

Hydrogen

supply and demand: present to 2030

Update november 2019

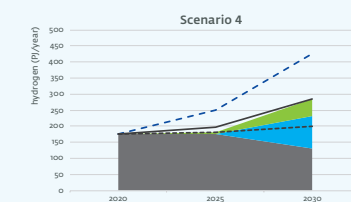
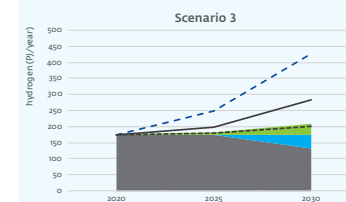
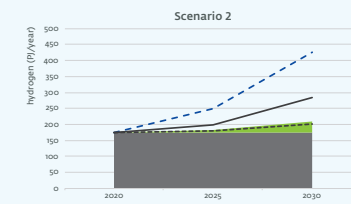
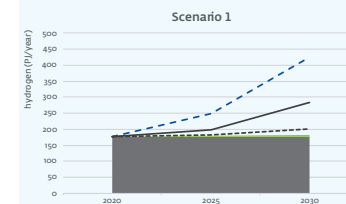
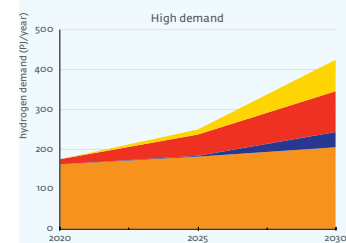
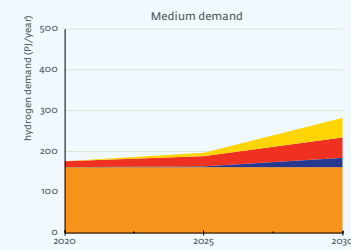
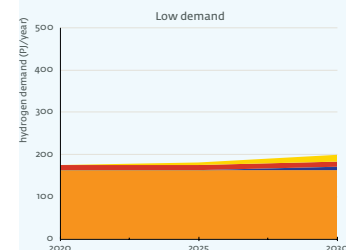
Contents

Summary	3
General approach to supply and demand scenarios and need for infrastructure.....	4
Current hydrogen market in the Netherlands	5
Hydrogen demand	6
Hydrogen demand in various sectors.....	7
Hydrogen as a feedstock for industry.....	8
Hydrogen for heating processes in industry	9
Hydrogen in transport & mobility.....	10
Hydrogen in the built environment	11
Hydrogen for zero-carbon electricity production.....	12
Potential of blending hydrogen with natural gas	13
Hydrogen supply.....	14
Supply scenarios	15-18
Import & export	19
Bibliography	20
Appendix	21

Summary

When the Dutch Climate Agreement was drawn up in November 2018, the cross-sectoral working group on hydrogen calculated the potential hydrogen supply and demand in the Netherlands in 2030. In the calculations, demand scenarios were created for the different sectors, with a low, medium and high projection. Various supply scenarios were also made. In this update, these scenarios have been fine-tuned using the latest insights:

- The current demand for hydrogen is, in the chemical industry in particular, significantly higher than originally projected: 175PJ (48.8TWh or 1.5Mton) rather than 110PJ.
- In 2030, the demand for and supply of sustainable hydrogen will have just started to get going; a significant increase is expected towards 2050 due to its use in several sectors, such as the built environment and aviation and shipping. This projection is currently being elaborated in the II3050 study.
- The supply and demand scenarios presented are not necessarily in balance with each other. The loss of large projects on either the supply or demand side (or both) can seriously disrupt the balance.
- A demand higher than shown for the medium scenario could possibly lead to the need to import foreign hydrogen. It is still unclear whether sufficient imports could be arranged in the period leading up to 2030.
- Gasunie will put the consequences of these scenarios for the infrastructure on the agenda separately.



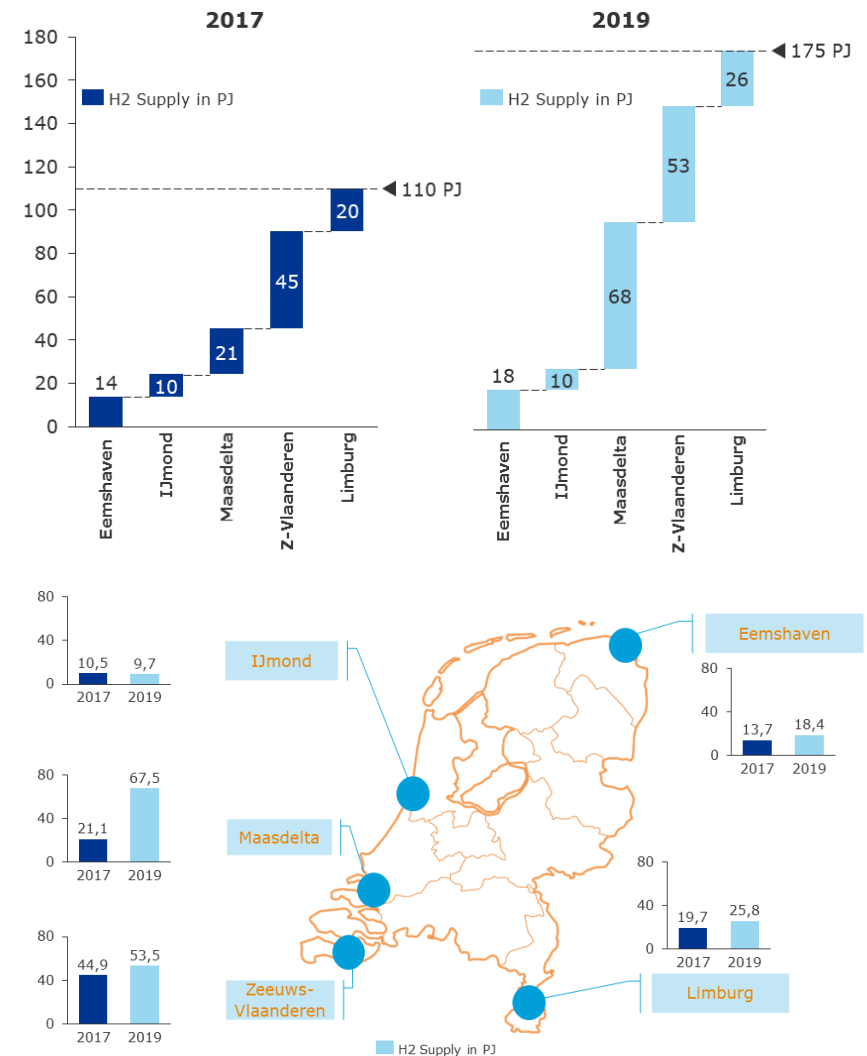
General approach to supply and demand scenarios and need for infrastructure

