100 | 360 | 682 |
| Rhineland-Palatinate | 0 | 0 | 0 | 0 | 0 | 0 |
| Saarland | 0 | 108 | 238 | 75 | 292 | 353 |
| Benelux | 0 | 249 | 475 | 269 | 671 | 705 |
| Benelux + Neighbouring regions | 0 | 754 | 1751 | 720 | 2,036 | 2,598 |
| Europe | 0 | 1562 | 3709 | 2,100 | 4,218 | 5,500 |


Hydrogen demand for steel (max scenario)
H2 demand (kton/y)
5000
4000
3000
2000
1000
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe


Share of hydrogen demand for steel in 2050
53%
47%
34%
13%
Benelux
Neighbouring regions
Rest of Europe

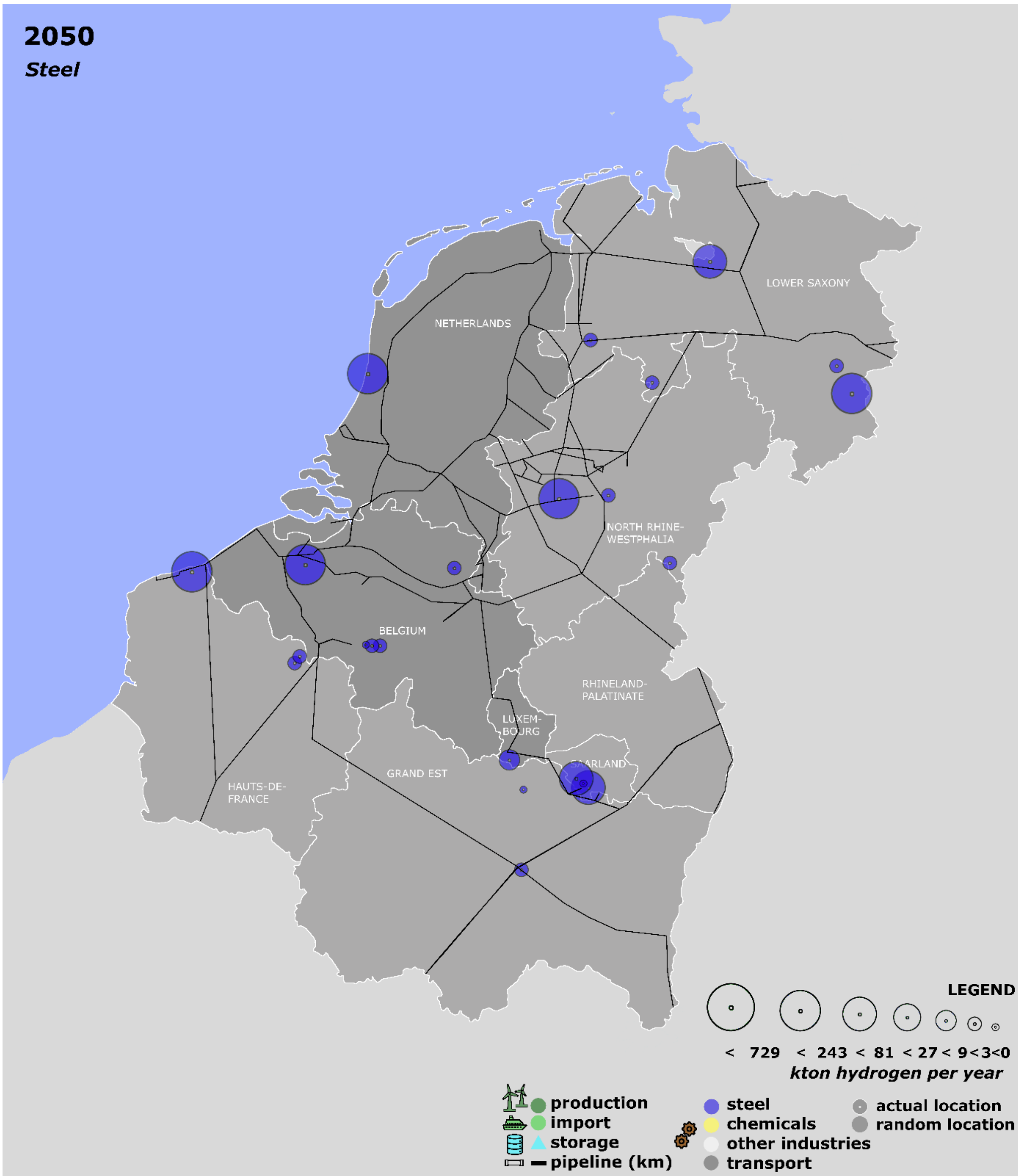



Figure 17: Geographical representation of hydrogen demand for steel in 2050 (maximum scenario)

Table 7: Summary of quantitative hydrogen demand data for the steel sector extracted from national and regional strategies, plans and literature

| Country | National/regional strategies | | | NECP H2 | European Hydrogen Backbone (EHB) | | | Theoretical potential (100% $H_2$) | H2 penetration rate EHB over theoretical potential for 2050 | Share of the $H_2$ demand in the neighbouring regions w.r.t. their country | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2030 | 2040 | 2050 | 2030 | 2030 | 2040 | 2050 | 2050 | 2050 | 2050 | 2050 |
| Hydrogen demand | kton/y | | | | | | | | % | % | % |
| Netherlands | 97 | 380 | - | 140 | 96 | 102 | 355 | 472 | 75 | - | - |
| Belgium | - | - | - | 160 | 129 | 273 | 237 | 344 | 69 | - | - |
| Luxembourg | - | - | - | 0 | 0 | 0 | 0 | 18 | 100 | - | - |
| France | - | - | - | 130 | 205 | 471 | 562 | 806 | 70 | 100 | 180 |
| 2 French states | - | - | - | - | - | - | - | 449 | - | 56 | 100 |
| Hauts-de France | - | - | - | - | - | - | - | 438 | - | 54 | 98 |
| Grand Est | - | - | - | - | - | - | - | 11 | - | 2 | 2 |
| Germany | - | - | - | 1,870 -5,660 | 534 | 1,488 | 1,799 | 1,949 | 92 | 100 | 114 |
| 4 German states | | - | - | - | - | - | - | 1,712 | - | 88 | 100 |
| Lower Saxony | 100 | - | - | - | - | - | - | 590 | - | 30 | 34 |
| North Rhine-Westphalia | 30 | 360 | 1,275 | - | - | - | - | 739 | - | 38 | 43 |
| Rhineland-Palatinate | - | - | - | - | - | - | - | 0 | - | 0 | 0 |
| Saarland | 75 | - | - | - | - | - | - | 384 | - | 20 | 22 |
| Benelux | - | - | - | - | 225 | 375 | 592 | 834 | 71 | - | - |
| Benelux + Neighbouring regions | - | - | - | - | - | - | - | 2,996 | - | - | - |
| Europe | - | - | - | - | 1,613 | 4,219 | 5,215 | 7,459 | 70 | - | - |

## 6.2 REFINERIES, AMMONIA, METHANOL

### Status of refinery, ammonia and methanol sector in the Benelux and neighbouring regions

The **refinery sector** is decently represented in the Benelux and its neighbouring regions. Information regarding individual plant capacities is available through CONCAWE[40] and company websites, whereas the EU overview is available CONCAWE. The **Benelux hosts 8 plants** in the Netherlands (Pernis, Rotterdam (3), Vlissingen) and Belgium (Antwerp (3)), while there are **5 such plants in the neighbouring regions** (Germany (Wilhelmshaven, Lingen, Salzbergen, Gelsenkirchen, Wesseling). The combined capacity of these plants is **95.000 kton in the Benelux** and **132.000 kton in the Benelux and the neighbouring regions**. This is respectively **16%** and **22% of the total refining capacity in Europe.**

The **ammonia sector** is well represented in the Benelux and its neighbouring regions. Information regarding individual plant capacities is available through company websites, whereas the EU overview is available from the FCHJU Observatory[41]. The **Benelux hosts 4 plants** in the Netherlands (Sluiskil, Geleen) and Belgium (Antwerp, Tertre), while there are **3 such plants in the neighbouring regions** (France (Ottmarsheim) and Germany (Köln, Ludwigshafen). The combined capacity of these plants is **4.100 kton in the Benelux** and **5.975 kton in the Benelux and the neighbouring regions**. This is respectively **23%** and **35% of the total ammonia production capacity in Europe.**

The **methanol sector** is well represented in the Benelux and its neighbouring regions. Information regarding individual plant capacities is available through from public literature[42] and company websites, whereas the EU overview is available from the FCHJU Observatory[41]. The **Benelux hosts 1 plant** in the Netherlands (Delfzijl), while there are **3 such plants in the neighbouring regions** (Germany (Gelsenkirchen, Wesseling, Ludwigshafen). The combined capacity of these plants is **990 kton in the Benelux** and **2.140 kton in the Benelux and the neighbouring regions**. This is respectively **30%** and **65% of the total methanol production capacity in Europe.**

An overview of the number of plants, plant capacities and plant capacity shares for refineries, ammonia and methanol production in the Benelux, the neighbouring regions and Europe is provided in Table 8.

### The role for hydrogen and its derivatives explained for refining, ammonia and methanol production explained

The use of hydrogen is intrinsic in these sectors for hydrocracking or hydrotreating of (synthetic) oil products and for the synthesis of ammonia and methanol. Therefore, **hydrogen is playing a major role in these sectors already**. The hydrogen needed for these processes are often based on traditional fuels (natural gas, naphtha, LPG) or by-product hydrogen and the transition towards the introduction of green hydrogen requires process adjustments or the introduction of new plant types with different feedstocks.

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40 https://www.concawe.eu/refineries-map/
41 https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand
42 https://repository.tno.nl/islandora/object/uuid%3A7bccc026-6f42-4948-91b8-cd585f58d21c

Table 8: Number of plants, plant capacities and plant capacity shares for refineries, ammonia and methanol production in the Benelux, the neighbouring regions and Europe.

| Country | # of Plants | Refinery production capacity | % Share of Capacity | | # of Plants | Ammonia production capacity | % Share of Capacity | | # of Plants | Methanol production capacity | % Share of Capacity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Refineries | | | | Ammonia | | | | Methanol | | | |
| | | | | | | | | | | | | |
| | # | kton/y | % | % | # | kton/y | % | % | # | kton/y | % | % |
| Netherlands | 5 | 61,500 | 10 | 47 | 2 | 3,000 | 17 | 50 | 1 | 990 | 30 | 46 |
| Belgium | 3 | 33,500 | 6 | 25 | 2 | 1,100 | 6 | 18 | 0 | 0 | 0 | 0 |
| Luxembourg | 0 | 0 | | | 0 | | | | 0 | | | |
| France | 7 | 58,600 | 10 | | | 1,045 | 6 | | 1 | 10 | 0 | |
| 2 French states | 0 | 0 | | | 1 | 650 | 4 | 11 | 0 | 0 | | |
| Hauts-de France | 0 | 0 | | | 0 | | | | 0 | | | |
| Grand Est | 0 | 0 | | | 1 | 650 | 4 | 11 | 0 | | | |
| Germany | 16 | 108,400 | 18 | | | 3,130 | 18 | | 4 | 1,810 | 55 | |
| 4 German states | 5 | 37,000 | 6 | 28 | 2 | 1,225 | 7 | 21 | 3 | 1,150 | 35 | 53 |
| Lower Saxony | 3 | 8,100 | 1 | 6 | 0 | | | | 0 | | | |
| North Rhine-Westphalia | 2 | 28,900 | 5 | 22 | 1 | 350 | 2 | 6 | 2 | 700 | 21 | 32 |
| Rhineland-Palatinate | 0 | 0 | | | 1 | 875 | 5 | 15 | 1 | 450 | 14 | 21 |
| Saarland | 0 | 0 | | | 0 | | | | 0 | | | |
| Benelux | 8 | 95,000 | 16 | 72 | 4 | 4,100 | 23 | 69 | 2 | 990 | 30 | 46 |
| Benelux + Neighbouring regions | 13 | 132,000 | 22 | 100 | 7 | 5,975 | 35 | 100 | 5 | 2,140 | 65 | 100 |
| Europe | 84 | 595,000 | 100 | 451 | | 17,300 | 100 | 231 | | 3,300 | 100 | 153 |

General estimates of hydrogen demand for the processing of (synthetic) oil products are not straightforward and will significantly depend on the processes applied and the outputs produced. Therefore, applying conversion factors for refineries may lead to deviations in comparison to applying a plant-based approach. Conversion numbers applied vary between 0,008, 0,009[43] and 0.03[44] kton per kton of refined oil products. In the study, **0.008 kton of hydrogen is taken to convert 1 kton of refined oil**. The hydrogen demand for ammonia and methanol production is determined based on process characteristics for production. Hence, **0.178 kton and 0.125 kton of hydrogen is required to produce 1 kton of ammonia and methanol respectively**.

## Sector's decarbonisation perspective

### Refineries

The decarbonisation options considered for refineries are[45]:

- carbon capture and storage (CCS)
- electrification
- hydrogen as fuel for furnaces
- co-processing of bio-based feedstocks
- waste heat utilization

### Ammonia and methanol production

The decarbonisation options considered for ammonia and methanol production are relatively straight forward and include (see Figure 18)

- the use of green hydrogen as a replacement of the hydrogen contained in the syngas
- the application of CCUS
- other strategies, including efficiency improvement, demand side measures, the use of synthetic or biogas and cross-sectoral use of emissions/heat

43 https://www.pbl.nl/sites/default/files/downloads/pbl-2022-decarbonisation-of-the-industry-cluster-botlek-pernis-rotterdam-4946.pdf
44 https://www.fchobservatory.eu/sites/default/files/reports/Section%202%20-%20FCHO%20Market%20-%202022%20Final.pdf
45 https://www.pbl.nl/en/publications/decarbonisation-options-for-the-dutch-refinery-sector

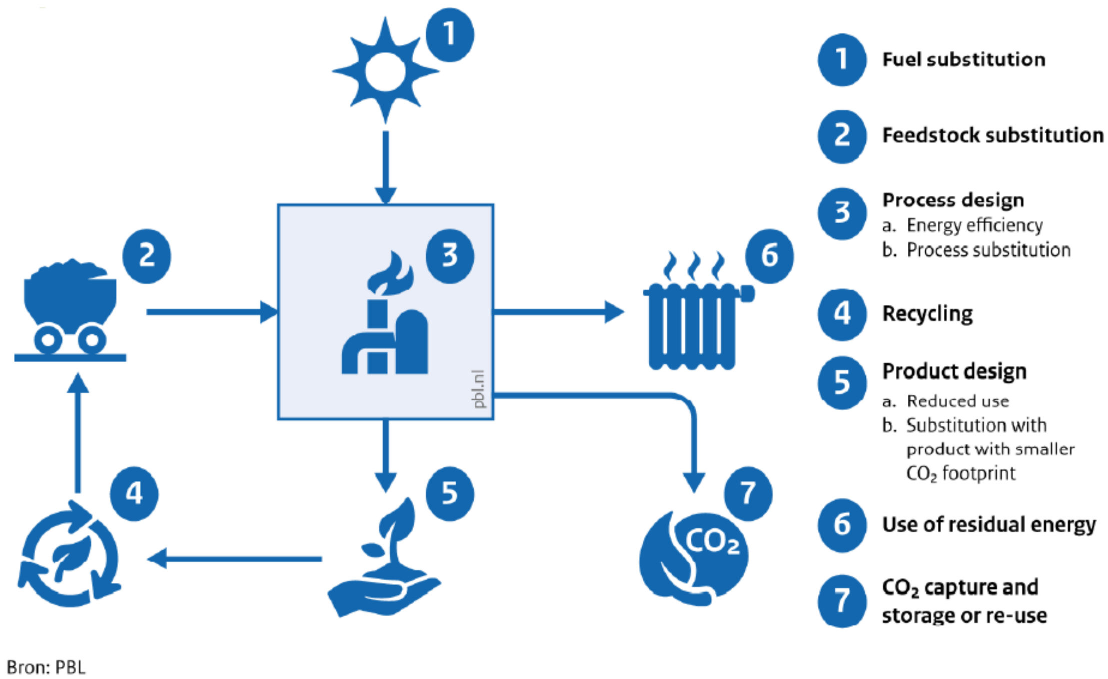



Figure 18: Decarbonisation option for the fertiliser industry[46]

## Quantification hydrogen demand in national/regional hydrogen strategies and studies in 2030 – 2050 timeframe

The need for decarbonisation and the use of green hydrogen as a key decarbonisation option for these sectors is clearly expressed in national and regional hydrogen strategies, but quantifications of the amount of hydrogen are typically not made or are grouped under the header chemicals.

A more populated quantification of potentials of hydrogen demand for refining, ammonia and methanol up to 2030 is provided based on an interpretation of Member States' National Energy and Climate Plans (end November 2019)[47]. This study is performed by Trinomics. An overview of the results of hydrogen demand in strategies and NCEPs are shown in Table 11 to Table 13. It is considered an important source of information as it is based on the Member States' 10-year energy and climate plans.

Long term projections (2040–2050) are generally developed as part of literature studies and an overview of several penetration and technology scenarios is presented in Table 10. The markets addressed are the current markets for which the products are being used, and do not include new markets like transport fuel or plastics. An important reflection that needs to be made here is that the maximum scenario is not based on information from the literature studies, but on the REDIII proposal that at least 50% of the hydrogen that is used in replaced by green hydrogen in 2030.

An **important consideration** that is often not reflected in the penetration scenarios but is referred to in studies is the **import of hydrogen**. The main routes considered for hydrogen import are as liquified hydrogen or as hydrogen carriers, mainly being ammonia or methanol. The dehydrogenation of

[46] https://www.pbl.nl/sites/default/files/downloads/pbl-2019-decarbonisation-options-for-the-dutch-fertiliser-industry_3657.pdf
[47] https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans

hydrogen carriers is adding a considerable cost to the final costs of hydrogen, and it is in generally viewed that before dehydrogenation, markets for ammonia and methanol should be facilitated by the green ammonia/methanol obtained through import directly. It could therefore be envisaged that the **domestic demand for hydrogen for the synthesis of ammonia and methanol may become obsolete** when the import of these carriers takes off.

The implementation scenarios for green hydrogen in refineries is scare but considering the close relationship of refineries with the production of methanol (from naphtha), the scenarios applied to methanol will be taken for refineries as well, except for the maximum scenario as refineries to not seem to fall under the industry targets of the REDIII proposal.

The final minimum and maximum green hydrogen penetration scenarios selected are shown in Table 9. The minimum scenario is based on literature studies, whereas the maximum scenario is based on the green hydrogen penetration rates as currently foreseen in the draft REDIII proposal.

Table 9: Overview of minimum and maximum scenario selected for the calculation of the final hydrogen demand for refineries, ammonia and methanol production

| | | Demand | | Green $H_2$ penetration | | |
|---|---|---|---|---|---|---|
| | | % change 2050 | | 2030 | 2040 | 2050 |
| **Refineries** | | | | | | |
| **Minimum penetration scenario** | | **-15%** | | **0%** | **20%** | **80%** |
| **Maximum penetration scenario** | | **-15%** | | **7%** | **40%** | **100%** |
| **Ammonia** | | | | | | |
| **Minimum penetration scenario** | | **0%** | | **0%** | **15%** | **40%** |
| **Maximum penetration scenario** | | **0%** | | **50%** | **80%** | **100%** |
| **Methanol** | | | | | | |
| **Minimum penetration scenario** | | **0%** | | **0%** | **20%** | **80%** |
| **Maximum penetration scenario** | | **0%** | | **50%** | **80%** | **100%** |

Based on these scenarios, the final demand for green hydrogen is shown in Table 14 (refineries), Table 15 (ammonia) and Table 16 (methanol). A geographical representation of the hydrogen demand in 2050 is shown in Figure 19 (refineries), Figure 20 (ammonia) and Figure 21 (methanol).

The demand for hydrogen in the Benelux and its neighbouring regions for refineries, methanol and ammonia production is 25%, 35% and 65% respectively of the total hydrogen demand for these sectors in Europe.

Table 10: Overview of literature studies assessed and hydrogen uptake scenarios selected

| Study | Parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| | Scope | Demand | Efficiency | Green $H_2$ penetration | | | Fuel mix |
| | | % change 2050 | 2050 | 2030 | 2040 | 2050 | 2050 |
| **Refineries** | | | | | | | |
| CLIMACT (2021) | - | -15% | +10% | - | - | - | Synfuels, CO2 capture |
| Trinomics (2021) | - | - | - | 16%-24% | - | - | |
| **Ammonia** | | | | | | | |
| European Hydrogen Backbone (2022) | EU, MS | 0% | - | 7% | 50% | 100% | Green & blue hydrogen |
| Trinomics (2021) | EU, MS | +10% | - | 0-5% | - | - | |
| CLIMACT (2020) | Flanders | 0% | +25% | 0% | 15% | 40% | Biofuels/synfuels + CCUS |
| Jülich (2021) | NRW | 0% | - | 30% | 80% | 100% | Green & blue hydrogen |
| IPTS (2021) | NL | - | - | - | - | 100% | |
| Pessimistic $H_2$ penetration scenario | | 0% | | 0% | 0% | 0% | |
| Low $H_2$ penetration scenario | | 0% | | 0% | 15% | 40% | |
| High $H_2$ penetration scenario | | 0% | | 7% | 50% | 100% | |
| **Methanol** | | | | | | | |
| CLIMACT (2021) | Flanders | - | - | 0% | 20% | 80% | CCUS |
| Trinomics (2021) | EU, MS | +15% | - | 0-7% | - | - | |
| Jülich (2021) | NRW | 0% | - | 10% | 40% | 100% | Green & blue hydrogen |
| IPTS (2021) | NL | - | - | - | - | 100% | |
| Pessimistic $H_2$ penetration scenario | | 0% | | 0% | 0% | 0% | |
| Low $H_2$ penetration scenario | | 0% | | 0% | 20% | 80% | |
| High $H_2$ penetration scenario | | 0% | | 7% | 40% | 100% | |

Table 11: Summary of quantitative hydrogen demand data for the refineries extracted from national and regional strategies, plan and literature

| REFINERIES | | | | | |
|---|---|---|---|---|---|
| Country | Current demand | National/regional strategies | | | NECP $H_2$ |
| Year | 2020 | 2030 | 2040 | 2050 | 2030 |
| Hydrogen demand | kton/y | | | | |
| Netherlands | 562 | - | - | - | 42 – 68 |
| Belgium | 168 | - | - | - | 11 – 16 |
| Luxembourg | 0 | - | - | - | 0 |
| France | 236 | - | - | - | 23 – 40 |
| 2 French states | 0 | - | - | - | - |
| Hauts-de France | 0 | - | - | - | - |
| Grand Est | 0 | - | - | - | - |
| Germany | 737 | - | - | - | 24 – 61 |
| 4 German states | 251 | - | - | - | - |
| Lower Saxony | 55 | - | - | - | - |
| North Rhine-Westphalia | 196 | - | - | - | - |
| Rhineland-Palatinate | 0 | - | - | - | - |
| Saarland | 0 | - | - | - | - |
| Benelux | 730 | - | - | - | - |
| Benelux + Neighbouring regions | 982 | - | - | - | - |
| Europe | 3,987 | - | - | - | - |

Table 12: Summary of quantitative hydrogen demand data for ammonia extracted from national and regional strategies, plan and literature

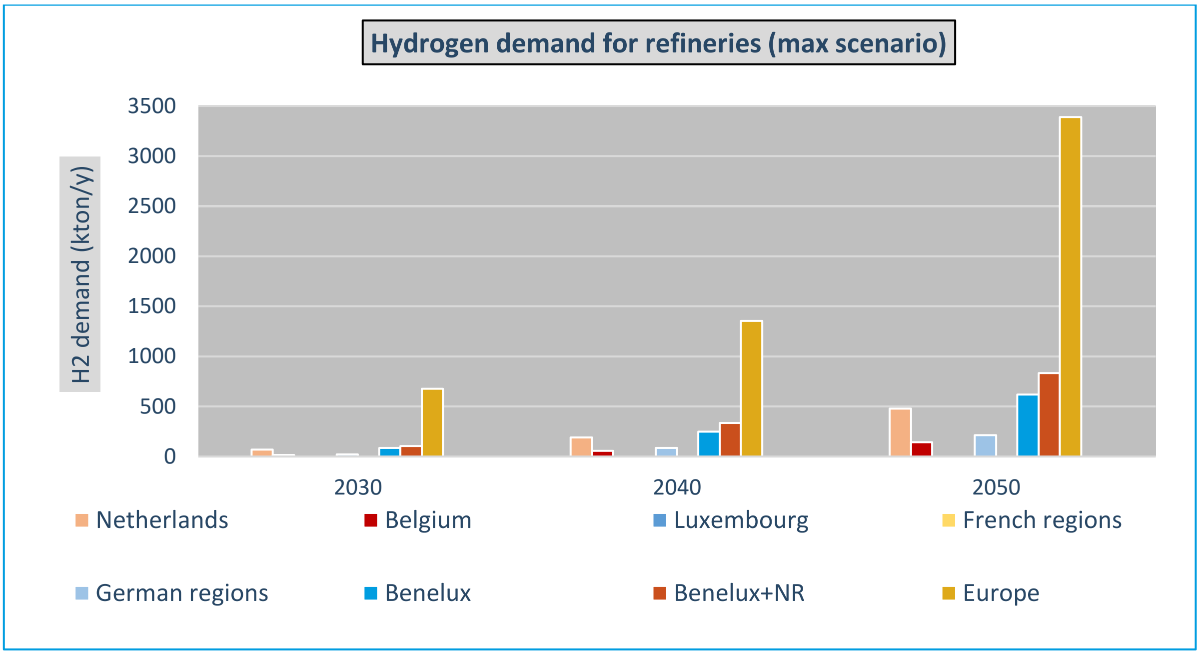
| AMMONIA | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Country | Current demand | National/regional strategies | | | NECP $H_2$ | European Hydrogen Backbone (EHB) | | |
| Year | 2020 | 2030 | 2040 | 2050 | 2030 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | | | |
| Netherlands | 534 | - | - | - | 0 – 21.2 | 57 | 304 | 380 |
| Belgium | 196 | - | - | - | 0 – 7.9 | 29 | 152 | 190 |
| Luxembourg | 0 | - | - | - | 0 | 0 | 0 | 0 |
| France | 186 | - | - | - | 0 – 9.6 | 33 | 176 | 220 |
| 2 French states | 116 | - | - | - | - | - | - | - |
| Hauts-de France | 0 | - | - | - | - | - | - | - |
| Grand Est | 116 | - | - | - | - | - | - | - |
| Germany | 557 | - | - | - | 0 – 21.2 | 28 | 333 | 556 |
| 4 German states | 218 | - | - | - | - | - | - | - |
| Lower Saxony | 0 | - | - | - | - | - | - | - |
| North Rhine-Westphalia | 62 | - | - | - | - | - | - | - |
| Rhineland-Palatinate | 156 | 30% | 80% | 100% | - | - | - | - |
| Saarland | 0 | - | - | - | - | - | - | - |
| Benelux | 730 | - | - | - | - | 86 | 456 | 570 |
| Benelux + Neighbouring regions | 1,064 | - | - | - | - | | | |
| Europe | 3,080 | - | - | - | - | 170 | 1,367 | 3,112 |

Table 13: Summary of quantitative hydrogen demand data for methanol extracted from national and regional strategies, plan and literature

| METHANOL | | | | | |
|---|---|---|---|---|---|
| Country | Current demand | National/ regional strategies | | | NECP $H_2$ |
| Year | 2020 | 2030 | 2040 | 2050 | 2030 |
| Hydrogen demand | kton/y | | | | |
| Netherlands | 124 | - | - | - | 1.2 – 4.4 |
| Belgium | 0 | - | - | - | 0 – 0.03 |
| Luxembourg | 0 | - | - | - | 0 |
| France | 1.3 | - | - | - | 0 – 0.1 |
| 2 French states | 0 | - | - | - | - |
| Hauts-de France | 0 | - | - | - | - |
| Grand Est | 0 | - | - | - | - |
| Germany | 226 | - | - | - | 0 – 7.4 |
| 4 German states | 144 | - | - | - | |
| Lower Saxony | 0 | - | - | - | - |
| North Rhine-Westphalia | 88 | 10% | 40% | 100% | - |
| Rhineland-Palatinate | 56 | - | - | - | - |
| Saarland | 0 | - | - | - | - |
| Benelux | 124 | - | - | - | - |
| Benelux + Neighbouring regions | 268 | - | - | - | - |
| Europe | 413 | - | - | - | - |

Table 14: Final demand growth selected for refineries

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Refineries | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 42 | 96 | 382 | 68 | 191 | 478 |
| Belgium | 11 | 29 | 114 | 16 | 57 | 143 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 23 | 40 | 160 | 40 | 80 | 201 |
| 2 French states | 0 | 0 | 0 | 0 | 0 | 0 |
| Hauts-de France | 0 | 0 | 0 | 0 | 0 | 0 |
| Grand Est | 0 | 0 | 0 | 0 | 0 | 0 |
| Germany | 24 | 125 | 501 | 61 | 251 | 626 |
| 4 German states | 8 | 43 | 171 | 21 | 86 | 214 |
| Lower Saxony | 2 | 9 | 37 | 5 | 19 | 47 |
| North Rhine-Westphalia | 6 | 33 | 134 | 16 | 67 | 167 |
| Rhineland-Palatinate | 0 | 0 | 0 | 0 | 0 | 0 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 53 | 124 | 496 | 84 | 248 | 621 |
| Benelux + Neighbouring regions | 61 | 167 | 667 | 112 | 334 | 834 |
| Europe | 380 | 678 | 2711 | 678 | 1356 | 3389 |


Hydrogen demand for refineries (max scenario)
H2 demand (kton/y)
3500
3000
2500
2000
1500
1000
500
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

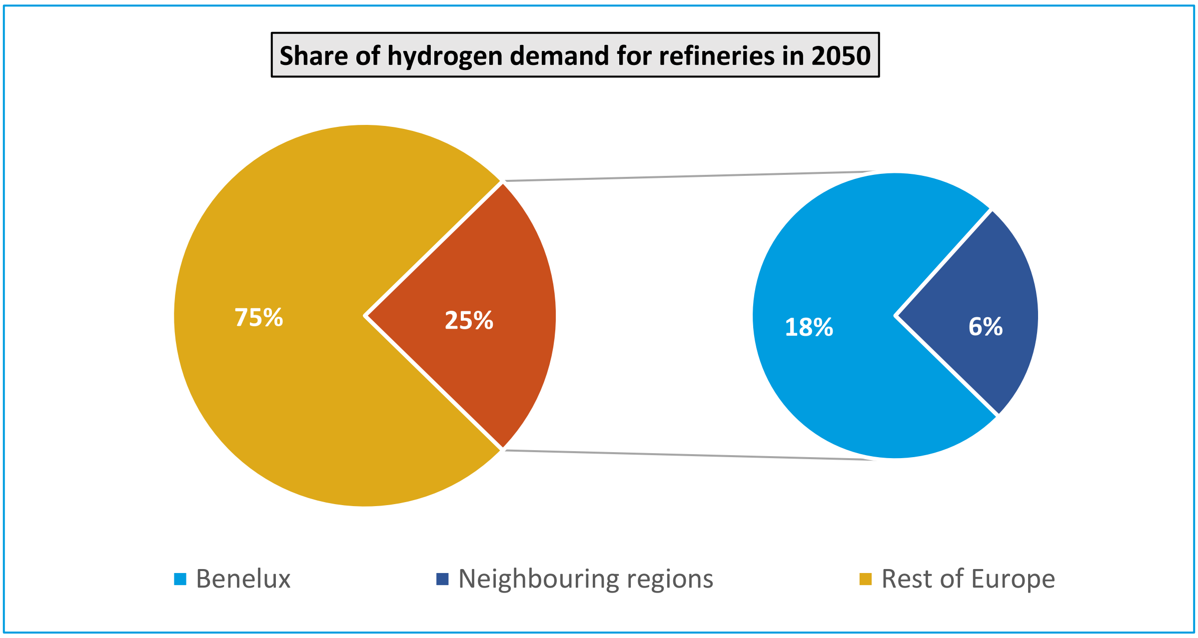
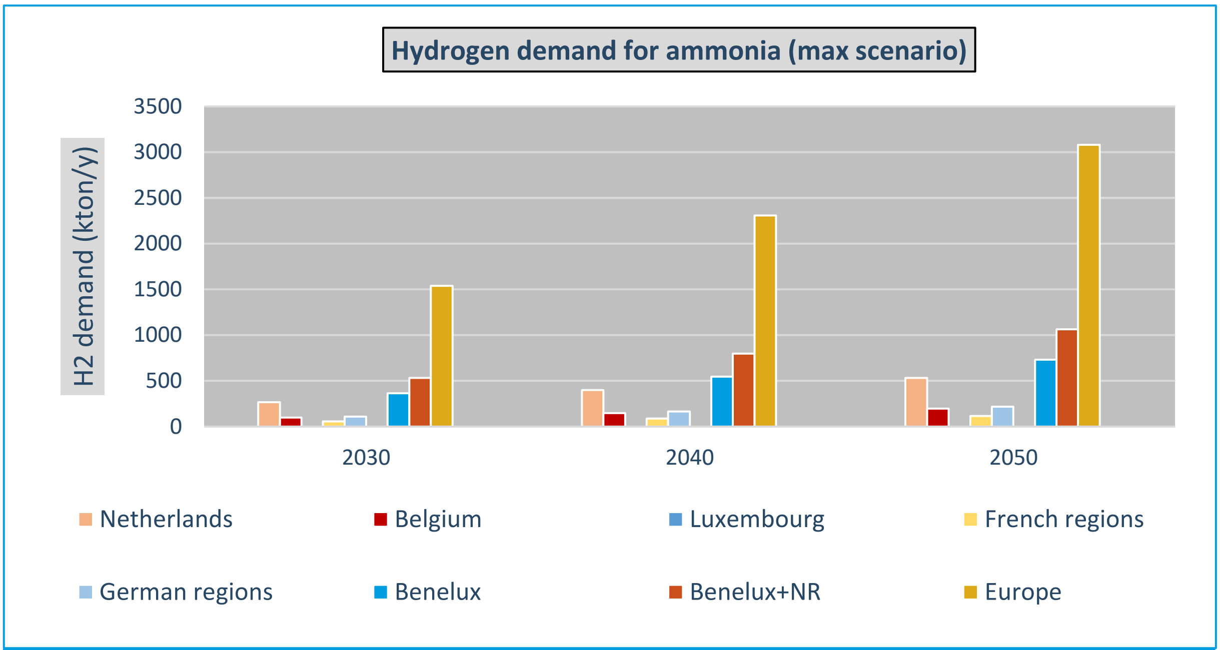
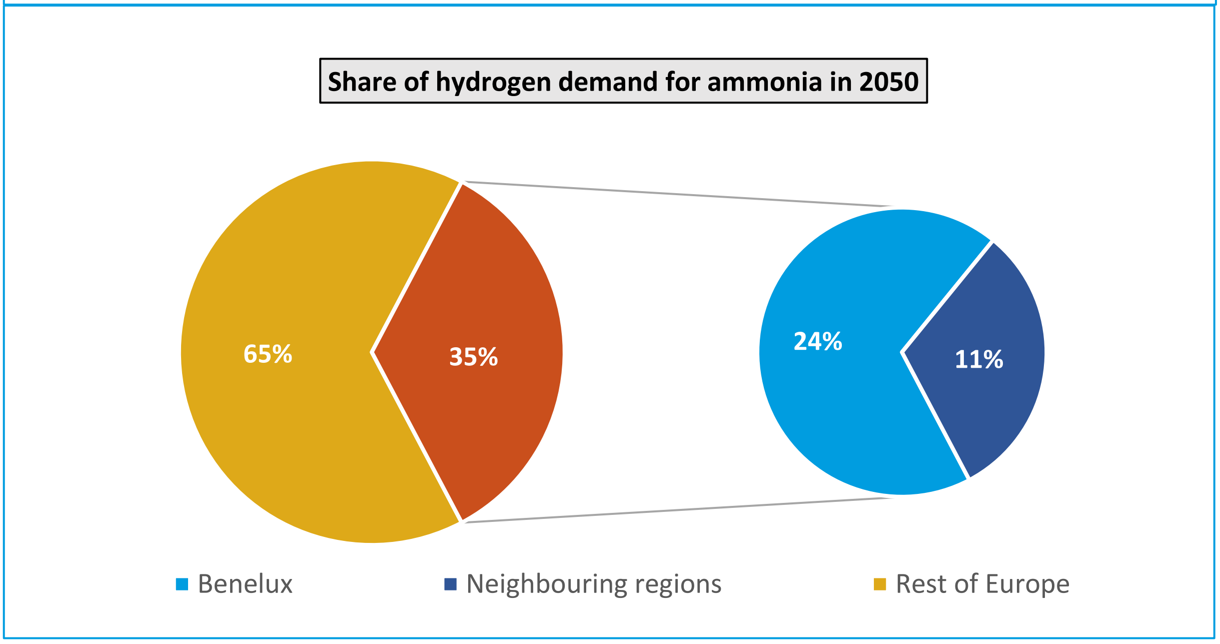

Share of hydrogen demand for refineries in 2050
75%
25%
18%
6%
Benelux
Neighbouring regions
Rest of Europe

Table 15: Final hydrogen demand selected for ammonia

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Ammonia | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 80 | 214 | 267 | 401 | 534 |
| Belgium | 0 | 29 | 78 | 98 | 147 | 196 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 0 | 28 | 74 | 93 | 140 | 186 |
| 2 French states | 0 | 17 | 46 | 58 | 87 | 116 |
| Hauts-de France | 0 | 0 | 0 | 0 | 0 | 0 |
| Grand Est | 0 | 17 | 46 | 58 | 87 | 116 |
| Germany | 0 | 84 | 223 | 279 | 418 | 557 |
| 4 German states | 0 | 33 | 87 | 109 | 164 | 218 |
| Lower Saxony | 0 | 0 | 0 | 0 | 0 | 0 |
| North Rhine-Westphalia | 0 | 9 | 25 | 31 | 47 | 62 |
| Rhineland-Palatinate | 0 | 23 | 62 | 78 | 117 | 156 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 0 | 110 | 292 | 365 | 548 | 730 |
| Benelux + Neighbouring regions | 0 | 160 | 426 | 532 | 798 | 1064 |
| Europe | 0 | 462 | 1232 | 1540 | 2310 | 3080 |



