

Scenarios for Clean Hydrogen Demand in Europe

Final Report

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Scottish Enterprise

Advisian
Worley Group

advisian.com

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Assignment Purpose and Objectives

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Scotland stands at the threshold of a unique prospect: the development of an export-oriented, low-carbon hydrogen market. The forthcoming decade is critical in establishing the bedrock of this transformative industry. It is imperative, therefore, to understand the precise envisioning of markets – the off-takers, locations, and nations involved. This pivotal insight serves as the cornerstone to enabling a robust evidence base on which the Scottish Government, enterprise agencies, other public bodies and industry can collaboratively develop effective strategies and policies for hydrogen commodity exports.

Purpose

This work provides a comprehensive understanding of the sources of demand for hydrogen in Europe and, critically, the assumptions behind this demand. The focus is on **Northwest European** countries such as Germany, the Netherlands, Belgium and England. Domestic use inside Scotland is out of scope, focusing only on export.

This work has been developed with the explicit understanding that it will allow further analysis to assess the size of the commodity export opportunity in Europe and, within this, Scotland's opportunity.

Assignment Objectives

To develop a suite of information to allow:

- ✓ Quantification of hydrogen end-use demand by sector and region, by scenario and comparatively across the scenarios.
- ✓ Development of an understanding of the current assumptions on imports and exports, and if any correlations by sector exist.
- ✓ Mapping of the assumptions that are being used in the varying scenarios.
- ✓ Identify how the different scenarios are being developed, which can be cross compared directly, and which need to be seen as stand alone.
- ✓ Further analysis by the Scottish Government, Scottish Enterprise and partners in developing hydrogen policy.

Assignment Methodology

Task 1

SCENARIO COLLATION

Collate public & private sector scenarios on future hydrogen demand in Northern Europe.

Key filters:

1. Scenarios are published, or updated, after 1st Jan 2020.
   - Due to the geopolitical changes, earlier scenarios are no longer viable
2. Scenarios have to be original and not reworked from other reports.

DELIVERABLE

1. Documentation of all scenarios used.

Task 2

KEY METRIC ANALYSIS

Using the key metrics:

1. By Hydrogen product - hydrogen, ammonia, jet fuel, etc
2. For which off take market – refineries, etc
3. Analysis over time
4. Import market – how much, by when and to where (offtake).

DELIVERABLE

2. A series of dashboards analysing the information and cross comparing across the scenarios.

Task 3

HYDROGEN IMPORT

Due to the importance of this metric, we have broken this out into a separate sub-task.

For this task, a cross-scenario analysis has been undertaken on the projected use of import. If imports are not included, the scenario methodologies and underlying assumptions have been interrogated as to why.

DELIVERABLE

3. A separate series of dashboards on the projected use and demand of hydrogen imports across the scenarios.

Task 4

SCENARIO INTERROGATION

Assessment On:

1. How the scenarios are created and whether the background information can be accessed or is a black box.
2. Assumptions that feed into the scenario
   - Critically this has focussed on policy, costs, learning curves, transportation and distribution and offtake markets.

DELIVERABLE

4. Documentation on each scenario with key assumptions table.

Task 5

REPORTING

The overall reporting of the results is highly graphical with a series of dashboards and key insights. All the data used, and generated, in the project has also been collated into a separate excel spreadsheet.

DELIVERABLES

5. Report including all dashboards and key insights
6. Excel spreadsheet of all data collated and generated during the project.

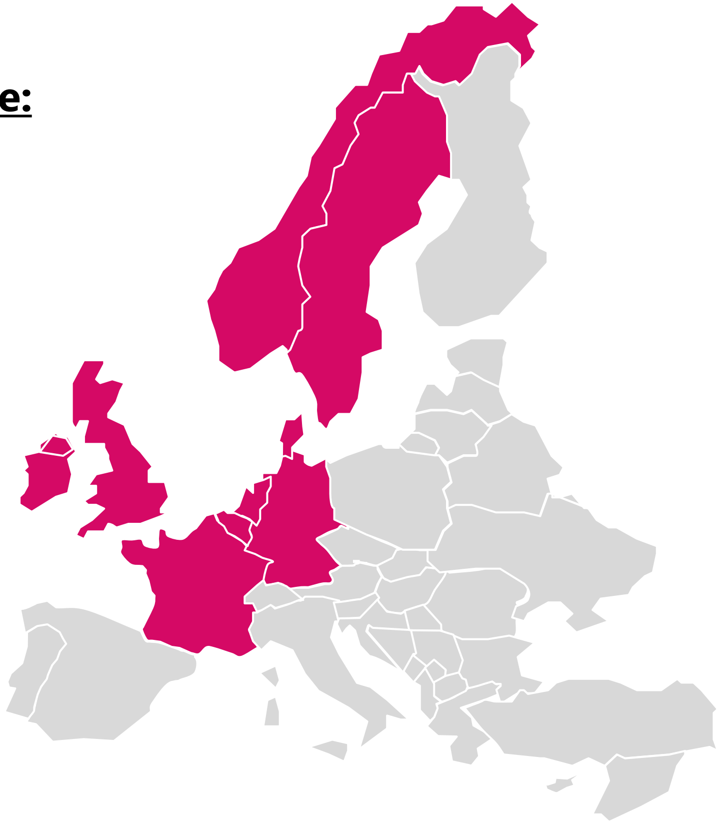
Assignment Scope of Work

Advisian has evaluated the potential Global/ European Markets for low carbon hydrogen demand based on a selection of hydrogen scenarios from various technical reports.

Advisian scope includes 10 countries as listed below:

North West Europe:

- Belgium
- Denmark
- France
- Germany
- Ireland
- Luxembourg
- Netherlands
- Norway
- Sweden
- United Kingdom



Our scope of analysis

- Advisian's assessment focuses on scenarios which cover the listed NW European countries, looking at hydrogen demand and domestic supply in each.
- Other countries are included if beneficial and relevant scenarios are available.
- Europe-wide scenarios have been evaluated to provide some insights into the domestic production capacity of Southern Europe/Spain and hydrogen trade flows. Based on an assessment by the IEA, it has been assumed that NW Europe would account for 60% of the total European demand*.
- This study has focused on public domain sources which can be referenced.

**Based on the IEA's 2021 report* (Hydrogen in North-Western Europe A vision towards 2030), North Western Europe is responsible for 60% of the total European hydrogen demand[1]. Note that, North Western refers to *Belgium, Denmark, France, Germany, the Netherlands, Norway and the United Kingdom.*

1. Hydrogen in North-Western Europe – Analysis - IEA

Scenario Collation and Shortlisting

Definitions - Scenarios vs Forecasts

For this study, given the level of future uncertainty in low carbon hydrogen markets, we believe predictions beyond 2030 should be considered as scenarios even if labelled as forecasts.

Forecast vs Scenario: Intergovernmental Panel on Climate Change (IPCC) Definitions

- **A scenario** is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; each scenario is one alternative image of how the future can unfold. A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in projections.

- When a projection is branded "most likely“, it becomes a **forecast** or prediction. A forecast is often obtained using deterministic models, possibly a set of these outputs, enabling some level of confidence to be attached to projection.

- **Forecasts** are constructed by applying quantitative data and trends to predict one probable future scenario an organisation uses for its plans. It is a shorter-term tool that provides certainty based on known variables in the system.

- **Scenario** planning allows longer-term forecasting for risk and uncertainty.

Definitions – Exploratory vs Normative

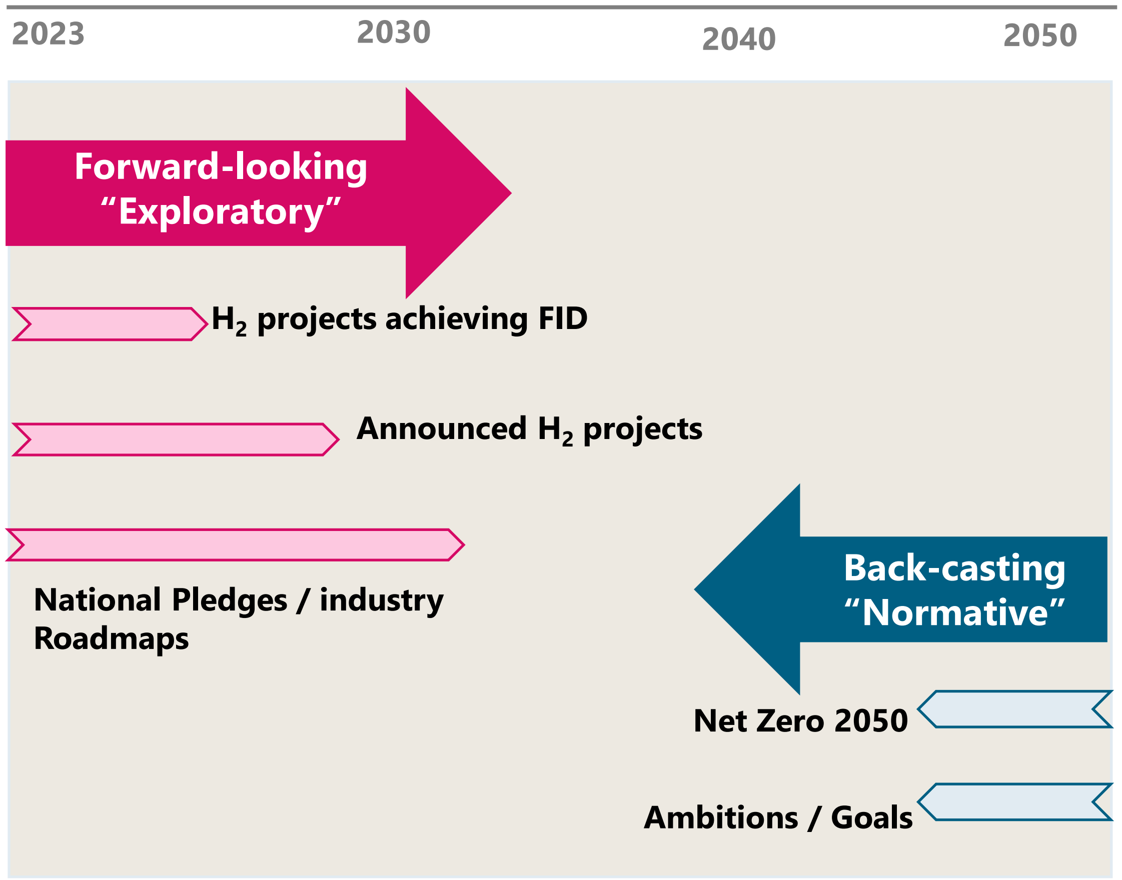
We have classified the scenarios into two categories: Exploratory and Normative

Exploratory vs Normative

- **Exploratory** scenarios begin in the **present** and explore a range of plausible futures based on a range of drivers. These can be described as "forward-looking".

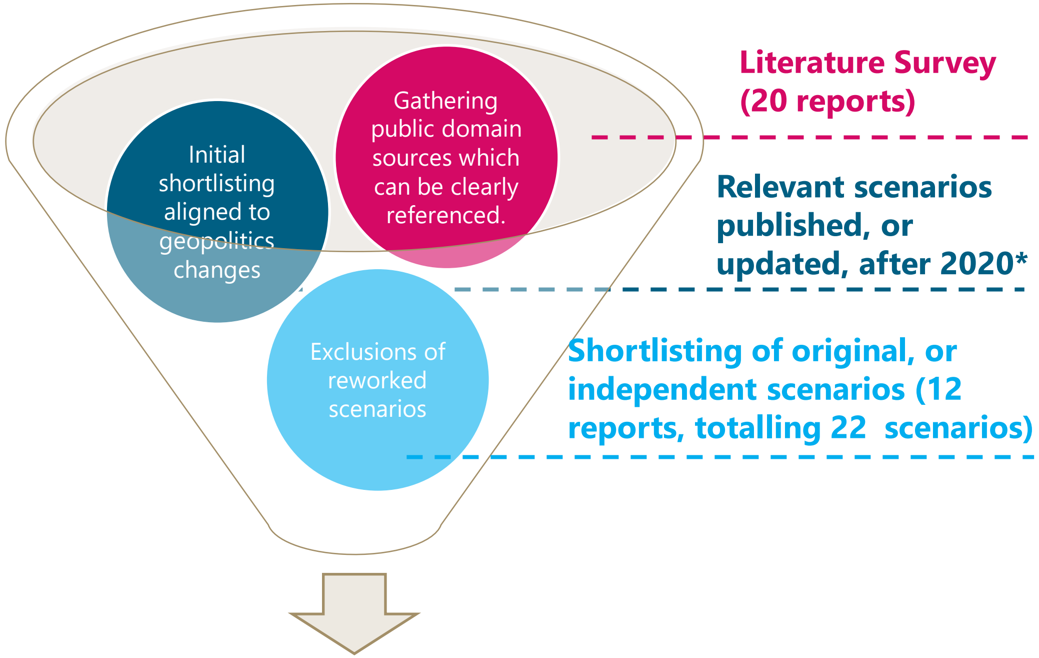
- **Normative** scenarios describe a **desired future**; this scenario can also be considered a goal or vision statement.

- A good normative approach example is assuming Net Zero by 2050 and working backwards ("back-casting") to see what needs to be done to make this happen.
- Some normative scenarios explore different sensitivities surrounding the energy transition systems, government policies and developing technologies.



Scenario Collation

Advisian has collated public & private sector scenarios on future hydrogen demand at global, EU-wide and NW EU countries levels. Key filters were applied to select the scenarios for further analysis.



Further analysis applied to initial shortlisted scenarios resulting in a final list of 6 reports (11 scenarios) to be evaluated.

Scenario Sources:

- Intergovernmental Organisations / Global Forums (IRENA, IEA, World Energy Council)
- Industrial Alliances such as Hydrogen Council, Hydrogen Europe, European Hydrogen Backbone Initiative (TSOs), IOGP
- Oil & gas company energy projections (bp, Shell, Total Energies)
- Management consultancies, often in collaboration with the above (McKinsey, Deloitte, PwC, etc.)
- Other Consultancies (Bloomberg, Rystad, Wood Mackenzie, etc.)
- Academic Papers & Reports (e.g. Oxford Institute for Energy Studies - OIES).

** Scenarios developed before 2021 were not considered due to the significant geopolitical changes that have occurred since, such as the Russia-Ukraine conflict.*

Data Types for Scenario Development

Input Data Types for Qualitative H_2 Demand Models

- List of hydrogen projects under development
- National hydrogen & decarbonisation strategies
- EU polices and mandates
- Industry sector low carbon technology deployment roadmaps (refining, iron & steel, cement, etc)
- Spatial/location data (major industrial facilities, industrial clusters, major infrastructure, etc)

Post Final Investment Decision (FID)

Pre-Front End Engineering Design (FEED) / FEED completed

Memorandum of Understanding

Press Release

Decreasing certainty of project implementation

Preliminary Shortlist of Scenarios

An initial scenario screening process resulted in the shortlisting of 12 reports giving a total of 23 scenarios to be further considered.

Source	Published year	Scenario name	Scenario Category
Aurora Energy Research	2021	• Low demand • Central demand • High demand	Normative
bp Energy Outlook	2023	• Accelerated • Net Zero • New Momentum	Normative Normative Exploratory
DNV	2022	• Hydrogen Forecast to 2050	Exploratory
European Hydrogen Backbone Initiative	2021	• European Hydrogen Backbone (EHB)	Exploratory
EU Joint Research Centre (JRC)	2021	• The Net Zero scenario/JRC TIMES • JRC Energy Scenario	Normative Normative
IOGP Europe report – Deloitte, IFPEN, Carbon Limits, SINTEF	2022	• Technology diversification • Renewable push	Normative Normative
Hydrogen Council – McKinsey	2022	• Efficient decarbonization	Normative
IEA NW Europe	2021	• Baseline • Accelerated	Exploratory Normative
IRENA	2022	• Global Hydrogen Trade to Meet the 1.5°C Climate Goal	Normative
Oxford Institute for Energy Studies (OIES)	2023	• REPowerEU • Fit for 55 • 2020 Unbated H2	Normative
Shell	2023	• Sky 2050 • Archipelagos	Normative Exploratory
TotalEnergies	2022	• Momentum • Ruptures	Exploratory Normative

Heat Map for Shortlisted Scenarios

Advisian has selected the scenarios for further analysis considering available data on metrics such as region breakdown, timeframe, sectoral analysis and description of the methodology.

Source	Region Breakdown*	2030 Timescale	2050 Timescale	Sectors Analysis	Is the methodology clear?
Aurora Energy Research	**				
bp Energy Outlook					
DNV					
European Hydrogen Backbone Initiative					
EU Joint Research Centre TIMES					
IOGP Europe report – Deloitte, IFPEN, Carbon Limits, SINTEF					
Hydrogen Council – McKinsey	**				
IEA NW Europe					
IRENA					
Oxford Institute for Energy Studies					
Shell					
Total Energies					

* We categorised the region breakdown as color-coded below. ** The report presents a breakdown that enables us to get a NW or EU/Europe data.

NW EU Specific EU/Europe Specific Global or non-EU/Europe Specific

Final List of Scenarios

- **Applying our Heat Map approach, Advisian selected six reports (totalling 11 scenarios) for further comprehensive analysis. Most of these reports present a timeframe between 2030 and 2050 for hydrogen demand, providing Europe/EU demand by sub-sector and a transparent methodology.**

  - **Aurora – 3 scenarios**
  - **European Hydrogen Backbone (EHB) – 1 scenario**
  - EU Joint Research Centre (EU JRC) - 2 scenarios
  - Hydrogen Council/McKinsey* – 1 scenario
  - International Energy Agency (IEA) – 2 scenarios
  - **IOGP (Deloitte/IFPEN/SINTEF/Carbon Limits) – 2 scenarios**

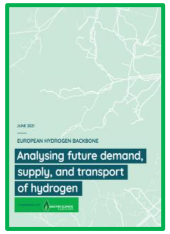
- **EHB, IOGP and Aurora are potentially the top 3 reports with the best-described scenarios and more detailed assumptions.**

** There are two Hydrogen Council/McKinsey reports which were selected for further analysis. They do not have a comprehensive analysis for Europe/EU hydrogen demand, however, they will be combined and used for detailed analysis in a dashboard format.*

Links to access the reports

Aurora - https://auroraer.com/wp-content/uploads/2021/06/Aurora-MCS-Enabling-the-European-hydrogen-economy-Report-20210611.pdf

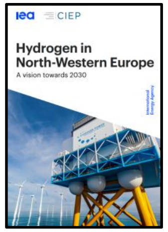
Hydrogen Council - https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-for-Net-Zero.pdf



European Hydrogen Backbone - EHB#2_report_part1_210614.indd

IGOP - https://www.hydrogen4eu.com/_files/ugd/2c85cf_e934420068d44268aac2ef0d65a01a66.pdf

EU JRC TIMES - https://publications.jrc.ec.europa.eu/repository/handle/JRC131299
JRC Energy - https://publications.jrc.ec.europa.eu/repository/handle/JRC131864



IEA - https://iea.blob.core.windows.net/assets/ccbc3b01-7403-4c15-90a2-af11dfb92c62/Hydrogen_in_North_Western_Europe.pdf

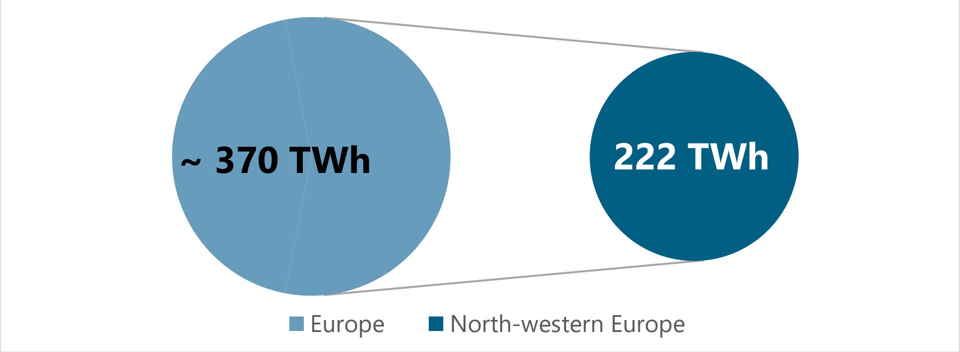
Key Considerations for the Assessed Scenarios

Background – Current NW Europe Hydrogen Demand

- According to the IEA's report on hydrogen in North-Western Europe (2021)[1], the region concentrates around 5% of global and 60% of European demand, with **more than 200 TWh (~6.7 Mt) of hydrogen used** every year[1].
- The **demand** for grey hydrogen **in ammonia production and refineries** in NW Europe has remained relatively stable at around 3.7 Mt/y (~**122 TWh**) over the last decade. Ammonia production (1.8 Mt/y or 60 TWh) and oil refining (1.6 Mt/y or 53 TWh) are the primary sources of demand, with minor contributions from other industries (such as electronics, steel and glassmaking) and new applications (such as transport or grid injection) [1].
- **Demand for hydrogen blended** with other carbon-containing gases has varied between 2.4 Mt/y and 3.0 Mt/y (**79-100TWh**) over the last decade. Most of this demand comes from **petrochemical processes** (1.4 -2.0 Mt/y, 64 TWh) and **the steel industry** (0.5-0.7 Mt/year, 24 TWh). A small share **comes from** dedicated applications, such as **methanol production** (0.35 Mt/y, 12 TWh) and direct reduced iron (DRI) steel production (25 kt H2/y) [1].

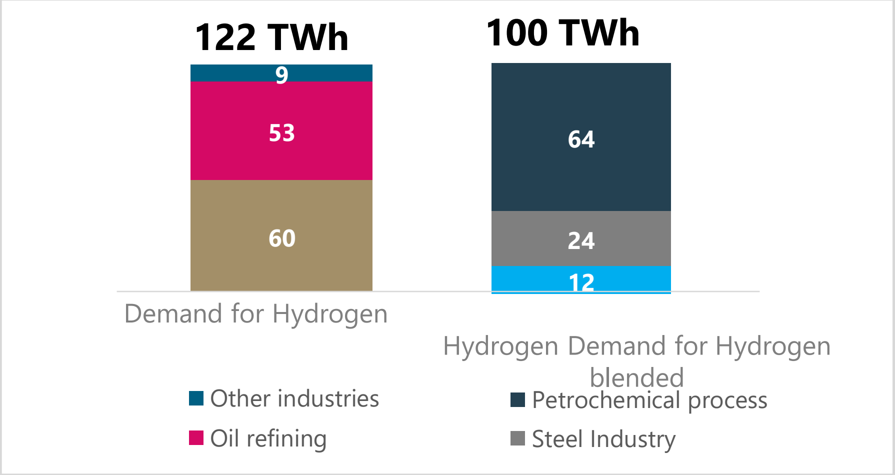
1. Hydrogen in North-Western Europe – Analysis - IEA

2019 Hydrogen demand in Europe and in NW Europe (TWh)



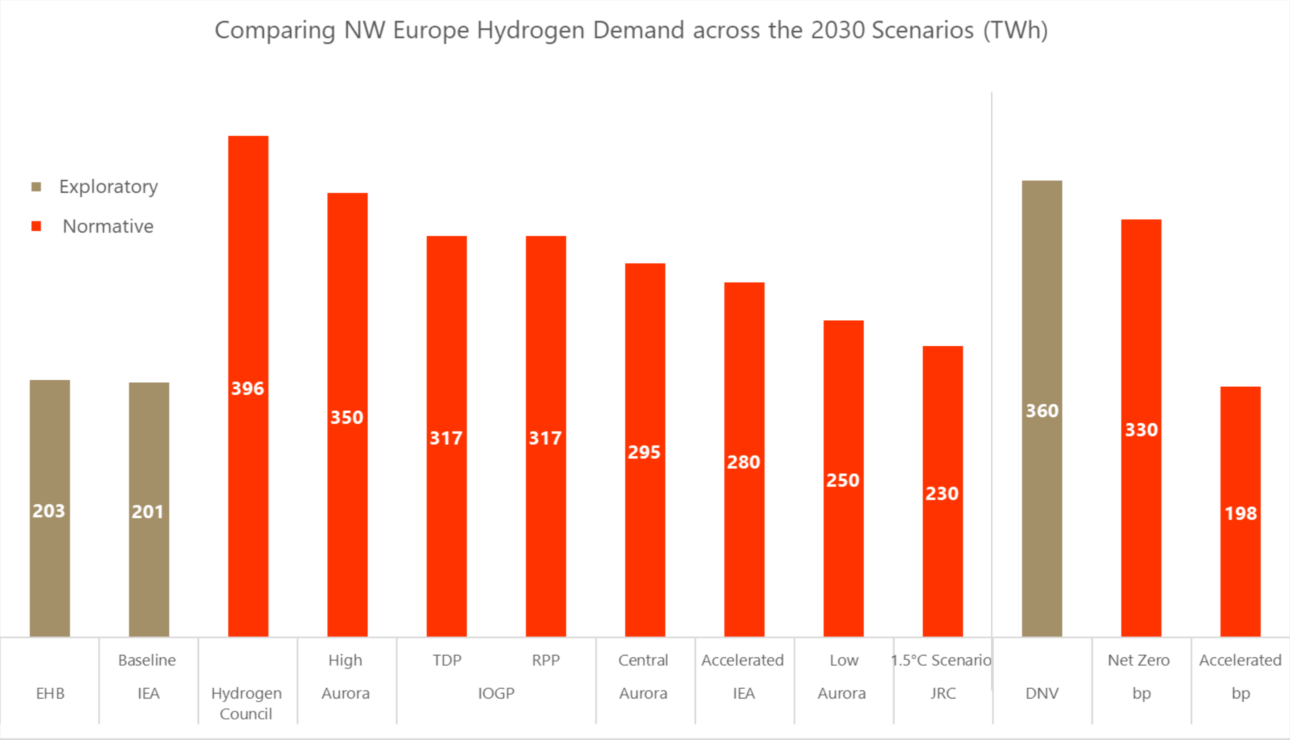
Source IEA- NW Europe Hydrogen Report accounting for 60% European demand

2019 Hydrogen demand in North-western Europe (TWh) by sector



Key Considerations – 2030 Scenarios

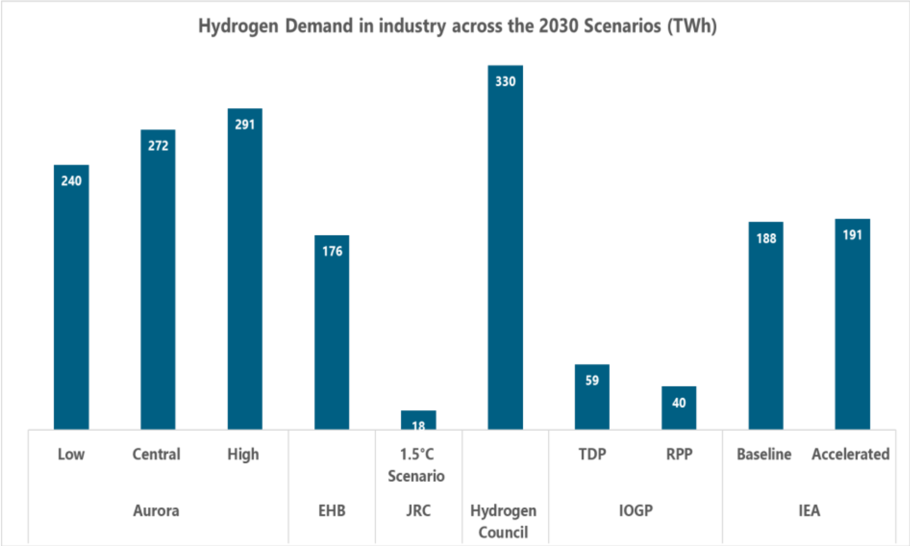
- Based on all scenarios evaluated (including global reports), **hydrogen demand across NW Europe could range from ~200 to 396 TWh in 2030.**
- The lowest demand can be seen in the EHB, JRC Times, IEA Baseline and bp Accelerated scenarios.
- High-case scenarios show **hydrogen demand** in NW Europe between 280 TWh (IEA) and 396 TWh (Hydrogen Council), and the **average across scenarios would be about 280 TWh in 2030**.
- When **looking at 2030, the exploratory scenarios would be expected to be more accurate** than normative ones as 2030 is nearer to now than backcasting from 2050. EHB, IEA baseline, and bp accelerated scenarios would fall under an exploratory perspective.
- **Advisian has identified that EHB, IOGP and Aurora reports are the most transparent in their use of assumptions and data.**

