Industrial Decarbonization utilizing CCS and Hydrogen in the Netherlands

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1 EXECUTIVE SUMMARY

Cost-effective decarbonisation

The Netherlands is aiming for a rapid energy transition that will reduce its heavy reliance on fossil fuels while boosting economic growth. To drive this transition, the Netherlands has focused energy and climate policy on GHG (Greenhouse Gas) emissions reductions. Dutch industry is required to reduce its GHG emissions by 59% (14.3 million tons of CO_2 per year) by 2030 and become climate neutral by 2050. The challenge for Dutch industry is to decarbonize in adherence to the national climate target, while maintaining international competitiveness.

The presence of these dual goals has resulted in the formation of policy instruments prioritizing technologies that are more established and can decarbonize industry in the lowest cost manner, such as Carbon Capture and Storage (CCS), over emerging technologies such as green hydrogen and electrification.

Key policy measures

The Netherlands has implemented a carrot-and-stick approach towards climate policy:

- The National CO_2 Tax, introduced in 2021, acts as the stick, penalizing emitters that do not engage in emission reduction activities. The carbon tax acts as a top-up to the ETS price, in effect putting a floor on the carbon price. For industry the price rises linearly from EUR 30.5/tCO_2 in 2021 to EUR127/tCO_2 in 2030, incentivizing industry to decarbonize. The national carbon tax is not expected to have a significant impact since ETS prices are currently higher than the prescribed tax rates.
- The Stimulation of sustainable energy production and climate transition (SDE++), a key policy instrument introduced in 2020 supporting the uptake of low carbon technology, acts as the carrot. The SDE ++ works as a type of contract-for-difference scheme which compensates the additional costs for adopting a low carbon technology. The SDE++ prioritizes technologies which have a lower cost of carbon abatement and are closer to deployment over emerging technologies that are in the research and development phase.

One of the major criticisms of the SDE++ scheme is that it favors mature technologies such as CCS over long-term technological innovation. A redesign of the SDE++ scheme to allow for separate tenders across different ‘buckets’ of technologies or production processes, as is currently being considered, could support investment in emerging technology in lieu of low-cost emissions reductions. Additionally, dedicated innovation funding is made available for technologies that are at still lower TRL levels via instruments such as DEI+ (Demonstration Energy and climate Innovation). DEI+ is discussed in greater detail in section 5.1.2.

CCS

CCS has considerable techno-economic potential in the Netherlands for industrial decarbonization. This is due to the clustered and concentrated nature of Dutch industry, the existing pipeline transportation network, ample capacity for offshore storage, the scale at which CCS can be applied and its cost-effectiveness for CO_2 abatement. CCS policy has built on these advantages and thus far has been a success in the Netherlands. Cluster energy policies, development of shared infrastructure, and a subsidy mechanism that has removed carbon price uncertainty have brought forward projects such as Porthos for which financial support has been reserved and an FID is expected in 2022. Other key CCS projects in the Netherlands are Aramis, Delta Corridor Project and CO2TransPorts. These projects are discussed in greater detail in the subsequent sections.

CCS has, however, historically been controversial in the Netherlands since the public perception is that CCS could enable the fossil fuel industry to become locked in for future years. A number of measures has been put in place to limit the role of CCS to a transition technology: a) a cap has been placed on the amount of subsidy that can be made available for CCS, b) CCS can only be subsidized if there are no cost-effective alternatives and c) no new fossil CCS subsidy decisions will be carried out after 2035, which means that a project subsidized in 2035 can receive subsidy until 2050.

The Netherlands therefore faces the dilemma of considering CCS as an emissions reduction technology to meet its climate targets until 2030, while simultaneously having to consider how to subsidize alternative technologies beyond 2035. Decreasing cost and increasing EU ETS prices can allow CCS projects to take place unsubsidized beyond 2035.

Blue Hydrogen

Blue hydrogen is seen as a fuel which can develop the hydrogen economy in the Netherlands such that it paves the way for green hydrogen in the longer term. The Netherlands has a large refining and chemical industry which produces considerable amounts of hydrogen from natural gas for use in industry. The key blue hydrogen business case is to decarbonize the grey hydrogen forming parts of the residual gas, since replacement with green hydrogen is not straightforward in these applications. Blue hydrogen is not supported by the SDE++ scheme as a separate technology, however blue hydrogen projects are expected to be sufficiently subsidized when the CCS part of the project is subsidized. The SDE++ scheme is able to support blue hydrogen production via CCS retrofits on existing grey hydrogen production units.

SDE++ support is insufficient to fully cover a blue hydrogen project such as H-vision which requires construction and installation of new reformers, but the proposed separate SDE++ category for 2022: “Production of hydrogen from residual gases” is expected to bring the required support for blue hydrogen projects in the Netherlands requiring the new reformers.

Green hydrogen

The Netherlands has ambitious plans for green hydrogen with 4 GW electrolyzer capacity being planned for 2030 and recently EUR 15 billion being allocated to ‘advanced renewable energy carriers’, a portion of which is expected to be earmarked for green hydrogen. As recently as 13 of April 2022, the two largest coalition parties publicly announced to increase the electrolyzer ambition to 8GW.

The Northern Netherlands has also been fully committed to the development of hydrogen ecosystems. With a hydrogen project pipeline in excess of 50 projects and with a plan for EUR 9 billion in investments by 2030 via public-private partnerships, this region has gained European recognition and is now acknowledged to be a potential leading “Hydrogen Valley” in Europe. A hydrogen valley is a geographical area or an industrial cluster where several hydrogen applications are combined together into an integrated hydrogen ecosystem covering production, storage, distribution and final use consuming a significant amount of hydrogen and thereby improving the economics behind the project.

The Dutch cabinet is coming up with a plan to adapt existing gas pipelines for the transport of hydrogen. Recent studies have shown that it is feasible, safe and cost-effective to reuse existing gas networks for hydrogen. Seizing this opportunity the Dutch government is now developing the roll-out plan for a national hydrogen transport network (Hydrogen backbone). The National hydrogen backbone can facilitate the development of local hydrogen production by connecting all major industry clusters with central storage locations.

Although the hydrogen economy seems poised to kick-start in the Netherlands, the reality is that hydrogen policy is incomplete and at present insufficient to enable gigawatt scale green hydrogen projects to take positive FIDs. While there has been welcome R&D funding, small-scale demonstrations, and larger scale projects in the planning stages, the costs of deployment cannot be met through current policy, given that green hydrogen is not competitive within the current SDE++ framework.

Green hydrogen can benefit from the plan for SDE++ to allow for separate tenders across different buckets of technologies, but at present it is uncertain by how much. The EUR 15 billion earmarked to support advanced renewable energy carriers and the announced 8 GW electrolyzer ambition by 2030 indicates that the government is making serious plans to take a more active and leading role in green hydrogen deployment. Furthermore, the existing gas infrastructure, including the plans for building the national hydrogen backbone and plans for scaling up offshore wind make the Netherlands strategically positioned to pioneer with hydrogen deployment.

Until as recent as a few months ago, one would conclude that there is no overall Dutch hydrogen model that can be recommended for application in other countries. The recent announcements by Government are however very encouraging and could change this view radically. Clarity on when additional budget will be made available and how it will be deployed is required to bring confidence to investors and industry and kick-start the green hydrogen economy in the Netherlands.

2 INTRODUCTION TO DUTCH INDUSTRY

The Netherlands has a large and competitive economy. Despite its relatively small population and size, the Netherlands is the 17th largest economy in the world in 2021 (IMF, 2020). Industry is a key contributor to the competitiveness of the Dutch economy and is focused on energy intensive activities such as steel, chemicals production and oil refining. Dutch heavy industries contribute significantly to the economy by employing nearly 120,000 people and contributing EUR 17 billion (2017) in revenue to the economy (EZK, 2020). Since 1959 the Groningen gas fields have been a strong driver behind the development of energy intensive basic industries in the Netherlands and have given these industries comparative advantages. These goods are also subject to global competition, largely cost-driven, which has resulted in large scale production with high capital intensity and very high labor productivity (House of Representatives, 2018-2019). Around three-quarters of production is intended for export (CPB, 2019).

The Netherlands is also highly reliant on fossil fuels: in 2018, fossil fuels covered 90% of the primary energy supply. natural gas and oil are the most important fuels making up 77% of total final consumption (IEA, 2020). The Netherlands is also the country in the EU with the largest share of natural gas in the fuel mix (44% compared to the EU average of 22% in 2019). The energy intensive nature of Dutch industry combined with its reliance on fossil fuels contribute to it being a major emitter of GHG emissions. This is one of the reasons why Dutch GHG emissions per capita are substantially higher than the European average (Dutch greenhouse gas emissions calculated according to international standards were 12.3 tonnes per capita in 2017, compared to the EU28 average of 8.8 tonnes (EuroStat)) .

Industry accounts for the largest proportion (27%) of direct emissions in the Netherlands. Industrial emissions in the Netherlands are heavily concentrated in industrial clusters and can be further clustered into sub-industries and major emitters. Sub-industries such as chemicals, refining, food processing and metals have the highest emissions intensity and together contribute to 90% of the industrial emissions in the Netherlands (Figure 1). The heaviest emitter is the chemical sector, representing 44% of industrial emissions. These four sectors also account for a significant share of industry's Scope 2 emissions, as they represent 72% of the electricity use of the manufacturing sector (EuroStat), (OECD, 2021). Additionally the twenty major emitters account for 60% of the industrial emissions. Dutch industry and its emissions are further concentrated in six major industrial clusters spread across the country: Rotterdam-Moerdijk; Smart Delta Resources; Chemelot; Noord Nederland, Noordzeekanaalgebied and The Zesde cluster as shown in Figure 2.

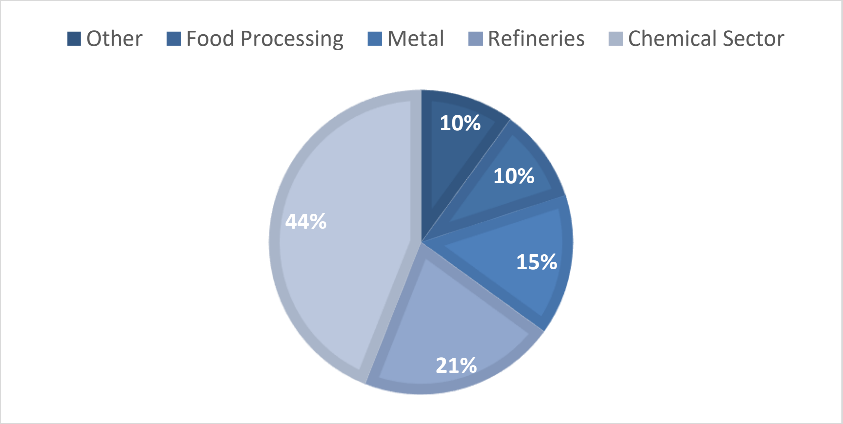


Figure 1: GHG emissions of Dutch Industry by sub-sector, 2018 (Source: Eurostat, (OECD, 2021))

The Netherlands has a decarbonization dilemma. On the one hand, the clustered and concentrated nature of Dutch industry allows for economies of scale and cost-effective measures to reduce emissions. On the other hand, the Netherlands remains heavily reliant on fossil fuels and has a concentration of energy and emission-intensive industries that will be hard to decarbonize while maintaining competitiveness. A loss of competitiveness could cause industry to shift to foreign countries with more favourable tax regimes. In the absence of mechanisms to penalize carbon intensive imports, this move can impact the efficiency of national industrial decarbonization efforts by shifting emissions abroad rather than reducing them.

3 INDUSTRIAL DECARBONIZATION OPPORTUNITIES

The Netherlands is aiming for a rapid energy transition that will reduce reliance on fossil fuels while boosting economic growth. To drive this transition, the Netherlands has focused energy and climate policy on GHG emissions reductions (IEA, 2020). The core of the Dutch Climate Plan is the Climate Agreement, which is a set of agreements between government bodies, companies and public organizations in the Netherlands to reduce the greenhouse gas emission by 49% in 2030 and 95% by 2050 when compared to 1990 levels. The Dutch climate agreement is discussed in more detail in section 4.2. Additionally, in 2013, the Urgenda Foundation commenced a case against the Dutch government, seeking an order to reduce GHG emissions of the Netherlands. The court of first instance of The Hague in 2015 ordered the Dutch government to reduce GHG emissions by at least 25 percent by the end of 2020, compared to 1990 levels. The greenhouse gas (GHG) emission levels in the Netherlands in 2020 were 25.5 percent below the level of 1990. The 25% target introduced by Urgenda was therefore achieved.

These targets have significant impact on Dutch industry since they are the largest contributor to direct emissions in the Netherlands. Being heavily reliant on fossil fuels and with a concentration of emission intensive industries, the challenge for Dutch industry is to decarbonize in adherence with national climate targets, while maintaining international competitiveness. Apart from affecting economic prosperity, a loss of competitiveness can reduce the efficiency of the global energy transition by shifting emissions abroad instead of reducing them (OECD, 2021).

According to the Dutch government’s vision towards 2050 (EZK, 2020), Climate policy will fundamentally change basic industries worldwide. The carbon footprint of many end products are determined by the raw materials and process emissions part of their manufacturing processes. Customer demand is for instance expected to change towards sustainable goods which would require a movement towards a carbon neutral footprint for industry. This means that industry would have to become more circular, with the usage of high-quality recycling of feedstock and other materials, and the circular design of finished products and semi-manufactures. The advent of sustainable electrification, hydrogen and fundamentally different production processes such as bioplastics are also expected to change the way products are made in industry. Moving towards 2050, industry is also expected to become increasingly connected to the immediate surroundings. Practices such as reuse of residual heat and supply of captured carbon dioxide to greenhouses are likely to increase. The development of a new hydrogen infrastructure which is vital for sustainable transport, flexibility in the energy system and for parts of the built environment is expected to start in industrial clusters and expand from there.

The Netherlands is strategically positioned to utilize these sustainable developments for its competitive edge, with the following advantages:

1. **The North Sea:** The industrial clusters of Smart Delta Resources, Rotterdam-Moerdijk, Noordzeekanaalgebied and Noord-Nederland are located near the North Sea, whose shallow waters are ideal for the large-scale production of green electricity and hydrogen from offshore wind. The cost of producing electricity from offshore wind is declining rapidly. This provides the clusters with a competitive advantage in the future due to their access to cheap electricity. Additionally, the Dutch part of the North Sea has ample depleted offshore gas fields which could be utilized for storing carbon and hydrogen storage.

2. **Ports:** Dutch ports play a key role in global and regional energy trade, with the Port of Rotterdam being the largest deep-water port in Europe. Dutch ports have one of the largest concentrations of oil refining and marine bunkering fuels in Europe and a major liquefied natural gas (LNG) terminal at Rotterdam. The ports are uniquely positioned to give Dutch industry access to worldwide markets to sell products while being an ideal transit hub for goods to the wider European markets. Dutch industry has historically benefitted from low-priced raw material coming into the port for transport into European markets and this is expected to be a major differentiator for the Netherlands in the low carbon transition.

3. **Transport Infrastructure:** The Netherlands has an extensive natural gas network in which gas can be transported (see Figure 3). The gas network consists of both low and high calorific pipelines and connects all the industrial clusters in the Netherlands. Cross border pipelines exist between the ports of Antwerp and

Rotterdam, chemical clusters in the Benelux and Germany's Ruhr area. Around 40% of European petrochemical production takes place in the Antwerp-Rotterdam-Rhine-Ruhr area cluster (Osborne et al., 2018), making it one of the largest in the world. Good infrastructural links provide a strategic advantage for industrial clusters in the Netherlands, especially those located near the German and Belgian borders. The Rotterdam port area already has Europe's largest biofuel production cluster, and the existing network of gas pipelines could be the basis for a European network for hydrogen and biogas transport (House of Representatives, 2019-2020).

Dutch industry is mandated to reduce its GHG emissions by 59% (14.3 million tons of CO_2 per year) by 2030 and become climate neutral by 2050. Several policy packages have been unveiled in order to incentivize industry to decarbonize while staying competitive. The policy instruments have been discussed in more detail in section 4. There are several emerging technologies for emissions reduction in industry.

- The focus during the previous decades was on efficiency improvements, however climate mandates require significant reduction steps which require the use of emerging technology.
- Electrification of heat and power is seen as a crucial technology to achieve the required emissions reductions, however electrification has technical limitations in its applicability to industry. As an example, high temperatures required in production of cement and steel are currently not achievable with electrification and require alternative fuel usage.
- Hydrogen is the preferred long-term choice of technology to deliver deep decarbonization in industry with a fuel shift, however large scale hydrogen projects are not expected to be realized in a short timescale.
- This makes CCS an unavoidable option to deliver significant emissions reductions this decade (Akerboom et al., 2021). In the Netherlands, industry, government, and environmental NGOs have agreed to subsidize CCS projects until 2035, after which other reduction technologies must have emerged or new CCS projects must proceed unsubsidized.

This report will be focused on the policy enablement required to support technologies such as CCS and hydrogen to decarbonize Dutch industry.

3.1 Role of CCS and Hydrogen in Industrial Decarbonization

3.1.1 Carbon Capture and Storage

Carbon Capture and Storage involves the capture of CO_2 from industrial emissions and flue gases, transporting the CO2 through pipelines or other means and storage in the subsurface to avoid its release into the atmosphere. Due to the scale at which CCS can be applied, it has been labelled a critical technology to reduce CO2 emissions and to achieve global climate goals. For energy intensive, hard-to-abate sectors, technical and cost-effective options to reduce emissions without CCS is currently limited. The Netherlands considers CCS to be a transitionary technology; industry, government, and environmental NGOs have agreed to subsidize fossil CCS projects until 2035, with an expectation of 8.7 million tons of emissions reductions annually to come from CCS deployment by 2030. Additionally, BECCS (Bioenergy with carbon capture and storage) and DACCS (Direct air carbon capture and storage) have been considered necessary for meeting net zero goals according to many estimates published. Beyond 2035, alternative emissions reductions technologies are expected to have matured technologically and CCS would proceed unsubsidized. CCS faces a dual challenge in the Netherlands: how to scale up CCS this decade and how to transition away from fossil CCS projects in the long term – the end of subsidies beyond 2035 being a first marker in the transition process (Akerboom et al., 2021). The policy support for CCS is further elaborated in section 5.1.1.

3.1.2 Hydrogen

Hydrogen is predominantly produced from natural gas (58%), or generated from the processing of oil products (39%). The main applications of pure hydrogen are fertiliser production and hydrogenation and desulphurization by oil refineries

(TNO, 2020). Hydrogen forms a significant part of the nearly 3000 PJ total gross energy consumption in the Netherlands and therefore has a considerable impact on the emissions intensity of industry.

