gasunie
crossing borders in energy

Edition 2018

Survey 2050

Discussion paper

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March 2018

LET'S DESIGN OUR ENERGY

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Foreword

The transition towards a CO_2-neutral energy supply by 2050 is one of the greatest challenges facing Dutch society and Gasunie wants to help accelerate this transition by making an active contribution. Against this background, Gasunie published its 'Survey 2050' in May 2016, in which we describe our vision of a possible route towards a reliable and affordable CO_2-neutral energy supply in the Netherlands by 2050.

We are now publishing a revised version of this Survey following the positive response to the earlier version, valuable comments and recent developments.

This Survey shows that it is possible to achieve a reliable, affordable and sustainable energy supply by 2050 and what this might look like.

It also shows what a large and complex task this is, requiring large-scale social commitment with often difficult decisions and radical changes.

We have come to the conclusion that a sustainable, reliable and affordable energy supply can only be achieved through an integrated solution involving a combination of different energy carriers (electricity, hot water, various gases). Energy infrastructure companies need to respond flexibly to the ongoing challenges presented by the energy transition. The growing share of sustainable energy sources will result in increasing fluctuations in the energy supply. Society must, nevertheless, be able to count on a reliable energy supply even in the face of changing dynamics.

This Gasunie Survey is our opportunity to share our knowledge and vision with you based on our most recent insights. We would welcome your input so that we can continue to define our energy transition vision more precisely. We believe in sharing knowledge and insight and joining forces so that the energy transition can be effected in the most socially responsible manner.

Han Fennema

CEO and Chairman of the Executive Board of Gasunie

Introduction

The public debate about the transition towards a CO_2-neutral energy supply seems to have gained momentum since the publication of the first "Gasunie Survey 2050" (May 2016). The Dutch government has confirmed its commitment to the Paris Climate Targets for 2050 and has included a more stringent ambition for 2030 in its recent "Dutch Coalition Agreement": by 2030, the Netherlands must have reduced its CO_2-equivalent emissions by 49% compared with 1990. A reduction of 95% is being applied for 2050. The Netherlands is currently producing 11% less CO_2-equivalent emissions than in 1990[1]

Given that some CO_2-equivalent emissions in the Netherlands are difficult to reduce (particularly non-energy-related emissions within the Food and Nature functionality[2]), this Survey assumes that energy-sector-related CO_2-emissions must be reduced to 0% by 2050. A CO_2 reduction of 54% compared to 1990 is being applied to the energy sector for 2030[3]. These targets apply to energy sources being used for energy-related purposes. Apart from making a few references to non-energy-related use, this Survey does not cover it in detail.

Important changes have been made with respect to the previous Survey. Whilst sources such as geothermal energy and biomass remain very important, they have been estimated more conservatively in this Survey. Offshore wind cost trends have been revised downwards and hydrogen is given a bigger part to play as an energy carrier. On the demand side, there are new insights about economic growth and opportunities for efficiency improvements. These analyses could be further substantiated thanks to input from a number of social organisations.

This Survey is based on existing technologies, including the potential for improvement. There should be prospect for economic application in 2030 or 2050. Lock-in investments are avoided and revolutionary game changers are disregarded. It is assumed that the Netherlands will maintain its current level of industry and commerce, it will keep the reliability of the energy system intact and society will continue to enjoy the same level of comfort with regard to security of energy. The Survey is not simply a sector-based volume analysis, but also an analysis of the hourly capacities and conversion technologies required.

1 *Source: 'Emissies broeikasgassen, 1990-2015.'('Greenhouse Gas Emissions, 1990-2015.') Compendium voor de Leefomgeving (Living Environment Compendium). September 2016. http: // www.clo.nl/indicatoren/ nl016529-broeikasgasemissies-in-nederland*

2 *A distinction is made between the following functionalities for the purpose of compiling the Energy Agenda: 1. Power and Light (electricity), 2. High-temperature heat (intensive industry), 3. Low-temperature heat (built environment), 4. Transport and Mobility and 5. Food and Nature (agricultural sector). Source: https: //www.rijksoverheid.nl/binaries/rijksoverheid/documenten/brieven/2017/06/02/ bijlage-2-jaarverslag-ministerie-van-infrastructuur-en-milieu-2016-34725-xii-1/bijlage-2-jaarverslag-ministerie- van-infrastructuur-en-milieu-2016-34725-xii-1.pdf*

3 *This 54% reduction leads to an overall reduction in CO2-equivalents of 55%, the level to which the Netherlands is committed in a European context.*

Quintel's Energy Transition Model (ETM) was used for the modelling. We performed our own supplementary analyses in places where this model did not offer sufficient analysis options. Consultancy firm Berenschot calculated the costs. The mutual cohesion within the complex energy landscape involving sectors, functionalities, energy sources, energy carriers and conversion technologies are brought to life by the flow charts.

The first part focuses on 2050, however significant action will be required by 2030 to fulfil the ambition of making the Dutch energy sector fully CO_2-neutral by 2050. Therefore, the second part considers what the situation will be around the year 2030 and the steps towards it. A cost analysis[4] and an overview of the main efforts required will form the final part of the Survey.

4 *In the previous version of the Survey 2050, the estimated costs involved in the realisation of the energy transition were contained in a separate publication; however the cost analysis has now been integrated into this revised version.*

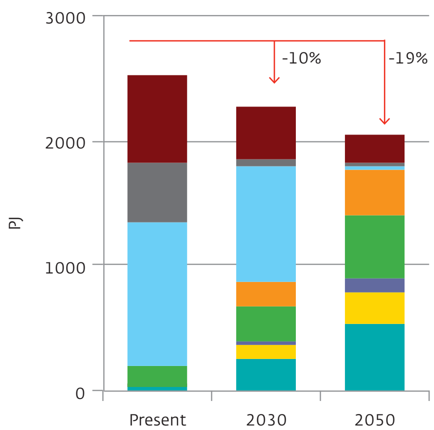
Summary

CO_2-neutral is feasible but requires dedicated effort and cooperation

A completely CO_2-neutral, reliable energy supply by 2050 is technically and economically feasible. In order to fulfil this ambition, significant action will have been required by 2030. This will require many different measures, which must be considered in relation to each other. Different energy sources, energy carriers and energy technologies can back each other up in an integrated energy system. Wind, biomass, CO_2 storage, solar-PV, geothermal energy and hydrogen are important alongside energy savings and energy efficiency in order to meet interim and ultimate targets.

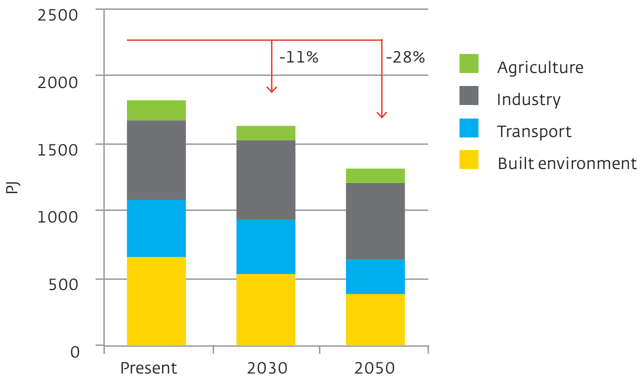
A crucial element of the future energy supply is the ability to bridge times when there is a high demand for, or a limited supply of, sustainable electricity. National and local energy infrastructures must offer sufficient flexibility to guarantee a reliable energy supply even at times of substantial discrepancies between supply and demand. Large-scale storage of sustainable energy is essential in this regard. As there will not be sufficient potential for storing energy in electricity carriers, it will be necessary to use sustainable gases that can be stored. There are no other options for flexible energy storage on the scale required. It is therefore necessary to use relatively expensive biomass. Biomass is currently used primarily for combustion; however, that use will mainly change to gasification, which gives far greater energy efficiency for the same quantity of biomass. The use of storage facilities means that this production of green gas can be used at times of peak demand.

Primary Energy Consumption excl. energy consumption for feedstock



	2030	2050
Oil	-38%	-69%
Coal	-90%	-93%
Natural gas	-18%	-98%
Hydrogen	New	New
Biomass	+54%	>100%
Geothermal	>500%	>500%
Solar energy	>500%	>500%
Wind energy	>500%	>500%

Final energy consumption excl. ambient heat



	2030	2050
Agriculture	-27%	-27%
Industry	0%	-3%
Transport	-10%	-42%
Built environment	-17%	-41%

By 2050, the built environment will be fully CO2-neutral

By 2050, the energy demand in the built environment will have fallen by more than 40% compared to today. Solar panels on roofs will supply electricity and this will be supplemented by sustainable electricity from solar fields, wind farms and hydrogen power plants. A considerable proportion of the heat supply will be electrified, either by the use of heat pumps in all-electric homes (mainly newly built) or by the use of hybrid heat pumps. The remaining buildings will be heated by heat networks based on geothermal energy and residual heat.

In the built environment, gas will only have a part to play on cold days and the volume required will be limited: approximately 20% of what is used today. By 2050 there will be sufficient green gas available to meet this demand for gas (natural gas will no longer be necessary in the built environment).

Industry will focus on energy efficiency, hydrogen and CCS

The demand for refined products will decline as a result of the electrification of passenger transport. There will be no impact on the demand for other industrial products. The effects of economic growth, efficiency improvements and declining energy intensity will mainly cancel each other out, meaning that total energy demand for industry will fall slightly on balance.

In 2050, the fuel mix in the industrial sector will look quite different: electrification will have increased substantially but the demand for molecule-based energy will prevail. Coal and oil will still be used in the steel and petrochemicals industry in 2050 but in combination with CCS to capture the CO_2 and store it underground.

Industry will make increasing use of hydrogen (75 PJ in 2050). With regard to non-energy-related use, companies themselves will be converting natural gas into hydrogen less and less frequently – the hydrogen will be supplied by other parties. Natural gas pipelines can be re-used for transporting hydrogen to industries. Insofar as natural gas is still being used in industry after 2030, that will be in combination with CCS as much as possible; natural gas as a primary energy source will have largely disappeared by 2050.

By 2050 road transport will no longer use fossil fuels

In line with an increasing supply of electric power and climate-neutral hydrogen, there will be a large-scale move to electrically-powered vehicles for road transport. How passenger transport will be divided between battery-powered cars and hydrogen cars will depend on desired functionalities and also the availability of charging/refuelling infrastructure. What is clear is that bio-fuel will still be used to a limited extent for heavy-goods road transport in 2050. Green gas and natural gas or LNG will be used during the transitional period towards 2050.

Lots of electricity from sun, wind and hydrogen

By 2030, wind farm capacity, mostly offshore, will have increased to 28 GW (currently 4 GW), and 20 GW will be will be available from solar panels on roofs and in solar fields; the electricity grid will have been significantly extended.

By 2050, the extent of electrification in Dutch society will have doubled. Solar and wind power will have continued to grow. 66 GW will be represented by solar panels and offshore wind capacity will have expanded to 55 GW, 15 GW of which will be used for dedicated hydrogen production. A limited quantity of hydrogen will be produced onshore from residual electricity, in addition to storage in batteries and use for power-to-heat. Offshore wind cost trends are an important parameter for total energy transition costs. Power plants will step in during periods of little sun or wind. By 2050, these power plants will be running exclusively on hydrogen (250 PJ); fossil energy will no longer be used for generating electricity.

Hydrogen from dedicated wind farms, from residual electricity and from natural gas (with CCS)

By 2050, 15 GW of offshore wind capacity will be used for the dedicated production of green hydrogen that is transported to the mainland via pipelines. Hydrogen will be produced onshore from sustainably generated residual electricity and Norwegian hydrogen will also be imported. The latter will be produced from natural gas, the CO_2 being captured and stored in Norway. This 'blue hydrogen' will still be an important part of the energy mix in 2050. The future will show whether it is economically more attractive to produce hydrogen in the Netherlands from (imported) natural gas rather than importing it. Over the coming decades, the global market for sustainable hydrogen will develop further, mainly based on solar energy in remote areas. The timing of this is extremely uncertain but, by around the middle of this century, the global market for sustainable hydrogen will have become tangible and will displace the market for hydrogen based on natural gas with CCS.

Biomass and geothermal energy will play an important part

Including imports, the quantity of biomass available for inland energy-related use in 2050 will be 500 PJ. This will be used to produce around 180 PJ of green gas and around 105 PJ of biofuels. The quantity of geothermal energy will be 115 PJ, sufficient for a quarter of Dutch buildings and half of the energy demand in agriculture and horticulture.

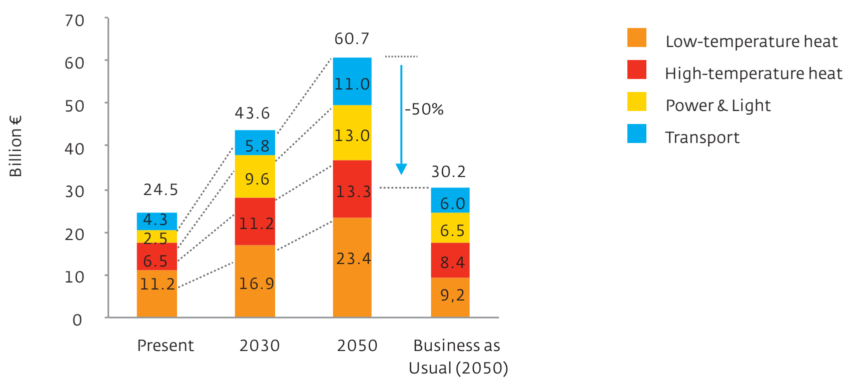
CCS will be necessary

The use of CCS is unavoidable if targets of 100% CO_2 reduction in the energy supply by 2050 and 54% CO_2 reduction by 2030 are to be met in an affordable and reliable manner. Large-scale use of sustainable electricity may mean that CO_2 capture will remain limited to refineries (oil) and steel production (coal), together responsible for the production of around 16 Mton of CO_2. The CO_2 will also be captured when green gas and biofuels are produced from biomass and from waste processing plants, which will give rise to negative emissions. This Survey assumes that between 2030 and 2050, around 20 Mton of CO_2 per year will be captured and stored in empty offshore gas fields; of this between 3 Mton and 6 Mton of CO_2 will have been captured during the production of green gas (negative emissions).

A CO2-neutral energy supply will lead to sharply rising energy costs

Total annual costs for the energy supply will rise from the current amount of 25 billion euros to more than 60 billion euros in 2050. This type of future-oriented cost calculation must be viewed in the light of the fact that the results are surrounded by uncertainty due to the many presuppositions. The results must therefore be seen as indicative; taxes and levies on CO_2 emissions and subsidies have not been taken into account in the calculated annual costs.

Total costs of CO2 reduction in 2030 and 2050 compared to present level, according to Gasunie's Survey (in € billion).



The differences in costs between 2030 and 2050 are partly attributable to the assumed sharp increase in biomass prices between 2030 and 2050 (+250%). A smaller proportion of the cost increase will be caused by the increased use of hydrogen instead of natural gas.