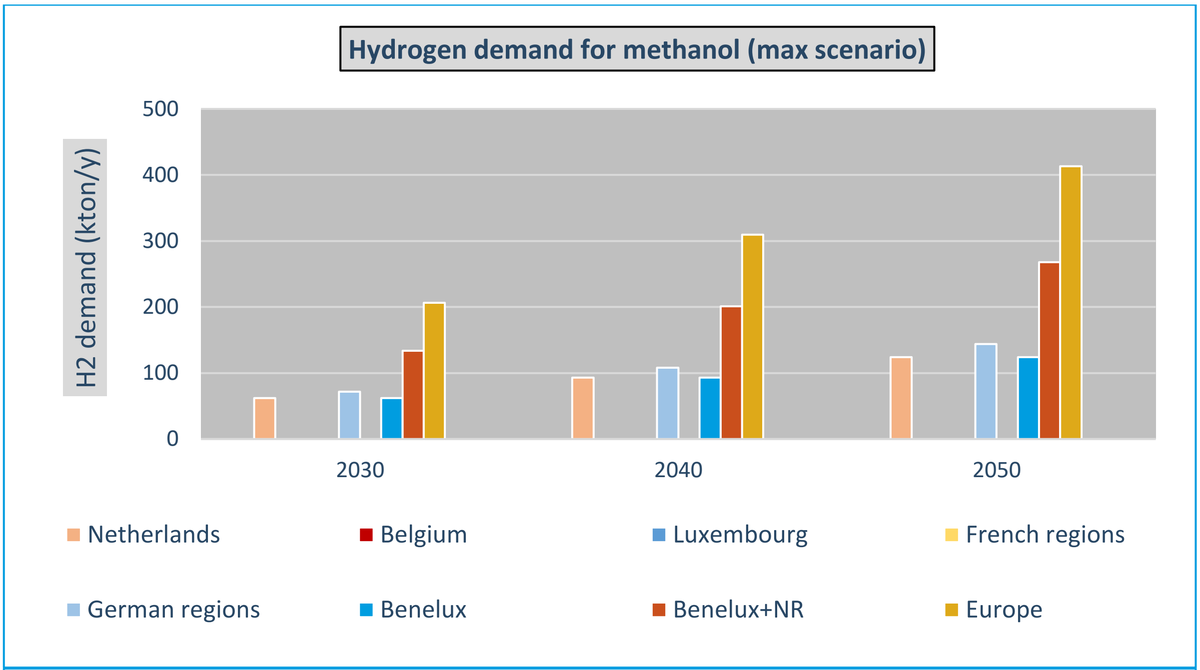
Hydrogen demand for ammonia (max scenario)
H2 demand (kton/y)
3500
3000
2500
2000
1500
1000
500
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

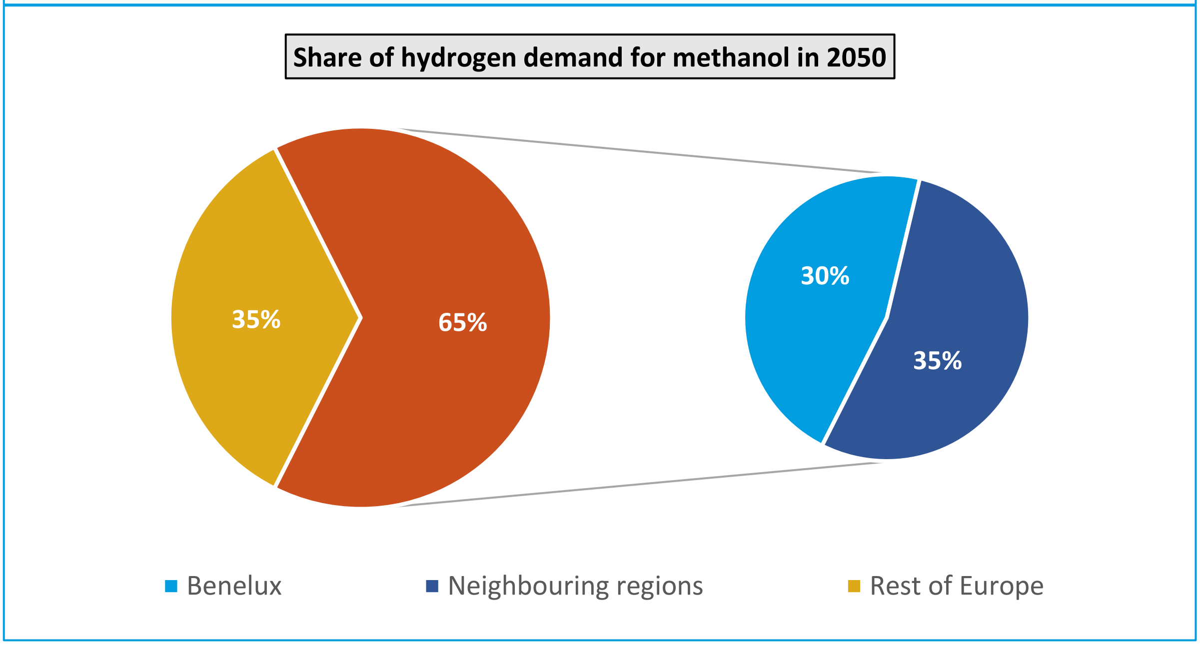



Share of hydrogen demand for ammonia in 2050
65%
35%
24%
11%
Benelux
Neighbouring regions
Rest of Europe

Table 16: Final demand growth selected for methanol

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Methanol | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 25 | 99 | 62 | 93 | 124 |
| Belgium | 0 | 0 | 0 | 0 | 0 | 0 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 0 | 0 | 1 | 1 | 1 | 1 |
| 2 French states | 0 | 0 | 0 | 0 | 0 | 0 |
| Hauts-de France | 0 | 0 | 0 | 0 | 0 | 0 |
| Grand Est | 0 | 0 | 0 | 0 | 0 | 0 |
| Germany | 0 | 45 | 181 | 113 | 170 | 226 |
| 4 German states | 0 | 29 | 115 | 72 | 108 | 144 |
| Lower Saxony | 0 | 0 | 0 | 0 | 0 | 0 |
| North Rhine-Westphalia | 0 | 18 | 70 | 44 | 66 | 88 |
| Rhineland-Palatinate | 0 | 11 | 45 | 28 | 42 | 56 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 0 | 25 | 99 | 62 | 93 | 124 |
| Benelux + Neighbouring regions | 0 | 54 | 214 | 134 | 201 | 268 |
| Europe | 0 | 83 | 330 | 207 | 310 | 413 |


Hydrogen demand for methanol (max scenario)
H2 demand (kton/y)
500
400
300
200
100
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe


Share of hydrogen demand for methanol in 2050
35%
65%
30%
35%
Benelux
Neighbouring regions
Rest of Europe

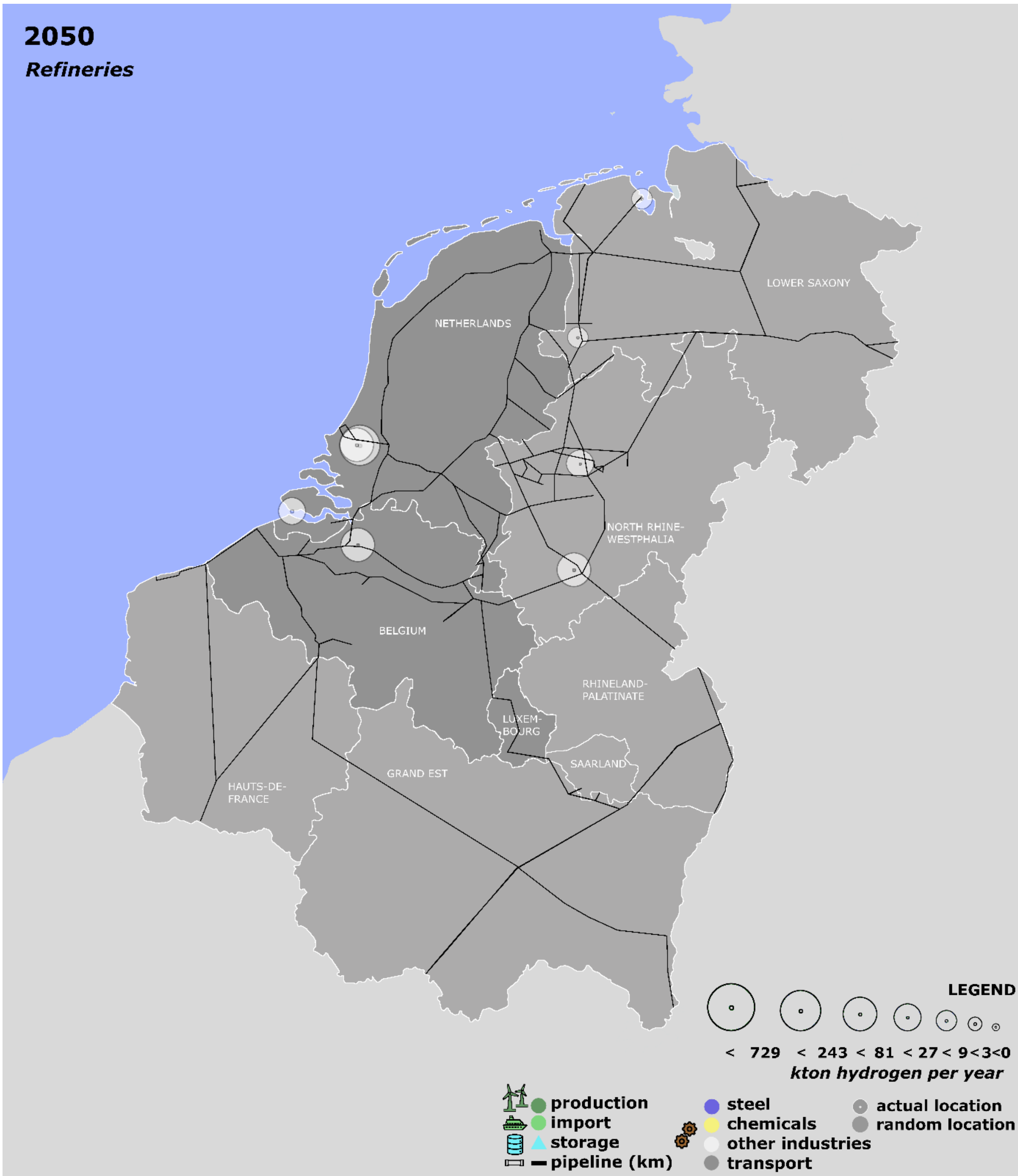



Figure 19: Geographical representation of hydrogen demand for refineries in 2050 (maximum scenario)

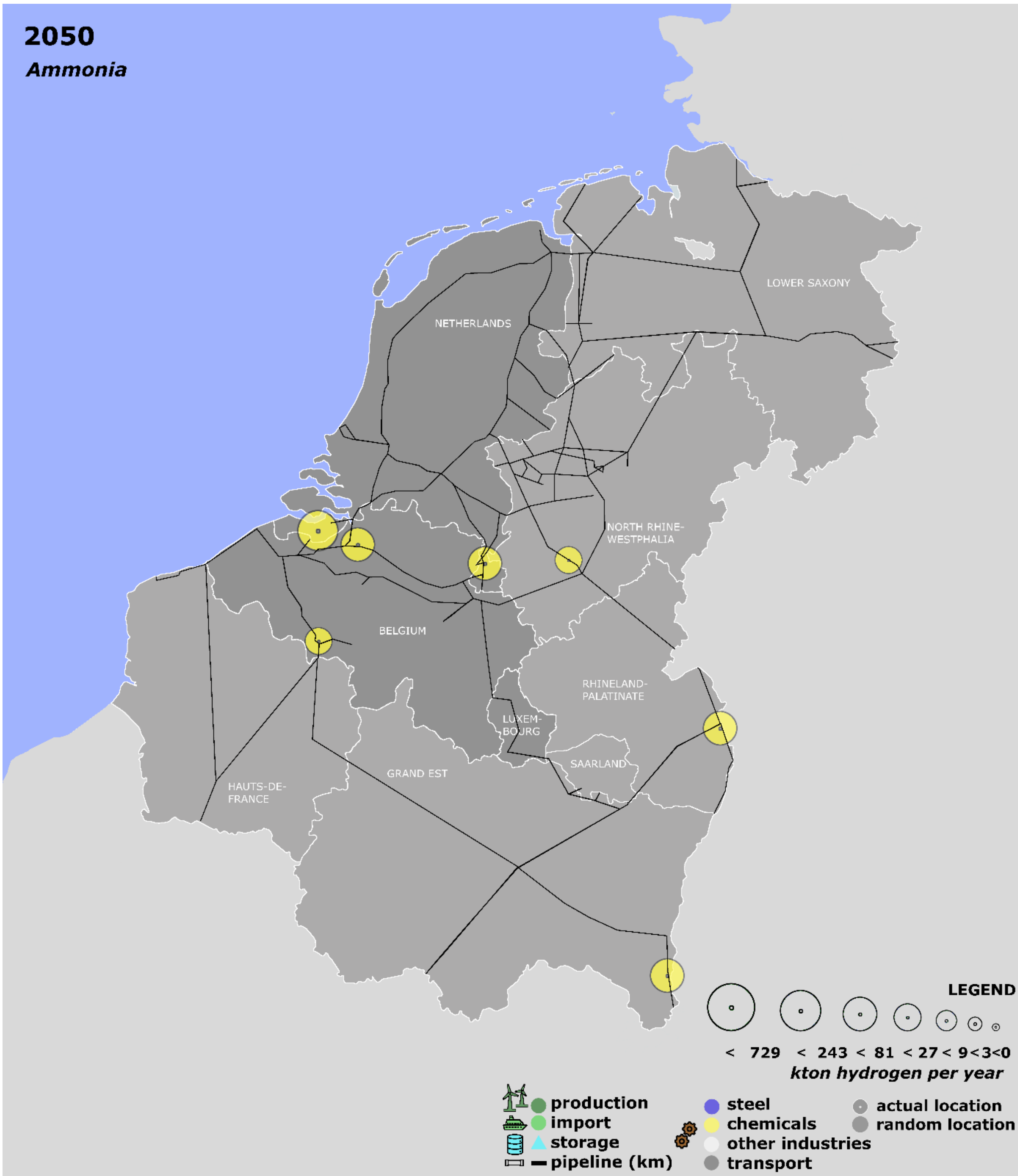



Figure 20: Geographical representation of hydrogen demand for ammonia in 2050 (maximum scenario)

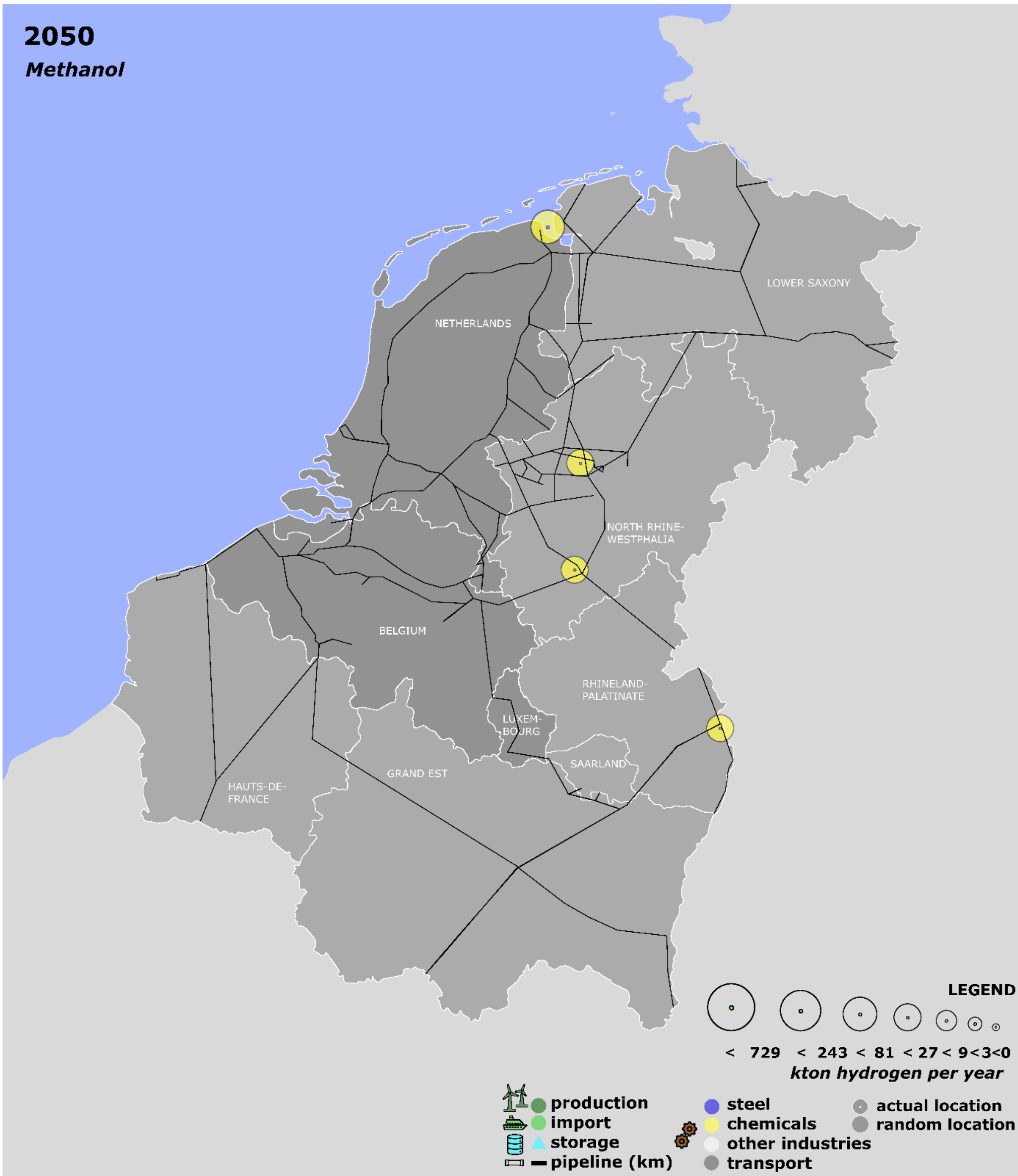



Figure 21: Geographical representation of hydrogen demand for methanol in 2050 (maximum scenario)

## 6.3 CEMENT, OLEFINS, AROMATICS AND HEAT

### Status of the sector in the Benelux and neighbouring regions

The cement sector is not a very transparent sector in terms of production volumes and plant capacities; hence the assessment of production capacities is approximated. A bottom-up approach could not be applied and hence the cement production capacity of the country[48] is taken and equally distributed over the share of integrated plants (IP), clinker plants (CP) and griding plants (GP) in the neighbouring regions. It is estimated that the **share of the production capacity of cement industry in the Benelux and its neighbouring regions is 5% and 15% respectively in comparison to Europe**.

The production volumes of olefins (ethylene, propylene, butylene used for chemical and polymer products) and aromatics (benzene, toluene and the xylenes used for consumer products) are obtained from Trinomics[49]. Olefins are predominantly created through steam cracking of naphtha/LPG and aromatics through catalytic reforming of naphtha. An estimate of the production volumes at the neighbouring regions for olefins is based on the share of steam cracker capacity[50] in the region compared to the national production capacity. An estimate of the production volumes at the neighbouring regions for aromatics is based on the share of refinery capacity[51] in the region compared to the national production capacity. The **production capacity of olefins is predominantly represented in the Benelux and its neighbouring regions as 28% and 51% of the European production capacity** is hosted in the regions, whereas the **production capacity of aromatics is predominantly represented as well in the Benelux and its neighbouring regions as 23% and 42% of the European production capacity** is hosted in the regions.

The users of high temperature heat are very dispersed and difficult to map. The quantification of the hydrogen demand as a replacement for natural gas for high temperature heat demand is performed in the frame of the hydrogen demand analysis in the European Hydrogen Backbone study. Hence, the penetration of hydrogen for high temperature heat is taken from this study and therefore no stock taking of high temperature heat demand is performed.

An overview of the production volumes and the distribution across the Benelux and the neighbouring countries in shown in Table 17.

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[48] https://www.statista.com/statistics/1291068/european-cement-production-volume-by-country/#:~:text=Turkey%20was%20the%20largest%20producer,nearly%2035.5%20million%20metric%20tons.

[49] https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans

[50] https://www.petrochemistry.eu/about-petrochemistry/petrochemicals-facts-and-figures/cracker-capacity/

[51] https://www.concawe.eu/refineries-map/

Table 17: Number of plants, plant capacities and plant capacity shares for cement, olefins and aromatics production in the Benelux, the neighbouring regions and Europe.

| Country | # of Plants | | | Production volume | % Share of Capacity | | Production volume | % Share of Capacity | | Production volume | % Share of Capacity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | | | | | | Olefins | | | Aromatics | | |
| | IP | CP | GP | | | | | | | | | |
| | | # | | kton/y | % | % | kton/y | % | % | kton/y | % | % |
| Netherlands | 0 | 0 | 2 | 2,000 | 1 | 7 | 5,345 | 15 | 30 | 1,462 | 16 | 38 |
| Belgium | 3 | 1 | 4 | 6,000 | 3 | 22 | 4,499 | 13 | 25 | 602 | 7 | 16 |
| Luxembourg | 0 | 1 | 1 | 1,400 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 27 | 0 | 20 | 20,000 | 12 | | 5,047 | 15 | | 840 | 9 | |
| 2 French states | 6 | 0 | 4 | 4,400 | 2 | 16 | 687 | 2 | 4 | 0 | 0 | 0 |
| Hauts-de France | 2 | 0 | 3 | 1,500 | 1 | 6 | 687 | 2 | 4 | 0 | 0 | 0 |
| Grand Est | 4 | 0 | 1 | 2,900 | 1 | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| Germany | 33 | 0 | 18 | 30,000 | 17 | | 10,849 | 31 | | 2,712 | 30 | |
| 4 German states | 14 | 0 | 7 | 13,000 | 8 | 49 | 7,292 | 21 | 41 | 926 | 10 | 24 |
| Lower Saxony | 2 | 0 | 0 | 1,900 | 1 | 7 | 0 | 0 | 0 | 203 | 2 | 5 |
| North Rhine-Westphalia | 10 | 0 | 5 | 9,200 | 6 | 35 | 5,846 | 17 | 33 | 723 | 8 | 19 |
| Rhineland-Palatinate | 2 | 0 | 2 | 1,900 | 1 | 7 | 1,446 | 4 | 8 | 0 | 0 | 0 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 3 | 2 | 7 | 9,400 | 5 | 35 | 9,844 | 28 | 55 | 2,064 | 23 | 69 |
| Benelux + Neighbouring regions | 23 | 0 | 19 | 26,700 | 15 | 100 | 17,823 | 51 | 100 | 3,830 | 42 | 100 |
| Europe | | | | 173,300 | 100 | 649 | 34,619 | 100 | 194 | 9,169 | 100 | 239 |

## The role for hydrogen/derivatives for cement, olefins, aromatics and high temperature heat

The **cement industry** is one of the sectors that requires high temperature heat and has intrinsic $CO_2$ process emissions. The direct demand for hydrogen comes for the provision of heat, whereas an indirect demand for hydrogen can be envisaged in order to convert the intrinsic $CO_2$ process emission to a synthetic fuel, e.g., synthetic methanol. The latter option is considered to be rather unlikely by the cement sector.

The hydrogen demand for cement is estimated at **0,03 kton of hydrogen per kton of clinker produced** and **0,002 kton of hydrogen per kton of clinker grinded**[52]. For the methanol synthesis, a hydrogen demand of **0,14 kton per of kton $CO_2$ emissions** is required[53].

The production of olefins and aromatics could provide a significant indirect demand for hydrogen as methanol can be used to produce these chemicals through MTO (methanol-to-olefins) and MTA (methanol-to-aromatics) routes. For the production of 1 kton olefins/aromatics, 3 kton of methanol is required and hence 0,38 kton of hydrogen, so **0,38 kton of hydrogen is required to produce 1 kton of olefins/aromatics**[54].

The replacement of fuel (natural gas, coal) through hydrogen follows a conversion of energy densities. High temperature heat is considered for heat requirements as of 500°C, but during the workshops is also became clear that heat requirements as of 250°C may provide a small segment for hydrogen.

## Sector's decarbonisation perspective

In the 2050 low carbon roadmap of the **cement sector**[55] foresee many decarbonisation options that focussed on the whole value chain. The use of alternative fuels (biomass, and CCUS) is among the main options considered.

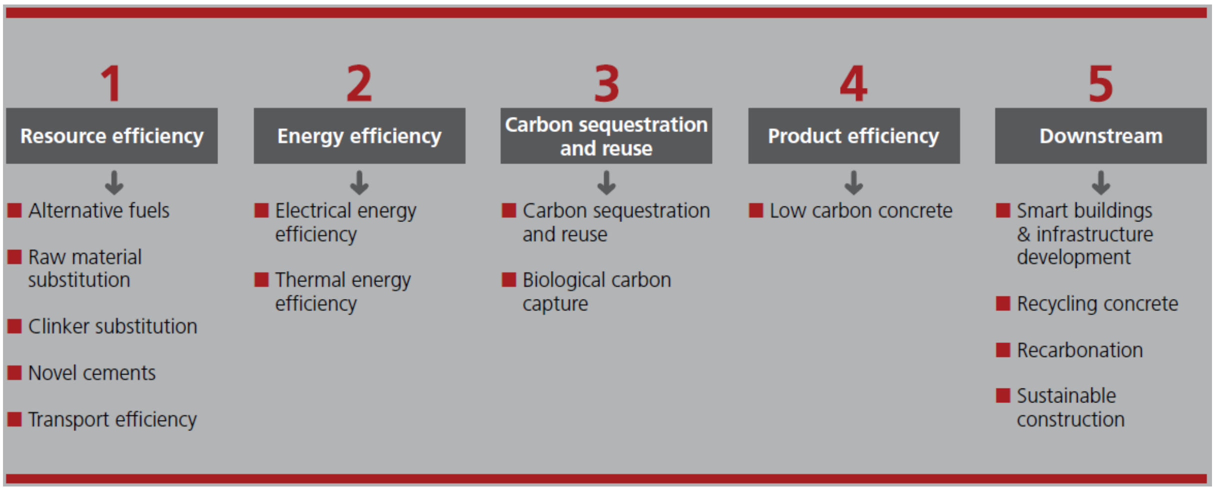



Figure 22: Decarbonisation options for cement sector

52 An average energy consumption of 3.2 and 0.22 GJ/t (grinded) clinker is considered state of the art for the dry process
53 This is based on the chemical production process of methanol
54 https://pubs.acs.org/doi/10.1021/acscatal.5b00007
55 https://cembureau.eu/media/cpvoin5t/cembureau_2050roadmap_lowcarboneconomy_2013-09-01.pdf

The **methanol-to-olefins and methanol-to-aromatics** are relatively new production routes, and these routes are as consider one of many options which include among others use of biomass, ethane steam cracking, electrification, chemical recycling of plastics and propane dehydrogenation[56].

For **high temperature heat**, electric heaters are often considered in parallel to hydrogen however, temperature requirements above 500-800$^{o}$C are considered a prima area of hydrogen. Other fuels like synthetic natural gas are also considered.

### Quantification hydrogen demand in national/regional hydrogen strategies and studies in 2030 – 2050 timeframe

The potential of hydrogen as a source for high temperature heat in the chemical sector is clearly expressed in national and regional hydrogen strategies, but quantifications of the amount of hydrogen are typically not made or are grouped under the header chemicals.  The MTO/MTA route are typically not mentioned, but cement often is as an intrinsic $CO_2$ emitter, but not quantified.

The study performed by Trinomics to quantify the hydrogen demand based on an interpretation of Member States' National Energy and Climate Plans (end November 2019) [57] does include estimates for hydrogen demand for olefins and aromatics and it included in the literature review.

The long-term projections (2030–2050) are generally developed as part of literature studies and an overview of several penetration and technology scenarios is presented in Table 18. For cement, the minimum and maximum hydrogen penetrations scenario is based on the equal adoption of high temperature heat and includes in the maximum penetration scenario methanol synthesis. Considering the dispersed character of the sector, it is assumed that only 10% of the $CO_2$ emission are locally converted to synthetic methanol.

[56] CLIMACT (2021)
[57] https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans

Table 18: Overview of literature studies assessed and hydrogen uptake scenarios selected

| Study | Parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| | Scope | Demand | Efficiency | $H_2$ penetration | | | Fuel mix |
| | | % change 2050 | 2050 | 2030 | 2040 | 2050 | 2050 |
| **Cement** | | | | | | | |
| Low H2 penetration scenario | | 0% | - | 0% | 15% | 25% | Heat |
| High H2 penetration scenario | | 0% | - | 15% | 40% | 50% | Heat |
| Low H2 penetration scenario | | 0% | - | 0% | 20% | 80% | Methanol synthesis, 10% converted |
| High H2 penetration scenario | | 0% | - | 7% | 40% | 100% | Methanol synthesis, 10% converted |
| **Olefins/aromatics** | | | | | | | |
| European Hydrogen Backbone (2021) | | - | - | 5% | 20% | 33% | |
| CLIMACT (2021) | | +15% | - | 0% | 10% | 15% | Ethane cracking, biomass, plastic recycling, electrification |
| Fraunhofer[58] (2019) | | 0% | - | - | - | - | |
| Trinomics (2021) | | - | - | 0 - 1.5% | - | - | |
| Low H2 penetration scenario | | 0% | | 0% | 10% | 15% | |
| High H2 penetration scenario | | 15% | | 5% | 20% | 33% | |
| **High temperature heat** | | | | | | | |
| European Hydrogen Backbone (2021) | | - | - | 15% | 40% | 50% | Replacement of natural gas |
| Low H2 penetration scenario | | 0% | | 0% | 15% | 25% | |
| High H2 penetration scenario | | 0% | | 15% | 40% | 50% | |

[58] https://ec.europa.eu/clima/system/files/2020-07/industrial_innovation_part_2_en.pdf

The final minimum and maximum green hydrogen penetration scenarios selected are shown in Table 19. The hydrogen demand for heat in Luxembourg was updated as part of feedback obtained from the workshops.

Table 19: Overview of minimum and maximum scenario selected for the calculation of the final hydrogen demand for cement, olefins, aromatics and high temperature heat

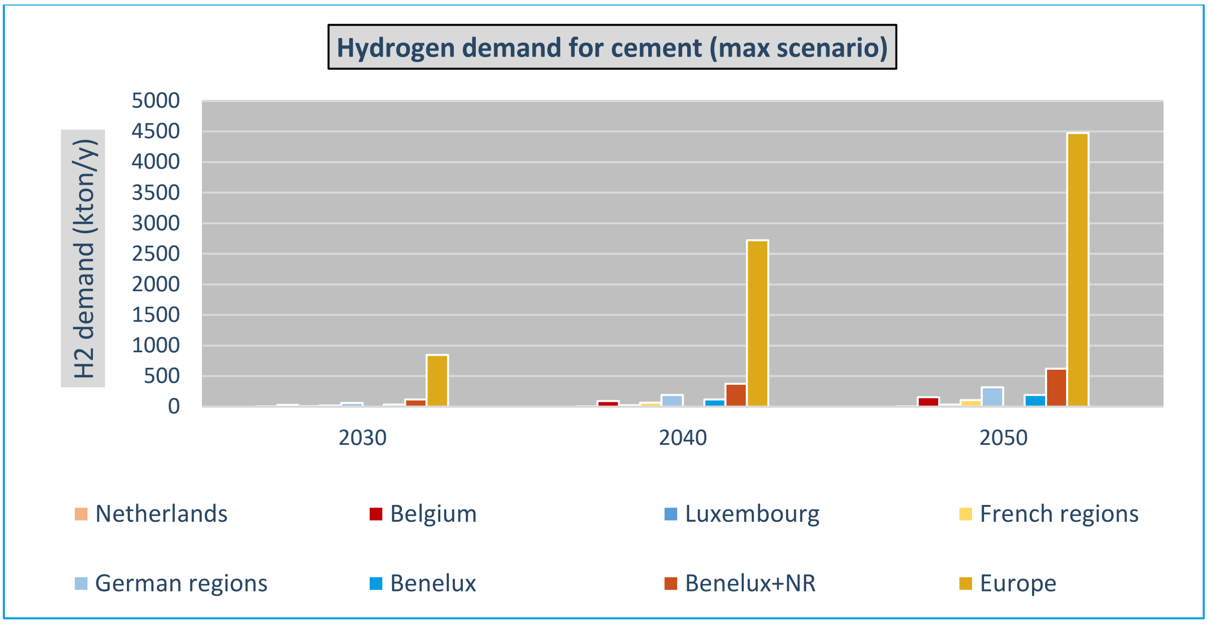
| | | Demand | | Green $H_2$ penetration | | |
|---|---|---|---|---|---|---|
| | | % change 2050 | | 2030 | 2040 | 2050 |
| **Cement** | | | | | | |
| Minimum penetration scenario | | 0% | | 0% | 15% | 25% |
| Maximum penetration scenario | | 0% | + 10% MeOH synthesis | 15% | 40% | 50% |
| **Olefins/aromatics** | | | | | | |
| Minimum penetration scenario | | 0% | | 0% | 10% | 15% |
| Maximum penetration scenario | | 15% | | 5% | 20% | 33% |
| **Heat** | | | | | | |
| Minimum penetration scenario | | 0% | | 0% | 15% | 25% |
| Maximum penetration scenario | | 0% | | 15% | 40% | 50% |

Based on these scenarios, the final demand for green hydrogen is shown in Table 20 (cement), Table 21 (olefins), Table 22 (aromatics) and Table 23 (high temperature heat). A geographical representation of the hydrogen demand in 2050 is shown in Figure 23 (cement), Figure 24 (olefins), Figure 25 (aromatics) and Figure 26 (heat).

The demand for hydrogen in the Benelux and its neighbouring regions for cement, olefins, aromatics and heat is 14%, 51%, 33% and 35% respectively of the total hydrogen demand for these sectors in Europe.