The Netherlands aims for low-carbon hydrogen to play a major role in supporting the achievement of emissions reduction targets and has already started a strong policy push for low-carbon hydrogen through the Hydrogen Strategy. The government is developing a broad policy framework under the Hydrogen Programme to scale up low-carbon hydrogen production, infrastructure and demand. The 2019 Climate Agreement and 2020 Hydrogen Strategy define numerous targets and support schemes for low-carbon hydrogen covering a wide range of sectors and applications. The country already has significant hydrogen production (from natural gas) linked to strong hydrogen demand in the Dutch chemical, petrochemical and refining sectors. The Netherlands plans to rapidly scale up low-carbon hydrogen production in industrial clusters with existing hydrogen production via carbon capture and storage (CCS) and electrolysis powered by renewable energy, with a focus on leveraging the low cost and potential high availabilities of Dutch offshore wind generation in the future. The Netherlands is also taking an integrated approach to electricity and gas infrastructure development, with a clear intention to support the production, transport and storage of hydrogen, including by leveraging existing natural gas infrastructure. The Netherlands’ central location in Europe, extensive cross-border energy infrastructure and large port facilities also support the potential for the country to play a role in developing a robust regional and global market for low-carbon hydrogen.

Most of the hydrogen supply in the Netherlands is produced in the five largest industrial clusters of Rotterdam-Moerdijk, Smart Delta Resources, Noordzeekanaalgebied, Chemelot, Noord-Nederland. In 2019, these clusters produced an estimated 175 PJ of hydrogen (DNV, 2019). Production is concentrated in the Rotterdam-Moerdijk and Smart Delta Resources clusters, which are home to the majority of Dutch chemical and petrochemical facilities. Hydrogen production in the Netherlands has been growing. From 2008 to 2018, hydrogen production associated with oil refining and key chemical production processes increased by 34%. Almost all hydrogen production in the Netherlands is based on steam methane reforming (SMR) of natural gas. The CO2 emissions are also concentrated in these six major industrial clusters.

Grey hydrogen (hydrogen produced from natural gas without CCS) production in the different clusters is associated with a significant portion of the industrial emissions in the Netherlands. Grey hydrogen can be replaced with blue hydrogen by installing a carbon capture facility and establishing a connection to a planned CO2 transport and storage network. Parts of the grey hydrogen demand can also be replaced by green hydrogen in a straightforward manner. According to the different cluster energy strategies (section 3.2), most reduction will be achieved by replacing grey hydrogen with blue hydrogen by 2030, before transitioning onto predominantly green hydrogen by 2050, and by deploying carbon capture and storage (CCS), carbon capture and utilization (CCU) and electrification. The Dutch energy network operator Gasunie is building a national hydrogen network, which will connect industries, hydrogen storage facilities and production sites, as well as the countries surrounding the Netherlands, thereby facilitating the transfer of hydrogen to and between the clusters. This hydrogen network, called the Dutch hydrogen backbone, will be developed primarily utilizing existing infrastructure and to a lesser extent new infrastructure that is to be built, Section 3.3 provides more detail on the Dutch infrastructure plans and the cross border opportunities.

The different industrial clusters have formulated their climate targets and pathways to enable them to meet these targets. The cluster energy strategies have been elaborated in the section below.

3.2 Cluster Energy Strategies

Each of the clusters have developed different GHG emission reduction targets and strategies to meet these GHG reduction targets. Sub sections below describe the current emissions, emission reduction targets and key hydrogen and CCS projects to facilitate the decarbonization of these industrial clusters. Figure 2 below depicts the six major industrial clusters, their total industrial emissions and their respective hydrogen production capacities.

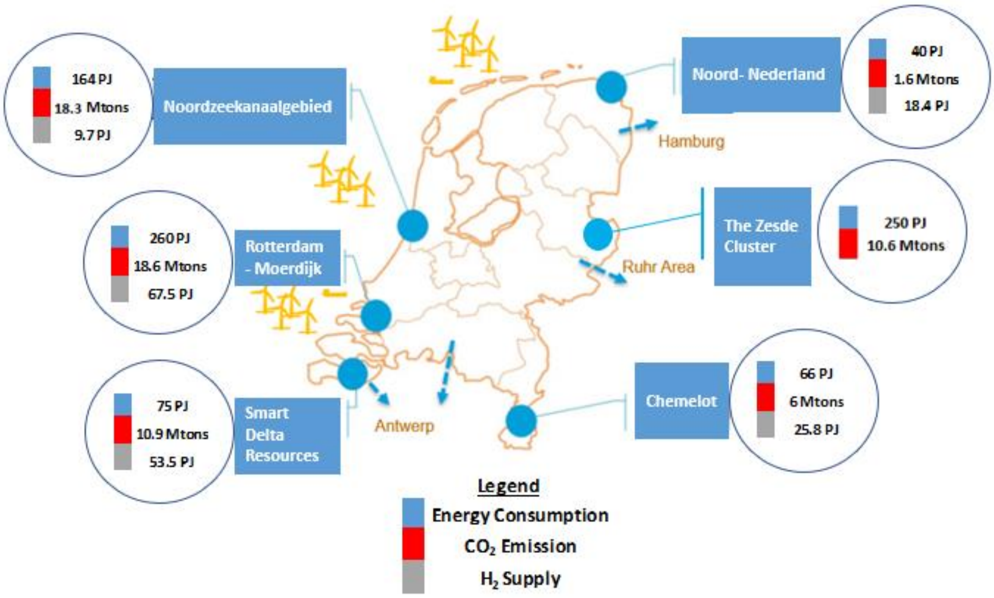


Figure 2: Major industrial clusters in the Netherlands along with their hydrogen supply and emissions (from (DNV, 2019)

3.2.1 Rotterdam-Moerdijk (R-M)

The Rotterdam-Moerdijk cluster is an Energy hub within north-western Europe with significant imports and exports of oil products (5,950 PJ of import and 5,830 PJ export). The difference of 120 PJ is due to the residual gases produced, which is utilized as an energy source. The GHG emissions of this cluster total 18.6 Mtons CO2 per year (Klimaattafel Haven en Industrie Rotterdam - Moerdijk, 2020), with 5 refineries contributing a little less than 50% of the total. The cluster represents 385 000 jobs and a total value addition of EUR 45.5 billion in economic value (6.2% of GDP). The target emissions for the cluster is between 8.1 and 10.4 Mtons (scope 1) per year by 2030 and down to 2 Mtons CO2 per year by 2050. The range in target reductions depict the role that technical and non-technical uncertainties play in the plans. The total energy consumption is 254 PJ and 0.5 Mtons CO2 is earmarked for the OCAP project which aims to collect CO_2 emissions from Dutch oil refineries and provide the CO2 to greenhouses in the Western part of the Netherlands.

The Porthos project (section 6.1) is a CCS project located in the Port of Rotterdam and is set up to store carbon emissions from industry in empty gas fields near the shore of the Netherlands. The Porthos project is essential to achieving the objectives of this cluster prior to 2030 and the tight timeline for Porthos especially in view of the licensing requirements act as an uncertainty in achieving the cluster plans. Aramis is another key CCS project in this region, aiming to provide 5 Mtons CO_2 storage potential by 2026. Various hydrogen projects are under planning, however they require a connection to the hydrogen backbone prior to 2030 through the development of local hydrogen infrastructure. The key hydrogen project planned in this cluster is the H-vision project which aims to produce blue hydrogen predominantly from residual gasses to produce 46 PJ of energy with an emissions reduction potential of 2.7 Mtons CO2 annually. The delivery of H-vision is planned for 2026 and upscaling planned by 2032. Key hydrogen projects planned in this region include:

- H2Fifty (a 250 MW electrolyzer)
- One 200 MW electrolyzer on wind power from the Holland Kust Noosr wind farm
- Curthyl (hydrogen production from excess electricity from a wind farm with a limitation in the grid connectivity)

- MULTIPHLY (a high temperature electrolyzer for the production of advanced biofuels)
- Other initiatives contributing to 100MW electrolyzer capacity

The Rotterdam-Moerdijk cluster has developed their roadmap in 3 steps:

- Step 1 (2018-25): Residual heat from industries is planned to be utilized to heat houses, offices, and greenhouses and the CO2 will be captured and utilized in greenhouses or stored under the North Sea. The CO2 abatement potential of step 1 is 4.9 Mt CO2 by 2030. Additionally, efficiency measures will be evaluated.
- Step 2 (2020-30): Oil and gas used as heat in the industrial production process will be replaced by renewable electricity and hydrogen, initially blue hydrogen and then green hydrogen. The CO2 reduction potential is 3.5-4 Mt CO2 in 2030.
- Step 3 (2030-50): Replace fossil fuels in the chemicals and transportation sectors with biomass, recycling and reuse of CO2 in combination with hydrogen. The CO2 reduction potential is 1 Mt CO2 in 2030. The majority of the emissions reductions required to reach carbon-neutrality in 2050, occur between 2030 and 2050.

3.2.2 Smart Delta Resources (SDR)

Smart Delta Resources is an initiative aiming at reducing the industrial use of energy and feedstock in Zeeland and Oost-Vlaanderen (Belgium). The initiative is taken up by eleven energy and feedstock intensive companies, provinces of Zeeland and Oost-Vlaanderen and North Sea Port. Key industries in this region include the production of chemicals, steel, energy and food. SDR is specifically known for its use of grey hydrogen which is currently 520 kt annually, corresponding to 33% of current industrial consumption in the Netherlands. The use of hydrogen in SDR has the potential to grow to more than 1 Mt annual consumption by 2050. The SDR region is also known for its wind energy potential with Windpark Borsele 1, 2, 3 and 4 amounting to a total installed capacity of 1.4 GW (RVO, n.d.). The presence of large-scale wind parks offer an opportunity for the production of green hydrogen. Green hydrogen can be produced from electricity grid surpluses or through direct coupling with a wind and/or solar farm. It is expected that the majority of electricity from offshore wind can be integrated within the electricity grid, however the RVO expects a full integration can result in grid congestion.

Current CO_2 emissions is 20.4 Mtons/year (Dutch side - 10.9 Mtons CO_2/year, Belgian Side - 9.5 Mtons CO_2/year) (Smart Delta Resources, 2020). The SDR region CO2 reduction target is 11 Mtons in 2030 and the provisional ambition for 2050 is to reduce emissions by 18 Mtons CO2 (Smart Delta Resources, 2020). The emissions reduction target applies to both the Dutch and Belgian side (Emissions reduction target Dutch side = 5.6 Mtons CO_2/year by 2030 and 9 Mtons CO_2/year by 2050, Belgian side emissions reduction target equals 5.5 Mtons CO_2/year by 2030 and 9.3 Mtons CO_2/year by 2050). This target is still not enough to reach climate neutrality. Most reduction will be achieved by replacing grey hydrogen with mostly blue hydrogen in 2030 and mostly green hydrogen in 2050, and by deploying carbon capture and storage (CCS), carbon capture and utilization (CCU) and electrification. Four main programs have been identified as part of the GHG reduction plan: Hydrogen Delta, Carbon Connect Delta, Spark Delta and Heat Delta. Key hydrogen projects planned in this region include:

- Exchange of hydrogen (by-product) via a pipeline between Dow and Yara (completed in 2018)
- “ELYGator”, Air Liquide has a project for 200 MW electrolysis in Terneuzen
- “H2ero”, 150 MW electrolyser in Vlissingen on-site at Zeeland Refinery
- “Haddock”, 100 MW electrolyser on-site at Yara Sluiskil, project with Ørsted
- “Hy2Zer0” at Dow in Terneuzen, where methane-rich waste streams from the cracking process are used to produce hydrogen and the current crackers are adapted to run entirely on hydrogen
- “North-C- Methanol”, is being used by ENGIE and ArcelorMittal, among others, via the project in Ghent to make hydrogen to make methanol from CO2
- “SeaH2Land”, 500 MW electrolyser by Ørsted in Vlissingen-Oost, with potential growth to 1GW
- Development of regional cross-border open-access hydrogen pipeline infrastructure by Gasunie, Fluxys and North Sea Port

Conditions to ensure the SDR GHG reduction plan is a success are: regional hydrogen infrastructure, infrastructure for CCUS, enough sustainable energy and favorable regulations (e.g. favorable permitting procedure, smooth resolution to differences in regulations between the Netherlands and Belgium).

3.2.3 Chemelot

Chemelot is a chemical business park consisting of leading chemical producers responsible for 6 Mtons of CO2 emissions annually (Chemelot, 2020). The target is to reduce GHG by 50% by 2030 and become climate neutral in 2050. Hydrogen is seen as key to achieving the GHG target with plans to produce 50 kt blue hydrogen by 2030 and 200 kt (blue and green) hydrogen by 2050. Chemelot also has the ambition to become the first circular hub through a) the replacement of fossil fuels by sustainable alternatives and b) electrification of production process with green electricity. The FUREC project aims to construct an installation that processes the residual waste into raw material pellets, which are then converted into circular hydrogen at Chemelot. In this way, natural gas consumption at Chemelot decreases by more than 200 million m3 per year. In addition, it results in a CO2 reduction of 380,000 tons per year. Two solutions for 2030 are the reduction of nitrous oxide emissions and CCS. Nitrous oxide is not yet included in the Emission Trading System (ETS) system and therefore, some low-hanging fruits still exist to reduce the annual emissions of nitrous oxide by 0.9 Mt CO2 (equivalent) by 2030. A substantial amount of almost pure CO2 is available for capture at the Chemelot site. The challenge going forward for Chemelot is to ensure the required infrastructure solutions for CO2 transport and storage are available.

3.2.4 Noordzeekanaalgebied (NZKG)

“Noordzeekanaalgebied” which consists of Amsterdam, Zaanstreek and IJmuiden represents almost thirty companies in the North Sea canal area. Key industry sectors in this cluster are steel, food and energy. This cluster is responsible for 18.3 Mt CO2 emissions per year (11% of the CO2 emissions in the Netherlands) (Noordzeekanaalgebied, 2020). A large part of these emissions (6.3 Mtons) are emitted by Tata Steel. The ambition of NZKG is a 50% CO_2 emissions reductions by 2030. Different scenarios of technology development is envisioned by NZKG. Emissions reductions between 2025 and 2030 are expected to take place predominantly via installation of solar, wind, electrification of transport, CCS and blue hydrogen. The contribution of the different technologies however depend on the scenario in question. Key hydrogen projects planned in this region include:

- “H2ermes”: 100 MW hydrogen production via electrolysis to make steel industry more sustainable, with possible upscaling to 1 GW
- “P2F Hemweg”: Production of 10 MW green hydrogen with possible upscaling to 100 MW green hydrogen for the production of synthetic fuels
- "Rietlanden”: a transhipment terminal in the port area of Amsterdam where the transition from coal to hydrogen related activities or a logistics role in the transition of the port is being investigated
- H2 in gas-fired power station: deployment of controllable, flexible hydrogen-powered power stations in 2030 - 30% vol addition of Hydrogen in existing NG plant Hemweg with possible upscaling to 100% Hydrogen in the 2030 to 2040 period

Conditions to ensure the NZKG GHG emission reduction plan is a success include: reduction of uncertainty for investors regarding future subsidies, an increasing ETS price, an increase in subsidies to facilitate important non-profitable investments and energy infrastructure improvements. Getting the energy infrastructure ready for transmission is seen as a crucial step and consists of strengthening the electricity network, gradually converting the gas network to a hydrogen network and the construction of a CO_2 network.

3.2.5 Noord-Nederland

The Noord-Nederland cluster contains industries concentrated in Eemshaven, Delfzijl and Emmen (Industrietafel Noord-Nederland, 2020). This is the smallest industry cluster in the Netherlands. Key industries related to this cluster consist of the chemical industry, food, data centers, metal and biorefinery. The Northern Netherlands has also been fully committed to the development of hydrogen ecosystems. With a hydrogen project pipeline in excess of 50 projects and with a plan for EUR 9 billion in investments (FCH JU, 2020) by 2030 via public-private partnerships, this region has gained European recognition and is now acknowledged to be a potential leading hydrogen valley in Europe. The region has ambitious plans covering the full hydrogen value chain including up to 6 GW offshore wind, 50 to 75 PJ green hydrogen production and 1150 km of connected north western hydrogen pipelines. The plan is to upscale in two phases:

Phase 1: (2020 to 2025). Up until 2025, the plan is to scale up to between 5 and 10 PJ of hydrogen capacity annually.

Phase 2: (2025 to 2030). From 2025, the plan for this region is to grow to 100 PJ per annum of Northern Netherlands hydrogen capacity by 2030 of which 75 percent will be green hydrogen (6 GW equivalent) and 25 percent will be blue hydrogen production. The region expects to grow to serve the northwestern European hydrogen markets by 2030. Large projects such as NorthH2, HyNetherlands and H2M (detailed below) are envisioned to drive the growth while domestic and cross-border connections are matured to connect the Northern Netherlands to northwestern European offtake markets such as Benelux, western Germany and northern France. GHG emissions reductions in this industry cluster are expected to be achieved through process innovation, changing energy sources and improved energy-efficiency.

Key hydrogen projects planned in this region include:

- $NorthH_2$ – NortH2 is an international consortium (Groningen Seaports, Eneco, RWE, Equinor, Shell and Gasunie, province of Groningen), jointly investigating the feasibility of large-scale production, storage and transmission of green hydrogen. The aim of this project is to be able to supply industry with 4GW of green hydrogen by 2030. The ambition however goes further than that. NortH2 wants to upscale to more than 10 gigawatts of green hydrogen production capacity by 2040
- H2M – Vattenfall, Equinor and Gasunie have formed a consortium to explore the large-scale production and off-take of blue hydrogen in the Northern Netherlands and to establish a clean hydrogen value chain that paves the way for a sustainable hydrogen economy. Blue hydrogen will be produced from Norwegian gas and CO_2 will be stored in the Norwegian continental shelf. This 'H2M'-project has the potential to reduce Dutch CO_2 emissions with 2 million tons per year from 2024 onwards
- HyNetherlands – HyNetherlands project focuses on combining renewable energy and biogenic CO_2 to produce e-methanol in the province of Groningen. Phase 1 is expected to produce 100MWe by 2025 with a scale up to 1.85GWe in early 2030
- DJEWELS – Djewels is a project that aims to demonstrate the operational readiness of a 20 MW electrolyzer for the production of green methanol in real-life industrial and commercial conditions. It will bring the technology from TRL 7 to TRL 8 and lay the foundations for scaling up towards a 100 MW electrolyzer on the same site
- Eemshydrogen – Eemshydrogen consists of the construction of a 50 megawatt electrolyser. Electricity from RWE's Westereems onshore wind farm will be used to produce green hydrogen
- HyStock – HyStock is working on the first large scale underground storage of hydrogen in salt caverns in the Netherlands

3.2.6 The Zesde cluster

Zesdecluster which literally translates to "The sixth cluster" contains all industry which is not represented in the five clusters described above. The sixth cluster consists of the following industry sectors: food processing, paper, chemical, glass, ceramic, waste and recycling, information and communication technologies (ICT), metallurgical, oil and gas. The reduction target is 4.3 Mt CO2 (Het zesdecluster, 2020) and the roadmap to reach this target consists of a number of different initiatives including electrification, geothermal, efficiency improvement and sustainable energy. Among others, requirements to meet the GHG emissions reduction targets include access to hydrogen and CCUS infrastructure, R&D support and access to finance and subsidies.