A sensitivity analysis shows that the costs could also come out much lower in 2050, at around 47 billion euros. If the costs relating to offshore wind turbines are 50% lower than assumed based on IEA assumptions for 2050, then annual costs may fall by 8 billion euros. The latest North Sea auctions give an encouraging vision for this. Biomass costs are another important cost parameter. At present, high scarcity costs are assumed (WLO high scenario[5]), according to which the price of biomass is more than three times higher than at present by 2050. If a more moderate increase of 50% is assumed for the biomass price[6], for example because supply and demand are better balanced on the global market, then the energy costs will come out 6 billion euros lower.

In a Business as Usual scenario, the current energy supply is calculated using the assumed prices for 2050, without any provision for a decrease in CO_2 emissions. With regard to the Business as Usual scenario, additional costs per year by 2050 are over 30 billion euros but, as stated in the paragraph above, that may also only come out at 17 billion euros.

5 *This Survey 2.0 applies prices for gas, biomass, coal and oil in accordance with the WLO high scenario. This is in line with the report by the Netherlands Environmental Assessment Agency (PBL) "Verkenning van klimaatdoelen - Van lange termijn beelden naar korte termijn actie (2017)"("Exploring climate targets – from long-term visions to short-term action (2017)"). The price of biomass, in particular, is considerably higher than in the previous Survey. No CO_2 prices are included in costs.*

6 *According to the WLO low scenario.*

The Netherlands in 2050

Emissions reduction targets

The Paris Climate Agreement sets out radical reductions in greenhouse gas emissions. This Survey carries out an analysis aiming at emissions reductions of 95% in 2050 compared to 1990. The analysis aims to visualise the greatest future challenges. For the Dutch energy sector, the points set out above mean that 100% reduction in CO_2 emissions must be achieved.

General picture

By 2050, CO_2 emissions in the Dutch energy sector will be negligible, hence fulfilling the ambition of making this sector fully CO_2-neutral. To this end, the energy demand has been reduced in 2050, the proportion of sustainable energy has significantly increased and new technologies and energy carriers are being applied. Energy awareness is ever-present, using the available energy efficiently is a common goal. Price incentives and other market mechanisms are set up in such a way that they encourage citizens and businesses to save energy every day, by using (partly) automated systems and to choose the form of energy which is most readily available.[7]

Public debate is likely to focus on the cost aspect of the required changes. .Therefore, it is expected that, in addition to political guidance and inducements, especially incentives from the financial and technical sectors will play a role.

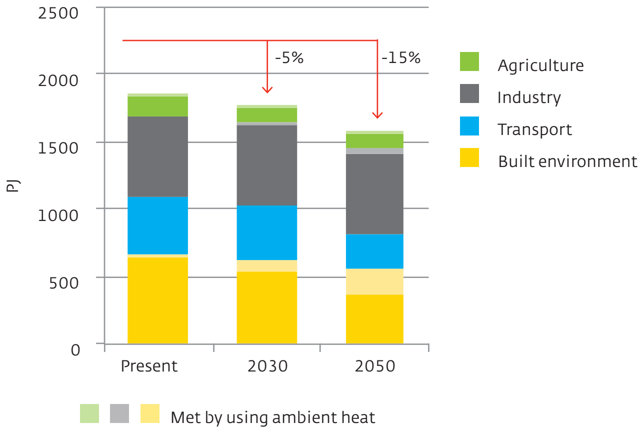
Energy demand[8]

General picture

Despite economic growth of an average 1.6% per year, final energy consumption[9] (excluding ambient heat) has fallen by 28% by 2050 compared to today's demand. Significant energy savings of around 40% are being achieved in the built environment and transport sector in particular.

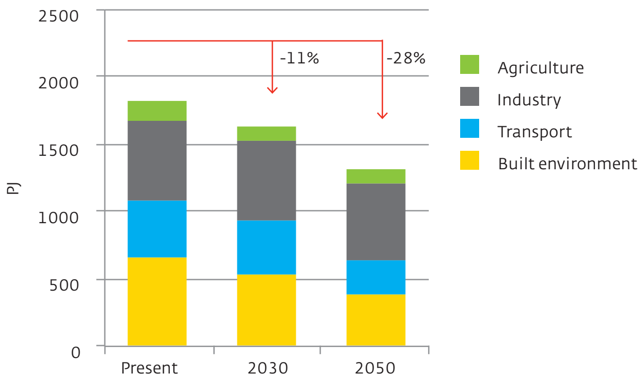
7 *Energy trading points are also making this possible. Gasunie, Alliander and DNVGL are developing EN | square to this end.*
8 *This relates to the final energy demand, which is the energy consumption at end user level (final), after conversion losses. The primary energy demand is the demand for energy carriers, prior to conversion losses.*
9 *In this document, 'final energy consumption' always means gross final energy consumption.*

Final energy consumption incl. ambient heat



2030	2050
-23%	-21%
+3%	+4%
-10%	-42%
-4%	-13%

Final energy consumption excl. ambient heat



2030	2050
-27%	-27%
0%	-3%
-10%	-42%
-17%	-41%

According to the CBS definition, ambient heat is included in final energy consumption. As can be derived from the graphs above, ambient heat is not currently used a great deal but there will be much greater use by 2050 (especially in the built environment). In order to prevent confusion, in the Survey we have elected not to include ambient heat in the graphs of the various market sectors, however the calculations do include the demand for ambient heat.

Built environment

By using a combination of green gas, green power, ambient heat, geothermal energy and residual heat, the built environment will be CO_2-neutral by 2050. In 2050, 25% of all buildings will be connected to a heat network and the remaining buildings will have a (hybrid) heat pump or an open loop ground sourced heat pump.

The final energy consumption in the built environment will have fallen by more than 40% in 2050 compared to the present demand[10]. The number of electrical appliances in households and utility buildings will have increased further by 2050, but as a result of considerable efficiency improvements the final energy demand for lighting and other appliances (excluding heat pumps) will be a fraction lower than now.

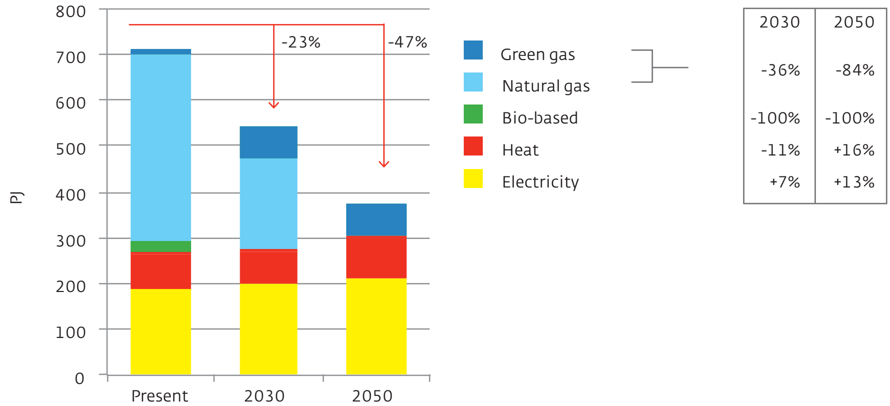
Two-thirds of the decline in the energy demand will be the result of a large-scale application of advanced, very efficient heating technologies that make optimal use of the ambient heat available[11]. The use of insulation and consumers' increased energy awareness will account for the remainder. Stand-alone High Efficiency boilers, gas cookers and luxury gas applications such as fireplaces will have practically fallen out of use.

In 2050, 25% of homes will be heated via a heat network. Geothermal energy will be increasingly available after 2020 and this will significantly boost the continued development of heat networks. Green gas (or hydrogen) will be brought into play via auxiliary boilers to supply sufficient heat at times of high demand or in unforeseen circumstances; this will guarantee security of supply. In 2050, (solid) biomass will no longer be used as a fuel source for heat networks.

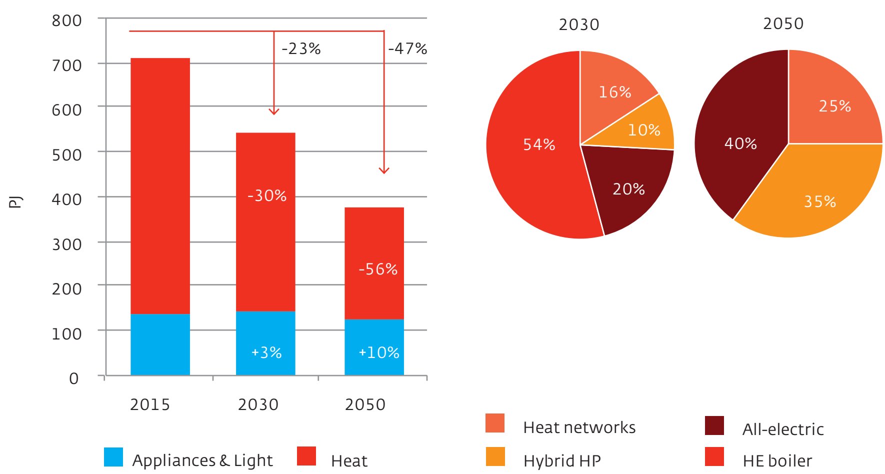
10 *Source: 'De systeemkosten van warmte voor woningen' ['System costs of heating for homes'] by Energieonderzoek Centrum Nederland (ECN) and consultancy firm Ecofys, in cooperation with network administrators TenneT, Gasunie Transport Services and Alliander, among others. November 2015. http://www.ecofys.com/nl/press/keuze-verwarmingstechnologie- huishoudens-grote-invloed-op-netwerkkosten/ en 'Verkenning Energievoorziening 2035'('Study of the Energy Supply in 2035') by Energieonderzoek Centrum Nederland (ECN). May 2017. https://www.ecn.nl/publicaties/ECN-E--17-026 and 'Een klimaatneutrale warmtevoorziening voor de gebouwde omgeving "update 2016" van CE Delft'('A climate-neutral heat supply for the built environment "2016 update" by CE Delft'). September 2016. http://www.ce.nl/publicaties/1838/een-klimaatneutrale-warmtevoorziening-voor-de-gebouwde-omgeving-a-update-2016.*

11 *Only the "major" technologies are mentioned. Heat network also includes district CHP. Hybrid heat pumps also includes fuel cells and the all-electric includes open loop ground sourced heat pumps.*

Final energy consumption for the built environment excl. ambient heat



Final energy consumption for the built environment according to functionality



In 2050, electric heat pumps will play an important part in areas in the Netherlands that do not have geothermal energy and/or residual heat. Electrically driven ground source heat pumps will be commonplace in houses (particularly new buildings) that can be well insulated, larger (utility) buildings or housing complexes will be equipped with an open loop ground sourced heat pump. In buildings where insulation is more problematic and the heat demand cannot be reduced sufficiently (existing buildings) hybrid heat pumps combined with green gas will ensure a sustainable heat supply. This means that ambient heat from the ground or the air will have become an important source of heat for homes and buildings.[12]

12 *Ambient heat is not included in the graph entitled "Energy use in the built environment" because this relates to energy that is not competing with use elsewhere. 'Heat' includes geothermal energy and heat from a CHP for a heat network, among others.*

Many houses or residential districts will have their own home batteries for bridging day-to-night imbalances. However, even by 2050, battery technology does not provide a solution or seasonal imbalances. Thermochemical technologies involving heat storage will be emerging by 2050 but not yet widely applied.

In 2050, the gas demand of the built environment will be fully met by green gas (68 PJ). Green gas, combined with renewable electricity (hybrid heat pumps) will be used in those sections of the built environment where introducing sustainability in other ways is difficult to achieve. All-electric will be the preferred alternative for well insulated homes (including newbuilds) but is not efficient for application in other places. It is expected that heat networks based on geothermal energy and residual heat will be available in 25% of the built environment. Biomass will no longer be used as an energy source for heat networks.

An alternative to using green gas in the built environment is to use hydrogen; thanks to research undertaken abroad (Leeds) consideration of this method has gained momentum in the Netherlands[13]. The existing gas infrastructure can be used for hydrogen, subject to a few minor adaptations; However, the burners in domestic heating devices would require replacement. This Survey assumes that, by 2050, sufficient green gas will be available to meet the remaining heat demand in the built environment and that this cost-effective option will be preferable to using hydrogen. It will become very clear over the next 5-10 years whether there is a possible role for hydrogen in the built environment.

Industry

In 2050, industry will still be the sector with the greatest energy demand although it will use 3% less energy than now. This will result from a decline in the energy intensity of the industrial sector and economic growth of an average 1.6%[14] per year. Where possible, the residual heat produced by the industrial sector will be re-used.

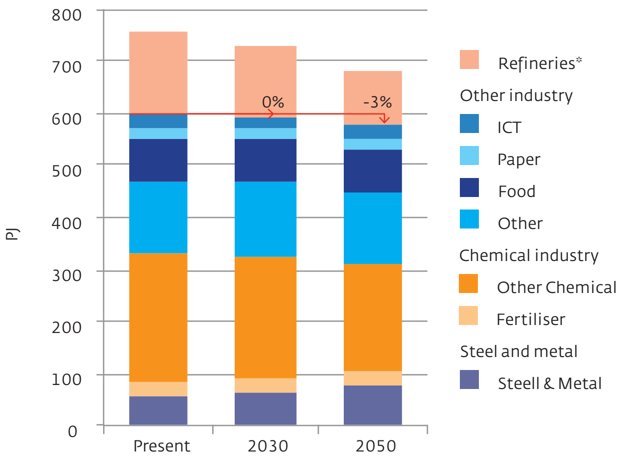
In 2050, some industries will have disappeared from the Netherlands, other industries will have implemented a process redesign[15] and other industries will have expanded or have been newly launched. Certain industrial activities, which had moved to other continents during the twentieth century, will return to Europe and the Netherlands after 2030. In addition to developments such as nanotechnology, 3D printing and robotisation, global CO_2 considerations will play a part: moving production overseas will not lead to a reduction in global CO_2 emissions in the production process but will increase global CO_2 emissions from maritime transport.

