Hydrohub

Final report

Integration of Hydrohub GigaWatt Electrolysis Facilities in Five Industrial Clusters in The Netherlands

This report has been prepared in cooperation with following Partners:

Contents

Project Number	SI 50-07
Doc Number	20072001
Project Title	Integration of Hydrohub GigaWatt Electrolysis Facility in Five Industrial Clusters in The Netherlands
Subtitle	Part 2, Interregional cooperation
Funded by	TKI Energie & Industrie
Program management	ISPT: Andreas ten Cate, Carol Xiao, Lia Bouma
Project managers	Hans van 't Noordende, Peter Ripson
E-mail contact person	Hans.vantnoordende@ispt.eu
Project start	1-6-2019
Project original end date	31-1-2020
Web version available	**https://ispt.eu/projects/hydrohub-gigawatt/**

Prepared by	Bieuwe Pruiksma- DNV GL Bastian Knoors and Piyush Katakwar-RHDHV Hans Huiting and Johann Poinapen - KWR
Date	11-5-2020
Edited and checked by	Hans van 't Noordende
Date	13-5-2020
Approved by	Andreas ten Cate on behalf of GW Project Partners
Date	15-6-2020

Revision	Description	Date
0	For comments	3-3-2020
A	For approval	13-5-2020
B	Final	15-6-2020

Institute for Sustainable Process Technology

Groen van Prinstererlaan 37 t. +31 (0)33 700 9797

3818JN Amersfoort www.ispt.eu

EXECUTIVE SUMMARY

Introduction

Hydrogen is a crucial element -as feedstock and energy carrier- in the chemical, fertiliser and food industry. Water electrolysis from renewable electricity is mature technology for green hydrogen production and contributes to reduction of industrial CO_2 emissions. Scalability, investments and innovation are required to levy the mature technology to the gigawatt level for increasing the competitiveness with natural gas based grey and blue (CCUS) hydrogen.

The current hydrogen consumption in Dutch industry is about 1,500,000 ton, which is expected to grow due to the targets of the Dutch Climate Agreement (Klimaatakkoord). This will lead to higher demand in green hydrogen and upcoming new products/markets, like synthetic fuels and mobility. More renewable electricity is required than the scheduled 11 Gigawatt (GW) offshore renewable production in 2030. In each region in the Netherlands opportunities are present for GW green hydrogen facilities. This also requires investments in electrical, hydrogen and water infrastructure. Efficient integration in industry clusters on GW scale is necessary to realize affordable green hydrogen at industrial scale based on competitive Levelised Costs of Hydrogen. The reality is that present electrolysis plants are modules in the order of megawatt (MW) scale. There is clearly a need for upscaling of modules but also for upnumbering of stacks per modules.

The ISPT Hydrohub Innovation Program carries out innovation in this field and the Hydrohub GW electrolysis project is the landmark project of this program. It delivers an optimised competitive design with blueprints for GW green hydrogen production facilities in five different energy and industrial clusters (Regions) in The Netherlands. These regions are Noordzeekanaalgebied, Northern Netherlands, Zeeland (and Ghent), Chemelot, Rotterdam.

Further technology development is required, which should lead to a cost reduction of green hydrogen of a factor 3 to 4. State of the art PEM (Proton Exchange Membrane) and Alkaline water electrolysis technologies have been considered. Thus, providing the perspective to deliver economically viable green hydrogen production on a GW scale before 2030 and accelerating the hydrogen economy. This will be achieved by developing and applying a science, business and engineering approach. In this report the results of the business approach from a first assessment with regional stakeholders are presented.

Results

- GW scale green hydrogen facilities are possible in all 5 industrial clusters and present industrial demand is sufficient to take-off this green hydrogen.
- A total of 22 locations are identified and available space and infrastructure have been evaluated.
- Maximum surface requirements needed for alkaline amounts to 17 ha,whereas the minimum case amounts to 10 ha. The maximum for PEM is 13 ha (Figure 3) and here the minimum case requirement is 8 ha (Figure 4). In principle all locations have sufficient space for a GW facility.
- An internet-based map with possible plots and infrastructure connections for GW green hydrogen facilities in five regions, see figure S1 on next page, is accessible via:

https://rhk.maps.arcgis.com/apps/webappviewer/index.html?id=d94d70425c6b4c6f88a8143eda028d11

Boundary conditions of GW water electrolysis plant in five different industrial clusters

- In this study boundary conditions for integration of GW green hydrogen facilities into five industrial clusters have been assessed:
  - potential locations, hydrogen demand and plot sizes for these GW facilities;
  - system integration regarding infrastructure connections;
  - availability of water and co-siting opportunities.

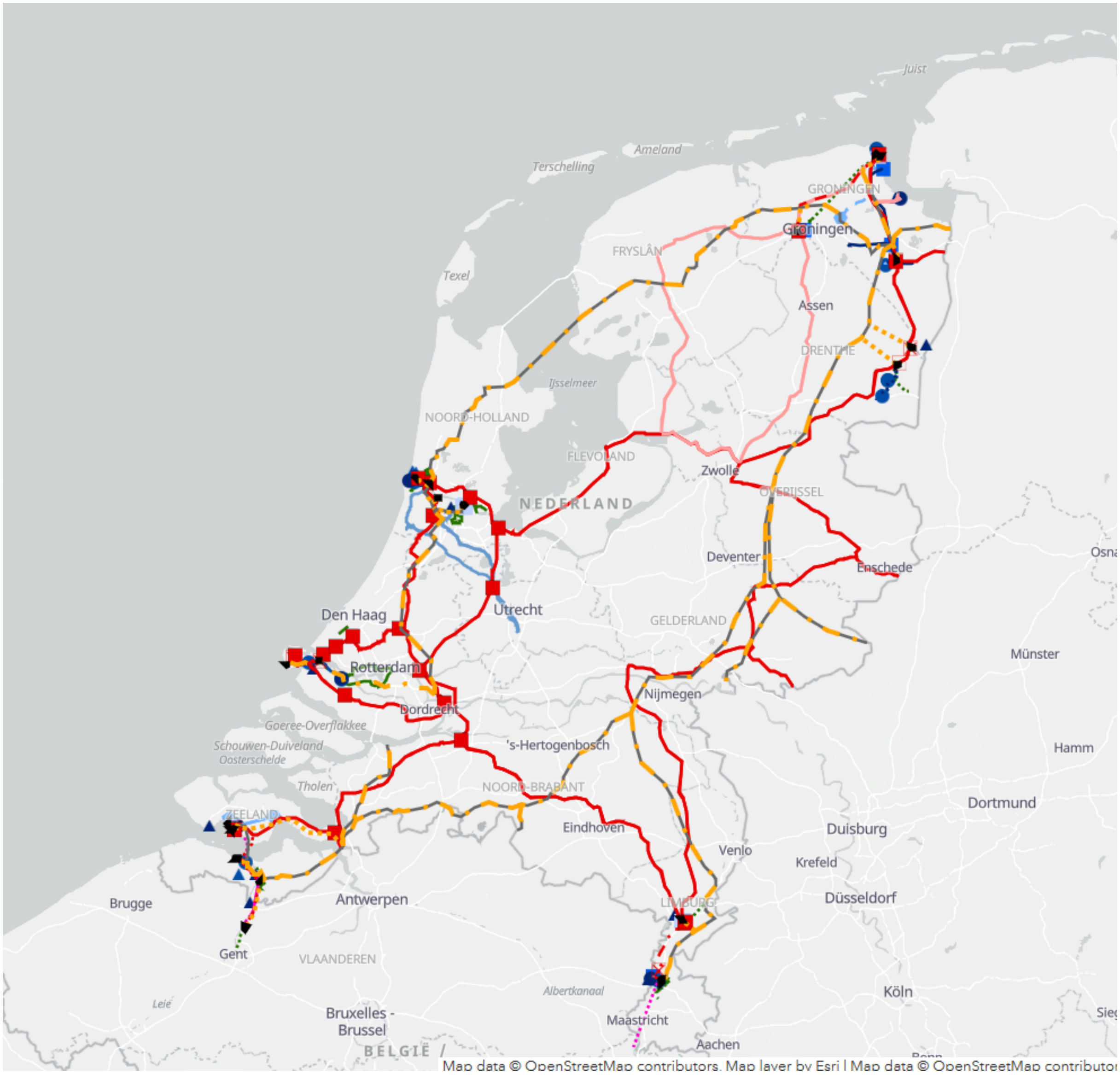


Figure S1: Internet Map ISPT GW electrolysis project (legend via link)

- Multiple locations for GW green hydrogen facility and available plot sizes have been identified and discussed with stakeholders in regional workshop in each industrial cluster. Therefore, plot plans have been made to determine required plot size requirements. Also, potential demand and endusers have been looked into.
- The GW facilities can play an important role in rationalising large grid investments and dynamic operation to support balancing and grid stability due to intermittency in renewable electricity supply.
- The supply of ultra-pure water for the GW electrolyser is paramount to produce hydrogen. About 25-30% of electricity losses from water electrolytic process need to be cooled down. Therefore, a survey of availability of industry, demin. and cooling water supply and discharge is executed. Closed recirculation cooling systems have been selected to reduce thermal discharge into surface water. Assessed co-siting opportunities include use of existing assets for substations, pipelines and demin/cooling water as well as heat recovery for district heating.
- Boundaries of the GW facilities have been analysed regarding system integration aspects with connections from the high-voltage electricity grid and natural gas/hydrogen networks to the identified plots. The relevant infrastructure has been mapped for each region and location, distinguishing between current infrastructure, planned, projected and required infrastructure.

Green hydrogen production and demand

- Annual production of 1GW water electrolysis facility is about 90 kton of hydrogen per year. This is based on 1GW power input, 5000h/a, and new stacks. The assumed operating mode is flexible load with minimum load 15%. The annual 5000 h are full load hours, of which 4000 h/a from 2018 profile from Northsea windfarm. We consider 1000h/a back-up power (with certificates) to meet the 15% min load, increasing hydrogen output and minimising degradation effects on electrolyser stacks. Moreover, full load hours tend to increase with larger and higher wind turbines over time.
- Existing and future demand for (green) hydrogen and oxygen in each region has been investigated. Existing demand is 1,5Mton/a. It was found that in all industrial regions present industrial demand is sufficient to take-off this green hydrogen. Future demand may increase, e.g. with power plants, mobility and synthetic fuels.
- Flexible operation of existing assets (SMR) allow for turndown ratio down to 0.7 -in case of modifications- meeting variable loads and hydrogen production due to intermittency.
- Offtake of large volumes of oxygen is interesting in case of steel plants and possibly for oxyfuel applications, e.g. steam generation, allthough much smaller volumes.

Plot size

- In total 22 different location in the five industrial regions have been assessed. Based on the available plot sizes and the required space, it was found that 13 locations (should) have enough space available, seven locations require more compact design, and for two locations the available space is unclear. One location in each region is expected to be sufficient for hydrogen supply to one or more endusers.

- Plot plans have been designed for both Alkaline and PEM GW electrolysis installation to determine the required plot sizes relative to available plots. The applied building dimensions are only for indication of space requirements. In total four plot plans have been made, see next figures: baseline design and a compact design for both PEM and Alkaline technology. An area of about 17 ha is required for a state-of-the-art baseline design using Alkaline electrolysers whereas this is 13 ha for PEM design. In case of a compact design using Alkaline electrolysers an area of about 10 ha is required whereas this is 8 ha for PEM technology.

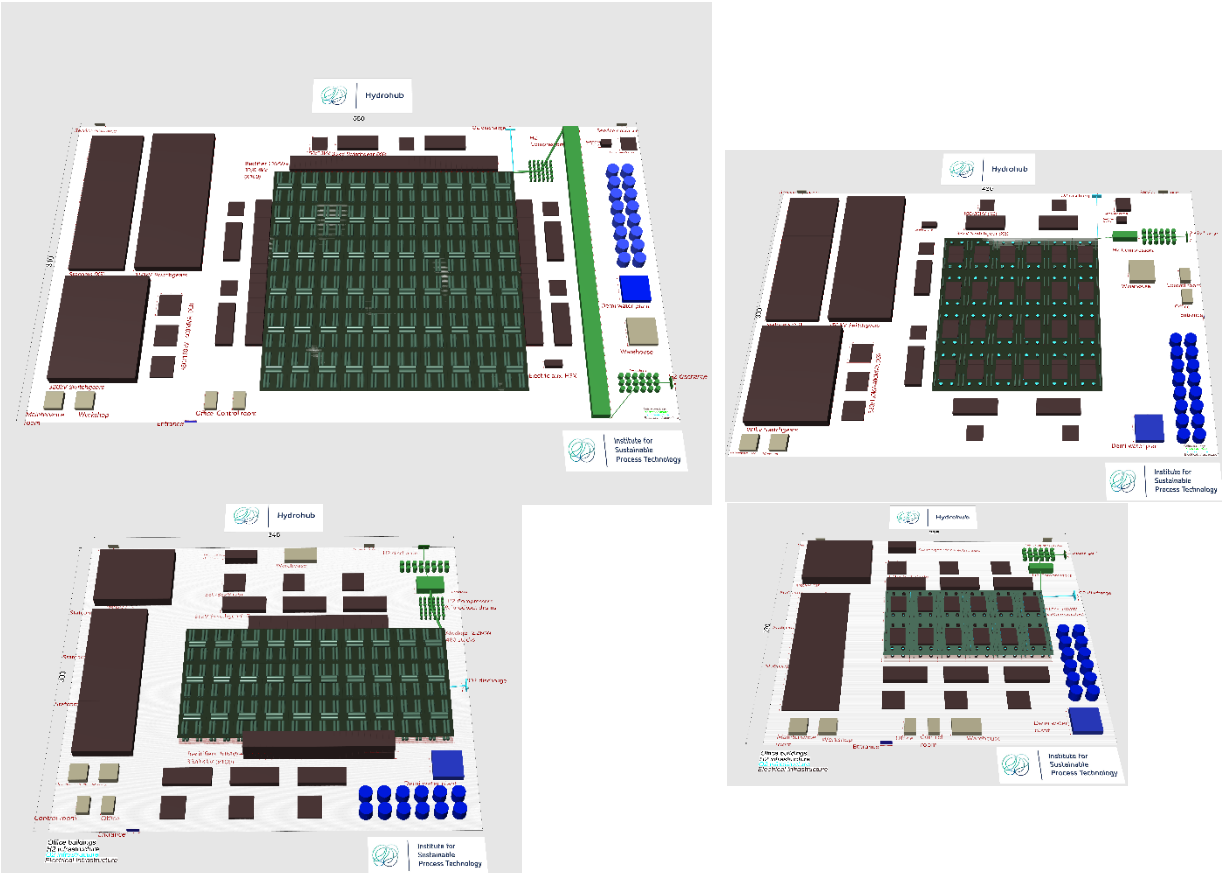


Figure S2-5: (Clockwise) Baseline design Alkaline and PEM; Compact design Alkaline and PEM

- One of the important findings is that the electrical (HV-MV) installations require similar footprints compared to the Alkaline electrolyser building (including rectifiers and 33/0.4kV transformers). As expected, PEM electrolysers offer significant savings in space as the spatial footprint of PEM building is less than half of Alkaline electrolysers building. Other space saving options could be realized by adapting the HV installation.
- Selection of potential locations for the GW electrolyser facility depends on the availability of critical infrastructure to be able to operate. As part of the assessment, the infrastructure for water supply, electricity supply and hydrogen transport has been evaluated.

Electrical infrastructure

- For the identified locations, it was found that five locations have an existing or planned 380kV substation to which can be connected by 2030; eight locations have no existing 380kV substation or no sufficient connection capacity, but a new substation or an extension is planned or projected, and for eight locations there is no existing 380kV substation or no sufficient connection capacity, and there are no plans and no projections.
- GW electrolyser facility will be ideally located close to the 380kV grid as 380kV grid connection seems most appropriate, because of the high-power flows. A connection to the 150kV grid is not recommended, as this would lead to additional barriers like insufficient transformer capacity (from 380kV to 150kV), limited available connection capacity at the substations at 150kV, and limited space for the 150kV connections between the substation and the location of the GW electrolyser facility. There are different options to realize a 380kV connection, as one can differentiate in among others design (standard design versus compact design), intermediate voltage levels, level of redundancy, type of connection and future possibilities.
- For the baseline design of the electrical installation, a standard design has been assumed with a double busbar at 380kV, three 380/150kV transformers, a double busbar at 150kV, three statcoms (tentative rating 200Mvar each), six 150/33kV transformers, 100 33kV/1kV transformers of which each supplies a 10 MW rectifiers, and each rectifier supplies four 2.5 MW, 1kV electrolysers. Two space saving options have been assessed: using gas insulated switchgears (GIS) instead of air insulated switchgears (AIS), and direct transformation of voltage from 380kV to 33kV (removing the intermediate voltage step 150kV). Those options have been applied to the compact design (minimum case) and result in a plot size of the electrical installation which is half of the baseline design.

Water infrastructure

- Concerning all locations across the five regions, it was found that currently there is no existing nor any projected facility that can provide the demin water demand of around 200m3/h and quality required for the GW electrolyser. Accordingly, in all locations a new water treatment facility is required to treat the water to the desired quality. Most locations have a readily available industry water source, from sweet surface water which can be treated and is roughly the double demin water consumption flowrate. In cases where a sewer network is not available for the discharge of the waste stream from the GW electrolyser, a dedicated waste collection and management system is needed. Significant connecting pipeline infrastructure is required for the water supply connections. Regarding run-off (rain) water this is usually provided by the port authorities.
- It is anticipated that the GW electrolyser will generate a waste heat of around 250 MW. Cooling water system and potential heat recovery regarding district heating are investigated. Water demand for cooling system with cooling towers based on 5 recirculation cycles amounts to 375 m^3/h (including a blowdown of 75 m^3/h). For cooling water make-up, industry water is available. In the case of once-through cooling, the water demand is between 32,000 – 43,000 m^3/h, however, this is not the preferred cooling system option as water availability and thermal discharge is expected to be an issue in many locations, especially regarding trend with seasonable droughts.
-

- Heat recovery for demin water production from brackish or seawater, like Membrane Distillation, is worthwhile examining as this could avoid or reduce cooling system requirements and thermal discharge.
- District heating is an option in all regions although (additional) back-up cooling is still required. Also, greenhouses may be supplied with waste heat like in Westland near Rotterdam. Currently, there is limited infrastructure in any location to take advantage of this waste heat for district heating. The actual demand at the required level is not present yet, especially at temperature of 70-80degC, but most Provinces and cities indicate that district heating demand may develop in the future as alternative for natural gas.

Hydrogen infrastructure

- Regarding the possibilities to connect to the hydrogen backbone, it was assessed that all locations could be connected. 14 locations are within 10 km of distance to the foreseen backbone, three locations just over 10 km and two locations over 50 km. Those last locations are the two Rotterdam locations, for which there are plans to develop a regional backbone. The three locations near Borssele are close to existing infrastructure, but the potential use to connect to the national hydrogen backbone (at about 40 km) is not yet clear.
- According Gasunie Transport Services B.V. (GTS) large parts of the Dutch natural gas transmission system owned could be reused. The backbone will connect the large industry clusters to exchange hydrogen demand and supply and give access to large scale underground storage in Groningen Province. Changes in the Dutch energy system such as, phasing out of Groningen-gas, electrification, expiration of long-term supply contracts and the energy transition overall, will make significant transport capacity available. Many trajectories include redundant (GTS) pipelines of at least 36 inch. This allows for cleaning existing gas infrastructure for hydrogen transport, alongside the natural gas system that will still be in operation. In addition, gas compression stations have to be replaced and new dedicated hydrogen pipelines have to be developed, like in Rotterdam port and some other areas, and of course for connecting large scale hydrogen facilities. The topics of pipeline integrity, compression, safety, and quality (contamination) still need to be clarified.
- The building and commissioning of the hydrogen backbone is expected between 2025 and 2030 and expected cost is approximately €1.5 billion. Technically the backbone could be ready by 2026 and the Northern part in 2023, in case the final investment decision is made on a relatively short term (2021). Sufficient hydrogen supply and demand is required or should be expected in the foreseeable future to (start to) develop the backbone.

Conclusions

- It can be concluded that in all five regions it is technically possible to deliver -economically viable- green hydrogen production on a GW scale before 2030.
- There is sufficient space available at virtual all locations for the required plot size of 8-17 ha.
- Potential industrial hydrogen demand exceeds green hydrogen production on GW-scale in five regions.
- In all regions the electrical infrastructure is available or planned/projected except some locations like Zeeuws Vlaanderen where there are no concrete plans yet.
- Hydrogen backbone and interconnecting pipelines to all locations and sites can be timely realised starting in the North, allowing for transport and buffering, also between the regions, in the backbone and caverns.
- Water supply and infrastructure for demin. water and cooling water supply and discharge is in most locations not considered as a problem. District heating is an opportunity for heat recovery that needs to be further investigated, especially for large-scale low temperature demand. Also, heat recovery for demin water production, like Membrane Distillation, is worthwhile examining.
- The large-scale deployment of industrial green hydrogen will boost the hydrogen economy with power sector, built environment and mobility.
- Moreover, GW green hydrogen in all regions can improve (combined) auctions for offshore wind investments, prevent curtailment and rationalise grid investments.
- The business cases however need to be improved in reducing the capex and opex costs. This is the core of the Part 3 of the GW water electrolysis project: conceiving, integrating and delivering a blueprint design achieving competitive Levelised Costs of Hydrogen.

Next steps

- The interregional cooperation with partners in the industrial clusters is being continued. In the next steps a selection of following topics will be addressed.
- Compact design: area usage and space requirements in relation to topics like safety and environmental contours, HV- electricity set up, cable and pipeline infrastructure, system integration aspects. Some of the other topics mentioned below will support this topic;
- Safety: specific items to cover: Safety contours of the GW- facilities, safety aspects of oxygen-emissions and requirements on permitting process;
- System Integration aspects, like technical feasibility of usage of residual heat, or co-siting opportunities and synergies with other water consumers/producers;
- Hydrogen quality: optimum specification to serve the industry and other off-takers at lowest cost
- Input to business plans with (integration)-cost savings, synergies and upsides.

1. INTRODUCTION

1.1. About ISPT

The Institute for Sustainable Process Technology (ISPT) is an open innovation network for the process technology community with partner organizations cooperating on developing and realizing sustainable process technology innovations to solve common industrial needs. The more than 100 partner organizations comprise process industry, grid operators, port authorities, SME's, knowledge institutes, Universities. ISPT sets up, defines, starts and runs with its partners open, collaborative new process technology innovation programs and activities. Thus, ISPT activities contribute to improvement of the competitive and sustainable position of the (Dutch) Process Industry and supply chain.

1.2. GW Water electrolysis project

1.2.1. Green hydrogen

Green hydrogen from renewable electricity is key to achieve the targets of the Dutch Climate Agreement (Klimaatakkoord). For 2030 there are plans to deliver 10 Gigawatt offshore renewable power production. Further there is an ambition to deliver 3 to 4 GW water electrolysis at that time – which provides approximately 400 kiloton per year hydrogen. The single concentrated sector that can handle hydrogen at this large scale is the process industry, that currently handles around 800 kiloton per year. Drop-in replacement is a fast solution to reduce industrial CO2 emissions, and further large-scale use of hydrogen in the industry will develop over time.

Achieving this requires significant upscaling. Currently water electrolysis is performed at the Megawatt scale (up to 10 MW operating, 20 MW being installed and projects for 40, 80, 100 and 250 MW announced). This is still about a factor 10 to 100 too small. The question is how to achieve this scale-up in a smart way that leads to cost reductions by a factor 3, needed to make hydrogen a competitive solution.

The ISPT Hydrohub Innovation Program carries out innovation to realize affordable green hydrogen at GW scale based on competitive Levelised Costs of Hydrogen. The GW water electrolysis project is the landmark project of this program that explores scaling-up. It delivers an optimised design and five regional blueprints, taking into account the need for dynamic operation to support balancing and grid stability due to intermittency in renewable electricity supply.

1.2.2. Aim

The target is to obtain the key insights to achieve a cost reduction for CAPEX from current 1,000 to 350 €/kW total installed costs.[1] This is achieved by developing and applying a science-based design approach and executing design cycles delivering five GW plant blueprints for the industrial clusters. This provides the perspective to deliver economically viable green hydrogen production on a GW scale by 2030.

[1] Electricity costs and availability of renewable electricity are important aspects for the business case but not included in this study.

1.2.3. Three parts

The GW-project consists of three coherent parts that together deliver a complete and optimized design tuned to the local requirements in the five industry clusters, see Figure 1: ISPT GW electrolysis project.

1. Part one brings a science basis and tools to support design optimization of electrolysers.
2. Part two focuses on business investigating the regional conditions for integration of GW water electrolysis facility in five industrial clusters.
3. Part three, focuses on design optimization and engineering across the full plant to achieve cost reduction.

The scope of this report is Part two.

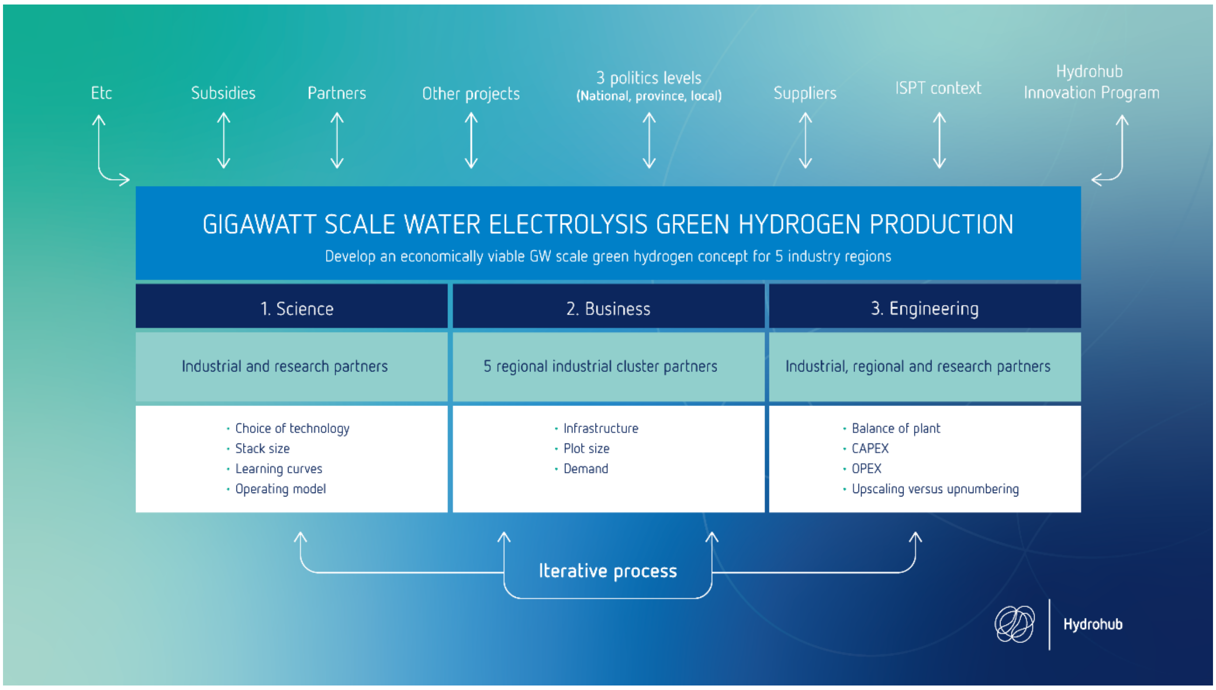


Figure 1: ISPT GW electrolysis project

1.3. This project

1.3.1. Five regions

In the GW project, regional cooperation with stakeholders is important to create the right conditions and enablers and necessary infrastructure with pipelines and electricity grid. Furthermore, interregional cooperation is organised by ISPT to share lessons learned, address common aspects, like included in this report, and accelerate the hydrogen economy.

The following five regions with its potential areas, stakeholders and main partners are involved in this project for integration of a 1-GW electrolyser plant, see Table 1. For each region, leading parties are assigned participating in GW project Part 2 (see in bold below the regional leads).

Table 1: Regional stakeholders and partners

Regions/Clusters	**Main areas**	**Regional stakeholders**	**Main companies/ partners**
Northern Netherlands	Eemshaven, Delfzijl	**Prov. Groningen** Groningen Seaports	Nouryon
Rotterdam	Rotterdam, Maasvlakte	**Port of Rotterdam** Deltalinqs, Provincie Zuid-Holland, Stedin, Gemeente Rotterdam	Nouryon
Zeeland/ Ghent North Sea Port	Terneuzen, Sluiskil, Vlissingen, Ghent	**Smart Delta Resources**, North Sea Port	Yara, DOW
Noordzeekanaal Area (NZKG)	Velsen/IJmuiden/ Amsterdam	**Port of Amsterdam** Provincie Noord-Holland, Gemeente Amsterdam	Tata-Steel
Chemelot	Chemelot	USG. Chemelot, Sitech	**OCI**
All regions		TenneT	GasUnie, Ørsted

1.3.2. Scope of work

This report looks at business opportunities and system integration in five industrial clusters in The Netherlands. To this end ISPT has commissioned consultants DNV GL, RHDHV and KWR to perform explorative studies as follows:

- Selection of potential site locations and boundary conditions resulting in plot plans in five regions;

- Exploring system integration aspects regarding grid connections, co-siting and hydrogen pipelines:
- Identifying cooling and demi water requirements, water supply and district heating opportunities

Division of roles, responsibilities and tasks is:

ISPT:	Project management, technical supervision, coordination
Regional leads:	Regional coordination, selection of locations and providing input
DNV GL:	Electricity grid connection/layout, study on locations, hydrogen demand and supply, and electricity and hydrogen infra
KWR:	study on water supply, cooling and district heating
RHDHV:	study on plot plans and description GW electrolyser, maps, safety

2. Basis of Study

2.1. Approach

The study comprises four steps, see Figure 2: Approach below: kick-off and preparation, workshops for the five industrial clusters, processing the information and elaboration of the results, and the consolidation of the five workshops into one report.

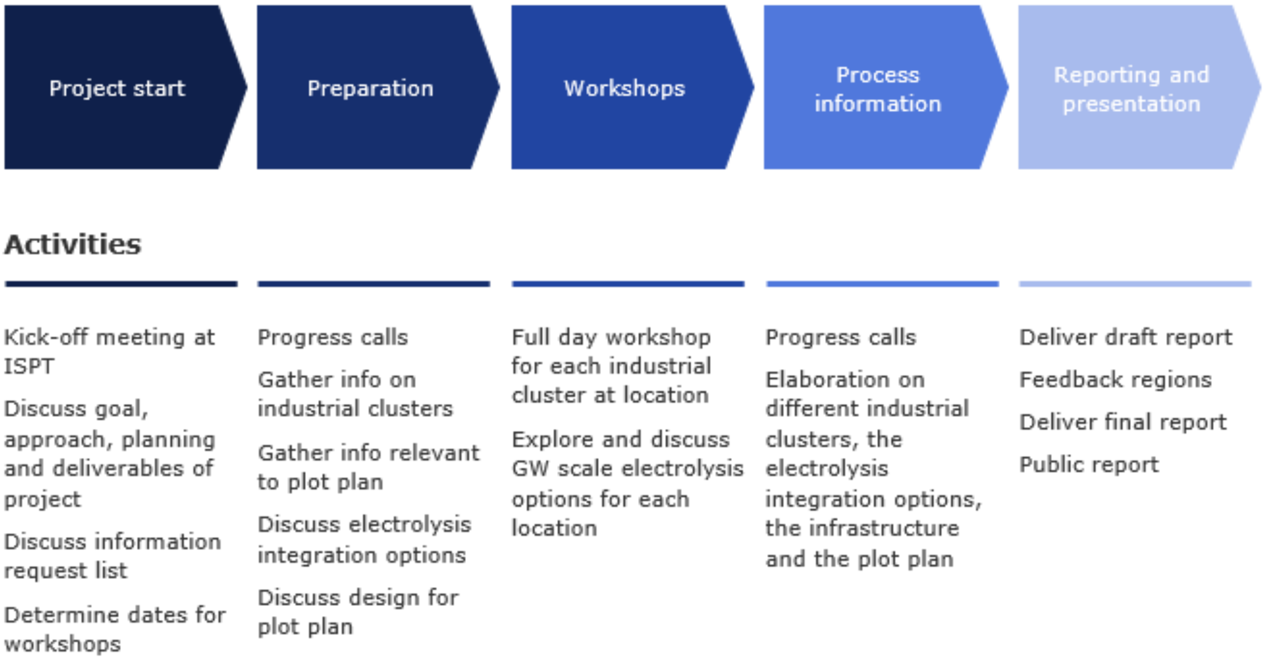


Figure 2: Approach

First a kick-off meeting has been organized (29 October 2019) with the partners and regions to be clear about the goal, scope, approach, deliverables and planning of the study. During the kick-off the information request that was shared before has been discussed, and the option of organizing workshops for each region considered. As a next step, the workshops haven been planned for each region, taking place at location. To prepare for the workshops, information has been gathered for the different regions, locations and infrastructure. Besides, the possibilities to integrate GW scale electrolysis has been discussed, together with potential layouts /plot plans. The plot plans for different designs (maximum and minimum case in terms of space, for both Alkaline and PEM electrolyser facilities) are presented in Chapter 3.

During the workshops with each industrial cluster, the options for a GW electrolyser installation has been discussed for the various potential locations. This way insight has been gained into (dis)advantages and (im)possibilities of the various locations. As a follow-up to the workshops, additional questions have been submitted to the different regions and partners.

The options and conditions for the realization and integration of GW electrolysis capacity has been explored by performing a quick scan, providing insights into required surface areas, site suitability and availability of (required) infrastructure. In the next paragraph, the generic inputs and assumptions will be explained that are applicable to all regions. The findings of this first assessment for each industrial cluster is reported in a separate chapter, see Chapter 4 - 8.

The chapter per region is organized as follows:

- First an overview of the different locations is presented, after which the main findings are summarized for the region. A map is presented to show the different locations per region, with the different infrastructure and connections .
- Second hydrogen demand and supply (developments) is provided for the region.
- Third, each potential location for GW electrolysis is presented in more detail. This includes:
    - A summary of the main findings.
    - Description of the location (landowner, available space, current use, permits, spatial planning).
    - Description of the different infrastructure. A map is presented depicting the different relevant infrastructure for the location[2], by distinguishing between existing infrastructure, planned infrastructure (i.e. there is commitment to realize infrastructure, investment decision has been taken), projected infrastructure (i.e. need for new infrastructure is foreseen, but until now no commitment / no investment decision), and finally required infrastructure (from the GW electrolyser installation perspective).

The **map** (ArcGIS) with results for all regions is accessible[3] via:

https://rhk.maps.arcgis.com/apps/webappviewer/index.html?id=d94d70425c6b4c6f88a8143eda028d11

2.2. Input and assumptions

One of the main starting points of this study is the development of a GW scale electrolyser facility. Currently, no such capacity exists, as the GW capacity indicates large scale electrolysis. Recently, the first (1 MW) electrolyser in the Netherlands for green hydrogen production was commissioned near Groningen. This is part of the HyStock[4] initiative. For the coming years, several plans have been announced for the development of pilots and (demonstration) plants of electrolysis in the Netherlands, like DJEWELS[5] (20-60MW), H2ermes[6] (100MW), and two 250MW plants in the Port of

[2] It should be noted that the different infrastructure depicted is indicative and based on a high-level assessment and does not necessarily represent actual or foreseen routings and trajectories. It merely indicates that new infrastructure, e.g. a pipeline or a 380kV connection, needs to be developed between location A and B.

[3] The link is publicly available until end of 2020.

[4] See https://www.gasunie.nl/nieuws/gasunie-zet-duurzame-energie-om-in-waterstof-met-eerste-1-mw-power-to-gas-installatie-van-nederland.

[5] See https://www.gasunie.nl/nieuws/consortium-nouryon-en-gasunie-wint-eu-steun-voor-groen-waterstofproject.

[6] See https://www.portofamsterdam.com/nl/nieuwsbericht/nouryon-tata-steel-en-port-amsterdam-werken-samen-aan-project-h2ermes-groene-waterstof.

Rotterdam area (of which H2-fifty)[7]. Afterwards, the capacity should be scaled up to about 3-4 GW by 2030 in line with ambitions as stated in the Dutch Climate Agreement[8]. Moreover, large-scale electrolysis is not entirely new. In 1940, the world's largest water electrolysis plant was built in Rjukan, Norway, with a total capacity of more than 30,000 Nm3/hour of hydrogen production from hydropower.[9]

Other starting points of the study relate to the GW electrolyser facility, the connection with required infrastructure (electricity, hydrogen, water), safety and hydrogen demand and supply. The input and assumptions related to those topics are further introduced and explained below in separate sections.

2.2.1. GW electrolyser facility

Two technologies are chosen to create plot plans for 1 GW electrolyser facility: Alkaline and Proton Exchange Membrane (PEM) water electrolysers.

The major components of plot plans include electrical infrastructure, electrolysers, gas & electrolytes separators, scrubbers, H2 compressors, deoxidisers, and other balance of plant.

For the standard concept design, the assumptions on spatial footprints of electrical layout, electrolysers and BOPs are indicated in this section.

Electrical layout

The electrical layout consists of

1. 380kV switchgears with 2 (or 3) incoming feeders for 380kV lines and outgoing feeders to inhouse transformers. It is assumed that the metering point (also called point of common connection) will be at the "incoming bays" of the electrolyser substation.
2. The transformers are used to bring down the voltage to 150kV (400MVA) and are placed in front/proximity of 380kV switchgears to ensure minimal cable routings, thereby optimizing CAPEX.
3. Further, 150kV switchgears are required which are feed by above mentioned transformers. The switch gears are preferably placed close to the transformers to provide minimal length of cable routings.
4. Static synchronous compensators (STATCOM) are placed for voltage stability.
5. The 150kV outgoing feeders of 150kV switchgears are fed to 6:150/33/33kV transformers (180/90/90MVA). These transformers are located adjacent to the edges of the electrolyser building to ensure minimal cable routings.
6. 33kV switchgears take incoming feed and supply the power to 33kV/400V transformers placed at the edges of the Alkaline electrolyser building. But, for PEM electrolyser building, the transformers are placed inside to create a more compact design.

[7] See https://www.portofrotterdam.com/nl/nieuws-en-persberichten/bp-nouryon-en-havenbedrijf-rotterdam-werken-samen-aan-studie-naar-groene.
[8] See https://www.klimaatakkoord.nl/.
[9] See https://nelhydrogen.com/about/.

7. The 33kV/400 transformer (11MVA) is placed inside a container along with 10MW diode rectifier, thereby providing flexibility to place them close to the electrolysers.

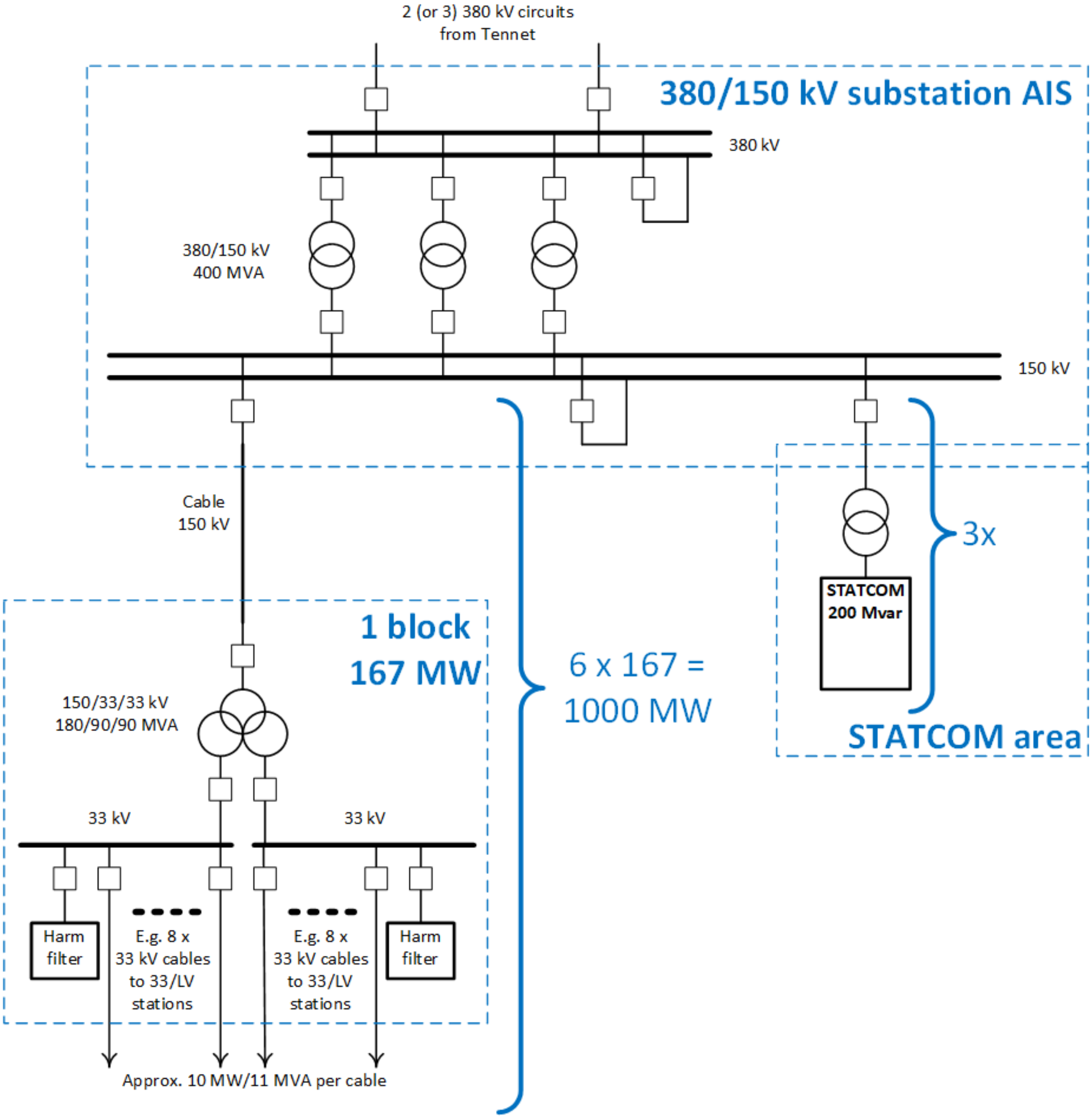


Figure 3: Single diagram diagram for electrolyser facility- Maximum case

The following components are considered in - **380kV/150kV/33kV/400V**. The size includes busbar, maintenance access and surrounding protection area (excluding cable routing space).

Component	Plot space (L x W)
Switchgears (AIS) 380kV	100x75 m^2 Incoming feeders 2 Outgoing feeders 9
Transformer 380/150kV 400 MVA	20x20 m^2 each Units 3
Switchgears (AIS) 150kV	150x60 m^2 Incoming feeders 3 Outgoing feeders to transformers 6 Outgoing feeders to statcoms 3
Statcom	50x50 m^2 each Units 3
Transformer 150/33/33kV 180/90/90 MVA	15x15 m^2 each Units 6
Switchgears (AIS) 33kV	40x15 m^2 each Units 6
Transformer 33kV/400V 11 MVA	15x5 m^2 each Units 100 Incl. diode based 10MW rectifier and 400V busbar to rectifier

Electrolyser building- modular sizing

PEM layout

The base layout of electrolyser building is proposed to contain; PEM electrolysers, rectifiers & transformers (11MVA) and O2- electrolyte separators. Other electric auxiliaries and pipelines are not detailed out at this stage of the project.