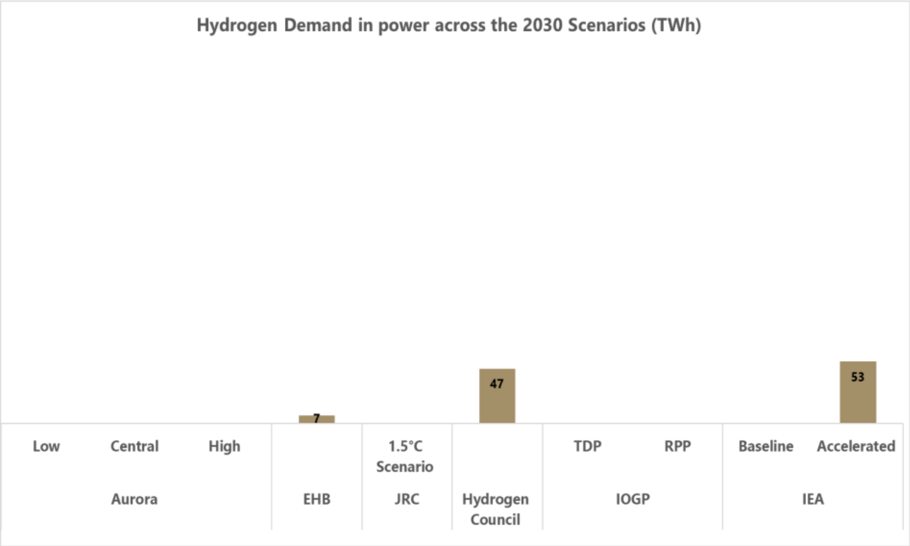


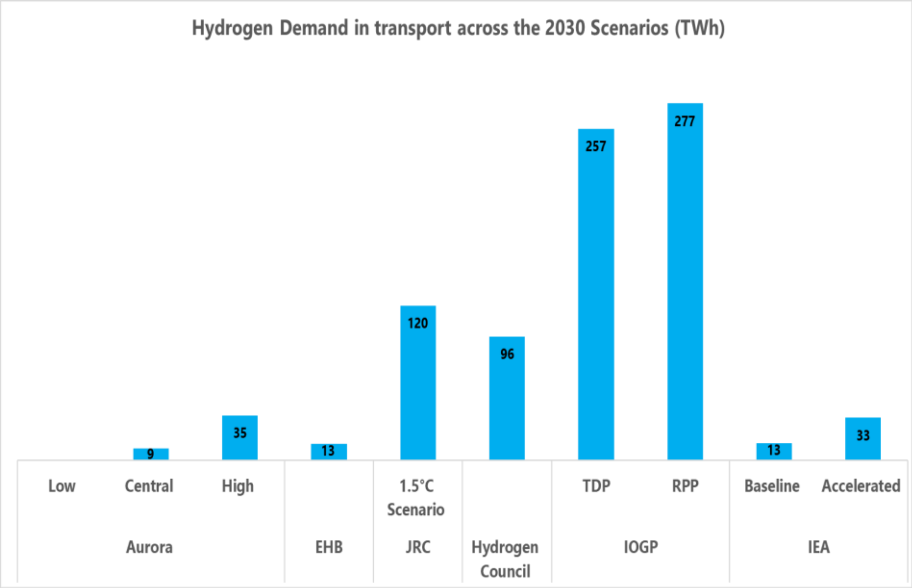
***Aurora scenarios**: We have considered that NW Europe demand is 60% of the total hydrogen demand of European Union countries and Norway presented in the report. **EHB scenario**: We have assumed that NW Europe demand is 60% of the total hydrogen demand of the European Union introduced in the report. **JRC scenario** covers hydrogen demand for EU Member States; we did not apply the assumption that 60% of its demand comes from NW Europe. **Hydrogen Council:** We have considered that NW Europe demand is 60% of the total European hydrogen demand presented in the report. **IOGP scenarios:** We have assumed that NW Europe demand is 60% of the total hydrogen demand estimated for European countries in the report. **IEA scenarios:** the report shows hydrogen demand for North-Western European countries and refers to Belgium, Denmark, France, Germany, the Netherlands, Norway and the UK. **bp scenarios:** Based on the report, it can be assumed that 20% of the global hydrogen demand forecasted is coming from European Union countries, and therefore, the numbers presented in the graph refer to the EU. **DNV scenario:** NW EU Hydrogen demand was based on the assumption that 14% of the global demand is located in Europe (Global hydrogen demand forecast by region 2030-2050 | Statista), and we considered that 60% of its demand comes from NW Europe.*

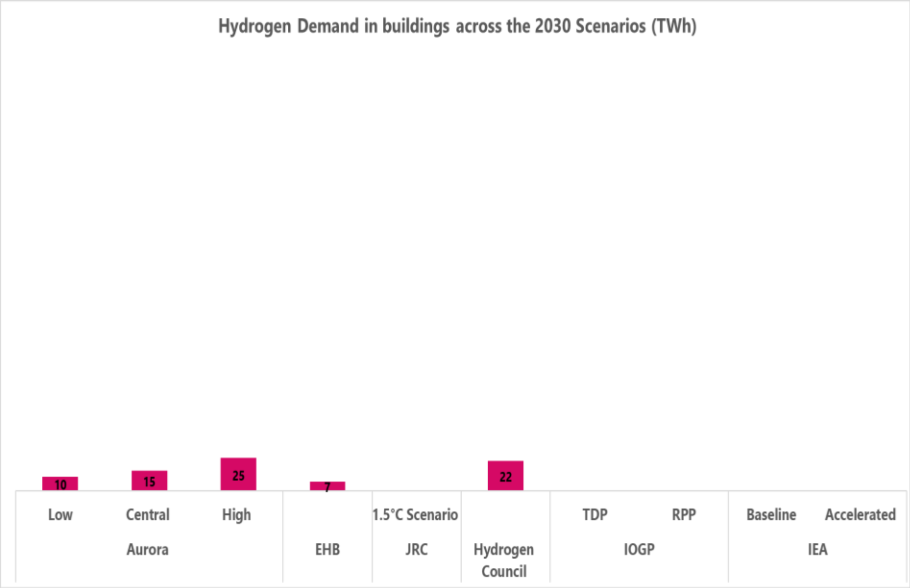
Current grey hydrogen demand in NW Europe is around ~ 220 TWh.

Key Considerations – NW Europe 2030 Scenarios by Sector









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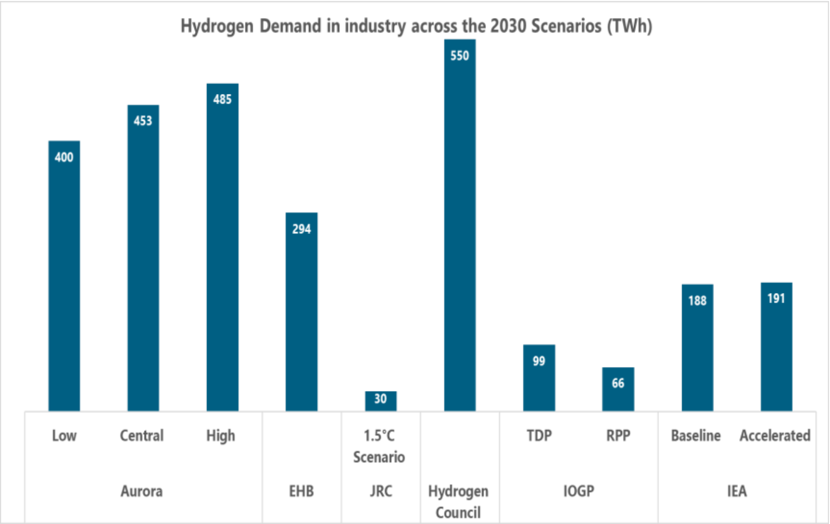
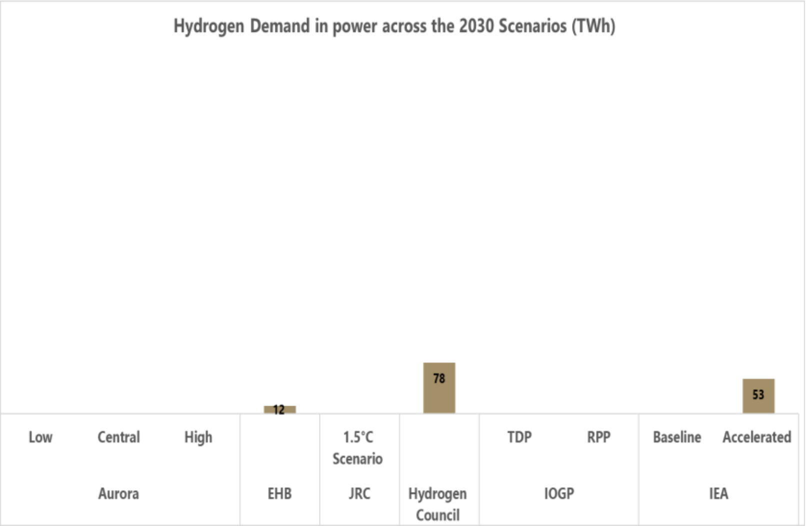
Key Considerations – EU 2030 Scenarios by Sectors

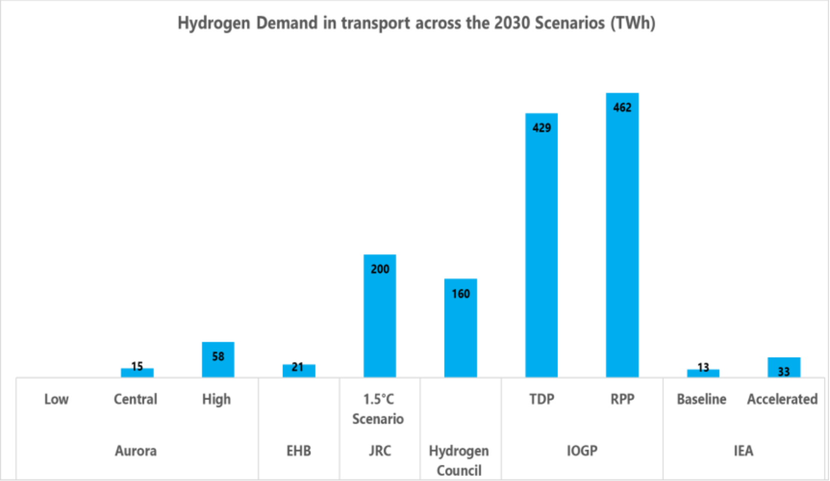
- Hydrogen demand comes mainly from industry in 2030 according to Aurora, EHB, Hydrogen Council and IEA scenarios. In contrast, JRC Times and IOGP scenarios foresee hydrogen use mainly in the transport sector in 2030. However, note that in the IOGP scenario, oil refining is covered under the transport sector.

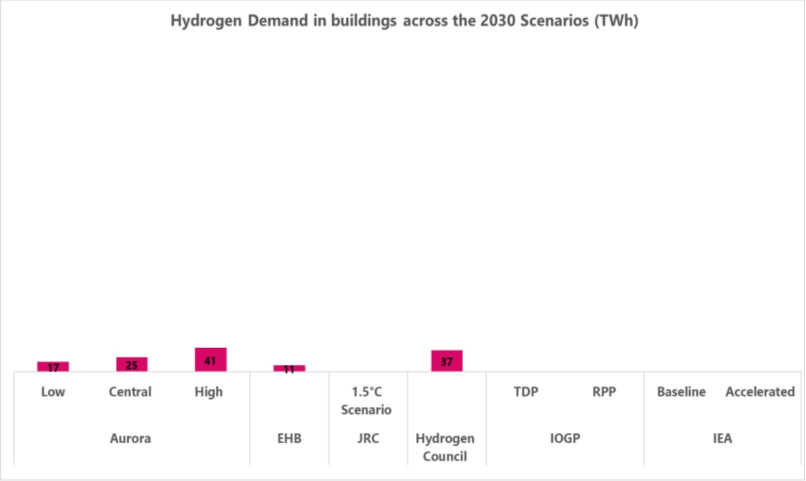
- A few scenarios consider that hydrogen could reach the power sector. It is not a part of Aurora's core demand assumptions. Hydrogen could provide firm capacity to the energy mix in the EHB, Hydrogen Council and IEA scenarios. The Hydrogen Council and IEA mention that hydrogen is crucial in decarbonising the final demand (1-3%) in a fully decarbonised grid.

- All Aurora scenarios see hydrogen use in the buildings sector as well as the Hydrogen Council's scenario, and in less extension in the EHB. Aurora considers hydrogen adoption in building applications such as H_2 heat boilers and hybrid heat pumps, mentioning the potential for hydrogen to replace fossil fuels in district heating in specific locations via converting combined heat and power (CHP) generation to hydrogen.





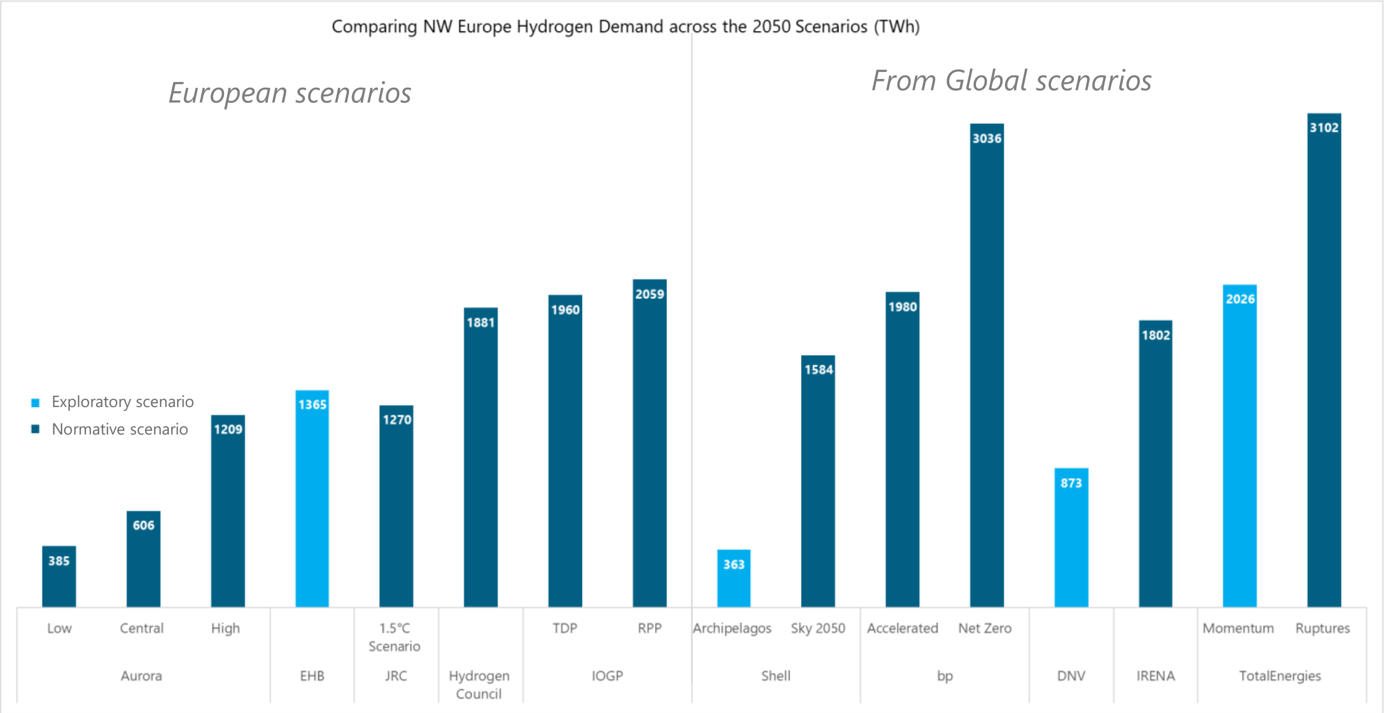




Charts reflect the overall hydrogen demand in each sector presented in the reports. Note that each scenario has a distinct country scope. Aurora, EHB and JRC include demand from all European Union countries. Hydrogen Council and IOGP cover demand in Europe. IEA includes specific NW Europe countries.

Key Considerations - 2050 Scenarios

- Based on all scenarios evaluated (including global reports, **hydrogen demand across NW Europe could reach over 3000 TWh in 2050, with an average of around 2125 TWh in 2050**.
- **Aurora low-case and Shell Archipelagos** show **that hydrogen demand** in NW EU **increase only ~70% by 2050,** from 220 TWh in 2021 to ~360-380 TWh in 2050.
- In the 2050 scenarios, the European scenarios - **Aurora, EHB and JRC show a conservative uptake** of hydrogen compared to normative scenarios such as Hydrogen Council, IOGP, bp and TotalEnergies.
- **Global scenarios such as bp and TotalEnergies show hydrogen demand over 3000 TWh.**



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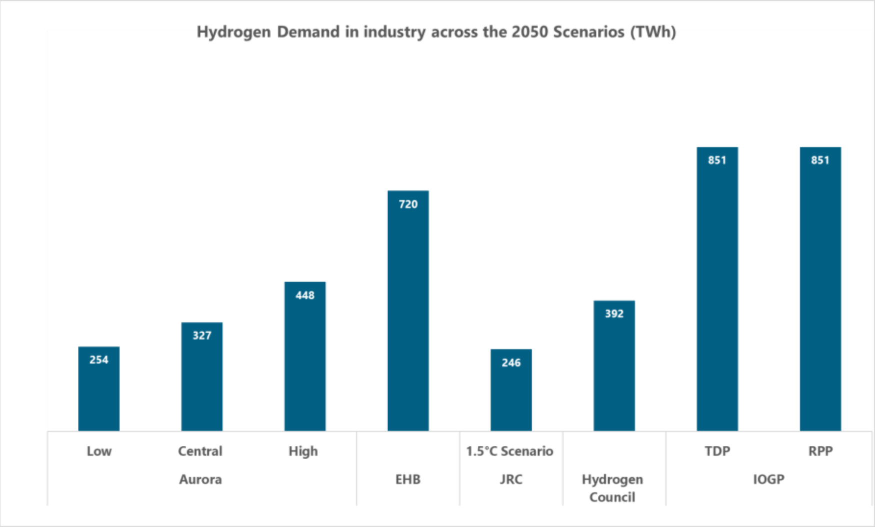
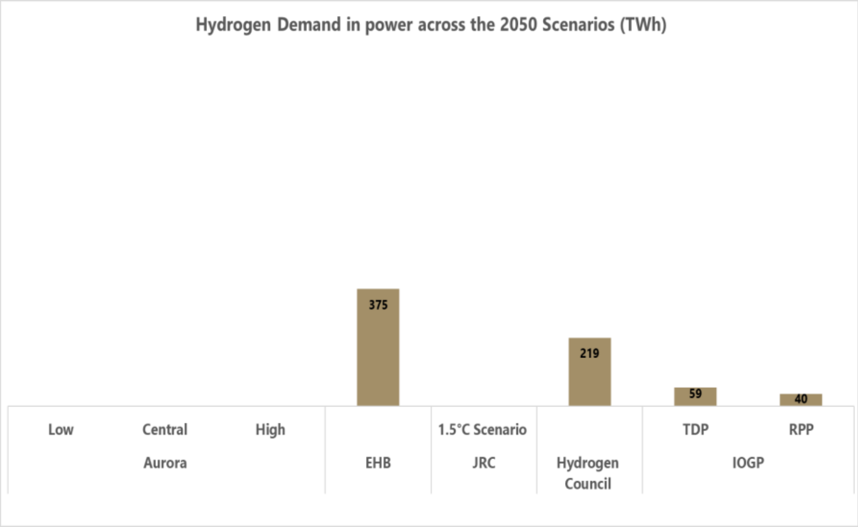
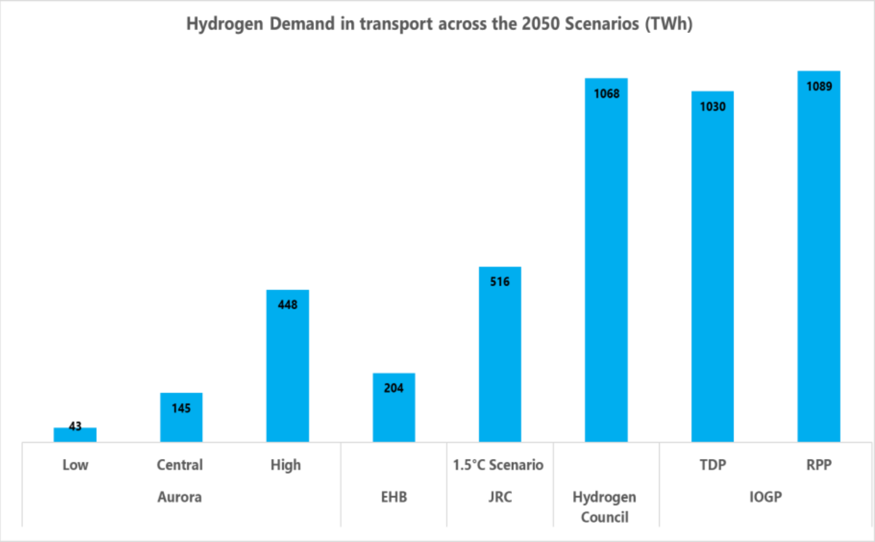
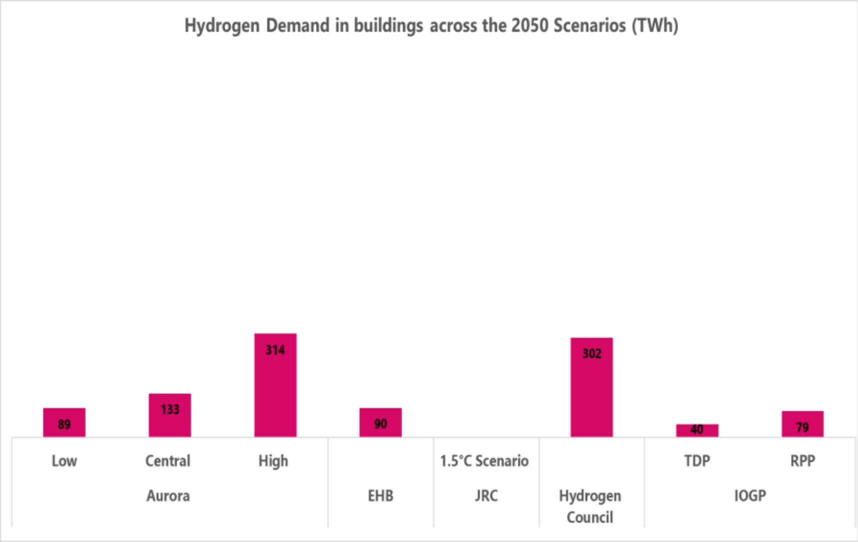
Current grey hydrogen demand in NW Europe is around 220 TWh.

Key Considerations – NW Europe 2050 Scenarios by Sector





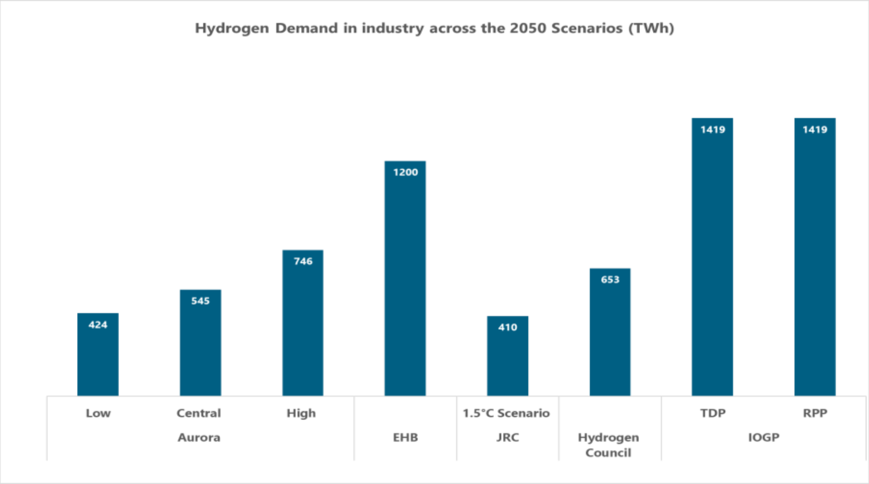


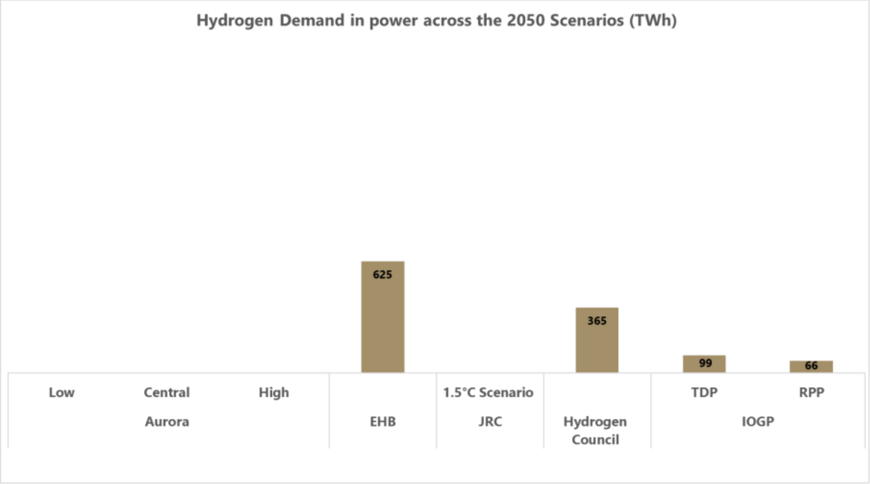


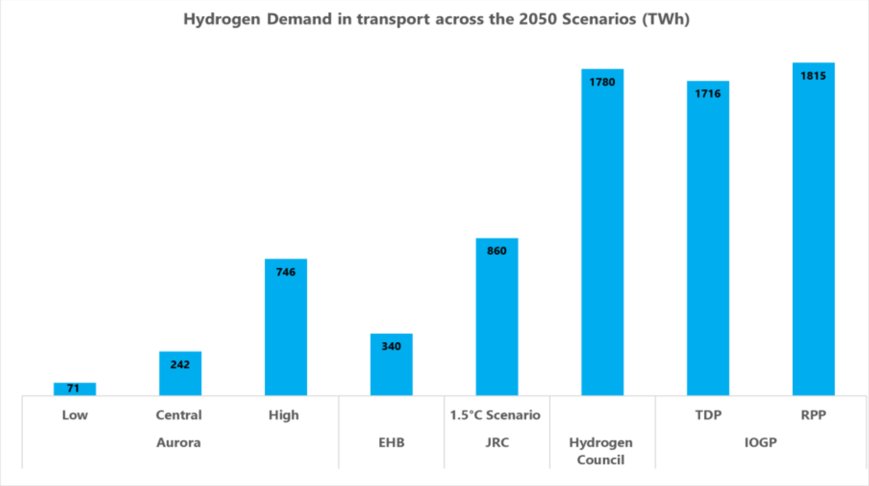
Aurora scenarios*: We have considered that NW Europe demand is 60% of the total hydrogen demand of European Union countries and Norway presented in the report.* ***EHB scenario****: We have assumed that NW Europe demand is 60% of the total hydrogen demand of the European Union introduced in the report.* ***JRC scenario*** *covers hydrogen demand for EU Member States; we applied the assumption that 60% of its demand comes from NW Europe.* ***Hydrogen Council:*** *We have considered that NW Europe's demand is 60% of the total European hydrogen demand presented in the report.* ***IOGP scenarios:*** *We have assumed that NW Europe demand is 60% of the total hydrogen demand estimated for European countries in the report.*

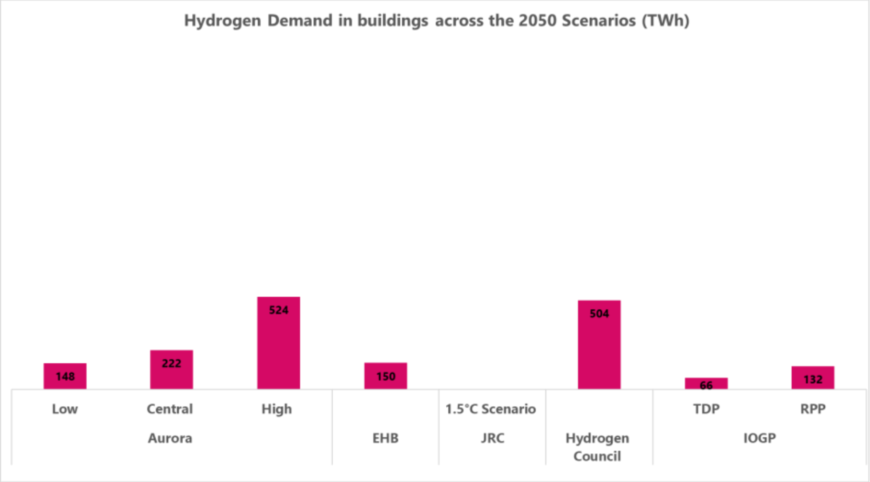
Key Considerations – EU 2050 Scenarios by Sector

- In 2050's scenarios, hydrogen has a noteworthy penetration in industry and transport sectors, playing a pivotal role in complementing electrification.
- EHB sees hydrogen playing a dual role in power generation and energy storage from 2040 onwards. Hydrogen Council and, in less extension, IOGP also foresee hydrogen use in the power sector.
- In buildings, the Aurora high-case and Hydrogen Council see widespread adoption of hydrogen, with the development of up to 14 million hydrogen boilers by 2050 in Aurora.