13 *See, inter alia, "Net voor de Toekomst"("Network for the Future") by CE Delft, 2017*

14 *Source: 'Verkenning Energievoorziening 2035' ('Study of the Energy Supply in 2035') by Energieonderzoek Centrum Nederland (ECN). May 2017. https: //www.ecn.nl/publicaties/ECN-E--17-026*

15 *Source: 'Economische ontwikkeling energie-intensieve sectoren,'('Economic trends of energy-intensive sectors') CE Delft. September 2014. http://www.ce.nl/publicatie/economische_ontwikkeling_energie-intensieve_sectoren/1516 and 'Energy Transition: Mission (im)possible for industry?, McKinsey commissioned by VEMW. April 2017. https://www.mckinsey. com/business-functions/sustainability-and-resource-productivity/our-insights/energy-transition- mission-impossible-for-industry*

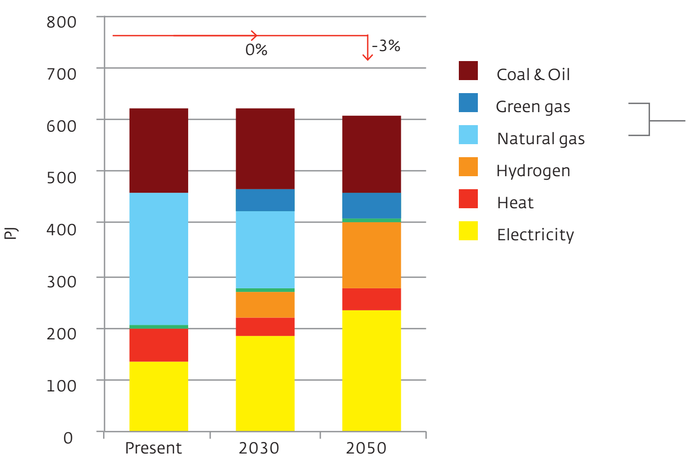
Final energy consumption for industry excl. feedstock and ambient heat



	2030	2050
Other industry	+2%	-1%
Chemical industry	-6%	-16%
Steel and metal	+20%	+43%

* For illustration purposes: CBS statistics do not include the energy demand for refineries

Final energy consumption for industry (excl. feedstock and ambient heat)



	2030	2050
Coal & Oil	-1%	-4%
Green gas / Natural gas	-26%	-79%
Hydrogen	New	New
Heat	-24%	-28%
Electricity	+37%	+72%

By 2050, there will be a considerably higher demand for electricity from the industrial sector and many of the current industrial natural gas users will have switched to hydrogen. Some of the energy requirement will also be met by green gas. Industries using natural gas or other fossil fuels will capture their CO_2 emissions for storage (CCS). Furthermore, CCS quantities will fall steadily after 2050 having been replaced by sustainable alternatives.

The greatest drop in the energy demand will occur in the refinery sector where the demand for oil will decrease by 25% following electrification of much of the road transport sector. The demand for oil products in international shipping, aviation and petrochemistry[16] will certainly continue to exist until 2030 and possibly beyond.

Today's relatively modern steel industry in the Netherlands will continue to modernise towards 2050, nevertheless it will continue to use coal (with CCS). Switching to hydrogen is possible but complex and expensive. International companies will convert the less efficient factories abroad as a first step. It is assumed that the Dutch steel industry will not switch to large-scale hydrogen use before 2050.

Industrial processes will have been electrified or switched to hybrid forms by 2050, where this is possible, efficient and cost-effective. A considerable quantity (50 PJ) of excess sustainable electricity produced can be used in this way. The demand for energy in molecular form for high-temperature heat will, however, continue to prevail[17]. As, by 2050, copious amounts of sustainable electricity will often be available, hardly any industrial combined heat and power (CHP) installations will still be in use.

Agricultural sector

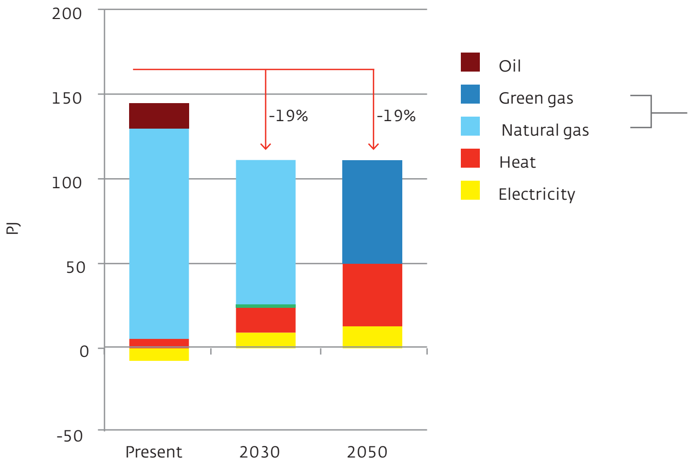
The growth in population, on a global scale, means that the demand for agricultural and horticultural products will be higher in 2050 than it is at present. Technological developments mean that energy can be handled efficiently in the agricultural sector. This will cause energy consumption to fall during the period up to 2030, after which it will stabilise.

There will be a change in the way that the sector's energy demand is met. In 2050, established natural-gas-based CHP capacity in horticulture is only one-third compared to now (for more information about CHP assumptions see the section on electricity generation). There will, moreover, be an increasing use of geothermal energy and electric heat pumps.

16 *This relates to NAFTA and other petroleum products used as fuel for the petrochemical industry, currently around 100 PJ.*

17 *The EU reference scenario [1] assumes that the Netherlands' final energy consumption will comprise 28% electrification by 2050. This is based on a continuation of the current policy. Electrification will vary from member state to member state, with Sweden having the greatest proportion at 43%. A number of decarbonisation scenarios have also been calculated in the same study by means of the PRIMES model, resulting in proportions of between 29% and 39%. Other studies such as the World Energy Council scenarios [2] arrive at worldwide electrification of between 25% and 29%. The Dutch government [3] assumes electrification of 18% in 2030 based on existing policy, rising to 26% where there is increasing electrification of heating and transport. Sources: [1] Roadmap 2050, impact assessment and scenario analysis (https://ec.europa.eu/energy/sites/ener/files/documents/roadmap2050_ia_20120430_en_0.pdf); [2] World Energy Council, World Energy Scenarios 2016 (https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Scenarios-2016_Full-Report.pdf); [3] Ministry of Economic Affairs, Energierapport (Energy Report), 2016 (https://www.rijksoverheid.nl/documenten/rapporten/2016/01/18/energierapport-transitie-naar- duurzaam)*

Final energy consumption for agriculture and horticulture



2030	2050
-100%	-100%
-32%	-51%
>100%	>500%
-	-

Transport[18]

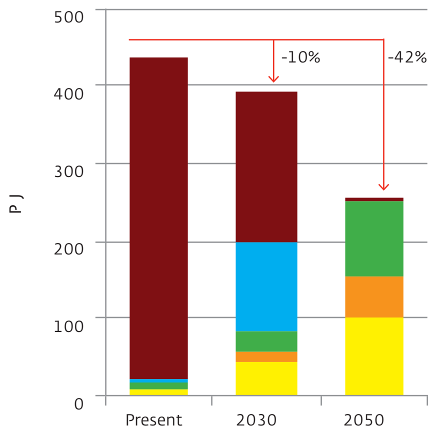
By 2050, road transport will be CO_2-neutral, the demand for fossil fuels having been reduced to nil in this sector.

By 2050, private cars will probably be mainly battery-electric vehicles. Long distance freight transport will run partly on a combination of hydrogen and electricity (fuel cell electric vehicle), partly on biofuel and partly on green gas or bio-LNG. The ratio between battery-electric and fuel-cell-electric will ultimately be determined by economic aspects. Fossil CNG and LNG will have been phased out as transitional fuels by 2050.

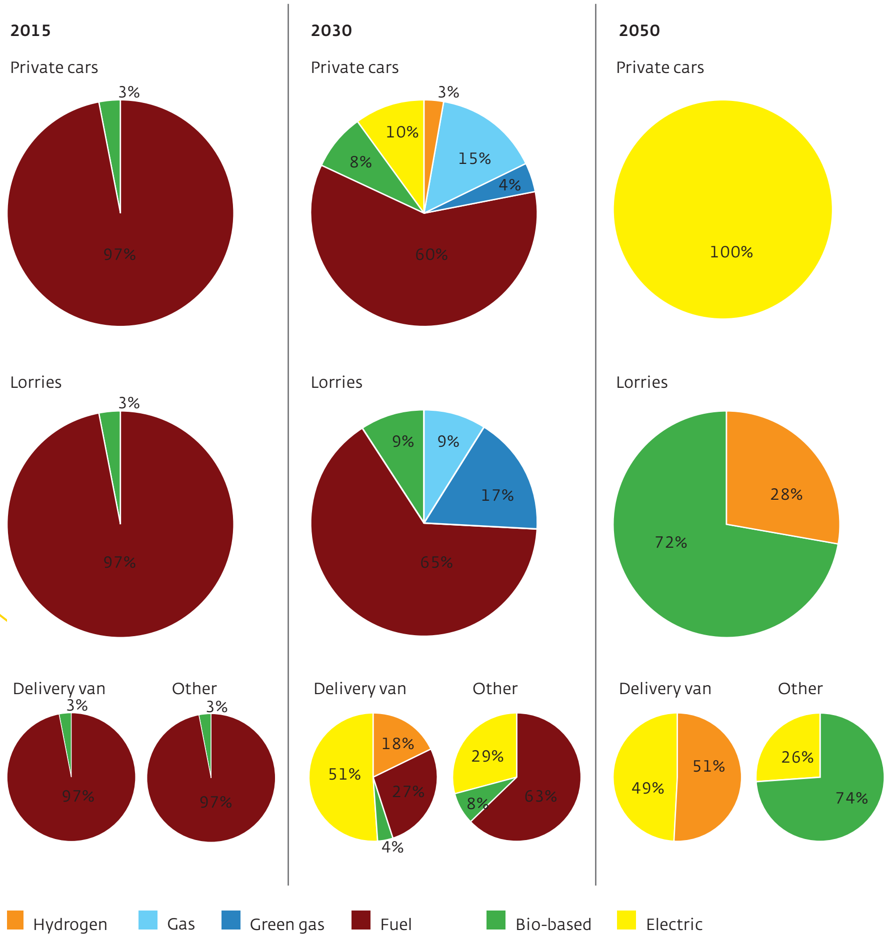
International aviation and shipping are not included in national CO_2 targets and have therefore been left out of the figures in this Survey. By 2050, both sectors will be based partly on oil, partly on LNG or bio-LNG and partly on biomass. Whether hydrogen sourced, electrically driven planes are going to play a decisive role in future aeronautics be is impossible to predict at this stage.

18 *'De Brandstofvisie' ('The Fuel Vision') sub-reports and final report of the Fuel Tables sets the direction for the desired developments, TNO, ECN and CE Delft. June 2014. https://www.energieakkoordser.nl/nieuws/brandstofvisie.aspx*

Final energy consumption for transport



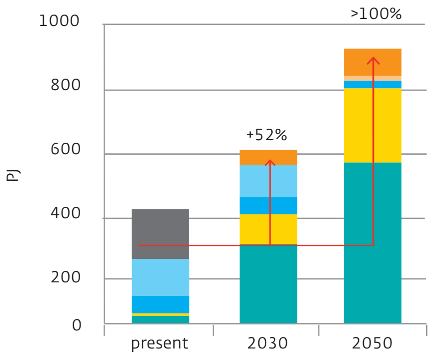
	2030	2050
Oil	-53%	-100%
Natural gas	>500%	-100%
Bio-based	>100%	>500%
Hydrogen	New	New
Elektricity	>500%	>500%



Electricity generation

The consumption of electricity will have increased considerably in almost all market sectors by 2050. The extent of electrification in Dutch society may have doubled (see page 54: The relationship between CO_2 emissions, renewable energy and the extent of electrification of society). The sources responsible for producing this amount of electricity differ from those of today. Fossil sources will have been fully phased out, replaced mainly by wind, sun and hydrogen; on an annual basis, no net imports or exports of electricity are anticipated.

Electricity supply



	2030	2050
Coal power plants	-100%	-100%
Hydrogen power plants	New	New
Natural gas power plants	-12%	-100%
Hydrogen CHP	New	New
(Green) Gas CHP	-8%	-65%
Sun	>500%	>500%
Wind	>500%	>500%

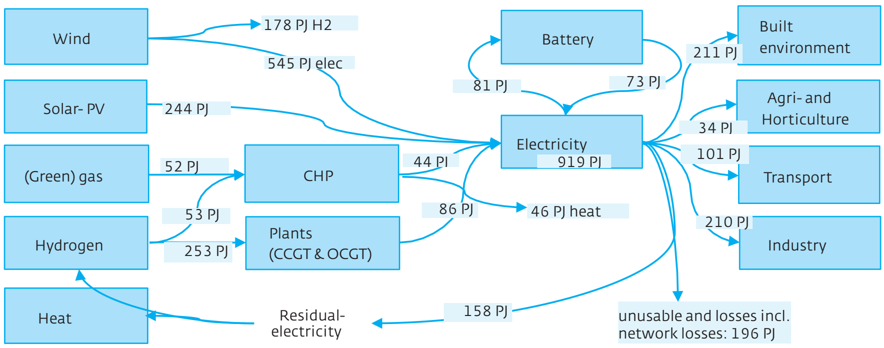
By 2050, sun and wind represent by far the most important sources for producing electricity, accounting for a total of almost 800 PJ. However, even in 2050, there will still be significant periods during which insufficient sustainable electricity is produced in the Netherlands and it is uncertain whether enough (sustainable) electricity is available from neighbouring countries[19]. Periods of insufficient sustainable electricity will occur typically in winter (no sun and periods with less wind) or at night in the shoulder months. In general, periods with insufficient sustainable electricity will occur simultaneously throughout Northwest Europe [20]; during these periods, home batteries will not be charged sufficiently to be able to compensate for the shortage in sustainable electricity.

In 2050, 28 GW of back-up capacity will be necessary to guarantee security of supply; a combination of CCGTs and OCGTs will be used for this, using hydrogen as the energy source. These hydrogen power plants will produce 86 PJ of electricity, around 10% of the total electricity needed in the Netherlands. The back-up power plants will therefore be brought into action for approximately 1 month net per year, at times when there are shortages in the supply of sustainable energy.

19 *See also the graph in the section about conversion technologies.*

20 *Source: 'Windless Winter Weeks.' White Paper by Ecofys. Juriaan van Tilburg, Kees van der Leun, Maarten Staats, and Carsten Petersdorff (Ecofys). December 2016. https://www.ecofys.com/en/news/windless-winter-weeks-the-impact-of-future-heating-supply-on-the-energy-inf/*

Electricity 2050



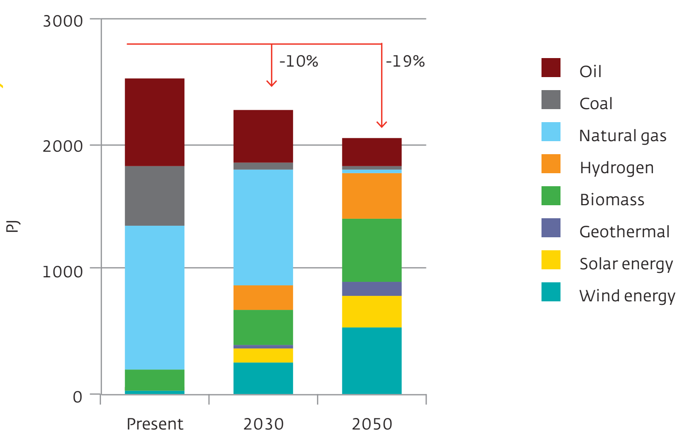
Energy supply

General picture

In 2050, the primary energy supply in the Netherlands will look completely different. Wind, sun and biomass will make the most important contribution to the energy mix in 2050 and insofar as fossil fuels are still being used, these will usually be combined with CCS.