Table 2: Component setup for system configuration of 40MW, PEM.

Component	**Dimensions**	**Color**
10 MW stack	L-12m, W-1m, H-1,5 m Units 4	Green
Transformer 33kV/1kV 11 MVA	L-15m, W-5m Units 4 Incl. diode based 10MW rectifier and 1kV buswork to rectifier	Light brown
O2 & electrolyte separators	D-3,2 m, L-2m Units 4	Light blue
Electrolyser building	Plot space- 3 hectares	Green

Figure 4: Layout of PEM modules, 4 *10= 40MW total. depicts layout of PEM consisting of 10MW stacks, transformer & rectifier containers, and O2 separators.

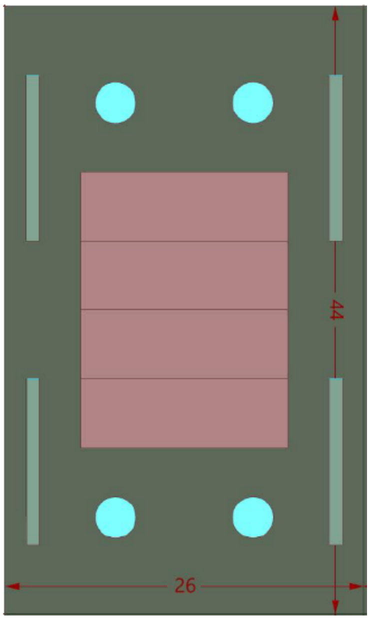


*Figure 4: Layout of PEM modules, 4 *10= 40MW total.*

Alkaline layout

The base layout of electrolyser building is proposed to contain; Alkaline electrolysers, H2- electrolyte separators and, O2- electrolyte separators. Rectifiers and transformers (11 MVA) are placed at the edges of the building. Other electric auxiliaries and pipelines are not detailed out at this stage of the project.

Table 3: Component setup for system configuration of 17,6MW, Alkaline

Component	**Dimensions**	**Color**
2,2 MW stack	D-2,5m, L- 12,5m Units 8	Green
Transformer 33kV/400V 11 MVA (placed externally	L-15m, W-5m Incl. diode based 10MW rectifier and 1kV buswork to rectifier	Light brown
O2 & electrolyte separators	D-3,2 m, L-14m Units 1	Light blue
H2 & electrolyte separators	D-3,2 m, L-14m Units 1	Light green
Electrolyser building (incl. adjacent rectifiers and transformers 11MVA building)	Plot space- 5 hectares	Green

Figure 5: Layout of Alkaline modules, 8 *2,2MW= 17,6 MW total depicts layout of Alkaline consisting of 10MW stacks, transformer & rectifier containers, and H2 and O2 separators.

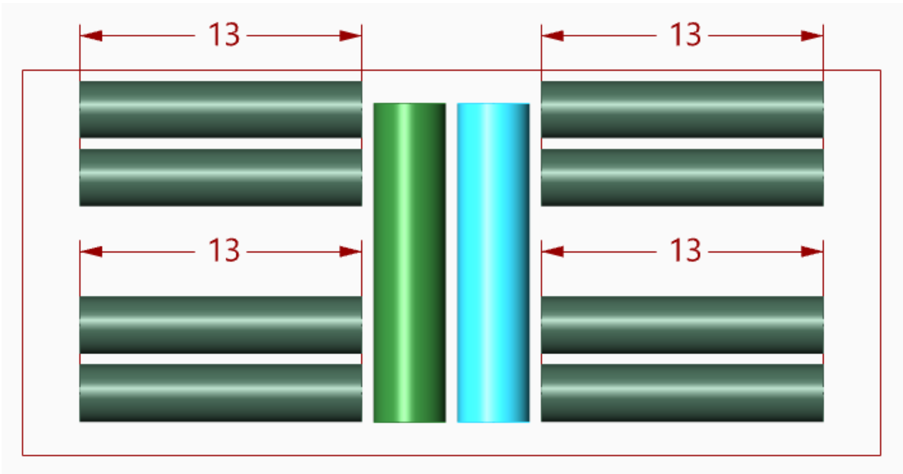


*Figure 5: Layout of Alkaline modules, 8 *2,2MW= 17,6 MW total*

2.2.2. Electricity infrastructure

The GW electrolyser facility is a large off taker of electricity and because of the high power flows a connection to the 380kV electricity grid seems most obvious. This could be the first connection of a consumer to the 380kV grid, as until now only generation (and HVDC interconnectors BritNed, NorNed and Cobra) is directly connected to the 380kV grid. A connection to the 150kV grid is possible, but would lead to additional barriers like insufficient transformer capacity (from 380kV to 150kV), limited available connection capacity at the substations at 150kV, and limited space for the 150kV connections between the substation and the location of the GW electrolyser facility.

The Dutch High-voltage electricity grid

Appendix A shows the electricity transmission grid in the Netherlands[10]. TenneT TSO B.V (TenneT) manages the high-voltage grid from 110kV and higher in the Netherlands (and large parts of Germany, TenneT TSO Duitsland B.V.). The 220kV and 380kV grids are known as the *koppelnet* and constitute the backbone of the electricity supply system, connecting electricity producers to consumers, and integrating electricity markets internationally via so-called interconnectors (cross-border connections, both via HVDC subsea cables and HVAC overhead lines)[11].

A number of developments are impacting the (further) development of the high-voltage grid, that are mainly related to meeting climate goals and the energy transition, further market integration, and economic developments. For instance, it is anticipated that demand for electricity will increase due to developments like growth of the ICT sector (e.g. data centres), and electrification of heat supply (e.g. heat pumps and electric boilers) and transport (e.g. electric vehicles).

The development of offshore wind also has an impact on the development of the high-voltage grid. In 2013 over 40 different parties concluded the National Energy Agreement[12], with the main target that 16% of energy must be generated from renewable energy sources by 2023. By 2030, around 70% of all electricity must come from renewable sources. Offshore wind plays a major role in the energy transition, with a target of 4.5 GW of installed power in 2023 (supplying 3.3% of all energy in the Netherlands) and around 11 GW in 2030 (about 8.5% of all energy). This should contribute to the climate agreement goal of reducing CO_2 emissions by 49% in 2030 compared to 1990 [1].[13]

As the offshore grid operator[14], TenneT has the task of ensuring that offshore wind farms are connected to the onshore grid. Until 2023, five wind farms will be realized of at least 0.7 GW each, being Borssele (2x), Hollandse Kust Zuid (2x) and Hollandse Kust Noord (1x). During the period 2023 – 2030, another 6 GW of offshore wind should be developed, as stated in the Routekaart windenergie op zee 2030 [2][15], being Hollandse Kust West (2 times 0.7GW), Ten noorden van de Waddeneilanden (0.7GW), and IJmuiden Ver (4 times 1GW), see overview in Appendix B.

[10] See also https://www.tennet.eu/nl/bedrijf/nieuws-en-pers/pers/netkaarten/.

[11] In the 1960s, the SEP (N.V. Samenwerkende Elektriciteits-Productiebedrijven, 1949 – 2000) took the decision to start developing the 380kV grid to meet the increasing demand for electricity due to economic growth. The 'first' 380kV ring was closed in the early 1990s.

[12] See https://www.rijksoverheid.nl/documenten/convenanten/2013/09/06/energieakkoord-voor-duurzame-groei.

[13] See https://www.klimaatakkoord.nl/.

[14] Announced in 2014 by Minister Henk Kamp of Economic Affairs, formally appointed in 2016.

[15] See https://www.rijksoverheid.nl/documenten/kamerstukken/2018/03/27/kamerbrief-routekaart-windenergie-op-zee-2030.

The grid connection of the GW electrolyser

For the grid connection of a GW electrolyser installation a 380kV connection seems most appropriate. Accordingly, it is likely that the GW electrolyser facility will be located somewhere close to the 380kV grid. There are different options to realize a 380kV connection, as one can differentiate in among others design (standard design versus compact design), intermediate voltage levels, level of redundancy, type of connection and future possibilities.

There are various options to further optimize this grid connection, for instance one can aim to maximize reliability, availability and maintainability of the connection, to minimize the spatial footprint or to minimize the CAPEX. For instance, it could be an option to use 380/132kV and 132/33kV transformers instead as 132kV is a more prevailing voltage level internationally.

There are several options to save space. Using gas insulated switchgears (GIS) instead of air insulated switchgears (AIS), one can save quite some space (at least a factor 2 should be possible). Further options to reduce space are to stack the equipment, and to adopt an offshore substation design. Of course, this has an impact on other factors like costs, the environment (SF_6), and maintainability.

Normally, a grid connection is requested by the grid operator. In general, TenneT provides connections with power greater than (approximately) 100 MW and the regional grid operators connections for less than (approximately) 100 MW[16]. Another option is to realize a direct connection between the GW electrolyser and a generator of electricity. This connection is non-regulated and without intervention of the regulated electricity grid, though it is allowed that one of the parties (either the generator or the consumer) is connected to the public grid. A direct line needs to be reported to the Dutch regulator ACM[17].

Related to this direct line, one could think to directly connect offshore wind to onshore demand for electricity. However, this is currently not allowed. Since TenneT has been appointed as the offshore grid operator, TenneT has the legal obligation to connect offshore wind farms to the onshore electricity grid on land. However, this could change in the future with more and more installed capacity of offshore wind. There is a proposal to amend the offshore wind energy Act to support the further development of offshore wind energy. Among other things, it proposes to allow the direct use of electricity generated by offshore wind energy in industry or on land for other energy carriers, without the requirement to realize a connection to the offshore grid or to the onshore high-voltage electricity grid[18].

In case the GW electrolyser will be directly connected to offshore wind, the grid connection depends on what voltage level is used for the transport cables. For the Dutch offshore wind farms, often 220kV AC will be used according the grid connection concept of TenneT. This implies that the 220kV AC needs to be transformed into 33kV AC, which requires less equipment, space and costs compared to a 380kV connection.

It could be an option to realize a DC-DC connection instead of an AC-DC connection. In case a direct connection with offshore wind will be allowed, it might be possible in the future to connect a large-scale electrolysis installation with offshore wind via HVDC cables. However, the offshore wind

[16] See https://www.tennet.eu/electricity-market/connecting-to-the-dutch-high-voltage-grid/which-connection/.

[17] See https://www.acm.nl/nl/onderwerpen/energie/netbeheerders/melding-directe-lijn.

[18] See Wijziging van de Wet windenergie op zee (ondersteunen opgave windenergie op zee) https://zoek.officielebekendmakingen.nl/kst-35092-3.html.

farm IJmuiden Ver will be connected to the onshore 380kV grid using 525kV DC transport cables and a 525kV DC / 380kV AC converter station. In this case there is still a conversion required via AC, leading to power losses, so for instance from 525kV DC to 380 kV AC to 150kV AC and lower voltages. Though it might seem more optimal to directly convert from DC to DC, this technology is not yet available. DC/DC converters do exist, but this technology is available for voltage levels up to tens of kV and some MVA, and not expected to become available for voltage levels up to hundreds of kV and MVA in the next decade.

Hydrogen in the electricity value chain

Converting power to hydrogen offers several attractive functionalities. A functionality of power to hydrogen is the potential to balance supply and demand of electricity on different timescales, as it can add flexibility[19] to the power system. Due to the shift from conventional generation based on fossil and nuclear fuels to renewable energy sources (e.g. solar, wind, hydro and geothermal), the share of controllable generation is expected to decease while the share of variable renewable energy sources like solar-PV and wind turbines will increase. Wind and solar are not dispatchable, meaning they generate electricity whenever the wind blows and the sun shines, even if the demand for electricity is limited. Overproduction of electricity can be curtailed, but a lack of production (e.g. during periods with high demand and low winds and no sunshine[20]) must be solved in other ways, for instance with dispatchable (fossil based) generation or storage. With the further electrification of demand, like heat demand, this effect will become more present. Power to hydrogen can provide flexibility to the electricity system[21], as hydrogen is quite easily converted from and to electricity and can be stored for a long time without significant losses. It can provide flexibility on different time scales, for instance to accommodate hourly, daily and weekly fluctuations in renewable generation and seasonal variations in renewable generation and demand. [3] [4]

Next to the value power-to-hydrogen can have in balancing supply and demand on the middle term (hours to days) by absorbing oversupply of generation, and on the long term (weeks) by providing a solution to store large quantities of energy, electrolysis could potentially also provide flexibility services to the power system on the short term (within the hour). Increasing fluctuation in residual demand[22] creates the need for rapidly available ramp-up and -down resources on both small and large scale. Electricity balancing services such as frequency containment reserves (FCR) and frequency restoration reserves (FRR) are essential for a safe operation of the power system. These services could be provided by electrolysers, as these are able to respond on a sub-second level. Electricity network operators could therefore use electrolysers to balance supply and demand. [5]

Next to the balancing function, power to hydrogen facilitates the further integration of the electricity and gas system, thereby enabling the optimization of infrastructure investments and the decarbonization of the gas sector. Converting electricity into hydrogen could reduce and prevent otherwise required reinforcements of the electricity grid. This is mainly because large parts of the current gas infrastructure could be reused while new electricity infrastructure should be built, andbecause investments in electricity infrastructure are relatively significantly higher compared to

[19] The ability to adapt electricity load and generation in time to changing circumstances.

[20] Often the term *Dunkelflaute* is used.

[21] Besides other measures like curtailment, storage of electricity, demand response, power to heat.

[22] Demand minus generation from variable renewable energy sources like wind and solar.

gas due the high energy content and density of molecules versus electrons. In addition, transporting the same amount of energy in the form of electricity requires much more space compared to molecules. One of the main conclusions of the Infrastructure Outlook 2050 was that "the location, capacity and operation of power to hydrogen installations are decisive factors and must be aligned with both electricity and gas TSOs" [4], implying that locating large scale electrolyser installations near renewable production facilities can reduce the need for electricity grid expansion. GW scale electrolysis increases the demand for electricity and could lead to or worsen infrastructural bottlenecks in case capacities and locations of the power to hydrogen installations are not properly aligned with the grids. For the Netherlands, this implies that in general locating large-scale electrolysis close to the connection of offshore wind seems plausible. This way, congestion and required grid investments could be reduced and avoided.[23]

Current governmental plans account for the rollout of about 11 GW offshore wind in the North Sea by 2030. The electricity grid should be capable to facilitate this amount of offshore wind, though part of this capacity might be connected further inland [2]. However, initiatives are being developed to increase this installed capacity significantly up to the year 2050 (like 60 GW). To accommodate such large amounts of offshore wind energy, power to hydrogen seems an inevitable solution. Enabling power to hydrogen (next to power to heat) in industrial clusters along the coast could support the system and potentially lead to lower investment costs by reducing the strain on the transport grid through the creation of demand at the point of feed-in, although reinforcement of the local grid might be necessary to support the added load. Additionally, the added demand could reduce the price risk for investments in further offshore wind development, enabling a faster transition to a sustainable system.

Finally, power to hydrogen provides decarbonization options to different sectors like industry in the form of sustainable feedstock for chemical and processing industries, and clean fuel for the transport sector and the built environment.

Cost of electricity infrastructure

The Capex assumed for electricity infrastructure is based on ballpark figures and is for indicative use. Further cost assessments are required to get a clearer picture of expected costs. The following Capex[24] is assumed:

- 380kV overhead line connection: 2,000 – 2,600 MVA capacity about 1.5 MEUR/km (including installation costs), dependent on among others routing[25].
- 380kV cable connection: 2,000 – 2,600 MVA capacity about 10 MEUR/km.
- 380kV substation: about 40-60MEUR, dependent on transformer and connection capacity.
- Capex of the grid connection of the baseline design (to the 33kV level) of the GW electrolyser is assumed to be around 35MEUR.

[23] Also steam methane reformers (SMR) could provide rapid ramp-up and down capacity to smoothen potential fluctuations of green hydrogen production related to offshore wind power, potentially reducing the need for short-term storage facilities and reinforcements of the electricity grid.

[24] Including installation costs, not including costs like project costs, permitting costs, land costs, contingency.

[25] In case of using Wintrack towers, Capex will be significantly higher, about a factor 3.

2.2.3. Hydrogen infrastructure

National hydrogen network (backbone).

Part of the Dutch natural gas transmission system (see Appendix C[26]), owned by GTS, is currently considered to be reused as a large-scale hydrogen network, called "the hydrogen backbone". The backbone will connect the large industry clusters to exchange their hydrogen demand and supply and give access to large scale underground storage. Changes in the Dutch energy system such as, phasing out of Groningen-gas, electrification, expiration of long-term supply contracts and the energy transition overall, will make significant transport capacity available. Many trajectories include multiple (GTS) pipelines for the transport of different gas[27] types, of at least 36 inch (about 15GW of transport capacity). This allows for repurposing existing gas infrastructure for hydrogen transport, alongside the natural gas system that will still be in operation. Next to the transport of hydrogen, it could be possible to reuse the existing infrastructure for other commodities like carbon dioxide. A visualisation of the hydrogen backbone till 2030 is illustrated in Figure 6.

Figure 6: Visualisation of the Gasunie hydrogen backbone. [source: Gasunie]

It can be seen from Figure 6 that the main part of the backbone consists of existing GTS infrastructure, and that some new dedicated hydrogen infrastructure has to be developed. These new pipelines are mainly required to connect to the industrial clusters in the Netherlands.

[26] See also https://www.gasunietransportservices.nl/netwerk-operations/het-transportnetwerk.

[27] Two gas types are transported by Gasunie (i) high calorific gas (H-gas) and (ii) low calorific gas (L-gas). The gasses are distinguished in gas composition due to their location or gasfield of origin, which results in different hydrocarbon concentrations and thus energy content. One of the specific low calorific gasses is the gas from the Groningen field, also known as "Groningen gas" (G-gas). Tis is the most common low calorific gas in the Gasunie network.

In 2018 the first hydrogen connection was commissioned in Zeeland, between DOW (hydrogen supplier) and YARA (consumer). This "show case project" considered existing natural gas pipelines and proved successful in the opportunity of re-using this infrastructure.

In addition to hydrogen transport, Gasunie set up the company HyStock, that focusses on the conversion of electricity to hydrogen and storage. HyStock is a first step to utilize hydrogen for integrating supply and demand in a sustainable energy system. Large scale storage should become available with underground salt caverns near Zuidwending (Groningen), where large volumes of hydrogen (roughly 250 - 500 GWh) can be stored under high pressure.

Uncertainties hydrogen network

Hydrogen transport through pipelines is already a proven technology and has been applied at large scale in the industry. However, there is still some uncertainty with respect to reusing natural gas infrastructure as this was specifically designed for natural gas transport. Research is being conducted focusing on topics as follows.

1. **Pipeline integrity**

   Pipeline integrity issues need to be further examined. Hydrogen could induce embrittlement and could influence resistance to steel fatigue. Steel with a high hardness is especially sensitive to these mechanisms. In 2017, DNV GL conducted a study on re-using the existing natural gas infrastructure and concluded that integrity would probably not be an issue [6]. *Strict monitoring and reduction of pressure cycles is however recommended. These findings are also supported by Gasunie.*

2. **Compression**

   Hydrogen properties strongly differ from natural gases, e.g. the mol mass is 8 times lower and transport is in the dense phase. Compressors in the existing natural gas network are not fit for the compression of hydrogen and need to be replaced. Velocity should be increased by 174% for the same increase of pressure [6]. *As the backbone pipelines are oversized for the expected throughput until 2030 and possibly beyond the operating pressure can be much lower than the design pressure, e.g. 30 bar instead of 68bara.*

3. **Safety**

   One of the most important topics is safety. Converting natural gas pipeline to hydrogen operation has a safety impact. This needs to be analysed.

4. **Quality**

   In addition, quality of the hydrogen is an important topic of investigation and includes water content, hydrocarbons and oxygen. Also, the contamination may be expected due to long term natural gas service even after cleaning.

Hydrogen distribution and connection to the backbone

The building and commissioning of the hydrogen backbone is expected between 2025 and 2030 and expected cost is approximately €1.5 billion. Technically the backbone could be ready by 2026 and the Northern part even in 2023 as stated by GTS, in case the final investment decision is made on a relatively short term (2021). Sufficient hydrogen supply and demand is required or should be expected in the foreseeable future to create the opportunity. GTS is a regulated organisation and is monitored by the Dutch Authority of Consumer and Market (ACM). The regulatory situation for GTS in hydrogen transport is still unsure and needs to be defined.

To bridge the gap and to connect hydrogen production to the backbone or the local consumers, additional infrastructure is needed. The exact trajectory and aspects of this connection will differ for each location, but a rough estimate is made to give an indication of the connection properties. Like the backbone and existing natural gas infrastructure, transport of hydrogen is considered in gaseous form, by pipeline. The design and dimensions of a pipeline are highly dependent on the type of gas, the operating conditions, the length of the pipeline and the maximum allowable pressure drop. Therefore, some rough estimations were made to give a range to indicate a range of the required pipeline diameters.

The estimation assumes an input pressure (from electrolyser) of 30-35 bar and a minimum outlet pressure of 25-30 bar (at the consumer). It is assumed that the distance between hydrogen production and backbone or local consumer will range from 15-45 km. For a 1 GW electrolyser, with a hydrogen production capacity of 200,000-220,000 Nm^3/h, this would require a pipeline of 14-18 inch.

In addition, the same assumptions were made for an oxygen pipeline, 30-35 bar in, 25-30 bar out, 15-45 km and an oxygen production of 100,000-110,000 Nm^3/h. A pipeline of 18-22 inch would be required for oxygen transport.

Cost of hydrogen infrastructure

The Capex assumed for hydrogen infrastructure (pipelines) is based on generic cost estimates and is for indicative use. Further cost assessments are required to get a clearer picture of expected costs[28]. The following Capex is assumed:

- For 14-18 inch diameter, about 1 MEUR/km (including installation costs)
- For 36 inch diameter about 2 MEUR/km (including installation costs)

2.2.4. Water infrastructure

The production of high-quality water for the GW electrolyser is a critical step in hydrogen production from water electrolytic process. Accordingly, various aspects of water supply and quality relevant to the project have been assessed as far as possible based on information available and gathered during consultations from the regional partners and stakeholders. The design of a suitable water treatment facility capable of ensuring supply of demineralised water (Demi water) depends on the water source and water quality required by the type of electrolyser, namely Alkaline and PEM electrolysers.

Although this study looked at some preliminary key aspects of water supply and infrastructure, the next step calls for a more detailed investigation to fill the gaps identified and meet the requirements to develop a concept design. For instance, a detailed inventory of the available/existing infrastructure, water sources and quality, future demands, security of supply,

[28] E.g. to account for costs depending on the trajectory.

waste and residuals management including treatment and discharge, water and wastewater permitting and other regulatory guidelines, supply and discharge of cooling water.

Basis of design for water supply

The preliminary basis of design for the water supply system as agreed by the ISPT project team is shown in Table 4 below.

Table 4: Water quality and quantity requirements to the Electrolyser and Cooling system

Criteria	Range	For design	Unit
Feed water quantity to Electrolyser	200 - 215	215	m^3/hr
EC to Alkaline Electrolyser	1.0 - 2.0	1.0	µS/cm
EC to PEM Electrolyser (acc. ISO 3696 STANDARD GRADE 2)	0.1	0,1	µS/cm
Raw water to WTP (50-70%)	310 - 430	430	m^3/hr
Waste/concentrate stream	110 - 215	215	m^3/hr
Potential heat recovery	250 - 300	250	MW
Water demand for open recirculation cooling tower (Recirc. Cycle 5)	375	375	m^3/hr
Water demand for one-through cooling (ΔT = 6 °C)	35,850 - 43,000	43,000	m^3/hr
Water demand for one-through cooling (ΔT = max 8 °C)	26,900 - 32,300	32,300	m^3/hr

The feed water flow rate to the Electrolyser is set by the Manufacturer based on the type of electrolyser. The electrolyser feed water will be guaranteed for 365 days and 24 hours/day. Depending on the water source and quality of the source water, treatment options will be considered to meet the electrolyser feed water demand.

As shown in Table 4 above, the required water electrical conductivity (EC) for the Proton Exchange Membrane (PEM) is much stricter than the Alkaline Electrolyser, namely 0.1 µS/cm compared with 1.0 µS/cm. Although additional water parameters are yet to be confirmed by ISPT, it was agreed that at this stage of the project, EC values alone are a good starting point for the conceptual design.

Water treatment cases

The water quality requirements are set by the type of electrolyser to be installed. To achieve the required water quality for the electrolyser demands a level of treatment which is dependent on the source of water. Therefore, understanding the type of water source is critical to ensure that the appropriate treatment scheme is in place to produce the desired feed water to the electrolyser.

Various water sources were explored in the five regions to sustainably provide the feed water to the electrolyser after treatment. These are demineralised water, tap water, seawater, surface water, brackish groundwater and treated sewage effluent.

For each of the above types of water, a treatment process scheme was developed based on existing and innovative technologies to produce the required water quality to be fed to the electrolyser. Table 5 below shows the treatment scheme and the associated ancillary units proposed for each type of water.

Table 5: Treatment process scheme for each type of water

Treatment process scheme		Water source						
No.	**Treatment technologies**	**Demin water**	**Tap water**	**Seawater**	**Surface water**	**Brackish groundwater**	**Brackish water (estuary)**	**Treated sewage effluent**
1	Chlorination and Dechlorination				Y			Y
2	Coagulation and Flocculation			Y	Y		Y	
3	Media Filtration/Disolved Air Flotation Filtration			Y	Y		Y	Y
4	Microfiltration/Ultrafiltration			Y	Y		Y	Y
5	Nanofiltration/IonExchange softening (WAC)		Y	Y			Y	
6	Reverse Osmosis/Membrane Distillation		Y	Y	Y	Y	Y	Y
7	ElectroDeIonisation/Mixed Bed Ion Exchange	Y	Y	Y	Y	Y	Y	Y
	Ancillary units							
8	Waste stream	Y	Y	Y	Y	Y	Y	Y
9	Chemical dosing	Y	Y	Y	Y	Y	Y	Y
10	Holding/Storage tanks	Y	Y	Y	Y	Y	Y	Y
11	MCC	Y	Y	Y	Y	Y	Y	Y
12	SCADA	Y	Y	Y	Y	Y	Y	Y
	Remarks/Comments			High waste stream produced		Relatively high waste stream produced		Chlorination is yet to be confirmed

Nomenclature:

Y – Yes required; UF – Ultrafiltration; MF – Microfiltration; NF – Nanofiltration; RO – Reverse osmosis; MD – Membrane distillation; CEDI – Continuous electro deionisation; MCC – Motor control centre; SCADA - Supervisory control and data acquisition

A high-level multi-criteria analysis (MCA) was conducted to assess the various water treatment options for each water source considering criteria such as cost, efficiency, durability/robustness, ease of operation and maintenance, environment and social considerations. This MCA is discussed in Appendix D.

Heat recovery and usage

It is expected that the waste heat from the electrolyser will be recovered using a cooling water system. The waste heat of 250 MW generated by the Electrolyser will pass through a cooling water system where the heat will be recovered for potential usage. The important considerations for the project cooling water system are listed.

A substantial amount of cooling water is required to cool down the 250 MW waste heat. Preliminary water demand for the cooling system with 5 recirculation cycles amounts to 375 m^3/h (including a blowdown of 75 m^3/h). In the case of once-through cooling, the water demand is between 32,000 – 43,000 m^3/h.

The intake and discharge points of the cooling water with respect to the location of the electrolyser plant are key to assess the viability of the heat recovery and usage option.

There could be potential interest in using the heat recovered for district heating. Connection to the existing infrastructure is an important consideration to maximise the viability of this prospect.

Heat recovery for demin water production from brackish or seawater, like Membrane Distillation, is worthwhile examining as this could avoid or reduce cooling system requirements and thermal discharge.

The possibility of co-siting exists in many locations where existing assets can be used to support the cooling water system. For example, in a few locations, old coal fired plants that would be decommissioned in the coming years have cooling water system that could be beneficial to the GW Electrolyser project. These existing cooling water systems can be assessed for potential re-use.

Therefore, discussions with these partners and companies need to happen well before the decommissioning of the coal fired plants so that the any reusable assets can be retained.

Cost of water infrastructure

Table 6: Capex used for water infrastructure below list the Capex assumed for water infrastructure, based on a high-level estimate of costs of water supply, treatment and discharge as well as waste heat water cooling system. The details of the Capex for each location selected in the respective region are shown in Appendix E.

Table 6: Capex used for water infrastructure

Description	Capex rate
Pipeline (mm/dia/m length)	€ 1,00
WTF, source sea water (per m^3/d)	€ 3.000
WTF, source surface water (per m^3/d)	€ 1.500
WTF, source tap water (per m^3/d)	€ 750
EDI polishing, source Demi water (per m^3/d)	€ 375
Cooling water intake station (per m^3/d)	€ 75
Cooling system (per kW)	€ 60

2.2.5. Safety

An important issue in the ISPT GW water electrolysis project is to determine safety distances regarding the plot of the facilities and the surroundings. Also, dispersion calculations for oxygen venting would be necessary regarding fire prevention. An analysis on effect distances which are likely to occur after a loss of containment of hydrogen from the proposed 1 GW electrolyser plant needs to be performed based on acceptance criteria which are often used in the industry in The Netherlands:

1. Maximum effect distance (irrespective of probability)
2. Maximum credible effect distances (effects that are likely to occur during the lifetime of the facility.
3. Risk based distances (Individual risk, location specific risk, etc.)

Scenarios like fire and explosion, and releases of oxygen and hydrogen and liquid spills need to be assessed. Also, the effects from fire, deflagration/ detonation need to be determined regarding radiation and pressure waves with possibly secondary effects. More design information which is not yet available in this phase of the project is required to calculate gas volumes and analyse scenario's and effects. This includes for instance causes which potentially could lead to explosive hydrogen-oxygen mixtures, line breaks and vessel ruptures. Therefore, safety aspects will be addressed and detailed in the course of the Design Part 3 of the ISPT GW electrolysis project.

2.2.6. Hydrogen supply and demand

The hydrogen supply and demand are estimated by:

1. A study to current hydrogen supply and demand in 5 industrial clusters in the Netherlands [7], including industry plans and regional studies of the different industry clusters.
2. A Study by ISPT, Hydrohub HyChain 1 to estimate future hydrogen demand [8].
3. An inventory part of this study.

Current hydrogen supply and demand

Recognizing the need for updated data on hydrogen supply in the Netherlands, the 2019 supply from the five largest industrial clusters in the country (where the majority of hydrogen is produced) was analysed, using among others the Roads2HyCom study as starting point [7]. Work is ongoing to further update the figures, and based on recent information the following hydrogen production capacity is presumed adding up to 1,575 kton/a[29]:

- Eemshaven-Delfzijl (Northern Netherlands): 150 kton/a
- Noordzeekanaal Area: 80 kton/a
- Rotterdam (incl Moerdijk): 580 kton/a
- North Sea Port – Sealand: 550 kton/a
- Limburg – Chemelot: 215 kton/a.

Future hydrogen demand

ISPT previously coordinated the HyChain 1 study [8] to explore the possible future role of hydrogen in different end-use sectors in the Netherlands. The prime focus was on industry sector for which potential demand was projected until 2050. Additionally, expected adoption of hydrogen was studied in adjacent sectors: built environment, agriculture and mobility.

Data from literature review and a series of interviews with stakeholders from the different sectors was used to perform an end-use sector-based analysis. The assumptions were based on the current energy use, thereby, no growth in energy demand was assumed. In the maximum H_2 scenario a high uptake of hydrogen is expected across all sectors leading to roughly 1,600 PJ or 13 Mton/yr.[30]

The study gave two figures (i) for hydrogen demand per sector across the Netherlands as a whole (ii) and the respective share per cluster for each sector. With these two figures combined, an estimate could be generated for the hydrogen demand per sector and cluster (see Appendix F). For example, half of the max assumed demand in 2050 would originate form the industry cluster in Rotterdam.

It is much more difficult to predict the hydrogen demand on the short and medium term in 2030, since this is depending on business cases, government policies and infrastructure, which are not yet there.

[29] E-mail communication DNV-GL to ISPT 12/5/2020
[30] Calculated with lower heating value 120 MJ/kg

Hydrogen supply and demand in this study

The annual production of 1GW water electrolysis facility is estimated roughly at:

- 90 kton/a hydrogen
- 200,000 Nm3/h hydrogen
- 720 kton/a oxygen
- 100,000 Nm3/h oxygen
- 200-300 MW low value heat (<80degC)

This is based on 1GW power input, 5000h/a, and new stacks. The assumed operating mode is flexible load with minimum load 15%. The annual 5000 h are full load hours, of which 4000 h/a from 2018 profile from Northsea windfarm [31]. We consider 1000h/a back-up power (with certificates) to meet the 15% min load, increasing hydrogen output and minimising degradation effects on electrolyser stacks. Moreover, full load hours tend to increase with larger and higher wind turbines over time.

The existing hydrogen consumption in the Netherlands in 2019 is 1,5Mton/a[32]. In the workshops potential demand for 1GW green hydrogen in five industrial clusters has been explored. Potentially, in all industrial regions (existing) demand is sufficient to take-off 1GW green hydrogen each, provided there is a business case and all conditions are in place. In the following table for each region existing industries are indicated, which could take-off up to 90 kton/a hydrogen or more at competitive levelised costs of hydrogen. For each region this will be more elaborated on regional level in the sections 4-8. Also, additional demand could develop like power plants and cleantech companies investing in new industrial facilities, e.g. synthetic fuel (kerosine) plants.

Region	Existing industries
Noordzeekanaal Area	Steel plant, Power plants
Chemelot	Ammonia plant
North Sea Port	Ammonia plant, Chemical plants, Steel plant, Cogens, Refinery, Methanol plant
Northern NL	Methanol plant, Power plants
Rotterdam	Refineries, Chemical plants, Biofuels plant, Power plants, Cogens

[31] Ørsted, 950MW Northsea wind farm, 2018

[32] DNV GL, personal communication (TIKI), 2020.

3. Plot plans

3.1. Minimum and maximum cases

The plot plans for PEM and alkaline based electrolyser facilities are elaborated in this chapter. In addition to electrolyser space optimization, also size reduction of electrical layout is explored.

Two cases are proposed to create a better understanding of minimum and maximum plot sizes:

1. Maximum case, entails standard design
    a. Air insulated 380kV switchgear and 380/150/33 kV transformation
    b. Electrolyser building level- ground floor
    c. Atmospheric electrolysis (Alkaline) and mechanical compression
2. Minimum case entails compact design where options to reduce plot space for electrical layout & electrolysers are evaluated.
    a. Gas insulated 380kV switchgear and 380/33 kV transformation
    b. Electrolyser building level- ground + 1 floors
    c. Pressurised electrolysis with reduced size of H2 compression units

The two cases are prepared for PEM based and Alkaline technology. Table 7, depicts an overview of space acquired by major components in the plot plans. Further, Figure 7: Overview of plot space- maximum & minimum cases. visualizes space utilization in decreasing order of magnitude from bottom to top by various components in plot plans. The plot plans and dimensions can be found in section 3.4 and annex N-Q.

Note that the actual plot size is higher due to extra space required to fit all components in one rectangular plot. Also, some space is required for roads, pavements and other infrastructure.

Table 7: Overview of plot space- maximum & minimum cases (units in hectares)

	Max case Alkaline	**Max case PEM**	**Min case Alkaline**	**Min case PEM**
Electrical instruments	6.4	6.4	3.2	3.2
Electrolyser building *[33]	6.5	3.0	3.5	1.5
Demi water & cooling tower units	1.0	1.0	1.0	1.0
Offices & other buildings	0.4	0.4	0.4	0.4
H_2 units downstream electrolyser	0.7	0.3	0.5	0.3
Total	14.9	11.0	8.6	6.4
Plot size	**17**	**13**	**10**	**8**

[33] Electrolyser building includes required space for rectifier (10MW) and transformer (33/0.4kV). 100 units of this setup is included in the building.

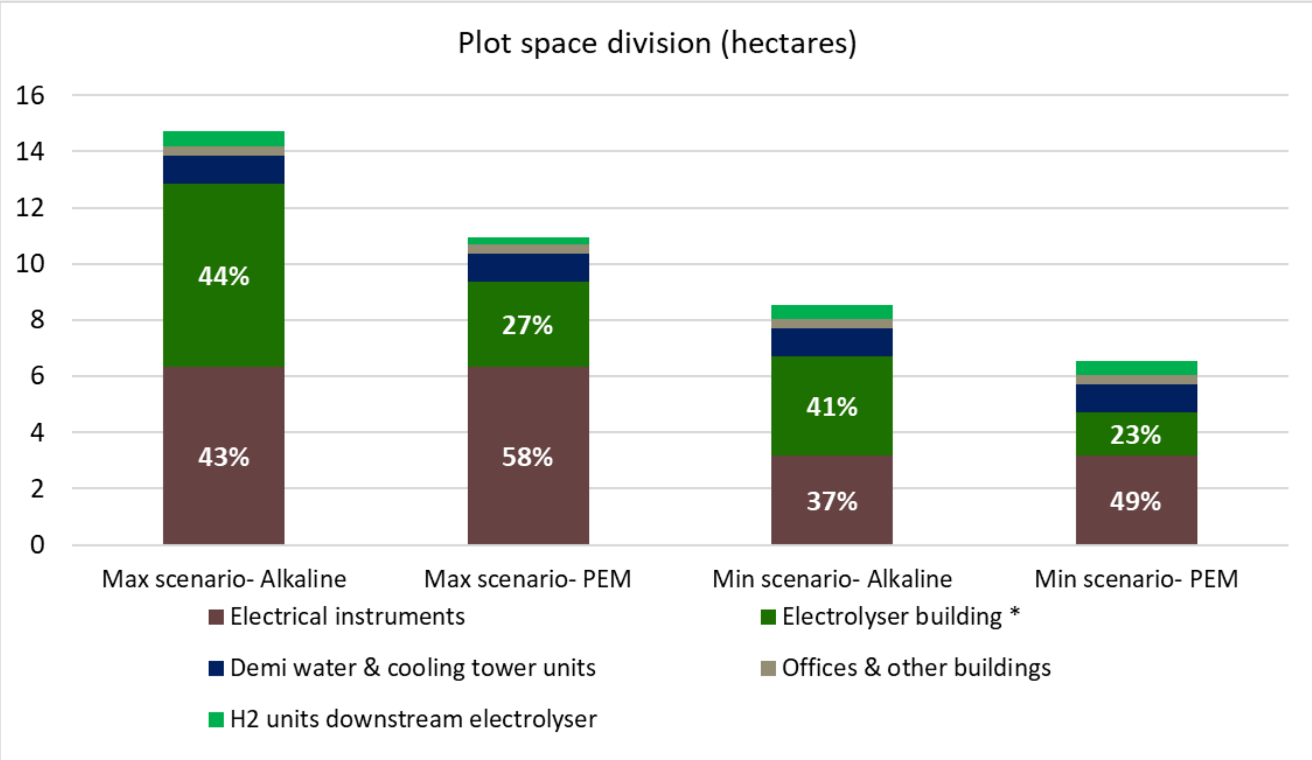


Figure 7: Overview of plot space- maximum & minimum cases.

As seen in the figure above:

- Electrical instruments require similar footprints as compared to Alkaline electrolyser building (including rectifiers and 33kV transformers).
- PEM electrolysers offer significant savings in space as compared to Alkaline electrolysers. The spatial footprint of PEM building is less than half of Alkaline electrolysers building.
- The use of 380kV GIS instead of 380kV AIS offer significant savings in space.
- Further, direct transformation of voltage from 380kV to 33kV offer a large amount of saving potential for plot area.

3.2. Electrical layout

The plot space used for each component of electrical infrastructure is mentioned in Annex N-Q. These values are used to estimate plot space for the maximum cases of PEM and Alkaline plants. However, for minimum case, following changes have been proposed;

380/33kV Transformers- Instead of earlier mentioned 380/150/33 kV transformation of voltage, a direct conversion to 33kV is proposed. The direct conversion is technically feasible but could require more cables & cable routings. This will save huge amount of space required otherwise, for 150kV switchgears and 380/150kV transformers.

Gas insulated switchgears (GIS)- In the minimum case, GIS is used instead of traditional AIS. This could reduce the space needed for switchgears by one-third.

However, the proposed measured need to be accessed in detail regarding their technical feasibility. GIS is widely used, yet it uses SF6 which is a greenhouse gas[34] . Technology break through will be crucial to find alternatives for SF6 in order to make the GIS eco- efficient. Suppliers are looking for alternatives for SF6 in their GIS products portfolio.[35]

Following components are considered in Minimum space case- **380kV/33kV/1kV**. The size includes busbar, maintenance & operation, and surrounding protection area (excluding cable routings space).

Table 8: Overview of electrical components- minimum case

Component	Plot space (L x W)
Switchgears (GIS) 380kV	60x70 m^2 Incoming feeders 2 Outgoing feeders 9
Statcom	50x50 m^2 each Units 3
Transformer 380/33/33kV 180/90/90 MVA	20x20 m^2 each Units 6
Switchgears (AIS) 33kV	40x15 m^2 Units 6
Transformer 33kV/400V 11 MVA	15x5 m^2 each Units 100 Incl. 10MW rectifier and 1kV busbar to rectifier

Figure 8 demonstrates, single line diagram of the electrolyser facility for maximum and minimum cases. As mentioned earlier, for maximum case 380kV/150kV/33kV/1kV intermediate transformers are used with traditional AIS. Whereas, for minimum case 380kV/33kV/1kV intermediate transformers are used with GIS for 380kV.

[34] https://energypost.eu/grid-switchgear-uses-sf6-the-worlds-most-potent-greenhouse-gas-how-do-we-regulate-it/

[35] https://new.abb.com/high-voltage/gis/eco-efficient-gas-insulated-switchgear

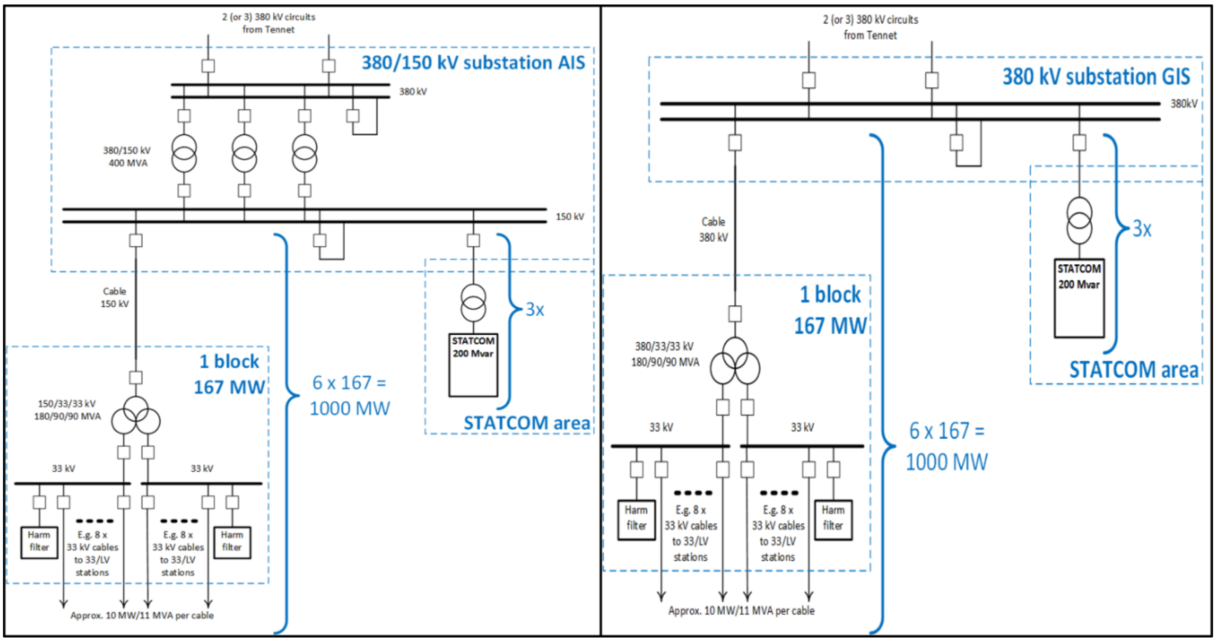


Figure 8: Single line diagrams for the electrolyser facility- maximum & minimum cases

3.3. Electrolysers building

For the maximum case, layout as depicted in Figure 4: Layout of PEM modules, 4 *10= 40MW total. is used with electrolysers set up on ground floor level inside the electrolyser building. Whereas, for minimum case, ground +1 floors level are assumed for electrolyser building which potentially, could reduce the plot space by half. However, the feasibility of this case from design and engineering perspectives shall be accessed. Figure 9 depicts the difference between the cases for PEM based electrolysers building.