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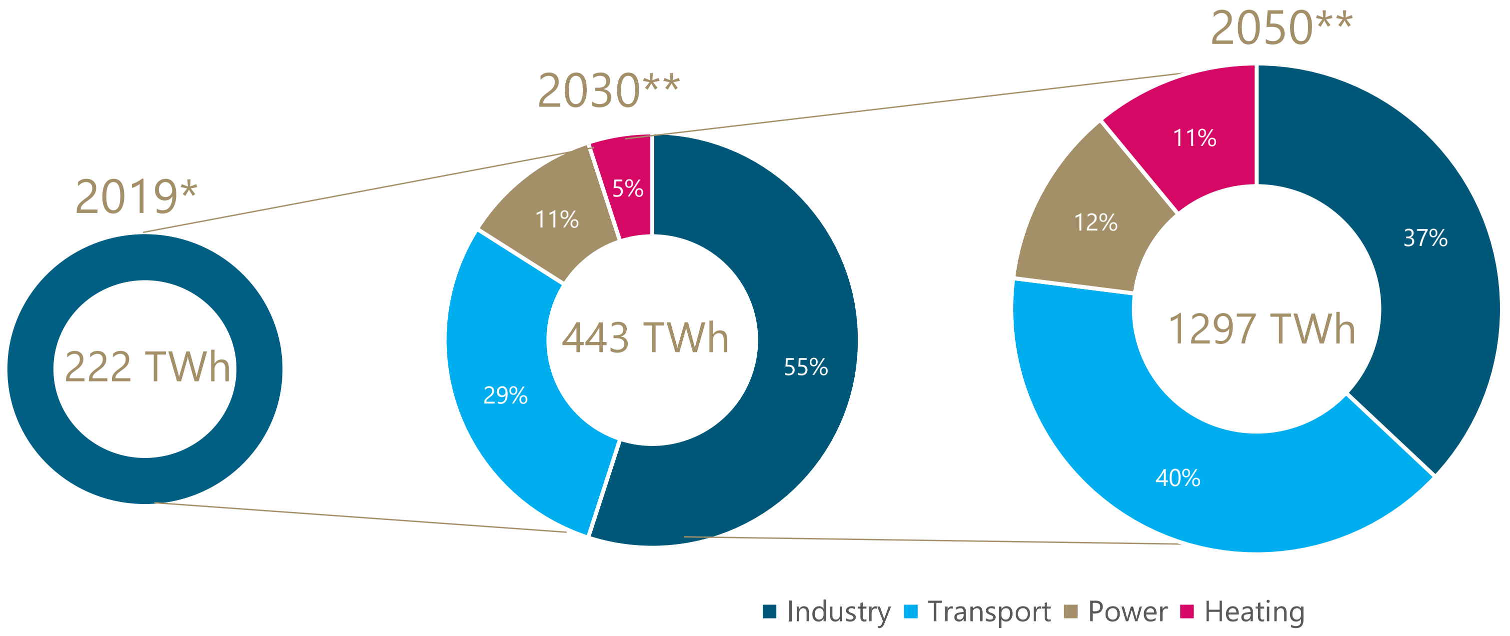
Average Hydrogen Demand in NW Europe (TWh)

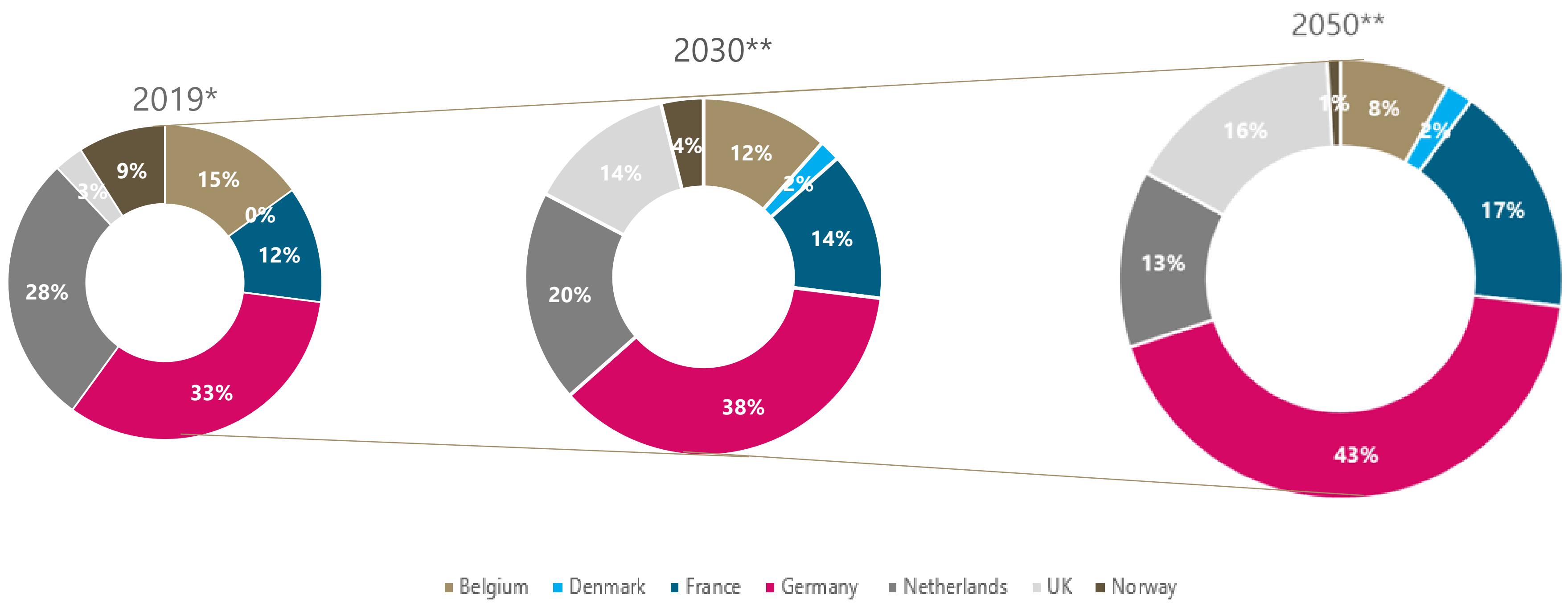


- In 2030, the average hydrogen demand in industry accounts for 55% of the average hydrogen demand in NW Europe, while transport makes up 29% of the average demand.
- The average hydrogen demand in 2050 is nearly three times higher, showing increased hydrogen use over time.
- In 2050, the industry's share of the total average hydrogen demand decreased to 37%, with transport's share increasing to 40%, suggesting growth of hydrogen use in the transport sector.

**The 2019 demand has only been taken from the IEA report; all hydrogen is used in the industrial sector.*

***The average demand in 2030 and 2050 has been taken over all six reports.*

Average Hydrogen Demand by Country (TWh)



The 2019 demand has been taken from the IEA report only.

***As some reports do not provide demand breakdown by country, the average has been taken over the EHB, IEA, and Aurora reports.*

- The EHB, IEA, and Aurora reports show hydrogen demand breakdown by country. Advisian calculations show that across these scenarios, Germany holds an average share of 38% of the hydrogen demand in 2030, rising to 43% in 2050. These reports outline the following reasons for Germany having the majority of hydrogen demand in the region:

- **Strong industrial sector –** Germany's sector has a high energy demand, contributing to the need for hydrogen as a low carbon energy source.
- **Hydrogen strategy and investment –** The German hydrogen strategy focuses on developing 5GW electrolyser capacity by 2030.
- **Market Development and Regulatory Factors –** The growth in hydrogen project proposals and investor interest suggests a move towards a broader hydrogen market beyond industrial use.

Scenario Dashboards

Introduction

- This section provides a detailed analysis of hydrogen demand scenarios for the selected reports.
- These scenarios exhibit variations in terms of geographical coverage and basis of assumptions.
- Notably, Aurora and JRC encompass all European Union countries, while EHB includes the UK as a significant participant in the Hydrogen Backbone.
- Conversely, the Hydrogen Council and IGOP reports present scenarios about Europe as a whole without offering region-specific or country-specific analyses.
- In contrast, the IEA report concentrates on a regional analysis, encompassing eight North-Western European countries, including the UK.
- It should be emphasised that making direct comparisons between these reports may lead to misconceptions, as they are based on distinct methodologies and assumptions.
- All the scenarios used different metrics; where required, these have been converted to TWh (LHV). Conversion factors are detailed in the following page.

AURORA
ENERGY RESEARCH

Aurora Report Overview

- The report "Enabling Hydrogen Economy" was prepared by Aurora Energy Research, an analytics and research firm focussing on the energy market. Aurora's report presents three normative scenarios: Low, Central and High hydrogen demand.
- Aurora's study on European hydrogen scenarios is sponsored by a consortium of European energy consumers and producers comprising ArcelorMittal, EDF, Fortum and UPM.
- The report is focused on the European Union (EU) and its decarbonisation strategy. It specifically addresses how hydrogen can contribute to meeting the EU's decarbonisation objectives and the development of a hydrogen economy within the EU context.
- In the report, it is stated that the EU's current hydrogen demand is approximately 313 TWh, mainly used in refineries and as an industrial feedstock such as ammonia production. The report also details projections for future hydrogen demand in 2030 and 2050 under three scenarios: Low, Central, and High.
- **Projected demand for 2030:** 417 TWh (Low), 492 TWh (Central) and 584 TWh (High)
- **Projected demand for 2050:** 642 TWh (Low), 1010 TWh (Central) and 2015 TWh (High)
- Countries with large industrial bases and higher populations and GDPs, such as Germany, are expected to dominate the demand for hydrogen in 2050.
- The report identified the following drivers for the increased hydrogen demand:

- **Policy Support and Regulatory Frameworks:** The development of the hydrogen economy in the EU is heavily influenced by policy decisions.
- **Economic Viability and Energy Mix Considerations:** The report assumes that Europe can produce enough hydrogen to meet its demand using renewable electricity and other low carbon sources.
- **Integration with the Overall Energy System:** The role of hydrogen in the broader EU energy system, including its interaction with other forms of energy and technology, is a key driver.

The report provides a breakdown of hydrogen demand by sector for each scenario, including hydrogen demand in transport, industry, power, and buildings.

The report's predictions for hydrogen demand are based on several key assumptions: **Decarbonisation Strategy:** Hydrogen is crucial for the EU's strategy to decarbonise sectors that are difficult to electrify, like steel production and heavy transport. **Policy Support:** Developing a hydrogen economy in the EU depends heavily on policy decisions focusing on scenarios that optimise rapid decarbonisation while minimising full lifecycle emissions and reducing costs. **Energy Mix:** The report assumes that Europe can produce enough hydrogen to meet its demand using **all forms** of decarbonised electricity. **Economic Viability:** Using all forms of renewable and decarbonised electricity for hydrogen production is projected to be more cost-effective and result in fewer overall emissions than relying solely on additional new-build renewables.

Aurora Policy Overview

The report "Enabling the European Hydrogen Economy" discusses several policies, assessing future hydrogen demand in different sectors, including transport, industrial, buildings, and power.

- **Transport - Demand Mandates and Renewable Energy Directive (RED II)**: The report considers the role of demand mandates for hydrogen produced from renewable energy sources (RES) and decarbonised electricity, specifically in the transport sector. It also references RED II, which guarantees hydrogen production comes from verified renewable sources. The report points out that restricting hydrogen supply to production from additional new-build renewables may limit the hydrogen produced, thereby affecting the demand estimates in the transport sector, especially in areas like aviation, which are challenging to decarbonise using other means.
- **Industry - Carbon Contracts for Difference (CCfDs)**: The report discusses sector-specific CCfDs to support the decarbonisation of hard-to-abate industrial sectors. This policy consideration is crucial for enabling hydrogen demand in the industrial sector, as it influences the economic feasibility and, thus, the adoption rate of hydrogen technologies in these industries.
- **Power - Renewable and Decarbonised Electricity Support**: The report emphasises the importance of policies that support hydrogen production from all forms of renewable and decarbonised electricity for the power sector. This broad policy framework is essential for assessing hydrogen demand in the power sector, as it influences the availability and cost of hydrogen as an energy source.

Overall, the report integrates these policies into its analysis to evaluate future hydrogen demand in these sectors. The demand mandates, CCfDs, RED II, and support for renewable and decarbonised electricity production are key policy considerations that have been factored into the demand outlook for the transport, industrial, buildings, and power sectors.

Aurora Energy Research – Methodology & Assumptions

AURORA ENERGY RESEARCH

Aurora Scenarios Description

The report presents three scenarios that reflect different views of how quickly and extensively hydrogen will be adopted within the EU's energy system by 2050. They vary in optimism regarding the factors that can drive or hinder the development of a hydrogen economy, such as technological breakthroughs, cost reductions, consumer acceptance, and the stringency and effectiveness of policy measures.

The low demand scenario assumes all hydrogen uptake is slow across all sectors. There will be minimal policy interventions to drive the transition to a hydrogen economy, slower technological advancements and higher costs for hydrogen production, storage, and transportation. In this scenario, hydrogen will play a minor role in meeting overall energy demand by 2050, with the majority of demand continuing to be met by conventional energy sources.

Considering current policy, regulatory, and macroeconomic factors, the central demand scenario reflects a moderate transition towards hydrogen. It assumes a balanced energy mix with a role for hydrogen in specific sectors but does not rely on it as the primary energy source. Policy support is considered to increase over time but less aggressively than in the high scenario.

The high demand scenario considers that hydrogen is essential in decarbonising the economy. It assumes an aggressive shift towards hydrogen, particularly in hard-to-abate sectors such as heavy industry and heavy-duty transport. Policy measures such as Carbon Contracts for Difference (CCfDs), demand mandates, and subsidies would promote hydrogen use. It considers faster technological advancements that make hydrogen production, storage, and transportation more cost-effective, as well as an extensive development of hydrogen infrastructure, enabling higher penetration of hydrogen in various sectors.

Industry

In the industry and chemicals sector, hydrogen demand will be led by five main sectors: high value chemicals (including methanol), ammonia, refineries, steel, and cement.

The primary basis for the assumptions is that some industrial sectors will find it difficult or not credible to decarbonise via electrification. Thus, demand for hydrogen in industry is anticipated to continue to dominate overall demand for hydrogen.

Additionally, hydrogen provision at industrial hubs will require less infrastructure build-out than for its use in buildings or transport, allowing faster penetration of hydrogen into the sector.

Buildings

The uptake of **hydrogen in buildings** is predicted to be slow until at least the 2030s, given the very high level of grid infrastructure investments required, such as for repurposing of the existing gas grid and replacement of boilers.

Hydrogen is also not seen as an efficient choice when compared to electrification. However, in countries with older, poorly insulated housing stock, hydrogen demand is expected for buildings where the energy for heat demand is currently supplied by natural gas.

There is also potential for hydrogen to replace fossil fuels in combined heat and power (CHP) for district heating.

Transport

In transport, particularly for heavy goods vehicles and mass transport, technological challenges surrounding battery ranges mean electrification may not be a practical option for decarbonisation, with the deployment of hydrogen presenting a viable alternative.

Infrastructure build-out will be crucial for the commercial deployment of hydrogen in transport, especially for long-distance freight vehicles, and thus, the uptake of hydrogen until at least the 2030s will be minimal.

The direct use of hydrogen as a fuel source in shipping and aviation is not considered, owing to the immaturity of this technology. The use of ammonia in shipping and hydrogen-derived synthetic fuels in aviation presents a viable decarbonisation pathway for these sectors. It is assumed that ammonia in shipping will be widely rolled out in the 2030s. After that, there will be broader decarbonisation goals for the shipping industry and the availability of technology that can use ammonia as a fuel.

Demand will vary across scenarios according to factors such as the cost-competitiveness of hydrogen fuels, infrastructure developments and regulatory frameworks such as subsidies or mandates.

The methodology has not been published in the report. Aurora has its own power/energy modelling methodology that might have been used to develop these hydrogen scenarios; see:

auroraer.com

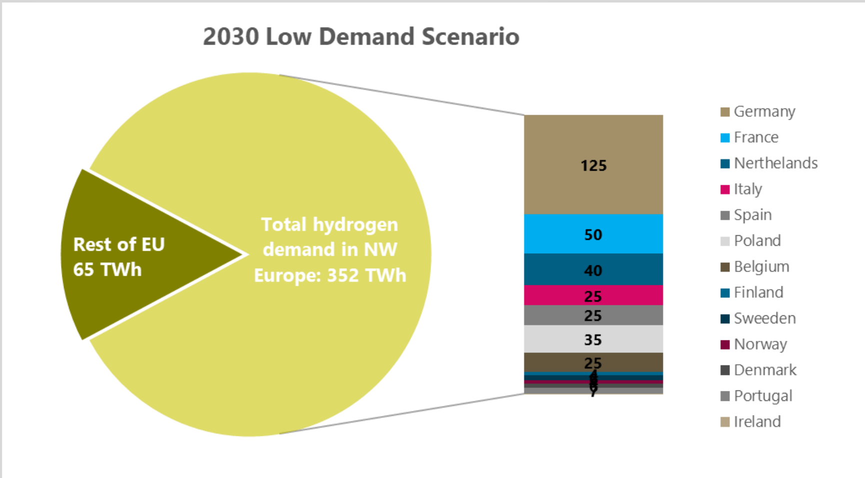
Aurora Presentation (nic.org.uk)

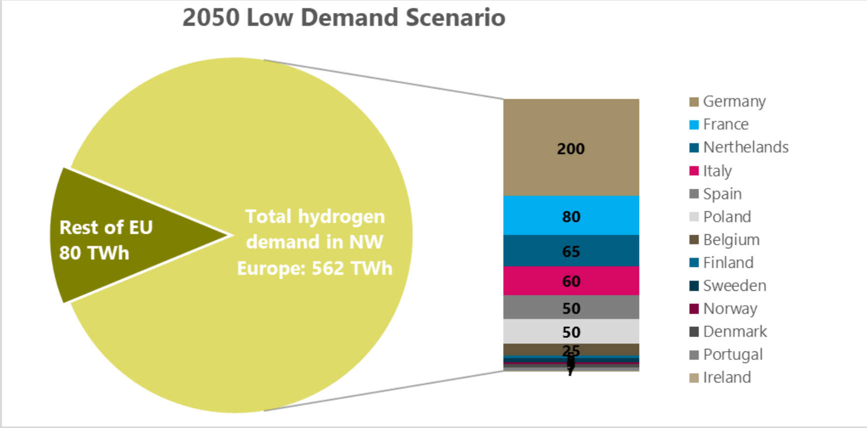
Aurora Energy Research – Low Demand Scenario

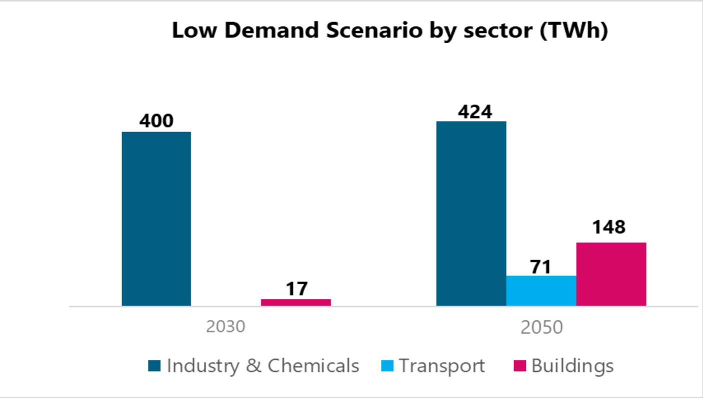
Under **Aurora's low demand scenario**, hydrogen is part of the decarbonisation options for the industrial, transport and buildings sectors, potentially reaching **7% of the EU's total** energy demand by 2050.

Aurora Low Demand Scenario

Based on the report, the current demand for hydrogen in the EU stands at 313 TWh/y (2020), primarily utilised in refineries and ammonia production. Hydrogen demand would reach 417 TWh in Aurora's low demand scenario in 2030, increasing by 2050 to 642 TWh.







In the low-demand case, Germany will make ~30% of the total forecast demand for hydrogen, with Germany, France and the Netherlands comprising around 50% of the total demand in 2030 and 2050. Countries with large industrial bases and higher populations and GDPs will, therefore, dominate the demand for hydrogen. These considerations are also valid for the central and high-demand case.

Note: The report shows data for specific EU countries including Belgium, Denmark, Finland, France, Germany, Italy, Ireland, Netherlands, Norway, Poland, Portugal, Spain and Sweden. The remaining EU hydrogen demand is grouped as the rest of the EU.

In the low scenario, the industrial sector is projected to account for 95% of hydrogen demand in 2030. Industrial segments such as methanol, ammonia, refineries, steel, and cement will rely on hydrogen. Hydrogen will enable a 70% reduction in emissions, with the overall size of the sector shrinking. In 2050, hydrogen use will expand into the transportation and building sectors, accounting for just over 30% of the demand.

Within the land-based transport sector, hydrogen will primarily be used in hydrogen fuel cells in buses and rail, representing 4% of the total energy demand by 2050. The infrastructure build-out limits the uptake. For aviation and shipping, it is assumed that hydrogen derivatives will meet only 1% of the energy needs due to technological and economic barriers, with fossil fuels and biofuels maintaining dominance in these areas.

By 2050, buildings are projected to represent about 23% of the total hydrogen demand; countries that lead this have a poorer housing stock where heat demand is currently met with natural gas.

*Some biofuels such as HVO and HEFA-SAF will also have a hydrogen demand; this is counted under industrial demand.

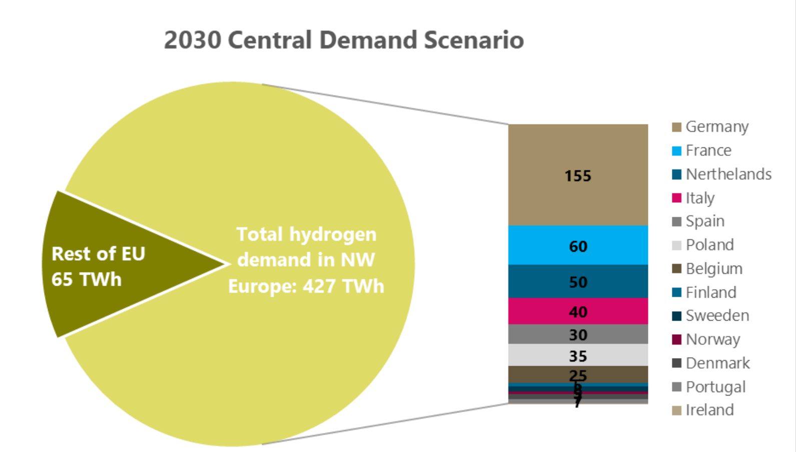
The report does not present further details or rationality behind the number and percentages shown in the report.

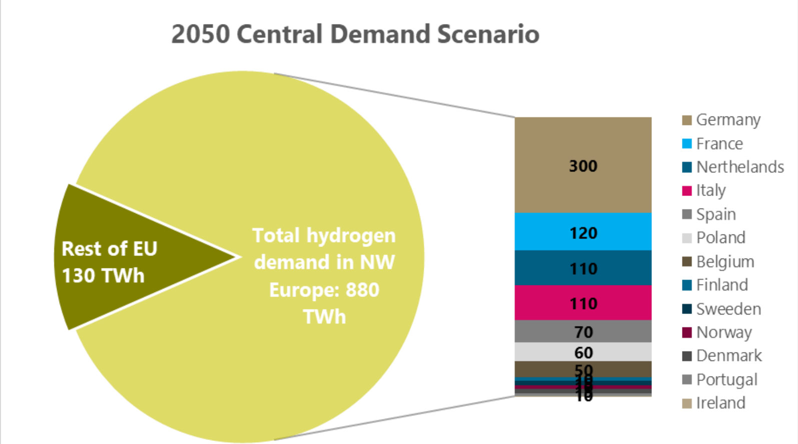
Aurora Energy Research – Central Demand Scenario

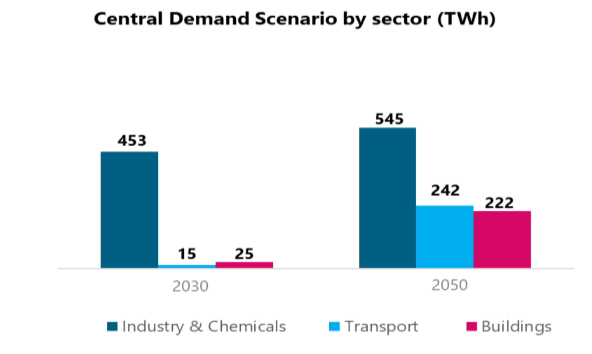
Hydrogen demand is projected to **increase by 50% by 2030** compared to current levels, proliferating as the EU continues its transition to a decarbonised energy system. By 2050, hydrogen is projected to account for approximately 11% of the EU's total energy demand.

Aurora Central Demand Scenario

Based on the report, the current demand for hydrogen in the EU stands at 313 TWh/y, primarily utilised for refineries and ammonia production. Hydrogen demand would reach 492 TWh in Aurora's central demand scenario in 2030, increasing by 2050 to 1010 TWh.







The central scenario suggests a moderate hydrogen demand across the economy, with some policy incentives in place but still a slower pace of technology improvements and infrastructure build-out compared to the high-case scenario.

Note: The report shows data for specific EU countries including Belgium, Denmark, Finland, France, Germany, Italy, Ireland, Netherlands, Norway, Poland, Portugal, Spain and Sweden. The remaining EU hydrogen demand is grouped as the rest of the EU.

In the central scenario, 92% of hydrogen demand in 2030 comes from the industry and chemical sectors, reflecting the current usage of hydrogen as a feedstock. It is considered that the infrastructure needed for the widespread adoption of hydrogen in transport and buildings is not expected to be rolled out by 2030. This includes refuelling stations for hydrogen vehicles and the retrofitting of gas networks to handle hydrogen for buildings.

In 2050, hydrogen will continue to play a role in the industry; however, transport and buildings account for nearly 50% of the EU's hydrogen demand. In the long term, infrastructure development, competitive hydrogen-based technologies, and policy frameworks will enable widespread hydrogen uptake in these sectors.

Hydrogen demand in transport will reach 23% in 2050 as technology for hydrogen fuel cells matures, and hydrogen becomes more economically competitive in heavy goods and mass transit.

The building sector is predicted to reach 22% of total hydrogen demand, predominately in countries that currently rely on natural gas, where it is more feasible to switch to hydrogen due to the existing gas network infrastructure. The electrification of buildings prevails due to the efficiency of technologies like heat pumps and the ongoing developments in district heating systems.

The report does not present further details or rationality behind the number and percentages shown in the report.

*Some biofuels such as HVO and HEFA-SAF will also have a hydrogen demand; this is counted under industrial demand.

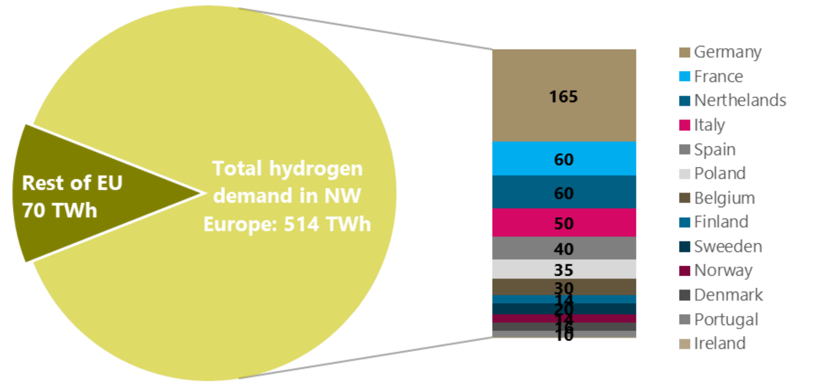
Aurora Energy Research - High Demand Scenario

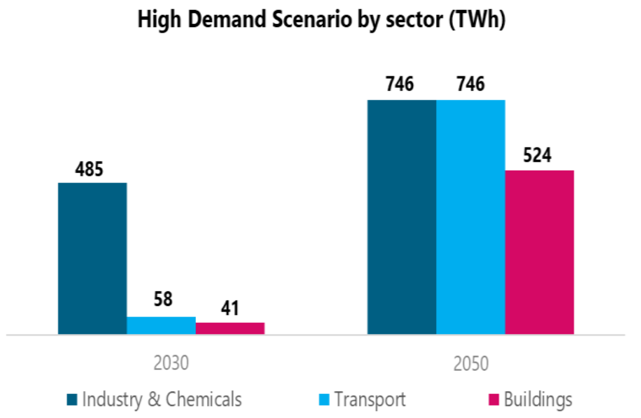
Hydrogen demand is projected to **increase by 75% by 2030** compared to current levels, proliferating as the EU continues its transition to a decarbonised energy system. By 2050, hydrogen will be a central part of the energy mix.

Aurora High Demand Scenario

Based on the report, the current demand for hydrogen in the EU stands at 313 TWh/y, primarily used in refineries and ammonia production. Hydrogen demand would reach 584 TWh in Aurora's high demand scenario in 2030, increasing by 2050 to 2015 TWh.

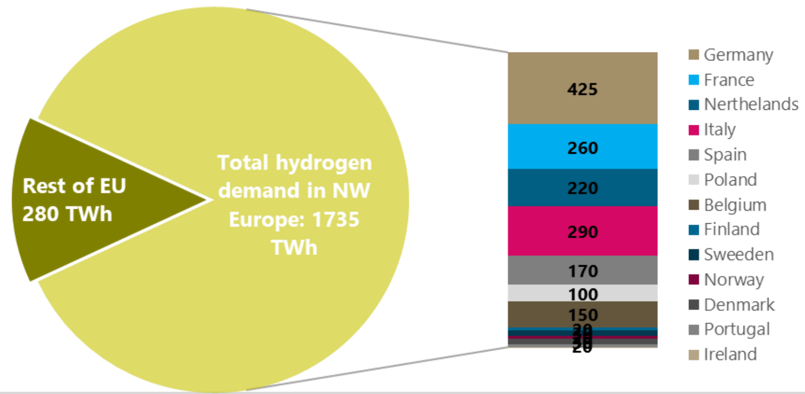
2030 High Demand Scenario





Under this scenario, 95% of the industry sector will be decarbonised through the use of hydrogen by 2050. Economies of scale will make hydrogen a more economically viable option. This includes the creation of hubs, improvements in the production, storage, and transportation of hydrogen, as well as reductions in the cost of production.
Additionally, there will be stronger decarbonisation actions across all sectors, policy interventions, and economic incentives, such as sector-specific Carbon Contracts for Difference (CCfDs) and demand mandates.
Hydrogen will become a major energy source for buildings across Europe, especially in countries where buildings are predominantly met by natural gas, providing 32% of overall building heating demand.

2050 High Demand Scenario



Assuming a more effective resolution of the barriers to hydrogen adoption in the transport sector, hydrogen is predicted to provide 34% of energy for land-based transport by 2050. This scenario envisions notable technological advancements in hydrogen technologies, particularly for heavy-duty vehicles and mass transit systems. Moreover, it is projected that 20% of energy in shipping and aviation will come from hydrogen derivatives by 2050, driven by advancements enabling efficient production and utilisation of these derivatives, including hydrogen-based fuel engines and turbines.

The report does not present details about the rationality behind the numbers and percentages shown.

Note: The report shows data for specific EU countries including Belgium, Denmark, Finland, France, Germany, Italy, Ireland, Netherlands, Norway, Poland, Portugal, Spain and Sweden. The remaining EU hydrogen demand is grouped as the rest of the EU

*Some biofuels such as HVO and HEFA-SAF will also have a hydrogen demand; this is counted under industrial demand.