The remaining fossil energy consumption in industry in 2050 will consist mainly of coal in the steel industry and oil for the production of kerosene, fuel oil/diesel, lubricating oil and semi-finished goods for the petrochemical industry. Hydrogen can be an alternative in almost all cases. Where semi-finished goods for the petrochemical industry apply, that will involve a combination of hydrogen with CO_2 ("CO_2 utilisation"). The rate at which the conversion to hydrogen takes place will depend on technological progress and cost trends. This Survey taking a conservative approach and hence anticipating that conversion to hydrogen in the petrochemical industry will not happen before 2050.

Primary energy consumption excl. energy consumption for feedstock



	2030	2050
Oil	-38%	-69%
Coal	-90%	-93%
Natural gas	-18%	-98%
Hydrogen	New	New
Biomass	+54%	>100%
Geothermal	>500%	>500%
Solar energy	>500%	>500%
Wind energy	>500%	>500%

Sun and wind for electricity production

By 2050, the Netherlands will be harnessing solar and wind power for large-scale energy generation. The North Sea will have evolved into the largest wind location in Europe and solar panels on roofs will have become commonplace throughout Northwest Europe. Batteries will be used almost routinely in every house for day/night energy balancing. In addition, 'unproductive' public spaces (along motorways, at airports, etc.) will be used for solar fields where possible.

Significant expansions in installed capacity of solar PV and offshore wind will have carried on after 2030. The North Sea will contain wind farms producing electricity and wind farms producing hydrogen.

	Solar panels on roofs	Solar fields	Onshore wind	Offshore wind Electricity	For info: Offshore wind Hydrogen
Today	2,5 GW		3 GW	1 GW	0 GW
2030	12 GW	8 GW	8 GW	19 GW	0 GW
2050	32 GW	34 GW	10 GW	40 GW	15 GW

Installed capacity of onshore wind will see only limited growth after 2030 due to a lack of suitable locations and this will stabilise at an already significant 10 GW[21]21. In 2050, 545 PJ of electricity and 178 PJ of hydrogen will be produced from wind.

An increasing awareness of sustainable practices and a breakthrough in solar panel design will have greatly increased the use of these panels on homes and other buildings. Many parties and cooperations will have invested in solar fields. By 2050, there will be a total installed capacity of 66 GW of solar PV which will produce 244 PJ of electricity based on an operating time of 1000 hours.

In 2050, electricity produced from sun and wind often exceeds demand. As neighbouring countries will also have invested in solar and wind power, there will be limited opportunities for transfers. A significant proportion of the remaining electricity will be stored in batteries or converted into heat via power-to-heat or into hydrogen via power-to-gas. The greatest peaks in solar and wind production will occur relatively infrequently and will therefore not be used.

21 *Source: "Verkenning van klimaatdoelen - Van lange termijn beelden naar korte termijn actie"("Exploring climate targets – from long-term visions to short-term action") by the Netherlands Environmental Assessment Agency (PBL). October 2017. http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2017- verkenning-van-klimaatdoelen-van-lange-termijnbeelden-naar-korte-termijn-actie-2966. pdf*

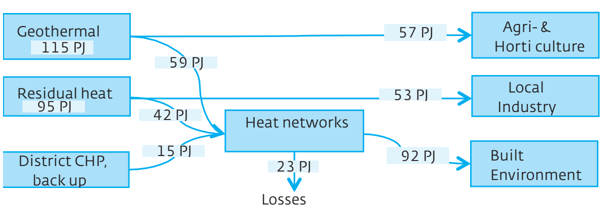
Ambient heat

In 2050, heat pumps in the built environment will be extracting more than of 190 PJ of sustainable ambient heat from indoor and outdoor air and from the earth for heating buildings and will consume around 60 PJ electricity for that purpose. Heat pumps are also being applied in the agricultural sector and in industry, extracting a total of around 55 PJ of ambient heat for which 18 PJ of electricity is necessary. This will bring total usage of ambient heat to almost 250 PJ in 2050.

Geothermal energy and residual heat

By around 2050, geothermal energy will be the most important heat source in places where it is available and it will be made available to the market locally. There are varying estimates for potential geothermal energy[22]; this Survey estimates the quantity of geothermal energy available as being 115 PJ. The pumps used for the heat/ geothermal systems consume around 25 PJ of electricity.

Geothermal energy and residual heat 2050



Residual heat from industrial processes will also be available in 2050; a total of 95 PJ of industrial residual heat will be reused. Slightly less than half of this total supply of residual heat from industry[23] (42 PJ) and approximately half of the supply of geothermal energy (59 PJ) will be fed into heat networks.

Security of supply of heat provided by heat networks will be guaranteed by means of auxiliary boilers running on green gas. These auxiliary boilers will be brought into action to guarantee sufficient heat at times of very high demand or system breakdown (i.e. as back-up).

22 *Netherlands Environmental Assessment Agency (PBL) and CE Delft (PBL: http://www.pbl.nl/ sites/default/files/cms/publicaties/pbl-2017-toekomstbeeld- klimaatneutrale-warmtenetten-in-nederland-1926.pdf, or CE Delft: http://www.ce.nl/publicaties/download/2166)*

23 *Netherlands Environmental Assessment Agency (PBL) and CE Delft (PBL: http://www.pbl.nl/ sites/default/files/cms/publicaties/pbl-2017-toekomstbeeld-klimaatneutrale-warmtenetten-in-nederland-1926.pdf, or CE Delft: http://www.ce.nl/publicaties/ download/2166)*

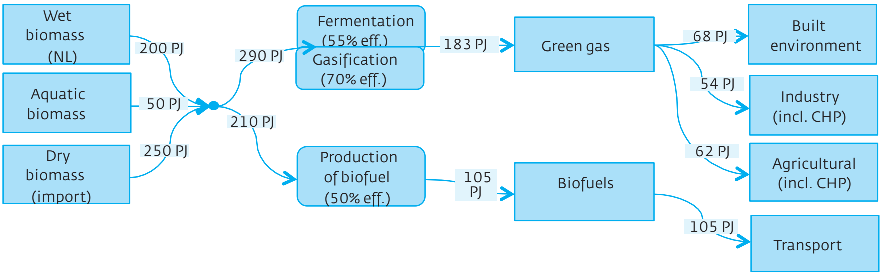
Biomass

Biomass will be seen as a scarce and valuable resource which must be handled carefully. By 2050, not only will proper regulations be in place for ethical aspects, weighing up food supply/energy supply, but there will also have been great strides in the field of logistics.

The Netherlands is a densely populated country. For biomass the Netherlands will soon be reliant on imports. By 2050, around 850 PJ will be available, of which 600 PJ will be imports[24]; of this biomass, 350 PJ will be used for air traffic/shipping and non-energy-related use. By upscaling gasification and fermentation technologies, which are highly developed, the remaining 500 PJ of biomass will be converted into green gas and biofuels for mobility (biodiesel, bioethanol) in 2050. It will be preferable to use green gas in the built environment, in which the introduction of sustainable practices can be challenging, and in the agricultural sector (CHPs) and smaller industries. Biofuels will be used for heavy transport. As hydrogen will be already available on a large scale, biomass will not be used for hydrogen production.

In 2050, CO_2 emissions released when converting biomass into green gas and incinerating waste will be captured and stored, resulting in negative CO_2 emissions (6 Mton).

Biomass 2050



There is much discussion about available quantities of biomass over the long term, particularly on the global market. This Survey 2.0 estimates the quantity available more conservatively than in the version published in May 2016, however, in practice the role of biomass may well be greater than currently presumed.

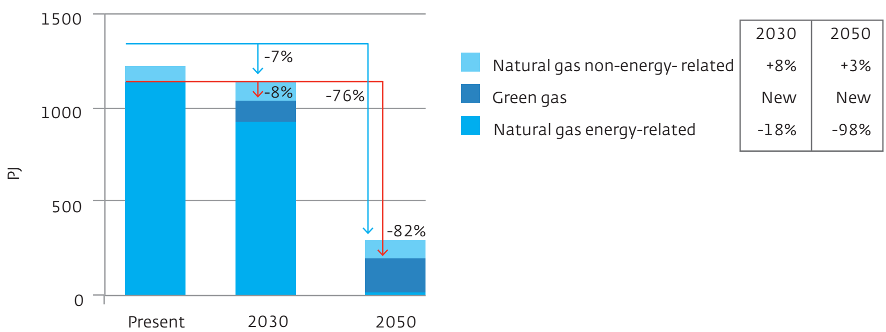
24 *In 2035, potential biomass available will be 203 PJ according to DNVGL study: https://www.gasunie.nl/uploads/fckconnector/5105fcba-372b-4da0-b4b4-56fd9f9c1854*

Gases

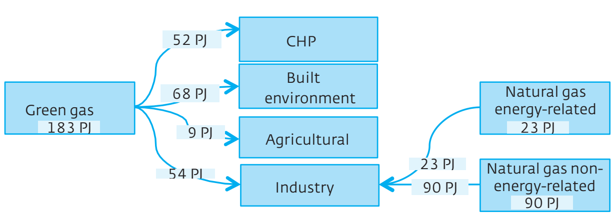
Several gases will be used in 2050: natural gas, green gas and hydrogen. By 2050, natural gas consumption will have fallen to almost nothing compared to today. Usage is currently around 1130 PJ, by 2050 that figure will be around 20 PJ for energy-related use and 90 PJ for non-energy-related use (feedstock). Dutch demand for natural gas will have fallen by around 90%.

In addition to natural gas, 183 PJ of green gas will be produced from biomass; this is described in more detail in the section about biomass.

Gas demand



Gas usage 2050



By 2050, hydrogen will be an important energy carrier (444 PJ), forming a significant part of the energy supply. As with other renewable gases, it is CO_2-neutral, can be stored in large quantities relatively inexpensively (in salt caverns, for example), and can also be transported cheaply via existing gas infrastructure25[25].

25 *In principle, only limited investment would be required to make Gasunie's pipeline network suitable for hydrogen transport. Investments would mainly relate to compressors. Each pipeline segment to be switched over should, of course, also be checked beforehand. If end consumers switch to using hydrogen, they will have to adapt their burners. See also ' Verkenning waterstofinfrastructuur in opdracht van Ministerie van economische zaken.'('Study of hydrogen infrastructure commissioned by the Ministry of Economic Affairs.') DNVGL. November 2017. https://topsectorenergie.nl/nieuws/waterstoftransport-gasnet-dichterbij*

Approximately 110 PJ of hydrogen is currently being used in the Netherlands. Some of this is released as a by-product in industry, other volumes are produced from natural gas involving emissions of the CO_2 released (grey hydrogen). It is anticipated that these CO_2-emissions will be captured and stored in future. In this way, hydrogen can be made without CO_2-emissions, although based on fossil energy (blue hydrogen). Conversion can take place in the Netherlands, with the CO_2 being stored in Dutch offshore gas fields, but also upstream meaning that the Netherlands will import hydrogen. In that model the producer, for example Norway, is responsible for capturing and storing the CO_2 in its own territory; this latter model is the scenario assumed by this Survey.

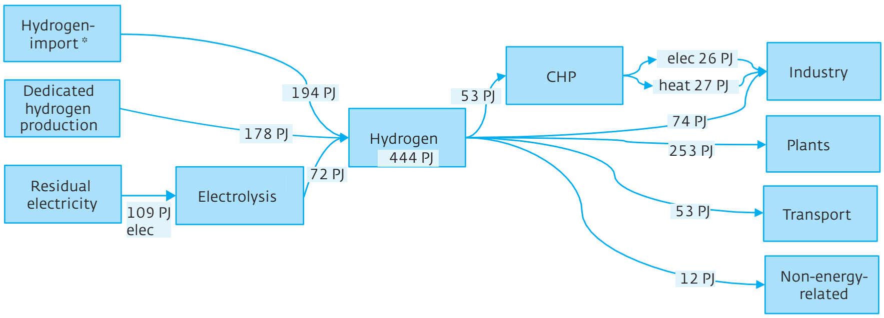
A second way of making hydrogen is by using temporary surpluses on the electricity market ('residual electricity'). This technology, also known as power-to-gas, can be beneficial for making practical use of residual electricity by converting it into green hydrogen. The volume of hydrogen produced from residual electricity will be limited, for economic reasons.

After 2030 there will be another new way of producing green hydrogen in the Netherlands: dedicated wind farms in the North Sea. The hydrogen farms will often be located somewhat further away from the coast, as the wind blows more constantly there and transporting hydrogen to the coast is around 10 times cheaper than transporting electricity.

It is anticipated that, by 2050, 15 GW of dedicated (electric) capacity will be available for producing hydrogen from wind energy, accounting for the production of 178 PJ of green hydrogen. Hydrogen wind farm capacity will grow further after 2050.

Green hydrogen may also, over time, be imported from Africa or the Middle East, where it has been produced from solar energy. This means that the role of natural gas with CCS as a source for blue hydrogen will, over the long term, decrease and eventually disappear.

Hydrogen 2050



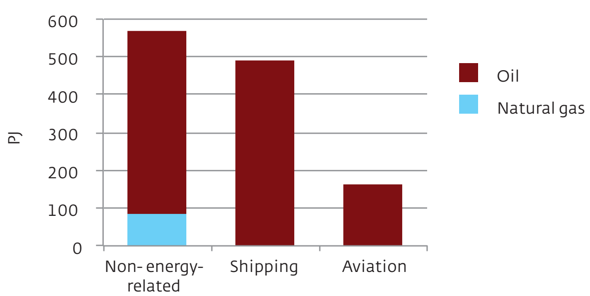
* If hydrogen is produced from natural gas in the Netherlands, then 259 PJ of natural gas will be required.

If, in 2050, the Netherlands does not import CO_2-neutral blue hydrogen (as is now assumed), but produces it itself from natural gas, this will require 259 PJ of natural gas. If this quantity is included, then the drop in natural gas consumption will be around 70% instead of more than 90%. Converting it in the Netherlands means additional CO_2 capture of 14 Mton maximum. In that case, natural gas consumption after 2050 will fall further because the growing supply of green hydrogen will displace blue hydrogen.

Non-energy related fuel consumption, air traffic and shipping

These three sectors fall outside the scope of national CO_2 targets and are therefore not included in many scenarios and policy documents. However, these sectors consume a lot of fossil and other energy and, moreover, air traffic and international shipping cause fine particles, nitrogen oxide and sulphur oxide in addition to CO_2 emissions.

Energy consumption special sectors (2015, CBS)



The CO_2 emissions from these sectors are not included in national targets.

Steps must also be taken in these sectors to reduce CO_2 emissions if we are to achieve a CO_2-free society. A first step for international shipping and air traffic would be to use LNG, which would, in any case, significantly reduce emissions of fine particles, nitrogen oxide and sulphur oxide. The Survey assumes that, in the medium term, biomass will meet part of this demand and we have, for 2050, assigned a considerable proportion of the biomass available for the Netherlands to these categories. In the long term, by which we mean the period after 2050 in this Survey, hydrogen will be appearing in these sectors. Carbon is usually also necessary when using hydrogen as a (non-energy-related) raw material; biomass can then be used for this purpose, or possibly CO_2.