- The main focus is on the year 2030. For the demand for hydrogen, three demand scenarios (low, medium, high) have been developed for each market segment, while, for supply of hydrogen, four supply scenarios have been developed. A 'strict match' has not been made between the supply and demand scenarios.
- In November 2018, a survey was made of all available studies for hydrogen demand in the various market segments in the Netherlands for the 2015-2050 period. Studies covering Europe and the world have been 'recalculated' to arrive at the equivalents for the Dutch situation. This survey was used when drafting the Dutch Climate Agreement.
- For the 2020-2030 period, based on information about projects, studies and other climate tables, demand scenarios were developed using a bottom-up approach. For all scenarios it is shown how these compare to the study findings.
- For the 2030 supply, four scenarios were developed based on the different plans and possibilities in the market.
- In this update, the assumptions used last year were tested against the latest insights concerning the supply and demand of hydrogen between now and 2030.
- In the report, the amount of hydrogen is expressed in petajoules (PJ). 100PJ is equivalent to 827kt, 9.2bcm, and 28TWh. The lower combustion value of hydrogen has been used in all calculations.

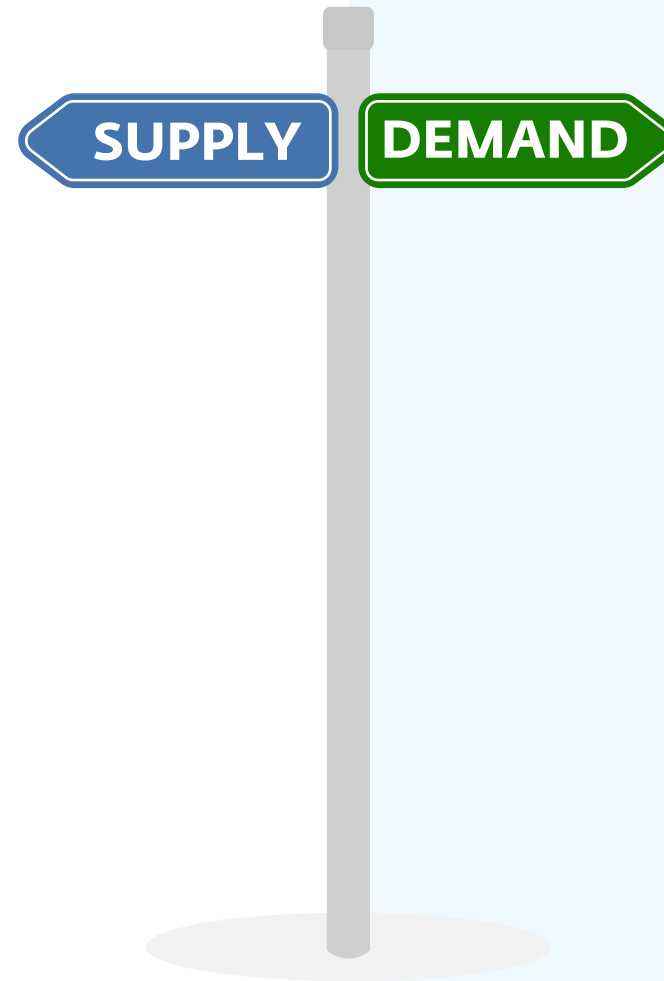
Current hydrogen market in the Netherlands

DNV GL recently surveyed the current hydrogen market in the Netherlands. The 2017 analysis used the data from the Roads2Hy project (2007). Current supply and demand appears to be 175PJ, however, significantly higher than the previously projected 110PJ. This increase can be explained, in particular, by the investments in additional hydrogen production in the Rhine-Meuse delta area, an increase in the capacity for methanol production in Delfzijl, and an update on the ammonia production.

At present, the supply and demand of hydrogen shows virtually no fluctuations in the Netherlands. Only a small amount of hydrogen is imported using a hydrogen grid shared with Belgium. With the exception of the clusters in the Zeelandic-Flanders region and the Rhine-Meuse delta, which are connected using the same hydrogen grid, supply and demand are matched per industrial cluster.