Aurora Scenario Findings Summary

Low Case

- Hydrogen is expected to play only a small part in meeting overall energy demand in the EU by 2050. The primary driver of hydrogen demand is its use in industrial sectors. This assumption stems from the existing demand in the industrial sector, which is considered challenging to decarbonise solely through electrification due to technical and economic constraints.
- Hydrogen demand in the transportation and building sectors is only expected to be small. By 2050, industry is expected to account for 66% of the total hydrogen demand.
- Just ~4% of surface transport's total energy demand is expected to be met by hydrogen, dominated by use in buses and rail, owing to the slow build-out of the required infrastructure. For shipping and aviation, hydrogen demand (via ammonia and synthetic fuels) is expected to supply just 1% of the energy owing to a lack of investment by the sector, with fossil fuels and biofuels dominating.
- The adoption of hydrogen for buildings is expected to increase gradually as the infrastructure takes time to develop. By 2050, hydrogen is estimated to represent 8% of total heat demand (23% of the total hydrogen demand), with electrification prevailing.

Central Case

- Aurora's central scenario also sees hydrogen demand being driven in 2030 by its use in industrial sectors, representing 54% of hydrogen demand.
- Increased infrastructure build-out, government mandates, and investment will increase hydrogen demand from the transport sector.
- As in the low scenario, heat in buildings is expected to be predominately met through electrification. Hydrogen demand in buildings increases slowly, reaching 12% of total heat demand in 2050.

High Case

- The Aurora high-demand scenario expects significantly increased demand for hydrogen, especially within the transport sector.
- In 2050, hydrogen demand in the industry and transport each represents around 37% of the forecasted demand, while for buildings, it is about 26%.
- In land-based transport, hydrogen use is expected to meet ~34% of the total energy demand. Hydrogen derivatives use also significantly increases in aviation and shipping, meeting 20% of all energy.
- Hydrogen demand in buildings is now expected to represent 32% of overall heating demand, directly replacing natural gas demand, especially in North-Western Europe. This would require significant policy decisions to enable.

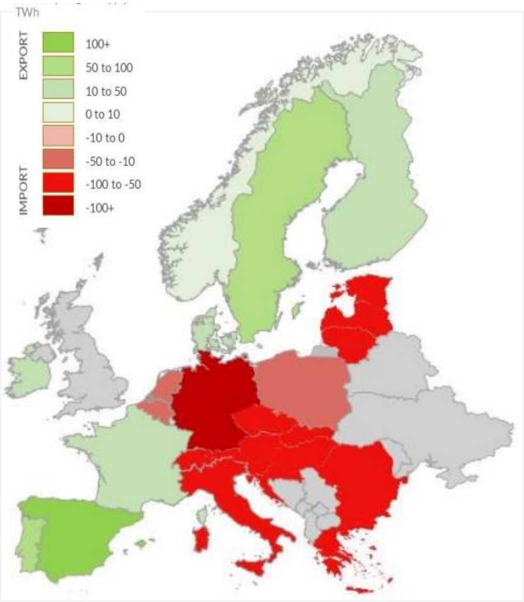
Aurora Energy Research – Imports & Exports Analysis

AURORA ENERGY RESEARCH

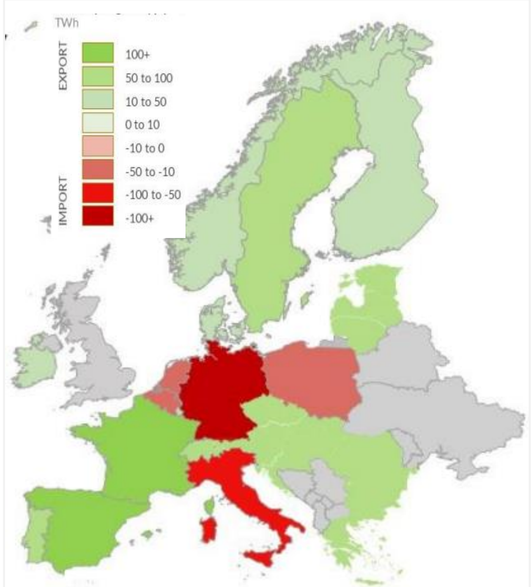
The report on hydrogen scenarios does not analyse hydrogen production within Europe in detail, nor the potential need for imports. Key considerations are highlighted:

The volumes of green hydrogen that could be produced from additional renewable capacity will not be sufficient to meet the central demand forecast, resulting in a supply gap which would hamper decarbonisation efforts and increase the EU's reliance on imports. **The EU has a net deficit of 69 TWh in 2050 if only new-build RES is used for hydrogen production (central demand scenario basis).**

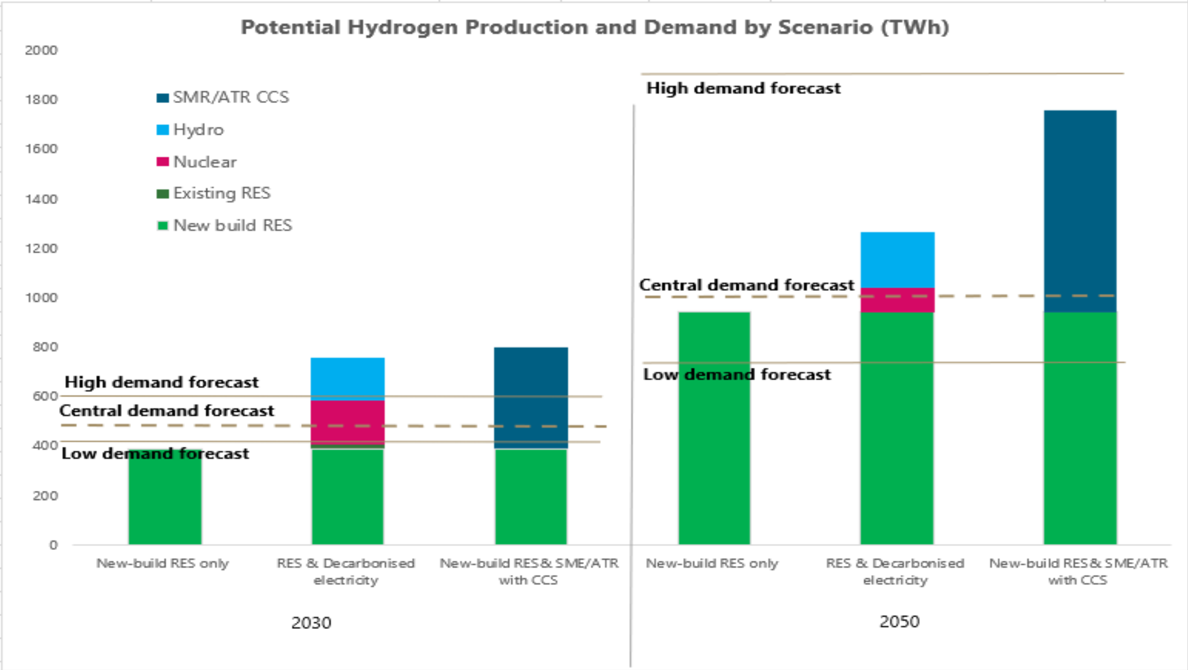
By allowing all forms of renewable and decarbonised electricity (e.g. nuclear) and including blue hydrogen production, the EU could produce enough hydrogen to meet demand in both 2030 and 2050 scenarios, avoiding imports and reliance on fossil-fuel derived hydrogen. (**A net surplus of 253 TWh in 2050 – central demand scenario**).



2050, Hydrogen supply – hydrogen demand, New-build RES only (TWh)



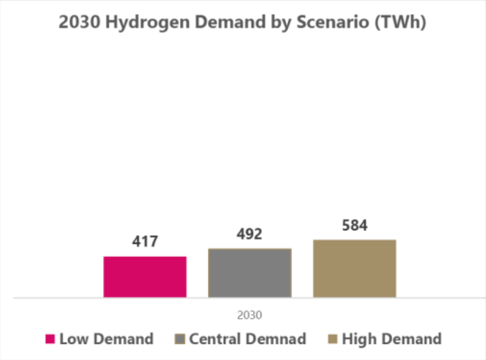
2050, Hydrogen supply – hydrogen demand, RES & Decarbonised electricity (TWh)

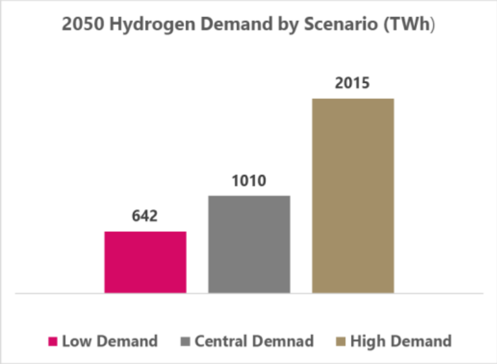


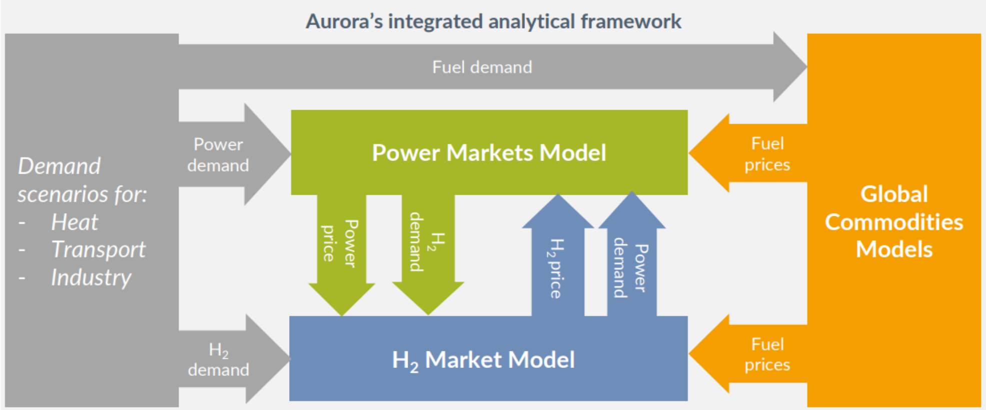
High Level Insights

Key Northern European countries which are seeing hydrogen demand are Germany, France, Netherlands, and Belgium.

- **In each scenario, demand** is expected to be **met by local production** within Europe using renewable and decarbonised electricity; however**, only if all forms of renewable and decarbonised electricity are considered** (not restricting hydrogen supply to production from additional new-build renewables only).
- The scenarios make clear that hydrogen demand in regions without a strong potential for offshore wind, such as those found in the North Sea, will require supplementary provision from either non-renewable based hydrogen or importing.
- Industrial decarbonisation is the base market, and Aurora sees transport as the swing market between the scenarios. We would suggest that the industrial market would be more likely to be served by volume through a pipeline network and, therefore, more likely to see early adoption of imports through a pipeline/port network. A distributed hydrogen network for land transport is more likely to serve surface transport due to the expense of transporting hydrogen away from the potential future pipelines.
- These scenarios were published before the invasion of Ukraine, the creation of ReFuelEU, and the increased geopolitical tension between the US and China. Without being able to interrogate the data, especially around natural gas switching, the impact of these events on the scenarios cannot be thoroughly analysed. However, this will likely increase renewable penetration and electrification to the detriment of hydrogen, especially in the heating sector.







Details on Aurora's approach to hydrogen scenarios can be found in the report on Hydrogen in the GB energy system: auroraer.com

European Hydrogen Backbone Report Overview

- **In 2021, the European Hydrogen Backbone group published a detailed analysis on future demand,** supply, and hydrogen transport across Europe. The report is a collaboration with Gas for Climate and is supported by Guidehouse.
- The report "Analysing the Future Demand, Supply, and Transport of Hydrogen" was produced under the European Hydrogen Backbone (EHB) initiative, a collaboration of European gas Transmission System Operators (TSOs) focused on developing a dedicated hydrogen infrastructure across Europe, primarily through repurposing existing natural gas pipelines.
- The report is focused on Europe and addresses the future role of hydrogen in helping Europe transition to a climate-neutral continent by mid-century.
- While the report does not explicitly state the current hydrogen demand in Europe, it details projections for the future hydrogen demand by 2030 and 2050.
- **Projected Demand for 2030:** 340 TWh
- **Projected Demand for 2050:** 2300 TWh
- The report identifies several drivers for the increased demand for hydrogen:

- **Steel Sector and Fuel Production**: There has been an increase in hydrogen demand in the steel sector and for fuel production.
- **Transport Sector**: In the transport sector, hydrogen plays a role as a fuel, alongside electrification and biofuels.
- **Synthetic Fuels in Aviation**: Additional hydrogen will be required to produce synthetic fuels in aviation.

The report provides a breakdown of hydrogen demand by sector for both scenarios, including hydrogen demand in transport, industry, power, and buildings.

The assumptions underpin the report’s projections for hydrogen demand include key input assumptions uniformly across the analysed countries in each relevant demand sub-chapter (industry, transport, power, and buildings). For the transport sector, a bottom-up analysis determines the total EU+UK energy demand pathway for heavy road transport and aviation.

European Hydrogen Backbone Policy Overview

The EHB report mentions several government supports and policies for hydrogen uptake in the industry, along with the sectors where these policies will be applied:

- **European Commission's Strategic Objective for Green Hydrogen**: The European Commission has set a strategic objective to install at least 40 GW of green hydrogen electrolysers by 2030 and produce up to 10 million tonnes of green hydrogen in the EU. This policy is vital for scaling up green hydrogen, which is expected to substantially contribute to climate change mitigation.

- **Transport Sector Policies**: There is a focus on deploying Fuel Cell Electric Vehicles (FCEVs), along with adopting hydrogen in rail and shipping. Supporting measures include zero-emission vehicle mandates, internal combustion engine (ICE) bans, direct purchase subsidies, and low-carbon fuel standards.

- **Power Generation Sector**: In the power generation sector, hydrogen has short-term limited potential due to high costs and low efficiencies. However, it can be used to generate carbon-free peak load electricity. The realization of this potential depends on the adoption of supporting policies and regulations.

EHB – Methodology & Assumptions

EHB Scenario

EHB assessed the demand for hydrogen in combination with insights from prior studies commissioned by a third-party consultancy.

The **Quantitative scenario** is built using **demand** projections per sector **estimated using NUTS 2** (Nomenclature of Territorial Units for Statistics) and country-level and aggregated to EU and UK-wide levels.

Analysis was carried out using **bottom-up, geography- and sector-specific analyses alongside top-down estimations, applying homogeneous assumptions** across the analysed countries.

In its analysis, the **Quantitative EHB scenario** considers a **range of technologies and decarbonisation options for each sector**. For instance, industry will be decarbonised using mainly H_2 and CCUS, whereas electrification and biofuels are the main options for transport. Biomethane, hydrogen, and a mix of heating technologies play a part in buildings, and hydrogen demand can be expected to be required in dispatchable electricity production.

Industry

Industry: The methodology was based on a bottom-up analysis of sector-specific future hydrogen demand in fuels, high-value chemicals, ammonia, and iron and steel.

- Company announcements, sector decarbonisation roadmaps and interviews with relevant stakeholders informed the bottom-up pathway.
- The hydrogen demand for industrial process heat is based on a top-down analysis of areas that are hard to electrify.

Transport

Transport: The methodology was based on the IEA MoMo model to estimate annual distance travelled and energy consumption. Technology share assumptions are based on the Gas for Climate 2020 Pathway Study (which doesn't account for the recent geopolitical changes), company announcements and literature.

- Unlike other reports, no hydrogen derivatives are expected to be used in shipping; electrification and bio-LNG are the preferred routes.
- Hydrogen use in surface transport will be limited to long-haul trucks and buses; rail is not discussed. The extent of hydrogen's role depends on the development of technology, infrastructure, and competitiveness of alternative fuels.
- In aviation, hydrogen-based fuels have been identified as a main route to decarbonise the sector.

Power

Power: The analysis of hydrogen demand for the power system was based on ENTSO-E's TYNDP 2020 Scenario Report and the Gas for Climate 2020 'Gas Decarbonisation pathways study'. It assumes that the EU electricity system in 2050 will be powered by 6% nuclear power and 84% renewable sources, of which 15% are solar, 50% are wind, 13% are hydropower, and 6% are other renewables. This leaves 10% to be supplied using flexible, dispatchable generation technologies, including renewable gas turbines and fuel cells.

- The report outlines the share of gas generation assumed to be replaced by hydrogen—1% by 2030, 35% by 2040, and 70% by 2050—taking into account a hydrogen-to-power efficiency of 50%. These assumptions reflect an expectation of a gradual increase in the use of hydrogen for power generation, with a significant ramp-up by mid-century as part of the broader transition to a decarbonised gas sector.

Buildings

Buildings: Analysis for this sector included assumptions on estimated fuel share mix per EU country, considering two sub-scenarios under energy energy-related renovation approach (light, medium and deep scenario).

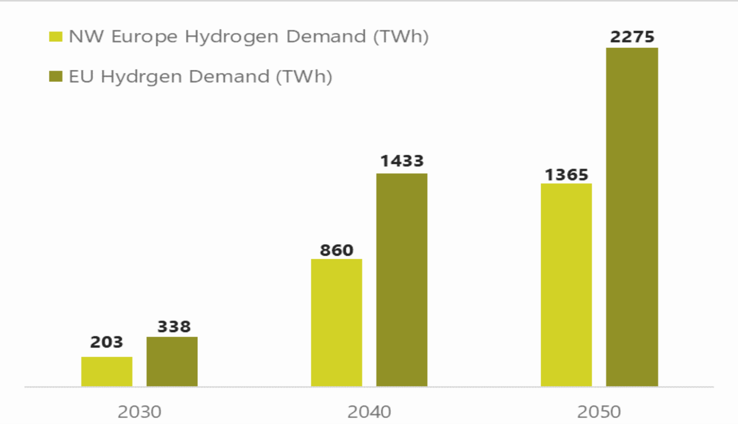
- The hydrogen demand depends on the relative shares of biomethane and hydrogen, the mix of building technologies and the renovation rates. The renovation rates relate to the pace at which existing buildings are upgraded or retrofitted to improve their energy efficiency and incorporate new technologies that can use hydrogen for buildings.
- Some (gas) DSOs see hydrogen as an option for buildings of buildings, including 100% hydrogen boilers, e.g. in the UK, the Netherlands, and Germany. In some areas, a choice for hydrogen could mean that biomethane would not be available.
- H_2 can be deployed in three places: Hybrid heat pumps, district heating and 100% hydrogen boilers in areas where it is expected that the gas in the distribution grid will be replaced by hydrogen within the lifetime of a boiler.

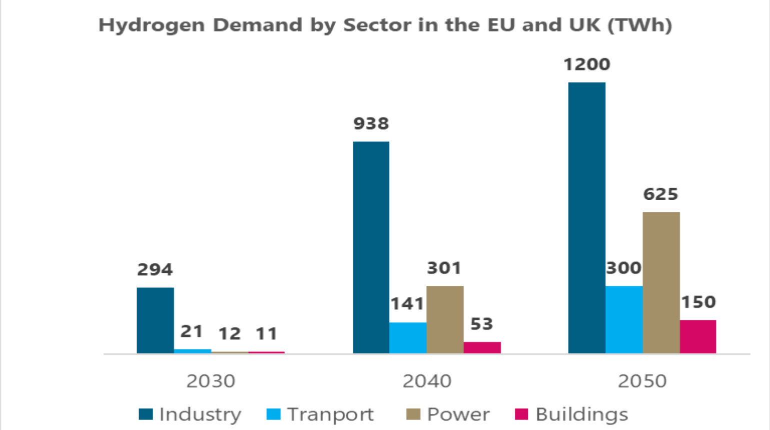
European Hydrogen Backbone (EHB)

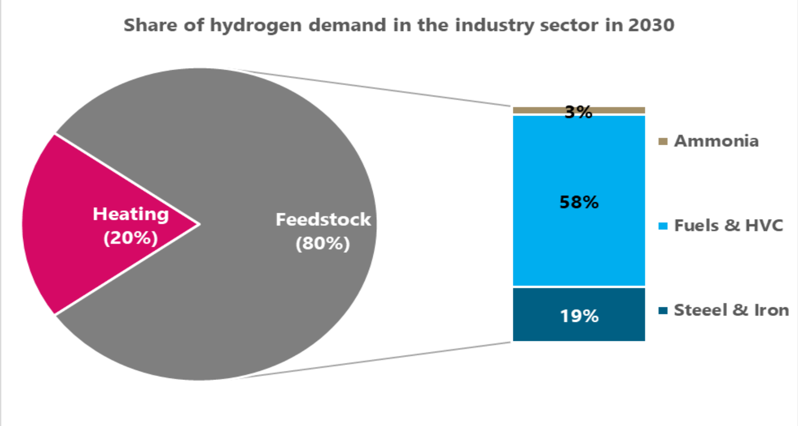
EHB initiative is a group of European Gas Transmission System Operators (TSOs). EHB developed a single scenario. This study explores the future role of hydrogen in enabling Europe to become a climate-neutral continent by developing the hydrogen backbone (infrastructure needed to operate the nascent hydrogen market).

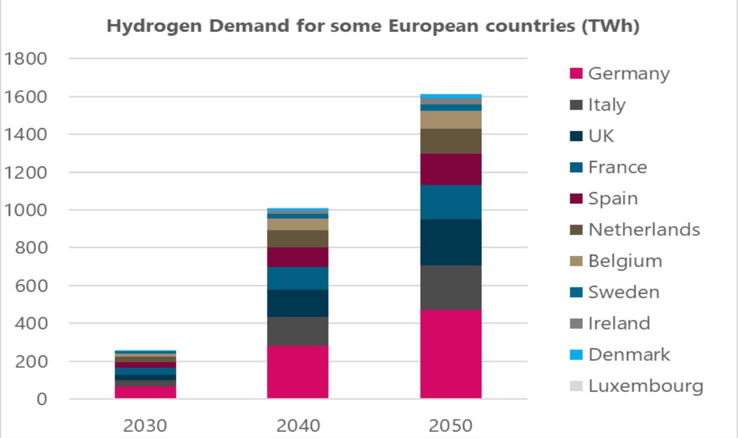
EHB Scenario

EHB scenario on future hydrogen demand across the EU and UK concludes that demand can be around 340 TWh in 2030 and 2300 TWh in 2050. It does not provide a figure for the current hydrogen demand.









Low-carbon hydrogen is crucial for industrial decarbonisation, particularly for iron and steel, ammonia, and fuel productions, where grey hydrogen is primarily used as feedstock. Hydrogen is also expected to replace natural gas in medium and high temperature industrial processes.

In EHB's scenario, hydrogen plays a dual role in power generation and energy storage from 2040 onwards. Gas-based technologies such as biomethane and hydrogen are anticipated to play a role in decarbonising the power sector. In the short term, hydrogen can be blended with natural gas in gas-fired turbines. Over time, these gas turbines are expected to transition to being powered by 100% hydrogen, which is anticipated to occur progressively, with significant impact expected post-2040.

The scope for hydrogen in transportation is mainly for use in heavy road vehicles and aviation since they are more challenging to decarbonise than passenger vehicles and short-range transportation modes, which can more readily use battery-electric solutions.

European Hydrogen Backbone Scenario Findings Summary

- EHB has built its scenario as the basis for developing a dedicated European hydrogen pipeline infrastructure – the hydrogen backbone. It considers repurposing natural gas pipelines to connect hydrogen demand clusters and regions with high renewable energy potentials cost-efficiently.

- The main NW European countries expected to have the **highest hydrogen demand are Germany and the UK**, **followed by France and the Netherlands**.

- The EHB Scenario sees a significant demand from the industrial sector – **87% of hydrogen demand in 2030** and **53% in 2050 comes from industry,** where hydrogen is primarily used as feedstock and hydrogen demand is located at the fuel production installations including chemicals as well as and new industrial hydrogen hubs such as around steel production and e-fuels production.

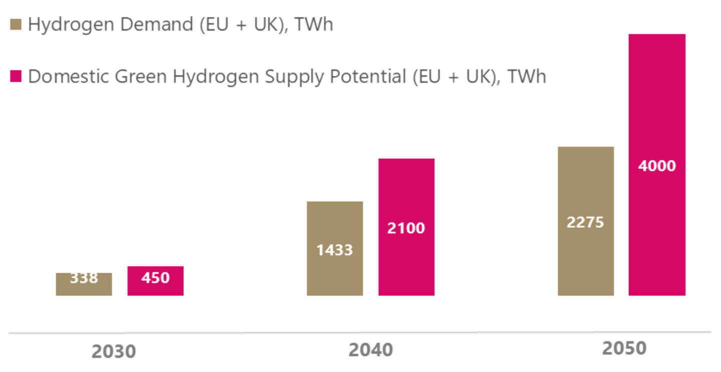
    - This is due to the model behind the scenario, including assumptions that green or blue hydrogen is the main decarbonisation option for ammonia, methanol and jet fuel (the hydrogen demand is associated with the industry sector rather than transport as seen in the other reports, this results in industry accounting for a high percentage of demand especially when compared to transport) as well as for hydrogen-based steel making.

- Within the **transport sector, which covers aviation and heavy road vehicles**, hydrogen direct use (as fuel) in 2050 is forecasted to **account for 13% of total transport energy demand**, powering 55% of trucks, 25% of buses, and 10% of aeroplanes (see note on jet fuel above).

- Overall demand is forecast to be addressed by local production and imports from neighbouring regions (North Africa, Norway, and potentially the Middle East) in the ramp-up phase to 2030.

EHB – Imports & Exports Analysis

According to EHB estimates, the EU and UK's potential for hydrogen supply could meet demand in 2030 and exceed final demand substantially by 2040 and 2050



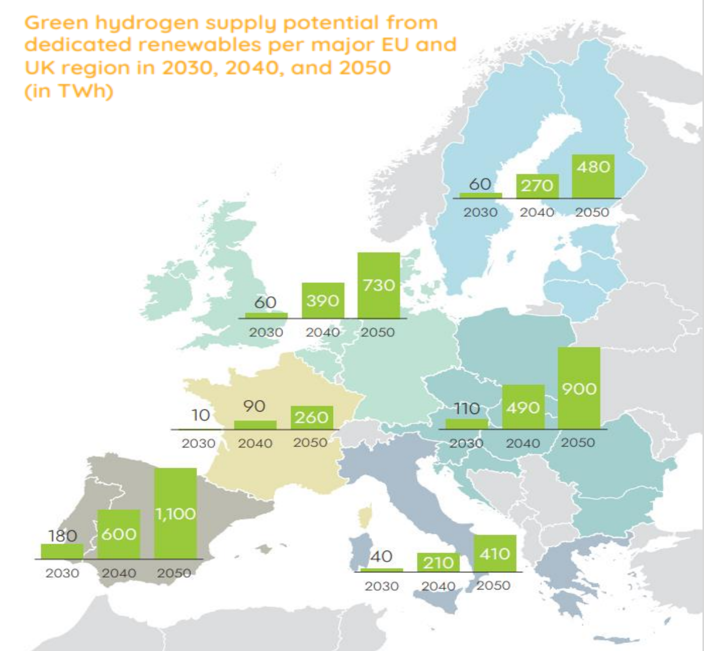
EHB analysis of potential green hydrogen production across the EU and UK shows that the region has a technical renewable energy potential to meet domestic demand. A renewable energy supply potential of around 11,100 TWh/year is estimated to correspond to approximately 5,600 GW (5.6 TW) of cumulative renewable installed capacity. This is translated from renewable energy supply potential to green hydrogen supply potential – taking into account the needs for electricity and conversion losses – in 2030, 2040, and 2050. It is assumed that hydrogen will be transported and stored cost-efficiently by developing the hydrogen backbone pipelines.

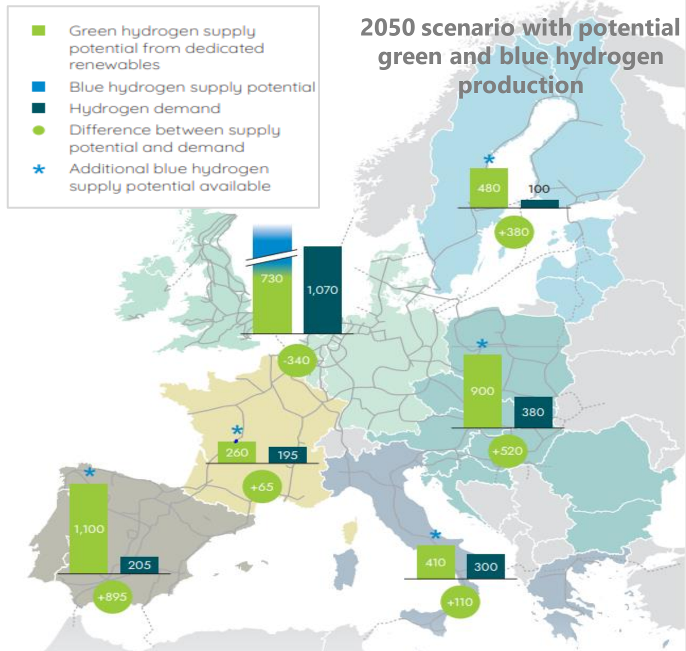
However, it is mentioned that realistic renewable power potential should consider land availability, minimum capacity factors and regulations.

It describes that in the ramp-up phase to 2030, **additional supply sources, including domestic blue hydrogen and** green hydrogen **imports** from neighbouring regions, **will be needed** to meet local and regional demand **without a fully interconnected European hydrogen backbone**.

EHB analysis shows the green and blue hydrogen supply potential across EU countries and the UK. This estimate considers final electricity demand, land availability, environmental regulations, and technology deployment rate.

Based on the EHB study, **developing a domestic hydrogen supply to meet demand within Europe might only be optimal in some circumstances due to practical, economic, and political** reasons. For example, it requires two times more renewable energy capacity to be built by 2030 compared to what is targeted in existing national climate and energy plans. Additionally, not all domestic green hydrogen supply potential—excluding policy support—will be cost-competitive with alternative decarbonised options (e.g. blue hydrogen). **EHB analysis shows that the supply-demand picture is highly country-specific;** some countries, such as Spain, have the potential to be in a renewable energy surplus, whereas others are likely to find themselves in a deficit and will likely need to import (e.g. Germany).