Apart from the points made in this section, energy consumed by these sectors is not given any further consideration in the analyses.

Energy infrastructure

Networks

The energy landscape will be extensive and varied in 2050. The systems will be integrated with each other, will extend to far into the North Sea and will be closely connected to those of our neighbouring countries. Significant investments in the electricity network both offshore and onshore are necessary. Heat networks should be extended and linked to each other. Repurposing natural gas pipelines is the starting point for the development of a hydrogen and CO_2-infrastructure, meaning these costs are kept under control.

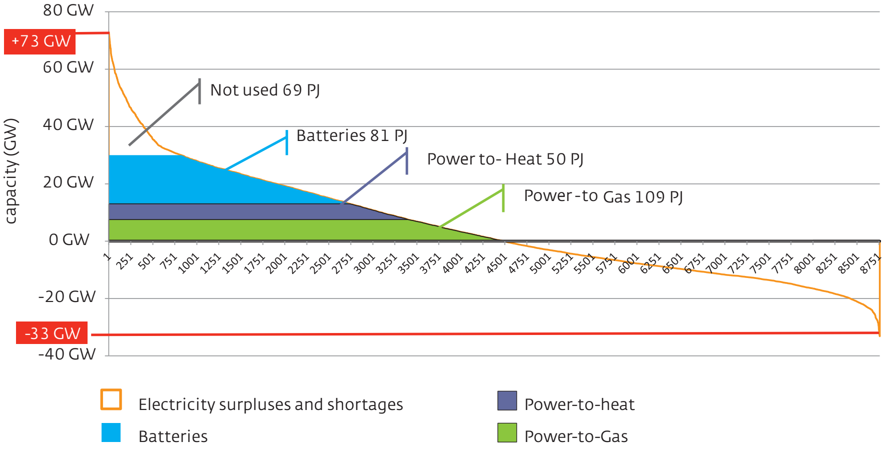
By interlinking gases, heat and electricity, the Netherlands has a very robust and reliable energy infrastructure in 2050, in which changes in the production of energy or technical faults are handled within the system (electricity, gas, heat). Energy infrastructure enables energy forms to reinforce and complement each other.

Conversion technologies

In 2050 there will be so much established capacity that not all the electricity produced by renewable electricity generation can be used directly. Using the highest peak values in electricity production is still not profitable and therefore these peaks will not be used within the Netherlands. If it is not possible to exchange this electricity with neighbouring countries, production will not take place and some wind turbines will be turned off.

The residual electricity used for conversion will be used for storage in home batteries and for the following technologies that are by 2050 mature and economically profitable: power- to-heat (6 GW in industry) and power-to-gas (7.5 GW for hydrogen production). This assumes that power-to-gas installations can be used in an economically viable manner with an operating time of around 3500 hours. An operating time of around 2500 hours can be taken as a rough estimate for power-to-heat.

Use of electricity surpluses and shortages

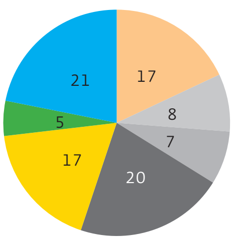


Carbon Capture and Storage

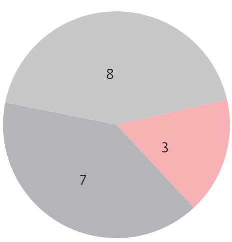
Due to its non-sustainable features and the efficiency losses resulting from its use, CCS[26] is deemed to be a least preferred option. It is, however, an unavoidable option for the purpose of achieving the sustainability targets. From the point of view of cost, CCS is only feasible if sufficiently high operating times can be achieved, and if the production process can contain centralised points of incineration and capture.

In 2050, post-combustion CO_2 capture will be mainly applied at refineries (oil) and steel production (coal). As these industries are mainly located in coastal regions, an extensive onshore network for transporting the captured CO_2 is not necessary. The CO_2 will also be captured when green gas and biofuels are produced from biomass. In 2050, a total of 22 Mton of CO_2 will be captured.

2030

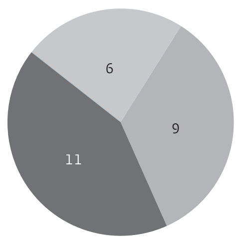


CO2 emissions before applying CCS

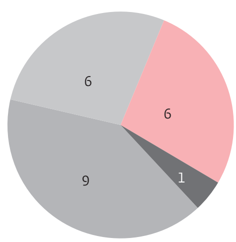


CCS

2050



CO2 emissions before applying CCS



CCS

- Power plants
- Steel
- Built environment (incl CHP & Heat network)
- Transport
- Refining
- Other industry (incl CHP)
- Agri (incl WKK)
- Negative emissions biomass

26 Source: IEA ETSAP October 2010, CO2 Capture & Storage: efficiency 85%, efficiency loss: 10% (coal-fired power plant from 45% to 35%). Moreover, pre-combustion CCS is a far more efficient method for capturing CO2, see the Berenschot study: https: //www.berenschot.nl/publish/pages/5757/berenschot-rapportage-co2-vrije-waterstofproductie-uit-gas. pdf

As regards the industrial sector, the points mentioned above mean that only industries which have not switched over to hydrogen (mainly the refinery and steel sectors) will have to invest in the capture of CO_2 that is released in the production process. This relates here to the capture of a total 16 Mton CO_2.

Capturing CO_2 when green gas and biofuels are produced will give rise to 6 Mton of negative emissions. These negative emissions can compensate for the limited emissions from smaller industries (for which switching to hydrogen is not feasible and CCS is too expensive).

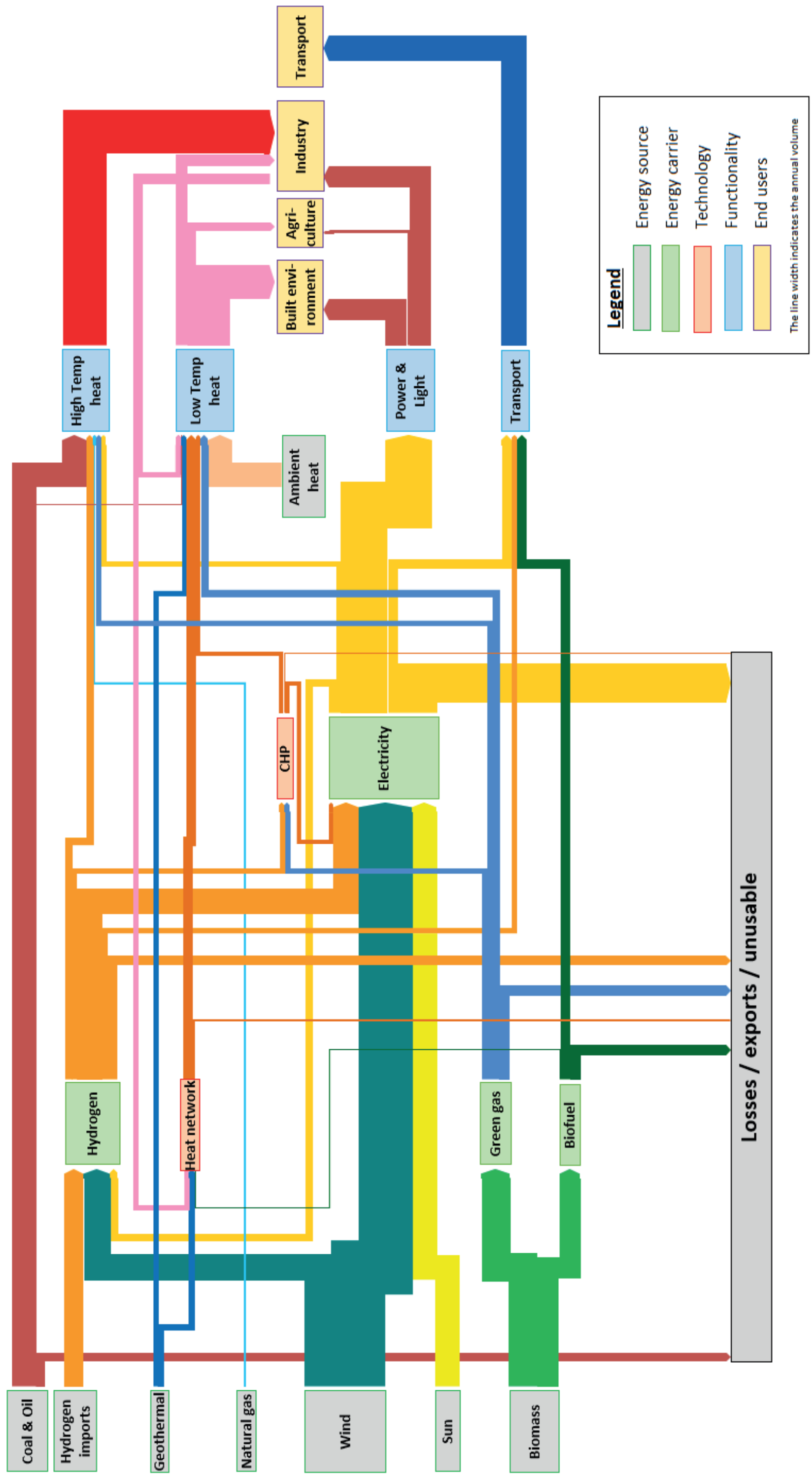
In 2050, depleted (offshore) gas fields will be used for storing CO_2[27]; a CO_2 transport infrastructure must be established for this. One alternative is to transport CO_2 by ship or pipeline to offshore Norwegian aquifers and to store the CO_2 there.

As described in the section about gases, if the production of blue hydrogen from natural gas were to take place in the Netherlands, we would have to allow for an extra 14 Mton (pre-combustion) of CO_2 capture.

In addition to Carbon Capture Transport and Storage there will also be research into extending the application of Carbon Capture and Utilisation, for example in greenhouses (relatively small quantity) or for non-energy-related use. This, combined with sustainable energy and closing the CO_2 cycle, might lead to a sustainable solution.

27 *Theoretically, the storage capacity in the Netherlands comes to 2340 Mton CO2 (excluding Groningen, 7000 Mton) of which more than 50% is offshore.*

2050 vision visualised



The Netherlands in 2030

Emissions reduction targets

A CO_2-equivalent emissions reduction of 54% compared to 1990[28] has been applied to the energy sector for 2030. This will require significant steps to be taken within a relatively short period with regard to the current situation. This chapter gives a concise account of the anticipated situation in 2030. The possible approach towards it is illustrated by looking at several current projects.

General picture

CO_2 emissions must be reduced to 75 Mton if the target of 54% CO_2 reduction in the energy sector is to be met by 2030. By making energy savings and using biomass, hydrogen and sustainable electricity extensively, CO_2 emissions can be reduced to 91 Mton. This reduction will take place mainly in industry (35 Mton[29]), in the transport sector (21 Mton[30]) and in the built environment (17 Mton[31]) The additional 16 Mton of CO_2 reduction needed can be achieved[32] by applying CO2 capture at refineries (oil), during steel production (coal) and during the production of green gas and biofuels.

In 2030, the final energy demand will be 11% lower than current demand. Developments in the built environment, in particular, will be responsible for this. The energy transition will be already clearly visible in the composition of the energy mix: oil and coal, but also natural gas, are in decline and replaced to some extent by green gas and biofuels from biomass, geothermal energy and hydrogen. Fossil fuels still make up around 60%[33] of the energy demand. Around 70% of the electricity can be generated sustainably. Fossil energy is still used predominantly for different industrial processes. However, a clear shift is already visible: oil and gas have been partially replaced by hydrogen, which accounts for 10% of the total energy demand.

28 *This 54% CO2 reduction in the energy sector results in a 55% reduction in CO2-equivalent emissions in the Netherlands.*
29 *Including CHP*
30 *Including CHP*
31 *Including CHP*
32 *There are even negative CO2 emissions as the CO2 has already been removed from the atmosphere at an earlier stage of the biological cycle in the green gas production chain. This is the advantage of using gasification and fermentation to convert biomass into green gas.*
33 *Excluding non-energy-related use*

Energy demand

Built environment

An increase in the use of new, advanced heating technologies and further insulation will ensure that the energy demand in the built environment, excluding ambient heat, will have fallen by 23% in 2030. The number of stand-alone HE boilers in use will have almost halved, with homes now frequently having a hybrid heat pump, a connection to a heat network or an all-electric heat supply. Newly built homes will no longer have a gas connection.

By 2030, around 25% (68 PJ) of the gas quantity required in the built environment (around 295 PJ), including gas for heat networks and district CHP, may be provided by green gas. Adjustments to net metering regulations have resulted in more home batteries being in use than now[34]; around 13 PJ can be stored in home batteries.

A wide range of measures and initiatives is necessary, well before 2030, to encourage a reduction in the use of natural gas in the built environment. A major incentive will be a decrease in the costs of energy-saving measures such as home insulation and heat pumps. Initiatives such as the Green Deals for 'gas-free districts' offer new insights in possible solutions. Long-term regional plans setting out transitional paths give direction to a structured integral approach.

Citizens want to be given accessible recommendations regarding which measures they can take to contribute towards the energy transition. Municipal energy information offices and (commercial) consultancy firms can take up this role in the run-up to 2030. The installation sector should have sufficient knowledge and manpower to be able to adapt and/or replace large quantities of heating installations. One of the biggest challenges will be persuading building owners to undertake substantial investments.

In 2030, the number of houses and buildings supplied with heat by heat networks will be around 16%. Heat networks powered by CHPs still have an important role to play (existing situation, no requirement to build a new one). These CHPs account for approximately half of the heat supplied to the built environment via heat networks. The infrastructure already present 'behind the CHPs' can be re-used for supplying heat from sources other than natural gas without requiring significant adaptations.

The Zuid Holland Heat Roundabout[35] project should, inter alia, pave the way for a growing number of buildings that will use heat as an energy source in this region. Extending this heat network with new CO_2-free sources and new connections is necessary.

34 Source: see, inter alia, https: //www.energieleveranciers.nl/nieuws/salderingsregeling-zonnepanelen-tot-2023
35 See, inter alia, http://warmopweg.nl/warmterotonde/

Gas is also used to be able to compensate for disruptions and other times when there is an insufficient supply of heat. The necessary quantity of gas for heat network peak demand is around 20% of the total volume demand of the heat network.[36]

Industry

In 2030, industry's demand for energy is comparable to the current demand for energy. The refinery sector is an exception to this; this sector will experience a slight drop in energy demand due to the slowly declining demand for petrol and diesel.

The composition of the energy mix for industry will already be changing in 2030. Relatively speaking, the consumption of electricity will rise the most, whilst hydrogen will also be increasingly available; the use of natural gas will be declining.

In areas where a hydrogen infrastructure is already present or can be developed relatively easily by repurposing natural gas pipelines, as is already anticipated in Zeeland by around 2020[37], other industries will also switch to hydrogen.

