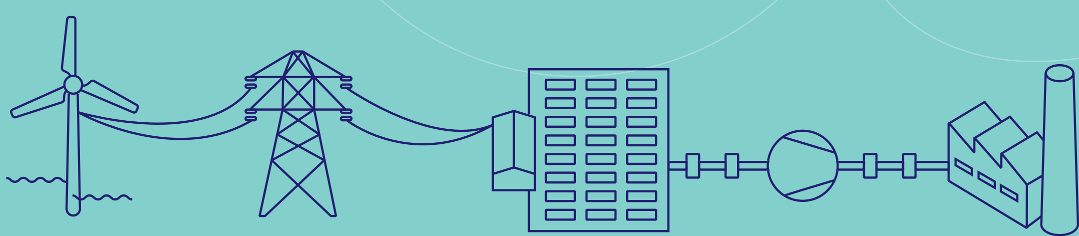
Hydrohub
Innovation
Program

Public summary

Integration of gigawatt scale electrolyser in five industrial clusters

Interregional cooperation



Foreword

This report comes at a time when we face unprecedented public health challenges. Challenges that are also having a major economic impact. Amid all this, the climate targets have not changed.
Efforts for economic recovery are going to have to go hand in hand with efforts to make our energy supply carbon-neutral. As we reignite economic growth, we can also accelerate the energy transition and create sustainable jobs. Success will then hinge on collaboration across regional borders and industry boundaries.

Such cross-border collaboration is exactly what the Institute for Sustainable Process Technology (ISPT) and participating organisations have engaged in as part of this Hydrohub Innovation Programme. We have looked across our boundaries and set ourselves the joint goal of being able to develop hydrogen on such a large scale that we can achieve the targeted carbon reduction in a way that is affordable. Industry, which is a major driver of the Dutch economy, can thus make a significant contribution to moving our country further towards sustainability.

To make this happen, we are going to need to develop an integrated approach in a cooperation comprising industry, ports, infrastructure companies, network operators, knowledge institutions and government bodies. Key aspects in this respect are the availability of land and water, sufficient capacity on the power grid, and optimum utilisation of our current gas infrastructure for the transmission and storage of hydrogen. All parties involved are already working hard on this.

The Netherlands is uniquely positioned for this development and to grow into the hub of the north-western European hydrogen roundabout. We have great offshore wind potential and robust, dense infrastructure in place. We have major ports that enable large-scale imports and transit, and our innovation capacity is highly developed. But above all, we have a shared drive to make the energy supply sustainable in an affordable and reliable way by harnessing the potential of hydrogen. The aim is to realise the Dutch ambitions for 2030 and beyond. I look forward to working together to make this a success!

Han Fennema

CEO en voorzitter van de Raad van Bestuur GasUnie

Contents

Introduction

In the European Green Deal an important role is foreseen for green hydrogen, produced by means of water electrolysis using renewable (e.g. wind or solar based) electricity (visit link). This hydrogen can be produced in a flexible way adapting to the fluctuations in wind and solar power generation. On top of that, it enables a pathway to sustainability in industrial production, mobility and heating.

However, this is conditional to the upscaling potential and related economical improvements: where state-of-the-art water electrolysis is of the order of 10-100 MW, production should be enhanced at least to 1 GW scale to be of any significance. This can be illustrated by the present hydrogen consumption in the Dutch (petro-)chemical industry which amounts to approximately 1.5 million tonnes per year. Compare this to the annual production of about 90.000 tonnes of hydrogen by 1 GW water electrolysis facility[1] and the need for upscaling is evident. In parallel to upscaling the electrolyser chain, the Levelised Cost of Hydrogen (LCOH) and corresponding CAPEX should be reduced with a factor of three to be competitive e.g. with blue hydrogen production.

The study presented here is part of the Hydrohub GigaWatt Scale Electrolyser project, which aims to deliver conceptual designs (blueprints) for future (2030 and beyond) GW water electrolysis facilities in the five main industrial clusters in the Netherlands (figure 3). This will serve as a basis for understanding the cost structure of such facilities and achieving cost reduction through scaling up, numbering up and process innovation.

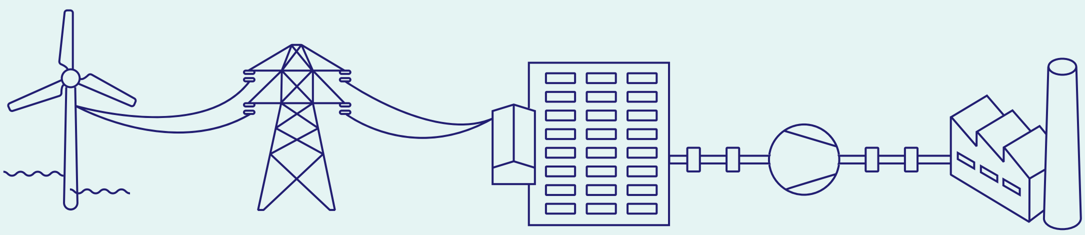


Figure 1

[1] This is based on 1 GW power input, 5000 h/a, and new stacks. The assumed operating mode is flexible load with a minimum load of 15 %. The annual 5000 h are full load hours, of which 4000 h/a from the 2018 profile from a North Sea windfarm (Ørsted, 950 MW North Sea wind farm, 2018). We consider 1000 h/a back-up power (with certificates) to meet the 15 % minimum 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.

As a starting point, the GigaWatt Scale Electrolyser project has delivered base line designs for GW scale electrolyser facilities based on PEM (Proton Exchange Membrane) and Alkaline electrolysis technologies according to the current (2020) state of the art. The aim of the study presented here was to investigate the possibilities for such a facility in each of the five industrial clusters in The Netherlands. By analysing relevant aspects of the local situation, such as power supply and product demand, we obtain valuable insights into the extent to which large scale electrolysis facilities can be standardized or should be tailor made to the local situation.

We have assessed the suitability of a total of 22 regional available plots for large scale electrolysis. We have assessed the infrastructure for electricity, water and hydrogen, as well as the regional demands for hydrogen. Adding to this, we have looked at the potential for residual heat usage.

The conclusion of this study, which is part of the Hydrohub Innovation Program and was carried out with support of TKI Energy & Industry, is that GW scale green hydrogen facilities are possible in all five industrial clusters. Furthermore, present industrial demand is sufficient as driver for take-off of large scale green hydrogen production.

The GigaWatt Scale Electrolyser project will build further on this study to develop advanced future designs aimed at cost reduction. Maximum attention will be given to aspects of system integration and safety, to understand their implications on design, costs and feasibility. Furthermore, the cooperation with the industrial clusters will be extended towards developing the infrastructure required for the future designs, and towards identifying synergies and upsides such as the use of oxygen and residual heat.
All this to arrive at the final deliverable: blueprints for economically viable GW scale electrolysers in all five clusters.