Table 20: Final demand growth selected for cement

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Cement | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 1 | 1 | 1 | 2 | 2 |
| Belgium | 0 | 24 | 40 | 29 | 94 | 154 |
| Luxembourg | 0 | 6 | 9 | 7 | 22 | 36 |
| France | 0 | 79 | 132 | 96 | 309 | 509 |
| 2 French states | 0 | 17 | 28 | 21 | 66 | 109 |
| Hauts-de France | 0 | 6 | 10 | 7 | 23 | 38 |
| Grand Est | 0 | 11 | 19 | 14 | 45 | 74 |
| Germany | 0 | 114 | 190 | 139 | 445 | 733 |
| 4 German states | 0 | 49 | 82 | 60 | 193 | 318 |
| Lower Saxony | 0 | 7 | 12 | 9 | 28 | 46 |
| North Rhine-Westphalia | 0 | 35 | 58 | 43 | 137 | 225 |
| Rhineland-Palatinate | 0 | 7 | 12 | 9 | 28 | 46 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 0 | 30 | 50 | 37 | 117 | 193 |
| Benelux + Neighbouring regions | 0 | 97 | 161 | 117 | 377 | 620 |
| Europe | 0 | 1127 | 2885 | 847 | 2719 | 4477 |


Hydrogen demand for cement (max scenario)
H2 demand (kton/y)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

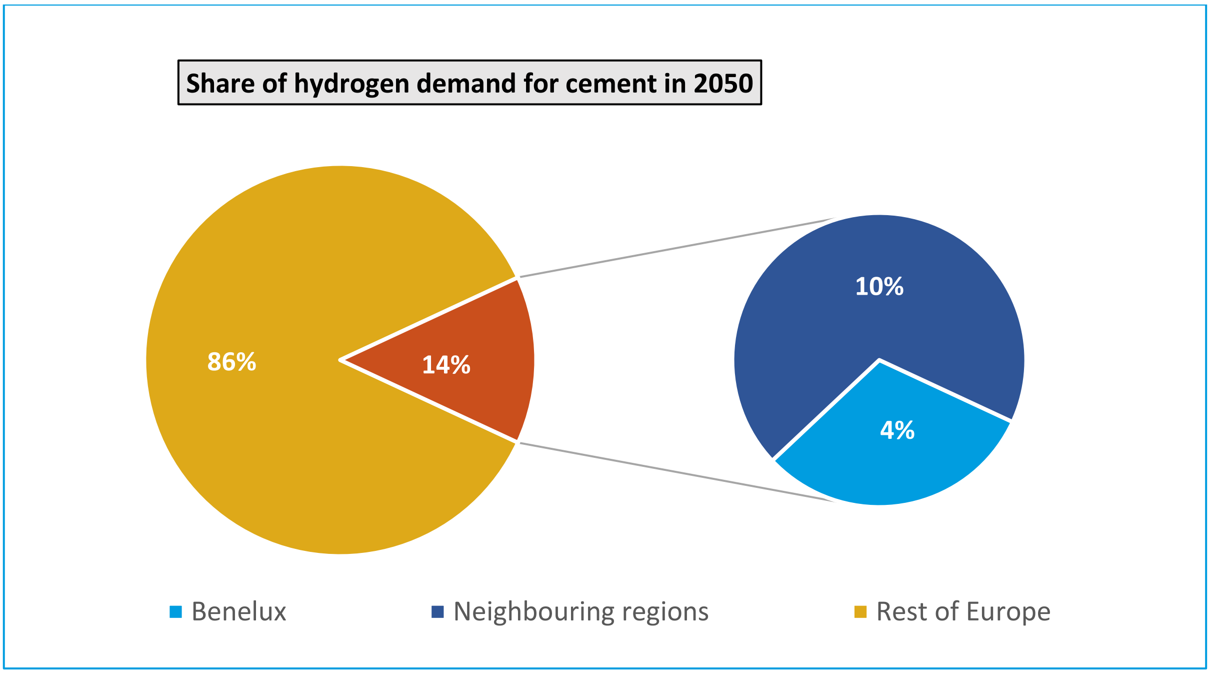
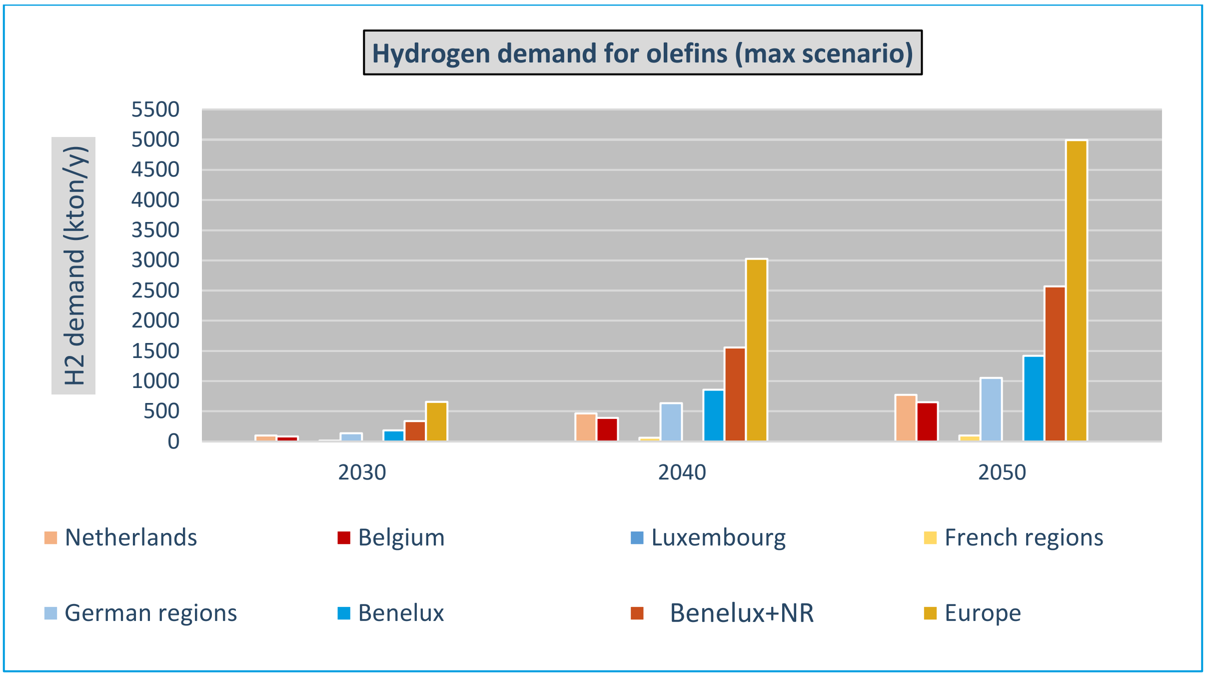

Share of hydrogen demand for cement in 2050
86%
14%
10%
4%
Benelux
Neighbouring regions
Rest of Europe

Table 21: Final demand growth selected for olefins

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Olefins | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 203 | 305 | 102 | 467 | 771 |
| Belgium | 0 | 171 | 256 | 85 | 393 | 649 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 0 | 192 | 288 | 96 | 441 | 728 |
| 2 French states | 0 | 26 | 39 | 13 | 60 | 99 |
| Hauts-de France | 0 | 26 | 39 | 13 | 60 | 99 |
| Grand Est | 0 | 0 | 0 | 0 | 0 | 0 |
| Germany | 0 | 412 | 618 | 206 | 948 | 1565 |
| 4 German states | 0 | 277 | 416 | 139 | 637 | 1052 |
| Lower Saxony | 0 | 0 | 0 | 0 | 0 | 0 |
| North Rhine-Westphalia | 0 | 222 | 333 | 111 | 511 | 843 |
| Rhineland-Palatinate | 0 | 55 | 82 | 27 | 126 | 209 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 0 | 374 | 561 | 187 | 860 | 1420 |
| Benelux + Neighbouring regions | 0 | 677 | 1016 | 339 | 1558 | 2570 |
| Europe | 0 | 1316 | 1973 | 658 | 3026 | 4992 |


Hydrogen demand for olefins (max scenario)
H2 demand (kton/y)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

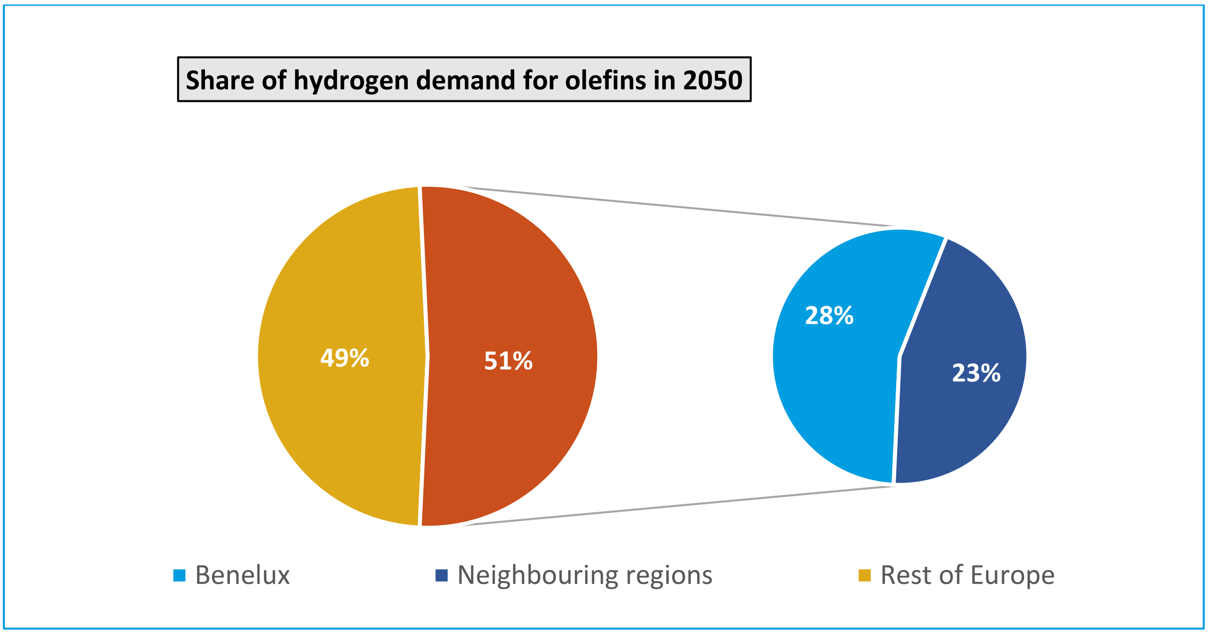
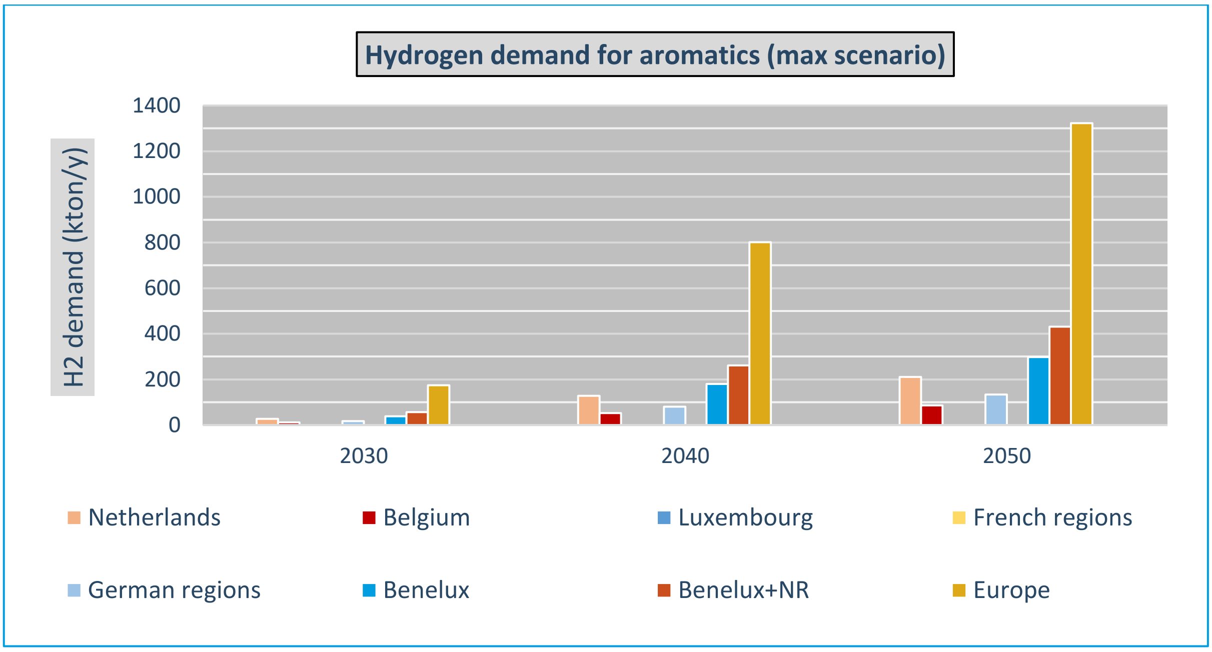

Share of hydrogen demand for olefins in 2050
49%
51%
28%
23%
Benelux
Neighbouring regions
Rest of Europe

Table 22: Final demand growth selected for aromatics

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Aromatics | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 56 | 83 | 28 | 128 | 211 |
| Belgium | 0 | 23 | 34 | 11 | 53 | 87 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 0 | 32 | 48 | 16 | 73 | 121 |
| 2 French states | 0 | 0 | 0 | 0 | 0 | 0 |
| Hauts-de France | 0 | 0 | 0 | 0 | 0 | 0 |
| Grand Est | 0 | 0 | 0 | 0 | 0 | 0 |
| Germany | 0 | 103 | 155 | 52 | 237 | 391 |
| 4 German states | 0 | 35 | 53 | 18 | 81 | 134 |
| Lower Saxony | 0 | 8 | 12 | 4 | 18 | 29 |
| North Rhine-Westphalia | 0 | 27 | 41 | 14 | 63 | 104 |
| Rhineland-Palatinate | 0 | 0 | 0 | 0 | 0 | 0 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 0 | 78 | 118 | 39 | 180 | 298 |
| Benelux + Neighbouring regions | 0 | 114 | 170 | 57 | 261 | 431 |
| Europe | 0 | 348 | 523 | 174 | 801 | 1322 |


Hydrogen demand for aromatics (max scenario)
H2 demand (kton/y)
1400
1200
1000
800
600
400
200
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

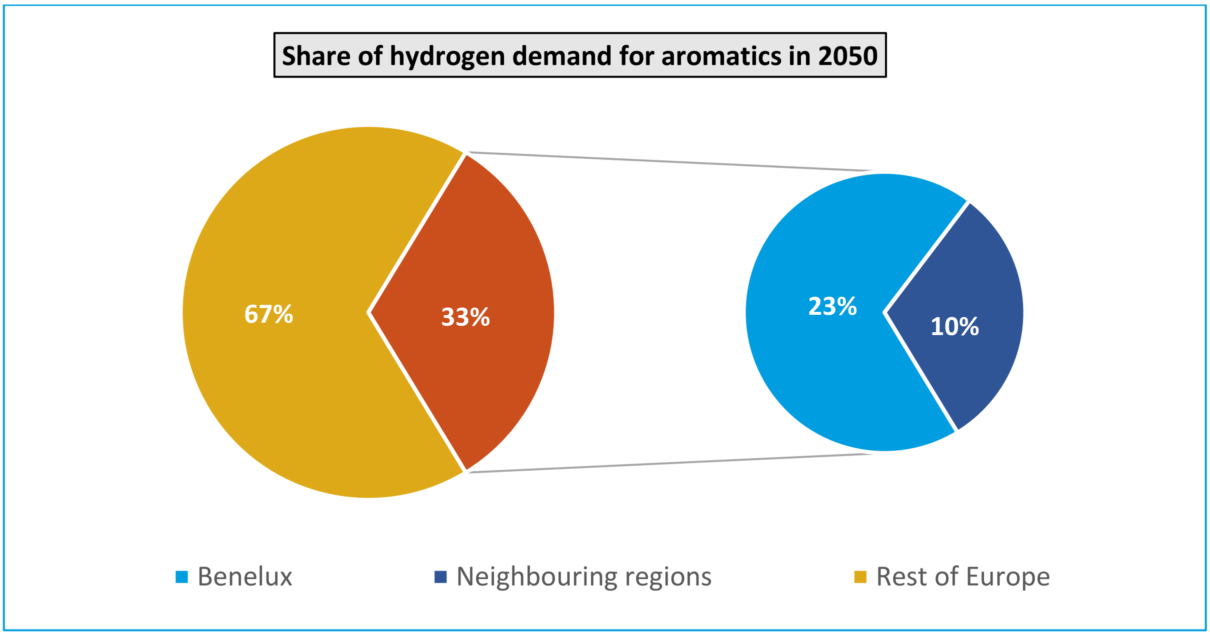
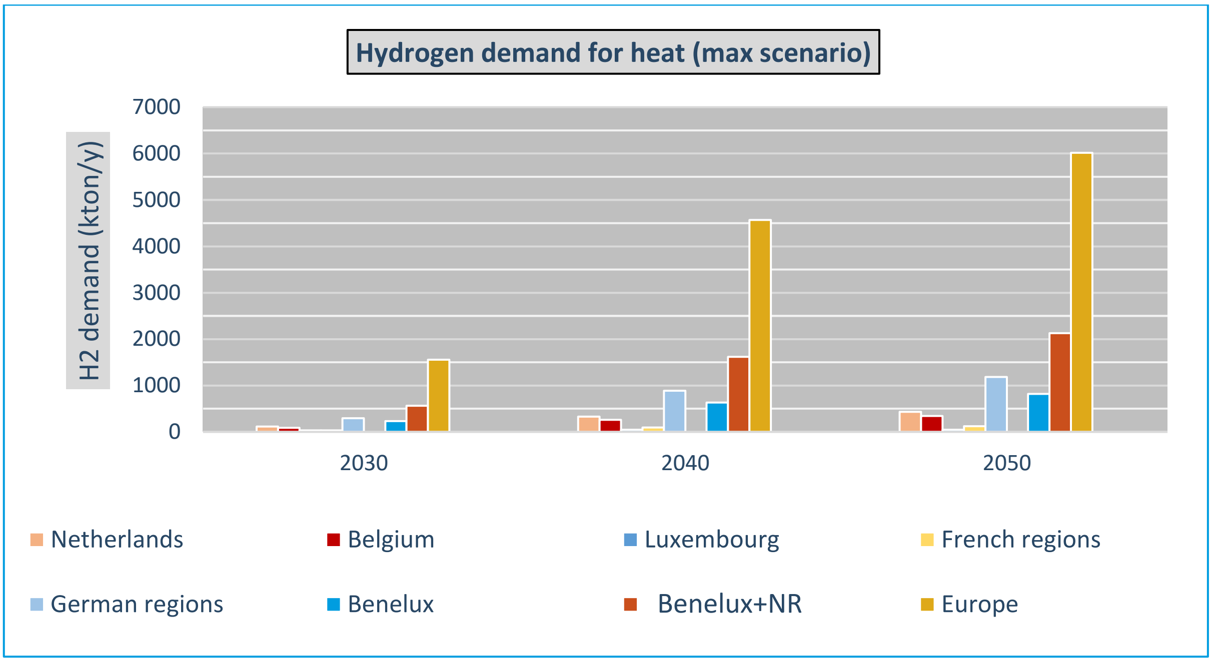
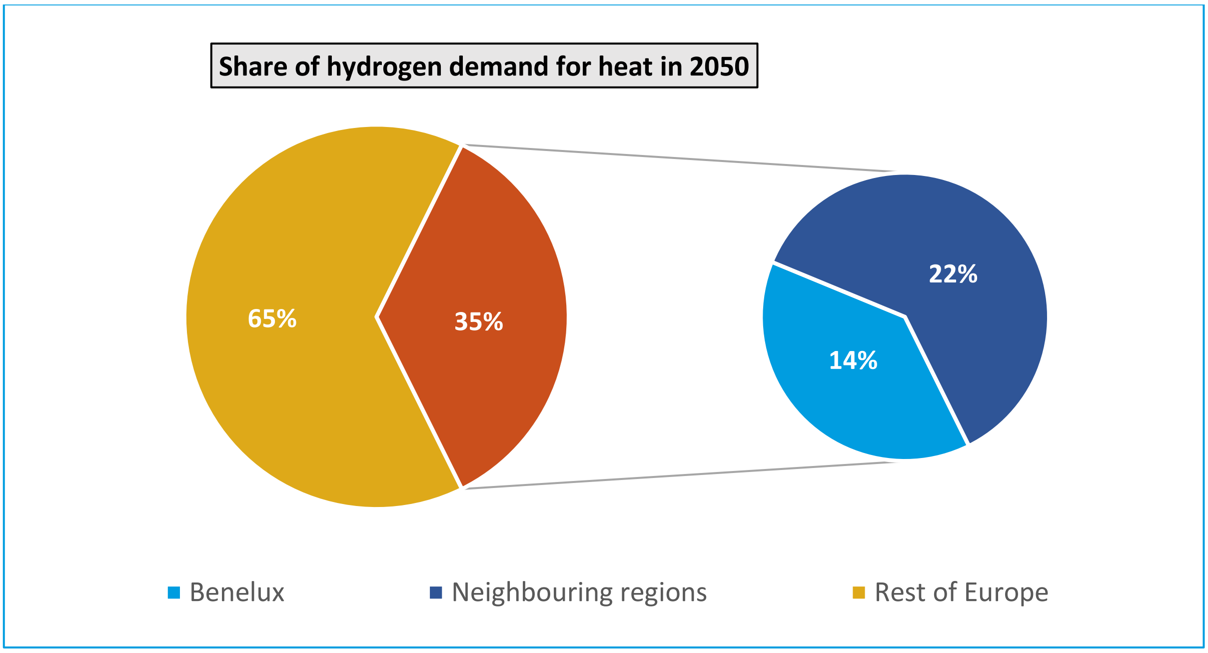

Share of hydrogen demand for aromatics in 2050
67%
33%
23%
10%
Benelux
Neighbouring regions
Rest of Europe

Table 23: Final demand growth selected for high temperature heat

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Heat | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 113 | 215 | 113 | 328 | 430 |
| Belgium | 0 | 91 | 171 | 91 | 262 | 341 |
| Luxembourg | 0 | 17 | 25 | 11 | 26 | 29 |
| France | 0 | 158 | 308 | 158 | 467 | 616 |
| 2 French states | 0 | 32 | 62 | 32 | 93 | 123 |
| Hauts-de France | 0 | 16 | 31 | 16 | 47 | 62 |
| Grand Est | 0 | 16 | 31 | 16 | 46 | 61 |
| Germany | 0 | 498 | 986 | 498 | 1484 | 1972 |
| 4 German states | 0 | 299 | 592 | 299 | 890 | 1183 |
| Lower Saxony | 0 | 75 | 148 | 75 | 223 | 296 |
| North Rhine-Westphalia | 0 | 75 | 148 | 75 | 223 | 296 |
| Rhineland-Palatinate | 0 | 75 | 148 | 75 | 222 | 296 |
| Saarland | 0 | 74 | 148 | 74 | 222 | 295 |
| Benelux | 0 | 235 | 410 | 212 | 612 | 800 |
| Benelux + Neighbouring regions | 0 | 566 | 1063 | 543 | 1596 | 2106 |
| Europe | 0 | 1555 | 3009 | 1555 | 4568 | 6018 |


Hydrogen demand for heat (max scenario)
H2 demand (kton/y)
7000
6000
5000
4000
3000
2000
1000
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe


Share of hydrogen demand for heat in 2050
65%
35%
22%
14%
Benelux
Neighbouring regions
Rest of Europe

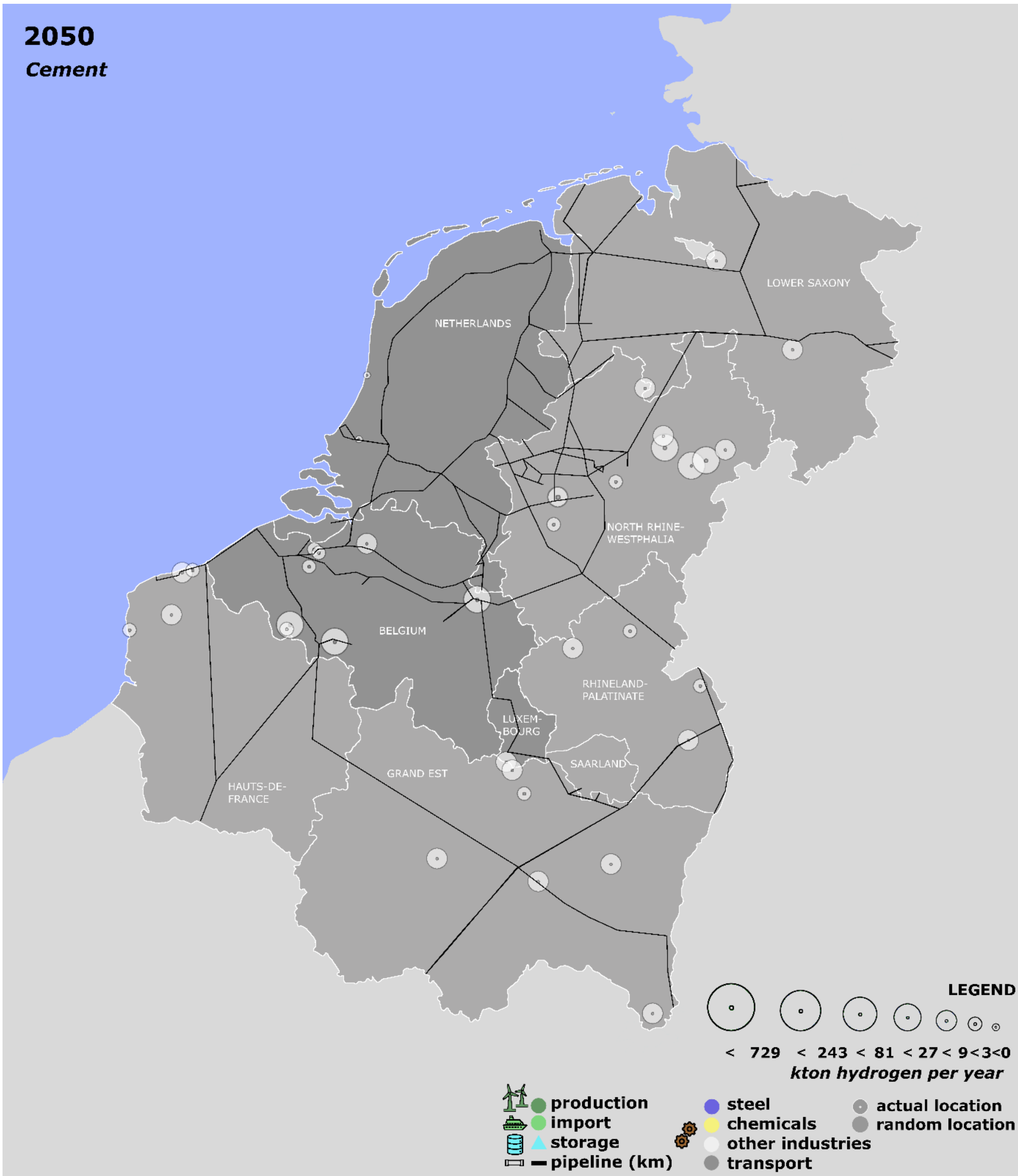



Figure 23: Geographical representation of hydrogen demand for cement in 2050 (maximum scenario)

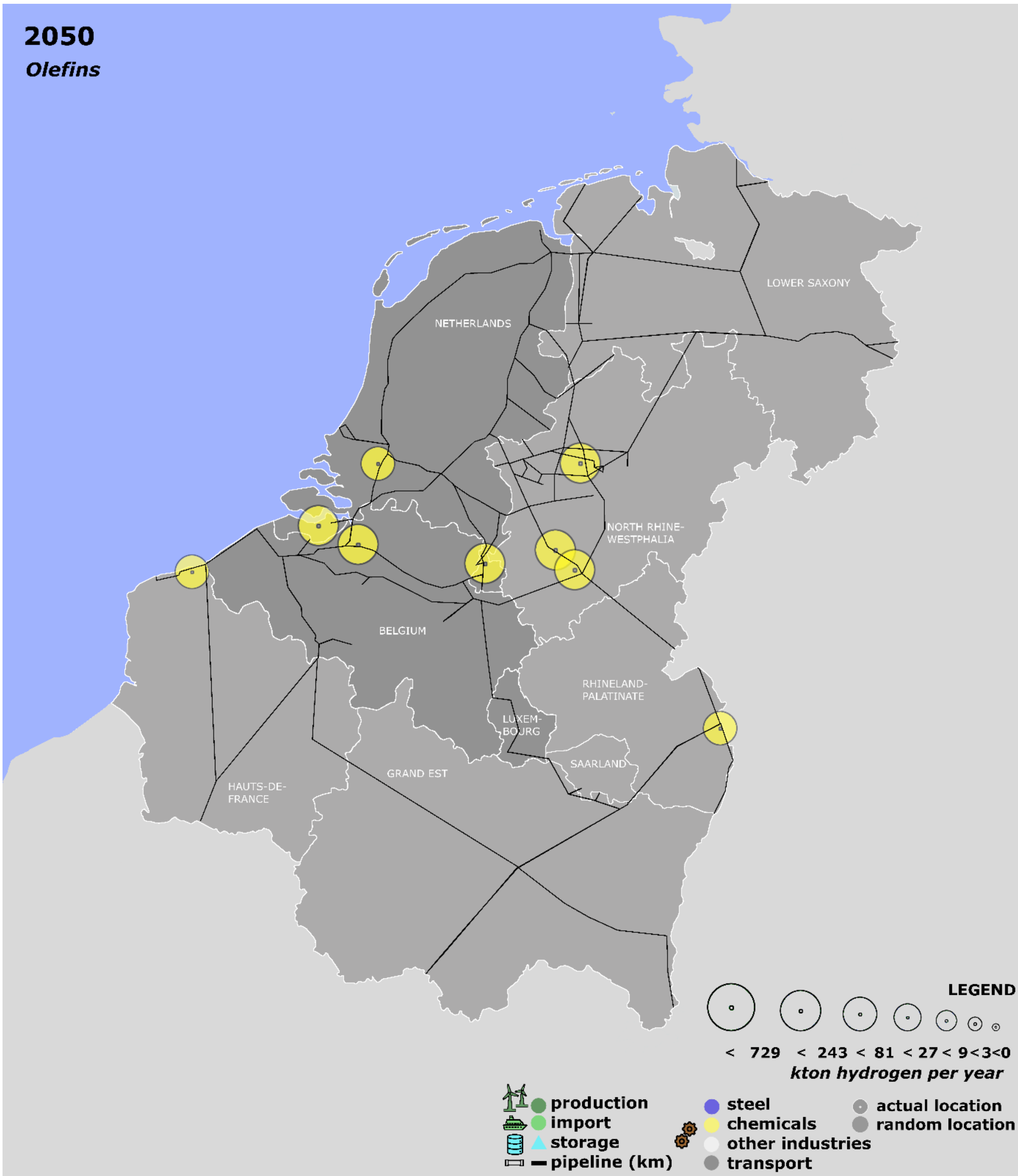



Figure 24: Geographical representation of hydrogen demand for olefins in 2050 (maximum scenario)

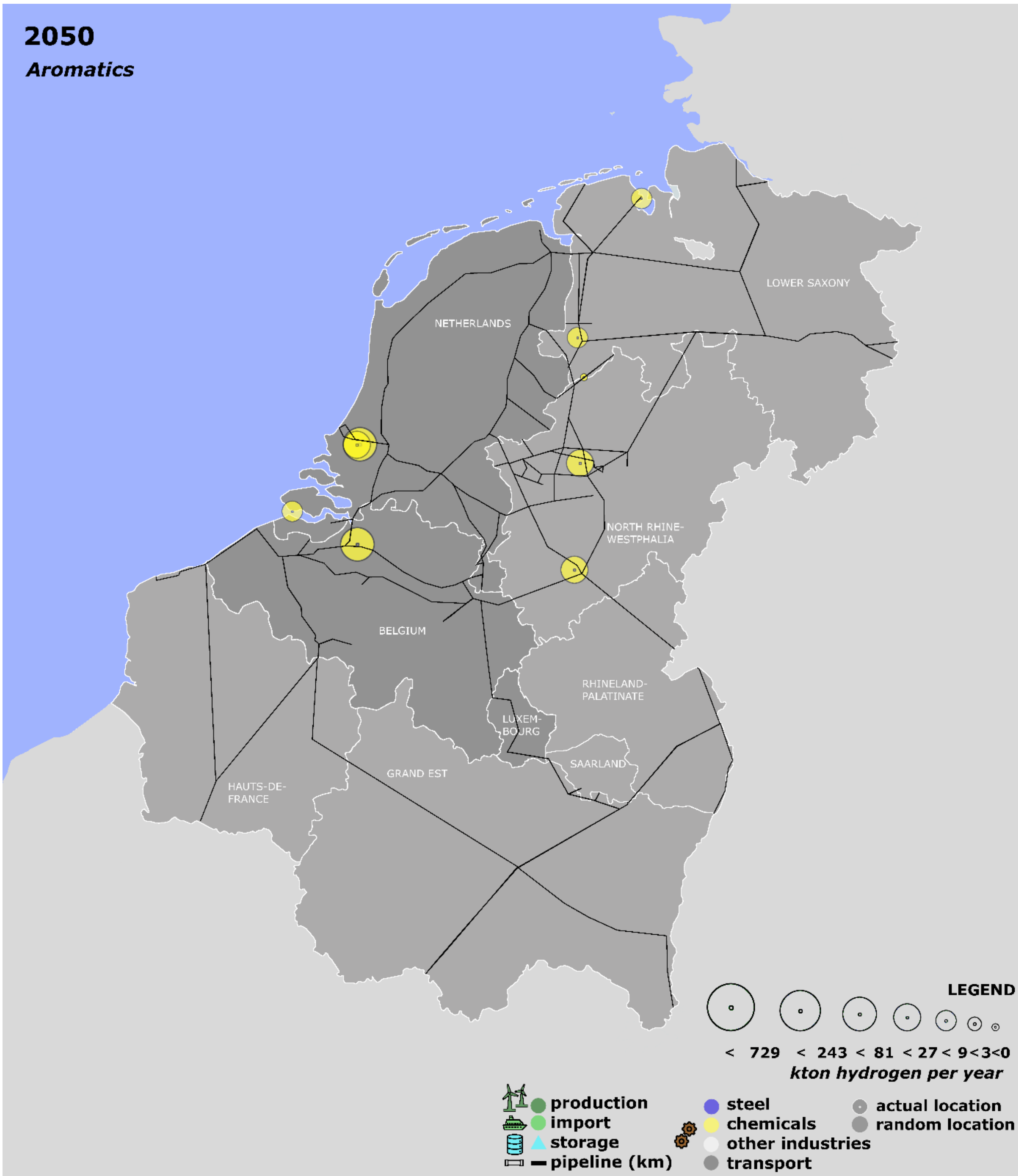



Figure 25: Geographical representation of hydrogen demand for aromatics in 2050 (maximum scenario)

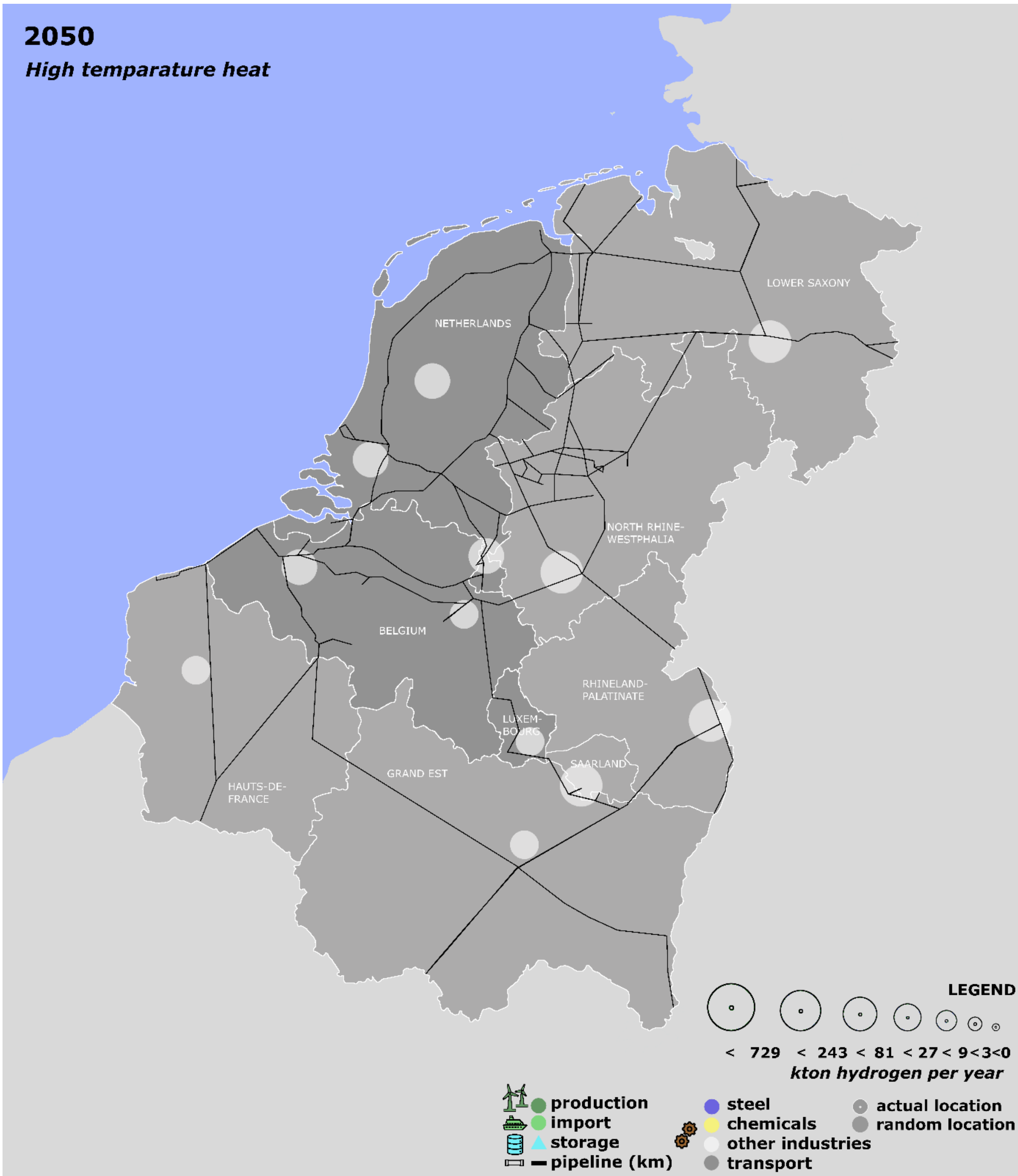



Figure 26: Geographical representation of hydrogen demand for heat in 2050 (maximum scenario)

## 6.4 TRANSPORT

### Status transport sector in the Benelux and neighbouring regions

The scope of the analysis of the transport sector includes buses, cars, trucks, rail, aviation and navigation.

The transport sector is decently represented in the Benelux and its neighbouring regions. Information regarding the current demand for energy (fossil fuel based) in the transportation sector is available through Trinomics[59]. It should however be noted that the rail sector is not predominantly based on fossil fuels, so a replacement of fossil fuels is thus based on the current stock of diesel locomotives. The distribution of the different transportation segments is rather equally dispersed across Europe. Considering all sectors, the demand for transport in the Benelux and its neighbouring regions is between 15% to 25% depending on the sector. All sectors combined, the demand for energy in the Benelux and its Neighbouring regions is **676 TWh per year**. This is **20% of the total energy demand in the transport sector in Europe** (see Table 24).

[59] Fuel Cells and Hydrogen 2 Joint Undertaking (study done by Trinomics), Study on Opportunities arising from the inclusion of Hydrogen Energy Technologies in the National Energy & Climate Plans (2020)

Table 24: Fossil fuel-based energy demand in the transport sector

| Country | Energy consumption transport | | | | | | | % Share of energy consumption | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | |
| | BUS | CAR | TRUC | RAIL | AVIA | NAVI | TOT | BUS | | CAR | | TRUC | | RAIL | | AVIA | | NAVI | |
| | TWh/y | | | | | | | % | % | % | % | % | % | % | % | % | % | % | % |
| Netherlands | 3.1 | 90 | 30 | 0.4 | 44 | 3 | 171 | 4 | 24 | 4 | 24 | 4 | 20 | 3 | 14 | 9 | 36 | 6 | 42 |
| Belgium | 3.4 | 55 | 40 | 0.6 | 16 | 2 | 117 | 4 | 27 | 3 | 14 | 5 | 26 | 4 | 21 | 3 | 13 | 4 | 28 |
| Luxembourg | 1.3 | 15 | 10 | 0.1 | 5 | 0 | 31 | 2 | 10 | 1 | 4 | 1 | 7 | 1 | 4 | 1 | 4 | 0 | 0 |
| France | 7.6 | 368 | 111 | 1.6 | 79 | 6 | 573 | 9 | | 18 | | 14 | | 10 | | 17 | | 12 | |
| 2 French states | 1.4 | 66 | 20 | 0.3 | 14 | 1 | 103 | 2 | 11 | 3 | 17 | 2 | 13 | 2 | 11 | 3 | 12 | 2 | 14 |
| Hauts-de France | 0.7 | 34 | 10 | 0.2 | 7.4 | 0.5 | 53 | 1 | 6 | 2 | 9 | 1 | 7 | 1 | 7 | 2 | 6 | 1 | 7 |
| Grand Est | 0.7 | 32 | 10 | 0.1 | 6.8 | 0.5 | 50 | 1 | 6 | 2 | 8 | 1 | 7 | 1 | 4 | 1 | 6 | 1 | 7 |
| Germany | 9.5 | 417 | 137 | 3.7 | 112 | 3.3 | 683 | 11 | | 21 | | 17 | | 23 | | 24 | | 7 | |
| 4 German states | 3.5 | 155 | 51 | 1.4 | 42 | 1.2 | 254 | 4 | 28 | 8 | 41 | 6 | 34 | 9 | 50 | 9 | 35 | 2 | 17 |
| Lower Saxony | 0.9 | 40 | 13 | 0.4 | 11 | 0.3 | 66 | 1 | 7 | 2 | 10 | 2 | 9 | 3 | 14 | 2 | 9 | 1 | 4 |
| North Rhine-Westphalia | 2.0 | 89 | 29 | 0.8 | 24 | 0.7 | 146 | 2 | 16 | 4 | 23 | 4 | 19 | 5 | 29 | 5 | 20 | 1 | 10 |
| Rhineland-Palatinate | 0.5 | 21 | 7 | 0.2 | 6 | 0.2 | 35 | 1 | 4 | 1 | 6 | 1 | 5 | 1 | 7 | 1 | 5 | 0 | 3 |
| Saarland | 0.1 | 5 | 2 | 0.0 | 1 | 0.0 | 8 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Benelux | 7.8 | 160 | 80 | 1.1 | 65 | 5.0 | 319 | 9 | 61 | 8 | 42 | 10 | 53 | 7 | 39 | 14 | 54 | 10 | 69 |
| Benelux + Neighbouring regions | 13 | 381 | 151 | 2.8 | 121 | 7.2 | 676 | 15 | 100 | 19 | 100 | 19 | 100 | 18 | 100 | 25 | 100 | 15 | 100 |
| Europe | 84 | 2010 | 801 | 16 | 476 | 49 | 3436 | 100 | 661 | 100 | 528 | 100 | 530 | 100 | 571 | 100 | 393 | 100 | 681 |

## The role for hydrogen/derivatives for transport

The transport sector is often seen as the first sector in which hydrogen is introduced. A portfolio of projects has been executed in which all transport segments are addressed and has led to the introduction of commercial solutions and applications. Alongside battery-electric solutions, a further roll out of hydrogen is foreseen in the automotive, bus, truck and train segment. Although it is often argued based on efficiency considerations that the introduction of battery-electric solutions will dominate in the automotive and short-distance bus, truck and train journey, it is also understood that the electricity system will not be able to cope with the ever-increasing demand for electricity across the whole energy system. Hence, the need to deploy an alternative renewable energy transport and storage mechanisms other than electricity only based solutions is vital for an operationally realisable and financially affordable transition towards deep decarbonisation of among others the transport sector.