High Level Insights

- The EHB scenarios and research are updated relatively frequently using publicly accessible information, marking this as a very different class of published scenarios compared to the others covered in this report. This ability to interrogate the data behind the scenarios is critical to assessing the veracity of the findings.

- As with the other scenarios covered, this is not without bias. As the group behind the EHB is primarily the gas network operators, it is an understandable assumption to make that this would show the value add of hydrogen pipelines. But the corollary to this statement is that there is no other pan-European hydrogen transport option apart from pipelines.

- The overall demand numbers align with policy in the early phases and seem to align with the EU Climate Law by the middle of the century.

EU JRC TIMES Overview

- The Joint Research Centre of the European Commission created the JRC TIMES scenario as part of various policy support activities.
- The report focuses on the European Union and covers various aspects of hydrogen use. It refers to a Net Zero scenario, with the EU reaching carbon neutrality by 2050. The TIMES model on future hydrogen demand across the EU estimated the predicted hydrogen demand in 2030, 2040 and 2050.
- **Projected Demand for 2030:** 230 TWh
- **Projected Demand for 2040:** 900 TWh
- **Projected Demand for 2050:** 1270 TWh
- The report indicates that the increased demand for hydrogen is primarily driven by its use in producing refined oil products and fertilisers.
- The report provides a breakdown of hydrogen demand by sector, including transport, industry, power, and buildings. The report does not provide information on hydrogen trade flows.
- The report's assumptions to predict hydrogen demand focus on the infrastructure and energy sources needed to produce hydrogen.

EU JRC Policy Overview

- The JRC Global Energy and Climate Outlook does not provide specific details on the exact policies considered or the sectors where they will be applied. However, the report does mention government support and policies related to the uptake of hydrogen in industry.

- The report states that while many countries have announced hydrogen strategies, only a few have actually implemented policies to incentivize increased hydrogen demand or supply. This cautious approach is attributed to the significant uncertainty surrounding the role of hydrogen and its derivative fuels in the global energy market.

- The report suggests that the renewable potential in different world areas will be a key factor in determining the new patterns of energy trade, which will affect industries, services, transportation, and households globally.

JRC EU TIMES – Methodology & Assumptions

JRC Scenario

The JRC-EU-TIMES model provides one scenario and **is a linear optimisation bottom-up technology model** generated with the TIMES model generator of the International Energy Agency.

The model helps understand the role of energy technologies and their innovation needs for meeting European policy targets related to energy and climate change.

The model covers the energy system of the EU 28 and neighbouring countries from 2010 to 2070.

The model's algorithm simultaneously solves for the optimum investment portfolio of energy technologies and their operation.

The full methodology is not accessible within the report on *the role of hydrogen in energy decarbonisation scenarios and could not be found in the public domain.**

Industry

It is projected that there will be a reduction in industrial energy consumption of 9% in 2030. In 2050, industrial energy demand is expected to decrease by 10%.
This scenario sees a rapid increase in electrification to decarbonise industry, and it is expected that bioenergy consumption in the EU's industrial energy demand will be lower than in 2019 (11% in the final demand in 2019) by 2050.
Hydrogen will compete with bioenergy and fossil fuels with CCS across industrial subsectors.

Transport

There will be a reduction in energy demand in the transport sector under this scenario.

Assumptions are based on the uptake of renewable alternatives, with 30% of the total energy demand in the transport sector being met by electricity by 2050. Hydrogen accounts for 36% of energy demand, bioenergy for 16%, fossil fuels for 16%, and e-fuels for 2%.

The shipping and aviation sectors are not analysed in detail.

Power

This scenario does not see any role for hydrogen in power generation and no basis/assumptions were available to help understand the rationality behind this.

Buildings

There is no role for hydrogen in the building sector under the JRC EU TIMES scenario. It assumes a decrease in total energy demand in the EU buildings sector.

As the share of fossil fuels reduces, the drive to decarbonise will increase electricity demand in the building sector. Electricity amounted to 32% of the total energy supply in the sector in 2020. By 2030, its share will increase to 45%. Projected electricity usage would reach 1847 TWh in JRC TIMES by 2050 (a 33% increase compared to 2020).

JRC Publications Repository - The role of hydrogen in energy decarbonisation scenarios (europa.eu)

EU JRC TIMES Scenario

EU JRC (European Commission Joint Research Centre) is the Commission's science and knowledge service that provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society. It has developed a single scenario.

JRC TIMES Scenario

JRC TIMES scenario was created by the Joint Research Centre of the European Commission as part of various policy support activities.

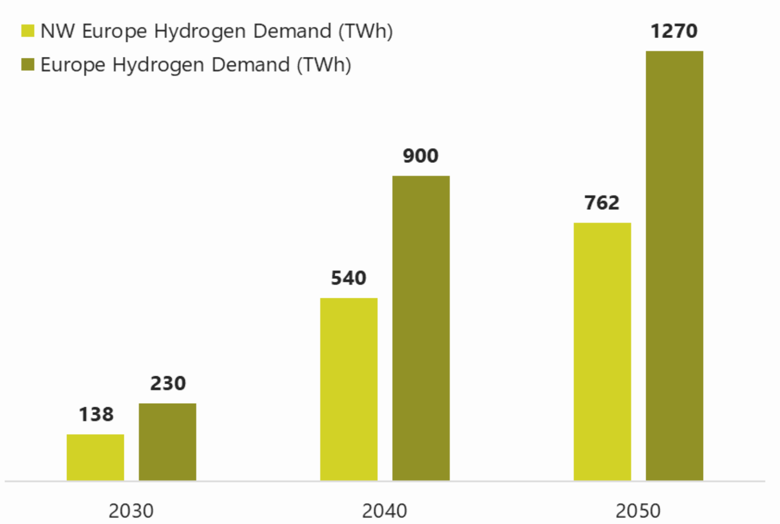
In 2021, the JRC EU TIMES model was released into the public domain after some updates. Although the publication is from 2021, its **model was created in 2019;** therefore, it doesn't account for increased ambition or recent geopolitical events.

It refers to a Net Zero scenario, with the EU reaching carbon neutrality in the EU by 2050.

JRC-EU-TIMES is a model that represents all sectors of the energy system of the EU28 and neighbouring countries: **buildings, transport, industry, power and agriculture**. The JRC-EU-TIMES model produces projections (or scenarios) of the EU energy system, showing its evolution up to 2060 under different assumptions and constraints.

Note: This report does not analyse hydrogen production or imports**.**

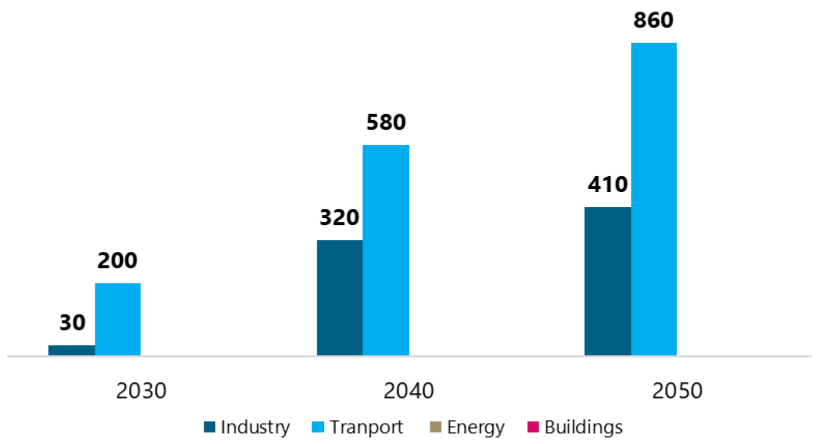
JRC TIMES scenario on future hydrogen demand across European Union shows demand can be around 230 TWh in 2030 and circa of 1270 TWh in 2050.



JRC EU TIMES scenario sees a role for hydrogen in the EU's projected fuel mix by 2030 onwards, with demand reaching 1270 TWh in 2050. **Hydrogen and its derivatives, such as e-fuels and ammonia are responsible for 2.6% of the energy used under this scenario by 2030** (~ 7 million tonnes or 230 TWh). The JRC TIMES scenario does not see any role for hydrogen in power generation and building sectors.

Transport and industry will be the two main EU sectors in which hydrogen will be used. In transport, hydrogen demand increases from 200 TWh in 2030 to 860 TWh in 2050. In this scenario, low carbon hydrogen demand in the industry will slowly increase in the EU (below 1 million tonnes) by 2030; however, it dramatically increases in the 2030s.

Hydrogen Demand by Sector in the EU Sectors (TWh)



The report does not detail the rationality behind this scenario.

**Report gives values for Europe – the assumption that NW Europe's hydrogen demand is 60% of Europe's total demand gives data for NW Europe demand.*

EU JRC TIMES High Level Insights

- **Under the JRC TIMES scenario**, energy demand in power and buildings is met mainly by renewable electricity, and thus **hydrogen does not play a significant role in power generation or buildings; the** report does not provide any justification.

- Based on the JRC TIMES scenario**, hydrogen plays a vital role along with electrification in the transport sector**, although there will be an energy reduction, particularly in road transport. **Hydrogen use in the industry sector** is expected to roll out slowly, **increasing rapidly in the 2040s**.

- The projections under the JRC Energy scenario consider the impact of macroeconomic, fuel price, and technology trends and policies on the evolution of the EU energy system, transport, and greenhouse gas (GHG) emissions.

JRC Energy Scenario – Methodology & Assumptions

Energy JRC Scenario

The data presented in this scenario is based on the latest projections elaborated by the European Commission, particularly the EU Reference Scenario 2020. **It builds upon the logic of the MIX scenario as included in the impact assessment supporting the 2030 Climate Target Plan**, but is based on the updated Reference scenario as a baseline.

MIX scenario refers to one of the three core policy scenarios that EU JRC produced to serve as standard tools for analysis across the impact assessments of various initiatives of the Green Deal Policy Package, relying on both carbon price signal extension to road transport and buildings and substantial intensification of energy and transport policies.

No assumptions were available to help understand the basis for these scenarios.

The full methodology is not accessible within the report, nor could it be found in the public domain.

It does not provide any analysis of production or imports.

Industry

Industry includes iron and steel, cement, glass, chemicals, petrochemicals, the production of plastics (non-energy uses), food and paper, agriculture, forestry and fishing**.**

- 2030 scenario: Use of coal and waste is reduced by 40% compared to 2019. There is an increased use of decarbonised electricity.
- 2050 Scenario: Coal and waste are no longer used. Electrification and hydrogen use are measures to decarbonize the sector.

Transport

Total energy use in transport includes all types of transport (road, air, water), including energy for international aviation and shipping.

- 2030 scenario: The EU use of fossil oil is reduced by 25% compared to 2019. The EU's use of electricity in transport is almost triple.
- 2050 Scenario: There is a large reduction in the use of fossil oil and a considerable increase in electrification. Hydrogen and e-fuels are almost entirely used by trucks, aviation and maritime.

Power

The power sector includes the energy needed to produce and distribute electricity, district heating, hydrogen and e-fuels (derived from electricity), gasoline, diesel, kerosene and advanced biofuel. Refineries are included in the energy industry.

- The 2030 FF55 MIX scenario is based on the assumption that the use of coal and waste is reduced by 65% compared to 2019, and in 2050, coal, waste, and fossil oil will no longer be used.

Buildings

In the buildings sector, the final energy use includes all heating (residential, commercial and public services). It includes energy for space heating, hot water, lighting and other appliances.

- 2030 scenario: Coal and oil-based heating are already marginal in 2030. EU gas use is reduced by 35% compared to 2019. The main renewable alternatives are renewable electricity and biofuel (e.g., biomethane).
- 2050 scenario: Fossil fuels are not used for heating and cooling. Final energy is reduced by 27% compared to 2019.

JRC Energy Scenario

EU JRC launched (2021) a new tool to explore the future of European energy. This is a single scenario with a 2030 and 2050 timeframe. Note that it is an online tool and there is no report published with further details.

Energy JRC Scenario

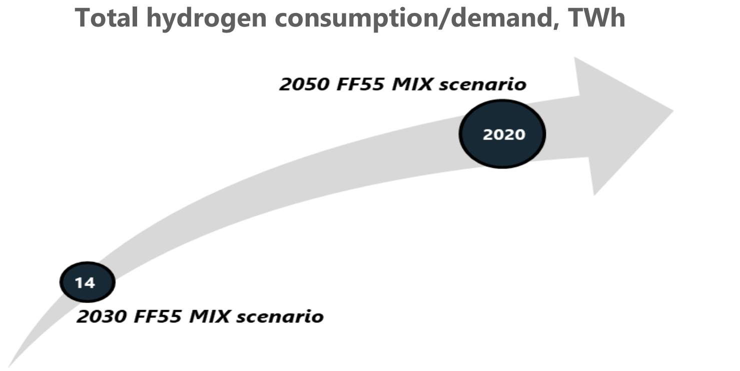
The JRC has launched an online tool to compare current energy consumption and sources with several future scenarios.

It is a normative energy mix scenario which is available in the public domain at JRC Energy Scenarios (europa.eu)

The tool shows **the 2030 FF55 MIX** scenario, in which **EU achieves net 55%** GHG emission reduction by 2030 compared to 1990, **and the 2050 FF55 MIX** scenario, in which **EU achieves the net zero objective for 2050**.

This policy scenario shows EU energy consumption in the future with the current policies (2019-2021) and what is needed – both in terms of energy efficiency and renewable energy sources – to meet the 55% reduction target taking into account the Fit for 55 Package.

JRC Energy scenario on future hydrogen demand across European countries shows demand can be around 2020 TWh in 2050.



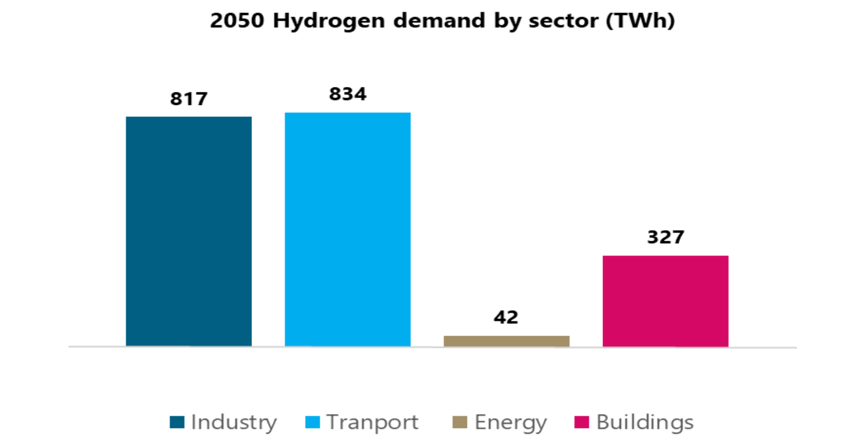
Based on JRC's 2030 scenario, hydrogen and e-fuels are used only in transport sector in 2030, accounting for a hydrogen demand of 14 TWh. Renewable energy targets are mostly met by using biofuels and electrification.

In the 2050 scenario (2050 FF55 MIX scenario) achieves the net zero objective for 2050 and EU hydrogen demand reaches 2020 TWh. According to the 2050 outlook, there will be a hydrogen demand in NW Europe countries of around 1200 TWh.

In the 2050 policy MIX scenario, hydrogen plays a role across the different sectors: transport, industry and buildings.

A similar demand for hydrogen and its derivatives in 2050 (around 800 TWh) is seen within the EU industry and transportation sectors. Within these two sectors, electrification also is a significant decarbonisation option.

Hydrogen will account for 21% of the EU industrial energy demand. In the transport sector, hydrogen will be used in heavy vehicles (trucks) as well as in the aviation and maritime sectors.



The report does not detail the rationality behind this scenario.

JRC Energy High Level Insights

- There will be an anticipated minimal low carbon hydrogen demand across all sectors by 2030 under the JRC Energy Scenario, with a significant increase by 2050.

- JRC Energy Scenario is a policy-based scenario that seems not to have been updated and aligned to recent policy proposals such as the RePowerEU Plan (published in 2022) targeting 10 million tonnes (~ 330 TWh) per year of green hydrogen by 2030, coupled with renewable hydrogen imports of the same magnitude by 2030.

- As the scenario is not updated, it does not align with the expected demand for green hydrogen in industries subject to specific targets outlined in REDIII. These targets aim for a 42% transition from grey to green hydrogen in the industrial sector.

Hydrogen Council Report Overview

- The Hydrogen Council produced the "Hydrogen for Net-Zero" report in collaboration with McKinsey & Company.
- The report has a global focus, addressing the role of hydrogen in achieving net-zero emissions worldwide while also providing European demand.
- The current global hydrogen demand is estimated to be around 3000 TWh in the report and is predicted to be about 21780 TWh by 2050, constituting about 22% of the world's final energy demand.
- **Predicted European hydrogen demand by 2030:** 660-825 TWh
- **Predicted European hydrogen demand by 2040:** 1780-2145 TWh
- **Predicted European hydrogen demand by 2050:** 3050-3300 TWh
- The report mentions several drivers for the increase in hydrogen demand:
  - **Regulatory Incentives:** including carbon pricing, tax credits and blending mandates making clean hydrogen more economically viable and competitive.
  - **Supportive Policy Environment:** In Europe, a more supportive policy environment is expected to be implemented, which will likely accelerate the phase-out of grey hydrogen, resulting in a larger share of clean hydrogen demand.
  - **Decarbonisation Goals:** The main reason for employing hydrogen in new use cases, such as mobility and steelmaking, is to achieve decarbonisation goals. The report emphasises the importance of not meeting these new demands with grey hydrogen, highlighting the need for clean or green hydrogen solutions to ensure environmental sustainability.
- The report provides a breakdown of hydrogen demand by sector, including hydrogen demand in transport, industry, power and buildings.
- The assumptions behind the hydrogen demand predictions include Hydrogen's ability to complement other decarbonisation technologies in achieving net-zero emissions by 2050. Hydrogen can potentially contribute to 20% of the total CO_2 abatement needed by 2050. The scalability and cost-effectiveness of hydrogen for deep decarbonisation in hard-to-abate sectors.

Hydrogen Council Policy Overview

The uptake of hydrogen in various industrial sectors is heavily reliant on policy support and incentives. The report "Hydrogen for Net-Zero" details how policy plays a critical role in different sectors:

- **Policy-Driven Conversion**: High carbon prices combined with incentives can lead to a conversion of up to 50% of current grey hydrogen capacity to clean hydrogen. Examples include RED II/RED III in Europe.
- **Role of Governments in Accelerating Hydrogen Deployment**: Governments play a crucial role in incentivising decarbonisation through clean hydrogen and are expected to create demand, ensure access, and lower costs.
- **Regulatory Policies for Grey Hydrogen Phase-Out**: The report discusses the need for regulatory policies to phase out grey hydrogen, such as a carbon price and blending mandates for clean fuels or ammonia.
- **Government Commitments and Investments**: National governments have committed to or targeted investments in hydrogen, which could exceed the volume of announced investments.
- **Global Government-Backed Hydrogen Strategies**: Thirty-nine countries are covered by government-backed hydrogen strategies. This global recognition reflects the importance of hydrogen in meeting climate targets.

Overall, the report highlights the critical role of government policies and investments in promoting the adoption of hydrogen across various sectors, especially in clean hydrogen production, infrastructure development, and transitioning away from grey hydrogen.

Hydrogen Council – Methodology & Assumptions

Hydrogen Council

Demand Projections

The potential role hydrogen could play is based on detailed cost competitiveness calculations per sub-segment combined with market intelligence.

The analysis estimates hydrogen uptake for each of the 39 sub-segments by considering cost-competitiveness relative to other decarbonised alternatives, such as biofuels, direct electrification, batteries, and carbon capture and storage (CCS).
It also includes an implicit assumption that the macro environment remains stable, i.e., steady GDP growth globally, no major geopolitical shifts, and that commodity prices remain stable over time.

It is assumed that hydrogen technology reaches technological maturity and cost levels as laid out in the "Path to Hydrogen Competitiveness" report (2021).
Further, it also considers the carbon abated using clean hydrogen, the changes in the hydrogen supply mix towards 2050, and the investments required in the hydrogen value chain to realise the demand projections.

Industry

The Industry sector includes both existing and new industry uses. It is mentioned that hydrogen will be used in industrial sectors such as for iron and steel, fertilisers/ ammonia, refining, methanol, and other current industrial uses.

It is assumed that clean hydrogen will decarbonise applications like ammonia, methanol, and refining, accounting for about 15% of demand in 2050 (global). The report projects that steel decarbonisation will require 35 million tonnes of hydrogen in 2050. Low carbon steel could be made competitive by a carbon price of between 50-100 USD/t projected in the report for an accelerated transition.

Hydrogen for industrial heat is included in the building sector.

Power

The key decarbonisation solution within power generation is expanding renewable energy generation capacity. However, solar and wind power is inherently volatile, and the energy system will require short- and long-duration balancing. Hydrogen is crucial in decarbonising the final 1-3% of demand in a fully decarbonised grid because it can provide long-duration seasonal storage and potentially peak shaving.

Transport

The transport sector includes hydrogen applications within **ground mobility** (including cars, heavy trucks, regional trains, long-range passenger trains and coaches), **maritime** and **aviation.**

The report states that the early adoption of hydrogen in these sectors will be driven by regulators and industry commitments. The report also predicts that hydrogen adoption in 2030 will be relatively low in these sectors (at about 1% and 6%) but will establish the decarbonisation of these sectors longer-term by up to 60% by 2050.

- Hydrogen complements direct electrification through batteries in long-range, high uptime and fast refuelling cases.
- Aviation will become a significant consumer of hydrogen-derived fuels for long-range flights. Hydrogen (probably in liquid form) is expected to play a significant role in short-range flights.

Buildings

The buildings sector includes **industry heat** and heating for residential and commercial buildings.

In 2050, the hydrogen demand for building heat could total 1320 TWh, particularly in regions that currently rely on natural gas for heating. The report mentions that blending hydrogen into existing natural gas grids could be an early step toward developing fully hydrogen-ready pipeline networks.

The report states that hydrogen is vital in decarbonising industry heat, mainly for high-grade heat (temperatures above 400 degrees Celsius) applications such as cement plants, glassmaking, and aluminium remelting.

Hydrogen Council

The World Hydrogen Council is a global CEO-led initiative of 132 leading energy, transport, industry and investment companies.

Hydrogen Council Scenario

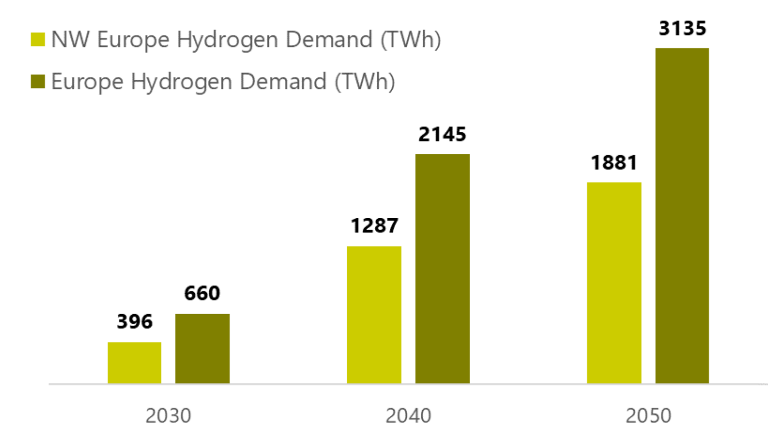
The Global Hydrogen Flows Perspective (2022) and the Hydrogen for Net-Zero report (2021), co-authored by the **Hydrogen Council** and **McKinsey**, have been selected for assessment to provide a detailed analysis of demand and hydrogen imports.

Despite being focused on global perspectives on hydrogen demand, they also present Europe-specific data.

Hydrogen Council is a **normative scenario** in which the hydrogen demand view is aligned with a **net-zero trajectory that limits global warming** to 1.5-1.8 C, in line with the Paris Accord and the recent IPCC 6th Assessment report.

The analysis was carried out by developing an advanced analytics optimisation model that balances supply and demand across all regions and multiple carriers and end users. The Hydrogen Council members provide industry data.

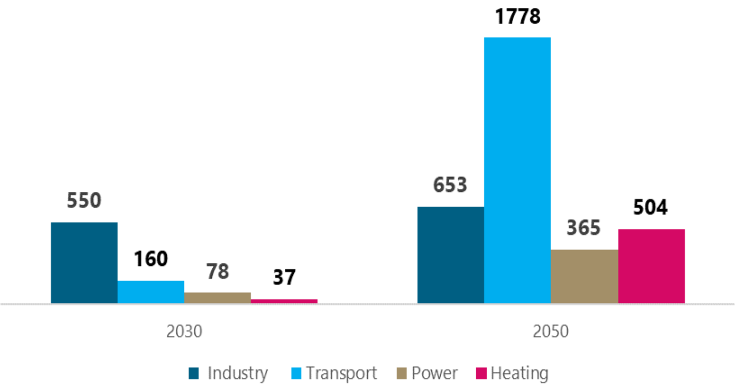
The World Hydrogen Council's perspective on hydrogen demand exports that future hydrogen demand across Europe could be around 660-825 TWh in 2030, 1780-2145 TWh in 2040 and 3050-3300 TWh in 2050.



Hydrogen Council scenario forecasts that global hydrogen demand will rise 7.5 times from now (~ 3000 TWh) through 2050 (around 21780 TWh). It is considered that around 15%-17% of hydrogen demand will be located in Europe. Europe will generate a demand of 3300 TWh of clean hydrogen by 2050 based on current energy consumption – with 70% of all hydrogen coming from renewable sources by 2050.

** Report gives values for Europe – the assumption that NW Europe's hydrogen demand is 60% of Europe's total demand gives data for NW Europe demand.*

Hydrogen demand by sector (TWh)



Under this scenario, substantial hydrogen demand comes from industry, current industrial uses such as refining ammonia synthesis, and iron and steel is expected to have an increasing demand. Clean hydrogen is a cost-competitive option when taking into account carbon abatement costs. Regulations and industry commitments will drive the early adoption of hydrogen in the transport sector. While hydrogen adoption in 2030 will be relatively low in these segments, it lays the foundation to decarbonise these sectors by up to 60% by 2050, depending on the region. Hydrogen use in power and buildings plays a role in decarbonising current fossil-fuelled power generation assets through blending in the natural gas grid.

Hydrogen Council Scenario Findings Summary

- The hydrogen council scenario shows that 65% of global hydrogen demand is concentrated in North America, Europe and East Asia. However, there is a mismatch between the best locations for hydrogen production and demand centres.

- In regions where there is a large mismatch between hydrogen production and demand, hydrogen is likely to be relatively expensive owing mainly to limitations in the development of renewables.

- Demand locations where cheap hydrogen supply is limited, such as densely populated regions of Europe, domestically produced hydrogen will be significantly more expensive. Driving the cost is the fact that domestic hydrogen production will be constrained because of land availability, resulting in difficulties in developing the additional onshore wind and solar power needed to be competitive globally.

- Transport will be the largest single hydrogen end-use sector in 2050, representing ~65% of demand. The transport sector includes hydrogen applications within ground mobility, and hydrogen as feedstock to produce maritime and aviation fuels.

Hydrogen Council – Imports and Export Analysis

Based on the Hydrogen Council's perspective on global hydrogen flows, there will be a mismatch between the best locations for hydrogen production and demand centres.

Early growth in clean hydrogen deployment will likely centre on Europe, Japan, and Korea, accounting for about 30% of new low carbon demand. By 2050, Europe and North America are expected to account for 95 million tonnes (MT) of low carbon hydrogen demand each. This positions Europe as one of the significant consumers of hydrogen globally, following China, which is projected to be the largest single market with about 200 MT of demand.

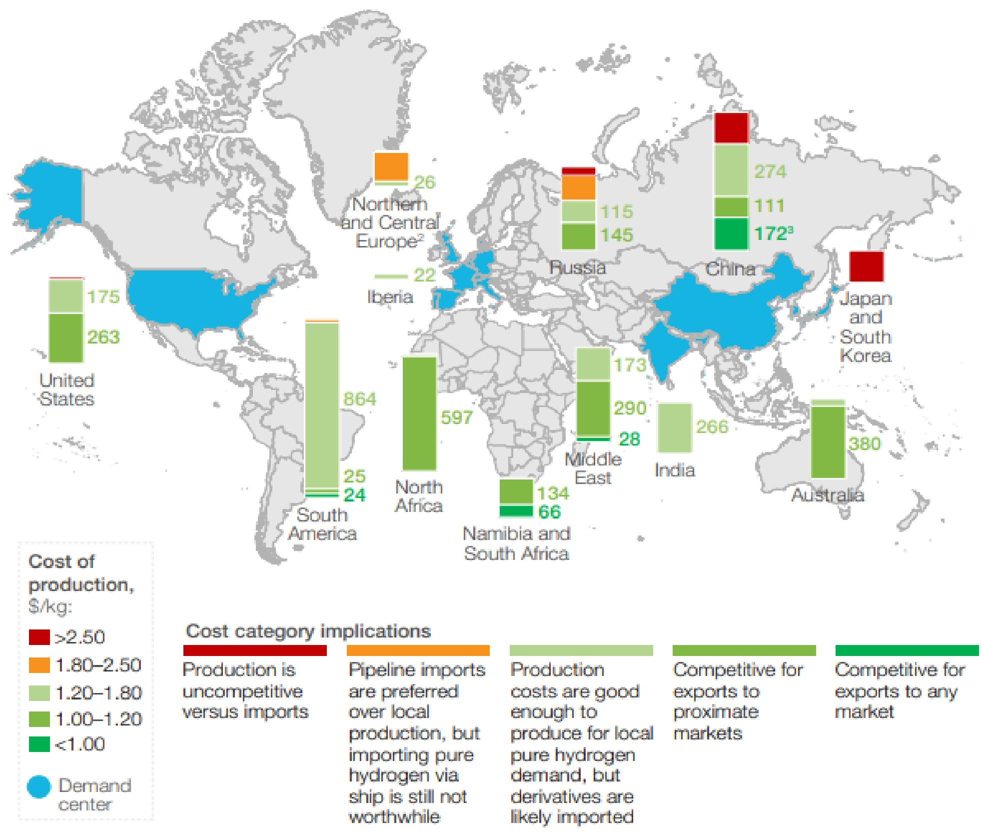
The report also notes that Europe's low carbon hydrogen demand is expected to be partially supplied by imports and will likely scale up proportionally earlier than in other geographies. This indicates a substantial reliance on hydrogen imports to meet Europe's low carbon hydrogen demand.