Figure 2: Impression of the five regional stakeholder consultation workshops

Scope of this regional study

In this study generic 'plot plans' were drawn based on the GW project baselines, thus establishing the space requirements for a GW green hydrogen facility both for PEM and Alkaline electrolysis technologies. For each of the five industrial clusters potential locations were identified, and assessments were made of:

- Existing and future hydrogen demand;
- Connections to the electrical infrastructure (380 kV stations);
- Infrastructure needed to connect to the hydrogen backbone of Gasunie;
- Plants and infrastructure for feed- and cooling water and wastewater; and
- Opportunities for the use of residual heat.

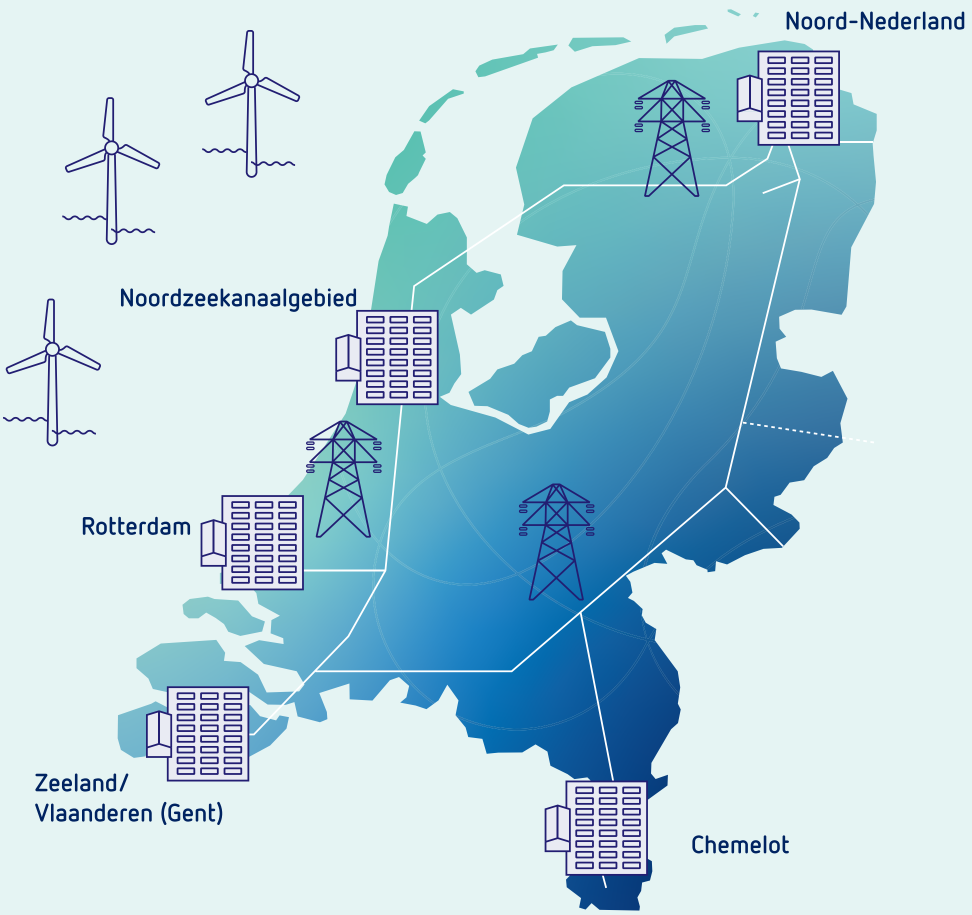


Figure 3: The five industrial regions of the Netherlands

Plot plans

Plot plans have been drawn for baseline designs of the GW green hydrogen facility in layouts that determine the minimum and maximum space requirements. The exact size depends on the chosen electrolysis technology (PEM or Alkaline), the design principles of the electrolysers (current density, pressure, cell surface) and the layout of the electrolysis building and electrical installations. Design choices for electrical utilities and installations for gas compression and treatment and utilities also affect plot size.

Figures 5-8 depict the range of plot sizes resulting from this exploration. The maximum surface requirement amounts to 17 ha when Alkaline technology is applied (fig. 5) and 13 ha in the case of PEM (fig. 6). The minimum surface requirement is 10 ha for Alkaline (fig. 7) and 8 ha for PEM (fig. 8).

The constituent parts of a GW green hydrogen facility

All four plot plans depict the main constituent parts of the facility:

- Electrical installations (in brown);
- Electrolyser building (in dark green);
- Gas compression and treatment (in light green);
- Utilities (in blue).

The electrical installations consist of the connection to the 380 kV grid; transformers and switchgear; and power electronics. Electrolysers operate at low voltage and direct current. Connecting them to the grid requires high voltage power transformers and switchgear. Power electronics (rectifiers) are needed to convert the alternating current (AC) of the grid to direct current (DC) and to control the power quality.

In principle, the power supply is the same for PEM and Alkaline technology. In the PEM plot plans, the power electronics are positioned inside the electrolyser building. In the Alkaline plot plans, the medium voltage transformers and rectifiers are placed at the edges of the building. All in all, the space requirements of the electrical installations are similar to the space requirements of the electrolyser building.

The electrolyser building contains:
- For Alkaline technology: Modules of 17 MW electrolyser stacks and gas-liquid separators;
- For PEM technology: Modules of 40 MW stacks and separators, and -transformer-rectifiers in compartments.

In general, the spatial footprint of the PEM building is less than half the footprint of the Alkaline electrolyser building. The dimensions given here are only for one big building to indicate space requirements whereas in the artist impression three buildings are shown. Further optimisation of cabling and piping is foreseen.

Gas compression and treatment equipment consist of compressors, needed to lift the hydrogen pressure to grid pressure; deoxidisers, to remove traces of oxygen; and drying equipment, to remove traces of water.

The utilities comprise mainly facilities for cooling and water treatment. As electrolysis efficiency for PEM is generally lower than for Alkaline, more heat is generated and therefore more cooling is required. Heat recovery to district heating networks is possible. Construction access, maintenance and operational access around the infrastructure are shown as white spaces in between the layout. Also other buildings for services are included in the plot plans.

Figure 4: Artist impression for a gigawatt green hydrogen facility, based on Alkaline electrolysis design