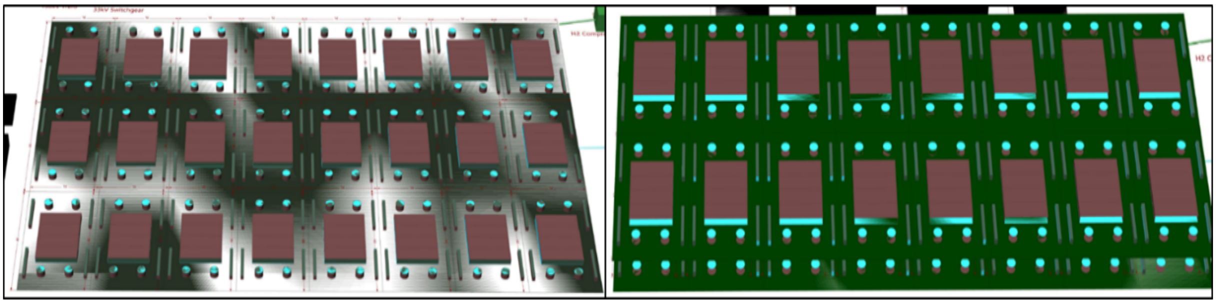


Figure 9: Maximum vs minimum cases for PEM electrolyser building.

Figure 10 depicts, the difference between the cases for Alkaline based electrolysers building. Maintenance and operational space (3-5 metres) is provided between stacks. Also, space required for heat exchangers and scrubbers are provided between each set of electrolyser stacks.

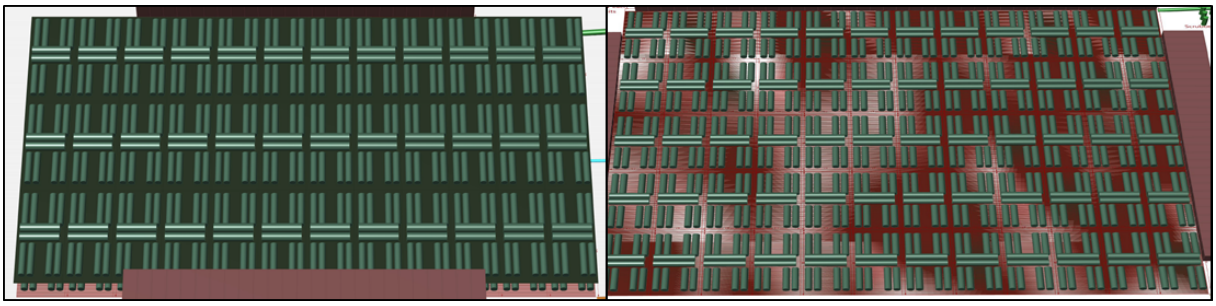


Figure 10: Minimum vs maximum cases for Alkaline electrolyser building.

It should be noted that no attempt is made to optimise the cable and piping routing. Also, safety requirements are not considered. The building dimensions are only for indication of space requirements. The width/length ratio of the actual building and hence plot plan could be different.

3.4. Overall plot plans

The plot plans for 2 cases are shown in this section for the GW electrolyser facility. Construction access, maintenance & operational access around the infrastructure are made available (white spaces in between the layout)

3.4.1. Maximum case

Figure 11-12: Plot plan Alkaline- maximum case

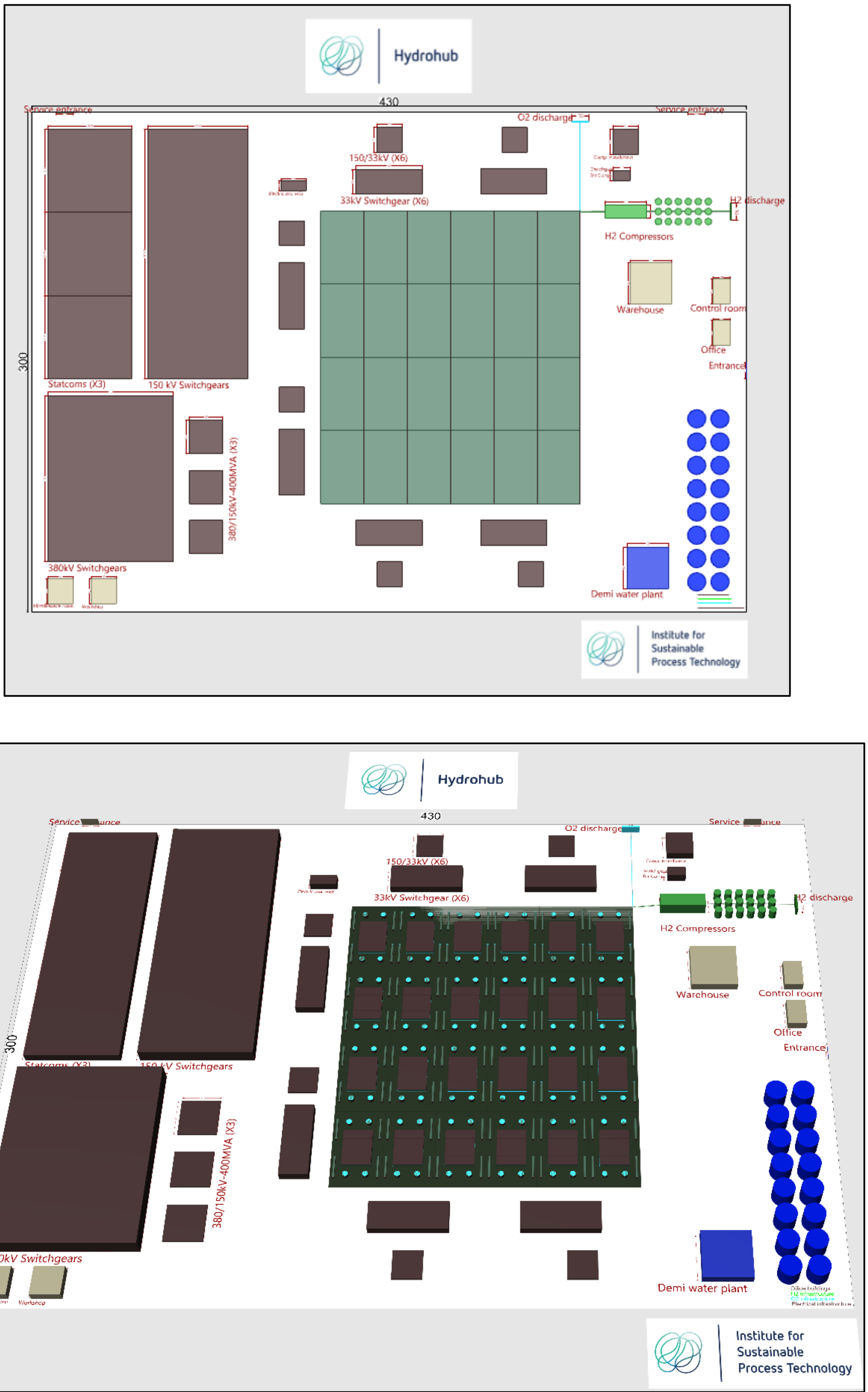
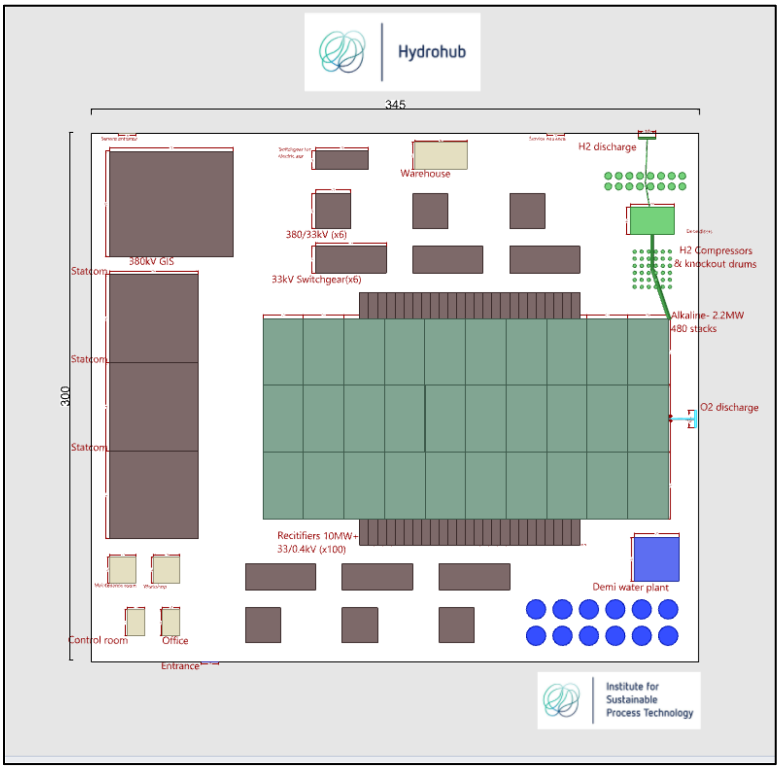
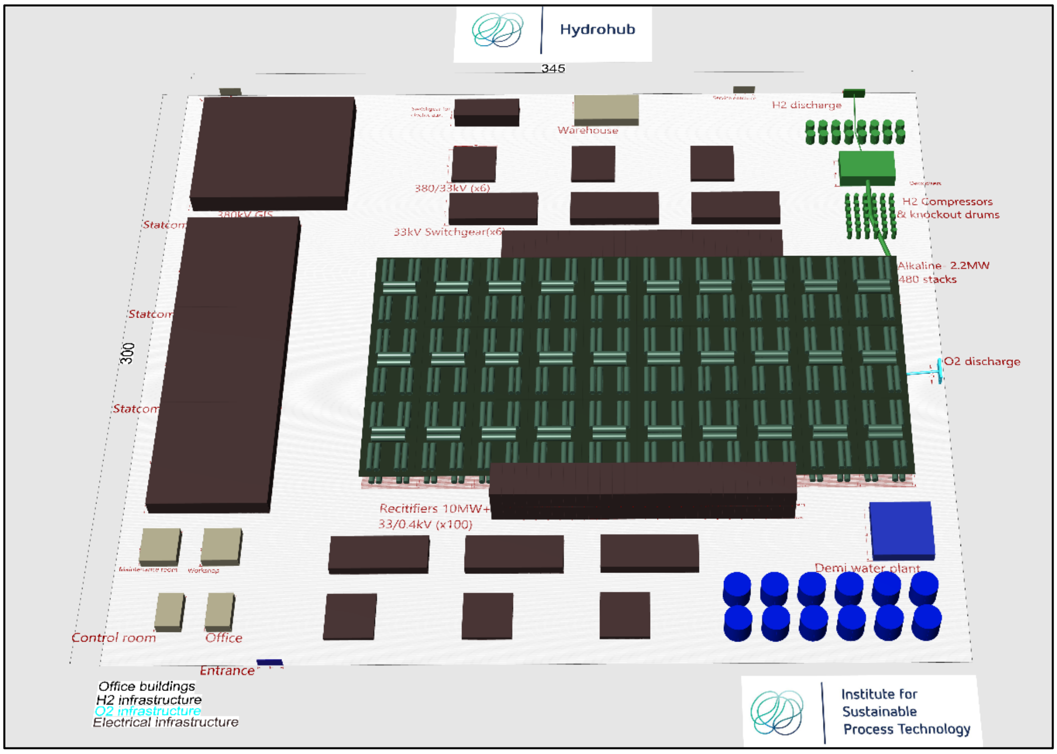


Figure 13: Plot plan PEM- maximum case

3.4.2. Minimum case





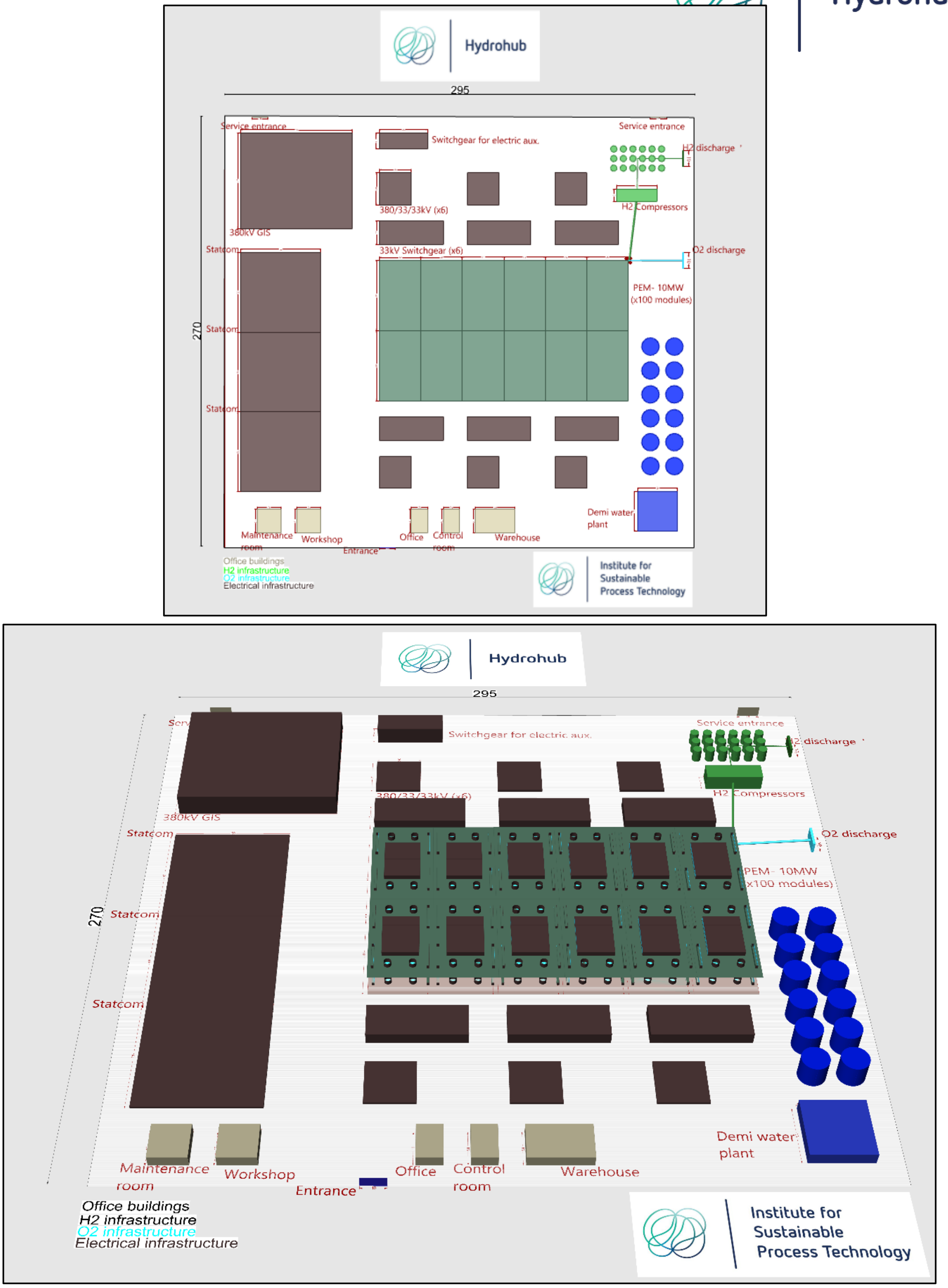


Figure 15:Plot plan PEM- minimum case

4. Noordzeekanaal Area

For the Noordzeekanaal area (Noordzeekanaalgebied - NZKG), four different locations are considered for large-scale electrolysis: the Hemweg location near the Vattenfall power plant, the Bosweg location near Tata Steel IJmuiden, and (indicative) locations near the crossing of the 380kV grid and the hydrogen backbone (Beverwijk and Spaarndam). Figure 16 provides an overview of the potential locations for the Noordzeekanaal Area. For more (spatial) information regarding the locations see Appendix G.

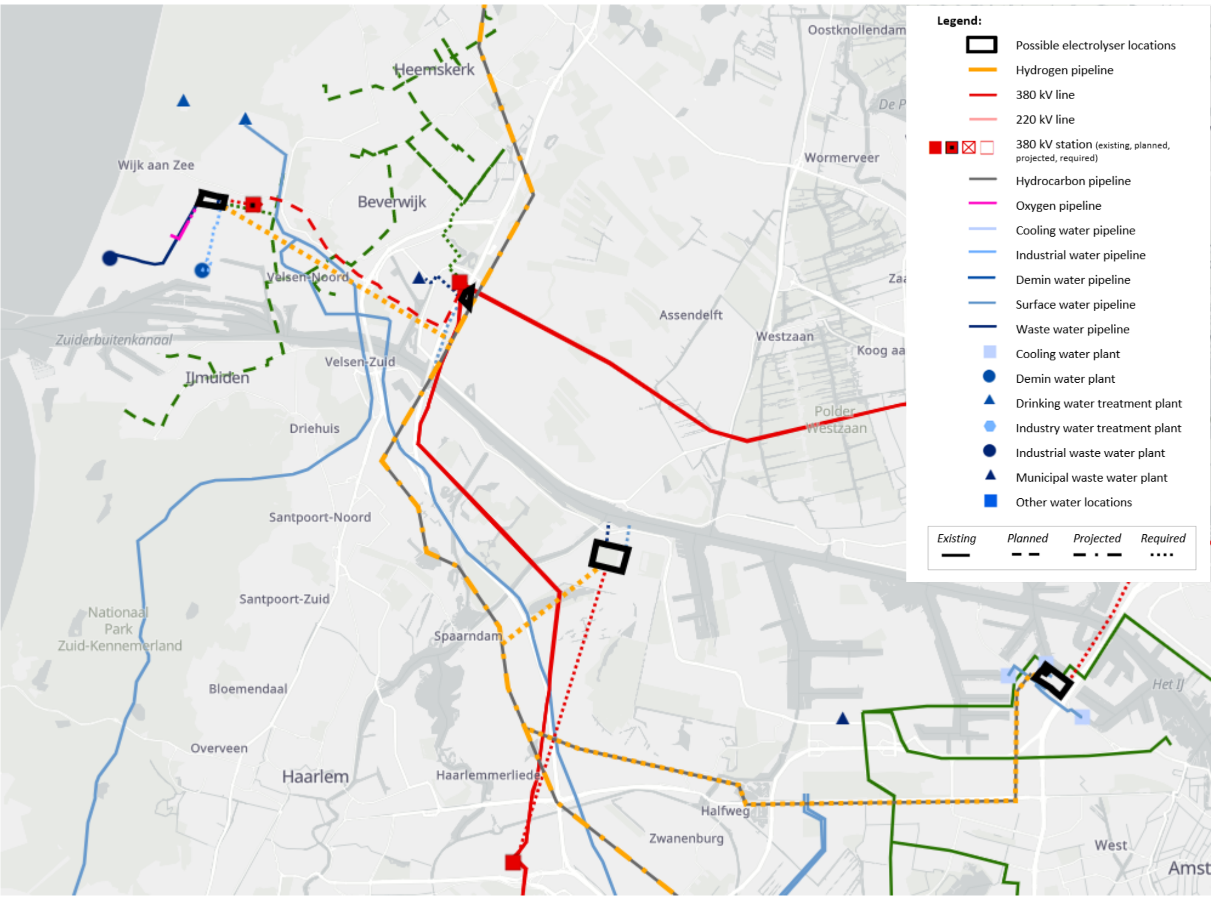


Figure 16: Overview of potential locations Noordzeekanaal Area (indicated by the dark rectangles)

4.1. Summary of findings

An overview of the findings per location for the Noordzeekanaal Area is presented in Table 9. Based on the available information, the following preliminary key observations can be determined:

- Regarding the available space and suitability of the locations, it seems that Hemweg has sufficient space in case of demolition with potential reuse of assets; for other locations is not clear yet as available space and permit requirements is not known for Beverwijk and Spaarndam, and Bosweg/ Tata requires more attention regarding (potential) permitting and social acceptance.

- Regarding critical infrastructure – e.g. water, electricity and hydrogen – it seems that Bosweg/Tata and Spaarndam have good connections whereas Hemweg require 380kV connection and substation

Table 9: Overview of findings per location Noordzeekanaal Area[36]

Location	Hemweg	Bosweg	Beverwijk	Spaarndam
Space	About 12-17 ha. Probably would fit due to reuse of existing assets.	Available space not fully clear. Requires compact design.	Available space not known.	Available space not known.
Suitability	Industrial location. Owned by Vattenfall.	Ownership not clear. Industrial location, but there is public resistance and location is next to Zeestraat.	Ownership unknown. Currently mainly agricultural land. Spatial planning unknown.	Ownership unknown. Currently mainly forest and agricultural land. Spatial planning unknown.
Water supply	Water source available and can be treated to meet Electrolyser water quality targets.	Only one water source is via Tata. Water can be treated to meet Electrolyser water quality targets.	Unknown water source.	Unknown water source.
Electricity supply	150kV not sufficient. Requires 380kV connection. This is not projected and needs to be investigated.	New 380kV station planned and upgrade foreseen.	Close to 380kV substation Beverwijk. But probably no sufficient connection capacity, which requires extension.	Requires 380kV connection to nearby 380kV substation Vijfhuizen, about 5-10 km.
Hydrogen infra	About 10-15 km from backbone. Unknown if existing infra can be used. Connection to	About 5-10 km from backbone. No potential existing infra identified. Connection to	Next to backbone, could be realized by 2030.	About 2km from backbone, could be realized by 2030.

36 For an explanation of the colour scheme, see Appendix M.

Location	Hemweg	Bosweg	Beverwijk	Spaarndam
	backbone could be realized by 2030.	backbone could be realized by 2030.		
Hydrogen demand	Potential demand at Hemweg Powerplant	Can be consumed by Tata Steel IJmuiden.	No demand in vicinity.	Close to potential demand port area.
Oxygen demand	No demand in vicinity.	Can be consumed by Tata Steel IJmuiden.	No demand in vicinity.	No demand in vicinity.
District heating	There is heat demand in vicinity.	No demand in vicinity.	No demand in vicinity.	No demand in vicinity.

As an example, the plot plan is depicted at the Bosweg location in the Figure 17. The available plot space is sufficient for PEM and Alkaline based electrolysers facility with regards to **the minimum case.**

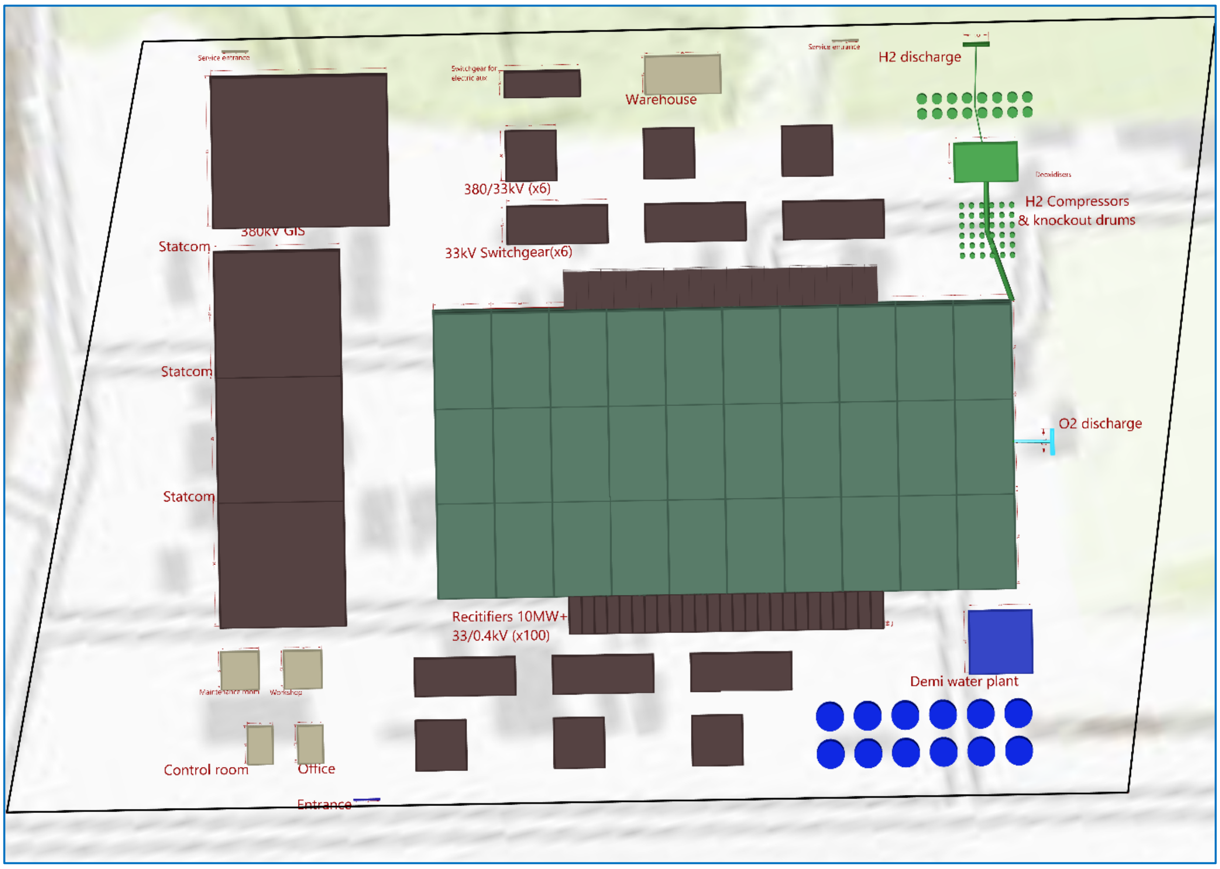


Figure 17: Plot plan - Bosweg

4.2. Hydrogen demand and supply

The Noordzeekanaal area is currently one of the smallest hydrogen clusters. Current hydrogen production is estimated at 80 kton annually, mainly produced at Tata Steel IJmuiden [9]. Also, small volumes of hydrogen are produced in food and chemical industries as by-product and is used locally.

Tata Steel IJmuiden is involved in the development of a hydrogen cluster in the Noordzeekanaal area and aims to decrease their CO_2 emissions by integrating hydrogen and oxygen in their production processes. A consortium of the Port of Amsterdam, Tata Steel IJmuiden and Nouryon is working on the development of a 100 MW electrolyser within the premises of Tata. The project, called H_2ermes, will add an annual hydrogen production of 20 kton and final investment decision is planned in 2021.

For the integration of 1 GW electrolysis, Tata Steel indicated they could potentially absorb all hydrogen in current blast furnaces. Also, hydrogen could be used in new processes between steel and chemical industries to increase value and reduce CO2 footprint:

- Additional hydrogen will be used to enriching blast furnace gases and convert carbon monoxide (or carbon dioxide) into methanol as building block[37].
- Another chemical route with offgases from steel plants is making syngas and converting to naphta as feedstock for crackers to produce plastics[38].

Regarding use of oxygen, current oxygen offtake at Tata is more than 100,000 Nm^3/h. This volume could be supplied by an electrolyser instead of existing air separation unit. Potentially this could increase with additional 100,000 Nm^3/h through the integration of new production processes (Hisarna).

Other potential hydrogen demand was identified near the Amsterdam harbour area. The Hemweg power plant could potentially consume a significant volume of hydrogen for energy production. Initially (2030), cofiring with 30% hydrogen would result in a demand of 63 kton annually. Later (2035), the plant could consume pure (100%) hydrogen, resulting in a demand of 180 kton annually.

Furthermore, studies are ongoing for potential future production of synthetic fuel in the harbour area. Significant volumes of hydrogen could be consumed, but no further detail was available.

[37] See https://ispt.eu/news/carbon-monoxide-re-use-industrial-symbiosis/

[38] See https://ispt.eu/projects/s2c/.

4.3. Hemweg

4.3.1. Location

The Hemweg location is anticipated for hydrogen related activities and is located in the western port area next to the A10 highway and the Nieuwe Hemweg. The location is owned by Vattenfall, accommodating the Hemweg 9 gas-fired power plant (435MWe) and the Hemweg 8 coal-fired power plant (600MWe) which is decommissioned 23 December 2019. Dismantling Hemweg 8 will take several years, after which space becomes available for new activities. Together with available space of the former Hemweg 7 power plant, the total space available is estimated to be around 12-17 ha.

The location has the destination for heavy industry[39] and environmental permits apply. Besides, it is a SEV3[40] location meaning that the location is assigned for energy related activities. Accordingly, large-scale electrolysis could be possible at this location. A hydrogen safety study has been performed study in order to check the safety contour for different hydrogen scenarios and did not reveal major issues for hydrogen production and storage[41].

4.3.2. Infrastructure

Figure 18 provides an overview of the infrastructure relevant for the Hemweg location.

Electricity

The Hemweg location has a 150kV connection via the Hemweg 150kV substation, which is connected to the Oostzaan 380kV substation. The 150kV connection does not have additional transport capacity to facilitate new demand like a GW electrolyser facility.

After 2025, TenneT expects the following developments: realisation of a new 150 kV substation Oostzaan, with spare bays (located next to the 380 kV substation Oostzaan); new (rebuild) substation Hemweg (150 kV) with spare bays; and the installation of a fourth transformer (500 MVA) at Oostzaan380; hereafter some 300-400 MW of new demand can be facilitated at one of these 150 kV substations. Concluding, this is not sufficient to connect a GW electrolyser.

Accordingly, a 380kV connection is required and should be realized with Oostzaan380. This requires sufficient connection capacity at Oostzaan which is to be investigated. Furthermore, the possibilities for the 380kV connection between Oostzaan380 and the Hemweg need to be investigated (e.g. is the same trajectory as the 150kV overhead lines and 150kV cables possible?). The distance is about 5-10 km and the costs of this connection need to be further assessed as potentially drilling is required. Costs are expected to be relatively high, as cable connections are significantly more expensive compared to overhead lines and drilling is expensive. In general, realizing new connections can take several years (3-10 year).

It is not fully clear what the impact would be on the 380kV grid of the addition of 1 GW of load at this location. An additional 1GW load could be beneficial given the future connection of offshore wind (2.1 GW) close by. However, in the most recent planning document of TenneT [10] [42], it is

[39] The location is a BRZO (Besluit Risico's Zware Ongevallen) environment.

[40] Structuurschema elektriciteitsvoorziening.

[41] This study has not been shared and accordingly has not been checked.

[42] Kwaliteits- en capaciteitsdocument, 2017, TenneT. As of this year, it will be the investment plan.

foreseen that a bottleneck might occur on the connection Beverwijk – Oostzaan. Accordingly, 1 GW additional load could increase congestion on this connection.

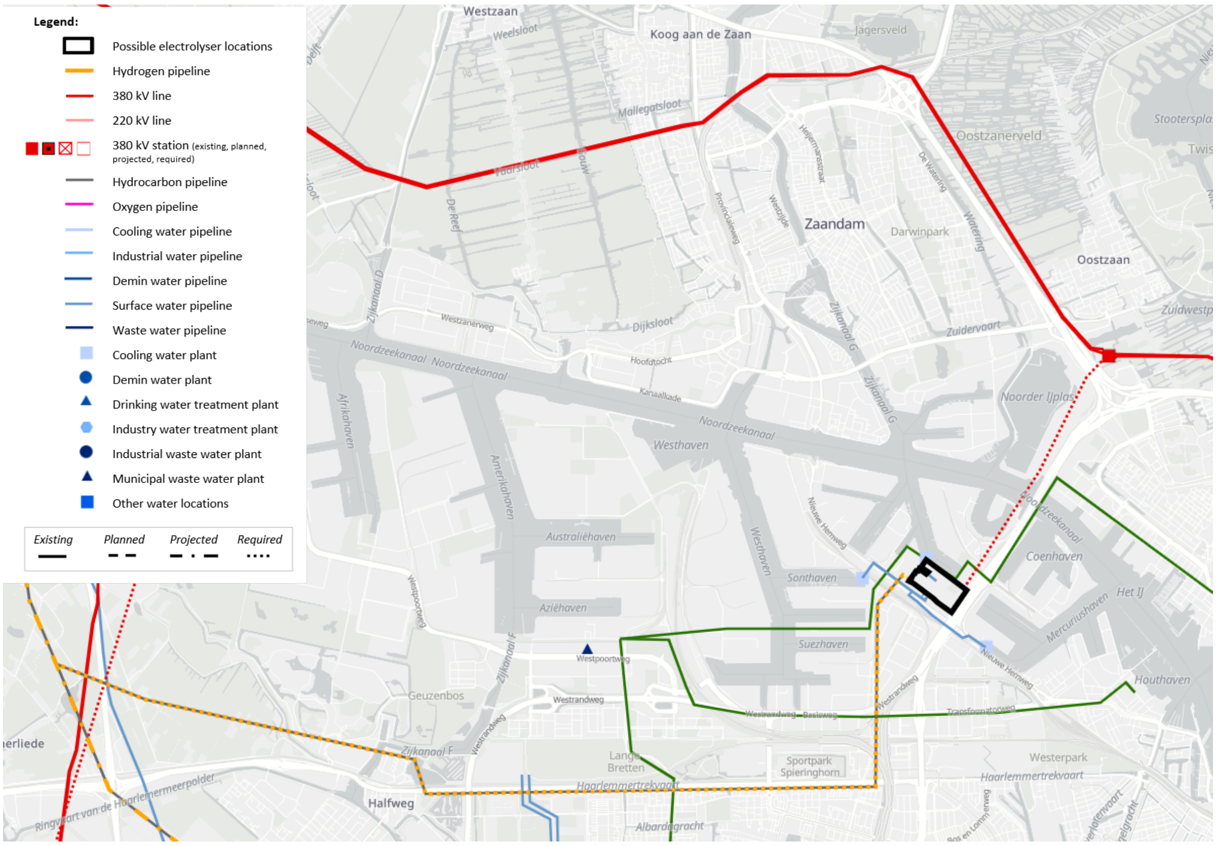


Figure 18: Map of infrastructure for the Hemweg location

Hydrogen

Placement of the electrolyser at the Hemweg location has the advantage of being directly next to the gas fired powerplant. Most hydrogen could be consumed at this location, which reduces the need for additional hydrogen infrastructure. However, a connection to the backbone or to other local consumers (e.g. TATA steel) could be beneficial. The Amsterdam harbour area's sustainability ambitions[43] could include the roll-out of a hydrogen network to offer hydrogen to local consumers[44]. The connection to the backbone or other consumers would require the conversion of existing natural gas infrastructure or new pipeline.

The Hemweg location is currently connected by a H-gas pipeline to supply the Hemweg powerplant. The routing of this (GTS) pipeline (12 inch) runs south of the Amsterdam harbour area and connects to the larger H-gas network near Spaarndam. Here, a connection to the backbone could

43 https://www.portofamsterdam.com/nl/business/vestigen-en-ladingstromen/waterstof

44 Currently no tangible plans or projections for such a network are known.

be made as multiple Gasunie pipelines pass this point. One of these pipelines could become part of the backbone.

It is however unclear whether the existing pipeline that connects to the Hemweg location could be used for the connection of the electrolyser and the backbone. Future plans include the conversion of the Hemweg power plant to hydrogen, but the pipeline also supplies other consumers and it is not sure whether these consumers could also be converted to hydrogen. The map of the Dutch natural gas transmission system (appendix C), shows one exit point at the Hemweg, but this would require further assessment. Furthermore, the pipeline diameter, capacity and integrity should be further assessed.

In case existing infrastructure is not available, a new hydrogen pipeline should be built to connect the Hemweg location to the backbone and/or to Tata steel. The distance is about 10-15 km, resulting in a Capex of about 10-15MEUR for a 14-18 inch pipeline.

Oxygen

No existing or planned oxygen infrastructure was identified near the Hemweg location. In case a connection between the electrolyser and potential oxygen demand is needed, a new pipeline would be required to transport all oxygen.

Water

At Hemweg, the information gathered for the supply of water and any planned, projected and required water infrastructure is summarised in Table 10 below. Although water sources are available, significant treatment is needed to meet the water demand and quality of the electrolyser.

Table 10: Summary of water infrastructure available and required at Hemweg

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	(i) Brackish water at the Port. (ii) Sewage treated effluent (Waternet) approx. 5-6 km from location. (iii) Tap water (Waternet), but currently not available. (iv) Demin water very limited quantity, 5m^3/hr.	There are no plans to treat any of these water sources to meet the demin water quantity and quality.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Although water sources are available, they will require significant treatment to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	No.	No.	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No, only intake and outlet of cooling water is available.			Confirmation is needed on whether the intake pumps will be removed at HW08.
Is there a water connection possible/available for water supply? If not, is there space for this?	No, there is no existing pipe reticulation for the supply of water to the GW plant location.			New pipeline is required from the water source to Hemweg.

District heating

The information gathered for the possibility of using the waste heat generated by the GW project for district heating is listed below in Table 11. Use of residual heat from hydrogen production can be very interesting in this region due to possible lack of natural source (research on geothermal energy is still taking place). The production of hydrogen with residual heat may provide a win-win situation for this area (in terms of cost and space).

Table 11: District heating potential at Hemweg

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	Yes	No.	In the future.	Recovery of waste heat could be considered if there is a prospective demand.
Is there available infrastructure for district heating? If not, is there space for this?	Westpoort Warmte	No.	Space and housing development plans are available on the East of the A10 highway.	Connection Hemweg towards Westpoort Warmte

4.4. Bosweg

4.4.1. Location

The Bosweg location is situated between Beverwijk and Wijk aan Zee, near the Zeestraat between the Tata Steel factories. It is not exactly clear what area is available for the GW electrolyser installation, and it is not known who the landowner of the remaining area is. It is known that the area is currently not available but could potentially be made available for large-scale electrolysis. Tata Steel has indicated that it is their preference to not realize the GW electrolyser on the Tata Steel premises. In addition, TenneT has acquired land around the Bosweg to realize the 380/220kV substation for the connection of offshore wind and potentially customer connections.

The Tata Steel location is heavy industry as Tata Steel has a lot of BRZO installations. There is strong public resistance from local residents and neighbouring cities to Tata Steel, and there is no room for additional environmental permits at the Tata Steel premises. Apart from the realization of the high-voltage substation by TenneT, spatial planning regarding the location near the Bosweg is not clear. The location is not in use by industry and needs a new permit. Noise is a problem at the location so additional noise from for instance cooling equipment could be an issue and should be mitigated. Furthermore, it should be noted that the Zeestraat is a public road, but there are no other specific nearby functions that influence the Bosweg location.

4.4.2. Infrastructure

Figure 19 provides an overview of the infrastructure relevant for the Bosweg location.

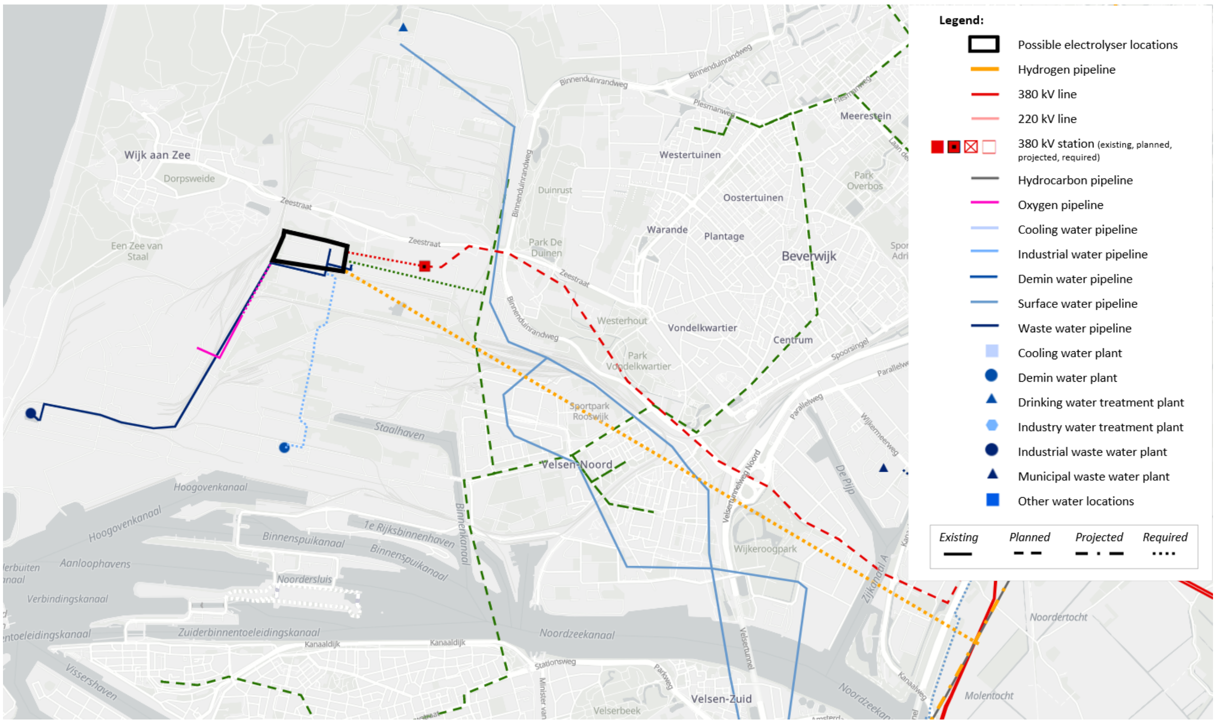


Figure 19: Map of infrastructure for the Bosweg location

Electricity

The nearest substation to this location is the 150kV Velsen substation, which is connected to the 380 kV grid via the 380kV substation Beverwijk. From Beverwijk there is no sufficient transport capacity available via the 150kV grid to Velsen, meaning that currently there is no opportunity to facilitate new (large) demand in this area.

After 2025, TenneT expects the following developments to further reinforce the grid: realisation of a new 150 kV substation Beverwijk, with spare bays (close to the 380 kV substation Beverwijk). This station could facilitate approximately 400 MW of additional demand at the new 150 kV substation Beverwijk, although this requires an extra 380/150kV transformer (500 MVA) at Beverwijk substation. Concluding, this is still not sufficient to connect a GW electrolyser.