Using hydrogen on a large scale is a major challenge for the industrial sector. By 2030, industry will be using 47 PJ of hydrogen and a hydrogen infrastructure will have been established, particularly in the industrialised regions of the Netherlands. Professor Ad van Wijk's "Noordelijk Waterstofplan" (Northern Netherlands Hydrogen Plan) is a major driving force[38] behind using more hydrogen in the Northern Netherlands industrial sector.

In the Europoort region, network operators, local industries and the port authority are working together to put the transition to a CO_2-neutral port into practice, in which hydrogen is playing an important part. The knowledge gained from the initial testing ground is a driver for other industries to focus on this energy carrier.[39]

36 *20% assumption based on heat network output identified by GTS.*

37 *Hydrogen will be transported from Dow via an old Gasunie gas pipeline to Yara and ICL-IP. Limiting transport movements will reduce CO2 emissions and transport through pipelines is also safer. Source: http://www.greendeals.nl/waterstof-gaat-veilig-door-de-buis/*

38 *Source: see, inter alia, http://verslag.noordelijkeinnovationboard.nl/ and http://profadvanwijk.com/tag/ noordelijke-innovation-board*

39 *Source: 'Europoort West, Stappen voor een gecontroleerde ontwikkeling van aanbod, transport en afzetmarkten met de nieuwe energiedrager.'('Europoort West, steps required for a controlled development of supply, transport and sales markets with the new energy carrier'.) Port of Rotterdam, Deltalinqs, Stedin, GTS, TenneT. November 2017 and see also Wuppertal Institute, 2016. Decarbonisation pathways for the industrial cluster of the Port of Rotterdam, Wuppertal: Wuppertal Institute. https: //www.portofrotterdam.com/nl/ file/18544/download? token=4Ri58reM*

Agricultural sector

There will be many opportunities for further innovation in the horticulture sector during the period up to 2030; for example there is an important role for the 'smart greenhouses' concept[40], which will lead to increases in efficiency.

Another important change in the horticultural sector up to 2030 relates to replacing 'must-run' CHP systems by geothermal energy. Low electricity prices mean that the must-run CHPs are no longer economical for the sector, causing the established capacity of CHP in horticulture to halve. The non-must-run systems alone will remain in operation. Geothermal energy and CHPs will each provide half of the total heat demand for the agricultural sector. Following a decline in local electricity production, this sector's demand for electricity 'from the network' will increase.

Transport

By 2030 there will be a transitional situation, a mixture of electric, petrol, diesel and gas cars being used for passenger transport. Most cars will still be running on fossil fuels. Cars running on gas, including green gas, CNG and LPG will represent a temporary niche market, meaning that savings are already being made to the necessary CO_2 emissions with regard to petrol and diesel. Electric cars will have become much more popular and are, by then, a familiar sight on the roads. A quarter of private cars and half of all delivery vans will be electric.

A fairly new technology for road transport is the use of hydrogen; heavy goods vehicles in particular will be electrically powered by hydrogen. Around 20% of the delivery vans will have a fuel cell that converts hydrogen into electricity to drive the engine. These delivery vans have a greater range than electric vehicles which store their electricity in batteries. The increase in the number of hydrogen filling stations will be a major boost for an increasing number of vehicles running on hydrogen.[41]

By 2030, lorries will have made the transition from diesel to more sustainable energy sources, such as LNG, bio-LNG[42] and biodiesel; one or two hydrogen lorries will also have found their way onto the roads.

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40 *For various innovations in horticulture, see, for example: https: //www.agriholland.nl/dossiers/kassenbouw/dosnieuws. html and https://www.duurzaambedrijfsleven.nl/landbouw/7393/markt-voor-slimme-kassen-is-in-2020-12-mrd-waard*

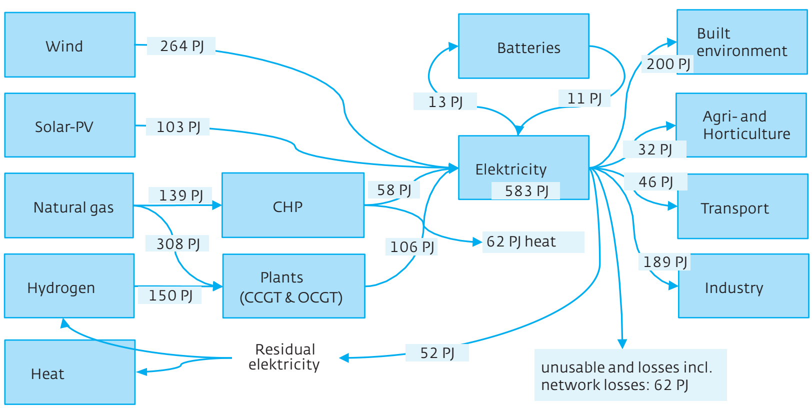
41 *See, for example, http://www.waterstofautos.nl/ and https://www.holthausen.nl/sites/default/files/downloads/our_number_1_element.pdf*

42 *See, for example: https: //www.vopak.com/newsroom/news/gasunie-and-vopak-sign-agreement-shell-launching-customer-lng-break-bulk-terminal*

Electricity generation

The proportion of sustainable electricity will have significantly increased (around 70% of the total volume). However, a considerable quantity of electricity will still be required from conventional power plants in 2030, for there will be significant periods during which insufficient sustainable electricity will be available. Coal-fired and nuclear power plants are already being phased out prior to 2030. Power plants are mainly fuelled by natural gas (65%). Following the example of the Magnum power plant, one-third of power plants will have switched to hydrogen (35%).[43] The Magnum Power Plant project has generated new application options and opportunities for using hydrogen in power plants.

Elektricity 2030



In 2030, there will be 52 PJ of residual electricity available to make hydrogen via power-to-gas or heat via power-to-heat. Power-to-gas is an existing technology which will have been further developed by 2030 and then considerably scaled up. The HyStock project provided a vital initial boost for the Netherlands in 2017 by bringing a 1 MW installation into use.[44]

43 *https://www.nuon.com/nieuws/nieuws/2017/nuon-statoil-en-gasunie-werken-samen-aan-de-inzet-van-waterstof-in-een-co2-vrije-energiecentrale/*

44 *Source: https: //www.gasunie.nl/nieuws/gasunie-zet-duurzame-energie-om-in-waterstof-met-eerste-1-mw-power*

Energy supply

Sun and wind for electricity production

The established capacity of solar and wind energy must increase significantly between now and 2030. At 8 GW, all designated sites onshore will have almost reached their maximum capacity by 2030.

A lot of effort can be put into developing offshore wind if costs continue to fall as a result of competition and innovative strength, resulting in 19 GW of offshore wind by 2030. Operating times will increase slightly because wind farms will be built further out at sea where the wind blows more.

More large wind farms, in addition to those already planned offshore (Borssele, North and South Holland coast), must be developed in order to meet the targets. This will probably happen at locations further from the coast, such as IJmuiden Ver, Dogger Bank and north of Eemshaven (German Bight), which have already been designated as potential sites[45]

Ambient heat

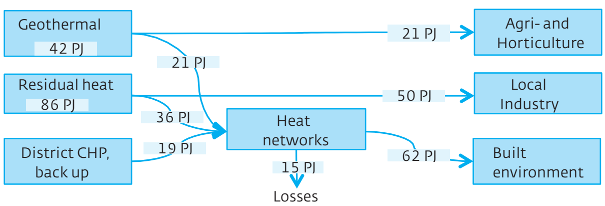
By 2030, the vital role of ambient heat will be clearly visible, with 30% of buildings using heat pumps (which may or may not be hybrid). These existing technologies can be developed further. In 2030, (hybrid) heat pumps will be extracting around 81 PJ of ambient heat from indoor and outdoor air and from the ground for heating buildings. Heat pumps are also being applied in the agricultural sector and in industry on a limited scale, using a total of almost 30 PJ of ambient heat.

45 *Source: see, for example, what is planned on https: //nl. wikipedia. org/wiki/Lijst_van_ windmolenparken_in_de_ Noordzee*

Geothermal energy and residual heat

In 2030, industries and power plants will be supplying residual heat, in particular, for local industrial use (50 PJ). For example, the steel industry will switch, prior to 2030, to the more efficient HIsarna technology which releases residual heat[46] 36 PJ of residual heat will be used in heat networks.

Geothermal energy and residual heat 2030



By 2030, at 42 PJ, geothermal energy will represent a relevant energy source. Approximately half of the geothermal energy available will be used in heat networks for the built environment, the other half being used directly in the agricultural sector. This Survey anticipates that the development of geothermal energy will still take some time before it is put to large-scale use outside the horticultural sector.

Biomass

In 2030 in the Netherlands, around 250 PJ of biomass, mostly domestic (wet) biomass, will be available for energy-related use at home. By using advanced gasification and fermentation technologies, these 250 PJ of biomass can be converted into 31 PJ of biofuels for mobility (biodiesel, bioethanol) and 114 PJ of green gas. In 2030, CO_2 emissions released when converting biomass will be captured and stored, resulting in negative CO_2 emissions (3 Mton).

Examples of new technologies are SCW (gasification), Ambigo (gasification), Torrgas (gasification)[47] and Bareau (fermentation)[48]. These projects are currently at the research or pilot stage, still requiring substantial commitment and investment to make substantial quantities of green gas and biofuel available by 2030.

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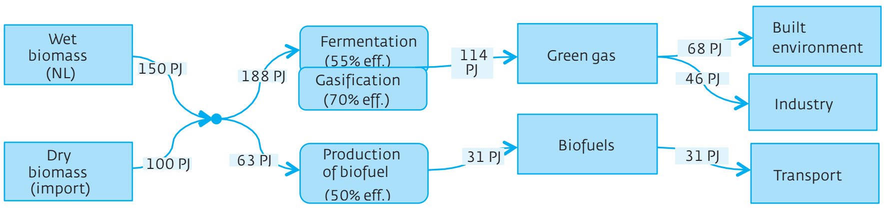
46 Source: https: //www.tatasteel.nl/nl/innovatie/HIsarna/De-mensen-achter-HIsarna and https: //www.tatasteeleurope.com/en/innovation/hisarna/timeline
47 Source, see: https: //www.gasunienewenergy.nl/
48 Source: http://www.bareau.nl/

Biomass 2030



Gases

By 2030, primary use of natural gas has fallen by 16% to 1018 PJ (of which 924 PJ energy-related use). The final consumption of natural gas is admittedly clearly falling but is mainly compensated for by replacing coal-fired power plants with gas-fired power plants.

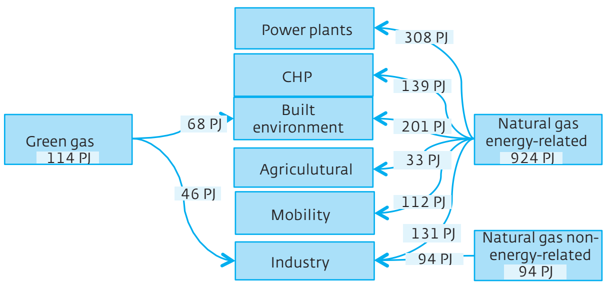
Green gas is giving a considerable boost to sustainable practices in the built environment. Green gas production is described in more detail in the section about biomass.

By around 2030, hydrogen is emerging as an energy carrier; due to the sharp increase in the established capacity of solar and wind energy there are sometimes surpluses of sustainably generated electricity that can be converted into hydrogen. In 2017, the Norwegian company Statoil started to explore the potential for exporting hydrogen produced from natural gas[49]; so-called 'blue' hydrogen[50]. In the light of this development[51] it is expected that the Netherlands can import hydrogen produced abroad in 2030.

Hydrogen-dedicated offshore wind turbines represent another production method for hydrogen and the first step towards achieving a 'North Sea Wind Power Hub' was made in 2017 by TenneT, Energienet.dk and Gasunie[52]. Here the key principle is that, after 2030, the supply of offshore wind energy will be so great that this energy will not only be transported via power lines but also by means of hydrogen transport pipelines. Repurposing offshore natural gas pipelines would be a possible part of this process.

49 *Source Statoil: https: //www.statoil.com/en/news/evaluating-conversion-natural-gas-hydrogen.html*
50 *The International Hydrogen Council calls this 'clean' hydrogen.*
51 *Source: https: //www.statoil.com/en/news/evaluating-conversion-natural-gas-hydrogen.html*
52 *https://www.tennet.eu/nl/nieuws/nieuws/gasunie-treedt-toe-tot-north-sea-wind-power-hub/*

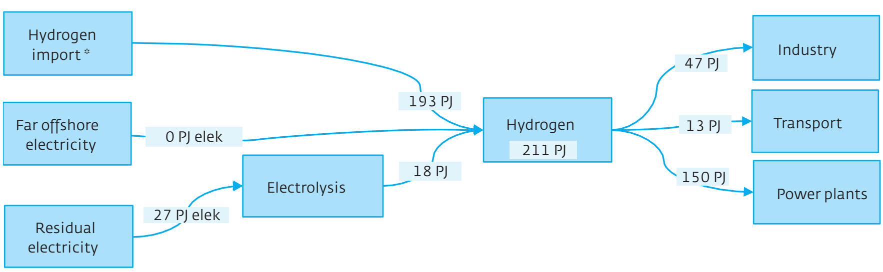
Gas usage2030



Different factors ultimately determine the quantity of hydrogen produced offshore, for example: cost trends for cables and electrolysers, the demand for hydrogen and electricity and how flexible customers can be in switching between different forms of energy.