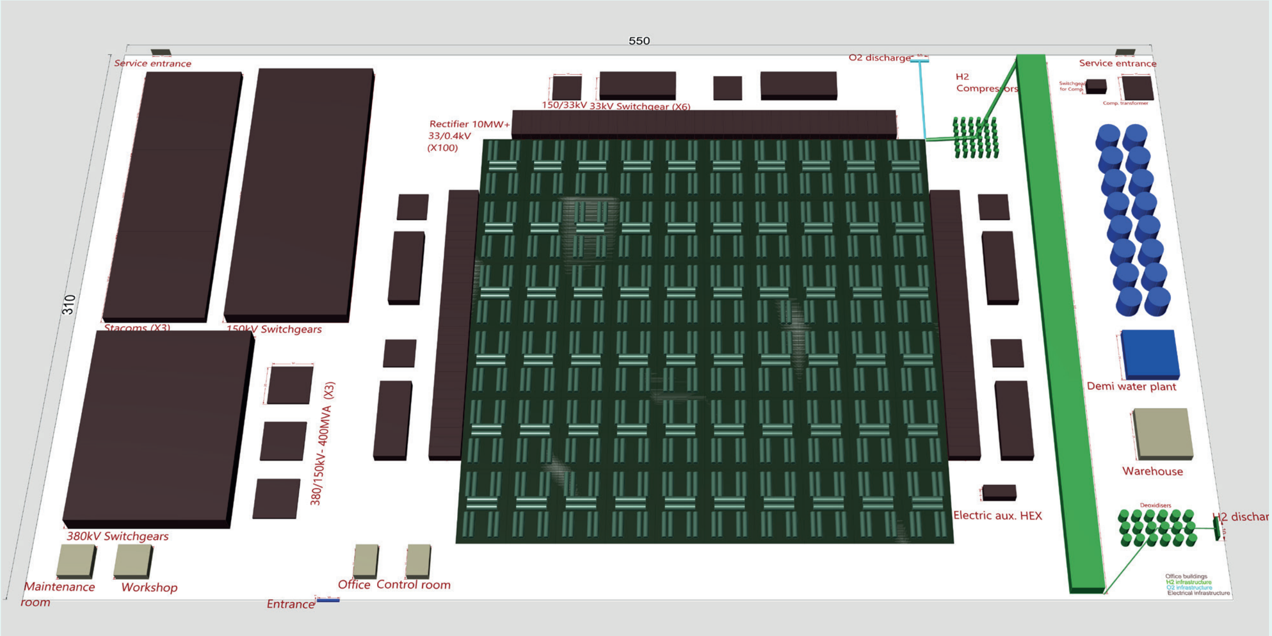


Figure 5: GW green hydrogen facility, Alkaline, max. case: 17 ha

Main characteristics: Two-step power conversion (380-150-33 kV), large electrolysis building, atmospheric electrolysis

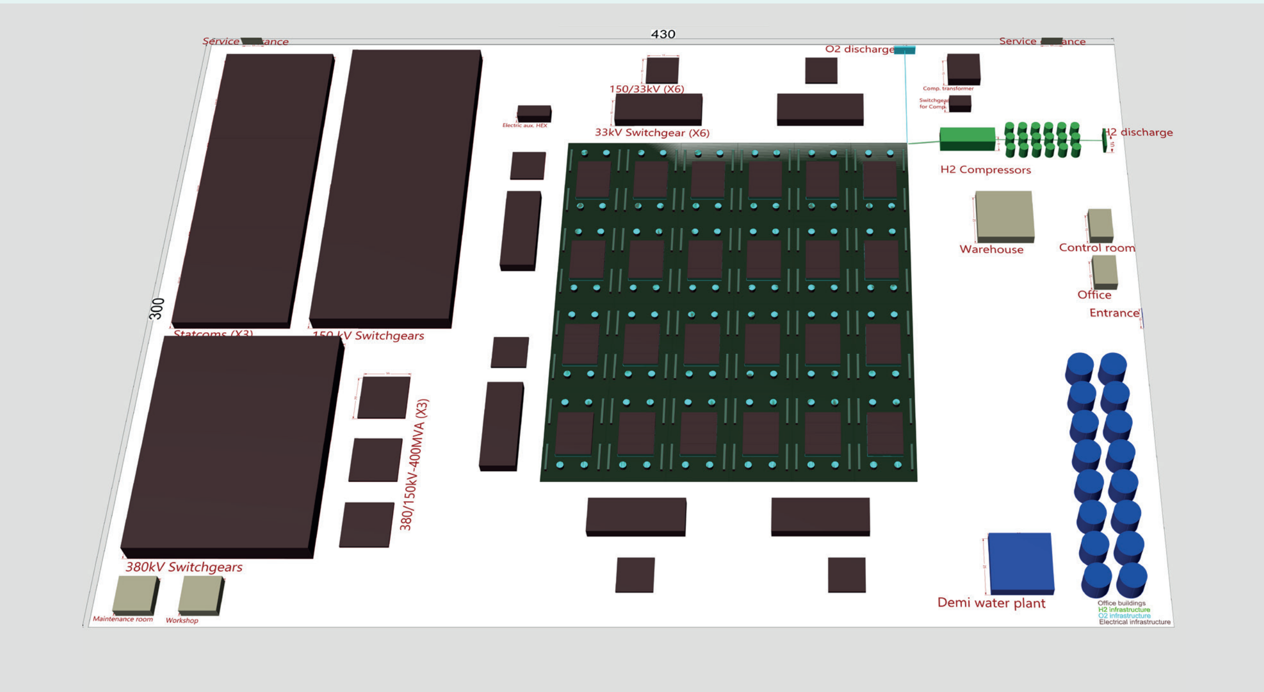


Figure 6: GW green hydrogen facility, PEM, max. case: 13 ha

Main characteristics: Two-step power conversion (380-150-33 kV), single floor electrolysis building, pressurised electrolysis.

Reduction of plot size

There are multiple options for reducing the surface requirement of a plot plan. Regarding the electrical utilities, deleting the otherwise common 150 kV station can lead to both cost and space reduction. This requires the conversion of 380 kV AC to 33kV AC in one single step. Furthermore, the footprint of the electrolyser building depends on the space required for the electrolysis equipment within. As technology progresses, this can be expected to decrease. As an approximation of this, in the minimum size plot plans a two-story design was applied, effectively reducing the footprint of the electrolyser building by a factor of 2. Adding to this, for Alkaline electrolysis the minimum plot design has been based on pressurised electrolysis whereas the maximum case uses atmospheric electrolysis. Therefore less mechanical gas compression equipment is required to obtain final pressure.