An important development for this location relates to the development of offshore wind in the Netherlands (see Appendix B). The offshore wind farms *Hollandse Kust-Noord* (0.7GW) and *Hollandse Kust-West* (1.4GW) will be connected to the existing Maasvlakte station. As the generated electricity offshore will be brought onshore with 220kC AC cables, a new 380/220kV AC station is required. This station will be built next to the Tata Steel premises around the Bosweg and is planned to be in service by 2023. Accordingly, it will be connected to the 380kV substation Beverwijk using 380kV AC underground cables.

To connect the GW electrolyser to the onshore 380kV grid, a connection with the new 220/380kV substation is required. This should be possible before 2030 as it is foreseen that the new 220/380kV substation near the Bosweg will be made ready for future with a new 380 kV substation expansion to facilitate new demand like electrolysis.[45] The distance to the new substation is expected to be within one km.

Given the connection of offshore wind to this location, an additional 1GW load connected to this substation would be beneficial to any potential congestion on the 380kV grid. As it was foreseen by TenneT that a bottleneck might occur on the connection Beverwijk – Oostzaan, 1 GW additional load connected at this location could decrease any potential congestion on nearby connections.

Hydrogen

Currently, there is no indication of existing infrastructure which could become available for hydrogen transport between the Bosweg area and Tata Steel IJmuiden or to the backbone. As the location is right next to Tata Steel, hydrogen transport only needs to bridge a short distance.

For the connection to the backbone, new infrastructure is expected to be built. The plans for the backbone (Figure 6) indicate a new connection to the location near Tata Steel IJmuiden, which also could be used to connect the electrolyser to the backbone. The distance is about 5-10 km, resulting in a Capex of about 5-10MEUR for a 14-18 inch pipeline.

Oxygen

Tata Steel indicated there is existing oxygen infrastructure within their premises, between Lindegas and the Oxysteel factory. As current oxygen demand is more than 100,000 Nm^3/h, it is expected that the oxygen infrastructure is fitted to this capacity at a minimum. The connection from the Bosweg location to the existing oxygen infrastructure is approximately 200 m which requires a new pipeline.

[45] See also https://www.netopzee.eu/hollandsekustnoord/wat-is-het-net-op-zee-hollandse-kust-noord-en-west-alpha.

Water

At Bosweg, the information gathered for the supply of water and any planned, projected and required water infrastructure are summarised in Table 12 below.

Table 12: Summary of water infrastructure available and required at Bosweg

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	WRK water (pre-treated surface water) via Tata is the only source available.	There are no plans to further treat this water to meet the demin water quantity and quality.	There are no projected plans to treat this water source to meet the demin water quantity and quality.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Although a water source is available, significant treatment is required to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Yes.	No.	No.	Yes, it is possible to make use of the exisitng sewer network for discharge of wastewater.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply? If not, is there space for this?	Possible use of existing pipe reticulation.	No.	No.	Possible use of existing pipe reticulation, but need to confirm distance.

District heating

The prospect of using the waste heat generated by the GW project for district heating is summarised below in Table 13.

Table 13: District heating potential at Bosweg

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	No.	Warmtenet IJmond	No.	Recovery of waste heat could be considered if there is a prospective demand.
Is there available infrastructure for district heating? If not, is there space for this?	No.	Warmtenet IJmond	No.	Connection Bosweg towards Warmtenet IJmond

4.5. Crossing 380kV and gas infra near Beverwijk

4.5.1. Location

Near Beverwijk a potential location can be found close to the 380kV grid and the hydrogen backbone for large-scale electrolysis. However, there is no clearly defined location and it is not known what area is available for the GW electrolyser installation. The landowner is not known but probably agricultural land and privately owned. Spatial planning is unknown.

4.5.2. Infrastructure

Figure 20 provides an overview of the infrastructure relevant for the location near Beverwijk.

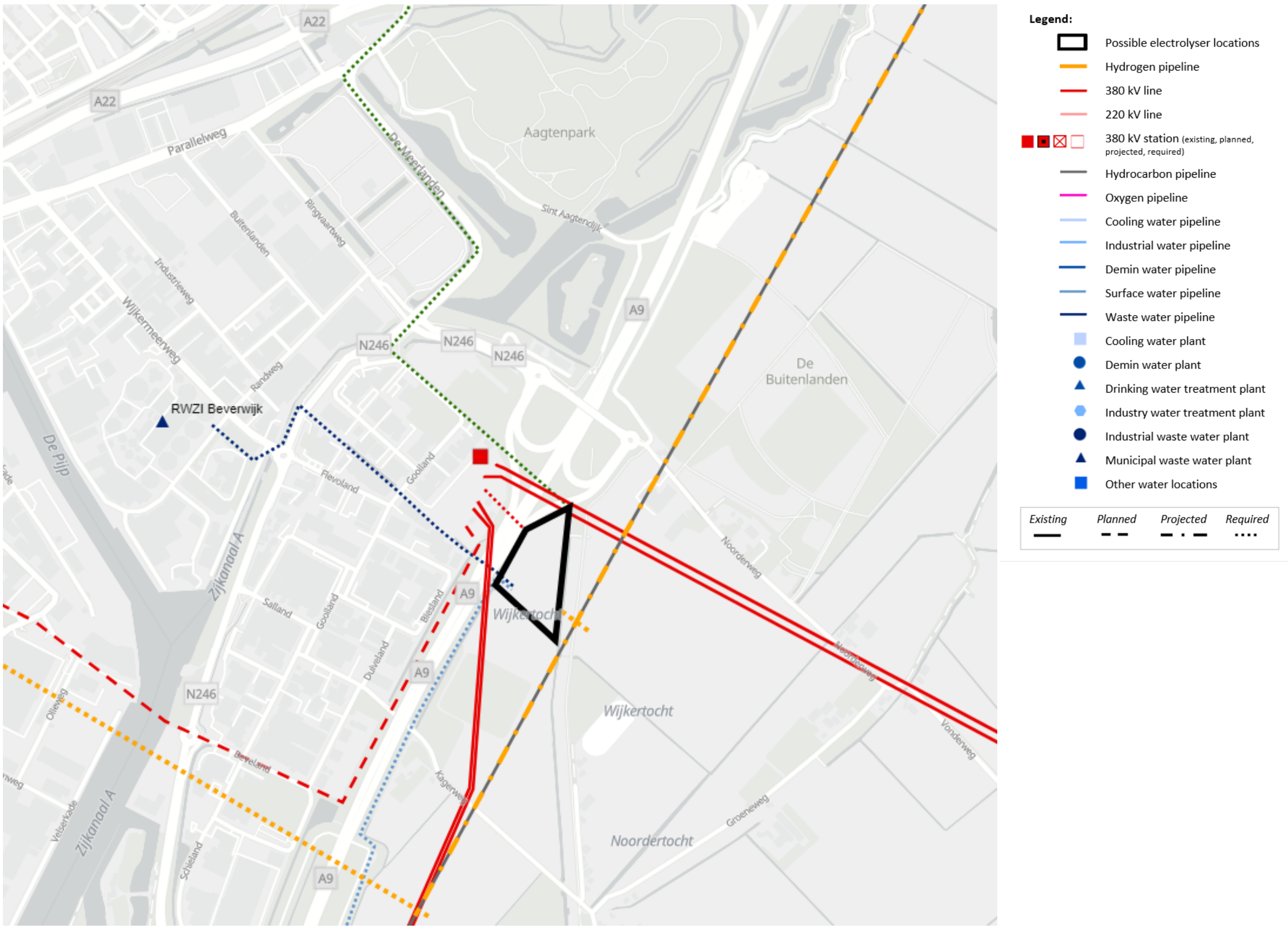


Figure 20: Map of infrastructure for the location near Beverwijk

Electricity

This location is close to the 380kV substation Beverwijk. This substation has been reinforced in 2016, though it is expected there is no sufficient connection capacity (this needs to be investigated). To connect the GW electrolyser to the onshore 380kV grid, a connection with Beverwijk380 is required. As this probably requires extension of the substation, it is not known whether this will be feasible before 2030. The distance to the new substation is expected to be within 1km.

Given the connection of offshore wind to this location, an additional 1GW load connected to Beverwijk380 would be beneficial to any potential congestion on the 380kV grid. As it was foreseen by TenneT that a bottleneck might occur on the connection Beverwijk – Oostzaan, 1 GW additional load connected at this location could decrease any potential congestion on nearby connections.

Hydrogen

This location is directly near the existing gas infrastructure, which is anticipated to be used for the backbone. If the electrolyser will be built at this location, a coupling with the backbone would be possible.

It should be noted that (parts of) the backbone is planned for 2025-2026 at its earliest which could limit earlier development of the 1 GW electrolyser at this location. A possible solution is a new pipeline to Tata Steel IJmuiden.

Oxygen

No existing or planned oxygen infrastructure was identified at this location. In case a connection between the electrolyser and potential oxygen demand is needed, a new pipeline would be required to transport all oxygen.

Water

At the Crossing 380kV and gas infra near Beverwijk, the information gathered for the supply of water and any planned, projected and required water infrastructure are summarised in Table 14.

Table 14: Summary of water infrastructure available and required near Beverwijk

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	Unknown.	No.	No.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Once water source and quality are identified, the required treatment scheme will be considered to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	No.	No.	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply? If not, is there space for this?	No.	No.	No.	New pipeline is required from the water source to the Crossing Hydrogen Backbone location.

District heating

The prospect of using the waste heat generated by the GW project for district heating is summarised below in Table 15. Use of residual heat from hydrogen production can be very interesting in this region due to possible lack of natural source (research on geothermal energy is still taking place). The production of hydrogen with residual heat may provide a win-win situation for this area (in terms of cost and space).

Table 15: District heating potential at the Crossing 380kV and gas infra near Beverwijk

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	No.	Warmtenet IJmond	No.	Recovery of waste heat could be considered if there is a prospective demand.
Is there available infrastructure for district heating? If not, is there space for this?	No.	Warmtenet IJmond	No.	Connection Bosweg towards Warmtenet IJmond.

4.6. Spaarndam – Houtrakpolder

4.6.1. Location

Near Spaarndam a potential location Houtrakpolder can be found, which is close to the port area, the 380kV grid and the hydrogen backbone for large-scale electrolysis. However, there is no clearly defined location and it is unknown what area is available for the GW electrolyser installation and who is landowner. Probably it is agricultural land and privately owned. Spatial planning is unknown.

4.6.2. Infrastructure

Figure 21 provides an overview of the infrastructure relevant for the location near Spaarndam.

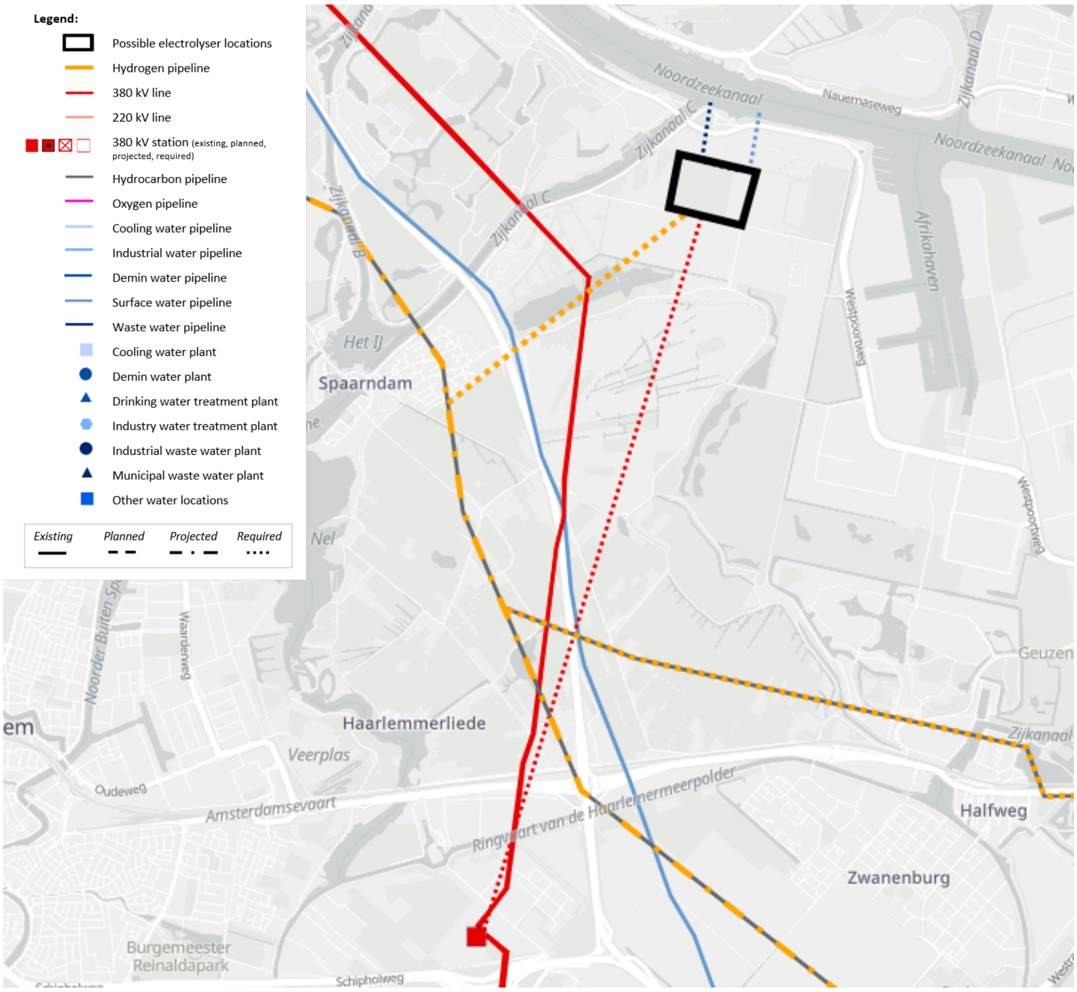


Figure 21: Map of infrastructure for the location Houtrakpolder near Spaarndam

Electricity

This location is close to the new 380kV substation Vijfhuizen, which is expected to have sufficient connection capacity, though this needs to be investigated. To connect the GW electrolyser to the onshore 380kV grid, a connection with Vijfhuizen380 is required, and is expected to be feasible before 2030. The distance to the new substation is expected to be within 1km.

It is not fully clear what the impact would be on the 380kV grid of the addition of 1 GW of load at this location. In the most recent planning document of TenneT [10] [46], it is foreseen that a bottleneck might occur on the connection Vijfhzuien – Beverwijk. Accordingly, 1 GW additional load could increase congestion on this connection.

Hydrogen

This location is relatively close (within 5km) from the existing gas infrastructure, which is anticipated to be used for the backbone. If the electrolyser will be built at this location, a coupling with the backbone is expected to be possible by 2030. It should be noted that (parts of) the backbone is planned for 2025-2026 at its earliest which could limit earlier development of the 1 GW electrolyser at this location.

Oxygen

No existing or planned oxygen infrastructure was identified at this location. In case a connection between the electrolyser and potential oxygen demand is needed, a new pipeline would be required to transport all oxygen.

Water

The information gathered for the possible location near Spaarndam for the supply of water and any planned, projected and required water infrastructure are summarised in Table 16 below.

Table 16: Summary of water infrastructure available and required near Spaarndam

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	Unknown.	No.	No.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Once water source and quality are identified, the required treatment scheme will be considered to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	No.	No.	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply? If not, is there space for this?	No.	No.	No.	New pipeline is required from the water source to the Crossing Hydrogen Backbone location.

[46] Kwaliteits- en capaciteitsdocument, 2017, TenneT. As of this year, it will be the investment plan.

District heating

The prospect of using the waste heat generated by the GW project for district heating is summarised below in Table 17: District heating potential at the Crossing 380kV and gas infra near Spaarndam (Houtrakpolder). Use of residual heat from hydrogen production can be very interesting in this region due to possible lack of natural source (research on geothermal energy is still taking place). The production of hydrogen with residual heat may provide a win-win situation for this area (in terms of cost and space).

Table 17: District heating potential at the Crossing 380kV and gas infra near Spaarndam (Houtrakpolder)

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	Unknown.	No.	No.	Recovery of waste heat could be considered if there is a prospective demand.
Is there available infrastructure for district heating? If not, is there space for this?	No.	No.	No.	

5. Chemelot

For Limburg, four different locations are considered for large-scale electrolysis. Three locations are at Chemelot: Chemelot South with two locations and a potential future location North of Chemelot. Besides Chemelot also the location Clauscentrale powerplant near Maasbracht is explored as option. The latter location has not been discussed with the owner. Figure 22 provides an overview of the potential plots at Chemelot. For more information regarding the locations see Appendix H.

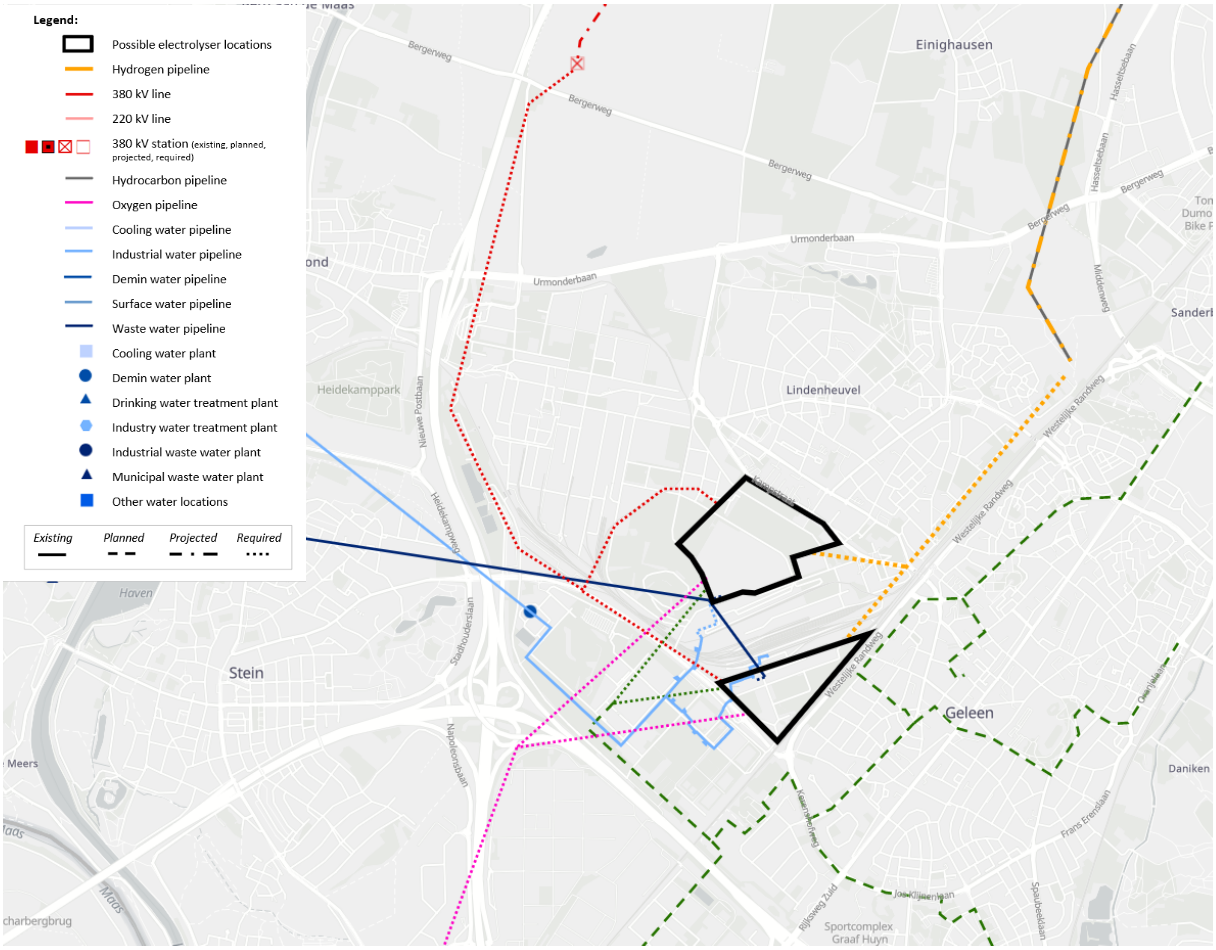


Figure 22: Overview of potential locations Chemelot (indicated by the dark rectangles)

5.1. Summary of findings

An overview of the findings for Chemelot and Maasbracht is presented in Table 18. Based on the available information, the following preliminary key observations can be determined:

- Regarding the available space and suitability of the locations, it seems that the future plot is a more logical location, as plot 1 and 2 are close to residential areas and public roads and other developments are planned as well for those locations. Regarding the future plot permitting issues exist and stakeholders need to be consulted with respect to development of new industrial zone.
- Regarding critical infrastructure – e.g. water, electricity and hydrogen – it seems that Maasbracht is also an interesting location with good connections besides Chemelot, as the difference in costs required for the connection with infrastructure is expected to be

significantly lower for Maasbracht compared to Chemelot, and hydrogen transport to Chemelot is in time possible through the backbone.

Table 18: Overview of the findings Chemelot and Maasbracht[47]

Location	Chemelot – plot 1 and 2	Chemelot – future plot	Maasbracht
Space	Up to 30 ha for plot 1. Up to 20 ha for plot 2.	Up to 60 ha available.	Around 5-10 ha could be available. Requires compact design.
Suitability	Not discussed with landlord (owned by DSM). Currently light industry. Other developments are taking place. Next to residential areas and public roads.	Owned by DSM and assigned for expansion. Social acceptance issues should be addressed	Owned by RWE, next to Claus C power plant. Spatial planning unknown.
Water supply	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.
Electricity supply	Currently no 380kV and no plans, but projected.	Currently no 380kV and no plans, but projected.	The 380kV substation Maasbracht will be fully renovated. Transport capacity to be investigated.
Hydrogen infra	Requires new connection to backbone (within 5 km), could be realized by 2030.	Requires new connection to backbone (within 5 km), could be realized by 2030.	Requires new connection to backbone (~5 km), could be realized by 2030.
Hydrogen demand	Can be consumed by OCI.	Can be consumed by OCI.	No hydrogen demand.
Oxygen demand	No demand in vicinity. Connection to Air Liquide might be possible.	No demand in vicinity. Connection to Air Liquide might be possible.	No demand in vicinity.

47 For an explanation of the colour scheme, see Appendix M.

Location	Chemelot – plot 1 and 2	Chemelot – future plot	Maasbracht
District heating	Possible connection to "Het Groene Net".	Possible connection to "Het Groene Net".	Roermond relatively close, but no heat grid present yet

As an example, the plot plan at Chemelot is depicted in Figure 23. The available plot space is sufficient for PEM and Alkaline based electrolysers facility with regards to **maximum and minimum cases.**

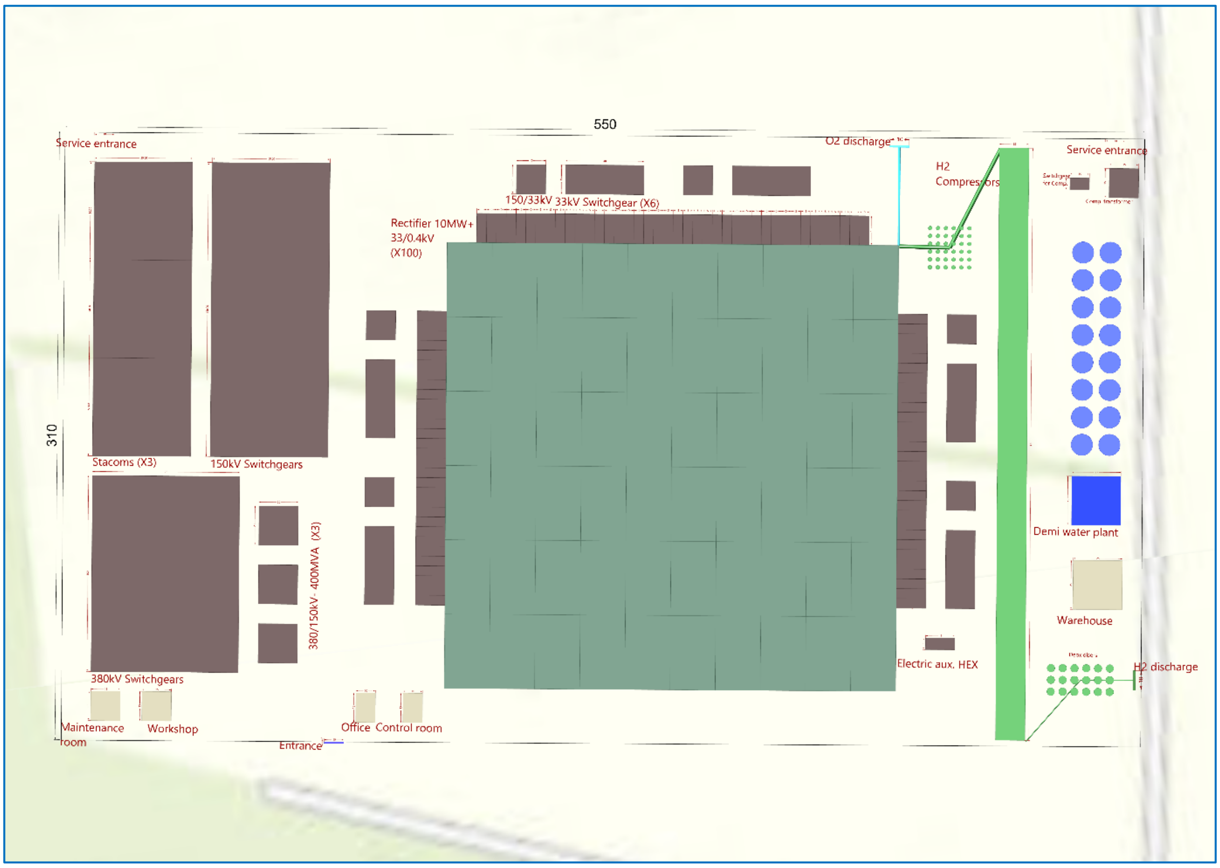


Figure 23: Plot plan- Chemelot

5.2. Hydrogen demand and supply

Chemelot is currently the third largest hydrogen cluster where hydrogen is produced mainly from steam methane reforming (SMR) or as a by-product from industrial processes. The main use of hydrogen is feedstock for ammonia production at OCI Nitrogen as raw material for other chemical plants at Chemelot. Current production amounts to roughly 185 kton annually [9]. Also, Sabic produces hydrogen as byproduct which is used as fuel. The total production at Chemelot is about 215 kton/a.

OCI is exploring several decarbonization options to reduce their CO_2 emissions. Electrolysis is one of the solutions to be considered and could replace the two existing SMR units (total 1.3-1.4 GW electrolysis). Replacement of one SMR unit would require an electrolyser of roughly 700 MW (operated at full load), possibly in 2030. Their demand is estimated at roughly 200 kton annually before 2030, which could grow to 250 kton onwards. Security of supply is however an important aspect as their complete ammonia production process depends on a steady hydrogen supply. The hydrogen demand pattern should be considered as base load. Co-production with the SMR units could offer flexibility as both are capable of operating between 80-100% of their production capacity, but this requires a timeframe of roughly 5-15 hours.

From the HyChain 1 study, future hydrogen production and demand in the Chemelot area is estimated at 765 kton in a high scenario whereas low scenario is consistent with above values. Most will be used as feedstock or for industrial heat [11].

5.3. Chemelot

5.3.1. Location

Two locations are identified with two plots at Chemelot South and one potential future location North of Chemelot.

The plots 1 and 2 are located at the Chemelot area. For both locations the landowner is DSM. Plot 1 is situated just North of the rail terminal up to the Kampstraat. There is about 30 ha of space available, though this is partially claimed for other developments. Plot 2 is situated just South of the rail terminal and further confined by the public roads Kerenshofweg and the Westelijke Randweg. There is about 20 ha of space available, though part of the plot will be used for expansion and access of the railway.

Both plot 1 and 2 have destinations for partial light industry, and since the whole Chemelot area is under one permit[48] ('koepelvergunning'), this permit also applies to those locations. The permit is for an indefinite period and is controlled by the competent authority (e.g. a revision could be demanded). The ground has been cleaned until a few meters of depth, as the ground is contaminated due to mining activities. It should be noted that both locations are next to residential areas, which implies that there could be restrictions to noise and height. In addition, public resistance could play a role and needs to be considered.

The future location North of Chemelot has similar connections with different infrastructure and hydrogen demand and supply as the other plots and therefore will not be explained in detail. Figure 22 provides an overview of the different infrastructure relevant for the future plot. The future plot is located near the Chemelot area and comprises about 60 ha. This plot is owned by DSM and currently not in use by industry but assigned for expansion of Chemelot. Until 2026, DSM has the sole right to formulate a plan for this area.

5.3.2. Infrastructure

Figure 22 provides an overview of the different infrastructure relevant for plot 1 and 2.

Electricity

Chemelot has its own electricity distribution network and is connected to the 150kV grid via 150kV substation Graetheide. The 150 kV is transformed down to 30 kV or 10 kV at USG substations Oude Postbaan, Kerensheide, Swentibold and Neerbeek. USG Industrial Utilities supplies the entire Chemelot industrial park with electricity and operates the grid. An average capacity of about 250 MW is supplied, of which the main part is produced locally from the Swentibold CHP power plant (150 MW). The GW electrolyser cannot be facilitated from this Chemelot distribution network.

A number of works on the 150kV grid of TenneT are being undertaken, like the realization of a underground 150kV connection between substation Lutterade and Graetheide and between Born and Graetheide, while removing the 150kV connections between Born and Lutterade and between Lutterade and Urmond[49]. However, also the 150kV TenneT grid cannot facilitate a GW of extra demand. Accordingly, a connection to the 380kV grid is required. As the nearest 380kV substation is Maasbracht (which will be fully renovated), the most convenient solution would be to realize a

---

48 Wabo permit, Wet algemene bepalingen omgevingsrecht

49 See https://www.tennet.eu/nl/ons-hoogspanningsnet/onshore-projecten-nederland-2/ and https://www.tennet.eu/fileadmin/user_upload/Our_Grid/Onshore_Netherlands/Born/IND-Zuidholland-v4.pdf.

new 380kV station near Chemelot. This seems possible as the current 150kV connection Maasbracht – Graetheide could possibly be upgraded to 380kV using the same towers and trajectory, and then the 150kV station Graetheide needs to be renovated and upgraded to a 308/150kV substation. It is expected that this requires a shorter time period compared to building a new 380kV connection and substation, which takes about 10 years. Accordingly, this could be possible before 2030, though the different possibilities need to be investigated. Finally, a 380kV connection is required between the new 380kV station and the GW electrolyser. The following Capex for electricity infrastructure would be required[50]:

- Overhead line connection between Graetheide and Maasbracht. As the distance is about 25 km, the Capex for a new 380kV overhead line connection would be about 37.5 MEUR. Accordingly, it should be possible to realize this within 37.5MEUR as it is assumed that current towers can be used, but this requires further investigation.
- Extension or renovation of the 150kV station Graetheide to a 380/150kV substation. The Capex for a new 380/150kV substation is estimated at around 40-60 MEUR, dependent on among others transformer and connection capacity. Accordingly, it could be possible to realize this within 40-60 MEUR, but this requires further investigation.
- A 380kV connection between the GW electrolyser facility and the 380kV substation (about 2-3 km). Costs to be investigated.

In the most recent planning document of TenneT [10][51] a bottleneck is determined for the connection Eindhoven – Maasbracht. Accordingly, 1 GW additional load could increase congestion on this connection. However, it is not fully clear what the impact would be on the 380kV grid of the addition of 1 GW of load at this location, also because currently there is no 380kV grid nearby Chemelot and the 380kV substation Maasbracht is fully renovated. Moreover, the connection Eindhoven – Maasbracht will be upgraded (1,975 MVA to 2,635 MVA).

Hydrogen

The Chemelot area is currently supplied by a bundle of pipelines (H-gas and G-gas) from the North, mainly large diameter pipelines (at least 36") operated at 60-70 bar. One of these pipelines could be allocated for the backbone and connect the Chemelot area to the other hydrogen clusters. The most plausible pipeline is the H-gas pipeline that runs East of Maasbracht with an operating pressure of 60-70 bar. It is unclear if a similar operating pressure will be chosen. To assure the same level of safety and integrity, the pipeline could be operated at a lower pressure. The pipeline could also be operated at a lower pressure when such high pressure is simply not needed at the end point (for instance OCI needs ~30 bar) or when capacity is sufficient at lower pressures. H-gas will still be available at the Chemelot area in the future as there are multiple pipelines. New pipeline connection is required from Chemelot to the foreseen hydrogen backbone. Also at the Chemelot area itself, it is unclear whether existing infrastructure will become available for hydrogen transport and additional pipelines may be required. The trajectory of this new connection

[50] Again, The Capex assumed for electricity infrastructure is based on ballpark figures and is for indicative use. Further cost assessments are required to get a clearer picture of expected costs. Costs include installation costs, but not including costs like project costs, permitting costs, land costs, contingency.

[51] Kwaliteits- en capaciteitsdocument, 2017, TenneT. As of this year, it will be the investment plan.

requires further analysis. The distance to the backbone is about 5 km, resulting in a Capex of about 5MEUR for a 14-18 inch pipeline.

Oxygen

Potential oxygen demand could come from cement production company CBR (part of Heidelberg Cement group), between Maastricht and Liège in Belgium. The use of oxygen in the cement industry could reduce greenhouse gasses, though it needs to be investigated whether CBR is willing and capable to use the oxygen from the electrolyser. Currently, oxygen infrastructure exists that connects Geleen to Liège which is managed by Air Liquide. It is however unknown if sufficient capacity is available and if additional new infrastructure is required to connect to CBR. Another option is to simply connect to the Air Liquide network (see Appendix L) and act as an oxygen producer in Air Liquide's network. However, it should be noted that Air Liquide manages their network by providing different industrial gasses to their customers via dedicated pipelines, and that this network is not open-access infrastructure.

Water

At Chemelot Plots 1 and 2, the information gathered for the supply of water and any planned, projected and required water infrastructure are summarised in Table 19 and Table 20 below.

Table 19: Summary of water infrastructure available and required at Chemelot Plot 1

Water	Information gathered			
	Current	**Planned**	**Projected**	**Required**
What are the available water sources for hydrogen production and can they be used?	(i) Treated Juliana canal water (ii) Demin water from USG but limited excess available. (iii) IAZI WWTP effluent. (iv) Tap of WML, but availability is unknown.	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Although water sources are available, they will require significant treatment to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Yes, the existing sewer to IAZI.	No.	No.	Possible use of the existing sewer to IAZI for discharge of demin plant waste stream.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	Yes at Demi-S but capacity needs to be assessed.	No.	No.	Yes, storage is available at Demi-S but capacity needs to be assessed. If not sufficient, then additional storage is required.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply? If not, is there space for this?	Yes, in the vicinity for both treated canal water and demin water.	No.	No.	Existing infrastructure needs to be assessed for suitability and augmentation.

Table 20: Summary of water infrastructure available and required at Chemelot Plot (North of Chemelot)

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	(i) Treated Juliana canal water (ii) Demin water from USG but limited excess available. (iii) IAZI WWTP effluent. (iv) Tap of WML, but availability is unknown.	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Although water sources are available, they will require significant treatment to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	No.	No.	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply? If not, is there space for this?	Yes, there is an existing pipe reticulation South of Urmonderbaan.	No.	No.	Possible use of existing pipe reticulation South of Urmonderbaan, but need to confirm distance.

District heating

The information gathered for the possibility of using the waste heat generated by the GW project for district heating at the Chemelot Plot 1 and Plot 2 location is listed below in Table 21: District heating potential at Chemelot Plot 1 and Plot 2 location.

Table 21: District heating potential at Chemelot Plot 1 and Plot 2 location

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	Yes	Yes	Possibly in the future	
Is there available infrastructure for district heating? If not, is there space for this?	Het Groene Net in Sittard	Extension of Het Groene Net to - Geleen Zuid and Beek - Stein - Geleen Noord and Fortuna	No.	Connection Plot 1/Plot 2 towards Het Groene Net

5.4. Maasbracht

5.4.1. Location

The potential Maasbracht location is situated on RWE premises near the Claus C power plant (CCGT, 1,304MWe). It should be noted that RWE was not involved in this project and did not participate in the discussions for this location. Claus C was officially opened on 26 June 2012 unit C, replacing the conventional gas-fired power plant Claus B. For economic reasons Claus C was mothballed on 1 July 2014. In October 2018, RWE decided to put Claus C back into operation, due to changing market conditions and increasing demand for controllable capacity. It is expected that Claus C will be back into normal operation by the beginning of 2020.

There is space available at this location as RWE was planning to build a similar plant adjacent to unit C (former Claus A location). Relevant approvals were granted in 2016, but RWE decided not to build the unit due to difficult economic prospects. Currently there are no concrete plans to build the unit[52]. It is estimated that around 5-10 ha could be available.

5.4.2. Infrastructure

Figure 24 provides an overview of the different infrastructure relevant for plot 1 and 2.

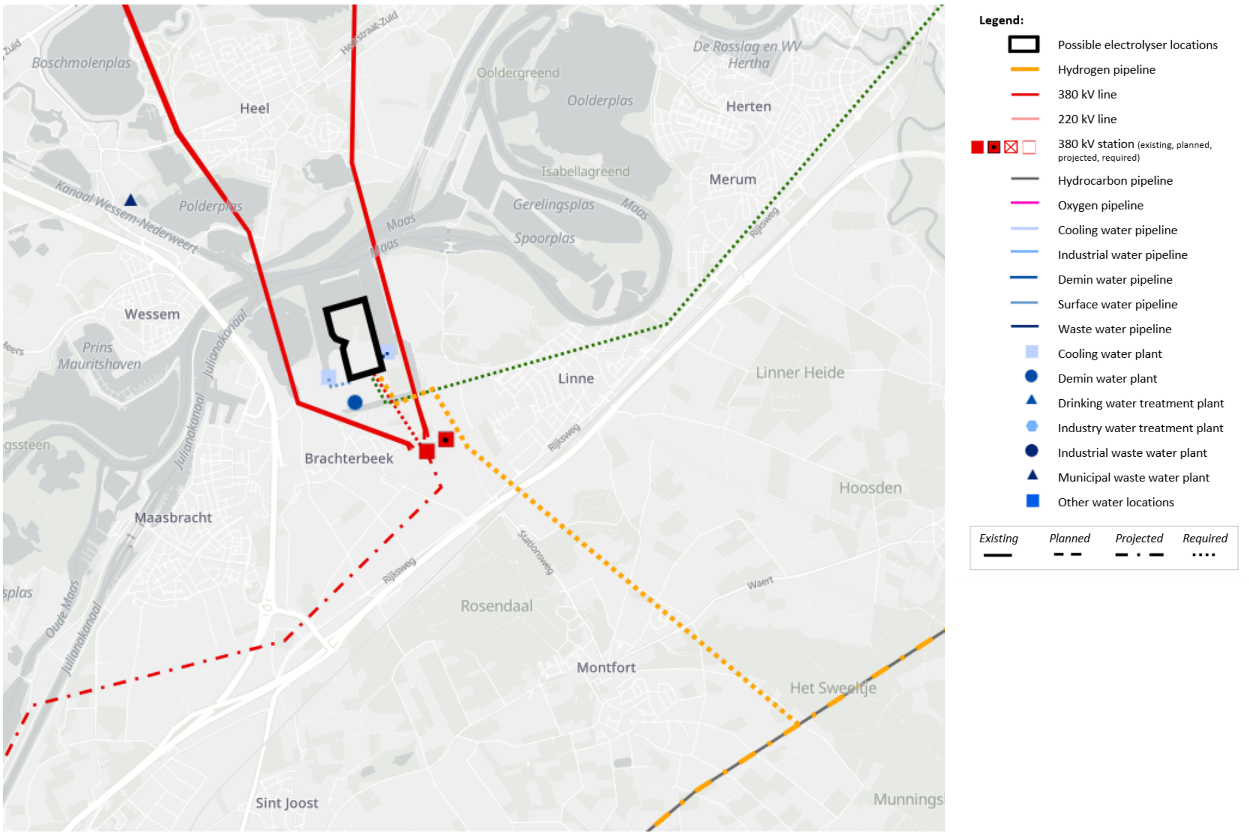


Figure 24: Map of infrastructure for the Maasbracht location

[52] See https://www.group.rwe/en/our-portfolio/our-sites/claus-c-power-plant/?.

Electricity

The 380kV substation Maasbracht will be fully renovated, starting work in 2021 and expected to be completed by 2028[53]. Maasbracht is an important substation as it is connected with both the Belgium and German grid and is key for the supply of power to the 150kV grid.

A connection between the GW electrolyser and the renovated 380kV Maasbracht substation is required and should be possible by 2030. However, the transport capacity towards Maasbracht should be further investigated (given developments like demand for electricity, cross-border flows and the RWE Claus power plant[54]).

As the distance to the (renovated) 380kV substation is short, the Capex required is mainly for realizing the grid connection.

In the most recent planning document of TenneT [10][55] a bottleneck is determined for the connection Eindhoven – Maasbracht. Accordingly, 1 GW additional load could increase congestion on this connection. However, it is not fully clear what the impact would be on the 380kV grid of the addition of 1 GW of load at this location, also because currently there is no 380kV grid nearby Chemelot and the 380kV substation Maasbracht is fully renovated. Moreover, the connection Eindhoven – Maasbracht will be upgraded (1,975 MVA to 2,635 MVA).

Hydrogen

The potential location near Maasbracht is on the premises of the Claus power plant. If the powerplant would convert to mixed or to pure hydrogen, only a short connection between the electrolyser and the power plant would be required. However, it is not clear if there are plans to switch to hydrogen as fuel fort the power plant. Moreover, in this case it is found unlikely that the powerplant and the electrolyser will operate simultaneously. Accordingly, a connection to the backbone is required, to transport the hydrogen to other clusters, or to use the storage at Zuidwending.

One of the Gasunie pipelines (H-gas), East of Maasbracht (below Montfort) is most likely allocated for the hydrogen backbone. The pipelines to the West of Maasbracht are still expected to stay in use for natural gas transport. For the connection between the electrolyser and the backbone, new infrastructure is required. The distance to the backbone is about 5 km, resulting in a Capex of about 5MEUR for a 14-18 inch pipeline.

Oxygen

No oxygen demand or (required) infrastructure is identified for this location.

Water

At the Claus powerplant location, information gathered for the supply of water and any planned, projected and required water infrastructure are summarised in Table 22 below.

---

53 See https://www.tennet.eu/nl/ons-hoogspanningsnet/onshore-projecten-nederland/station-maasbracht/.

54 Claus C will be back in operation by end of 2020. Moreover, there are plans to connect the power plant to the Belgian grid. However, the Dutch Minister of Economic Affairs and Climate is not happy with this and hindering the plan. See for instance https://energeia.nl/energeia-artikel/40086907/wiebes-blokkeert-directe-verbinding-clauscentrale-met-belgisch-elektriciteitsnet.

55 Kwaliteits- en capaciteitsdocument, 2017, TenneT. As of this year, it will be the investment plan.

Table 22: Summary of water infrastructure available and required at Claus powerplant

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	(i) River Muse (need WQ data) (ii) Tap water from WML (need WQ data) (iii) Effluent from Heel WWTP (might not be sufficient)	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	The level of water treatment required will depend on the source available. For instance, tap water will only require an ion exchange and polishing step to meet the demin water quality.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	No.	No.	No.	Possible use of the Heel WWTP.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply? If not, is there space for this?	Yes.	No.	No.	Yes, but need to assess the pipeline and any augmentation required.