The use of hydrogen fuel cells is anticipated across all transportation sectors, however, the long-haul heavy-duty transport segment, aviation and navigation may also rely on hydrogen combustion solutions and the use of synthetic fuels, like ammonia, methanol, sustainable aviation fuels (SAF). It is assumed that for the production of 1kton of synthetic kerosene, 0.43 kton of hydrogen is needed[60], and that for the production of 1 kton of synthetic LNG, 0.5 kton of hydrogen is needed.

## Quantification hydrogen demand in national/regional hydrogen strategies and studies in 2030 – 2050 timeframe

The need for decarbonisation and the use of green hydrogen as a key decarbonisation option is clearly expressed in national and regional hydrogen strategies. An overview of the ambitions plans and quantifications for the transport sector expressed in national and regional hydrogen strategies are show in Table 25.

Table 25: Overview of ambitions, plans and quantification of demand as expressed in national and regional hydrogen strategies

| National hydrogen and regional strategies |
|---|
| **Netherlands** |
| • 50 hydrogen refuelling stations by 2025, 15,000 fuel cell cars and 3,000 heavy vehicles; 300,000 fuel cell cars by 2030 will be signed with stakeholders in 2020.<br>• In line with the RefuelEU proposal, 2% of the aviation fuels in the Netherlands will be sustainable by 2025. This includes a sub-target for synthetic kerosene, the level of which has not yet been fixed. Kerosene sales in 2019 were 3.82 billion kilograms. With a calorific value of 43.5 TJ per million kilograms, this is 166 PJ: 0.7% of this is 1.2 PJ of synthetic fuel The production of synthetic kerosene based on CO2 and H2 has an efficiency of about 65%. This means that to produce 1.2 PJ of synthetic kerosene, about 1.8 PJ of H2 is needed. If green H2 is used, this counts towards the RFNBO obligation for transport.<br>• For 2035, based on the 2019 figure, this would increase to 8.3 PJ of synthetic kerosene which would already require 12.8 PJ of H2. In line with the RefuelEU proposal, 6% of the aviation fuels |

[60] https://www.grtgaz.com/sites/default/files/2021-06/European-Hydrogen-Backbone-report-June2021.pdf

| |
|---|
| refuelled in the Netherlands are sustainable. There is also a sub-target for synthetic kerosene, the amount is not yet known.<br>• Sustainable Aviation Agreement to achieve 14% blending of renewable fuels by 2030 and 100% by 2050.<br>• Have at least 150 inland waterway vessels equipped with a zero-emission power train (electricity/hydrogen)<br>• A 35% to 50% reduction in emissions of environmental pollutants from inland navigation compared to 2015. In 2050, to have achieved a virtually emission-free and climate-neutral inland navigation.<br>• Total demand of 1 Mton of hydrogen demand in 2050. |
| **Belgium** |
| • Wallonia has mentioned in the NECP that 1% of its passenger cars should be hydrogen driven by 2030, and that hydrogen could become an alternative fuel to decarbonise heavy logistic vehicles. To enable this shift to hydrogen, 10 hydrogen refuelling stations would be required by 2025 and 20 by 2030.<br>• Flanders anticipates 34 kton in 2030 and 459 kton in 2050 |
| **Luxembourg** |
| • Road, air, river and rail transport could generate a demand of the order of 2 to 4 TWh per year (H2 or renewable synthetic fuel derived from H2). |
| **Grand Est** |
| • Support 10 mobility territories in the transition of their fleets to low carbon within 5 years.<br>• Develop 5 multi-use hydrogen energy ecosystems (production-distribution-use) by 2030.<br>• Network the territory with 30 hydrogen refuelling stations, as a priority on the European freight transport corridors, then on national transport corridors, then on national roads and urban areas by 2030.<br>• Deploy 700 buses, 50 coaches, 1200 trucks and refuse collection vehicles, 100 barges, and identify a fleet of light rail vehicles by 2030. |
| **Lower Saxony** |
| • In 2030, the construction of a filling station network is necessary. According to a rough estimate, around 250 hydrogen filling stations are needed in northern Germany for nationwide supply.<br>• In 2045, the use of 59 TWh of hydrogen for the transport sector is conceivable. Additionally, it is expected that energy amounts of 159 TWh as hydrogen derivatives for aviation and shipping in particular.<br>• In 2050, 15% of traffic will be covered by fuel cell vehicles. This leads to a hydrogen requirement of 7 TWh. The remaining 85% are served by battery electric vehicles. It was assumed that 15% of the traffic demand cannot be covered by battery electric vehicles due to long ranges or payloads. |
| **North Rhine-Westphalia** |
| • Targets for 2025: 400+ fuel cell trucks, 20+ truck filling stations, 60 car filling stations, 500 hydrogen buses for public transport, the first hydrogen-powered barges. |

| |
|---|
| • Targets for 2030: 11000 fuel cell trucks over 20 tonnes, 200 filling stations for trucks and cars, 1000 fuel cell waste bins, 3800 fuel cell buses for public transport. |
| **Saarland** |
| • 2023: The "SENECA" project of H2 MOBILITY Germany is intended to promote the nationwide expansion of a refuelling station infrastructure. For Saarland, the expansion of the existing hydrogen filling station in Saarbrücken-Gersweiler and the construction of a new site are planned for 2023.<br>• 2025: The initial plan is to procure around 20 fuel cell buses. Two to three mobile filling stations could be used in Saarland at locations with initially low hydrogen requirements. As soon as demand increases, these can be replaced by stationary and suitably dimensioned filling stations. The mobile filling stations will then be used again at alternative locations with continued low hydrogen requirements. However, due to the currently low demand for a mobile filling station and the recently (August 2021) published federal funding programs for setting up its own supply structures, the use of mobile filling station solutions will not be pursued further for the time being. |

A more populated quantification of potentials of hydrogen demand for the transportation sector to 2030 is provided based on an interpretation of Member States' National Energy and Climate Plans (end November 2019)[61]. This study is performed by Trinomics and is presented in Table 26. It is considered an important source of information as it is based on the Member States' ten-year energy and climate plans.

Table 26: Quantification of total numbers and hydrogen demand per transportation segment

| Country | Quantification of hydrogen targets | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2030 | | | | | | |
| | BUS | CAR | TRUCK | RAIL | AVIA/NAVI | TOTAL | HRS |
| | # | | | | GWh/a | GWh/a | # |
| Netherlands | 110-230 | 105-211k | 5.8-11.8k | 12-40 | 90-853 | 788-2614 | 198-380 |
| Belgium | 160-320 | 65-130k | 5.7-11.5k | 5-20 | 41-388 | 543-1571 | 128-249 |
| Luxembourg | 10-20 | 2.8-5.6k | 120-230 | 0-1 | 12-115 | 90-318 | 5-11 |
| France | 1.2-2.4k | 352-703k | 46-92k | 60-181 | 202-1917 | 2703-7818 | 635-1113 |
| Germany | 760-1510 | 477-954k | 32-65k | 110-340 | 227-2160 | 3125-9078 | 783-1342 |

A reflection that was shared during the workshop is that the numbers for hydrogen cars seem high.

Long term projections (2040–2050) are generally developed as part of literature studies and an overview of several penetration and technology scenarios is presented in Table 28. The study performed by the European Hydrogen Backbone[62] provides a good overview of the different uptake scenarios for hydrogen in the transport sector. In addition to this, the REDIII proposal foresees an uptake between 2.6% and 5.7% of hydrogen (RFNBOs) in the transport sector. This target is set of the transport sectors as a whole, but in this study, it will be applied per application. Like for the chemical

[61] https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans

[62] European Hydrogen Backbone, Analysing future demand, supply, and transport of hydrogen, 2021

industry, this will be reflected in the maximum scenario. In the ReFuelEU Aviation proposal, an uptake of synthetic aviation fuels is foreseen of 0.7% in 2030, 8% in 2040 and 28% in 2050.

The final minimum and maximum green hydrogen penetration scenarios selected are shown in Table 27.

Table 27: Overview of minimum and maximum scenario selected for the calculation of the final hydrogen demand for transport sector

| | | Demand | | Green $H_2$ penetration | | |
|---|---|---|---|---|---|---|
| | | % change 2050 | | 2030 | 2040 | 2050 |
| **Buses** | | | | | | |
| Minimum penetration scenario | | +25% | | 1% | 10% | 15% |
| Maximum penetration scenario | | +25% | | 6% | 21% | 25% |
| **Cars** | | | | | | |
| Minimum penetration scenario | | +40% | | 0,5% | 10% | 15% |
| Maximum penetration scenario | | +40% | | 6% | 21% | 25% |
| **Trucks** | | | | | | |
| Minimum penetration scenario | | +50% | | 0,5% | 20% | 40% |
| Maximum penetration scenario | | +50% | | 6% | 30% | 55% |
| **Trains** | | | | | | |
| Minimum penetration scenario | | +25% | | 12% | 30% | 50% |
| Maximum penetration scenario | | +25% | | 36% | 50% | 75% |
| **Aviation** | | | | | | |
| Minimum penetration scenario | | +50% | | 0,7% | 8% | 5%+28 % |
| Maximum penetration scenario | | +50% | $H_2$+SyntAF | 0%+1 % | 1%+8 % | 9%+28 % |
| **Navigation** | | | | | | |
| Minimum penetration scenario | | +20% | | 0,5% | 6% | 12% |
| Maximum penetration scenario | | +20% | | 6% | 10% | 19% |

Based on these scenarios, the final demand for green hydrogen is shown in Table 29 (buses), Table 30 (cars), Table 31 (trucks), Table 32 (trains), Table 33 (aviation) and Table 34 (navigation). A geographical representation of the hydrogen demand in 2050 is shown in Figure 27.

The demand for hydrogen in the Benelux and its neighbouring regions for buses, cars, trucks, trains, aviation and navigation is 15%, 19%, 19%, 18%, 26% and 14% respectively of the total hydrogen demand for these sectors in Europe.

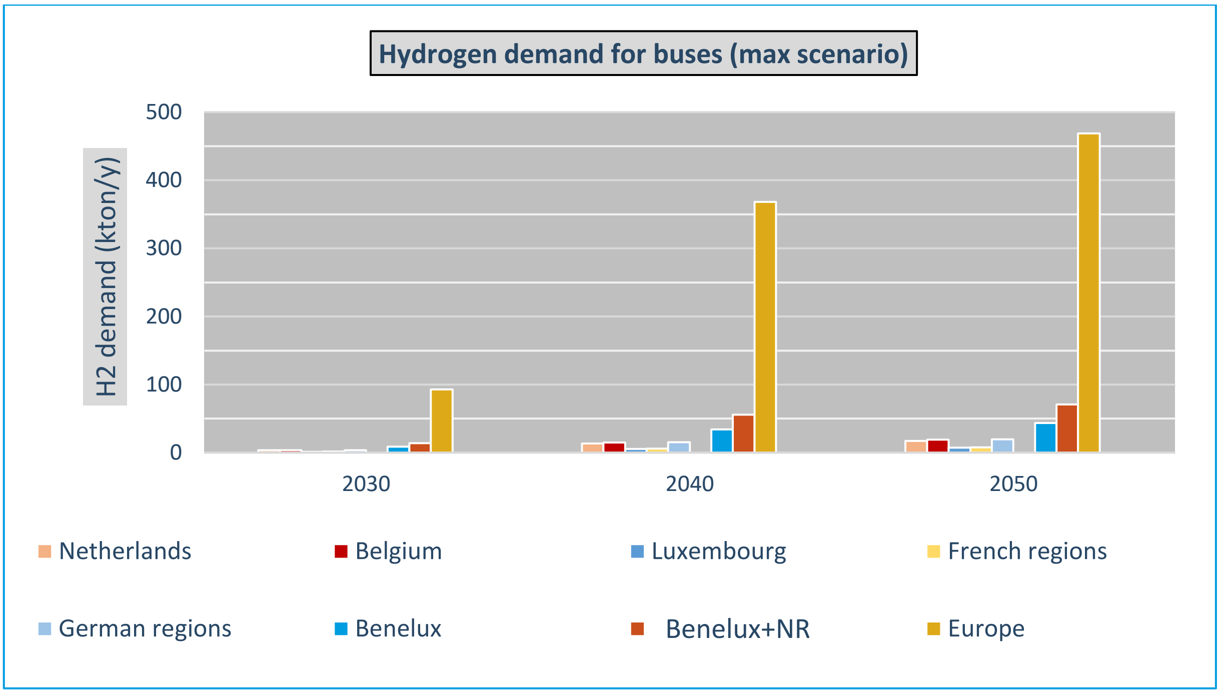
Table 28: Overview of literature studies assessed and hydrogen uptake scenarios selected

| Study | Parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| | Scope | Demand | Efficiency | H2 penetration | | | Fuel mix |
| | | % change 2050 | 2050 | 2030 | 2040 | 2050 | 2050 |
| **Buses** | | | | | | | |
| Trinomics (2020) | | +8% (2030) | - | 1-2% | - | - | |
| European Hydrogen Backbone (2021) | | - | - | 4% | 21% | 25% | 75% battery-electric |
| Low penetration scenario | | +25% | | 1% | 10% | 15% | |
| High penetration scenario | | +25% | | 4% | 21% | 25% | |
| **Cars** | | | | | | | |
| Trinomics (2020) | | +13% (2030) | - | 1-2% | - | - | |
| | | - | - | | - | - | |
| Low penetration scenario | | +40% | | 1% | 10% | 15% | (see bus scenario) |
| High penetration scenario | | +40% | | 4% | 21% | 25% | (see bus scenario) |
| **Trucks** | | | | | | | |
| Trinomics (2020) | | +29% (2030) | - | 0.5-1% | - | - | |
| European Hydrogen Backbone (2021) | | - | - | 5% | 30% | 55% | 0% diesel, 17% biomethane, 28% battery-electric |
| Low penetration scenario | | +50% | | 0.5% | 20% | 40% | |
| High penetration scenario | | +50% | | 5% | 30% | 55% | |
| **Rail** | | | | | | | |
| Trinomics (2020) | | - | - | 12-36% | - | - | |
| | | - | - | - | - | - | |
| Low penetration scenario | | +25% | | 12% | 30% | 50% | |
| High penetration scenario | | +25% | | 36% | 50% | 75% | |
| **Aviation** | | | | | | | |
| Trinomics (2020) | | +18% (2030) | - | 0.2-1.9% | - | - | |

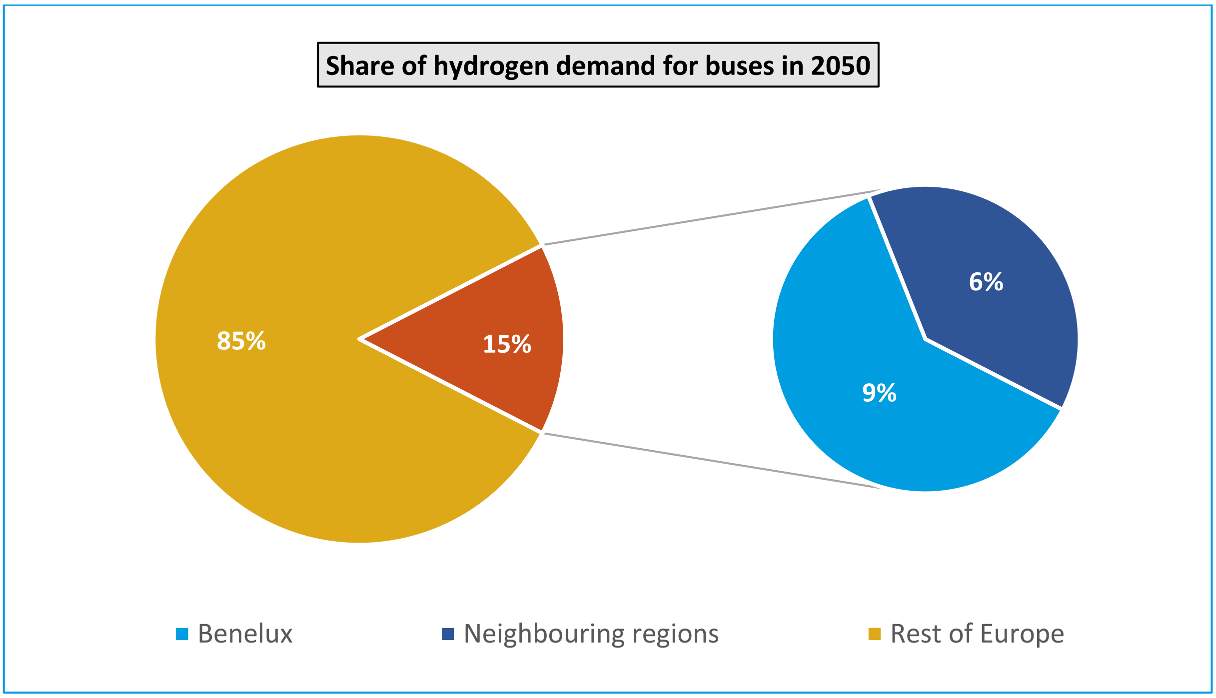
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| European Hydrogen Backbone (2021) | | +100% | 1.5% | 0% | - | - | Direct hydrogen demand |
| European Hydrogen Backbone (2021) | | - | - | 7% | 33% | 40% | Synthetic kerosine demand |
| Low penetration scenario | | +50% | | 0%+2% | 0%+16% | 5%-20% | |
| High penetration scenario | | +50% | | 0%+7% | 1%+33% | 9%+40% | |
| Navigation | | | | | | | |
| Trinomics (2020) | | +7% (2030) | - | 0.2-1.9% | 6% | 12% | |
| European Hydrogen Backbone (2021) | | - | - | 0% | 0% | 0% | Hydrogen |
| European Hydrogen Backbone (2021) | | - | - | 5% | 35% | 70% | Bio-LNG |
| Low penetration scenario | | +20% | | 0%+0% | 0%+20% | 0%+40% | |
| High penetration scenario | | +20% | | 2%+0% | 6%+35% | 12%+70% | |

Table 29: Final demand growth selected for hydrogen buses

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Bus | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 1 | 6 | 10 | 3 | 14 | 17 |
| Belgium | 1 | 7 | 11 | 4 | 15 | 19 |
| Luxembourg | 0 | 3 | 4 | 1 | 6 | 7 |
| France | 1 | 16 | 25 | 8 | 33 | 42 |
| 2 French states | 0 | 3 | 5 | 2 | 6 | 8 |
| Hauts-de France | 0 | 1 | 2 | 1 | 3 | 4 |
| Grand Est | 0 | 1 | 2 | 1 | 3 | 4 |
| Germany | 2 | 20 | 32 | 11 | 42 | 53 |
| 4 German states | 1 | 7 | 12 | 4 | 15 | 20 |
| Lower Saxony | 0 | 2 | 3 | 1 | 4 | 5 |
| North Rhine-Westphalia | 0 | 4 | 7 | 2 | 9 | 11 |
| Rhineland-Palatinate | 0 | 1 | 2 | 1 | 2 | 3 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 1 |
| Benelux | 2 | 16 | 26 | 9 | 34 | 44 |
| Benelux + Neighbouring regions | 2 | 27 | 43 | 14 | 56 | 71 |
| Europe | 16 | 175 | 281 | 93 | 368 | 469 |



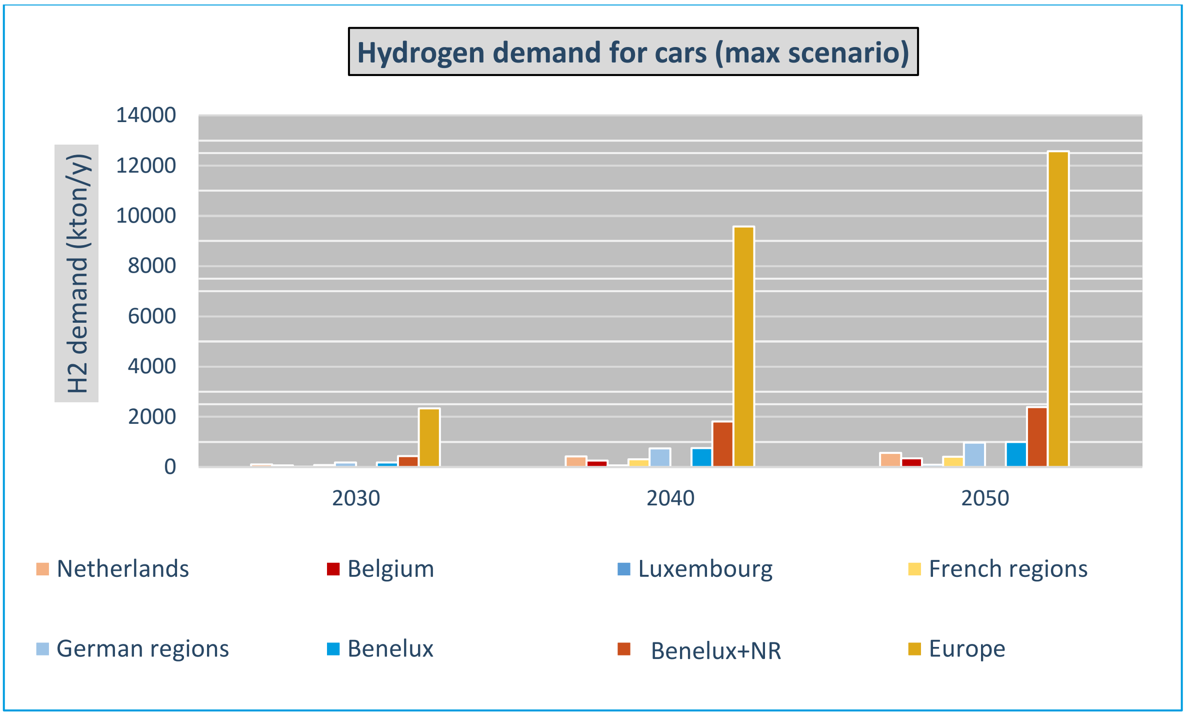
Hydrogen demand for buses (max scenario)
H2 demand (kton/y)
500
400
300
200
100
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

Share of hydrogen demand for buses in 2050
85%
15%
6%
9%
Benelux
Neighbouring regions
Rest of Europe

Table 30: Final demand growth selected for hydrogen cars

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Cars | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 9 | 204 | 338 | 104 | 429 | 563 |
| Belgium | 6 | 125 | 206 | 64 | 262 | 344 |
| Luxembourg | 2 | 34 | 56 | 17 | 71 | 94 |
| France | 37 | 835 | 1381 | 427 | 1753 | 2302 |
| 2 French states | 7 | 150 | 248 | 77 | 314 | 413 |
| Hauts-de France | 3 | 77 | 128 | 39 | 162 | 213 |
| Grand Est | 3 | 73 | 120 | 37 | 152 | 200 |
| Germany | 42 | 946 | 1565 | 483 | 1986 | 2608 |
| 4 German states | 16 | 352 | 582 | 180 | 738 | 970 |
| Lower Saxony | 4 | 91 | 150 | 46 | 191 | 250 |
| North Rhine-Westphalia | 9 | 202 | 334 | 103 | 424 | 557 |
| Rhineland-Palatinate | 2 | 48 | 79 | 24 | 100 | 131 |
| Saarland | 1 | 11 | 19 | 6 | 24 | 31 |
| Benelux | 16 | 363 | 600 | 186 | 762 | 1001 |
| Benelux + Neighbouring regions | 39 | 864 | 1430 | 442 | 1815 | 2383 |
| Europe | 204 | 4559 | 7544 | 2330 | 9573 | 12573 |


Hydrogen demand for cars (max scenario)
H2 demand (kton/y)
14000
12000
10000
8000
6000
4000
2000
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

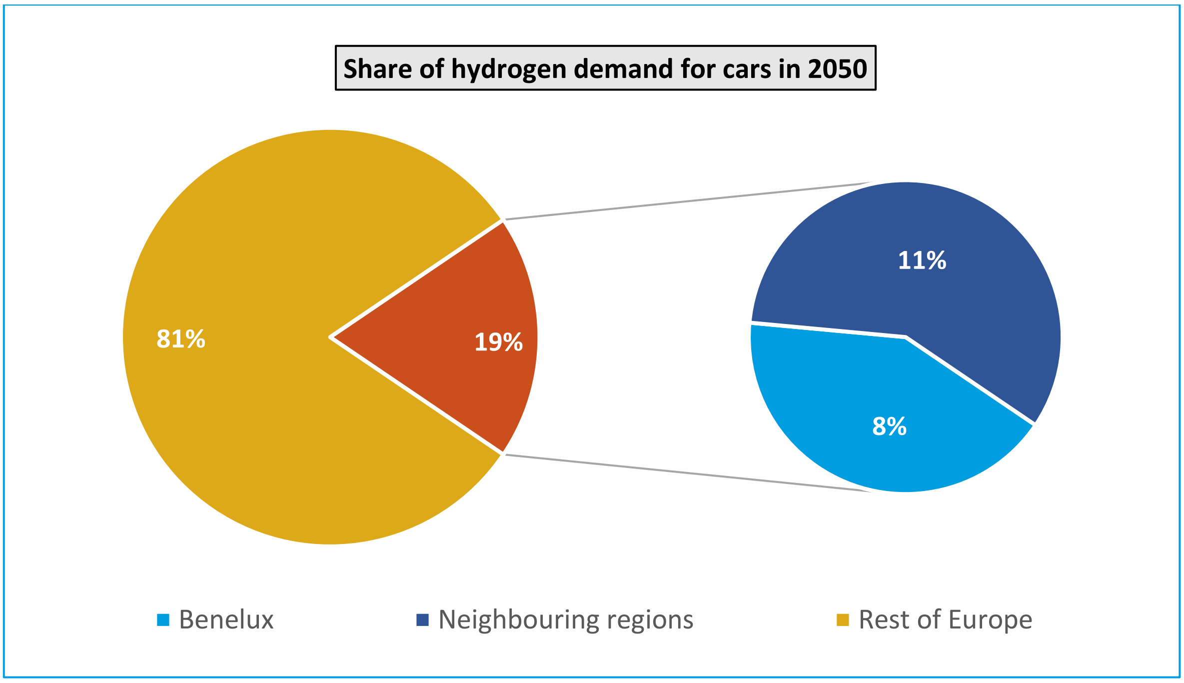
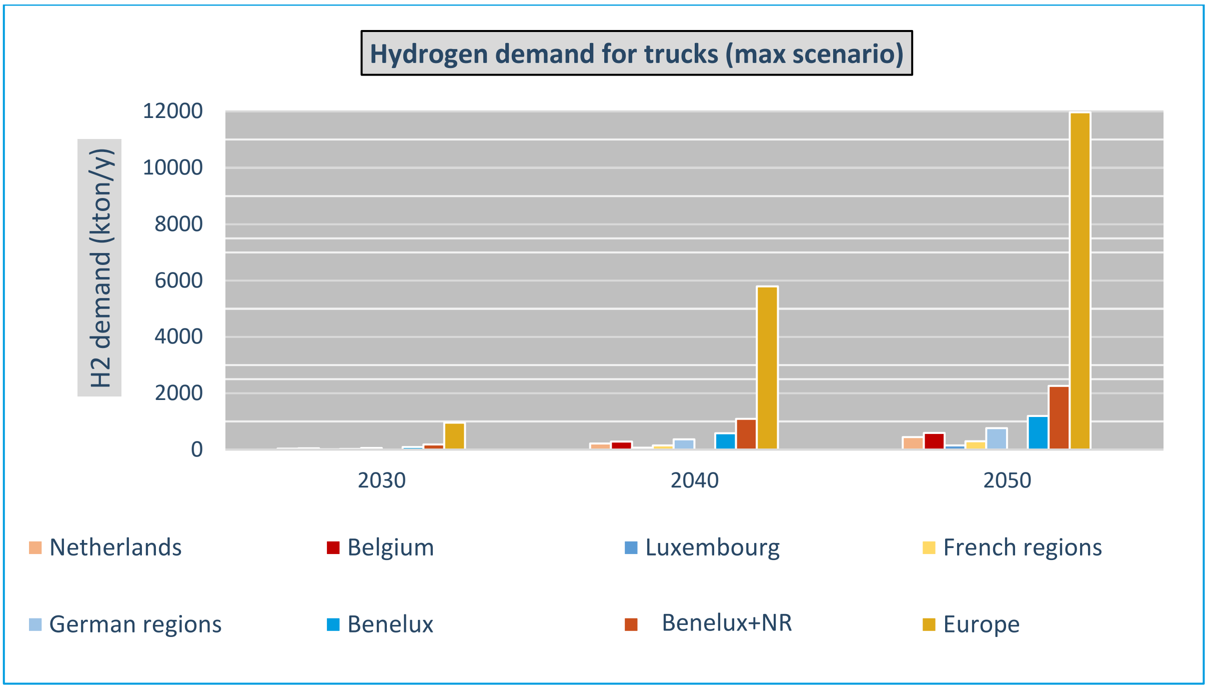

Share of hydrogen demand for cars in 2050
81%
19%
11%
8%
Benelux
Neighbouring regions
Rest of Europe

Table 31: Final demand growth selected for hydrogen trucks

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Trucks | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 3 | 145 | 326 | 36 | 217 | 448 |
| Belgium | 4 | 193 | 435 | 48 | 289 | 598 |
| Luxembourg | 1 | 48 | 109 | 12 | 72 | 149 |
| France | 12 | 535 | 1207 | 133 | 803 | 1659 |
| 2 French states | 2 | 96 | 217 | 24 | 145 | 299 |
| Hauts-de France | 1 | 48 | 109 | 12 | 72 | 149 |
| Grand Est | 1 | 48 | 109 | 12 | 72 | 149 |
| Germany | 14 | 661 | 1489 | 164 | 991 | 2048 |
| 4 German states | 5 | 246 | 554 | 61 | 369 | 762 |
| Lower Saxony | 1 | 63 | 141 | 16 | 94 | 194 |
| North Rhine-Westphalia | 3 | 140 | 315 | 35 | 210 | 434 |
| Rhineland-Palatinate | 1 | 34 | 76 | 8 | 51 | 105 |
| Saarland | 0 | 10 | 22 | 2 | 14 | 30 |
| Benelux | 8 | 386 | 870 | 96 | 579 | 1196 |
| Benelux + Neighbouring regions | 16 | 728 | 1642 | 181 | 1093 | 2257 |
| Europe | 84 | 3864 | 8708 | 962 | 5796 | 11974 |


Hydrogen demand for trucks (max scenario)
H2 demand (kton/y)
12000
10000
8000
6000
4000
2000
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

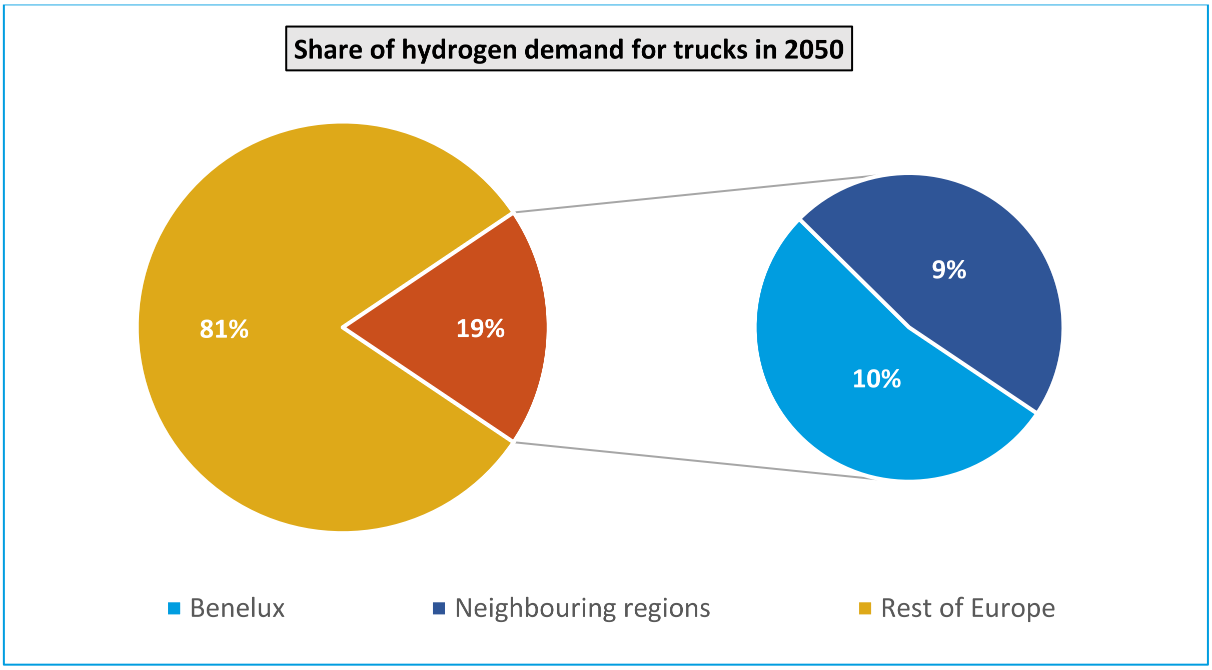
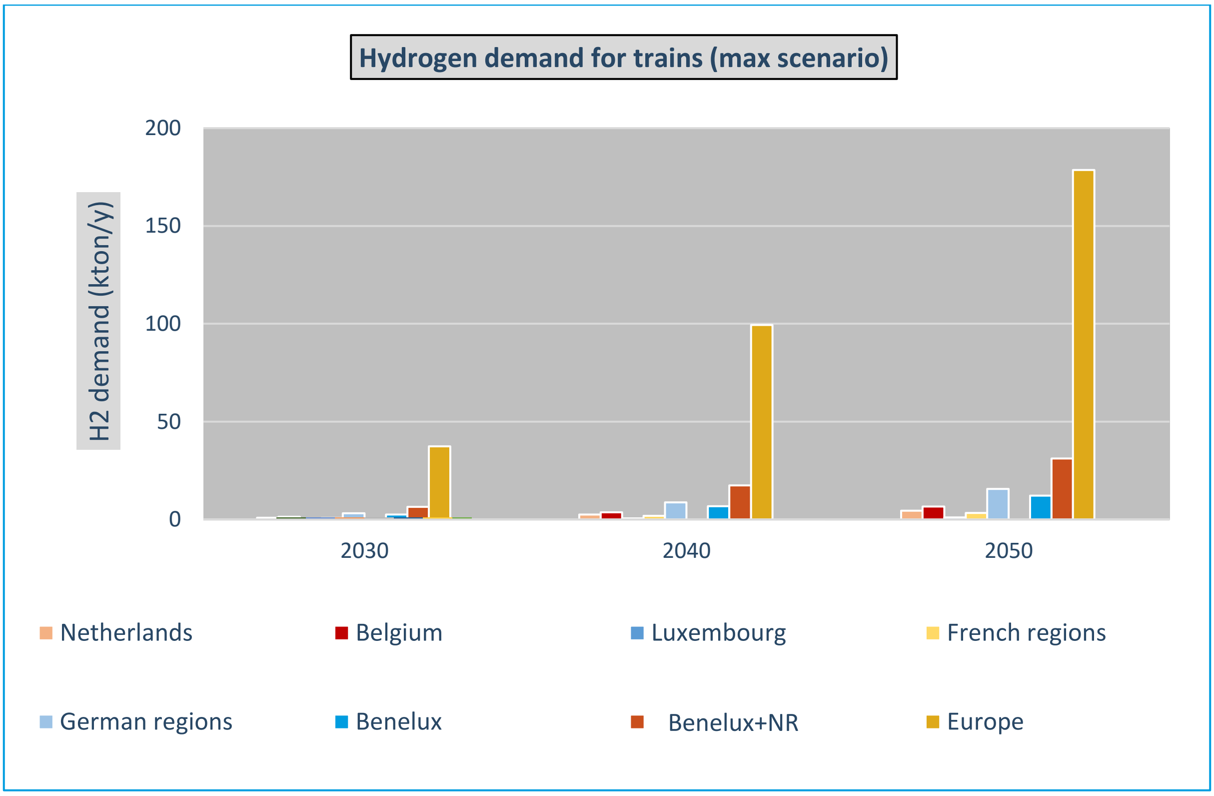

Share of hydrogen demand for trucks in 2050
81%
19%
9%
10%
Benelux
Neighbouring regions
Rest of Europe