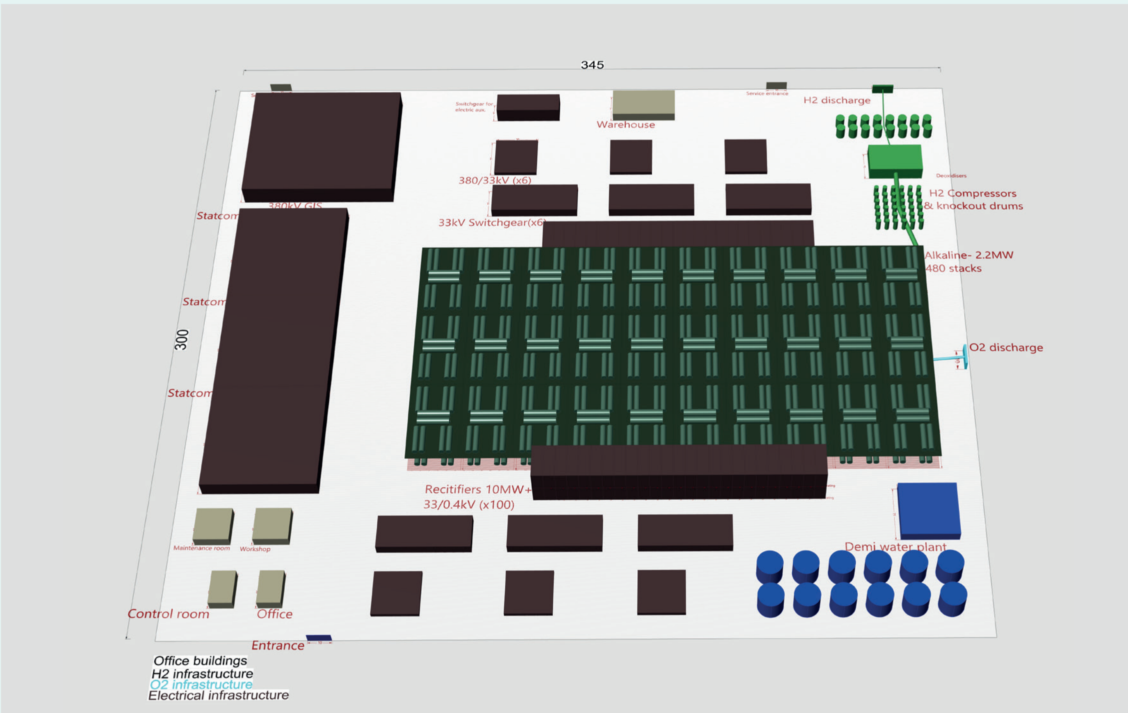


Figure 7: GW green hydrogen facility, Alkaline, min. case: 10 ha.

Main characteristics: One-step power conversion (380-33 kV), smaller electrolysis building, pressurised electrolysis.

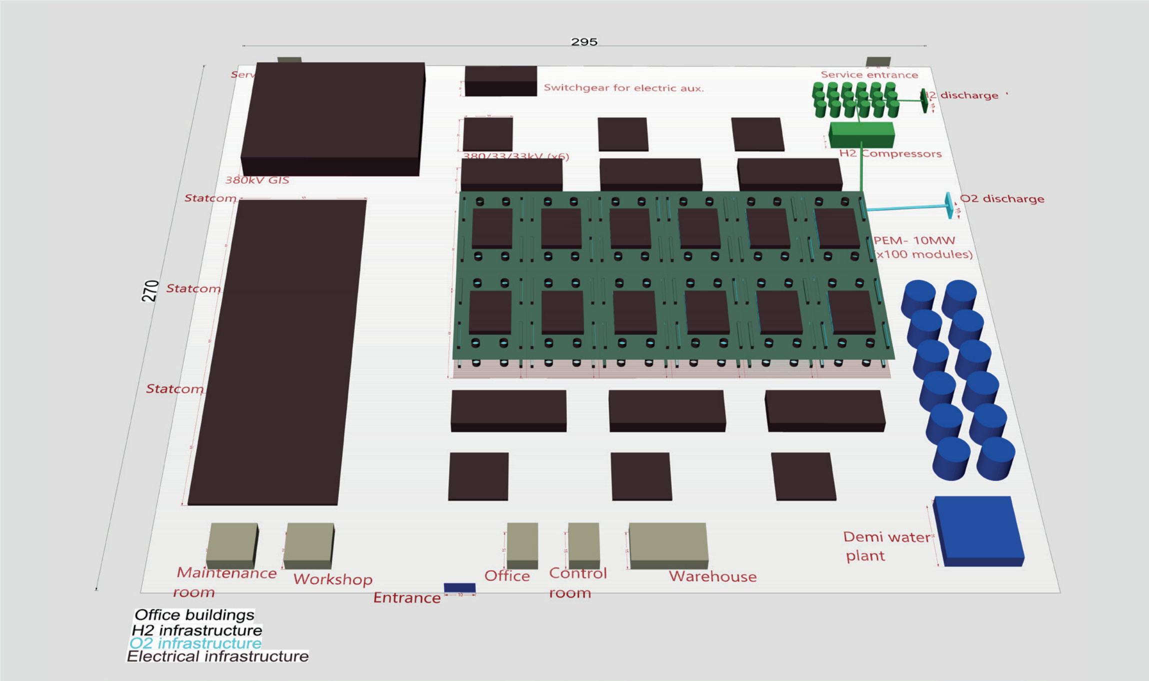


Figure 8: GW green hydrogen facility, PEM, min. case: 8 ha.

Main characteristics: One-step power conversion (380-33 kV), double floor electrolysis building, pressurised electrolysis.

Outlook

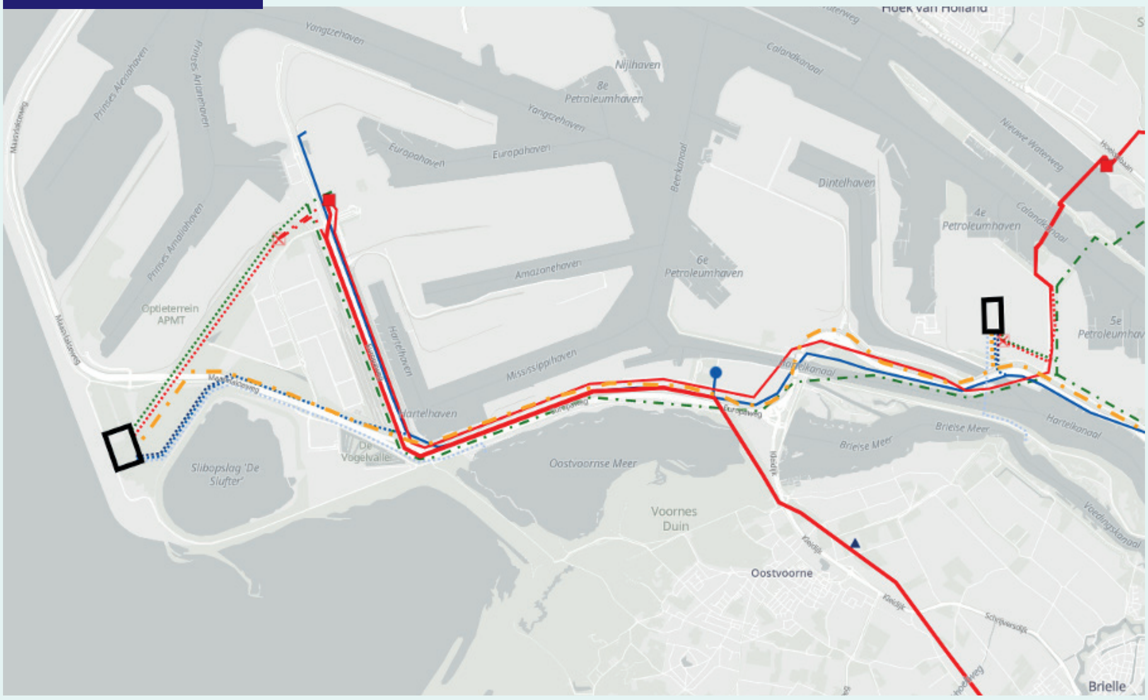
The plot plans presented above are based on current state-of-the-art Alkaline and PEM technology, using data from selected suppliers. During the course of the project already progress in electrolyte technology development and power electronics have been observed. This gives confidence that plot sizes can be further reduced. Even more important is that based on these plot plans the five industrial regions already can find the space for accommodating a GW facility. In the project blue print designs will be delivered to demonstrate the cost-effectiveness of design improvements on power conversion and electrolysis.