District heating

The information gathered for the possibility of using the waste heat generated by the GW project for district heating at the Claus powerplant location is listed below in Table 23.

Table 23: District heating potential at Claus powerplant location

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	No.	Slim Energienet Roermond		Recovery of waste heat could be considered if there is a prospective demand.
Is there available infrastructure for district heating? If not, is there space for this?	No.	Suburb Tegelarijeveld	No.	Connection Maasbracht towards Slim |Energienet Roermond

6. North Sea Port

For the North Sea Port Region, at least seven locations are considered for large-scale electrolysis, which can be clustered into three different areas: near Borssele/Vlissingen(Zuid-Beveland); near Terneuzen (Zeeuws-Vlaanderen); near Ghent (Belgium).

Figure 25 provides an overview of the potential locations for the North Sea Port Region. Near Borssele four different locations are projected: near Zeeland Refinery, near the current nuclear power plant, the former Thermphos area and a location in the north west part of the port called 'Zanddepot'. Near Terneuzen two potential locations are foreseen: near DOW Chemical and near Yara Sluiskil. The location near Ghent (Belgium) is at the Rodenhuize industry area. For more (spatial) information regarding the locations see Appendix I. All geographical plots are indicative.

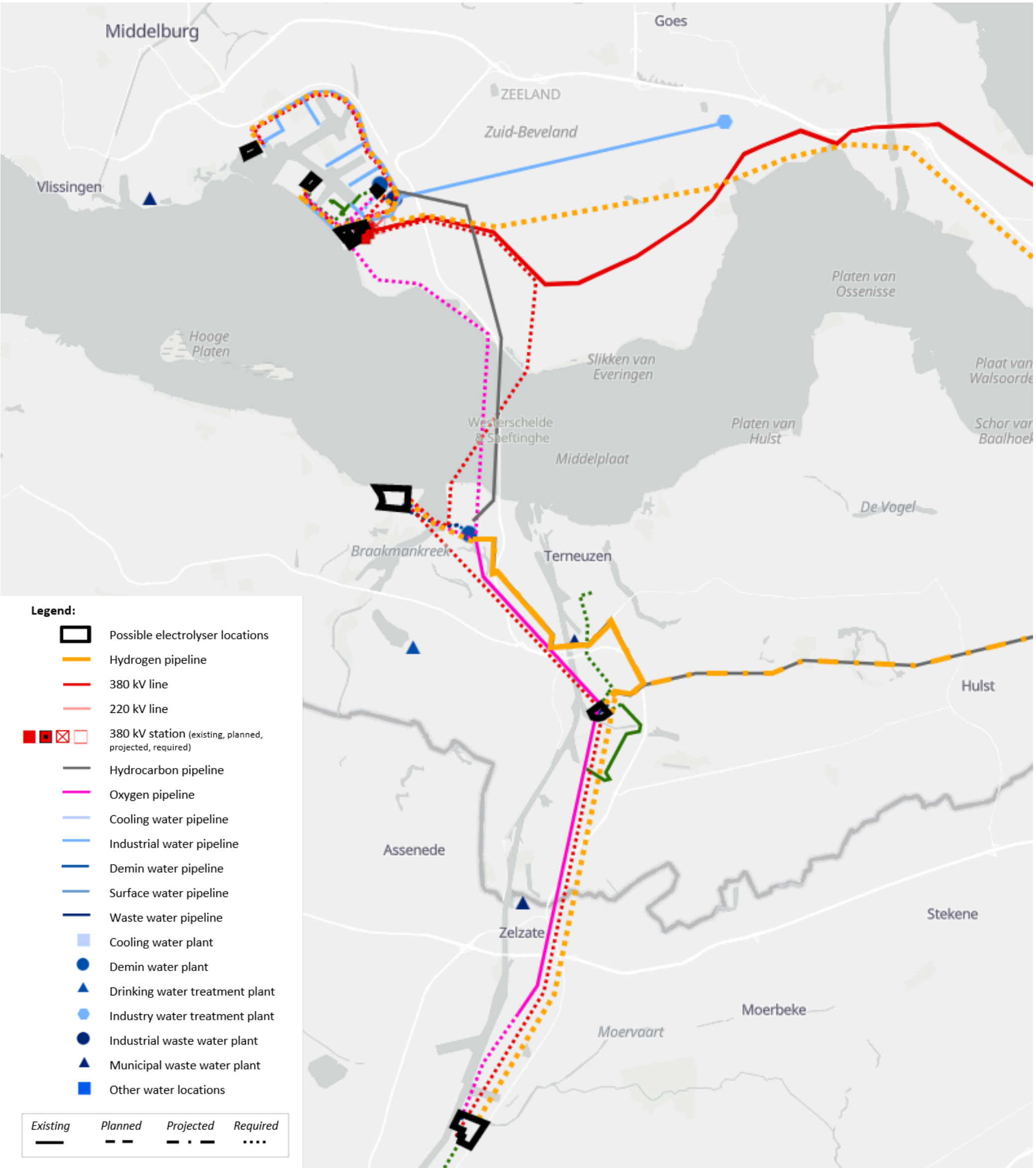


Figure 25: Overview of potential locations North Sea Port Region (indicated by the dark rectangles)

6.1. Summary of findings

An overview of the findings for North Sea Port is presented in Table 24. Based on the available information, the following preliminary key observations can be determined:

- Regarding the available space and suitability of the locations, it seems that almost all sites have good potential although some may need more compact design or possibly co-siting for cooling/demin water and service buildings. One or two central location(s) may be worthwhile for Ghent, Terneuzen/Sluiskil and Borssele and hydrogen can be transported to all sites and end users.
- Regarding critical infrastructure – e.g. water, electricity and hydrogen – it seems there is no preferred location. For the locations in Zuid-Beveland near Borssele/Vlissingen, 40-50 km of pipeline should be realized to connect to the backbone, i.e use of existing gas pipelines is not sure. For the locations near Terneuzen/Sluiskil there is currently no 380kV grid. For extension of the grid to Zeeuws-Vlaanderen a new substation near Borssele would be required including crossing and new overhead lines. In case of connection to Belgium TSO ELIA laws and policies may need to be changed. The location at Rodenhuize is not studied in detail but seems to provide good infrastructure connections and is close to offtake for both hydrogen and oxygen.

Table 24: Overview of findings locations North Sea Port[56]

	Borssele/Vlissingen(Zuid-Beveland)				**Zeeuws-Vlaanderen**		**Ghent**
Location	**Zeeland Refinery**	**Former Thermphos**	**Zanddepot**	**Power plant Borssele**	**DOW Chemical**	**Yara Sluiskil**	**Roden-huize**
Space	About 11 ha. Requires PEM or compact design.	Around 40 ha available.	Around 40 ha available.	About 8-15 ha. Probably requires PEM or compact design.	About 70-75 ha available.	About 10-12 ha available. Probably requires PEM or compact design	About 70-75 ha available.
Suitability	Owned by Zeeland Refinery. Industrial location. Already plans for 100-150 MW facility.	Owned by North Sea Port. Industrial location.	Owned by North Sea Port.	Owned by EPZ. Industrial location. Next to nuclear power plant, close to city of Borssele.	Valuepark Terneuzen, joint venture of DOW and North Sea Port. Industrial location. Next to DOW.	Owned by Yara. Industrial location. Next to Yara.	Owned by ENGIE. Industrial location. Next to Rodenhuize 380kV substation.

56 For an explanation of the colour scheme, see Appendix M.

	Borssele/Vlissingen(Zuid-Beveland)				**Zeeuws-Vlaanderen**		**Ghent**
Location	**Zeeland Refinery**	**Former Thermphos**	**Zanddepot**	**Power plant Borssele**	**DOW Chemical**	**Yara Sluiskil**	**Roden-huize**
Water supply	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.	Water source available and can be treated to meet Electrolyser water quality targets.
Electricity supply	Sufficient transport capacity. No sufficient connection capacity and extension required in case IJmuiden Ver will be connected to Borssele380.	Sufficient transport capacity. No sufficient connection capacity and extension required in case IJmuiden Ver will be connected to Borssele380.	Sufficient transport capacity. No sufficient connection capacity and extension required in case IJmuiden Ver will be connected to Borssele380.	Sufficient transport capacity. No sufficient connection capacity and extension required in case IJmuiden Ver will be connected to Borssele380.	Currently no 380kV and no plans. Consultation with TenneT started.	Currently no 380kV and no plans. Consultation with TenneT started.	Next to Rodenhuize 380kV substation. Transport and connection capacity to be investi-gated and to be checked with Elia.
Hydrogen infra	Existing infra is available, but potential use will be investigated.	Existing infra is available, but potential use is will be investigated.	Existing infra is available, but potential use will be investigated.	Existing infra is available, but potential use will be investigated	Almost direct connection to DOW-YARA pipeline and connection to backbone, could be realized by 2030.	Almost direct connection to DOW-YARA pipeline and connection to backbone, could be realized by 2030.	Potential synergy with foreseen hydrogen infra to backbone. Or third access to Air Liquide network?
Hydrogen demand	Potential demand at Zeeland Refinery.	Potential demand at Zeeland Refinery (and Yara if new or existing infra	Potential demand at Zeeland Refinery (and Yara if new or existing infra	Potential demand at Zeeland Refinery (and Yara if new or existing infra	Can be consumed by YARA.	Can be consumed by YARA.	Local hydrogen demand present.

	Borssele/Vlissingen(Zuid-Beveland)				Zeeuws-Vlaanderen		Ghent
Location	**Zeeland Refinery**	**Former Thermphos**	**Zanddepot**	**Power plant Borssele**	**DOW Chemical**	**Yara Sluiskil**	**Roden-huize**
		underneath Westerschelde can be used)	underneath Westerschelde can be used).	underneath Westerschelde can be used).			
Oxygen demand	Small scale oxygen demand at Zeeland Refinery	No demand in vicinity.	No demand in vicinity.	No demand in vicinity.	Potential (small) oxygen demand at DOW.	Unknown whether extra demand can be realized. Potential Demand from ArcelorMittal	Potential demand from ArcelorMittal. Spoly could also be form other locations using existing O2 line from DOW
District heating	Sloewarmte, industry-to-industry, possible extension for district heating	Possible district heating	Possible district heating	Sloewarmte, industry-to-industry	Possible district heating for the city of Hoek.	WarmCO$_2$	Possible district heating for Ghent.

As an example, the plot plan is depicted at the Borselle location in

Figure 26. The available plot space is sufficient for PEM and Alkaline based electrolysers facility with regards to **maximum and minimum cases.**

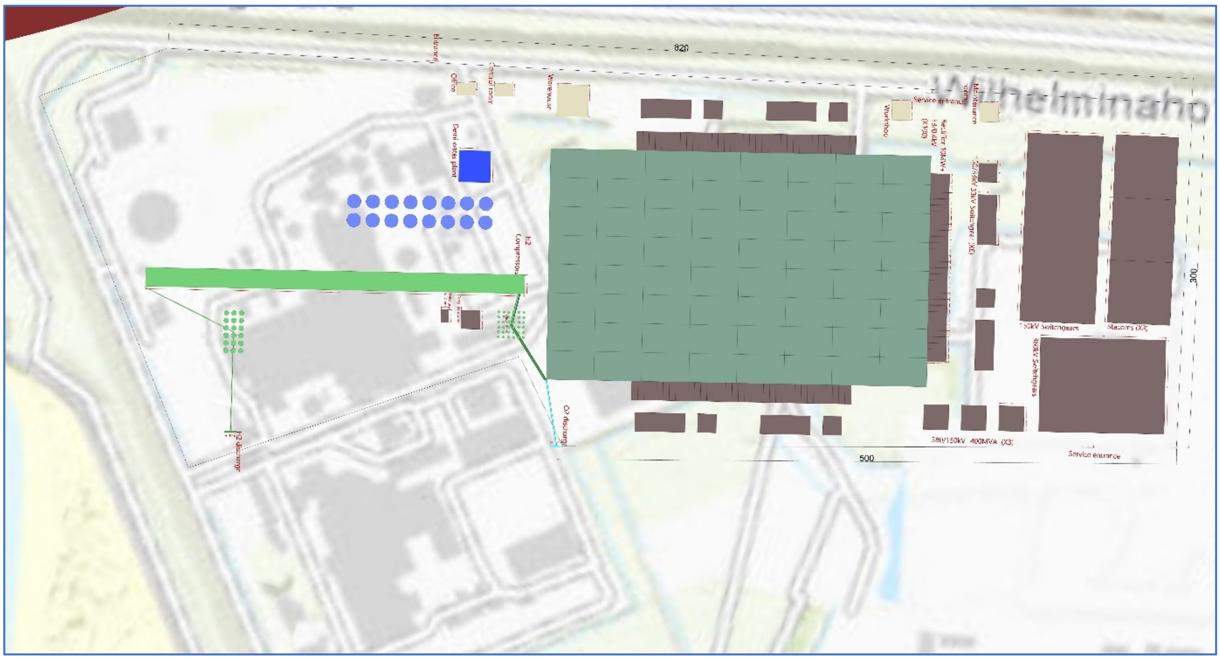


Figure 26: Plot plan- Borselle

6.2. Hydrogen demand and supply

The North Sea Port/ Zeeland Region is with Rotterdam the largest hydrogen cluster in the Netherlands. Hydrogen is produced by SMR or as a by-product and could also be supplied from the Air Liquide network. Most hydrogen is used locally as feedstock or in fuel refining. Total production is estimated at 420 - 480 kton annually [9], of which Yara ~320 kton and Zeeland refinery ~100 kton. Also DOW and other industries in Zeeland as well as Bergen op Zoom produce/consume hydrogen like for hydrogenation. Total production is about 550 kton/a (excl. Ghent). [57]

In an ongoing study by Smart Delta Resources to integrate large scale electrolysis (GW) in the Zeeland area, main locations are identified as potential green hydrogen consumers [12].

- Yara, in Sluiskil, as one of the largest hydrogen producers (SMR) and consumers for the production of ammonia: 380 kton/a.
- Zeeland Refinery, situated near Vlissingen: about 100kton/a
- ArcelorMittal Steel plant with ENGIE Rodenhuize, across the border in Belgium, North of Ghent, potentially future demand.

Yara could accept turn down of ~70% and Zeeland refinery up to 50% provided that the heat integration, operations and controls are secured and safe. Dow/ Elsta cogen could possibly run on oxyfuel and/or natural gas could be blended with hydrogen. For ArcelorMittal similar opportunities exist as for other Steel plants, see section Noordzeekanaal Area. Hydrogen is considered as a necessary solution for decarbonising the industry in the Zeeland area.

[57] Personal communication DNV-GL and Smart Delta Resources

Recently, an agreement was closed between Yara and DOW, where hydrogen from DOW (by-product) is being transported to and used by YARA. The initiative includes the use of existing Gasunie 16” infrastructure and was commissioned in 2019.

The HyChain 1 study estimates a future hydrogen demand in the Zeeland area of 1,490 kton as feedstock or for industrial heat in a high scenario. [11]

6.3. Locations near Borssele/ Vlissingen (Zuid-Beveland)

The four locations are: Zeeland Refinery, near power plant, former Thermphos area, Zanddepot.

6.3.1. Locations

At the Zeeland Refinery location about 1 ha of space is currently available. In the near future about 4-9 ha might become available for large-sale electrolysis, and potentially another 6 ha. The land is owned by Zeeland Refinery. There are first plans for a 100-150MW electrolyser installation. The location is situated in the industrial port area and in use for heavy industry (category 6).

The former Thermphos location comprises at least 40 ha. Though a first assessment indicated that about 11 ha is available on the short term, it is stated that extra ha can be available for future development of large-scale electrolysis. The location has a destination for heavy industry (environmental category 6). The location is situated in the industrial port area. Zanddepot equals max. 40 ha. The location has a destination for heavy industry (environmental category 5.3). The location is situated in the industrial port area. For both locations discussions will still need to be held with North Sea Port concerning detailed site(s) availability.

The location near the Borssele nuclear power plant covers about 40-45 ha. The site is owned by EPZ (PZEM owns 70% of the EPZ shares, RWE 30%). About 8-15 ha is available for development. The location has a destination for heavy industry (category 6) and is earmarked for nuclear activities. This could lead to several barriers for the realisation of a GW electrolyser facility, including safety and security issues. The location is situated South of the industrial port area.

6.3.2. Infrastructure

Figure 27 provides an overview of the infrastructure relevant for the locations near Borssele.

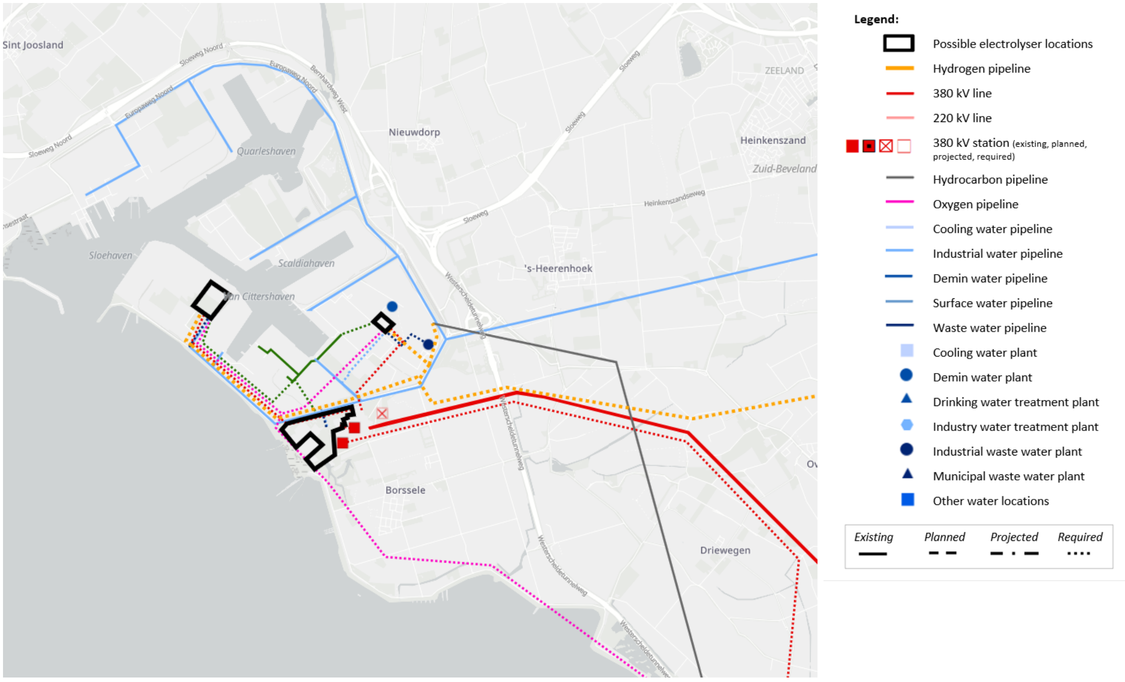


Figure 27: Map of infrastructure for the locations near Borssele/ Vlissingen

Electricity

The 380kV electricity grid in Zuid-Beveland runs via the new 380kV substation Rilland to 380kV substation Borssele (see Appendix A), which is close to the four potential locations for large-scale electrolysis. Borssele has a 380kV connection with the Sloe gas-fired power plant, and about 1,500 MVA transformer capacity 380/150kV, which connects among others to the Borssele nuclear power plant, Zeeland Refinery, the (former) Thermphos location and the region.

An important development for the Zeeland area relates to the development of offshore wind in the Netherlands (see Appendix B). The offshore wind farms *Borssele 1-5* (about 1.5 GW) will be connected to the Borssele substation. As the generated electricity offshore will be brought onshore with 220kV AC cables, the Borssele substation will be extended with a 380/220kV AC station. In addition, the Borssele substation is being considered for connecting part of the offshore wind farm IJmuiden Ver (2GW), expected commissioning between 2027-2030. IJmuiden Ver will be connected via 525kV direct current connections, meaning that first onshore a DC/AC converter station needs to be built, before it can be connected to the 380kV AC grid.

Next to the development of offshore wind, several works are going on as part of the project Zuid-West 380kV (Borssele to Tilburg). The 380kV connection between Borssele and Tilburg is upgraded with a second 380kV connection, and should be realized by 2022. In addition, both the newbuilt of the 380kV substation Rilland and the extension of the Borssele 380kV substation has been realized.

To connect to the onshore 380kV grid, a connection between the GW electrolyser and Borssele380 is required. All potential locations for the electrolyser facility are relatively close to Borssele380, within a few km. There is currently no issue with transport capacity. After the connection of offshore wind farm Borssele 1-5 there is sufficient connection capacity. However, this may change concerning possible 2 GW of offshore wind of the IJmuiden Ver wind farm by the year 2030.

For interconnection of IJmuiden Ver wind farm to 380kV grid two possibilities exist which is not yet planned or projected: Borssele or Geertruidenberg. In case 2 GW of offshore wind of the IJmuiden Ver wind farm will be interconnected to Borssele380, it is not sure whether the connection capacity of Borssele380 will be sufficient for a 1GW facility and likely another extension of Borssele380 is required. In the case of 2GW of IJmuiden Ver interconnection to Geertruidenberg380 the connection to Borssele380 seems possible.

Another option is that the GW electrolyser is directly connected to the offshore wind farm IJmuiden Ver via DC connection. At present, such a direct connection is not expected for the windfarm IJmuiden Ver, as this is not allowed according the law and related regulations. Besides, TenneT is already working on this connection. However, it could be a possibility for future offshore wind farms also in view of possible combi-tenders.

It is not expected that the addition of 1 GW of load at this location causes congestion on the 380kV grid, as the 380kV connection between Borssele and Tilburg will be upgraded by 2023 and due to the addition of 380kV substation Rilland. It even could be beneficial given the presence of generation capacity and the future connection of offshore wind. However, this requires more detailed analysis.

Hydrogen

Potential gas infrastructure for the backbone is located East of the Beveland area and Zeeuws Vlaanderen (see appendix I). The Zebra pipeline is routed next to Gasunie infrastructure and smart combinations could unlock one of these pipelines for the backbone. The Zebra pipeline (28 inch) has been acquired by Gasunie and Gasunie will have the ownership as of January 2021. Initially, this pipeline is intended for transport of natural gas, but parts of the redundant pipelines could become available for the hydrogen backbone. Additional existing (G-gas) gas infrastructure connects the Vlissingen harbour to the National gas infrastructure, but Gasunie indicated this would not be available for hydrogen transport.

In the same area, multiple other pipelines are adjacent to the Gasunie pipeline and are owned by different companies. The pipelines are owned by Enduris, Enexis, Delta Pipe, and RWE but it is unknown if these pipelines could become available for transporting hydrogen. Probably the Delta pipeline will not become available. Further investigation and alignment with these companies might create opportunities.

Another existing pipeline (Naphtha) connects the Vlissingen harbour to Terneuzen. The Naphtha pipeline could potentially be used for hydrogen transport and a direct connection to the backbone could be made close to DOW. However, capacity is probably an issue as the pipeline diameter is only 6”. Moreover, it should be investigated to what extent the pipeline can be reused (e.g. cleaning).

If existing infrastructure is not available for hydrogen transport and a connection to the backbone, new infrastructure (40-50 km) would be required. However, it is stated that there are several options to reuse existing infrastructure, which will result in lower Capex.

Oxygen

No oxygen demand or required infrastructure was identified for this location during the workshop. In case a connection between the electrolyser and potential oxygen demand is needed, a new pipeline would be required to transport all oxygen. In future potential oxygen demand could come from the cracker in case the transition is made to oxyfueling, or a connection could be made with ArcelorMittal Ghent.

Water

From the seven locations identified in Zeeland region, four of them, namely Former Thermphos, Zanddepot, Zeeland Refinery and PZEM/EPZ, have the same information applicable to the supply of water and any planned, projected and required water infrastructure. These are summarised in Table 25 below.

Table 25: Summary of water infrastructure available and required near Borssele

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	(i) Evides considering supplying demin water. (ii) Biesbosch water (by Evides) (WQ available) (iii) Use existing demin from steam methane reforming installation.	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	The level of water treatment required will depend on the source available. For instance, tap water will require an ion exchange step to meet the demin water quality.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Yes, AWZI Sloe owned by Evides Industrie Water	No.	No.	Possible use of the existing AWZI Sloe.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	Yes at EPZ.	No.	No.	The existing cooling system needs to be assessed for suitability.
Is there a water connection possible/available for water supply?	Only for industrie water, not for demin water supply.	No.	No.	New pipeline is required from the water source to the water treatment plant location.

District heating

Similar to the water infrastructure, the information gathered for the possibility of using the waste heat generated by the GW project is the same for the four locations. This is summarised below in Table 26.

Table 26: District heating potential near Borssele

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 0C), and how much?	Industry	No.	No district housing projects yet.	
Is there available infrastructure for district heating? If not, is there space for this?	a regional waste heat infrastructure is in operation near Zeeland Refinery (Sloewarmte, industry-to-industry); this could be expanded.	No.	Future connections to residential cores of Borssele, Vlissingen, Goes and Middelburg might be possible	Connection towards heat grid Sloewarmte

6.4. Locations near Terneuzen (Zeeuws-Vlaanderen)

Near Terneuzen two potential locations are foreseen: near DOW Chemical and near Yara Sluiskil.

6.4.1. Locations

At the location near DOW Chemical about 70-75 ha of space is available. The location is called the Valuepark Terneuzen, which is a joint venture between DOW Chemical and North Sea Port. The location is situated to the West of DOW Chemical along the Westerschelde. A first assessment indicated that the location has an environmental category 5.3 and currently not in use for heavy industry. . For this location discussions will still need to be held with Valuepark Terneuzen concerning detailed site availability.

The location near Yara Sluiskil is situated at the premises of Yara Sluiskil up to the Koegorsstraat. It is not exactly known what area is available, but a first assessment indicated a plot of about 10-12 ha. The landowner is Yara. The location is in use for heavy industry (environmental category 6).

6.4.2. Infrastructure

Figure 28 provides an overview of the infrastructure relevant for the locations near Terneuzen.

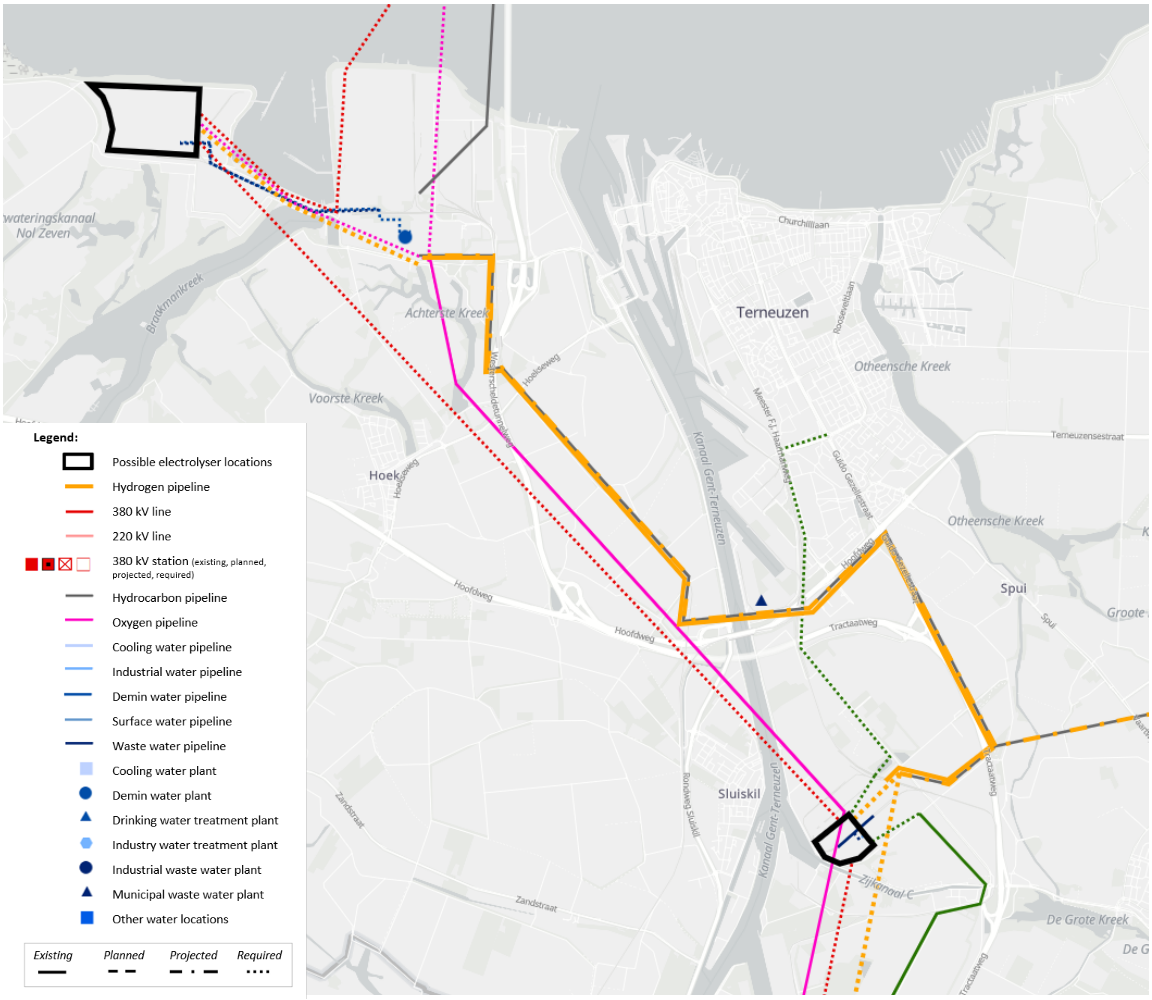


Figure 28: Map of infrastructure for the locations near Terneuzen

Electricity

There is no 380kV grid at Zeeuws-Vlaanderen. Both locations Yara and DOW are connected to the 150kV grid, Dow via the 150/50kV substation Terneuzen and Yara via the 150/50kV substation Westdorpe. The 150kV grid cannot facilitate a GW of additional load.

A connection with Borssele380 could be an option, but comes across the same barriers as for the locations near Borssele. In addition, there is another challenge, being the realization of a subsea 380kV connection between Borssele and a location near Terneuzen or Westdorpe. It is expected that there will be several technical complexities to be overcome. Currently there are no plans and this requires further investigation. Consultation with TenneT is taking place.

The distance between Borssele and Dow and Yara is about 20-30 km and the costs of this connection need to be further assessed as potentially drilling is required. Costs are expected to be relatively high, as cable connections are significantly more expensive compared to overhead lines and drilling is expensive. In general, realizing new connections can take several years (3-10 year), which needs to be taken into account.

Another option that could be explored further is the realization of a direct connection between the GW electrolyser and a generator of electricity. Within the Netherlands, this concept of a direct line is allowed under certain conditions. This connection is non-regulated and without intervention of the regulated electricity grid, though it is allowed that one of the parties (either the generator or the consumer) is connected to the public grid. It could be an option to investigate whether this is possible between Belgium and the Netherlands. Also the option of another interconnector could be explored.

In case a 380kV connection can be realized with Borssele380, it is not expected that the addition of 1 GW of load at this location causes congestion on the 380kV grid for the same reasons.

Hydrogen

In 2018 a hydrogen pipeline was commissioned between DOW and YARA (with a connection to ICL-IP halfway, see appendix I). To this end, existing Gasunie infrastructure (16 inch, about 66 bar for natural gas) was converted for hydrogen transport and transports about 4-5 kton of hydrogen from DOW to Yara on an annual basis (about 30 bar). The pipeline will eventually be connected to the backbone to exchange hydrogen with the other industrial clusters and with the storage at Zuidwending. Electrolysis close to either DOW or Yara only requires a short new pipeline and connection to the existing hydrogen pipeline. This allows the hydrogen to be transported to either Yara for consumption, or to the backbone. The foreseen backbone is close to Yara.

Oxygen

Currently, DOW has a small hydrogen demand (10 kton/y) and is considering the possibilities of oxy-fuel combustion. This would increase oxygen demand significantly, consuming all oxygen produced by the electrolyser.

Other demand is located towards Gent, at ArcelorMittal and the cement industry near Gent. This is further discussed in section 0. Existing oxygen infrastructure connects from the Zeeuws-Vlaanderen area to the Area of Rodenhuize, but exact details about the trajectory and capacity (around two times 6 inch should exist) are unknown.

In case a connection between the electrolyser and oxygen demand is needed, a new pipeline would be required to transport all oxygen.

Water

At the Dow Benelux and Yara Sluiskil locations, the information gathered for the supply of water and any planned, projected and required water infrastructure are summarised in Table 27 and Table 28 below.

Table 27: Summary of water infrastructure available and required at Dow Benelux location

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	(i) Evides considering supplying demin water from Deco plant. (ii) Biesbosch water (by Evides) (WQ available)	No	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality	The level of water treatment required will depend on the source available. For instance, tap water will require an ion exchange step to meet the demin water quality
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Possibly DOW salt biox	No	No	Possible use of DOW salt biox
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	Yes	No	No	A treated water storage facility needs to be considered as part of the water treatment plant
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No	No	No	Yes, a new cooling system is required for the waste heat
Is there a water connection possible/available for water supply?	Yes	No	No	New pipeline is required from the water source to the water treatment plant location

Table 28: Summary of water infrastructure available and required at Yara Sluiskil location

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	(i) Evides considering supplying demin water. (ii) Biesbosch water (by Evides) (WQ available) (iii) Use existing demin from steam methane reforming installation	No	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality	The level of water treatment required will depend on the source available. For instance, tap water will require an ion exchange step to meet the demin water quality
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Yes, Yara WWTP	No	No	Possible use of Yara WWTP
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	Yes	No	No	A treated water storage facility needs to be considered as part of the water treatment plant
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No	No	No	Yes, a new cooling system is required for the waste heat
Is there a water connection possible/available for water supply?	Yes	No	No	New pipeline is required from the water source to the water treatment plant location

District heating

The information gathered for the possibility of using the waste heat generated by the GW project for both Dow and Yara locations is summarised below in Table 29 and Table 30.

Table 29: District heating potential at Dow Benelux location

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	Yes, possibly for the city of Hoek.	No.	Possible district heating for the city of Hoek.	
Is there available infrastructure for district heating? If not, is there space for this?	No.	No.	A regional study is performed on waste heat for district heating in the Kanaalzone Terneuzen-Gent. Insertion of electrolysis waste heat at 80°C is being studied	Connection towards heat grid Kanaalzone Terneuzen-Gent

Table 30: District heating potential at Yara Sluiskil location

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	No.	No.	No.	
Is there available infrastructure for district heating? If not, is there space for this?	Regional waste heat infrastructure is in operation near Yara (WarmCO_2, 100 MW possible extension to heat Axel)	No.	A regional study is performed on waste heat for district heating in the Kanaalzone Terneuzen-Gent. Insertion of electrolysis waste heat at 80°C is being studied	Connection towards heat grid Kanaalzone Terneuzen-Gent

6.5. Location Rodenhuize Ghent (Belgium)

6.5.1. Location

The ENGIE Rodenhuize location comprises in total about 70-75 ha. The location is owned by ENGIE and has a destination for heavy industry. The location is situated in the industrial port area of Ghent next to the substation Rodenhuize of Elia between the Ghent-Terneuzen canal and the John F. Kennedylaan.

6.5.2. Infrastructure

Figure 29 provides an overview of the different infrastructure relevant for the Rodenhuize location.

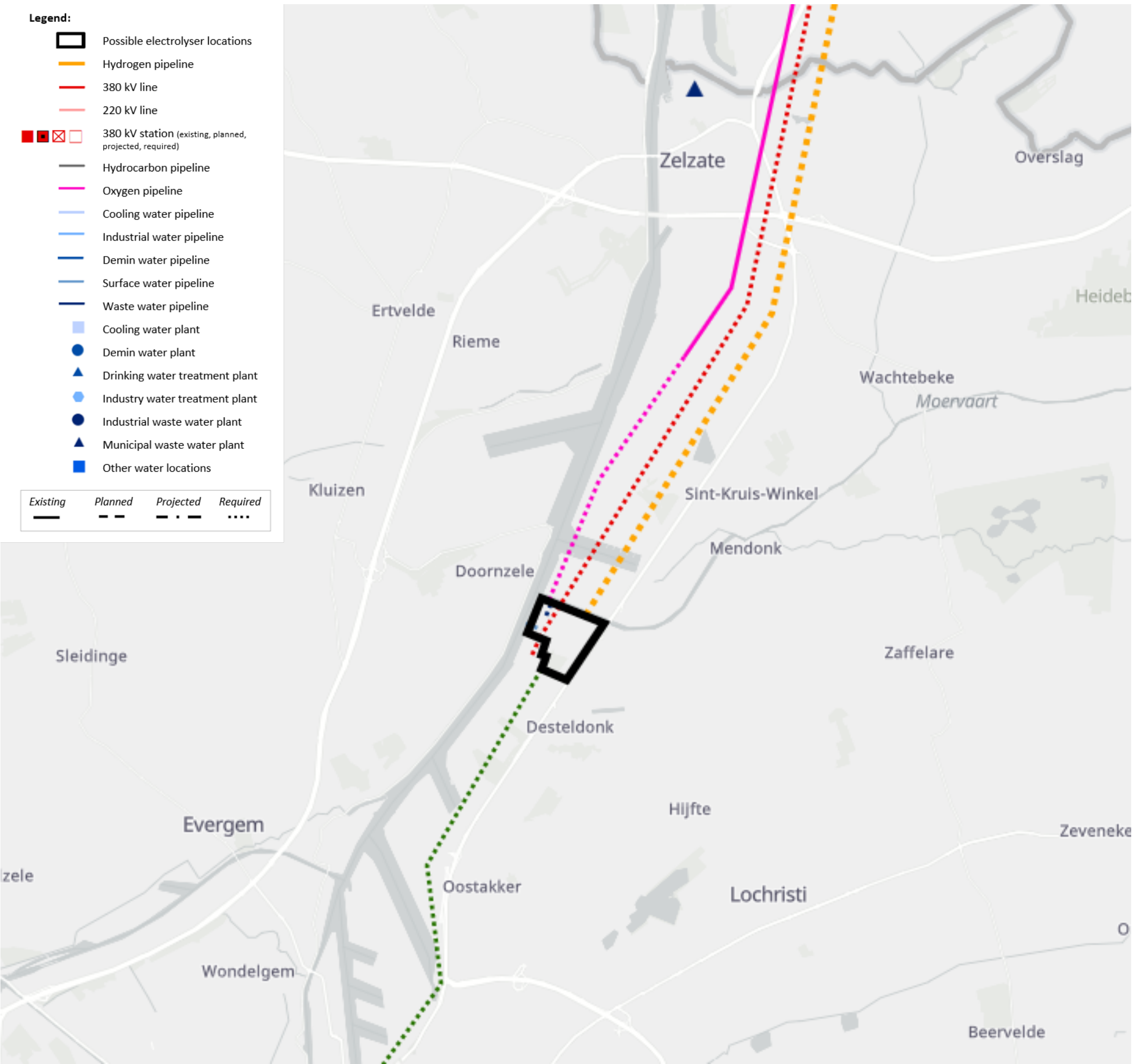


Figure 29: Map of infrastructure for the Rodenhuize (Belgium) location

Electricity

The location is next to the 380/150kV substation Rodenhuize of Elia. For a 380kV connection with the GW electrolyser, sufficient connection and transport capacity is required. Since this is an area with quite some demand for electricity due to the presence of industry and the city of Ghent, it needs to be investigated and discussed with Elia whether another GW of additional load can be facilitated. There could be possibilities, as Rodenhuize is connected with Zeebrugge via the substations Horta, Eeklo Noord, Van Maerlant and Gezelle. Zeebrugge is connected with UK via the 1GW HVDC interconnector NEMO, and with offshore wind (2.2 GW by 2020)[58].

Hydrogen

Infrastructure to connect different large industrial organisations in and between the areas of Ghent, Rodenhuize and Zeeland is explored in the CUST study (Clean Underground Sustainable Transport) [13]. Twelve organisations[59] were involved, who investigate ways of decarbonising their operations. The study includes infrastructure for hydrogen, CO_2, heat and naphtha. The study is exploring possibilities and does not yet give a conclusive indication whether the infrastructure will be built, but the study concludes there is a high potential.

One of the assumptions is the connection with existing infrastructure and exchange with other industries. Although the backbone still has to be realized, it is safe to assume that the infrastructure from the CUST study would connect to the backbone. This allows for hydrogen transport to the other industrial clusters and a connection of the electrolyser to the backbone. It is stated that gas pipelines are redundant between the Dutch and Belgian boarder and Yara, that could be made available for transport of hydrogen. Within the CUST study, the trajectory of infrastructure is determined. For the connection to the Rodenhuize Ghent area only a short new pipeline is required from the electrolyser. See appendix I.

Additionally, Air Liquide operates a hydrogen network which connects to the Area of Ghent, Rodenhuize and Zeeland. It is unknown if hydrogen could be injected in this network and whether the capacity is sufficient. However, it should be noted that Air Liquide manages their network by providing different industrial gasses to their customers via dedicated pipelines, and that this network is not open-access infrastructure.

For distribution within the Rodenhuize area itself, a pipeline from Arcelor Mittal could be a solution. During the workshop it was indicated that the pipeline is at atmospheric pressure and capacity is most likely not sufficient, but space was reserved in the same corridor for new pipelines in the zoning plans. The pipelines between Rodenhuize and Arcelor Mittal could follow the corridor of the existing blast furnace gas pipeline. The distance is about 5km.

Oxygen

Arcelor Mittal could potentially consume oxygen. Arcelor Mittal is involved in the development of a connection with the Air Liquide network to Temse for oxygen. The construction started in 2018. Other demand could come from the cement industry near Gent. In case a connection between the electrolyser and oxygen demand is needed, a pipeline would be required to transport the oxygen. An oxygen pipeline of about 36-48 inch would potentially be available, but the routing is unknown.

[58] Zie https://economie.fgov.be/nl/themas/energie/energiebronnen/hernieuwbare-energieen/hernieuwbare-energiebronnen-de/belgische-offshore-windenergie.

[59] Zeeland Refinery, Sloecentrale, Dow (including WKC Elsta), Trinseo, Yara, Cargill Sas van Gent, Arcelor Mittal (including ENGIE Knippegroen), Oleon, ENGIE Rodenhuize, Cargill Gent, Stora Enso, Kronos.

The pipelines between Rodenhuize and Arcelor Mittal could follow the corridor of the existing blast furnace gas pipeline.

Water

The information gathered for the supply of water and any planned, projected and required water infrastructure at Rodenhuize Gent are summarised in Table 31 below.

Table 31: Summary of water infrastructure available and required at Rodenhuize Ghent

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	(i) WaterLink (ii) Farys	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	The level of water treatment required will depend on the source available. For instance, tap water will require an ion exchange step to meet the demin water quality.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	No.	No.	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	A treated water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply?	No.	No.	No.	New pipeline is required from the water source to the water treatment plant location.

District heating

As far as district heating requirement is concerned, the information gathered is summarised below in Table 32.