3.3 Infrastructure development and cross-border opportunities

The Netherlands has an extensive natural gas network in which gas can be transported. (see Figure 3). The gas network consists of both low and high calorific pipelines and connects all the industrial clusters in the Netherlands. The plan is to convert parts of the gas network for hydrogen transmission in a phased manner. The Dutch energy network operator Gasunie is building a national hydrogen network, which will connect industries, hydrogen storage facilities and production sites, as well as the countries surrounding the Netherlands, thereby facilitating the transfer of hydrogen to and between the industrial clusters. This hydrogen network, called the Dutch hydrogen backbone, will be developed primarily utilizing existing infrastructure and to a lesser extent new infrastructure that is to be built. It is expected that large parts of this national hydrogen backbone can be realized before 2026. The parts of the hydrogen backbone in dark blue denote the areas where local networks need to be developed in order to connect to the existing hydrogen network. Local private H2 networks are being realized in the R-M, NZKG and SDR clusters, which, in terms of timing, are in line with the realization of electrolysers up to 250 MW and the expected realization of the blue hydrogen projects in the R-M region. Prioritization of which parts of the backbone depends on supply and demand between production locations, clusters and industries, strategic choices and spatial integration. The north of the Netherlands is a logical starting point since large scale hydrogen production is expected here in 2027. Subsequently, a connection to Chemelot would be the priority since Chemelot has limited possibilities for hydrogen production. This also offers an opportunity to connect with the North Rhine Westphalia cluster in Germany. Finally, the western side of the backbone, where GW-scale electrolysis is expected in 2029/2030 is expected to be realized. Subsequently the connection of east with west, as well as further connections with Belgium via Chemelot is envisioned (DNV GL, 2020).

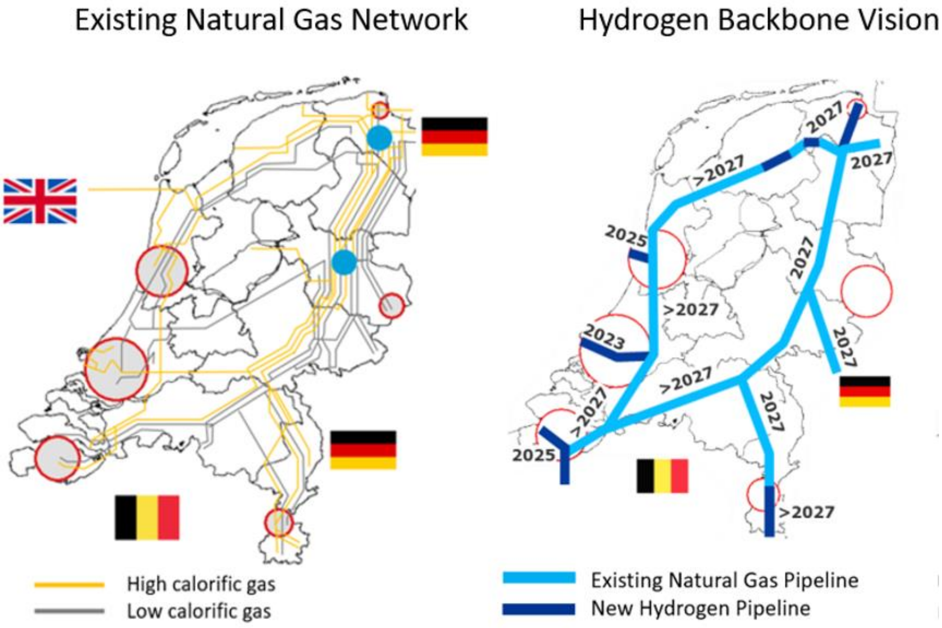


Figure 3: Existing Natural Gas network in the Netherlands (left) and envisioned hydrogen network (right) (Source: (DNV GL, 2020)

Cross border pipelines exist between the ports of Antwerp and Rotterdam and with chemical clusters in the Benelux and Germany's Ruhr area. Around 40% of European petrochemical production takes place in the Antwerp-Rotterdam-Rhine-Ruhr area cluster, making it one of the largest in the world. Good infrastructural links provide a strategic advantage for industrial clusters in the Netherlands, especially those located near the German and Belgian borders, as well as for Germany and Belgium. This infrastructure also provides a good basis for the transport of renewable raw materials, energy carriers and sustainable products in the future. The transport capacity demand is currently uncertain. This introduces a risk that the transport capacity will not be fully utilised during certain periods. The Dutch Government can in principle cover such risk or compensate for the risk by providing subsidies (Tweede Kamer der Staten-Generaal, 2021-2022).

The flagship CCS projects being planned in the Netherlands are Porthos, Aramis and the OCAP CCU project. Porthos (Port of Rotterdam CO2 Transport Hub & Offshore Storage) is a project of the Port of Rotterdam Authority, Gasunie and Energie Beheer Nederland (EBN) for the development of CO2 infrastructure with a pipeline through the port area of Rotterdam, a compressor station on the Maasvlakte and a pipeline at sea to block P18. The Porthos project has been discussed in section 6.1.

Aramis is an initiative of EBN, Gasunie, TotalEnergies and Shell, which aims to develop a large-scale CO2 transport and storage network from the Port of Rotterdam to the depleted gas fields in the K and L blocks in the North Sea. The initiative includes the construction of a new transport pipeline and compressor on the Maasvlakte. Aramis intends to utilize the Porthos pipeline and potentially supply by (inland) vessel from different parts of the Netherlands. A new terminal for supply by ship is also intended to be built. CO_2 supply scenarios beyond 2026 for Aramis are still uncertain. Towards 2030, a volume of approximately 10 Mtons CO_2 per year is expected. For the supply in this phase, supply from Belgium, Germany and France is also taken into account. Towards 2035, Aramis expects a further roll-out of the transport and storage network (approximately 20 Mtons CO2 per year). In order to transport and store these volumes of CO_2, extra ship movements, the potential addition of future pipelines from Germany and Belgium and the availability of several storage locations would be required. Figure 4 illustrates a possible schematic.

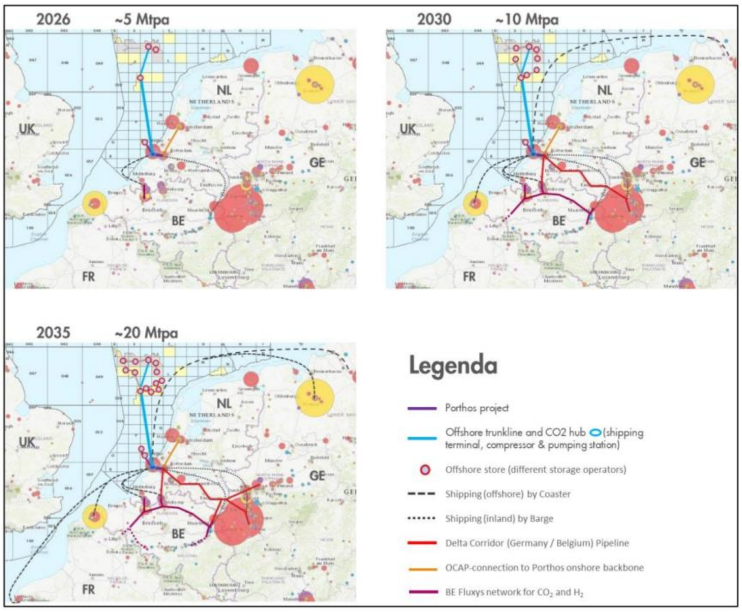


Figure 4: Potential implementation of CO_2 storage through the Aramis project (EZK, 2021)

The Athos project was another flagship project conceptualized with the expectation that the CO_2 volumes from Tata steel would be made available for storage. However since the decision by Tata Steel in 2021 to switch to DRI technology the Athos partners have jointly agreed to terminate the Athos project in the form it was expected to proceed (Gasunie, 2021).

Important projects to mention in the context of CO_2 transport are the Delta Corridor project and the CO2 TransPorts project. The Delta Corridor Project (Port of Rotterdam, 2022) is an important step toward development of large-scale European hydrogen infrastructure. Recognizing the need for infrastructural developments in meeting climate ambitions, the Delta Corridor project was listed on the Multi annual program infrastructure energy and climate (MIEK) (detailed in section 4.2.1). This project is expected to be key to unlocking large scale CCS solutions (potential for around 22 Mtpa avoided and abated emissions per year) for industry located in across Moerdijk, Geertruidenberg, Chemelot, and NRW

(Gelsenkirchen, Cologne and wider areas). Preparatory work is currently being carried out by the Dutch government in cooperation with both private and public partners. During the pipeline feasibility, which focused on the transport of C4-LPG, propylene, hydrogen and CO2 between Rotterdam and Chemelot, the potential value of extending this pipeline the Germany was also recognized. This component is expected to be worked out in greater detail with relevant authorities and partners. Figure 5 below shows a representative illustration of the Delta Corridor project.

Figure 5: Delta Corridor Project illustration (Port of Rotterdam, 2022)

The CO_2TransPorts project (European Commission, 2022) aims to establish infrastructure to facilitate large-scale capture, transport and storage of CO_2 from Rotterdam, Antwerp and the North Sea Port in depleted fields offshore. The project is planned in 3 phases. Phase 1 will focus on developing an onshore pipeline through the Port of Rotterdam, a compressor station and an offshore pipeline to the P18 gas fields. Phase 2 will focus on developing a CO_2 collection network in the Port of Antwerp and North Sea Port, and an interconnection between them and the Port of Rotterdam. Phases 1 and 2 will provide CO_2 transport infrastructure for up to 10 Mtons CO_2/year. Phase 3 will investigate potential for increased demand beyond the capacity delivered by Phases 1 & 2. Figure 6 below provides an illustrative schematic.

Figure 6: Illustration of the CO_2 TransPorts pipeline network (European Commission, 2022)

Clusters Chemelot, Zeeland and the Zesde cluster have a requirement for CCS, however since the storage possibilities are limited, these clusters are expected to transport their CO_2 to the Porthos project. The CO_2 transport can take place by means of pipelines or ships. In terms of timeline, the pipeline developments for Porthos could be realized in 2026, however CO_2 transport can start earlier if it takes place through inland vessels and ships. A terminal infrastructure would however be required for this. By 2030, when the infrastructure plans between clusters are realized, opportunities are created for connections with Belgium and Germany.

Hydrogen demand in Germany is expected to increase up to 2030 and can be met in part through imports from the Netherlands. The region of North Rhine Westphalia (NRW) in particular is looking at the Netherlands as a potential source of either domestically produced or imported and re-exported hydrogen. NRW was an important electricity exporter in for many years due to its large coal reserves, however is expected to lose this status with the decision to phase out coal fired power. Without sufficient locations for renewable generation, NRW expects to import 90% of its hydrogen demand by 2050. Pipeline transport of hydrogen from the Netherlands is expected to be important to NRW's energy future (Ministry of Economic Affairs, Innovation, Digitalization and Energy of the state of North Rhine-Westphalia, 2020). Table 1 present an overview of current hydrogen demand and expected hydrogen use by 2030, respectively, for Germany as a whole, and for North Rhine-Westphalia in particular (CE Delft, 2022).

	2021		2030			
Sector	Germany (MT/yr)	North Rhine Westphalia (MT/yr)	Germany (MT/yr)	Germany (MT/yr)	North Rhine Westphalia (MT/yr)	North Rhine Westphalia (MT/yr)
			Low	High	Low	High
Industry	1.65	0.51	1.05	-	0.55	0.55
Transport	-	-	0.6	-	0.13	0.13
Electricity	-	-	0.75	-	0	0.09
Others	-	-	-	-	0.01	0.01
Total	**1.65**	**0.51**	**2.4**	**3.3**	**0.69**	**0.78**

Table 1: Hydrogen demand in Germany and North Rhine-Westphalia, 2021 and 2030 (from (CE Delft, 2022))

Hydrogen Import Potential

The Netherlands imports a large amount of fossil energy that is (after eventual processing in for instance the Port of Rotterdam) exported to neighboring countries. There is simply too much energy consumed and exported to produce all this energy domestically. Frans Timmermans, head of the EU on climate issues, was reported stating at a meeting with the environmental committee of the European Parliament that hydrogen will be the driving force behind the energy system of the future EU, but that the bloc will have to rely on imports. Low carbon hydrogen imports could play an important role to overcome this issue and ports such as Rotterdam, Amsterdam and Zeeland could play a key role in the trade of low carbon hydrogen. Studies are currently being conducted on the feasibility of the creation of corridors for the import and export of hydrogen. In 2021, the Dutch Government signed letters of intent with Chile, Portugal, Namibia, Colombia, UAE and Uruguay for the import of hydrogen and associated carriers.

The Port of Rotterdam along with the port industries and government envision that they will together be able to supply Europe with at least 4.6 Mtons of hydrogen annually by 2030, with imports of up to 4 Mtons per annum. The overall import target for 2050 has been set at 20 Mtons hydrogen annually. The hydrogen imported would be for utilization in the Dutch market but also to a large extent for export to e.g. Germany.

Being independent of imports from outside of the EU is valued from a geopolitical standpoint. At the same time, complementing domestic production with imports can lower the overall system cost. The National Hydrogen Program formulates an import ambition which is significantly lower than the ambitions of the port companies with an ambition of 0.4 Mton of imported hydrogen by 2030. The Netherlands is also expected to play a transit function with hydrogen transports to Germany and Belgium. The Port of Amsterdam set an ambition of 1 Mton RFNBO (Renewable fuels of non-biological origin) import by 2030 (Port of Amsterdam, 2021). Also SDR and Groningen Seaport have ambitions for import of hydrogen(carriers).

In discussions with Port of Rotterdam, Port of Amsterdam and SDR it was stated that an import volumes mentioned above could be feasible by 2030, in line with the provisions of the Renewable Energy Directive (RED), and at a price that is competitive with domestic production of RFNBOs. This would require swift policy decisions to substantiate the demand, and a task force of Government, the Dutch sea harbors, companies active within the harbors, hydrogen consuming industry and hydrogen importers to realize the task. The realization of import chains of RFNBOs is also relevant for the period after 2030, when demand is expected to grow further.

At the moment, one of the most promising identified routes is between Iceland and Rotterdam. Iceland has abundant renewable resources, as well as stable electricity supply from geothermal power and hydropower that ensures a high capacity factor of the electrolyzer. The Port of Rotterdam has already set up a study into the feasibility of hydrogen import with Landsvirkjun, the national energy company of Iceland (Port of Rotterdam, 2021). Import from Iceland would already become realistic between 2025 and 2030.

The Port of Rotterdam actively facilitates the development of green hydrogen import. An example is the HyTransPort.RTM hydrogen pipeline development, which is being developed by the Port of Rotterdam and Gasunie. Another example is the support for the setup of the Trans hydrogen Alliance, in which various companies actively collaborate to have a first green hydrogen import project operational in 2024.

4 POLICY FRAMEWORK IN THE NETHERLANDS RELATED TO CCS AND HYDROGEN

4.1 European context

In December 2019 the European Commission presented the European Green Deal. The Green Deal is a set of policy initiatives coordinated across the EU members to speed up the energy transition towards net zero Greenhouse gas emissions by 2050 and the decoupling of the use of natural resources from economic growth. It provides a roadmap with actions to boost the efficient use of resources across all sectors. In 2021 the intermediary goal for 2030 has been increased to 55% emission reductions in 2030 compared to 1990 levels. On July 29th 2021 these targets have been made binding in the European Climate Law. In order to align these greenhouse gas targets for 2030 and 2050 with the current laws the European Commission has published a revision of its climate, energy and transport-related legislation. This has been done under the so-called "Fit for 55" package. The following legislative proposals and policy initiatives are relevant in the context of industrial decarbonization:

Directive	Proposed amendment	Impact for industry
ETS	EU emission trading system. The EU commission has proposed a set of changes that should result in an overall emission reduction to the sector covered by the EU ETS system of 61% by 2030 compared to 2005.	The EU-ETS price will likely increase giving EU industry wide an incentive to reduce CO_2 emissions. However, due to the Dutch CO_2 levy the potential impact on Dutch industry is limited.
	The scope of the system is proposed to be widened to the maritime sector. Further, a separate ETS system has been proposed for road transport.	The widening of the EU-ETS system or establishment of comparable systems to the transport sector will incentivize the demand for renewable transportation fuels. This will result in reduced demand for fossil refinery products and increasing supply of renewable fuels.
	The Commission proposed a phase out of free allocation of emission allowances to aviation and to the sectors that are to be covered by the carbon border adjustment mechanism (CBAM).	The reduction of free allocation of emission allowances will lower the amount of free rights that can be sold due to decarbonization efforts. This will likely result in higher SDE++ payments. SDE++ stands for the Stimulation of sustainable energy production and climate transition, a key policy instrument introduced in 2020 supporting the uptake of low carbon technology. The SDE ++ works as a type of contract-for-difference scheme which compensates the additional costs for adopting a low carbon technology. This subsidy mechanism is further detailed in section 5.1
CBAM	The introduction of a carbon cross border adjustment mechanism. The mechanism is introduced to prevent the possibility that the emission reduction efforts of the EU are offset by increasing emission outside of the EU by relocation of production.	The CBAM will create a more level playing field for industries who are investing in decarbonization measures compared to competitors outside the EU who are not making similar investments. The risk for delocalization of industry is reduced.