Results per industrial cluster

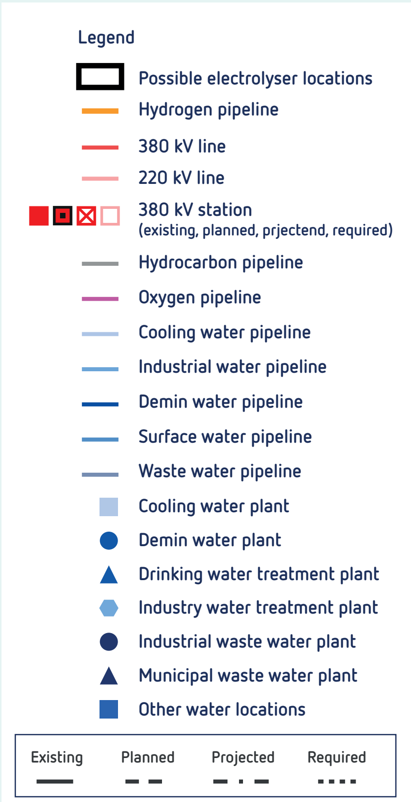
See corresponding map online >

For each of the five industrial regions of the Netherlands we have assessed the potential for large scale electrolysis. We have identified locations, assessed the infrastructure for electricity, water and hydrogen, as well as the current and future demands for hydrogen. Adding to this, we have looked at the potential for residual heat usage.

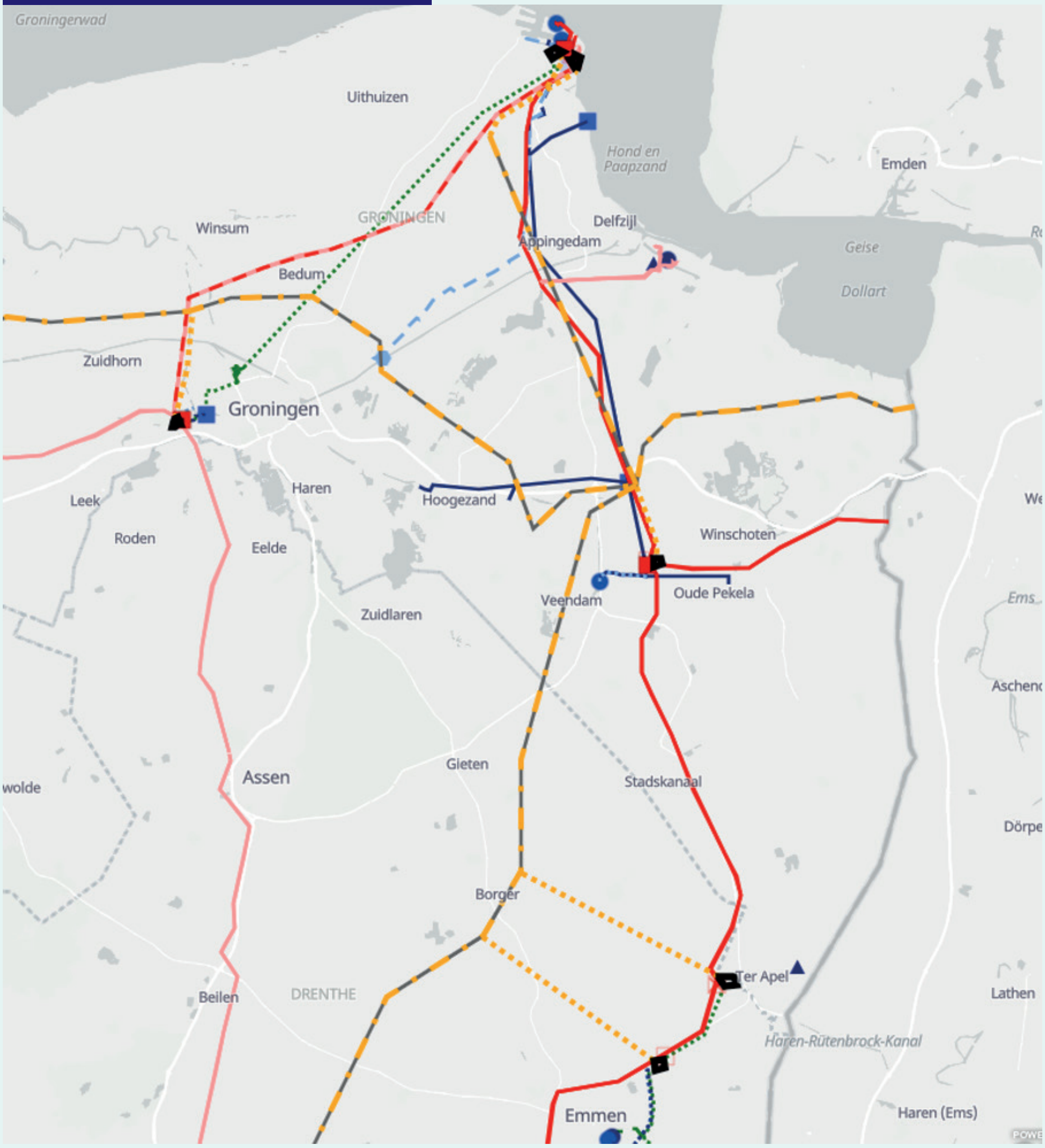
Rotterdam



- **Locations:** The Maasvlakte is the designated area for a 2 GW conversion park. Also there are two 250 MW projects from BP/ Nouryon (H2-Fifty) and Shell in the study phase. (Source: Nouryon 250 MW project)
- **Hydrogen demand:** There is a large existing demand (550 ktons/y) that accommodates more than one GW green hydrogen plant in addition to blue hydrogen plans (H-vision project).
- **380 kV connection:** Concrete plans for establishing connections are in place.
- **Hydrogen infrastructure:** A local 70 km pipeline is required and projected for blue and green hydrogen, to connect the region to the planned Gasunie backbone.
- **Facilities:** Water facilities and compression stations could be developed as a common service by the Port of Rotterdam.
- **Residual heat:** There is potential for use in district heating and horticulture.

