Jobs from investment in green hydrogen

Update and extension

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Summary

Report highlights

- Green hydrogen will create jobs in the Netherlands: between 6,000 and 17,300 FTE in 2030 and between 16,400 and 92,400 FTE in 2050.
- Demand for labour will increase more than proportionally to hydrogen demand, because as hydrogen demand rises, more of the hydrogen chain will be in the Netherlands and because relatively labour-intensive sectors are involved (mobility and built environment).
- Some of the jobs will be due to job substitution, others will be additional due to new economic activity.
- It is far from clear whether the labour market can provide enough suitably qualified workers to fill the jobs. Even today, many companies in the sectors concerned are unable to find duly qualified personnel to implement the energy transition in the tempo envisaged.

Introduction

An energy carrier with zero CO_2 combustion emissions like green hydrogen has a major role to play In a climate-neutral energy system. In 2018 CE Delft carried out a study on the employment effects of green hydrogen. The present report is an extension and update of that study.

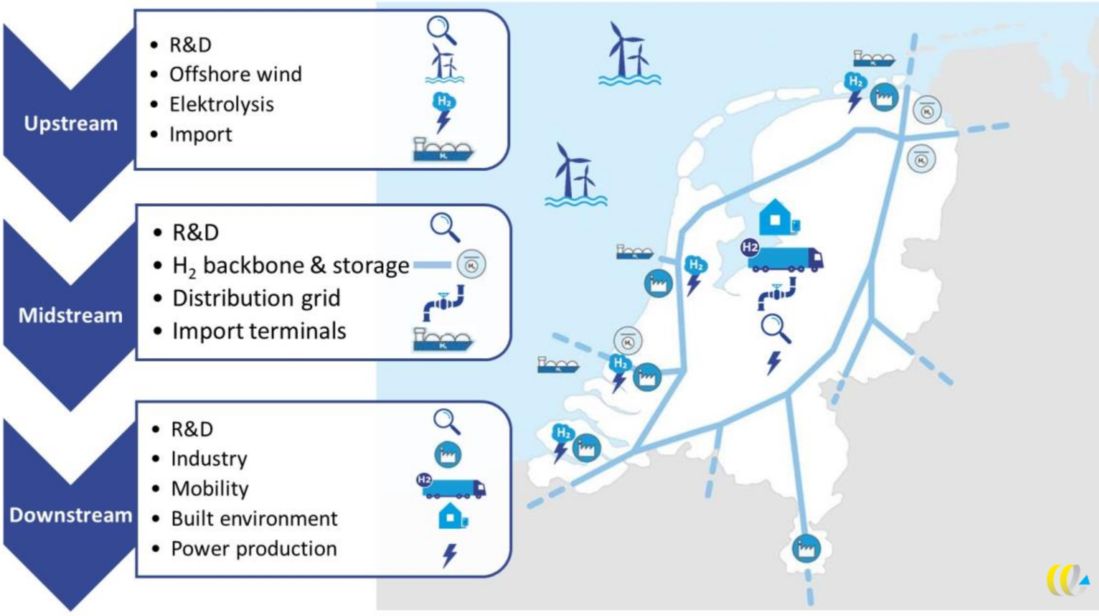
This study again investigates the potential demand for labour associated with green hydrogen in the Netherlands in 2030 and 2050. This was done per sector for a ‘low’ and a ‘high’ scenario. The entire value chain was considered: one-off jobs in construction and grid installation and recurrent jobs for maintenance and operation. Labour demand is expressed as ‘gross employment’.

Although both scenarios are climate-neutral, ‘low’ has minimum use and minimum domestic production of green hydrogen, while ‘high’ has maximum use and domestic production.

One-off and recurrent demand for labour in the Netherlands

Demand for labour was calculated from hydrogen demand. This was done for offshore wind (the share used for hydrogen production), electrolysis, infrastructure, imports, R&D, mobility, industry and the built environment. These sectors are shown in Figure 1.

Figure 1 – Hydrogen value chain in the Netherlands



Source: EZK, adapted by CE Delft.

One-off labour demand is expressed as average full-time equivalents (FTE) per annum, recurrent labour demand as FTE per annum at a particular time. Table 1 provides a synopsis of the study's findings.

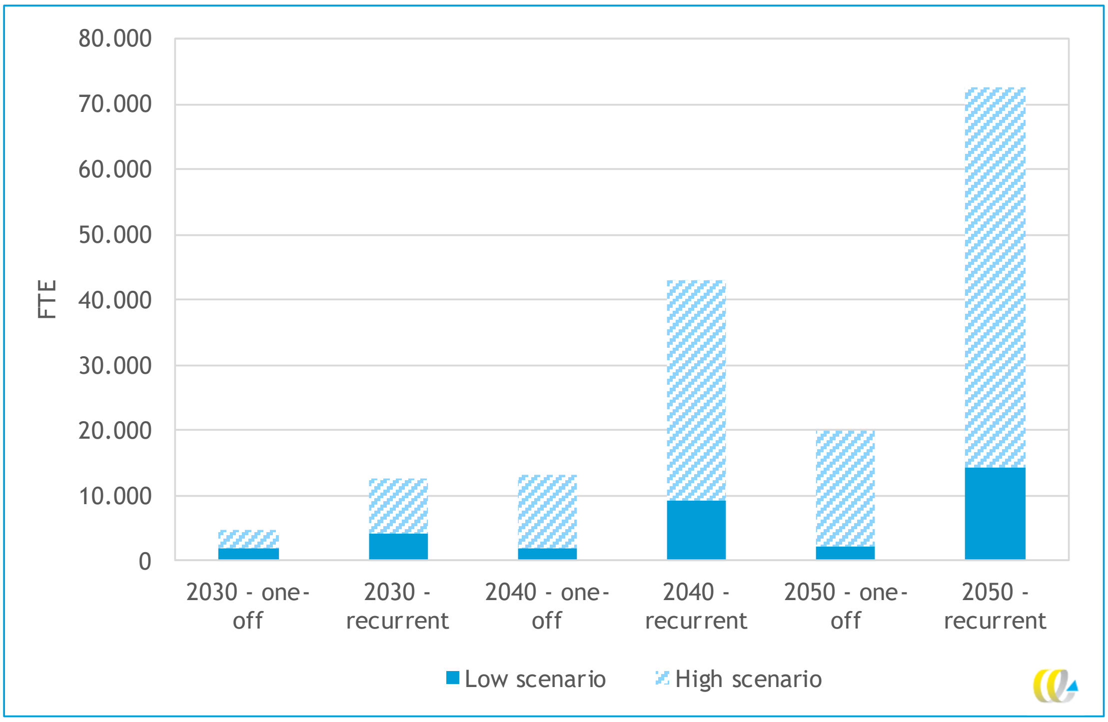
Table 1 – Synopsis of labour demand (rounded to hundreds)

Year	Demand for green hydrogen (PJ)	Total one-off labour demand (average, FTE/y)	Recurrent labour demand (FTE/y)
2030	10-40	1,800-4,700	4,200-12,500
2040	132-317	2,000-13,000	9,200-43,000
2050	254-593	2,200-20,000	14,200-72,600

Figure 2 shows how the low and high scenario differ in labour demand, for both one-off and recurrent jobs. As can be seen, while the high scenario has over double the hydrogen demand, the associated labour demand in 2040 and 2050 is at least a factor four higher than in the low scenario.

In short, demand for labour increases more than proportionally to hydrogen demand. This is not only because more of the upstream value chain is in the Netherlands in the high scenario, but also because of the difference between limited use and predominant use in mobility and the built environment, in both of which relatively limited hydrogen demand has a major effect on labour demand. These are both relatively labour-intensive sectors.

Figure 2 - Difference in labour demand between low and high scenario



A key issue in estimating future labour demand is the kind of jobs involved. In virtually all the sectors mentioned in this report, labour demand comprises mainly technically schooled workers (secondary vocational training, MBO). The required expertise will be specifically geared to the ins and outs of hydrogen (conversion, storage, safety, etc.).

In the scenarios examined, it is far from clear whether the labour market can provide enough suitably skilled workers. Even today, many companies in the sectors concerned are unable to find duly qualified personnel to implement the energy transition in the tempo envisaged. Given the fact that MBO intake is declining, the shortfall is likely to grow even further, while demand for such personnel will only rise.

How will reality pan out?

To what extent reality moves more in the direction of the high scenario depends on several factors, all of which are amenable to policy decisions.

First, the capacity to produce major volumes of hydrogen domestically in the Netherlands is the ultimate driver of labour demand from green hydrogen. That capacity depends directly on the amount of offshore wind capacity installed.

Second, the market for green hydrogen is yet to be developed. How that will pan out depends among other things on the price of green hydrogen, however, an issue beyond the scope of the present study.

Third, how far individual sectors develop towards the high scenario depends on specific policy decisions and measures. This is particularly true of sectors where green hydrogen is not the only climate-neutral solution, such as the built environment and mobility.

In short, how things develop will depend on incentivisation – not just investments but also product standardisation, value chain integration and R&D. Clarity on the regulatory framework for hydrogen infrastructure is also key to a well-functioning market.

FTE per GW electrolysis capacity

The figures for installed electrolysis capacity and labour demand in the Netherlands can be combined to establish total FTE in the entire value chain per unit electrolysis capacity for each of the two scenarios. This is shown in Table 2. The one-off and recurrent labour demand have been summed and the jobs involved in hydrogen import omitted, as these are unlinked to the electrolysis capacity installed in the Netherlands.

Table 2 – FTE (one-off and recurrent) per installed GW electrolysis capacity, rounded

	2030	2040	2050
Installed capacity - low (GW)	1	2.4	3.7
Installed capacity - high (GW)	4.1	18.8	33.4
One-off FTE_{av} - low	1,200	1,000	1,200
One-off FTE_{av} – high	4,000	12,100	18,900
Recurrent – low	4,100	6,400	8,600
Recurrent – high	12,500	40,100	67,000
FTE/GW - low	**5,100**	**3,100**	**2,700**
FTE/GW - high	**4,000**	**2,800**	**2,600**

In 2030, each GW of electrolysis capacity is associated with a total labour demand of some 4,000-5,000 FTE in the value chain as a whole. Although total employment increases over time, value-chain employment per GW electrolysis capacity gradually declines. This is because at first there is relatively more labour demand in R&D and creation of the hydrogen backbone and other construction work, both of which are crucial for ultimate development of the chain as a whole. Mobility, too, already creates considerable labour demand by 2030, even though installed electrolysis capacity is then still relatively modest.

Methodology

For most links in the chain, labour demand was calculated using a model driven by green hydrogen demand. Investment data were then indexed to FTE, giving a figure for one-off labour demand. Demand for recurrent labour was calculated from maintenance and operating costs. Both the one-off and recurrent labour demand are counted as gross, full-time jobs (both additional and non-additional).

1 Introduction

Hydrogen is now part and parcel of the future plans of both government and industry. As we move towards 2030 and particularly 2050, (green) hydrogen is set to play a major role in the economy, both as an energy source and as a raw material

Although plenty was already known about the uses of hydrogen and their climate implications, that did not hold for the potential effects on employment. In 2018 CE Delft conducted a study on the impact of green hydrogen on labour demand in the Netherlands in 2030 and 2050, looking at both one-off and recurrent jobs over most of the value chain (CE Delft, 2018b). It was concluded that green hydrogen could contribute substantially to employment in the Netherlands; see Table 3.

Table 3 – Demand for labour in the 2018 study

Year	Total one-off labour demand (average, FTE/y)	Recurrent labour demand (FTE/y)
2030	350–1,750	800–16,500
2050	850–4,750*	17,500–75,000

* Excl. employment from investments in transport grids and storage, for lack of suitable data for post-2030.

Since 2018, plans for hydrogen have become more concrete. The Dutch Climate Agreement has been undersigned, for example, and plans for investment in hydrogen are now more advanced. More is also known about potential future energy scenarios and the role of hydrogen therein, as sketched in II3050.[1]

This new information gives good reason to update the 2018 study. Shell, one of the key players in developing the hydrogen economy, commissioned CE Delft to carry out such an update, to provide a reasoned assessment of the added value of the hydrogen economy — besides greening the energy system — for Dutch society.

1.1 Research question

The aim of this follow-up study is to update and extend the 2018 study, addressing the same research question: *What are the employment effects of introduction of green hydrogen in the Netherlands?*

1.2 Project horizon

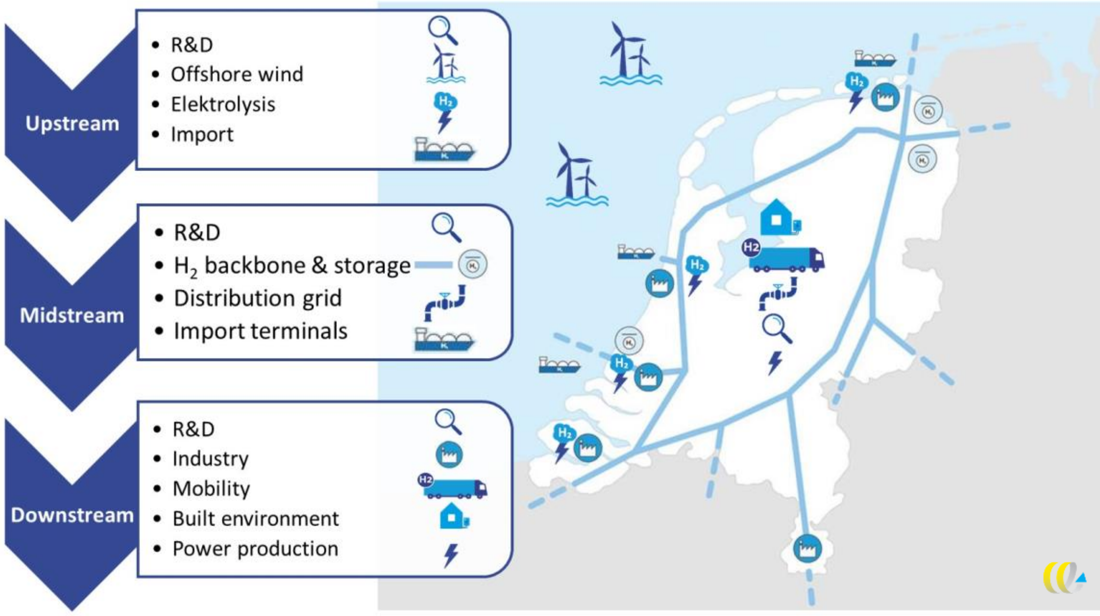
The project's horizon is 2050, with waypoints in 2030 and 2040. The figures for 2040 are linearly interpolated between 2030 and 2050.