EED	The Commission has proposed to revise the current Energy Efficiency Directive by increasing the target for energy efficiency from 32.5% to 36% for final, and 39% for primary energy consumption.	Although the target is not nationally binding the Netherlands has to contribute to these EU targets. Therefore, it is expected that industry will also have to contribute to the target to some extent. This will incentivize further energy efficiency measures.
RED	Industrial hydrogen consumption needs to be 50% renewable of non-biological origin by 2030.	The target will provide a strong incentive for industry to either grow the renewable hydrogen consumption or substitute existing grey hydrogen with renewable hydrogen.
ETD	The Commission has proposed a revision of the taxation of energy products and electricity. The main aims are to align the taxation with the energy, climate and environmental policies while maintaining the capacity of member states to generate sufficient revenues for their budget.	For industry, that will mean the tariff differentiation of energy taxation based on consumption stops. Also, for some activities exemptions are going to be prevented.
ESR	The (national) emission reduction target for sectors that are not covered by the EU-ETS or land use, land-use change and forestry (LULUCF) is increased from 29% to 40% compared to 2005 levels.	Emission reduction by industry outside the ETS can contribute to achieving this target. Decarbonization targets for these industries could be increased.
CO_2 emission performance standards for new passenger cars and light commercial vehicles	The Commission has proposed to increase the standard for CO_2 emissions by cars and vans for 2030 and set a zero emission standard by 2035.	The ban of fossil powered cars will reduce demand for fossil fuels. This will impact the demand for refinery products and incentivize the switch to renewable fuels.
ReFuelEU Aviation	The Commission has proposed ReFuelEU Aviation to promote the use of sustainable aviation fuels. The potential for this sector to reduce emissions has been untapped and advanced biofuels and synthetic fuels could significantly reduce these emissions.	The target will reduce demand for fossil fuels in aviation. This will impact the demand for refinery products (kerosene) and incentivize the switch to renewable fuels.
FuelEU Maritime - Greener fuels in shipping	For the shipping sector the Commission is proposing to amend the directive on the use of renewable and low-carbon fuels in maritime transport. The proposal sets a target of reducing greenhouse gas intensity of energy used on-board by ships by up to 75% in 2050.	The target will reduce demand for fossil fuels in shipping. This will impact the demand for refinery products and incentivize the switch to renewable fuels.

4.2 Dutch context

In the Netherlands the targets that are set by the European Union are anchored in the Climate Law. The Climate Law was adopted on July 2nd 2019 and sets a binding greenhouse gas reduction target of 95% for 2050 compared to 1990 levels. In order to achieve this target there is an aim for 2030 to reduce the greenhouse gas emission by 49% and become net-zero by 2050. It is expected that the Dutch Climate Law will be amended in 2022 to align with the revised European target of 55% for 2030. In addition to the compliance with the European targets the government has announced in the Coalition Agreement to be aiming for a 60% emission reduction by 2030 to accelerate the energy transition. Also, intermediate goals of a 70% reduction by 2035 and 80% reduction by 2040 are introduced. These revised targets need to be amended in the Climate Law. An overview of the Climate Law is given in Figure 7 below.

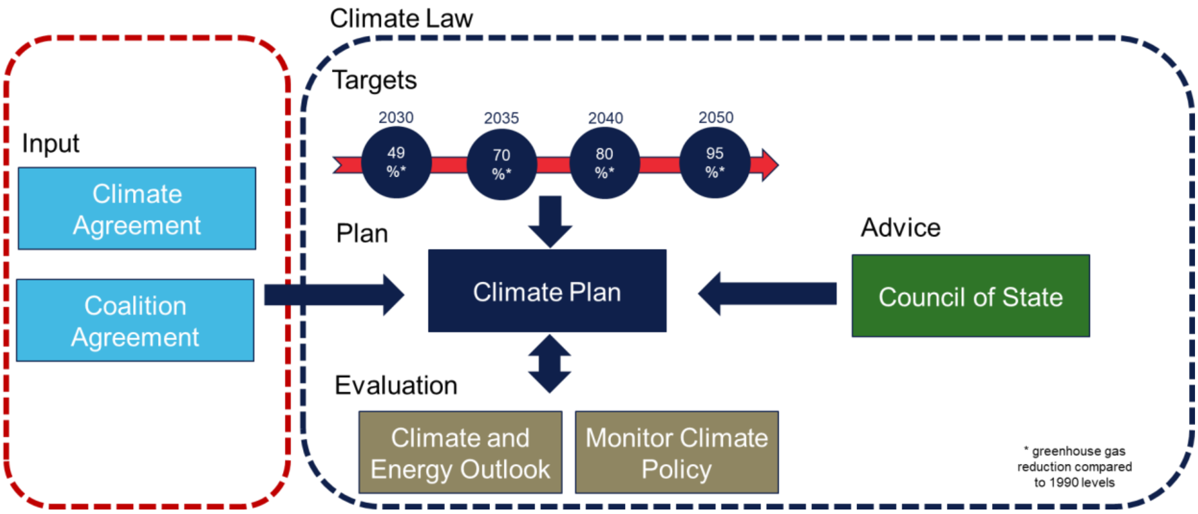


Figure 7: Overview of Dutch climate law

In order to implement the goals of the Climate Law the government has the obligation to the publish a Climate Plan, have an annual monitoring report and publish an annual climate paper. The annual plan has to contain the main elements of the climate policy for the next 10-years. The Council of State are required to provide advice on the plan. Based on the Coalition Agreement a scientific advice panel will also be installed.

In addition to the Climate Plan there are two formal reports that help the government track the progress of the national climate policy. Firstly, the Planbureau voor de Leefomgeving (PBL) every year has to publish a scientific outlook for the consequences of the existing policies (“Climate Outlook”). Secondly, the government publishes a report Monitoring Climate Policy in which the progress in the past year on the existing policies is reported. The Climate Outlook and Monitoring Climate Policy are used to monitor the progress towards the national greenhouse gas emission reduction targets.

The core of the Climate Plan is the Climate Agreement. The Climate Agreement is a set of agreements between government bodies, companies and public organizations to reduce the greenhouse gas emission by 49% in 2030. Specific agreements have been made for the sectors built environment, mobility, electricity production, industry, agriculture and land use. These agreements are followed-up by a monitoring committee. To a large extent the implementation of the Climate Agreement is done through the Regional energy strategies. A nationwide network of thirty regions is responsible for implementing many of the national targets. The six different industrial clusters have developed their own Cluster Energy Strategies. The cluster strategies have been elaborated in section 3.2.

In addition to the Climate Agreement the government has published a new Coalition Agreement. In this agreement more ambitious targets and additional policy measures are announced. Towards the middle of 2022 the government will publish a policy program Climate and Energy which will build upon the Climate Agreement and the Coalition Agreement.

4.2.1 Infrastructure

The government has announced that before summer 2022 it will publish a National plan energy system 2050. This plan will outline the required infrastructure for the future energy system and is intended to provide the government with a greater degree of coordination in the energy transition. For the shorter term the government has the Multi annual program energy infrastructure and climate (MIEK). This program is aimed at planning and tracking progress of infrastructure projects that are of national interest. The input for these projects originate from three main sources: the Cluster Plans, the Network Investment Plans and the Electrification roadmap. In order to accelerate the development process for these large scale infrastructure projects of national interest and have a greater degree of coordination the government has set up a Program infrastructure renewable industry (PIDI). The overview of the infrastructure planning in relation to other elements in the climate policy is depicted below:

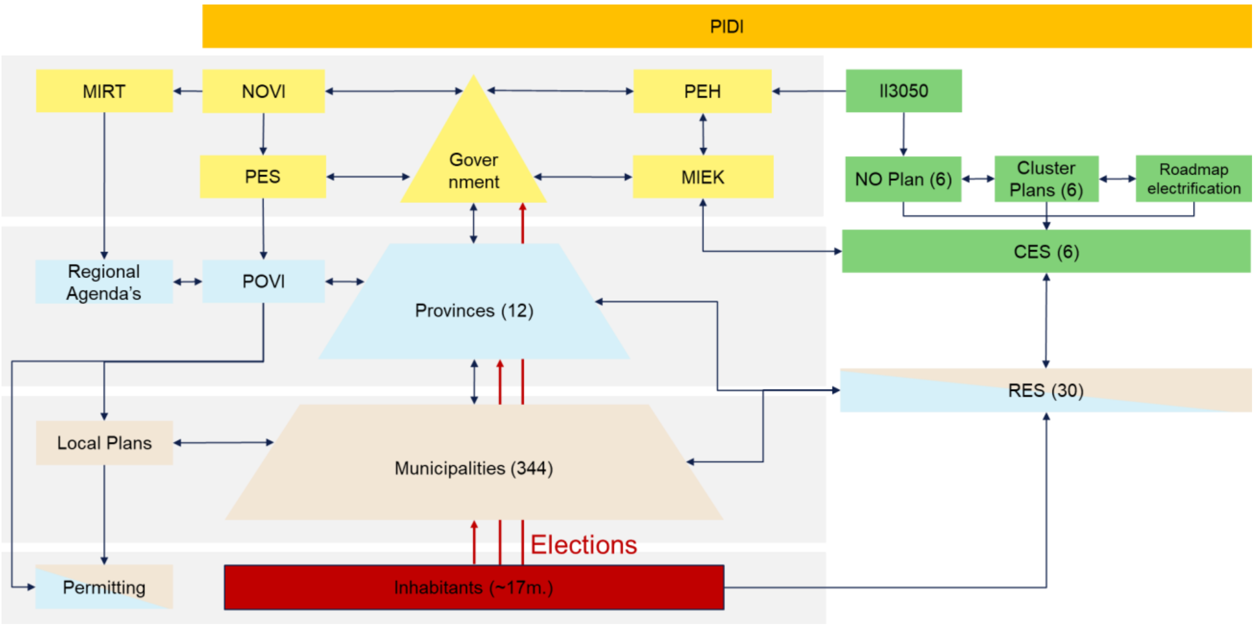


Figure 8: Overview of Program Infrastructure Renewable Industry (PIDI)

MIRT	Multi-year program infrastructure, space and transport
NOVI	National environmental vision
PES	Program energy system
MIEK	Multi annual program energy infrastructure and climate
PEH	Main energy structures program
POVI	Provincial environmental vision
RES	Regional energy strategy
CES	Cluster energy strategy

Table 2: Acronyms used in Figure 8 (translated from Dutch)

4.2.2 Hydrogen

For hydrogen the national ambitions of the Netherlands are laid out in the Climate Agreement. These ambitions will be further detailed in a National Program Hydrogen. A roadmap is expected to be published in Summer 2022. The following targets have been agreed:

- The ambition to realize 500 MW of electrolyzer capacity by 2025 and scaling-up to 3-4 GW by 2030. As recently as 13 of April 2022, the two largest coalition parties have proposed to increase this ambition to 8GW.
- By 2022 50 refueling stations, 15,000 Fuel Cell Electric Vehicles (FCEV), passenger cars and 3,000 FCEV HDV. Accelerated growth towards 2030 and 2050 with the aim for 300,000 FCEV passenger cars by 2030. This will be structured by a sectoral covenant.

The government has decided to regulate the operation at the national hydrogen network and has the intention to appoint Gasunie as the operator. Further legislation is expected in 2022.

A new Dutch coalition government has been sworn in during January 2022, with ambitious climate plans. This new coalition has backed its plans with a EUR 35bn climate change and transition fund with EUR 15bn being earmarked for the development and scaling of “Advanced Renewable Energy Carriers”. It is not clear what is included and not in the definition of ‘Advanced Renewable Energy Carriers’, however green hydrogen developments are expected to be part of this package. Additionally blue hydrogen is not expected to be covered in this package since it is produced from natural gas, not from renewables.

4.2.3 CCS

For CCS some boundary conditions are set in the Climate Agreement. These are:

- A filter on the different CCS segments. This instrument provides the government with a tool to only allow CCS projects to be financed for which no cost competitive alternatives exists.
- A ceiling in the subsidy amount. The ceiling is set in such way that only 7.3 Mton of CO_2 reduction by CCS is subsidized, with plans to increase the ceiling by 1.5 Mton CO_2 in the 2022 subsidy round
- A time limit on subsidy applications. The applications for SDE++ subsidy are only possible until 2035. Afterwards no new CCS projects are able to apply for subsidy. The exception is for the projects where capture will result in negative emissions.

The infrastructure development of CO_2 pipelines is not foreseen to be regulated due to the business-to-business projects and the appetite for different competitors to build infrastructure.

4.3 Strategic aims for policies

In the Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action article 15 it is stated that each member state “shall prepare and submit to the Commission its long-term strategy with a perspective of at least 30 years. Member States should, where necessary, update those strategies every five years”. The Dutch government used the Climate Law, Climate Agreement, Climate Plan and the Coalition Agreement as important tools to set-out the policies to reach the intermediary goals but at the same time sketching the outlines of the pathways towards climate neutrality and a complete circular industry in 2050.

The Dutch government recognizes that for the long term strategy many subjects still have a high degree of uncertainty. Therefore, the Dutch strategy is focused on setting the agenda for the next years while recognizing that not all answers are known. The strategy can be divided into two main subjects:

4.3.1 Current policy focused on the long term

Drivers

The main driver for the long-term strategy is the Climate Law which sets a legally binding long term target for 2050 to reduce emissions by 95% compared to 1990. Also, it ensures the evaluation and necessary policy adjustments to reach this target. There is only one national carbon reduction target instead of the multiple sub-targets that are incorporated into the European legislation. The Dutch government is confident that the policies aimed at reaching the emission reduction targets will automatically also result in complying with the sub-targets. Also, the intermediary indicative goals are enabling a gradual transition where everybody can participate and companies can adjust.

Innovation and circular economy

An innovation agenda is developed in line with these reduction targets that enables meeting the short term goals (2030) but also lays the foundation for meeting the long term goals (2050). The short term innovations are aimed at development, demonstration and roll-out. The long term innovations are more oriented on research and development. This innovation agenda is mission driven, this means the agenda is supportive to identify societal challenges and help to overcome them.

The transition towards a circular economy has an impact on the design of the energy system. In particular, the interaction between energy policy and spatial planning will become more important. In general, renewable energy has a bigger spatial impact than the current fossil system has. The consequence is that the coordination between central and local planning needs to be aligned. In the Regional Energy Strategies the government seeks local alignment for renewable generation projects by providing a national guideline on an evaluation framework. The circular economy is an important driver for the industrial decarbonization agenda of the Netherlands since globally all industries need to decarbonize in light of moving towards the circular economy.

The integration of the different energy carriers will become increasingly important in order to develop an efficient renewable system. The ability to balance between carriers and between central and local systems needs to be reinforced to accommodate intermittent generation and provide security of supply. The government is investing into demonstration projects for increased flexibility and R&D programs.

Biomass

The government sees an important role for the application of renewable biomass in moving toward a circular economy. However, the appropriate certification of the biomass is key in achieving this goal. Also, the available biomass needs to be allocated towards the highest value-added application cascading down. Therefore, the government is working towards the establishment of a unified framework to guarantee that all biomass used in the Netherlands can be classified as renewable.

Hydrogen

For renewable hydrogen and biomethane the government mainly sees an important role in sectors where other decarbonization options are either more expensive or difficult to realize. For example, industry, heavy duty transport and long-haul transport, dispatchable power generation and certain parts of the built environment.

The approach in the Climate Agreement for the Industrial sector is focused on accelerating decarbonization towards 2030 but at the same time providing an outlook and foundation for the residual emissions towards 2050.

Strategic challenges

The energy transition is not only about the reduction of emissions. The energy transition is also about the type of society that people will live in by 2050. This means that in order for the energy transition to succeed an appealing perspective is necessary for all relevant stakeholders. Hence climate policy can never be a stand-alone but has to be integrated into other policy areas. For example, there needs to be explicit connections to the circular economy, air quality, and cradle-to-cradle agriculture. It also needs to be recognized that transforming the energy system means dealing with complexity between different governmental levels.

Climate policies have to be able to cope with the inherent uncertainty that surrounds the energy transition. This means the government has to facilitate the rules of the game but should leave the way the game is played open to the participants. It needs to be cautious and not to be too prescriptive in the solutions that need to be applied. New innovations or new insight can change perceptions over time and the policy needs to be holistic to accommodate this. However, this doesn't mean there are no obligations. On the contrary as the transition progresses the policy needs to evolve from incentivizing front runners to join to more binding action for everybody. Otherwise, the pace of change will be determined by the laggards and the Paris goals will not be reached. The government aims to keep the policies nimble and flexible.

As soon as countries get closer towards the net-zero goals international cooperation becomes unavoidable. International cooperation is needed to promote cross-border projects that balance the different national interests. For example, some countries might have excess potential to store CO_2 where other countries lack these opportunities but do have the desire to capture the CO_2. In these cases, international cooperation should result in the most efficient solution for the common interest of emission reduction.

4.4 Policies in place to achieve targets

With the Climate Agreement in 2019, the Dutch industry committed itself to reducing CO_2 emissions in 2030 by 14.3 MT per year. The national CO_2 tax was introduced to safeguard the realization of this goal. The new Coalition Agreement has increased the target for industry by 5 to 5.9 MT per year. The national CO_2 tax can result in up to 4 MT per year CO_2 reductions. In 2020 the government has set-up its industrial decarbonization policy.

4.4.1 Key areas for government

Four areas were identified where the government would take an active coordination role. These areas are:

1. **Innovation**

The availability of new technologies is seen as critical for reaching the climate targets. Not only to facilitate an affordable transition but also to help industrial processes to decarbonize for which no technical alternatives are available. The government has started a Mission driven top sector and innovation policy (MTIB). There are twenty-five challenges formulated for four social themes that need to be addressed by this policy. For the theme Energy transition and sustainability there are six challenges identified. The government is supporting these challenges through an Integrated knowledge and innovation agenda (IKIA). This agenda has been agreed on as part of the Climate Agreement. In this agreement the research that is needed to reach the goals of the Climate Agreement are identified. These mission driven agendas require long term research programs: thirteen Multiple Mission driven innovation programs (MMIPs) have been set up for climate and energy.

Further, the government also started separate programs for certain key technologies that are deemed critical for the medium term. These programs cover for example the Electrochemical conversion and materials (ECCM) to significantly reduce the costs of producing hydrogen.

2. **Upscaling industrial technologies**

The government identified that its existing policies mainly coved the early steps in research and innovation phases of technology development. A bottleneck was recognized in the scaling-up of technologies that are proven on a pilot scale and need to be rolled-out on a large scale. These high risk high costs projects were found as hard to finance without government support. Therefore, the government wanted to increase its supportive policies for large scale roll-out of new technologies. A number of technologies are identified for the industry. These technologies are renewable hydrogen, CCS, electrification and electrochemical conversion, and technologies supporting circularity. The government has the goal in the next four years to establish one or two flagship projects for each technology. The National Growth Fund is set-up to support this goal. In the first round of projects EUR 338 million has been allocated to renewable hydrogen and renewable chemicals projects. In round two another EUR 500 million has been allocated to the scale-up of renewable hydrogen production with projects of at least 100MW.