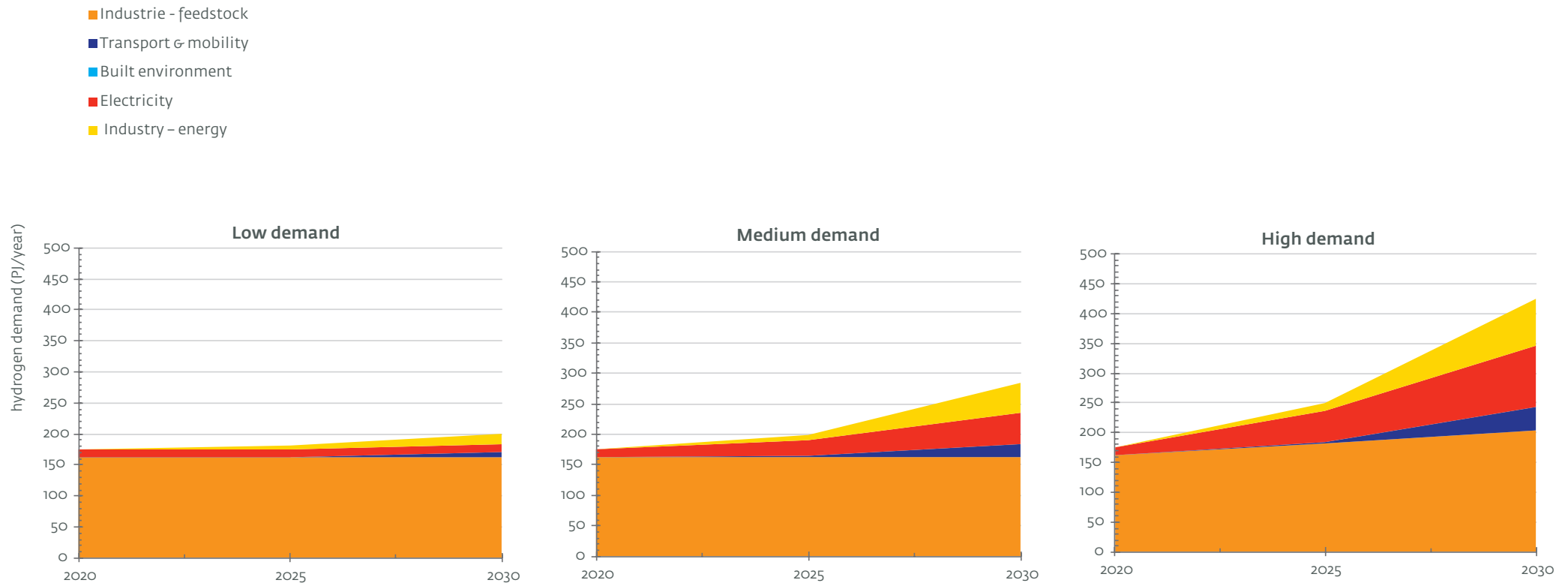


Hydrogen demand



Hydrogen in various sectors

Three scenarios for 2030



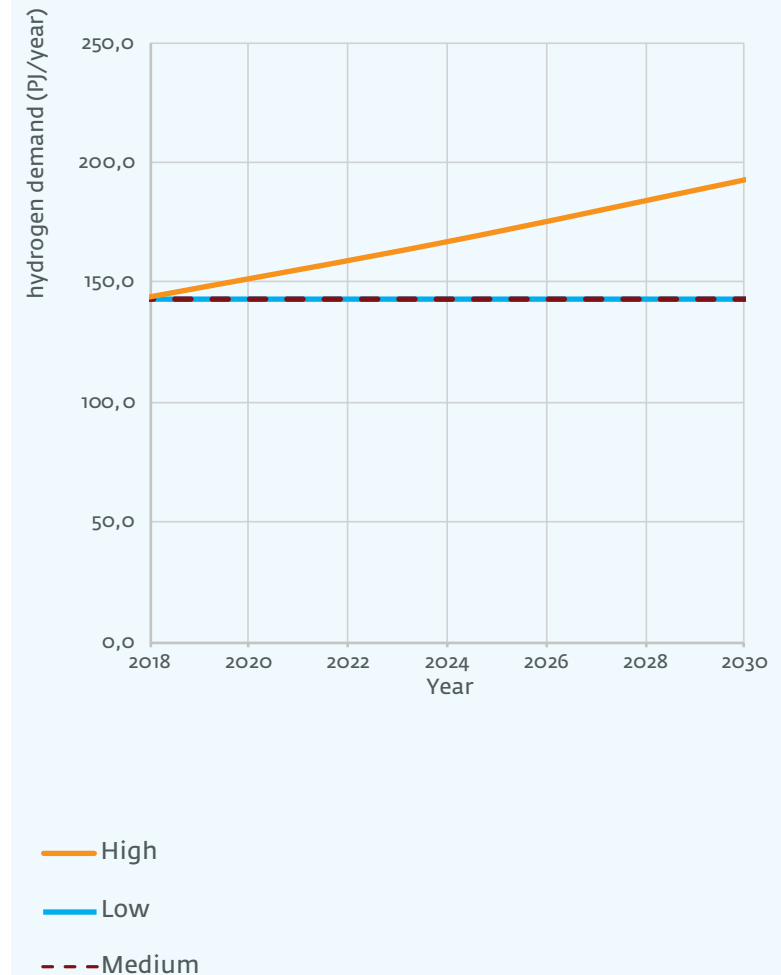
Hydrogen as a feedstock for industry

The current demand for hydrogen as a feedstock is 163PJ, broken down as follows:

- Ammonia (65PJ): where hydrogen is combined with nitrogen (N_2) to produce ammonia (NH_3), generally for the production of fertilizer.
- Refining (59PJ): where hydrogen is used for removing sulphur from petroleum products (hydrotreating) and for cracking long-chain hydrocarbons from petroleum to produce shorter chains.
- Methanol (18PJ): where hydrogen is reacted with carbon dioxide to produce methanol (CH_3OH), which can then be used either as a fuel or as a feedstock in various chemical processes.
- Various other chemical processes (21PJ) such as hydrogenation (converting double bonds into single bonds; used for hardening oils for example), production of hydrogen peroxide, and steel treatment.

Assumptions for the three scenarios:

- The low scenario assumes a stable demand until 2030 and thereafter a decrease of 5% per five years due to a declining demand for oil products, among other things.
- The medium scenario assumes a stable demand until 2030, with the expected decrease in oil products being offset by an increasing demand for hydrogen in new chemical processes.
- The high scenario assumes an increase of 12% every five years thanks to an increasing demand for refining, ammonia and fuels or chemicals. Examples include the production of methanol, synthetic fuels, steel2chem and waste2chem.