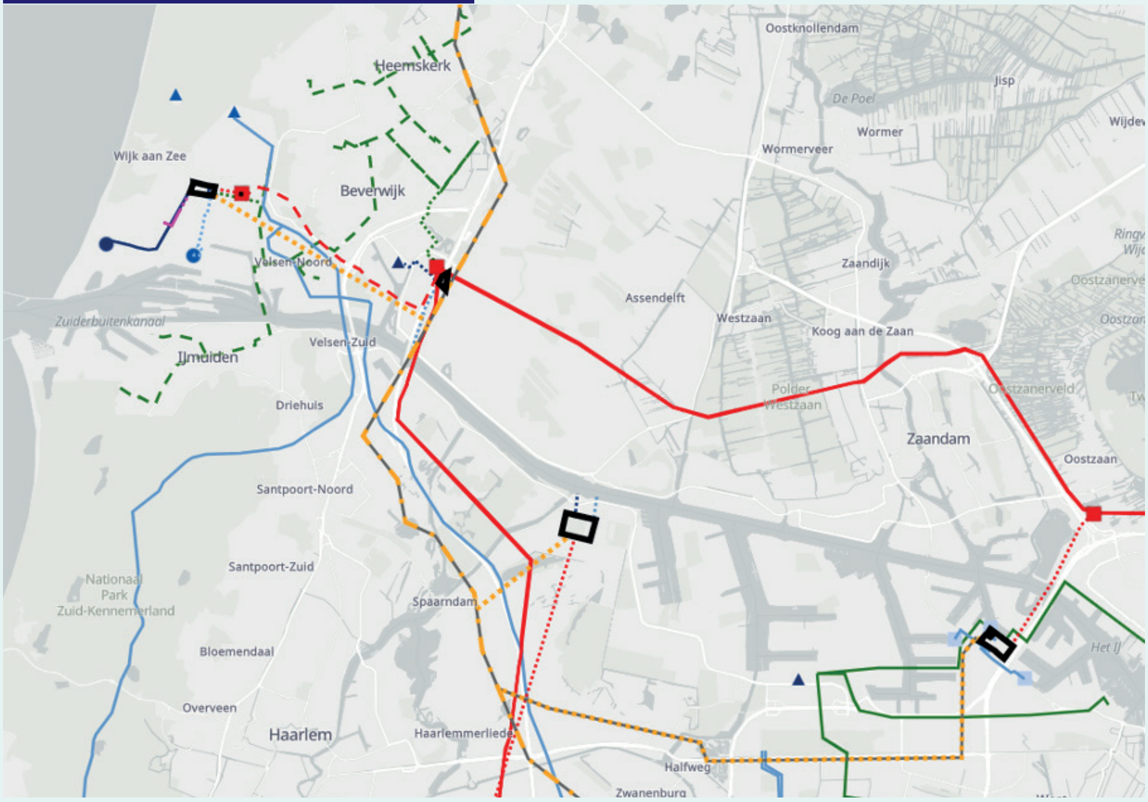


Northern Netherlands

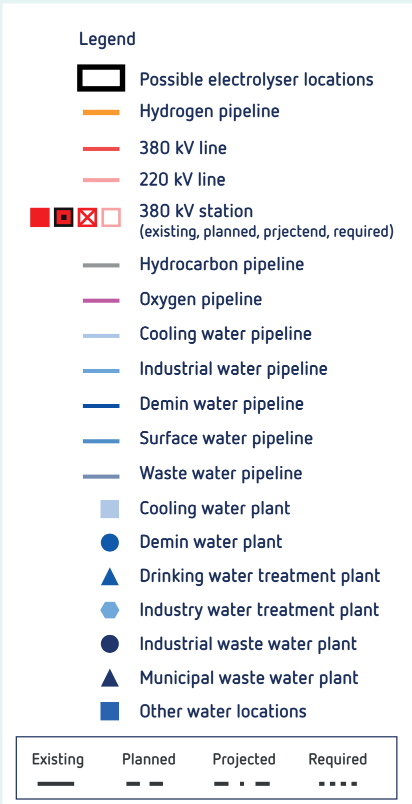


- **Locations:** Several locations are available, including Eemshaven, to contribute to a current EU-funded project to deve¬lop the green hydrogen chain in the Northern Netherlands (HEAVENN) and realise green hydrogen ambitions up to 10 GW (NortH2).
- **Hydrogen demand:** A growing hydrogen demand is to be expected in relation to local industry (150 kton/y), the power sector and the potential hub function.
- **380 kV connection:** For the Eemhaven location timely planning of a 380kV substation is required.
- **Hydrogen infrastructure:** The Gasunie backbone and connecting infrastructure of roughly 10 km to Eemshaven, and underground storage (Hystock), are planned first to be developed by Gasunie.
- **Facilities:** Water facilities are needed and can be provided by Northwater.
- **Residual heat:** There is a potential for district heating (Warmtestad).

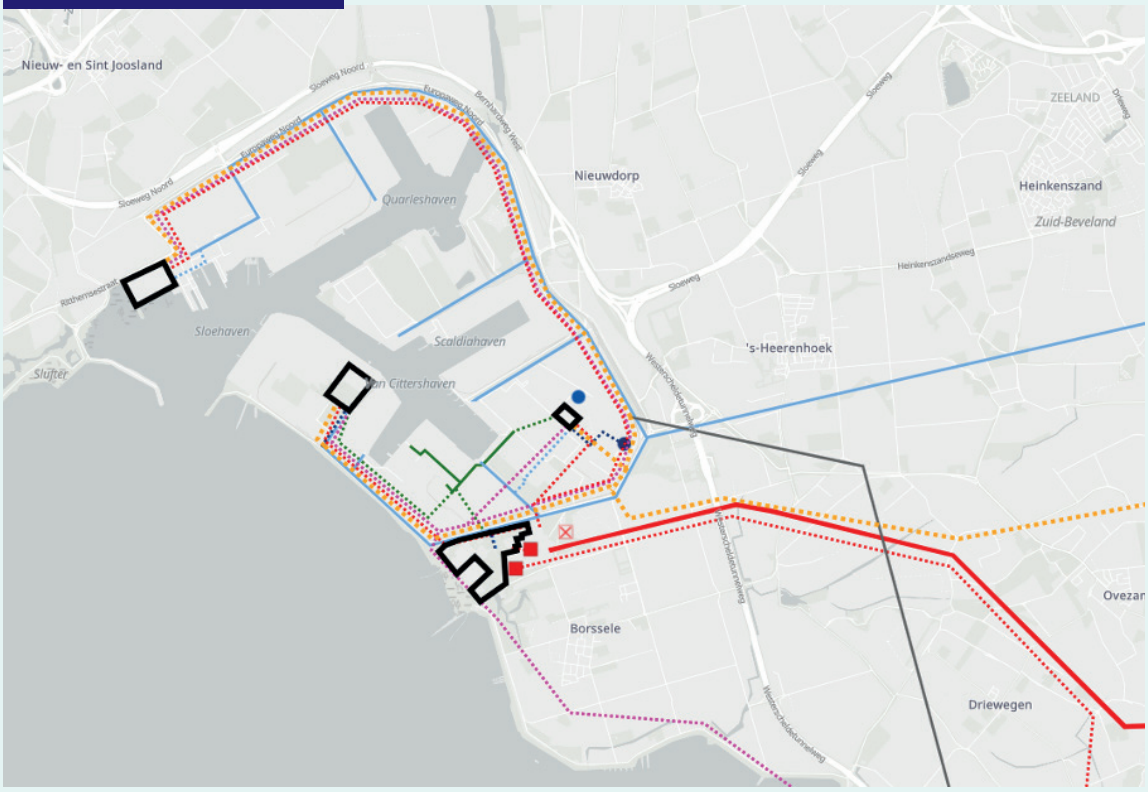
Noordzeekanaal Area



- **Locations:** Four locations are available. Spaarndam/ Houtrak polder is an interesting option as it is close to Westpoort Industrial area and Tata with good infrastructure connections. Also the location near the Tata Steel site has already been identified as a possible project site (H_2ermes) with potentially extension and could also consume large volumes of O_2. The Hemweg location near the Vattenfall power plant has been mentioned as a potential hub.
- **Hydrogen demand:** According to Tata Steel all hydrogen could potentially be absorbed in current blast furnaces. Hydrogen could also be used in new joint processes of the steel and chemical industries, avoiding carbon emissions.
- **380 kV connection:** This js possible at two locations (Spaarndam and Tata), other locations are to be reviewed. Hemweg only has a 150 kV connection.
- **Hydrogen infrastructure:** All locations are close to the Gasunie backbone, within 1 - 10 km.
- **Facilities:** At Tata and Hemweg co-siting opportunities exist for water supply.
- **Residual heat:** Potential use for district heating: Westpoort and IJmond Warmte.