3. **Infrastructure**

The Netherlands has a reliable interconnected energy infrastructure. However, in order to achieve the emission reduction target coordinated adaptation of this infrastructure is needed. The government recognizes that additional efforts are needed on top of the existing investments that infrastructure companies are carrying out. Especially, the realization of large scale new infrastructure requires a more active involvement of the government. These investments require large upfront investments without the guarantee that the capacity will be fully used. Also, a lot of coordination between different public and private stakeholders is necessary. The government has initiated different initiatives to coordinate a timely infrastructure development. These tools are the MIEK, PIDI, PEH and Government coordination arrangement (RCR).

4. **Legislation**

These three areas require a stable and predictable legislative framework that provides industrial companies the appropriate incentive and confidence to commit to these long term investments. The government sees the carbon tax and the adjustments in the European ETS mentioned in section 4 key to create the right incentives but at the same time provide a level playing field in Europe.

4.4.2 Key supportive policies

In order to achieve the policy targets for the industrial clusters the following supporting policies are in place.

1. **Targets and levies**

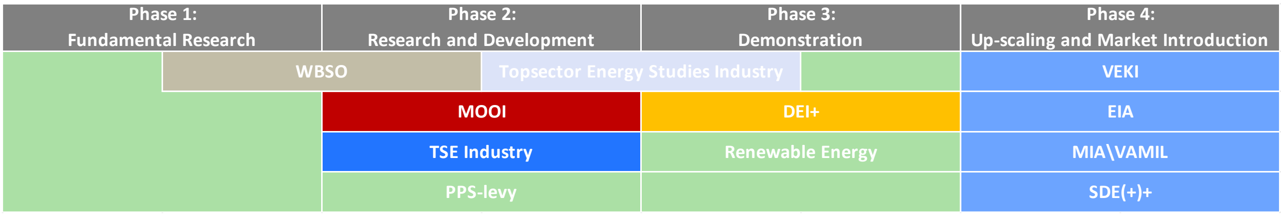
   a) Increase of CO_2 tax and introduction of minimum CO_2 price - The government has proposed to increase the CO_2 tax and to research if there is a European interest to introduce a minimum CO_2 price for industry. These policy measures are intended to provide a stable investment basis for industrial companies.

   b) Adjustment of energy taxation - In order to stimulate the industrial decarbonization the government intends to increase the taxation for large industrial consumers of natural gas and simultaneously lower the tax for renewable energy. These changes are expected to be announced in the taxation plan for 2023. Further, the tax exemption and tax rebates for metallurgical companies are abolished to stimulate energy savings in this sector.

   c) Increase of energy savings obligation - The current energy savings obligation requires industrial companies to implement energy savings investments with a payback time shorter than five (5) years. From 2023 the obligation will be expanded to also include companies under the ETS scheme. This CO_2 tax has been further elaborated in section 5.2.

2. **Stimulating and facilitating decarbonization**

Intensify existing instruments. Besides binding targets and levies the government wants to stimulate and support companies to decarbonize. Therefore, it has established subsidies for decarbonization and innovation, and the timely realization of infrastructure. In recent years the following subsidies have been made available:



Phase 1: Fundamental Research	Phase 2: Research and Development	Phase 3: Demonstration	Phase 4: Up-scaling and Market Introduction
WBSO	Topsector Energy Studies Industry		VEKI
	MOOI	DEI+	EIA
	TSE Industry	Renewable Energy	MIA\VAMIL
	PPS-levy		SDE(+)+

Figure 9: Breakdown of different subsidies depending on the phase of development

MOOI	Mission-driven research, development and innovation
WBSO	Dutch promotion of research and development act
DEI+	Demonstration energy and climate Innovation
TSE Industry	Top sector energy Industry
PPS Levy	Allowance for research and innovation
VEKI	Accelerated climate investments for industry
EIA	Energy investment deduction
MIA\VAMIL	Environmental investment deduction\ Arbitrary depreciation of environmental investments
SDE++	Stimulation of sustainable energy production and climate transition

Table 3: Acronyms used in Figure 9 (translated from Dutch)

In addition to the current subsidy programmes the government has the intention to introduce a National investment scheme climate projects industry (NIKI). This new subsidy scheme will be in addition to the SDE++ scheme and has the aim to facilitate the large scale roll-out of renewable chemicals and electrification.

Reinforcement of national coordination and acceleration of renewable infrastructure. The MIEK is set-up to facilitate the timely realization of infrastructure that is of national interest. However, the infrastructure requirements that follow from the CES do not match with the timeline that comes from the MIEK. Therefore, the PIDI has been established to try to bring the requested and expected dates closer together.

3. Tailor made agreements largest emitters

The twenty largest emitters are responsible for 33.2 MT of the total 54.6 MT of industrial emissions. In order to maximize the impact of decarbonization efforts and to accelerate the energy transition the government wants to conclude tailor-made binding agreements with these companies. This should also position the Netherlands a front-runner in renewable technology and sustainable business models. The necessary investments should preferably come from the existing support schemes to avoid conflicts with European state support rules. However, alternatively the Climate Fund can be used for this.

4. Stimulating Circular economy

The government is setting-up a programme to execute the ambitions for the circular economy. Many of these projects will also result in CO_2 savings, decarbonization of feedstock or reduction in feedstock usage. The existing subsidy schemes are intended to be amended to better support large scale circular projects. This new supporting policy is expected at the end of 2022.

4.5 Regulatory landscape for CCS and Hydrogen

4.5.1 Hydrogen

There is close to 5,000 km of hydrogen pipelines globally, four storages and hardly any transport by ship. In contrast there is currently around 3 million kilometres of pipeline transporting natural gas, around 670 gas storage sites and a large network of shipping terminals. This difference reflects the local nature of production and consumption of hydrogen. Hydrogen is predominantly consumed in refining, ammonia and methanol production on large industrial sites. Onsite reforming of natural gas is the dominant production technology for the required hydrogen. In the Netherlands there is one hydrogen pipeline that is connected to an international network operated by Air Liquide and stretches around 1,000 km. Additionally, there is one repurposed pipeline (12 km length) running between two industrial sites that is operated by Hynetwork Services (100% subsidiary of Gasunie). Furthermore, there is a local pipeline of 140 km that is operated in the Rotterdam Area by Air Products (see Figure 10). This means there are currently limited requirements for a large interconnected transportation network. This highly local business-to-business characterization of the hydrogen market has not required specific regulation. At the moment hydrogen in the Netherlands is only regulated by general competition legislation. There is no specific oversight by a regulator.

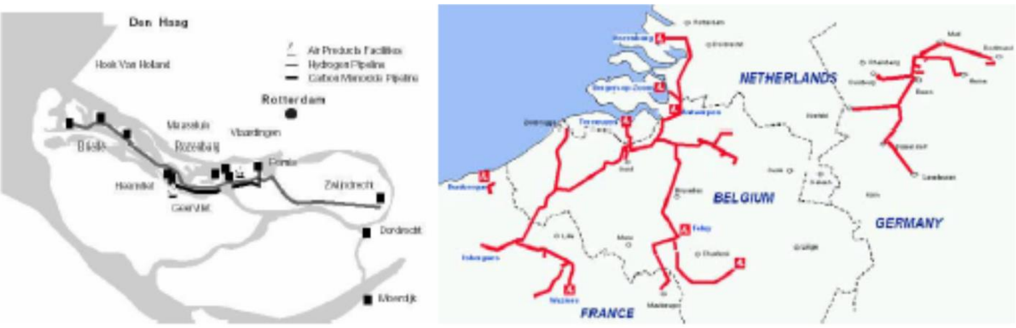


Figure 10: Existing hydrogen pipelines operated by Air Products (left) and Air Liquide (right) (DNV, 2017)

However, on December 15th 2021 the European Commission has published the proposed Hydrogen and decarbonised gas market package. In this package new European regulation for hydrogen markets and infrastructure is introduced. With the proposal the European Commission wants to prevent fragmentation of hydrogen regulation which could pose a barrier to the establishment of cross-border networks. It addresses the lack of rules for tariff-based investments in networks, the ownership and operation of dedicated hydrogen networks and harmonization of rules on (pure) hydrogen quality. The main elements of the package are the unbundling requirements, third party access, tariff regulation and the establishment of European Network of Network Operators for Hydrogen. In the new proposed legislation there is a clear separation in time before and after 2030. Before 2030 individual member states are allowed to grant exemptions from the regulation. Afterwards this is not allowed anymore. This newly proposed European legislation which will set the boundaries within the Dutch regulatory framework, will be further developed.

4.5.2 CCS

The European Commission has introduced Directive 2009/31/EC to regulate the safe storage of CO_2 in underground reservoirs. In the Netherlands the relevant obligations are translated into the Mining Act. The regulation focusses on the storage of CO_2 and not on the capture, re-use and transport. However, the European Directive does require the transport and storage of CO_2 to be accessible to third parties on a transparent and non-discriminatory basis. This implies that on the storage and transport of CO_2 a third party access regime has to be established.

Additionally, in the Netherlands the government has decided that CO_2 storage will only be allowed in offshore sites. Onshore storage of CO_2 is excluded. This means that suitable underground onshore geological reservoirs are not allowed to be used for the storage of CO_2.

5 POLICY INSTRUMENTS TO SUPPORT INVESTMENTS IN CCS AND HYDROGEN

This chapter aims to provide a description of the policy instruments that are most relevant for the decarbonization of the Dutch industry and discusses their relevance to support investment in Hydrogen and CCS projects

5.1 SDE++

The Stimulation of sustainable energy production and climate transition (SDE++) support scheme is a key policy instrument to support renewable energy production and carbon emissions reduction in the Netherlands. It is being implemented as an update of the 2011 SDE+ scheme. The main principle of the SDE+ policy instrument is operational subsidy attribution, where the producer of renewable energy receives a compensation for every unit of electricity being produced. The SDE ++ works as a type of contract-for-difference in which compensation is based on the difference between the market price (“the correction price”) of electricity and the production cost of renewable electricity, heat and gas (“the base price”). If the base price is higher than the correction price, the producer is eligible for a compensation. This basically means the SDE++ subsidizes the unprofitable part of the project – and is more cost-effective.

In the specific case of CCS technologies, the correction price is adjusted for the Emission Trading System (ETS) CO2 price in case the market party falls under ETS. In addition, the correction price has a lower bound limited to the base energy price and the base CO_2 price, both in turn based on two thirds of the average expected revenue along the project lifetime. The SDE++ is a type of carbon contract for difference with respect to CCS, as it is based on a CO_2 abatement cost. For other technologies, SDE++ is based on the power price, and so is not a carbon contract for difference.

Each year, a technology specific base price is determined for the following year, which sets the limit for compensation. Compensation is granted for 8-15 years and is awarded via auctions, which ensures competitive renewable energy production and CCS (SDE++, 2018). The decisive parameter that determines the subsidy is the subsidy intensity. The subsidy intensity is calculated for both CCS and CCU by Equation 1.

Equation 1: Subsidy Intensity calculation for CCS and CCU projects:

$$Subsidy\ intensity\ [euro/ton\ CO_2]\ =$$

$$(requested\ subsidy\ [euro/ton\ CO_2]\ -\ long\ term\ market\ price\ [euro/\ ton\ CO_2])\ /$$

$$(emission\ factor\ [kg\ CO_2/ton\ CO_2]\ /\ 1.000)$$

The subsidy intensity for other categories is calculated by Equation 2.

Equation 2: Subsidy Intensity calculation for other categories of projects:

$$Subsidy\ intensity\ [euro/ton\ CO_2]\ =$$

$$(requested\ subsidy\ [euro/kWh]\ -\ long\ term\ market\ price\ [euro/kWh])\ /$$

$$(emission\ factor\ [kg\ CO_2/kWh]\ /\ 1.000)$$

In Figure 11 the subsidy scheme is illustrated by means of a graph.

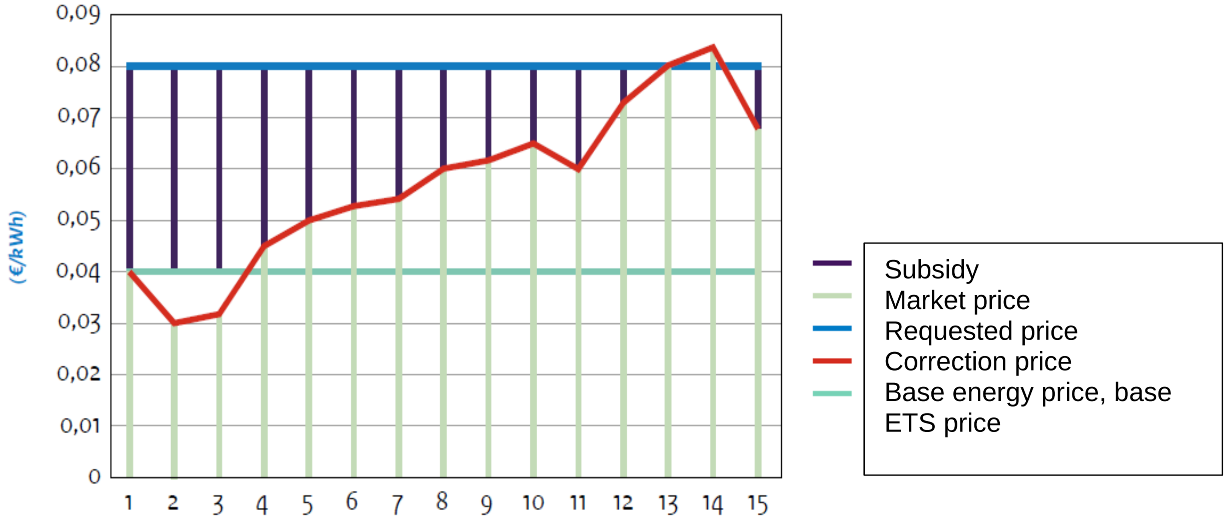


Figure 11: Illustration of SDE++ scheme allowance mechanism. On the x-axis the years are shown, which could be shorter than 15 years. It should be noted that this is only applicable for non-CCS and CCU categories. Otherwise, the y-axis should be replaced with the CO_2 avoidance cost [EUR/ton CO2].

Between 2011 and 2020, roughly EUR 60 billion has been allocated to renewable energy projects in the Netherlands through the SDE+ scheme. From 2020 onwards, the SDE+ scheme has been extended to other technologies based on their avoided CO_2 emissions and this extended subsidy scheme is called SDE++. Firms apply for a subsidy amount per unit of avoided CO_2 emissions in an auction, with a maximum subsidy intensity of EUR 300/tCO_2. Projects are prioritized by increasing subsidy intensity as shown in Table 4. The opening rounds of the SDE++ have 4 phases. During each phase, projects can apply for subsidies only up to a mandated amount of subsidy intensity. The earlier the subsidies are applied for, the greater is the chance for success for the project due to limited budgets. This helps to make emissions reductions cost-effective, however emerging technology such as hydrogen is not supported sufficiently by this instrument. The Dutch government allocated a budget of EUR 5 billion in 2020 and 2021 SDE++ tender. For 2022 the budget reserved is expected to be EUR 13 billion. The higher budget is due to an increase of the base rate to EUR 11 billion and due to a upward revisal in the ETS rates which translate to an additional EUR 2 billion increase in budget. The SDE++ scheme is specifically tailored to industrial emissions, heating and transportation. Examples of the technologies relevant for emissions reduction in these sectors are hydrogen and CCS. Since this report focuses on the latter two technologies, these will be elaborated upon.

SDE++ Phase	1	2	3	4
Phase limit subsidy intensity (EUR/ton CO_2)	60	80	115	300

Table 4: Phased opening of SDE++

5.1.1 SDE++ support for CCS and CCU projects

It is possible for both CCS and CCU (Carbon Capture and Utilization) projects to receive subsidy under the SDE++ scheme. CCS projects receive subsidies over a period up to 15 years based on the amount of CO_2 stored, which depends on the technology used. Currently CCS is considered to be the only cost-effective carbon emission reducing technology for industry in the short run (IEA, 2020). Especially for the hard to abate industries such as cement, steel, chemicals, oil refining and chemicals production that are all present in the Netherlands. It is expected that the subsidies for CCS will decrease over time with the maturation of alternative cost effective decarbonization technologies and with increasing ETS prices. The ETS prices have increased considerably since 2020 (2022 ETS price is nearly 3 times 2020 prices). The subsidy allocated for CCS within the 2020 SDE++ round was EUR 2.12 billion, however considering such significant increases in ETS prices, it is expected that only a part of the subsidy would need to be paid out .

In order to make sure CCS does not block other technologies that enable industrial sustainability (by consuming all available subsidies), eligible CO_2 emissions are limited to 7.2 Mt CO_2, of which a maximum of 3 Mt CO_2 is allocated to the electricity sector. This upper limit is increased by 1.5 Mt CO_2, with the new SDE++ for 2022. In total the expected required emission reduction in industry according to the Climate agreement in the Netherlands is 14.3 Mt in 2030. In addition, CCS deployment has been restricted to industrial emissions alone and only applicable in case of offshore storage of CO_2. CCS projects are also only subsidized if there are no cost-effective alternatives. Furthermore, no new CCS projects are eligible for SDE++ subsidy beyond 2035. As such the Dutch Government aims to not make CCS an inhibitor of industrial sustainability and would like to pivot towards CCU and CCS in combination with bioenergy.