To supply hydrogen demand by 2050 (around 21780 TWh) in a cost-optimal way, the Hydrogen Council analysis considers a mix of both renewable and low-carbon hydrogen supply, requiring 300 to 400 GW of new renewables, as well as 1485–1815 TWh of low-carbon hydrogen production capacity and associated carbon storage infrastructure.

Under this analysis, each region's production costs and commercial potential vary widely. They are driven by factors such as the levelised cost of production, availability and costs to access feedstock and country-specific factors, including the region's investment attractiveness (market efficiency, workforce availability, or country risk factor) and local public acceptance of building new infrastructure.

According to the estimated 2050 hydrogen production potential, countries like the US, Saudi Arabia, Australia and China will be well-placed for export opportunities. These regions' capacity to produce hydrogen efficiently and in large quantities makes them suitable for becoming significant exporters. Some Northern European countries (e.g. Germany) will be potential importers.

Hydrogen production potential,[1] 2050, million tons per annum



1. Potential for renewables and low-carbon hydrogen, constrained by a maximum of 0–3% land availability.
2. Only includes third-tier production potential, assuming that the higher-tier locations use renewable power.

Hydrogen Council – Imports and Export Analysis

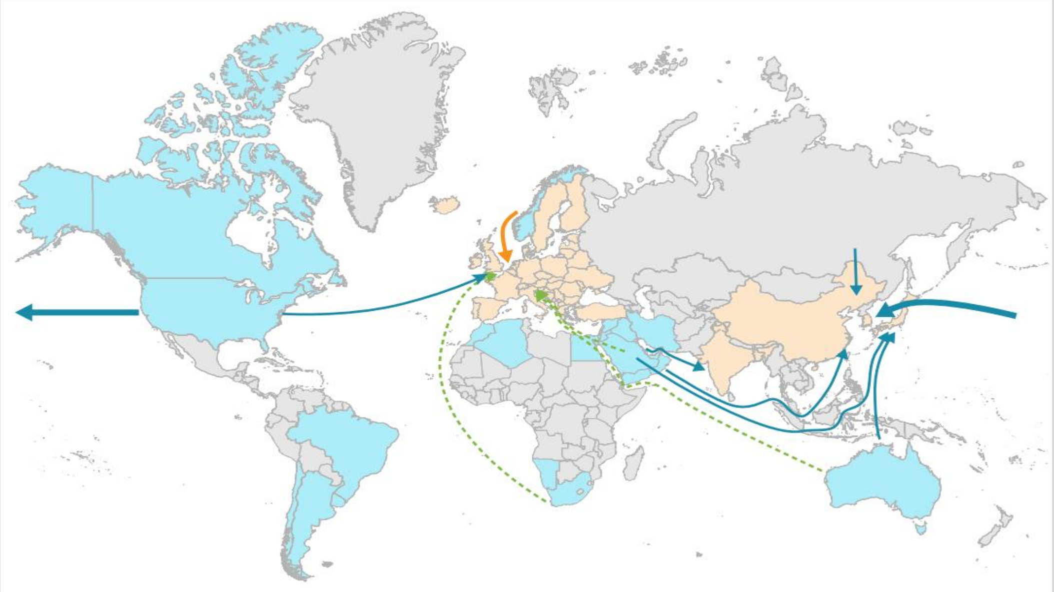
The black-box model identifies Europe as a significant importer establishing offtake contracts with exporting countries in North Africa.

This perspective reports that the first pipeline imports into Europe will occur by **2030** as domestic hydrogen supply is constrained and available renewable capacity is built up to decarbonise power.
The pipeline imports will facilitate competitive low-carbon supplies from markets such as Norway. Flows to Asia and **Europe** from competitive production locations such as Latin America, including Brazil and Chile; North Africa; and Southern Africa will also start to emerge, initially at small volumes.
Long-distance trade from Australia to Europe could also materialise if more local suppliers cannot meet demand.

The Global Hydrogen Trade Model predicts that by 2050, there will likely be more than **40** different trade routes with more than 1 MTPA capacity, with the largest reaching more than **20 MTPA.**

Pipelines will primarily supply Europe. By **2050,** the market is expected to mature with significant liquidity.

Europe will require more hydrogen imports, opening up significant pipeline imports, particularly North African renewable hydrogen.



Note: Major flows of hydrogen and derivatives, million tons hydrogen equivalent in 2030.

Net trade flows, million tons hydrogen per annum

- Region consumes more than it produces
- Neutral
- Region produces more than it consumes
- > 20
- 10–20
- 5–10
- 1–5
- Mostly shipped
- Mostly piped
- Alternative potential flows if optimal sources constrained

2050 Fully mature trade market: Pipeline transport continues to scale, reaching **140 MTPA**

2040 Market growth: Pipeline transport accelerated exceeding **60 MTPA.** Hydrogen-carrier shipping reaches scale.

2030 Pipelines unlocked: First long-distance pipelines facilitate large scale transportation of hydrogen within North America and Europe.

2025 First derivatives: Trade of clean H_2 to replace some of the existing trade of grey ammonia and methanol to Europe and Asia from North America, the Middle East and Norway

Note: 1MT = 33TWh

High Level Insights

- The Global Trade Model is a black-box model that is reported to take more than 1.5 million trade options into account to determine optimal trade routes and supply options. Modelled flows include pure hydrogen, hydrogen carriers, and hydrogen derivatives. The report derives investment requirements from segment-specific estimates accounting for five primary hydrogen transmission and distribution routes.
- This is the only scenario in the basket covered in this report that sees transport as the primary user by 2050.
- The timeline for pipelines is in alignment with the EHB initiative analysis.
- As described in its title, the Global Hydrogen Flows Perspective is primarily a global report on international trade flows. As the report highlights, the analysis was done before the introduction of the Inflation Reduction Act (IRA) in the United States, and the ultimate impact of the IRA on global trade flows is still uncertain.

IEA Report Overview

- The Hydrogen in North-Western Europe: A Vision Towards 2030 report was produced by the International Energy Agency (IEA) and the Clingendael International Energy Programme.
- The report focuses on the status of hydrogen in the North-Western European region and its potential evolution towards 2030. In this report, the North-western European region, comprising Germany, the Netherlands, Belgium, France, and the UK, is a significant area for hydrogen adoption as a clean energy vector. This region accounts for about 5% of global hydrogen demand and 60% of European demand, primarily due to its large industrial ports and well-developed natural gas infrastructure, which could be partially repurposed for hydrogen delivery.
- The report details projections for future hydrogen demand in the region to 2030, the Baseline and Accelerated scenarios.
- **Current demand of grey hydrogen (2019):** 222 TWh
- **Projected demand for 2030:** 201 TWh (Baseline), 280 TWh (Accelerated)
- The report provides a breakdown of hydrogen demand by sector for both scenarios, including hydrogen demand in transport, industry, power and buildings.
- The assumptions in this report to predict hydrogen demand and supply include current policies, confirmed plans from major industrial stakeholders, and the potential influence of broader European energy transition goals. The report highlights the importance of national policies and international collaboration in achieving these targets and transitioning to a low-carbon hydrogen economy.

IEA Policy Overview

The report "Hydrogen in North-Western Europe" considers several policies beyond individual country strategies, which are applied across various sectors. These policies include:

- **EU 2030 Climate and Energy Framework**: This framework targets a 55% reduction in greenhouse gas emissions. It plays a significant role in shaping the hydrogen market, as hydrogen is a key component in achieving these emission reduction targets.
- **Climate Change Act 2008 (2050 Target Amendment) Order 2019**: This policy sets long-term goals for emission reductions, influencing the development and adoption of hydrogen technologies to meet these objectives.
- **Adoption of Measures to Deliver the EU and National Hydrogen Strategies**: This involves implementing specific measures to realize the objectives set out in the EU-wide and national hydrogen strategies.
- **Adoption of Zero-Emission Vehicle (ZEV) Mandates/Purchase Incentives and Low-Carbon Fuel Standards**: These policies are designed to promote the use of hydrogen in transportation, such as in fuel cell electric vehicles (FCEVs), by providing incentives for zero-emission vehicles and setting standards for low-carbon fuels.
- **Policy Support through the EU Green Deal**: The EU Green Deal provides a framework and support for the transition to a green economy, which includes the development of the hydrogen sector.
- **Company-Level or Country-Level Deployment Targets**: Setting specific targets for hydrogen deployment at both the company and country levels helps drive the development of the hydrogen market.

IEA NW Europe – Methodology & Assumptions

IEA NW Europe

The projections presented in both scenarios take into account the potential impacts on the hydrogen industry through the adoption of different levels of ambition and policy support for hydrogen technologies.

The **Baseline scenario** describes how demand for hydrogen could evolve **considering** energy- and climate-related **policies currently in place** in the countries in the region (e.g. **EU ETS, RED II, EU 2030 Climate & Energy Framework**) **and** mature **projects** that are **under construction** or have reached **FID.**

The Accelerated scenario is based on enacting **more ambitious energy- and climate-related policies** and implementing supporting mechanisms that could facilitate the adoption of hydrogen technologies. For instance, it considers achieving 2030 emission reduction targets (**EU Green Deal, 55% GHG emissions reduction**), adopting measures to deliver the EU and **national hydrogen strategies**, policy support, etc.

The methodology is based on the modelling and supply/demand analysis by the IEA and the national policies analysis by CIEP.

There is no transparent methodology and assumptions described in the report.

Industry

The following sub-sectors have been grouped to represent the industry sector: Refining, ammonia production, methanol production, iron and steel and other uses of pure and mixed hydrogen.
Lower demand for oil-based transport fuels in the Baseline scenario means that hydrogen demand in refineries will drop around 15% by 2030 in NW Europe compared to 2019. In the Accelerated scenario, there would be a sharper decline in oil-based fuels, leading to a reduction of 35 TWh in hydrogen demand for oil refining.
Hydrogen demand for ammonia production and in petrochemical processes follows the same trend observed for the oil refining sub-sector. However, using ammonia as a shipping fuel would generate new demand, especially in Belgium, the Netherlands, Norway and the United Kingdom.
New industrial uses in the iron and steel industry generate a demand for hydrogen. With Germany's strong iron and steel industry, this new demand is concentrated in Germany, building on its existing DRI capacity.
IEA results suggest a change in the distribution of these demands, highlighting that the next decade can be critical for adopting hydrogen as an energy carrier beyond industry.

Transport

The reduction in hydrogen demand from industry is partly compensated by the generation of demand from new applications in transport as a consequence of EV mandates, etc.
The transport sector includes the following sub-sectors: Aviation-Synfuel, Rail, Shipping-NH_3, Shipping-H_2, heavy-, medium- and light-duty vehicles (HDC, MDV, LDV), passenger-light vehicles (PLDV) and buses. In the Accelerated case, hydrogen use expands to light-commercial vehicles (LCV) and passenger light vehicles (PLDV) as well as shipping, resulting in an overall hydrogen demand of 33 TWh by 2030.

Buildings

The report includes no information on subsectors included in the power sector. It is mentioned that power generation is a sector where hydrogen use has short-term limited potential due to high costs and low efficiencies in the case of the whole cycle Power-to-Hydrogen-to-Power. However, it can serve to generate carbon-free peak load electricity.
Energy efficiency improvements and electrification of heating will be central to emission reductions, with heat pumps reaching higher efficiency compared to other low-carbon alternatives. Hydrogen could also be blended into the natural gas grid to meet up to 2% of the region's energy demand for natural gas.

IEA NW Europe: Baseline Scenario

The Hydrogen in North-Western Europe*: A vision towards 2030 study was carried out by the International Energy Agency and the Clingendael International Energy Programme to evaluate the status of hydrogen in this region and assess how the sector could evolve.

IEA Scenario

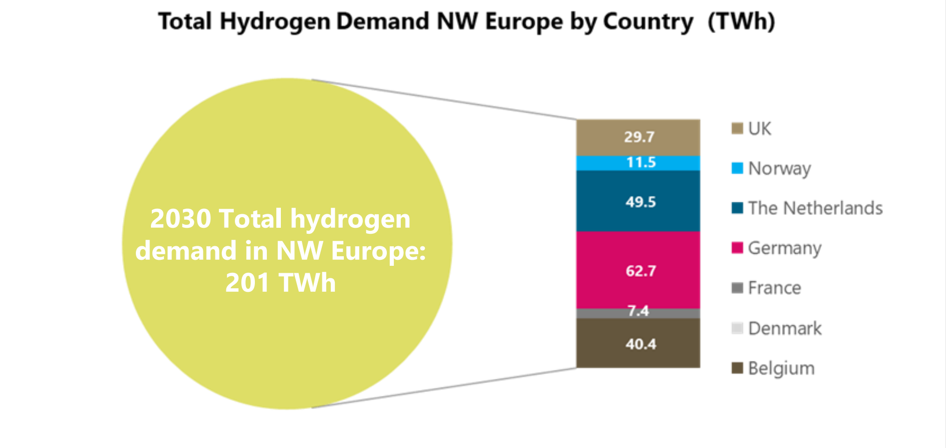
The study brings together national policies and project plans for hydrogen development to identify opportunities and assess the potential of hydrogen as a clean energy vector.

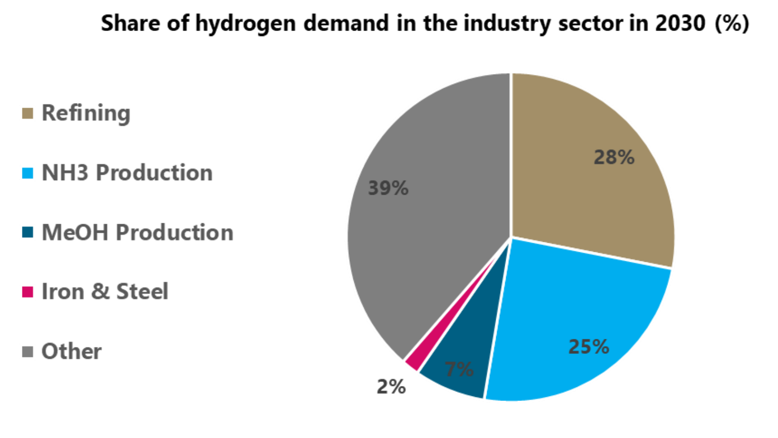
The **report presents two scenarios** based on the analysis underpinning the report: the "**Baseline Scenario" and "Accelerated Scenario".**

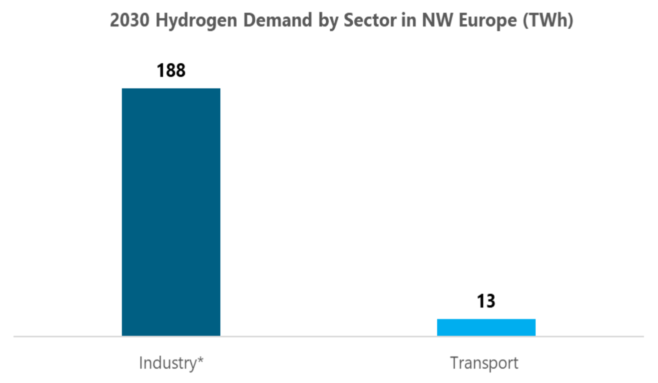
The **Baseline Scenario** can be considered **exploratory**, while the Accelerated Scenario is more normative, assuming that 2030 emissions reduction targets are achieved.

Potential evolution of hydrogen demand and supply projections by 2030 are based on analysis informed by IEA consultants, government officials and energy experts from different institutions.

The Baseline scenario describes how demand for hydrogen could evolve considering energy- and climate-related policies currently in place in the countries in the region, mature projects that are under construction or have reached FID.







North-Western Europe region concentrates around 5% of global hydrogen demand and 60% of European demand. The baseline scenario forecasts a slight decrease in demand by 2030 from today's level (from ~220 TWh to ~200 TWh). This is because the oil refining, ammonia production and petrochemical sectors are facing strong international competition from regions with access to lower-cost feedstock (e.g. the Middle East, the United States and China), resulting in a slowdown in their activity in recent years. Germany has the most significant hydrogen demand in the region, and it is expected to have a new demand for hydrogen in its strong iron and steel industry. The Netherlands also is expected to continue to have a significant hydrogen demand.

**NW Europe definition under IEA covers Belgium, Denmark, France, Germany, the Netherlands, Norway and the United Kingdom.*

IEA NW Europe: Accelerated Scenario

The Hydrogen in North-Western Europe*: A vision towards 2030 study was carried out by the International Energy Agency and the Clingendael International Energy Programme to evaluate the status of hydrogen in this region and assess how the sector could evolve.

IEA Scenario

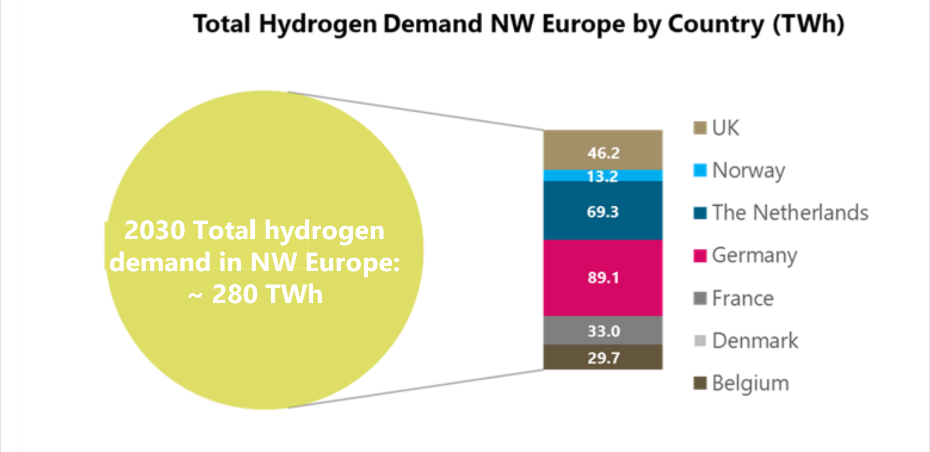
The study brings together national policies and project plans for hydrogen development to identify opportunities and assess the potential of hydrogen as a clean energy vector.

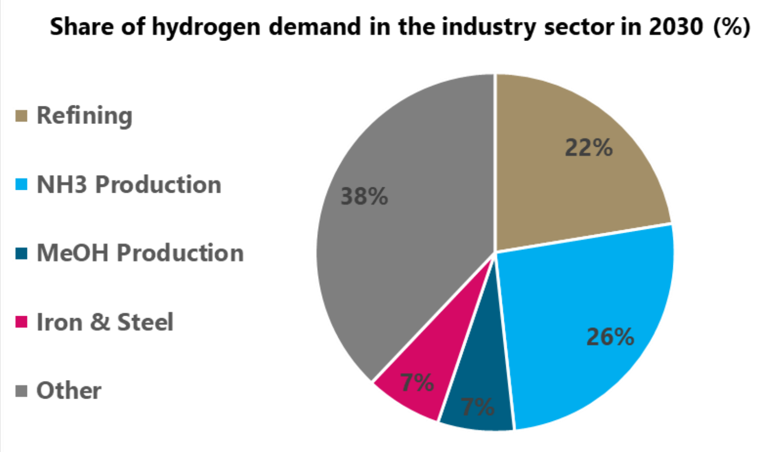
The **report presents two scenarios** based on the analysis underpinning the report: the "**Baseline Scenario" and "Accelerated Scenario**",

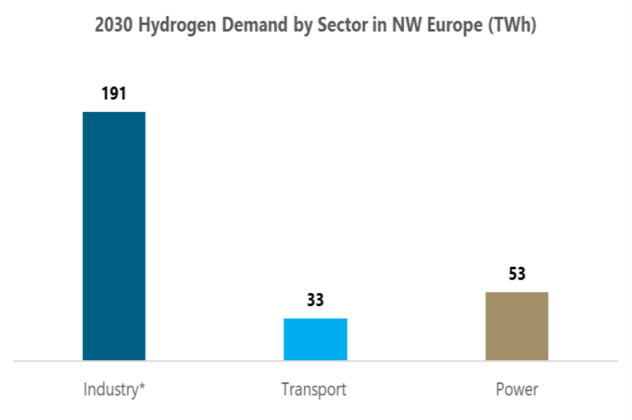
The **Baseline Scenario** can be considered **exploratory**, while the Accelerated Scenario is more normative, assuming that 2030 emissions reduction targets are achieved.

Potential evolution of hydrogen demand and supply projections by 2030 are based on analysis informed by IEA consultants, government officials and energy experts from different institutions.

The Accelerated scenario is based on enacting more ambitious energy- and climate-related policies and implementing supporting mechanisms that could facilitate the adoption of hydrogen technologies.







In the **Accelerated scenario**, the hydrogen sector observes significant expansion. Demand for hydrogen could grow by as much as 35%, with total hydrogen demand reaching **280 TWh** in NW Europe in 2030. The use of hydrogen in oil refining in the region would suffer a sharper decline driven by more ambitious policies and targets for deploying low-carbon transport technologies. Ammonia used as a shipping fuel would generate significant new demand, especially in Belgium, the Netherlands, Norway and the United Kingdom. There is also a strong growth of hydrogen demand in new applications such as power generation and transport.

**NW Europe definition under IEA covers Belgium, Denmark, France, Germany, the Netherlands, Norway and the United Kingdom.*

IEA Scenario Findings Summary

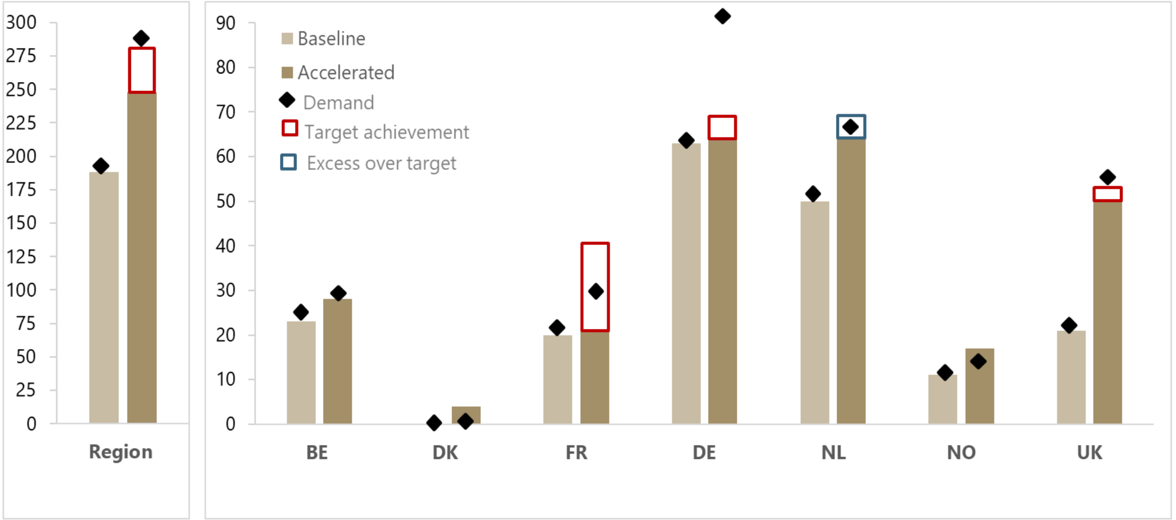
- IEA presents two 2030 hydrogen demand scenarios based on how EU energy- and climate-related policies evolve by 2030. According to the **Baseline scenario, hydrogen demand drops slightly** from current levels. Under the Accelerated scenario, hydrogen demand would increase by **around 50%** due to significant expansion in power and transport.
- The results from the study suggest a change in the distribution of hydrogen demand – highlighting the next decade as critical to the **adoption of hydrogen as an energy carrier beyond the industry sector** (hydrogen demand in the industry does not vary according to these scenarios).
- In the Accelerated scenario, **new industrial uses in the iron and steel industry** generate a hydrogen demand of around 26 TWh. The majority of this new demand is concentrated in **Germany.** Hydrogen demand from **oil refining would sharply decline** – driven by more ambitious policies and targets for deploying low-carbon transport. Hydrogen demand in ammonia production would be smaller for the Accelerated scenario than the Baseline scenario – driven by the successful demonstration of **ammonia as a shipping fuel**, generating new demand, particularly in **Belgium, the Netherlands, Norway** and the **United Kingdom.**
- In the Baseline case, **hydrogen demand for transport** in the region would **reach around 10 TWh by 2030**, driven by hydrogen use in fleets, such as buses and trucks, corresponding to close to 10% of the hydrogen demand in the region. Under the Accelerated scenario, **hydrogen use expands to light-commercial vehicles** (LCV) and PLDV **as well as shipping** (mainly in the form of ammonia), resulting in an overall hydrogen demand of more than 33 TWh by 2030 (around 15% of the region's overall hydrogen demand. IEA's scenarios do not expect hydrogen demand in the aviation sub-sector.
- Additionally, demand for hydrogen in new applications would also see significant growth under the Accelerated scenario. These applications include hydrogen being blended into the national gas grid to meet 2% of the region's demand for natural gas, which results in a hydrogen demand greater than 40 TWh.

IEA NW Europe – Imports & Exports Analysis

Hydrogen supply in the region would also evolve differently under the Baseline and Accelerated scenarios. However, both scenarios share a feature: the pipeline of announced projects seems insufficient to meet the expected hydrogen demand by 2030.

In both the Baseline and Accelerated scenarios, there are differences between demand and supply across countries in the region, with some countries developing a supply capacity that could exceed their demand and others unable to meet the demand they could create. In both scenarios, the expansion of the production capacity that could be achieved with the currently proposed projects would be insufficient to meet the projected demand in the region, resulting in a supply deficit of around - 35 TWh under the Accelerated scenario.

Projected regional and country hydrogen supply and demand in TWh under the IEA's scenarios



The development of a hydrogen trade between countries in NW Europe depends on the evolution of hydrogen supply and demand in each country and other factors, such as development of cross-border hydrogen infrastructure and regulation. The supply projections are based on current production capacities and the potential increase achieved with the announced project pipeline.

According to the IEA's analysis, hydrogen produced in the Netherlands, Norway or Denmark (provided that all expected projects are realised) could be exported to Belgium, France, Germany and the United Kingdom to meet their markets' demand. This situation for France and the United Kingdom will be different if they meet their national ambition for low-carbon hydrogen production (e.g., the development of blue and pink hydrogen in France). If that is the case, supply in both countries would meet or exceed their demand.

In terms of hydrogen supply options, the Baseline scenario would be similar to current supply. Deploying some small projects for hydrogen production through electrolysis would account for around 1% of the total supply. The shares of natural gas and oil-based production, both with and without CCUS, remain almost unchanged.

In the Accelerated scenario, blue hydrogen production would match the amount of hydrogen produced from natural gas, and green hydrogen would account for 4% of supply. The report states that, in this scenario, low-carbon hydrogen production would provide more than a third of the total hydrogen supply. This contrasts with the current situation where low-carbon hydrogen meets only approximately 5% of the supply.

High Level Insights

- The Baseline Scenario is based on policies already in place in 2020 (such as EU ETS, REDII, etc.) and projects which have reached a Final Investment Decision (FID), whilst the Accelerated Scenario assumes EU 2030 targets based on the EU Green Deal (e.g. 55% GHG emissions reduction) and more uncertain projects at earlier stages of development.
- Therefore, note that these policy-based scenarios were produced before the EU Fit-for-55 Package and other recent policy developments such as the RePowerEU and CBAM.
- The report was produced with the financial assistance of the Dutch Ministry of Economic Affairs and Climate Policy. The Scottish Government is credited with providing input and review through Stuart McKay.
- In terms of all of the reports identified, this has a geographic focus most closely aligned to the terms of reference for this study.
- As projections are only to 2030, there is a higher confidence that the actual demand forecast will fall between the Baseline and Accelerated scenarios.

IOGP Report Overview

Hydrogen4EU
CHARTING PATHWAYS TO ENABLE NET ZERO

- The Hydrogen4EU report was produced by a consortium comprising Deloitte Finance, IFPEN, Carbon Limits and SINTEF.
- The report focuses on hydrogen demand in Europe. While the report does not explicitly state the current hydrogen demand in Europe, it details projections for future hydrogen demand in the region in 2030 and 2050 under two scenarios: Technology Diversification and Renewable Push pathways.
- **Predicted Demand for 2030:**

  - In both the Technology Diversification and Renewable Push pathways, the hydrogen demand in Europe is expected to exceed 495 TWh.
- **Predicted Demand for 2050:**

  - In both pathways, the hydrogen demand is projected to reach around 3,300 TWh by 2050, aligning with the European Commission's REPowerEU plan.
- The report outlines the following drivers for increased hydrogen demand:

- **Policy and Regulatory Frameworks:** These include carbon pricing and subsidies for low-carbon technologies, which make hydrogen more competitive against fossil fuels.
- **Technological Developments:** Improved efficiency, reduced electrolyser costs, and advancements in hydrogen storage and transport technologies make green hydrogen more viable.
- **Market Dynamics and Industrial Strategies:** The evolving dynamics of the energy market, including the increasing competitiveness of renewable energy sources.