Table 32: Final demand growth selected for hydrogen trains

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Trains | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 1 | 2 | 4 | 1 | 2 | 4 |
| Belgium | 1 | 4 | 5 | 1 | 4 | 7 |
| Luxembourg | 0 | 1 | 1 | 0 | 1 | 1 |
| France | 4 | 10 | 14 | 4 | 10 | 18 |
| 2 French states | 1 | 2 | 3 | 1 | 2 | 3 |
| Hauts-de France | 0 | 1 | 2 | 0 | 1 | 2 |
| Grand Est | 0 | 1 | 1 | 0 | 1 | 1 |
| Germany | 9 | 23 | 33 | 9 | 23 | 41 |
| 4 German states | 3 | 9 | 12 | 3 | 9 | 16 |
| Lower Saxony | 1 | 2 | 4 | 1 | 2 | 4 |
| North Rhine-Westphalia | 2 | 5 | 7 | 2 | 5 | 9 |
| Rhineland-Palatinate | 0 | 1 | 2 | 0 | 1 | 2 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 3 | 7 | 10 | 3 | 7 | 12 |
| Benelux + Neighbouring regions | 7 | 17 | 25 | 7 | 17 | 31 |
| Europe | 37 | 99 | 143 | 37 | 99 | 179 |


Hydrogen demand for trains (max scenario)
H2 demand (kton/y)
200
150
100
50
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

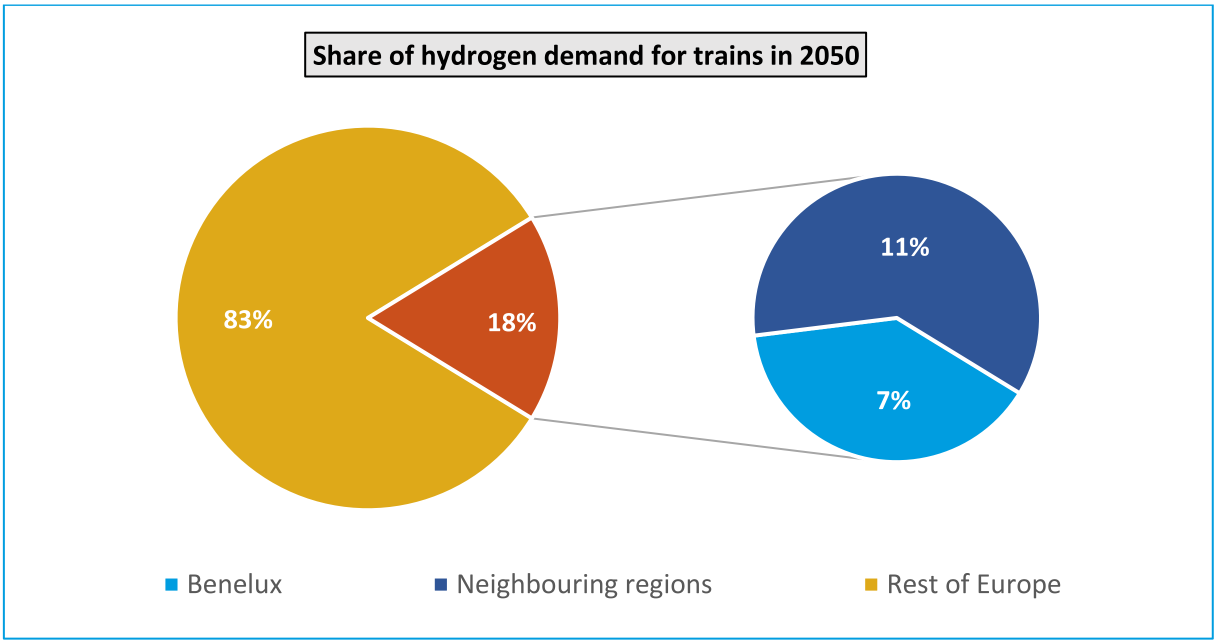
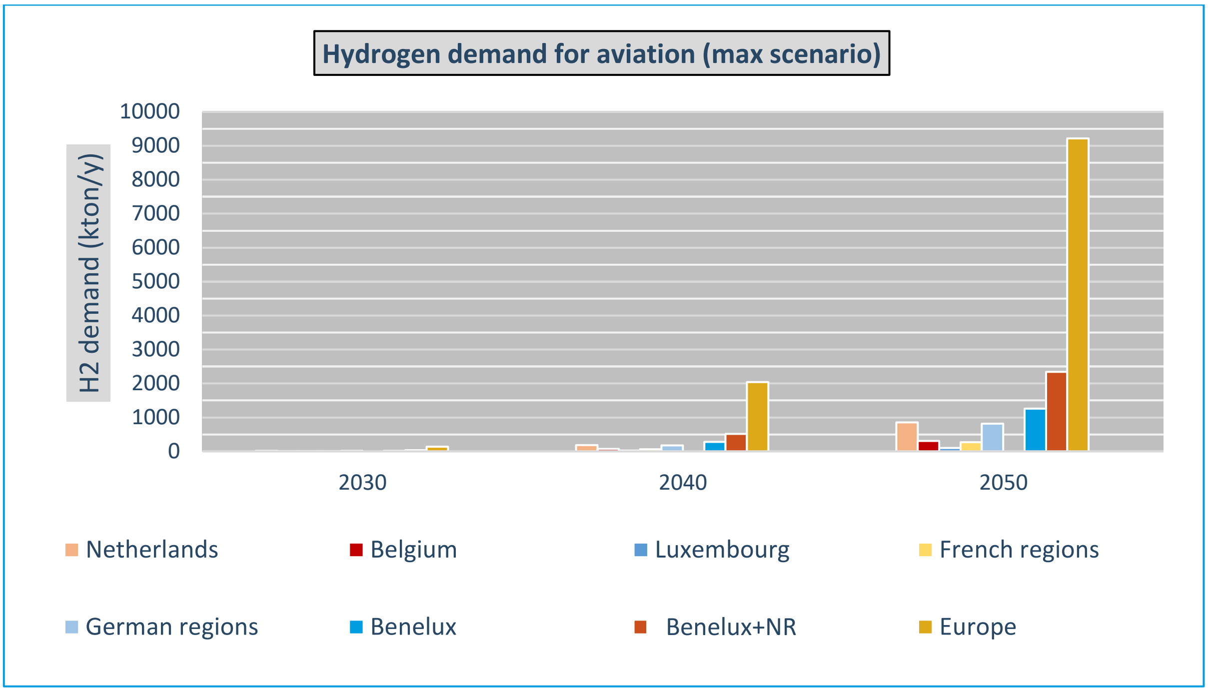

Share of hydrogen demand for trains in 2050
83%
18%
11%
7%
Benelux
Neighbouring regions
Rest of Europe

Table 33: Final demand growth selected for hydrogen aviation

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Aviation | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 13 | 171 | 773 | 19 | 188 | 852 |
| Belgium | 5 | 62 | 281 | 7 | 68 | 310 |
| Luxembourg | 1 | 19 | 88 | 2 | 21 | 97 |
| France | 23 | 306 | 1387 | 33 | 338 | 1530 |
| 2 French states | 4 | 54 | 246 | 6 | 60 | 271 |
| Hauts-de France | 2 | 29 | 130 | 3 | 32 | 143 |
| Grand Est | 2 | 26 | 119 | 3 | 29 | 132 |
| Germany | 33 | 434 | 1966 | 47 | 479 | 2169 |
| 4 German states | 12 | 163 | 737 | 18 | 180 | 813 |
| Lower Saxony | 3 | 43 | 193 | 5 | 47 | 213 |
| North Rhine-Westphalia | 7 | 93 | 421 | 10 | 103 | 465 |
| Rhineland-Palatinate | 2 | 23 | 105 | 3 | 26 | 116 |
| Saarland | 0 | 4 | 18 | 0 | 4 | 19 |
| Benelux | 19 | 252 | 1141 | 28 | 278 | 1259 |
| Benelux + Neighbouring regions | 36 | 469 | 2124 | 51 | 518 | 2344 |
| Europe | 141 | 1846 | 8357 | 201 | 2037 | 9220 |


Hydrogen demand for aviation (max scenario)
H2 demand (kton/y)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe

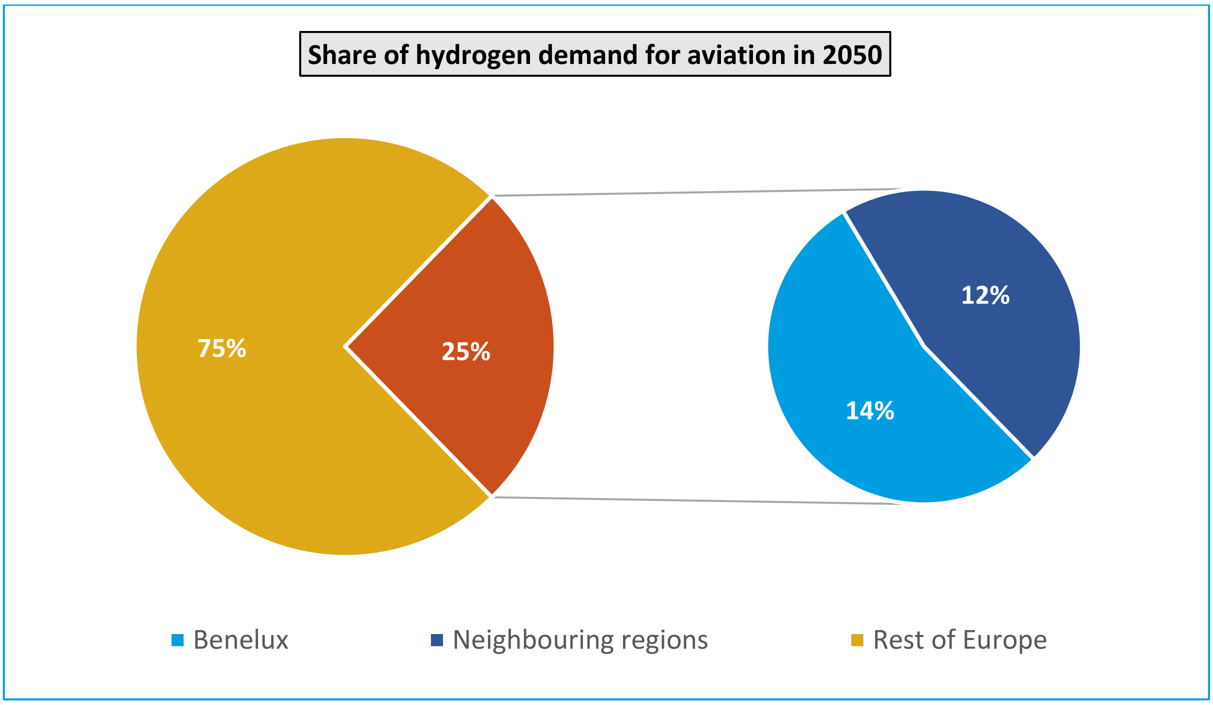
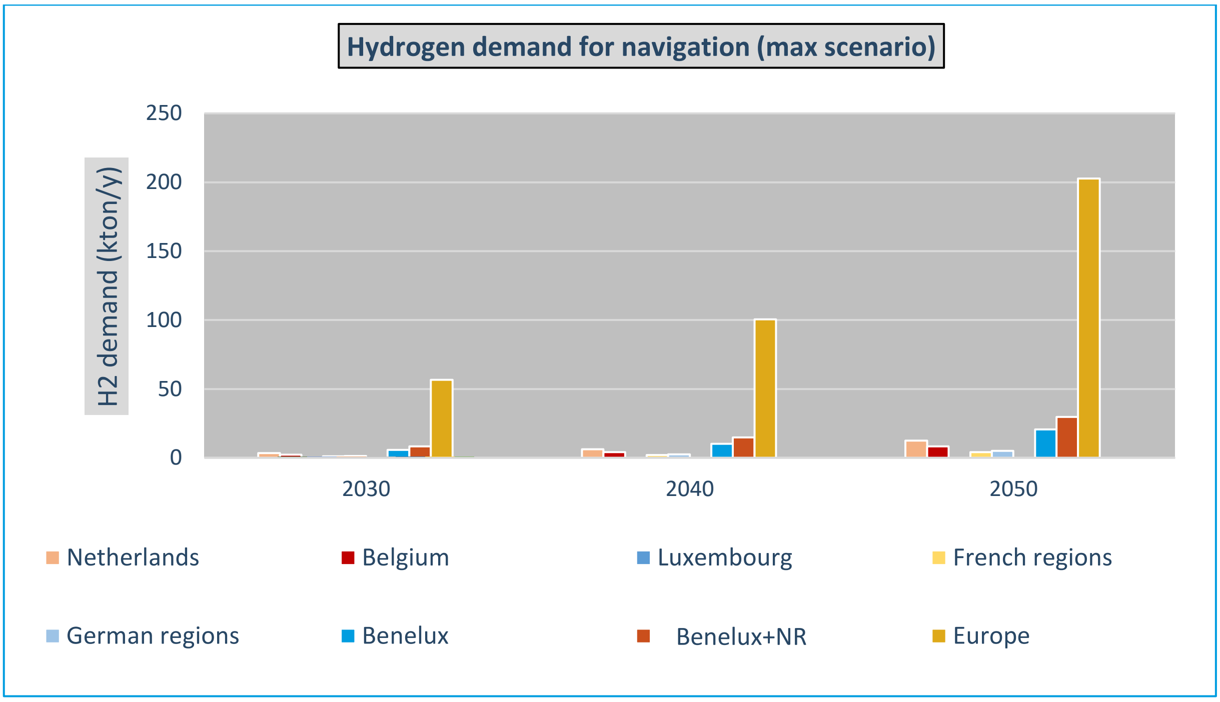
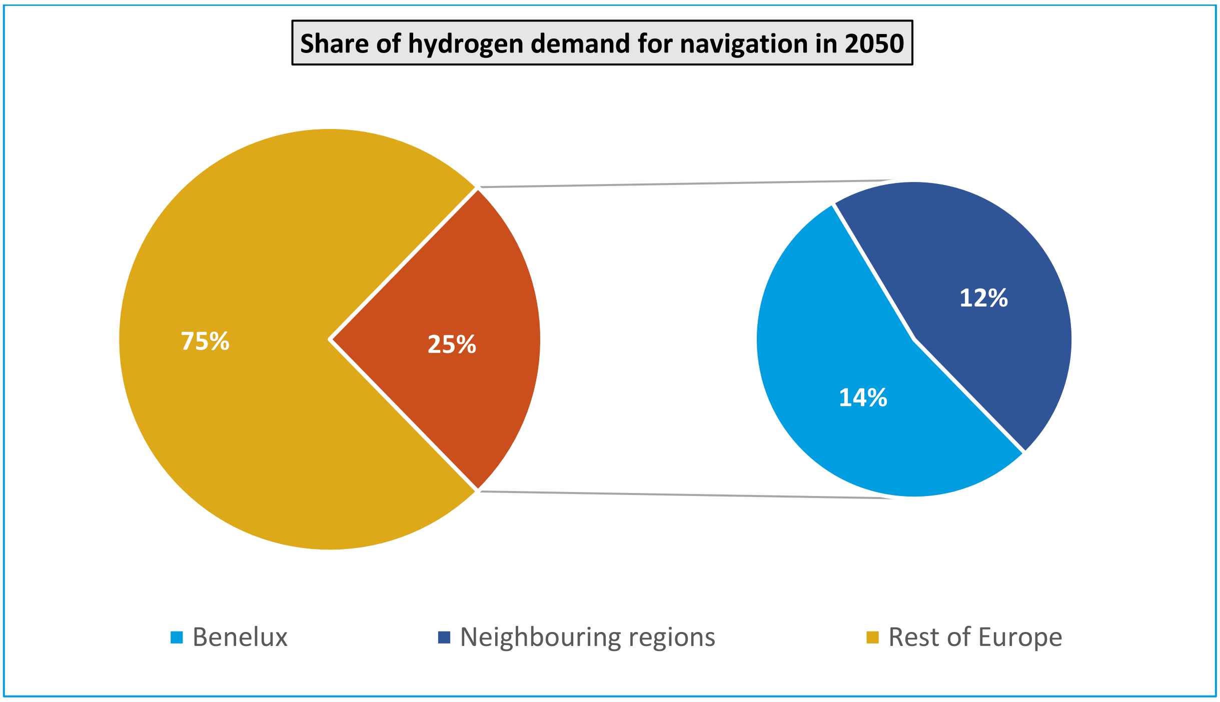

Share of hydrogen demand for aviation in 2050
75%
25%
12%
14%
Benelux
Neighbouring regions
Rest of Europe

Table 34: Final demand growth selected for hydrogen navigation

| Country | Final demand growth hydrogen selected | | | | | |
|---|---|---|---|---|---|---|
| Navigation | Minimum scenario | | | Maximum scenario | | |
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Hydrogen demand | kton/y | | | | | |
| Netherlands | 0 | 4 | 8 | 3 | 6 | 12 |
| Belgium | 0 | 2 | 5 | 2 | 4 | 8 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 1 | 7 | 16 | 7 | 12 | 25 |
| 2 French states | 0 | 1 | 3 | 1 | 2 | 4 |
| Hauts-de France | 0 | 1 | 1 | 1 | 1 | 2 |
| Grand Est | 0 | 1 | 1 | 1 | 1 | 2 |
| Germany | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 German states | 0 | 1 | 3 | 1 | 2 | 5 |
| Lower Saxony | 0 | 0 | 1 | 0 | 1 | 1 |
| North Rhine-Westphalia | 0 | 1 | 2 | 1 | 1 | 3 |
| Rhineland-Palatinate | 0 | 0 | 1 | 0 | 0 | 1 |
| Saarland | 0 | 0 | 0 | 0 | 0 | 0 |
| Benelux | 0 | 6 | 13 | 6 | 10 | 21 |
| Benelux + Neighbouring regions | 1 | 9 | 19 | 8 | 15 | 30 |
| Europe | 5 | 60 | 128 | 57 | 101 | 203 |


Hydrogen demand for navigation (max scenario)
H2 demand (kton/y)
250
200
150
100
50
0
2030
2040
2050
Netherlands
Belgium
Luxembourg
French regions
German regions
Benelux
Benelux+NR
Europe


Share of hydrogen demand for navigation in 2050
75%
25%
12%
14%
Benelux
Neighbouring regions
Rest of Europe

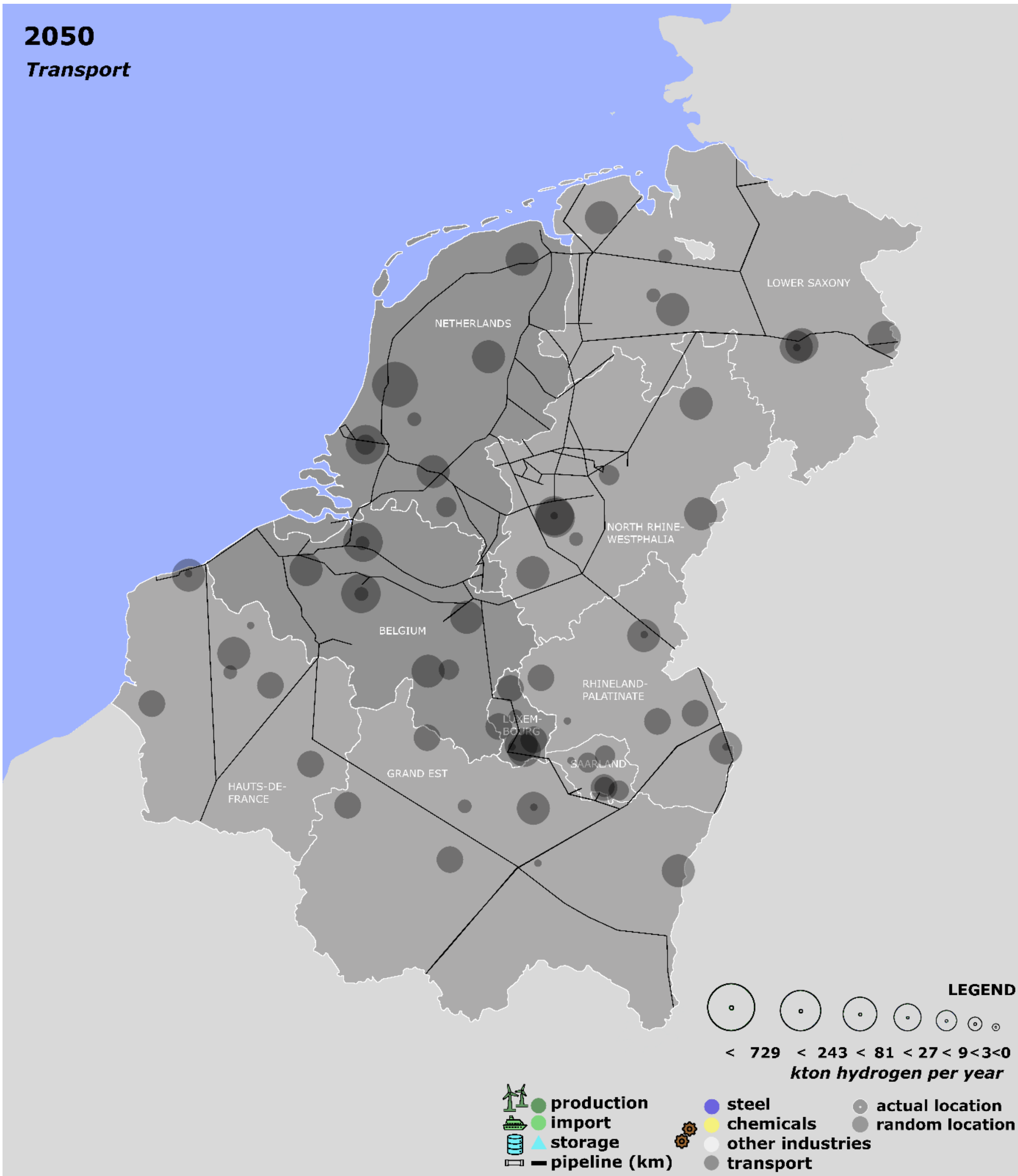



Figure 27: Geographical representation of hydrogen demand for transport in 2050

## 6.5 IMPORT, PRODUCTION & SEAPORTS

### Hydrogen production & import in the Benelux and neighbouring regions

Historically, hydrogen is produced using fossil fuels either from oil and coal through gasification, or from natural gas through Steam Methane Reforming. However, since the Paris agreement and the net zero emission goals of Europe for 2050, production of hydrogen from carbon-free sources is becoming more and more important and promoted. This is going to mainly happen either through Carbon Capture and Storage (CCS) process or using green electricity from solar, wind or nuclear energy. To this end, many European countries, including the Benelux, have set specific targets for production of green hydrogen via electrolysis using offshore and onshore wind and solar energy, in the coming decades.

However, due to intermittent nature of solar and wind, the hydrogen production will be interrupted. Next to this, the green electricity production capacity required for the amount of hydrogen that would cover the entire demand in Europe, and specifically in the Benelux region, is certainly not enough. That is why next to hydrogen production within Europe, the import of hydrogen, specifically low-cost hydrogen produced in the countries with abundant cheap green electricity, is of great importance. Accordingly, main ports in Europe are considered as potential gateways for import and transport of green hydrogen to the rest of Europe.

The Benelux region hosts several sea and inland ports, which are amongst the largest ports in Europe, including **3 main seaports in Belgium** (Port of Antwerp-Bruges, Port of Oostende, Port of Ghent), **6 main seaports in the Netherlands** (Port of Rotterdam, Port of Amsterdam, Groningen Seaport, Moerdijk Seaport, Zeeland Seaport, Port of Den Helder), and **1 inland port in Luxembourg** (Port de Mertert). Almost all these ports are involved in different hydrogen development activities, from offshore and on shore green hydrogen production, to terminals for import of hydrogen and its derivatives, to port infrastructure for hydrogen transport, and to supplying hydrogen to the end-users in the port area.

Next to the Benelux countries, there are several important sea and inland ports located in the Benelux neighbouring regions, including **Dunkirk in Hauts-de-France**, **Port of Strasbourg in Grand Est**, **Port of Wilhelmshaven in Lower Saxony, Duisport in North Rhine-Westphalia, and Ports of Ludwigshafen in Rhein in Rhineland-Palatinate.** The same as the ports in the Benelux region, these ports are also mostly involved in different hydrogen developments.

### National and regional strategies for hydrogen production

The European Union has committed to cut greenhouse gas emissions by 55% compared to 1990 by 2030[63], a key milestone in reaching climate neutrality in 2050. Consequently, all the European member states have started revising their energy and climate policies to move towards zero emission in 2050, with intermediate plans for 2030 and 2040. More recently, the new geopolitical and energy market realities require us to drastically accelerate our clean energy transition and increase Europe's energy independence from unreliable suppliers and volatile fossil fuels. REPowerEU is the European Commission's plan to make Europe independent from Russian fossil fuels well before 2030, in light of Russia's invasion of Ukraine[64]. In this package, next to accelerating the production of renewable electricity, there is emphasis on accelerating the production of renewable hydrogen as well, which is

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[63] European Commission (2021) – Proposal for a recast Directive / Regulation on gas markets and hydrogen (COM(2021) 803 final) / (COM(2021) 804 final). Source: https:// energy.ec.europa.eu/topics/markets-andconsumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en

[64] European Commission (2022) – REPowerEU: Joint European Action for more affordable, secure, and sustainable energy (COM(2022) 109 final). Source: https://energy.ec.europa. eu/repowereu-joint-european-action-more-affordable-secure-and-sustainable-energy_en

expected to be produced from renewable electricity. Accordingly, amongst other measures, REPowerEU has announced an ambition to reach **an additional 15 million tons (Mt) of renewable hydrogen on top of the 5.6 Mt foreseen** under Fit for 55 plan, going beyond the targets of the EU's hydrogen strategy. The REPowerEU sets a target of 10 million tons of domestic renewable hydrogen production and 10 million tons of renewable hydrogen imports by 2030[65].

Meeting these targets will require a rapid acceleration of the development of hydrogen production, infrastructure, hydrogen storage facilities, port, and demand. We cannot underestimate the challenge of producing green hydrogen at the scale needed to deliver the 2050 net-zero targets. It is clear that sustainable electricity from renewable sources will be the major future energy source for dedicated hydrogen production. Wind, in particular, will be at the centre of the green hydrogen revolution, and vice versa hydrogen will unlock additional demand potential for offshore wind installations and solar.

According to the European Commission[66], the energy production targets for offshore renewable energy (ORE) in all of the EU's sea basins are **at least 60 GW by 2030 and 340 GW by 2050**. Recently Germany, Belgium, The Netherlands and Denmark signed the Esbjerg Declaration[67], pledging **to deliver 65 GW by 2030 and at least 150 GW by 2050 of offshore wind capacity** only in the North Sea area. Add to that, ambitions from UK, Norway and other countries, the North Sea will end up being the "powerhouse" for wind energy.

Table 35 summarizes the planned electrolyser (electrical) capacity according to the national and regional strategies within Europe, the Benelux and its neighbouring regions.

[65] Hydrogen Europe Position Paper, Delivering REPowerEU through a strong, European hydrogen industry, May 2022
[66] The European parliament and the council of the european union. Offshore wind energy in Europe, 2020 https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659313/EPRS_BRI(2020)659313_EN.pdf
[67] https://windeurope.org/wp-content/uploads/files/policy/position-papers/20220518-Declaration-of-energy-ministers.pdf

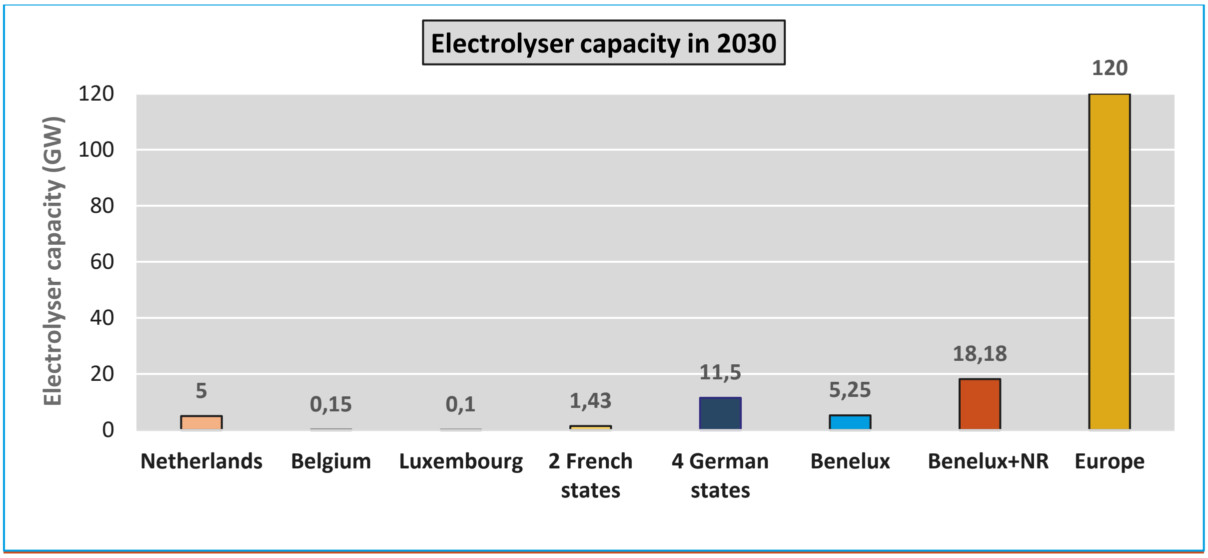
Table 35: Overview of the national and regional plans for electrolyser plants and hydrogen production capacities in the Benelux, neighbouring regions and Europe

| Countries/Regions | Total Plant Capacity | | | Total Plant H2 production (4000 hours/y and 65% efficiency) | | |
|---|---|---|---|---|---|---|
| Year | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 |
| Netherlands[68] | 5 GW | >10 GW | - | 390 kt/y | >780 kt/y | - |
| Belgium[69] | 0.15 GW by 2026 | - | - | 12 kt/y | - | - |
| Luxembourg[70] | 0.1 GW | - | - | 8 kt/y | - | - |
| France[71] | 6.5 GW | - | - | 507 kt/y | - | - |
| Hauts-de France | 0.3 GW by 2023 and 0.83 GW by 2028 (Dunkirk) | - | - | 26 kt/y by 2023 and 65 kt/y by 2028 at Dunkirk | - | - |
| Grand Est[72] | 0.6 GW | - | - | 47 kt/y | - | - |
| Germany[73,74] | 10 GW | - | >50 GW | 780 kt/y | - | >3900 kt/y |
| Lower Saxony[75] | 0.5 GW (by 2025) and 8.5 GW by 2030 | - | 18.5 GW | 663 kt/y (285 kt/y at Wilhelmshaven) | - | 1443 kt/y |
| North Rhine-Westphalia[76] | 1-3 GW | - | - | 78-234 kt/y | - | - |
| Rhineland-Palatinate | - | - | - | - | - | - |
| Saarland | - | - | - | - | - | - |
| Benelux | 5.25 GW | | | 410 kt/y | | |
| Benelux + Neighbouring regions | 18.18 GW | | | 1419 kt/y | | |
| Europe | 120GW | - | - | 10000 kt/y | - | - |

[68] Routekaart 2022
[69] BE Hydrogen Strategy
[70] NECP Lux Trinomics
[71] National strategy for the development of decarbonised and renewable hydrogen in France
[72] Une stratégie HYDROGENE pour le Grand Est; 2020-2030
[73] Germany National Hydrogen Strategy 2021
[74] Prognos, Öko-Institut, Wuppertal-Institut (2021): Klimaneutrales Deutschland 2045.
[75] Strategy North Germany
[76] NRW Hydrogen Roadmap

A graphical representation of the electrolyser capacity for the Benelux countries and the neighbouring regions by 2030 (based on the data shown in Table 35), as well as the percentage share of the Benelux and neighbouring regions in 2030 in comparison to Europe is shown in Figure 28. Before doubling the electrolyser capacity plan in EU, **hydrogen production in Europe was predominantly taking place in** the Benelux and its neighbouring regions **(almost one-third of the production)**. After announcing the REPowerEU plan in May 2022, in which the decarbonization targets are raised by the European Commission, **still around one-sixth of the hydrogen production in EU will be in the Benelux and its neighbouring regions**. The rest of the production comes mainly from Spain and other southern European countries to meet the new targets.

**NOTE:** It is important to note that the announce target of 80 GW local hydrogen production capacity in REPowerEU, and other announced targets by the European Commission including Green Deal, refers to the hydrogen output and not to the electrical capacity of the electrolyser. Hence, 80 GW electrolyser hydrogen capacity is equivalent to about 120 GW electrolyser capacity based on 65% efficiency and 4000 hours production within a year. It is obvious that with other load-factor and other efficiency, the installed (electrical) electrolyser capacity will be more or less than 120 GW. This is in contrast to the announced projects and also national strategies, which refer to electrical capacity of the electrolyser.



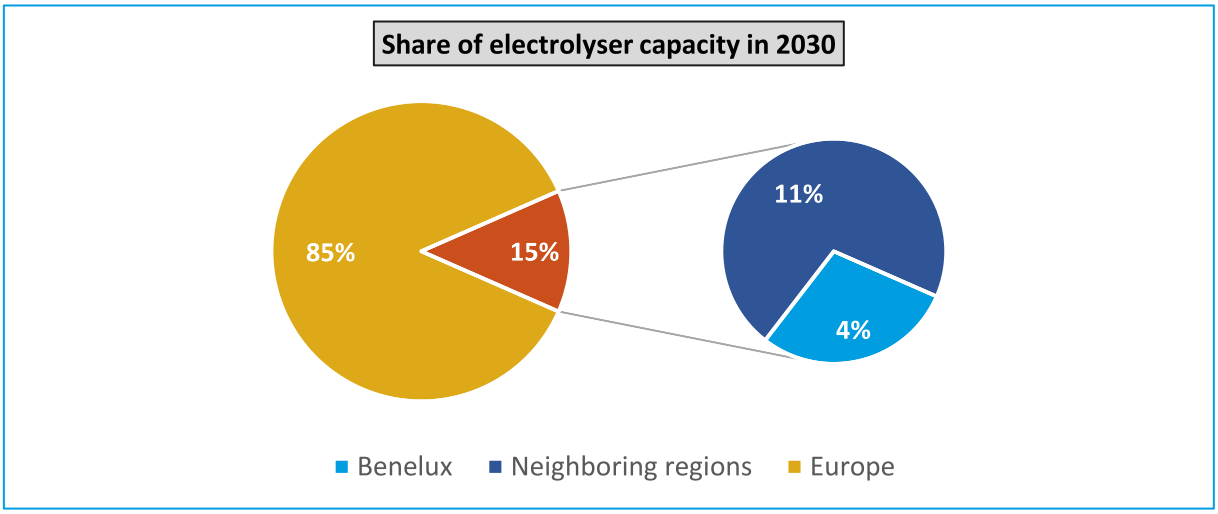




Figure 28: Planned electrolyser capacity in the Benelux and its neighbouring regions and their share compared to entire Europe

### Hydrogen production projects in the Benelux and its neighbouring regions

Next to the national and regional strategies for developing electrolyser plants, several projects have been already announced with the aim of producing green hydrogen in large scale by 2030. These projects are at different stages, some have already finished the feasibility study, some are at investment phase, and some are the installation phase. The following tables (Table 36 to Table 45) summarizes the main hydrogen projects in the Benelux and its neighbouring regions.