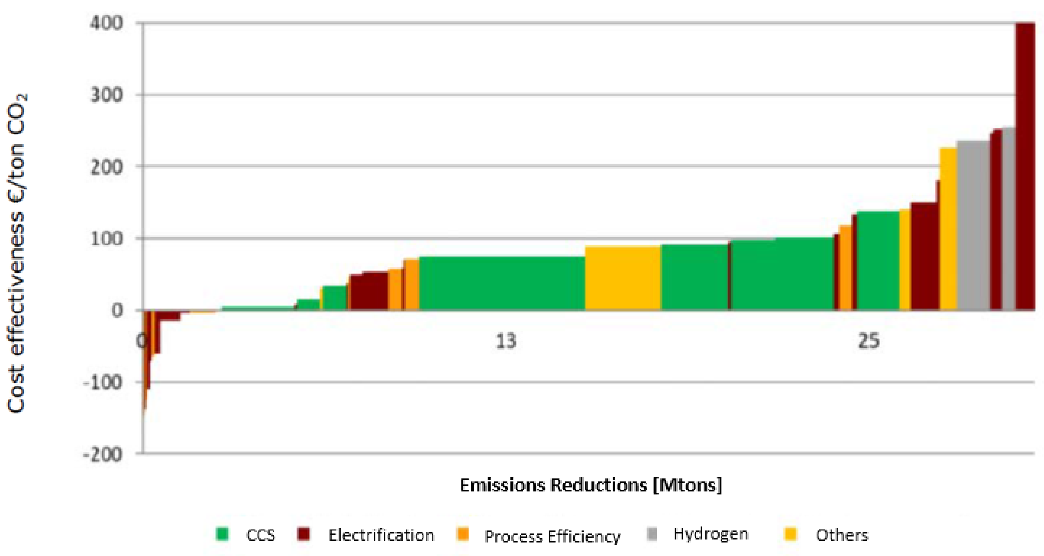


Figure 12: Marginal abatement cost curve for Dutch industry (PBL, 2019)

SDE++ application combinations are possible for both CCS and CCU. The subsidy for CCS is limited to 8,000 full load hours and again determined by the base price minus the correction price. The correction price is composed of the ETS price (if the operator directly or indirectly benefits from avoided cost under the ETS regime) and the market value of CO_2, which is zero at the moment. The SDE++ however does not consider savings from the carbon tax to determine the subsidy rate and only considers the EU ETS price. This implies that CCS project can get over compensated for its emissions reductions. The subsidy for CCU is limited to 4,000 full load hours, and currently only applicable to greenhouse applications.

Figure 12 shows the marginal abatement cost curve for Dutch industry. There is quite a large technical potential for CCS across industry. As seen in Figure 12, a significant portion of industrial CO_2 emissions can be reduced by CCS and quite a lot can be reduced for less than 100 EUR/ton. Due to the low level of subsidy intensity required and the large impact on emission reductions that CCS projects can deliver, they are prioritized in the SDE++ scheme.

According to the CCS concept advice for SDE++ 2022 (PBL, 2022), CO_2 can be captured in industrial processes through both pre-combustion and post-combustion capture. Post combustion captures CO_2 from the residual gas while pre-combustion techniques remove CO_2 in the production process. CO_2 capture costs are case specific and are determined by the volume of the gas stream from which CO_2 is captured, the concentration of CO_2 in the gas stream, the process from which it is captured, the technology chosen and whether it is a new or existing plant. These factors are also a major factor in determining the base price required for different CCS projects and therefore the probability of being awarded a subsidy.

Apart from the costs of capturing the CO_2, companies also have to pay for the transport and storage of CO_2. In conjunction with the Porthos and Aramis projects, CO_2 networks are being planned in Rotterdam. Interested companies can request a connection to the network and will have to pay a processing fee for transport and storage. The realization of the CO_2-transport network is not considered part of the SDE++, however a processing fee is taken into account that must be paid for having the CO_2 transported and stored. This processing surcharge is an operational cost item and covers the costs of realizing the CO_2 transport network (pipelines, ships, CO_2 tanks, compressors, etc.), operating costs (energy, maintenance, monitoring, etc.) and the liability risks in the event of leakages etc. Companies unable to connect to the CO_2 network can also transport CO_2 by ship. Costs for these options are higher than transport by pipeline, which means that a higher processing fee for transport by inland vessel is taken into account. When transport by ship is considered, it is currently assumed that the CO_2 will be pumped into the Porthos network for storage.

Based on the type of capture installation (existing or new) and the point of capture, various SDE++ subcategories are defined:

1. **CCS with existing capture installations**
    a. Part storage for gaseous and liquid phase transport (Concept 1A, 2A)
    b. Full Storage for gaseous and liquid phase transport (Concept 1B, 2B)
2. **New Capture installations at existing industrial installations**
    a. Pre-combustion capture for gaseous and liquid phase transport (Concept 3, 4)
    b. Post-combustion capture for gaseous and liquid phase transport (Concept 5, 6)
3. **New Capture installations at new industrial installations**
    a. Pre-combustion capture for gaseous and liquid phase transport (Concept 7, 8)
    b. Post-combustion capture for gaseous and liquid phase transport (Concept 9, 10)

The difference between the concepts is depicted in Figure 13. The sensitivity of CCS project cost and base amount estimation to different parameters is depicted in Table 5.

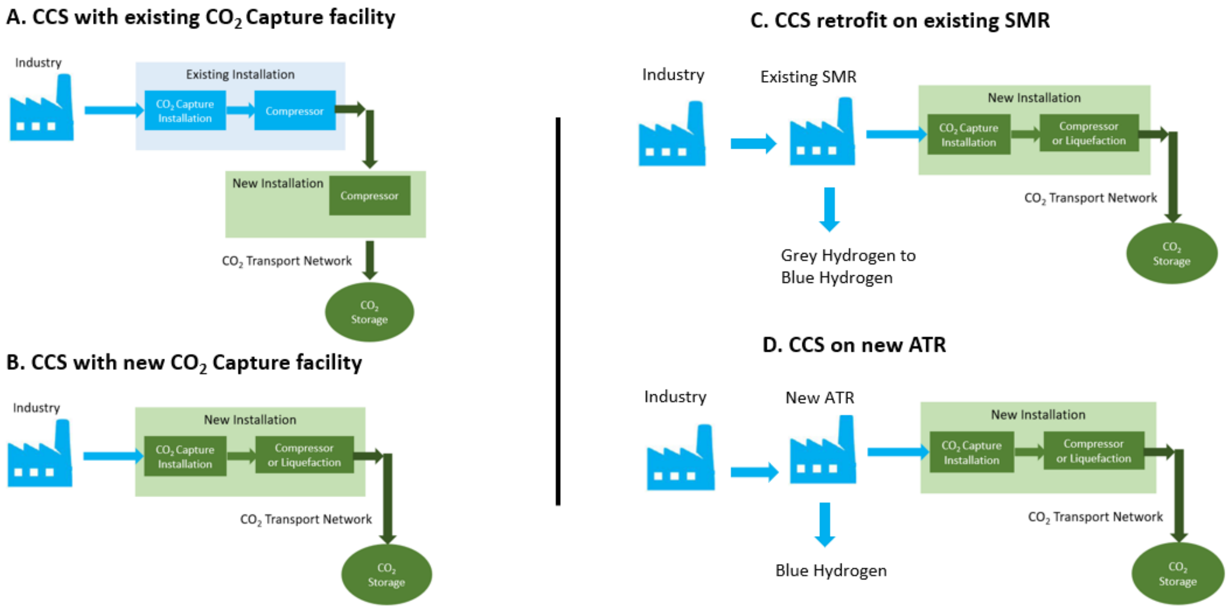
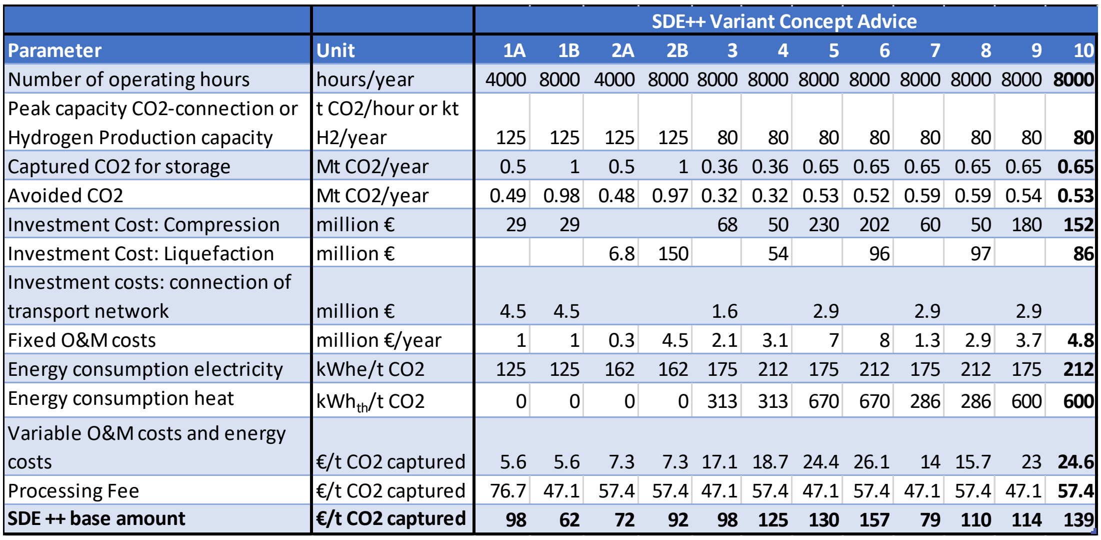


Figure 13: Schematic of typical CCS projects (DNV, PBL, 2022)



		SDE++ Variant Concept Advice											
Parameter	**Unit**	**1A**	**1B**	**2A**	**2B**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Number of operating hours	hours/year	4000	8000	4000	8000	8000	8000	8000	8000	8000	8000	8000	**8000**
Peak capacity CO2-connection or Hydrogen Production capacity	t CO2/hour or kt H2/year	125	125	125	125	80	80	80	80	80	80	80	**80**
Captured CO2 for storage	Mt CO2/year	0.5	1	0.5	1	0.36	0.36	0.65	0.65	0.65	0.65	0.65	**0.65**
Avoided CO2	Mt CO2/year	0.49	0.98	0.48	0.97	0.32	0.32	0.53	0.52	0.59	0.59	0.54	**0.53**
Investment Cost: Compression	million €	29	29			68	50	230	202	60	50	180	**152**
Investment Cost: Liquefaction	million €			6.8	150		54		96		97		**86**
Investment costs: connection of transport network	million €	4.5	4.5			1.6		2.9		2.9		2.9	
Fixed O&M costs	million €/year	1	1	0.3	4.5	2.1	3.1	7	8	1.3	2.9	3.7	**4.8**
Energy consumption electricity	kWhe/t CO2	125	125	162	162	175	212	175	212	175	212	175	**212**
Energy consumption heat	kWh_{th}/t CO2	0	0	0	0	313	313	670	670	286	286	600	**600**
Variable O&M costs and energy costs	€/t CO2 captured	5.6	5.6	7.3	7.3	17.1	18.7	24.4	26.1	14	15.7	23	**24.6**
Processing Fee	€/t CO2 captured	76.7	47.1	57.4	57.4	47.1	57.4	47.1	57.4	47.1	57.4	47.1	**57.4**
SDE ++ base amount	**€/t CO2 captured**	**98**	**62**	**72**	**92**	**98**	**125**	**130**	**157**	**79**	**110**	**114**	**139**

Table 5: Techno-economic parameters for CCUS SDE++ base rate calculation (PBL, 2022)

With the proposed base amounts for 2022, CCS projects with existing capture plants can receive up to EUR 98 per ton of CO_2 avoided, while new capture installations in existing industrial installations can receive up to EUR 157 per ton of CO_2 avoided. New capture plants in new industrial installations can receive up to EUR 139 per ton of CO_2 avoided. Pre-combustion capture within this category uses an Auto-Thermal Reformer (ATR) as the reference capture technology and has the low base amount of EUR 79 per ton of CO_2 avoided for gaseous CO_2 transport.

Post combustion capture technologies suffer from having lower percentages of CO_2 in the capture stream. The effort required to capture CO_2 is thus higher and thereby the cost level is higher. Post combustion capture has on average a 27% higher base amount when compared to pre-combustion capture. Both liquid and gaseous phase transport are supported with liquid phase transport having on average a 39% higher proposed base amount for CCS projects predominantly due to the need for liquefaction facilities.

In 2020, as per the information published by the Dutch Government, the following parties applied for CCS SDE++ subsidy: Shell Nederland Raffinaderij B.V., Air Products Nederland B.V., Air Liquide Industrie B.V. and Esso Nederland B.V. Even though the individual volumes of CCS are not publicly available, the combined awarded CO_2 volume of all projects was 2.34 Mt CO_2. A total amount of EUR 6.4 billion was applied for in the 2020 round of SDE++, through 4112 applications, of which the combined budget for CCS was EUR 2.12 billion within 7 projects which are part of the Porthos project (RVO, 2020). The total amount of SDE++ subsidies available in 2020 was EUR 5 billion. Of this, existing plants could receive up to EUR 39 per avoided ton of CO_2, and new capture installations (to be installed) for new plants up to EUR 76 per avoided ton of CO_2. New capture installations within existing plants can receive up to EUR 85 per avoided ton of CO_2.

In 2021, a total of 43 projects applied for subsidies under the heading “CO_2-lean production”. 11 of them were for CCS, requesting (RVO, 2020) EUR 6.13 billion for a combined CO_2 reduction of 4.74 Mt CO_2 annually and 29 were for CCU projects requesting (RVO, 2021) EUR 1.15 billion for a 0.67 Mt CO2 annual CO2 reduction.

Figure 13 depicts four potential settings for CCS projects in the Netherlands:

1. Figure 13A and 13B show situations when an existing CO_2 capture facility requires connection to a transport and storage (T&S) network and when a new capture facility is required to be constructed and connected to a T&S network. Such projects are cost effective in terms of CO_2 emissions abatement and would receive full subsidy under the SDE++ scheme.
2. Figure 13C shows a situation when a new capture facility is retrofitted on to an SMR unit producing grey hydrogen. Such projects are also cost competitive under the SDE++ scheme and would receive full subsidy.
3. Figure 13D shows a situation when a new ATR is constructed for producing hydrogen and CCS infrastructure is developed to convert the grey hydrogen into blue hydrogen. In this case the project only receives partial funding; the CCS part of the project receives full subsidies, however the cost of constructing and installing the reformer is not subsidized under the current SDE++ scheme. Section 5.1.2 discusses this particular setting in more detail.

5.1.2 SDE++ support for hydrogen projects

The SDE++ support for hydrogen projects can be differentiated into blue and green hydrogen projects. Blue hydrogen, from fossil fuel (gas) combined with CCS, is not supported under the SDE++ scheme as a separate technology, however blue hydrogen projects are expected to be sufficiently subsidized when the CCS part of the project is subsidized. Blue hydrogen projects which have existing reformer facilities are subsidized, however costs for installing and operating a new reforming plant, and the operational CO_2 emissions are not subsidized as is the case for H-vision (Berenschot, 2021). It is also important to distinguish between the end use of blue hydrogen produced; according to (Berenschot, 2021) the CO_2 avoidance cost is nearly 2.5 times higher when the hydrogen is used as a fuel when compared to its use as a feedstock. The difference arises when looking at the cost efficiency of the CO_2 reduction. With hydrogen as a fuel, all costs incurred are factored in as additional costs, including the construction of a reforming installation and losses during the operation. This is in contrast to hydrogen use as a feedstock which is based on the assumption that only the construction and operation of the capture installation will incur additional costs. The operational losses and the extra CO_2 emissions due to the operational losses are not factored in to the calculation of avoidance costs. The SDE++ scheme for 2022 has proposed to include a new category on the production of hydrogen from residual gases (capture of CO_2, which remains during the production of hydrogen from industrial residual gases). Inclusion of this category is expected to support blue hydrogen projects such as H-vision which aims to capture CO_2 from residual gas streams in industrial processes.

Green hydrogen, from renewable electricity, is supported under the SDE++.scheme. Currently, hydrogen produced via electrolysis is eligible for SDE++ when the rated power is above 0.5 MW. The subsidy is limited to 2,940 full-load hours in 2021. The reason for this upper limit is to make sure the electricity used by the electrolysis is renewable, which is linked to the available hours of renewable electricity in the grid. The number of full-load hours gradually increases towards 2025. From 2026 onwards, 5,000 full-load hours are eligible. In case fewer load hours are used between 2021 and 2023, eligible hours could be “banked” by means of the banking principle.

Moreover, the correction amount for hydrogen is determined by the TTF gas price. The power price is however not included as part of the correction amount. This exposes the operator to power market risk. The power price is calculated only once at the point of subsidy allocation and thereafter considered a project risk. This poses a clear problem for green hydrogen producers especially when both power and gas prices move up in tandem, since the revenues from selling H_2 produced via gas is corrected for higher energy prices, however the cost of power used is not subsidized.

Two types of banking exist under the SDE++ policy regime depending on the technology considered: forward banking and backward banking. Forward banking means there is underproduction in earlier years that can be caught up in later years (“bank account” is uncapped). Backward banking means that production is higher in earlier years at the expense of later years (“bank account” capped at 25% of annual production). Hydrogen produced by electrolysis is only qualified for forward banking up to 2,000 additional full load hours per year. Backward banking is not allowed for electrolysis. However, for other technologies within SDE++ backward banking is limited to 25% additional full load hours per year (RVO, 2021).

SDE++ support is currently not considered to be sufficient to overcome the cost gap for hydrogen projects. Therefore, green hydrogen projects could apply to both the SDE++ scheme and the DEI+ (The Demonstration of Energy and Climate Innovation) scheme resulting in a combined subsidy up to EUR 1,000 per ton of CO_2 abated (IEA, 2020). In 2022, a new eligible category will be opened to SDE++, enabling direct coupling of hydrogen production with solar and wind power production. Within the DEI+, these projects will in any case be eligible to receive a subsidy for 25% of the eligible costs. Depending on the type of company, this amount may be up to 45% of the project’s eligible costs of technologies for scaling up green hydrogen. In 2022, the available DEI+ budget is EUR 58.6 million, with a maximum subsidy of EUR 15 million available for each project.

In 2020, there has been only one green hydrogen project that applied for SDE++, which was in phase 2 with a 2 MW application. However, no subsidy was awarded. In 2021, there were two subsidy applications, with a combined power of 2 MW. The subsidy intensity was EUR 80 per ton CO_2.

5.2 National Carbon tax

A national carbon tax was introduced for industry in the Netherlands on January 2021. The carbon tax puts a minimum price on the emission of greenhouse gases by industrial companies predominantly under the EU ETS. The carbon tax for industry is priced linearly from EUR 30.5 to 127 per ton of CO_2 eq between 2021 and 2030 as shown in Figure 14. No tax is paid if the ETS price is above the carbon tax price, however if the ETS price is lesser than the carbon tax for a year then a tax equivalent to the difference between the carbon tax and the average ETS price for the year is paid out. The Carbon tax thus sets a minimum level (floor price) for the carbon price, while allowing the price to increase when ETS prices increase. The carbon tax of EUR 127 per ton CO_2 in 2030 has been set to be consistent with the national decarbonization targets and will be reviewed and revised each year to maintain alignment with the targets.

In order to provide industry with time to achieve emissions reductions, exceptions are made to the tax called dispensation rights. This means that on some proportion of a benchmarked quantity of efficient emissions, no tax is payable. Every year, companies will thus receive a certain amount of CO_2 allowances, or carbon credits which they are allowed to trade amongst themselves. The proportion of benchmark emissions qualifying for dispensation rights will reduce over time.