The report provides a breakdown of hydrogen demand by sector for both scenarios, including hydrogen demand in transport, industry, power, and buildings.

The assumptions behind the hydrogen demand predictions are rooted in the broader goals for achieving climate neutrality in Europe, which aligns with the European climate law. The projections consider the dynamic policy environment, technological advancements, and market developments in the context of decarbonisation efforts.

IOGP Policy Overview

The Hydrogen4EU report discusses government support and policies to facilitate the uptake of hydrogen in industry. Key points include:

- **EU and National Government Initiatives**: The EU and national governments have implemented financial instruments and support schemes to de-risk first hydrogen projects and encourage innovation and investment. The TEN-E regulation update also supports hydrogen projects by facilitating faster permitting, lower financing costs, and eligibility for Connecting Europe Facility grants.
- **Mandates, Targets, and Exemptions**: The Fit-for-55 and Hydrogen and Decarbonised Gas Market package propose mandates, binding targets, and tax or levy exemptions to improve the competitiveness of low-emission technologies, including hydrogen.
- **International Collaboration and Import Strategies**: Germany leads the hydrogen import market with the H2Global mechanism, using public funding to bridge the price gap between sellers and buyers. MoUs with hydrogen-exporting countries aim to develop trade partnerships and accelerate hydrogen supply to Europe.
- **Carbon Contract for Difference (CCFD)**: CCFD is considered a promising option to incentivize hydrogen investments by rewarding projects based on CO2 abatement costs.

The report indicates that these policies and support mechanisms are primarily aimed at fostering the development and commercialization of hydrogen technology, particularly in the energy sector, including both renewable and low-carbon hydrogen production.

IOGP– Methodology & Assumptions

Hydrogen4EU
CHARTING PATHWAYS TO ENABLE NET ZERO

IOGP Scenario Methodology

The scenarios were built via a cost-optimisation approach using a combination of three models: a detailed European TIMES-type model (MIRET-EU), an aggregated model for the European energy system, allowing endogenous cost reductions based on technology deployment in a dynamic programming formulation for investment strategies (Integrate Europe); and a dedicated model for assessing hydrogen import options for Europe (HyPE).

The MIRET-EU model is a bottom-up techno-economic multiregional model of the European energy system and provides proven methodology based on linear programming to represent the European energy system.

The hydrogen import model HyPE assesses the competition between domestic hydrogen production in Europe and imports from non-European countries. The imports model follows a point-to-point optimisation - calculating the optimal hydrogen delivery routes to Europe. It is built on the whole delivery value chain up to an entry point in Europe to determine the specific LCOH of each European importing route.

Technology Diversification Pathway

The Technology Diversification Pathway assumes a perfect market where the European energy technology transition is underpinned by European climate law in combination with approved national targets and overarching objectives for renewable energy share and energy efficiency.

The pathway assesses how a wide range of technologies can be leveraged to transform the energy system at the least cost through perfect market foresight, where investment decisions are made with full knowledge of future developments.

Further deployment of technologies needed for decarbonisation of the energy system occurs at the time of demand without delays.

Renewable Push Pathway

The Renewable Push pathway starts at the same point with respect to currently implemented policies, policy announcements and overarching objectives.

The pathway is set up to assess the framework orientated towards investments in renewable energies. This is implemented in the form of a series of targets on the share of renewables in final energy consumption.

The Renewable Push pathway is more ambitious for 2030 than previous policies (45% versus 40% in the Technology Diversification pathway, reflecting the proposed increase in the REPowerEU plan). It Includes binding targets for 2040 (at 60%) and 2050 (at 80%).

Industry

The industry sector includes the following sub-sectors: Iron & steel, Chemicals, Pulp & Paper and Steam & Heat.

Transport

Demand for hydrogen in the transport sector includes domestic and international aviation and maritime bunkers. Hydrogen end-use in transport also includes the potential for hydrogen and hydrogen-embedded energy carriers as shipping fuels. Hydrogen use in refineries is included in this sector.

Buildings

Hydrogen can provide space heating but will face competition from various other decarbonisation options, including energy efficiency, heat pumps for buildings, biogas or continued use of natural gas.

Power

Electrification is one of the main pillars of the energy transition. Power-to-x is considered to play a crucial role in addressing flexibility needs, storing and transporting the variable production from wind and solar energy.

IOGP – Technology Diversification pathway

Co-authored by Deloitte Finance, IFPEN, Carbon Limits, and SINTEF, the report addresses the potential of hydrogen to decarbonise the European energy system. It presents two policy-relevant scenarios: Technology Diversification and Renewable Push.

IOGP Technology Diversification Scenario

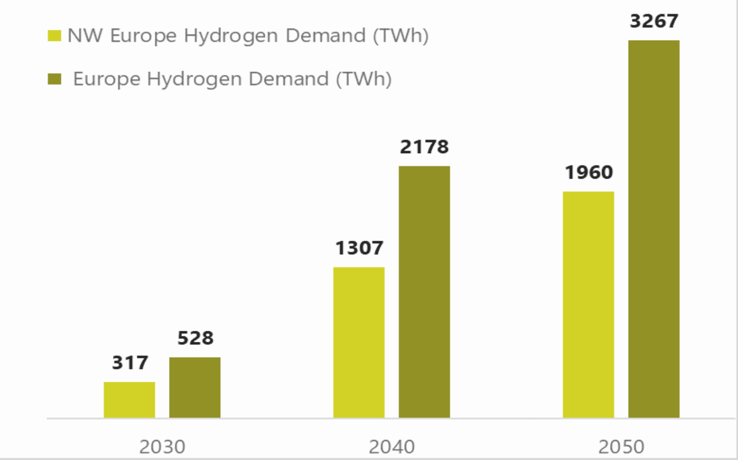
IOGP is the **International Association of Oil & Gas Producers.**

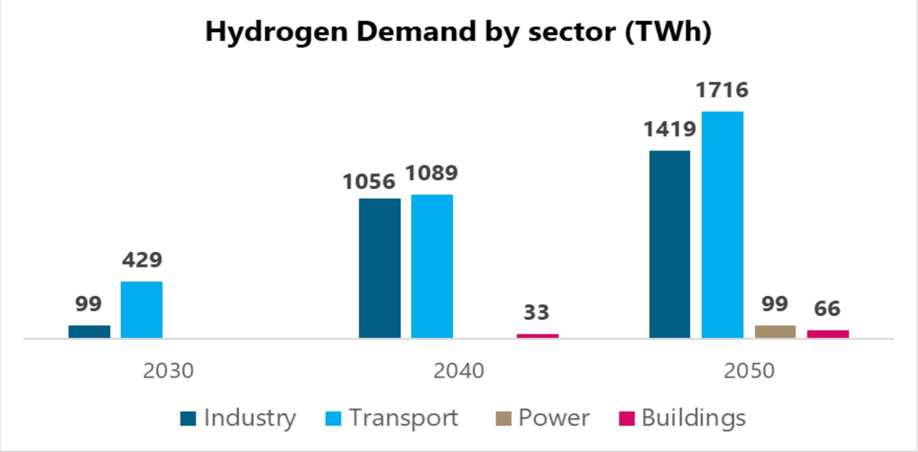
The IOGP report explores the potential of hydrogen to decarbonise the European energy system based on the updated Fit-for-55 legislative framework (55% reduction of emissions in 2030 compared to 1990) and targets net-zero emissions by 2050.

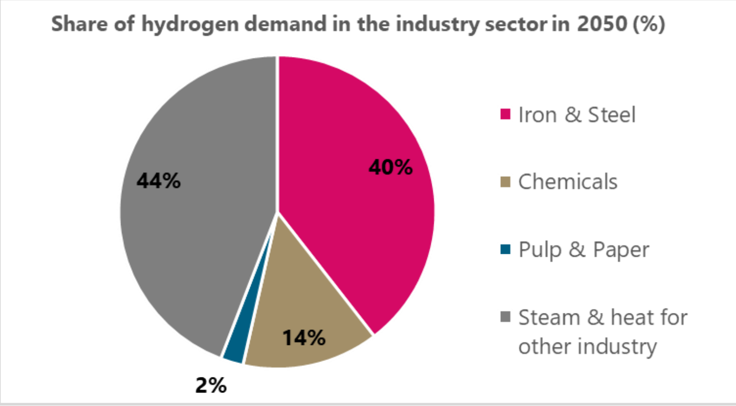
The report presents **two normative scenarios**: the **Technology Diversification pathway** and the **Renewable Push pathway**; both will lead to climate neutrality in 2050, but the Renewable Push scenario sets new reinforced targets for renewable technologies in Europe.

The Scope of the study assesses the potential role of hydrogen in serving energy demand across the entire European energy system (24 EU Member States and three non-EU countries: Norway, Switzerland and the UK).

The "Technology Diversification" pathway provides insight into an inclusive approach to energy transition, considering a range of decarbonisation technologies and aims to achieve a cost-efficient transformation of the European energy system by 2050.







European hydrogen demand in the Technology Diversification pathway reaches 528 TWh in 2030 and 3267 TWh by 2050. The increased demand is driven mainly by industry and transport – two hard-to-abate sectors. Hydrogen will be used in the transport sector through fuel cell vehicles, refineries and power-to-liquids. In industry, the largest hydrogen-consuming subsector is steel-making by 2050. The report states current decarbonisation initiatives highlighting the role of hydrogen in decarbonising steel. Large volumes of hydrogen will also be consumed to produce process heat and steam in other industries as hydrogen-fuelled heaters and boilers are well placed to play a role in the sector's decarbonisation. Hydrogen demand in buildings and for power is limited compared to hard-to-abate sectors.

**Report gives values for Europe – the assumption that NW Europe's hydrogen demand is 60% of Europe's total demand gives data for NW Europe demand.*

IOGP – Renewable Push pathway

Hydrogen4EU
CHARTING PATHWAYS TO ENABLE NET ZERO

Co-authored by Deloitte Finance, IFPEN, Carbon Limits, and SINTEF, the paper addresses the potential of hydrogen to decarbonise the European energy system. It presents two policy-relevant scenarios: Technology Diversification and Renewable Push.

IOGP Renewable Push Scenario

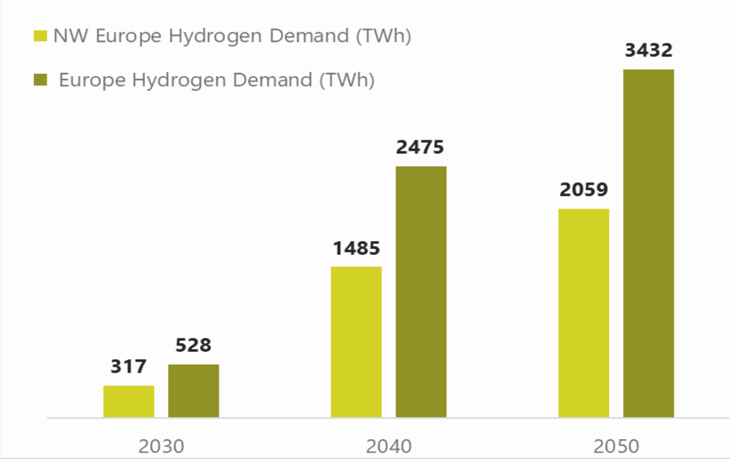
IOGP is the **International Association of Oil & Gas Producers.**

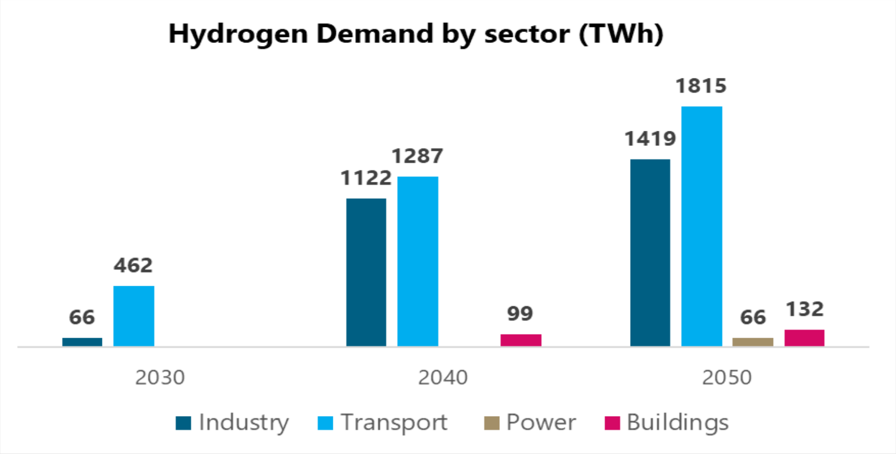
The IOGP report explores the potential of hydrogen to decarbonise the European energy system based on the updated Fit-for-55 legislative framework (55% reduction of emissions in 2030 compared to 1990) and targets net-zero emissions by 2050.

The report presents **two normative scenarios**: the **Technology Diversification pathway** and the **Renewable Push pathway**; both lead to climate neutrality in 2050, but the Renewable Push scenario sets new reinforced targets for renewable technologies in Europe.

The Scope of the study assesses the potential role of hydrogen in serving energy demand across the entire European energy system (24 EU Member States and three non-EU countries: Norway, Switzerland and the UK).

The "Renewable Push" pathway evaluates the conditions and implications of an increased focus on renewable energy, reflecting the current policy preferences in Europe. This is represented by a series of targets on the share of renewable energy in gross final energy consumption.





European hydrogen demand in the Renewable Push pathway reaches 528 TWh in 2030 and 3432 TWh by 2050. Similarly to the Technology Diversification pathway, the increased demand in the Renewable Push pathway is driven mainly by industry and transport. Following the same logic as the Technology Diversification pathway, hydrogen use in the transport sector will be seen in fuel cell developments, refineries and power-to-X liquid fuels. By 2050, e-fuel consumption in aviation will reach 25 Mt (35% of final energy consumption). As both pathways follow the same logic, the largest hydrogen-consuming subsector in the industry under the Renewable Push pathway is steel-making in 2030.

The report does not provide a breakdown of the share of hydrogen demand in the industry sector for the Renewable Push pathway. However, as both pathways follow similar trends, it is assumed that the share is likely the same.

**Report gives values for Europe – the assumption that NW Europe's hydrogen demand is 60% of Europe's total demand gives data for NW Europe demand.*

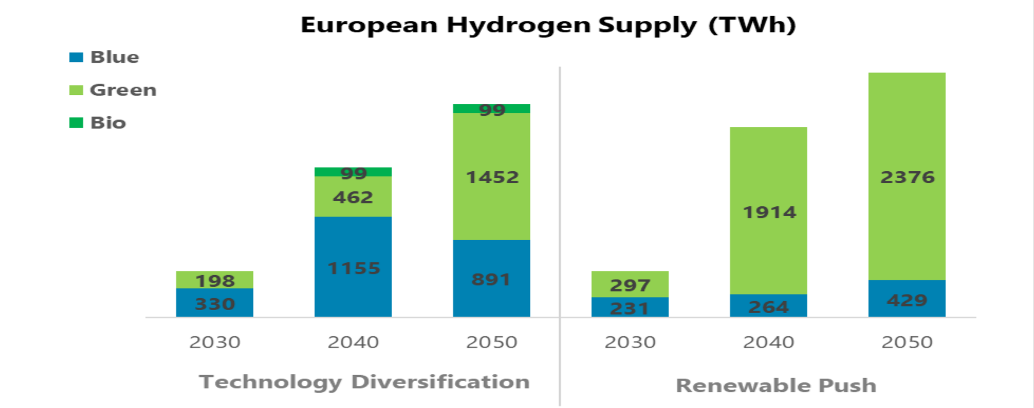
IOGP Scenario Findings Summary

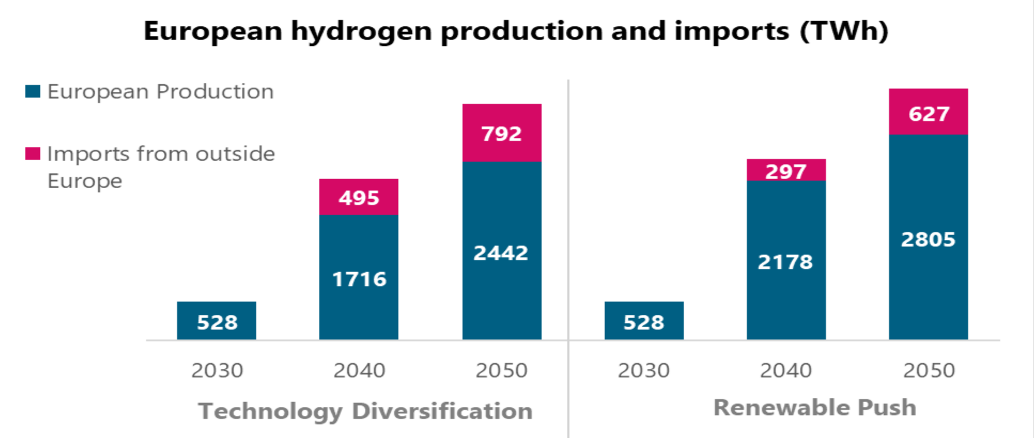
- IOGP presents two scenarios based on pathways to climate neutrality in Europe, The "Technology Diversification" and The "Renewable Push" pathway. Due to the ambitious decarbonisation objective for 2030 – a 55% reduction in GHG emissions compared to 1990 levels (Fit-for-55) - and the RePower EU Plan, European hydrogen demand in both pathways will exceed 500 TWh by 2030.
- Both pathways confirm the need for rapid increase in hydrogen production in the current decade, indicating that European production of renewable and low-carbon hydrogen must grow to reach about 500 TWh by 2030.
- The biggest hydrogen consumer in 2030 is the transport sector (Fuel cell in transport), with demand estimated at 363 TWh. Hydrogen demand in this sector will reach 1815 TWh in 2050, used either as a fuel for fuel cells or as a feedstock for synthetic fuels and biorefineries.
- Hydrogen demand in Industry increases from ~100 TWh in 2030 to around 1000 TWh by 2040 in both scenarios, primarily for energy purposes related to heat and steam production. Hydrogen is a critical solution for steel-making and chemical industries.
- The Renewable Push pathway, characterised by more ambitious targets for renewable energy deployment, anticipates hydrogen demand reaching 528 TWh in 2030 and exceeding 2475 TWh by the first half of the outlook period. In the Technology Diversification pathway, hydrogen demand reaches 528 TWh in 2030 and 2178 TWh in 2040.

IOGP – Imports & Exports Analysis

Norway and the UK are Europe's top hydrogen producers in the Technology Diversification pathway and the Renewable Push pathway. Norway is expected to export nearly all its hydrogen production to other countries, with lower export volumes in the Renewable Push pathway. Denmark and the UK also show notable export potential in the Renewable Push pathway.

Imports complement the acceleration of hydrogen uptake in the 2030s and 2040s. In both scenarios, hydrogen is imported to complement European production. In the Technology Diversification Pathway, imports from North Africa, the Middle East, and other smaller exporters will reach 495 TWh in 2040 and nearly 825 TWh in 2050, covering a quarter of European demand.





Under the Technology Diversification scenario, blue hydrogen production in Europe is crucial in meeting domestic hydrogen demand (over 50% of the hydrogen production comes from natural gas combined with CCS technology in the 2030s and 2040s). In contrast, in the Renewable Push Pathway, hydrogen demand is met mainly by European countries producing renewable (green) hydrogen.

Based on these scenarios, several European countries plan to complement local hydrogen production with imports due to limitations on high land use requirements and resources for hydrogen production.

The main industrial countries with large hydrogen demand will become significant consumers by 2050 and must import hydrogen to complement their local production. Germany, France (the report does not mention pink hydrogen), Netherlands, and Poland are the importer countries in both scenarios.

In both pathways, hydrogen imports, mainly from North Africa and the Middle East, complement European production and enable the uptake of the European hydrogen economy. The shipping of hydrogen will add considerably to the cost, especially when compared to a pipeline.

In the Technology Diversification pathway, hydrogen imports from North Africa, the Middle East, and other smaller exporters will reach 495 TWh in 2040 and over 800 TWh in 2050 - making up a quarter of European hydrogen demand.

More ambitious targets for renewable energy shares in the Renewable Push pathway result in lower import requirements. However, imports still reach significant levels at around 300 TWh in 2040 and over 600 TWh in 2050.

High Level Insights

- This policy-based report considers reaching net-zero emissions in 2050, as targeted by European policymakers, requiring a coordinated strategy across all sectors that achieves further electrification of end-uses, energy efficiency improvements, renewable energy deployment and the development of alternative technologies, carriers and fuels, such as hydrogen, biofuels, ammonia or synthetic fuels.
- Both Hydrogen for Europe pathways show a fundamental transformation in the primary energy mix, manifested by a significant switch from fossil sources to renewable energy. This is supported by increasingly constraining targets for GHG emission reduction, continued technology improvement, and binding targets on their deployment.
- In the transport sector, Electricity is the second largest contributor to the decarbonisation of transport after hydrogen and its derivatives. Energy efficiency also plays a significant role: electrification of the powertrain, automation, technological improvements, and modal shifts allow for substantial efficiency gains over the next thirty years. Final electricity consumption in the sector will almost double by 2050, with most passenger cars, light- and medium-duty vehicles, and most trains being electrified by 2050. Hydrogen fuel cell vehicles lead the way for decarbonising buses and heavy-duty trucks due to their higher energy density and lighter fuel reservoir than electric vehicles. The report predicts that by 2050, 90% of buses and heavy-duty trucks will be fuelled directly by hydrogen via fuel cell engines. However, the report states that this is contingent on the timely roll-out of a Europe-wide refuelling infrastructure.
- In industry, decarbonisation relies primarily on electricity, hydrogen and distributed heat, efficiency increases and deployment of CCUS.
- The development of European hydrogen production requires a rapid ramp-up of corresponding production capacities, both for off-grid and on-grid electrolysers and reformers with CCS. In the Technology Diversification case, blue hydrogen production (Reformer with CCUS) is a significant component of total low carbon production, with green hydrogen only dominant after 2040. In the Renewable Push Pathway, over 85% of the green hydrogen production in Europe comes from electrolysis after 2040).
- Under these scenarios, several European countries would complement local hydrogen production with imports. Hydrogen imports can exceed 300 TWh in 2040 and 600 TWh in 2050.

Imports/Exports Analysis

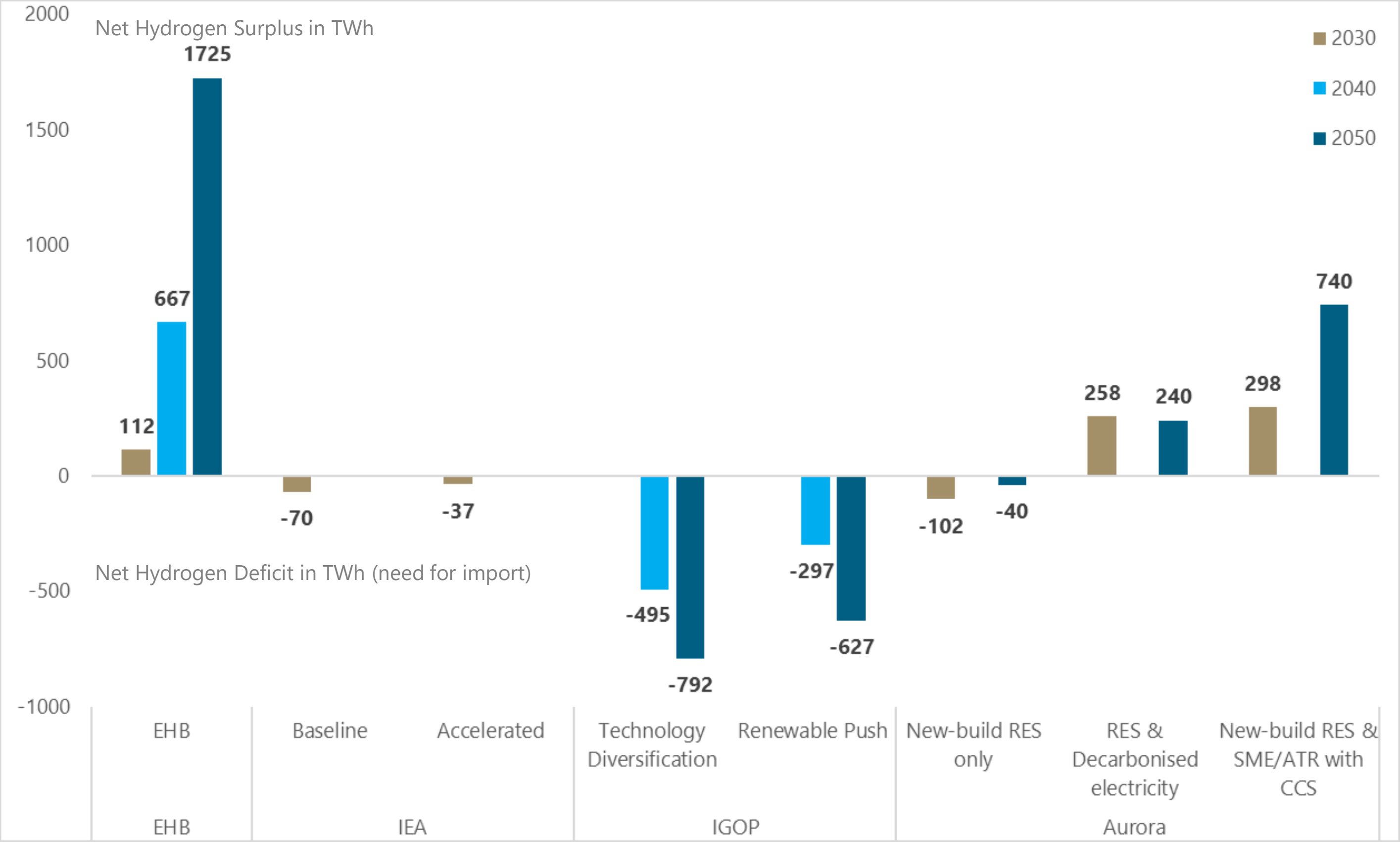
Hydrogen Imports and Exports Analysis

Report	Potential volume of imports/exports by country	Potential off-taker sectors
Aurora	• **If only new-build RES is used: EU net deficit of 69TWh.** • **Importing countries:** Germany, Belgium and the Netherlands (around 100-150 TWh of hydrogen imports in 2030). • **Germany:** import >100TWh, **Belgium** and the **Netherlands**: import 10 to 50TWh. • **Exporting countries:** France, Denmark, Norway and Sweden (around 60-110 TWh of hydrogen imports in 2030). • **Sweden:** export 50 to 100TWh, **France** and **Denmark:** export 10 to 50TWh, **Norway:** export up to 10TWh • **If all forms of RES and decarbonised electricity are used** for hydrogen production, there will be an EU **net surplus of 253TWh** from the potential exporting countries.	Clean hydrogen will supply **industry** needs by 2030, with demand for hydrogen reaching between 400-485 TWh.
EHB	• **Germany** has a **hydrogen deficit of 340TWh** when considering the production of green hydrogen alone. • **Countries with potential net surplus: Spain:** 895TWh, **France:** 65 TWh, **Italy:** 110TWh, **Sweden:** 380TWh	Hydrogen to supply demand of ~300 TWh of hydrogen for fuel production **(in refineries) and chemicals production.**
Hydrogen Council	• **Europe,** as a significant **importer**, is establishing potential offtake contracts with importing countries in North Africa and neighbouring countries.	Hydrogen will be used mainly in **refining and ammonia synthesis and steel** in 2030.
IEA	• **Baseline Scenario:** NW Europe has a **net hydrogen deficit** of around **6.6 TWh in 2030.** • **Belgium, Germany** and the **UK** have a net deficit of around ~ 2 TWh. **France and** the **Netherlands** have a net deficit of about ~1 TWh. • **Denmark** has a **net surplus** of 4 TWh. • **Accelerated Scenario:** NW Europe has a **net hydrogen deficit** of **35TWh** in the Accelerated scenario by 2030. • Net deficit from **Belgium** of ~ 2TWh, **France:** ~10TWh and **Germany: ~** 25 TWh. • **Denmark** and **Norway** have a **net surplus** of 4 TWh, and the **Netherlands** has a net surplus of around 5TWh.	Hydrogen supply is required to meet industry demand (mainly **refining and ammonia production**). However, **Germany** has the largest share of hydrogen demand and aims to use hydrogen in its extensive iron and steel industry, which is the main contributor to demand (>9.9 TWh).
IOGP	• Under the Technology Diversification and Renewable Push Pathways, **European hydrogen demand must be met with imports from outside Europe.** • Technology Diversification: import of **792 TWh** required to meet 2050 demand. • Renewable Push: import of **627 TWh** required to meet 2050 demand.	A focus on hydrogen use in transport either as a fuel **for fuel cells or as a feedstock for synthetic fuels (refineries)** and biorefineries.