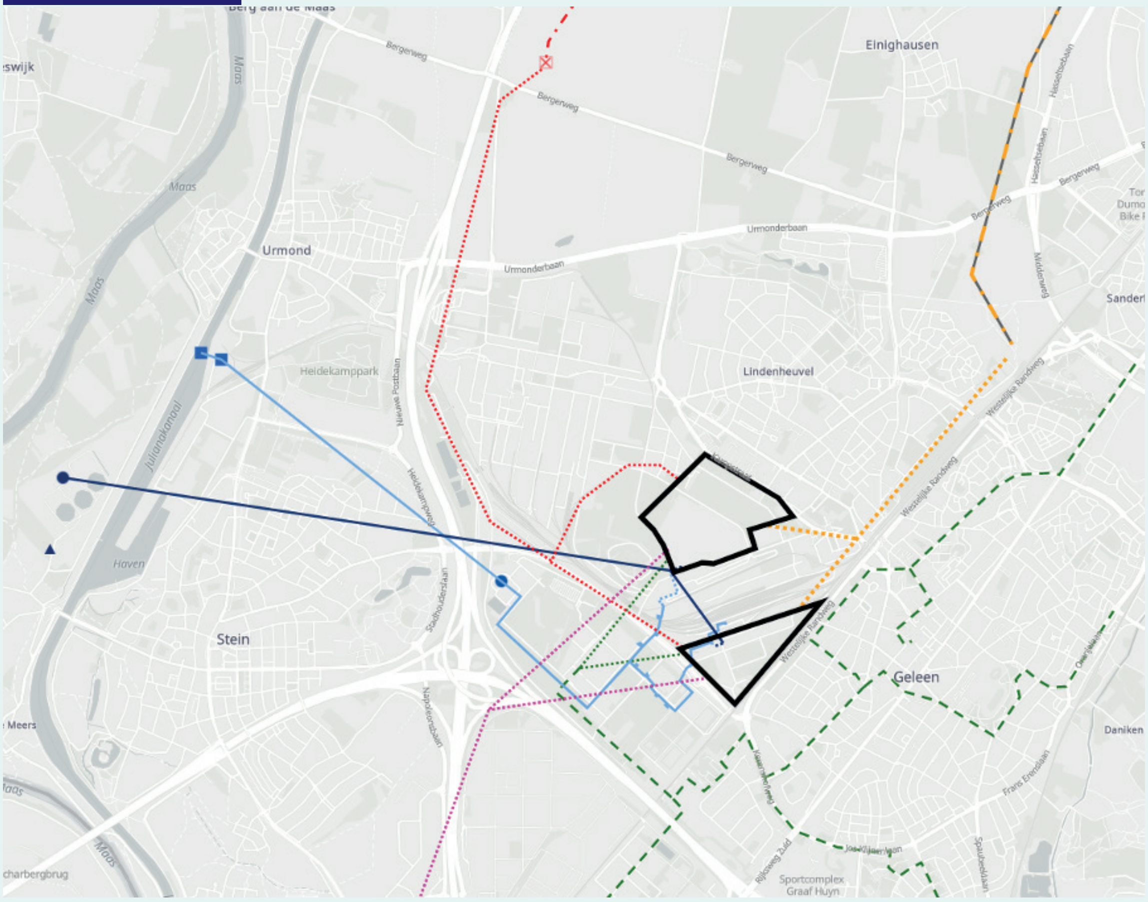


North Sea Port



- **Locations:** Especially Thermphos and Zanddepot (at Sloe area Vlissingen) have a large potential, with about 40 ha of space. Also, the DOW and Yara industrial sites in Terneuzen and Engie in Ghent are possible. The latter could supply Arcelor Mittal with hydrogen and oxygen.
- **Hydrogen demand:** The present demand (550 kTon/y, of which 380 kton/y for Yara's fertiliser plants) more than ensures opportunities.
- **380 kV connection:** There's no existing 380 kV grid in Zeeuws-Vlaanderen but this can be worked around by means of a connection to the Borssele nuclear plant. Technically, another option would be to extend the Belgian grid from Ghent, owned by ELIA.
- **Hydrogen infrastructure:** Some H_2 infrastructure is already in place between DOW and Yara; connection to Gasunie backbone is projected in Zeeuws-Vlaanderen. However, for the locations near Vlissingen, 40-50 km of pipeline should be realized to connect to the backbone, i.e the use of existing gas pipelines is not sure.
- **Facilities:** Raw water supply is present, treatment facilities are needed.
- **Residual heat:** There's potential for use by industry , horticulture, and for district heating development with heat grids Sloewarmte, Kanaalzone and Ghent.

Chemelot



- **Locations:** Three different locations are considered: Chemelot South with two locations and a potential future location to the north of Chemelot.
- **Hydrogen demand:** Present demand of 185 kton/a could accommodate 1 GW green hydrogen production. This is envisioned for the long term. At first, other options for hydrogen production are being explored.
- **380 kV connection:** A new connection is projected.
- **Hydrogen infrastructure:** The proposed locations are within 5 km from the Gasunie backbone.
- **Facilities:** Cooling water requirements may become more restrictive.
- **Residual heat:** There's potential for extending the district heating "Groene Net".

Legend

- Possible electrolyser locations
- Hydrogen pipeline
- 380 kV line
- 220 kV line
- 380 kV station (existing, planned, prjectend, required)
- Hydrocarbon pipeline
- Oxygen pipeline
- Cooling water pipeline
- Industrial water pipeline
- Demin water pipeline
- Surface water pipeline
- Waste water pipeline
- Cooling water plant
- Demin water plant
- Drinking water treatment plant
- Industry water treatment plant
- Industrial waste water plant
- Municipal waste water plant
- Other water locations

Existing | Planned | Projected | Required

Conclusions

First of all, this study demonstrates the commitment of relevant stakeholders in all five industrial clusters, willing to investigate in depth all the (regional) issues related to the development of large-scale water electrolysis. Although there are significant differences between the investigated clusters regarding various aspects of the study, all clusters qualify to accommodate a GW water electrolysis facility. Furthermore, present hydrogen demand is sufficient to absorb green hydrogen produced at gigawatt scale before 2030; present industrial hydrogen consumption in the Netherlands already corresponds to more than 15 green hydrogen production chains of 1 GW each. However, to realize a transition towards green hydrogen, all possible developments and optimizations concerning the total value chain are necessary to accompany the technical possibilities with the right economics.