[1] II3050 is the Dutch 'Integrated Infrastructure Outlook' for the period 2030-2050, in which the numbers have been crunched on several climate-neutral energy scenarios (Berenschot & Kalavasta, 2020).

Hydrogen value chain and its subdivisions

The hydrogen value chain can be broken down into three parts: upstream, midstream and downstream. This is shown schematically in Figure 3, with the geographical implications for the Netherlands.

Figure 3 – Hydrogen value chain in the Netherlands



Source: EZK, adapted by CE Delft.

The subsegments of the hydrogen economy value chain covered by the present study are shown in yellow in Table 4 below.

Most elements were determined quantitatively using a model driven by hydrogen demand. Some were calculated quantitatively top-down from current labour demand data. In this top-down method, current employment in a particular segment (CBS data) was used to calculate future labour demand. Several subsegments are described only qualitatively.

Table 4 - Segments and subsegments of the hydrogen economy value chain. Yellow subsegments are within the scope of the present study.

Chain	Segments	Subsegments	Method
Upstream	R&D	R&D on green hydrogen	Model
	Offshore wind (share for H_2 production)	Production of wind turbines and components	
		Wind farm construction	Model
		Power grid reinforcement and onshore landing via H_2 lines	Qualitative
		Wind farm and grid maintenance	Model
	H_2 production (domestic)	Electrolysis	Model
		SMR	
		Chlor-alkali	
		(CCS)	
		Pyrolysis	
Midstream	Infrastructure and distribution	LH_2-ships, liquefaction	
		Built environment	Model
		H_2 infrastructure (pipelines, industry) and storage (tanks, underground)	Qualitative
		H_2 distribution in tube trailers	
		Modification of existing natural-gas grid	Top-down
		Port terminals	Top-down
		Green hydrogen transit	Top-down
Downstream	Feedstocks (inputs for H_2 production)	Natural gas	
		(Renewable) electricity (offshore wind)	Model
		Biomass	
		Residual hydrogen production	
		Imported hydrogen	Top-down
	Mobility	Cars and taxis, HGVs, LDVs, buses	Model
		Fork-lift trucks, inland and marine shipping, rail	
		H_2 fuelling stations	Model
	Industry (current and new processes / applications)	Chemical industry: ammonia, polymer and resin production	Qualitative
		Refining and transport fuels, incl. synthetic fuels	Qualitative
		Iron and steel (incl. DRI)	Qualitative
		Other sectors (e.g. glass, food, semi-conductors)	
		Fuel cells (fuel cells for prime power and cogeneration - PEM)	
		H_2 boilers and furnaces	Model
		Large-scale power generation (H_2 combustion)	

1.3 Scope

Compared with the 2018 study, this follow-up has several new elements, including labour demand from offshore wind[2] and a quantitative exploration of impacts in industry. Table 5 compares the scope of the two studies.

[2] Onshore wind and solar PV are beyond the scope of the study.

Table 5 - Comparison of scope of 2018 and 2021 studies

Sector	2018 study	Present study
Offshore wind for H_2 production		✓
Electrolysis	✓	✓
HT heat, industry	Qualitative	✓
Industrial feedstock	Qualitative	Qualitative
LT heat, built environment	✓	✓
Mobility	✓	✓
R&D		✓
Infrastructure	✓	✓
Import terminals		✓
Staffing, import terminals & wholesale fossil trade		✓

1.4 Model

For calculating certain elements (see Table 4) a model was used. This model, also used in the 2018 study, calculates labour demand from hydrogen demand. The underlying assumptions can be found in Appendix B.

1.5 Methodology

The methodology adopted in this study is the same as that used in the earlier study. This means the employment factor approach was used; see Figure 4.

Figure 4 - Methodologies (and scopes) for calculating employment effects

	Sectoral studies	Macro-economic impact studies (all/cross-sectoral)	
Direct, Gross jobs	Employment factor approach (indices)	Corrected net input-output modelling (with correction for 'consumption vector' and comparison with reference scenarios)	*Direct, Gross jobs*
Direct & indirect, Gross jobs	Gross input-output modelling (multipliers)	Economic modelling under different scenarios	*Direct & indirect, Gross jobs*

Source: Hinicio.

The **employment factor approach** provides insight into the direct, 'gross jobs', allowing for the anticipated labour productivity of the various links in the value chain. The term 'gross jobs' refers to both additional jobs, i.e. positions filled by people who would otherwise be unemployed, and non-additional jobs, i.e. those merely involving a change in employment. The advantage of this approach is that it provides relatively rapid insight into job numbers based on available information and data, with an acceptable accuracy and with no need for complex and labour-intensive macro-economic modelling.

The analysis takes as its starting point the trend in investments in the green hydrogen chain, which ultimately result in new economic activity generating jobs. To this end we took the total investments obtained using the cost-price method, allowing for the fact that major production elements are capital-intensive, creating relatively few new jobs per unit investment.

This study calculates full-time jobs (FTE). Given the relatively high percentage of part-time jobs in the Netherlands, the number of actual positions will be higher.

In this report the term 'labour demand' is generally used rather than 'employment', because supply needs to be in line with demand before potential future positions are indeed filled. Ultimately, in the long term, the 'equilibrium employment' will be determined by the size of the labour force, as the Netherlands has no structural unemployment under normal economic circumstances and has usually well-functioning labour markets.

There is no assurance that labour supply and demand will match up, however, and this holds all the more for the value chains of the hydrogen economy. Even today, many companies involved in the energy transition fail to find enough technically skilled personnel. There is already insufficient growth of suitably skilled workers, so every instance of demand for labour cited in this study may well translate to growing scarcity. In assessing the data presented in this study, this should be borne in mind at all times.

2 Development of the hydrogen economy

This chapter explains the scenarios underlying the present study. First the current position of hydrogen in the economy is sketched, followed by a discussion of the scenarios used in this study and a comparison of these with those used in the earlier study.

2.1 Current and future hydrogen applications

Today, hydrogen is used in the Netherlands predominantly as an industrial feedstock. This is 'grey' hydrogen produced mainly from natural gas, totalling around 170 PJ (10% of total Dutch natural gas consumption). There are currently major plans to introduce hydrogen as an energy carrier and feedstock in many more sectors of the economy.

Hydrogen production requires substantial amounts of energy and 'grey' hydrogen produced from natural gas is accompanied by high CO_2 emissions. If this CO_2 is captured and sequestered the hydrogen is termed 'blue'. Hydrogen produced using renewable electricity is termed 'green'. There is also 'yellow' hydrogen, produced using solar power in sunny regions.

Although there are numerous pilots and demonstration projects, green (or blue) hydrogen is still nowhere profitable. If ambitions vis-à-vis green hydrogen are to come to fruition, there will need to be huge developments on both the supply and the demand side of the market.

The Netherlands aspires not only to making substantial use of hydrogen in the future, but also to producing much of it domestically using offshore wind (EZK, 2020). The import of hydrogen can also come to play a major role in the future, however, and would create opportunities for the Netherlands as a transit nation.

The cost price (relative to alternatives) is obviously a key factor determining the size of the hydrogen market, whether for domestic consumption or for transit. These financial aspects are beyond the scope of this study, though, so use was made of existing scenarios, described below.

2.2 Supply and demand scenarios

Given the national ambitions, the aim is not only for green hydrogen to be used in the Netherlands but also for it be produced here, at least in part. As a result, there is a degree of tension between hydrogen supply and demand in the scenarios. The available offshore wind output will not be used entirely for hydrogen production and the demand for hydrogen will not be covered entirely using electricity from offshore wind.

To ease some of the tension between supply and demand, there is stepwise prioritisation in the scenarios. First, hydrogen produced using offshore wind has priority over hydrogen import. Second, regular electricity demand has priority over demand for hydrogen production. Third, it is assumed that electrolysis capacity exactly matches the share of offshore wind available for hydrogen production, i.e. that there is zero electrolysis capacity connected primarily to the main power grid with its associated source mix. The three elements (offshore wind, hydrogen demand and meeting demand) are explained further below.

Offshore wind

Large-scale production of green hydrogen in the Netherlands requires substantial offshore wind capacity. Here, we have worked with one scenario for 2030 (11.5 GW), as announced in the (Dutch) road map offshore wind 2030, and two scenarios for 2050, representing an upper and lower bound, based on the North Sea Energy Outlook (DNV GL, 2020). This leads to a range of 38 to 72 GW for total installed offshore wind capacity in 2050, covering 7.5% and 13.4% of the Dutch section of the North Sea, respectively.

The share of offshore wind used for electrolysis is based on the same Outlook. In the minimum scenario 6.5% of the electricity from this source is available for hydrogen production and in the high scenario 33.4% (DNV GL, 2020). Both scenarios proceed on the assumption that electricity demand is met first.

It was also assumed that the share of offshore wind available for electrolysis rises linearly from 2023 to 2050.

Hydrogen demand

In 2030 demand for green hydrogen will still be relatively modest. As a lower bound 10 PJ was taken, as an upper bound 40 PJ. The Dutch Climate Agreement has a target of 3-4 GW electrolysis capacity in 2030, equivalent to roughly 40 PJ. Both scenarios start from 2023.

For 2050 we assumed climate-neutrality and based hydrogen demand on the 'Regional governance' and 'International governance' scenarios in II3050, which served, respectively, as our 'low' and 'high' scenario (Berenschot & Kalavasta, 2020). This gives a range of 254-593 PJ green hydrogen; see Figure 5.

Figure 5 - Green hydrogen demand for Dutch consumption, low and high scenario

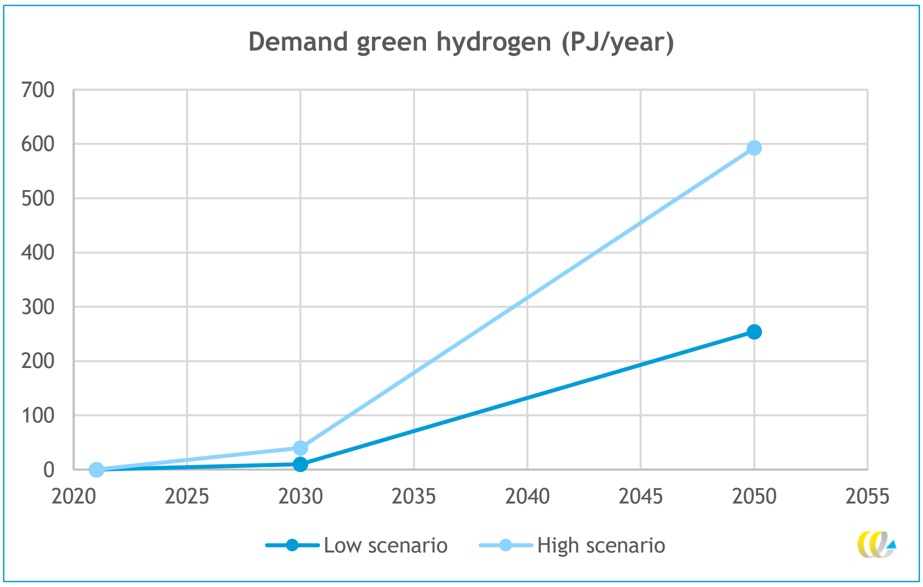


Table 6 details the demand from individual sectors. Our two scenarios represent two extremes and II3050 has two other scenarios in between. It is therefore important to realise that we have here truly a minimum and a maximum scenario (two 'corners of the pitch').

Table 6 - Potential hydrogen demand in 2050 in 'Regional governance' ('low') and 'International governance' ('high') scenarios

	Regional governance (PJ)	International governance (PJ)
Built environment	0	54
Mobility	12	104
Industry - feedstock	14	134
Industry - energy	95	225
Power generation	129	70
Other	4	6
Total demand	**254**	**593**

In both scenarios 'mobility' refers exclusively to road transport. Inland and marine shipping are not within the scope of II3050. This means that in 2050 there may well be substantial demand for hydrogen in the Dutch bunker sector (for shipping and aviation), on top of the demand indicated in the above scenarios. If potential demand for sustainable shipping and aviation fuels is covered entirely by hydrogen, demand could rise by 523–1,055 PJ; see Table 7.

Table 7 - Potential demand for sustainable fuels in 2050 for bunkers and kerosine

	Regional governance	International governance
Bunkers and kerosine	523 PJ	1,055 PJ

Source: (Berenschot & Kalavasta, 2020).

We return to this issue in the Section 3.8 on mobility.

Meeting demand

As set out above, in this study offshore wind takes priority over import in both the high and the low scenario. This differs from how demand is met in II3050, where in the 'International governance' scenario demand is met primarily by import, it being assumed there that the cost price of hydrogen (from high-solar regions) will be so low that offshore wind will be only mildly competitive in 2050.

On this point note, however:

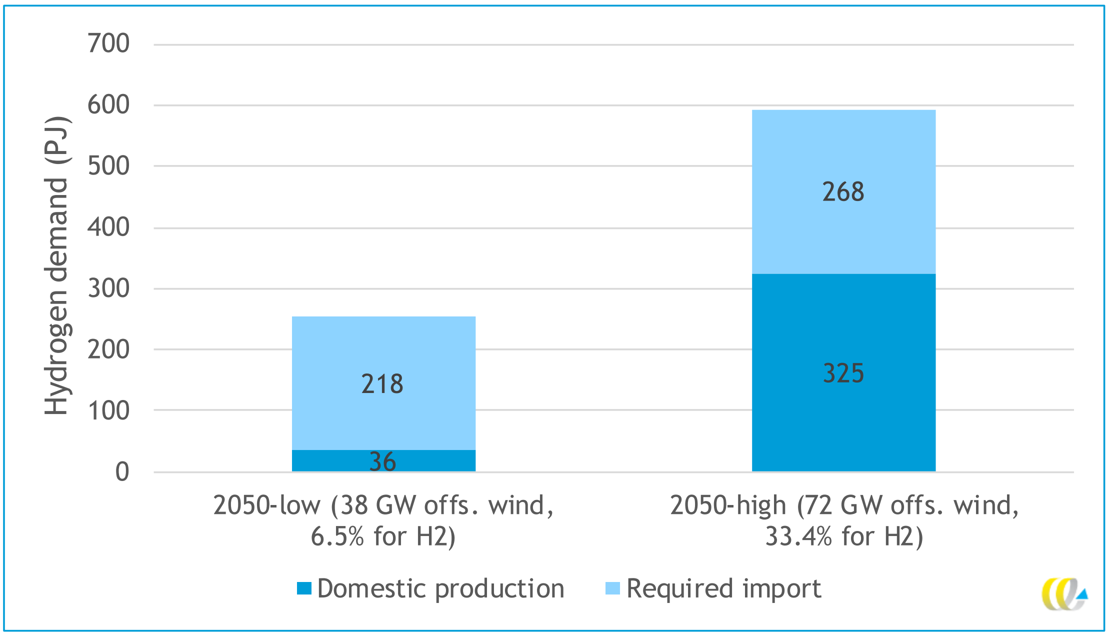
The four II3050 scenarios stand for four future extremes, but it is not a question of choosing among them. They can be readily combined and reality will in all likelihood lie somewhere in between, with certain accents towards the four corners, which may well differ per sector or energy carrier or conversion route. It is thus entirely feasible that solutions in one scenario will in practice also occur in others; numerous mixes are conceivable. The scenarios were chosen explicitly to serve as extreme projections, so grid operators can allow for all options (Berenschot & Kalavasta, 2020, p.10).