Table 32: District heating potential at Rodenhuize

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	No.	No.	Possibly Gent.	
Is there available infrastructure for district heating? If not, is there space for this?	City of Ghent has an expanding district heating system, at various temperature levels	No.	A regional study is performed on waste heat for district heating in the Kanaalzone Terneuzen-Gent. Insertion of electrolysis waste heat at 80°C is being studied	Connection towards heat grid City of Ghent

7. Northern Netherlands

For the Northern Netherlands region (Noord-NL), several locations are considered for large-scale electrolysis: Eemshaven, near Meeden, near Vierverlaten, near Ter Apel and near Emmen. Figure 30 provides an overview of the potential locations for Noord-NL. For more (spatial) information regarding the locations see Appendix J.

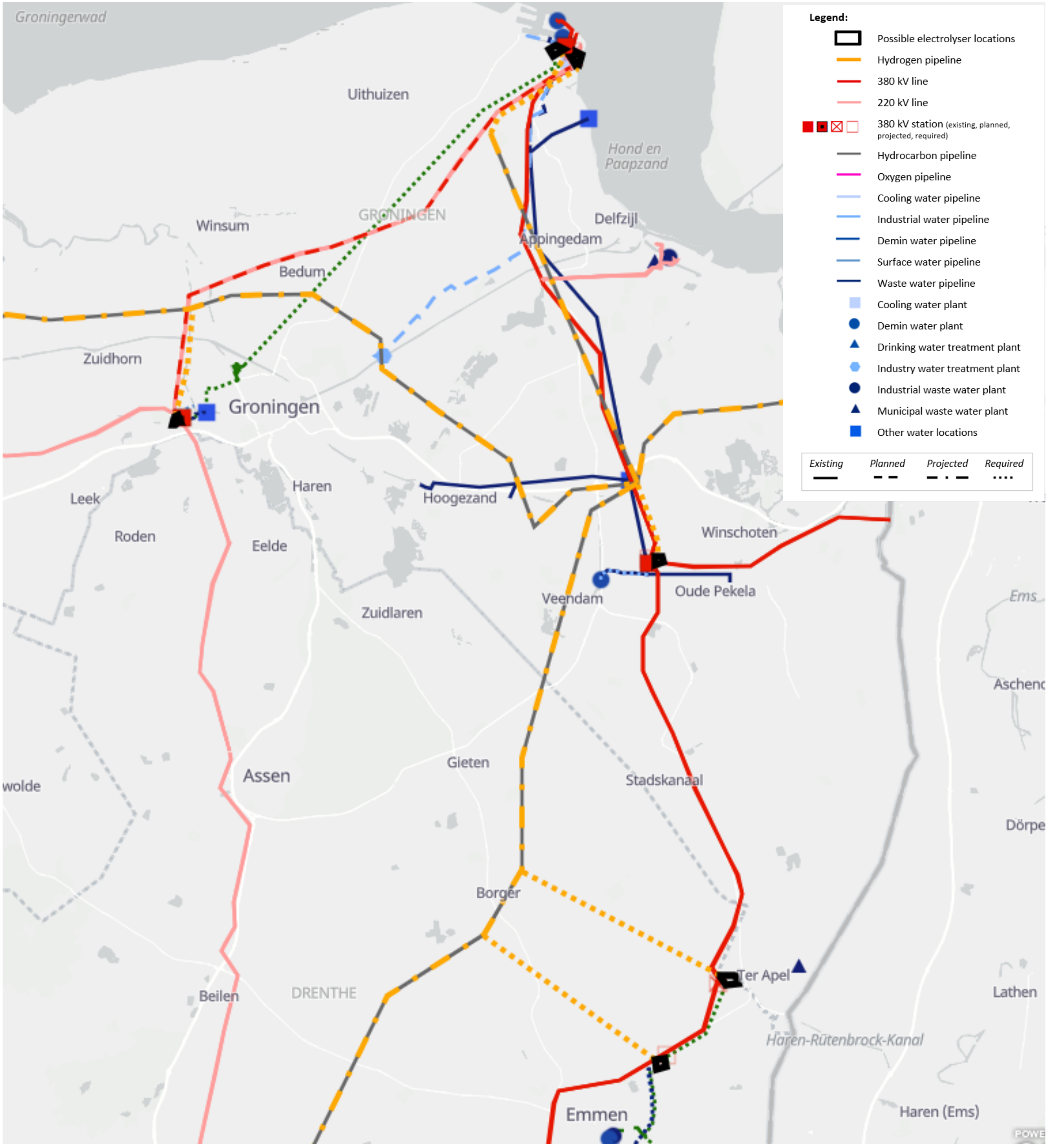


Figure 30: Overview of potential locations Northern Netherlands (indicated by the dark rectangles)

7.1. Summary of findings

An overview of the findings for Northern Netherlands is presented in Table 33. Based on the available information, the following preliminary key observations can be determined:

- Regarding the available space and suitability of the locations, there is no preferred location as it is too early to analyse this. At Eemshaven, space is available just outside the port area, but this is not in use by industry and ownership and spatial planning is unknown. Concerning the other locations the destination is not industrial and ownership is not clear.
- Regarding critical infrastructure – e.g. water, electricity and hydrogen – it seems that near Vierverlaten is a good location, but also Eemshaven provided that 380kV substation will be timely planned.

Table 33: Overview of findings locations North Netherlands[60]

Location	**Eemshaven**	**Emmen**	**Other locations**
Space	Space is available inside and outside of port area, though exact amount of space and location is not clear. Also location at power plant facility	Location and available space unknown. It is expected that sufficient space is available.	Location and available space unknown. It is expected that sufficient space is available. Vierverlaten sufficient space.
Suitability	Ownership of green field plot unknown, probably privately owned. Not in use for industry but agricultural. Spatial planning unknown.	Ownership unknown, probably privately owned. (Probably) not in use for industry. Spatial planning unknown.	Ownership unknown, probably privately owned. (Probably) not in use for industry. Spatial planning unknown. Vierverlaten is mostly designated industrial area and owned by municipality of Groningen.
Water supply	Water source available and can be treated to meet Electrolyser water quality targets.	Possible deminwater supply from Emmtec or from NieuWater Puurwater plant.	Water source available and can be treated to meet Electrolyser water quality targets.
Electricity supply	No connection capacity available at Eemshaven380 or Oudeschip380 substation. Extension and new	No plans for Emmen.	Vierverlaten could be possible by 2030. New 380kV substation near Ter Apel is foreseen, but no plans.

60 For an explanation of the colour scheme, see Appendix M.

Location	Eemshaven	Emmen	Other locations
	substation not planned or projected.		No plans for Meeden.
Hydrogen infra	Existing NAM infrastructure is available (2023), but still requires a new 9 km pipeline for a full connection to the backbone.	All locations relatively close to backbone. Unknown if existing infra can be used. Connection to backbone could be realized by 2030.	All locations relatively close to backbone. Unknown if existing infra can be used. Connection to backbone could be realized by 2030.
Hydrogen demand	Local hydrogen demand present.	Potential hydrogen demand from Emmtec.	Potential hydrogen demand from Suikerunie
Oxygen demand	No oxygen demand, though demand might exist in coming years due to entry of new company.	Unknown. Potential demand from medical care sector (hospitals).	Unknown. Potential demand from medical care sector (hospitals).
District heating	Possibly the Warmtestad project will require heating for Groningen city.	Heat grid Emmen 10 MW, Emmtec 60 MW, Greenhouses Rundedal 100 MW	Possibly the Warmtestad project will require heating for Groningen city.
Cooling Capacity 250 MW	Once Through Cooling possible	Recirculating Cooling Tower required	Recirculating Cooling Tower required

As an example, the plot plan is depicted at the Eemshaven in the Figure 31. The available plot space is sufficient for PEM and Alkaline based electrolysers facility with regards to **maximum and minimum cases.**

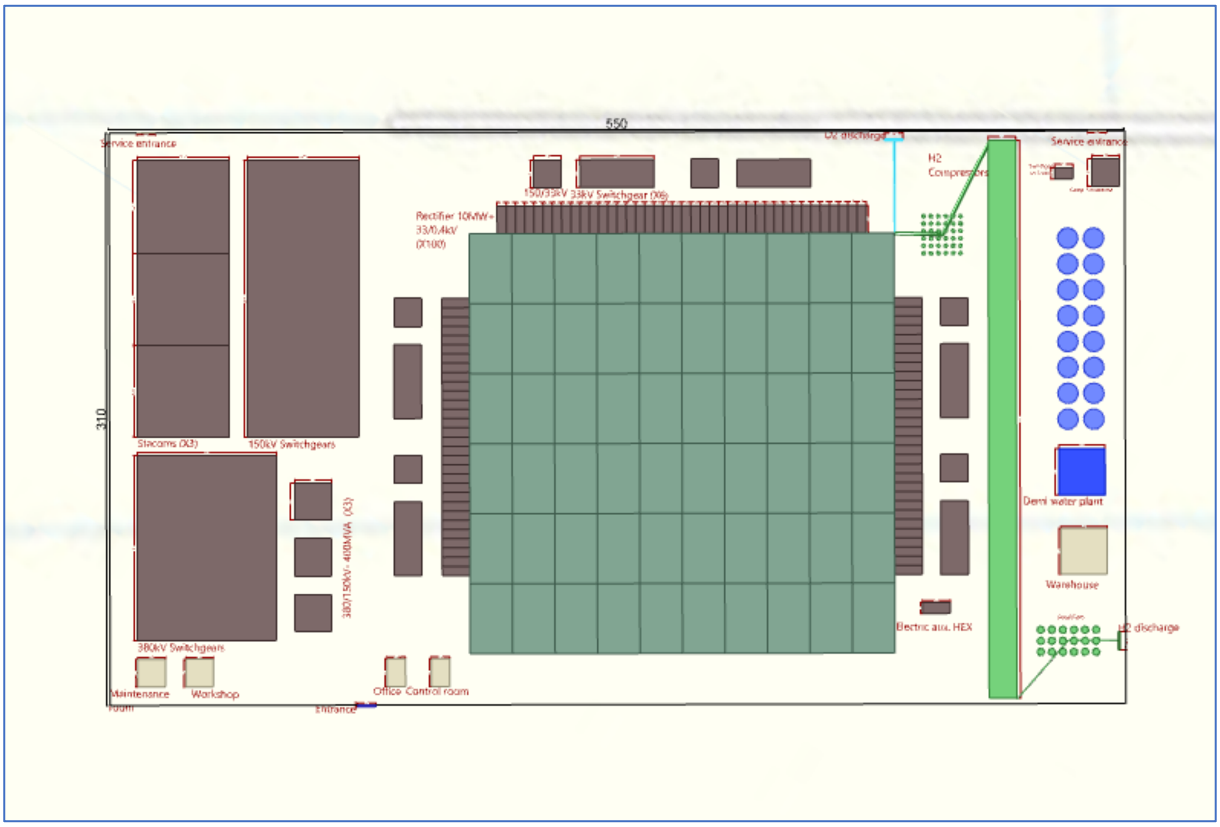


Figure 31: Plot plan - Eemshaven

7.2. Hydrogen demand and supply

The North of the Netherlands, near Eemshaven and Delfzijl, is one of the Dutch hydrogen clusters. Hydrogen is produced by SMR, as a by-product and a small volume is produced by the 1 MW electrolyser (HyStock). Most hydrogen is used for methanol production and a small portion is used for mobility. The current annual hydrogen production is estimated at roughly 150 kton in total [9].

The North of the Netherlands is known as "hydrogen valley" and receives financing for the development of a (green) hydrogen chain (HEAVENN). The region consists of the provinces of Groningen, Drenthe and Friesland. The European Union allocated 20 M€ to subsidize the initiative and an additional 70 M€ will come from public-private co-financing[61]. Many projects are announced (summarized below) considering hydrogen production/conversion, infrastructure, mobility and consumption. Most of these projects are situated near the Eemshaven and Delfzijl.

- A total electrolyser capacity to be installed before 2024 is estimated at 165 MW and later upscaling towards 2030 is estimated at 1.5 GW.
- Also Engie is considering the use of hydrogen in their gas-fired powerplant, and on building a large GW scale electrolyser (2026-2030).

[61] https://newenergycoalition.org/en/hydrogen-valley/

- One approved project by EU is Nouryon 20MW DJEWELS electrolyser project for producing hydrogen for BioMCN in Delfzijl.
- Converting existing natural gas infrastructure and building new hydrogen infrastructure and creating undergrounds hydrogen storage capacity near Zuidwending HYSTOCK.
- Fuel switching to use hydrogen as an energy carrier for energy and heat production and hydrogen use for mobility and a pilot in Hoogeveen for residential hydrogen use.
- Recently the project NortH2 was announced by Gasunie, Shell and Groningen Seaports, with the ambition to realize about 3-4 GW of electrolyser capacity in 2030 (and 10GW in 2040), using electricity generated by planned offshore wind farms but also new offshore wind project beyond 2030.

An overview of all projects in the North of the Netherlands is given in the investment agenda for this region[62].

One of the most prominent blue hydrogen projects is the H2M project by Vattenfall, Equinor and Gasunie. It is the plan to produce blue hydrogen from natural gas, with about 1 GW of capacity. The captured CO_2 should be transported to offshore gas fields near Norway and stored underground. The hydrogen can be used for generating flexible (CO_2 neutral) electricity in the Magnum powerplant, but also can be used for other purposes like transport or stored underground in salt caverns[63].

[62] https://www.snn.nl/sites/default/files/2019-07/Investment%20Agenda%20Hydrogen%20Northern%20Netherlands%20-%20April%202019%20%285%29.pdf

[63] See https://www.gasunienewenergy.nl/projecten/magnumcentrale

7.3. Near Eemshaven

7.3.1. Location

Near the Eemshaven a potential location can be found for large-scale electrolysis, as there is ample space around the Eemshaven. Though it is indicated that space is available within the port area, there is no clear defined location for the GW electrolyser installation. Locations outside of the port area also seem suitable, though this is agricultural land and not managed by the port.

7.3.2. Infrastructure

Figure 32 provides an overview of the different infrastructure relevant for the Eemshaven locations.

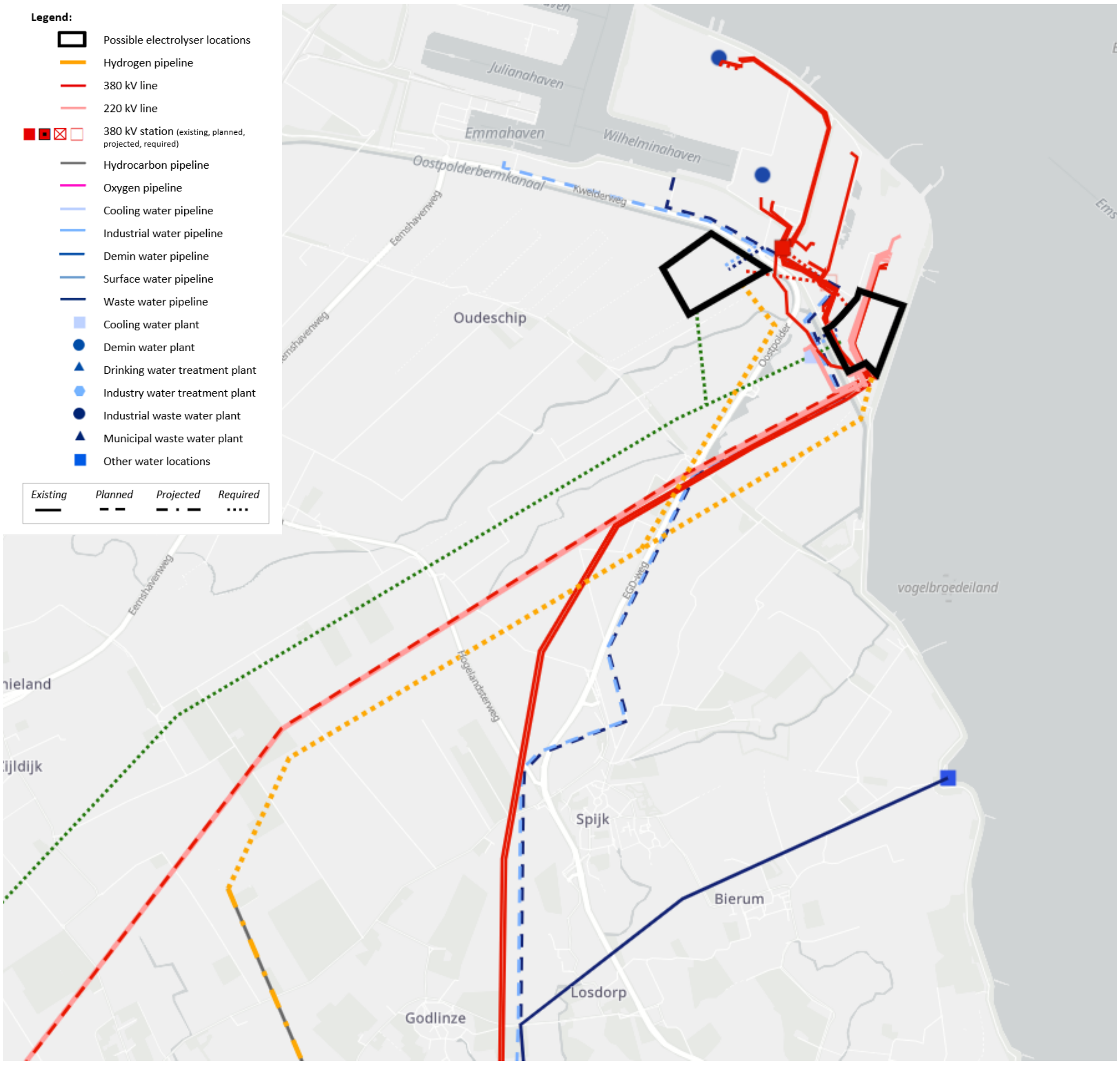


Figure 32: Map of infrastructure for the Eemshaven

Electricity

The 380kV electricity grid in Groningen is connected via the 380kV substation Meeden to the Eemshaven area (see Appendix A). The Eemshaven area is a real electrical node, with several substations, connections to a significant amount (>4GW) of thermal generation capacity (380kV connection of Nuon and RWE with Oudeschip380, Engie with Eemshaven380) a connection with the 600MW offshore wind farm Gemini (380kV connection with Oudeschip380), and cross-border connections with both Norway and Denmark via the subsea HVDC interconnectors NorNed (380kV connection to Eemshaven380) and Cobra (380kV connection to Oudeschip380) of each 700MW.

Several works are going on as part of the project Eemshaven - Vierverlaten. The 220kV connection between Eemshaven and Vierverlaten will be replaced by a new 380kV connection and should be realized by 2023. In addition, the 220kV substation Vierverlaten will be extended with a 380/220kV installation. By 2026, the 700MW offshore wind farm *Ten Noorden van de Waddeneilanden* (TNvdW) should be realized. Potential locations for the connection of offshore wind farm TNvdW are Eemshaven, Vierverlaten, and Burgum.

A 380kV connection between the GW electrolyser and the 380kV grid is required. A GW of additional load can be facilitated at this location. However, currently there is no sufficient connection capacity at either Eemshaven380 or Oudeschip380. Accordingly, this requires additional connection capacity (extension) and potentially a new 380kV substation. This is currently not planned neither projected. Besides, a 380kV connection between the GW electrolyser facility and the 380kV substation is required (probably within one km).

It is not expected that the addition of 1 GW of load at this location causes congestion on the 380kV grid. On the contrary, it is expected to be beneficial given the presence of generation capacity, the interconnectors (with net imports) and the connection of offshore wind. Also, the realization of the 380kV connection Eemshaven – Vierverlaten helps in this respect.

Hydrogen

Due to a decline of gas extraction from the Groningen gas field, Gasunie infrastructure is expected to become available and could be allocated to the backbone. There is an existing connection which currently supplies the Eemshaven with H-gas and is still required in the foreseeable future. Infrastructure is available for the backbone towards Tjuchem, from where other options need to be considered to connect the Eemshaven and the electrolyser. The distance is about 12-13 km, leading to a Capex for the pipeline of about 12-13 MEUR.

Here the NAM infrastructure could provide a solution. Pipelines between multiple NAM locations will become available and already connect to the Gasunie infrastructure (backbone) in Tjuchem. The NAM infrastructure could be partially used for the connection of the Eemshaven to the backbone and these pipelines have sufficient capacity (could be 28 inch, cannot be confirmed), according to the NAM. The nearest point of NAM infrastructure to the Eemshaven is two kilometres North of t'Zand. New infrastructure, approximately 9 km, is still required for the remaining connection.

The Northern part of the backbone could already become available in 2023, as indicated by Gasunie. This includes initial underground storage capacity in 2023 at Zuidwending [14]. This enables a first connection with potential hydrogen demand in the North (including Emmen) and opens future connection with the other large hydrogen clusters in the other regions.

Oxygen

Currently, there is no oxygen demand and infrastructure for this location. However, it is expected that within a few years a new company will be located here which needs oxygen.

Water

At Eemshaven, the information gathered for the supply of water and any planned, projected and required water infrastructure are summarised in Table 34 below. In the region, there is plenty of expertise and experience in the production of ultrapure water.

Table 34: Summary of water infrastructure available and required at Eemshaven

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	NorthWater canal water (WQ data available). NorthWater is willing to have a DBFO plant.	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Although water sources are available, they will require significant treatment to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Yes, there is an existing sewer network from Google Data Centre to the VKA.	No.	No.	The use of the existing sewer network from Google Data Centre to the VKA needs to be assessed for suitability.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	Will be part of NorthWater DBFO Demin plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Could be part of NorthWater DBFO Demin plant.
Is there a water connection possible/available for water supply?	No.	No.	No.	Could be part of NorthWater DBFO Demin plant.

District heating

There are no current requirements for the use of waste heat for district heating at Eemshaven as shown in Table 35. Currently there is a project for industrial use of waste heat in the Eemshaven area, connecting a heat source with multiple off takers. There are plans to use waste heat from the Eemshaven for district heating in Groningen and other urban areas.

Table 35: District heating potential at Eemshaven

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	Limited	Industrial use of waste heat, connecting a heat source with multiple offtakers.		
Is there available infrastructure for district heating? Are there plans for this?	Warmtestad Groningen Noordwest	No.	Extention of the Warmtestad project for Groningen city.	Connection towards heat grid Warmtestad

7.4. Other potential locations Noord NL

Several other potential locations are explored for GW electrolysis, that are relatively close to both the 380kV grid and the projected hydrogen backbone. These locations are near: Vierverlaten, r Meeden, Ter Apel, and Emmen. Locations near Vierverlaten and Meeden are both close to the current 380kV substation. No further information is available regarding the available space, land ownership, zoning, permitting, and developments for the coming decade.

7.4.1. Infrastructure

Figure 33 provides an overview of infrastructure relevant for the other locations in Noord NL.

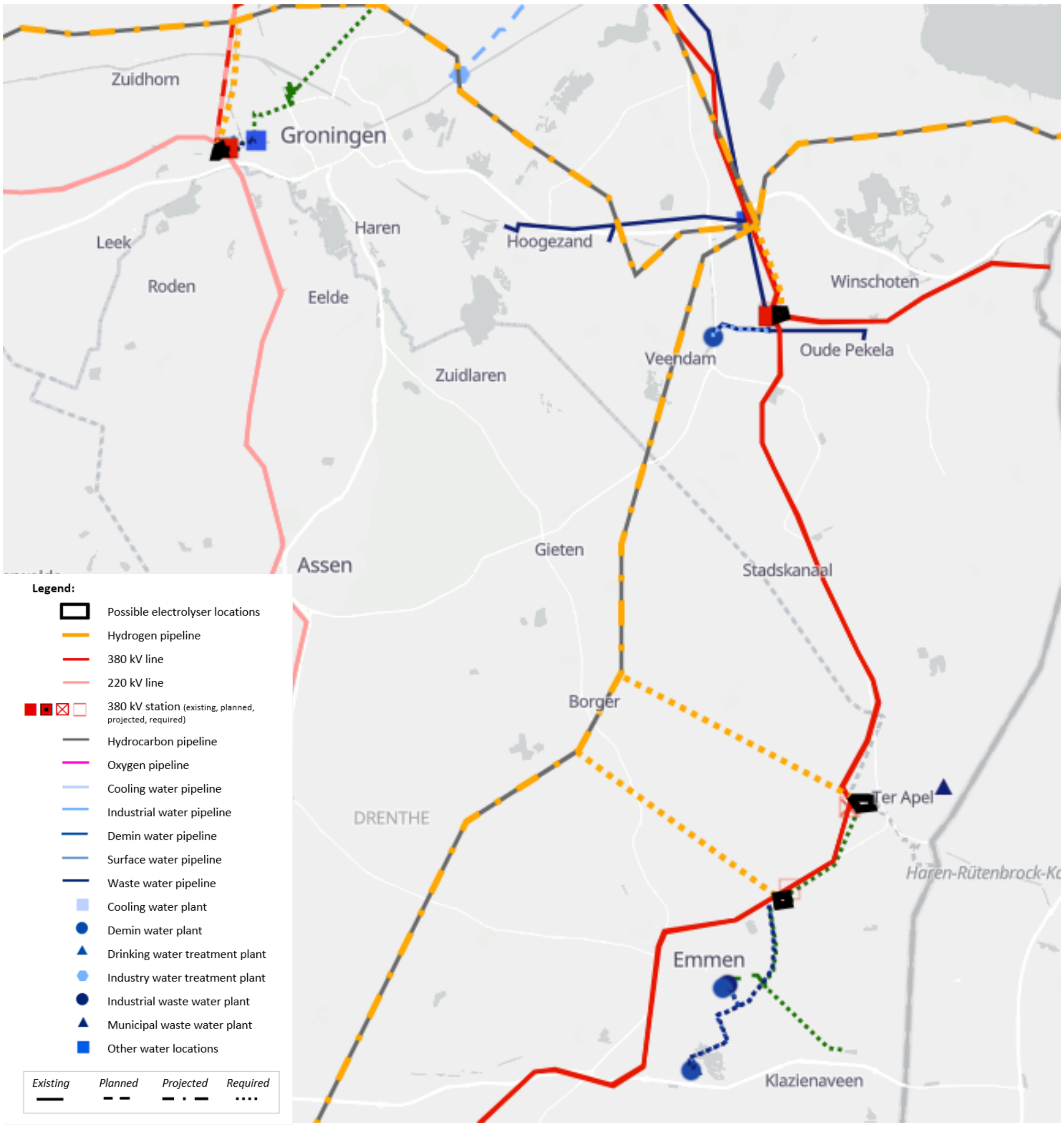


Figure 33: Map of infrastructure for the other locations in Noord NL

Electricity

As mentioned, the 220kV substation Vierverlaten will be extended with a 380/220kV installation, as part of the project Eemshaven – Vierverlaten while replacing the 220kV connection between Eemshaven and Vierverlaten by a new 380kV connection. This should be realized by 2023, and afterwards there should be sufficient transport and connection capacity to facilitate a GW electrolyser.

The 380/220/100kV substation Meeden is connected with Zwolle380 and Eemshaven380, and has a 380kV connection with Diele in Germany. Substation Meeden is being reinforced among others to increase the 380kV transport capacity of the interconnection with Germany, and to connect the nitogren plant Gasunie is building near Zuidbroek. However, it is expected that there is no sufficient connection capacity at this substation to connect a GW additional load, though this should be further explored.

The 380kV grid runs from Meeden to Zwolle along Ter Apel and Emmen. To develop a GW electrolyser at (one of) these locations, a new 380kV substation is required to realize a 380kV grid connection. A new 380kV substation is not planned for this area, though the possibility is explored for the Ter Apel area due to the (anticipated) increase of renewable energy.

Water

For Vierverlaten, Ter Apelkanaal, Meeden and Emmen, similar information was gathered for the supply of water and any planned, projected and required water infrastructure are summarised in Table 36 and

Table 37 below. In the region, there is plenty of expertise and experience in the production of ultrapure water.

Table 36: Summary of water infrastructure available and required at Emmen

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	Emmtec Industry and Business Park: Demin production 210 m3/h, surplus unknown NieuWater Puurwater plant: Demin production 340 m3/h, surplus unknown	Emmtec Industry and Business park: extension demin production 50 m3/h	No.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Although water sources are available, they will require significant treatment to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Emmtec Industry and Business Park: Biological (aerobic) Wastewater Treatment plant 300-350 m3/h Municipal Wastewater Treatment Plant Emmen	Emmtec Industry and Business park: extension WWTP with 2 anaerobic reactors	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	Yes.	No.	No.	A demin water storage facility needs to be considered as part of the water treatment plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	Emmtec Industry and Business Park: Small cooling system 10 MW	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply?	No.	No.	No.	New pipeline is required from the water source (Emmtec or NieuWater) to the water treatment plant location.

Table 37: Summary of water infrastructure available and required at Vierverlaten, Ter Apelkanaal and Meeden

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	NorthWater canal water (WQ data available). NorthWater is willing to have a DBFO plant.	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	A water treatment plant capable to meet the total water demand and water quality of the GW electrolyser. Although water sources are available, they will require significant treatment to meet the demin water quality target of 0.1 µS/cm.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	Unknown.	No.	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	No.	No.	No.	Will be part of NorthWater DBFO Demin plant.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Could be part of NorthWater DBFO Demin plant.
Is there a water connection possible/available for water supply?	No.	No.	No.	Could be part of NorthWater DBFO Demin plant.

Hydrogen

The trajectory of the backbone is planned to run South, from the area of Winschoten to the area of Hoogeveen in almost a straight line. The potential electrolyser locations (near Emmen and Ter Apel) are roughly 20-30 km from the backbone (leading to a Capex for the pipeline of about 20-30

MEUR) and there are no plans for a connection to these locations. The industrial cluster of Emmen itself (South of the city) however might be connected to the backbone and is seen as a potential "hydrogen hub" [14][64]. The Emmen cluster is closer to the potential electrolyser locations, roughly 10-15 km.

Furthermore, NAM infrastructure might be available for hydrogen transport, but further detail is unknown. NAM, Gasunie and Enexis currently investigate hydrogen production in this area, including the reuse of existing infrastructure[65]. An existing NAM pipeline is considered between the industrial cluster of Emmen or GZI and a NAM location near Roswinkel (near the potential electrolyser location).

For the other potential locations, Meeden and Vierverlaten, little detail is available regarding hydrogen infrastructure. Both Meeden and Vierverlaten are about 8-10 km from the planned trajectory for the backbone, while Ter Apel and Emmen are over 15 km from the backbone.

Oxygen

No oxygen demand or (required) infrastructure has been identified for this location.

District heating

There are no current or planned requirements for the use of waste heat for district heating at Vierverlaten, Ter Apelkanaal, Meeden and Emmen as in Table 38.

Table 38: District heating potential at Vierverlaten, Ter Apelkanaal, Meeden and Emmen

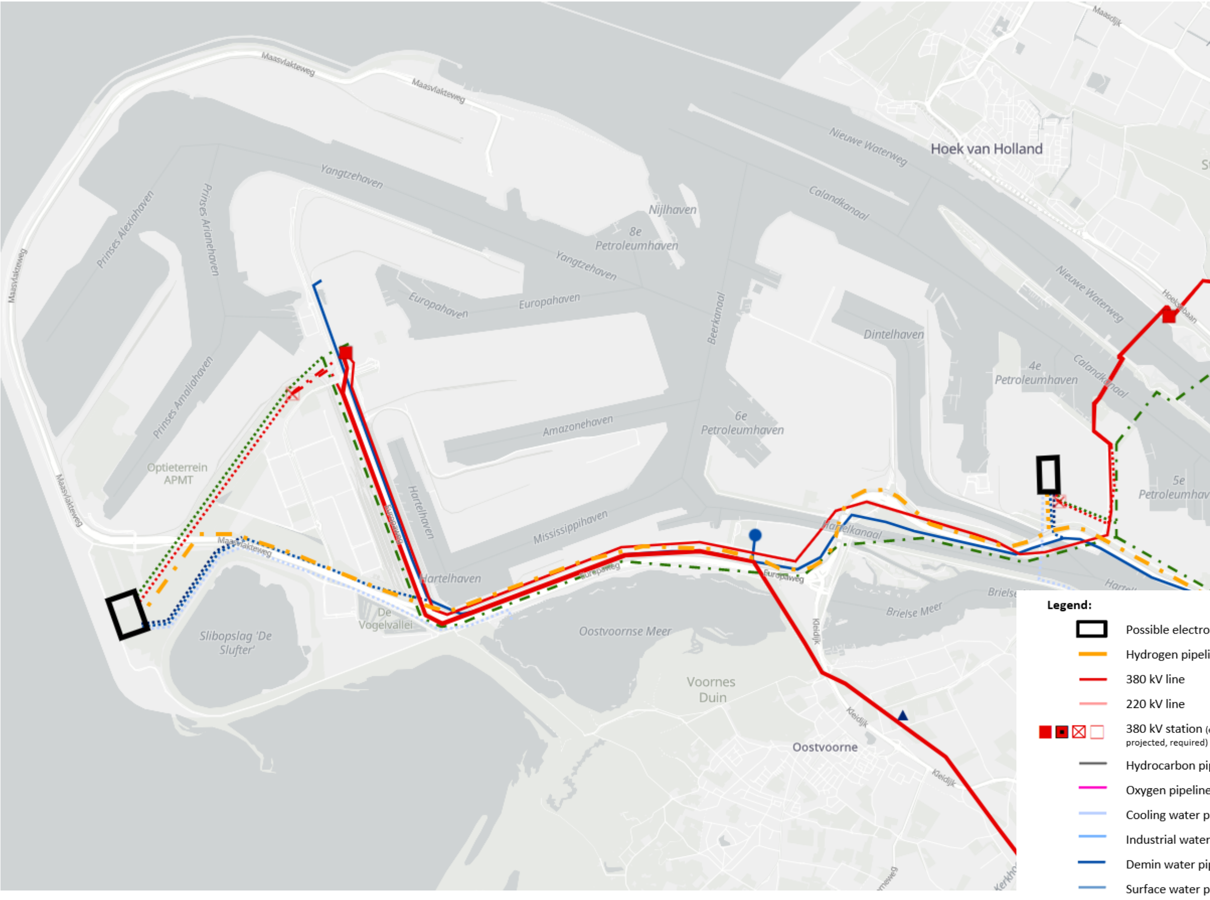
District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	No.	Heat grid Enpuls Emmen upto 15 MW	Possibly Warmtestad for Groningen city Emmtec 60 MW heat demand Greenhouses Rundedal 100 MW heat demand Vierverlaten 25.000 households and industry (paper, sugar, tobacco)	
Is there available infrastructure for district heating?	Warmtestad Groningen	Emmen/Enpuls		Connection to heat grids Warmtestad and Emmen/Enpuls

64 https://www.snn.nl/sites/default/files/2019-07/Investment%20Agenda%20Hydrogen%20Northern%20Netherlands%20-%20April%202019%20%285%29.pdf

65 https://www.enexisgroep.nl/nieuws/explosieve-groei-duurzame-energie-op-land/

8. Rotterdam

Two locations in Rotterdam port area selected as locations for a potential 2GW conversion facility: Location A and Terrain 7. Figure 34 provides an overview of the potential locations for the Rotterdam region. For more (spatial) information regarding the locations see Appendix K.



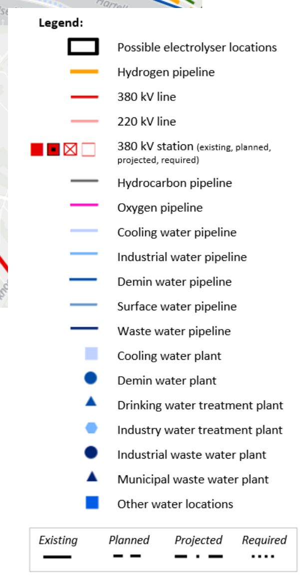


Figure 34: Overview of potential locations Rotterdam (indicated by the dark rectangles)

8.1. Summary of findings

An overview of the findings for Rotterdam is presented in Table 39. The following preliminary key observations can be determined:

- Regarding the available space and suitability of the locations, it seems that both locations are possible depending on port planning, new investors and deep sea access. For Terrain 7 space is limited to 10 ha, but potentially more space is available by 2030. The preferred location is location A as part of designated area for conversion park.
- Regarding critical infrastructure – e.g. water, electricity and hydrogen – all connections can be developed by Port of Rotterdam and grid operators. A new 380kV station is projected for both locations depending on investment decisions. A hydrogen pipeline of around 70km is required to connect to endusers and hydrogen backbone.

.

Table 39: Overview of findings locations Rotterdam[66]

Location	Rotterdam – Location A	Rotterdam – Terrain 7
Space	15 ha available.	10 ha available, potentially more space available by 2030. Requires compact design.
Suitability	Owned by Port of Rotterdam. Assigned for industrial activities. Close to beach and potential future converter station TenneT.	Owned by Port of Rotterdam. Industrial location. Area limited by surrounding silos and tanks.
Water supply	Water source available and further treatment and capacity augmentation are required from the existing demi water facility at EIW to meet the electrolyser water quality and quantity targets.	Water source available and further treatment and capacity augmentation are required from the existing demi water facility at EIW to meet the electrolyser water quality and quantity targets.
Electricity supply	New 380kV substation is required and projected. Could be realized by 2030.	New 380kV substation is required and projected. Could be realized by 2030.
Hydrogen infra	Plans to connect to backbone. About 60 km from backbone. Connection to backbone could be realized by 2030. Unknown if existing infra[66] can be used.	Plans to connect to backbone. About 70 km from backbone. Connection to backbone could be realized by 2030. Unknown if existing infra can be used.
Hydrogen demand	Local hydrogen demand present.	Local hydrogen demand present.
Oxygen demand	Unknown. Existing pipeline runs to Rozenburg.	Unknown. Existing pipeline runs to Rozenburg.
District heating	Possibly at the Warmte Rotonde, leiding over West	Possibly at the Warmte Rotonde, Leiding over West

As an example, the plot plan is depicted at the Maasvlakte in the Figure 35. The available plot space is sufficient for PEM and Alkaline based electrolysers facility with regards to **maximum and minimum cases.**

[66] For an explanation of the colour scheme, see Appendix M.

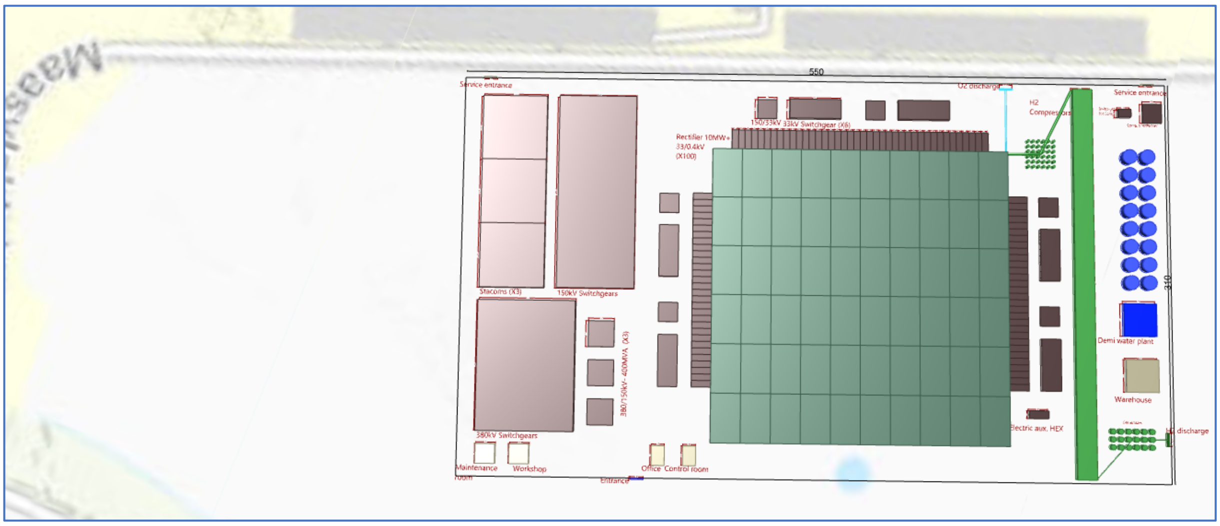


Figure 35: Plot plan- Maasvlakte

8.2. Hydrogen demand and supply

Rotterdam is one of the largest hydrogen cluster in the Netherlands. Hydrogen is produced by SMR or as a by-product from industrial processes and could also be supplied from the Air Liquide network. Most hydrogen is used locally as feedstock in refining or used as other feedstock. Total production is estimated at 479 kton annually [9]. This is adjusted regarding hydrogen consumption at refineries. Also at different chemical plants hydrogen as by-products is included. Most recent figure for 2019 is 550 kton/a.[67]

The potential for hydrogen use in the Rotterdam area is large up to ~1,200 kton/y and significantly contributes to the decarbonisation of the industry in the area of Rotterdam [15]. In 2050 this could go up to 7,000 kton/a. This concerns both the use of hydrogen as energy and as feedstock, and the development of blue hydrogen and green hydrogen. See for instance the H-vision initiative[68]. The study outlines the production and use of low-carbon hydrogen from natural gas and refinery fuel gas, combined with carbon capture and storage (CCS) in the Porthos project[69], to produce blue hydrogen. In a later phase, blue hydrogen production could be complemented by large scale electrolysis.

Recently, BP, Nouryon and the Port of Rotterdam joined forces to explore the feasibility of a 250 MW electrolyser plant (H2-Fifty project)[70]. Nouryon would build and operate the facility based on its leadership position in sustainable electrochemistry. Also Shell Nederland has announced plans for 250MW facility in Rotterdam using green electricity from wind power. This wind power will

67 Personal communication DNV-GL with Port of Rotterdam

68 See https://www.deltalinqs.nl/h-vision-en and https://www.tno.nl/nl/over-tno/nieuws/2019/7/h-vision-rotterdamse-haven-verduurzamen-met-blauwe-waterstof/

69 Porthos is a collaboration between the Port of Rotterdam, Gasunie and EBN with the aim of capturing, transporting and storing CO_2 from the Rotterdam area under the North sea (in gas fields).

70 https://www.nouryon.com/news-and-events/news-overview/2019/bp-nouryon-and-port-of-rotterdam-partner-on-green-hydrogen-study/

preferably come from the Hollandse Kust (noord) offshore wind farm. Through their joint venture CrossWind, Shell and Eneco are participating in the tender for this wind farm. [71]

The Port of Rotterdam would facilitate local infrastructure and investigate options for further development of a green hydrogen hub in the area. The hydrogen could be used by the refineries of BP and Shell and other industries. This would be seen as a first step towards the development of a sustainable hydrogen cluster in the Rotterdam area.

Prospects for the whole area estimate significant hydrogen demand according to the HyChain 1 study. In 2050, the high scenario describes a total demand of about 1,660 kton. Similar to the findings in H-vision, the majority will be used for heat generation, but a significant amount will also be used as feedstock. Other important sectors include hydrogen for electricity generation and use in agriculture [11]. When also incorporating the use of hydrogen for transport and mobility (incl. aviation and shipping), the estimated total demand would be about 7 Mton by 2050.

[71] https://www.shell.nl/media/nieuwsberichten/2020/wind-als-energiebron-voor-groene-waterstoffabriek-in-rotterdam.html

8.3. Location A

8.3.1. Location

Location A is situated to the Southwest of the Maasvlakte area, between the Slufter and the beach. The available area for the development of large-scale electrolysis is about 15 ha and is managed by the Port of Rotterdam. The area is selected as location for the 2GW conversion facility. The area next to location A is also explored for the onshoring of the IJmuiden Ver wind farm. There are wind turbines along the Slufter, and that the BritNed interconnector runs South of location A along the coast. The area is currently not in use by industry and not close to residential areas but close to the nearby beach which has a recreation function.