*Table 36: Hydrogen production projects in Flanders, Belgium*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| PowertoMethanol – Antwerpen[77] | 5 MW (by 2023) with possible upscaling to 50 MW | Industrial application | Yes |
| Large scale green $H_2$ plant - Antwerpen[78] | 100 MW | Different applications | Yes |
| HyoffWind – Zeebrugge[79] | 25 MW (by 2023) | Industrial scale facility and mobility | Yes |
| NorthCHydrogen – Rodenhuize[80] | 63 MW (by 2023) and upscaling to 600 MW | Different applications | Yes |
| HyPort – Oostende[81] | 300 MW | Different applications | Not clear |
| Terranova Hydrogen – Ghent[82] | 1-5 MW | Industrial applications | Yes |

*Table 37: Hydrogen production projects in Wallonia, Belgium*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| Columbus – Amercoeur[83] | 75 MW | Production of e-methane | No (connection with NG grid) |
| KerolHyme - Tihange and Hermalle[84] | 100 MW scalable to 1000 MW | Transported to Lhoist industrial site to be combined with $CO_2$ | Yes |

[77] https://powertomethanolantwerp.com/concept/
[78] https://www.ir.plugpower.com/press-releases/news-details/2022/Plug-to-Build-Large-Scale-Green-Hydrogen-Generation-Plant-in-Europe-at-Port-of-Antwerp-Bruges/default.aspx
[79] https://www.gie.eu/hyoffwind/
[80] https://northccuhub.eu/north-c-methanol/
[81] https://www.portofoostende.be/en/news/hyportr-green-hydrogen-plant-in-ostend
[82] https://economie.fgov.be/sites/default/files/Files/Energy/IPCEI-hydrogen-List-BE-Potential-Direct-participants.pdf
[83] https://innovation.engie.com/en/news/medias/green-mobility/engie-s-columbus-power-to-methane-project-wins-the-febeliec-energy-award-2020/24706
[84] https://innovation.engie.com/en/innovation-trophies-2021/kerolhyme/25557

*Table 38: Hydrogen projects in the Netherlands*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| Hynoca Alkmaar[85] (from certified biomass residues) | 240t-1.300t $H_2$/year (by 2023) | Local application | No |
| Djewels-2 – Delfzijl[85] | 40 MW (by 2025) and upscaling to 100 MW | Different applications | Yes |
| Djewels-1 – Delfzijl[86] | 20 MW | Different applications | Yes |
| VoltH2 -Terneuzen[85] | 25 MW (by 2025) and upscaling to 80 MW | Different applications | Yes |
| Energiepark Eemshaven-West[85] | 10 MW-100 MW (phase) | Mobility & Industry | Yes |
| ELYgator – Terneuzen[85] | 200 MW (by 2027) | Mobility & Industry | Yes (to AL network) |
| H2 Conversion Park – Maasvlakte[85] | 200 MW of Shell (2024) and 250 MW of H2-Fifty (BP and HyCC; 2025) – upscaling plans to 2000 MW | Different applications | Yes |
| H2ero – Vlissingen85[85] | 150 MW (by 2026) | Zeeland Refinery in Vlissingen | No |
| MULTIPLHY – Rotterdam[85] | 2.6 MW (operation in Q2 2022) | refinery's processes | No |
| Haddock – Sluiskil[85] | 100 MW (by 2026) and upscaling to 1000 MW | neutral fertilizer products, food value chain, shipping fuel | Yes |
| SeaH2Land – North Sea Port[85] | 1000 MW | Local industrial cluster | Yes |
| CurtHylproject – Maasvlakte II[85] | 200 MW (by 2026) | Mobility & Industry | Yes |
| VoltH2 -Vlissingen[85] | 25 MW (by 2025) and upscaling to 100 MW | Mobility & Industry | Yes |
| Uniper – Maasvlakte[85] | 100 MW (by 2025) and upscaling to 500 MW | Mobility & Industry | Yes |
| Eemshydrogen – Westereems[85] | 50 MW (by 2025) with upscaling to 500 MW | Hard-to-abate industrial sectors | Yes |

[85] TKI New Gas 2022, Overview of Hydrogen Projects in the Netherlands
[86] https://djewels.eu/

| | | | |
|---|---|---|---|
| Hy4Am – Hemweg [85] | 10 MW (by 2026) | Mobility and industry | - |
| GreenH2UB – Eindhoven[85] | 5-10 MW (by 2025) | Industry, mobility and built environment | No |
| GZI NEXT – Emmen[85] | 10 MW (by 2025) | Local application | No |
| Hydrogen Wind Turbine – Wieringermeer[85] | 2.3 MW (by 2023) | - | Yes |
| H2ermes – Amsterdam[85] | 100 MW (with possible upscaling to 500 MW) | Tata Steel | No |
| HyNetherlands – Eemshaven[85] | 100 MW (by 2025) and upscaling to 1 GW | Chemical industry | - |
| GldH2 – Zutphen[85] | 2 MW (by 2023) | Different applications | Yes |
| NorthH2 – Groningen[87] | 3000 MW | Different applications | Yes |
| PoDH2 (Zephyros) – Den Helder[88] | 2 MW | Mobility (port application) | No |
| H2era – Amsterdam[89] | 500 MW | Industry and mobility applications | Yes |
| P2F – Hemweg [90] | 10 MW (by 2050) and upscaling to 100 MW | Synthetic methanol and kerosine | Yes |

*Table 39: Hydrogen projects in Luxembourg*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| GPSS (multiple projects)[91] | 50 MW | Different applications | - |

*Table 40: Hydrogen projects in Hauts-de-France region*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| SHYMED – Dunkirk[92] | 1 MW (by 2024), upscaling to 2MW | Mobility | No |
| REUZE – Dunkirk[93] | 400 MW | Industry | - |
| H2V59 – Loon-Plage[94] | 200 MW | Industry | - |

[87] https://www.north2.eu/en/
[88] https://zephyros-nhn.nl/
[89] https://www.hycc.com/nl/nieuws/hycc-lanceert-500-megawatt-waterstofproject-in-de-haven-van-amsterdam
[90] https://www.portofamsterdam.com/sites/default/files/2021-10/Hydrogen%20Hub%20NZKG_uk_v06_LR%2005-10.pdf
[91] GSPP company's planning for hydrogen production in Luxembourg
[92] https://www.dunkerquepromotion.org/en/2021/10/towards-the-roll-out-of-a-hydrogen-sector-in-dunkirk/
[93] https://www.reuze.eu/
[94] https://h2v59-concertation.net/

| | | | |
|---|---|---|---|
| DRI Arcelor – Dunkirk[95] | 400 MW | Industry | - |
| Anonymous | 2 MW | Industry | - |
| H2 SOMME VERT | 1 MW | Mobility | - |
| HYLEOS – Lille[96] | 2 MW | Mobility | - |
| TADAO – Artois-Gohelle[97] | 1 MW | Mobility | - |

*Table 41: Hydrogen projects in Grand Est region*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| Hyvia – Batilly[98] | 1 MW (by the end of 2022) | direct use in HRS | No |
| John Cockerill production plant - Aspach-Michelbach[99] | 200 MW (by the end of 2022) with upscaling to 1000 MW | Different applications | Yes |
| R-Hynoca – Strasbourg | 1-2 MW (2024) | Industry and mobility | No |
| Anonymous – Strasbourg | 1-2 MW (2026) | Industry and mobility | No |

*Table 42: Hydrogen project in Lower Saxony region*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| Element Eins - East Frisia[100] | 100 MW | Industrial costumers | Yes |
| Clean Hydrogen Coastline – NI[101] | 400 MW (by 2026) with upscaling to 2200 MW | Industry | Yes |
| GET H2 – Lingen[102] | 100 MW (2024)<br>200 MW (2025)<br>300 MW (2026) | Industry and mobility | Yes |
| LGH2 – Lingen[103] | 100 MW (by 2025) with upscaling to 500 MW (by 2027) | Industry and mobility | Yes |

[95] https://corporate.arcelormittal.com/media/press-releases/arcelormittal-accelerates-its-decarbonisation-with-a-1-7-billion-investment-programme-in-france-supported-by-the-french-government
[96] https://www.euoffice.lillemetropole.fr/news/hyleos-project-future-based-green-hydrogen
[97] https://www.engie-solutions.com/en/business-cases/hydrogen-buses-hauts-france
[98] https://www.hyvia.eu/en/
[99] https://h2.johncockerill.com/en/hydrogene-vert-nouvelle-avancee-de-john-cockerill-%E2%80%A8dans-linstallation-dune-gigafactory-en-france/
[100] https://thyssengas.com/en/innovation/element-eins.html
[101] https://www.wasserstoff-niedersachsen.de/en/clean-hydrogen-coastline/
[102] https://www.get-h2.de/en/implementation/
[103] https://lingen-green-hydrogen.com/en/

| | | | |
|---|---|---|---|
| HyBridge – Emsland[104] | 100 MW | Industry and mobility | Yes |
| $H_2$ercules – Western Lower Saxony[105] | 1000 MW | Different applications | Yes |
| SALCOS 100 MW (2025)[106] | 500 MW (2030) | Industry | Yes |
| Green Wilhelmshaven[107] | 1000 MW (2030) | Different applications | Yes |
| HySynGas – Brunsbüttel[108] | 50 MW | Different applications | Yes |

*Table 43: Hydrogen projects in North Rhine-Westphalia region*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| GreenMotionSteel – Duisburg[109] | 120 MW (by 2024) | Steel industry and mobility | Yes (to AL network) |
| Green Steel – Duisburg[110] | 500 MW | Steel industry | No |

*Table 44: Hydrogen projects in Rhineland-Palatinate region*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| Hy4Chem – Ludwigshafen[111] | 50 MW with the upscaling possibility | Chemical industry | No |

*Table 45: Hydrogen projects in Saarland region*

| Project | Total Plant Capacity 2030 | End-users | Backbone Connection |
|---|---|---|---|
| Hydrohub Fenne – Völklingen[112] | 53 MW (by 2026) | Different applications | Yes (local network) |

[104] https://www.hzwei.info/blog/2021/05/27/element-eins-und-hybridge-gestoppt/
[105] https://www.h2ercules.com
[106] https://www.bgr.bund.de/DE/The men/Min_rohstoffe/Veranstaltungen/Rohstoffkonferenz_2022_Rohstoffversorgung_Deutschlands/Redenius.pdf?__blob =publicationFile&v=3
[107] https://www.greenwilhelmshaven. de/en
[108] Https://www.arge-netz.de/fileadmin/user_upload/presse/190404_hysyngas_pm_power-to-gas_hub_brunsbu%cc%88ttel_arge-netz_man_vattenfall_final.pdf
[109] https://www.wirtschaft.nrw/pressemitteilung/europas-wasserstoffwirtschaft-nimmt-fahrt-auf-nordrhein-westfalen-beteiligt-sich
[110] https://www.thyssenkrupp-steel.com/en/newsroom/press-releases/steag-and-thyssenkrupp-are-planning-joint-hydrogen-project.html
[111] https://www.bmwk.de/Redaktion/DE/Wasserstoff/Downloads/ipcei-standorte.pdf?__blob=publicationFile&v=6
[112] https://grande-region-hydrogen.eu/en/projects/hydrohub-fenne/

Table 46 presents a summary of the total production plans based on these projects per country and regions.

Table 46: Overview of the total electrolyser capacity and hydrogen production in the Benelux and its neighbouring regions based on the announced projects

| Countries/Regions | Total Plant Capacity | Total Plant H2 production (4000 hours/y and 65% efficiency) |
|---|---|---|
| Year | 2030 | 2030 |
| Netherlands | 10.6 GW | 827 kt/y |
| Belgium | 1.25 (1.08 Fl, 0.17 Wa) GW | 98 kt/y |
| Luxembourg | 0.05 GW | 4 kt/y |
| France | | |
| Hauts-de France | 1.01 GW | 79 kt/y |
| Grand Est | 1.01GW | 79 kt/y |
| Germany | | |
| Lower Saxony | 5.75 GW | 449 kt/y |
| North Rhine-Westphalia | 0.62 GW | 48 kt/y |
| Rhineland-Palatinate | 0.05 GW | 4 kt/y |
| Saarland | 0.05 GW | 4 kt/y |
| Benelux | 11.9 GW | 928 kt/y |
| Benelux + Neighbouring regions | 20.39 GW | 1591 kt/y |

By comparing the announced projects with the national and regional strategies, we see in Figure 29 that some of the countries are already exceeding the national strategies based on the planned projects and some need more investment to be able to meet the governmental strategies, despite the planned projects in their regions. Figure 29 shows how these projects and the governmental strategies are aligned.

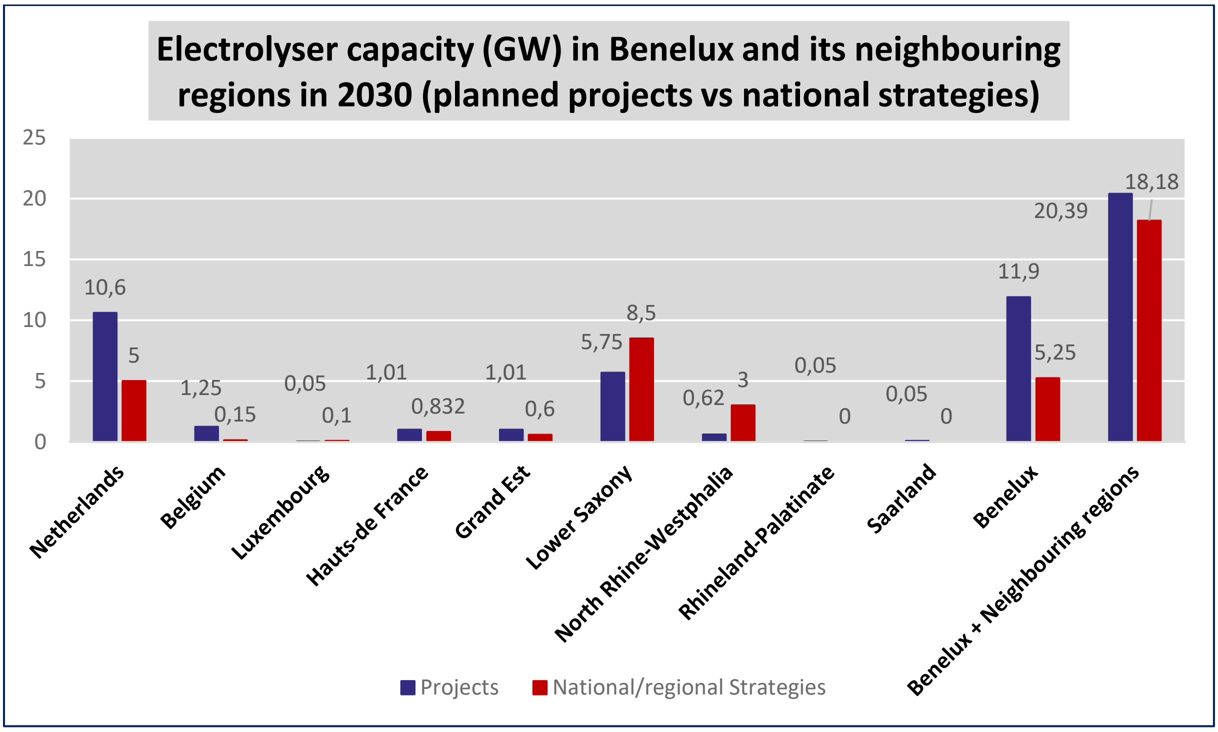



Figure 29: Comparing the electrolyser capacities in 2030 in the Benelux and its neighbouring regions based on the announced projects and the national and regional strategies

A geographical representation of the hydrogen production plant capacities is illustrated in Figure 30.

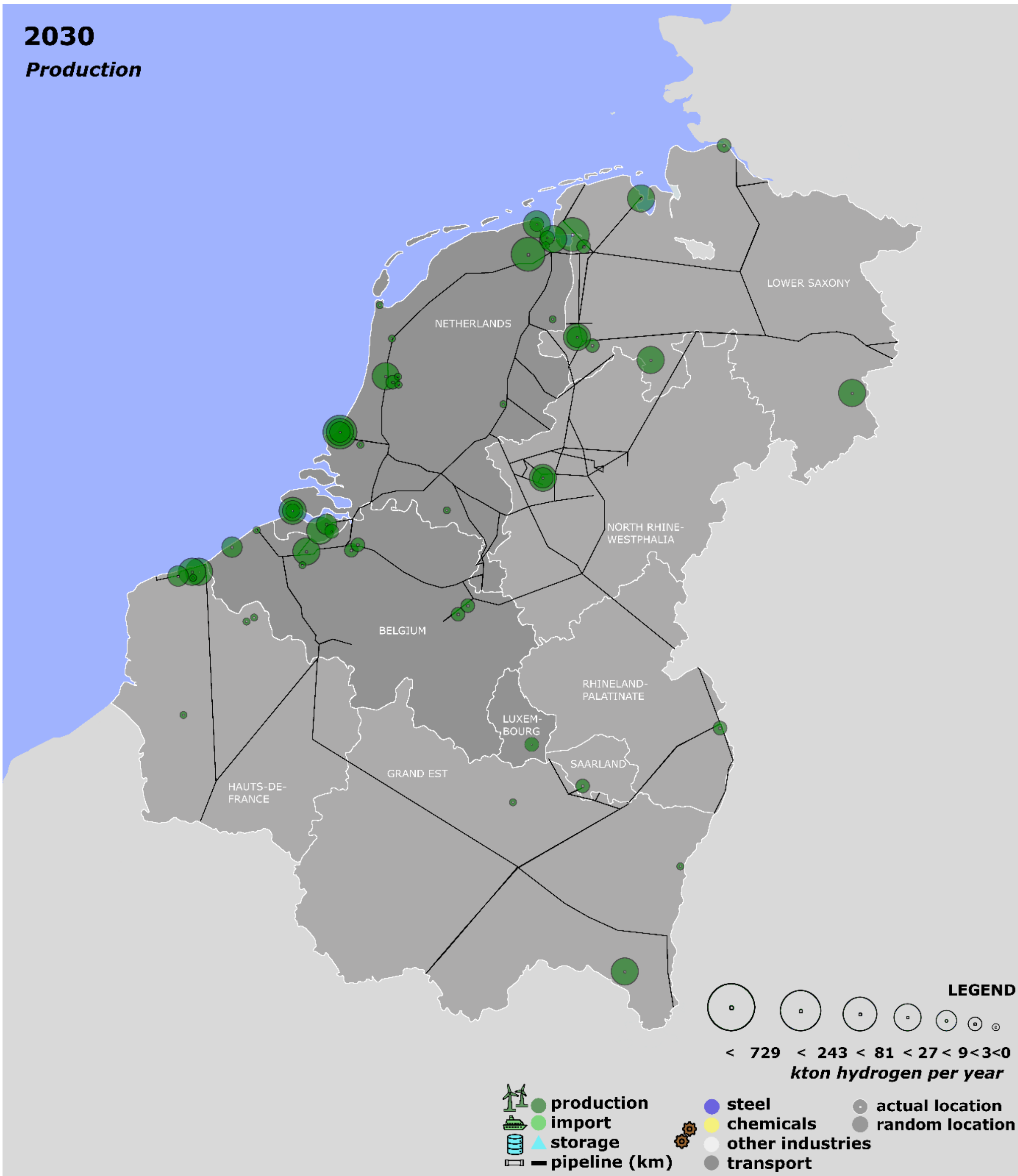



Figure 30: Electrolyser plant capacity based on the announced projects in the Benelux and its neighbouring region in 2030

## National and regional strategies for hydrogen import

Europe in general, including the Benelux and its neighbouring regions, will not have enough renewable electricity to produce the required amount of green hydrogen for different applications. Therefore, import of hydrogen is needed. Areas with a lot of space combined with cheap solar and wind are attractive as production sites of green hydrogen resulting in lower hydrogen price. The produced green hydrogen can be transported as pure hydrogen (in gaseous or liquid form depending on the distance) or, after synthesis with carbon or nitrogen, as a "hydrogen carrier" such as methanol, methane or ammonia. Such hydrogen carriers can be more efficient to transport and use, depending on the case.

In May 2020, Port of Rotterdam presented its vision, in which besides already mentioned local production of hydrogen, a large role for importing hydrogen has been defined, including hydrogen terminals and hydrogen trading platform (see Figure 31). Actually, several memorandums of understanding have been agreed between The Netherlands and other countries to analyse the feasibility.

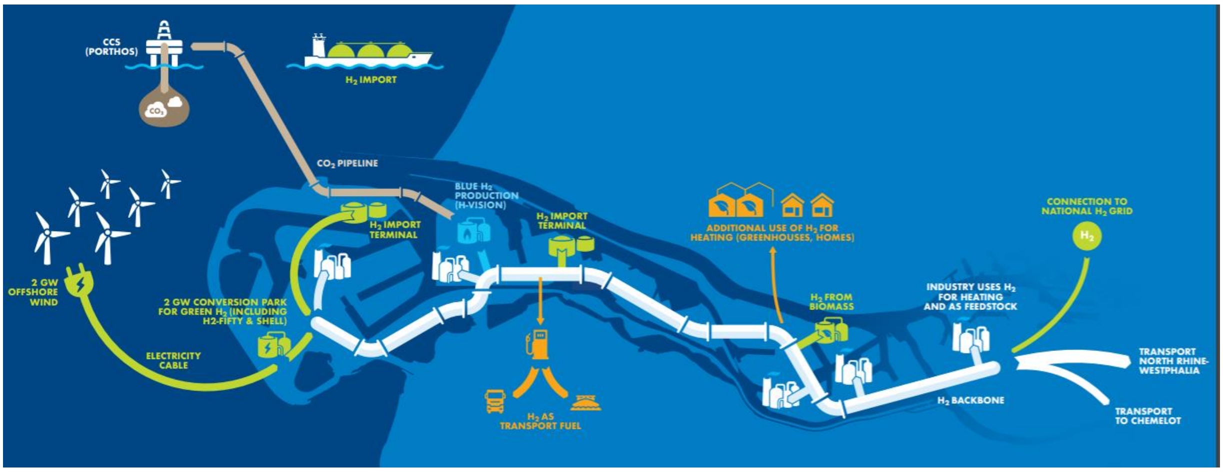



Figure 31: Regional hydrogen backbone port of Rotterdam combined with local production and import[113]

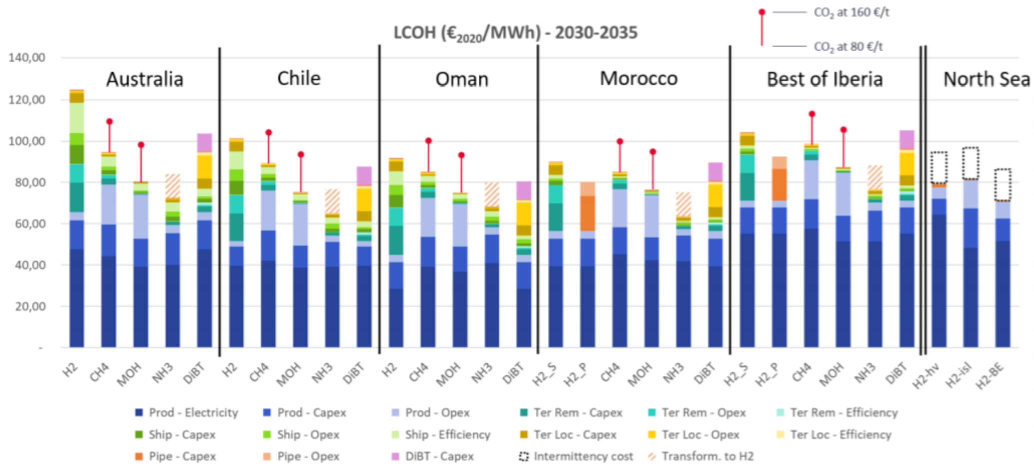
In January 2021, the Hydrogen Import Coalition (DEME, Exmar, Engie, Fluxys, port of Antwerp, port of Zeebrugge, WaterstofNet) presented the results of different scenarios for large scale import hydrogen carriers[114] (Figure 32 and Figure 33).

[113] https://www.portofrotterdam.com/

[114] Shipping sun and wind to Belgium is key in climate neutral economy, Hydrogen Import Coalition


Source: hydrogen import coalition

Figure 32: Large scale hydrogen import routes




Source: hydrogen import coalition

Figure 33: Possible import routes and estimated costs for different hydrogen carriers in 2050

These are examples of the studies and plans attempting to pave the path for hydrogen import from the main ports in Europe. Based on these studies, the cost and routes for importing hydrogen or its derivatives (ammonia, methanol, Liquid Organic Hydrogen Carriers, etc.) are estimated. The general consensus is the following[115],[116],[117]. For all possible **hydrogen transport routes within or near Europe** that can be served by pipeline, **a pipeline is a more cost-effective option than any shipping method**, assuming sufficient volumes are being transported to justify a pipeline at least 36 inches in diameter because pipelines with higher throughputs are less expensive. There is an exception of course where there is no pipeline available in a short term, and hence, **hydrogen can be transported using inland shipping**. An example for this is in the Upper Rhine region, where an efficient connection to the Hydrogen Backbone is not expected before 2040. The recent study[118] "Innovation Region Fessenheim"

[115] European Hydrogen Backbone, Analyzing the future demand, supply and transport of hydrogen (June 2021)

[116] IEA, The future of Hydrogen (2019)

[117] ISPT, HyChain2: Cost implications of importing renewable electricity, hydrogen and hydrogen carriers into the Netherlands from a 2050 perspective (2019)

[118] https://www.eucor-uni.org/wp-content/uploads/2022/08/FinalReport_Innovation-Region-Fessenheim-1.pdf

suggests the use of inland shipping to bridge the existing need for the import of green hydrogen in the meanwhile. In general, **shipping should be reserved for long distance, intercontinental trade separated by ocean.** Shipping is also advantageous from the perspective of security and flexibility of supply. Pipelines can be difficult to construct across politically unstable regions, and shipping routes can be modified to react to changes in market dynamics. When hydrogen is shipped, **export and import locations should be selected as close to the production and demand sites** as possible because the marginal cost of shipping per km is higher than that of pipelines.

To give a visual presentation for the transport cost, comparing pipelines and ships, EHB report[39] has used three routes for hydrogen import to Europe: 1) North Africa, 2) Saudi Arabia, 3) Australia. The results show that for the first route, as an illustrative exercise, Marrakech was selected as a representative location of hydrogen production and Cologne was selected as a representative location of hydrogen demand. Figure 34 compares the costs of the various transport options.

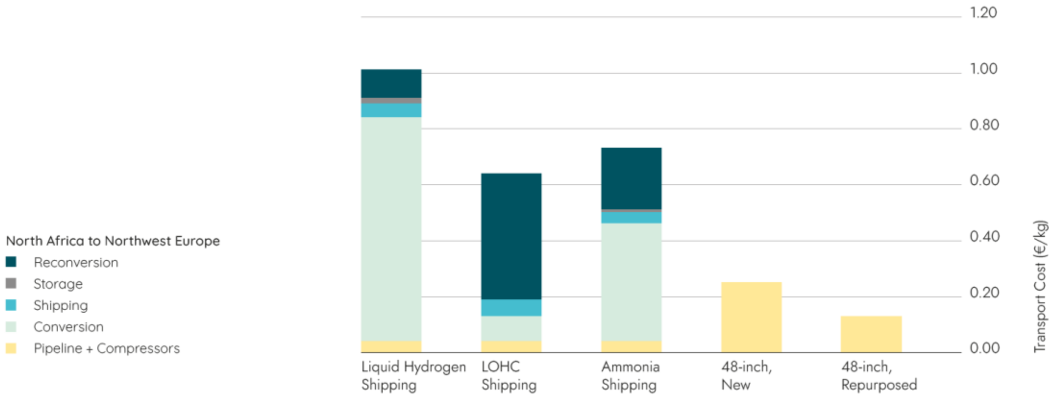



Figure 34: Hydrogen transport cost comparison for North Africa to Northwest Europe[39]

Pipeline is by far the most cost-effective of the three options, adding 0.13-0.25 €/kg hydrogen delivered for 48” pipelines compared to 0.65-1.03 €/kg hydrogen for the shipping options. For the second route, NEOM was selected as the representative production site and Milan was selected as the representative demand site. Figure 35, compares the transport cost using pipeline and ships.

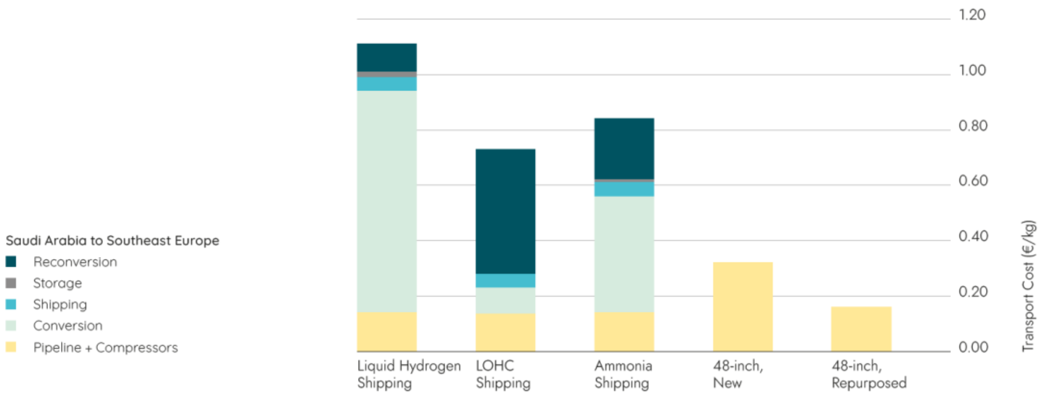



Figure 35: Hydrogen transport cost comparison for Saudi Arabia to Southeast Europe[39]

The shipping options are more competitive for this route because the distance is greater, however pipeline is still significantly more cost-effective than any of the shipping options. Australia was examined as a third potential exporter of hydrogen due to its renewable generation potential and vast landmass. A shipping route was modelled including a pipeline to Melbourne, a shipping route from Melbourne to Sicily and a pipeline from Sicily to Milan.

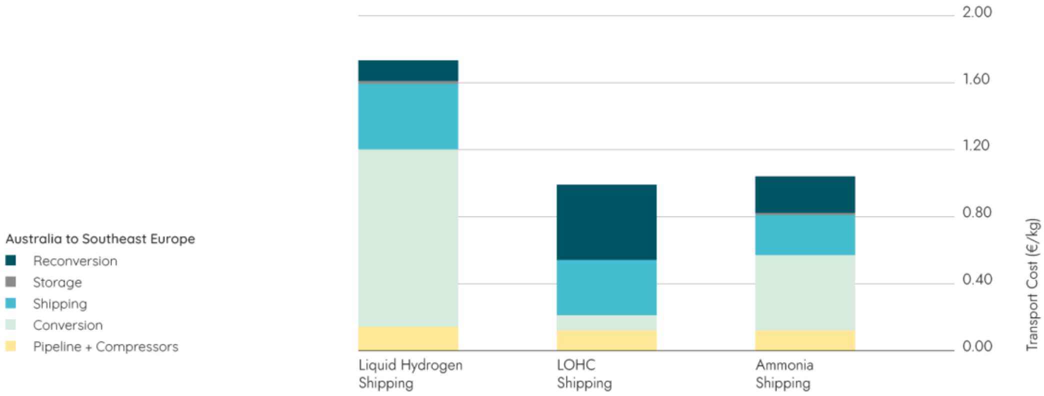



Figure 36: Hydrogen transport cost comparison for Australia to Southeast Europe[39]

Pipeline is obviously an unrealistic transport method for this route, while shipping transport costs from Australia can be compared to those from other potential exporters. Figure 36 indicates that the cheapest mode of transport of hydrogen from Australia to Southeast Europe is LOHC shipping with a levelized cost of €1.00/kg.

Different countries and regions, including the Benelux and its neighbours, have foreseen certain capacities for hydrogen import. Table 47 summarizes the import plans mainly from national and regional strategies, as well as plans of the port's authorities for 2030 and 2050. Ports have different plans for the import of hydrogen or hydrogen derivatives; it is important to note that the import quantities in Table 47 are hydrogen equivalents. So, depending on the carrier that is used, the imported quantity can be much higher. For instance, to import 0.1 Mt of hydrogen, 0.7-0.8 Mt ammonia is required.

Table 47: Hydrogen import (either pure or its equivalent using hydrogen derivatives) plans based on national and regional strategies as well as the ports for 2030 and 2050

| **Countries/Regions** | **Total Import Plan** | |
|---|---|---|
| **Year** | **2030** | **2050** |
| **Netherlands** | **The port of Rotterdam**[119] has the ambition to import **4.6 Mt by 2030; North Sea Port**[120] is planning to import **0,3 to 0,5 Mt by 2030**. | **Port of Rotterdam** expects to import circa **18 Mt by 2050** from which ***13 Mt be transported*** *to the Germany and other EU countries*); **North Sea Port** has potential of **2 to 6 Mt for import in 2050** |
| **Belgium**[121] | **0.6 Mt** | **6-10.5 Mt** |
| **Luxembourg** | - | - |
| **France** | - | - |
| **Germany**[122] | About **3 Mt** | **8 Mt** (via Rotterdam) **+ 3 Mt** from other locations |
| **Lower Saxony**[123] | **0.87 Mt** (Wilhelmshaven) | **3-4 Mt** |
| **North Rhine-Westphalia**[124] | about **0.16 Mt** (90% of $H_2$ demand) | About **3 Mt** |
| **Rhineland-Palatinate** | - | - |
| **Saarland** | - | - |
| **Benelux** | **5.7 Mt** | **34.5 Mt** |
| **Benelux + Neigh. regions** | **6.73 Mt** | **41.5 Mt** |
| **Europe**[125] | **10 Mt** | |

Note that some of the countries or regions haven't yet announced specific targets for import while they all have mentioned in their hydrogen strategy that import will play an import role to meet their demand in the years between 2030 and 2050.

[119] https://www.portofrotterdam.com/nl/nieuws-en-persberichten/rotterdam-kan-europa-in-2030-van-46-mton-waterstof-voorzien
[120] https://www.northseaport.com/file/download/20400/7647286CD06981FE7767D0AFE2F7D433
[121] Belgian Hydrogen Strategy, October 2022
[122] https://www.rechargenews.com/energy-transition/germany-plans-to-import-hydrogen-from-uae-using-liquid-organic-carrier-technology/2-1-1188575
[123] LowerSaxony210701, Hydrogen Technology Study
[124] NRW hydrogen roadmap
[125] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

### Comparing hydrogen supply (production + import) vs. hydrogen demand

In this final section, we compare hydrogen production and import plans versus the hydrogen demand in 2030 for each of the Benelux countries. This comparison will show whether there is a gap between supply and demand for hydrogen and based on this, how the strategies need to be adjusted or adapted. These values are shown in Table 48. As we can see, in the Benelux countries, hydrogen demand can be met in 2030 if the countries follow their national strategies and the planned projects, and there will be even surplus of hydrogen to be imported to the neighbouring countries or regions. However, the total hydrogen demand in Europe cannot be met by only relying on the production and import plans.

Table 48: Local production based on the announced projects and national strategies, plus import (= hydrogen supply) versus demand in 2030

| Countries | Local production Projects Mt/y | Local production Strategies Mt/y | Import Mt/y | Supply (projects) Mt/y | Supply (strategies) Mt/y | Demand Mt/y |
|---|---|---|---|---|---|---|
| Netherlands | 0.83 | 0.39 | 5.1 | 5.93 | 5.5 | 0.80 |
| Belgium | 0.1 | 0.01 | 0.6 | 0.7 | 0.61 | 0.58 |
| Luxembourg | 0.004 | 0.01 | 0 | 0.004 | 0.01 | 0.01 |
| Benelux | 0.93 | 0.41 | 5.7 | 6.63 | 6.12 | 1.4 |
| Europe | - | 10 | 10 | - | 20 | 30 |

These differences are also illustrated in Figure 37. Although this could be promising results for the Benelux in 2030, we should not forget that demand keeps increasing after 2030, and hence, the production and import plans need to follow accordingly. However, if the Benelux region follow this trend for production and import of hydrogen for the years after 2030, it will definitely **become an important hydrogen hub for the rest of Europe for importing green hydrogen and its derivatives**. This plan has been already clearly stated by Port of Rotterdam, where in 2050, the port expects to import about 27 Mt of green hydrogen and its derivatives from which 20 Mt will be transported to Germany and other EU countries.

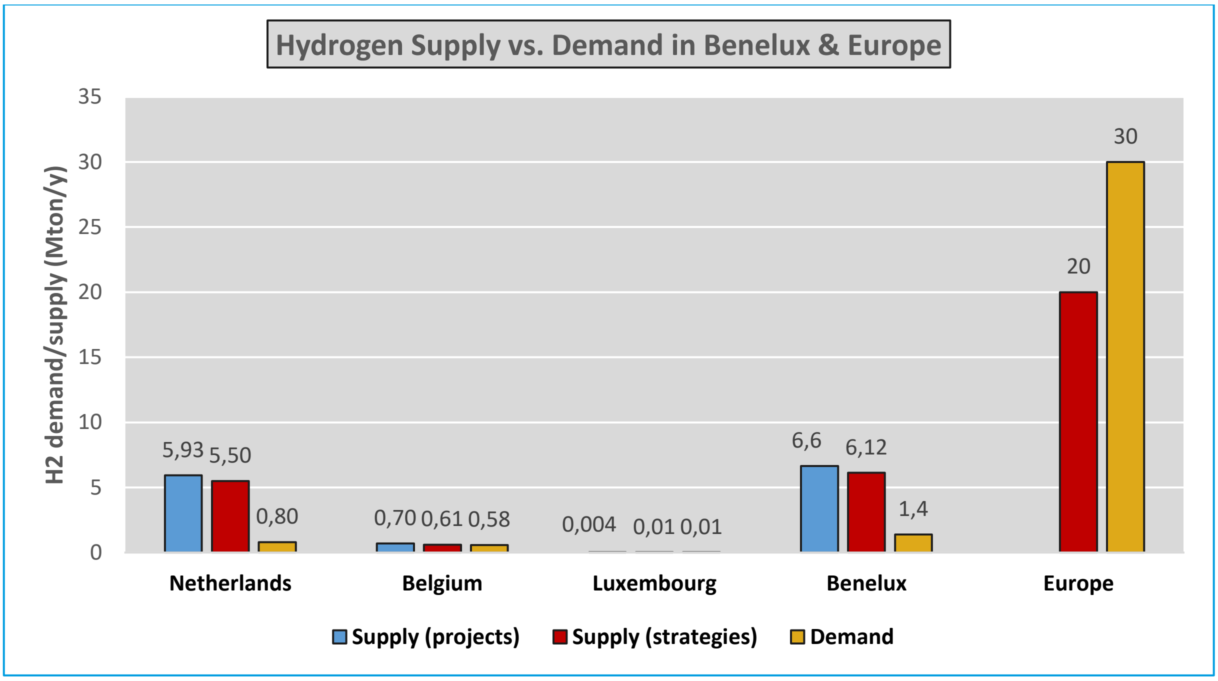



Figure 37: Comparison between hydrogen demand and supply in the Benelux and Europe in 2030

## 6.6 INFRASTRUCTURE & STORAGE

### Infrastructure

Recently, the essential role for hydrogen pipeline infrastructure in fostering market competition, security of supply, and security of demand was recognised in the European Commission's hydrogen and decarbonised gas package, published in December 2021[126].

Following the invasion of Ukraine by Russia, the impetus for a rapid clean energy transition has never been stronger. Europe has accelerated its climate targets for 2030, with a much bolder and more ambitious hydrogen target of 20 Mton by 2030 in response to the RePowerEU plan to phase out Russian fossil fuel imports well before 2030[127]. This includes a 10 Mton target of domestic EU hydrogen supply, as well as a 10 Mton target of hydrogen imports from outside the EU[128]. These targets are strengthened by accelerated national climate ambitions as well as the accelerated development of the European hydrogen market.

These new targets, naturally, demand for faster deployment of the hydrogen transport infrastructure and possible storage facilities. Across different regions in Europe, there are significant differences in the hydrogen supply-demand balance (as shown in Figure 38). Some regions are characterised by a net supply of low-cost hydrogen resources. These regions benefit from vast renewable energy potential, high-capacity factors and substantial land availability. Other regions will require hydrogen imports from other European or neighbouring regions to meet their hydrogen demand. Hydrogen pipeline infrastructure can bridge these regional supply-demand differences across Europe in a cost-effective manner[129].

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[126] European Commission (2021) – Proposal for a recast Directive / Regulation on gas markets and hydrogen (COM(2021) 803 final) / (COM(2021) 804 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0803&qid=1640002501099; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A804%3AFIN&qid=1640001545187

[127] European Commission (2022) – REPowerEU: Joint European Action for more affordable, secure, and sustainable energy (COM(2022) 109 final). https://energy.ec.europa.eu/repowereu-joint-european-action-moreaffordable-secure-and-sustainable-energy_en

[128] The RePowerEU target of 10 Mton of imports includes 6 Mton of renewable hydrogen and 4 Mton of imported ammonia/ derivatives.