Natural gas pipelines will also be re-used onshore for transporting hydrogen. Repurposing a former natural gas transportation pipeline for transporting hydrogen from Dow to Yara in Zeeland Flanders lays the foundation for converting natural gas pipelines into hydrogen pipelines.[53] Projects such as HyStock pave the way for storing hydrogen in caverns.[54]

Hydrogen 2030

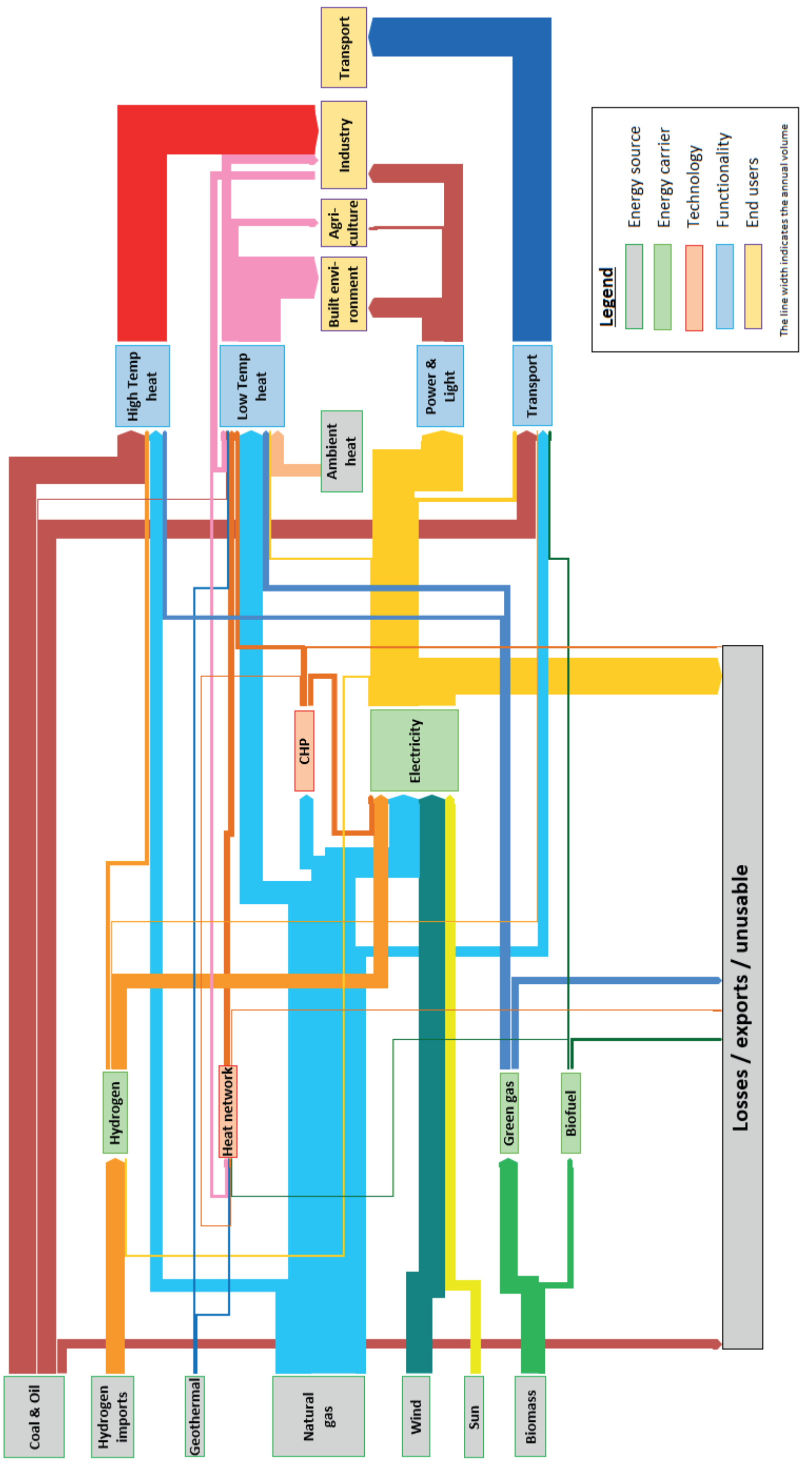


* If the production of hydrogen from natural gas takes place in the Netherlands, 257 PJ of natural gas will be required.

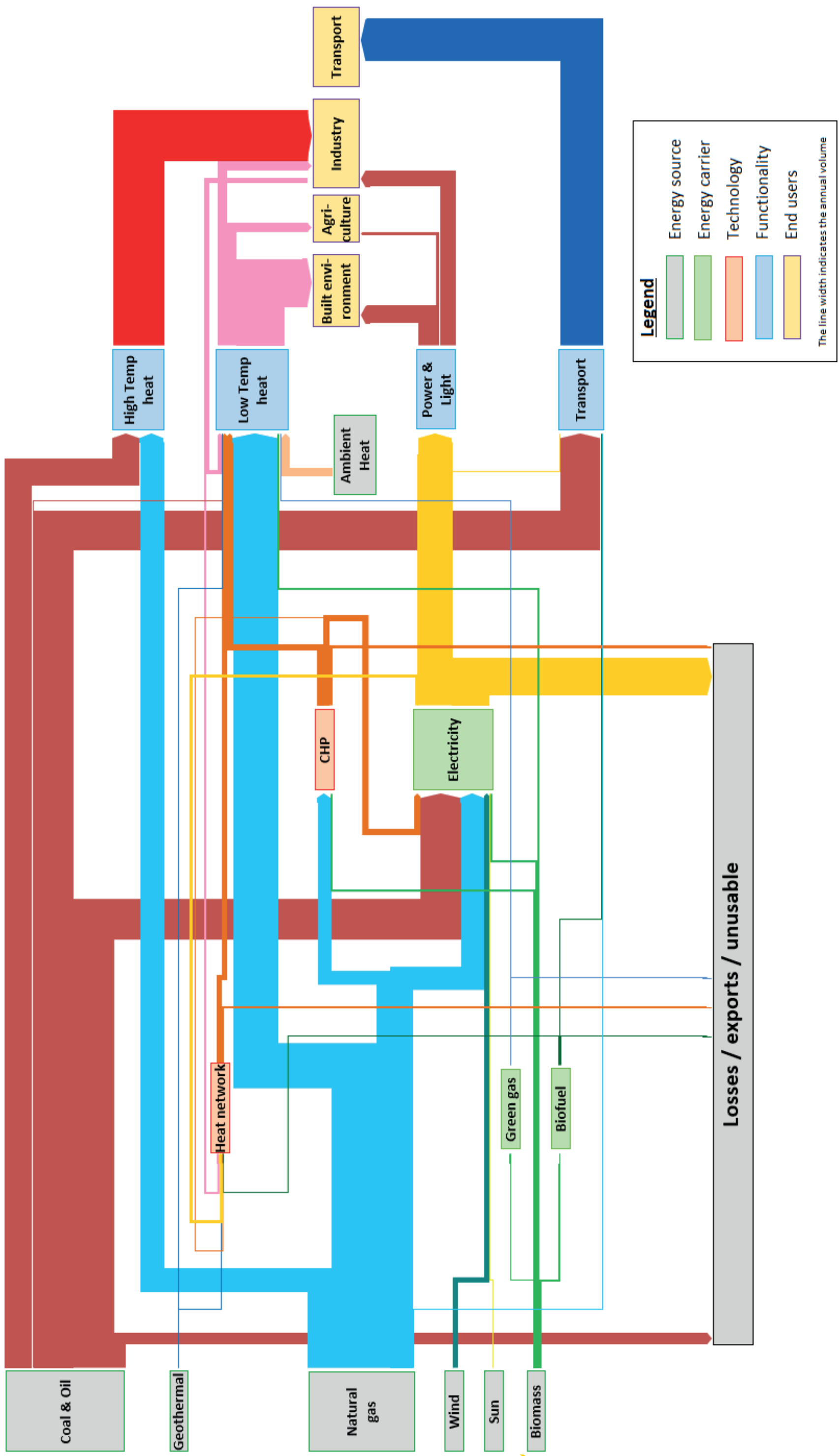
53 Source: *http://www.greendeals.nl/waterstof-gaat-veilig-door-de-buis/ en https://www.rijksoverheid.nl/actueel/nieuws/2016/03/14/chemiebedrijven-wisselen-waterstof-uit-via-pijpleiding*

54 Source: *https://www.gasunie.nl/nieuws/gasunie-zet-duurzame-energie-om-in-waterstof-met-eerste-1-mw-power*

2030 vision visualised



Present situation visualised



Costs

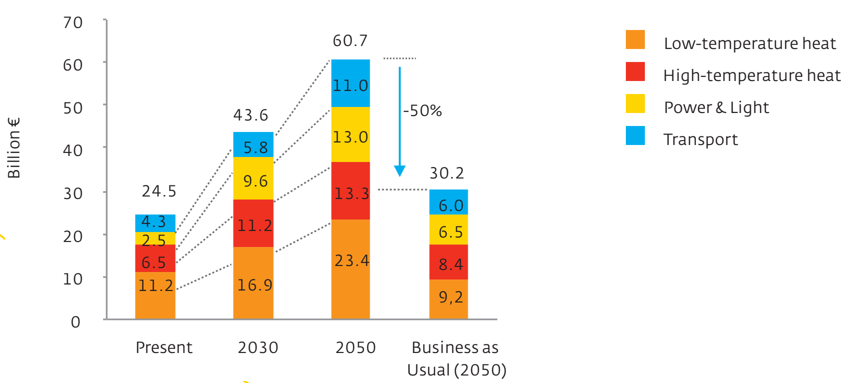
The costs associated with the visions outlined for 2030 and 2050 have, at Gasunie's request, been calculated by Berenschot. The calculations have been performed on the basis of Quintel's Energy Transition Model, supplemented by subsequent calculations outside the model. The ultimate total costs for the Dutch energy supply are calculated on an annual basis; taxes, levies on CO_2 emissions and subsidies do not form part of the calculated annual costs. The WLO high scenario[55] is used for fuel costs. Fuel costs for non-energy-related use are not included in the cost calculation. Where possible, assumptions are substantiated on the basis of recent literature but uncertainty relating to future costs and fuel prices will always prevail. The results of the cost calculations must therefore be considered as an estimate.

The costs are categorised according to the four functionalities established by the Dutch government: low-temperature heat, high-temperature heat, transport and power and light. In this way, the electricity costs (for example, for installing wind turbines, solar PV and hydrogen power plants) are allocated to the different functionalities based on electricity consumption. These costs are, therefore, not allocated entirely to the 'Power and Light' category (but only the proportion of the costs used for energy for lighting and appliances).

Costs will increase considerably compared to current levels

Based on this Survey, the annual costs for providing energy will rise from the current level of 25 billion euros to almost 44 billion euros in 2030, and to 61 billion euros in 2050.

Total costs of CO2 reduction in 2030 and 2050 compared to present level, according to Gasunie's Survey (in € billion).



55 *WLO scenarios established by the Netherlands Environmental Assessment Agency (PBL). Aalbers et al. 2016, Matthijsen et al. 2015. www.wlo2015.nl*

The difference in costs between 2030 and 2050 shown in the Survey can be largely explained by the increase in the price of biomass in 2050, which, according to the WLO, will increase by 250% compared to 2030.

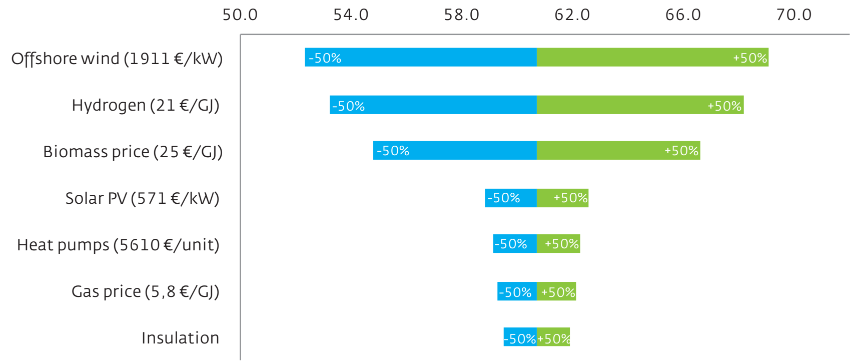
If calculations are based on the current energy supply situation with assumed prices for 2050, then the costs in 2050 will come to around 30 billion euros. This is more than 5 billion euros more than current costs, particularly due to the assumed price increases for fossil fuels. In this scenario, referred to as the 'Business as Usual scenario', there is no provision for reducing CO_2 emissions.

Sensitivity analysis illustrates the possibility of much lower costs

A sensitivity analysis has shown that the costs could also come out much lower in 2050, at around 47 billion euros. That analysis does not use the IEA assumptions for wind turbines or WLO high- assumptions for biomass but looks at current developments (realised projects) in, for example, the costs of offshore wind, which also affect the costs of hydrogen produced with dedicated offshore wind.

The results of the sensitivity analysis for the main cost items are shown in a tornado diagram.

Sensitivity analysis relating to the cost calculations used for relevant parameters, with an assumed 50% shift (in € billion per year)



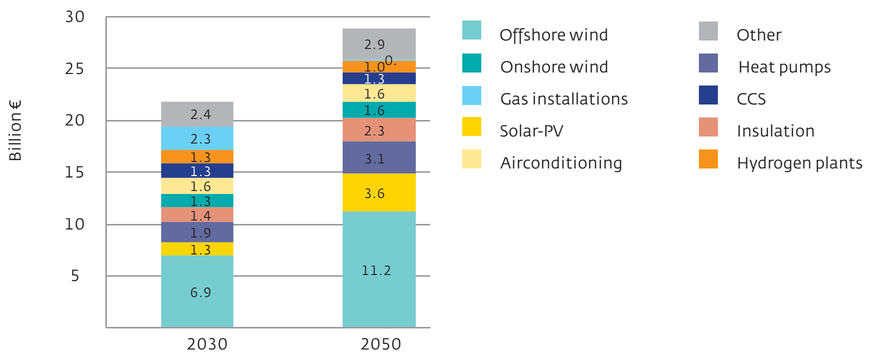
If offshore wind costs, in particular, are much lower than those predicted by the IEA for 2050, this has a substantial impact on the costs. Offshore wind costs already appear to be at the level predicted by the IEA for 2050. An assumption of 50% lower costs than those anticipated by the IEA for 2050 results in annual costs being lower by 8 billion euros: more than 5 billion euros from offshore electricity production and almost 3 billion euros from dedicated offshore hydrogen production. Current wind turbine cost trends indicate that it is feasible that costs are falling faster than the IEA is reporting. The latest North Sea auctions[56] are encouraging in this respect and this means, moreover, a drop in the average hydrogen price from 21 euros to 14 euros per GJ.

Another important cost parameter is the price of biomass for which, at present, high scarcity costs are assumed (WLO high scenario[57]). If the WLO low scenario is used for the price of biomass, then energy costs may fall by 6 billion euros. In addition to this, hydrogen costs are also important; these are also dependent on the wind turbine costs mentioned above, on cost trends for electrolysis and on the price of natural gas.

Offshore wind is the main item within investment and maintenance costs for both 2030 and 2050

In 2050, 47% of the cost of the energy supply will be determined by investment and maintenance costs. In both 2030 and 2050, investment costs for offshore wind are by far the greatest. In 2050, heat pumps, solar PV and insulation will represent the other main cost items.

Investment and maintenance costs in Gasunie's Survey (in € billion)



56 *Auction prices of € 50-65/MWh for Denmark, the Netherlands and the UK. Please note, this may then relate to wind farms that only need to be completed in 2021-2025 and in which cost reductions, for example as a result of larger wind turbines, have been taken into account and in which a whole range of planning uncertainties have been removed by governments. These auction prices are also often exclusive of cable costs. An English study, written in 2017, gives prices of £ 90-120/MWh for wind turbine prices in 2020. https://www. thecrownestate.co.uk/media/5493/ei-offshore-wind-cost-reduction-pathways-study.pdf Both the IEA's cost figures (which Berenschot uses) and these English figures include the cost of the cables. Onshore costs for adapting the electricity network in order to be able to incorporate power from wind farms are part of Quintel's ETM model*

57 *This Survey 2.0 applies prices for gas, biomass, coal and oil in accordance with the WLO high scenario. This is in line with the report by the Netherlands Environmental Assessment Agency (PBL) "Verkenning van klimaatdoelen - Van lange termijn beelden naar korte termijn actie (2017)"("Exploring climate targets – from long-term visions to short-term action (2017)"). The price of biomass, in particular, is considerably higher than in the previous Survey. No CO2 prices are included in costs.*

With regard to insulation costs, it is assumed that there will be a shift from the "low" to the "high" category (Ecofys 2015 categorisation) for the 1.5 million homes in the "low" category. This is equivalent to a shift from label D to G inclusive to label A+ and above. No significant adaptations are assumed for homes in categories C to A inclusive.