8.3.2. Infrastructure

Figure 36 provides an overview of the different infrastructure relevant for the Location A.

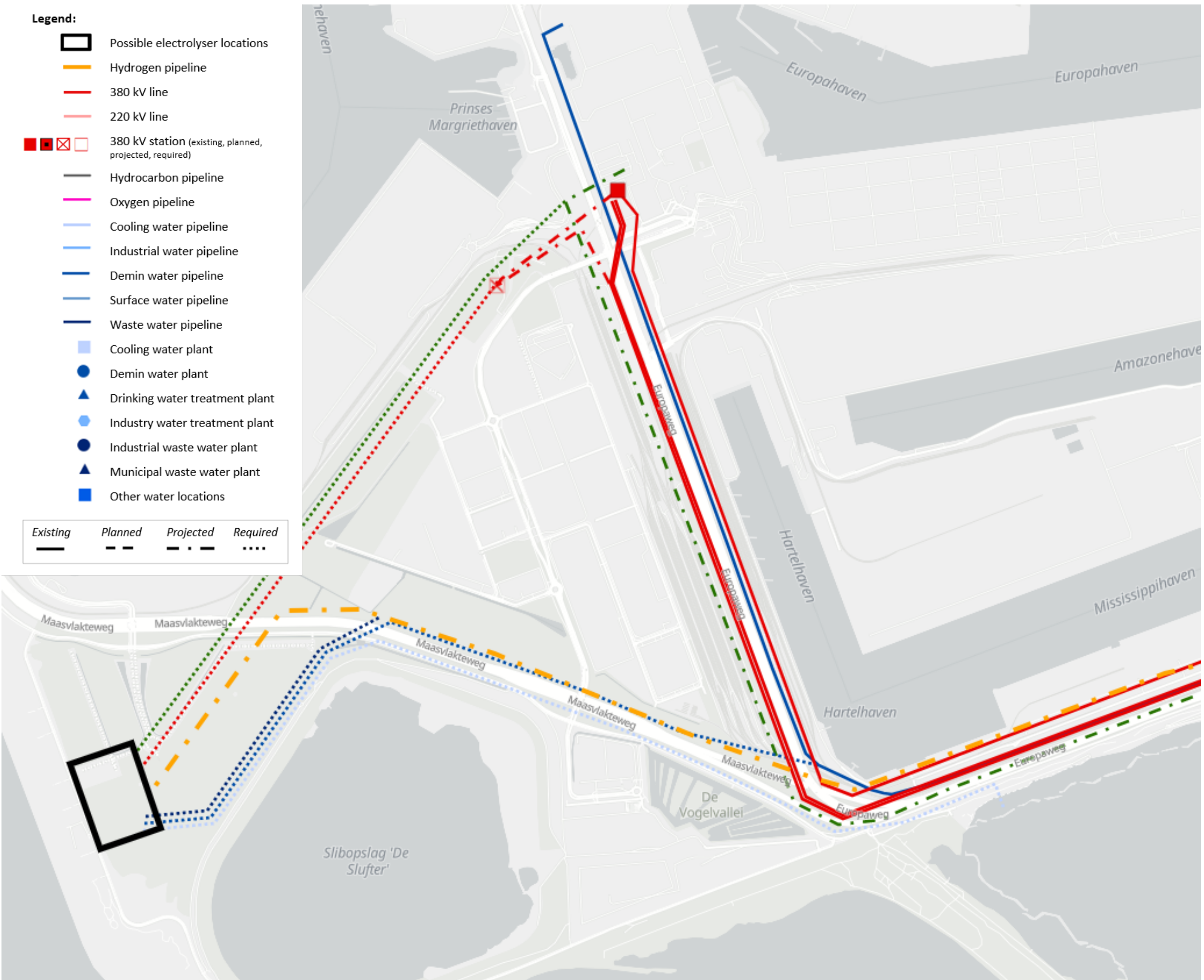


Figure 36: Map of infrastructure for Location A

Electricity

The port of Rotterdam area is connected to the 380kV electricity grid and has a 380/150kV station at the Maasvlakte (see Appendix A and H), which is not that far from Location A. The Maasvlakte station is connected via 2 circuits with the 380kV stations Simonshaven and Hoek van Holland. The Maasvlakte station has an underground 380kV connection with the gas-fired Enecogen power plant

(CCGT, 870MW capacity), a connection with the BritNed interconnector (via the DC/AC convertor station, 1GW capacity), and about 1,000 MVA transformer capacity 380/150kV.

An important development at the port of Rotterdam area relates to the development of offshore wind in the Netherlands (see Appendix B). For the Port of Rotterdam area, the offshore wind farm *Hollandse Kust-Zuid Alpha & Beta* will be connected to the existing Maasvlakte station. As the generated electricity offshore will be brought onshore with 220kC AC cables, a 380/220kV AC station is required. This station will be built along the coast North of the Maasvlakte. Accordingly, it will be connected using 380kV AC underground cables to connect to the Maasvlakte station. In addition, the Maasvlakte is being considered for connecting part of the offshore wind farm IJmuiden Ver (2GW), expected commissioning between 2027-2030. IJmuiden Ver will be connected via 525kV direct current connections, meaning that first onshore a DC/AC converter station needs to be built, before it can be connected to the 380kV AC grid. One of the options for the onshoring of IJmuiden Ver and the converter station is near the Southwest of the Maasvlakte, near Location A.

To connect to the onshore 380kV grid, a new 380kV substation is required as the existing Maasvlakte substation does not have any additional connection capacity. This applies to the connection of IJmuiden Ver as well as other client connections like a GW electrolyser. A new 380kV substation[72] close to the current Maasvlakte substation is foreseen by TenneT, and is also mentioned in the study *Een haven vol nieuwe energie*[73], which looks as reinforcement of the electricity grid in the Port of Rotterdam area due to anticipated growth of demand and supply of electricity. As commissioning of the first part of offshore wind farm IJmuiden Ver is planned for 2027/2028, it is the planning to have this new 380kV substation (and of course the converter station) ready before commissioning of IJmuiden Ver. Another option for the connection of IJmuiden Ver is 380kV substation Simonshaven (which then also requires reinforcement). It is expected that only a 380kV switching station is required, which will result in lower required Capex compared to a transformer substation. The GW electrolyser at Location A requires a connection to the new 380kV substation that is foreseen close to the current Maasvlakte station, distance is about 2-3 km.

Another out-of-the-box option is that the GW electrolyser is directly connected to the offshore wind farm IJmuiden Ver via a DC connection. Such a direct connection is not expected for the windfarm IJmuiden Ver, as this is not allowed according the law and related regulations. Besides, TenneT is already working on this connection. However, it could be a possibility for future offshore wind farms.

It is not expected that the addition of 1 GW of load at this location causes congestion on the 380kV grid. It even could be beneficial given the presence of thermal generation capacity and the HVDC interconnector at the Maasvlakte, and the future connection of offshore wind. With the addition of offshore wind, some issues with transport capacity at the 380kV grid are foreseen by 2030 between Maasvlakte – Westerlee and Maasvlakte – Crayenstein [10]. A GW electrolyser could decrease any potential congestion, though this requires more detailed analysis.

[72] 380kV switching station, no connection to 150kV grid via 380/150kV transformers.

[73] See https://www.tennet.eu/nl/nieuws/nieuws/verzwaring-elektriciteitsnet-rotterdamse-haven-kan-efficienter-en-goedkoper/.

Hydrogen

A connection between the Maasvlakte and the backbone is planned, however, the nearest point of connection to the backbone is near Wijngaarden, which is about 60-70 km from the Maasvlakte. For a connection, new infrastructure would be required. Capex is about 60-70MEUR for a 14-18 inch pipeline. Such a regional backbone is also part of the decarbonisation roadmap of the Rotterdam cluster.

Currently, hydrogen infrastructure exists and is operated by Air Liquide (See Appendix L). This pipeline is mainly dedicated to provide hydrogen as feedstock to industry, and the diameter is below 20 inch. Moreover, it runs to Rozenburg and does not connect to location A. However, it should be noted that Air Liquide manages their network by providing different industrial gasses to their customers via dedicated pipelines, and that this network is not open-access infrastructure.

Oxygen

No tangible plans or opportunities have been identified for the use of oxygen. In case a connection between the electrolyser and potential oxygen demand is needed, a new pipeline would be required to transport all oxygen.

Water

For both the Maasvlakte A and the Europoort Terrain 7 locations, similar information was gathered for the supply of water and any planned, projected and required water infrastructure and this is summarised in Table 40 below.

Table 40: Summary of water infrastructure available and required at Maasvlakte A and Europoort Terrain 7

Water	Information gathered			
	Current	Planned	Projected	Required
What are the available water sources for hydrogen production and can they be used?	Evides-IndustryWater (EIW) Demin (2µS/cm) water.	No.	There are no projected plans to treat any of these water sources to meet the demin water quantity and quality.	Further treatment of the existing demin water is required to meet the GW electrolyser demin water quality target of 0.1 µS/cm. Also, augmentation of the plant is required to meet the water demand.
Are there existing wastewater treatment plants for the discharge of the GW project wastewater?	(i) Pressurised sewer system to RWZI Oostvoorne (ii) Centrale WWTP (CAB by EIW)	No.	No.	A waste neutralisation unit needs to be provided as part of the water treatment plant to cater for the waste stream produced.
Is a water storage facility available (incl. sub-surface) to store treated water for security of supply?	Yes, at DWP Maasvlakte and DWP Botlek.	No.	No.	Possible use of the storage facility at DWP Maasvlakte and DWP Botlek.
Are there existing cooling installations that can be used to cool down the excess heat of ~250 MW?	No.	No.	No.	Yes, a new cooling system is required for the waste heat.
Is there a water connection possible/available for water supply?	No.	No.	No.	Yes, EIW Demin water pipeline.

District heating

The information gathered for the possibility of using the waste heat generated by the GW project for district heating at Maasvlakte A and Europoort Terrain 7 is listed below in

Table 41.

Table 41: District heating potential at Maasvlakte A and Europoort Terrain 7

District heating	Current	Planned	Projected	Required
Is there nearby heat demand (LT <55 ^{0}C), and how much?	No.	No.	Possibly at the Warmte Rotonde, leiding over West	
Is there available infrastructure for district heating?	Not yet at Maasvlakte A-plot but yes at Europoort Terrain 7.	No.	Warmte Rotonde, leiding over West.	Connection towards heat grid Warmte Rotonde

8.4. Terrain 7

8.4.1. Location

Terrain 7 is an area of about 10 ha and is managed by the Port of Rotterdam. The area is selected as location for the 2GW conversion facility. The location is next to Europoort Rotterdam just North of the Moezelweg. In the future, more area could become available due to developments related to the energy transition. The 380kV overhead lines run just next to terrain 7.

The area is currently surrounded by industrial activities, being mainly storage of hydrocarbons in silos and tanks. The location is not close to residential areas and no public resistance is expected against the development of large-scale electrolysis at this location.

8.4.2. Infrastructure

Figure 37 provides an overview of the different infrastructure relevant Terrain 7.

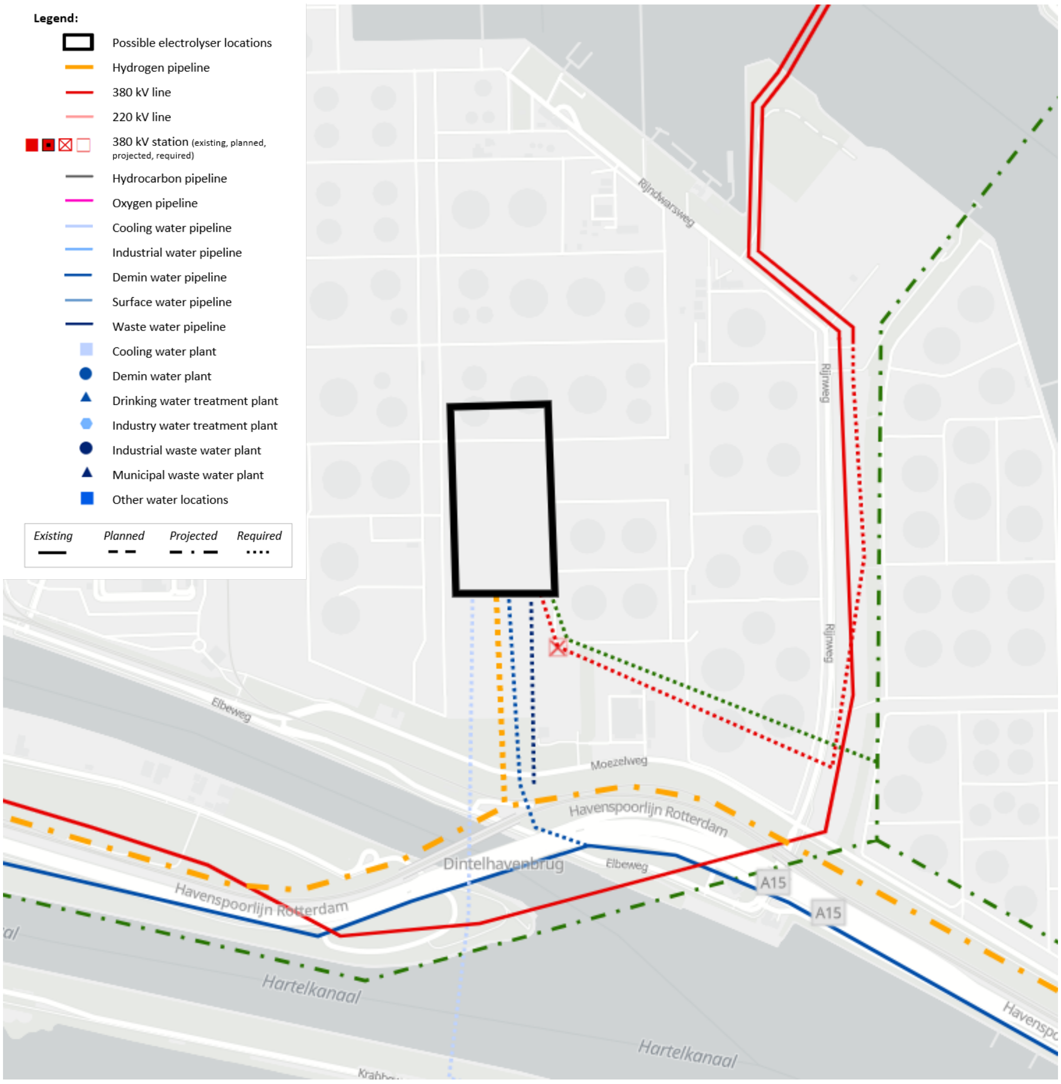


Figure 37: Map of infrastructure for Terrain 7

Electricity

Regarding the electricity infrastructure, the same situation and developments apply to Terrain 7. For Terrain 7 the situation is a bit different compared to Location A as this location is not close to a current 380kV substation. However, the 380kV overhead lines run just next to terrain 7.

The GW electrolyser at Terrain 7 requires a connection to a new 380kV substation. This could be the new 380kV station that is foreseen close to the current Maasvlakte station. It could also be a new 380kV substation close to Terrain 7, as this last option is mentioned as well in the study *Een haven vol nieuwe energie*[74]. Based on new insights, it is expected that this new *Europoort* 380kV substation will be realized before 2030, an investment decision is planned for end of 2020.

Another out-of-the-box option is that the GW electrolyser is directly connected to the offshore wind farm IJmuiden Ver via a DC connection. Such a direct connection is not expected for the windfarm IJmuiden Ver, as this is not allowed according the law and related regulations. Besides, TenneT is already working on this connection. However, it could be a possibility for future offshore wind farms.

Hydrogen

Requirements with regard to hydrogen infrastructure for terrain 7 are similar to those of location A. Development of hydrogen infrastructure and connection to the backbone is foreseen and this new infrastructure passes terrain 7. Only a short pipeline to connect the electrolyser to the new infrastructure would then be required.

Oxygen

No tangible plans or opportunities have been identified for the use of oxygen. In case a connection between the electrolyser and oxygen demand is needed, a pipeline in the order of 18-22 inch would be required to transport all oxygen.

Water

Refer to Table 40 for information about water supply and infrastructure.

District heating

Refer to

Table 41 for information about district heating requirements and prospect.

[74] See https://www.tennet.eu/nl/nieuws/nieuws/verzwaring-elektriciteitsnet-rotterdamse-haven-kan-efficienter-en-goedkoper/.

9. Results and analysis of locations and boundaries

The main results based on the analysis of locations concerning boundaries are presented in following table.

Region	Space and suitability of the locations	Critical infrastructure – e.g. water, electricity and hydrogen –
Noordzeekanaal Area and Amsterdam Westpoort	Hemweg has sufficient space in case of demolition with potential reuse of assets; for Beverwijk and Spaarndam available space and permit requirements are not yet known; Bosweg/ Tata requires more attention regarding (potential) permitting and social acceptance.	Bosweg/Tata and Spaarndam seem to have good connections; Hemweg require electrical connection and 380 substation.
Chemelot and Maasbracht	The potential future plot North of Chemelot is a more logical location, as Chemelot plot 1 and 2 are close to residential areas and public roads and other developments are planned as well for those locations. Regarding this future plot permitting issues exist and stakeholders need to be consulted with respect to development of new industrial zone.	It seems that Maasbracht has good connections too next to Chemelot, as the difference in costs required for the connection with infrastructure is expected to be significantly lower for Maasbracht compared to Chemelot, and hydrogen transport to Chemelot is in time possible through the backbone.
Zeeland and Ghent	All sites have good potential although some may need more compact design or possibly co-siting for cooling/demin water and service buildings. One central location may be worthwhile for Ghent, Terneuzen/Sluiskil and Borssele and hydrogen can be transported to all sites and endusers.	For the locations in Zuid-Beveland near Borssele/Vlissingen, 40-50 km of pipeline should be realized to connect to the backbone, i.e use of existing gas pipelines is not sure. For the locations near Terneuzen/Sluiskil there are is currently no 380kV grid; a new substation near Borssele would require crossing and new overhead lines. In case of connection to Belgium TSO

Region	Space and suitability of the locations	Critical infrastructure – e.g. water, electricity and hydrogen –
		ELIA laws and policies may need to be changed. The location at Rodenhuize is not studied in detail but seems to provide good infrastructure connections and is close to offtake for both hydrogen and oxygen.
Northern Netherlands	It is too early to analyse the suitability of the locations. At Eemshaven, space is available just outside the port area, but this is not in use by industry and ownership and spatial planning is unknown. Concerning the other locations the destination is not industrial and ownership is not clear.	It seems that near Vierverlaten is a good location, but also Eemshaven provided that 380kV substation will be timely planned.
Rotterdam	There are two locations at Maasvlakte2 with Location A and at Europoort with Terrain 7. Both are possible depending on port planning, new investors and deep sea access. For Terrain 7 space is limited to 10 ha, but potentially more space available by 2030.	All connections can be developed by Port of Rotterdam and grid operators. A new 380kV station is projected for both locations depending on investment decisions. A hydrogen pipeline of around 70km is required to connect to endusers and hydrogen backbone.

10. Conclusion

The GW electrolysis project is about efficient integration of hydrogen production facility into industrial clusters addressing system integration, location and co-siting aspects. Further technology development should lead to a cost reduction of green hydrogen of a factor 3 to 4, making it competitive with natural gas based grey and blue (CCUS) hydrogen. This will accelerate the business cases for uptake of green hydrogen for industries, power sector and mobility.

This study has explored, identified and assessed the boundary conditions of a GW water electrolysis plant of five different energy and industrial clusters (Regions) in The Netherlands, and analysed the system integration aspects regarding grid connection to the electricity grid, water supply, hydrogen networks, oxygen demand and district heating. The relevant infrastructure has been investigated and mapped for each region and location, distinguishing between current infrastructure, planned infrastructure, projected infrastructure and required infrastructure. It should be noted that this quick scan of the (im)possibilities and (dis)advantages of the different locations concerns a first assessment, based on available information. Furthermore, plot plans have been designed for both Alkaline and PEM GW electrolysis installations, including a baseline design and a compact design.

It can be concluded that in all five regions it is technically possible to deliver economically viable green hydrogen production on a GW scale by 2030. There is sufficient space available, potential industrial demand exceeds GW production and infrastructure connections can be made available. This will accelerate the business cases for uptake of green hydrogen for industries, power sector and mobility. These business cases however need to be improved in reducing the capex and opex costs. This is the core of the Part 3 of the GW water electrolysis project delivering a blue print design and cost reduction by a factor 3.

Based on 5,000 operating hours per year, the annual production of 1GW water electrolysis facility is about 90 kton of hydrogen. It was found that in all industrial regions demand is sufficient to take-off this green hydrogen.

Following the analysis of the plot plan of the GW electrolyser facility, it was found that an area of at least 8 ha is required for the compact design using PEM electrolysers. The baseline design using Alkaline electrolysers requires an area of about 17 ha. One of the important findings is that the electrical installation require similar footprints as compared to the Alkaline electrolyser building (including rectifiers and 33/1kV transformers). As a comparison was made between using PEM electrolysers versus Alkaline electrolysers, it was observed according expectations that PEM electrolysers offer significant savings in space. The spatial footprint of PEM building is less than half of Alkaline electrolysers building. Other space saving options could be realized by adapting the electrical installation.

In total 22 different location in the five industrial regions have been assessed. Based on the available plot sizes and the required space, it was found that 13 locations (should) have enough space available, seven locations require PEM or a compact alkaline design, and for two locations the available space is unclear.

Next to the requirement of having sufficient available space for the GW electrolyser facility, the plant depends on the availability of critical infrastructure to be able to operate. As part of the assessment, the infrastructure for water supply, electricity supply and hydrogen transport has been evaluated.

Regarding the electrical installation, it was found that a 380kV grid connection seems most appropriate, among others because of the high power flows. A connection to the 150kV grid is also possible, but would lead to additional barriers like insufficient transformer capacity (from 380kV to 150kV), limited available connection capacity at the substations at 150kV, and limited space for the 150kV connections between the substation and the location of the GW electrolyser facility. Accordingly, it is likely that the GW electrolyser facility will be located somewhere close to the 380kV grid. There are different options to realize a 380kV connection, as one can differentiate in among others design (standard design versus compact design), intermediate voltage levels, level of redundancy, type of connection and future possibilities.

For the baseline design of the electrical installation, a standard design has been assumed with a double busbar at 380kV, three 380/150kV transformers, a double busbar at 150kV, three statcoms (tentative rating 200Mvar each), six 150/33kV transformers, 100 33kV/1kV transformers of which each supplies a 10 MW rectifiers, and each rectifier supplies four 2.5 MW, 1kV electrolysers. Two space saving options have been assessed: using gas insulated switchgears (GIS) instead of air insulated switchgears (AIS), and direct transformation of voltage from 380kV to 33kV (removing the intermediate voltage step 150kV). Those options have been applied to the compact design (minimum case) and result in a plot size of the electrical installation which is half of the baseline design.

Based on the available information, it was found that six locations have an existing or planned 380kV substation to which can be connected by 2030; eight locations have no existing 380kV substation or no sufficient connection capacity, but a new substation or an extension is planned or projected, and for eight locations there is no existing 380kV substation or no sufficient connection capacity, and there are no plans and no projections.

The supply of ultra-pure water for the GW electrolyser is paramount for the production of hydrogen from water electrolytic process. From the body of information gathered in all locations across the five regions, it was found that currently there is no existing nor any projected facility that can provide the water demand and quality required for the GW electrolyser. Accordingly, in all locations a new water treatment facility is required to treat the water to the desired quality. Most locations have a readily available water source, from either surface water or tap water, which can be treated using the available treatment technologies to meet the required water quality for the electrolyser. In Rotterdam, there is the possibility of using the existing demi water from Evides Industriewater (EIW), however, the facility will still need additional treatment process and augmentation to meet the quality and quantity required by the GW electrolyser. In general, the treatment scheme will consist of a pre-treatment step with media filters and membrane filtration, followed by desalination and demineralisation processes by reverse osmosis and ion exchange systems.

In addition to the water treatment facility, significant pipeline infrastructure is required for the water supply from the water source to the electrolyser. In cases where a sewer network is not available for the discharge of the waste stream from the GW electrolyser, a dedicated waste collection and management system is needed.

It is also anticipated that the GW electrolyser will generate a waste heat of around 250 MW. This waste heat will need to pass through a cooling water system where the heat can be recovered for potential usage should there be a demand. Given the amount of waste heat that would be generated, a substantial amount of cooling water is required to cool it down. Preliminary water demand for the cooling system with 5 recirculation cycles amounts to 375 m3/h (including a blowdown of 75 m3/h). This water demand is readily available from the existing surface water source identified in all locations. In the case of once-through cooling, the water demand is between 32,000 – 43,000 m3/h, however, this is not the preferred cooling system option as water supply could be an issue in many locations.

The outcome of this study gave valuable information on the current and future status of each region with respect to the water-related aspects of the GW electrolyser project. However, there are still a number of questions unanswered and data sets needed to move to a decision where a concept design of the water infrastructure and associated accessories/requirements can be developed. It is anticipated that the next phase of the project will look into filling these gaps and investigate the requirements to develop a concept design. For instance, a detailed inventory of the available/existing infrastructure, water sources and quality, future demands, security of supply, waste and residuals management including treatment and discharge, water and wastewater permitting and other regulatory guidelines, supply and discharge of cooling water. Accordingly a full survey is required at each preferred location to conduct the asset inventory. Thereafter, a concept design for water supply and associated requirements for each location/region can be done based on the extensive investigation and information gathered from the inventory/survey. Additionally, it is recommended to conduct a life cycle assessment of the preferred concept for each region.

Regarding the so-called hydrogen backbone, it was found that large parts of the Dutch natural gas transmission system owned by GTS could be reused, which is being considered. The backbone will connect the large industry clusters to exchange hydrogen demand and supply and give access to large scale underground storage. Changes in the Dutch energy system such as, phasing out of Groningen-gas, electrification, expiration of long-term supply contracts and the energy transition overall, will make significant transport capacity available. Many trajectories include multiple (GTS) pipelines of at least 36 inch. This allows for repurposing existing gas infrastructure for hydrogen transport, alongside the natural gas system that will still be in operation. As explained, the main part of the backbone consists of existing GTS infrastructure, and some new dedicated hydrogen infrastructure has to be developed. These new pipelines are mainly required to connect to the industrial clusters in the Netherlands. Hydrogen transport through pipelines is already a proven technology and has been applied at large scale in the industry, though research is being conducted on among others the topics pipeline integrity, compression, safety, and quality.

The building and commissioning of the hydrogen backbone is expected between 2025 and 2030 and expected cost is approximately €1.5 billion. Technically the backbone could be ready by 2026 and potentially parts of the backbone earlier, in case the final investment decision is made on a relatively short term (2021). Sufficient hydrogen supply and demand is required or should be expected in the foreseeable future to (start to) develop the backbone.

Regarding the possibilities to connect to the backbone, it was assessed that all locations could be connected. 14 locations are within 10 km of distance to the foreseen backbone, three locations just over 10 km and two locations over 50 km. Those last locations are the two Rotterdam locations, for which there are plans to develop a regional backbone. The three locations near Borssele are close to existing infrastructure, but the potential use to connect to the national hydrogen backbone (at about 40 km) is not yet clear.

Given the relatively high waste heat production and oxygen production by the GW electrolyser, the possibility of recovering heat for district heating and using oxygen has been considered in all regions. Currently, there is no existing infrastructure in any locations to take advantage of this waste heat for district heating. For waste heat, the demand is not currently present, although there are a few locations that might have a district heating demand in the future. This is an opportunity that needs to be further investigated in the next phase of the project. For oxygen demand, there is currently one location with concrete demand, three locations with some demand, and 17 locations with no demand in the vicinity or it is not known.

11. References

[1] „Klimaatakkoord," Den Haag, 28 juni 2019.

[2] „Routekaart windenergie op zee 2030," Minister van Economische Zaken en Klimaat, Den Haag, 27 maart 2018.

[3] „Whitepaper Hydrogen in the electricity value chain," DNV GL, 2019.

[4] „Infrastructure Outlook 2050," Gasunie, TenneT, 2019.

[5] „Whitepaper Power-to-gas in a decarbonized European energy system based on renewable energy sources," DNV GL, European power-to-gas, 2017.

[6] „Verkenning waterstofinfrastructuur," DNV GL, 2017.

[7] D. GL, „Filling the data gap: an update of the 2019 hydrogen supply in the Netherlands," 2019.

[8] ISPT, „Hydrohub HyChain 1," 2019.

[9] „Hydrogen supply and demand in 5 industrial clusters in the Netherlands," DNV GL, 2019.

[10] TenneT, „Kwaliteits- en capaciteitsdocument 2017, Deel II Investeringen net op land 2018 - 2027," 2017.

[11] Royal Haskoning DHV, Quintel Intelligence en ECN part of TNO, „Hydrohub HyChain 1," Institute of Sustainable Process Technology (ISPT), 2019.

[12] A. D. Little, „1 GW Electrolyser, H2 Plan Study," 2019.

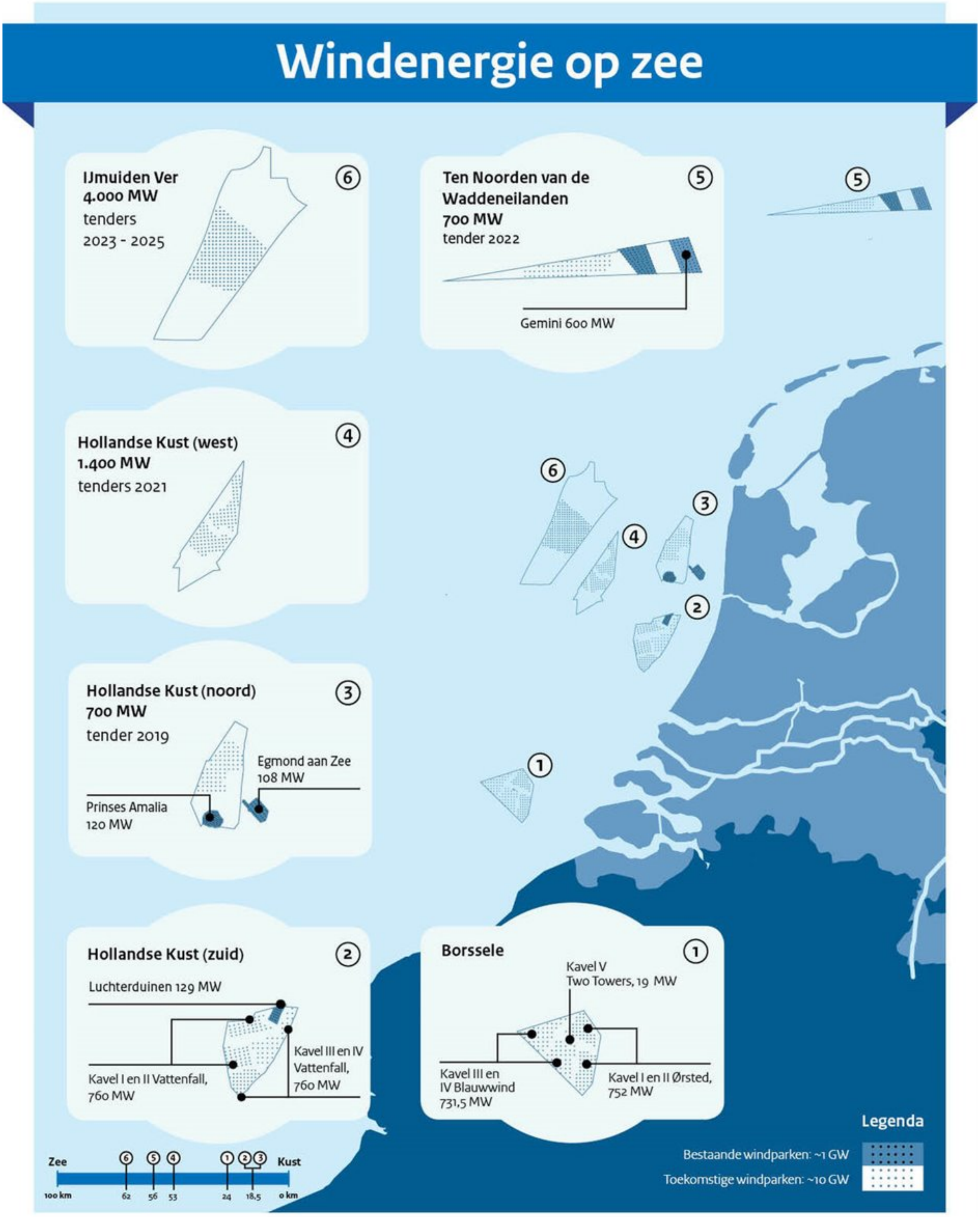
[13] Royal Haskoning, CE-Delft, M-Tech en Sitech, „Onderzoek Clean Underground Sustainable Transport (CUST)," 2019.

[14] N. Nederland, „Investeringsagenda waterstof Noord Nederland," 2019.

[15] „Decarbonization Pathways for the industrial cluster of the Port of Rotterdam," Wuppertal Institute, 2016.

Appendix A – Map Electricity transmission grid NL

Appendix B – Map Offshore wind NL



Appendix C – Map transmission grid Gas NL

Appendix D – Multi-criteria analysis of water treatment options

As highlighted in

Table 5: Treatment process scheme for each type of water, there are many treatment options that can be employed depending on the water source and quality. Accordingly, a high-level multi-criteria analysis (MCA) was conducted to assess various water treatment options for each water source considering criteria such as cost, efficiency, durability/robustness, ease of operation and maintenance, environment and social considerations.

Each criterion was given a weighting according to what is usually considered as the most important and relevant drivers for such projects. The outcome of the MCA is shown in Table 42 below.

Table 42: Multi-criteria analysis of various water treatment technologies and processes for the GW electrolyser water supply

				Score (1-5)			
	No.	Criteria	Weight (%)	Low (1)	Medium (3)	High (5)	Aggregate
Demin water	1	Capex	30			5	30%
	2	Opex	20	1			4%
	3	Efficiency	10			5	10%
	4	Durability/Robustness	5			5	5%
	5	Water availability	10		3		6%
	6	Ease of operation & maintenance	5			5	5%
	7	Environment friendly	10			4	8%
	8	Social acceptance	10			5	10%
		Total	**100**				**78%**

				Score (1-5)			
	No.	Criteria	Weight (%)	Low (1)	Medium (3)	High (5)	Aggregate
Tap water	1	Capex	30			5	30%
	2	Opex	20	1			4%
	3	Efficiency (Yield)	10			5	10%
	4	Durability/Robustness	5			5	5%
	5	Water availability	10	1			2%
	6	Ease of operation & maintenance	5			5	5%
	7	Environment friendly	10			4	8%
	8	Social acceptance	10		3		6%
		Total	**100**				**70%**

				Score (1-5)			
	No.	Criteria	Weight (%)	Low (1)	Medium (3)	High (5)	Aggregate
Sea water	1	Capex	30	1			6%
	2	Opex	20	1			4%
	3	Efficiency	10		3		6%
	4	Durability/Robustness	10		3		6%
	5	Water availability	5			5	5%
	6	Ease of operation & maintenance	5		3		3%
	7	Environment friendly	10		3		6%
	8	Social acceptance	10			5	10%
		Total	**100**				**46%**

				Score (1-5)			
	No.	Criteria	Weight (%)	Low (1)	Medium (3)	High (5)	Aggregate
Surface water (river)	1	Capex	30		3		18%
	2	Opex	20		3		12%
	3	Efficiency	10			4	8%
	4	Durability/Robustness	10			5	10%
	5	Water availability	5			5	5%
	6	Ease of operation & maintenance	5		3		3%
	7	Environment friendly	10		3		6%
	8	Social acceptance	10		3		6%
		Total	**100**				**68%**

				Score (1-5)			
	No.	Criteria	Weight (%)	Low (1)	Medium (3)	High (5)	Aggregate
Brackish groundwater	1	Capex	30	2			12%
	2	Opex	20	2			8%
	3	Efficiency	10		3		6%
	4	Durability/Robustness	10			4	8%
	5	Water availability	5		3		3%
	6	Ease of operation & maintenance	5		3		3%
	7	Environment friendly	10		3		6%
	8	Social acceptance	10		3		6%
		Total	**100**				**52%**

				Score (1-5)			
	No.	Criteria	Weight (%)	Low (1)	Medium (3)	High (5)	Aggregate
Treated sewage effluent	1	Capex	30		3		18%
	2	Opex	20		3		12%
	3	Efficiency	10			4	8%
	4	Durability/Robustness	10			4	8%
	5	Water availability	5			4	4%
	6	Ease of operation & maintenance	5			4	4%
	7	Environment friendly	10		3		6%
	8	Social acceptance	10			4	8%
		Total	**100**				**68%**

Note that a high Capex will give a low score and similarly high Opex will have a low score.

As expected from the MCA, the use of demi water is preferred should it be available in sufficient quantity. This is the cheapest water source based on the criteria assessed. Demi water is followed by tap water, surface (river) water and treated sewage effluent, brackish water and lastly sea water, which requires significant treatment to meet the electrolyser water quality.

Appendix E – Estimation of Capital Expenditure for water supply and treatment

Also shown is a cost estimate for the operation and maintenance (O&M) of the water infrastructure. This O&M estimate does not include labour, energy and chemicals costs.

A high-level estimate of capital expenditure (Capex) for the water supply, treatment and discharge as well as that for the cooling system has been performed. Table 43: Estimation of Capital Expenditure for water supply and treatment below shows the costs and criteria adopted for each preferred location in the respective region. Also shown is a cost estimate for the operation and maintenance costs (O&M) of the water infrastructure. This O&M estimate does not include labour, energy and chemicals costs.

Table 43: Estimation of Capital Expenditure for water supply and treatment

North Sea Canal		Water Source	Flow (m^3/h)	Length (m)	Diameter (mm)	Capex	O&M	Remarks
Bosweg Tata Steel	Water treatment facility required	WRK pre-treated surface water	360			€ 21.060.000	€ 1.048.000	Feed WTF 360 m^3/h Demi water 215 m^3/h
	Feed and cooling water pipeline	WRK pre-treated surface water	785	2000	500	€ 1.300.000	€ 20.000	Cooling water 425 m^3/h
	Waste water pipeline		220	500	250	€ 163.000	€ 484.000	From WTF 145 m^3/h From Cooling 75 m^3/h
	Cooling system	WRK pre-treated surface water	425			€ 24.375.000	€ 1.231.000	Design 250MW waste heat No reuse of waste heat
					Total	€ 46.898.000	€ 2.783.000	
Chemelot		Water Source	Flow (m^3/h)	Length (m)	Diameter (mm)	Capex	O&M	Remarks
North of Chemelot	Water treatment facility required	Treated Juliana canal water	360			€ 21.060.000	€ 1.048.000	Feed WTF 360 m^3/h Demi water 215 m^3/h
	Feed and cooling water pipeline	Treated Juliana canal water	785	750	500	€ 488.000	€ 8.000	Cooling water 425 m^3/h
	Waste water pipeline		220	750	250	€ 244.000	€ 967.000	From WTF 145 m^3/h From Cooling 75 m^3/h
	Cooling system	Treated Juliana canal water	425			€ 24.375.000	€ 1.231.000	Design 250MW waste heat No reuse of waste heat
					Total	€ 46.167.000	€ 3.254.000	
North Sea Ports		Water Source	Flow (m^3/h)	Length (m)	Diameter (mm)	Capex	O&M	Remarks
PZEM Borselle	Water treatment facility required	Industry water (pre-treated surface water)	360			€ 21.060.000	€ 1.048.000	Feed WTF 360 m^3/h Demi water 215 m^3/h
	Feed and cooling water pipeline	Industry water (pre-treated surface water)	785	500	500	€ 325.000	€ 5.000	Cooling water 425 m^3/h
	Waste water pipeline		220	500	250	€ 163.000	€ 484.000	From WTF 145 m^3/h From Cooling 75 m^3/h
	Cooling system	Industry water (pre-treated surface water)	425			€ 24.375.000	€ 1.231.000	Design 250MW waste heat No reuse of waste heat
					Total	€ 45.923.000	€ 2.768.000	
North NL		Water Source	Flow (m^3/h)	Length (m)	Diameter (mm)	Capex	O&M	Remarks
Eemshaven greenfield plot	Water treatment facility required	NorthWater treated canal	360			€ 21.060.000	€ 1.048.000	Feed WTF 360 m^3/h Demi water 215 m^3/h
	Feed and cooling water pipeline	NorthWater treated canal	785	500	500	€ 325.000	€ 5.000	Cooling water 425 m^3/h
	Waste water pipeline		220	500	250	€ 163.000	€ 484.000	From WTF 145 m^3/h From Cooling 75 m^3/h
	Cooling system	NorthWater treated canal	425			€ 24.375.000	€ 1.231.000	Design 250MW waste heat No reuse of waste heat
					Total	€ 45.923.000	€ 2.768.000	
Rotterdam		Water Source	Flow (m^3/h)	Length (m)	Diameter (mm)	Capex	O&M	Remarks
Maasvlakte	Water treatment facility required	Evides Industry Water Demin (2 µS/cm) water	230			€ 3.364.000	€ 5.078.000	Feed WTF 230 m^3/h Demi water 215 m^3/h
	Feed water pipeline	From Evides Industry Water Demin pipeline	230	4000	250	€ 1.300.000	€ 20.000	Feed 230 m^3/h
	Waste water pipeline		90	1500	150	€ 293.000	€ 202.000	From WTF 145 m^3/h From Cooling 75 m^3/h
	Cooling water intake and pipeline	Oostvoorne meer	425	5000	400	€ 3.595.000	€ 55.000	Cooling water 425 m^3/h
	Cooling system	Oostvoorne meer				€ 24.375.000	€ 300.000	Design 250MW waste heat No reuse of waste heat
					Total	€ 32.900.000	€ 5.660.000	

Appendix F – Future hydrogen demand Netherlands

Findings future hydrogen demand ISPT study HyChain 1 [8], for both a low and high scenario.