[129] European Hydrogen Backbone (2022), Five hydrogen supply corridors for Europe in 2030

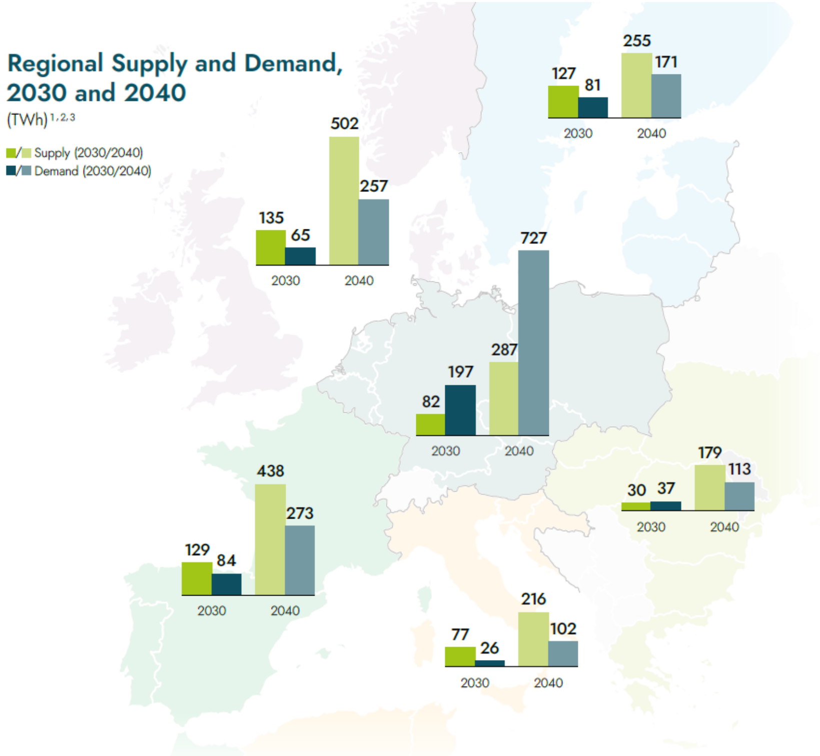


Figure 38: Regional hydrogen supply and demand across Europe in 2030 and 2040[131]

Local production and consumption of hydrogen (including storage) will be possible in many cases (e.g., hydrogen valleys[130]), especially in the early stage of hydrogen market development. However, since major hydrogen production areas will not always be close to major centres of demand and to fully realize the benefits of a (financially) liquid hydrogen market, a dedicated hydrogen infrastructure will be required[131].

This infrastructure has the following added values:

1) facilitates the export of cheaper green hydrogen from regions with high renewable electricity share;
2) provides better means to balance supply and demand, access to storage locations, and more security of supply;
3) allows for system coupling and can support the supply-demand management of the electricity system, grid congestion relief and existing grid use optimization (most specially offshore) on a variety of timescales; and
4) helps to transmit energy across longer distances and potentially more cost-effectively than (additional) electricity transmission infrastructure alone, adding cross-carrier opportunities for risk diversification and resilience.

The accelerated European Hydrogen Backbone (EHB) vision, now involving 31 energy infrastructure companies from 28 countries, shows that by 2030, five pan-European hydrogen supply and import corridors[132] could emerge, connecting industrial clusters, ports, and hydrogen valleys to regions of abundant hydrogen supply – and supporting the EC's ambition to promote the development of about

[130] https://h2v.eu/

[131] European Hydrogen Backbone (2021), Picturing the value of underground gas storage to the European hydrogen system

[132] The Benelux and its neighbouring regions lies at the heart of Corridor C: North Sea.

20 Mton renewable and clean hydrogen market in Europe[133]. The hydrogen infrastructure can then grow to become a pan-European network, with a length of almost 53,000 km by 2040, largely based on repurposed existing natural gas infrastructure[134].

The EHB for 2040 requires an estimated total investment of €80-143 billion. This investment cost estimate, which is relatively limited in the overall context of the European energy transition, includes subsea pipelines and interconnectors linking countries to offshore energy hubs and potential export regions. To provide an order of magnitude, German electricity remedial and grid strategic reserve actions cost +1Bn€/year[135] and the needed network reinforcements to develop the grid -onshore and offshore- whilst keep congestion at bay between now and 2035 are estimated[136] at +131Bn€ for Germany alone. Transporting hydrogen over 1,000 km along the proposed onshore backbone would on average cost €0.11-0.21 per kg of hydrogen, making the EHB the most cost-effective option for large-scale, long-distance hydrogen transport. In case **hydrogen is transported exclusively via subsea pipelines, the cost would be €0.17-0.32 per kg of hydrogen per 1,000 km transported**.[137]

A fast development of a European hydrogen backbone connected to storage capacities (one of the few clean means for weekly/seasonal storage) alongside a clear and simple certification framework for green hydrogen by electrolysers are key to guarantee the efficient/affordable fast deployment of renewables in Europe and the Benelux (avoiding curtailment, negative prices, excessive price volatility, overinvestment in grids and increased tariffs due to congestion).

It is important to note that based on the current planning[137] for 2030 (cf. Figure 39), there will not be any connected hydrogen backbone available in the Benelux and its neighbouring regions. This connection will be further developed by 2040, as shown in the EHB planning[137] of 2040 (cf. Figure 40). Since our focus in this study is on the Benelux and its neighbouring regions, the figures below are only focusing on these regions in which the European hydrogen backbone will be developed.

[133] According to REPowerEU, the additional 15 Mton (compared to 5.6 Mton foreseen in Fit for 55) would be made of 10 Mton of imported hydrogen from diverse sources and an additional 5 Mton of hydrogen produced in Europe.
[134] The share of repurposed natural gas pipelines in 2040 would be over 60%.
[135] ENTSOE Bidding Zones Technical Report.
[136] German e-TSOs official Netzentwicklungsplan Strom 2035 (2021 ed.).
[137] EHB Report (2022)

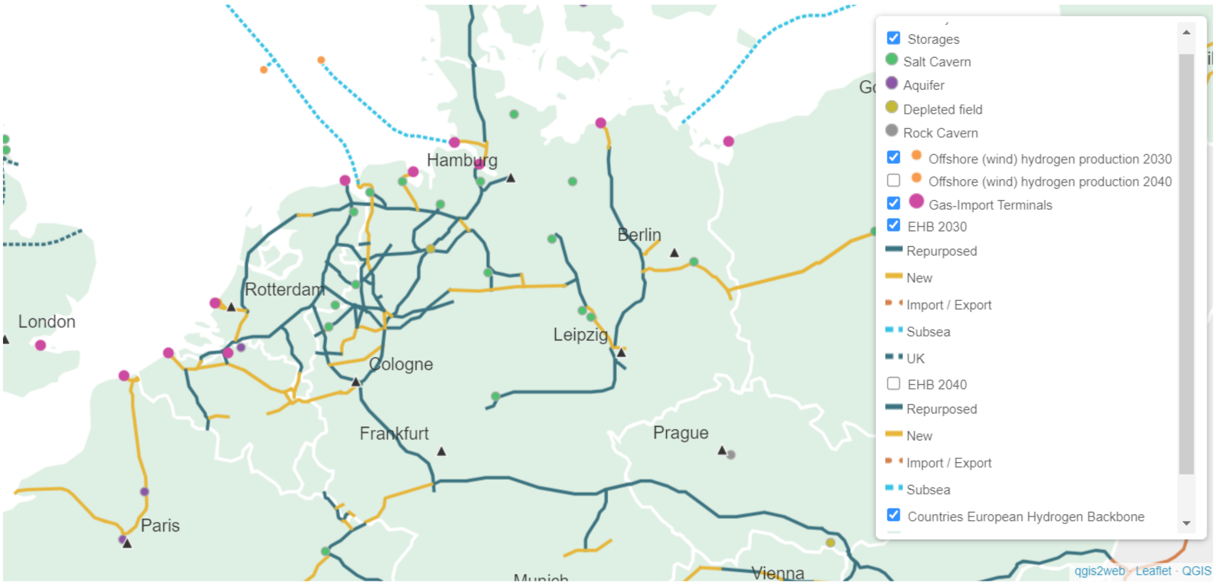


Figure 39: Emerging European Hydrogen Backbone in 2030, with focus on the Benelux and the neighbouring regions

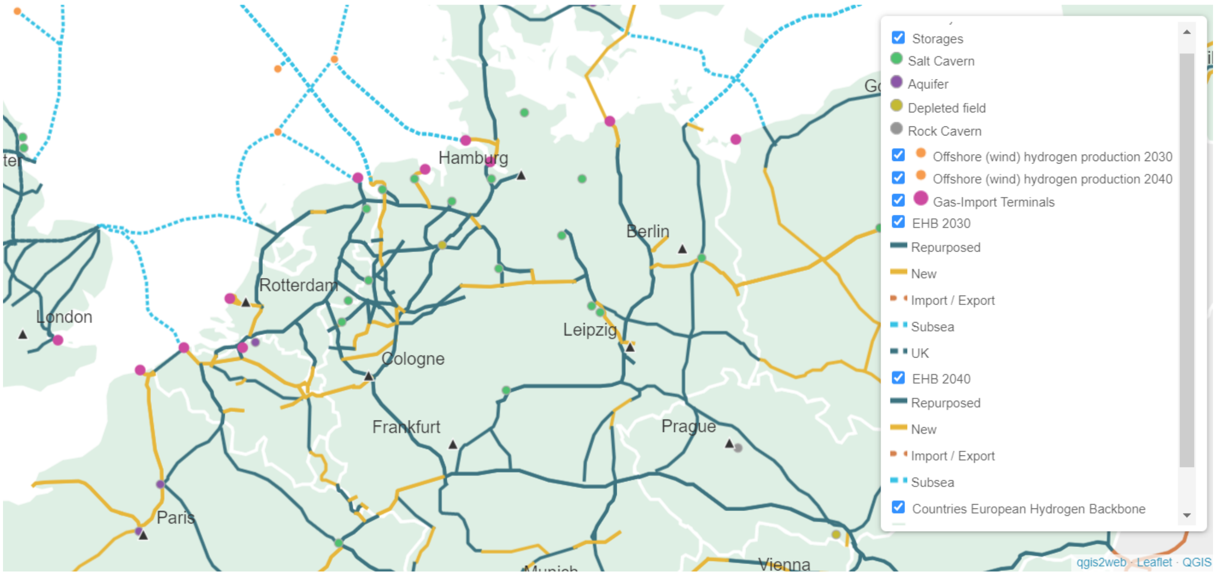


Figure 40: Mature European Hydrogen Backbone can be created by 2040, with focus on the Benelux and the neighbouring regions

The lack of an integrated Benelux hydrogen backbone is also striking considering the expected heavy developments (during the same 2030-2040 period) for offshore electricity interconnectors, energy islands and the requirements of the modular offshore grid under an offshore bidding zone configuration with self-balancing responsibilities (which will require Power2Gas and/or batteries to work better economically). Industrial batteries run up to 4-to-6 hours at power rating and cost projections to 2050 (though favourable) make them still expensive to use[138] (and subject to geostrategic considerations on concentration of industrial processes and raw materials that Europe does not control). The potential benefits of planned coordination offshore and of an integrated

[138] NREL (2021): https://www.nrel.gov/docs/fy21osti/79236.pdf

backbone in the Benelux to give an exit to this produced hydrogen for self-consumption and as transit towards Germany and France industrial centres are evident.

### Storage

Similar to the current system, energy storage in our new energy system is also of great importance, mainly due to the volatile nature of renewable energy sources and mismatch between supply and demand in different locations and different seasons. As expressed clearly in the recent study[139] by European Association for Storage of Energy (EASE), we need both electrons and molecules for short- and long-term storage, respectively. Figure 41 shows increasing wind and solar in the electricity mix mainly requires hourly storage (<10 hrs) up to a 60 % share of renewable generation in any given EU region. Beyond 60%, there is a sharp increase in the need for more daily and weekly storage. Seasonal storage becomes more critical beyond 80% variable renewables in the generation mix and will be important especially by 2050. This means by 2030 already the role of energy storage for system flexibility and energy shifting will be critical to integrating high shares of wind and solar.

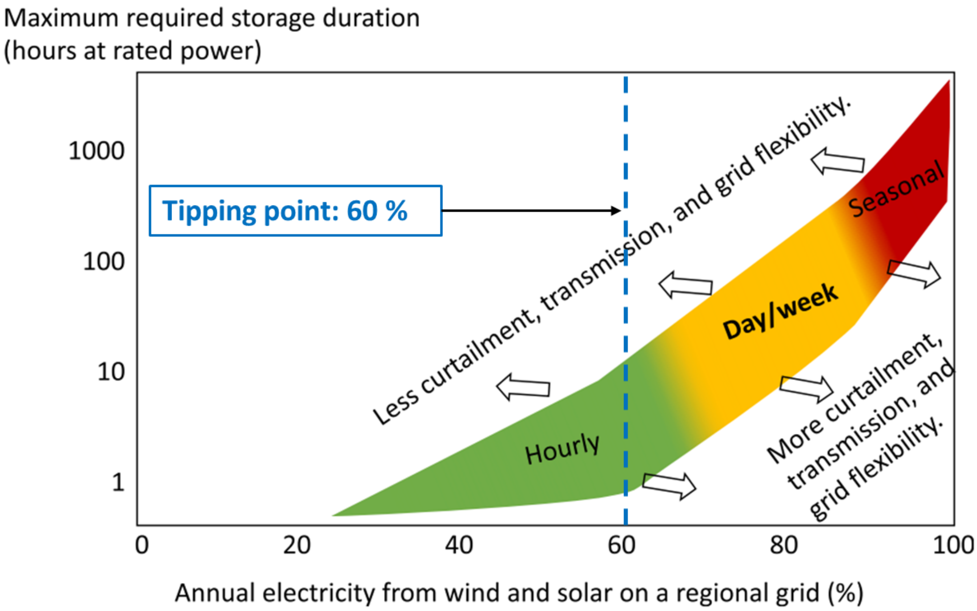


Figure 41: Y-axis shows maximum duration of electricity storage needed to ensure demand is met at all times (logarithmic scale) versus fraction of annual energy from variable renewable generators (wind and solar) on a regional/local level. The arrows indicate either more restrictive (to the left) or aggressive (to the right) assumptions for curtailment, transmission and grid flexibility. For example in a system where curtailment is minimised (arrow to the left), storage duration required is longer than in the case where more curtailment is allowed (arrow to right).

As such, hydrogen can play an important role in long-term energy storage. Hence, next to infrastructure for hydrogen transport, there is a great need for hydrogen storage infrastructure as well. Natural gas has been stored successfully at various scales and time durations for decades in a secure manner[140]. Large-scale, underground storage has been developed in salt caverns, depleted oil and gas fields, aquifers, and lined rock caverns. Underground gas storage provides several key services to the energy system:

[139] EASE (2022), "Energy Storage Targets 2030 and 2050 Ensuring Europe's Energy Security in a Renewable Energy System"
[140] See for instance Perry, K, Natural Gas Storage Experience and Technology: Potential Application to $CO_2$ Geological Storage, 2005, p. 815-825.

- Market value by providing flexibility on all timescales.
- System value by allowing for optimization in the gas and electricity systems.
- Insurance value by bringing security to the energy system in case of unforeseen events.

Similar to natural gas, hydrogen can be stored in many forms, including as a gas, liquid, another substance (e.g., methanol, ammonia), adsorbed to a surface, or in liquid organic hydrogen carriers. However, the only viable method for large-scale, long-term storage to provide balancing, optimization, and insurance for the electricity and hydrogen grids involves storing gaseous hydrogen in large, underground geological structures. These structures are comparatively cost effective and have the capability to store the massive volumes required for large scale hydrogen deployment[141].

The four major underground gas storage types are depleted gas reservoirs, aquifers, salt caverns, and (with a small share) hard rock caverns. Table 49 summarizes the existing natural gas storage capacity by type in the EU27 and the UK.

Table 49: Statistics on underground natural gas storage in the EU27 and the UK[142]

| Type of Storage | Depleted reservoirs | Aquifers | Salt caverns | Hard rock caverns |
|---|---|---|---|---|
| **Number of sites** | **80** | **27** | **63** | **1** |
| **Total working gas capacity (TWh/%)** | **792/68%** | **170/15%** | **206/18%** | **0.1/0.01%** |
| **Total max injection rate (TWh/day)** | **6.6** | **1.4** | **4.5** | **0.006** |
| **Total max withdrawal rate (TWh/day)** | **10.7** | **2.7** | **8.4** | **0.008** |

Underground storage will be critical to any large-scale hydrogen economy. The future hydrogen network could eventually operate in largely the same way as the existing natural gas network. Alternative ways of storing energy might be complementary to the deployment of underground hydrogen storage. Batteries and pumped hydro are more mature technologies (though most pumped sites are already developed in Europe and batteries will reduce their costs a lot but will remain relatively expensive[143] to 2050 and are of much more limited capacity), whereas liquid air energy storage or compressed air energy storage present newer alternatives. All of these could be utilized for the short-term balancing of power supply intermittency, either directly for the electricity system itself or when coupled with green hydrogen production. Longer-term balancing for both hydrogen and electricity systems will most likely have to utilize underground hydrogen storage given the combined needs for power rating and discharge time.

## National and regional strategies for hydrogen transport infrastructure

In this section a summary of national and regional strategies for implementation of hydrogen transport infrastructure between 2030 and 2040 is presented. Table 50 summarizes the planned hydrogen backbone in Europe, the Benelux and its neighbouring countries. The data about the specifications of the pipelines, such as the designed capacity, diameter, etc., are extracted from the report of European

[141] European Hydrogen Backbone (2021), Picturing the value of underground gas storage to the European hydrogen system
[142] Operational assets as of May 2021. From: GIE database, 2021
[143] NREL(2021): https://www.nrel.gov/docs/fy21osti/79236.pdf

Hydrogen Backbone (EHB)[144]. Moreover, the pipelines in 2040 are consisting of 69% repurposed existing infrastructure and 31% of new hydrogen pipelines according to EHB report.

Table 50: Planned hydrogen backbone in Europe, the Benelux and its neighbouring countries and its specifications

| Countries/Regions | Hydrogen pipelines (km) | | Pipe diameter (inch) | Pipe designed capacity (GW, LHV) | Operating Pressure (bar) |
|---|---|---|---|---|---|
| Year | 2030 | 2040 | | | |
| Netherlands[145] | 1400 | 1400 | 16-48 | 1.2-13 | 80 |
| Belgium[146] | 640 (100-160 till 2026) | 1200 | 24 | 1.2-1.5 | 65 |
| Luxembourg | 0 | 130 | 16-24 | 1.2 | 50 |
| France[146] | 630 | 4400 | 16-48 | 1.2-13 | 50 |
| Germany[147] | 5200[148] | 7600-8500[149] | 16-55 | 1.2-13 | 50-100 |
| Benelux | 2040 | - | 16-48 | 1.2-13 | 50-80 |
| Europe[144] | 28000 | 53000 | 16-48 | 1.2-13 | 50-80 |

An overview of the hydrogen pipelines planning in 2030 and 2040 as well as the share of the Benelux countries and its neighbours versus Europe are shown in Figure 42.

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144 Guidehouse (2021), A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 21 COUNTRIES

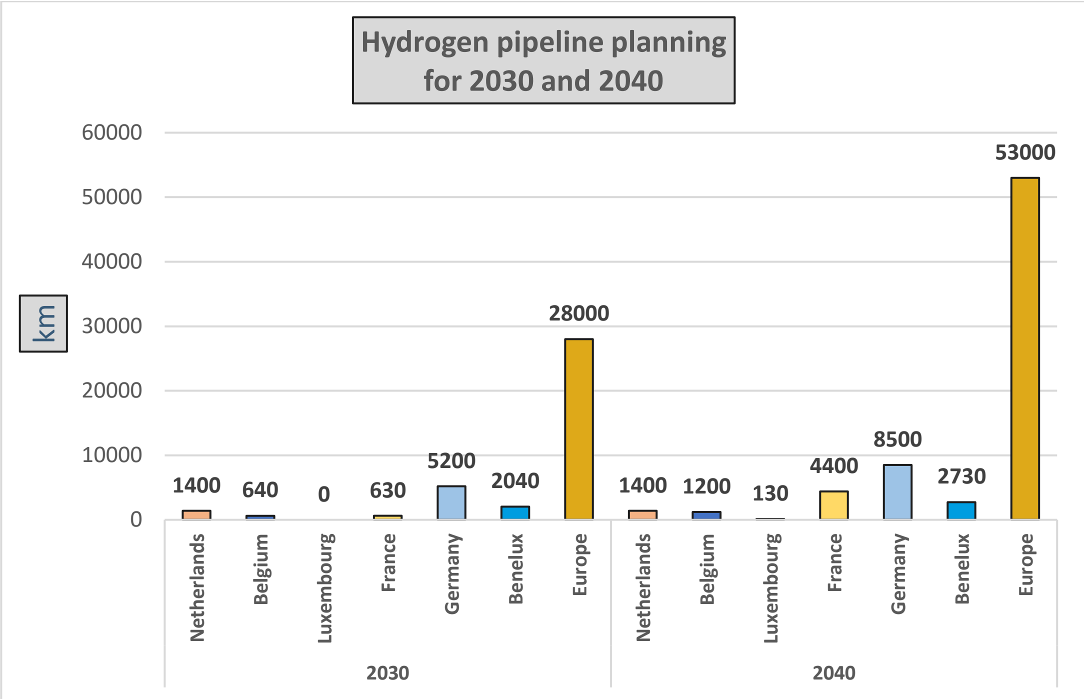
145 RVO (2021), Excelling in hydrogen, Dutch technology for a climate-neutral worlds. https://www.rvo.nl/sites/default/files/2021/03/Dutch%20solutions%20for%20a%20hydrogen%20economy.pdf

146 Https://gasforclimate2050.eu/wp-content/uploads/2021/06/gas-for-climate-priorities-for-the-eu-hydrogen-legislation-24-june-2021-2.pdf

147 Guidehouse (2022), A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 28 COUNTRIES

148 https://fnb-gas.de/wasserstoffnetz/h2-netz-2030/

149 No 2040 data published. Therefore NEP Gas 2022-2032 Zwischenstand vom 6.7.2022 by FNBGas is the best approximation for 2040 existing today, between 5,200 (2030)m and 13,300 (2050). https://fnb-gas.de/netzentwicklungspl%C3%A4ne/netzentwicklungsplan-2022/



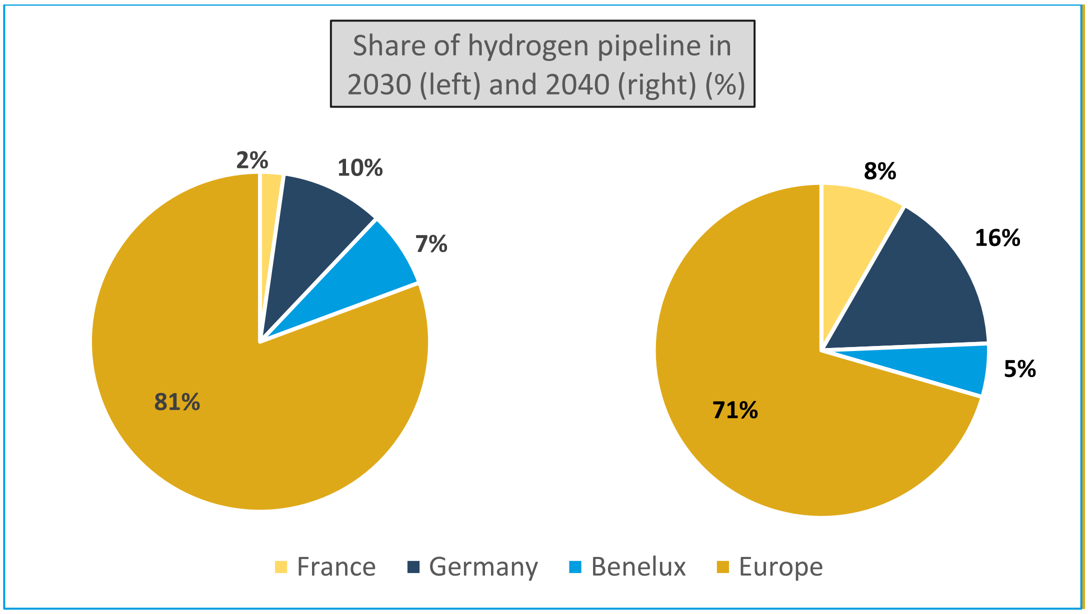




Figure 42: Share of repurposed and new hydrogen pipelines in the Benelux and its neighbouring countries vs. Europe in 2030

## National and regional strategies for hydrogen transport infrastructure

Below is a short summary of the plans of the Transmission System Operators in the Benelux and its neighbouring regions for the establishment of the hydrogen backbone.

### A. Netherlands

Current hydrogen transport in the Netherlands is summarized below[150].

- Hydrogen is currently only transported on a small scale. The current (2019) demand for hydrogen of around 50 TWh is mainly met with grey hydrogen, produced from natural gas and petroleum, with little or no capture of the $CO_2$ released during the process. Given that the fossil fuels required to make grey hydrogen are available in abundance in the industrial clusters, grey hydrogen can be produced close to where the end-users are based, and companies often even produce their own hydrogen.
- At plants where hydrogen, or hydrogen-rich residual gas, is released as a by-product, it is generally transported through local pipelines to other users on the same industrial estate.
- Air Products and Air Liquide are the only producers in the Netherlands who supply pure hydrogen to external customers through their proprietary network of pipelines. In a study[151] these volumes were estimated to be lower than 2.7 TWh/year:
    - Air Products operates a pipeline system of approximately 140 km in the Rotterdam/ Moerdijk industrial cluster, which runs from Botlek to Moerdijk and Zwijndrecht;
    - Air Liquide operates Europe's largest hydrogen network, which extends to around 1,000 km, is made up of 15.4 cm-diameter pipelines, and runs from the northern France to Rotterdam, connecting various production plants to customers in northern France, Belgium, and the southwestern Netherlands. Import and export are possible and currently roughly balanced.
- Aside from that, Gasunie operates a 12 km hydrogen network between Dow Benelux and Yara at the Zeeland province industrial cluster. This is a former natural gas pipeline that was repurposed for hydrogen transmission in 2018.
- Small quantities of hydrogen (less than 50 GWh/year) are also transported by lorry.

In the Netherlands Gasunie operates and owns a gas network of approximately 11,700 kilometres. The most ambitious project Gasunie worked on in 2020 concerns the development of a national transport network for hydrogen, the 'hydrogen backbone'. For this network, Gasunie is repurposing existing gas pipelines as these become available due to declining demand for natural gas, done by its new entity called Hynetwork Services. This backbone could be in place as early as 2026. Thanks to this hydrogen infrastructure, the Netherlands and northern Germany can be the market leaders in Europe for the global hydrogen market, just as they are now for natural gas. This hydrogen backbone connects the large industrial hubs to factories that will soon be producing blue and green hydrogen. This will enable major companies to wean themselves off natural gas, massively reduce their carbon footprint and maintain jobs, their export strength and innovation capacity for the Dutch economy[152].

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150 https://www.hyway27.nl/en/latest-news/hyway-27-realisation-of-a-national-hydrogen-network
151 Roads2HyCom (2007), PART II: Industrial surplus hydrogen and markets and production.
152 Guidehouse (2021), A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 21 COUNTRIES

As an independent network operator, Gasunie wants to transport hydrogen from various providers to the large industrial clusters in the Netherlands through a newly developed hydrogen backbone with nationwide coverage (see Figure 43). Together with TenneT and the Ministry for Economic Affairs and Climate Policy, Gasunie is exploring the possibilities through a study called HyWay 27, named for the year when the backbone is supposed to be ready. This study will answer the question whether and on what conditions part of the existing gas infrastructure can be used for hydrogen transport and storage. The first results of this study have been published in 2021, so that an investment decision could be made in time.

By making maximum use of the existing natural gas transport infrastructure, the national hydrogen backbone can have a capacity of approximately 10-15GW by 2030. The first regions in the Netherlands where hydrogen transport infrastructure can be built are the Rotterdam-Rijnmond region (2024) and the northern Netherlands region (2025). The province of Zeeland, the Amsterdam-IJmond region and the province of Limburg will follow after that. The national backbone can be ready by 2027 and used as a pipeline ring by 2030, whereby the connection to seaports will also be an important point.

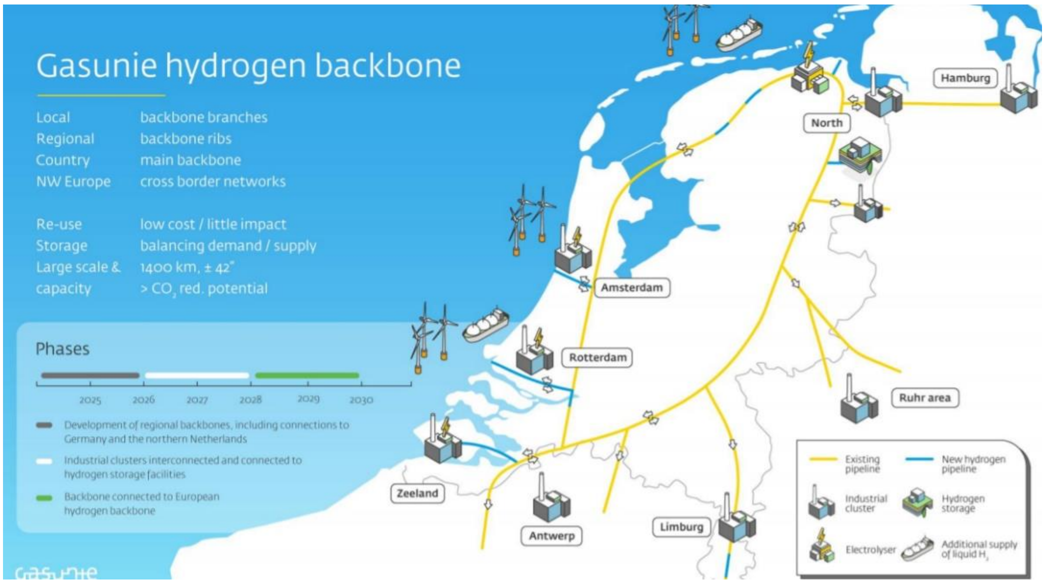


*Figure 43: Gasunie planning for hydrogen backbone in the Netherlands in 2030*

In collaboration with foreign network operators, neighbouring industrial areas can be connected to each other and the Zuidwending hydrogen storage facility. A hydrogen partnership agreement was signed with EWE, northern Germany's largest regional energy distribution company. EWE operates large natural gas caverns, making them predestined to be part of the future large-scale hydrogen storage landscape. By mutually aligning plans for hydrogen transport and storage, joint Dutch and northern German hydrogen infrastructure is very much a possibility. Additionally, green hydrogen will be used to integrate large amounts of offshore wind energy, particularly in the north of the Netherlands. Here the North Sea Wind Power hub expects to build 180 GWs of offshore wind by 2050 and a vital role is foreseen for hydrogen to integrate the large amounts of energy into the system and provide seasonal storage[153].

[153] Gasunie, Hydrogen backbone, https://www.gasunie.nl/en/projects/hydrogen-network-netherlands

## B. Belgium

Fluxys Belgium is the owner and operator of gas transmission, storage and LNG regasification facilities in Belgium. The network consists of 4,000 km of pipelines and 18 interconnection points with neighbouring countries and import facilities. Fluxys has adapted the steps towards the long-term vision of the hydrogen backbone in Belgium to reflect the discussions with Belgian industrial players to identify production and consumption potential and with policymakers. However, the timing of the investments for new pipelines and repurposed pipelines depends on the evolution of natural gas demand and the uptake of hydrogen demand[154].

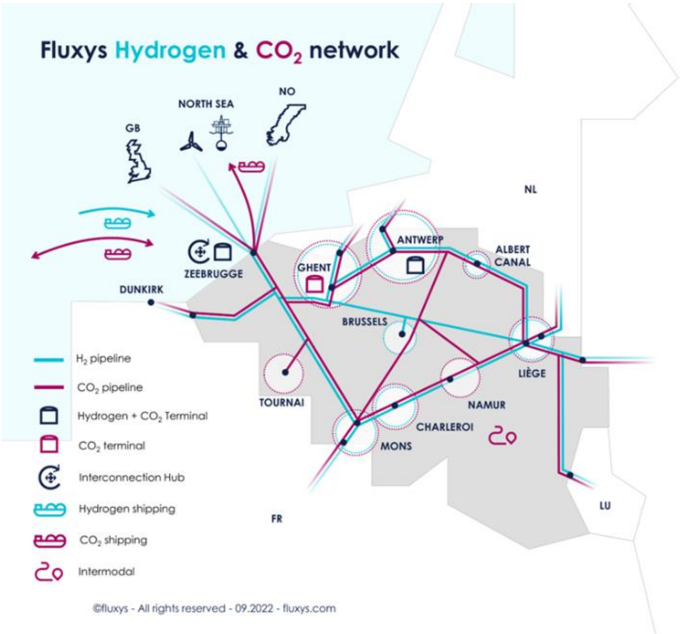


*Figure 44: Fluxys planning for development of hydrogen and $CO_2$ infrastructure in Belgium*

The Belgian national backbone (see Figure 44) is expected to emerge through developments in and around the industrial clusters in Antwerp, Ghent, and along the industrial valley in Wallonia. Given the proximity between Antwerp and Rotterdam, port-to-port interconnections with the Netherlands are likely. In addition, interconnections with France and Germany provide Belgium access to hydrogen from/to neighbouring countries. Hydrogen demand in Belgium is – especially from 2040 - expected to exceed production capacity. Imports and exports with all neighbouring countries including the UK – if technical and economic conditions are right – and imports through the Zeebrugge terminal could shape the North-Western European hydrogen market by 2040 and beyond[155].

On October 18th, 2022, the federal government of Belgium published its updated hydrogen strategy[156]. The Belgian federal strategy consists of 4 pillars and aims to position Belgium as an import and transit hub in Europe for green hydrogen, to make their country a leader in hydrogen technologies, to create a robust hydrogen market through the implementation of a hydrogen open access backbone, and finally to encourage the different stakeholders to pool their strengths and know-how. The creation of

[154] Guidehouse (2021), A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 21 COUNTRIES

[155] Fluxys, Hydrogen Backbone, https://www.fluxys.com/en/news/fluxys-belgium/2020/200717_news_european_hydrogen_backbone#:~:text=A%20group%20of%20eleven%20European,hydrogen%20at%20an%20affordable%20cost

[156] https://economie.fgov.be/sites/default/files/Files/Energy/View-strategy-hydrogen.pdf

a robust hydrogen market requires the ability to transport the molecules easily between the import locations such as Zeebrugge, the different industrial clusters and with neighbouring countries. To this end, the federal government allocates 95 million EUR support for developing hydrogen infrastructure by 2026 (between 100 and 160 km of hydrogen pipelines) and an acceleration of the interconnection with Germany, France and the Netherlands by 2028 (300 million EUR support foreseen).

By 2030, the federal government wants an open access backbone for hydrogen connecting the ports (Zeebrugge, Ghent, Antwerpen) to the industrial zones and with our neighbouring countries. A first phase will already be realized in 2026 within the hydrogen backbone project under the National Plan for Recovery and Resilience from Belgium. This requires initial investments, but these become more limited in the case of repurposing existing natural gas network.

The European Commission has published its Hydrogen Strategy[157] in July 2020 and is also expected to publish by the end of 2021 the first proposal of the Hydrogen and gas market decarbonization package[158]. The European Offshore Renewable Energy Strategy[159] (2020) recognised a role for offshore hydrogen production.

The primary drivers for regulation of the infrastructure sector in energy are to ensure:

- open access to transmission infrastructure on a non-discriminatory basis
- transparency and clear access rules
- neutrality of network operators
- proper competition – consumer protection
- well-coordinated or joint network development plans with an overall energy system perspective in mind
- overall system optimization and economic efficiency (i.e., to ensure the right scaling of new investments and to develop synergies between regulated networks)
- an optimal use of the infrastructure (including repurposing of existing assets)
- environmental protection and social justice – universal supply
- reliable, simple and interoperable certification systems

Fluxys therefore already integrates the basic principles of regulation in its process of interaction and within its initial approach of offering infrastructure services.

### C. Luxembourg

Luxembourg's gas (and electricity) network operator, Creos, operates a natural gas grid of 2.175,9[160] km with interconnections to Belgium, France, and Germany. It mostly serves residential clients, but also serves industry mostly located in the South of Luxembourg. In the longer-term, Luxembourg could also serve as transit of hydrogen, while use of hydrogen in other sectors beyond industry could also pick up[161].

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[157] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[158] https://ec.europa.eu/energy/topics/markets-and-consumers/market-legislation/hydrogen-anddecarbonised-gas-market-package_en
[159] https://ec.europa.eu/energy/sites/ener/files/offshore_renewable_energy_strategy.pdf
[160] gb_creos_annual_report_2021.pdf (creos-net.lu)
[161] Guidehouse (2021), A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 21 COUNTRIES

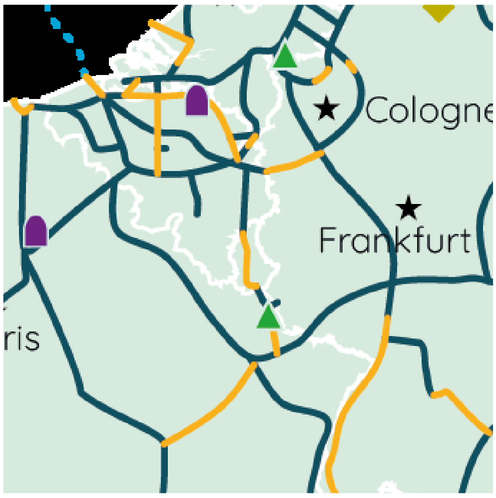


*Figure 45: Planned hydrogen backbone in Luxembourg is 2040*

By 2040, a north south connection could emerge, if a significant decrease in both residential and industrial gas flows allow it, and hydrogen demand picks up (see Figure 45). A new pipeline would be built connecting to Belgium at Bras to the MosaHyc project near Perl at the German border and the GRTgaz hydrogen grid in the north of France. The existing natural gas infrastructure connecting currently Luxembourg to Belgium could be repurposed after 2040, if the structure of end customers would no longer justify continuing the conventional operation and provided that security of supply of the customers can be guaranteed. Currently, Fluxys Belgium and CREOS Luxembourg are looking into development of interconnections between the two countries after 2035. The network of Luxembourg would connect Germany or France to Belgium and thus in the future could also serve a transit role[162].