There is therefore sufficient justification for meeting demand differently than in II3050.

Hydrogen import and domestic production

Combining the scenarios taken from the North Sea Energy Outlook and II3050 with the assumed stepwise prioritisation explained above, two complete supply-and-demand scenarios can be set up, with upper and lower bounds as shown in Figure 6.

Figure 6 - Import and domestic production of hydrogen for domestic consumption in 2050, low and high scenario (PJ)



In both the low and the high scenario substantial volumes of green hydrogen will need to be imported in 2050 (218 and 268 PJ, respectively). These numbers may be considerably larger if hydrogen for bunkers, synthetic kerosine and transit to other European countries are also factored in (for which see Section 3.10).

Table 8 reports the core data for the low and high 2050 scenario.

Table 8 - Key hydrogen data, 2050

	Unit	2050 - low	2050 - high
Offshore wind (total capacity)	GW	38	72
For electrolysis	PJ	48	433
Hydrogen production	PJ	36	325
Dutch hydrogen demand	PJ	254	593
Dutch import requirement	PJ	218	268

3 Labour demand from green hydrogen

3.1 Introduction

This chapter examines the sectoral labour demand in the Netherlands generated by introduction of green hydrogen in the scenarios set out in Chapter 2, looking in turn at the sectors listed in Table 9.

Table 9 – Sectors for which labour demand was determined and method employed

Sector	Calculation method
Offshore wind for hydrogen	Model
Electrolysis	Model
Hydrogen infrastructure	Based on model and investment plans/current jobs
Industry – energy	Model
Industry - feedstock	Qualitative
Built environment	Model and current jobs
Mobility	Model
R&D	Based on model and current jobs
Hydrogen import	Based on announced volumes and current jobs
Electricity production (reconversion)	Qualitative

3.2 Offshore wind for hydrogen

In this study the share of offshore wind earmarked for the production of green hydrogen is based on the ratios reported in the North Sea Energy Outlook scenarios for 2050, giving a range of 6.5-33.4%. It was assumed that this share increases linearly from 2023 to 2050. Table 10 shows the core scenario data used in this study.

Table 10 – Scenarios for offshore wind and share used for hydrogen production

	2020	2030 - low	2030 - high	2050 - low	2050 - high
Offshore wind (GW installed capacity)	1	11.5	11.5	38	72
Share for H_2 production (%)	0	1.9	9.6	6.5	33.4

The labour demand associated with offshore wind comprises three elements:
- supply of components for foundations[3];
- wind turbine installation;
- wind farm maintenance.

[3] While production of (parts for) wind turbines also contributes to labour demand in the Netherlands (e.g. steel for masts), this was not included in this study because it is hard to allocate this to green hydrogen.

The first two elements create one-off labour demand, the third recurrent demand. As both scenarios assume wind farm construction over the entire period 2030-2050, the 'one-off' effect is in fact 'recurrent' over that period. One-off labour demand is not distributed evenly over the whole period. During wind farm construction there will be peak periods and quieter periods. The one-off labour demand is therefore reported as an annual average.

To calculate the labour demand, use was made of data from the Chamber of Commerce's Trade Register and the literature (Knol & Coolen, 2019).

For TKI Wind, researchers (Knol & Coolen, 2019) have collaborated with players in the sector to make a robust, bottom-up-analysis of the employment due to roll-out of the (Dutch) road map offshore wind 2023 (six wind farms with 3,663 MW aggregate capacity). In 2020 a follow-up report was published (Knol & Coolen, 2020). From these two reports the core data shown in Table 11 were distilled.

Table 11 - Core data on wind farm construction

	FTE/GW (Road map 2023)	FTE/GW (Road map 2030)	FTE/GW (Road map 2050)
Supply of foundations	354	1,311	1,126
Installation	325	443	391
Maintenance & operation	88	69	63

Sources: (Knol & Coolen, 2019, Knol & Coolen, 2020).

Total labour demand was calculated using the core data in Table 11 and the data on installed offshore wind capacity. The results were adjusted for the share of offshore wind used for hydrogen production, since the bulk of that capacity is for the general grid and does not therefore contribute to jobs specifically for green hydrogen. Table 12 shows the outcome of these calculations.

Table 12 - Labour demand due to share of offshore wind for hydrogen production

	2020	2030 - low	2030 - high	2040 - low	2040 - high	2050 - low	2050 - high
Offshore wind (GW)	1	11.5	11.5	25	42	38	72
Share for H_2 production (%)	0	1.9	9.6	4.2	21.5	6.5	33.4
One-off labour demand (FTE_{av}/y)	0	38	178	95	795	146	1,359
Recurrent labour demand (FTE/y)	0	15	76	68	592	156	1,516

Wind turbine service life is now around 25 years and this may possibly rise for newer designs. Turbine replacement and possible disposal/recycling is beyond the scope of this study, but this issue may become relevant towards 2050.

Grid reinforcement for offshore wind

The above figures for labour demand already factor in cable-laying for hook-up to the national grid. Besides this cabling, specific points in the national grid will need reinforcing. Electrolysis will take place largely at coastal sites, since the first and largest electrolysis facilities will be constructed in the major industrial areas on the Dutch coast. This assumes offshore wind landing stations and power plants are also nearby.

Structural changes (solar PV, onshore wind, peak demand loads, etc.) are already necessitating substantial strengthening of the power grid. The labour demand associated with grid reinforcement can only be marginally allocated to electrolysis plant and was therefore not quantified in this study, nor included in the further analysis.

3.3 Electrolysis plant

The electricity from offshore wind can be used to produce hydrogen using electrolysis. The Dutch Climate Agreement cites a target of 3-4 GW installed capacity for electrolysis in 2030. If the low scenario is followed from there on, this figure will remain approximately unchanged through to 2050. Hydrogen demand will then be met mainly by import.

If the Netherlands intends to produce hydrogen domestically using offshore wind, considerable electrolysis capacity will need to be installed; see Table 13.

Offshore hydrogen production may play a role In the future. This is currently under study and for lack of data has not been taken on board in the present report.

Table 13 – Core data on installed electrolysis capacity in the Netherlands

	2020	2030 - low	2030 - high	2040 - low	2040 - high	2050 - low	2050 - high
Offshore wind (GW)	1	11.5	11.5	25	42	38	72
Hydrogen demand (PJ)	0	10	40	23	183	48	433
Installed electrolysis capacity (GW)	0	1	4	2.4	18.8	3.8	34.7
One-off labour demand (FTE_{av}/y)	0	229	900	256	1,968	235	2,004
Recurrent labour demand (FTE_{av}/y)	0	172	688	313	2,486	361	3,262

The high and low scenarios represent a lower and upper bound and not therefore a necessarily realistic scenario. One-off labour demand is given as an annual average, moreover, though during installation there may be a brief peak in labour demand far higher than the figure cited, as electrolysis plant construction takes only a limited amount of time.

3.4 Gas distribution grid

For distributing the hydrogen the high-pressure natural-gas transport grid will need to be modified and expanded, with investments comprising construction of a hydrogen backbone, possible modification of the distribution grid and creation of storage facilities.

3.4.1 National hydrogen backbone

The hydrogen backbone is a national 'ring line' between the country's main industrial centres that aims not only to facilitate hydrogen use in the Netherlands, but also to enable the country to play a leading role in hydrogen distribution internationally. Gasunie has plans for roll-out of a hydrogen backbone in 2024-2030, involving an investment of € 1.5 billion (Gasunie, 2021a).

This investment sum divided by average labour productivity (turnover per employee) yields a rough estimate of the resultant labour demand. A range of € 217,000-331,000 turnover per employee was taken; see Table 14.

Table 14 - Calculated turnover per employee in 2018

Economic sector (SBI code)	Average annual turnover per employee (€/employee/y)
281 Industrial engines, pumps, etc.	330,917
332 Installation of industrial plant	289,746
422 Pipeline and cable laying	287,500
432 Construction installation	217,568

Source: (CBS Statline, 2018).

With a value of € 1.5 billion and a ten-year construction/conversion period, the process of reconfiguring the gas distribution grid will likely involve 455-690 jobs per year.

The hydrogen backbone is an essential element of both the low and high scenario and its construction was therefore taken as a given in both. Although it may at first be used to facilitate transport of blue hydrogen, its ultimate purpose is future distribution of green hydrogen. The associated labour demand was therefore allocated to green hydrogen.

Backbone construction	2030	2040	2050
One-off FTE_{av}/y	573	0	0

On industrial sites connected to the backbone a dedicated hydrogen grid may need to be built alongside the existing natural-gas grid. In operational terms it is extremely complex to switch all users in a particular area from natural gas to hydrogen at exactly the same time. Companies will differ in their transitioning schedules and demand for hydrogen and for gas will therefore coexist for a certain time. Given the lack of clarity on this issue, the associated labour demand was not quantified in this study.

3.4.2 Hydrogen distribution grid

Besides the backbone, which is important mainly for industry and transit, the fine-meshed gas distribution grid for the built environment will need to be modified, provided that hydrogen is indeed used in the built environment. This only the case in the high scenario.

The modifications will be relatively minor and restricted mainly to compressor stations and end-users (changes to gas meters). The latter category is included under the headings 'industry' and 'built environment'. In 2018 KIWA calculated that this operation will cost € 700 million at most (KIWA, 2018). As hydrogen in the built environment only starts playing any significant role after 2030, it was assumed that work on modifying the gas distribution grid will only start then. For the period 2030-2050 this work involves on average 161 FTE/y over a 20-year period.

	2030-2050 (high scenario)
One-off FTE_{av}/a	161

3.4.3 Recurrent labour demand for gas distribution grid

In 2050 Gasunie will be working predominantly with hydrogen, which by then will be exclusively green (or yellow). A hydrogen market will also gradually have taken over the role of today's gas trading point TTF. Vertogas, a Gasunie subsidiary, will be issuing Guarantees of Origin for green and blue hydrogen. This means at least three-quarters of company jobs can be allocated to green hydrogen (with the remainder for green gas, CCU and heat infrastructure). The work will be largely the same (infrastructure management, trade, certificates), but with hydrogen rather than natural gas (Gasunie, 2021b).

To bridge mismatches between supply and demand, hydrogen can be stored temporarily in salt caverns. Based on scenario studies Gasunie anticipates needing 3 to 9 caverns for this purpose.

The hydrogen grid also needs to be kept up and running, which will involve regional grid operators, too. If there is no increase in gas grid capacity, this will ultimately probably require roughly the same number of jobs as for the natural gas grid. In 2018 14,000 full-time jobs were associated with operating the Dutch gas and power grids (CBS, 2020). This figure has remained stable since 2008. Assuming this continues to be the case and that the jobs are split evenly over gas and electricity, this would mean 7,000 recurrent FTE in 2050 for operation and maintenance of the hydrogen grid.

Table Table 15 gives the total contribution to labour demand for conversion and modification of the gas distribution grid.

Table 15 - Labour demand for modifying hydrogen distribution grid

		2020	2030 - low	2030 - high	2040 - low	2040 - high	2050 - low	2050 - high
One-off labour demand (FTE_{av}/y)	H_2 backbone	0	573	573	0	0	0	0
	Distribution grid	0	0	0	0	161	0	161
Recurrent labour demand (FTE_{av}/y)	Maintenance and operation	0	0	0	0	3,500	0	7,000

3.5 High-temperature heat in industry

Given that green hydrogen will have a high price tag for a while yet, it is unlikely to play a role in industrial HT heat production before 2030. It was assumed this application increases linearly post-2030, peaking at 95 PJ in the low and 225 PJ in the high scenario.

Comparison of fossil and hydrogen processes

Industrial process heat is generally raised in industrial boilers and furnaces, which have a combustion chamber into which gas (and possibly air) is injected under high pressure and turbulent flow conditions. Gas-air mixtures containing predominantly hydrogen differ in several ways from hydrocarbon gases like methane, propane and butane, including a higher (laminar) combustion rate (with a risk of flash-back with premixed burners), a higher (stoichiometric) flame temperature and less radiative heat transfer from the flames (with a risk of higher NO_x emissions). With a little product development, though, most existing burner designs can be fairly readily adapted for use with hydrogen.

Using pure hydrogen has the advantage of avoiding black carbon formation, minimising fouling of the burner and combustion chamber. In contrast to fossil fuels, (green) hydrogen contains no sulphur, moreover, making the condensate less corrosive, thus reducing maintenance and increasing service life. The other costs (installation, civil work and maintenance, training) are the same as for conventional units.

Safety aspects

The implicit assumption is that hydrogen safety regulations will not push up costs. There are currently no specific statutory regulations for using hydrogen in an industrial environment. However, the costs associated with installation and maintenance of a hydrogen detection system for a 50 MW plant, say, will be negligible compared with overall costs.

Labour demand

The labour demand for installation and maintenance of industrial boilers and furnaces was derived from the estimated investment costs (Table 34 and Table 35 in the Appendix). It was assumed that from 2030 to 2035 there will be both conversion and newbuild, with a linear annual increase towards 100% newbuild from 2035 onwards.

The sums were done exclusively for 50 MW furnaces and boilers. Direct heat from furnaces is used significantly more than steam from boilers. Using the TenneT-model, CE Delft has previously calculated that 21.5% of hydrogen demand can be allocated to boilers and 78.5% to furnaces (CE Delft, 2020). This split was assumed to remain unchanged in the future.
It was also assumed only one gas delivery station per boiler or furnace is needed.
The procurement and maintenance costs assumed in this study are reported in Table 34 in the Appendix.

The wage costs are an average for three sectors: electrical equipment manufacture, industrial plant installation & repair and specialised construction.

Table 16 shows how hydrogen demand translates to numbers of boilers and furnaces and the associated labour demand.