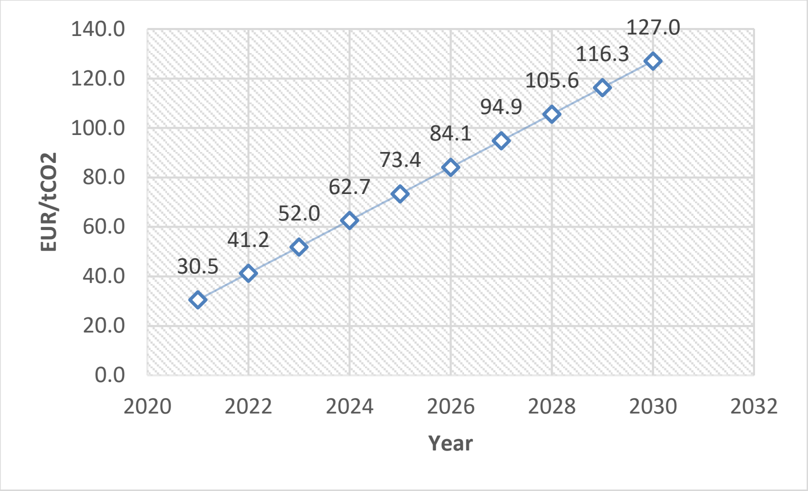


Figure 14: National carbon tax in the Netherlands (2021 to 2030)

The degree of alignment between the Dutch Carbon tax and the EU ETS rules causes some uncertainties. It is possible for companies to use foreign green gas certificates to comply with their reduction obligations. In this way the certificates will not lead to emission reductions in the Netherlands. CO_2 emissions in the electricity sector from residual gases in the steel sector also fall under the CO_2 tax. Applying CCS to these residual gases will lead to an emission reduction mainly in the electricity sector and much less in industry (PBL Netherlands Environmental Assessment Agency, 2021).

5.3 Groeifonds

The National Growth Fund is a government investment fund that aims to accelerate economic growth in the Netherlands long term. In total EUR 20 billion is available in the next five years (2021-2025). Key focus areas are knowledge development, innovation and research and development. The Netherlands Enterprise Agency evaluates whether proposals are meeting the previously agreed upon criteria.

In 2021, the Dutch Government announced the green hydrogen initiative Groenvermogen will receive EUR 338 million for their integral approach focusing on small scale hydrogen projects, research and development as well as human capital. Groenvermogen is an initiative of HTSM (High Tech Systemen and Materials, a research programme) and Topsector Chemie (one of the key sectors of strategic importance to the Netherlands) (Topsector Energie, 2022). Within the initiative Groenvermogen, subsidy is allocated to projects by the Ministry of Economic Affairs in collaboration with the Dutch Enterprise Agency. Key focus areas are: Production of green hydrogen, transport and storage of green hydrogen, direct use of hydrogen, hydrogen used in industry, hydrogen used in semi-finished products and hydrogen innovation throughout the value chain (Nationaal Waterstof Programma, 2020). In April 2022, Groenvermogen II has been awarded another EUR 500 million, for which EUR 250 million was under condition. The contribution to Groenvermogen II will be employed to set up tenders for electrolyzers with a capacity above 100 MW (Groenvermogen II, 2022).

Additionality risk (NB: not to be confused with the definition of additionality in the EU’s REDII Directive): This type of risk is a concern of for instance the Groeifonds and has been identified by InvestNL on behalf of the Groeifonds. It is defined as the risk of subsidizing projects via the Groeifonds that would crowd out other types of (private) finances. For example, Groenvermogen proposes to finance 70% by means of private finance and 30% public finance. In their proposal they explicitly mention the role of InvestNL, which would be able to judge the additionality risk. In the particular case of Groenvermogen, 30% public finance is justified according to InvestNL, given the unprofitable business case and the technological uncertainty. However, this does not mean additionality risk is ensured since it depends on a variety of continuously changing parameters: the ETS price, the natural gas price, the SDE++ subsidisable electrolyzer full load hours.

In order to mitigate additionality risk, InvestNL proposes the following measures:

- Gain insight into TRL levels per project (Invest-NL only invests from TRL-7) and to adjust the subsidy based on the TRL of a project.
- Get substantiation about the business case for each individual project including an analysis of technical and economic uncertainties in the value chain.
- Gain insight into rejections for individual projects at TRL 8/9 level by private investors.
- The use of a subsidy (percentage) that over the years gradually decreases as the CO_2 tax increases and the business case for green hydrogen develops positively.
- For more effective allocation of public funds, examine how the subsidy can move along with the development of the unprofitable part of the business case.

5.4 InvestNL

InvestNL is a private company that is financed with tax money. The focus is to invest in innovative scale-ups primarily active in the energy transition with a twofold goal. First, it aims to finance and develop societal transition. Second, it aims to finance companies if other financial institutions are unwilling or unable to do so. Its finances focus on either equity stakes or subordinated loans. In total, EUR 1.7 billion is available (Invest-NL, 2022). Several conditions apply to their investments:

1. The scope of investments is between EUR 5 to 50 million.
2. InvestNL always takes on a minority share in its participations.
3. The entrepreneur / management of the start-ups and scale-ups should always participate themselves.

Investments by InvestNL in CCS and hydrogen are as of today limited to an investment in SCW Systems of EUR 15 million (Invest-NL, 2019). SCW Systems develops supercritical water gasification in which organic waste streams are pressurized under high temperature to produce both green hydrogen and green gas.

5.5 Government financing apart from subsidies

Beside subsidies, the Dutch Government is also enabling the energy transition as financier. The prime example of that is the connection of offshore wind to the onshore grid. The investment is budgeted to be EUR 4 billion until the end of 2023 (WindopZee). The national TSO Tennet is borrowing this money from the Government with a repayment schedule lasting for 20 years. Per kWh of power brought onshore, the costs are approximately 1.4 euro cents. These costs are not what end users will see on their bills as they will see a lower cost coming from an average of different sources of power fed into the system of which offshore wind is only one.

Between 2024 and 2030, this investment is budgeted to be EUR 6 billion. This number dates from before the announced ambition to increase offshore wind by 10 GW by 2030 and will therefore likely increase significantly. By financing the TSO, the Government is supporting the infrastructure required for the realization of low carbon hydrogen generation. The support is very targeted, effective and cost efficient. These financial schemes could allow an operator to avail a larger share of low rate funding keeping the weighted average cost of capital at the lower levels necessary to realise their project.

6 CASE STUDIES

This chapter presents the results of 3 case studies illustrating the risks and uncertainties facing CCS, blue and green hydrogen projects in the Netherlands and the possibilities these projects have in the current policy landscape for securing subsidies to remain economically competitive. Case studies are conducted on the Porthos CCS project, the H-vision blue hydrogen project and on Tata Steel in the Netherlands.

6.1 Porthos

The Port of Rotterdam contributes significantly to the Dutch economy, however it also generates more than 10% of the emissions from the Netherlands. Porthos is a CCS project located in the Port of Rotterdam and is set up to store carbon emissions from industry in empty gas fields near the shore of the Netherlands. Porthos is a joint venture between Gasunie, EBN and the Port of Rotterdam. The CO_2 will be captured by a variety of companies located in the port area via a collective pipeline system (Porthos, 2022).

6.1.1 Technical

The total storage capacity is 37 Mt of CO_2, with 2.5 Mt of CO_2 being stored on an annual basis. The system consists of four main components:

1. The onshore pipeline system feeds the CO_2 to a compressor station at the Maasvlakte. The pipeline has a diameter of 108 cm and has an operating pressure between 15 and 40 bar. At an operational pressure of 40 bar, the pipeline can be used for a capacity of 5 Mton CO_2 per year.
2. The compressor system consisting of three compressors brings the CO_2 to a pressure of 130 bar, the pressure at which the gas is fed into the off-shore pipeline.
3. The offshore pipeline system has a 22 km pipeline with a diameter of 40 cm, which feeds the CO_2 to an old natural gas platform.
4. The storage system in the former natural gas field, where the CO_2 is stored in sandstone substratum.

6.1.2 Development

Porthos gauged the interest of companies in participating in the project through an expression of interest procedure. Afterwards, a Joint Development Agreement was signed in 2019, to set up the transport and storage contracts required with the participating companies. Participating companies are Shell, ExxonMobil, Air Products, and Air Liquide. The latter contracts became definite in December 2021. The development timeline is shown in Figure 15.

Porthos is currently focusing on three items. These items are expected to be resolved such that a final investment decision (FID) can be taken in the second half of 2022:

- Technical development of the transport and storage infrastructure
- Environmental Impact Assessment and permits
- Agreements with companies to supply CO_2 and with the Dutch government to enable CCUS

As soon as the investment decision has been taken, the construction of the infrastructure will start. It is expected that the system will be operational by 2024/2025.

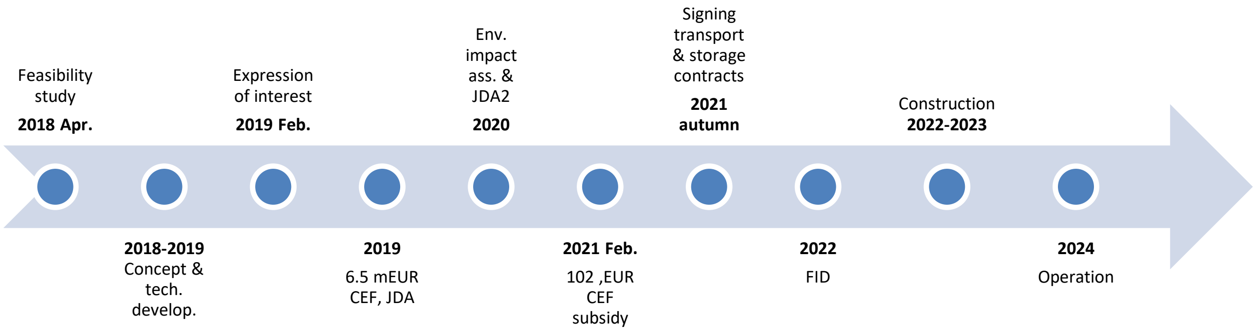


Figure 15: Development timeline Porthos project with major milestones indicated.

6.1.3 Financial

Three main financial instruments enabled the development of the Porthos project. First, the early stage support of the Connecting Europe Facility (CEF) Energy Programme. In 2019, EUR 6.5 million subsidy was committed to the project. Later on a further EUR 102 million was awarded to the project by CEF. Second, the SDE++ subsidy instrument enabled further development. In total a maximum of EUR 2.1 billion has been reserved for Porthos. As described in a previous section, the received subsidy depends on the ETS price, since the ETS price is subtracted from the subsidy per ton of CO_2. Therefore, the third instrument is the ETS price itself that provides the main incentive for CCS development. Under the EU legal framework CO_2 captured and permanently stored is considered not emitted and qualifies for ETS (Climate Action website, 2021). This provides primarily an indirect means of support as ETS revenues are subtracted from SDE support.

6.2 H-vision

The Port of Rotterdam authorities have evaluated potential decarbonization roadmaps and view the deployment of large scale CCUS and blue hydrogen as a cost efficient pathway for the short term. The H-vision project aims to kick-start the hydrogen economy in the Rotterdam area with the construction and operation of large-scale blue hydrogen facilities. The aim of the project is to develop the hydrogen economy in the Netherlands such that it paves the way for green hydrogen in the long term.

In the Rotterdam industrial area, the current natural gas consumption is 117 PJ per year for industry and 30 PJ per year for power production. In addition, there are 120 PJ of energy used in the form of residual gases (Rotterdam-Moerdijk Industry Cluster work group, 2018). Residual gas is a mixtures of gasses derived as by-product from the industrial processes such as steam cracking and steel production. By-product hydrogen can be a part of industrial residual gas and accounted for 41% of global hydrogen production in 2019. Converting these natural gas and residual gas streams to hydrogen and removing the CO_2 could lead to a potential reduction in CO_2 emissions of 12-15 Mt per year. The Port of Rotterdam currently utilizes 40 to 55% of the hydrogen production in the Netherlands as feedstock for crude and bio-oil refineries. The hydrogen is predominantly produced from natural gas by steam methane reforming with a lesser share produced as a by-product in the production of chlorine and crude oil refining. H-vision differentiates itself from other low carbon hydrogen projects since about 90% of the feedstock would be residual gasses and about 10% natural gas. Some key factors contributing to the production of blue hydrogen in Rotterdam are:

1. It is significantly less complex and more cost effective to convert hydrogen produced as a by-product of industrial processes to low-carbon hydrogen by the implementation of CCS rather than replacing them using green hydrogen
2. Blue hydrogen is able to provide a stable, constant and predictable offtake which is well suited for industrial heating applications
3. The vision for the H-vision project aligns well with the Porthos project which aims to develop large scale CCS in the Rotterdam area

The H-vision project is currently progressing towards the pre-FEED phase (Front-End Engineering Design). Currently work is being carried out on the design and location of the hydrogen production facilities. By the first half of 2022, a decision on the design and the location of the production facilities is expected to be taken. The first production facility is planned to be operational by 2027 with an emissions reduction potential of 1.3 Mtons CO_2 per year. The plan is to scale up to 2.7 Mtons CO_2 abatement per year by 2032 with the installation of additional production facilities. The CO_2 avoidance costs for this scope would vary from 86 to 146 EUR/tonne depending on the macro-economic scenario (H-vision, 2019). The total H_2 production capacity requirement is estimated at a total of 1.5 GW. The storage requirements estimated by H-vision is 288 MT of CO_2 over the project lifecycle; this is feasible since the Dutch continental shelf has about 1,700 Mton storage capacity (EZK, 2021) available under the North Sea, the majority of which is in depleted gas fields. Most available gas fields are located in the K and L blocks in the middle of the Dutch part of the North Sea. One of the risks here is the preparation of these fields in time to meet the required injection capacity.

The CO_2 avoidance cost in the reference scenario is 107 EUR/ton CO_2. When compared to the subsidies granted within the SDE+ scheme, for heat producing categories, only 5 out of the 29 categories which produce heat have a lower avoidance costs w.r.t H-vision. Therefore H-vision is either more cost effective or of similar cost to technologies which have been granted subsidies. When compared to electrification options, electrical options have higher CO_2 avoidance cost except for heat pumps for low temperatures. Post combustion CCS options have comparable reduction costs while heat production with green hydrogen has much higher CO_2 avoidance costs.

Cost Structure	
Investments:	1-3 B€
Yearly gas input (reference):	1.2 BCM
CO_2 T&S tariffs:	80-165 M€/yr.
Other OPEX:	60 M€/yr.
Revenues	
CO_2 certificates	2.6 Mt/yr
Power production	5 MWh/yr.
Financial Gap	**0-78 €/ton**

Table 6: Cost Structure, Revenue streams and financial gap for the H-vision project (H-vision, 2019)

The economic feasibility of H-vision depends to a large extent on political and macro-economic developments. Large uncertainties about the commodity and CO_2 pricing are especially an obstacle to get H-vision started since they have a major impact on the business cases. Government support in the form of participation, contracts for differences, risk bearing loans or subsidies are required to get H-vision started given its low, non-commercial rate of return. The cost structure and financial gap for the H-vision project is shown in Table 6. This financial assessment was carried out in 2019 and would need to be revisited given the recent increases in gas prices. Some of the key risks foreseen for the H-vision project are as follows:

- ETS prices are lower than assumed

- 5000 running hours are assumed for power plants running on Hydrogen. Lower running hours would mean less revenue from the sale of power
- Large scale CCS has yet to be realized
- Installation and operating costs for ATR (Auto-Thermal Reformer) not yet supported under SDE++ scheme

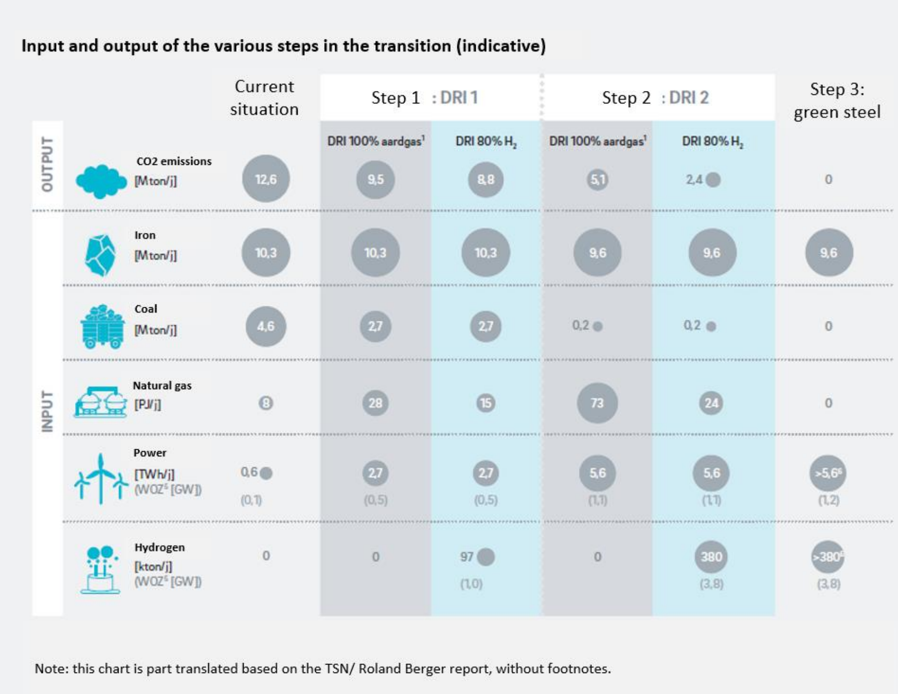
Until 2022, regulations have been lagging behind, there was no specific support for the H-vision project especially considering these 'first of a kind' type projects involve a high investment risk and need a safety net. However the SDE++ scheme for 2022 has decided to include a new category on the production of hydrogen from residual gases (capture of CO_2, which remains during the production of hydrogen from industrial residual gases). Inclusion of this category is expected to support the H-vision and more widely the blue hydrogen business case in the Netherlands.

6.3 Tata Steel Netherlands

Tata Steel Nederland (“TSN”) is the largest single energy consumer and CO_2 emitter of the Netherlands. It has an energy consumption of 4.6 Mton of coal, 8 PJ natural gas and 0.6 TWh of power. The annual emissions are 12.6 Mton of CO_2.