In its goal to become an important player of the energy transition, Encevo group (having Creos Deutschland as a subsidiary), along with the partners Creos Deutschland, GazelEnergie, GRTgaz, H2V, Hydrogène de France, Stahl-Holding-Saar GmbH and Steag GmbH have constituted themselves as the European Economic Interest Grouping (EEIG) "Grande Region Hydrogen". In addition to the strong regional transformation potential, the Grande Region Hydrogen is to contribute to develop and optimise the European hydrogen economy. Through the interaction of the members of the initiative, the coordinated development of the entire value chain (production, hydrogen infrastructure and use) for a flourishing hydrogen economy should be made possible. The Grande Region Hydrogen addresses the first and second phase of the European Hydrogen Strategy towards a hydrogen strategy for a climate-neutral Europe.

The members of the European Economic Interest Grouping (EEIG) of the Grande Region Hydrogen have set themselves the goal of establishing an integrated cross-border hydrogen system in the Grande Region by linking cross-sectoral projects for the decarbonisation of the industry and some segments of the mobility sectors. The focus is on the federal state of Saarland (Germany), the Grand Est region in France and the Grand Duchy of Luxembourg. The aim is to promote a hydrogen economy along the entire value chain, taking advantage of the outstandingly suitable structural conditions of our area.

Currently, CREOS Luxembourg & GRTgaz (French TSO) are assessing the opportunity of a possible cross-border hydrogen interconnection between France and Luxembourg. GRTgaz and CREOS announced[163]

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[162] Creos, Hydrogen backbone, Source: https://www.creos-net.lu/de/aktuelles/aktuelles/article/european-hydrogen-backbone-grows-to-meet-repowereus-2030-hydrogen-targets.html

[163] https://www.grtgaz.com/medias/communiques-de-presse/hydrogene-lancement-mosahyc

their collaboration to create a 100% hydrogen European transmission network, linking the Saarland (Germany), the Grand Est (France) and the Luxembourg border. This unprecedented agreement between the two gas transport operators aims to make a 70 km hydrogen transport infrastructure accessible, by adapting existing gas infrastructures. This network will thus contribute to the development of a regional, cross-border hydrogen ecosystem between three countries.

The mosaHYc (Moselle Sarre HYdrogen Conversion) project, led by the two transport operators, aims to convert two existing gas pipelines to 100% hydrogen transport, making it possible to interconnect Völklingen, Perl (Saar), Bouzonville and Carling (Moselle) (see Figure 46). The first phase of the project will consist of guaranteeing a secure supply of hydrogen for mobility uses (train, bus, cars, heavy goods vehicles, etc.) in a cross-border region experiencing heavy daily road traffic. The project will thus contribute to the mobility decarbonization ambitions of the Grand Est region in France, the Land of Saarland in Germany and Luxembourg. It is fully in line with the European objectives of energy transition and improvement of air quality in the Saar-Lor-Lux region.

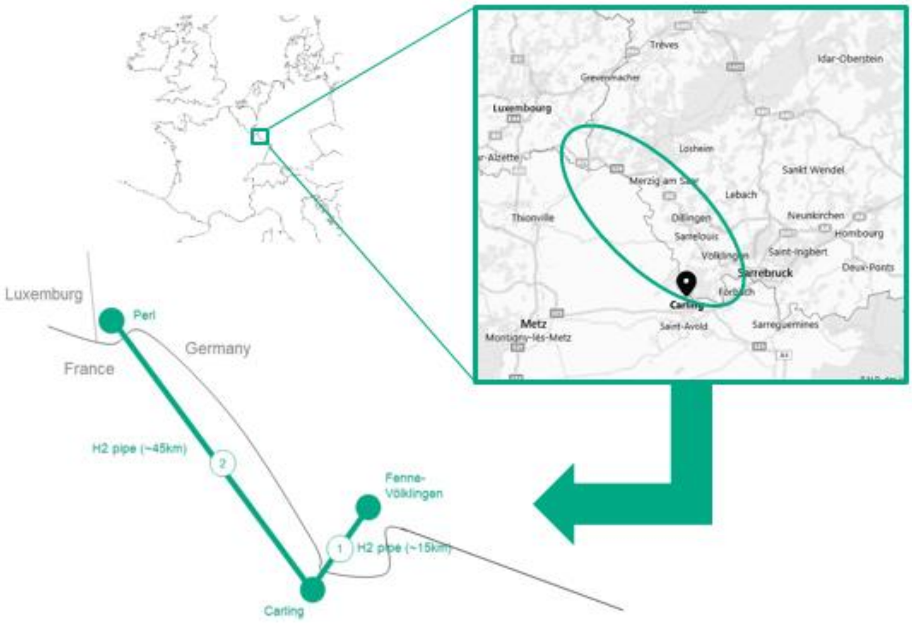



*Figure 46: Planning of the mosaHYc project*

The hydrogen transport network is ideally located to ultimately support the development of hydrogen uses for industrial sites in Saarland and the Grand Est, such as Völklingen or Carling. The mosaHYc project will thus contribute to strengthening the economic and industrial attractiveness of these territories.

To carry out this project, the two gas network operators intend to apply the strictest standards in terms of safety and quality before carrying out the conversion of their pipelines. GRTgaz and CREOS will work closely with the French and German authorities on the technical, political and regulatory aspects in order to take the final investment decision by 2023. The engineering studies are underway to be able to put into service in 2027 in accordance with customers' need.

### D. France

France's current gas network is operated by GRTgaz, which operates 23,000 kilometers of pipelines and Teréga, which operates a 5,000 km network in the south-west. The networks serve industry, power and residential customers while GRTgaz also transits gas to Switzerland, Italy and Teréga transports gas to and from Spain. Both TSOs are convinced that hydrogen and biomethane, next to electrification, will play an important role in the future French energy system. GRTgaz have ongoing hydrogen projects such as mosaHYc, Jupiter 1000, Hyfen, while Teréga is involved in trials around hydrogen storage as HyGéo project and studying a hydrogen dispatchable power plant (Lacq Hydrogen project). The "France Hydrogène" association study estimates French hydrogen demand to increase to approximately 110 TWh/y by 2040[164].

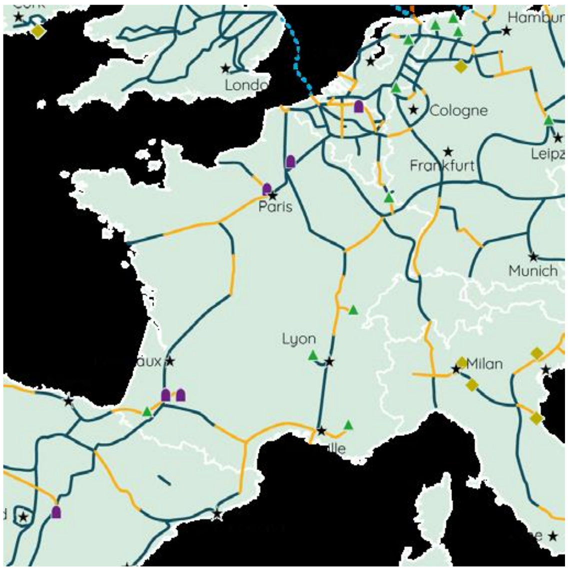



*Figure 47: Planned hydrogen backbone in France by 2040*

The majority of France's future hydrogen backbone would exist of repurposed pipelines, hereby providing a cost-effective way to transport hydrogen (see Figure 47). By 2030, regional dedicated hydrogen networks will emerge around industrial clusters, with existing fossil hydrogen production or consumption, in Dunkirk, in the Seine Valley from Le Havre to the vicinity of Paris, and around Lyon, Lacq and Marseille. These first regional hydrogen networks will foster the achievement of the French Government ambition, issued in September 2020, which aims to reach 6.5 GW of electrolysis capacity installed in 2030, to decarbonise industrial and mobility uses.

GRTgaz conducted France's first national clean and renewable hydrogen market stakeholders' consultation in 2021-2022 to identify the needs of hydrogen market stakeholders in terms of transport and storage infrastructure. The majority of stakeholders stress the importance of a transport network infrastructure that meets their challenges. GRTgaz has built on the consultation feedback to launch projects in the Fos-Marseille, Dunkirk, Valenciennes, Moselle and Rhine Valley basins to develop pipeline transport infrastructure projects to support emerging hydrogen ecosystems. These are shown in the map below (see Figure 48), which is taken from the consultation report[165]

[164] Guidehouse (2021), A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 21 COUNTRIES
[165] https://www.grtgaz.com/medias/actualites/consultation-acteurs-marche-hydrogene-restitution

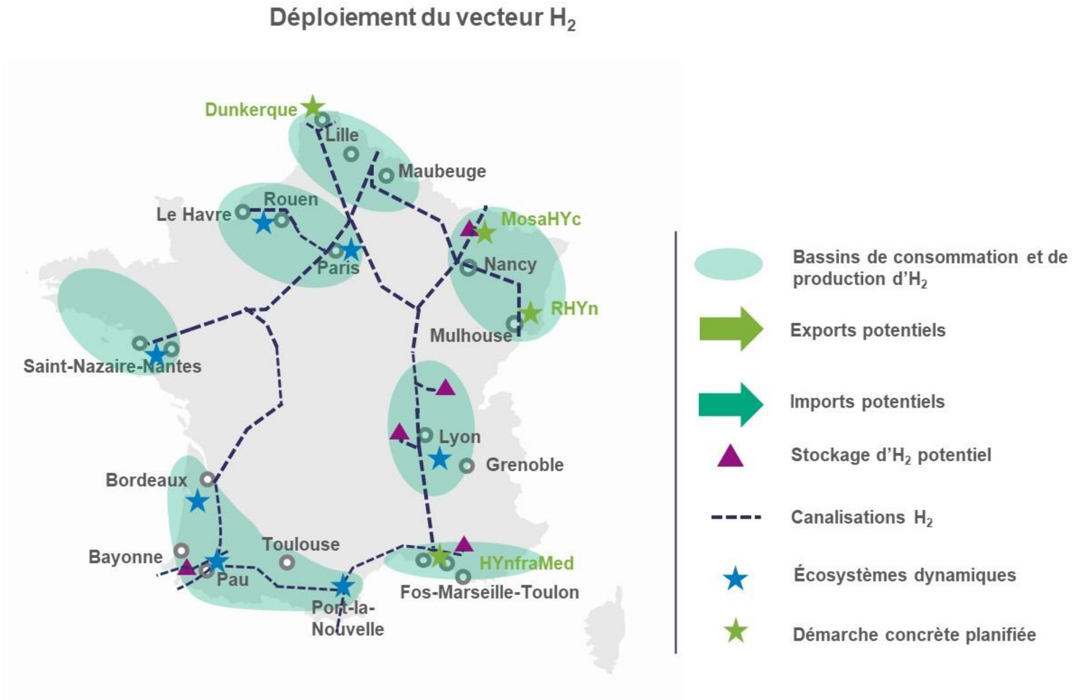



Figure 48: Extract from the FINAL REPORT ON THE NATIONAL LOW-CARBON AND RENEWABLE HYDROGEN MARKET STAKEHOLDERS' CONSULTATION

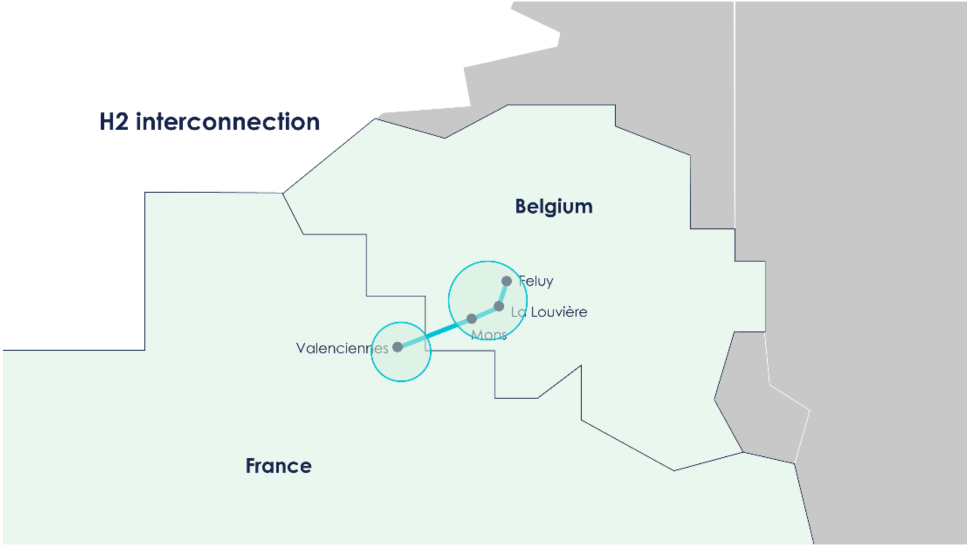
In the Region Hauts-de-France, in the North of France, two main hydrogen ecosystems are developing in the Port of Dunkirk and in the vicinity of Valenciennes city. GRTgaz has thus launched Open Seasons in these two basins to confirm the economic interest in a hydrogen pipeline transport infrastructure. These Open Seasons are transparent and non-discriminatory calls for interest[166].

The hydrogen network project in the Port of Dunkirk aims to develop a hydrogen transmission network to connect emerging clean hydrogen production and consumption projects. The ambition is to develop a 30 km long infrastructure from the West to the East of the Port, that will contribute to the decarbonisation of a major $CO_2$-emission zone in France especially industry uses. In a later phase of the project, the network could stretch towards Belgium to create a hydrogen connection between North Sea Ports.

Regarding the cross-border project in the area of Valenciennes in France and Mons in Belgium, based on positive feedback and the many interests expressed in the Open Season process, Fluxys and GRTgaz have decided to launch the feasibility study for the cross-border hydrogen transmission system in October 2022. Forming the first clean hydrogen infrastructure between Belgium and France, this network would span around 70 km and would help decarbonise this area, which is known for its strong shared industrial heritage. The project is intended to connect emerging clean hydrogen production and consumption projects in the Valenciennes area in France and the greater Mons area, including La Louvière and Feluy in Belgium and to foster the development of a cross-border, clean hydrogen ecosystem that ensures security of supply, flexibility and local impetus through shared network infrastructure.

[166] For more details on these processes, see here: https://www.grtgaz.com/nos-actions/open-season-hydrogène-dunkerque and https://www.grtgaz.com/nos-actions/open-season-hydrogene-valenciennes

This project marks the first step in the development of interconnected networks transporting clean hydrogen in Europe, as envisaged by the European Hydrogen Backbone initiative.




As mentioned for Luxembourg, in the region Grand Est, GRTgaz and CREOS announced in 2020 their cooperation to create a 100% hydrogen European transmission network, linking the Saarland (Germany), the Grand Est (France) and the Luxembourg border. The MosaHYc (Moselle Sarre Hydrogen Conversion) project aims to convert 70km existing gas pipelines to hydrogen transport, making it possible to interconnect Völklingen, Perl (Saar), Bouzonville and Carling (Moselle). This network will have a transport capacity up to 80,000 $Nm^3/h$ between France and Germany laying the foundations for the construction of a first European interconnection.

Concerning the further development of MosaHYc towards Luxembourg, currently, CREOS Luxembourg and GRTgaz assess the opportunity of a possible cross-border hydrogen interconnection between France and Luxembourg (see Figure 49).

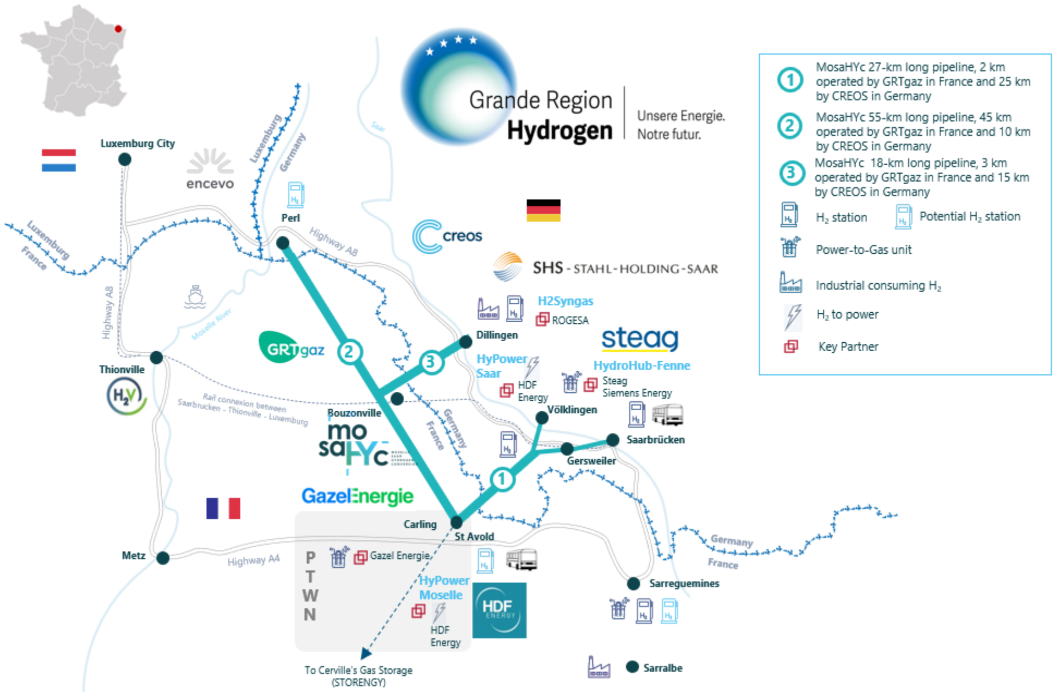



Figure 49: MosaHYc project within its ecosystem: Grande Region Hydrogen

The southern clusters in Marseille-Fos and Lacq are also expected to have access to green hydrogen from solar PV and Mediterranean offshore wind. Lastly, dynamic development of green hydrogen for fuel cell projects and industrial uses is expected to continue and to lead to a need for a dedicated hydrogen pipeline in the region surrounding Lyon. By 2035, additional hubs emerge near Saint Nazaire/Nantes, Bordeaux and along the Mediterranean coast, powered by offshore wind or low-carbon electricity and combined with the evolution of Seaports activities. Those hubs will connect to Region of Paris, and to Lyon along the Rhone Valley, thus enabling the decarbonisation of existing grey hydrogen consumptions and the development of new hydrogen uses in mobility (road, inland navigation, rail, airports).

The North-West of France will also be connected to the East of France and to the Region of Paris via the retrofitting of existing gas pipelines. This will enable interregional transit and an easier integration of renewable electricity in the energy system, and it will bring flexibility to the system. The French network will also allow a transnational transit from Spain to Belgium, Germany or Luxembourg. By 2040, a mature network has emerged of mostly repurposed pipelines which has 3 interconnectors with Spain, while also connecting to Belgium, Germany, and Switzerland. The three interconnectors to Spain enable security of supply and flexibility in the large, expected flows of hydrogen from Spain and possibly North Africa into the rest of Europe. On the west side another stretch also provides a different route within France to transport hydrogen, while also serving local customers and industry on the way. In the south, Teréga's storage locations could provide another way to store the intermittent production of green hydrogen, hereby enabling a stable and secure hydrogen supply further up north.

## E. Germany

OGE, headquartered in Essen, operates the largest German gas transmission system spanning 12,000 kilometres. Two thirds of natural gas consumed in Germany flow through OGE's pipeline system, comprising about 100 compressor units and about 1100 exit points. The OGE 2030+ strategy aims to secure the OGE transmission business in the long run and prepares the pipeline network and numerous compressor stations for new gaseous energy carriers. OGE actively support the European gas market and work together with the European distribution network operators to create the prerequisites for transnational[167].

ONTRAS Gastransport GmbH is a national gas transmission system operator in the European gas transport system based in Leipzig. ONTRAS operates Germany's second-largest gas transmission system, with approximately 7,500 km of pipelines and about 450 interconnection points. ONTRAS links the interests of transport customers, dealers, regional network operators and producers of regenerative gases.

The German government published the National Hydrogen Strategy (NWS) in June 2020 which aims to create a coherent framework for action for the future production, transport, and utilization of hydrogen and thus for corresponding innovations and investments. The German government will intensify the cooperation with countries around the North and Baltic Seas, primarily to accelerate hydrogen production from offshore wind. It also regards hydrogen as a foundation for strengthening energy partnerships beyond Europe. An update of the NWS with higher hydrogen ambitions is expected by the end of 2022[168].

On regional level, the regional government of North Rhine Westphalia, for instance, has published targets for 2025 with the establishment of almost 500 kilometers of hydrogen pipeline in Germany, of which 120 kilometers are in North Rhine-Westphalia. In the hydrogen roadmap in Germany, the green gas scenario in the Gas 2020-2030 network development plan is strongly supported, and therefore the establishment of a hydrogen network of around **1,300 kilometers by 2030** (240 kilometers of which are in North Rhine-Westphalia). The analyses conducted by FZJ have clearly emphasized that the conversion or continued use of existing infrastructures makes a crucial contribution to a cost-efficient and, above all, timely transformation[169]. Other regions have also developed hydrogen strategies including plans for establishing a hydrogen backbone.

German transmission system operators determine the need for entry and exit capacity as part of the network development plan process in order to be able to provide the necessary transport capacities. Regarding sources of hydrogen an increase in domestic production as well as additional imports of hydrogen from the Netherlands, Norway Denmark, as well as from Southern Europe are expected.

As part of the network development plan process (2020-2030), the German transmission system operators queried specific projects for the generation or use of hydrogen by means of a market partner query. For 2030, the market participants asked for 1 GW of green hydrogen feed-in capacity. The exit capacity requested for the same point in time was significantly higher with 3 GW. This should be based on an annual hydrogen requirement of around 20 TWh for industrial purposes only. To close the gap in the entry-exit balance for hydrogen in 2030, the network operators envisaged hydrogen imports from the Netherlands, the connection of cavern storage facilities and additional feeds from wind farms that were equipped with electrolysers. The plans for the German "$H_2$ start network 2030" has foreseen pipeline connections to the Dutch hydrogen grid.

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[167] Guidehouse (2021), A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 21 COUNTRIES
[168] https://www.bmbf.de/bmbf/en/news/national-hydrogen-strategy.html#:~:text=The%20National%20Hydrogen%20Strategy%20integrates,to%20become%20a%20new%20brand
[169] NRW hydrogen roadmap

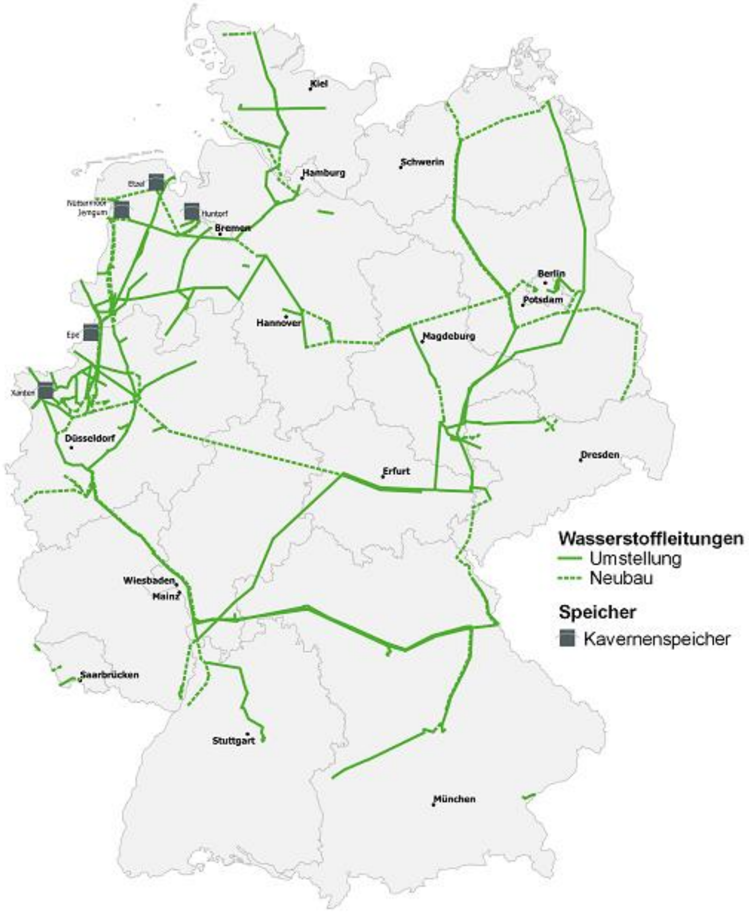


*Figure 50: Concept of hydrogen backbone in Germany[170]*

The market feedback on hydrogen demand from the market partner query in spring 2021 for the NDP (2022-2032) has increased drastically compared to the last network development plan. The German TSOs have already been able to conclude declarations of intent (MoUs) for a transport requirement of 165 TWh, of which around 90% can be connected to the hydrogen network in 2032. This network shows a further development of the "$H_2$ start network 2030" from the last NDP Gas 2020-2030 (the transport requirement based on the market partner query has tenfold) with a network length of 7,600-8,500 km by 2032 (see Figure 50).

It can be assumed that further requirements will become apparent in the coming years. In the updated map for 2032, next to connections from Denmark, the Netherlands and the German coast in the North, an accelerated repurposed connection from the Czech border is possible in order to import hydrogen from the south and east via the Czech Republic to Germany. In the Western part, a new pipeline from Belgium emerges which is further connected to the mainly repurposed pipelines reaching the industrial clusters of the Ruhr and Cologne/Bonn area as well as areas in South-Western Germany. As of current data that pipeline connection might still be needed for natural gas, depending on development of demand and policy decisions. According to EHB 2022, there is a perspective for an import connection from France to Germany.

[170] NDP 2022-2032 publication of FNBGas. https://fnb-gas.de/wp-content/uploads/2022/07/2022_07_06_Zusammenfassung_NEP-Gas-2022-2032-Zwischenstand.pdf

## OGE project

With its OGE 2030+ strategy implemented in 2018 the company defined a new purpose, namely, to enable energy supply today and in the future energy mix. While dedicated to providing efficient and reliable transport services for natural gas, the main focus in business development today is to become a leading provider of infrastructure in a decarbonised energy system in Germany and Europe, re-purposing natural gas infrastructure for transporting pure hydrogen, securing international import routes for hydrogen and investigating the transport of $CO_2$ are key areas of activity today.

In order to speed up the process of building a German hydrogen industry and infrastructure, OGE and RWE jointly developed the national infrastructure concept called “H2ercules”. The infrastructure is set to connect electrolysers as well as storage and import facilities in the north of the country with industrial consumers in the west and south of Germany.

H2ercules opens up new opportunities for connecting Germany to major import routes – initially via pipelines to Belgium and the Netherlands, and at a later stage via Norway as well as southern and eastern Europe, additionally via import terminals for green molecules in northern Germany in the future. In this way the project will contribute towards the creation of a European hydrogen market with a strong initial focus on Northwest Europe in general and the Benelux region in particular.


## Creos Germany project

As already mentioned for both France and Luxembourg, GRTgaz SA and Creos Germany GmbH are collaborating to create a 100% pure hydrogen infrastructure, connecting the Saar (Germany), Lorraine (France) and the Luxembourg border. With the infrastructure project mosaHYc (moselle-saar-hydrogen-conversion), the distribution network operators Creos Deutschland (Germany) and GRTgaz (France), in cooperation with the energy company Encevo (Luxembourg), want to establish an approximately 100-kilometre-long hydrogen pipeline in the Grande Région. About 70 kilometers of existing gas pipelines, some of which are out of service, are to be converted into hydrogen pipelines. An additional construction of about 30 kilometers of hydrogen pipelines will create a first hydrogen network.

Specifically, existing pipelines in the area of Völklingen (Germany), Carling (France), Bouzonville (France) and Perl (Germany) will be examined for their suitability as hydrogen pipelines. A major new construction will be built from Bouzonville in the direction of Dillingen. The initial network will provide a capacity of up to 120,000 m3/h, depending on the maximum operating pressure. The pipeline network is scheduled to be commissioned in 2026. In 2030, the transport of more than 50,000 t of hydrogen per year is expected. In the long run, the project paves the way to accelerate the development of an interregional market for hydrogen.

As a project between France, Germany and Luxembourg, MosaHYc considers itself as a European and cross-border pioneer project in the Grande Région within Saarland, Grande Est and Luxembourg to provide a first and exemplary infrastructure for the cross-border transport of hydrogen. Thus, MosaHYc represents the essential link to bring hydrogen producers and users together in this region: MosaHYc allows potential hydrogen producers to safely feed in their volumes and hydrogen consumers to safely receive the quantities of hydrogen they need for their processes.

MosaHYc is a good example of a cross-border hydrogen infrastructure project. Since the demand for hydrogen in the future cannot be met locally alone, European networking is also needed on a larger scale to ensure the future import of required green hydrogen from more distant countries as well. For the Grande Région, mosaHYc is therefore the nucleus that enables the connection to the European Hydrogen Backbone network.

### National and regional strategies for hydrogen storage

As mentioned before, similar to natural gas, there is a great need for hydrogen storage in our new energy system. Hydrogen can be stored both under as well as on the ground. Europe, and specifically the Benelux and its neighbouring regions, has many existing storage facilities that can be used or adopted to be used for hydrogen storage. Table 51 summarizes the storage possibilities and capacities in different regions. The data of this table are extracted from the recent study[171] by EHB, which estimated need for hydrogen storage in EHB focus countries[172]. The study includes only 19 of the EU MSs + UK[173]. The hydrogen demand forecast[174] in each of the analysed countries might be different from other national forecasts or even national strategies. The EHB demand analysis has been chosen for the consistency of its approach across all modelled countries. Our estimations of the hydrogen storage needs might differ in a similar way.

[171] European Hydrogen Backbone (2021), Picturing the value of underground gas storage to the European hydrogen system
[172] Data for natural gas working gas capacities are taken from GIE datasets for all operational storage as of May 2021.
[173] Austria; **Belgium**; Czech Republic; Denmark; Estonia; Finland; **France; Germany**; Greece; Hungary; Ireland; Italy; **Luxembourg; Netherlands**; Poland; Slovakia; Slovenia; Spain; Sweden; UK
[174] European Hydrogen Backbone, Analysing future demand, supply, and transport of hydrogen, 2021. The demand is for hydrogen use in industry, transport and the power sector (both 2030 and 2050).

Table 51: Summary of storage plans and potentials for the Benelux, its neighbouring regions and Europe

| Countries/Regions | Total Storage plan (kton) | | Total Storage need[175] (kton) | | Potential salt cavern (kton) | Potential all type of storage (kton) |
|---|---|---|---|---|---|---|
| Year | 2030 | 2050 | 2030 | 2050 | | |
| Netherlands[176] | 2025: 1 or 2 salt caverns | - | 189 | 949 | 27 | 1183 |
| Belgium[177] | - | - | 132 | 670 | 0 | 66 |
| Luxembourg | - | - | 3 | 21 | 0 | 0 |
| France[171] | - | - | 246 | 1294 | 75 | 958 |
| Germany[171] | - | - | 477 | 3345 | 1186 | 1844 |
| Lower Saxony | +2 caverns | Between 75-ca. 99 caverns | - | - | 675 | - |
| Benelux | - | - | 324 | 1640 | 27 | 1114 |
| Europe[171] | - | - | 2168 | 14006 | 1502 | 7949 |

The Netherlands with the current ambition of 3-4 GW electrolysis capacity in 2030, 3-4 salt caverns with a volume of approximately 1,000,000 $m^3$ are needed. Moreover, according to the Belgium hydrogen strategy, the country has limited potential for the (subsurface) storage of hydrogen and thus, looks to foreign countries to store (temporary) surpluses from hydrogen production or import. It is being examined though whether the aquifer in Loenhout can be used to store hydrogen. Furthermore, the region of Grand Est in France has launched two projects: one relating to the transport of hydrogen by pipeline, the other relating to the hydrogen storage by saline cavity.[178]

A graphical representation of the required storage vs. the storage potentials in the Benelux and its neighbouring countries are presented in Figure 51. As can be seen, it is obvious that the regions as well as Europe are in **great need to provide the required storage capacity by 2050**.

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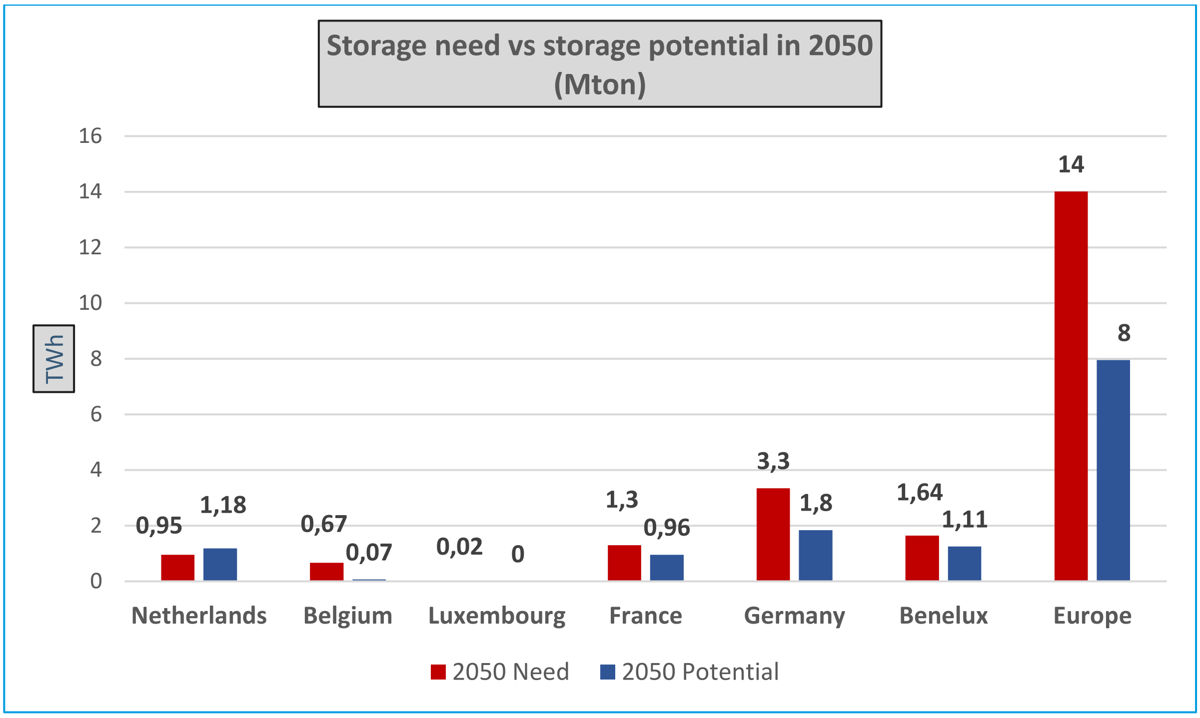
[175] In the study, the storage need is obtained by multiplying hydrogen demand by current ratio of natural gas storage to natural gas demand (average ratio of the studied countries).
[176] Gasunie, Hydrogen backbone, https://www.gasunie.nl/en/projects/hydrogen-network-netherlands
[177] Https://gasforclimate2050.eu/wp-content/uploads/2021/06/gas-for-climate-priorities-for-the-eu-hydrogen-legislation-24-june-2021-2.pdf
[178] Une stratégie HYDROGENE pour le Grand Est; 2020-2030, p. 5



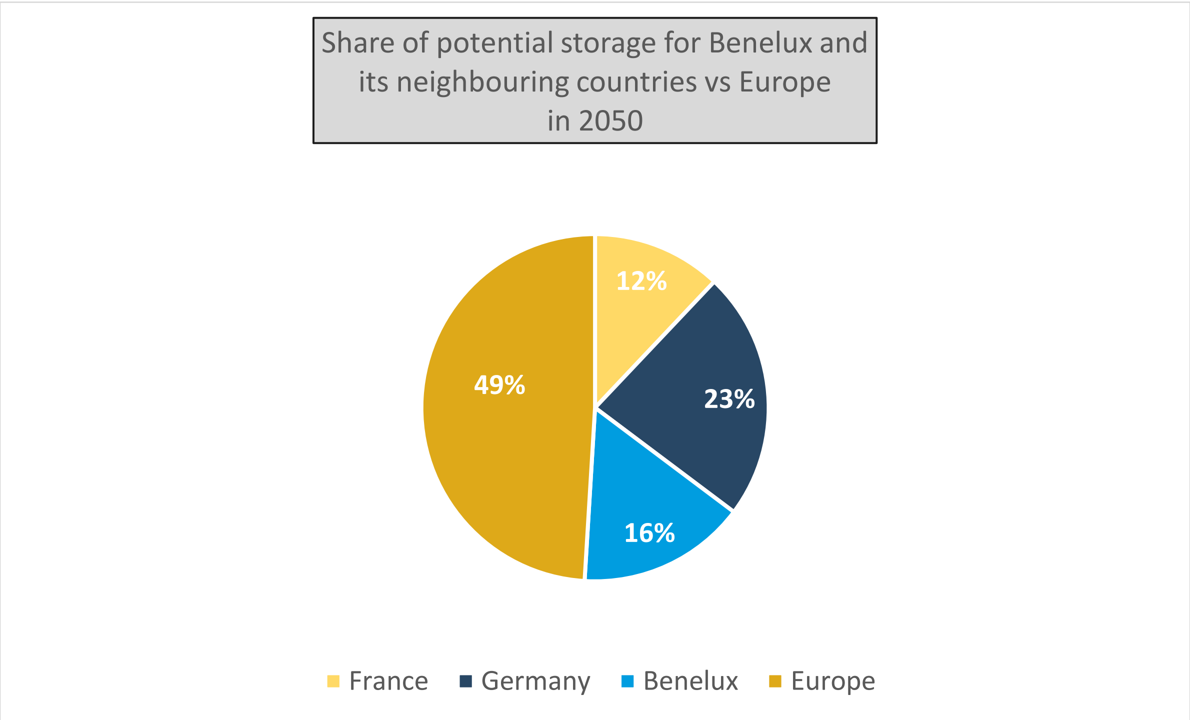




Figure 51: Share of potential hydrogen storage in the Benelux and its neighbouring countries vs. Europe

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