Table 16 – Labour demand for installation and maintenance of industrial boilers and furnaces (50 MW)

	2020	2030 - low	2030 - high	2040 - low	2040 - high	2050 - low	2050 - high
Hydrogen demand (PJ)	0	0	0	47.5	112.5	95	225
Number of boilers	0	0	0	6	15	13	30
Number of furnaces	0	0	0	23	55	47	110
One-off FTE_{av}	0	0	0	38	289	51	794
Recurrent FTE	0	0	0	71	168	142	336

3.6 Hydrogen as industrial feedstock

(Grey) hydrogen has been in use as an industrial feedstock for many decades. In the Netherlands it is estimated that annual consumption stands at around 175 PJ (Gasunie, 2021b), making the country the second-largest consumer in Europe after Germany (Oxford Institute of Energy, 2021).

3.6.1 Hydrogen feedstock, current situation

Hydrogen is currently used in the following industrial sectors, with the greatest volumes mainly for ammonia production (for fertilisers), chemicals and refineries:

- **Chemicals**: ammonia, polymer and resin production is presently the main industrial market for hydrogen; globally, 80% of the ammonia is used for nitrogen fertiliser production.
- **Refineries**: globally, refineries are the second-biggest consumers of hydrogen in the industrial segment. It is used for hydrocracking[4] and fuel desulphurisation.
- **Iron and steel**: hydrogen is used for steel annealing (heat treatment for processed metal to restore ductility after deformation). The associated hydrogen demand is relatively low compared with the previous sectors.
- **Other industrial processes:** hydrogen is used in various other processes, though these currently represent only a small fraction of aggregate demand. These include glass, food (for hardening fats), bulk chemicals, property chemicals, electrical generator cooling, semiconductors and aerospace.

3.6.2 Hydrogen feedstock, future situation

Today, hydrogen is produced from fossil feedstocks, in the Netherlands mainly from natural gas by means of Steam Methane Reforming (SMR). As pre-combustion capture of CO_2 (for later CCS) is easier to implement with Autothermal Reforming (ATR) it is anticipated that this route will come to be increasingly used. This will then be to produce blue hydrogen.

Demand for *green* hydrogen as a feedstock in 2050 is estimated at 14 and 134 PJ in the low and high scenario, respectively. This can in principle be used directly in industrial processes instead of grey or blue hydrogen. As fertiliser production requires simultaneous supply of CO_2, green hydrogen cannot simply serve as one-to-one substitute for natural gas. As the two Dutch fertiliser plants (in Zeeland and Limburg) are both in an industrial centre where CCS is planned, though, there is likely to be more than enough CO_2 available.

4 Hydrocracking is a two-step process combining catalytic cracking and hydrogenation whereby heavy feedstock is cracked in the presence of hydrogen under high pressure and temperature to produce an array of products.

Given the uncertainties about precise future demand for green hydrogen as a feedstock, the associated labour demand cannot yet be quantified. What follows is therefore a qualitative description of the possible used of green hydrogen:

- **Production of biofuels and methanol from biomass:** if the Fischer-Tropsch process is used, major quantities of hydrogen are required, essentially for the same reason as in current oil refining: cracking longer hydrocarbon chains to create shorter ones requires extra hydrogen atoms.
- **Production of (bio)synthetic fuels and feedstocks:** examples include petrol, diesel, kerosene, methanol (so-called Power-to-Liquids), green gas (methanisation) and naphtha, by combining H_2 and CO_2. The CO_2 is then either biogenic in origin or obtained through Direct Air Capture (DAC) or fossil-sourced (carbon capture). Despite the limited energy efficiency of the overall production process, these routes can deliver renewable energy and feedstocks to sectors with limited options for emissions reduction like the chemical industry, shipping, aviation and long-haul road transport. One example in this category is the Steel-2-Chemicals route[5], whereby carbon monoxide (CO) from the steel industry (ArcelorMittal, Tata Steel) is combined with hydrogen and a catalyst developed by Dow Terneuzen to produce a synthetic naphtha that Dow can use as a feedstock.
- **Reduced use of coking coal for chemical reduction of iron ore:** coking coal is currently used as the carbon source in steel production, serving as a reducing agent for the iron ore (driving out the oxygen (O_2) with carbon monoxide (CO), yielding CO_2). An alternative and innovative process known as Direct Reduction via Hydrogen (DRI-H), whereby cokes use is avoided, is currently in the pilot phase and is regarded as a route for energy-efficient and low-carbon steel production (the O_2 is now driven out by H_2, leaving water (H_2O) as a waste product). Tata Steel of IJmuiden also sees this as the route of the future and intends to implement it in 2050 to produce climate-neutral steel. A pilot DRI-H plant under construction at Luleå, Sweden may be on line by 2025, but an industrial-scale facility is unlikely to be up and running before 2035.
- **New chemical industry.** Chemical recycling of waste streams and other processes can yield methanol, an important chemical feedstock. These processes require hydrogen.

3.7 Built environment

In the built environment, hydrogen can serve as an energy carrier for hydrogen-fuelled central heating boilers (CHB) and hybrid heat pumps (HHP) as well as to drive a district heating grid. In the minimum scenario in this study, hydrogen plays no role at all in the built environment, climate-neutrality being achieved by other means (incl. geothermal, green gas and improved insulation). In the maximum scenario 60% of households and buildings are heated using a hydrogen HHP (plus 15% district heat and the remainder all-electric).

HHP combine an electrical heat pump with a hydrogen CHB, running electrically most of the year but around a third of the time (during peak demand) on hydrogen.

The core data for the minimum and maximum scenarios for hydrogen in the built environment are as follows:

	2020	2030	2040 - low	2040 - high	2050 - low	2050 - high
H_2 households (PJ)	0	0	0	20.5	0	41
H_2 buildings (PJ)	0	0	0	6.5	0	13
H_2 HPs (million)	0	0	0	3.5	0	6.95

5 A pilot plant came on-line at Dow Terneuzen at the end of 2018 and was transferred after about a year to Tata Steel, IJmuiden.

Boiler production and hybrid heat pump installation

Most CHB for the Dutch market are domestically produced. The production process for gas boilers can be readily tweaked for hydrogen boilers, requiring only limited technical modifications (Reijerkerk & van Rhee, 2019). There are currently ten domestic producers, with a joint workforce of around 1,600 (Kamer van Koophandel, 2021), which will remain essentially unchanged after widespread introduction of hydrogen in the built environment.

As HHP installation is fairly labour-intensive, it will generate a fair amount of (additional) labour demand. The recurrent labour demand will be for CHB maintenance and production and will replace jobs currently associated with HE boiler installation and production.

Table 17 shows the modelled effects on labour demand. As can be seen, in the high scenario labour demand in the built environment will be substantial.

Table 17 – One-off and recurrent labour demand in the built environment

	2030	2040 - low	2040 - high	2050 - low	2050 -high
One-off labour demand (FTE_{av}/y)	0	0	3,767	0	7,534
Recurrent labour demand (maintenance, FTE/y)	0	0	2,841	0	5,681
Recurrent labour demand (production, FTE/y)	0	0	800	0	1,600

3.8 Mobility

Mobility is considered to be one of the first sectors where green hydrogen can be effectively used, as early as 2030. Heavy vehicles, in particular, will switch to hydrogen, because the primary option for passenger vehicles is all-electric. In the 'high' 2050 scenario, however, 40% of passenger vehicles are hydrogen-fuelled, this having become competitive in certain situations through innovation and a decline in price.

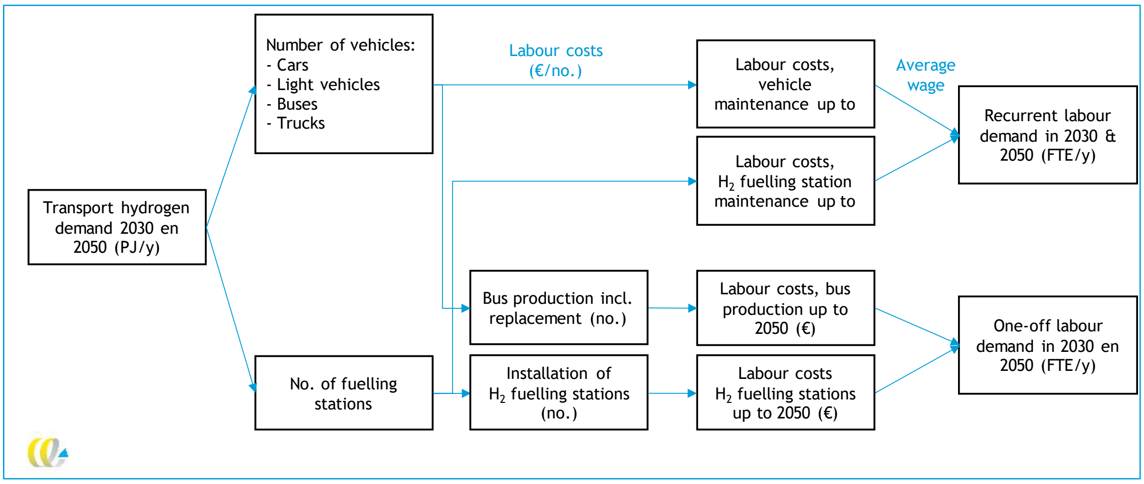
Table 18 shows the demand scenarios used in this study. Here, only road transport is included, with inland and marine shipping and aviation outside the scope.

Table 18 – Hydrogen demand for road mobility

	2020	2030 - low	2030 - high	2050 - low	2050 - high
H_2 mobility (PJ)	0	2.7	20	12	104

The labour demand generated by hydrogen as a transport fuel consists mainly of shifts in current jobs (e.g. for vehicle maintenance). For vehicle production it was assumed that only buses are produced in the Netherlands. As explained in the methodology, the model calculates labour demand from hydrogen demand. This is shown schematically in Figure 7.

Figure 7 - Schematic calculation of transport sector employment



To convert hydrogen demand to number of vehicles, assumptions were made on lifetime vehicle mileage and tank-to-wheel efficiency. To estimate the number of fuelling stations, assumptions were made on the ratio of vehicles to fuelling stations.

Annual production of buses and installation of fuelling stations were then determined, assuming 12 years' service life for buses. Annual bus production is thus the sum of the number of new hydrogen buses plus the number of hydrogen buses due for replacement (reinvestment).

Finally, labour costs for maintenance, installation and production were established, based largely on interviews carried out for the 2018 study. To determine FTE, CBS data were used for labour costs per FTE for various sectors. The assumptions are detailed in Appendix B.

Labour demand

One-off labour demand is estimated at 315-2,360 jobs in 2030, rising to 815-7,026 in 2050. These jobs are in bus production and hydrogen fuelling station construction. Recurrent labour demand rises from 1,134-8,413 jobs in 2030 to 5,164-44,770 in 2050. These jobs are in fuelling station staffing and maintenance and vehicle maintenance. See Table 19.

Table 19 - Labour demand, mobility sector

Labour demand	2030	2040	2050
One-off labour demand (FTE_{av}/y) - low	**315**	**619**	**815**
One-off labour demand (FTE_{av}/y) - high	**2,360**	**5,116**	**7,026**
Recurrent labour demand (FTE/y) - low	1,134	3,157	5,164
Recurrent labour demand (FTE/y) - high	8,413	26,646	44,770

Labour demand in mobility is relatively high compared with other sectors. It should be noted that the estimate is for *gross* employment, however, with only a small fraction anticipated to be additional. In the long run, maintenance of fuel-cell vehicles is expected to be broadly similar to that of today's combustion-engine vehicles. We are therefore talking mainly about preserving existing jobs, though with some form of additional training or retraining.

Hydrogen in shipping

As mentioned in Chapter 2, at some point in the future shipping may potentially generate major demand for hydrogen. As yet this is far from clear, though. There is presently virtually no hydrogen bunkering infrastructure and storage costs are still very high. On-board energy-conversion technology is not yet mature enough for large-scale application, moreover. The significant technical differences between conversion from conventional sources and hydrogen mean the latter is in practice only really an option for newbuild vessels. Converting the hydrogen to ammonia might be a more cost-effective option, but this is still in the development phase, being examined in initiatives like the RH2INE project, which is looking at hydrogen for shipping on the Rhine corridor.

Securing the sustainability target of the International Maritime Organization (IMO) – 50% GHG emissions reduction by 2050 – is estimated to require a worldwide investment of 1 to 1.4 billion dollars over the period 2030-2050 (Global Maritime Forum, 2020). Green hydrogen (converted to ammonia) is deemed the principal option for achieving this, with an estimated 44% of this 1 billion being for hydrogen production.

Rotterdam is the world's second-largest bunker port (after Singapore), with a market share of around 15% (Aymelek, 2014, Maritime Fairtrade, 2019). If shipping, too, gradually switches to hydrogen, Rotterdam will have to respond if it is to retain its leading position.

Given the uncertainties and merely tentative initiatives to date, the potential contribution of green hydrogen to labour demand in the shipping sector could not be included quantitatively in the present study.

3.9 Research & development

The transition from a fossil to a hydrogen economy will obviously require a great deal of innovation and research, thus generating employment in R&D (as is indeed already the case). As always, the costs precede the benefits.

Particularly in the run-up to concrete projects and in developing new applications, major innovative efforts will be required. Given the spread of the transition over various sectors and the entire hydrogen chain, though, in this study it was assumed that the associated employment in R&D will continue through to 2050 and beyond. At first these R&D jobs will continue to grow, subsequently declining as technologies and markets reach maturity.

Current R&D in green hydrogen

To arrive at an estimate of green hydrogen-related jobs in R&D, we first looked at current employment. Based on the number of academic papers and communications with the Netherlands Energy Research Alliance (NERA) and private parties, we estimate there are currently around 800 FTE in green hydrogen R&D at higher-education and research institutes. Most of this is R&D on electrolysis, the use of electrolysis in the future energy market, market models and scenario development.

CBS reports statistics on the split of R&D jobs over higher education, research institutes and industry. This split has remained stable over the past few years. In the Netherlands 71% of R&D FTE is in industry, 6% in research institutes and 23% in higher education (CBS, 2019).

Based on these data and information on higher education and research institutes, we estimate there are currently 1,959 FTE in industry, implying a total of 2,759 FTE in green hydrogen R&D in 2020, which is 1.8% of all R&D FTE in the Netherlands (150,400).

R&D in 2030, 2040 and 2050

R&D is somewhat divorced from the physical developments in the hydrogen economy and to an extent precedes them. In this study it was therefore opted to index R&D employment linearly to average investments in electrolysers over the seven following years, given that R&D is essential for roll-out and so precedes investments in these units.

It was also assumed that until 2035 4.7% of CAPEX on electrolysers is for R&D in the Netherlands. This is an average based on ECN data on employment in the energy sector. ECN estimate that 5-10% of outlay is for R&D, with 50-75% of this occurring in the Netherlands (ECN, 2016).