The "other" category includes home batteries, CHP, geothermal energy, oil-fired and coal-fired installations (industry), electric boilers, steam recompression (MVR installations), hydro, biomass installations and the additional costs of electric transport compared to conventional transport.

Total fuel costs will increase and shift from fossil to green gas, biofuels and hydrogen, the biomass price assumption being relevant to this.

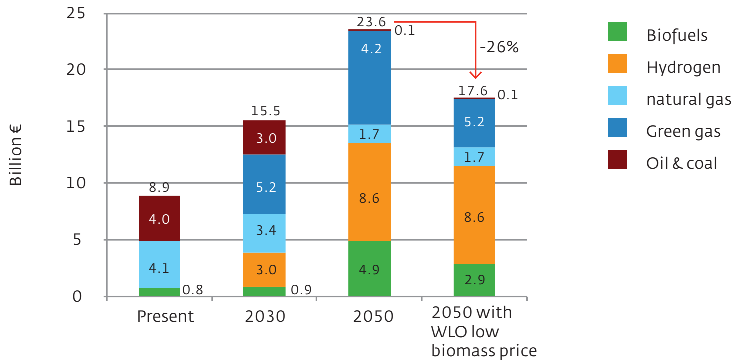
In 2050, 40% of the cost of the energy supply will be determined by fuel costs. Fuel costs will increase from the current 9 billion euros to 16 billion euros in 2030 and 25 billion euros in 2050. This cost trend is particularly attributable to the gradual shift towards hydrogen, biofuels and green gas.

Higher fuel prices are assumed for 2050 (WLO high scenario) than for 2030, with the price of biomass, in particular, having a significant effect on the costs of green gas and biofuels. If the WLO low scenario were to be assumed for biomass, then fuel costs would be 6 billion euros lower. This can be seen from the sensitivity analysis in column 4 of the graph on the next page.

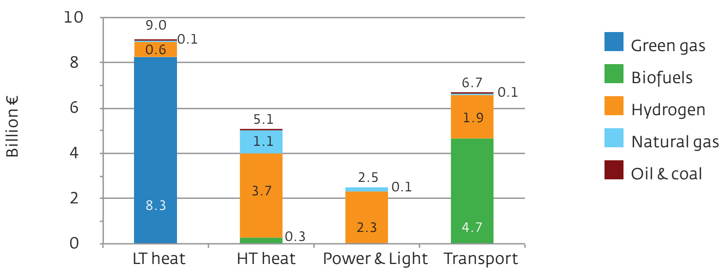
In 2050, hydrogen costs consist, for the main part, of costs for dedicated hydrogen production from offshore wind. Remaining costs are those related to hydrogen from natural gas and hydrogen from power-to-gas (residual electricity).

In 2050, the various functionalities will be using fuels very differently, which will be reflected in the cost of fuels. Green gas will take up a large proportion (8.3 billion euros) of the total costs and will be used exclusively for low-temperature heat. Hydrogen, on the other hand, accounts for roughly the same amount (9.5 billion euros), but will be spread over several functionalities. Biofuel will represent the largest cost item in the transport functionality, caused by the use of biofuels for lorries at a relatively high biomass price.

Fuel costs in 2030 and 2050 compared to present level, according to Gasunie's Survey (in € billion)



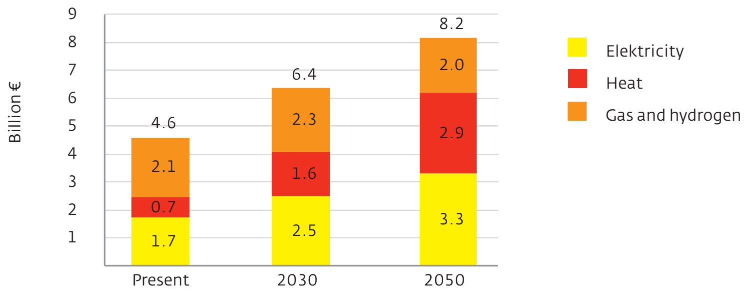
Fuel costs for 2050 according to Gasunie's Survey, allocated according to functionalities (in € billion)



The infrastructure costs are mainly attributable to the electricity network and the heat network

In 2050, 13% of the cost of the energy supply will be determined by energy network costs.

Infrastructure costs in 2030 and 2050 compared to present level according to Gasunie's Survey (in € billion)



In 2030, the costs relating to the energy infrastructure will increase as a result of electrification and a greater proportion of energy from heat. Gas and hydrogen network costs will also rise slightly.

Electrification will be more widespread by 2050, meaning a further increase in the costs for this network. The number of heat networks will also be increasing. In 2050, costs relating to the gas and hydrogen network will fall slightly due to a lower gas distribution volume in the built environment. Infrastructure costs for offshore hydrogen production are not included in infrastructure costs but are included in fuel costs for hydrogen instead.

Main assumptions made when calculating costs

Fuel prices

Cost element	Baseline 2015 (ETM)	Value 2030	Value 2050	Source for 2030/2050
Gas	13.50 €/MWh	18.00 €/MWh	20.50 €/MWh	WLO 2016
Oil	30.39 $/barrel	80.00 $/barrel	80,00 $/barrel	WLO 2016
Coal	37.00 $/ton	85.00 $/ton	85.00 $/ton	WLO 2016
Biomass	139.09 €/ton	125.44 €/ton	439.00 €/ton	WLO 2016

PV – Investment costs

Cost element	Baseline 2015 (ETM)	Value 2030	Value 2050	Source for 2030 / 2050
PV investment	980 €/kW	800 €/kW	571 €/kW	Henning & Palzer (2015)

Wind turbines – Investment costs

Cost element	Baseline 2015 (ETM)	Value 2030	Value 2050	Source for 2030/2050
Onshore wind	1391 k€/MWe	1443 k€/MWe	1410 k€/MWe	IEA World Energy Outlook 2016
Offshore wind	3902 k€/MWe	2506 k€/MWe	1911 k€/MWe	IEA World Energy Outlook 2016

Power2Gas

Cost element	Baseline 2015 (ETM)	Value 2030	Value 2050	Source for 2030/2050
P2G investment	N/A	650 €/kW	300 €/kW	Dechema for Cefic (2017)
P2G O&M	N/A	2-5% of CAPEX/ year	2-5% of CAPEX/ year	Dechema for Cefic (2017)

Hydrogen from natural gas

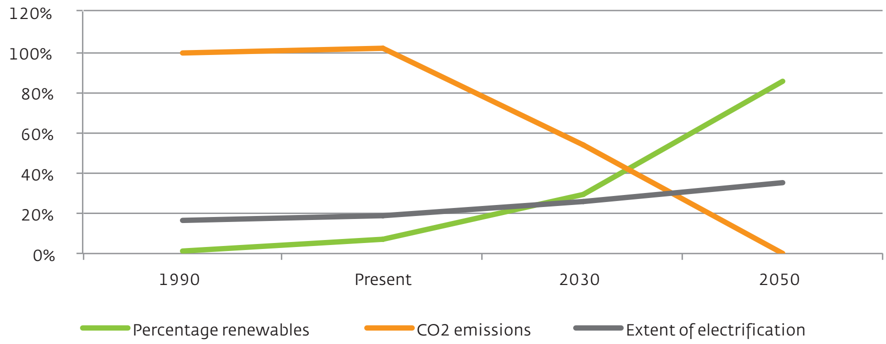
Cost element	Baseline 2015 (ETM)	Value 2030	Value 2050	Source for 2030/2050
Production costs of hydrogen (on top of natural gas price)	N/A	7.60 €/GJ	7,60 €/GJ	TNO, Berenschot. Feasibility study hydrogen from natural gas (2017)

Final Remarks

The relationship between CO2 emissions, renewable energy and the extent of electrification of society.

In the Survey, CO_2 emissions are used as a starting point in accordance with the aspirations of the Dutch government. In addition to reducing CO_2 emissions in the energy supply, the extent to which sustainable practices have been introduced is also important. In order to achieve desired CO_2 targets, the Survey provides for large-scale expansion of wind and solar energy, large numbers of heat pumps, significant extension in geothermal energy, the use of green hydrogen and increased biomass imports. As can be seen from the graph, this causes the percentage of renewable energy to rise from just over 6% to almost 30% in 2030 and then to around 85% in 2050.

Trends in the percentages of renewable energy, CO2 emissions and the extent of electrification from 1990 onwards



We can also deduce from the graph that the assumptions in the Survey lead to a doubling in the extent of electrification in Dutch society. This variable is defined as the ratio between total electricity demand (see market sector use in the 'Electricity 2050' diagram) and the gross final energy demand (see 'Final Energy Consumption' graph). In 1990, the extent of electrification was almost 17% and since then this has slowly risen to approximately 19%. The Survey predicts a sharp increase to 26% in 2030 and then to 35% in 2050, which also means that, in 2050, 65% of the energy demand will still be based on molecules in which hydrogen and green gas, in particular, will play a prominent role.

Costs per ton of CO2 emissions avoided

In the Survey, CO_2 emissions have been phased out completely by the energy sector by 2050. In comparison to the Business as Usual scenario, where this does not happen, total additional costs are calculated to be 30.5 billion euros per year. This means that the average cost per ton of CO_2 emissions avoided is 185 euros. A CO_2 savings percentage of 54% applies for 2030 and this comes out at 195 euros per ton of CO_2 emissions avoided; please note that there is considerable uncertainty regarding calculated costs.

Both amounts are considerably higher than the current CO_2 market price under the ETS. This implies that, unless the CO_2 market price is going to rise substantially, supplementary measures will be necessary because the market will not resolve the issue itself.

The average cost per ton of CO_2 emissions avoided in 2050 appear to be comparable to 2030; two factors play a role here. First of all, there are the 'lessons learned', as a result of which measures become increasingly cost-effective, secondly 'higher hanging fruit' results in higher costs.

What needs to be done?

Substantial efforts will be required to arrive at a CO_2–neutral energy supply in the Netherlands by 2050, including:

Built environment:

- Newly built EPC=0 or higher and no gas connection.
- 50,000 existing houses labelled G to D inclusive to be insulated to level A+ or higher.
- Half of all HE boilers replaced annually must be replaced by a (hybrid) heat pump. Installation of 180,000 (hybrid) heat pumps per year (excluding replacements).
- Installation of 250,000 home batteries per year (excluding replacements).

Industry:

- Current gas consumption will have to be converted at an average rate of approximately 1% per year by the use of hydrogen and also 1% per year by the use of electricity.
- Energy intensity in industry must be improved by 2% per year by making efficiency measures.

Transport:

- By 2050, private cars, estimated at 8 million, will have become mainly electric, a replacement rate of 250, 000 per year is necessary for this.[58]
- Just under 1 million freight transport vehicles (mainly delivery vans) must be using biofuels, hydrogen, green gas and electricity by 2050. A replacement rate of 30,000 vehicles per year is necessary for this.
- Dutch filling stations, of which there are around 4000, will switch to offering sustainable fuels and electricity at a rate of 125 per year.

Electricity generation:

- Installation of 10 new wind turbines of 10 MW offshore per month < 2050 (excluding replacements).
- Installation of 5 wind turbines of 3 MW offshore per month < 2030 (excluding replacements).
- Every month, 300,000 solar panels will be installed on roofs and approximately the same number will be erected in solar fields (excluding replacement).
- Coal-fired and nuclear power plants will start to be phased out prior to 2030.
- Construction of 28 GW hydrogen power plant capacity <2050, either through new construction or by converting existing natural gas power plants.

Sustainable heat:

- Construction of 2 geothermal doublets (wells) per month.

Glossary

The Gasunie Survey uses the Petajoule (PJ) as a unit of energy. A Joule is a unit of energy, but it is very small, and therefore the prefix peta (= 1015 = 1000 trillion) is used here.

1 PJ is approximately[59] equal to (expressed in current state-of-the-art technologies):

- The energy produced every year by 9 large offshore wind turbines (8 MW wind turbines)
- The energy generated by 1 million solar panels
- The energy generated by 6 geothermal doublets
- The energy generated by 6 green gas digesters
- Around 30 million m3 green gas/Groningen gas
- Around 0.3 TWh electricity

58 *In 2015 it was estimated that 450,000 cars were sold per year [CBS – https://www.cbs.nl/-/media/_pdf/2016/25/tm2016_web.pdf]*

59 *The energy produced depends on aspects such as the size of the wind turbines, wind speeds, efficiency of the solar panel, depth of the geothermal doublets, size of the digester installation, etc. etc.*

To transport 1 PJ per day:

- o You need 1 gas pipeline (36 inch pipeline)
- o You need 12 electricity cables (1 GW per cable)

Biomass	In this document this means sustainable biomass. Its use for energy purposes leads only to emissions of CO2 previously extracted from the air.
Business as Usual scenario	Scenario in which the current energy supply situation is extrapolated using prices assumed for 2050.
CC(T)S	Carbon Capture (Transport) and Storage. The capture of CO2 in processes, followed by transport and permanent storage in underground earth layers; below the seabed alone for the purpose of this Survey.
CCGT	Combined Cycle Gas Turbine.
CHP	Combined Heat and Power. Simultaneous generation and usage of electricity and heat from green gas, natural gas or hydrogen.
CNG	Compressed Natural Gas. Natural gas that is highly compressed (for example, 300 bar) making its use more suitable for mobility.
CO2-neutral	A measure or situation involving no net CO2 emissions, for example, as a result of the CO2 emissions being stored underground or CO2 emissions being offset.
ETM	Energy Transition Model. See www.energytransitionmodel.com.
Final energy consumption	The quantity of energy used by companies, households and transport in the Netherlands (according to the CBS definition).
Geothermal energy	The use of geothermal heat from shallow, deep or ultra-deep earth layers.
GW	Gigawatt. Energy produced per unit of time (capacity), in this case 1 billion Joules per second.
Hybrid	The use of different energy carriers within 1 appliance.
IEA	International Energy Agency.
LNG	Liquefied Natural Gas. Natural gas which is chilled so that it becomes liquid.
OCGT	Open Cycle Gas Turbine.
Power-to-Gas (P2G)	Conversion of electricity to hydrogen through electrolysis of water.
Power-to-heat (P2H)	The conversion of electricity into heat that can be used.
Primary energy consumption	(or: Energy Supply). The quantity of energy primarily available for consumption in the Netherlands (according to the CBS definition).
PV	Photo Voltaic. Conversion of sunlight into electricity.
Residual electricity	The proportion of the electricity production that is surplus to the electricity demand at that moment.
WLO	Welfare and Living Environment. Future scenarios established by the Netherlands Environmental Assessment Agency (PBL).

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