TSN was initially aiming for decarbonization driven by the implementation of CCS, however, on 15 September 2021, TSN announced a strategic change away from CCS and in favor of conversion to hydrogen use. The change to hydrogen use would additionally require the introduction of direct reduced iron (DRI) technology and construction of electric arc furnaces. The rationale is that CCS is seen as intermediate solution and hydrogen use as the preferred end solution. Opting for hydrogen now and skipping CCS is seen as more ambitious. The Tata Steel decision to switch to the DRI technology also means that the Athos project cannot proceed in its current form.

Green hydrogen has a lower emission intensity when compared to CCS with coal and therefore the change to H2-DRI technology can result in local environmental benefits. The transition to hydrogen is planned to first replace coal with natural gas and later to convert from natural gas to hydrogen. These two phases are applied to two furnaces, so 4 phases are foreseen to complete the transition. In the intended end situation, the energy consumption is 5.6 TWh per year power and >380 kt hydrogen per year.



Input and output of the various steps in the transition (indicative)

		Current situation	Step 1 : DRI 1		Step 2 : DRI 2		Step 3: green steel
			DRI 100% aardgas[1]	DRI 80% H_2	DRI 100% aardgas[1]	DRI 80% H_2	
OUTPUT	CO2 emissions [Mton/j]	12,6	9,5	8,8	5,1	2,4	0
INPUT	Iron [Mton/j]	10,3	10,3	10,3	9,6	9,6	9,6
	Coal [Mton/j]	4,6	2,7	2,7	0,2	0,2	0
	Natural gas [PJ/j]	8	28	15	73	24	0
	Power [TWh/j] (WOZ[5] [GW])	0,6 (0,1)	2,7 (0,5)	2,7 (0,5)	5,6 (1,1)	5,6 (1,1)	>5,6[6] (1,2)
	Hydrogen [kton/j] (WOZ[5] [GW])	0	0	97 (1,0)	0	380 (3,8)	>380[6] (3,8)

Note: this chart is part translated based on the TSN/ Roland Berger report, without footnotes.

Figure 16: Roadmap to green steel (Roland Berger, 2021)

If all hydrogen is from electrolyzers fed by green energy, the power for H_2 sums up to about 19 TWh/y, making the total power need about 24 TWh/year. To put this in perspective, this is about 1/6th of the national power consumption of the Netherlands today and the H_2 use is more than the current H2 use of the port of Rotterdam area today and more than half the domestic (fossil) H_2 production of today. In terms of off-shore wind, being one of the largest sources for green power energy expansion for the Netherlands, this is more than 8 GW of installed capacity (around 20% of the foreseen Dutch offshore wind capacity by year 2040). While the strategy is praised for its ambition and positive effects on the air quality in the local area, there are very significant hurdles that need resolving before the planned scenario becomes viable. These are listed by TSN themselves as

- Creation of required infrastructure for green power, H_2 and natural gas
- Sufficient and affordable supply of green H_2, green power and natural gas
- Support of the government in four areas
    - Tailor made financial support and creation of level playing field in Europe
    - Fast track permitting to reduce implementation times
    - Changes to policies to realize energy transition
    - Stimulation of H_2 markets and infrastructure

The commodity prices of coal, gas, carbon emissions, H_2 and power have a decisive impact on the cost of realizing the TSN strategy. Any economic shortfall would require financial support in the form of subsidies or other support policies. The spreads between the commodity prices will determine the financial support required from society. The TSN/Roland Berger report contains below graph that demonstrates that the first step to switch from coal to gas will be cost effective at the CO_2 price level of EUR 77/ton.

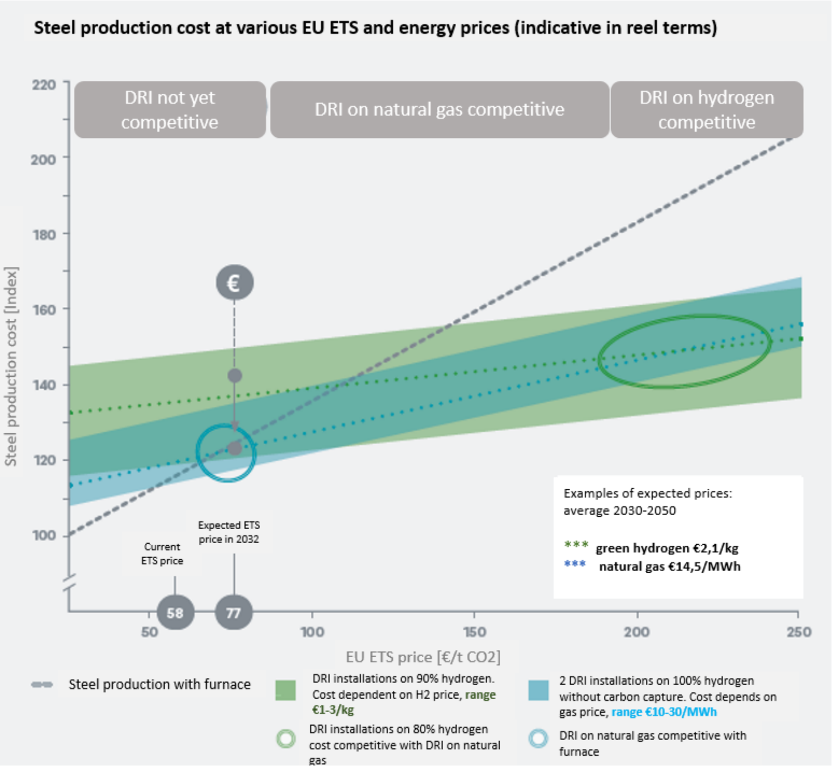


Figure 17: Steel production cost at various ETS prices((Roland Berger, 2021), translated)

It however assumes a gas price of EUR 14.50/MWh and a CO2 price of EUR 77 by 2032. While the current market price of CO_2 is already within 10% of said target price, the gas price has increased nearly by a factor six at EUR 102/MWh as of April 26th 2022 due to geopolitical tensions. It remains to be seen how much gas prices move on the longer term, when short term tension may have eased and long term strategic supply decisions come into play.

The report mentions a green H_2 cost range of EUR 1-3 per kg, which leads to a need for financial support of EUR 490 million per year. Application of current market price for the forward calendar years for both power for green hydrogen and gas and CO_2 would cause both the domestic green H_2 price and financial deficit to be roughly twice as high. It might be a challenge to find political support when the required financial support doubles, however the time period for which the transition is foreseen is in the medium to long term future when price levels may have normalized to some extent.

The moving commodity prices also pose a challenge for the SDE++ support policy. Some of the price assumptions will need updating, although it is not clear whether this will happen before the next SDE++ allocation round. Under the SDE++ support regime, CCS is regarded as the cheapest means of CO_2 abatement at EUR 75 per ton CO_2 abated, as per the 2021 SDE++ tender and green hydrogen the most expensive one at EUR 928 per ton as per 2021 base price estimates. The difference is a factor twelve. Projecting the market changes of the last 6 months on the cost gap between the CCS and hydrogen strategy will have enlarged, at least when served with domestic hydrogen because both power (required for green hydrogen) and gas (required for blue hydrogen) have become considerably more expensive. Large scale hydrogen production in the MENA may have marginally increased in cost (due to rising PV panel prices) but not nearly as much as European energy prices that drive domestic hydrogen production. This may make import from MENA a competitive hydrogen supply. At the same time, the increased market prices for gas have pushed up hydrogen prices in Europe to serve existing hydrogen feedstock demand. With hydrogen getting more expensive in Europe due to commodity market developments and CCS cost not nearly being affected to the same extent, we conclude that the price gap between the CCS and hydrogen route for TSN using the SDE++ approach will only have increased further in recent months.

Continued use of coal for industry (TSN) and power sector could be required in the medium term to provide security of supply. According to (IEA, 2021), use of coal for power production is expected to have increased 9% globally in 2021. Continued use of coal is a viable alternative, however goes against the trend of gradually abandoning coal use in Europe. Continued coal use could increase the potential for application of CCS projects, however would be less environmentally friendly compared to the green hydrogen route.

7 KEY FINDINGS

This chapter presents the key finding from the analysis of the policy instruments carried out in chapters 4,5 and 6.The findings have been grouped into the 1) main success factors and 2) the risks and uncertainties that need to be overcome in order to support industrial decarbonization in the Netherlands through CCS and Hydrogen.

7.1 Success Factors

The Netherlands is strategically positioned to take a leading role in industrial decarbonization, due the following advantages: 1) The presence of shallow waters in the North sea suitable for installation of offshore wind and its proximity to the industrial clusters in the Netherlands, 2) The presence of some of the largest deep water ports in Europe leading to the availability of cheap raw materials for the energy transition and the added advantage for export of Dutch products and 3) Existing natural gas infrastructure and cross border trade which can be utilized for hydrogen and CO_2 transport.

The Netherlands climate law, the climate agreement and the CES/RES structure has the potential benefit of providing wide societal alignment on emission reduction and decarbonization plans. The government taking lead on critical infrastructure has the advantage of dealing with the chicken-and-egg problem for investment, allowing companies to de-risk their investment decisions.

The SDE++ instrument is the first scheme similar to carbon contract for difference in the European Union. The scaling up of the SDE++ scheme from EUR 5 billion in 2021 to EUR 13 billion in 2022 demonstrates the commitment of the Dutch government to support industry in implementing and scaling up its clean energy technology and infrastructure.

The SDE++ scheme maximizes CO_2 emissions reductions at competitive cost through an auction process where technologies and projects compete on a cost basis. The impact of market price on the project revenues are included such that projects are not over subsidized when market conditions are favorable which has been the case recently with rising ETS prices.

The Porthos CCS project was initially supported by the CEF subsidy in the early stages and later on received a significant funding reservation through the SDE++ instrument. The increase in ETS price since 2020 provides additional incentive for this project to proceed to deployment. With a final investment decision expected in the second half of 2022, the Porthos project has benefitted from the policy landscape in the Netherlands. CCS policy in the Netherlands has thus been successful in bringing forward projects such as Porthos to the deployment stage.

By-product hydrogen forms part of residual gasses from industrial processes accounts for nearly 41% of global hydrogen production in 2019. By-product hydrogen is also predominantly utilized in industrial heating. Converting this by-product hydrogen to blue hydrogen through the application of CCS can result in significant emissions reductions. The proposed separate SDE++ category for 2022: “Production of hydrogen from residual gases” is expected to bring required support for blue hydrogen projects in the Netherlands requiring the construction and installation of new reformers to produce hydrogen from residual gasses.

The Dutch cabinet is coming up with a plan to adapt existing gas pipelines for the transport of hydrogen. Recent studies have shown that it is feasible, safe and cost-effective to reuse existing gas networks for hydrogen. Seizing this opportunity the Dutch government is now developing the roll-out plan for a national hydrogen transport network (Hydrogen backbone). The National hydrogen backbone can facilitate the development of local hydrogen production by connecting all major industry clusters with central storage locations.

Green hydrogen projects are able to transfer unused subsidies as a result of production lower than the maximum allowable load hours to future years. This allows subsidies to be granted in future years for production over the allowable limit of load hours for subsidies.

7.2 Risks and Uncertainties

7.2.1 CCS

Due to the scale at which CCS can be applied, it has been labelled a critical technology to reduce CO_2 emissions and to achieve global climate goals. For energy intensive, hard-to-abate sectors, technical and cost-effective options to reduce emissions without CCS is currently limited. There are however multiple barriers limiting the large scale deployment of CCS for industrial decarbonization. Firstly, there is the potential for increased energy consumption, due to the increased energy requirements for CCS. Lock-in of fossil fuel usage for industry is considered an additional concern.

There are also possible risks of carbon dioxide leakage from geological storage and CO_2 transport infrastructure associated with CCS, although given that no known leakage has occurred at a CO_2 storage site to date these risks are considered low. Long term liability for CO_2 storage and monitoring is a regulatory issue requiring significant financial security to be provided. Private companies would be required to have adequate credit strength to receive a bank guarantee for participation in storage activities. This can limit potential participants in CCS storage activities. Considerable financial guarantee needs to be provided by the government in order to make the project bankable for private parties.

Ensuring sufficient storage is prepared is an important step for a CCS project. It is a step that requires significant capital because permitting processes need to be put in place, the site needs to be characterized and storage potential needs to be evaluated by conducting exploratory drilling. For depleted gas fields, the capital requirements could be lower due to availability of injection wells and known reservoir characterization and storage potential. However depending on the age of the field, resolution of well integrity issues, geo-mechanical or other containment and injectivity issues would require considerable intervention. Preparing storage capacity is also a time consuming process which can take in excess of 5 years for a single field. However it is a classic-chicken-and-egg situation since the storage provider needs a contract with the emitter to prepare a site and an emitter needs to know where to store the CO_2 prior to making an investment decision on their capture project. Additionally regulatory clarity must be provided to the emitter for possibilities in CO_2 transport or shipping.

There is a large technical potential for CCS across industry. As shown in Figure 12, significant amounts of CO_2 emissions can be reduced by CCS and a considerable volume of CO_2 emissions can be abated for less than 100 EUR/ton. The low level of subsidy intensity required combined with the large impact on emission reductions possible prioritizes CCS projects in the SDE++ instrument. However, due to the large emissions reductions potential of a single CCS project, the subsidy volumes required are also high. This means that even a single CCS project not deciding to participate in the subsidy auction has a large impact on the subsidy allocation and the potential delays in permitting storage fields and infrastructure can be considered high risk w.r.t meeting national climate targets

Since a ceiling has been placed on the total volume of emissions reductions related to CCS projects that can be subsidized, CCS project developers are expected to bid for the SDE++ subsidy as early as possible to ensure subsidies can be allocated to their projects. This can create the risk that large volumes of CCS projects bid for subsidies in the short term, effectively crowding out low TRL technologies that require subsidies for upscaling and increasing their technology maturity.

Subsidy intensity required for CCS projects are highly dependent on multiple factors such as whether they are pre or post combustion CCS, transporting liquid or gaseous CO_2, the emissions factors for different CCS technologies, new build or retrofits etc. CCS projects have not yet been realized in the Netherlands, therefore creating an uncertainty in the assumptions for calculating the subsidy intensity.

CCS projects are cost effective to be subsidized by SDE++ as seen in the case of the Porthos project. However, SDE++ does not consider savings from the carbon tax to determine the subsidy rate but only the EU ETS price. This introduces the possibility that CCS projects gets “overcompensated” for its emission reductions under conditions when the carbon tax is higher than the ETS price. This scenario is however unlikely given the recent increases in ETS prices.

The Netherlands faces the dilemma of considering CCS as an emissions reduction technology to meet its climate targets until 2030, while simultaneously having to consider how to subsidize alternative technologies beyond 2035. Decreasing cost and increasing EU ETS prices can allow CCS projects to take place unsubsidized beyond 2035.

7.2.2 Hydrogen

The correction amount for hydrogen for SDE++ is determined by the TTF gas price. The power price is however not included as part of the correction amount. This exposes the operator to power market risk. The power price is calculated only once at the point of subsidy allocation and thereafter considered a project risk. This poses a clear problem for green hydrogen producers especially when both power and gas prices move up in tandem, since the revenues from selling H_2 produced via gas is corrected for higher energy prices, however the cost of power used is not subsidized. Power prices need to be included in the correction amount to protect the operator from power market risk and thus reduce uncertainty and improve the bankability of green hydrogen projects

Although the hydrogen economy seems poised to kick-start in the Netherlands, the reality is that hydrogen policy is incomplete and at present insufficient to enable gigawatt scale green hydrogen projects to take positive FIDs. While there has been welcome R&D funding, small-scale demonstrations, and larger scale projects in the planning stages, the costs of deployment cannot be met through current policy, given that green hydrogen is not competitive within the current SDE++ framework.

Until as recent as a few months ago, one would conclude that there is no overall Dutch hydrogen model that can be recommended for application in other countries. The recent announcements of Government are very encouraging and could change this view radically, but this remains to be seen. However based on actual policy today, green hydrogen production at scale is not yet viable in the Netherlands.

The SDE++ prioritizes technologies which have a lower cost of carbon abatement and is closer to deployment over emerging technologies that are in research and development phase. One of the major criticisms of the SDE++ scheme is that it favors mature technologies such as CCS over long-term technological innovation. Some technologies such as green hydrogen are not expected to receive any subsidies from SDE++. At the same time, it ensures that green hydrogen production is not favored over for instance green electricity production, therefore not crowding out renewable energy production and electrification. A redesign of the SDE++ scheme to allow for separate tenders across different ‘buckets’ of technologies could support investment in emerging technology in lieu of low-cost emissions reductions. It is expected that buckets that reserve a set amount of subsidy for higher priced technologies will be introduced during the 2023 subsidy auctions.

The subsidy for hydrogen produced via electrolysis is eligible for SDE++ is limited to 2,940 full-load hours in 2021. The reasoning behind limiting the load is to ensure that the electricity used by the electrolysis is renewable. In 2022, a new eligible category will be opened to SDE++, enabling direct coupling of hydrogen production with solar and wind power production. Such a coupling of solar and wind to electrolysis could ensure that 100% renewable electricity is utilized for electrolysis and thereby reduce the limitation on full load hours that can be subsidized.

Additionality risk: This type of risk is a concern of for instance for the Groeifonds and has been identified by InvestNL on behalf of the Groeifonds. It is defined as the risk of subsidizing projects via the Groeifonds would crowd out other types of (private) finances. For example, Groenvermogen proposes to finance 70% by means of private finance and 30% public finance. In their proposal they explicitly mention the role of InvestNL, which would be able to judge the additionality risk. In the particular case of Groenvermogen, 30% public finance is justified according to InvestNL, given the unprofitable business case and the technological uncertainty . However, this does not mean additionality risk is ensured since it depends on a variety of continuously changing parameters: the ETS price, the natural gas price, the SDE++ subsidisable electrolyzer full load hours.

Two recent policy announcements were made by Government, in reaction to – or at least accelerated by – the energy crisis caused by the Russian invasion of Ukraine.

1. 10 GW extra off-shore wind, to get to a target of over 21 GW by 2030
2. EUR 15 billion funds allocated to advanced renewable energy carriers

The first fits well into the tradition to focus on technologies with a high TRL. There will be no SDE++ subsidies needed for this deployment, but indirectly the government will need to support the realisation of required grid connections.

The EUR 15 billion budget to support advanced renewable energy carriers indicates that the government is making serious plans to take a more active and leading role in green H_2 deployment. The existing gas infrastructure in the Netherlands makes it a very suitable country to pioneer with H_2 deployment. The challenge remains that there is a long way to go before the amount of green power exceeds the primary power demand and excess green power is available to be converted into hydrogen. Absence of clarity how and when the EUR 15 billion budget will be deployed makes it hard to predict the future of H_2 in the Netherlands.

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