It is to be anticipated that as technologies reach maturity, R&D expenditure will decline. It was therefore assumed that from 2035 onwards percentage expenditure on R&D will decline linearly from 4.7% to 1% in 2050. The figure of 1% is in line with sectors with low R&D expenditure like mining and refined oil (OECD, 2016). Combined with rising electrolyser capacity, this leads to a peak in labour demand shortly after 2030 and a slight subsequent decline thereafter.

With CBS flagging the R&D split between industry, research institutes and higher education as stable, it was assumed this will remain so in the future. For wage costs a figure of € 84,456/FTE was taken. Table 20 shows the estimated figures for green hydrogen R&D.

Table 20 - Green hydrogen-related R&D in the Netherlands

	2020	2030 - low	2030 - high	2040 - low	2040 - high	2050 - low	2050 - high
Installed capacity, electrolysers (GW)	0	0.2	4	2.6	24.9	3.8	34.7
Average investment (7 following years, € mln.)	25	50	455	24	229	7	27
FTE in R&D	**2,759**	**2,815**	**3,321**	**2,786**	**3,052**	**2,767**	**2,803**

3.10 Hydrogen Import

As described in Section 2.2, hydrogen import plays a major role in both the high and the low scenario. Given the working range of 38-72 GW for offshore wind in 2050, with 6.5-33.4% available for electrolysis, the Netherlands will then be able to supply 36-325 PJ of its hydrogen demand domestically. This means a need for 218 PJ import in the low scenario and 268 PJ in the high scenario.

Transit

Besides importing hydrogen for domestic use, the Netherlands can also play a key role in import and transit to other parts of Europe, as is the case with fossil fuels today. Rotterdam Port Authority is set on retaining its position as a key fuel transit hub (Havenbedrijf Rotterdam, 2020).

The Authority anticipates 20 Mt hydrogen (2,400 PJ) passing through the port in 2050, 8 MT of which for Germany and 5 MT for the rest of N.W. Europe. This means Rotterdam will then be covering one-third of aggregate German hydrogen demand (24 Mt). Of the 7 Mt (840 PJ) for the Netherlands, 4.2 is for aviation and marine shipping, neither of which are included in the scenarios used in the present study. We therefore took a figure of 86% for the share of hydrogen import to Rotterdam Port in 2050 not destined for domestic consumption.

Other ports

Besides Rotterdam, Amsterdam Port, Zeeland (North Sea Port) and Eemshaven Port (Groningen Seaports, 2019) also see opportunities for green hydrogen import. The Port of Amsterdam has announced its ambition to import 1 Mt/y for transit from 2030 onwards. For the other two ports no concrete plan have yet been announced. These imports (by tanker) are still exclusive of landing any hydrogen produced offshore in the North Sea, plans for which are being developed in the Den Helder Port area, among other places.

The fact that the high and low scenario both involve large-scale import implies that terminals will need to be built. In this study the associated labour demand was calculated using the Port of Rotterdam' projections.

Required infrastructure

Large-scale tanker import of hydrogen means infrastructure needs to be built or modified. For a port this will be mainly terminals, for hook-up to the hydrogen backbone. No such terminals exist as yet. To estimate labour demand we therefore based ourselves on LNG terminal construction. Construction of the Gate LNG terminal at Rotterdam Port, with a capacity of 9 bcm (approx. 285 PJ), required an investment of € 800 mln. (Gate terminal, 2007). Given the greater complexity of an H_2 terminal, we estimate around € 1 bln. for 3 Mt (324 PJ). Rotterdam Port Authority has scheduled completion of its first terminal by 2030, with work starting in (or around) 2025. In 2050 total import capacity is projected to stand at 20 Mt, implying the need for an additional 17 Mt capacity over 2030-2050, a slight speed-up compared with the preceding period. There will also be learning and scale effects. All in all, we worked with a rough estimate of € 5 bln.

Comparison with European scenario

As set out above, 13 Mt of the cited 20 Mt (2,400 PJ) is destined for transit to other countries, including Germany. In the ambitious European scenario drawn up by FCH, total hydrogen demand will be 8,107 PJ in 2050. The low (business as usual) scenario assumes 2,808 PJ in 2050. Only in the former does demand from aviation and shipping play a significant role (FCH JU, 2019).

Based solely on the 20 Mt figure, this would make the Netherlands a very significant player in the European hydrogen market: in the high scenario some 30% of European hydrogen demand would be met via the Netherlands.

One-off labour demand

Based on the average turnover data for construction installation and pipeline and cable laying, port terminal construction will generate 660 FTE/y on average in the period 2025-2030 and 943 FTE/y on average in the period 2030-2050.

Port terminal construction	2025-2030	2040	2050
One-off FTE_{av}/y	660	943	943

Recurrent labour demand

Hydrogen import also generates labour demand in the form of terminal operation and maintenance and the commercial jobs associated with trade and transit. There is presently substantial employment in wholesale fossil fuel trade in the Netherlands: 5,300 FTE (CBS Statline, 2018). The Port of Rotterdam is also assuming it will retain its market position as a key fuel transit hub.

How labour demand in this sector will develop as we transition to a hydrogen economy depends on the position the Netherlands manages to secure in that future. The port terminals built to handle hydrogen import will also need be staffed. As they are as yet non-existent, exact figures for the number of jobs involved are lacking. We therefore proceeded from the jobs associated with an LNG terminal, more specifically the Lake Charles LNG terminal, where around 50 people are employed for day-to-day operation (Shell, 2020). Scaled to the envisaged terminal capacity, this means a minimum of 50 recurrent jobs in 2030 and around 300 in 2050; see Table 21.

Table 21 - Labour demand for green hydrogen import

Recurrent FTE/y	2025-2030	2040	2050
No. of import terminals	1	4	6
Staffing of port terminals	50	175	300
Wholesale trade	0	2,650	5,300

3.11 Power generation (reconversion)

Despite the growing output of wind and solar power, every scenario factors in periods that the sun and wind don’t shine or blow. Because hydrogen is more amenable to long-term, high-volume storage than electricity, it can play a very useful role in a flexible electricity system, burning hydrogen produced in renewably powered electrolysis plants.

This power production route, known as reconversion, is included as an option in II3050, with a minimum of 0 PJ hydrogen and a maximum of 129 PJ. As only several hundred hours’ reconversion per annum is projected for 2050, there is still considerable uncertainty as to the business model, however.

While it is uncontested that there will ultimately need to be a certain amount of flexible power production capacity, how this will be fleshed out and what technologies will be used is still unclear. Given the major uncertainties, the labour demand associated with reconversion was therefore not quantified in this study.

3.12 Equipment part manufacture

In the 2018 study a rough figure was calculated for the labour demand associated with equipment part manufacture, under the assumption that the Netherlands can produce electrolyser parts, for example, which can then be exported. Although the country currently has no major manufacturers of electrolysers, the whole of the underlying value chain is present here. Virtually every province has several works where (components of) electrolysers could potentially be produced. In an analysis by FME and TNO it was established that there are at least 72 such plants in the Netherlands (FME & TNO, 2020).

As yet the main producers are located elsewhere, but even there production processes are not yet automated, nor are supply chains fully mature. There are therefore real opportunities for Dutch manufacturers. The FME & TNO study has detailed recommendations on incentives for electrolyser production in the Netherlands, including creation of a national R&D programme, incentives for supply-chain collaboration and creation of (EU) product standards.

While there therefore appear to be real opportunities here, given the uncertainties no quantitative job estimate has been included in the present update.

3.13 Conclusions on labour demand

In this chapter the labour demand associated with green hydrogen was calculated per sector. Figure 8 shows the overall picture for one-off labour demand. As can be seen, the high and low scenarios span a huge range, particularly in 2040 and 2050. The figure for import terminals is derived from the volume announced in the Port of Rotterdam's Outlook and is therefore the same in both scenarios.

Figure 8 - One-off labour demand, by sector

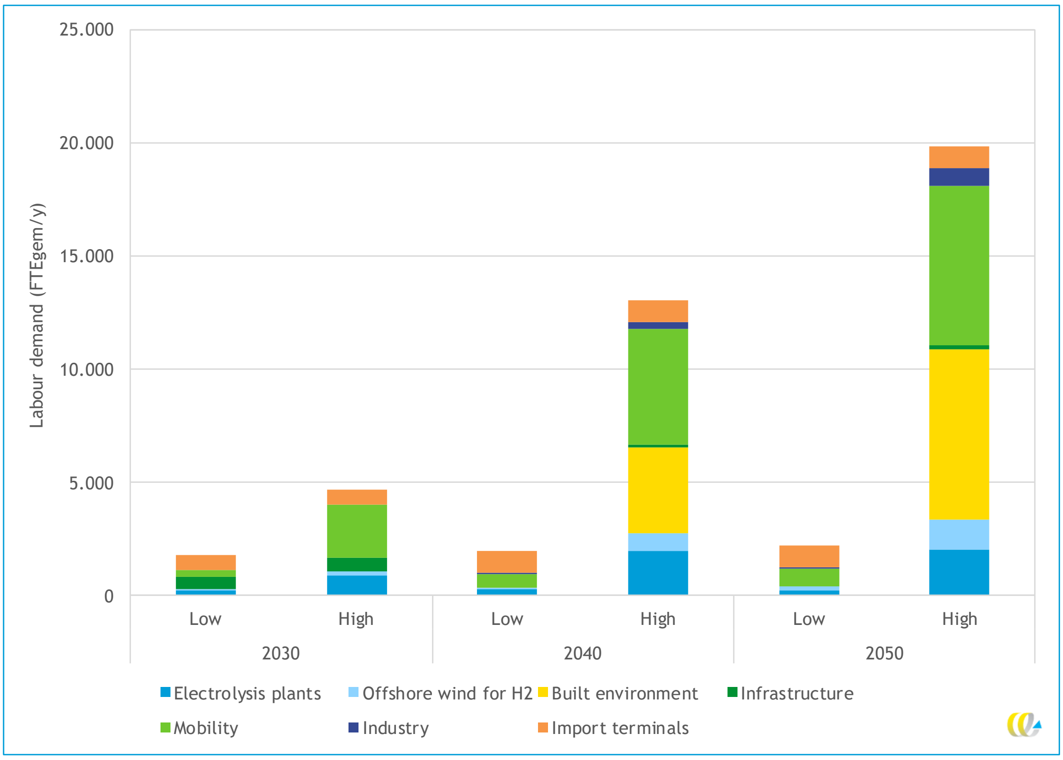
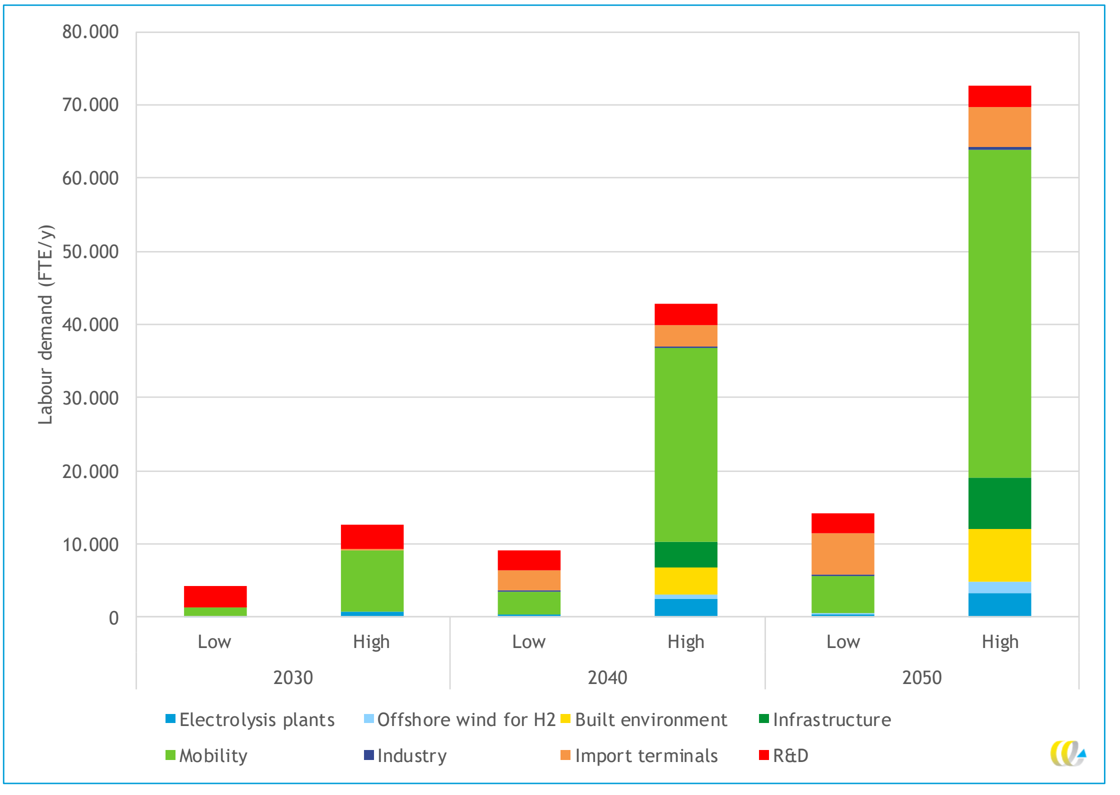


Figure 9 shows the recurrent sectoral labour demand associated with green hydrogen.

Figure 9 – Recurrent labour demand, by sector



For recurrent labour demand the differences between the low and high scenario are once again substantial, particularly after 2030. It is also striking that mobility accounts for an exceptionally large share of labour demand in the high scenario. Once again, the figure for import terminals is based on a single projection and is therefore the same in both scenarios.

Type of work

An important issue in estimating future labour demand is the type of work involved. While a hydrogen economy is in itself novel, the associated labour demand is very similar to that for the energy transition. In virtually all the sectors covered in this study (except R&D) the bulk of labour demand is for technically skilled personnel (secondary vocational training, MBO), with R&D requiring academic qualifications. Each sector will have its own specific requirements, while general expertise will be geared to the ins and outs of hydrogen.

According to a recent report by Ecorys (2021) an estimated 23,000 extra personnel (gross) are needed to secure the targets of the Dutch Climate Agreement (-49% emissions reduction in 2030). If that target is increased because of the European Green Deal (-55% in 2030), the shortfall will rise to 28,000 (Ecorys, 2021). While this shortfall rises, though, the pool of technical skilled personnel continues to fall, and do so substantially. As the Ecorys study clearly shows, even before 2030 there will in all likelihood already be a shortage of technically schooled personnel who are up to the challenges of the climate transition.