Hydrogen for heating processes in industry

Hydrogen can also be used in various industrial heating processes. The heating applications can be divided over nine specific industries, i.e.:

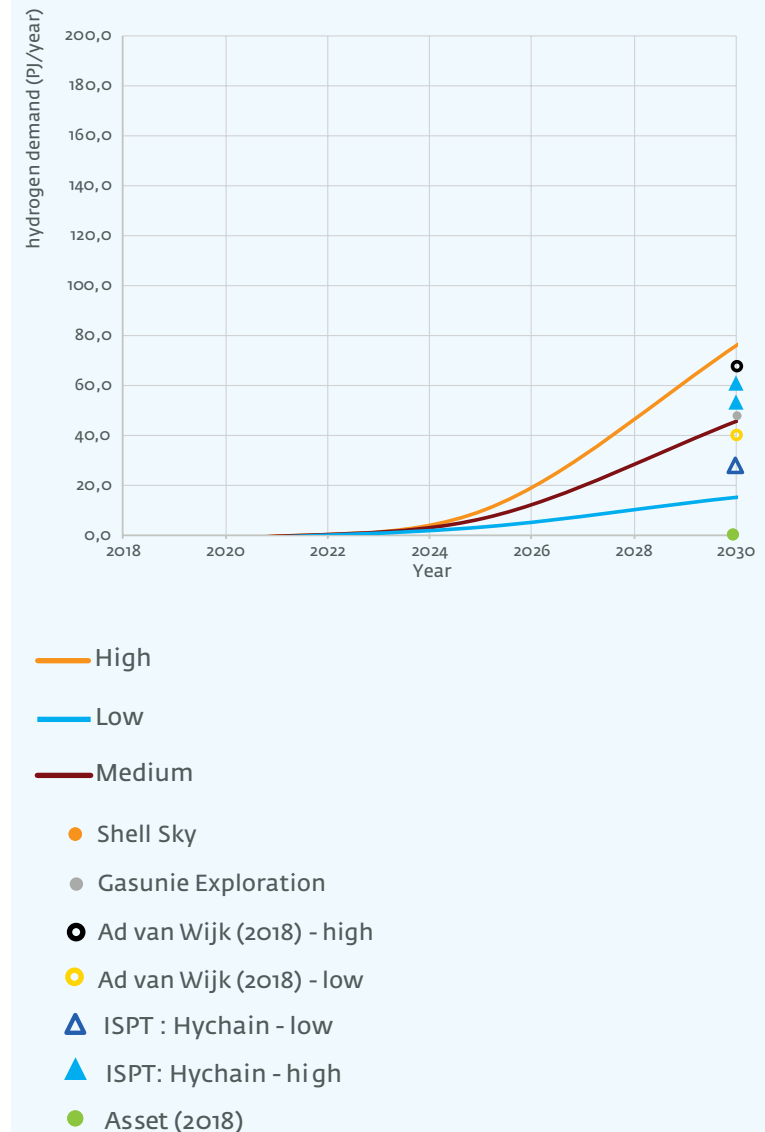
- Glass
- Ceramics
- Drying
- Chemical conversion/distillation
- Foundries
- Non-ferrous
- Smelting/annealing steel
- Other high-temperature processes
- Low temperatures

An estimate has been made for each specific industry based on the technical potential (DNV GL study¹) for pilot (5%), market introduction (50%) and implementation (100%) for the various industrial processes.

Assumptions for the three scenarios:

- The low scenario mainly assumes use in the electrification of the heating processes. The remaining role of hydrogen varies per specific industry.
- The high scenario assumes partly an electrification of the heating processes and partly a replacement of natural gas with hydrogen (70% of the current natural gas demand).
- The medium scenario is the average of the high and low scenario.

¹ - DNV GL, Exploration into the possibilities for replacing natural gas with hydrogen in industrial heating processes (2018)



Hydrogen in transport & mobility

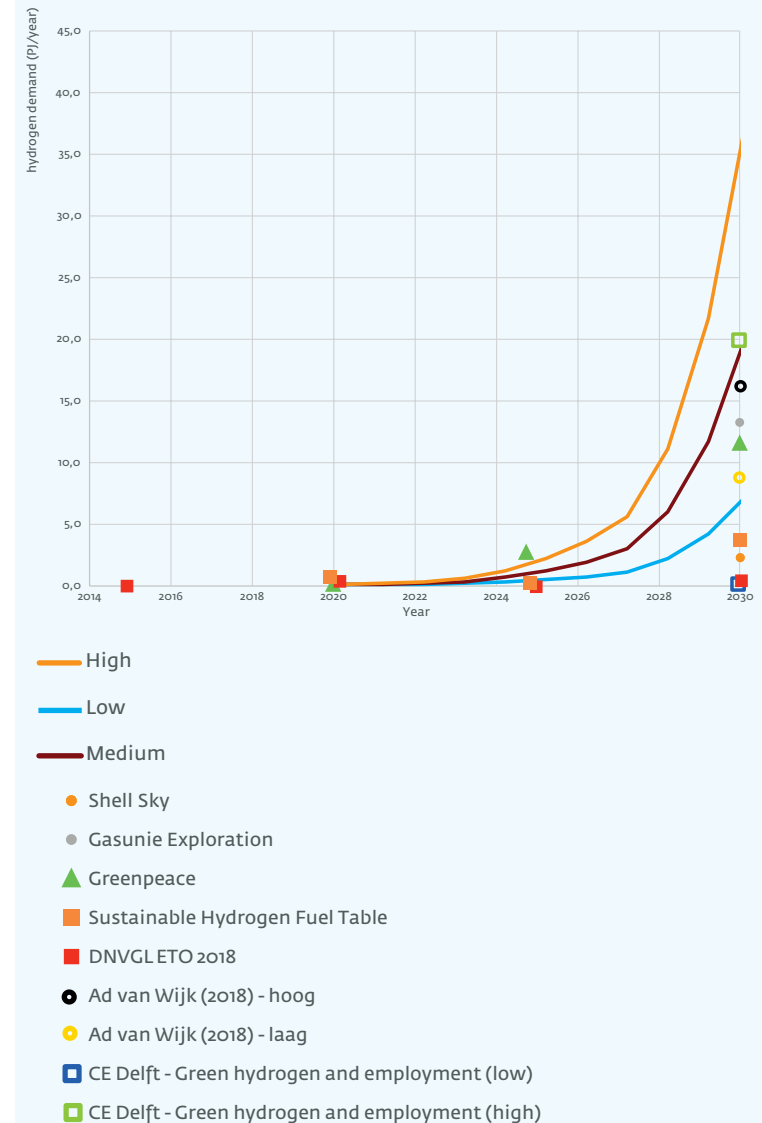
- The number of hydrogen cars is increasing in the Netherlands: there were around 50 fuel cell cars in 2018; in November 2019 this had climbed to 1762².
- In addition to the 176 cars, there are currently 7 buses, 7 trucks and 5 delivery vans that run on hydrogen.
- The Dutch Climate Agreement assumes there will be 15,000 passenger fuel cell electric vehicles (FCEVs) and 3000 heavy transport vehicles with a fuel cell by 2025. The number of passenger FCEVs may increase to 300,000 by 2030, while 5000 zero-emission buses will be carrying passengers³.