Learnings from the identification of locations show that the vicinity of the 380 kV infrastructure and a hydrogen backbone is at least as important as the location close to the shore and/or end users. Public infrastructure development, both regarding the hydrogen backbone of Gasunie and the 380 kV connections of Tennet, therefore is essential for success. Regarding plot sizes, there is ample potential for improvement (nearly a factor of 2) . More work on specific levers for this need to be done (see follow-up).

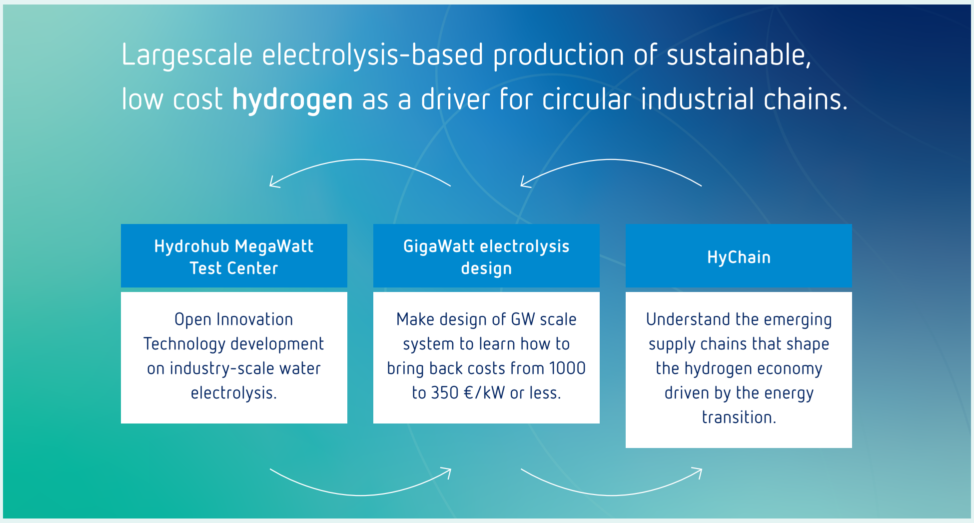
Follow-up

The following topics in relation to the industrial clusters will be addressed in the next phases of the project:

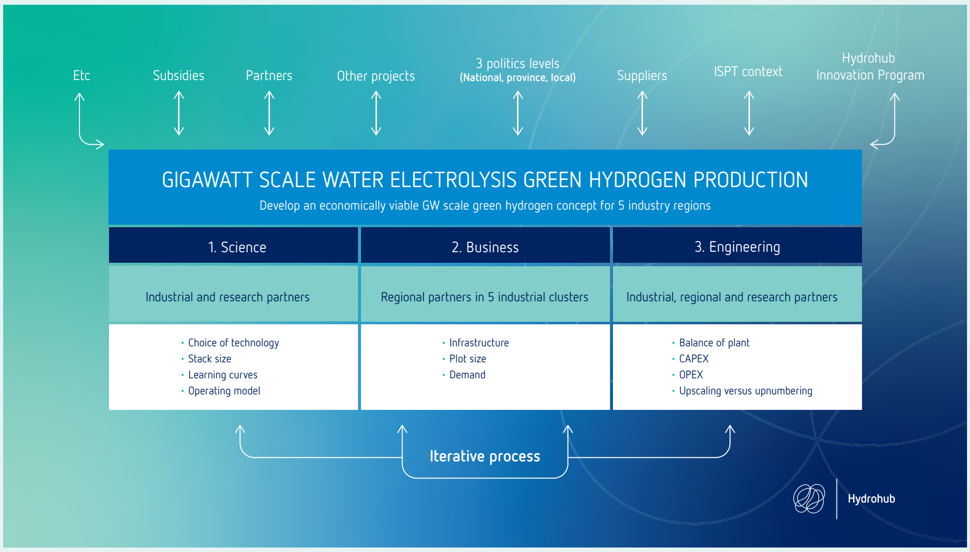
- **Compact design:** area usage and space requirements in relation to topics such as safety and environmental contours, HV-electricity set up, cable and pipeline infrastructure, and system integration aspects. Some of the other topics mentioned below will support this topic;
- **Safety:** safety contours of the GW facilities, safety aspects of oxygen-emissions, and requirements of the permitting process;
- **System integration aspects:** technical feasibility of usage of residual heat, co-siting opportunities and synergies with other water consumers/producers;
- **Hydrogen quality:** optimum specification to serve the industry and other offtakers at lowest cost;
- **Input to business plans** with (integration of) cost savings, synergies and upsides.

The GigaWatt Scale electrolyser project is part of the Hydrohub Innovation Program

The Institute for Sustainable Process Technology (www.ISPT.eu) is an open innovation network for the process technology community to support the development of sustainable processes. The GW electrolysis project is part of **Hydrohub Innovation Program** aiming at supporting the development of green hydrogen at scale for industrial use, see infographic.



The projects are financed by the industrial partners of ISPT and have received public funding from TKI Energie & Industrie – part of the Topsector Energie of the Ministry of Economic Affairs and Climate Policy of The Netherlands. This GW project focuses on upscaling and upnumbering of electrolysers to a GW facility, and optimizing system design including electrical installations and balance of plant.



As the infographic shows, the **GW electrolysis project** consists of 3 parts. **This study** is supporting the business part 2 and is investigating the interfaces in the five industrial clusters to make sure that the designs can land in each cluster in terms of space, infrastructure, demands, etc. Together with this study, the results from the scientific part 1 and engineering part 3 are used as input for the design development.

Colophon

Title

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About this report

This report was prepared by ISPT in close cooperation with regional partners. The study was performed by DNV GL for system integration, KWR for water infrastructure, and RHDHV for plot plans and map. The GW project is managed and coordinated by E4U Projects and Ekinetix on behalf of ISPT. This summary can be found online at https://ispt.eu/projects/hydrohub-gigawatt/

The Hydrohub GigaWatt Scale Electrolyser project

The Hydrohub GigaWatt Scale Electrolyser project is initiated by the Institute for Sustainable Process Technology (ISPT) and is part of the Hydrohub Innovation Program. The study has been done in close cooperation with five industrial clusters involving more than 25 regional stakeholders, including all port authorities, relevant provinces, industry associations, Gasunie, TenneT and major industries.

- Zeeland: North Sea Port, Smart Delta Resources;
- Northern Netherlands: Provincie Groningen, Groningen Seaports;
- Noordzeekanaal Area: Port of Amsterdam, Provincie Noord-Holland, Tata Steel, Gemeente Amsterdam;
- Rotterdam: Port of Rotterdam, Deltalinqs, Stedin, Provincie Zuid-Holland, Gemeente Rotterdam;
- Chemelot: represented by OCI Nitrogen

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