If the Netherlands is serious about securing its climate ambitions, there will need to be investments in secondary technical vocational training. Additional training and retraining can also help achieve a better match between labour supply and demand.

4 Regionalisation

4.1 Introduction

The last chapter discussed the sectoral labour demand generated by green hydrogen. In some sectors these jobs will be spread across the country, while in others they will be geographically concentrated. These differences may be important when planning for the future.

4.2 Spread and clustering

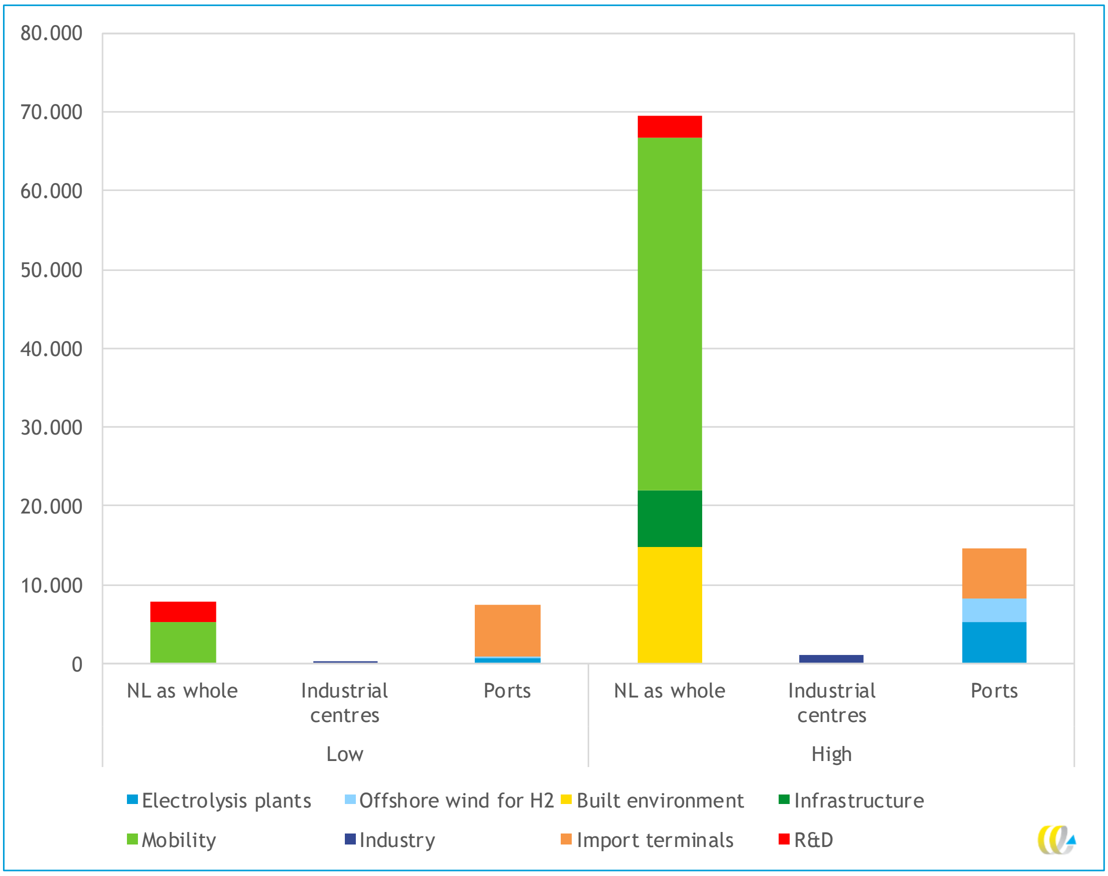
This chapter presents a regional picture based on Table 22. More detailed allocation to a specific port or industrial centre is unfeasible with the data gathered in this report, because for some developments it is as yet unclear where exactly activities will be located. This holds particularly for electrolysis plant and import terminals.

Table 22 – Assumed regional distribution of labour demand

	NL as a whole	Industrial centres	Ports
Offshore wind			✓
Electrolysis			✓
Infrastructure	✓		
Industry		✓	
Built environment	✓		
Mobility	✓		
R&D	✓		
Import terminals			✓

The assumed regional spread can be combined with the labour demand in the two scenarios for 2050. Summing the one-off and recurrent jobs, this gives the result shown in Figure 10.

Figure 10 - Regional spread of labour demand in 2050



4.3 Conclusion on regionalisation

Because mobility and the built environment account for such a major share of labour demand in 2050, most of this demand will be spread across the country. Nonetheless, the labour demand located in the port areas will still be substantial in relative terms.

5 Additional and substitute jobs

5.1 Introduction

This study calculates labour demand for two hydrogen demand scenarios in 2050. As explained in the methodology, the focus here is on ‘gross’ employment that can be allocated to green hydrogen, with no correction for any jobs lost due to the introduction of hydrogen.

Besides the loss of jobs in the ‘fossil sector’, there will also be substitution of jobs in numerous downstream sectors. Maintenance of conventional vehicles will transition into maintenance of hydrogen vehicles, for example, and installation of high-efficiency CH boilers into installation of hybrid heat pumps. Upstream in the hydrogen chain there will be new economic activity (offshore wind, electrolysis plant), creating new jobs.

In this chapter the job numbers presented in the previous chapters are categorised according to whether they are additional jobs or substituted.

5.2 Terminology

Labour demand is deemed **additional** if introduction of hydrogen creates jobs with no direct precedent in the traditional situation (e.g. electrolysis plant installation). There is job **substitution** if the labour demand can be readily traced back to currently existing jobs (e.g. conventional vehicle maintenance transitioning into hydrogen vehicle maintenance).

The term **job displacement** is also used in economics. This term is concerned with the functioning of the labour market and refers to a (temporary) additional demand for labour causing workers to opt for better-paid jobs. This may lead to certain sectors or segments being displaced. Displacement is always due to a scarcity of labour. This phenomenon is not investigated in this chapter.

5.3 Additionality and substitution

In practice it is very hard to distinguish reliably between additionality and substitution, one reason being that the former category of jobs can in principle be filled by people from other sectors (which amounts to displacement). The speculative split given in this chapter is therefore largely theoretical.

In the case of job substitution, moreover, efficiency gains in the new hydrogen chain segment may on balance lead to a loss of jobs compared with the parallel segment of the traditional economy. This issue has been ignored here, however.

The transition to a hydrogen-oriented economy may also involve the risk of absolute job loss, i.e. without any direct substitution. This issue has also basically been ignored here, but is briefly discussed in the context of the year 2050.

5.4 Additionality and substitution in 2030

In 2030 hydrogen still has a limited role and labour demand is generated mainly by initial work on the supply chain (installation of upstream and midstream elements). As Table 23 shows, labour demand is mainly additional, i.e. most are new jobs.

Table 23 - Type of labour demand in 2030

Chain	2030 Sector		FTE	Type
Upstream	R&D	Recurrent	2,815-3,321	Additional
	Offshore wind	One-off	38-178	Additional
		Recurrent	15-76	Additional
	Electrolysis	One-off	229-900	Additional
		Recurrent	172-688	Additional
Midstream	Infrastructure	One-off	573	Additional
	Import	One-off	660	Additional
		Recurrent	50	Additional
Downstream	Mobility	Recurrent	1,134-8,413	Substitute
	Total, additional		**4,552-6,446**	
	Total, substitute		**1,134-8,413**	

NB: The one-off labour demand (annual average in a given decade) is taken here as FTE in 2030.

As can be seen, additional labour demand in 2030 is between 4,552 and 6,446 FTE, substitute labour demand between 1,134 and 8,413 FTE.

5.5 Additionality and substitution in 2050

Post-2030 hydrogen will play an ever greater role in the economy and gradually displace the fossil alternatives. Both the future scenarios used in this study are climate-neutral in 2050, which means a CO_2-neutral economy in terms of both energy and feedstocks. This makes for a very different employment situation in 2050 compared with 2030. Besides additional and substitute jobs, there are entire sectors that may disappear for good, above all those geared fully to fossil fuels, where many thousands are currently employed; see Table 24.

Table 24 - Employment in entirely fossil sectors

Sector	FTE
Petroleum and natural gas recovery	2,800
Petroleum industry	5,400
Petrochemical industry	5,300
Wholesale Oil and coal trade	5,300

Source: (CBS Statline, 2018).

These jobs are set to disappear in their current form. As hydrogen takes over the role of fossil fuels, there will in all likelihood be some degree of transfer to additional jobs in the hydrogen economy. This is not a certainty, though, and the jobs were therefore not subtracted from the additional labour demand in 2050. Only the figure for wholesale oil and coal trade has been used as a reference for hydrogen wholesale (cf. Section 3.10).

Distinguishing between additional and substitute jobs is even harder in 2050 than in 2030. In 2050, moreover, hydrogen will be far further integrated with the economy as a whole (whether via domestic production or via import) and there will be more sectors directly or indirectly associated with hydrogen than considered here.

Table 25 shows our estimate of additional versus substitute labour demand in 2050. As can be seen, substitution only plays a role midstream and downstream. Upstream the jobs are all additional.

Table 25 - Type of labour demand 2050

Chain	2050 Sector		FTE	Type	Equivalent in traditional economy
Upstream	R&D	Recurrent	2,767-2,803	Additional	
	Offshore wind	One-off	146-1,359	Additional	
		Recurrent	156-1,516	Additional	
	Electrolysis	One-off	235-2,004	Additional	
		Recurrent	361-3,262	Additional	
Midstream	Infrastructure	One-off	161	Additional	
		Recurrent	0-7,000	Substitute	Natural gas grid, maintenance & operation
	Import	One-off	943	Additional	
		Recurrent	5,600	Substitute	Partly wholesale fossil fuel trade
Downstream	Industry (energy)	One-off	51-794	Additional	
		Recurrent	142-336	Substitute	
	Built environment	One-off	0-7,534	Additional	
		Recurrent	0-7,281	Substitute	Natural gas CH boilers, maintenance & production
	Mobility	One-off	815-7,026	Additional	
		Recurrent	5,164-44,770	Substitute	Conventional vehicles, maintenance
	Total, additional		**5,635-27,402**		
	Total, substitute		**10,906-64,987**		

NB: The one-off labour demand (annual average in a given decade) is taken here to be FTE in 2030.

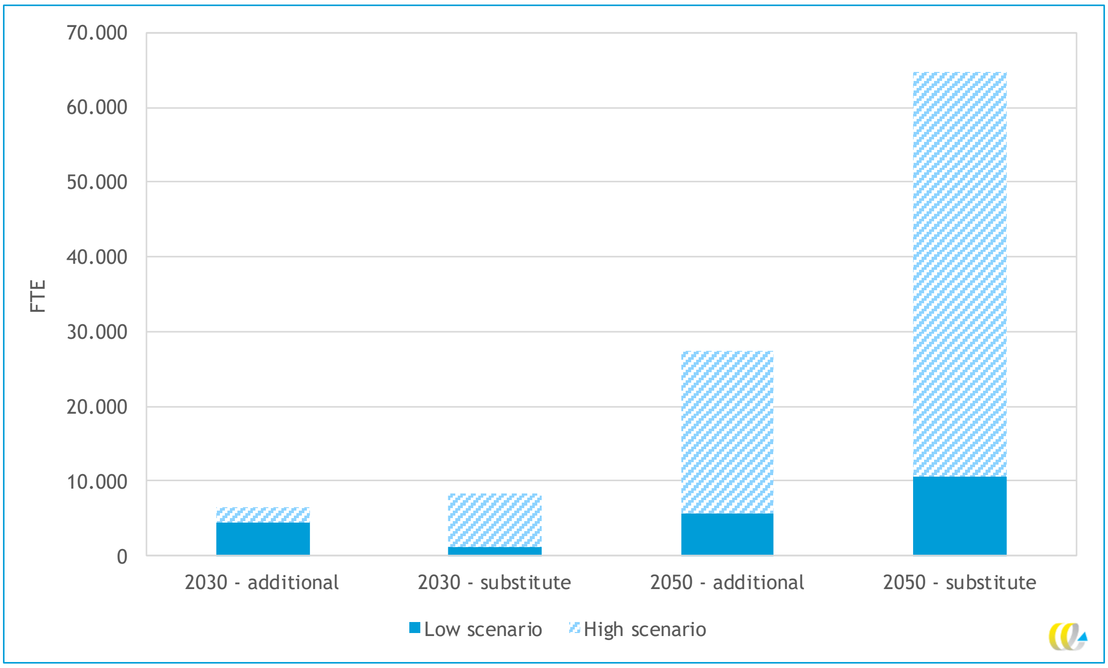
As Table 25 shows, while there are more substitute than additional jobs in 2050, the latter may not be insubstantial in the high scenario.

5.6 Conclusion on additional and substitute jobs

This chapter presented the estimated split between additional and substitute jobs in the hydrogen economy. The broader demand for labour that will trickle through to the rest of the economy (indirect employment), efficiency gains in the hydrogen chain compared with the conventional chain and loss of jobs connected to fossil fuels or high emissions were all beyond the scope of the present study.

Figure 11 reports the estimated split between additionality and substitution in 2030 and 2050 alongside one another. As can be seen, the bulk of the labour demand comprises substitute jobs. The relatively high share of additional jobs in the low scenario in 2030 is due mainly to R&D. It is also striking how many more jobs are created in the high scenario in 2050, both additional and substitute.