Assumptions for the three scenarios:

- The medium scenario assumes 375,000 hydrogen-powered vehicles in 2030, subdivided into 300,000 passenger vehicles, 65,000 delivery vans, 7700 trucks and 1700 buses.
- The low scenario assumes a total of 132,000 hydrogen vehicles, with the same distribution as the medium scenario.
- The high scenario assumes a total of 696,000 hydrogen vehicles, also with the same distribution as the medium scenario.
- Each of the three scenarios assumes an annual hydrogen consumption of 56GJ/yr (passenger vehicles) and 41GJ/yr (heavy transport).r).
- The significant potential for the use of hydrogen in the aviation and shipping sectors is currently anticipated for the period after 2030 and so is not included in this update.

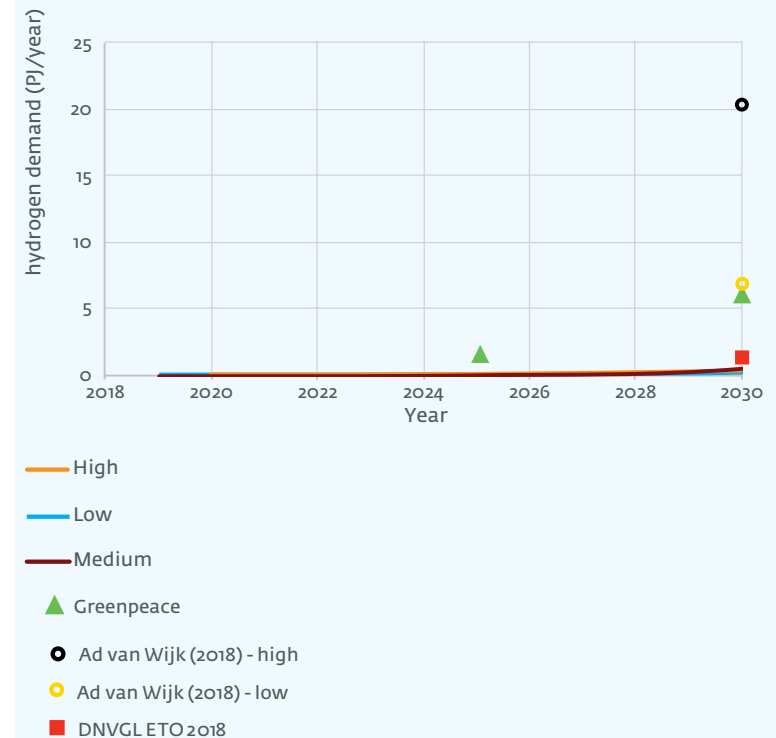
2 - Bronnen: Open data RDW (opendata.rdw.nl), <https://zerauto.nl/tienduizend-waterstofautos/en>
<https://www.leaseblog.nl/jaarwaterstofvraag> (PJ/jaar)030282026202420220202028102610241020,540,040,530,030,520,020,510,010,50,0 algemeen/aantal-waterstofautos-neemt-toe-in-2019/

3 - Dat is inclusief andere zero-emissie opties naast waterstof, voor waterstof wordt uitgegaan van 1700 bussen in het midden scenario



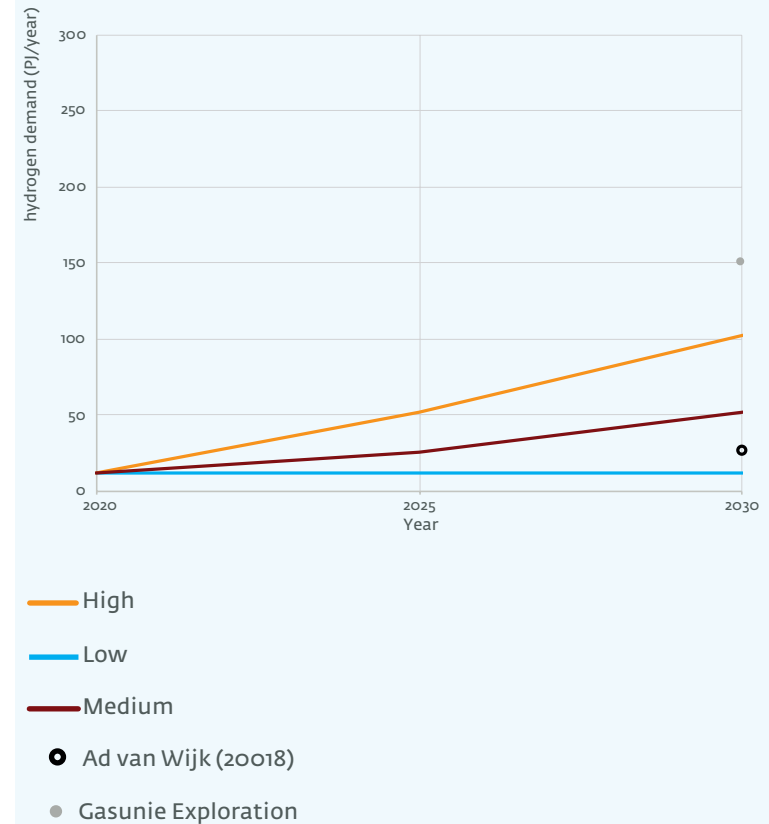
Hydrogen in the built environment

- The projected consumption of hydrogen in the built environment is based on a total dwelling stock of 8 million homes in 2050. The low scenario assumes 10% hydrogen for heating purposes; in the high scenario this is 30%.
- Assumptions for the two scenarios:
 - In the low scenario, 45 households are converted to hydrogen by 2020. This number multiplies every five years, meaning that 2800 homes are using hydrogen by 2030.
 - In the high scenario, the original number is 135 homes, which multiplies every five years, resulting in 11,000 hydrogen-heated homes by 2030.
 - The hydrogen consumption per household per year is equivalent to 1500m³ of natural gas.
- This means that, in both scenarios, the hydrogen consumption by 2030 is less than 1PJ, an insignificant amount compared to other sectors.