Low 2050 hydrogen demand per sector and per cluster in PJ.					
	IJmond	Limburg	Zeeuws Vlaanderen	Eemshaven	Maasdelta
Feedstock	-	27.20	40.80	-	-
Industry heat	2.80	4.20	7.28	0.28	13.44
Total	**2.80**	**31.40**	**48.08**	**0.28**	**13.44**

High 2050 hydrogen demand per sector and per cluster in PJ.					
	IJmond	Limburg	Zeeuws Vlaanderen	Eemshaven	Maasdelta
Feedstock	38.80	69.84	143.56	50.44	85.36
Industry heat	26	38	66	3	122
Electricity production	-	-	-	13	13
Agriculture	-	-	-	-	14
Total	**64**	**108**	**210**	**65**	**234**

Appendix G – Maps Noordzeekanaal area

Onshoring of offshore wind, location of new 220/380kV substation near the Bosweg and the connection with Beverijk380.[75]

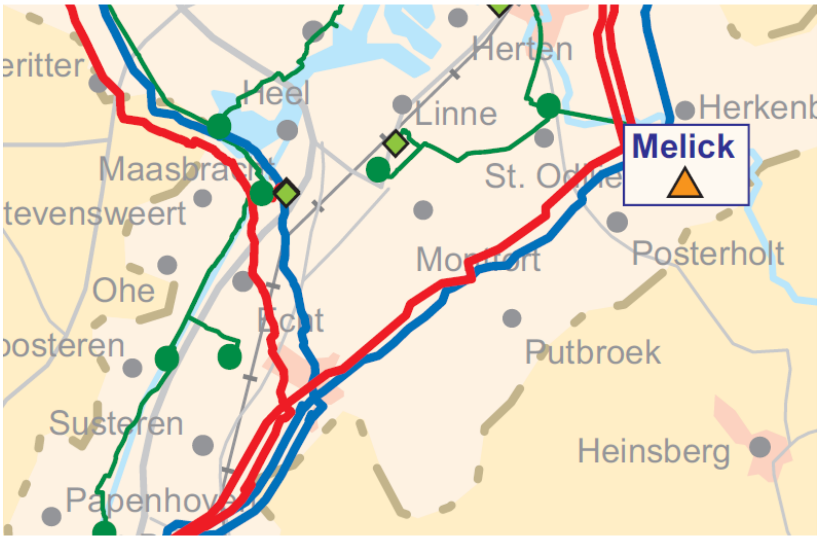
Gasunie infrastructure map of the North Sea Channel Area.

[75] See https://www.netopzee.eu/hollandsekustnoord/waar-ligt-de-netaansluiting-hollandse-kust-noord-en-west-alpha.

Appendix H – Maps Chemelot

Gasunie infrastrucutre near Chemelot.

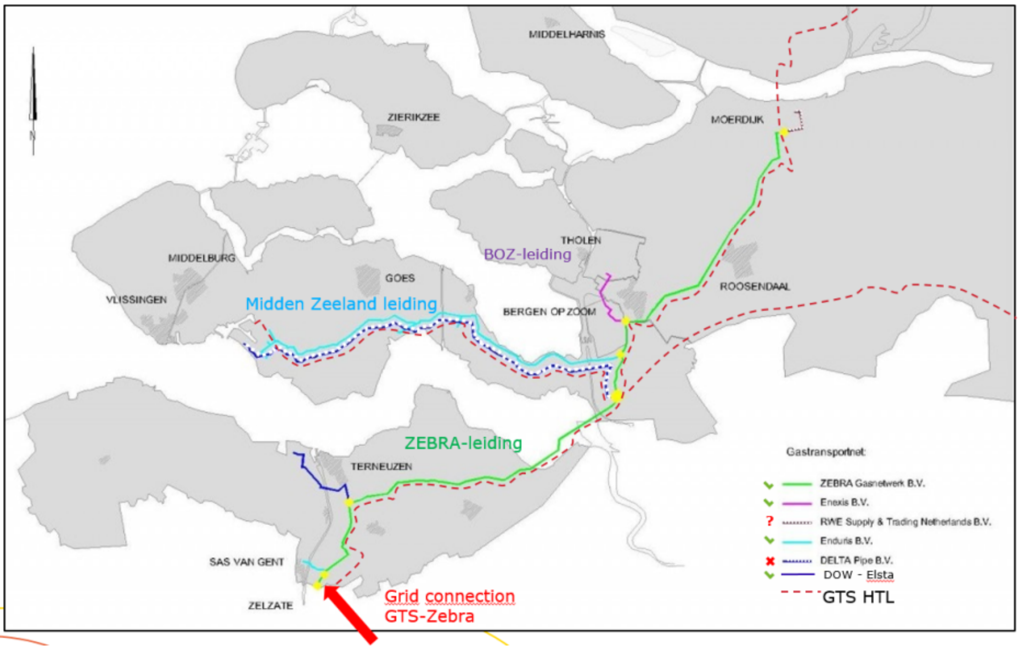
Gasunie infrastrucutre near the Maasbracht Claus power plant.



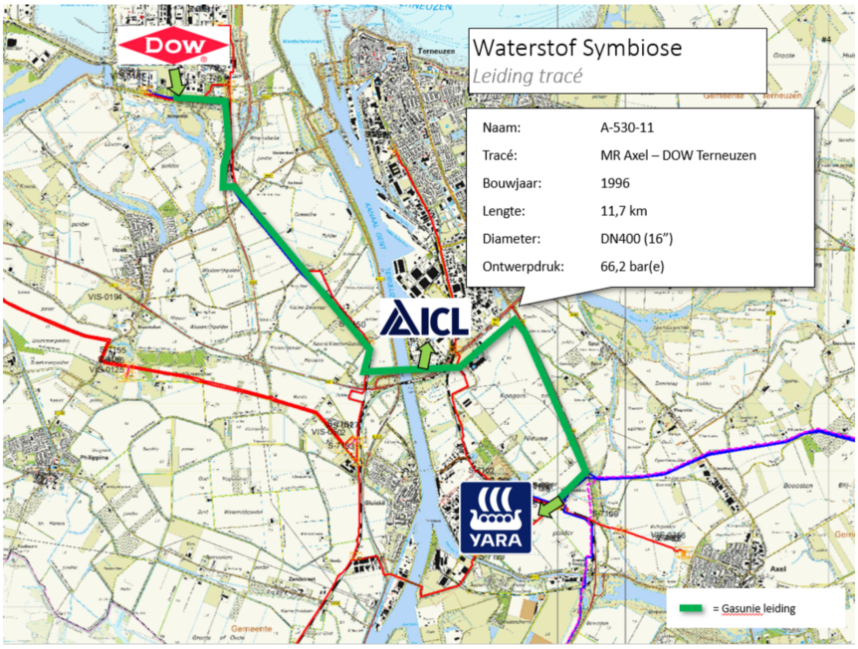
Appendix I – Zeeland / Smart Delta Resources

Map of potential locations

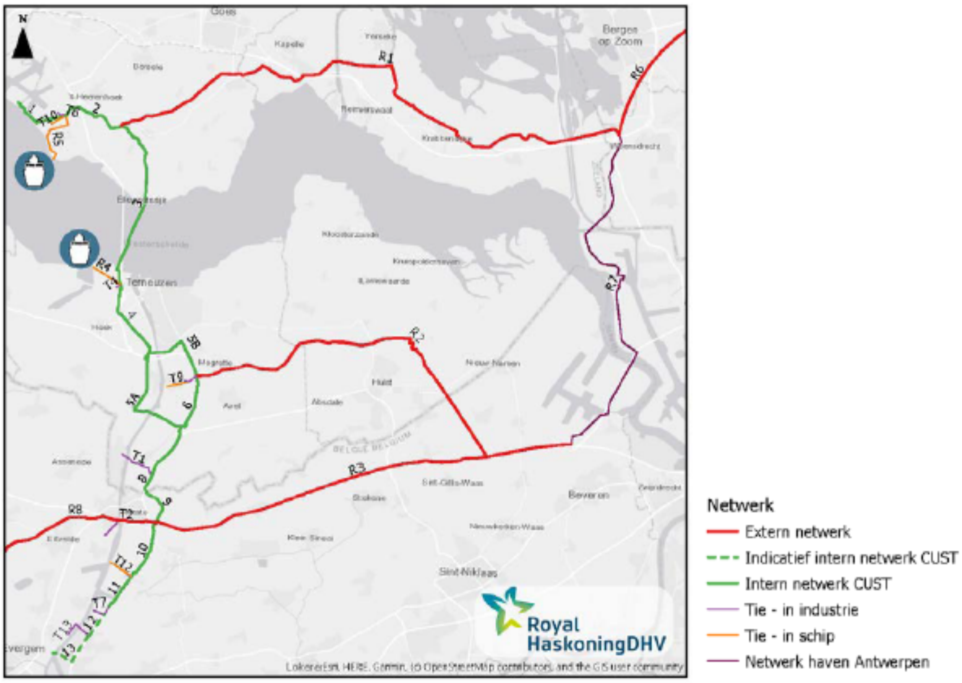
Map of gas infrastructure.



Map of hydrogen pipeline between DOW and YARA.



Map of CUST infrastructure.



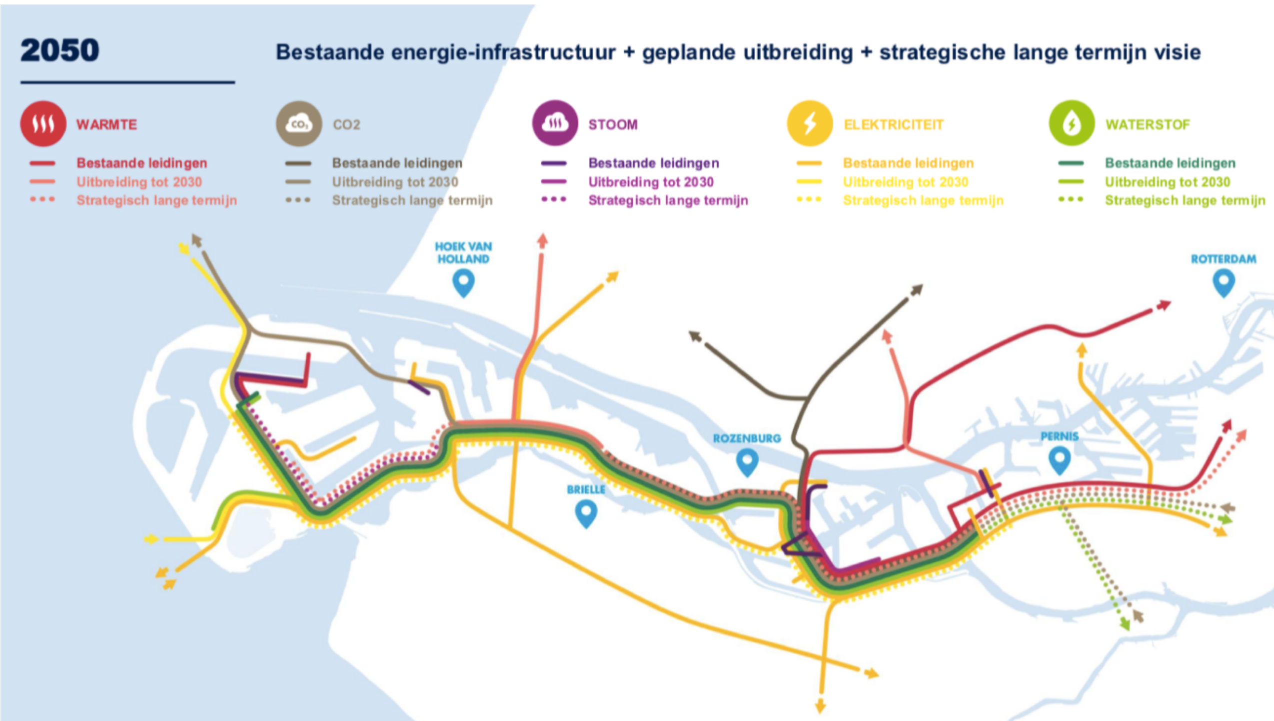
Appendix J – Maps Noord NL

Map of potential onshoring of offshore wind farm Ten Noorden van de Waddeneilanden

Map of existing Gasunie infrastructure.

Map of NAM production locations.

Appendix K – Maps Rotterdam area



Appendix L – Air Liquide Network

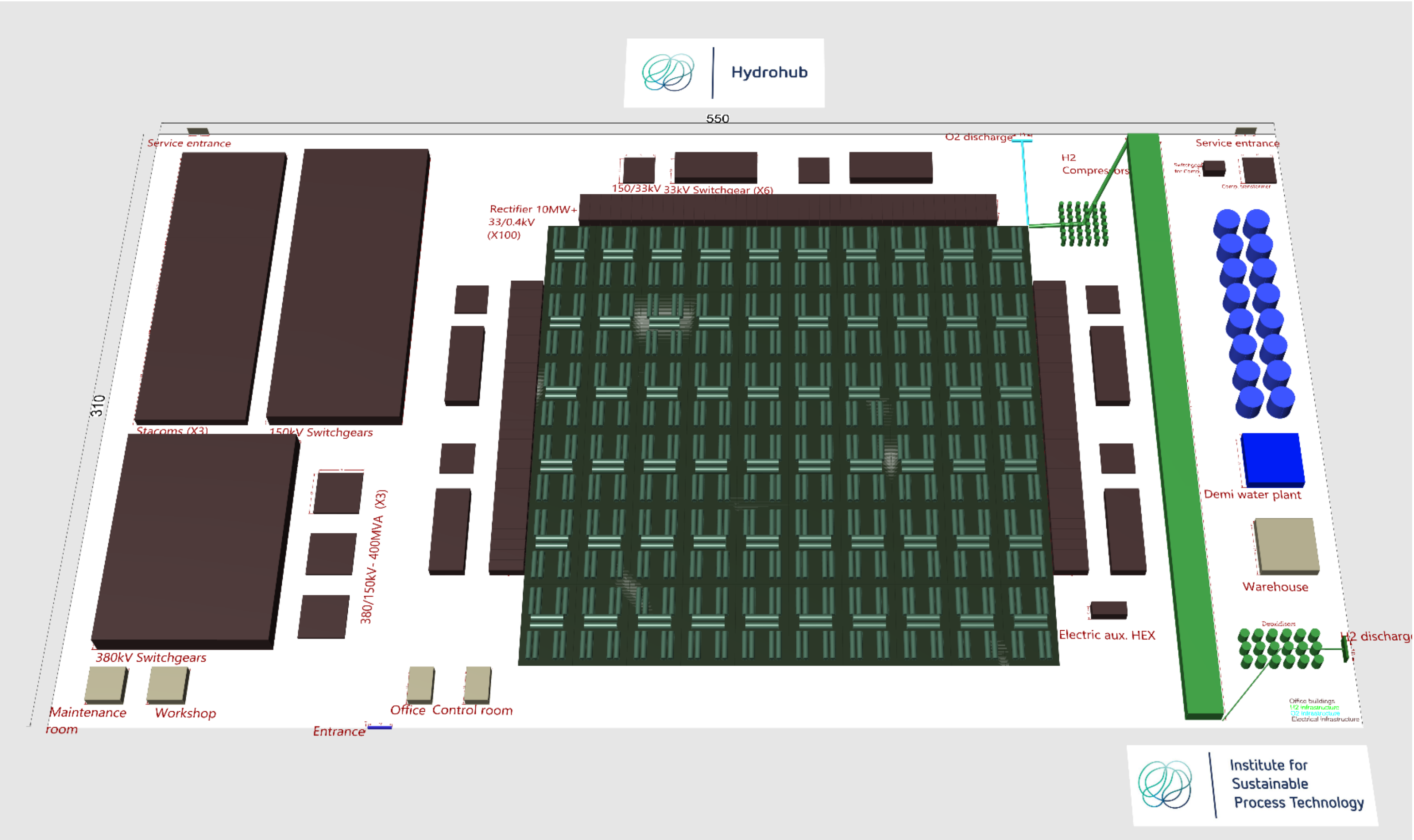
Below the Air Liquide network for Belgium and the Netherlands.[76]

76 See https://industrie.airliquide-benelux.com/sites/industry_benelux/files/air-liquide-benelux-pijpleidingen-nl.pdf.

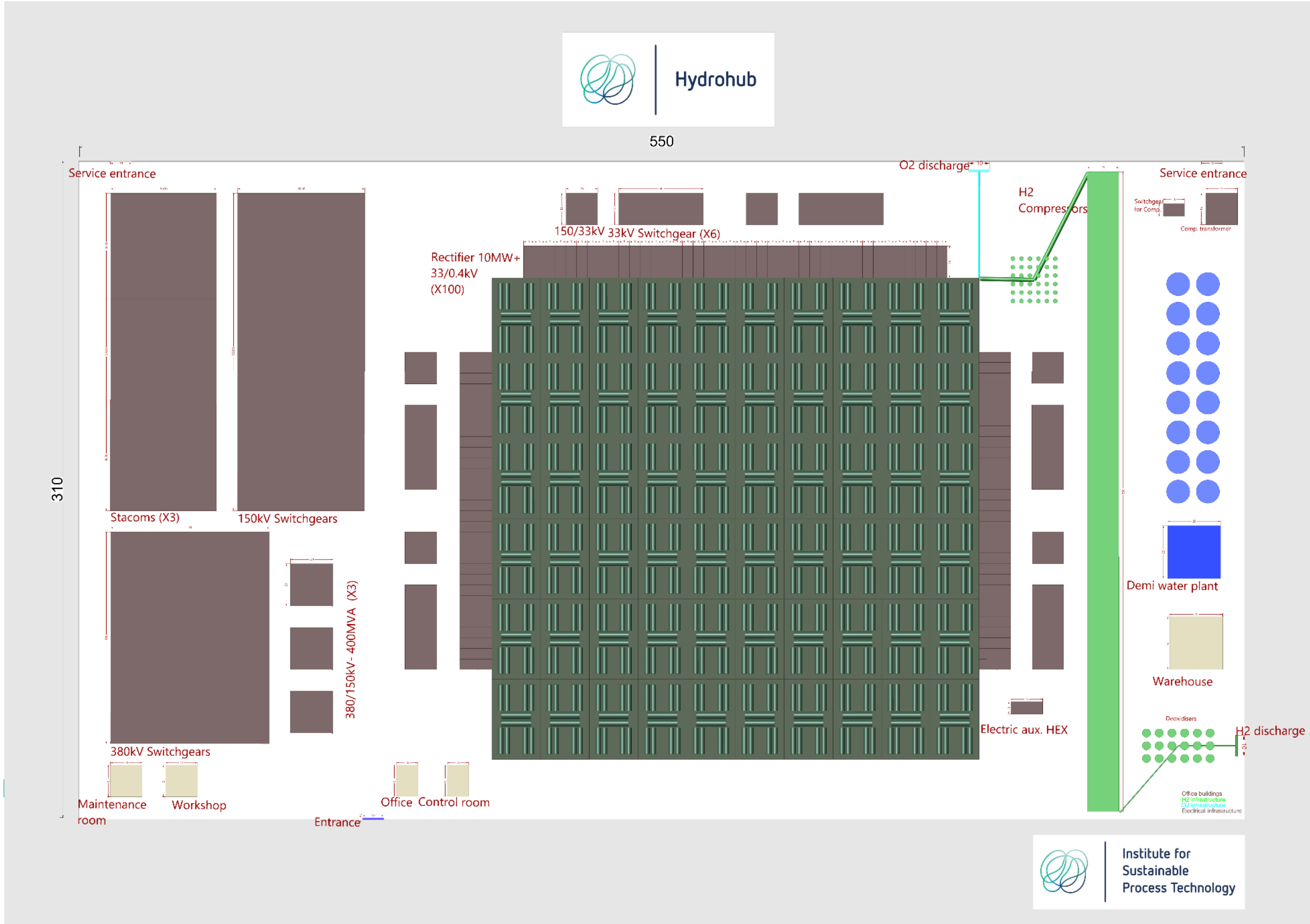
Appendix M – Explanation of colour scheme

Criteria	Green	Yellow	Red
Space	Green for sufficient space, also for base design.	Yellow when compact design is required or available space is not known.	Red in case there is not sufficient space.
Suitability	Green in case current use is also heavy industry, and no issues are foreseen with ownership, safety contour, permit and public resistance.	Yellow in case current use is not heavy industry, or when issues are foreseen with ownership, safety contour, permit and public resistance.	Yellow in case current use is not heavy industry, and when issues are foreseen with ownership, safety contour, permit and public resistance.
Water supply	Green means that the water treatment facility and pipe infrastructure are available for the supply of demi water.	Yellow means that there is water source available that can be treated with the existing treatment technologies for the production of demi water suitable for the electrolyser.	Red means that there is no water available or there is unknown information about a water source for the electrolyser.
Electricity supply	Green means infra is available or is planned.	Yellow in case infra is not existing or not sufficient but planned or projected.	Red in case infra is not existing or not sufficient, neither planned nor projected.
Hydrogen infra	Green in case distance to backbone is max 10 km.	Yellow when distance to backbone is larger than 10 km.	Red in case connection to backbone seems not possible.
Hydrogen demand	Green for nearby hydrogen demand.	Yellow in case nearby hydrogen demand is unknown.	Red when there is no nearby hydrogen demand.
Oxygen demand	Green for nearby oxygen demand.	Yellow in case of potential demand.	Red when there is no nearby oxygen demand.
District heating	Green for nearby district heating demand.	Yellow in case of potential district heating demand.	Red when there is no nearby district heating demand.

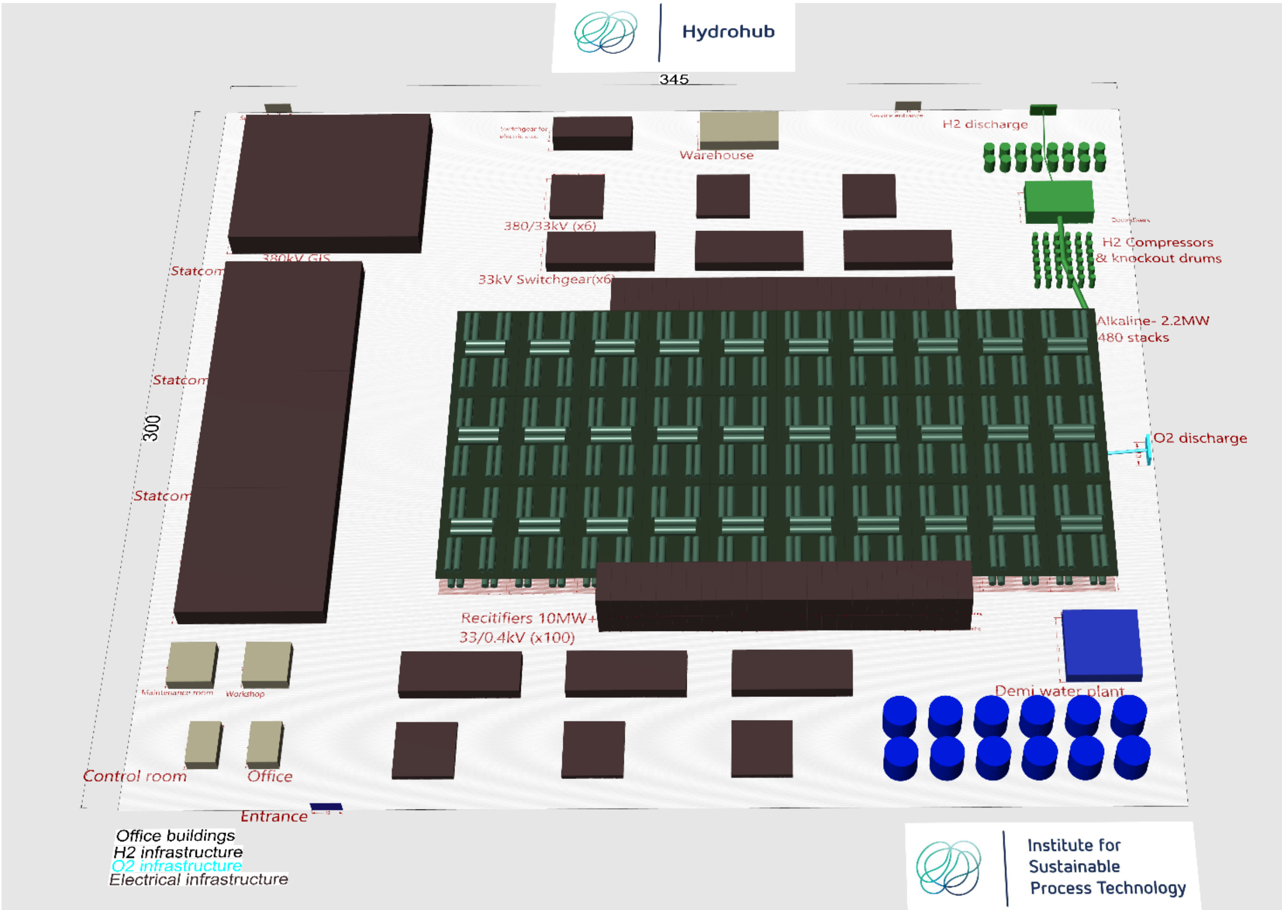
Appendix N – Plot plans maximum case: Alkaline electrolyser facility



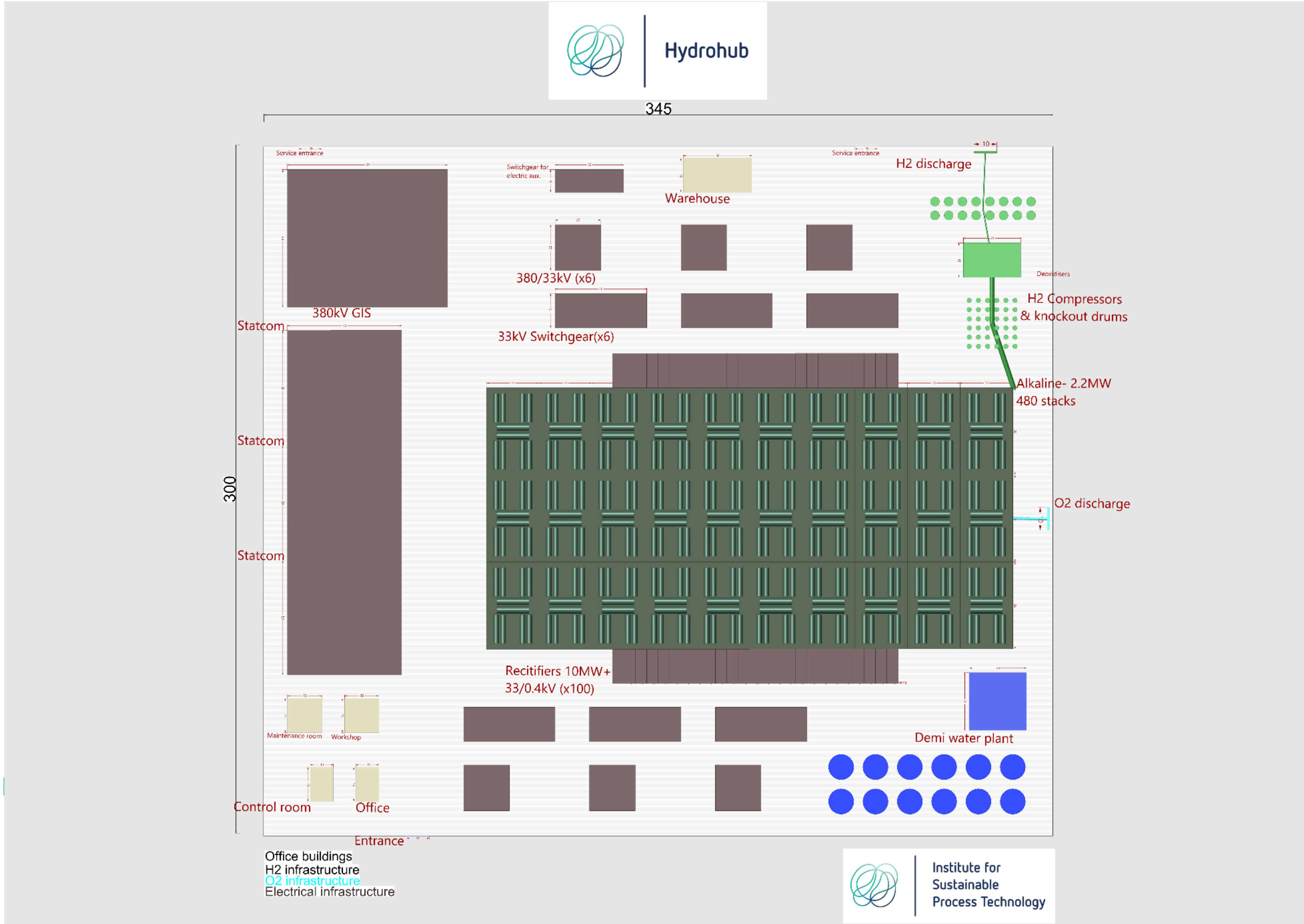
Institute for
Sustainable
Process Technology



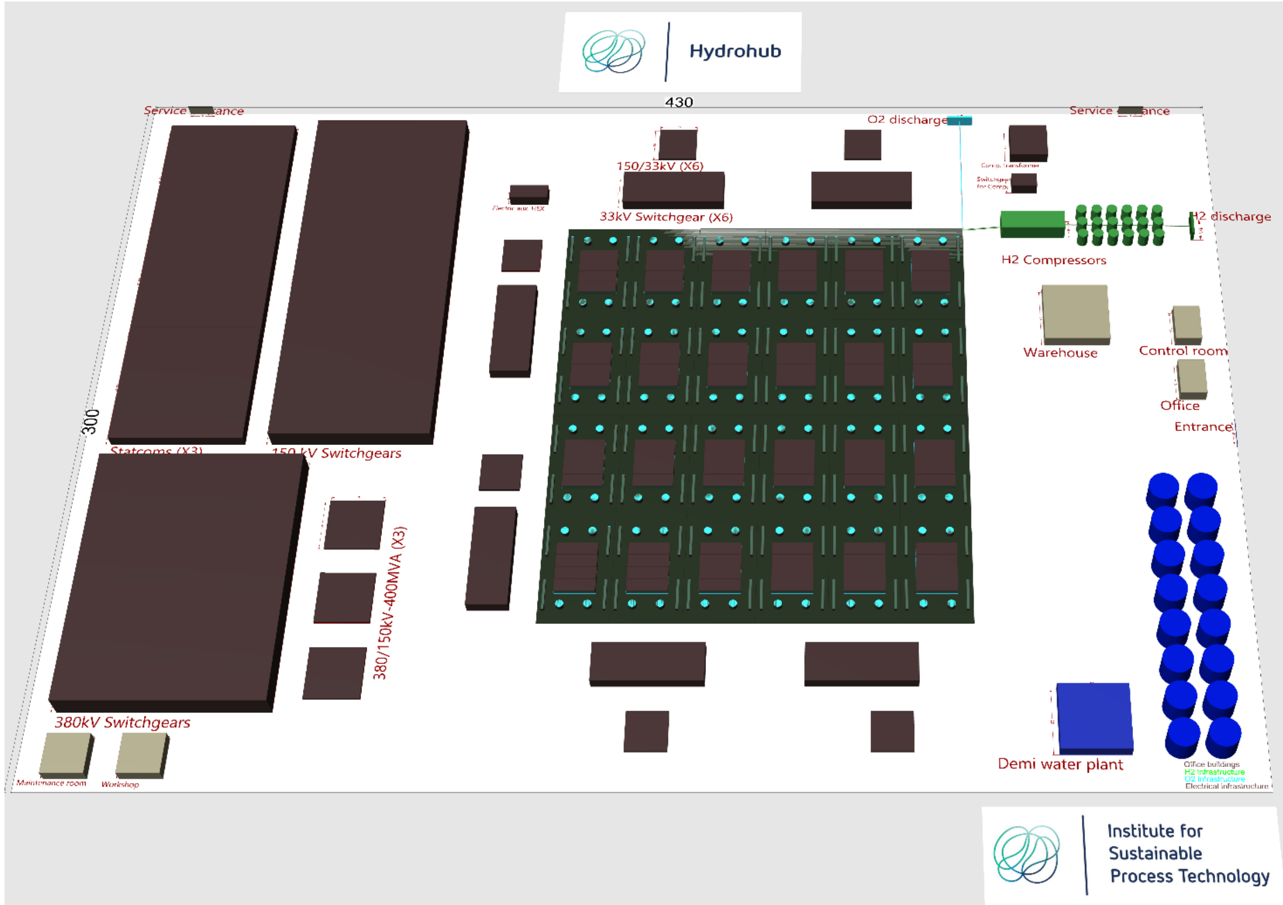
Appendix O – Plot plans minimum case: Alkaline electrolyser facility



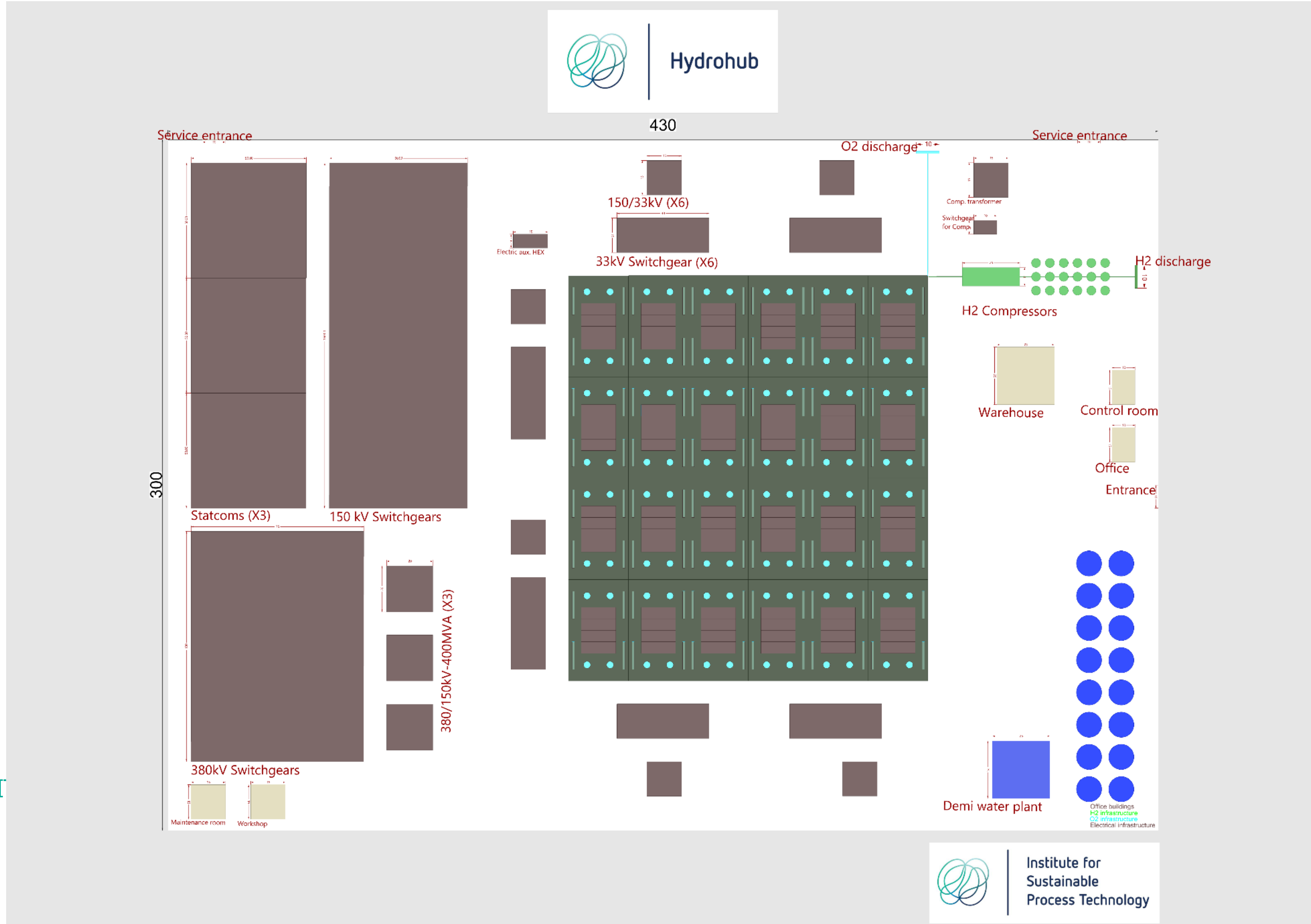
Institute for
Sustainable
Process Technology



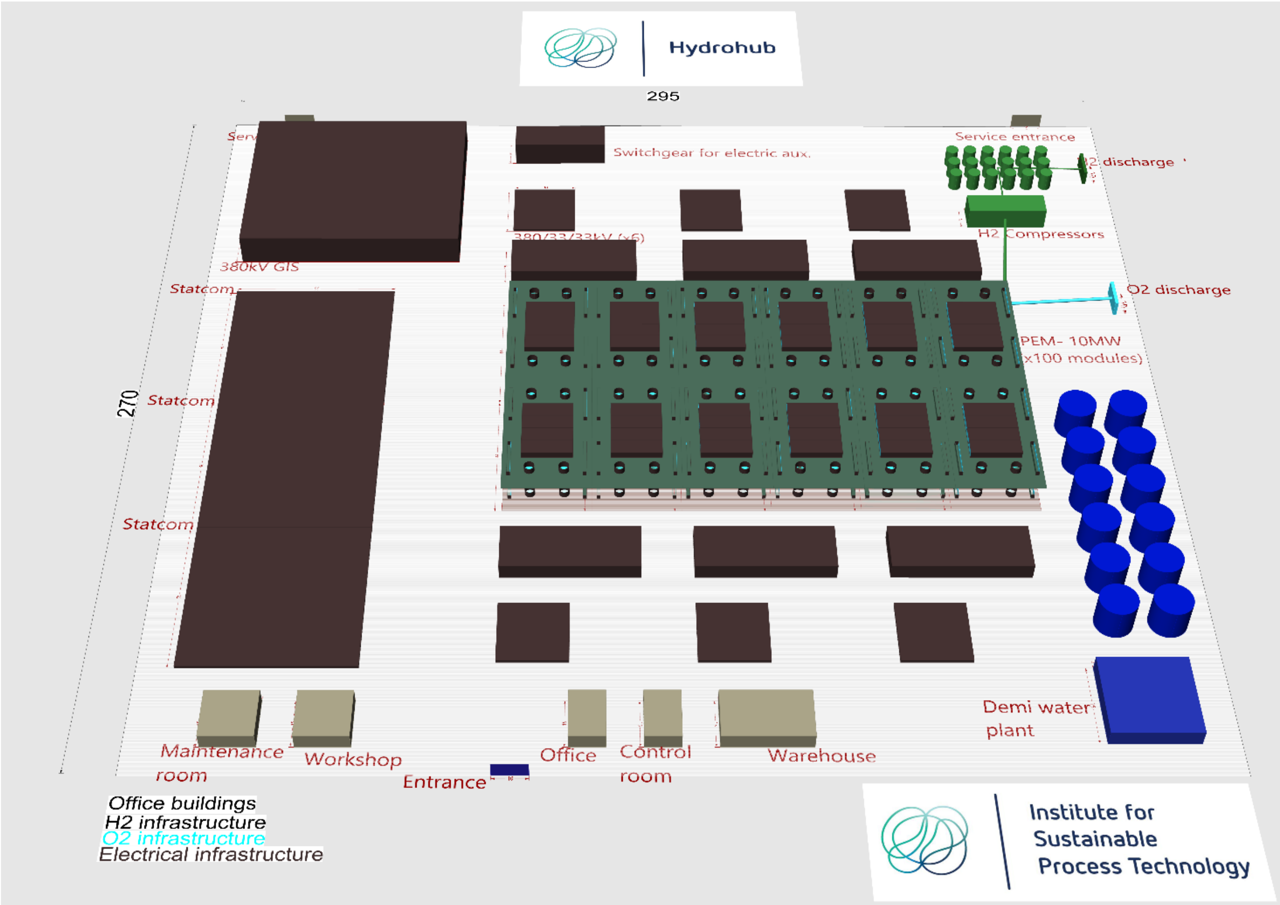
Appendix P – Plot plans maximum case: PEM electrolyser facility

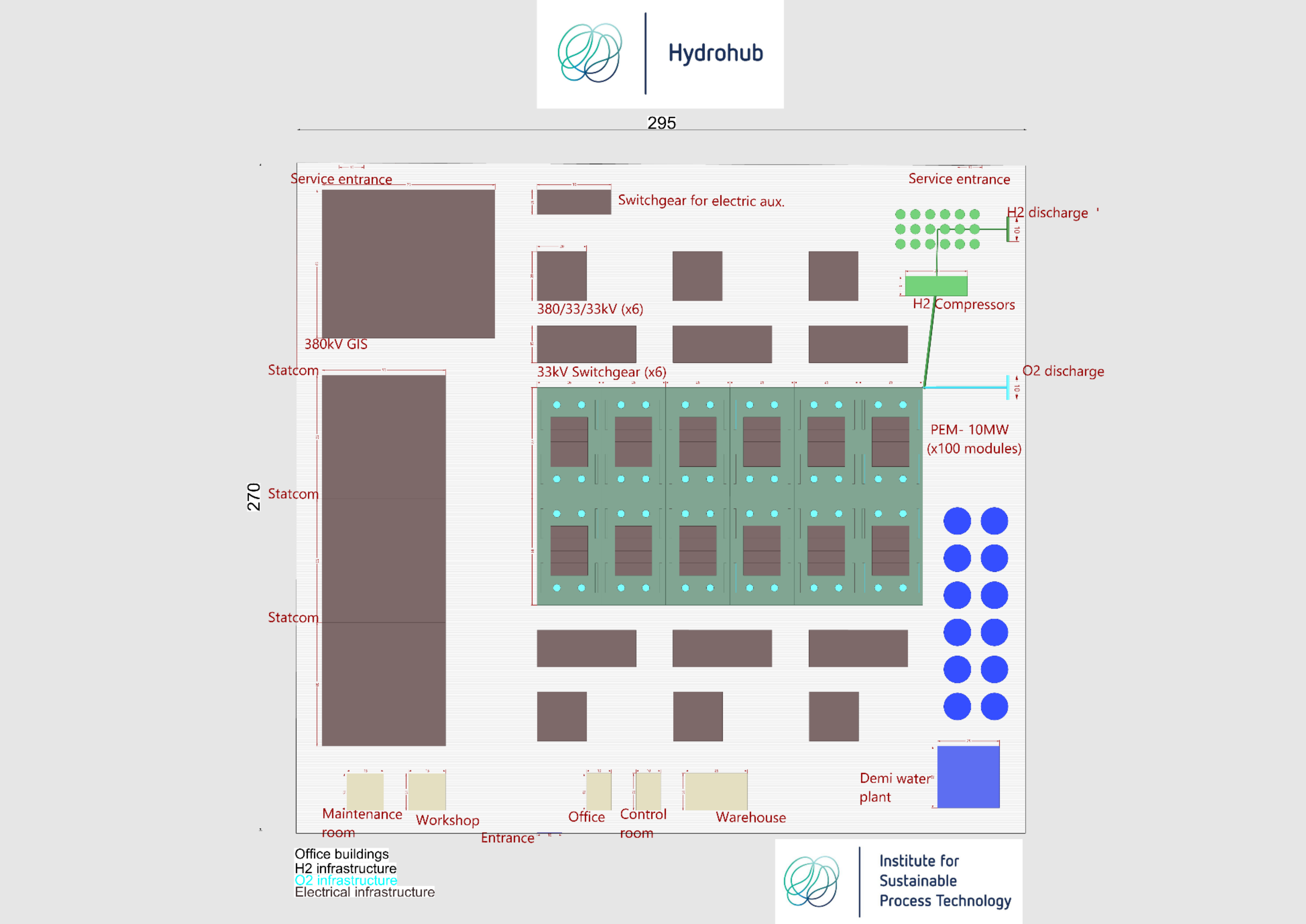


Institute for
Sustainable
Process Technology



Appendix Q – Plot plans minimum case: PEM electrolyser facility




Hydrohub
295
270
Service entrance
Switchgear for electric aux.
Service entrance
H2 discharge
380/33/33kV (x6)
H2 Compressors
380kV GIS
Statcom
33kV Switchgear (x6)
O2 discharge
PEM- 10MW
(x100 modules)
Statcom
Statcom
Demi water
plant
Maintenance
room
Workshop
Office
Control
room
Warehouse
Entrance
Office buildings
H2 infrastructure
O2 infrastructure
Electrical infrastructure
Institute for
Sustainable
Process Technology

[Titel]