Figure 11 - Additional and substitute labour demand in 2030 and 2050



6 Conclusions

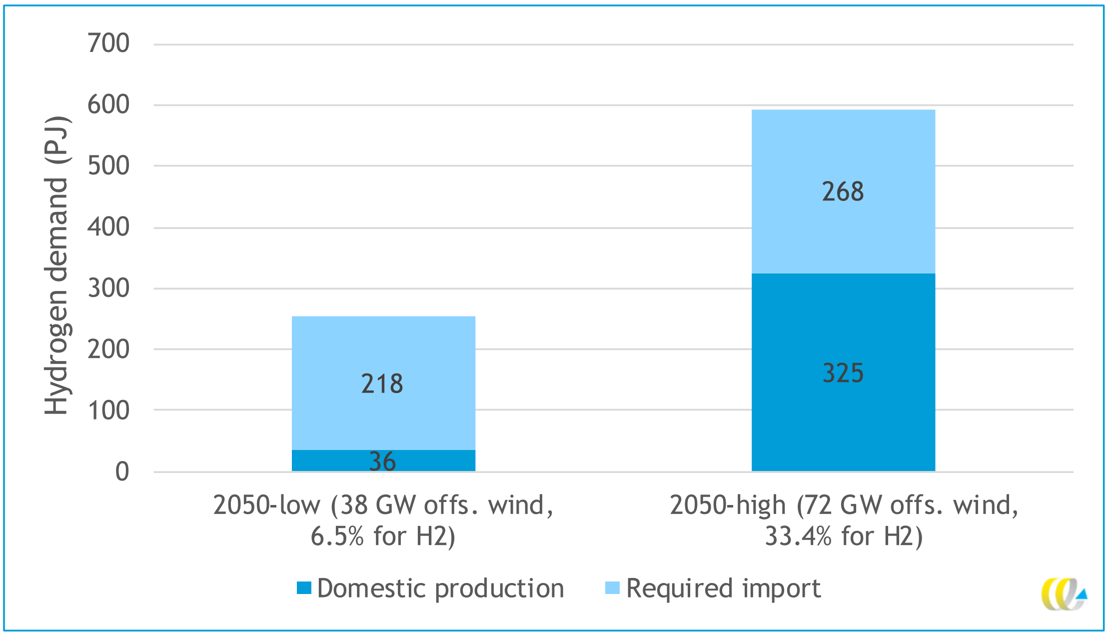
While electrification is one way of achieving partial climate neutrality of the energy system, there will always remain a need for physical molecules - as energy carriers and as raw materials. This is where green hydrogen comes in. Hydrogen produced using sustainably produced electricity provides a fuel with a high energy density that is a CO_2-neutral substitute for fossil fuels.

This study examined the labour demand potentially associated with introduction of green hydrogen in the Dutch economy in 2030 and moving on towards 2050. This report is an update and extension of the study carried out on the subject by CE Delft in 2018.

Low and high scenario

Labour demand was calculated for a 'low' and 'high' climate-neutral scenario for 2050. In the low scenario, demand for and Dutch production of green hydrogen are both minimal. In the high scenario they are maximal. For 2030 the high scenario is in line with the Dutch Climate Agreement (4 GW installed electrolysis capacity), with the low scenario assuming only 1 GW. For 2050 the low scenario translates to 254 PJ hydrogen demand, the high scenario to 594 PJ; see Figure 12.

Figure 12 – Hydrogen demand for domestic consumption, 2050 (PJ)



Besides domestic use of green hydrogen, the Netherlands may acquire a key role in its import for transit for use as a shipping and aviation fuel. The resultant potential labour demand was taken to be equal in the low and high scenario.

Labour demand in low and high scenario

In this study labour demand was calculated as 'gross employment', which means these are not necessarily only additional jobs. In the calculation a distinction was made between one-off and recurrent jobs, the first referring to installation and construction, the second to operation and maintenance. For the one-off jobs an average was taken for each decade (preceding the given year), because there may be pronounced peaks in labour demand.

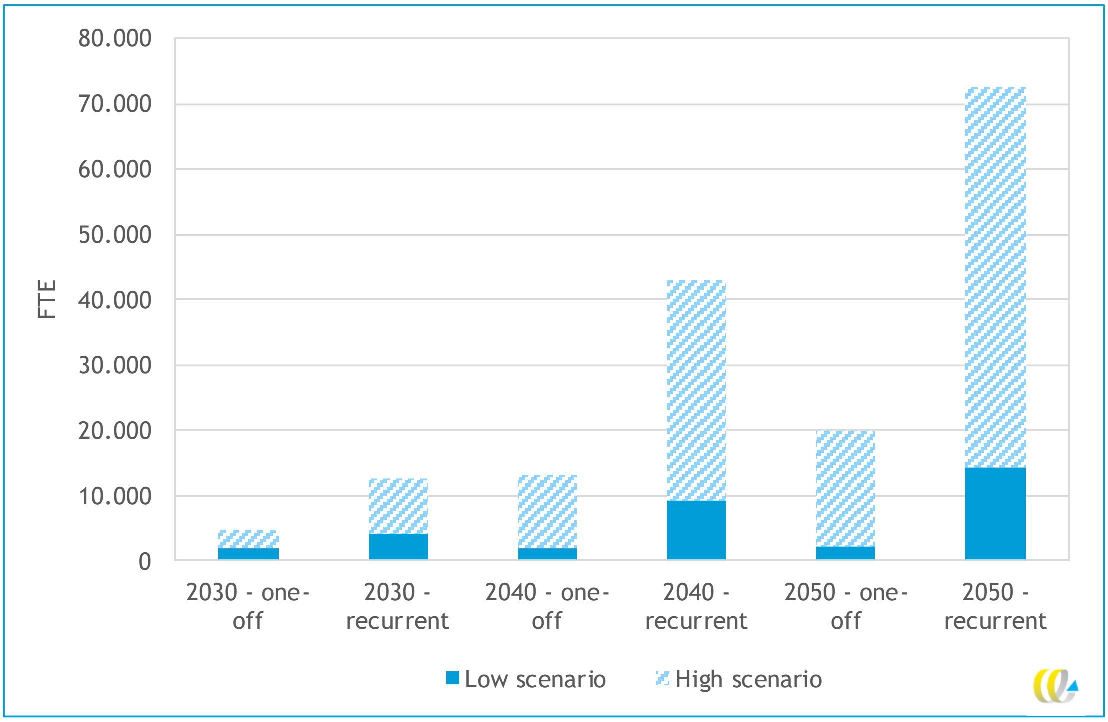
One-off labour demand is expressed as average full-time equivalents (FTE) per year, recurrent labour demand as FTE per year at a particular time. Table 26 provides a compact synopsis of the study's findings.

Table 26 - Synopsis of labour demand (rounded to hundreds)

Year	Total one-off labour demand (average, FTE/y)	Recurrent labour demand (FTE/y)
2030	1,800-4,700	4,200-12,500
2040	2,000-13,000	9,200-43,000
2050	2,200-20,000	14,200-72,600

Figure 13 shows how the low and high scenario differ in labour demand, for both one-off and recurrent jobs. As can be seen, while the high scenario has over double the hydrogen demand, the associated labour demand in 2040 and 2050 is at least a factor four higher than in the low scenario. There is, in short, a large non-linear difference in labour demand between the low and high scenario.

Figure 13 - Difference in labour demand between low and high scenario

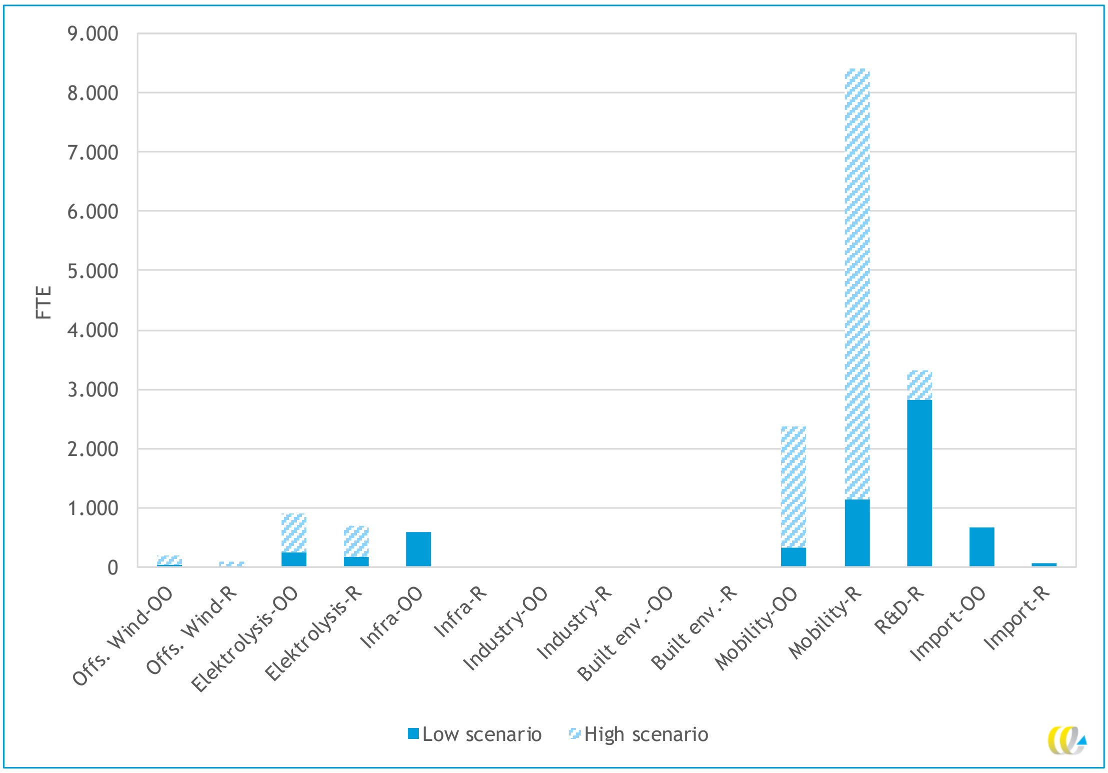


Sectoral labour demand

The data on sectoral hydrogen demand were used to model sectoral labour demand. For hydrogen import there was no difference between the low and high scenario, with the same volume being used for each. The next two figures show sectoral labour demand in 2030 and 2050 and the split between one-off and recurrent demand in each sector (except R&D).

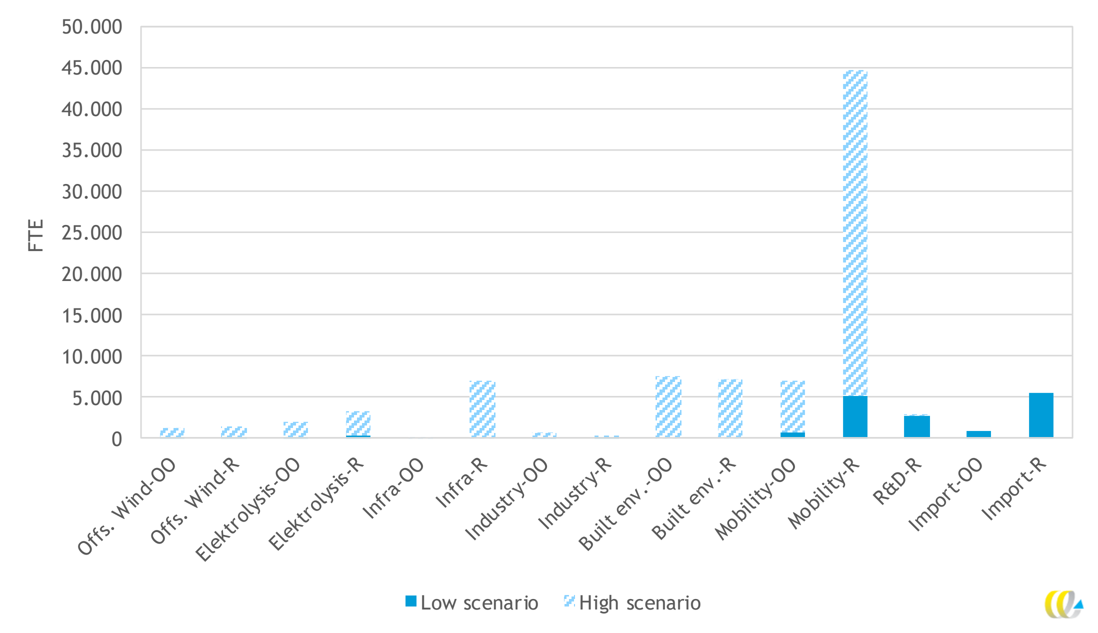
In 2030 green hydrogen is not yet in widespread use and the labour demand is generated mainly in R&D and mobility. The construction of import terminals and the hydrogen backbone also generate labour demand in both the low and high scenario. See Figure 14.

Figure 14 - Sectoral labour demand, 2030 (OO = one-off, R = recurrent)



By 2050, labour demand has been generated in multiple sectors, but especially in the high scenario. In the low scenario there is limited labour demand in two main sectors: mobility and import. See Figure 15.

Figure 15 - Sectoral labour demand, 2050 (OO = one-off, R = recurrent)



What do the results mean?

The results of this study are for two specific scenarios, both climate-neutral but with hydrogen playing two very different roles. While neither scenario is unrealistic, it is certainly plausible that reality will be somewhere intermediate. Whatever the case, though, hydrogen will unquestionably have a more prominent position than now and so in the low scenario there will still have to be substantial import to meet demand.

The labour demand generated in the two scenarios will obviously be very different. This study shows that the high scenario leads to disproportionally more jobs than the low scenario. While hydrogen plays an important role in the economy In the low scenario, the associated labour demand is relatively modest.

How will reality pan out?

To what extent reality moves more in the direction of the high scenario depends on several factors, all of which are amenable to policy decisions.

First, there is the issue of the amount of offshore wind capacity installed: 38 or 72 GW.

Second, the market for green hydrogen – as a whole – needs to be developed. There are initial signs that this process is indeed gradually beginning. On this point, though, the cost price of green hydrogen is also of the essence (compared with alternatives). This issue was beyond the scope of the present study, however.

Third, how far individual sectors develop towards the high scenario will depend on specific policy decisions and measures. This is particularly true of sectors where green hydrogen is not the only climate-neutral solution, such as the built environment and mobility.

In other sectors too, though, developments will depend on incentivisation – not just investments but also product standardisation, value chain integration and R&D.

Type of work

In virtually all the sectors covered in this study (except R&D) the bulk of labour demand is for technically skilled personnel (secondary vocational training, MBO), with R&D requiring academic qualifications. Each sector will have its own specific requirements, while general expertise will be geared to the ins and outs of hydrogen.

According to a recent report by Ecorys (2021) in 2030 the Dutch energy transition will see a shortfall of 23,000 to 28.000 in the workforce ('gross jobs') (Ecorys, 2021). While this shortfall rises, though, the pool of technically skilled personnel continues to fall, and do so substantially. As the Ecorys study clearly shows, ever before 2030 there will in all likelihood already be a shortage of technically schooled personnel who are up to the challenges of the climate transition.

If the Netherlands is serious about securing its climate ambitions, there will need to be investments in secondary technical vocational training. Additional training and retraining can also help achieve a better match between labour supply and demand.

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A Comparison with 2018 study

A.1 Scenarios

In the previous study the estimates for 2050 were based on two scenarios in our study *Net voor de Toekomst* ('Grid for the future', CE Delft, 2017), the predecessor of II3050, the lower bound being given by the 'generic governance' scenario, the upper by the 'national governance' scenario. For the present study, the data in the 2018 study were updated based on the improved understanding incorporated in II3050. Table 27 compares the scenarios used in the two reports.