Hydrogen for zero-carbon electricity production

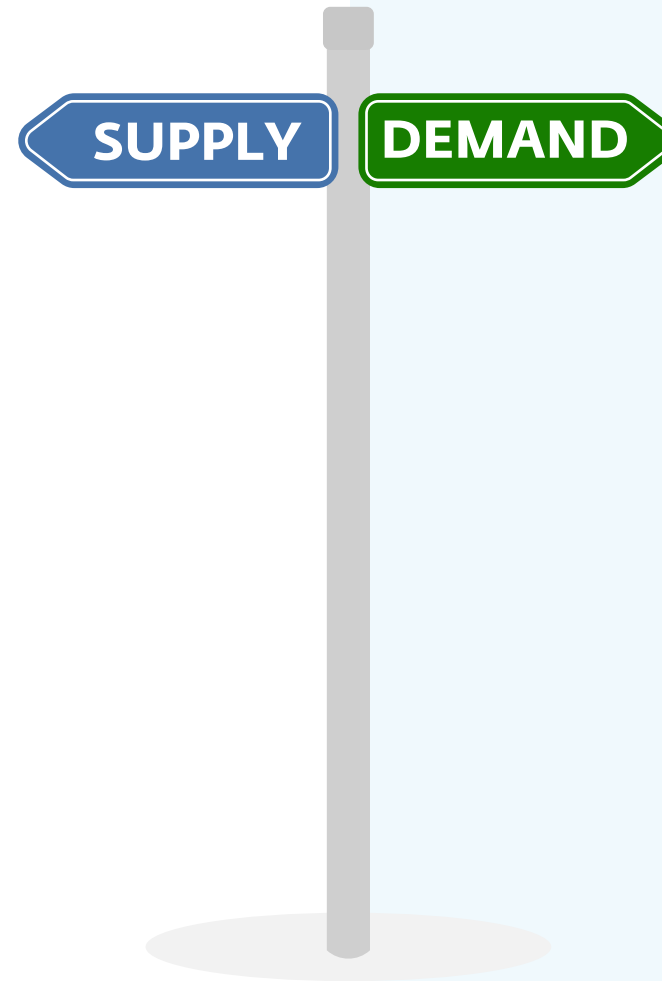
- Current demand for hydrogen for the generation of electricity is 12.6PJ. This mainly concerns hydrogen that is released as a by-product from the production of iron or chlorine or other chemicals and that is used locally to generate electricity.
- Assumptions for the three scenarios:
 - We assume that a converted 450MW gas turbine requires 13PJ of hydrogen per year to run (assuming 4000 operating hours).
 - To remain below the carbon emissions threshold for the electricity sector (12.4 megatonnes) and at the same time meet the demand for electricity (flexible zero-carbon capacity), we base our projections on converting gas-fired power stations to hydrogen-fired power stations.
 - The Dutch Climate Agreement estimates that approximately 27TWh zero-carbon control power capacity is required, although it does not say whether this will come from hydrogen-fired power stations alone.
 - PBL Netherlands Environmental Assessment Agency assumes 4.6TWh of electricity production from biomass and waste in 2030; it is not clear whether this would be flexible capacity.
- Scenarios:
 - The low scenario assumes that no gas-fired power stations will be modified to run on hydrogen.
 - The medium scenario assumes that one station is modified by 2025 and three (12TWh) by 2030. The first gas-to-power project, the Magnum power station, is projected for completion by 2025.
 - The high scenario assumes a larger number of hydrogen-fired power stations (in the provinces of Zuid-Holland, Limburg or Flevoland, for example), generating a total of 25TWh (90PJ; 7 x 450MW per station). This scenario assumes that there will no longer be any biomass-fired power stations by 2030.



Potential of blending hydrogen with natural gas

- By blending hydrogen with natural gas, current end-user applications can continue to be used to a certain extent with a few modifications. This is particularly important for high-temperature heating and electricity production in gas-fired power stations. This can be expected to be a possibility for the built environment too to some extent.
- The order of magnitude of the amount of hydrogen that can be used for this is given for a number of situations:
 - Gas turbines in power stations can often handle higher percentages. Assuming 30% H₂ at 3150MW (7 x 450MW), 4000 hours per year, and an efficiency of 60%, this results in a demand of 8.7PJ per year.
 - At around 80 locations in the Netherlands, there are groups of users whose terminal equipment can already handle a blend with a hydrogen percentage of 5%-30%. With a blend percentage of 20% in 10% of the Dutch regional transmission grid, this results in a demand of 4.5PJ.
 - A part of the transmission system can likely handle a higher percentage of hydrogen in the blend. If we assume that 5% can already handle a blend with 30% hydrogen, the hydrogen demand is then 3.4PJ.
 - With a blend percentage of 20% used throughout the transmission grid, the hydrogen demand would be 45PJ.
- The possibility of blending hydrogen with the natural gas has not, as yet, been taken into account in the demand scenarios.