Hydrogen Imports and Exports Analysis (From Global View)

Reports	Potential EU importers/exporters	Potential EU volumes of imports/exports
bp	• Under both the Accelerated and Net Zero scenarios, the EU produces around 70% of the low-carbon hydrogen for its uses in 2030. This share will fall to approximately 60% by 2050. • Of the **low-carbon hydrogen imported** to the region, around 50% is transported as pure hydrogen **via pipeline from North Africa and other European countries. The additional 50% is imported by sea as** hydrogen derivatives from global markets.	• The bp Energy Outlook does not provide a breakdown on the amount of hydrogen imported to countries within the EU.
DNV	• DNV's global hydrogen forecast identifies **Europe as a significant importing region.** • Europe will repurpose its natural pipelines with the Middle East and North Africa.	• DNV's global hydrogen forecast does not provide a breakdown of import values for European countries; however, it does report that Europe will import around **10TWh/yr** of hydrogen via pipelines by **2050** and states that in addition to local production, Europe has targets of **330TWh/yr renewable hydrogen imports**.
IRENA	• Hydrogen pipelines are mostly used for regional trade, with two major networks: Europe and Latin America. • **EU, Spain, Italy and China will form a trading hub.** In the area of trading hubs, net exports from **Spain** are almost double its demand. Still, total exports are three times larger, with it **acting as a transit country between the low-cost green hydrogen in North Africa and the rest of Europe through hydrogen pipelines**.	• The report does not provide a breakdown of import values for European countries; however, it states that in 2050, around **5097 TWh/year of green hydrogen will be globally traded.**

Hydrogen Supply and Demand (TWh)

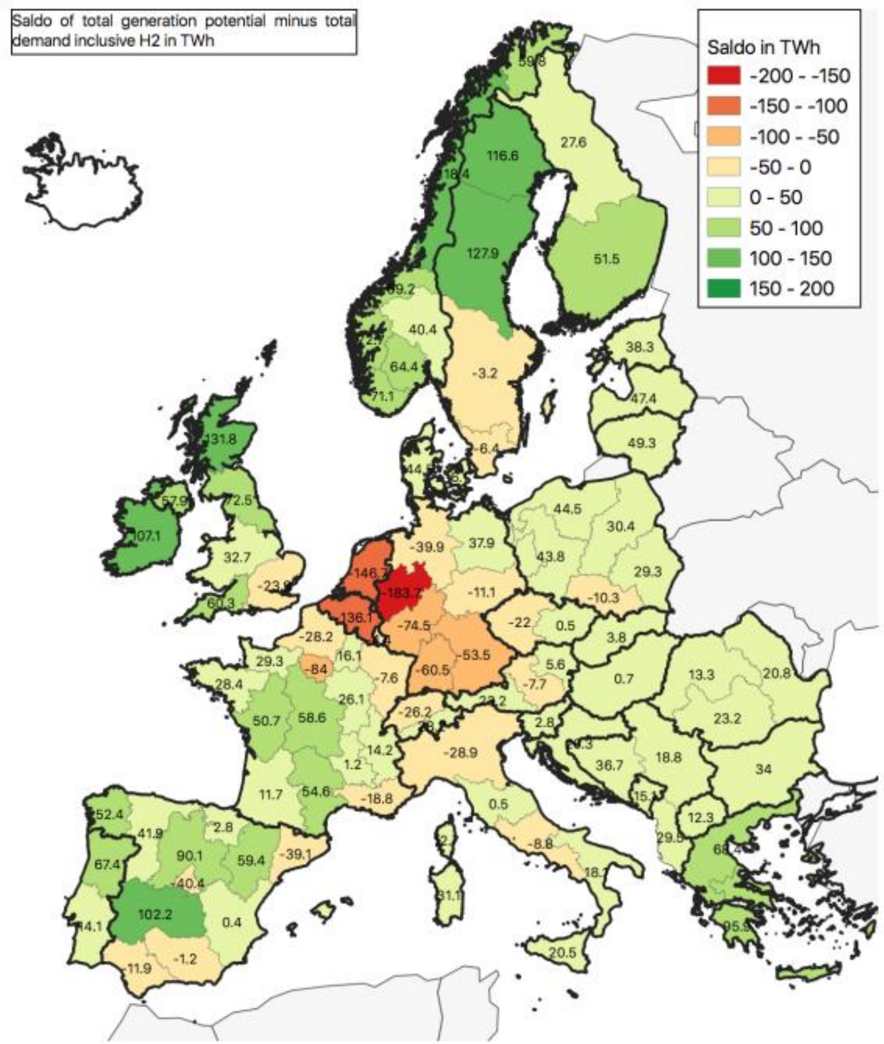


Analysis of EHB and Aurora scenarios shows that Europe can meet its hydrogen demand, assuming that the countries in the region will be producing low-carbon hydrogen (blue and green).

Considering only the production of green hydrogen, the IEA report predicts a net hydrogen deficit in North-West Europe by 2030. However, the report does state that this situation would be different for France and the United Kingdom if these countries met their national ambition for low-carbon hydrogen production capacity (e.g., the development of blue and pink hydrogen in France). If that is the case, supply in both countries would meet or exceed their demand.

IGOP also assumes that the countries will be producing green and blue hydrogen; however, it also predicts that imports from outside of Europe will be required to meet demand due to limitations on high land use requirements and resources for hydrogen production

Other studies on the need to import hydrogen



Balance of renewable generation potential and demand with electricity for hydrogen in Europe 2050[1]

This figure from the Infrastructure Needs policy brief shows a notable deficit of renewable generation potential for hydrogen production in Germany.

The report states that an electricity sink would be caused in Northwest Europe, particularly Germany, Belgium, and the Netherlands. It suggests that the industrial region in Northwest Europe must establish sufficiently robust and secure import and transit structures for electricity and hydrogen to relieve strain on the electricity grid.

The report states that import structures should enable intra-European import of remote areas with high renewable generation potential (e.g. Spain) and the import areas outside of Europe (e.g. North Africa).

1. [Infrastructure needs for deep decarbonisation of heavy industries in Europe: policy brief (wupperinst.org)]

Imports/Exports - Key Considerations

- The majority of scenarios foresee industry as the primary off-taker sector in the early 2030s, highlighting sizeable hydrogen demand in subsectors such as refineries for fuel production, ammonia production (fertiliser industry) and the iron and steel industry.
- Low-case scenarios under the European reports show that hydrogen demand in NW Europe could be met by domestic production, **highlighting the crucial role of low carbon hydrogen (e.g. blue hydrogen) in avoiding a net deficit of hydrogen supply across the region**.
- Most global and European high-case scenarios foresee Europe as an importer region due to its limited renewable resources (wind and solar) and that Europe will scale up its hydrogen economy proportionally earlier than in other geographies.
- According to global reports, hydrogen imports will be transported as pure hydrogen via pipeline from North Africa and other European countries (Norway and the UK) and imported by sea in the form of hydrogen derivatives (e.g. ammonia) from global markets.
- Many of these scenarios foresee Germany as an importer country, which is also emphasised in Germany's Hydrogen Strategy.

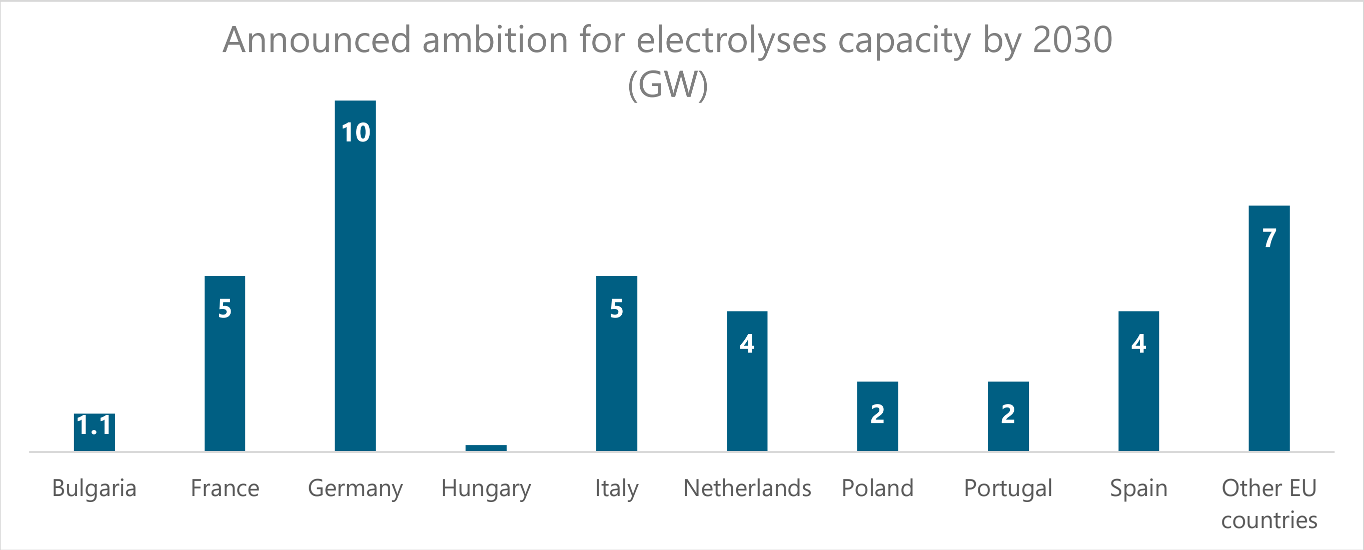
Current hydrogen trade background

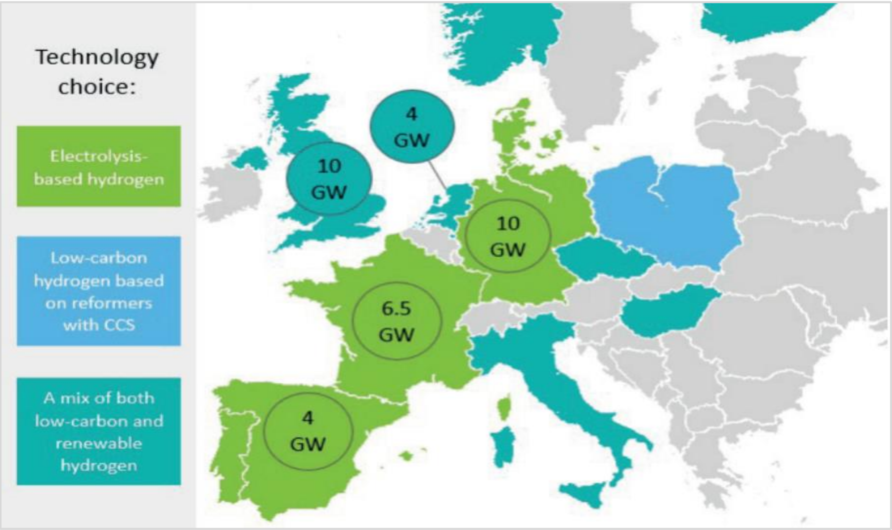
Hydrogen is not currently an international traded commodity. Whilst there is some local pipeline infrastructure of hydrogen pipelines in Texas and Northern Europe supplying major industrial hubs, the vast majority of hydrogen production is consumed in an adjacent industrial facility as feedstock or fuel, with just minimal piping in between. Hydrogen storage at scale is almost non-existent. There is a secondary market for very small users of hydrogen, met by supply of hydrogen in cylinders by truck. These amounts though are tiny in comparison to major industrial users. There is currently no infrastructure globally for import and export of hydrogen.

Individual Country H_2 Strategy Summary

European Union Hydrogen Strategies

- 16 EU Member States have adopted national hydrogen strategies, which collectively amount to 40 GW of electrolyser capacity targeted for 2030, or 5.6 million tonnes of renewable hydrogen (185 TWh)*.
- Strategies are seen as aspirational policy documents developed by the government rather than forecasts with detailed modelling behind them.
- According to Germany's updated version of its Green Hydrogen Strategy (2022), even though doubling the country's domestic electrolysis capacity target for 2030 to at least 10 GW, Germany will need to import around 50% to 70% of its hydrogen demand, forecast at 95 to 130 TWh in 2030 (currently German demand for hydrogen is 55 TWh - mostly grey hydrogen in industry)*.





*Factsheet Germany's National Hydrogen Strategy Update 2023_0.pdf (adelphi.de)

Scenarios Assumptions Table

Aurora Energy Scenario Assumptions Table

The public report summarises the findings of an industry-sponsored research undertaking. It is clear that significant amounts of modelling were done behind the report, but these have yet to be made public. The implication is that many of the essential data points are missing.

Aurora Scenario Building Blocks

Government Parameters

- *Policy*
- *Emissions Reduction Fund*
- *Certification schemes*
- *Regulation levels*
- *Carbon tax*

Policy

- *Future policy interventions should support the development of a scenario where full life cycle emissions are minimised.*
- *CFDs are stated to be preferred*
- *In the high-demand scenario, policy is seen as a market determinant with interventions taken to provide investment into markets.*

Hydrogen Other

- *Water availability is not discussed in the report. Therefore, it should be viewed as an implicit assumption of a non-limiting factor.*

Infrastructure

- *No hydrogen pipelines in place by 2030*
- *Implicit assumption that it will be in place by 2050, enabling adoption by industry.*

Geopolitical

- *No further geopolitical shocks are included; therefore, they are implicit in the modelling.*
- *Certification schemes are included to allow optionality outside of renewable hydrogen.*

Price

- *No specific data points on price-based attributes are provided. This needs to be considered a black box.*

Export Facilities

- *Implicit in the report is that export facilities are available when needed*

Price-Based Attributes

- *Technology CAPEX and OPEX*
- *Cost out curves*
- *Insurance etc*

Non-Price Attributes

- *Technology development*
- *Geopolitical movements*

EHB Hydrogen Scenario Assumptions Table

The EHB report summarises the findings of a group of thirty-three energy infrastructure operators with the vision of defining the critical role of hydrogen infrastructure – based on existing and new pipelines – in enabling the development of a competitive, liquid, pan-European renewable and low-carbon hydrogen market. It presents a transparent methodology, at the EU country-level, based on a bottom-up analysis of sector-specific future hydrogen demand (industry, transport, power and buildings). Sources and metrics used to build assumptions are detailed in the report.

EHB Scenario Building Blocks

Government Parameters

- *Policy*
- *Emissions Reduction Fund*
- *Certification schemes*
- *Regulation levels*
- *Carbon tax*

Policy

- *It is assumed that policy measures are implemented to support European and national climate mitigation goals. It includes adequate regulatory frameworks and financial incentives to scale green hydrogen up.*
- *CBAM, zero-emission policies in aviation, and the requirement of a strong policy to drive hydrogen uptake in the buildings sector are mentioned.*

Infrastructure

- *Key to the creation of the scenario, hydrogen pipelines are stated to be the most cost-efficient option for long-distance, high-volume transport of hydrogen to connect hydrogen supply regions with demand clusters within the EU+ UK.*
- *Europe's hydrogen pipeline infrastructure grows by repurposing existing natural gas pipeline infrastructure and building new ones.*

Price

- *Green and blue hydrogen production costs are provided at the country level, assuming hydrogen is produced from dedicated solar PV, onshore wind, or offshore wind projects (LCOH for green ~ 2 €/kg in 2030).*

Hydrogen Other

- *It is mentioned that existing and expected regional water supplies must be analysed carefully to ensure that local water supplies are not depleted for water electrolysis.*
- *Regional freshwater availability or feasibility of desalination was out of scope, an implicit assumption of a non-limiting factor.*

Geopolitical

- *When comparing hydrogen transport methods and supply routes, analysis was not performed to determine the optimal route from an economic, geographical, and geopolitical perspective.*

Export Facilities

- *Implicit export infrastructure is under consideration when assessing import routes into Europe.*
- *For example, it evaluated options for imports/exports via pipeline or shipping (e.g., shipping to Rotterdam, construction of subsea pipeline, etc.*

Price-Based Attributes

- *Technology CAPEX and OPEX*
- *Cost out curves*
- *Insurance etc*

Non-Price Attributes

- *Technology development*
- *Geopolitical movements*

EU JRC Scenario Assumptions Table

The publicly available scenario is a visual tool developed by the European Commission. It is clear that significant amounts of modelling are done behind the scenarios. A detailed report describing the model is available; however, it is dated 2013. The implication is that many essential data points must be updated with the latest EU policies and regulations.

EU JRC Scenario Building Blocks

Government Parameters

- *Policy*
- *Emissions Reduction Fund*
- *Certification schemes*
- *Regulation levels*
- *Carbon tax*

Policy

- *The EU 2050 roadmap policies, as considered in PRIMES, were used as a benchmark to decide on the policies included in the JRC-EU-TIMES model.*
- *Key policies mentioned: support to RES: Feed-in Tariffs and green certificates, REDII, and CO_2 targets (EU ETS).*
- *Note that the scenarios-basis was built in 2013 and has probably been updated; however, it is inaccessible.*

Infrastructure

- *Within the 31 modelled countries, grid infrastructure has the total installed trans boundary capacity increased from roughly 122 GW in 2005 to 193-195 GW in 2025 (a growth of ~57-60% from 2005) and up to 202-205 GW in 2050 (an increase of ~ 4-6% from 2025*
- *For the non-European countries with which there is a possibility for electricity trade, JRC-EU-TIMES considers both import/export processes regarding the existing infrastructures (capacity and flows) from the rest of the world.*

Price

- *No specific data points on price-based attributes are provided. This needs to be considered a black box.*

Hydrogen Other

- *Water availability is not discussed in the report. Therefore, it should be viewed as an implicit assumption of a non-limiting factor.*

Geopolitical

- *No further geopolitical shocks are included; therefore, they are implicit in the modelling.*
- *Certification schemes are included to allow optionality outside of renewable hydrogen.*

Export Facilities

- *In the JRC-EU-TIMES model, hydrogen delivery begins with hydrogen conditioning and is completed by delivering hydrogen to end users. Subprocesses include underground gas storage, liquefaction, compression, storage in tubes, pipeline distribution, and road and sea transportation and refuelling, depending on the selected pathway of hydrogen delivery.*
- *Implicit in the report is that export facilities are available when needed*

Price-Based Attributes

- *Technology CAPEX and OPEX*
- *Cost out curves*
- *Insurance etc*

Non-Price Attributes

- *Technology development*
- *Geopolitical movements*

Hydrogen Council Scenario Assumptions Table

The public report summarises the findings from a global perspective. It is clear that significant amounts of modelling have been done behind the report, but these have yet to be made public. The implication is that many of the essential data points are missing.

Hydrogen Council Scenario Building Blocks

Government Parameters

- *Policy*
- *Emissions Reduction Fund*
- *Certification schemes*
- *Regulation levels*
- *Carbon tax*

Policy

- *Future policy interventions should support the development of a scenario where full life cycle emissions are minimised.*
- *Rapid acceleration of grey phase-out depends to a large extent on the carbon price.*
- *Additional policies are required for net-zero scenarios, such as RED and swift phase-out of free allowances to convert grey hydrogen in use cases where CO_2 price is insufficient as policy instruments. Implementation of e-fuels mandate is also mentioned.*

Hydrogen Other

- *Water availability is not discussed in the report. Therefore, it should be viewed as an implicit assumption of a non-limiting factor.*

Infrastructure

- *Clear statement that an investment gap of over USD 170 billion remains within transmission, distribution, and storage.*
- *Investments in this part of the value chain are critical to enabling access to cost-competitive hydrogen supplies.*
- *Examples include connecting the regions with the lowest production costs to demand hubs, developing refuelling infrastructure for vehicles, or building pipelines to supply industrial plants.*

Geopolitical

- *Implicit assumption that the macro environment remains stable, i.e., steady GDP growth globally, no major geopolitical shifts, and that commodity prices remain stable over time (i.e., no long-term price spike or significant price fall long-term).*

Price

- *It is mentioned that the estimates on the share of newly built renewable and low-carbon hydrogen are based on production cost optimisation across regions and over time. However, no specific data points on price-based attributes are provided.*
- *This needs to be considered a black box.*

Export Facilities

- *Implicit in the report is that export facilities are available or built when needed.*
- *It is under the assumption that shipping terminals or domestic pipelines link production centres with either ports for exports or short-distance domestic transmission system operators (TSO) and pipeline connections for hydrogen distribution.*

Price-Based Attributes

- *Technology CAPEX and OPEX*
- *Cost out curves*
- *Insurance etc*

Non-Price Attributes

- *Technology development*
- *Geopolitical movements*

IEA Scenario Assumptions Table

The public report summarises the findings of a recognised international organisation. The report promotes the potential renewable energy in the North Sea, which is central to decarbonisation strategies for countries in this region. It is clear that significant amounts of modelling have been done behind the report, but these still need to be presented in the report. The implication is that many of the essential data points are missing.

IEA NW Europe Scenario Building Blocks

Government Parameters

- *Policy*
- *Emissions Reduction Fund*
- *Certification schemes*
- *Regulation levels*
- *Carbon tax*

Policy

- *Future policy interventions should support the development of a scenario where full life cycle emissions are minimised.*
- *Baseline scenario considers only policies already in place with specific measures enacted (EU, ETS, RED-II).*
- *Accelerated scenario is based on the achievement of 2030 emission reduction targets (e.g. Fif-for-55, EV mandates,* Adoption of measures to deliver the EU and national hydrogen strategies

Hydrogen Other

- *Water availability is not discussed in the report. Therefore, it should be viewed as an implicit assumption of a non-limiting factor.*

Infrastructure

- *The Accelerated scenario assumes a rapid deployment of enabling infrastructure.*
- *The potential for a hydrogen backbone to support a market creation for hydrogen is mentioned.*
- *It considers that hydrogen pipeline infrastructure is already in place, and a significant natural gas infrastructure could be repurposed as natural gas demand drops in the region.*

Geopolitical

- *The report mentioned possible cooperation within the North Sea region and geographically broader initiatives, such as the Hydrogen IPCEI as well as hydrogen imports from other continents via pipelines and shipping.*

Price

- *Low-carbon alternatives: production of blue costing EUR 1.9-2.1/kg H2 and from electrolysis EUR 2.7-7/kg H2.*
- *In combination with declining costs for electrolysers, hydrogen production costs from offshore wind could fall to EUR 2.5-3.5/kg H2, assuming offshore hydrogen production and including hydrogen transport costs to shore.*

Export Facilities

- *The development of hydrogen trade across the EU countries could use the well-known largest industrial ports in Europe, such as Rotterdam, Antwerp, Hamburg or Bremerhaven.*
- *The ports of Rotterdam and Zeebrugge together are an important liquefied natural gas hub and would be an ideal candidate to become a hydrogen hub.*

Price-Based Attributes

- *Technology CAPEX and OPEX*
- *Cost out curves*
- *Insurance etc*

Non-Price Attributes

- *Technology development*
- *Geopolitical movements*

IOGP Scenario Assumptions Table

The public report summarises the findings of a global organisation, the International Oil & Gas Producers Association. There are many considerations for blue hydrogen production, highlighting its crucial role to European countries in meeting their demand in 2030. It presents a transparent methodology for future hydrogen demand (industry, transport, power and buildings). Sources and metrics used to build assumptions are detailed in the report.

IOGP Scenario Building Blocks

Government Parameters

- *Policy*
- *Emissions Reduction Fund*
- *Certification schemes*
- *Regulation levels*
- *Carbon tax*

Policy

- *The modelling framework is aligned with the agenda of the European Green Deal and EU pillars and climate targets, incorporating the primary targets for CO_2 emission reductions, the share of renewable energy deployment, energy efficiency, and national decisions on the phasing out of coal and nuclear plants for power generation, among others.*
- *It includes policies such as REPowerEU, Fit-for-55 regulations, REDIII, EU ETS, etc.*

Hydrogen Other

- *The countries in scope for hydrogen exports suffer from water scarcity issues. While water availability and cost were taken by assuming water desalinisation units, further analyses could include the energy and carbon footprint and costs associated with brine handling.*

Infrastructure

- *The report considers the increasing need for a fully developed and efficient hydrogen infrastructure that connects hydrogen hubs and allows for the development of a liquid hydrogen market.*
- *Cumulative investments in transport, storage, distribution and refuelling top €850 billion.*

Geopolitical

- *Recent geopolitical and macroeconomic upheavals, including the invasion of Ukraine by Russia in February 2022, were considered.*
- *The current situation encourages European policymakers to double down on their climate neutrality commitments and those of energy security.*

Price

- *The model assumes that the market sends the right price signals to encourage switching to alternative technologies. However, many barriers exist at market and regulatory levels that prevent low carbon solutions from competing on a level playing field with today's emitting technology.*

Export Facilities

- *It is assumed that hydrogen import/export infrastructure will be developed.*
- *For national inland transport hydrogen trucks, either with compressed hydrogen or ammonia trucks. For international transport, pipelines, ammonia shipping and liquified hydrogen (LH2).*
- *A dedicated hydrogen network in the EU is progressively built by repurposing some natural gas pipelines and constructing new ones. Deployment of such a network would start from industrial clusters in 2030, expand to EU interconnectors by 2035 and reach some non-EU interconnectors by 2040.*

Price-Based Attributes

- *Technology CAPEX and OPEX*
- *Cost out curves*
- *Insurance etc*

Non-Price Attributes

- *Technology development*
- *Geopolitical movements*

Top Level Assessment

EHB, IOGP and Aurora are considered the best-described scenarios with clearer and more detailed assumptions. While EHB is an exploratory (quantitative) scenario, IOGP and Aurora fall under a normative perspective.

Source	Are the scenarios Exploratory (Quantitative) or normative?	Is it clear what the are?	Is the scenario methodology well documented?	Is this information accessible to be drilled into?	Are the assumptions clear and interpretable?	Are they following clear best practice?
Aurora Energy Research	Normative	Yes	Lack of details	Lack of details	Yes	Yes
European Hydrogen Backbone Initiative	Quantitative	Yes	Yes	Yes	Yes	Yes
EU Joint Research Centre TIMES	Normative	Yes	Lack of details	Lack of details	Lack of details	Lack of details
Hydrogen Council – McKinsey	Normative	Yes	No	No	No	Lack of details
IEA NW Europe	Quantitative	Yes	Lack of details	No	Lack of details	Lack of details
IOGP Europe report – Deloitte, IFPEN, Carbon Limits, SINTEF	Normative	Yes	Yes	Yes	Yes	Yes

Yes

Lack of details within the report/model

No

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Conclusions

Conclusions – Report Shortlisting

- 12 reports containing 23 scenarios were initially identified for initial screening. After applying our Heat Map approach, Advisian selected six reports (totalling 11 scenarios) for further detailed analysis.
- Key selection criteria were that the reports present a hydrogen demand timeframe between 2030 and 2050, provide Europe/EU demand by sub-sector, and provide a transparent methodology.
- Only one report was specific to NW Europe, the IEA report.
- There were several global reports which provided some European information. We have also extracted this information where possible.
- We identified very few research reports; the only one selected was by the individual authors of the IOGP report, who are not academics. We think this is because of the long lead time between academic paper development, review and publication. Our cut-off point was post-2020 for relevance.
- We have only used material in the public domain. We have not used scenarios that require paid subscriptions to access for two reasons. Firstly, the material cannot be shared. Second, the underlying models are considered IP and not disclosed for review.

Conclusions – Shortlisted Reports

- Generally, the reports are of high quality, which is one of the reasons they were shortlisted.
- The six reports shortlisted have their strengths and weaknesses and inevitable biases based on the composition of the report's sponsor.
- Exploratory scenarios are more likely to predict 2030 hydrogen demand than backcasting from 2050 outcomes based on normative scenarios.
- **In our opinion, the EHB initiative report and the IOGP stand out as the most thorough**. However, we expect the Scottish Government to take its view of the relative merits of the individual reports. It is essential to mention that IOGP is the most recent report and considers all current EU Green hydrogen-related policies, such as the REPowerEU Plan.
- The Aurora and the IEA NW Europe reports are also very good, but Aurora lacks details regarding methodology and assumptions within the report. The IEA report only goes out to 2030 and does not detail the methodology used.
- Water sourcing, decommissioning at end-of-life, and critical minerals were not included in any scenarios.
- None of the scenarios look at the underlying business cases or take a stance of ability to create profitable projects. They all assume it will be met if there is low carbon demand.
- Hydrogen supply/demand imbalances are generally not mentioned unless they relate to the need for blue hydrogen. There needs to be a move away from captive to include a spot market, which is not covered.

Conclusions – Further Reports

- Thinking on future hydrogen demand is continuously evolving, with a shift over the last year away from transport (except hydrogen derivatives for shipping and aviation) towards industrial use in hard-to-abate sectors. The industry sector is currently the primary user of hydrogen and is the only sector with a substantial demand across all scenarios. Hydrogen use in industry and industrial heating will likely increase with increased demand for hydrogen and its derivatives.
- Hydrogen for heating buildings is contentious; however, it is expected to play a role in some scenarios, assuming that policy decisions would support the deployment of hydrogen in this sector. The extent of its role varies widely between reports, with the IEA not considering it as an option. Counter to this; Aroura mentions that hydrogen would become a significant source for heating buildings in countries in Northwest Europe relying on natural gas. Although the authors recognise hydrogen is not the most efficient option for decarbonising buildings.
- Across all scenarios, hydrogen demand in transport through fuel cell electric vehicles (FCEV) is expected to be significant; however, how the FCEV market develops against the increasing market penetration by electric vehicles (EVs) is uncertain.
- Demand for hydrogen from the transport sector will also come through the development of low-carbon liquid fuels such as sustainable aviation fuel (SAF) and hydrotreated vegetable oil (HVO). However, the availability of sustainable, low-cost feedstocks will likely be a limiting factor in the development of this market.
- Updates to these reports (and new reports) will continue to emerge, so the findings inevitably reflect a snapshot in time.
- Where the scenarios are split into countries, Germany unsurprisingly has the highest demand.
- It is uncertain how much hydrogen will be produced in Europe – owing to competition with electrification and limitations in the supply chain. Therefore, domestic hydrogen production will likely be limited by increasing electrification ambition and supply chain, opening the market to imports.

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Appendix

Units of Measurement

Hydrogen Flow Basis	Yearly		Daily		Hourly		Reference conditions
	UOM	Amount	UOM	Amount	UOM	Amount	
Energy Flow (LHV)	TWh	**1000**	GWh	2740	GWh	114	
Energy Flow (HHV)	TWh	1182	GWh	3239	GWh	135	
Energy Flow (LHV)	PJ/y	3600	PJ/d	10			
Energy Flow (HHV)	PJ/y	4256	PJ/d	12			
Mass Flow	mill TPA	30	kTPD	82	t/h	3426	
Standard Gas Flow	BCMA	352	mill Sm^3/d	964	k Sm^3/h	40183	1 atm, 15°C
Normal Gas Flow	BCMA	334	mill Nm^3/d	914	k Nm^3/h	38090	1 atm, 0°C

List of Abbreviations

UOM	Unit of measurement
LHV	Lower heating value
HHV	Higher heating value
TPA	Tonnes per annum
BCMA	Billion cubic meters per annum

1000 TWh per year is equivalent to around 30 million tonnes of H_2

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