Table 27 – Comparison of scenarios for 2030 and 2050 in present and previous CE Delft study. Unless otherwise indicated, all data are PJ hydrogen

	Previous study			Present study		
	2020	2030	2050	2020	2030	2050
Low scenario						
Offshore wind (GW)	-	-	-	1	11.5	38
Electrolysis (GW)	0	0.22	13	0	1	3.8
Import *	-	-	-	0	0	218
Total H_2 demand **	0	2.7	164.2	0	10	254
HT heat, industry	-	-	-	0	0	95
Industrial feedstock	-	-	-	0	0	14
LT heat, built environment	0	0	0	0	0	0
Transport	0	0	22	0	2.7	12
High scenario						
Offshore wind (GW)	-	-	-	1	11.5	72
Electrolysis (GW)	0	4	45	0	4	34.7
Import*	-	-	-	0	0	268
Total H_2 demand **	0	50	560.7	0	40	593
HT heat, industry	-	-	-	0	0	225
Industrial feedstock	-	-	-	0	20	134
LT heat, built environment	0	0	203.2	0	0	54
Transport	0	20	96.7	0	20	104

* Only import directly meeting demand for Dutch consumption.

** Also includes industrial feedstock, power generation and transport losses.

A.2 Results

The results of the two studies are not readily comparable. The main factor driving the differences within particular sectors lies in the different scenarios used, as detailed in Table 27. This explains the substantial differences in the sectors electrolysis, mobility and built environment.

Second, the scope of the present study is different, as explained in Section 1.1. The export of electrolyser parts has no longer been quantified, while offshore wind, industry, R&D and hydrogen import have.

Third, in the previous study hydrogen demand was translated directly to installed electrolysis capacity, while in the present study that capacity was derived from the share of offshore wind available for hydrogen production (thus with a role for import, too).

Fourth, in this study jobs in bus and fuelling station production have counted as one-off rather than recurrent.

Besides the differences in scenarios and sectors included, numerous assumptions have been updated based on improved understanding. Labour productivity figures, vehicle efficiency indices, annual mileages and installation man-hours have all been updated, for example. For a full comparison of the assumptions we refer the reader to Appendix B of this report and the Appendices of the previous study.

Table 28 compares the results of the two reports sector by sector, with the understanding that the underlying assumptions differ.

Table 28 – Comparison of results of present and previous CE Delft study

		Previous study		Present study	
		2030	2050	2030	2050
Low scenario					
Offshore wind	One-off	-	-	38	146
	Recurrent	-	-	15	156
Electrolysis	One-off	60	850	229	235
	Recurrent	41	1,431	172	361
Built environment	One-off	0	0	0	0
	Recurrent	0	0	0	0
Industry (energy)	One-off	-	-	0	51
	Recurrent	-	-	0	142
Infrastructure	One-off	500	0	573	0
	Recurrent	-	-	0	0
Mobility	One-off	0	0	315	815
	Recurrent	0	15,147	1,134	5,164
Export	One-off	0	0	-	-
	Recurrent	743	1,119	-	-
R&D	Recurrent	-	-	2,815	2,767
Import	One-off	-	-	660	943
	Recurrent	-	-	50	5,600
High scenario					
Offshore wind	One-off	-	-	178	1,359
	Recurrent	-	-	76	1,516
Electrolysis	One-off	976	2,967	900	2,004
	Recurrent	747	4,885	688	3,262
Built environment	One-off	0	1,795	0	7,534
	Recurrent	0	5,448	0	7,281
Industry (energy)	One-off	-	-	0	794
	Recurrent	-	-	0	336
Infrastructure	One-off	500	-	573	161
	Recurrent	-	-	0	7,000
Mobility	One-off	0	0	2,360	7,026
	Recurrent	14,468	62,547	8,413	44,770

		Previous study		Present study	
		2030	2050	2030	2050
Export	One-off	0	0	-	-
	Recurrent	1,239	1,865	-	-
R&D	Recurrent	-	-	3,321	2,803
Import	One-off	-	-	660	943
	Recurrent	-	-	50	5,600

B Assumptions

This appendix provides further details on the assumptions made in the present study.

Table 29 - Assumptions for calculating labour demand for offshore wind for hydrogen

Assumption	2020	2030	2050 - low	2050 - high	
Percentage of offshore wind for H_2	0	1.9-9.6	6.5	33.4	(Berenschot & Kalavasta, 2020)
NB: percentage above rising linearly from 2023					
Foundation supply (FTE/GW) – Mainly metalwork and coating – Engineers – Process engineers – Logistics	354	1,311	1,126	1,126	(Knol & Coolen, 2019, Knol & Coolen, 2020); pers. comm.
Installation (FTE/GW) – Ship's crews – Offshore wind staff (mainly technicians) – Preliminary onshore work – Cable-layers	325	443	391	391	
Maintenance (FTE/GW) – Ship's crews – Offshore wind staff (mainly technicians)	88	69	63	63	
Representation of wind companies	437	+1%/new GW capacity			Trade Register, Chambers of Commerce
Component production in NL	No	No	No	No	
Installation & maintenance based on GW; turbine replacement ignored.					
Turbine installation proportional over the years.					

Table 30 - Assumptions for calculating labour demand for electrolysers

Assumption				Source
Hydrogen-based energy conversion	60% (55 kWh/kg H_2)			(SEI, 2014)
Annual hours of operation	4,500 h/a			As modelled in (CE Delft, 2018a)
Labour costs per FTE (€/FTE)	Average of 2016 CBS data for following sectors: – 41 General construction and project development – 43 Specialised construction – 33 Repair and installation of machinery			CBS
Electrolysers	– Alkaline (up to 2030) – PEM (post-2030)			
Non-equipment costs, CAPEX, Alkaline electrolyser (€/kWe)	**2020**	**2030**	**2050**	(Hinicio & Tractebel, 2017)
	236	156	95	
Non-equipment costs, CAPEX, PEM electrolyser (€/kWe)	**2020**	**2030**	**2050**	Ibid.
	528	186	80	
Non-equipment costs, OPEX, Alkaline electrolyser (€/kWe)	**2020**	**2030**	**2050**	Ibid.
	14	10	7	
	2020	**2030**	**2050**	Ibid.

Assumption				Source
Non-equipment costs, OPEX, PEM electrolyser (€/kWe)	21	12	7	
Cost calculation, intervening years	Linear			
Non-equipment costs: 1. DCS and EMU costs 2. engineering costs 3. Interconnection, commissioning and start-up costs	– As % of equipment costs, with same share of individual parts for PEM and Alkaline. – Same shares in 2020, 2030 and 2050. – Respectively 10, 15 and 20% for 2.5 MW.			(Hinicio & Tractebel, 2017)
Non-equipment OPEX (includes site management, land rent and taxes, administrative fees (insurances, legal fees…), site maintenance)	– 0.04% of non-equipment costs. – Same in 2020, 2030, 2050. – Same for PEM and Alkaline.			Ibid.

Table 31 – Assumptions for electrolyser costs

		2020	2030	2050
PEM (10 MW)	Service life (years)	20	23	27
	CAPEX (€/kW)	1470	810	510
	stack (%)	50	48	40
	power supply (%)	15	16	20
	gas cleaning (%)	13	12	14
	BoP (%)	22	24	26
	OPEX (€/kW)			
	O&M	13	9	7
Alkaline	Service life (years)	27	28	30
	CAPEX (€/kW)	920	690	500
	stack (%)	45	41	n/a
	power supply (%)	20	24	n/a
	gas cleaning (%)	20	15	n/a
	BoP (%)	15	20	n/a
	OPEX (€/kW)			
	O&M	19	24	26

Sources: (Hinicio & Tractebel, 2017, Smolinka et al., 2018).

Table 32 – Labour productivity trends since 2016

Sector	€/FTE, 2016	€/FTE, 2020
26 Manufacture of electronic equipment	81,800.00	92,042.24
27 Manufacture of electrical equipment	72,500.00	81,577.78
28 Manufacture of machinery and equipment	68,300.00	76,851.90
29 Manufacture of motor vehicles, trailers and semi-trailers	62,000.00	69,763.07
33 Repair and installation of machinery	74,200.00	83,490.64
41 General construction and project development	65,800.00	72,835.39
43 Specialised construction	57,100.00	63,205.18
45 Sale and repair of motor vehicles	50,100.00	54,973.08
Research & Development	77,494.95	84,455.61

Sources: (CBS Statline, 2021a, ECN, 2016).

Table 33 – Collective Agreement (CAO) trends used for updated labour productivity

CAO trends: % increase rel. to previous year							
Sector	**SBI Branch**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
26 Manufacture of electronic equipment	24-30, 33 Metal-electro	1.7%	1.8%	2.1%	2.1%	2.8%	5.0%
27 Manufacture of electrical equipment	24-30, 33 Metal-electro	1.7%	1.8%	2.1%	2.1%	2.8%	5.0%
28 Manufacture of machinery and equipment	24-30, 33 Metal-electro	1.7%	1.8%	2.1%	2.1%	2.8%	5.0%
29 Manufacture of motor vehicles, trailers and semi-trailers	24-30, 33 Metal-electro	1.7%	1.8%	2.1%	2.1%	2.8%	5.0%
33 Repair and installation of machinery	24-30, 33 Metal-electro	1.7%	1.8%	2.1%	2.1%	2.8%	5.0%
41 General construction and project development	F: Construction	1.2%	2.8%	1.7%	2.2%	2.6%	3.8%
43 Specialised construction	F: Construction	1.2%	2.8%	1.7%	2.2%	2.6%	3.8%
45 Sale and repair of motor vehicles	45 Motor vehicle trade and repair	0.4%	1.6%	1.7%	2.0%	2.2%	3.5%
Research & Development	A-U All economic activities	1.4%	1.9%	1.4%	2.0%	2.5%	2.8%

Source: (CBS Statline, 2021b).

Table 34 – Estimated costs of gas delivery station (50 MW_{th})

Gas delivery station	Procurement & installation (€)	Lifetime (year)	Maintenance/y
Gas flow meter (turbine meter, typically 8 bar or higher)	30,000	25	0.067%
Control line	15,000	25	0.033%
Housing	20,000	40	1-3%
Connecting line	50-100,000/km	40	1%
Labour, connecting line	100-200,000/km	-	-
1 km per station assumed			

Based on (US DOE, 2002).

Table 35 - Estimated costs of industrial boilers and furnaces

	Procurement (mln. €)	Maintenance (mln. €/y)
Industrial boilers (50 MW)	2030: 6.3 (50% labour) 2040: 5.6 (50% labour) 2050: 5.3 (50% labour)	0.2 (95% labour)
Industrial furnaces (50 MW)	2030: 3.7 (50% labour) 2040: 3.4 (50% labour) 2050: 3.1 (50% labour)	0.2 (95% labour)
Conversion of industrial boilers and furnaces (50 MW)	0.7 (50% labour)	
In 2020 only conversion, from 2035 only newbuild; linear progression.		
Euro/FTE	79,579	Average of electrical industry, repair and installation of machinery and specialised construction; see Table 32
Ratio of boilers to furnaces	21.5%-78.5%	
Instruction day for 3-4 person operating shift not included		

Based on (EPA, 2010, TNO, 2020).

Table 36 - Assumptions on built environment (HP = heat pumps)

	2020	2030	2050 - low	2050 - high	Source
No. of households	-	-	8.8 mln.	8.8 mln.	(Berenschot & Kalavasta, 2020)
H_2, households (PJ)	0	0	0	41 PJ	Ibid.
% hybrid HP	0	0	0	60%	Ibid.
No. of hybrid HP	0	0	0	5.28 mln.	
Outlay, HP (€)	-	6,500	6,500	6,500	(CE Delft, 2017); based on manufacturers' factsheets
H_2, buildings (PJ)	0	0	0	13 PJ	(Berenschot & Kalavasta, 2020)
% hybrid HP	0	0	0	60%	ibid.
No. of hybrid HP	0	0	0	1.67 mln.	
Total hybrid HP	0	0	0	6.95 mln.	

General assumptions:	
All hydrogen for the built environment is green.	
No hydrogen high-efficiency boilers, only hybrid heat pumps.	
60% of buildings = 60% of buildings' energy consumption.	
60% of all households in 2050 = almost 70% of existing housing stock.	
Cost of a hybrid heat pump will not fall, but efficiency will rise.	
PJ H_2 used in scenario = 100% of PJ in built environment (i.e. fact that hybrid HP delivers only 1/3 heat, 2/3 electricity is already factored in).	
Rising linearly from 2030.	
40.56 man-hours for installation of hybrid heat pump.	EPA measures
HP maintenance = 1.5 h/y.	
Labour = 100% maintenance costs (material costs negligible).	

Table 37 – Assumptions on mobility (FC = fuel cells)

Assumption		2018	2030	2050	Source
TTW efficiency (kWh/100 km)	FC cars (incl. taxis)	19.44	19.44	19.44	(JRC, 2020)
	FC LDV	49.5	49.5	49.5	(CE Delft, 2021, Oldenbroek et al., 2021)
	FC buses	243.09	243.09	229.78	(FCH JU, 2015)
	FC trucks	236.43	225.8	183	(FCH JU, 2020)
km/y	FC cars (incl. taxis)	22,000			
	FC LDV	35,000			
	FC buses	65,000			(FCH JU, 2015)
	FC trucks	100,000			(FCH JU, 2020)
Maintenance (€/km/y)	FC cars	0.023	0.023	0.023	
	FC LDV	0.24	0.055	0.055	
	FC trucks	0.5	0.115	0.115	
	FC buses	0.38	0.28	0.28	

Table 378 – Assumptions on hydrogen fuelling stations

	2020	2030	2050
% 200 kg/d stations	80%	0%	0%
% 400 kg/d stations	20%	60%	20%
% 1t/d stations	0%	35%	50%
% 2t/d stations	0%	5%	30%
No. of light vehicles per station	2,000	2,000	2,000
No. of buses per station	40	40	40
No. of trucks per station	100	100	100
Lifetime (y)	10	10	10
CAPEX (€), equipment @ 200 kg/d	1,000,000	-	-
CAPEX (€), equipment @ 400 kg/d	1,200,000	600,000	400,000
CAPEX (€), equipment @ 1,000 kg/d	2,240,000	1,000,000	800,000
CAPEX (€), equipment @ 2,000 kg/d	3,360,000	1,500,000	1,200,000
Non-equipment costs	30%	30%	30%
O&M (%CAPEX/y)	8%	5%	2%
FTE, equipment @ 200 kg/d	10% CAPEX		
FTE, equipment @ 400 kg/d	8% CAPEX		
FTE, equipment @ 1,000 kg/d	6% CAPEX		
FTE, equipment @ 2,000 kg/d	5% CAPEX		