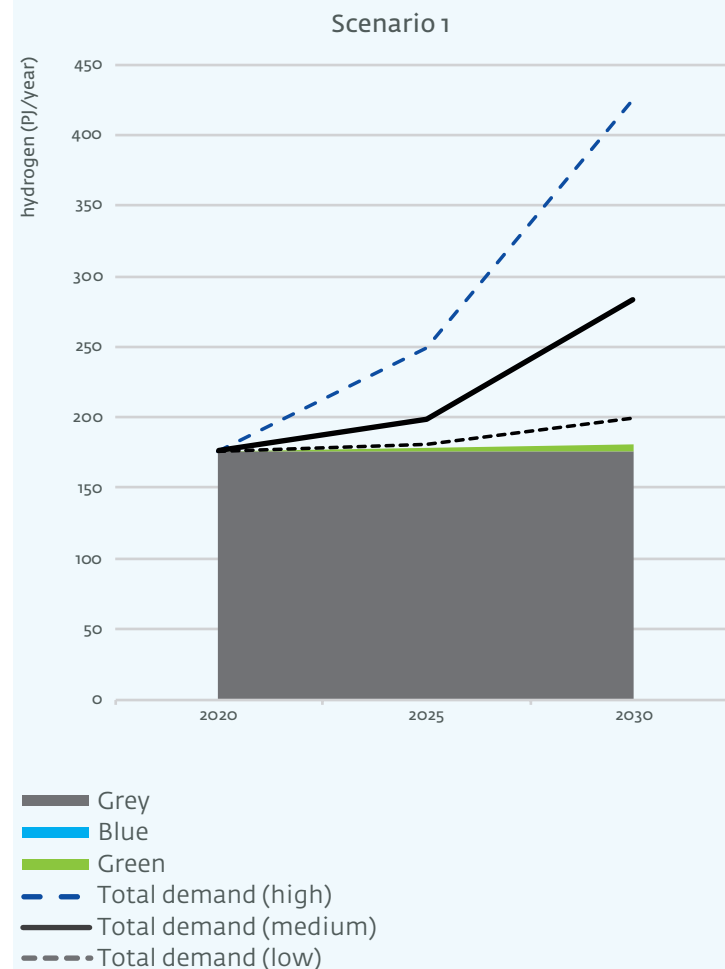
Hydrogen supply



Supply scenario 1:

No programmatic approach to electrolysis

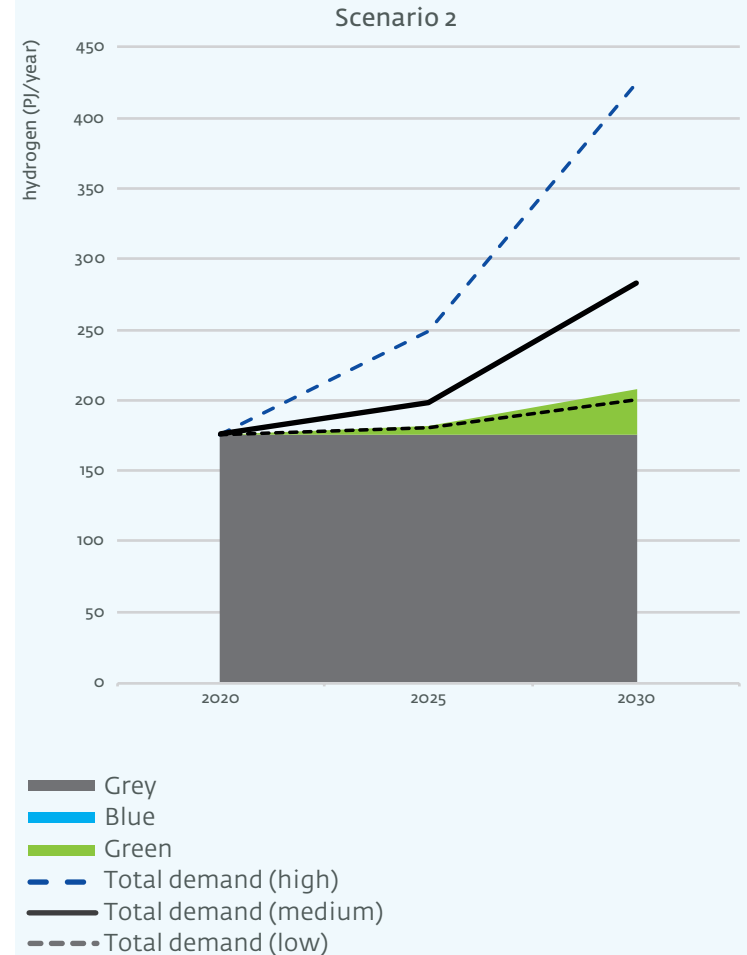
- Scenario 1 for the approach is based on a number of existing initiatives for the production of green hydrogen supplemented by support for a number of pilots and demonstration projects. In this scenario, there is no national programmatic approach for rolling out large-scale electrolysis of water.
- Offshore wind electricity generation is limited to that set out in the roadmap (10.5GW) commissioned by the Dutch Ministry of Economic Affairs and Climate Policy. This is approximately the volume of offshore wind energy that can still be connected to the onshore electricity grid in 2030.
- 10PJ in 2030 ~721MW electrolysis capacity:
 - 1MW pilot in Zuidwending
 - 20MW (Northern Netherlands)
 - 2 x 100MW (Northern Netherlands and Zeeland)
 - 1 x 500MW (onshore supplied via IJmuiden Ver).



Supply scenario 2:

Programmatic approach to electrolysis

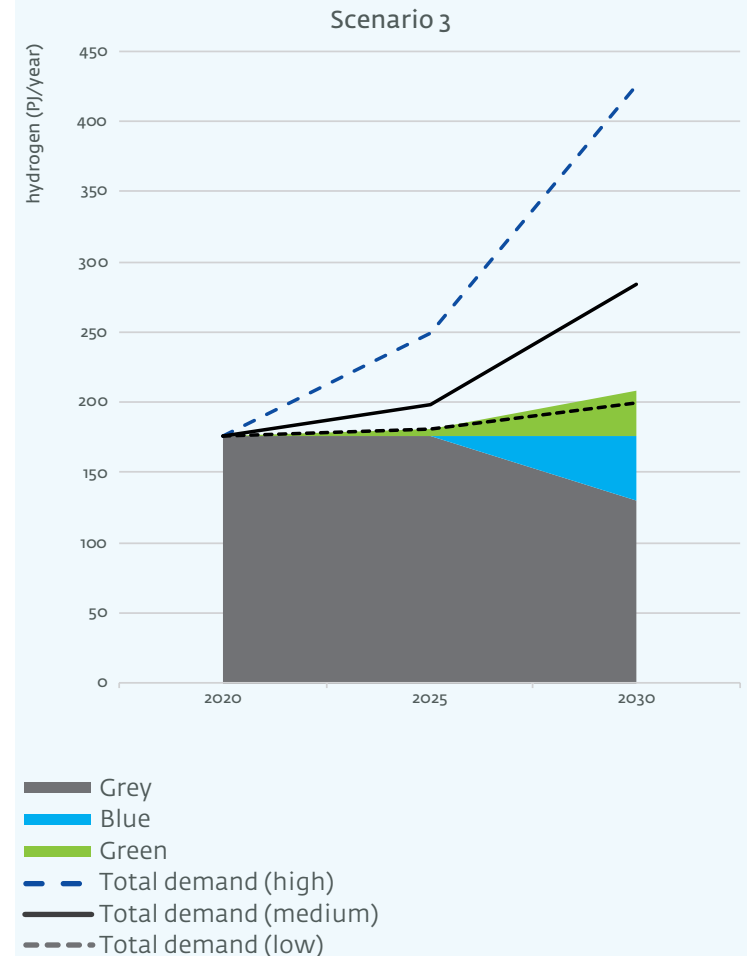
- Scenario 2 is based on a programmatic approach for green hydrogen using the proposals of the Dutch Hydrogen Coalition. This approach has been included in the Dutch Climate Agreement.
- For green hydrogen this means:
 - 500MW electrolysis capacity and 15kt (= 1.8PJ) from biogenic fuels in 2025;
 - 4000MW electrolysis capacity in 2030;
 - The calculations for the production of hydrogen have assumed an efficiency of 75% and 3000 full load hours. The electrolyzers are therefore included in the merit order and do not involve dedicated connections to wind farms.
- This scenario does not take blue hydrogen into account. It is assumed in this scenario that no carbon capture and storage (CCS) is being applied in the Netherlands.



Supply scenario 3:

Programmatic approach to electrolysis and use of CCS for existing hydrogen production

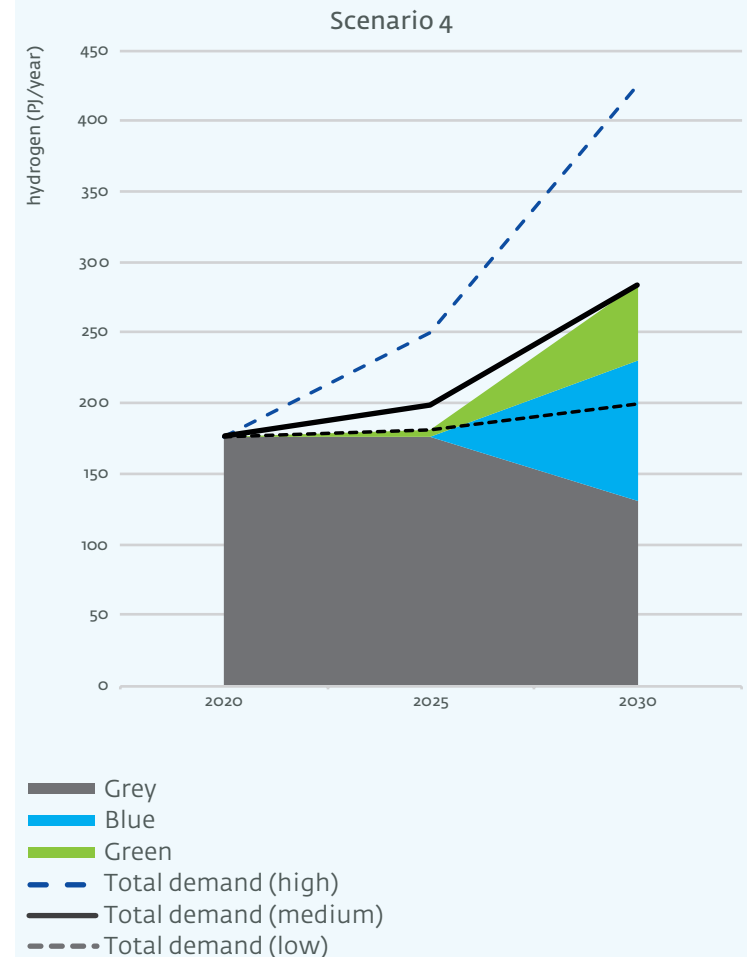
- Scenario 3 is based on the same programmatic approach for green hydrogen as in scenario 2, with the added roll-out of CCS for existing hydrogen production.
- Green hydrogen:
 - 500MW electrolysis capacity in 2025;
 - 4000MW electrolysis capacity in 2030;
 - The calculations for the production of hydrogen have assumed an efficiency of 75% and 3000 full load hours. The electrolyzers are therefore included in the merit order and do not involve dedicated connections to wind farms.
- Blue hydrogen:
 - CCS, for existing hydrogen production in Rotterdam in particular: blue displaces grey (45PJ).



Supply scenario 4:

Programmatic approach to electrolysis, use of CCS for existing hydrogen production, and additional hydrogen production

- The fourth scenario increases the production of hydrogen through additional production of blue hydrogen, in particular for zero-carbon electricity (Gas-to-Power). With the programmatic approach to the roll-out of electrolysis and use of CCS for existing hydrogen production, the following is assumed:
- Green hydrogen:
 - 500 MW electrolysis capacity in 2025;
 - 4000MW electrolysis capacity in 2030;
 - The calculations for the production of hydrogen have assumed an efficiency of 75% and 5000 full load hours (dedicated wind farms for these electrolyzers).
- Blue hydrogen:
 - CCS for existing hydrogen production: blue displaces grey (45PJ).
 - New hydrogen production, for the gas-to-power industry for example; additional blue hydrogen (55PJ).



Import & export

In the supply scenario with the highest level of hydrogen production, the annual volume of hydrogen produced roughly corresponds to the demand in the medium-demand scenario.

For the additional supply needed for a higher demand scenario, it may be worthwhile to consider importing hydrogen from abroad, using hydrogen pipelines or in liquid form on ships.

It is expected that the Dutch infrastructure will be such that export and import of foreign hydrogen will be possible by 2030; it is unclear, however, whether there will be sufficient supply and demand for this in the neighbouring countries at that time.

With regard to importing hydrogen by ship, it is currently difficult to estimate whether this is realistic for the period up to 2030.

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Appendix: graphs in TWH and ktonnes

- Industry – feedstock
- Transport & mobility
- Built environment
- Electricity
- Industry – energy

- Grey
- Blue
- Green
- Total demand (high)
- Total demand (medium)
- Total demand (low)

